ESE 2018
Prelims Exam

MADE EASY
Publications

Civil Engineering

Topicwise **Objective** Solved Papers

Volume-II

- Fully Solved with Explanations
- Thoroughly Revised and Updated

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Paghdal

23 Years
Previous Solved Papers

ESE 2018

UPSC ENGINEERING SERVICES EXAMINATION

Preliminary Examination

Civil Engineering

Topicwise **Objective** Solved Questions

Volume-II

Topicwise Presentation | *Thoroughly Revised and Updated*

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Civil Engineering : Volume-II
Topicwise Objective Solved Questions : (1995-2017)

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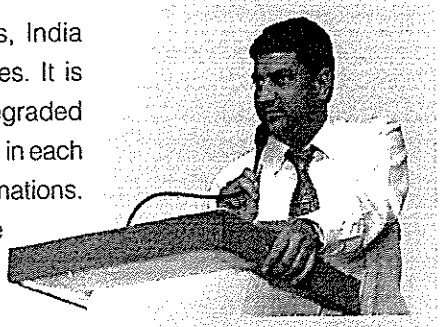
Director's Message



During the last few decades of engineering academics, India has witnessed geometric growth in engineering graduates. It is noticeable that the level of engineering knowledge has degraded gradually, while on the other hand competition has increased in each competitive examination including GATE and UPSC examinations. Under such scenario higher level efforts are required to take an edge over other competitors.

The objective of MADE EASY books is to introduce a simplified approach to the overall concepts of related stream in a single book with specific presentation. The topic-wise presentation will help the readers to study & practice the concepts and questions simultaneously.

B. Singh (Ex. IES)

The efforts have been made to provide close and illustrative solutions in lucid style to facilitate understanding and quick tricks are introduced to save time.

Following tips during the study may increase efficiency and may help in order to achieve success.

- Thorough coverage of syllabus of all subjects
- Adopting right source of knowledge, i.e. standard reading text materials
- Develop speed and accuracy in solving questions
- Balanced preparation of Paper-I and Paper-II subjects with focus on key subjects
- Practice online and offline modes of tests
- Appear on self assessment tests
- Good examination management
- Maintain self motivation
- Avoid jumbo and vague approach, which is time consuming in solving the questions
- Good planning and time management of daily routine
- Group study and discussions on a regular basis
- Extra emphasis on solving the questions
- Self introspection to find your weaknesses and strengths
- Analyze the exam pattern to understand the level of questions
- Apply shortcuts and learn standard results and formulae to save time

B. Singh (Ex. IES)
CMD, MADE EASY Group

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Civil Engineering Volume-II

Objective Solved Questions

of UPSC Engineering Services Examination

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OOOO

UNIT

I

Fluid Mechanics & Hydraulic Machines

Syllabus

Fluid Mechanics, Open Channel Flow, Pipe Flow: Fluid properties; Dimensional Analysis and Modeling; Fluid dynamics including flow kinematics and measurements; Flow net; Viscosity, Boundary layer and control, Drag, Lift, Principles in open channel flow, Flow controls. Hydraulic jump; Surges; Pipe networks.

Hydraulic Machines and Hydro power: Various pumps, Air vessels, Hydraulic turbines – types, classifications & performance parameters; Power house – classification and layout, storage, pondage, control of supply.

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OOOO

1 Fluid Properties

1.1 Which one of the following pressure units represents the LEAST pressure?

(a) millibar (b) mm of Hg

(c) N/mm^2 (d) kgf/cm^2

[ESE : 1997]

1.2 The surface tension of water at 20°C is 75×10^{-3} N/m. The difference in the water surfaces within and outside an open-ended capillary tube of 1 mm internal bore, inserted at the water surface would nearly be

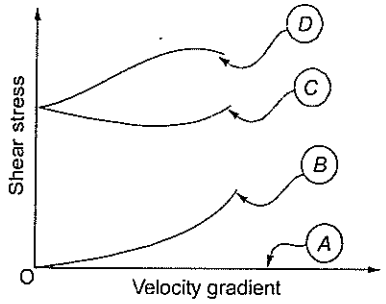
(a) 5 mm (b) 10 mm

(c) 15 mm (d) 20 mm

[ESE : 1998]

1.3 Match List-I (Curves labelled *A*, *B*, *C* and *D* in figure) with List-II (Type of fluid) and select the correct answer using the codes given below the lists:

List-I



List-II

1. Ideal plastic
2. Ideal
3. Non-Newtonian
4. Thixotropic
5. Rheopectic

Codes:

	A	B	C	D
(a)	2	3	1	5
(b)	3	2	1	5
(c)	4	2	5	1
(d)	2	3	5	1

[ESE : 1999]

1.4 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Concentrated sugar solution
B. Sewage sludge
C. Blood
D. Air

List-II

1. Dilatant fluid
2. Bingham plastic fluid
3. Pseudo-plastic fluid
4. Newtonian fluid

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	1	2	4	3
(c)	2	1	3	4
(d)	2	1	4	3

[ESE : 2001]

1.5 Match List-I (Definitions) with List-II (Properties) and select the correct answer using the codes given below the lists:

List-I

A. Newtonian fluid
B. Ideal fluid
C. Thixotropic fluid
D. Rheological fluid

List-II

1. Frictionless and incompressible
2. Viscosity is invariant with shear stress
3. Viscosity increases at higher shear stress
4. Viscosity decreases at higher shear stress

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	3	4
(d)	3	4	1	2

[ESE : 2002]

1.6 Which one of the following statements is correct?
(a) Dynamic viscosity of water is nearly 50 times that of air.
(b) Kinematic viscosity of water is 30 times that of air.
(c) Water in soil is able to rise a considerable distance above the groundwater table due to viscosity.
(d) Vapour pressure of a liquid is inversely proportional to the temperature.

[ESE : 2003]

1.7 Which of the following fluids can be classified as non-Newtonian?
1. Kerosene oil 2. Diesel oil
3. Human blood 4. Toothpaste
5. Water

Select the correct answer using the codes given below:
(a) 1 and 2 (b) 3 and 4
(c) 2 and 5 (d) 1 and 5

[ESE : 2003]

1.8 Assertion (A): At the standard temperature, the kinematic viscosity of air is greater than that of water at the same temperature.
Reason (R): The dynamic viscosity of air at standard temperature is lower than that of water at the same temperature.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2004]

1.9 The velocity distribution for flow over a plate is given by $u = 0.5y - y^2$ where 'u' is the velocity in m/s at a distance 'y' meter above the plate. If the dynamic viscosity of the fluid is 0.9 N-s/m^2, then what is the shear stress at 0.20 m from the boundary?
(a) 0.9 N/m^2 (b) 1.8 N/m^2
(c) 2.25 N/m^2 (d) 0.09 N/m^2

[ESE : 2005]

1.10 A flat plate of 0.15 m^2 is pulled at 20 cm/s relative to another plate, fixed at a distance of 0.02 cm from it with a fluid having μ = 0.0014 N-s/m^2 separating them. What is the power required to maintain the motion?
(a) 0.014 W (b) 0.021 W
(c) 0.035 W (d) 0.042 W

[ESE : 2006]

1.11 Which one of the following expresses the height of rise or fall of a liquid in a capillary tube?

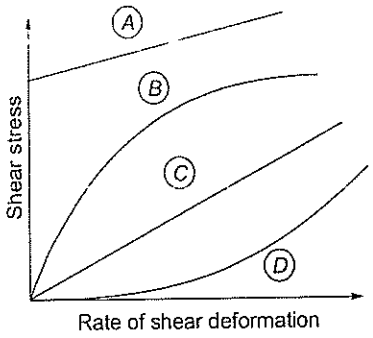
(a) $\frac{4wd}{\sigma\cos\alpha}$ (b) $\frac{\sigma\cos\alpha}{4w\alpha}$

(c) $\frac{4\sigma\cos\alpha}{wd}$ (d) $\frac{wd}{4\sigma\cos\alpha}$

where,
w = Specific weight of the liquid
α = Angle of contact of the liquid surface
σ = Surface tension

[ESE : 2007]

1.12 Match List-I (Curve identification in figure) with List-II (Nature of fluid) and select the correct answer using the codes given below the lists:



List-I	List-II
A. Curve *A*	1. Newtonian
B. Curve *B*	2. Dilatant
C. Curve *C*	3. Ideal bingham plastic
D. Curve *D*	4. Pseudo-plastic

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	2	4	1	3
(c)	3	1	4	2
(d)	2	1	4	3

[ESE : 2010]

1.13 Assertion (A): The movement of two blocks of wood welted with hot glue requires greater and greater effort as the glue is drying up.

Reason (R): Viscosity of liquids varies inversely with temperature.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

1.14 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

A. Specific Gravity
B. Coefficient of viscosity
C. Kinematic viscosity
D. Stress

List-II

1. $M^0L^2T^{-1}$
2. $M^0L^0T^0$
3. $ML^{-1}T^{-1}$
4. $ML^{-1}T^{-2}$

Code:

	A	B	C	D
(a)	2	3	1	4
(b)	4	3	1	2
(c)	2	1	3	4
(d)	4	1	3	2

[ESE : 2011]

1.15 Poise has the unit of

(a) Dyne-cm/s^2 (b) Dyne-cm/s
(c) Dyne-s/cm (d) Dyne-s/cm^2

[ESE : 2011]

1.16 Which one of the following statements is correct?

(a) For water at 100° Celsius at sea level, the vapour pressure is equal to atmospheric pressure.
(b) Surface energy (or tension) is caused by the force of adhesion between liquid molecules.
(c) Viscosity of a fluid is the property exhibited by it both in static and in dynamic conditions.
(d) Air is 50, 000 times more compressible than water.

[ESE : 2011]

1.17 Which one of the following statements is correct?

(a) Dynamic viscosity is the property of a fluid which is not in motion
(b) Surface energy is fluid property giving rise to the phenomenon of capillarity in water
(c) Cavitation results from the action of very high pressure
(d) Real fluids have lower viscosity than ideal fluids

[ESE : 2011]

Directions: Each of the next items consists of two statements, one labeled as the 'Statements (I)' and the other as 'Statement (II)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

1.18 Statement (I): As temperature increases, viscosity of air decreases.
Statement (II): As temperature increases, activity of the air molecules increases.

[ESE : 2013]

1.19 Statement (I): Fluid pressure is a scalar quantity.
Statement (II): Fluid thrust always acts downwards.

[ESE : 2013]

1.20 The velocity distribution in a laminar flow adjacent to a solid wall is given by $u = 3.0 \sin(5\pi y)$. The viscosity of the fluid is 5 poise. What is the shear stress at a section (*i*) $y = 0.05$ m; (*ii*) $y = 0.12$ m?

(a) 16.7 N/m^2 and 6.1 N/m^2
(b) 33.4 N/m^2 and Zero
(c) 16.7 N/m^2 and 12.3 N/m^2
(d) 16.7 N/m^2 and Zero

[ESE : 2014]

1.21 The surface tension in a soap bubble of 50 mm diameter with its inside pressure being 2.5 N/m^2 above the atmospheric pressure is

(a) 0.0125 N/m (b) 0.0156 N/m
(c) 0.2 N/m (d) 0.0312 N/m

[ESE : 2015]

1.22 The surface tension of water at 20°C is 75×10^{-3} N/m. The difference in water surfaces within and outside an open-ended capillary tube of 1 mm internal bore, inserted at the water surface, would nearly be

(a) 7 mm (b) 11 mm
(c) 15 mm (d) 19 mm

[ESE : 2016]

1.23 **Statement (I):** The shear strain graph for a Newtonian fluid is linear.

Statement (II): The coefficient of viscocity μ of the fluid is not constant.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

Answers Fluid Properties

1.1	(a)	1.2	(c)	1.3	(a)	1.4	(a)	1.5	(c)	1.6	(a)	1.7	(b)	1.8	(b)	1.9	(d)
1.10	(d)	1.11	(c)	1.12	(a)	1.13	(a)	1.14	(a)	1.15	(d)	1.16	(a)	1.17	(b)	1.18	(d)
1.19	(c)	1.20	(d)	1.21	(b)	1.22	(c)	1.23	(c)								

Explanations Fluid Properties

1.1 (a)

1 atm = 10.1 m of water
= 760 mm of Hg
= 1013 millibar
= 101.3 kPa
= 1.013 kgf/cm^2
= 0.1013 N/mm^2 (MPa)

$$1 \text{ millibar} = \frac{1}{1013}\text{atm}$$

$$1 \text{ mm Hg} = \frac{1}{760}\text{atm}$$

$$1 \text{ N/mm}^2 = \frac{1}{0.1013}\text{atm}$$

$$1 \text{ kgf/cm}^2 = \frac{1}{1.013}\text{atm}$$

From the above relation, it is clear that
1 millibar < 1 mm Hg < 1 kgf/cm^2 < 1 N/mm^2

1.2 (c)

$d = 1 \times 2 = 2$ mm

$$\Delta h = \frac{4\sigma}{d\gamma_w} = \frac{4 \times 75 \times 10^{-3}}{2 \times 10^{-3} \times 9.81 \times 1000}$$

$= 0.015$ m $= 15$ mm

1.3 (a)

Horizontal line representing zero shear stress for any velocity gradient is the condition for ideal fluid. The curve B represents dilatant fluid.

$$\tau = \mu\left(\frac{du}{dy}\right)^n \qquad n > 1$$

For pseudoplastic fluid,

$$\tau = \mu\left(\frac{du}{dy}\right)^n \qquad n < 1$$

For thixotropic fluid,

$$\tau = \tau_0 = \mu\left(\frac{du}{dy}\right)^n \qquad n < 1$$

For rheopectic fluid,

$$\tau = \tau_0 = \mu\left(\frac{du}{dy}\right)^n \qquad n > 1$$

For plastic fluid,

$$\tau = \tau_0 + \mu\left(\frac{du}{dy}\right) \text{ i.e. } \qquad n = 1$$

1.4 (a)

Newtonian Fluids: Air, water, mercury, glycerine, kerosene and other engineering fluids under normal circumstances.

Pseudoplastic: Fine particle suspension, gelatine, blood, milk, paper pulp, polymeric solutions such as rubbers, paints.

Dilatant fluids: Ultra fine irregular particle suspension, sugar in water, aqueous suspension of rice starch, quicksand, butter, printing ink.

Ideal plastics or Bingham fluids: Sewage sludge, drilling muds.

Visco-elastic fluids: Liquid solid combination in pipe flow, bitumen, tar, asphalt, polymerized fluids with drag reduction features.

Thixotropic: Printer's ink, crude oil, lipstick, certain paints and enamels.

Rheopectic fluids: Very rare liquid-solid suspensions, gypsum suspension in water and bentonite solutions.

1.5 (c)

For thixotropic fluid $\tau = \tau_0 + \mu\left(\frac{du}{dy}\right)^n \; n < 1$

As shear stress τ increases viscosity increases with higher rates of shear strain.

1.6 (a)

(i) Water is about 50 times more viscous than air.
(ii) Castor oil is about 1000 times more viscous than water.
(iii) Crude oil about 10 times more viscous than water.
(iv) Gasoline is about 1/3 times viscous than water.

Kinematic viscosity of air is more than that of water

1.7 (b)

Example of Newtonian fluids: Air, Water, Kerosene oil, Diesel oil

Example of non-Newtonian fluids: Toothpaste, Human blood, Paint, Shampoo.

1.8 (b)

Kinematic viscosity of air is greater because the density of air is very small compared to that of water.

1.9 (d)

Shear stress, $\tau = \mu\frac{du}{dy} = \mu(0.5 - 2y)$

at $y = 0.2$ m

$\tau = 0.9 \times (0.5 - 2 \times 0.2) = 0.09$ N/m^{2}©4

1.10 (d)

Force, $F = \mu\frac{du}{dy} \times A$

$= 0.0014 \times \frac{0.2}{0.02 \times 10^{-2}} \times 0.15$

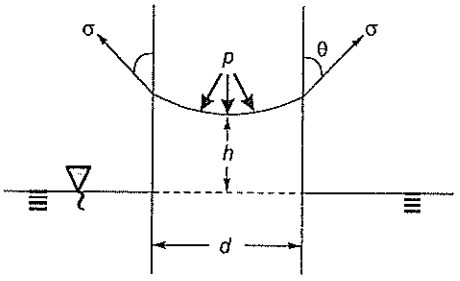
$= 0.21$ N

Power required $= F \times v$

$= 0.21 \times 0.2 = 0.042$ W

1.11 (c)

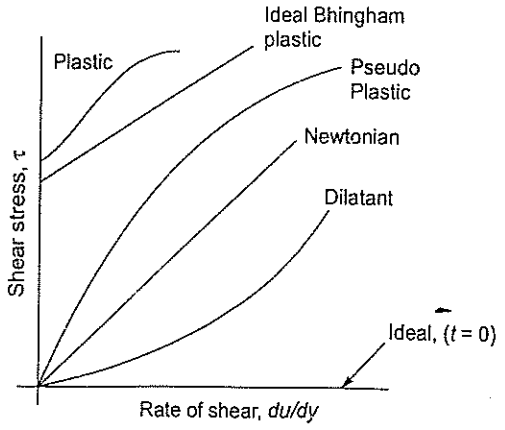
Let us suppose that the level of liquid has risen (or fallen) by 'h' above (or below) the general liquid surface when a tube of diameter 'd' is inserted in the liquid. For equilibrium of vertical forces acting on the mass of liquid lying above (or below) the general liquid level, the weight of liquid column 'h' (or the total internal pressure in the case of capillary depression) must be balanced by the force, at surface of the liquid, due to surface tension σ. Thus, equating these two forces we have



$$\frac{w\pi d^2}{4} \times h = \pi d\,\sigma\cos\theta$$

$$\Rightarrow \quad h = \frac{4\sigma\cos\theta}{wd}$$

1.12 (a)



1.13 (a)

Viscosity of liquids varies inversely with temperature so as the glue is dries up and cools down, its viscosity increases. Thus movement of two blocks of wood welted with hot glue would require greater effort.

1.14 (a)

Specific gravity is the ratio of specific weight of a fluid to the specific weight of a standard fluid. Being a ratio of two quantities with same units, specific gravity has no unit.

$\therefore M^0L^0T^0$

Coefficient of viscocity = μ

unit of μ = Ns/m^2

= $(MLT^{-2})T/L^2$

= $ML^{-1}T^{-1}$

Kinematic viscocity :

$$\nu = \frac{\mu}{\rho}$$

unit of ν = m^2/s

= L^2T^{-1}

= $M^0L^2T^{-1}$

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{MLT^{-2}}{L^2}$$

= $ML^{-1}T^{-2}$

1.15 (d)

Poise is unit of dynamic viscocity.

$$\text{Poise} = \frac{\text{Dyne} - \text{s}}{\text{cm}^2}$$

1 Poise = 0.1 Ns/m^2

1.16 (a)

At boiling point the vapour pressure of a fluid becomes equal to the atmospheric pressure. Water boils at 100°C therefore at 100°C at sea level the vapour pressure, is equal to the atmospheric pressure.

Surface tension is caused by the force of cohesion between liquid molecules. Viscocity is exhibited by only fluid under dynamic conditions. Air is about 20000 times more compressible than water.

1.17 (b)

Dynamic viscosity is the property of fluid in motion in which one layer of fluid exerts viscous force on the other layer. Cavitation occurs due to negative pressure.

Ideal fluids have no viscosity and surface tension and they are incompressible.

1.18 (d)

As the temperature increases, molecules move faster and there is an increase in molecular interaction. Molecules start colliding with each other, retarding the motion of gases, resulting in increase in viscosity of gases.

1.19 (c)

Fluid pressure is a scalar quantity. Its magnitude is defined but its direction is not. Fluid thrust can act in any direction.

1.20 (d)

$$\text{Shear stress, } \tau = \mu.\frac{\partial u}{\partial y}$$

$$= 0.5\frac{\partial}{\partial y}[3\sin(5\pi y)]$$

Here, μ = 5 poise = 0.5 Pa-s

$\tau = 0.5 \times 3 \times 5\pi \cos(5\pi y)$

$= 23.56\cos(5\pi y)\ N/m^2$

So, at y = 0.05 m

$\tau = 23.56\cos(5\pi \times 0.05)$

$\tau = 16.7\ N/m^2$

and at y = 0.12 m

$\tau = 23.56\cos(5\pi \times 0.12)$

$\tau = -7.28\ N/m^2$

Since Negative value is not acceptable.

$\therefore$ It is taken as zero.

1.21 (b)

$$p \times \frac{\pi d^2}{4} = \sigma \times 2(2\pi r)$$

$$= \sigma \times 2\pi d$$

$$\sigma = \frac{pd}{8} = \frac{2.5 \times 0.05}{8}$$

$$= 0.0156\ N/m$$

1.22 (c)

In this problem, the bore is not defined properly. Here bore is used for radius.

$$h = \frac{2\sigma\cos\theta}{\rho \cdot g \cdot R}$$

$$= \frac{2\left(75 \times 10^{-3}\right)}{10^3 \times 9.81 \times \left(1 \times 10^{-3}\right)}$$

$$= 15.29\ mm$$

■■■■

2 Manometry

2.1 A 10 m high rocket containing liquid fuel of specific gravity 1.2 lifts off at an acceleration of 5 g. The pressure on the bottom plate of the rocket during lift-off is

(a) 6.7 kg/cm^2 (b) 7.2 kg/cm^2
(c) 8.4 kg/cm^2 (d) 8.9 kg/cm^2

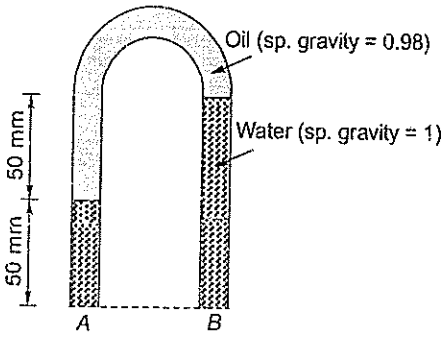
[ESE : 1995]

2.2 If a hole is made in the Torricelli's vacuum portion of a barometer, then the mercury

(a) level will fall in the stem and the mercury will collect in the reservoir
(b) level will oscillate between reservoir level and original level of the mercury in the stem
(c) will spill through the hole made
(d) level in the stem will remain at the same level indicating atmospheric pressure

[ESE : 1995]

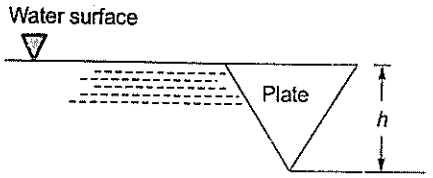
2.3 In the set-up shown in the given figure, assuming the specific weight of water as 10,000 N/m^3, the pressure difference between the points *A* and *B* will be



(a) 10 N/m^2 (b) –10 N/m^2
(c) 20 N/m^2 (d) –20 N/m^2

[ESE : 1999]

2.4 An equilateral triangular plate is immersed in water as shown in the figure below. The centre of pressure below the water surface is at a depth of



(a) $\frac{3h}{4}$ (b) $\frac{h}{3}$
(c) $\frac{2h}{3}$ (d) $\frac{h}{2}$

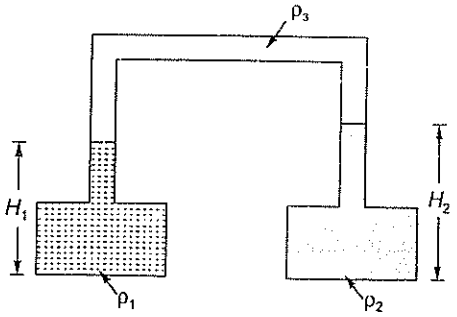
[ESE : 1999]

2.5 An isosceles triangular plate of base 3 m and altitude 3 m is immersed vertically in an oil of specific gravity 0.8. The base of the plate coincides with the free surface of oil. The centre of pressure will lie at a distance of (from free surface)

(a) 2.5 m (b) 2 m
(c) 1.5 m (d) 1 m

[ESE : 2002]

2.6 Which one of the following expresses the difference in the pressure at the floors of the tank shown above in the figure?



(a) $(\rho_2 - \rho_1)gH_2$
(b) $(\rho_2 - \rho_1)gH_1$
(c) $\rho_1 gH_1 + \rho_3 gH_2 - \rho_2 gH_2$
(d) $\rho_1 gH_1 + \rho_3 g(H_2 - H_1) - \rho_2 gH_2]$

where ρ_1, ρ_2 and ρ_3 are the densities of the different fluids.

[ESE : 2006]

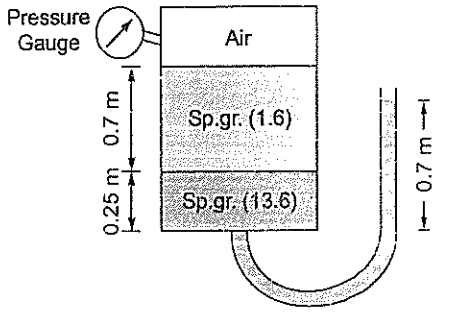
2.7 Multi U-tube manometers with different fluids are used to measure
(a) low pressures
(b) medium pressures
(c) high pressures
(d) very low pressures

[ESE : 2006]

2.8 A pressure gauge reads 57.4 kPa and 80 kPa, respectively at heights of 8 m and 5 m fitted on the side of a tank filled with liquid. What is the approximate density of the liquid in kg/m^3?
(a) 393 (b) 768
(c) 1179 (d) 7530

[ESE : 2008]

2.9 In the below figure the pressure gauge will record a gauge pressure equivalent to



(a) 6.12 m of water
(b) 1.21 m of mercury
(c) 0.5 bar
(d) 34,000 Pa

[ESE : 2011]

2.10 The absolute pressure at a point 2.5 m below the clear water surface is measured as 125.703 kN/m^2. If the atmospheric pressure is taken as 101.325 kN/m^2, the gauge pressure in kN/m^2 at this point would be
(a) 113.514 (b) 24.378
(c) 45.401 (d) 56.757

[ESE : 2013]

2.11 A centrifugal pump delivers a manometric head of 12 m when pumping a liquid of relative density 0.8. If all other factors remain the same but the liquid has a relative density of 1.2, the new manometric head would be:
(a) 8 m (b) 10 m
(c) 12 m (d) 18 m

[ESE : 2013]

2.12 The standard atmospheric pressure is 101.32 kPa. The local atmospheric pressure is 91.52 kPa. If a pressure at a flow path is recorded at 22.48 kPa (gauge), it is equivalent to
(a) 69.04 kPa (abs) (b) 88.4 kPa (abs)
(c) 114.0 kPa (abs) (d) 123.0 kPa (abs)

[ESE : 2014]

2.13 A rectangular pontoon has a width of 6 m, a length of 12 m, and a draught of 1.5 m in fresh water (density = 1000 kg/m^3). Its draught in sea water having density of 1025 kg/m^3 is
(a) 1.04 m (b) 1.24 m
(c) 1.46 m (d) 1.50 m

[ESE : 2014]

2.14 A mercury water manometer has a gauge difference of 0.8 m. The difference in pressure measured in metres of water is
(a) 0.8 (b) 1.06
(c) 10.05 (d) 8.02

[ESE : 2015]

■■■■

Answers Manometry

2.1	(b)	2.2	(a)	2.3	(b)	2.4	(d)	2.5	(c)	2.6	(d)	2.7	(c)	2.8	(b)	2.9	(c)
2.10	(b)	2.11	(a)	2.12	(c)	2.13	(c)	2.14	(c)								

Explanations Manometry

2.1 (b)

The height of fuel column, h = 10 m

Pressure at bottom, $p = \rho_{fuel}(a + g)h$

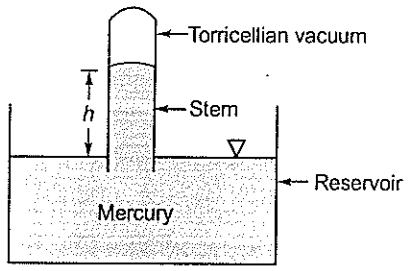
where a is the upward acceleration

$$\rho_{fuel} = \text{Specific gravity} \times \rho_w$$
$$= 1.2 \times 1000$$
$$= 1200 \text{ kg/m}^3$$
$$\therefore \quad p = 1200 \times (5g + g) \times 10$$
$$= 1200 \times 6 \times 10 \times 100$$
$$= 7.2 \times 10^5 \text{ N/m}^2$$
$$= 7.2 \text{ kg/cm}^2$$

2.2 (a)

Barometer measures the atmospheric pressure.

$$p_{atm} = \rho_{Hg}\, gh$$



If there is a hole in the vacuum portion, then there will be zero pressure difference at top and bottom of the stem. The mercury in the stem will show zero reading i.e. it will fall and get collected in the reservoir.

2.3 (b)

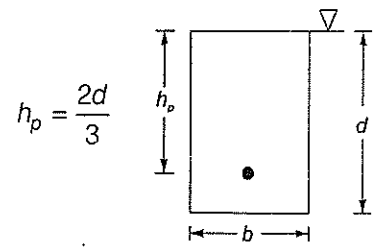
The equation for pressure at B is

$$p_A - \rho_w gh - \rho_{oil} gh + 2\rho_w gh = p_B$$
$$\therefore \quad p_A - p_B = \rho_{oil} gh - \rho_w gh$$
$$= (0.98 - 1) \times 10000 \times 0.05$$
$$= -10 \text{ N/m}^2$$

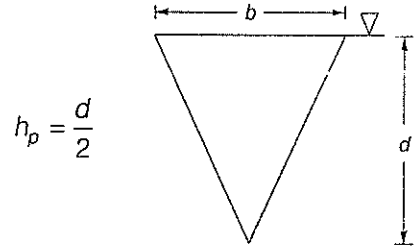
2.4 (d)

The centre of pressure for certain bodies are:

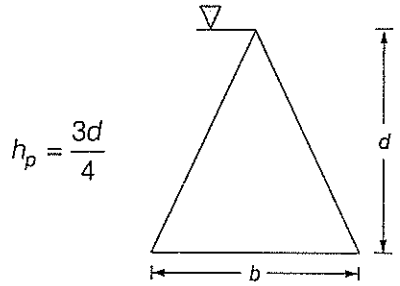
(a) Rectangular with face coinciding with free surface



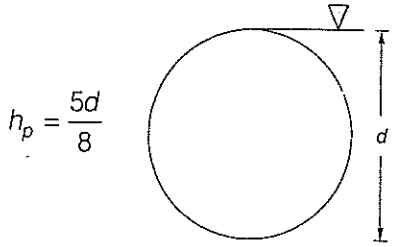
(b) Triangle with base at the free surface



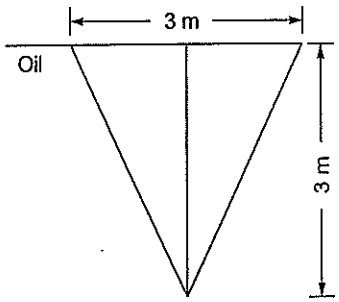
(c) Triangle with apex at free surface



(d) Circle touching free surface



2.5 (c)



Centre of Pressure depth

$$\bar{h} = \left(\bar{x} + \frac{I_G}{A\bar{x}}\right)$$

$$= \frac{3}{3} + \left(\frac{3 \times 3^3}{36 \times \frac{1}{2} \times 3 \times 3 \times \frac{3}{3}}\right)$$

$$= 1 + 0.5 = 1.5 \text{ m}$$

2.6 (d)

$$p_1 - \rho_1 g H_1 - \rho_3 g(H_2 - H_1) + \rho_2 g H_2 = p_2$$

$$\therefore \quad p_1 - p_2 = \rho_1 g H_1 + \rho_3 g(H_2 - H_1) - \rho_2 g H_2$$

2.7 (c)

When the pressure is high U-tube manometer with different fluid of specific gravity more than that of the liquid for which pressure is to be measured.

2.8 (b)

The pressure difference may be given as

$$p_1 - p_2 = \rho g (h_2 - h_1)$$

$$\Rightarrow \quad 80 \times 10^3 - 57.4 \times 10^3 = \rho \times 9.81 \times (8 - 5)$$

$$\Rightarrow \quad 22600 = \rho \times 29.43$$

$$\Rightarrow \quad \rho = 768 \text{ kg/m}^3$$

2.9 (c)

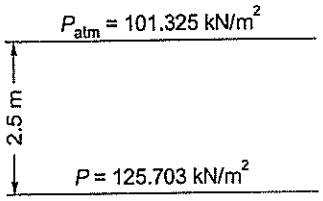
Let gauge pressure be = P

$P + (1.6 \times \rho_w) \times g \times 0.7 + (13.6 \times \rho_w) \times g \times 0.25 - (13.6 \times \rho_w) \times g \times 0.7 = 0$

$P = 5 \times g \times \rho_w$

$$= 50000 \frac{\text{N}}{\text{m}^2} = \frac{50000}{10^5} \text{bar} = 0.5 \text{ bar}$$

2.10 (b)



For gauge pressure,

$$P_{atm} = 0$$

$$\therefore \quad P = 125.703 - 101.325 = 24.378 \text{ kN/m}^2$$

2.11 (a)

$$P = \rho Q g h$$

$$\therefore \quad 800\, Qg(12) = 1200\, Qg(h)$$

$$\Rightarrow \quad h = 8\text{m}$$

2.12 (c)

The absolute pressure = local atmospheric pressure + gauge pressure

$$= 91.52 + 22.48$$

$$= 114 \text{ kPa}$$

2.13 (c)

Draught in sea water = (draught in fresh water) $\times \left(\frac{\rho_{freshwater}}{\rho_{sea\ water}}\right)$

$$= 1.5 \times \frac{1000}{1025} = 1.463 \text{ m}$$

2.14 (c)

$$x = h\left(\frac{\rho_m}{\rho_w} - 1\right)$$

$$= 0.8\left(\frac{13.6}{1} - 1\right)$$

$$= 10.08 \text{ m}$$

3 Hydrostatic Forces

3.1 A vertical gate 6 m × 6 m holds water on one side with the free surface at its top. The moment about the bottom edge of the gate of the water force will be (γ_w is the specific weight of water)

(a) $18\gamma_w$ (b) $36\gamma_w$

(c) $72\gamma_w$ (d) $216\gamma_w$

[ESE : 1997]

3.2 When the water surface coincides with the top edge of a rectangular vertical gate 40 m (wide) × 3 m (deep), then the depth of centre of pressure is

(a) 1 m (b) 1.5 m

(c) 2 m (d) 2.5 m

[ESE : 2000]

3.3 If a water tank, partially filled with water is being carried on a truck, moving with a constant horizontal acceleration, the level of liquid will

(a) rise and fall alternately on the front side of the tank

(b) fall on the rear side of the tank

(c) remain the same on both sides of the tank

(d) rise on the rear side and fall on the front side of the tank

[ESE : 2000]

3.4 As the depth of immersion of a vertical plane surface increases, the location of centre of pressure

(a) falls closer to the centre of gravity of the area

(b) moves away from the centre of gravity of the area

(c) ultimately coincides with the centre of gravity of the area

(d) falls much below the centre of gravity of the area

[ESE : 2003]

3.5 A rectangular tank 10 m × 5 m in plan and 3 m deep is divided by a partition wall parallel to the shorter wall of the tank. One of the compartments contains water to a depth of 3 m, and the other a lighter liquid of specific gravity 0.75 to a depth of 2 m. The resultant pressure thrust on the partition wall is

(a) 1000 kg (b) 1500 kg

(c) 2000 kg (d) 2500 kg

[ESE : 2012]

3.6 A square gate, 1.5 m × 1.5 m, one of the vertical sides of a fully filled water tank, has one side on the free water surface. It is hinged on the lower horizontal side and is held in position by a force applied on the vertical central line at a depth of 0.75 m below the free surface. The right magnitude of this force is

(a) 500 × 9.81 N (b) 600 × 9.81 N

(c) 750 × 9.81 N (d) 1000 × 9.81 N

[ESE : 2015]

3.7 A tank is 1.8 m deep and square length of 4.5 m at the top and square length of 3 m at the bottom. The four sides are plane and each has the same trapezoidal shape. The tank is completely full of oil weighing 936 kg/m^3. What is the resultant pressure on each side?

(a) 5750 kgf (b) 5500 kgf

(c) 5250 kgf (d) 5140 kgf

[ESE : 2016]

■■■

Answers Hydrostatic Forces

3.1 (d) 3.2 (c) 3.3 (d) 3.4 (a) 3.5 (*) 3.6 (*) 3.7 (a)

Explanations Hydrostatic Forces

3.1 (d)

The force on the gate = $\rho g h_c A$

$= \gamma \times 3 \times 36 = 108\gamma$

The depth of centroid from free surface,

$$h_p = \frac{2h}{3} = \frac{2\times 6}{3} = 4\,m$$

From bottom edge the centroid will be at a distance of 6 – 4 = 2 m

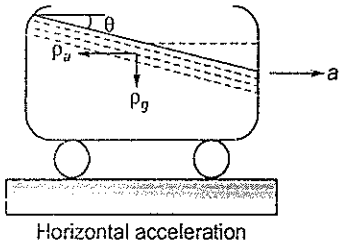
Therefore moment about the bottom edge of the gate of the water force = $108 \times 2\gamma = 216\gamma$

3.2 (c)

Depth of centre of pressure,

$$h_p = \frac{2d}{3} = \frac{2\times 3}{3} = 2m$$

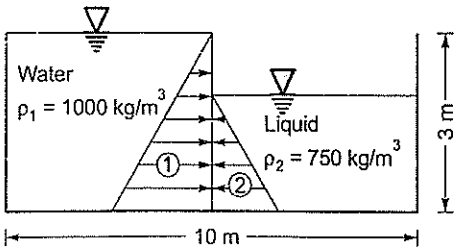
3.3 (d)



$$\theta = \tan^{-1}\left(\frac{a}{g}\right)$$

Water rises by θ angle on rear side and falls on the front end.

3.5 (*)



$$P_1 = \rho_1 \times \frac{3}{2} \times (3\times 5)$$

$$= 1000 \times \frac{3}{2} \times 3 \times 5 = 22500\ kg$$

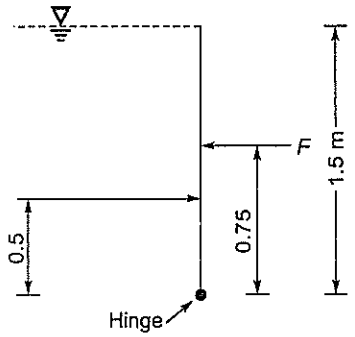
$$P_2 = \rho_2 \times \frac{2}{2} \times (2\times 5)$$

$= 750 \times 1 \times 2 \times 5 = 7500$ kg

Resultant pressure thrust,

$P_R = P_1 - P_2 = 15000$ kg

3.6 (*)



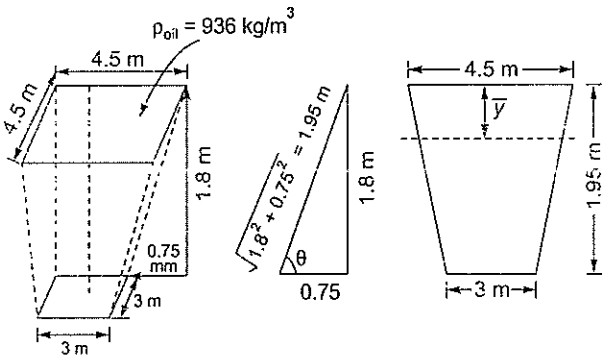
$(\rho g A \bar{h})0.5 = F \times 0.75$

$1000 \times 9.81 \times (1.5 \times 1.5) \times 0.75 \times 0.5$

$= F \times 0.75$

$F = 1125 \times 9.81$ N

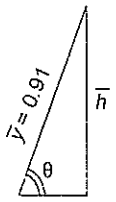
3.7 (a)



$$\sin\theta = \frac{1.8}{1.95}$$

$$\bar{y} = \left[\frac{2(3)+4.5}{3+4.5}\right] \times \frac{1.95}{3} = 0.91$$

Now, $\sin\theta = \frac{\bar{h}}{0.91}$



$$\frac{1.8}{1.9} = \frac{\bar{h}}{0.91}$$

$\bar{h} = 0.84$

$F = \rho \cdot g \cdot \bar{h} \cdot A$

$= (936)(9.81)(0.84)$

$\times \left[\frac{1}{2} \times (3+4.5) \times 1.95\right]$ N

$= 5749.38$ kgf

4 Buoyancy & Floatation

4.1 As depth of immersion of a vertical plane surface increases, the location of centre of pressure
(a) comes closer to the centre of gravity of the area
(b) moves apart from the centre of gravity of the area
(c) ultimately coincides with the centre of gravity of the area
(d) remains unaffected

[ESE : 1995]

4.2 A symmetrical right-circular cone of wood floats in fresh water with axis vertical and the apex down. The axial height of the cone is 1 unit. The submerged portion has a height h, measured upwards from the apex. What would be the height of the centre of buoyancy from the apex?

(a) $\frac{h}{2}$ (b) $\frac{5}{8}h$

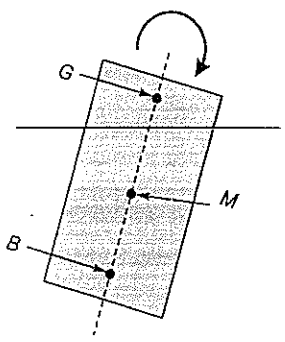
(c) $\frac{2}{3}h$ (d) $\frac{3}{4}h$

[ESE : 1998]

4.3 A homogeneous circular cylinder of length h, radius r and specific gravity S, floats in water. It is noted that $r = 2/3h$ Under which one of the following conditions will the flotation be unstable?
(a) $0.11 \le S < 0.22$ (b) $0.22 \le S < 0.33$
(c) $0.33 \le S < 0.66$ (d) $0.66 \le S \le 0.99$

[ESE : 1998]

4.4 A body is floating as shown in the given figure. The centre of buoyancy, centre of gravity and metacentre are labelled respectively as B, G and M. The body is



(a) vertically stable
(b) vertically unstable
(c) rotationally stable
(d) rotationally unstable

[ESE : 2000]

4.5 A metal cube of size 15 cm x 15 cm x 15 cm and specific gravity 8.6 is submerged in a two-layered liquid, the bottom layer being mercury and the top layer being water. The percentage of the volume of the cube remaining above the interface will be, approximately
(a) 68 (b) 63
(c) 40 (d) 25

[ESE : 2001]

4.6 Consider the following statements related to buoyancy in fluid statics:
1. Principle of buoyancy is applicable both to floating bodies and to submerged bodies.
2. Archimedes formulated the first theory of buoyancy.
3. In analyzing buoyancy of a floating body it is assumed that the resultant vertical force passes through centre of pressure.
4. In a free-body diagram of a floating body summation of all horizontal forces is taken as zero.

Which of these statements are correct?
(a) 1, 3 and 4 (b) 1, 2 and 4
(c) 1, 2 and 3 (d) 2, 3 and 4

[ESE : 2003]

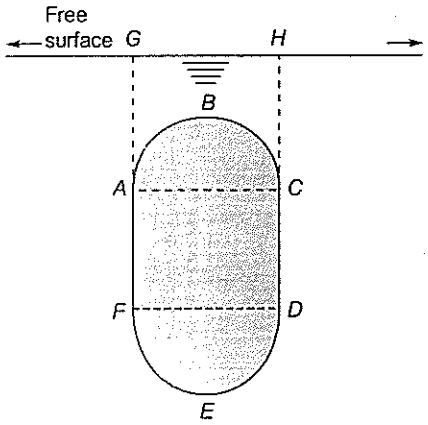
4.7 A solid cylinder of length L, diameter D and specific gravity 0.6 floats in neutral equilibrium in water with its axis vertical. What is the ratio of L to D?

(a) $\frac{\sqrt{3}}{2}$ (b) $\frac{2\sqrt{3}}{5}$

(c) $\frac{4}{5\sqrt{3}}$ (d) $\frac{5}{4\sqrt{3}}$

[ESE : 2004]

4.8 Consider the figure below relating to buoyancy in water.



What will be the downward force upon the top of the body *ABCDEF*?

(a) The weight of the liquid column *ABCHG*
(b) The weight of the liquid column *DEFGH*
(c) The weight of the liquid column *ABCHG* – the weight of the liquid column *DEFGH*
(d) The weight of the liquid column *ABCHG* + the weight of the liquid column *DEFGH*

[ESE : 2009]

4.9 A ship has a metacentric height of 0.90 m and its period of rolling is 20 seconds. The relevant radius of gyration is nearly

(a) 5.5 m (b) 7.5 m
(c) 9.5 m (d) 11.5 m

[ESE : 2015]

4.10 A solid cylinder of length H, diameter D and of relative density S floats in neutral equilibrium in water with its axis vertical. What is the ratio of H to D if $S = 0.6$?

(a) 0.86 (b) 0.72
(c) 0.52 (d) 0.46

[ESE : 2016]

4.11 A solid cylinder of circular section of diameter d is of material with specific gravity S_s. This floats in a liquid of specific gravity S_l. What is the maximum length of the cylinder if equilibrium is to be stable with the cylinder axis vertical?

(a) $\dfrac{dS_s}{2\sqrt{S_s(S_l - S_s)}}$ (b) $\dfrac{dS_l}{\sqrt{8S_s(S_l - S_s)}}$

(c) $\dfrac{dS_l}{\sqrt{2S_s(S_l - S_s)}}$ (d) $\dfrac{d}{\sqrt{8(S_l - S_s)}}$

[ESE : 2016]

4.12 An ocean liner, 240 m long and 24 m wide, displaces 654 MN of sea-water ($\rho = 1025$ kgf/m^3). The second moment of inertia of the water plane about its fore-aft axis is 2/3 of that of the circumscribing rectangle. The position of the centre of buoyance is 2.30 m below the centre of gravity. How high is metacentre above the centre of buoyancy (to the nearest cm)?

(a) 49 cm (b) 53 cm
(c) 58 cm (d) 65 cm

[ESE : 2017]

■■■■

Answers Buoyancy & Floatation

4.1 (a) 4.2 (d) 4.3 (c) 4.4 (d) 4.5 (c) 4.6 (b) 4.7 (d) 4.8 (a) 4.9 (c)
4.10 (b) 4.11 (b) 4.12 (b)

Explanations Buoyancy & Floatation

4.1 (a)

The centre of pressure from free surface is

$$h_p = h_c + \frac{I_G}{Ah_c}$$

where

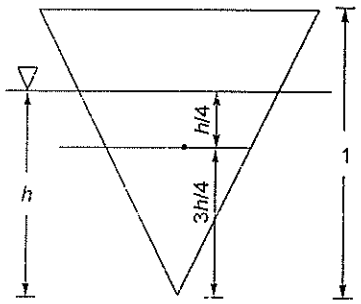
h_c is depth of centroid from free surface

I_G is moment of inertia of vertical plane about horizontal centroidal axis

A is area of the plane

As depth of immersion increases, h_c increases and therefore $\frac{I_G}{Ah_c}$ decreases. It means that centre of pressure comes closer to centroid.

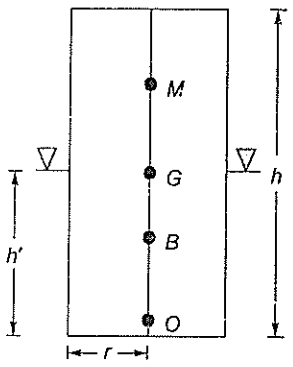
4.2 (d)



The centre of buoyancy from the water surface is $h/4$. So centre of buoyancy from apex is $3h/4$.

4.3 (c)

For unstable floatation GM < 0 i.e., metacentric height will be less than zero.



$$h'\pi r^2 = Sh\pi r^2$$

$$h = h'/S$$

$$OB = h'/2$$

$$OG = h/2$$

$$BM = I_G/V$$

$$r = \frac{2}{3}h = \frac{\pi r^4/4}{\pi r^2 h'} = \frac{r^2}{4h'}$$

$$= \frac{r^2}{4Sh} = \frac{\left(\frac{2}{3}h\right)^2}{4Sh} = \frac{h}{9S}$$

$$BG = \frac{h}{2}(1-S)$$

$$GM = BM - BG$$

$$= \frac{h}{9S} - \frac{h}{2}(1-S) < 0$$

$$= 2 - 9S + 9S^2 < 0$$

$$= 2 - 6S - 3S + 9S^2 < 0$$

$$= 2(1-3S) - 3S(1-3S) < 0$$

$$= (1-3S)(2-3S) < 0$$

$$S > \frac{1}{3} \text{ and } S < \frac{2}{3}$$

So $\frac{1}{3} < S < \frac{2}{3}$

4.4 (d)

Since metacentre is below centre of gravity the body is in unstable equilibrium in rotation.

4.5 (c)

Let the percentage of cube remain above interface is p. The buoyancy force is $\rho_w(0.01p) \times 15^3 g + 13.6\rho_w(1-0.01p) \times 15^3 g$

This will be equal to the weight of the cube $= 8.6\rho_w 15^3 g$

$\therefore\ 0.01p + 13.6\,(1-0.01p) = 8.6$

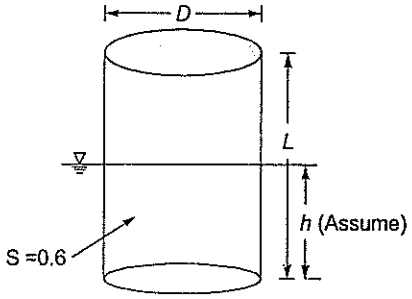
$12.6 \times 0.01p = 13.6 - 8.6 = 5$

$\therefore\ p = 39.7\%$

4.6 (b)

The resultant vertical force passes through centre of buoyancy.

4.7 (d)



$GM = 0$

$$\frac{I}{V_{Dis}} - BG = 0$$

$$\frac{\frac{\pi D^4}{64}}{\frac{\pi D^2}{4} \times h} = \frac{L}{2} - \frac{h}{2}$$

$$\frac{D^2}{8h} = L - h \qquad ...(i)$$

Force balancing

Weight of body = F_B

$$(600)\frac{\pi D^2}{4} \times L \times g = 10^3 \times \frac{\pi D^2}{4} \times h \times g$$

$$h = 0.6\,L \qquad ...(ii)$$

From (i) and (ii)

$$\frac{D^2}{8(0.6L)} = L - 0.6\,L$$

$$\frac{D^2}{L^2} = 8(0.6)(0.4)$$

$$\frac{D}{L} = \frac{4\sqrt{3}}{5}$$

or $$\frac{L}{D} = \frac{5}{4\sqrt{3}}$$

4.8 (a)

The downward force upon the top of the body *ABCDEF* will be equal to the weight of the liquid contained in the portion *ABC* extending vertically above the curved surface upto the free surface of the liquid.

4.9 (c)

Time period,

$$T = 2\pi\sqrt{\frac{k^2}{g\overline{GM}}} \text{ seconds}$$

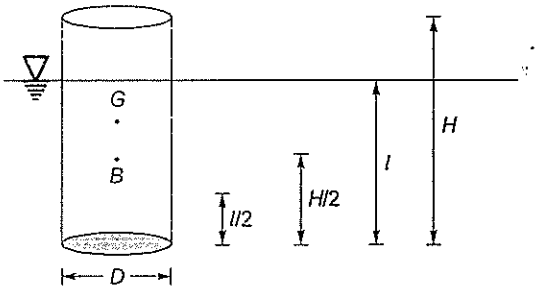
k = radius of gyration

GM = metacentric height = 0.90 m

$$20 = 2\pi\sqrt{\frac{k^2}{9.81 \times 0.9}}$$

$k = 9.5$ m

4.10 (b)



$$F_B = M_b \cdot g$$

$$(10^3)\left(\frac{\pi D^2}{4}\right) \cdot l \cdot g = (600) \cdot g \cdot H\left(\frac{\pi D^2}{4}\right)$$

$$l = 0.6\,H \qquad ...(i)$$

For Neutral equilibrium,

$GM = 0$

$$\frac{I}{\forall} - BG = 0$$

$$\frac{\frac{\pi D^4}{64}}{\frac{\pi D^2 \cdot l}{4}} - \frac{1}{2}[H - l] = 0$$

$$\frac{D^2}{16} - \frac{1}{2}[H - l] = 0$$

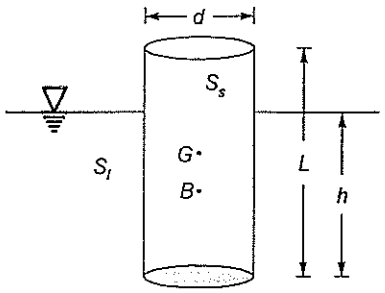
$$\frac{D^2}{8} = H - l$$

$$\frac{D^2}{8l} = H[1 - 0.6]$$

$$\frac{H^2}{D^2} = \frac{1}{8 \times 0.6 \times 0.4}$$

$$\frac{H}{D} = 0.721$$

4.11 (b)



$$M_b g = F_B$$

$$\rho_s \left[\frac{\pi d^2}{4}\right] Lg = \rho_l \left[\frac{\pi d^2}{4}\right] hg$$

$$\rho_s L = \rho_l h$$

$$h = \frac{\rho_s}{\rho_l} \times L$$

or $$h = \frac{S_s}{S_l} \times L \quad \text{...(i)}$$

Take GM = 0

$$\frac{I}{\forall} - BG = 0$$

$$\frac{\frac{\pi d^4}{64}}{\frac{\pi d^2}{4} \times h} - \frac{1}{2}(L-h) = 0$$

$$\frac{d^2}{16h} - \frac{1}{2}[L-h] = 0$$

$$\frac{d^2}{8h} = L - h$$

$$d = \sqrt{8h(L-h)}$$

$$= \sqrt{8\frac{S_l}{S_l} L\left(L - \frac{S_s L}{S_l}\right)}$$

$$= L\sqrt{8\frac{S_s}{S_l}\left[1 - \frac{S_s}{S_l}\right]}$$

$$= \frac{L}{S_l}\sqrt{8S_s[S_l - S_s]}$$

$$L = \frac{d \times S_l}{\sqrt{8S_s(S_l - S_s)}}$$

4.12 (b)

$\rho_{\text{sea water}} \times \forall_{\text{dis}} \times g$ = weight of displaced water

$$1025 \times \forall_{\text{dis}} \times 9.81 = 654 \times 10^6$$

$$\forall_{\text{dis}} = 65040.65\,\text{m}^3$$

$$\frac{I}{\forall_{\text{dis}}} - \text{BG} = \text{GM}$$

$$\frac{\frac{2}{3} \times 240 \times \frac{24^3}{12}}{65040.65} - 2.3 = \text{GM}$$

$$2.833 - 2.3 = \text{GM}$$

So, GM = 0.533 m

= 53.3 cm

≃ 53 cm

5 Fluid Kinematics

5.1 Match List-I with List-II select the correct answer using the codes given below the lists:

List-I

A. Stream lines
B. Streak line
C. Path lines
D. Equipotential lines

List-II

1. Tracing of motion of any fluid particle
2. Tracing of motion of different fluid particles
3. Identification of location of number of fluid particles
4. Orthogonal to streak lines
5. Location of equal piezometric heads

Codes:

	A	B	C	D
(a)	2	3	4	5
(b)	3	2	1	4
(c)	1	2	4	3
(d)	2	3	1	5

[ESE : 1995]

5.2 The stream function for a two-dimensional flow is given by $\psi = 2xy$. The velocity at (2, 2) is

(a) $4\sqrt{2}$ (b) 4
(c) $2\sqrt{2}$ (d) $\sqrt{2}$

[ESE : 1995]

5.3 Consider the following parameters related to fluid flow:

1. Vorticity
2. Velocity potential
3. Stream function

Among these, those which exist both in rotational flows and irrotational flows should include

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

[ESE : 1995]

5.4 Assertion (A): $\psi = 14.14y - 10x$ represents uniform flow at an angle of 45° to the X-axis with a velocity of 24.14 units along the X-axis.

Reason (R): The velocity component is derivable from the appropriate sum of the partial derivatives.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1996]

5.5 Given $\phi = 3xy$ and $\psi = \frac{3}{2}(y^2 - x^2)$, the discharge passing between the streamlines through the points (1, 3) and (3, 3) is

(a) 2 units (b) 4 units
(c) 8 units (d) 12 units

[ESE : 1996]

5.6 In a parallel two-dimensional flow in the positive x-direction, the velocity varies linearly from zero at $y = 0$ to 75 m/sec at $y = 1$ m. The expression for ψ is given by

(a) $22.5y^2$ (b) $30.0y^2$
(c) $37.5y^2$ (d) $45.0y^2$

[ESE : 1996]

5.7 Which of the following conditions will be satisfied by steady irrotational flow?

1. $\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} = 0$
2. $\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = 0$
3. $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

[ESE : 1997]

5.8 **Assertion (A):** The following potential function in two-dimensional flow field represents irrotational flow $\phi = 2x^2 - 3y^2$

Reason (R): For the given function $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

5.9 In steady flow of a compressible fluid through a pipe, the density, area and velocity at a particular section are 1.5 kg/m^3, 0.5 m^2 and 3 m/s, respectively. At another section the density and area are 0.75 kg/m^3 and 1.0 m^2 respectively. What is the velocity at this section?

(a) 1.5 m/s (b) 3.0 m/s
(c) 4.5 m/s (d) 6.0 m/s

[ESE : 1998]

5.10 The velocity potential ϕ at any point for a two dimensional steady irrotational flow in polar co-ordinates, is given by (with usual notations)

$\phi = \frac{m\cos\theta}{r}$

This equation represents a

(a) vortex (b) sink
(c) source (d) doublet

[ESE : 1998]

5.11 Which one of the following can be a set of velocity components of a two-dimensional flow?

(a) $u = x + y$ and $v = x^2 + y^2$
(b) $u = x + y$ and $v = x - y$
(c) $u = xy$ and $v = \frac{x}{y}$
(d) $u = x^2 + y^2$ and $v = x^2 - y^2$

[ESE : 1999]

5.12 For stream function $\psi = 3x^2 - y^3$, the magnitude of velocity at the point (2, 1) is

(a) 12.37 (b) 12
(c) 13 (d) 13.5

[ESE : 1999]

5.13 A two-dimensional flow is described by velocity components $u = 2x$ and $v = -2y$. The discharge between points (1, 1) and (2, 2) is equal to

(a) 9 units (b) 8 units
(c) 7 units (d) 6 units

[ESE : 2000]

5.14 The stream function for a two-dimensional flow is given by $\psi = 2xy$. The resultant velocity at a point $P(2, 3)$ is

(a) 8.45 units/s (b) 7.21 units/s
(c) 6.44 units/s (d) 5.18 units/s

[ESE : 2003]

5.15 Consider the following parameters related to fluid flow:

1. Vorticity
2. Velocity potential
3. Stream function

Which of these parameters exist both in rotational and irrotational flows?

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

[ESE : 2003]

5.16 Consider the following statements related to concept of continuity equation and the concept of control volume in deriving the equation:

1. Continuity equation relates velocity component and density of the fluid at a point in a fluid flow.
2. Continuity equation assumes that no void occurs in the fluid and fluid mass is neither created nor destroyed.
3. The shape of control volume for deriving the equation of continuity is assumed to be a parallelepiped.
4. For incompressible fluids the equation of continuity does not contain the viscosity terms.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1 and 2
(c) 2, 3 and 4 (d) 1 and 4

[ESE : 2003]

5.17 Match List-I (Format of representation) with List-II (Context/Relevant to) and select the correct answer using the codes given below the lists:

List-I

A. $\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}$

B. $\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}$

C. $u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}$

D. $\frac{q\theta}{2\pi}$

List-II

1. Relevant to a velocity potential
2. Rate of rotation about a relevant axis
3. Pressure gradient in a relevant direction
4. Continuity of flow

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	4	1	3	2
(c)	3	1	4	2
(d)	4	2	3	1

[ESE : 2007]

5.18 If the stream function $\psi = 3x^2 - y^3$, what is the magnitude of velocity at point (2, 2)?

(a) 9 (b) 13
(c) 15 (d) 17

[ESE : 2007]

5.19 A streamlined body is one for which the

(a) skin friction is zero
(b) thickness of the body is less than 1/100 of its length
(c) corners are rounded off
(d) separation occurs, if at all, at the farthest downstream part of the body

[ESE : 2007]

5.20 Consider the following statements:

1. Fluids of low viscosity are all irrotational.
2. Rotation of the fluid is always associated with shear stress.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2008]

5.21 Consider the following statements in respect of two-dimensional incompressible flow with velocity components u and v in x and y directions respectively:

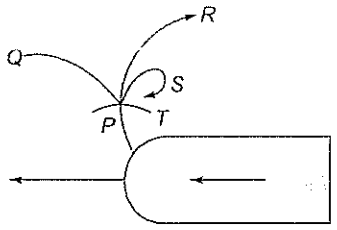
1. The continuity equation is $\frac{\partial u}{\partial x}=\frac{\partial v}{\partial y}$
2. The acceleration in x-direction is $a_x=\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}$
3. The condition of irrotationality is $\frac{\partial u}{\partial y}=\frac{\partial v}{\partial x}$
4. The equation of a streamline is $udy = -vdx$

Which of these statements are correct?

(a) 2 and 3 only (b) 1 and 2 only
(c) 1, 2 and 3 (d) 3 and 4

[ESE : 2009]

5.22 Match List-I (Name of curve) with List-II (Curve in figure) and select the correct answer using the codes given below the lists:



List-I	List-II
A. Equipotential line	1. *PQ*
B. Pathline	2. *PR*
C. Streakline	3. *PS*
D. Streamline	4. *PT*

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	4	1	3	2
(c)	2	1	3	4
(d)	4	3	1	2

[ESE : 2010]

5.23 Consider the following statements:

1. A streamline is an imaginary line within the flow for which the normal at any point relates to the acceleration at that point.
2. Convective acceleration is the change in velocity with respect to distance only.

3. Temporal acceleration expresses variation of velocity with respect to time only.
4. Both convective acceleration and temporal acceleration can coexist.

Which of these statements are correct related to fluid kinematics?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2 and 3 only (d) 2, 3 and 4 only

[ESE : 2010]

5.24 Consider the following statements:

1. There is no flow across a streamline.
2. Streamline spacing varies directly with velocity at the section.
3. Streamlines do not cross.
4. In steady flow, streamline pattern does not change with time.

Which of these statements in respect of stream flow pattern are correct?

(a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 1, 3 and 4 only (d) 2, 3 and 4 only

[ESE : 2011]

5.25 Flow measurements with a Prandtl-Pitot tube showed that the tip readings varied only across the flow while the side-opening readings varied only in the direction of flow. The type of flow is

(a) Uniform irrotational
(b) Uniform rotational
(c) Non-uniform irrotational
(d) Non-uniform rotational

[ESE : 2013]

5.26 An open cylindrical tank of 75 cm diameter and 1.5 m high contains water upto 1.2 m depth. If the cylinder is rotated about its vertical axis, what is the maximum angular velocity (in radians per second) that can be attained without spilling any water?

(a) 7.55 (b) 8.08
(c) 9.15 (d) 10.02

[ESE : 2013]

5.27 X-component of velocity in a two dimensional incompressible flow is given by $u = 2y^2 + 6xy$. If the Y-component of velocity v is zero at $y = 0$, the expression for Y-component of velocity is given by

(a) $v = 3y^2 + f(y)$ (b) $v = 3y^2 + f(x)$
(c) $v = -3y^2 + f(y)$ (d) $v = -3y^2 + f(x)$

[ESE : 2013]

5.28 In a two-dimensional flow, with its stream function $\psi = 2xy$, the velocity at a point (3, 4) is

(a) 12.0 units (b) 10.0 units
(c) 8.0 units (d) 6.0 units

[ESE : 2016]

5.29 A fluid flow is described by a velocity fluid $\vec{U} = 4x^2 i - 5x^2 yj + 1k$.

What is the absolute velocity (in magnitude) at the point (2, 2, 1)?

(a) $\sqrt{1802}$ (b) $\sqrt{1828}$
(c) $\sqrt{1840}$ (d) $\sqrt{1857}$

[ESE : 2016]

5.30 A line source of strength 15π m/s is situated within a uniform stream flowing at –12 m/s (i.e. right to left). At a distance of 0.6 m downstream from the source is an equal sink. How far will the stagnation points be from the nearest source/sink?

(a) 0.38 m (b) 0.46 m
(c) 0.52 m (d) 0.58 m

[ESE : 2016]

5.31 The velocity of water at the outer edge of a 60 cm diameter whirlpool, where the water level is horizontal is 2.5 m/s. The velocity of water at a level where the diameter of the whirlpool is 15 cm, is

(a) 1 m/s (b) 5 m/s
(c) 8 m/s (d) 10 m/s

[ESE : 2016]

5.32 A cylindrical vessel with closed bottom and open top is 0.9 m in diameter. What is the rotational speed about its vertical axis (with closed bottom below and open top above) when the contained incompressible fluid will rise 0.5 m at the inner circumference of the vessel and a space of 0.4 m diameter at the bottom will have no fluid thereon? Take $g = 10$ m/s^2.

(a) 650 rpm (b) 600 rpm
(c) 580 rpm (d) 470 rpm

[ESE : 2016]

5.33 A fluid flow field is given by

$$U = 2xyi + yzj - \left(2yz + \frac{z^2}{2}\right)k.$$

1. The flow is viscous.
2. The flow is steady.
3. The flow is incompressible.
4. The magnitude of the total velocity vector at a point (1, 4, 3) is nearest to 27 units.

Which of the above statements are correct?

(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

[ESE : 2017]

Answers Fluid Kinematics

5.1	(d)	5.2	(a)	5.3	(c)	5.4	(d)	5.5	(d)	5.6	(c)	5.7	(b)	5.8	(d)	5.9	(b)
5.10	(d)	5.11	(b)	5.12	(a)	5.13	(d)	5.14	(b)	5.15	(c)	5.16	(a)	5.17	(d)	5.18	(d)
5.19	(d)	5.20	(b)	5.21	(a)	5.22	(d)	5.23	(d)	5.24	(c)	5.25	(d)	5.26	(c)	5.27	(d)
5.28	(b)	5.29	(d)	5.30	(a)	5.31	(d)	5.32	(*)	5.33	(c)						

Explanations Fluid Kinematics

5.1 (d)

Streamlines are space curves drawn tangential to the velocity vector at all points in the flow field at any instant of time. Geometrically, they represent Eulerian approach for flow velocity description. They cannot intersect each other.

Streak line is the locus of the temporary location of all particles that have passed through a fixed point in the flow field.

5.2 (a)

$$u = -\frac{\partial \psi}{\partial y} = -2x$$

and $$v = \frac{\partial \psi}{\partial x} = 2y$$

At point (2, 2)

$u = -4$ units and $v = 4$ units

$$\therefore \quad V = \sqrt{u^2 + v^2}$$

$$= \sqrt{(-4)^2 + (4)^2}$$

$$= 4\sqrt{2}\,\text{units}$$

5.3 (c)

Stream function is a consequence of continuity equation. Vorticity is defined as

$$\vec{\Omega} = \vec{\nabla} \times \vec{V} = 2\vec{\omega}$$

For irrotational flow $\vec{\Omega} = 0$

The velocity potential function is derived from the condition of irrotationality. Thus in rotational flow there will be non-zero vorticity and velocity potential function can not be defined.

5.4 (d)

$$\psi = 14.14y - 10x$$

$$u = -\frac{\partial \psi}{\partial y} = -14.14 \text{ units}$$

Hence assertion (A) is wrong.

5.5 (d)

$$dQ = |d\psi| = |\psi_2 - \psi_1|$$

at (1, 3) $\psi_1 = \frac{3}{2}(3^2 - 1^2) = 12$ units

at (3, 3) $\psi_2 = 0$ units

$\therefore \quad dQ = 12$ units

5.6 (c)

The velocity $u = 75$

using $$u = \frac{\partial \psi}{\partial y}$$

$$\psi = 37.5y^2$$

5.7 (b)

For steady irrotational flow vorticity will be zero and continuity equation will be satisfied.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \text{[continuity equation]}$$

$$\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = 0 \quad \text{[zero vorticity]}$$

5.8 (d)

$$\phi = 2x^2 - 3y^2$$

ϕ must satisfy Laplace eq. Here

$$\nabla^2\phi = 4 - 6 \neq 0$$

So ϕ function is not valid here.

So assertion (A) is wrong.

5.9 (b)

Continuity equation for fluid flow is

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

$$V_2 = \frac{1.5 \times 0.5 \times 3}{0.75 \times 1} = 3\text{m/s}$$

5.10 (d)

Flow type	Stream function (ψ)	Velocity potential (ϕ)
A. Vortex (free)	$-\frac{C}{2\pi} lnr$	$\frac{C}{2\pi}\theta$
B. Sink	$-\frac{q}{2\pi}\theta$	$-\frac{q}{2\pi} lnr$
C. Source	$\frac{q}{2\pi}\theta$	$\frac{q}{2\pi} lnr$
D. Doublet	$-\frac{m\sin\theta}{r}$	$\frac{m\cos\theta}{r}$

5.11 (b)

For velocity components of a two or three dimensional flow continuity equation $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$ should be satisfied.

5.12 (a)

$$u = -\frac{\partial \psi}{\partial y} = 3y^2 = 3\text{units}$$

$$v = \frac{\partial \psi}{\partial x} = 6x = 12\text{units}$$

$$V = \sqrt{u^2 + v^2} = 12.37 \text{ units}$$

5.13 (d)

$$v = \frac{\partial \psi}{\partial x} = -2y \quad \text{...(i)}$$

$$u = -\frac{\partial \psi}{\partial y} = -2x \quad \text{...(ii)}$$

Integrating (i), we get

$$\psi = -2xy + f(y) \quad \text{...(iii)}$$

Differentiating (iii) w.r.t. y, we get

$$\frac{\partial \psi}{\partial y} = -2x + f'(y) \quad \text{...(iv)}$$

Equating (ii) and (iv), we get

$$f'(y) = 0 \quad \text{...(v)}$$

Inegrating (v), we get

$$f(y) = C$$

where C is a numerical constant which can be treated as zero.

From (iii), we get

$$\psi = -2xy$$

At (1, 1); $\psi_1 = -2$ units

At (2, 2); $\psi_2 = -8$ units

$$dQ = |d\psi| = |\psi_2 - \psi_1|$$
$$= 8 - 2 = 6 \text{ units}$$

5.14 (b)

$$u = -\frac{\partial \psi}{\partial y} = -2x = -4\text{units}$$

$$v = \frac{\partial \psi}{\partial x} = 2y = 6\text{units}$$

$$V = \sqrt{u^2 + v^2} = \sqrt{16 + 36}$$
$$= 7.21 \text{ units}$$

5.15 (c)

Velocity potential does not exist in rotational flow.

5.16 (a)

Continuity equation is mathematical form of principle of conservation of mass. It also assumes the continuum of fluid i.e. there are no air voids in the fluid.

The continuity equation from control volume approach is

$$\frac{\partial}{\partial t}\iiint_{CV} \rho dV + \iint_{CS} \rho \cdot \vec{V} \cdot d\vec{A} = 0 \text{ [Integral form]}$$

where

dV is volume of differential element

CV is control volume

CS is control surface

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot (\rho \vec{V}) = C \quad \text{[Differential form]}$$

5.18(d)

Stream function, $\psi = 3x^2 - y^3$

$$\therefore \quad \frac{\partial \psi}{\partial x} = 6x \text{ and } \frac{\partial \psi}{\partial y} = -3y^2$$

But $$u = -\frac{\partial \psi}{\partial y}$$

$$= -(-3y^2) = 3 \times 2^2 = 12$$

$$v = \frac{\partial \psi}{\partial x} = 6x = 6 \times 2 = 12$$

$\therefore$ Resultant velocity $= \sqrt{u^2 + v^2}$

$$= \sqrt{(12)^2 + (12)^2} = \sqrt{288}$$

$$= 16.97 \approx 17$$

5.19(d)

A streamlined body is defined as that body whose surface coincides with the streamlines, when the body is placed in a flow. For a well streamlined body the separation occurs only at the downstream end. As such the wake in this case is very small and consequently the pressure drag is also small. Thus, the total drag on the stream lined body will be due to friction only.

5.20(b)

Rotation of fluid is always associated with shear stresses. When the particles of fluid rotate, there is some torque acting on them which results in shear stresses which are eventually associated with viscous forces. In case of irrotational motion, there is no torque and hence there is no shear stress and thereby viscous forces are zero, which is true for ideal fluids. Thus ideal fluid flow is sometimes called as irrotational flow.

5.21(a)

For two dimensional incompressible flow,

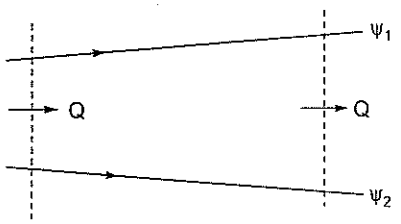
(i) the continuity equation is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$

(ii) the equation of a stream line is $vdx - udy = 0$

5.23 (d)

A streamline is an imaginary curve drawn through a flowing fluid in such a way that the tangent to it at any point gives the direction of the velocity of flow at that point.

5.24 (c)

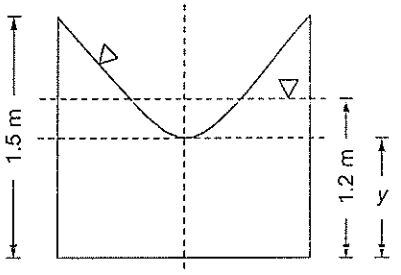


The space between the streamlines $\psi_1 - \psi_2$ shows the discharge per unit width. As the space between the streamlines increases velocity decreases so the discharge remains same. So streamlines spacing is inversely proportional to velocity. Thus statement 2 is incorrect.

5.25 (d)

As tip reading varied only across the flow while side-opening reading varied only in the direction of flow, velocity of flow is not constant in the direction of flow. Hence the flow is non-uniform rotational.

5.26 (c)



$$R = \frac{75}{2}\text{cm} = 0.375 \text{ m}$$

$\because$ Vol. of water is constant

$$\therefore \quad V_i = V_f$$

$$\Rightarrow \frac{\pi}{4}(0.75)^2(1.2) = \frac{\pi}{4}(0.75)^2 y + \frac{\frac{\pi}{4}(0.75)^2(1.5-y)}{2}$$

$$\Rightarrow \quad 1.2 = y + \frac{1.5-y}{2}$$

$$\Rightarrow \quad 2.4 = y + 1.5$$

$$\Rightarrow \quad y = 0.9 \text{ m}$$

$$\therefore \quad 1.5 - y = 1.5 - 0.9 = 0.6 \text{ m}$$

$$1.5 - y = \frac{\omega^2 r^2}{2g}$$

$$\Rightarrow \quad 0.6(2)9.81 = \omega^2(0.375)^2$$

$$\Rightarrow \quad \omega = 9.15 \text{ rad/s}$$

5.27 (d)

$$u = 2y^2 + 6xy$$

From continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

$$\Rightarrow \quad -6y = \frac{\partial v}{\partial y}$$

$$\Rightarrow \quad v = -3y^2 + C$$

At $y = 0, v = 0 \qquad [\because C = 0]$

$$\therefore \quad v = -3y^2 + f(x)$$

5.28 (b)

$$\psi = 2xy$$

$$u = -\frac{\partial \psi}{\partial y} = -2x = -(2)(3)$$

$$= -6 \text{ units}$$

$$v = \frac{\partial \psi}{\partial x} = 2y = 2(4) = 8 \text{ units}$$

Velocity of (3, 4),

$$V = \sqrt{(-6)^2 + (8)^2} = 10 \text{ units}$$

5.29 (d)

$$\vec{V} = 4x^2\hat{i} - 5x^2y\,\hat{j} + 1\hat{k}$$

$$u = 4\,(2)^2 = 16$$

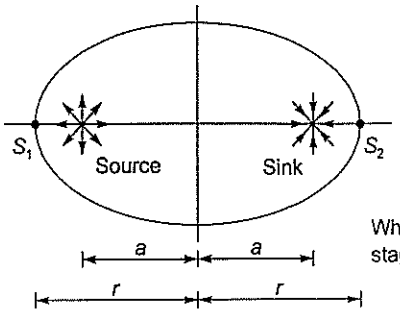
$$v = -5x^2y = -5(2)^2(2) = -40$$

$$w = 1$$

$$V = \sqrt{16^2 + (-40)^2 + 1^2}$$

$$= \sqrt{1857} \text{ m/sec}$$

5.30 (a)



Where S_1 and S_2 are stagnation point.

Given, $a = \frac{0.6}{2} = 0.3$ m

$u = 12$ m/sec

Now, $r = a\sqrt{\frac{Q}{\pi a U_\infty} + 1}$

$$0.3 = \sqrt{\frac{15\pi}{\pi(0.3)(12)} + 1}$$

$$= 0.6819 \text{ m}$$

So, $r - a = 0.6819 - 0.3$

$$= 0.381 \text{ m}$$

5.31 (d)

$$V \cdot r = \text{constant}$$

$$2.5 \times 30 = V \times 7.5$$

$$V = 10 \text{ m/sec}$$

6 Fluid Dynamics, Flow Measurements

6.1 In fluid flow, the line of constant piezometric head passes through two points which have the same
(a) elevation
(b) pressure
(c) velocity
(d) velocity potential

[ESE : 1995]

6.2 **Assertion (A):** Pressure intensity in a liquid flow is a form of energy.
Reason (R): The pressure gradient is a measure of the rate of energy dissipation in steady uniform flow.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

6.3 Two small orifices A and B of diameters 1 cm and 2 cm, respectively, are placed on the sides of a tank at depths of h_1 and h_2 below the open liquid surface. If the discharges through A and B are equal, then the ratio of h_1 and h_2 (assuming equal C_d values) will be
(a) 16 : 1 (b) 8 : 1
(c) 4 : 1 (d) 2 : 1

[ESE : 1997]

6.4 A right circular cylinder, open at the top, is full of water. It is rotated about the vertical axis at such a speed that half the liquid spills out. The pressure at the centre of the bottom would be
(a) one half of the original magnitude when the cylinder was full
(b) one-fourth of the original magnitude when the cylinder was full
(c) unchanged
(d) zero

[ESE : 1997]

6.5 A cylindrical vessel of radius 42.31 cm and height 1 m is open at the top. It holds water to half its depth. Which one of the following values approximates the speed at which the cylinder is to be rotated about the vertical axis, so as to make the apex of the paraboloid just reach the centre of the bottom of the vessel?
(a) 100 rpm (b) 150 rpm
(c) 250 rpm (d) 300 rpm

[ESE : 1998]

6.6 The coefficient of velocity for an orifice is given by (using usual notations)

(a) $\frac{x}{2\sqrt{yH}}$ (b) $\frac{2x}{\sqrt{yH}}$

(c) $\frac{x}{\sqrt{yH}}$ (d) $\sqrt{\frac{x^2}{2yH}}$

[ESE : 1998]

6.7 Match List-I (Name of instrument) with List-II (Variable measured) and select the correct answer using the codes given below the lists:

List-I
A. Hot-wire anemometer
B. Orifice meter
C. Pitot tube
D. Preston tube

List-II
1. Boundary shear stress
2. Discharge
3. Mean velocity
4. Pressure
5. Turbulence

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	5	2	3	4
(c)	2	5	1	3
(d)	5	2	3	1

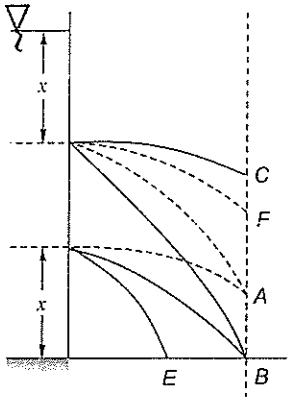
[ESE : 1998]

6.8 A 30 cm diameter, 90° elbow has one limb vertical. Average velocity of flow of water through the elbow is 5 m/s and the pressure intensity is 4 kPa. The vertical component of force to keep the elbow in position will be

(a) 0.28 kN (b) 1.49 kN
(c) 1.77 kN (d) 2.05 kN

[ESE : 2001]

6.9 One orifice is located at a distance 'x' from the free surface while another orifice is located at the same distance 'x' from the bottom of the tank as shown in the figure.



The water jets through the orifices

(a) intersect at point A
(b) intersect at point B
(c) strike the plane at point C and B respectively
(d) would be striking at E and F only

[ESE : 2002]

6.10 Match List-I (Equation/Principle) with List-II (Property) and select the correct answer using the codes given below the lists:

List-I

A. Energy equation
B. Continuity equation
C. Moment of momentum principle
D. Impulse-momentum principle

List-II

1. Force on a moving vane
2. Lawn sprinkler
3. Pressure at a point in a pipeline
4. Flow at two sections of a tapering pipe

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	1	2
(c)	4	3	1	2
(d)	3	4	2	1

[ESE : 2003]

6.11 Consider the following statements related to a horizontal venturimeter:

1. The velocity of flow in the main pipe is greater and the pressure is lesser than that at the throat section.
2. The velocity of flow in the main pipe is lower and the pressure is larger than that at the throat section.
3. The pressure difference between the main pipe and throat section is positive.
4. The pressure difference between the main pipe and throat section is negative.

Which of these statements are not correct?

(a) 1 and 4 (b) 1 and 2
(c) 2 and 3 (d) 3 and 4

[ESE : 2003]

6.12 When a body moves through still water at a constant velocity of 4.5 m/s, the velocity of water at 0.8 m ahead of the nose of the body is 3.0 m/s. What will be the difference in pressure between the nose and the point 0.8 m ahead of it?

(a) 875 N/m^2 (b) 1000 N/m^2
(c) 1125 N/m^2 (d) 1250 N/m^2

[ESE : 2003]

6.13 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. The type of vortex flow in which no external torque rotates the fluid mass
B. Flow of liquid inside the impeller of a centrifugal pump
C. Free surface of forced vortex flow
D. In forced vortex, the rise of liquid level at ends

List-II

1. The fall of liquid at the axis of rotation
2. Free vortex flow
3. Parabolic
4. Forced vortex flow

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	2	4	3	1
(c)	4	2	1	3
(d)	2	4	1	3

[ESE : 2003]

6.14 Match List-I (Causes) with List-II (Effects) pertaining to rotation and vertical/horizontal motion of liquid masses at constant acceleration and select the correct answer using the codes given below the lists:

List-I

A. The form of the free surface of liquid in a rotating open vessel
B. The form of surface of the liquid in a tanker moving in the direction of its length
C. The pressure at any point in a container's base moving with upward acceleration
D. The pressure at any point in a container's base moving with downward acceleration

List-II

1. An inclined plane
2. A paraboloid of revolution
3. Greater than the hydrostatic value
4. Less than the hydrostatic value

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	4	3	2	1
(c)	2	3	1	4
(d)	2	1	3	4

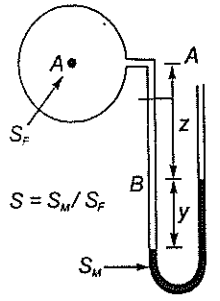
[ESE : 2004]

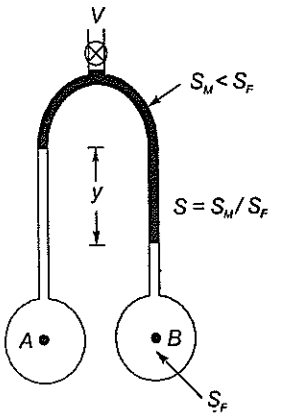
6.15 Match List-I (Features) with List-II (Type of manometers) and select the correct answer using the codes given below the lists:

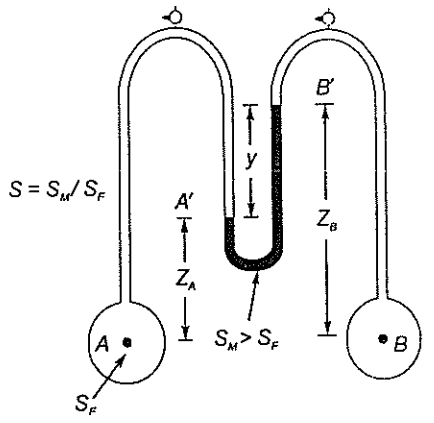
List-I

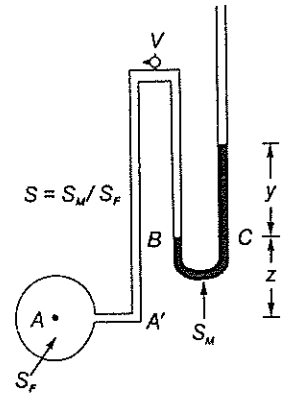
A. Open ended manometer for positive pressure
B. Negative pressure manometer
C. For measuring pressure in liquids or gases
D. For measuring pressure in liquids only

List-II

1.


2.


3.


4.


Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	1	2	3	4
(c)	3	2	1	4
(d)	1	4	3	2

[ESE : 2004]

6.16 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Equation of motion along a streamline
B. Euler's equation
C. Pressure exerted by a free jet
D. Rotating lawn sprinkler

List-II

1. Principle of moment of momentum
2. Bernoulli's equation
3. Equation for conservation of momentum
4. Momentum equation

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2005]

6.17 A Pitot-static tube, with a coefficient of 0.98 is used to measure the velocity of water in a pipe. The stagnation pressure recorded is 3 m and the static pressure is 0.5 m. What is the velocity of flow?

(a) 7.2 m/s (b) 6.8 m/s
(c) 5.9 m/s (d) 5.2 m/s

[ESE : 2006]

6.18 **Assertion (A):** It takes longer to drain a reservoir with a long vertical pipe taken down from its bottom discharging into atmosphere than with an orifice at the bottom.

Reason (R): The relative height of the water surface elevation in the reservoir compensates for the friction loss in the pipe besides the entry and exit losses in the pipe.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2006]

6.19 In an air flow the velocity is measured by a Pitot tube (coefficient = 1.0). The mass density of air can be taken as 1.2 kg/m^3. If the head difference in a vertical U-tube holding water is 12 mm, then what is the velocity of air in m/s?

(a) 10 (b) 14
(c) 17 (d) 20

[ESE : 2007]

6.20 **Assertion (A):** Total energy of flow decreases in the direction of flow.

Reason (R): The specific energy may decrease, increase or remain constant.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2009]

6.21 Consider the following:

1. Force on pipe bends and transitions
2. Jet propulsion
3. Flow velocities in open channel
4. Vortex flow

Which of the above admit employing the moment of momentum equation?

(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 3 only (d) 2, 3 and 4

[ESE : 2009]

6.22 Consider the following statements:

The moment of momentum equation in fluid dynamics can be used

1. to find the torque exerted on sprinklers by water
2. to determine the force in a flow passage, when stream changes direction/magnitude.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2010]

6.23 The movement of air mass in the case of Tornado can be described as

(a) Forced vortex throughout
(b) Free vortex throughout
(c) Forced vortex at the core and free vortex outside
(d) Free vortex at the core and forced vortex outside

[ESE : 2011]

6.24 Consider the following statements:
Euler's equation of motion
1. can be derived from Navier-Stokes equations.
2. refers to energy balance.
3. develops into Bernoulli's equation under appropriate conditions.
4. is applicable to rotational as well as irrotational flows.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 1 and 3 only (d) 3 and 4 only

[ESE : 2013]

6.25 At a distance of 20 cm from the axis of a whirlpool in an ideal liquid, the velocity is 10 m/s. At a radius of 50 cm, what will be the depression of the free surface of the liquid below that at a very large distance?
(Take $1/g = 0.102\ s^2/m$)
(a) 0.408 m (b) 0.612 m
(c) 0.816 m (d) 1.224 m

[ESE : 2013]

6.26 The Bernoulli's equation is applicable to:
(a) Both steady and unsteady flows
(b) Real fluids
(c) All fluids and flows along a stream tube
(d) Steady flow of ideal fluids along a stream tube

[ESE : 2013]

6.27 Statement (I): The integration of differential form of Euler's equation of motion yields to Bernoulli's equation.
Statement (II): Euler's equation is based on the assumption of conservation of mass.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2013]

6.28 A horizontal venturimeter with inlet diameter of 30 cm and throat diameter of 15 cm is used to measure the flow of water. The reading on a differential manometer connected to the inlet and the throat is 20 cm of mercury. If $C_d = 0.98$, the rate of flow is nearly
(a) 12.5 *l*/s (b) 25 *l*/s
(c) 125 *l*/s (d) 250 *l*/s

[ESE : 2014]

6.29 An open rectangular tank of dimensions 4m x 3m x 2m contains water to a height of 1.6m. It is then accelerated along the longer side. What is the maximum acceleration possible without spilling the water? If this acceleration is then increased by 10%, what amount of water will be spilt off?
(a) $1.472\ m/s^2$ and $0.48m^3$
(b) $1.962m/s^2$ and $0.48m^3$
(c) $1.472\ m/s^2$ and $0.52m^3$
(d) $1.962m/s^2$ and $0.52m^3$

[ESE : 2016]

6.30 While conducting the flow measurement using a triangular notch, an error of 2% in head over the notch is observed. The percentage error in the computed discharge would be
(a) +7% (b) –3%
(c) +5% (d) – 4%

[ESE : 2016]

6.31 An orifice is located in the side of a tank with its centre 10 cm above the base of the tank. The constant water level is 1.0m above the centre of orifice. The coefficient of velocity is 0.98. On the issuing jet, the horizontal distance from the vena-contracta to where the jet is 10 cm below vena-contracta is
(a) 1.62m (b) 1.00m
(c) 0.62m (d) 0.32m

[ESE : 2016]

6.32 Statement (I): When flow through a pipeline is measured through fixing a venturimeter, the computed flow will not be sensitive to the alignment of the centre line of the set-up — horizontal or sloping, up or down, along the flow direction.

Statement (II) : The difference in the readings on the manometer limbs is by itself always adjusted for the ratio of the densities of the two liquids — the manometer liquid and the liquid whose flow rate is being measured — in the development of the formula for computing the discharge.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2017]

■■■■

Answers Fluid Dynamics, Flow Measurements, Notches & Weir

6.1 (c)	6.2 (b)	6.3 (a)	6.4 (d)	6.5 (a)	6.6 (a)	6.7 (d)	6.8 (d)	6.9 (b)	
6.10 (d)	6.11 (a)	6.12 (*)	6.13 (b)	6.14 (d)	6.15 (d)	6.16 (b)	6.17 (b)	6.18 (a)	
6.19 (b)	6.20 (b)	6.21 (d)	6.22 (c)	6.23 (c)	6.24 (c)	6.25 (c)	6.26 (d)	6.27 (c)	
6.28 (c)	6.29 (b)	6.30 (c)	6.31 (c)	6.32 (a)					

Explanations Fluid Dynamics, Flow Measurements, Notches & Weir

6.1 (c)

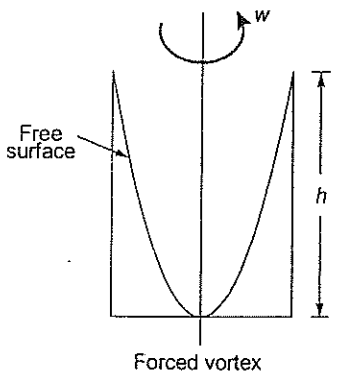
The sum of piezometric head and velocity head remains constant as per Bernoulli's equation. So for constant piezometric head line passing through two points, the velocity will remain same.

6.3 (a)

$$\text{Discharge, } Q = \sqrt{2gh_1}\left(\frac{\pi d_1^2}{4}\right) = \sqrt{2gh_2}\left(\frac{\pi d_2^2}{4}\right)$$

$$\therefore \quad \frac{h_1}{h_2} = \left(\frac{d_2}{d_1}\right)^4 = \left(\frac{2}{1}\right)^4 = 16$$

6.4 (d)



A cylinder rotating about the vertical axis has forced vortex flow. The free surface is paraboloid which has half the volume of cylinder of same height when half the liquid spills out, the centre of the bottom will be exposed and pressure will be zero.

6.5 (a)

Paraboloid reaches the centre of the bottom of the vessel when

$$H = \frac{\omega^2 R^2}{2g}$$

$$\Rightarrow \omega = \frac{\sqrt{2gH}}{R} = 10.469 \text{rad/s}$$

$$\therefore N = \frac{60}{2\pi} \times 10.469 = 100 \text{ rpm}$$

6.6 (a)

Coefficient of velocity can be determined by

(i) jet distance measurement method

$$C_v = \frac{x}{\sqrt{4Hy}} = \frac{x}{2\sqrt{Hy}}$$

(ii) velocity measurement method using Pitot tube at vena-contracta

(iii) momentum method $C_v = \dfrac{Wlg}{W_l y\sqrt{2gh}}$

where W_l is weight of liquid discharged through the orifice.

6.7 (d)

The constant temperature hot-wire anemometer may be conveniently used for velocity measurement even when the velocity fluctuations are large. Thus they can measure turbulence also.

6.8 (d)

$$F = pA + \rho AV^2$$

$$= (4 + 1 \times 5^2) \times \frac{\pi \times 0.3^2}{4}$$

$$= 2.05 \text{ kN}$$

6.9 (b)

Let depth in the tank is H.

For intersection, the horizontal distance travelled should be same. The trajectory

$$x^2 = 4Y_1 x^2 = 4Y_2(H - x)$$

$$\frac{Y_1}{Y_2} = \left(\frac{H-x}{x}\right)$$

Y_1 and Y_2 are the vertical distance of intersection point from top orifice and bottom orifice respectively. So the trajectories intersect at point B.

6.11 (a)

The cross-section area of main pipe is more than that of throat section. Therefore, from continuity equation velocity of flow in main pipe will be lower than that at the throat section. The flow from main pipe to throat takes place due to pressure gradient and therefore pressure in main pipe is more.

6.12 (*)

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g}$$

$$P_1 - P_2 = \frac{1000}{2}\left[4.5^2 - 3^2\right]$$

$$= 500\left[4.5^2 - 3^2\right]$$

$$= 5625 \text{ N/m}^2$$

No any option is given in the problem.

6.13 (b)

In forced vortex flow

- external torque rotates the fluid mass.
- the free surface of liquid is in parabolic shape.
- rise of liquid levels at the ends is equal to the fall of liquid at axis of rotation.

Flow of liquid inside impeller of a centrifugal pump is forced vortex flow.

In free vortex flow no external torque rotates the fluid mass.

6.14 (d)

Form of surface of liquid in

- Rotating open vessel- Paraboloid of revolution
- Tanker moving along length- inclined plane

Pressure at any point when container is:

- Moving downwards with acceleration a, $P = \rho(g - a)h$
- Moving upwards with acceleration a, $P = \rho(g + a)h$

6.16 (b)

The moment of momentum equation can be applied to analyze rotating systems, such as turbines, sprinklers, and fans. Bernoulli's equation is used to applicable to steady incompressible flow along a streamline. Euler's equation is based on conservation of momentum. Pressure exerted by free jet can be analyzed by momentum equation.

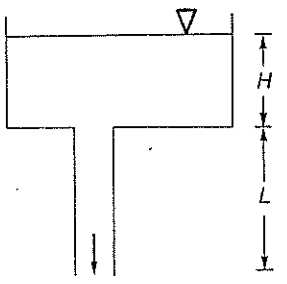
6.17 (b)

$$V = C_v\sqrt{2g\left(\rho_{stag} - \rho_{static}\right)}$$

$$= 0.98 \times \sqrt{2 \times 9.81 \times (3 - 0.5)}$$

$$= 6.86 \text{ m/s}$$

6.18 (a)



Let the length of pipe is L. So the velocity of flow at outlet is $\sqrt{2g(H+L)}$. For orifice the flow velocity will be $\sqrt{2gH}$. Therefore reservoir can be drained earlier with a long vertical pipe taken down from its bottom discharging into the atmosphere. However due to head loss, the speed reduces and the time taken in long vertical Z pipe case is more than that in orifice discharging at the bottom.

6.19 (b)

We know that, if h_1 and h_2 are heights of the columns of liquid of mass density ρ_1 and ρ_2 required to develop the same pressure p, at any point, then

$$p = \rho_1 h_1 = \rho_2 h_2$$

Here $\rho_1 = 1.2\ \text{kg/m}^3$

$\rho_2 = 1000\ \text{kg/m}^3$

$h_2 = 12\ \text{mm}$

$h_1 = ?$

$\Rightarrow 1.2 \times h_1 = 1000 \times 12$

$\therefore \quad h_1 = 10\ \text{m}$

The velocity of air,

$$V_0 = C\sqrt{2gh_1}$$

$$= 1 \times \sqrt{2 \times 9.81 \times 10}$$

$$= 14\ \text{m/s}$$

Alternatively,

$$V_0 = C\sqrt{2gx\left(\frac{S_m}{S} - 1\right)}$$

$$= \sqrt{2 \times 9.81 \times 12 \times 10^{-3} \times \left(\frac{1}{1.2 \times 10^{-3}} - 1\right)}$$

$$= 13.998 \approx 14\ \text{m/s}$$

6.20 (b)

Total energy of flow in real fluid always decreases in the direction of flow. The specific energy depends on elevation of bed of channel relative to elevation of total energy line so in varied flow it can decrease or increase. For uniform flow specific energy is constant.

Both statements are correct but reason does not explain assertion.

6.21 (d)

Force on pope bends employ the impulse momentum equation where as in vortex flow employ the moment of momentum equation. So answer is (d).

6.22 (c)

The moment of momentum equation is also referred to as the angular momentum equation. The moment of momentum equation for a fixed and non deforming control volume can be derived using by taking a material derivative of the angular momentum of a particle.

The moment of momentum equation can be stated in words as follows:

[Sum of external torques acting on the control volume] = [Time rate of change of angular momentum of the control volume] + [net rate of angular momentum flow through the control surface]

The moment of momentum equation can be applied to analyze rotating systems, such as turbines, sprinklers, and fans. In analyzing such systems, the vector form of the equation is often resolved into scalar form, and only the direction along the axis of rotation is considered.

6.23 (c)

For zero rotation of fluid particles about their respective mass centres, the flow is irrotational and the vortex is known as irrotational or free-vortex. If on the other hand, the circulatory flow is such that the fluid particles under go rotation about their mass centres, the flow is rotational and the resulting vortex is known as the forced vortex.

Forced vortex is also known as fly wheel vortex. Free vortex is also known as potential vortex. A combination of free and forced vortex is known as compound vortex or Rankine vortex. In a tornado inner core region experiences forced vortex while outer core region experiences free vortex.

6.24 (c)

The Euler's equation for steady flow of an ideal fluid along a streamline is a relation between the velocity, pressure and density of a moving fluid.

It is based on the Newton's Second Law of Motion. The integration of the equation gives Bernoulli's equation in the form of energy per unit weight of the following fluid.

It is based on the following assumptions:

- (i.e., the frictional losses are zero).
- The fluid is homogeneous and incompressible (i.e., mass density of the fluid is constant).
- The flow is continuous, steady and along the streamline.
- The velocity of the flow is uniform over the section.
- No energy or force (except gravity and pressure forces) is involved in the flow.

6.25 (c)

In a whirlpool in an ideal liquid,

$$v \propto \frac{1}{r} \text{ i.e. } vr = \text{constant}$$

Now, $v_1 = 10$ m/s, $r_1 = 20$ cm

When $r_2 = 50$ cm

$$v_2 = \frac{v_1 r_1}{r_2} = \frac{10 \times 20}{50} = 4 \text{ m/s}$$

According to fundamental equation of vortex flow,

$$dP = \frac{\rho v^2 dr}{r} - \rho g dz \; (dP = 0)\left\{v = \frac{c}{r}\right\}$$

$$dz = \frac{c^2 dr}{gr^3}$$

$$z = \frac{c^2}{g} \times -\frac{1}{2} \times \left[\frac{1}{r^2}\right]_{0.5}^{\infty}$$

$[c = vr = 0.2 \times 10]$

$$z = 0.816 \text{ m}$$

6.26 (d)

Bernoulli's equation is applicable to steady, incompressible flow along a streamline when the effect of viscosity is neglected.

6.27(c)

Euler's equation based on the assumption of conservation of momentum.

6.28(c)

In Venturimeter,

Rate of flow,

$$Q = \frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh}$$

Here, $h = 20\left(\frac{\rho_m}{\rho} - 1\right)$

$= 20\,(13.6 - 1)$

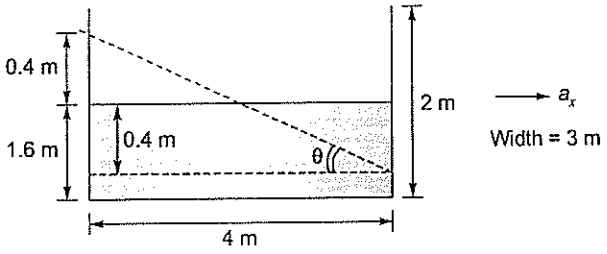
$= 252$ cm

$$\therefore \quad Q = \frac{0.98 \times \frac{\pi}{4} \times 30^2 \times \frac{\pi}{4} \times 15^2}{\sqrt{\left[\frac{\pi}{4} \times 30^2\right]^2 - \left[\frac{\pi}{4} \times 15^2\right]^2}} \times \sqrt{2 \times 981 \times 252}$$

$$= \frac{0.98 \times 30^2 \times \frac{\pi}{4} \times 15^2}{\sqrt{30^4 - 15^4}} \times \sqrt{2 \times 981 \times 252}$$

$= 125.76$ *l*/sec

6.29 (b)



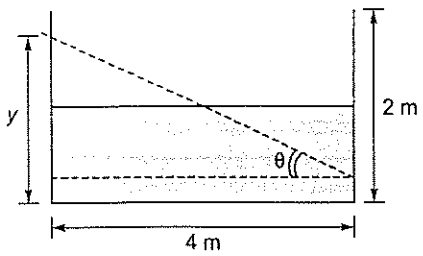
$$\tan\theta = \frac{a_x}{g}$$

$$\frac{0.8}{4} = \frac{a_x}{9.81}$$

$a_x = 1.962$ m/s^2

Now acceleration is increased by 10%

$a_x = 1.962 + 0.1962 = 2.158$ m/sec^2



$$\tan\theta = \frac{y}{4}$$

$$\frac{2.158}{9.81} = \frac{y}{4}$$

$$y = 0.8799 \text{ m}$$

Final volume

$$= (4 \times 3 \times 2) - \left[\frac{1}{2} \times 0.88 \times 4 \times 3\right]$$

$$= 18.72 \text{ m}^3$$

Initial volume

$$= 4 \times 3 \times 1.6 = 19.2 \text{ m}^3$$

Spillout volume

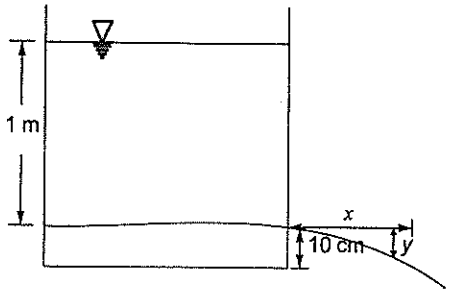
$$= 19.2 - 18.72$$

$$= 0.48 \text{ m}^3$$

6.30 (c)

$$\frac{dQ}{Q} = \frac{5}{2}\frac{dH}{H} = \frac{5}{2} \times 2 = +5\%$$

6.31 (c)



$$C_V = \frac{x}{2\sqrt{y \cdot H}}$$

$$0.98 = \frac{x}{2\sqrt{0.1 \times 1}}$$

$$x = 0.62 \text{ m}$$

7 Viscous Flow of Incompressible Fluid

7.1 Laminar flow occurs between extensive stationary plates. The kinetic energy correction factor is nearly

(a) 1.0 (b) 1.5

(c) 2.0 (d) 2.3

[ESE : 1996]

7.2 In steady laminar flow of a liquid through a circular pipe of internal diameter D, carrying a constant discharge, the hydraulic gradient is inversely proportional to

(a) D (b) D^2

(c) D^4 (d) D^5

[ESE : 1996]

7.3 For laminar flow between parallel plates separated by a distance $2h$, head loss varies

(a) directly as h (b) inversely as h

(c) inversely as h^2 (d) inversely as h^3

[ESE : 1996]

7.4 The highest velocity (in cm/sec) for flow of water of viscosity 0.01 poise to be laminar in a 6 mm pipe is

(a) 100/3 (b) 125/3

(c) 50 (d) 200

[ESE : 1996]

7.5 For laminar flow in a pipe carrying a given discharge, the height of surface roughness is doubled. In such a case, Darcy-Weisbach friction factor will

(a) remain unchanged

(b) be halved

(c) be doubled

(d) increase fourfold

[ESE : 1997]

7.6 In laminar flow, local instability occurs first at a point where (symbols have the usual meaning)

(a) u is maximum

(b) du/dy is maximum

(c) $\rho\frac{uy}{\mu}$ is maximum

(d) $\frac{\rho y^2 \frac{du}{dy}}{\mu}$ is maximum

[ESE : 1997]

7.7 Given that, as flow takes place between two parallel static plates, the velocity midway between the plates is 2 m/s, the Reynolds number is 1200 and the distance between the plates is 10 cm, which of the following statements are true?

1. The velocity of the boundary is 1 m/s.
2. The rate of flow is 0.1 m^3/s/metre width.
3. The flow is turbulent.
4. The energy correction factor is 2.0.

Select the correct answer using the codes given below:

(a) 2 and 3 (b) 2 and 4

(c) 1 and 3 (d) 1, 2, 3 and 4

[ESE : 1997]

7.8 **Assertion (A):** If laminar flow of oil between two points of a given pipeline is doubled, then the power consumption is increased to four times the original power

Reason (R): In laminar flow through circular pipes, head loss varies directly as the discharge.

(a) both A and R are true and R is the correct explanation of A

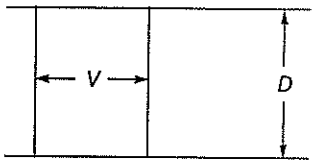
(b) both A and R are true but R is not a correct explanation of A

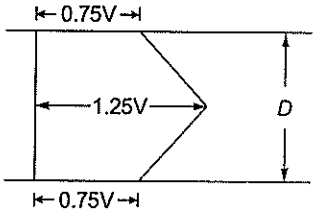
(c) A is true but R is false

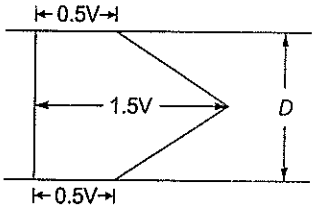
(d) A is false but R is true

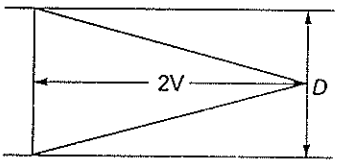
[ESE : 1998]

7.9 Consider the following velocity profiles in a pipeline:

1.


2.


3.


4.


Among these profiles, the momentum correction factor would be
(a) least in 4
(b) highest in 1
(c) more in 3 than that for 2
(d) the same in 1, 2, 3 and 4

[ESE : 2000]

7.10 If the velocity profile in laminar flow is parabolic, then the shear stress profile must be
(a) a hyperbola (b) a parabola
(c) a straight line (d) an ellipse

[ESE : 2000]

7.11 In a laminar flow between two static parallel plates, the velocity at mid-point is found to be 2.0 m/s. If the space between the plates is 10 cm, then the discharge per unit width (in $m^3/s/m$) will be
(a) 0.01 (b) 0.02
(c) 0.10 (d) 0.20

[ESE : 2001]

7.12 An oil of viscosity 9 poise is flowing through a horizontal pipe of 60 mm diameter. If the flow is laminar, the pressure drop in 100 m length of the pipe is 1800 kN/m^2. The average velocity of flow of the oil is
(a) 2.25 m/s (b) 0.55 m/s
(c) 5.5 m/s (d) 22.5 m/s

[ESE : 2002]

7.13 Oil (μ = 0.44 Pa-s, r = 888 kg/m^3) is filled in the space between two parallel plates which are 18 mm apart. The upper plate is moving at a velocity of 4 m/s. What is the shear stress on the plate?
(a) 97.8 Pa (b) 48.9 Pa
(c) 79.8 Pa (d) 87.9 Pa

[ESE : 2004]

7.14 The pressure gradient in the direction of flow is equal to the
(a) shear gradient parallel to the direction of flow
(b) shear gradient normal to the direction of flow
(c) velocity gradient parallel to the direction of flow
(d) velocity gradient normal to the direction of flow

[ESE : 2005]

7.15 A circular pipe of radius R carries a laminar flow of a fluid. The average velocity is indicated as the local velocity at what radial distance, measured from the centre?
(a) 0.50R (b) 0.71R
(c) 0.67R (d) 0.29R

[ESE : 2007]

7.16 In a 4 cm diameter pipeline carrying laminar flow of a liquid with μ = 1.6 centipoise, the velocity at the axis is 2 m/s. What is the shear stress midway between the wall and the axis?
(a) 0.01 N/m^2 (b) 0.0125 N/m^2
(c) 0.0175 N/m^2 (d) 0.02 N/m^2

[ESE : 2007]

7.17 Match List-I (Principle) with List-II (Effect) and select the correct answer using the codes given below the lists:

List-I
A. Hele Shaw Flow
B. Stoke's law
C. Hagen-Poiseuille flow
D. Pascal's law

List-II

1. Surface equal pressure
2. Settling of fine particles
3. Laminar flow between parallel plates
4. Laminar flow in tubes

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	3	2	4	1
(c)	2	3	1	4
(d)	3	2	1	4

[ESE : 2008]

7.18 Consider the following statements:

1. Shear stress is maximum at the centre line.
2. Maximum velocity is 3/2 times the average velocity.
3. Discharge varies inversely with the coefficient of viscosity.
4. Slope of hydraulic gradient line increases linearly with the velocity of flow.

Which of the above statements are correct in connection with a steady laminar flow through a circular pipe?

(a) 1, 3 and 4
(b) 3 and 4 only
(c) 1 and 3 only
(d) 2 and 4

[ESE : 2009]

7.19 Consider the following with respect to the application of the Navier-Stokes equations:

1. Laminar flow in circular pipes
2. Laminar flow between concentric rotating cylinders
3. Laminar unidirectional flow between stationary parallel plates
4. Laminar unidirectional flow between parallel plates having relative motion

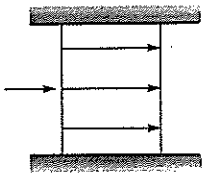
Which of these statements is/are correct?

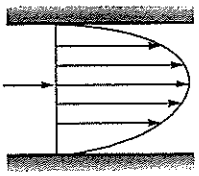
(a) 1 only (b) 2 and 3 only
(c) 3 and 4 only (d) 1, 2, 3 and 4

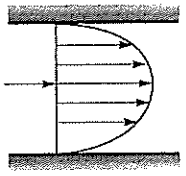
[ESE : 2009]

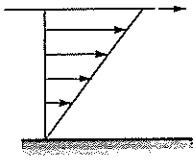
7.20 Match List-I (Velocity distribution) with List-II (Types of flow) and select the correct answer using the codes given below the lists:

List-I

A. 

B. 

C. 

D. 

List-II

1. Couette
2. Ideal fluid
3. Poiseuille
4. Turbulent

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	2	3	4	1
(c)	1	4	3	2
(d)	2	4	3	1

[ESE : 2010]

7.21 The terminal velocity of a small sphere settling in a viscous fluid varies as the

(a) inverse square of the diameter
(b) inverse of the diameter
(c) first power of its diameter
(d) inverse of the fluid viscosity

[ESE : 2010]

7.22 **Assertion (A):** Reynolds number of a fluid flow is indicative of the relative dominance of the effects of momentum transfer between adjacent layers of the flow over the viscous stresses.

Reason (R): For flow at high Reynolds numbers, the velocity profile is logarithmic.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

7.23 The terminal velocity of a sphere settling in a viscous fluid varies as
(a) the Reynolds number
(b) the square of its diameter
(c) directly proportional to the viscosity of fluid
(d) its diameter

[ESE : 2011]

7.24 The pressure drop in a 30 cm diameter horizontal pipe is 60 kPa in a distance of 15 m. The wall shear stress in kPa is
(a) 0.1 (b) 0.2
(c) 0.3 (d) 0.4

[ESE : 2012]

7.25 Consider the following statements in respect of steady laminar flow through a circular pipe:
1. Shear stress is zero on the central axis of the pipe.
2. Discharge varies directly with the viscosity of the fluid.
3. Velocity is maximum at the centre of the pipe.
4. Hydraulic gradient varies as the square of the mean velocity of flow.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1 and 3 only
(c) 2 and 4 only (d) 3 and 4 only

[ESE : 2012]

7.26 A wall shear stress of 40 Pa exists in a laminar flow in a 12 cm diameter pipe. At a distance of 2 cm from the wall, what will be the shear stress?
(a) 22.2 Pa (b) 24.0 Pa
(c) 26.7 Pa (d) 28.0 Pa

[ESE : 2013]

7.27 Consider the following statements regarding laminar flow through a circular pipe:
1. The friction factor is constant.
2. The frictional factor depends upon the pipe roughness.
3. The friction factor varies inversely with the Reynolds number of flow.
4. The velocity distribution is parabolic.

Which of these statements are correct?
(a) 1 and 3 (b) 3 and 4
(c) 2 and 3 (d) 2 and 4

[ESE : 2013]

7.28 In a laminar flow through a circular pipe of diameter 200 mm, the maximum velocity is found to be 1 m/s. The velocity at a radial distance of 50 mm from the axis of the pipe will be
(a) 0.5 m/s (b) 0.25 m/s
(c) 0.75 m/s (d) 1.25 m/s

[ESE : 2014]

7.29 In a laminar flow between two fixed plates held parallel to each other at a distance d, the shear stress is:
1. Maximum at plane $d/2$ away from each plate and zero at the plate boundaries.
2. Zero throughout the passage.
3. Maximum at the plate boundaries and zero at a plane $d/2$ away from each plate.

Which of the above statements is/are correct?
(a) 1 only (b) 3 only
(c) 2 only (d) 1, 2 and 3

[ESE : 2016]

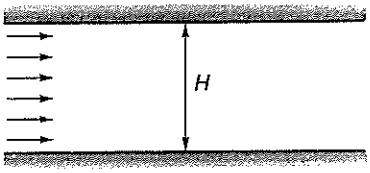
■■■■

Answers Viscous Flow of Incompressible Fluid

7.1	(b)	7.2	(c)	7.3	(d)	7.4	(a)	7.5	(a)	7.6	(c)	7.7	(a)	7.8	(a)	7.9	(c)		
7.10	(c)	7.11	(c)	7.12	(a)	7.13	(a)	7.14	(b)	7.15	(b)	7.16	(*)	7.17	(b)	7.18	(b)		
7.19	(d)	7.20	(b)	7.21	(d)	7.22	(b)	7.23	(b)	7.24	(c)	7.25	(b)	7.26	(c)	7.27	(b)		
7.28	(c)	7.29	(b)																

Explanations Viscous Flow of Incompressible Fluid

7.1 (b)



Assume width = 1

$$u = -\frac{1}{2\mu}\left(\frac{\partial P}{\partial x}\right)\left(Hy - y^2\right)$$

Kinetic energy correction factor (α)

$$\alpha = \frac{\int_0^H \frac{1}{2} d\dot{m} u^2}{\frac{1}{2}\dot{m}\bar{u}^2} = \frac{\int_0^H \rho(dy1)u.u^2}{\rho(H.1)\bar{u}.\bar{u}^2}$$

$$= \frac{\int_0^H u^3 dy}{H\bar{u}^3} = 1.543$$

where $\bar{u} = -\frac{1}{12\mu}\left(\frac{\partial P}{\partial x}\right)H^2$

7.2 (c)

For Laminar flow through pipe.

Hagen-Poiseuille's eq.

$$\frac{P_1 - P_2}{\rho g} = \frac{32\mu\bar{v}L}{\rho g D^2} \qquad Q = \left[\frac{\pi}{4}D^2\right]\bar{u}$$

or $$\frac{P_1 - P_2}{\rho g} = \frac{128}{\pi}\frac{\mu QL}{\rho g D^4}$$

7.3 (d)

For parallel plates

Head loss,

$$h_f = \frac{12\mu QL}{\rho g(2h)^2}$$

(Discharge remains same)

$$Q = (2h).\bar{u}$$

So $$h_f = \frac{12\mu QL}{\rho g(2h)^3}$$

7.4 (a)

For pipe flow critical Reynolds number,

$$Re_c = 2000$$

$$Re_c = \frac{\rho VD}{\mu} = 2000$$

$$\therefore \quad V = \frac{2000 \times 0.01}{1 \times 0.6} = \frac{100}{3} \text{ cm/sec}$$

7.5 (a)

Laminar flow is governed by Reynolds number only and the Darcy-Weisbach friction factor in the case of pipe flow is

$$f = \frac{64}{\text{Re}}$$

So flow will remain unchanged.

7.6 (c)

In laminar flow,

Local instability occurs first at a point where $\frac{\rho uy}{\mu}$ is maximum.

where $\frac{\rho uy}{\mu}$ is local Reynold's Number.

7.7 (a)

As the plates are stationary so velocity at boundary = 0.

The critical Reynolds number for flow between two stationary parallel plates is 1000. So flow is

turbulent. The energy correction factor for laminar flow is $\alpha = 1.54$.

In the case of turbulent flow it will be less than 1.54. So statements 1 and 4 are wrong.

7.8 (a)

$$h_f = \frac{8\mu VL}{\rho g R^2} \quad \text{Using } Q = \pi R^2 V$$

$$= \frac{8\mu QL}{\pi \rho g R^4}$$

As head loss is directly proportional to discharge (Q) so doubling the discharge will double the head loss.

Power consumption = $\rho g h_f Q$.

So power consumption will become four times of the original.

7.9 (c)

More uniform flow gives less moment correction factor.

The average velocity in all the cases is V. The momentum correction factor is defined as

$$\beta = \frac{1}{A}\int \left(\frac{v}{V}\right)^2 dA = \frac{1}{D}\int_0^D \left(\frac{v}{V}\right)^2 dy$$

Figure 1: $\beta_1 = 1.0$

Figure 2: $\beta_2 = \frac{2}{D}\int_0^{D/2}\left(\frac{1.25v - 0.5v\, y/D}{V}\right)^2 dy$

$$= 2\int_0^{1/2}\left(1.25 - 0.5\frac{y}{D}\right)^2 d(d/D)$$

$$= 1.27$$

Figure 3: $\beta_3 = 2\int_0^{1/2}\left(1.5 - \frac{y}{D}\right)^2 d(y/D)$

$$= 1.583$$

Figure 4: $\beta_4 = 2\int_0^{1/2}\left(2 - 2\frac{y}{D}\right)^2 d(y/D)$

$$= 2.33$$

Thus $\beta_1 < \beta_2 < \beta_3 < \beta_4$

7.10 (c)

Shear stress is proportional to velocity gradient.

So shear stress profile will be linear.

7.11 (c)

The average velocity

$$= \frac{2}{3} \times 2 = \frac{4}{3} \text{ m/s}$$

The discharge per unit width

$$= \frac{4}{3} \times 0.1 = 0.13 \text{ m}^3/\text{s/m}$$

7.12 (a)

1 poise = 0.1 N-s/m^2

$\therefore \quad \mu = 0.9$ N-s/m^2

$$V_{av} = \frac{1}{8\mu}\frac{dp}{dz}R^2$$

$$\frac{dp}{dz} = \frac{1800 \times 10^3}{100} = 18 \times 10^3 \text{ N/m}^2/\text{m}$$

$$R = \frac{60}{2} = 30 \text{ mm} = 0.03 \text{ m}$$

$$\therefore \quad V_{av} = \frac{1}{8 \times 0.9} \times 18 \times 10^3 \times (0.03)^2$$

$$= 2.25 \text{ m/s}$$

7.13 (a)

$$\text{Shear stress, } \tau = \mu\frac{du}{dy} = 0.44 \times \frac{4}{0.018}$$

$$= 97.8 \text{ Pa}$$

7.14 (b)

$$\frac{dp}{dx} = \frac{d\tau}{dy}$$

This is Navier-Stokes' equation for steady incompressible flow.

7.15 (b)

For laminar flow in a circular pipe, the local velocity may be given as

$$u = U_{max}\left[1 - \frac{r^2}{R^2}\right] \qquad \ldots(i)$$

For laminar flow in a circular pipe, the average velocity may be given as

$$V = \frac{U_{max}}{2} \qquad \ldots(ii)$$

Equating (i) and (ii), we get

$$\frac{U_{max}}{2} = U_{max}\left[1 - \frac{r^2}{R^2}\right]$$

$$\Rightarrow \quad \frac{r^2}{R^2} = 1-\frac{1}{2}$$

$$\Rightarrow \quad r^2 = 0.5R^2$$

$$\Rightarrow \quad r = 0.71R$$

7.16(*)

The wall shear stress is given as

$$\tau_0 = \frac{8\mu V}{D} \left[V = \frac{U_{max}}{2} = \frac{2}{2} = 1\text{m/s}\right]$$

$$\Rightarrow \quad \tau_0 = \frac{8\times1.6\times10^{-3}\times1}{4\times10^{-2}}$$

$$\Rightarrow \quad \tau_0 = 0.32\,\text{N/m}^2$$

The shear stress varies linearly from zero at the axis to τ_0 at the periphery.

$$\therefore \quad \frac{\tau}{r} = \frac{\tau_0}{R}$$

$$\Rightarrow \quad \tau = \tau_0 \times \frac{r}{R} \qquad \left[\because r = \frac{R}{2}\right]$$

$$\Rightarrow \quad \tau = \frac{0.32\times R}{2R}$$

$$\Rightarrow \quad \tau = 0.16\,\text{N/m}^2$$

7.17(b)

Here shaw flow is defined as low Reynond's number flow between parallel plates seperated by an infiltensimally small gap. It is important to micro flows.

7.18(b)

In a steady laminar flow through circular pipe, the shear stress is maximum at the walls of the pipe. Its magnitude is given by

$$\tau_0 = \frac{8\mu V}{D}$$

The maximum velocity in such a case is two times the overage velocity.

7.19(d)

In Navier's-Stoke equation viscous force term is considered and in all the above mentioned flow viscous force can't be neglected so correct answer is (d).

7.20 (b)

Ideal fluid has no friction so velocity distribution will be as shown in A. Turbulent flow velocity distribution will be more flat than Poiseuille's. Couette flow which is drag induced laminar flow of a viscous fluid in the space between two parallel plates, one of which is moving relative to the other will have velocity distribution as shown in *D*.

7.21 (d)

Terminal velocity of small sphere setting in viscous fluid.

$$v_t = \frac{gd^2(\rho_s - \rho_u)}{18\mu}$$

$$v_t \propto \frac{1}{\mu}$$

7.22 (b)

In laminar flow(low Reynold's number) momentum transfer between adjacent layer of flow is negligible whereas In turbulent flow(high Reynold's number) momentum transfer between adjacent layer of flow is significant. Flow is turbulent if Reynold's number is high and velocity profile for it is logarithmic.

7.23 (b)

Terminal velocity of a sphere settling in a viscous fluid is expressed by Stoke's equation.

$$V = \frac{1}{18}\frac{gd^2(\rho_s - \rho)}{\mu}$$

7.24 (c)

The wall shear stress, τ, is given by

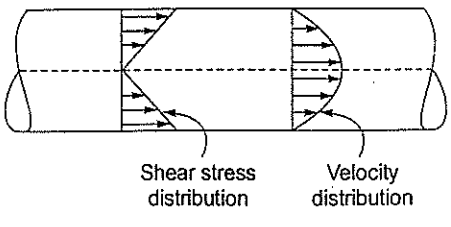
$$\tau = -\left(\frac{\partial P}{\partial x}\right)\frac{R}{2}$$

$$\tau = -\left(\frac{-60}{15}\right)\times\frac{15}{100\times2}$$

$$\tau = 0.3\,\text{kPa}$$

7.25 (b)

The shear stress and velocity distribution in a laminar flow through a circular pipe is as shown

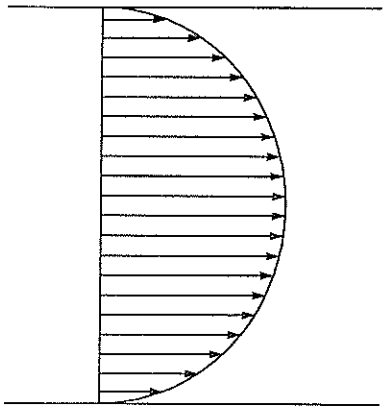


7.26 (c)

$$\tau = \tau_0 \frac{r}{R} = (40\text{Pa})\frac{4}{6} = 26.7\ \text{Pa}$$

7.27 (b)

$$\text{Friction factor} = \frac{64}{\text{Reynold's number}}$$



Velocity profile for laminar flow in pipe

Velocity distribution for laminar flow through circular pipe is parabolic.

7.28 (c)

In laminar flow, velocity

$$u = -\frac{1}{4\mu}\left(\frac{\partial P}{\partial x}\right)\left(R^2 - r^2\right)$$

Maximum velocity will be at $r = 0$

$$\Rightarrow -\frac{1}{4\mu}\left(\frac{\partial P}{\partial x}\right) = \frac{1}{(100)^2}$$

$\therefore$ Velocity at $r = 50$ mm

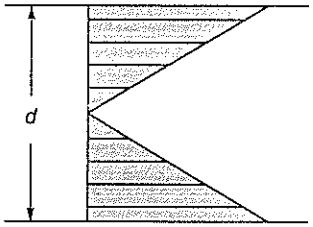
$$u = -\frac{1}{4\mu}\frac{\partial p}{\partial x}\left(100^2 - 50^2\right)$$

$$= \frac{1}{(100)^2}\left[(100)^2 - (50)^2\right]$$

$$= 0.75\ \text{m/sec.}$$

7.29 (b)

Shear stress is maximum at plate boundaries and zero at plane $d/2$ away from each plate.

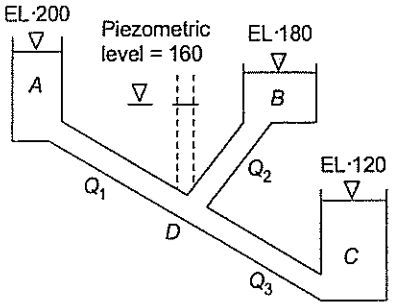


Shear stress

8 Flow Through Pipes

8.1 **Assertion (A):** A loss of head at a sudden contraction in a pipe is smaller than that at a sudden expansion.
Reason (R): When the flow contracts, it tends to become irrotational.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1995]

8.2 Three reservoirs *A*, *B* and *C* are interconnected by pipes as shown in the given figure. Water surface elevations in the reservoirs and the piezometric level at the junction *D* are also indicated in the figure.



Flow Q_1, Q_2 and Q_3 are related as
(a) $Q_1 + Q_2 = Q_3$
(b) $Q_1 - Q_2 = Q_3$
(c) $Q_2 - Q_1 = Q_3$
(d) $Q_1 + Q_2 + Q_3 = 0$
[ESE : 1995]

8.3 The cavitation and pitting can be prevented by creating which one of the following conditions?
(a) Reducing the pressure head
(b) Reducing the velocity head
(c) Increasing the elevation head
(d) Reducing the piezometric head
[ESE : 1995]

8.4 Which of the following pairs are correctly matched?
1. Piezometric head
...Sum of datum head and pressure head
2. Dynamic head
... Sum of datum head and velocity head
3. Stagnation head
...Sum of pressure head and velocity head
4. Total head
... Sum of piezometric head and dynamic head

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 2, 3 and 4
[ESE : 1995]

8.5 The following parameters relate to flow in a penstock:
1. Water level in the reservoir
2. Density of water
3. Elasticity of water
4. Roughness of pipe

Pressure rise due to water in a penstock depends upon
(a) 1 and 2 (b) 2 and 3
(c) 2 and 4 (d) 1, 2, 3 and 4
[ESE : 1995]

8.6 A pipeline of 5 cm diameter is reduced abruptly to 2.5 cm diameter at a section to enable measurement of the water flowing through it. The loss of head at the contraction is 0.5 m. Given that, in metric units, $\sqrt{2g} = 4.43$ and $\sqrt{g} = 3.132$, the mean velocity in the reduced section will be
(a) 0.5 m/sec (b) 1.1075 m/sec
(c) 1.566 m/sec (d) 4.43 m/sec
[ESE : 1996]

8.7 Consider the following statements:
A horizontal pipe reduces from 10 cm to 5 cm in diameter. If the pressure head at 10 cm section is 10 metres and velocity head is 1 metre, then the
1. total head at any point is 11 metres
2. pressure head at the 5 cm section is negative
3. discharge varies proportionate to the diameter
4. datum head at all sections is constant
Which of these statements is/are correct?
(a) 1, 2 and 4 (b) 1 and 3
(c) 4 alone (d) 1, 2, 3 and 4
[ESE : 1996]

8.8 A penstock is 2000 m long and the velocity of pressure wave in it is 1000 m/s. Water hammer pressure head for instantaneous closure of valve at the downstream end of pipe is 60 m. If the valve is closed in 4 sec, then the peak water hammer pressure head is equal to
(a) 15 m (b) 30 m
(c) 60 m (d) 120 m
[ESE : 1996, 2007]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

8.9 Assertion (A): Loss of head at a sudden expansion of a pipe is larger than that at a sudden contraction.
Reason (R): Separation of flow occurs at sudden contractions.
[ESE : 1997]

8.10 Assertion (A): In the equation $h_f = f\frac{L}{d}\frac{V^2}{2g}$, for laminar flow through the pipe, the term V (mean velocity of flow) is given by $V = \frac{(p_1 - p_2)r^2}{8\mu L}$
Reason (R): The term 'f' (friction factor) in the above equation equals $\frac{64}{Re}$ where Re is the Reynolds number.
[ESE : 1998]

8.11 The loss of head at various pipe fittings is given by the expression $K\frac{v^2}{2g}$. If values of K were 0.40, 0.90, 1.5 and 2.2, then these would correspond respectively to
(a) foot valve of pump, 45° elbow, 90° elbow and close return bend
(b) 45° elbow, 90° elbow, foot valve of pump and close return bend
(c) 90° elbow, foot valve of pump, close return bend and 45° elbow
(d) foot valve of pump, close return bend, 45° elbow and 90° elbow
[ESE : 1998]

8.12 A pipe network consists of a pipe of 60 cm diameter and branches out at a point T into two branches, one of 30 cm diameter and the other of 45 cm diameter. These branch pipes rejoin at a point B. The velocity in the first branch (of 45 cm diameter) is 1.5 m/sec. Which one of the following statements is true?
(a) The velocity in the second branch is 1.0 m/sec.
(b) The velocity in the second branch is 2.25 m/sec.
(c) The velocity in the second branch is $\frac{2}{3}$ (= 0.667) m/sec.
(d) The potential drop between T and B in both branches is the same.
[ESE : 1998]

8.13 Which of the following statements are true in relation to water hammer phenomenon?
1. It causes surface erosion in pipes.
2. The pressure rise is given by ρCU for sudden closure of valve.
3. It is accompanied by serious cavitation.
4. The volume modulus of fluid is the relevant fluid property.

5. It is governed by the Reynolds number of the flow.

Select the correct answer using the codes given below:

(a) 3 and 5 (b) 2 and 4
(c) 2 and 5 (d) 1, 2, 3 and 4

[ESE : 1998]

8.14 The friction factor (f), in terms of boundary shear stress (τ_0) is given by (ρ = mass density, V = mean velocity)

(a) $\frac{2\rho V^2}{\tau_0}$ (b) $\frac{\tau_0}{2\rho V^2}$

(c) $\frac{2\tau_0}{\rho V^2}$ (d) $\frac{\rho V^2}{2\tau_0}$

[ESE : 1998]

8.15 Assertion (A): Water flows through a pipe connecting two reservoirs. The line joining the water surface levels in the reservoirs is the hydraulic gradient.

Reason (R): There will be no negative gauge pressure anywhere in the pipeline, as long as the pipeline lies below the hydraulic gradient.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

8.16 A compound pipe (new cast iron) system consists of pipes of length 1800 m and diameter 50 cm, length 1200 m and diameter 40 cm and length 600 m and diameter 30 cm connected in series. The equivalent length of 40 cm diameter pipe will be nearly

(a) 4300 m (b) 4400 m
(c) 4500 m (d) 3600 m

[ESE : 1999]

8.17 Consider the following statements:

In order to have cavitation,

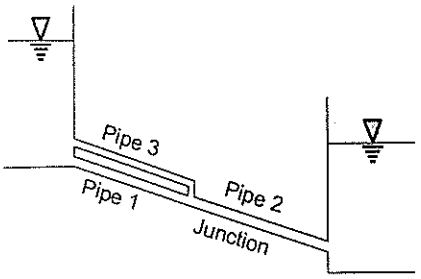
1. local velocity is increased so that the local pressure is decreased below vapour pressure
2. elevation is kept so high that the local pressure reduces below vapour pressure
3. general ambient pressure is increased to a very high magnitude
4. water hammer must occur in the system

Which of these statements are correct?

(a) 2 and 3 (b) 3 and 4
(c) 1 and 2 (d) 1 and 4

[ESE : 1999]

8.18 Consider the following conditions for the pipe network shown in the given figure (Notations have the usual meaning with suffixes 1, 2 and 3 referring to respective pipes):



1. $Q_1 = Q_3$ 2. $Q_2 = Q_1 + Q_3$
3. $h_{f1} = h_{f3}$ 4. $h_{f1} = h_{f2} = h_{f3}$

Which of these conditions must be satisfied by this pipe network?

(a) 1 and 3 (b) 2 and 3
(c) 1 and 4 (d) 2 and 4

[ESE : 2000]

8.19 Maximum pressure rise due to water hammer in a pipeline (a = area of the pipe; V_0 = Velocity, g = acceleration due to gravity; t = time period; L = length of the pipeline) is

(a) $\frac{aV_0}{2g}$

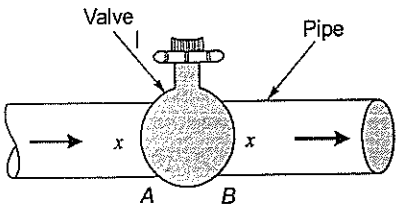
(b) $\frac{aV_0^2}{2g}$

(c) $\frac{LV_0}{gt}$

(d) Independent of the dimensions of the pipe

[ESE : 2000]

8.20 A and B are at the same elevation of 2.5 m above datum in the valve and pipe line shown in the given figure. Velocity head of 0.5 m, head loss in valve of 0.2 m and pressure head of 2.5 m are the parameters at A. Piezometric head at B is equal to



(a) 5.5 m (b) 5.3 m
(c) 5.0 m (d) 4.8 m

[ESE : 2000]

8.21 Two tanks are connected in parallel by two pipes *A* and *B* of identical friction factors and lengths. If the size of pipe *A* is double than that of pipe *B*, then their discharges will be in the ratio of

(a) 2 (b) 4
(c) 5.66 (d) 32

[ESE : 2001]

8.22 Water of ν = 1 centistoke flows through a 1 cm diameter pipe. Critical flow will correspond to a discharge of approximately

(a) 0.008 *l*/s (b) 0.013 *l*/s
(c) 0.016 *l*/s (d) 0.025 *l*/s

[ESE : 2001]

8.23 The procedure to be followed in solving for discharge in a simple pipe problem, when h_f, *L*, *D*, *V* and ε are given is to

[Note : Re is Reynolds number,
f = friction coefficient,
ε/*D* = relative roughness
V = velocity]

(a) assume *f*, compute : *V*, Re, ε/*D* and calculate *f*; and repeat if necessary
(b) assume Re, compute *f*, check ε/*D*
(c) assume *V*, compute Re and calculate *f*, *V* again
(d) assume ε, compute *V*, Re and calculate *f*

[ESE : 2002]

8.24 The Chezy's coefficient *C* is related to Darcy-Weisbach friction factor '*f*' as

(a) $C = \sqrt{(g/8f)}$ (b) $C = \sqrt{(8g/f^{1/4})}$
(c) $C = \sqrt{(8g/f)}$ (d) $C = \sqrt{(f/8g)}$

[ESE : 2002]

8.25 Assertion (A): Abrupt rise in pressure in a pipe line results from sudden closure of a valve.

Reason (R): Pressure wave propagates through elastic medium.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

8.26 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Flow development	1. Surge tank
B. Pipe network	2. Entrance length
C. Water hammer	3. Darcy-Weisbach equation
D. Friction loss	4. Hardy-Cross method

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	4	2	3	1
(c)	2	4	3	1
(d)	4	2	1	3

[ESE : 2003]

8.27 Which one of the following conditions must NOT be satisfied in the Hardy-Cross analysis of pipe network?

(a) Continuity principle demands that flow into a network junction is equal to the flow out of it.
(b) Momentum equation must be satisfied so that the force in each loop is balanced.
(c) Darcy-Weisbach head loss equation is to be used in computing head loss in elementary circuits. The equation is of the form $h_L = kQ^n$.
(d) $\Sigma h_L = \Sigma kQ^n$ must be equated to zero. If not, a flow correction factor ΔQ is to be made for arriving at a solution.

[ESE : 2003]

8.28 Which one of the following phenomena in a pipe flow is termed as water hammer?

(a) The sudden rise of pressure in a long pipe due to sudden closure of valve.
(b) The rise of a pressure in a pipe flow due to gradual closure of valve.
(c) The rise of negative pressure.
(d) The zero pressure in a pipe flow.

[ESE : 2003]

8.29 Which one of the following statements is not correct?

(a) Cavitation forms where the local pressure drops up to the vapour pressure conditions due to increase in local velocity.

(b) Cavitation takes place in turbine blades, runners of pumps, spillways where local velocity increases considerably.

(c) Cavitation may be prevented by maintaining the ambient pressure relatively higher at probable points of occurrence by raising their levels.

(d) Boundaries likely to be affected by cavitation can be protected against pitting by covering it with tough materials like stainless steel or rubber.

[ESE : 2003]

8.30 Two long pipes in parallel are used to carry water between two reservoirs. The diameter of one pipe is twice that of the other. Both the pipes have the same value of friction factor. Neglect minor losses. What is the ratio of flow rates through the two pipes?

(a) 2.8 (b) 5.6

(c) 8 (d) 11.3

[ESE : 2004]

8.31 Which one of the following statements is NOT correct?

(a) Water hammer is a phenomenon which occurs due to oscillation of water column away from the valve.

(b) Rigid water column theory specifies that water is incompressible and pipe material does not expand.

(c) Water hammer occurs under unsteady conditions of flow.

(d) Rigid water column theory is used less in practice as it does not reflect field situation.

[ESE : 2006]

8.32 Which one of the following statements is NOT correct?

(a) Solution of pipe network by Hardy Cross method is a trial and error solution.

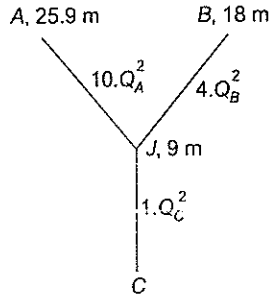
(b) At a junction of pipes, total inflow is equal to the total outflow.

(c) Loss of head due to flow in a clockwise direction should be equal to loss of head in flow in a counter clockwise direction.

(d) Hardy Cross method can be extended to open channel flow also.

[ESE : 2006]

8.33 Water flows into junction J from reservoirs *A* and *B* through connecting pipes, the head loss through these being, respectively $10.Q_A^2$ and $4.Q_B^2$. The water level elevations at the reservoirs at *A* and *B* are 25.9 m and 18 m, respectively. The inflow at *J* is discharged out at *C* into the atmosphere. The head loss through pipe *JC* is $1.Q_C^2$. The gauge pressure at *J* is 9 m. What is the residual gauge pressure of the outflow at *C*?



(a) 2.56 m (b) 1.86 m

(c) 1.16 m (d) 0.46 m

[ESE : 2006]

8.34 While using Darcy-Weisbach equation for estimating head loss in a pipe flow, the friction factor was misjudged by + 20% for this case, the error in estimating discharge is

(a) + 10% (b) + 40%

(c) – 40% (d) – 10%

[ESE : 2008]

8.35 What is the energy loss through a length of pipe from which all the discharge is taken out uniformly along its length, with respect to the case when all the discharge is delivered to the end?

(a) 2/3 (b) 1/3

(c) 3/2 (d) 1/2

[ESE : 2008]

8.36 The power transmitted through a pipeline is maximum when the head lost due to friction in the pipe is equal to

(a) the total supply head
(b) half of the total supply head
(c) one-third of the total supply head
(d) one-fourth of the total supply head

[ESE : 2009]

8.37 In a siphon system employed for carrying water from a reservoir *A* at a higher elevation to another reservoir *B* at lower elevation, both being separated by a higher hill, what will be the pressure at the 'Summit' (*S*)?
(a) Equal to the pressure at the water surface of reservoir *A*
(b) Higher than the pressure at the water surface of reservoir *A*
(c) Equal to the pressure at the water surface of reservoir *B*
(d) Less than the pressure at both *A* and *B* above

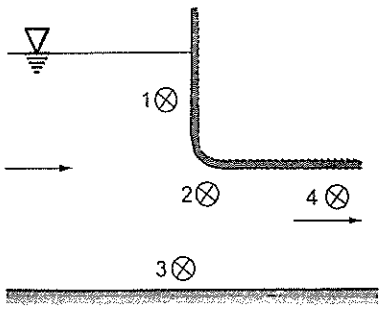
[ESE : 2009]

8.38 Consider the following statements:
Cavitation generally results from a combination of several influences
1. by reduction of pressure intensity below a limiting value
2. by increase in either elevation or the velocity of flow
3. by reduction of pressure load in the system
4. by decrease in the velocity of flow

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 3 and 4

[ESE : 2009]

8.39 A sluice inlet in a dam with streamlined entrance is shown in figure below.



If cavitation is expected to occur, it will first appear at the point
(a) 1 (b) 2
(c) 3 (d) 4

[ESE : 2010]

8.40 Consider the following statements which are related to the phenomenon of cavitation in fluid flow:
1. Cavitation occurs when local velocity is decreased so that local pressure increases to a high degree.
2. Cavitation occurs if elevation is high thereby decreasing ambient pressure.
3. Cavitation occurs if local velocity is increased so that the local pressure decreases.
4. Cavitation is dependent on vapour pressure of the fluid.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

[ESE : 2010]

8.41 In a pipe network of municipal water supply, a parallel pipe is sometimes installed over a portion of the pipe mainly for
(a) reducing water hammer pressure
(b) decreasing the pumping power need
(c) increasing the head available at the node
(d) increasing the discharge

[ESE : 2010]

8.42 Two identical pumps, each capable of delivering 0.2 cumec, against a head of 30 m, are connected in parallel. The resulting discharge is
(a) 0.4 cumec against a head of 30 m
(b) 0.4 cumec against a head of 60 m
(c) 0.2 cumec against a head of 30 m
(d) 0.2 cumec against a head of 60 m

[ESE : 2011]

8.43 Assertion (A): Loss of head at a sudden contraction in a pipe is smaller than the loss at a sudden expansion in the pipe.
Reason (R): Increase in turbulence level is higher at a sudden expansion than at a sudden contraction.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

8.44 In a pressure penstock 4500 m long, water is flowing at a velocity of 4 m/s. If the velocity of the pressure wave travelling in the pipe, due to sudden complete closure of a valve at the downstream end, is given as 1500 m/s, what would be the period of oscillation in seconds under frictionless conditions?
(a) 6 (b) 8
(c) 9 (d) 11

[ESE : 2011]

8.45 Three pipes *A*, *B* and *C* have the following basic geometries:

Pipe	*A*	*B*	*C*
Diameter	*D*	*D* / 2	2*D*
Length	*L*	*L*	4*L*

If these pipes are connected in series, by assuming the value of friction factor *f* to be same for all the three pipes and the equivalent pipe, this set of pipes in series is equivalent to a pipe of length L_e and diameter *D* and friction factor *f* with the equivalent length L_e being equal to

(a) $5\frac{1}{8}L$ (b) $4\frac{1}{8}L$
(c) $26\frac{1}{8}L$ (d) $33\frac{1}{8}L$

[ESE : 2012]

8.46 The velocity of pressure wave in water of infinite extent is 1414 m/s. The velocity of propagation of water hammer pressure in a pipe carrying water and having diameter = 40 cm, pipe thickness = 4 mm, with *E* (Modulus of elasticity) of the pipe material = 2.1×10^{11} Pa, and *K* (Bulk modulus of water) = 2.1×10^9 Pa, is
(a) 1410 m/s (b) 2000 m/s
(c) 1000 m/s (d) 700 m/s

[ESE : 2012]

8.47 If the velocity of flow as well as the diameter of the flowing pipe are respectively doubled through pipe system in use since long, the head loss will thereafter be
(a) Halved (b) Doubled
(c) Increased 4 times (d) No change

[ESE : 2012]

8.48 Let C_1 be the velocity of pressure wave travelling along rigid pipe carrying water with its bulk modulus 2.16×10^9 N/m^2. Let C_2 be the velocity of pressure wave travelling along a rigid pipe carrying oil of relative density 0.600 with its bulk modulus as 1.296×10^9 N/m^2 through a similar pipe. What will be the ratio $\frac{C_1}{C_2}$?
(a) 0.01 (b) 0.1
(c) 1.0 (d) 10.0

[ESE : 2012]

8.49 Which of the following pairs are correctly matched?
1. Piezometric head : Sum of datum head and pressure head
2. Dynamic head : Sum of datum head and velocity head
3. Stagnation head : Sum of Piezometric head and velocity head
4. Total head : Sum of Piezometric head and dynamic head

(a) 1, 2 and 3 only (b) 1, 3 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2012]

8.50 It is proposed to increase the discharge by 20% in circular pipe carrying oil in laminar regime. If all other factors remain unchanged, power consumption to maintain the modified flow relative to the original flow would increase by
(a) 10% (b) 20%
(c) 44% (d) 52%

[ESE : 2013]

8.51 In a pipe network:
(a) The algebraic sum of discharges around each elementary circuit must be zero
(b) The head at each node must be the same
(c) The algebraic sum of the drop in piezometric head around each elementary circuit is zero
(d) The piezometric head loss in each line of each circuit is the same

[ESE : 2013]

8.52 In a pipeline 1920 m long, the velocity of propagation of pressure wave is 960 m/s. Rapid closure of a downstream valve will entail, when the maximum time for the closure is:
(a) 8 s (b) 6 s
(c) 4 s (d) 2 s
[ESE : 2013]

8.53 **Statement (I):** Gravity is a determinant in estimating pipe flow magnitudes.
Statement (II): The term 'g' appears explicitly in Darcy-Weisback formula for pipe flow resistance.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true
[ESE : 2013]

8.54 A liquid of density ρ and bulk modulus K flows with a mean velocity V in a long rigid pipe of diameter D. A sudden closure of a valve at the downstream end of the pipe will produce a maximum water hammer head of
(a) $\frac{V\sqrt{\rho}}{g\sqrt{K}}$ (b) $\frac{V\sqrt{g}}{\rho\sqrt{K}}$
(c) $\frac{V\sqrt{K}}{g\sqrt{\rho}}$ (d) $\frac{V\rho}{\sqrt{gK}}$
[ESE : 2014]

8.55 Two reservoirs are connected by two pipes P and Q. The pipes have the same diameter and length and are placed in parallel. If the friction factor of P is 9 times that of Q, then the discharge in P to that in Q is
(a) 0.5 (b) 0.45
(c) 0.33 (d) 0.27
[ESE : 2015]

8.56 **Assertion (A):** Total energy line and the hydraulic gradient line for a pipe flow cannot intersect each other.
Reason (R): The vertical differences between these two lines must equal the velocity head.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2015]

8.57 What is the maximum power available at the downstream end of a pipeline 3 km long, 20 cm in diameter, if water enters at the upstream end at a pressure of 720 m of water, with taking pipe friction coefficient as 0.03 and g as 10 m/s^2?
(a) 770 mhp (b) 740 mhp
(c) 700 mhp (d) 660 mhp
[ESE : 2016]

8.58 In the design of pipeline the usual practice is to assume that due to ageing of pipelines:
1. The effective roughness increases linearly with time.
2. The friction factor increases linearly with time.
3. The flow through the pipe becomes linearly lesser with time.
Which of the above statements is/are correct?
(a) 1, 2 and 3 (b) 3 only
(c) 2 only (d) 1 only
[ESE : 2016]

8.59 Two tanks A and B, of constant cross-sectional area of 10 m^2 and 2.5 m^2, respectively, are connected by a 5 cm pipe, 100 m long, with $f = 0.03$. If the initial difference of water levels is 3 m, how long will it take for 2.5 m^3 of water to flow from A to B? Considering entry and exit losses, it can be grossly assumed that the flow velocity, in m/s, through the pipe is $1.75\sqrt{h}$, where h is in m, taking g = 10 m/sec^2, also, may take area of pipe as 2×10^{-3} m^2.
(a) 535 seconds (b) 516 seconds
(c) 485 seconds (d) 467 seconds
[ESE : 2016]

8.60 A pipe of 324 mm diameter, having friction coefficient as 0.04, connects two reservoirs with 15 m difference in their water levels through a 1500 m long pipe. What will be the discharge through the pipe?

(a) 104 lps (b) 134 lps
(c) 165 lps (d) 196 lps

[ESE : 2016]

8.61 **Statement (I) :** Pipes carrying water are anchored at bends and other points of unbalanced thrusts.

Statement (II): Pipes are anchored by firmly embedding in massive blocks of concrete or masonry to counter side thrusts due to hydrodynamic forces exerted on the joints.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

8.62 Cavitation is likely to occur if
1. Pressure becomes very high.
2. Temperature becomes low.
3. Pressure at the specific point falls below vapour pressure.
4. Energy is released with the onset of a high intensity wave due to noise and vibration of the machine.

Which of the above statements are correct?
(a) 1 and 3 (b) 2 and 3
(c) 3 and 4 (d) 2 and 4

[ESE : 2016]

8.63 Two reservoir maintain a constant difference of water levels of 11.25 m and are connected by a 10 cm diameter pipeline of 294.3 m length. The total of all head losses, by friction valve losses, bend losses, inlet and exit losses, and velocity head can be taken as $98.1\ v^2/2g$ (in m) where v is the flow velocity through the pipe (in m/sec). Assuming that the valve at the downstream end is suddenly opened so that there is no pressure wave, what will be the time taken for the velocity of flow in the pipe to attain 95% of the steady terminal velocity? Take $\frac{1}{9.81} = 0.102$.

(a) $2.25 \log_e 19$ (b) $2 \log_e 19$
(c) $2.25 \log_e 39$ (d) $2 \log_e 39$

[ESE : 2017]

■■■■

Answers Flow Through Pipes

8.1 (c)	8.2 (a)	8.3 (b)	8.4 (b)	8.5 (d)	8.6 (d)	8.7 (a)	8.8 (c)	8.9 (b)
8.10 (a)	8.11 (b)	8.12 (d)	8.13 (b)	8.14 (c)	8.15 (d)	8.16 (a)	8.17 (c)	8.18 (b)
8.19 (c)	8.20 (d)	8.21 (c)	8.22 (c)	8.23 (a)	8.24 (c)	8.25 (a)	8.26 (a)	8.27 (b)
8.28 (a)	8.29 (c)	8.30 (b)	8.31 (a)	8.32 (d)	8.33 (c)	8.34 (d)	8.35 (b)	8.36 (c)
8.37 (d)	8.38 (b)	8.39 (b)	8.40 (d)	8.41 (d)	8.42 (a)	8.43 (a)	8.44 (a)	8.45 (d)
8.46 (c)	8.47 (b)	8.48 (c)	8.49 (b)	8.50 (c)	8.51 (c)	8.52 (c)	8.53 (d)	8.54 (c)
8.55 (c)	8.56 (a)	8.57 (d)	8.58 (d)	8.59 (d)	8.60 (a)	8.61 (a)	8.62 (c)	8.63 (d)

Explanations Flow Through Pipes

8.1 (c)

In sudden contraction and expansion loss of head occurs due to deceleration of flow. In sudden expansion loss occurs due to formation of turbulent eddies when the flow enters from smaller pipe to larger pipe. Thus reverse flow under favourable gradient causes loss of head.

In sudden contraction the same phenomena occurs after vena-contracta and in this case the diameter of pipe in which eddies are formed, is less. Thus sudden contraction has lesser head loss than sudden expansion. The acceleration of flow till vena contracta and thereafter deceleration of flow occurs in sudden contraction. The formation of eddies means that flow is rotational.

8.2 (a)

The direction of flow can be determined from head difference as the flow occurs from high head to low head.

Piezometric head at A > Piezometric level at D so flow Q_1 is from A toward D.

Piezometric head at B > Piezometric level at D so flow Q_2 is from B towards D.

Piezometric head at C < Piezometric level at D so flow Q_3 is from D towards C.

$\therefore Q_1 + Q_2 = Q_3$

8.3 (b)

Cavitation occurs due to pressure falling below vapour pressure. Reducing the velocity head will increase pressure head and cavitation can be prevented.

8.4 (b)

As per Bernoulli's equation total head,

$$H = \frac{p}{\rho g} + Z + \frac{V^2}{2g}$$

where

$\frac{p}{\rho g}$ is pressure head or static head

Z is datum or elevation head

$\frac{V^2}{2g}$ is velocity head or dynamic head or kinetic head

$\frac{p}{\rho g} + Z$ is also called piezometric head

$\frac{p}{\rho g} + \frac{V^2}{2g}$ is also called stagnation head

(Kinetic energy is converted into pressure energy).

8.5 (d)

Pressure rise due to water in penstock is given by $P = \rho VC$.

As the flow velocity depends on roughness of pipe, reservoir's water level, density of water and modulus of elasticity of water. Pressure rise due to water in penstock is affected by all these parameters.

8.6 (d)

Head loss, $h_L = k\frac{V_2^2}{2g}$

Assuming, $k = 0.5$, we get

$$V_2 = \sqrt{\frac{h_L}{k}}\sqrt{2g}$$

$\Rightarrow$ $V_2 = 4.43$ m/s

8.7 (a)

Total head is given by

$$H_1 = Z_1 + \frac{p_1}{\rho g} + \frac{V_1^2}{2g}$$

$$= 10 + 1 = 11 \text{ m}$$

at 10 cm section. For horizontal pipe datum head will remain same.

Discharge $Q = VA = V\left(\frac{\pi D^2}{4}\right)$

Discharge is proportional to square of diameter.

From continuity equation discharge does not vary from 10 cm section to 5 cm section.

$V_1A_1 = V_2A_2$

$\therefore$ Velocity at 5 cm section,

$$V_2 = V_1 \times \left(\frac{10}{5}\right)^2 = 4V_1$$

Velocity head at 5 cm section

$$= \frac{V_2^2}{2g} = \frac{16V_1^2}{2g} = 16\text{m}$$

Using Bernoulli's equation, we get

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}=\frac{p_2}{\rho g}+\frac{V_2^2}{2g}$$

$$\frac{p_2}{\rho g}=11-16=-5\text{ m}$$

Thus pressure head at 5 cm section is negative.

8.8 (c)

We know that critical time is given by

$$T_0=\frac{2L}{C}$$

$$\Rightarrow \quad T_0=\frac{2\times 2000}{1000}$$

$$\Rightarrow \quad T_0=4\text{ s.}$$

Actual time for valve closure, $T = 4$s.

We know that if $T \le T_0$, then the closure is known as rapid closure or instantaneous closure. Therefore the peak water hammer pressure will be equal to the water hammer pressure head for instantaneous closure of the valve at the downstream end i.e. 60 m.

8.9 (b)

Loss of head at sudden expansion is more due to:

- higher intensity of formation of eddies.
- deceleration of flow as a result of area expansion.

Separation of flow from boundary occurs in case of sudden contraction of pipe.

8.10(a)

$$h_f=\frac{\text{Pressure gradient}\times\text{Length}}{\rho g}$$

$$=\frac{(p_1-p_2)}{\rho g}=f\frac{L}{d}\frac{V^2}{2g}$$

Since $f=\frac{64}{\text{Re}}$ and $\text{Re}=\frac{\rho Vd}{\mu}$

$$V=\frac{(p_1-p_2)r^2}{8\mu L} \qquad (\text{putting } d=2r)$$

8.11(b)

Fitting type	K-value
45° elbow	0.4
90° elbow	0.9
Pump foot valve	1.5
Close return bend	2.2
Gate valve wide open	0.2
Globe valve wide open	10

8.12(d)

From T to B the branches are parallel to each other. Therefore head loss in both pipes will be same.

$$h_f=f\frac{L}{d_1}\frac{V_1^2}{2g}=f\frac{L}{d_2}\frac{V_2^2}{2g}$$

$\therefore$ Velocity in second branch,

$$V_2=V_1\sqrt{\frac{d_2}{d_1}}=1.5\times\sqrt{\frac{30}{45}}=1.23\text{m/s}$$

8.13(b)

Water hammer is a transient flow condition and it is governed by Euler's model. The velocity of pressure wave.

$$C=\sqrt{\frac{k/\rho}{1+\frac{Dk}{Et}}}$$

Where E is the volume modulus of fluid

E_p is modulus of elasticity of pipe

d, t are diameter and thickness of pipe respectively

8.14(c)

We know that

Shear velocity

$$V^* = \sqrt{\frac{\tau_0}{\rho}}=V\sqrt{\frac{f}{8}}$$

where

V = mean velocity of flow

f = Darcy friction factor

$$\frac{\tau_0}{\rho} = V^2\frac{f}{8}$$

$$f = 8\frac{\tau_0}{\rho V^2}$$

$$f = 4f'$$

f' = Coefficient of friction

$$f' = \frac{2\tau_0}{\rho V^2}$$

8.15(d)

Because of entrance loss at the upstream reservoir, the hydraulic gradient line is not very well defined at the start.

8.16(a)

The equivalence of head loss in compound pipe and equivalent pipe is the basis for finding the equivalent length.

$$\frac{L_1}{D_1^5}+\frac{L_2}{D_2^5}+\frac{L_3}{D_3^5}=\frac{L_e}{D_e^5}$$

$$\therefore L_e=\left[\frac{1800}{(50)^5}+\frac{1200}{(40)^5}+\frac{600}{(30)^5}\right]\times(40)^5$$

$$= 4318.2 \text{ m}$$

8.17 (c)

Cavitation is the formation of liquid free zones such as vapour bubbles or voids in a flowing liquid where pressure falls below vapour pressure. When subjected to high pressure, the bubbles collapse. Increase in local velocity or high elevation can cause local pressure to reduce below vapour pressure and cause cavitation.

8.18 (b)

As per the continuity equation at the junction, $Q_1 + Q_3 = Q_2$

Since connect between pipe 1 and pipe 3 is parallel, $h_{f1} = h_{f3}$

Since diameter is not given no relation can be established between discharges.

8.19(c)

For instantaneous closure of valve, the pressure head at valve end is

$$\Delta h = \frac{CV_0}{g}$$

Time period for travel of pressure wave from one end to the other is

$$t = \frac{L}{C}$$

Therefore velocity of pressure wave

$$C = \frac{L}{t}$$

and $$\Delta h = \frac{LV_0}{gt}$$

8.20(d)

Piezometric head at B

= Pressure head + elevation head

= (2.5 – 0.2) + 2.5 = 4.8 m

8.21(c)

The head loss in both pipes will be same and it is proportional to $\frac{Q^2}{D^5}$

$$\therefore \quad \frac{Q_1^2}{D_1^5}=\frac{Q_2^2}{D_2^5}$$

$$\frac{Q_1^2}{Q_2^2}=\left(\frac{D_1}{D_2}\right)^5=2^5=32$$

$$\frac{Q_1}{Q_2}=4\sqrt{2}=5.66$$

8.22(c)

$Re_c = 2000$ for critical flow

Viscosity, $\nu = 0.01$ Stokes

$$\frac{VD}{\nu}=2000$$

Velocity of flow,

$$V=\frac{2000\times0.01}{1}=20 \text{ cm/s}$$

Flow at critical Reynolds number

$$Q = V\times\frac{\pi D^2}{4}=20\times\frac{\pi}{4}\times1$$

$$= 15.7 \text{ cm}^3/\text{s} = 0.0157 \text{ } l/\text{s}$$

8.23 (a)

(i) Assume f (It is function of Re and ε/D)

Head Loss, $h_f = f\frac{L}{D}\frac{V^2}{2g}$

(ii) From head loss formula compute V.

(iii) Find ε/D from given data.

Reynolds number, $Re = \frac{VD}{\nu}$

(iv) Now again find 'f'. (say from Colebrook equation)

(v) If the computed 'f' is same as assumed 'f', then stop, otherwise repeat the procedure with new value of 'f'.

8.24(c)

$h_f = f\frac{L}{4R}\frac{V^2}{2g}$ (Darcy-Weisbach equation for non-circular section)

$V = C\sqrt{RS}$ (Chezy's equation)

Slope, $S = \frac{h_f}{L}$

Equating both equations, we get $C = \sqrt{\frac{8g}{f}}$

8.25(a)

The water hammer phenomenon gives rise to sudden increase in pressure.

8.26(a)

Surge tanks are used to absorb the increase in pressure due to water hammer phenomenon.

Entrance length in a pipe is the length where boundary layer increases and the flow is established or developed fully. Entrance length (L_e)

$\frac{L_e}{D} = 0.07\text{Re}(0.06\text{Re})$ For laminar flow given by Rouse

$\frac{L_e}{D} = 50$ For turbulent flow

where D is the diameter of the pipe.

Entrance length for turbulent flow is much smaller than laminar flow.

8.27(b)

It is necessary to satisfy continuity equation.

The loss of head due to flow in clockwise direction must be equal to the loss of head due to flow in anticlockwise direction.

Darcy-Weisbach equation must be satisfied

$h_f = kQ^n$

8.28 (a)

Water hammer is a pressure surge or wave caused when water in motion is forced to stop or change direction suddenly (sudden momentum change). A water hammer commonly occurs when a valve closes suddenly at an end of a pipeline system, and there is sudden rise in the pressure. As a result a high pressure wave propagates in the pipe. It is also called hydraulic shock.

8.29(c)

Increase in local velocity decreases the pressure and therefore cavitation may occur.

Raising the levels of the point will cause higher gradient and flow velocities will increase. This may cause cavitation.

8.30(b)

Two parallel pipes have same frictional losses

Also, $D_1 = 2D_2$

$h_{f_1} = h_{f_2}$

$$\frac{fLQ_1^2}{12.1D_1^5} = \frac{fLQ_2^2}{12.1D_2^5}$$

$$\therefore \quad \frac{Q_1}{Q_2} = 2^{5/2} = 5.657$$

8.31(a)

Water hammer phenomenon occurs near to the valve.

8.32 (d)

The Hardy Cross method is an iterative method for determining the flow in pipe network systems where the inputs and outputs are known, but the flow inside the network is unknown. This method is not applicable to open channel flow.

8.33(c)

Using continuity equation,

$Q_C = Q_A + Q_B$

Head loss in pipe,

$AJ = 10Q_A^2 = 25.9 - 9 = 16.9\text{m}$

$\therefore \quad Q_A = 1.3\ \text{m}^3/\text{s}$

Head loss in pipe,

$BJ = 4Q_B^2 = 18 - 9 = 9\text{m}$

$Q_B = 1.5\ \text{m}^3/\text{s}$

$\therefore \quad Q_C = 1.3 + 1.5 = 2.8\ \text{m}^3/\text{s}$

Head loss in pipe,

$JC = 1Q_C^2 = 7.84\text{m}$

Residual head at,

$C = 9 - 7.84 = 1.16\ \text{m}$

8.34(d)

The head loss through the pipe is given by

$$h_L = \frac{fLQ^2}{12.1D^5}$$

If all the parameters remain same other than friction factor and discharge then

$$fQ^2 = \text{constant}$$

Let this constant be C, then

$$fQ^2 = C$$

$$\Rightarrow \quad Q^2 = \frac{C}{f} \qquad ...(i)$$

Differentiating Q w.r.t f, we get

$$2QdQ = C \times \left(-\frac{1}{f^2}\right) df \qquad ...(ii)$$

Dividing (ii) by (i), we get

$$\frac{2QdQ}{Q^2} = \frac{C \times \left(-\frac{1}{f^2}\right) df}{\frac{C}{f}}$$

$$\Rightarrow \quad \frac{2dQ}{Q} = -\frac{df}{f}$$

$$\Rightarrow \quad \frac{dQ}{Q} = -\frac{1}{2} \times \frac{df}{f}$$

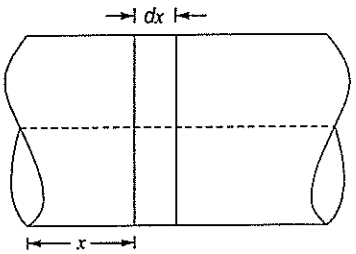
$$\Rightarrow \quad dQ = -\frac{Q}{2} \times \frac{df}{f}$$

$$\Rightarrow \quad dQ = -\frac{100}{2} \times \frac{20}{100}$$

$$\Rightarrow \quad dQ = -10\%$$

8.35 (b)

If the length of the pipe be L, diameter be D, discharge be Q, then head loss may be given as



$$h_{L_1} = \frac{fLQ^2}{12.1D^5} \qquad ...(i)$$

$$h_{L_2} = \int_0^L \frac{f(Q-qx)^2 dx}{12.1D^5}$$

$$= \frac{f}{12.1D^5}\int_0^L \left(Q^2 + q^2x^2 - 2Qqx\right)dx$$

$$= \frac{f}{12.1D^5}\left[Q^2x + \frac{q^2x^3}{3} - \frac{2Qqx^2}{2}\right]_0^L$$

$$= \frac{f}{12.1D^5}\left[Q^2L + \frac{q^2L^3}{3} - QqL^2\right]$$

But $Q = qL$

$$\therefore \quad h_{L_2} = \frac{f}{12.1D^5}\left[Q^2L + \frac{Q^2L}{3} - Q^2L\right]$$

$$h_{L_2} = \frac{fLQ^2}{36.3\,D^5} \qquad ...(ii)$$

Dividing (ii) by (i), we get

$$\frac{h_{L_2}}{h_{L_1}} = \frac{fLQ^2/36.3\,D^5}{fLQ^2/12.1D^5}$$

$$\Rightarrow \quad \frac{h_{L_2}}{h_{L_1}} = \frac{1}{3}$$

8.36 (c)

If H is the total supply head and h_f is the loss of head due to friction, then head available at the outlet of pipe (neglecting the minor losses) is $H - h_f$. If Q is the discharge through the pipe, V is the velocity of flow and L and D are the length and the diameter of the pipe respecting, then from dercy-Weisbach equation we have

$$h_f = \frac{fLV^2}{2gD} \text{ and } Q = \frac{\pi D^2}{4} \times V$$

The power available at the outlet of pipeline is given by

$$P = \gamma Q(H - h_f)$$

$$\Rightarrow \quad P = \gamma \times \frac{\pi D^2}{4} \times V \times \left(H - \frac{fLV^2}{2gD}\right)$$

For a given pipe and head at the entrance, the condition for the maximum power transmitted through the pipe line may be obtained by differentiating P w.r.t. V and equating it to zero

$$\therefore \quad \frac{dP}{dV} = \gamma \times \frac{\pi D^2}{4} \times \left(H - \frac{3fLV^2}{2gD}\right) = 0$$

$$\Rightarrow \quad H - \frac{3fLV^2}{2gD} = 0$$

$$\Rightarrow \quad H - 3h_f = 0$$

$$\Rightarrow \quad h_f = \frac{H}{3}$$

8.37 (d)

Pressure at summit i.e. at the highest point of siphon is always negative. Therefore there is a minimum limit for pressure at the summit. It can never be allowed to go below vapour pressure. Pressure at siphon will be less than at A and B.

8.38 (b)

When the pressure in any part of the flow passage reaches the vapor pressure (limiting value) of the flowing liquid, its starts vaporizing and small bubbles of vapor form in large numbers. The bubbles when reach to the high pressure zones, suddenly collapse as the vapor condenses to liquid again. Due to sudden collapsing of the bubbles or cavities the surrounding liquid rushes in to fill them. The liquid moving from all directions collides at the centre of the cavity, thus giving rise to very high local pressures. Any solid surface in the vicinity is also subjected to these intense pressures. The alternate formation and collapse of vapor bubbles may cause severe damage to the surface which ultimately fails by fatigue and the surface becomes badly scoured and pitted. This phenomenon is known as cavitation which is found to occur in turbines and pumps as well as in various hydraulic structures such as penstocks, gates valves, spillways etc. Since the total energy remains constant in the system thus if the pressure is reduced to limiting value, the velocity or elevation might have been increased and vice-versa.

8.39 (b)

Velocity will be maximum at point 2 and then there will be momentum change and possibility of pressure drop. Bubbles will generate at point 2 and collapse a little while flowing towards point 4.

8.40 (d)

Cavitation occurs when increase in local velocity causes local pressure to reduce below vapour pressure.

8.41 (d)

When Pumps are in parallel individual volume flow rates are added and head remains constant.

8.42 (a)

Pumps in Parallel: Total discharge is cumulative of discharge of individual pump while head remains same.

Pumps in Series: Discharge remains same while the total head is cumulative head of individual pump.

8.43 (a)

In the case of sudden expansion the fluid emerging from the smaller pipe being unable to take a sharp turn at the corners follows a path of streamlines. Consequently, the pockets of turbulent eddies are formed in the corners and result in dissipation of energy in the form of head. The lost hydraulic energy is thus converted into the thermal energy (raising slightly the fluid temperature) which is in turn lost to the surrounding medium.

Loss of energy at sudden enlargement is given by

$$h_L = \frac{V_1^2}{2g}\left(1-\frac{A_1}{A_2}\right)^2 = \frac{V_2^2}{2g}\left(\frac{A_2}{A_1}\right)^2$$

Loss of energy at sudden contraction is given by

$$h_L = \frac{V_2^2}{2g}\left(\frac{1}{C_c}-1\right)^2$$

C_c = Coefficient of contraction.

The turbulence level and fromation of eddies is more prominent in the case of sudden expansion than at sudden contraction.

8.44 (a)

Time period of oscillation refers to the total time that the wave takes to start from the closed valve and reach back at the same location after traversing the entire length of penstock twice.

$$T = \frac{2\times 4500}{1500} = 6\text{s}$$

8.45 (d)

The head loss in a circular pipe of diameter D, and length L, carrying a discharge Q is given by

$$h_f = \frac{f\times L\times Q^2}{12.1\times D^5}$$

When pipes are connected in series total head loss is given by

$$h_f = h_{f_A} + h_{f_B} + h_{f_C}$$

$$\Rightarrow \frac{f\times L_e\times Q^2}{12.1\times D^5} = \frac{f\times L\times Q^2}{12.1\times D^5} + \frac{f\times L\times Q^2}{12.1\times\left(\frac{D}{2}\right)^5} + \frac{f\times 4L\times Q^2}{12.1\times(2D)^5}$$

$$\Rightarrow \frac{L_e}{D^5} = \frac{L}{D^5} + \frac{32L}{D^5} + \frac{L}{8D^5}$$

$$\therefore \quad L_e = L + 32L + \frac{L}{8}$$

$$\Rightarrow \quad L_e = 33\frac{1}{8}L$$

8.46 (c)

$K = 2.1 \times 10^9$ Pa; $E = 2.1 \times 10^{11}$ Pa

$\rho = 1000$ kg/m^3; $D = 400$ mm

$t = 4$ mm

Velcoity of propagation of water hammer pressure

$$= \sqrt{\frac{K/\rho}{1+\frac{KD}{Et}}} = \sqrt{\frac{2.1\times\frac{10^9}{1000}}{1+1}} = 1024.7 \text{ m/s}$$

8.47 (b)

According to Darcy Weisback

$$h_f = \frac{fLV^2}{d\times 2g}$$

Now, $d' = 2d$, $V' = 2V$

$$\therefore \quad h_f' = \frac{fL(2V)^2}{2d\times 2g} = 2\times\frac{fLV^2}{d\times 2g}$$

$$\therefore \quad h_f' = 2h_f$$

8.48 (c)

Velocity of pressure wave is given by

$$C = \sqrt{\frac{K}{\rho}}$$

$$C_1 = \sqrt{\frac{2.16\times 10^9}{1000}}$$

Now, $$C_2 = \sqrt{\frac{1.296\times 10^9}{0.6\times 1000}}$$

$$\therefore \quad \frac{C_1}{C_2} = 1$$

8.49 (b)

As per Bernoulli's equation total head,

$$H = \frac{P}{\rho g} + Z + \frac{V^2}{2g}$$

Where,

$\frac{P}{\rho g}$ is pressure head or static head

Z is datum or elevation head

$\frac{V^2}{2g}$ is velocity head or dynamic head or kinetic head

$\frac{P}{\rho g} + Z$ is also piezometric head

$\frac{P}{\rho g} + \frac{V^2}{2g}$ is called stagnation head

8.50 (c)

$$P = \dot{m}gh_L = \rho Q g h_L$$

Now $$h_L = \frac{fLQ^2}{12\times D^5}$$

$$\therefore \quad P \propto Q^2$$

$$\Rightarrow \quad P_2 = \left(\frac{Q_2}{Q_1}\right)^2 \times P_1$$

$$P_2 = (1.44\, P_1)$$

$\therefore$ Power will increase by 44%.

8.51 (c)

To maintain continuity at junction,

Total Q_{in} = Total Q_{out}

In a network, algebraic sum of the drop in piezometric head is zero.

8.52 (c)

$$t = \frac{2L}{C} = \frac{2(1920)}{960} = 4 \text{ sec}$$

8.53 (d)

In pipe flow, flow occurs under pressure and not through gravity.

8.54 (c)

Pressure head rise due to water hammer for rigid pipe

$$\frac{P}{\rho g} = \frac{VC}{g} \qquad \text{where } C = \sqrt{\frac{k}{\rho}}$$

8.55 (c)

Pipes are placed parallel

$$\therefore \quad h_{f_P} = h_{f_Q}$$

$$\left(\frac{fLQ^2}{12.1D^5}\right)_P = \left(\frac{fLQ^2}{12.1D^5}\right)_Q$$

$$9fQ_P^2 = fQ_Q^2$$

$$Q_P = \frac{Q_Q}{3} = 0.33\, Q_Q$$

8.56 (a)

Total energy line and the hydraulic gradient line for a pipe flow cannot intersect each other. Hydraulic gradient line is sloping due to friction loss and other losses.

8.57 (d)

As per the question no options is matching with the solution.

$$h_f = \frac{H}{3} = \frac{720}{3} = 240 \text{ m}$$

$$H_{exit} = \frac{2H}{3} = 480 \text{ m}$$

$$h_f = \frac{8Q^2 \times f \times L}{\pi^2 g D^5}$$

$$240 = \frac{8Q^2 \times 0.12 \times 3000}{\pi^2 g \times 0.2^5}$$

$$\Rightarrow \quad Q = 0.0508 \text{ m}^3/\text{s}$$

$$P_{exit} = \rho Q g H_{exit}$$

$$= \frac{1000 \times 0.508 \times 9.81 \times 480}{735.5}$$

$$= 325.31 \text{ mhp}$$

Alternatively

In this problem, the value of friction factor is not defined properly. Friction coefficient is given as point 0.03 if we take $f = 0.03$, where f is friction factor then, we can choose (d) as nearest answer.

$$h_f = \frac{8Q^2 \times f \times L}{\pi^2 g D^5}$$

$$240 = \frac{8Q^2 \times 0.03 \times 3000}{\pi^2 g \times 0.2^5}$$

$$\Rightarrow \quad Q = 0.102 \text{ m}^3/\text{s}$$

$$P_{exit} = \rho Q g H_{exit}$$

$$= \frac{1000 \times 0.102 \times 9.81 \times 480}{735.5}$$

$$= 653.02 \text{ mhp}$$

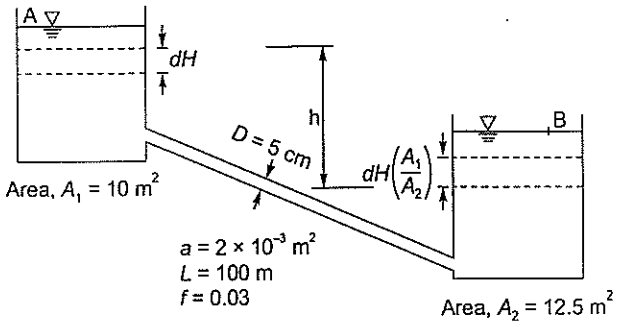
8.58 (d)

$$k_s = k_{s0} + \alpha t$$

k_s increases linearly with time.

8.59 (d)

Let at any instant the difference in the water levels in the two reservoirs be h and in time dt the water level in the tank A fall by an amount dH, Then, the water level will rise in tank B by an amount $\left(dH\frac{A_1}{A_2}\right)$. Now if dh is the change in difference in head causing the flow



$$dh = dH + dH\frac{A_1}{A_2}$$

$$dH = \frac{dh}{1 + \frac{A_1}{A_2}}$$

Now, $\quad -A_1\, dH = a.v.dt \qquad V = 1.75\sqrt{h}$

$$-A_1 \frac{dh}{1 + \frac{A_1}{A_2}} = a \times 1.75\sqrt{h}\, dt$$

$$\frac{-A_1A_2}{(A_1 + A_2)a(1.75)} \int_{h_1}^{h_2} \frac{dh}{\sqrt{h}} = \int_0^T dt$$

$$T = \frac{2A_1A_2}{a(A_1 + A_2)(1.75)}\left[\sqrt{h_1} - \sqrt{h_2}\right]$$

$h_1 \Rightarrow$ The difference of water levels in the reservoirs before flow commences

$h_1 = 3$ m

$h_2 \Rightarrow$ The difference of water levels in the reservoirs after flow commences

Level fall in tank A $= \frac{2.5}{10} = 0.25$ m

Level rise in tank B $= \frac{2.5}{2.5} = 1$ m

So, $\quad h_2 = h_1 - (1 + 0.25)$

$= 3 - (1.25)$

$= 1.75$ m

Now,

$$T = \frac{2(10)(2.5)}{\left(2 \times 10^{-3}\right)(10 + 2.5)(1.75)}\left[\sqrt{3} - \sqrt{1.75}\right]$$

$$= 1142.86\left(\sqrt{3} - \sqrt{1.75}\right) = 467.66 \text{ sec}$$

8.60 (a)

In this problem, the value of friction factor is not defined properly. Actually the value of friction factor is given but written as friction coefficient.

$$15 = \frac{8Q^2}{\pi^2 g} \times \frac{(0.04)(1500)}{(0.324)^5}$$

$$Q = 103.9 \; lps$$

8.62 (c)

Cavitation occurs when at a specific point fluid pressure becomes less than vapor pressure or temperature become too high. Energy is released with the onset of pressure wave of high intensity wave due to noise and vibration of machine.

8.63 (d)

$$H = \frac{V_0^2}{2g} + k \cdot \frac{V_0^2}{2g}$$

where $V_0 \Rightarrow$ steady flow velocity

$$11.25 = \frac{V_0^2}{2g}[1+k]$$

$$11.25 = \frac{V_0^2}{2g}[1+98.1]$$

$$11.25 = V_0^2 \times 5.051 = 1.49 \text{ m/sec}$$

Time take for establishment of flow

$$t = \frac{L}{(1+k)V_0} \ln \frac{V_0 + V}{V_0 - V}$$

$$= \frac{294.3}{(99.1)(1.49)} \ln \left(\frac{V_0 + V}{V_0 - V} \right)$$

$$= 2 \ln \left(\frac{V_0 + V}{V_0 - V} \right) \quad ...(1)$$

when $\frac{Q}{Q_0} = 0.95$

Then $\frac{V}{V_0} = 0.95$

Put the value in equation

$$t = 2 \ln \left(\frac{1+0.95}{1-0.95} \right) = 2 \log_e 39$$

■■■■

9 Drag and Lift Force

9.1 The flow of water in a wash hand basin when it is being emptied through a central opening, is an example of

(a) free vortex (b) forced vortex
(c) rotational vortex (d) Rankine vortex

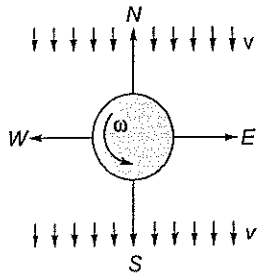
[ESE : 1995]

9.2 A sphere of certain diameter, when towed submerged under water, experiences a drag force of 4 N at a velocity of 1.5 m/s. If another sphere of twice the diameter of the sphere referred to above, is towed with the same velocity in water, the drag force experienced by this sphere will be

(a) 8 N (b) 16 N
(c) 24 N (d) 32 N

[ESE : 1995]

9.3 A circular cylinder held in uniform flow from north to south as shown in the figure, is rotated about its own axis in an anticlockwise direction. It will experience a lift force in the direction of



(a) N (b) S
(c) E (d) W

[ESE : 1995]

9.4 The overall drag coefficient of an aircraft of weight W and wing area S is given by

$$C_D = a + bC_L^2$$

where 'a' and 'b' are constants. The maximum drag in horizontal flight will be

(a) $W\sqrt{ab}$ (b) $2W\sqrt{ab}$
(c) $4W\sqrt{ab}$ (d) $6W\sqrt{ab}$

[ESE : 1996]

9.5 If Stokes' law is considered valid below a Reynolds number of unity, then the largest raindrop that will fall in accordance with this law will have a diameter of approximately
(assuming $\rho_w = 1000$ kg/m^3, $\rho_a = 1.3$ kg/m^3, $\nu_w = 10^{-6}$ m^2/s, $\nu_a = 1.5 \times 10^{-5}$ m^2/s)

(a) 0.75 mm (b) 0.3 mm
(c) 0.15 mm (d) 0.075 mm

[ESE : 1996]

9.6 In the Stoke's experiment of falling sphere, it is found that a sphere of 5 mm diameter falls in a liquid with terminal velocity 20 mm/s giving a drag coefficient of 240. The ratio of specific gravities is 2.85. Which one of the following is the kinematic viscosity of the liquid in stokes?

(a) 3.5 (b) 10.0
(c) 225.0 (d) 1000.0

[ESE : 1998]

9.7 A ping-pong ball, having a diameter of 3.6 cm and weighing 2.4 g is served with a horizontal velocity of 10 m/sec and a spin that gives rise to a coefficient of lift of 0.2. Assuming the density of air to be 0.00129 gf/cc, the lift experienced by the ball is nearly

(a) 13 gf (b) 1.3 gf
(c) 0.13 gf (d) 0.013 gf

[ESE : 1998]

9.8 **Assertion (A):** Total drag is reduced if the boundary layer on the surface of a cylinder separates further downstream of the leading point.
Reason (R): As the separation point moves further downstream, form drag is reduced and the skin drag is only marginally increased.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

9.9 Which one of the following statements relating to vortex flow is INCORRECT?
(a) In the formation of a free vortex, stream-lines are axisymmetric and irrotational.
(b) In a forced vortex, work transfer between the fluid and the surroundings takes place and the flow is rotational.
(c) In a free vortex, radial motion towards the core takes place due to variation of depth of water in the whirlpool or due to the difference of pressure resulting from higher velocity near the core.
(d) In a free vortex, there is no variation of energy from streamline to streamline and irrotationality is not deviated from near the core.

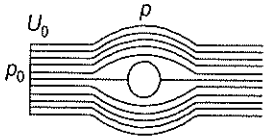
[ESE : 2001]

9.10 Magnus effect may be used advantageously in games such as cricket, tennis, table tennis and golf. In order to obtain a lift, i.e. a rising curve for the trajectory of the ball, from left to right, the nature of the spin to be given is
(a) anticlockwise in the vertical plane
(b) anticlockwise in the horizontal plane
(c) clockwise in the vertical plane
(d) clockwise in the horizontal plane

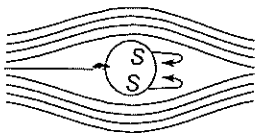
[ESE : 2001]

9.11 Match List-I (Flow pattern past a cylinder) with List-II (Pressure distribution) and select the correct answer using the codes given below the lists:

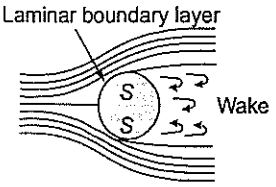
List-I

A. 

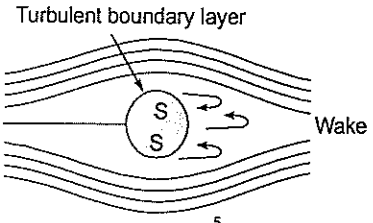
Re < 0.5

B. 

2 < Re < 30

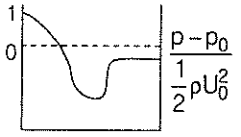
C. 

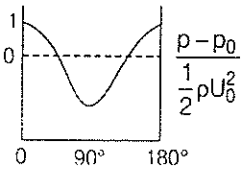
$10^3 \le Re \le 2 \times 10^5$

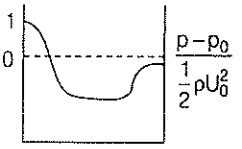
D. 

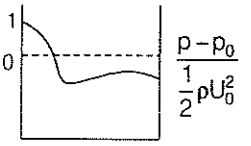
$Re > 2 \times 10^5$

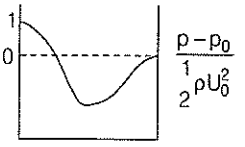
List-II

1. 

2. 

3. 

4. 

5. 

Codes:

	A	B	C	D
(a)	2	5	1	3
(b)	4	3	5	2
(c)	2	1	5	4
(d)	4	3	1	2

[ESE : 2002]

9.12 Which one of the following gives the lift force F_L produced on a rotating circular cylinder per unit length in a uniform flow?

(a) $F_L = \frac{u\Gamma}{\rho}$ (b) $F_L = \rho u \Gamma$

(c) $F_L = \frac{\rho\Gamma}{u}$ (d) $F_L = \frac{\rho u}{\Gamma}$

where,

u = free stream velocity

Γ = circulation

ρ = density of the fluid

[ESE : 2006]

9.13 Drag force on a cylinder for turbulent flow compared to laminar flow is

(a) same (b) more

(c) less (d) very high

[ESE : 2006]

9.14 Body M has twice the weight, twice the projected area and twice the drag coefficient of body N. How many times is the terminal velocity of the body M in air, compared to that of the body N?

(a) 8 (b) 2

(c) $\sqrt{2}$ (d) $1/\sqrt{2}$

[ESE : 2007]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

9.15 **Assertion (A):** If a cylindrical body is placed in a fluid stream and is rotated, then a lift force is produced on the body.

Reason (R): Rotation of the cylinder disturbs the symmetrical pattern which in turn alters the pressure distribution on the body.

[ESE : 2009]

9.16 **Assertion (A):** The drag force on a sphere is more in laminar flow than in turbulent flow.

Reason (R): C_D of a sphere is more in laminar flow than in turbulent flow.

[ESE : 2009]

9.17 An airplane is cruising at a speed of 800 km/h at an altitude where the air temperature is 0° C. The flight Mach number at this speed is nearly

(a) 1.3 (b) 0.67

(c) 0.25 (d) 2.4

[ESE : 2010]

9.18 Singing of telephone wires in the wind occurs due to

(a) Vibrations caused by birds as they sit on, or get off, the wires

(b) Tensioning at the ends

(c) Magnus effect

(d) Generation of Karman Vortex street

[ESE : 2011]

9.19 A high tension cable 5 cm in diameter is strung-out between two towers. At a wind velocity of 22.22 m/s (corresponding Reynolds number being 7.4×10^4) the frequency of vortex shedding is

(a) 100 Hz (b) 9.33 Hz

(c) 93.3 Hz (d) 10.0 Hz

[ESE : 2012]

9.20 A very small spherical particle of sand settles in a column of viscous liquid. If the Reynolds number corresponding to its terminal velocity is 0.25, the drag coefficient of the sand particle is:

(a) 256 (b) 128

(c) 96 (d) 64

[ESE : 2013]

9.21 When small sphere falls freely in Stokes range through a water column, which of the following statements are correct?

1. Viscosity, surface tension and gravitational forces act on the sphere.
2. There is no turbulence possible in the wake of the falling sphere.
3. Drag coefficient, $C_d = R/24$, where R is Reynolds number.
4. Proximity of the boundary moderates the drag and lift coefficients.

(a) 1 and 2 (b) 2 and 3

(c) 3 and 4 (d) 2 and 4

[ESE : 2013]

9.22 Which of the following statements are correct?

1. Friction and pressure drag depend upon the shape and position of immersed body.

2. If a thin plate is kept parallel to the direction of flow, then the pressure drag is zero.
3. If a thin plate is kept perpendicular to the moving fluid, then friction drag is zero.

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2013]

Directions: Each of the next items consists of two statements, one labeled as the 'Statements (I)' and the other as 'Statement (II)'. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

9.23 **Statement (I):** A tennis ball with a rough surface can be made to curve more markedly than the one with a smooth surface.

Statement (II): Circulation is increased in the case of a rough ball.

[ESE : 2013]

9.24 **Statement (I):** A rectangular bridge pier experiences lateral force during flood flow.

Statement (II): The bridge pier sheds vortices alternately from its either side into the wake flow.

[ESE : 2013]

9.25 For circular cylinders, with Reynolds number greater than 1000, how would the Strouhal number behave

(a) Varies as $Re^{1/6}$ (b) Varies as $Re^{1/4}$
(c) Almost ≈ 0.16 (d) Constant at 0.21

[ESE : 2014]

9.26 A man, 65 kg, descends to the ground with the helps of a parachute, 18 kg. The parachute is hemispherical in shape, 2 m diameter. Density of air can be taken as 0.00125 g/cm^3 and its kinematic viscosity as 0.15 stoke. What is the terminal velocity of the parachute? [Take C_D = 1.5 and g = 1000 cm/sec^2]

(a) 16.6 m/sec (b) 15.8 m/sec
(c) 15.0 m/sec (d) 14.1 m/sec

[ESE : 2017]

■■■■

Answers Drag and Lift Force

9.1	(a)	9.2	(b)	9.3	(d)	9.4	(b)	9.5	(d)	9.6	(b)	9.7	(b)	9.8	(a)	9.9	(d)
9.10	(a)	9.11	(a)	9.12	(b)	9.13	(c)	9.14	(d)	9.15	(a)	9.16	(a)	9.17	(b)	9.18	(d)
9.19	(c)	9.20	(c)	9.21	(d)	9.22	(d)	9.23	(a)	9.24	(a)	9.25	(d)	**9.26**	(a)		

Explanations Drag and Lift Force

9.1 (a)

Free vortex flow is irrotational flow and total head (energy) remains constant throughout flow field.

9.2 (b)

$$FD = C_D \times A \times \frac{1}{2} \times \rho \times V^2$$

(Since sufficient data is not given, Assume C_D = Constant.)

Then $F_D \propto A$

$F_D \propto D^2$

$$\frac{F_{D_1}}{F_{D_2}} = \left(\frac{D_1}{D_2}\right)^2$$

$$\frac{F_{D_1}}{F_{D_2}} = \left(\frac{D}{2D}\right)^2$$

$$F_{D_2} = 4F_{D_1}$$

9.3 (d)

As cylinder is rotated anticlockwise and wind is coming from north direction. Resultant velocity on the left half portion will be $V + \omega R$ and on right half portion will be $V - \omega R$. Thus pressure on left half will be less and on right half will be more and lift will be in the west direction

9.4 (b)

The lift force, $F_L = C_L S\left(\frac{\rho V^2}{2}\right)$

The drag force, $F_D = C_D S\left(\frac{\rho V^2}{2}\right)$

The weight of aircraft shall be equal to the lift force

$$C_L S\left(\frac{\rho V^2}{2}\right) = W$$

$\therefore$ Drag force, $F_D = \left(\frac{C_D}{C_L}\right)W$

It will be maximum when $\frac{C_D}{C_L}$ is maximum

Given $C_D = a + bC_L^2$

$\therefore$ $\frac{C_D}{C_L} = \frac{a}{C_L} + bC_L$

$$\frac{d(C_D / C_L)}{dC_L} = -\frac{a}{C_L^2} + b = 0$$

$$C_L = \sqrt{(a/b)}$$

$\therefore$ Maximum drag $= \left[\frac{a}{\sqrt{a/b}} + b\sqrt{a/b}\right]W$

$= 2W\sqrt{ab}$

9.5 (d)

The weight of rain drop,

$$W = \rho_w\left(\frac{\pi D^3}{6}\right)g$$

The drag force,

$F_D = 3\pi \mu_{air} DV$

where V is the velocity

$W = F_D$

$\therefore$ $V = \frac{\rho_w D^2 g}{18\mu_{air}} = \frac{\rho_w D^2 g}{18\rho_a \nu_a}$

Reynolds number,

$$\text{Re} = \frac{VD}{\nu_a} = \frac{\rho_w D^2 g}{18\rho_a (\nu_a)^2}$$

$\therefore$ $\frac{\rho_w D^3 g}{18\rho_a (\nu_a)^2} = 1.0$

$\Rightarrow$ $D = \left[\frac{18\rho_a (\nu_a)^2}{\rho_w g}\right]^{1/3}$

$$= \left[\frac{18 \times 1.3 \times (1.5 \times 10^{-5})^2}{1000 \times 10}\right]^{1/3}$$

$= 0.081$ mm

9.6 (b)

Drag coefficient, $C_D = \frac{24}{\text{Re}}$

$\therefore$ $\text{Re} = \frac{24}{240} = 0.1 < 1.0$

Now $\text{Re} = \frac{VD}{\nu}$

Given $V = 20$ mm/s $= 2$ cm/s

$D = 5$ mm $= 0.5$ cm

$\therefore$ $\nu = \frac{2 \times 0.5}{0.1} = 10$ stokes

9.7 (b)

Lift force, $F_L = C_L A_p \frac{\rho V^2}{2}$

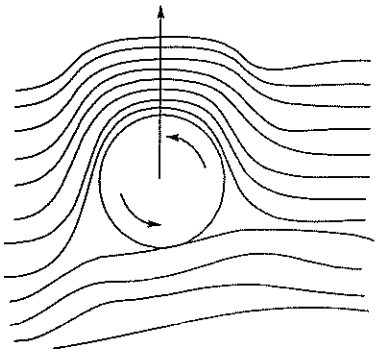
$$= 0.2 \times \frac{\pi \times (3.6)^2}{4} \times \frac{0.00129 \times (1000)^2}{2}$$

$$= 1.3 \text{ gf}$$

9.8 (a)

As the fluid velocity decreases the separation point moves further downstream. Skin friction is increased marginally but there is reduction in form drag resulting in decrease in total drag and form drag is generally more transkin drag.

9.10 (a)



To obtain a lift nature of spin should be anticlockwise in vertical plane.

9.9 (d)

In real fluid, in the central region of a free vortex, the viscous effects becomes quite predominant, due to which a central cave of fluid with rotational motion is developed, where $V \propto r$ similar to forced vortex motion.

9.11 (a)

With Re < 0.5, the pressure distribution is symmetrical on both upstream and downstream of cylinder, when the Reynolds number is very small. So A–2

With increase in Re, the flow separates at downstream. The flow pattern with respect to an axis perpendicular to the direction of flow becomes unsym-metrical. At Re ranging from 2 to 30, very weak vortices are formed on the downstream of the cylinder. So B–5

For $10^3 < \text{Re} < 2 \times 10^5$, the boundary layer is laminar and the points of separation are located on the upstream half of the cylinder. The pressure remains negative with a constant value on the downstream.

For $\text{Re} > 2 \times 10^5$, the turbulent boundary layer forms and the points of separation shift further downstream. The pressure distribution is negative on considerable portion of upstream and downstream end. The maximum negative pressure occurs on the upstream side.

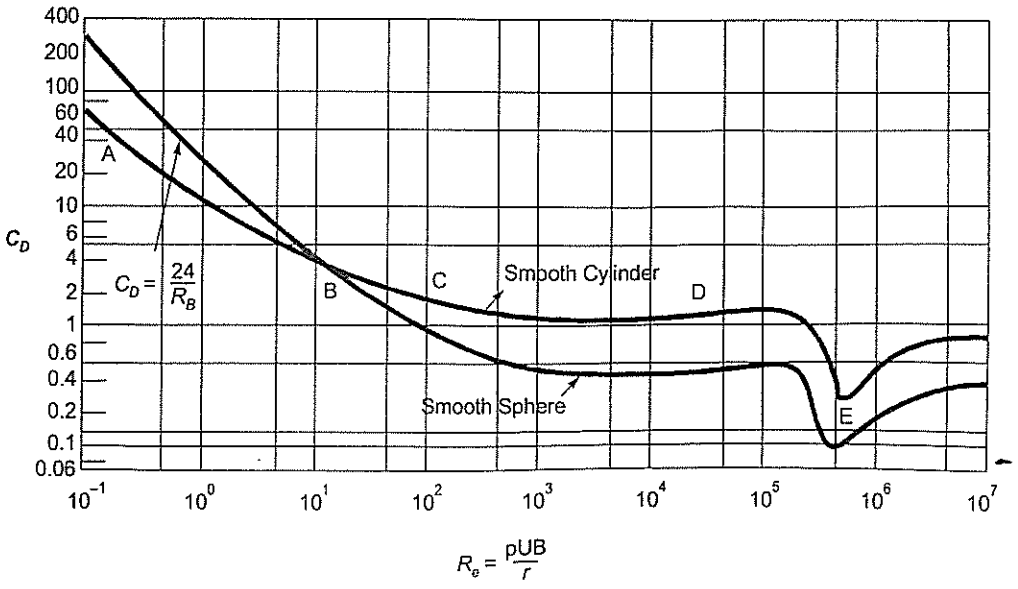
9.12 (b)

$F_L = \rho u \Gamma$

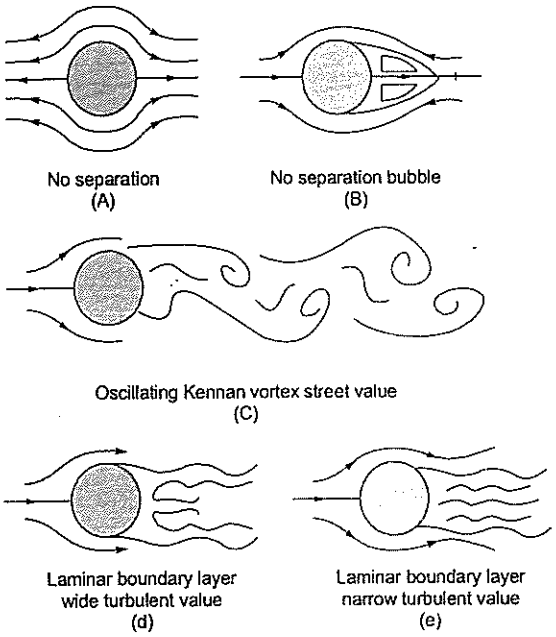
This equation is commonly known as Kutta-Joukowski equation for lift force.

9.13 (c)

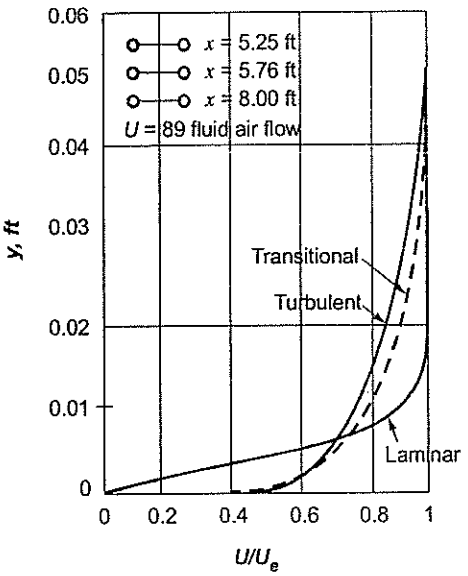
Drag coefficient as a function of Reynolds number for smooth circular cylinders and smooth spheres.



Flow patterns for flow over a cylinder: (A) Reynolds number = 0.2; (B) 12; (C) 120; (D) 30,000; (E) 500,000. Patterns correspond to the points marked on above figure.



Boundary layer profiles for laminar and turbulent flow



9.14(d)

Using subscript 1 and 2 for body *N* and *M* respectively. Now, to attain the terminal velocity, the drag force should be equal to the weight of the body.

$$F_D = C_D A \times \frac{\rho V^2}{2}$$

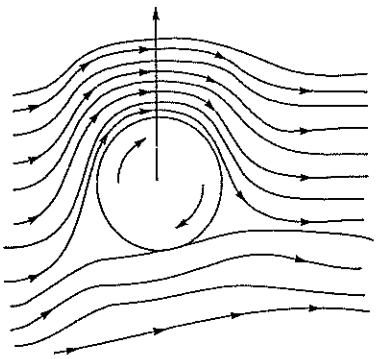
But $W = F_D$

$$\Rightarrow \quad \frac{W_1}{W_2} = \frac{C_{D_1} A_1 \times \frac{\rho V_1^2}{2}}{C_{D_2} A_2 \times \frac{\rho V_2^2}{2}}$$

$$\Rightarrow \quad \frac{W}{2W} = \frac{C_{D_1} A_1 \times V_1^2}{2C_{D_1} \times 2A_1 \times V_2^2}$$

$$\Rightarrow \quad \frac{V_2}{V_1} = \frac{1}{\sqrt{2}}$$

9.15 (a)



Rotation of cylinder causes crowded streamlines in top portion indicating increase in velocity while in bottom portion lines are further apart. Pressure on upper portion is lower than that at bottom so upward force will act on cylinder.

9.17 (b)

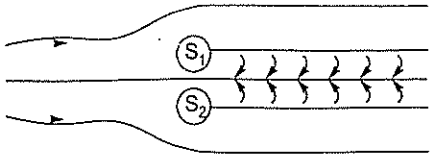
$$\text{Aeroplane} = 800 \times \frac{5}{18} = 222.22 \text{ m/sec}$$

$$\text{Mach No.} = \frac{222.22}{332} = 0.67$$

9.18(d)

With Re > 90, eddies are shed alternately from the two sides of the cylinder. As a result, two rows of vortices rotating in opposite direction are formed in the wake. This is known as Von-Karmann vortex street. Alternate shedding of vortices from the two sides of a cylinder gives rise to the phenomenon of singing of telephones or power lines in the mind.

9.19 (c)



The frequency of vortex shedding is given by the shrouhal No. (S)

$$S = \frac{nD}{u_\infty}$$

h = frequency of vortex shedding
D = Dia. of cylinder
u_∞ = free stream velocity

$$S = 0.198\left[1-\frac{19.7}{Re}\right]$$

For $250 < Re < 2 \times 10^5$

$$\frac{n \times 0.05}{22.22} = 0.198\left[1-\frac{19.7}{17.4\times10^4}\right]$$

$$n = 87.967Hz$$

So, the nearest option is (c).

9.20 (c)

$$C_D = \frac{24}{Re} = \frac{24}{0.25} = 96$$

9.21 (d)

Surface tension does not act on falling sphere and Drag coefficient $C_d = 24/R_e$.

9.22 (d)

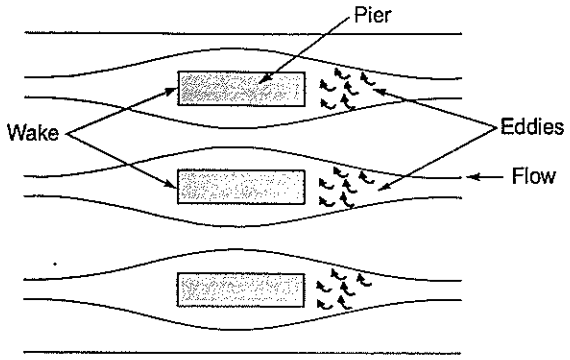
Friction drag and pressure drag depend on shape and position of immersed body.

When thin plate is held parallel to direction of flow, the projected area is nearly zero as plate is thin so pressure drag is zero and when thin plate is held perpendicular to direction of flow total drag is equal to pressure drag and friction drag is zero.

9.23 (a)

Tennis balls are designed to have rough surfaces that grab the air a little bit. So if the ball spins as it moves it will drag the air around it a little, which leads to air rotating around the ball, which makes the air on one side move faster than the air on the other, which leads to a lower pressure on one side compared to the other, which creates a net force and thus pushes the ball around.

9.24 (a)



9.25 (d)

An interesting feature of flow past two dimensional bodies is the formation and alternate release of vortices behind the cylinder for Re > 30. This vortex shedding leads to lateral vibration of two-dimensional bodies. The frequency of vortex shedding n is expressed as Strouhal Number

$$S = \frac{nD}{V_o}$$

For cylinder, the value of strouhal number S can be estimated by the formula

$$S = 0.198\left[1-\frac{19.7}{Re}\right]$$

Where, $250 < Re < 2 \times 10^5$

9.26 (a)

$$Mg = F_D$$

$$10 \times (65 + 18) = C_D \times \frac{1}{2} \times \rho \times A \times V_T^2$$

$$10 \times 83 = 1.5 \times \frac{1}{2} \times 1.25 \times \frac{\pi}{4}(2)^2 \times V_T^2$$

$$V_T = 16.79 \text{ m/sec}$$

■■■■

10 Boundary Layer Theory

10.1 **Assertion (A):** Flow in the boundary layer is always laminar.
Reason (R): In turbulent flow on a smooth boundary, a laminar sublayer still exists within the boundary layer.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1995]

10.2 The relative thickness (δ/x) of turbulent boundary layer on a flat plate
(a) decreases with distance (x)
(b) increases with distance (x)
(c) remains constant
(d) depends on relative roughness
[ESE : 1996]

10.3 The ratio of the coefficient of friction drag in laminar boundary layer compared to that in turbulent boundary layer is proportional to
(a) $R_L^{1/2}$ (b) $R_L^{1/5}$
(c) $R_L^{3/10}$ (d) $R_L^{-3/10}$
[ESE : 1996]

10.4 The displacement thickness of a boundary layer is
(a) the distance to the point where $(v/V) = 0.99$
(b) the distance where the velocity 'v' is equal to the shear velocity V_*, that is, where $v = V_*$.
(c) the distance by which the main flow is to be shifted from the boundary to maintain the continuity equation
(d) one half the actual thickness of the boundary layer
[ESE : 1997]

10.5 A fluid with kinematic viscosity v flows in laminar stage along a flat plate with free-stream velocity V. At a distance x from the leading edge, the Reynolds number of the flow is given by $R = \frac{Vx}{\nu}$. The thickness of the boundary layer at x will be proportional to
(a) $xR^{1/2}$ (b) $xR^{-1/2}$
(c) $R^{1/2}$ (d) $R^{-1/2}$
[ESE : 2001]

10.6 Match List-I with List-II and select the correct answer using the codes given below the lists:
List-I
A. $\left(\frac{\partial u}{\partial y}\right)_{y=0}$ is zero
B. $\left(\frac{\partial u}{\partial y}\right)_{y=0}$ is +ve
C. Displacement thickness
D. Momentum thickness
List-II
1. The flow is attached flow
2. The flow is on the verge of separation
3. $\int_0^{\delta} \frac{u}{U}\left(1-\frac{u}{U}\right)dy$
4. $\int_0^{\delta}\left(1-\frac{u}{U}\right)dy$

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	3	4
(c)	1	2	4	3
(d)	2	1	4	3

[ESE : 2002]

10.7 A thin smooth plate 1 m wide and 2 m long is towed through water at a velocity of 2 m/s. Assuming that boundary remains laminar, then drag on both sides of the plate is (kinematic viscosity = 10^{-6} m^2/s)
(a) 5.3 N (b) 26.6 N
(c) 53 N (d) 72.5 N
[ESE : 2003]

10.8 For a turbulent boundary layer (under zero pressure gradient), the velocity profile is described by the one-fifth power law. What is the ratio of displacement thickness to boundary layer thickness?
(a) 1/7 (b) 1/6
(c) 1/5 (d) 1/4
[ESE : 2004]

10.9 In a laminar boundary layer, the velocity distribution can be assumed to be given, in usual notations, as

$$\frac{u}{v} = \frac{y}{\delta}$$

Which one of the following is the correct expression for the displacement thickness (δ^*) for this boundary layer?
(a) $\delta^* = \delta$ (b) $\delta^* = \delta/2$
(c) $\delta^* = \delta/4$ (d) $\delta^* = \delta/6$
[ESE : 2005]

10.10 Which one of the following assumptions in deriving the boundary layer equation of flow past a flat plate at zero incidence is not correct?
(a) Uniform flow = 0
(b) Outside boundary layer velocity is v_0 throughout
(c) The boundary layer thickness δ is very small compared to distance x
(d) Pressure remains constant throughout the flow both within and outside the boundary layer
[ESE : 2006]

10.11 **Assertion (A):** Boundary layer theory is applicable only in the vicinity of the leading edge of the plate.
Reason (R): Boundary layer theory is based on the assumption that its thickness is small when compared to other linear dimensions.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2006]

10.12 A flat plate with a sharp leading edge is placed along a free stream of fluid flow. Local Reynolds number at 3 cm from the leading edge is 10^5. What is the thickness of the boundary layer?
(a) 0.47 mm (b) 0.35 mm
(c) 0.23 mm (d) 0.12 mm
[ESE : 2007]

10.13 What is the momentum thickness for the boundary layer with velocity distribution $\frac{u}{U} = \frac{y}{\delta}$?
(a) $\delta/6$ (b) $\delta/2$
(c) $3\delta/2$ (d) 2δ
[ESE : 2008]

10.14 **Assertion (A):** At the point of boundary layer separation, the shear stress is zero.
Reason (R): The point of separation demarcates between zones of forward and reverse flow close to the wall.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2011]

10.15 The thickness of the laminar boundary layer over a flat plate at two different sections P and Q are 0.8 cm and 2.4 cm respectively. If the section Q is 3.6 m downstream of P, the distance of section P from the leading edge of the plate is
(a) 0.32 m (b) 0.22 m
(c) 0.40 m (d) 0.53 m
[ESE : 2012]

10.16 **Statement-I:** Boundary layer theory is applicable only in the vicinity of the leading edge of a flat plate.
Statement-II: Boundary layer theory is based on the assumption that its thickness is small when compared to other linear dimensions in the flow.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true
[ESE : 2012]

10.17 The average drag coefficient for a laminar boundary layer over a flat plate was obtained as 0.018. If all other factors remain unchanged, and length of the plate is increased by 4 times its original value, this average drag coefficient would change to

(a) 0.0036 (b) 0.0056

(c) 0.008 (d) 0.009

[ESE : 2013]

10.18 The velocity distribution in the boundary layer is given by $\frac{u}{U}=\frac{y}{\delta}$, where u is the velocity at a distance of y from the boundary and $u = U$ at $y = \delta$, δ being boundary layer thickness. Then the value of momentum thickness will be

(a) $\frac{\delta}{2}$ (b) $\frac{\delta}{4}$

(c) $\frac{\delta}{6}$ (d) $\frac{\delta}{8}$

[ESE : 2016]

10.19 What are the values of coefficients a and c if velocity distribution in a laminar boundary layer on a flat plat is:

$$f(n)=\frac{u}{U_0}=a+bn+cn^2+dn^3 \text{ where, } n=\frac{y}{\delta}$$

(a) $\frac{1}{2}$ and 1 (b) 0 and 1

(c) $-\frac{1}{2}$ and 0 (d) 0 and 0

[ESE : 2016]

Answers Boundary Layer Theory

10.1 (d)	10.2 (a)	10.3 (d)	10.4 (c)	10.5 (b)	10.6 (d)	10.7 (a)	10.8 (b)	10.9 (b)
10.10 (a)	10.11 (d)	10.12 (a)	10.13 (a)	10.14 (b)	10.15 (c)	10.16 (d)	10.17 (d)	10.18 (c)
10.19 (d)								

Explanations Boundary Layer Theory

10.1 (d)

Flow in boundary layer remains laminar initially. For flat plate around $Re_c = 5 \times 10^5$ the flow in the boundary layer undergoes a transition and soon becomes turbulent.

10.2 (a)

$$\frac{\delta}{x}=\frac{0.376}{Re_x^{1/5}}$$

As x increase, Re_x increase

So $\frac{\delta}{x}$ decreases with x.

10.3 (d)

Laminar boundary layer, $\overline{C}_{f_L}=\frac{1.328}{Re_L}$

Turbulent boundary layer, $\overline{C}_{f_T}=\frac{0.074}{Re_L^{1/5}}$

$$\therefore \quad \frac{\overline{C}_{f_L}}{\overline{C}_{f_T}} = 17.95 Re_L^{-3/10}$$

10.4 (c)

The displacement thickness of a boundary layer is the distance by which main flow should be shifted in order to compensate for decrease in velocity in the *boundary layer* and to maintain the continuity equation.

10.5 (b)

$$\delta=\frac{5x}{\sqrt{Re}} \quad \text{(Blasius solution)}$$

10.6(d)

The point of separation is defined as the limit between forward and reverse flow in the layer very close to the wall, $\left(\frac{\partial u}{\partial y}\right)_{y=0} = 0$.

The minimum pressure occur little upstream of stagnation point.

10.7(a)

Friction coefficient, $\bar{C}_f = \frac{1.328}{\sqrt{Re_L}}$

$Re_L = \frac{VL}{\nu} = \frac{2\times 2}{10^{-6}} = 4\times 10^6$

$\therefore \bar{C}_f = \frac{1.328}{\sqrt{4\times 10^6}} = 6.64\times 10^{-4}$

The drag force on both sides of the plate,

$F_D = 2\bar{C}_f\left(\frac{1}{2}\rho V^2\right)(BL)$

$= 2\times 6.64\times 10^{-4}\times\frac{1}{2}\times 1000\times(2)^2\times 1\times 2$

$= 5.31\ N$

10.8(b)

$\frac{u}{u_\infty} = \left(\frac{y}{\delta}\right)^{1/5}$

$\delta^* = \int_0^\delta\left[1-\left(\frac{u}{u_\infty}\right)^{1/5}\right]dy$

$= \int_0^\delta\left[1-\left(\frac{y}{\delta}\right)^{1/5}\right]dy$

$= \delta - \frac{5\delta}{6} = \frac{\delta}{6}$

$\frac{\delta^*}{\delta} = \frac{1}{6}$

10.9(b)

$\delta^* = \int\left(1-\frac{u}{v}\right)dy = \delta\int_0^1(1-\eta)d\eta$

where $\eta = y/\delta$

$\delta^* = \delta/2$

10.10 (a)

Assumptions in deriving boundary layer equation

- Pressure is constant both within and outside the boundary layer
- Boundary layer thickness is very small compared to other linear dimensions
- Velocity outside boundary layer is constant throughout

10.11 (d)

Boundary layer theory is applicable in the vicinity of the surface of the plate.

Boundary layer thickness is very small compared to other linear dimensions.

10.12 (a)

Since the Reynolds number is less than 5×10^5, the boundary layer is laminar. The thickness of the laminar boundary layer may be given by the Blasius' equation i.e.

$\delta = \frac{5x}{\sqrt{Re_x}} = \frac{5\times 3\times 10}{\sqrt{10^5}}$

$\Rightarrow \quad \delta = 0.47\ mm$

10.13 (a)

The momentum thickness is given by

$\theta = \int_0^\delta\frac{u}{U}\left(1-\frac{u}{U}\right)dy = \int_0^\delta\frac{y}{\delta}\left(1-\frac{y}{\delta}\right)dy$

$= \int_0^\delta\left(\frac{y}{\delta}-\frac{y^2}{\delta^2}\right)dy = \frac{1}{\delta^2}\int_0^\delta(\delta y - y^2)dy$

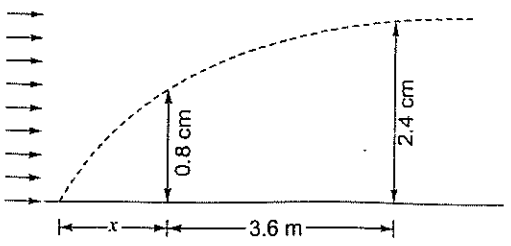
$= \frac{1}{\delta^2}\left[\frac{\delta y^2}{2}-\frac{y^3}{3}\right]_0^\delta = \frac{1}{\delta^2}\left[\frac{\delta^3}{2}-\frac{\delta^3}{3}\right]$

$= \delta\left[\frac{3-2}{6}\right] = \frac{\delta}{6}$

10.14 (b)

At a point of boundary layer separation, shear stress is zero because $\frac{du}{dy}$ at the surface bounday is zero.

10.15 (c)



For Laminar boundary layer
Over a flat plate

$$\frac{\delta}{x} = \frac{5}{\sqrt{Re_x}}$$

$$\delta \propto \sqrt{x}$$

So, $$\frac{0.8}{2.4} = \sqrt{\frac{x}{x+3.6}}$$

$$x = 0.45\ \text{m}$$

Since no any option is given.
So nearest answer is 0.4 m.

10.17 (d)

$$C_D = \frac{1.328}{\sqrt{Re_L}} = \frac{1.328}{\sqrt{\frac{\rho v L}{\mu}}}$$

$$\therefore \quad C_D \propto \frac{1}{\sqrt{L}}$$

$$\therefore \quad \frac{C_{D_1}}{C_{D_2}} = \frac{\sqrt{L_2}}{\sqrt{L_1}}$$

$$\Rightarrow \frac{0.018}{C_{D_2}} = \frac{\sqrt{4L_1}}{\sqrt{L_1}} \quad \Rightarrow \quad C_{D_2} = 0.009$$

10.18 (c)

$$\frac{u}{U} = \frac{y}{\delta}$$

$$\theta = \int_0^{\delta} \frac{u}{U}\left[1 - \frac{u}{U}\right] dy$$

$$= \int_0^{\delta} \frac{y}{\delta}\left[1 - \frac{y}{\delta}\right] dy$$

$$= \frac{\delta}{2} - \frac{\delta}{3} = \frac{\delta}{6}$$

10.19 (d)

Apply boundary condition,

$$a = 0$$

$$b = \frac{3}{2}$$

$$c = 0$$

$$d = -\frac{1}{2}$$

11 Turbulent Flow

11.1 Which of following conditions would entail a greater energy dissipation in turbulent flow?
1. Smaller eddy size
2. Lower viscosity
3. Large intensity of turbulence

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 and 2

[ESE : 1995]

11.2 Shear velocity is
(a) a non-dimensional quantity
(b) the velocity of fluid at the edge of laminar sublayer
(c) a fictitious quantity
(d) the velocity of fluid at the edge of roughness element

[ESE : 1995]

11.3 With increasing ageing of pipes, the proportion between the maximum velocity and mean velocity
(a) initially decreases and then increases
(b) initially increases and then decreases
(c) decreases
(d) increases

[ESE : 1996]

11.4 Match List-I (Flow phenomenon) with List-II (Associated equation/principle) and select the correct answer using the codes given below the lists:

List-I
A. Turbulent flow
B. Laminar flow
C. Lift on an aerofoil
D. Boundary layer

List-II
1. Circulation
2. Momentum integral equation
3. Mixing length
4. Hagen Poiseuille equation

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	4	1	2	3
(c)	3	4	1	2
(d)	1	2	3	4

[ESE : 1997]

11.5 Consider the following statements regarding friction factor variation in a pipe flow:
1. In hydrodynamically rough boundaries, friction factor 'f' is related to relative roughness ε/D, (ε is roughness and D is the diameter of pipe).
2. In hydrodynamically smooth boundaries, friction factor 'f' depends both on Reynolds number 'Re' and relative roughness.
3. If the friction factor, $f = \frac{0.316}{Re^{1/4}}$, then the value of the friction factor 'f' relates to that of the region of turbulent flow in smooth boundary.
4. Friction factor is directly related to the nature of boundary layer in a pipe flow.

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 2000]

11.6 Consider the following statements:
Due to aging of pipes in a pipe network,
1. the roughness increases linearly with time.
2. the pipes get rusted and bent.
3. the pipes become smoother with time.

Which of these statements is/are correct?

(a) 1 and 3 (b) 2 and 3
(c) 3 only (d) 1 only

[ESE : 2008]

11.7 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

A. Uniform flow
B. Laminar flow
C. Turbulent flow
D. Irrotational flow

List-II

1. Flow through a water supply pipe
2. Flow through a straight tube of uniform diameter and uniform roughness
3. Flow above the drain hole of a wash basin
4. Flow of blood in veins and arteries

Code:

	A	B	C	D
(a)	3	1	4	2
(b)	2	1	4	3
(c)	3	4	1	2
(d)	2	4	1	3

[ESE : 2011]

11.8 The maximum velocity U_m, the mean velocity U and shear velocity u_* in the case of turbulent flow through circular pipes are related as

$$\frac{(U_m - U)}{u_*} =$$

(a) 2.5 for rough boundary flow only
(b) 5.75 for smooth boundary flow only
(c) 3.75 for both smooth and rough boundary flows
(d) 5.75 for both smooth and rough boundary flows

[ESE : 2012]

11.9 The loss of head in a pipe carrying turbulent flow varies:

(a) Inversely as the square of the velocity of flow
(b) Inversely as the square of the diameter of pipe
(c) Directly as the square of the velocity of flow
(d) Directly as the velocity of flow

[ESE : 2013]

11.10 In turbulent flows through rough pipes, the ratio of the maximum velocity to the mean velocity is

(a) 2
(b) 4/3
(c) 1.1
(d) Dependent on the friction factor

[ESE : 2015]

11.11 Consider the following statements:

1. In flow through hydro-dynamically smooth pipes, the friction factor *f* is always a constant.
2. In flow through hydro-dynamically smooth pipes, the friction factor *f* is always a function of the flow Reynolds number.
3. In a fully developed rough turbulent pipe flow, the friction factor *f* is a function of relative roughness only.
4. In a fully developed rough turbulent pipe flow, the friction factor *f* is a function of the flow Reynolds number and relative roughness.

Which of the above statements are correct?

(a) 1 and 3 (b) 2 and 3
(c) 2 and 4 (d) 1 and 4

[ESE : 2016]

Answers Turbulent Flow

11.1 (c) 11.2 (c) 11.3 (d) 11.4 (c) 11.5 (d) 11.6 (d) 11.7 (d) 11.8 (c) 11.9 (c) 11.10 (d) 11.11 (b)

Explanations Turbulent Flow

11.1 (c)

In turbulent flow:

- Smaller eddy size – This means the wave size will be shorter which leads to smaller energy loss.
- Lower Viscosity – This implies smaller laminar sublayer. Boundary will behave as hydrodynamically rough boundary.

  The eddies will thus come in contact with the surface irregularities and large amount of energy loss will take place.
- Larger intensity of turbulence – Larger losses.

11.2(c)

Shear velocity, $V^* = \sqrt{\frac{\tau_w}{\rho}}$

where $\tau_w = \mu \frac{U}{\delta_s}$ is the boundary shear stress.

U_s is fluid velocity at the edge of laminar sublayer

δ_s is thickness of laminar sublayer

The dimensions of shear velocity is LT^{-1}

The shear velocity is used for scaling velocity in laminar sublayer. It is a fictitious quantity.

11.3(d)

$$\frac{u_{max}}{\bar{u}} = 1.43\sqrt{f} + 1$$

For both smooth and rough pipes, the friction factor (f) increases with ageing. So ratio $\frac{u_{max}}{\bar{u}}$ also increases.

11.5(d)

The friction factor in laminar flow, $f = \frac{64}{Re}$

For turbulent flow the pipe boundary can be classified as:

(i) Smooth boundary where f is a function of Reynolds number (Re) only

(ii) Transition boundary where f is a function of Re and relative roughness (ε/D)

(iii) Rough boundary where f is a function of ε/D only.

11.6 (d)

Due to aging of pipes, the roughness increases linearly with time as :

$K = K_0 + \alpha t$

Where á is the rate of increase in roughness and t is the time period.

11.7 (d)

In a straight tube of uniform diameter and uniform roughness the flow properties does not vary across the length of the pipe, hence uniform flow.

Flow of blood in veins and arteries occurs as a viscous flow, hence laminar

Flow above the drain hole of a wash basin is a free vortex motion. The molecules of water does not rotate about their centre of mass hence irrotational flow.

A water supply pipe carries water at high speed, leading to rapid mixing which causes highly turbulent condition.

11.8 (c)

Common mean velocity distribution equation

$$\frac{u - \bar{u}}{v^*} = 5.75\log_{10}\frac{y}{R} + 3.75$$

At y = R, u = u_{max}

$$\frac{u_{max} - \bar{u}}{v^*} = 3.75$$

11.9 (c)

$$h_f = \frac{fLV^2}{2gD} \Rightarrow h_f \propto V^2$$

11.10 (d)

$$\frac{u - \bar{u}}{v^{rt}} = 5.75\log_{10}\frac{y}{R} + 3.75$$

At $y = R$, $u = u_{max}$

$$\frac{u_{max} - \bar{u}}{\bar{u}\sqrt{f}B} = 3.75$$

$$= 1 + 1.33\sqrt{f}$$

12 Dimensional Analysis & Model Analysis

12.1 Match List-I (Non-dimensional numbers) with List-II (Application) and select the correct answer using the codes given below the lists:

List-I

A. Mach Number
B. Thoma Number
C. Reynolds Number
D. Weber Number

List-II

1. Waves in an ocean
2. Launching of rockets
3. Cavitation phenomenon
4. Capillary flow in soil
5. Motion of a submarine

Codes:

	A	B	C	D
(a)	1	3	5	2
(b)	3	2	4	1
(c)	2	3	5	4
(d)	2	1	3	4

[ESE : 1995]

12.2 A model of a weir made to a horizontal scale of 1/40 and vertical scale of 1/9 discharges 1 *l*ps. Then the discharge in the prototype is estimated as

(a) 1 *l*ps (b) 108 *l*ps
(c) 1080 *l*ps (d) 10800 *l*ps

[ESE : 1996]

12.3 There are four variables, namely, E (volume modulus of elasticity), p (pressure per unit area), g (acceleration due to gravity) and μ (viscosity of water). They are associated with Mach, Euler, Froude and Reynolds numbers, respectively, in the order

(a) E, p, μ, g (b) p, E, μ, g
(c) p, E, g, μ (d) E, p, g, μ

[ESE : 1997]

12.4 Assertion (A): In Rayleigh's method of dimensional analysis, the dependent variable is written as the function of exponential terms of independent variables.

Reason (R): In Rayleigh's method, when the number of independent variables exceeds three, the exponents of non-repeating variables are expressed as the exponents of repeating variables.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

12.5 Water having kinematic viscosity of 0.01 stokes flows at a velocity of 2 m/sec in a pipe of 15 cm diameter. For dynamic similarity, the velocity of oil of kinematic viscosity 0.03 stoke in a pipe of same diameter will be

(a) 0.33 m/sec (b) 0.66 m/sec
(c) 2 m/sec (d) 6 m/sec

[ESE : 1998]

12.6 In the model of a highway bridge constructed to a scale of 1 : 25, the force of water on the pier was measured to be 0.5 kg. The force on the prototype pier will be

(a) 7501.5 kg (b) 7622.5 kg
(c) 7812.5 kg (d) 7916.5 kg

[ESE : 1998]

12.7 Euler number or pressure coefficient may be represented as (notations have their usual meanings)

(a) $\frac{\Delta p}{\gamma H}$ (b) $\frac{\Delta p}{(\rho V^2/2)}$

(c) $\frac{\Delta p}{\mu V/L}$ (d) $\frac{\Delta p}{\rho L g}$

[ESE : 2000]

12.8 A spillway of an irrigation project is to be studied by means of a model constructed to a scale of 1 : 9. The prototype discharge is 1000 m^3/s. Neglecting the viscous and surface tension effects, the required flow rate for the model is

(a) 12.35 m^3/s (b) 111.11 m^3/s
(c) 4.11 m^3/s (d) 1.37 m^3/s

[ESE : 2002]

12.9 The distorted models, used in the hydraulic studies, are those which

(a) have exaggeration of the vertical scale and horizontal scale
(b) are not geometrically similar to the prototypes
(c) have same vertical and horizontal scale as that of the prototypes
(d) have same Froude number as that for the prototypes

[ESE : 2003]

12.10 A 1: 30 scale model of a submarine is to be tested in a wind tunnel for its drag when it is operating at 15 km/h in ocean. The kinematic viscosity of air is 1.51×10^{-5} m^2/s and for water 1.02×10^{6} m^2/s. What is the velocity of air in wind tunnel that should be maintained for kinematic similarity?

(a) 1500 m/s (b) 2000 m/s
(c) 1850.5 m/s (d) 2500.5 m/s

[ESE : 2004]

12.11 Which one of the follcwing statements is not correct?

(a) Models are always smaller than the prototypes.
(b) Dynamic similarity between a model and a prototype can be verified by equating Reynolds number in a viscous flow.
(c) Mach number achieves significance when the velocity of fluid approaches or exceeds the sonic velocity.
(d) Distorted models are always exaggerated on a vertical scale.

[ESE : 2005]

12.12 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Reynolds number
B. Froude number
C. Mach number
D. Weber number

List-II
1. Formation of liquid droplet
2. High speed flow of a gas
3. Flow in closed conduits
4. Sloping interface exists between fluids of different densities

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	2	1	3	4
(c)	3	1	2	4
(d)	2	4	3	1

[ESE : 2006]

12.13 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Froude number
B. Euler number
C. Reynolds number
D. Mach number

List-II
1. Related to inertia force and elastic force
2. Related to inertia force and viscous force
3. Related to inertia force and pressure force
4. Related to inertia force and gravity force

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2006]

12.14 In the model of a highway bridge constructed to a scale of 1 : 25, the force of water on the pier was measured as 5 N. What is the force (approximate) on the prototype pier?

(a) 15.6 kN (b) 25.3 kN
(c) 78 kN (d) 90 kN

[ESE : 2007]

12.15 A river model is constructed to a horizontal scale of 1 : 1000 and a vertical scale of 1 : 100. A model discharge of 0.1 m^3/s would correspond to a discharge in the prototype, of what magnitude?

(a) 10^2 m^3/s (b) 10^3 m^3/s
(c) 10^4 m^3/s (d) 10^5 m^3/s

[ESE : 2007]

12.16 In model similarity, if gravitational and inertial forces are the only important forces, then what is the discharge ratio?

(a) $L_r^{3/2}$ (b) $L_r^{1/2}$
(c) $L_r^{5/2}$ (d) $L_r^{1/3}$

where L_r = ratio of length dimension.

[ESE : 2008]

12.17 For a homologous model of a pump built to a scale ratio of 1 : 2, fluid and speed being the same in model and prototype, the ratio of model power to prototype power is

(a) 1/2.82 (b) 1/4
(c) 1/8 (d) 1/32

[ESE : 2010]

12.18 Distorted models are needed for:

1. Rivers
2. Dams across wide rivers
3. Harbours

(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2011]

12.19 In a 1 in 50 model of a spillway, discharge is 3 m^3/sec. Find the corresponding discharge in the prototype in m^3/sec.

(a) 1061 (b) 7500
(c) 53033 (d) 375000

[ESE : 2013]

12.20 A model of a boat is built to a scale of 1/100. It experiences a resistance of 0.10 N when simulating a speed of 5 m/s of the prototype. Water is the fluid in both the cases. Neglecting frictional forces, corresponding resistance in the prototype is:

(a) 1000 kN (b) 100 kN
(c) 10 kN (d) 1 kN

[ESE : 2013]

12.21 The performance of a hydraulic structure during a flood has been investigated in a 1/25 model based on Froude law of similarity. A flood wave passing through the model in 2 hrs. corresponds to a prototype period of:

(a) 50 hr (b) 12.5 hr
(c) 10 hr (d) 0.4 hr

[ESE : 2013]

12.22 A 1 : 25 model of a naval ship is towed at a velocity of 1.2 m/s to determine each of the two components of the total drag that may be experienced by the prototype. The wave-making drag of the model is duly estimated to be 0.37 kgf. What would be the wave making drag on the prototype ship?

(a) 1250 kgf (b) 1875 kgf
(c) 3750 kgf (d) 4625 kgf

[ESE : 2013]

12.23 A river whose discharge is 10^5 cumecs is to be studied by a 1 : 100 scale model in a laboratory. The discharge required in the model is:

(a) 0.5 m^3/s (b) 10 m^3/s
(c) 1 m^3/s (d) 5 m^3/s

[ESE : 2013]

12.24 In order to estimate the energy loss in a pipeline of 1 m diameter through which kerosene of specific gravity 0.80 and dynamic viscosity 0.02 poise is to be transported at the rate of 2 m^3/s, model tests were conducted on a 0.1 m diameter pipe using water at 20°C. If the absolute viscosity of water at 20°C is 1.00×10^{-2} poise, then the discharge required for the model pipe would be

(a) 60 *l*/s (b) 80 *l*/s
(c) 120 *l*/s (d) 160 *l*/s

[ESE : 2014]

12.25 A sphere is moving in water with a velocity of 1.6 m/s. Another sphere of twice the diameter is placed in a wind tunnel and tested with air which is 750 times less dense and 60 times less viscous (dynamically) than water. The velocity of air that will model dynamically similar conditions is

(a) 5 m/s (b) 20 m/s
(c) 10 m/s (d) 40 m/s

[ESE : 2015]

12.26 The flow in a river is 1500 cumecs. A distorted model is built with horizontal scale of 1/150 and vertical scale of 1/25. The flow rate in the model should be

(a) 0.04 m^3s^{-1} (b) 0.06 m^3s^{-1}
(c) 0.08 m^3s^{-1} (d) 0.10 m^3s^{-1}

[ESE : 2015]

12.27 An airfoil of surface area 0.1 m^2 is tested for lift L in a wind tunnel. (Conditions can be considered as incompressible flow). At an angle of attack of 5°, with standard air of density 1.22 km/m^3, at a speed of 30 m/sec, the lift is measured to be 3.2 kgf. What is the lift coefficient? For a prototype wing of area 10 m^2, what is the approximate lift at an air speed of 160 kmph at the same angle of attack of 5°?

(a) 0.572 and 700 kgf
(b) 0.603 and 700 kgf
(c) 0.572 and 570 kgf
(d) 0.603 and 570 kgf

[ESE : 2016]

12.28 **Statement (I):** Reynolds number must be the same for model and the prototype when both are tested as immersed in a subsonic flow.

Statement (II): A model should be geometrically similar to the prototype.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

12.29 Which of the following statements are correct?

1. Depression of mercury in a capillary tube is dependent on density and surface tension.
2. Modelling of flow-induced drag on a ship is done invoking both of Froude number and Reynolds number.
3. Flow of a fluid in a narrow pipe is relatable to both Reynolds number and Cauchy number.
4. Formation and collapse of a soap bubble is analyzed through employing surface tension and external pressure.
5. Flow over the downstream slope of an ogee spillway can be affected by surface tension.

Select the correct answer using the codes given below:

(a) 1, 2 and 4 (b) 1, 3 and 5
(c) 2, 3 and 4 (d) 3, 4 and 5

[ESE : 2017]

12.30 Which of the following factors are non-dimensional?

1. C in Chezy's equation
2. 11.6 as a measure of the sub-layer
3. $\frac{H}{N^2D^2}$ employed in comparing performance of pumps
4. $\frac{Q^2}{D^5}$ employed in computations in pipe networks
5. $\frac{U}{\sqrt{gL}}$ used in estimating wave-making drag

Select the correct answer using the codes given below:

(a) 2 and 5 (b) 2, 4 and 5
(c) 1 and 5 (d) 1, 3 and 4

[ESE : 2017]

■■■■

Answers Dimensional Analysis & Model Analysis

12.1 (c)	12.2 (c)	12.3 (d)	12.4 (b)	12.5 (d)	12.6 (c)	12.7 (b)	12.8 (c)
12.9 (b)	12.10 (c)	12.11 (a)	12.12 (a)	12.13 (c)	12.14 (c)	12.15 (d)	12.16 (c)
12.17 (d)	12.18 (d)	12.19 (c)	12.20 (b)	12.21 (c)	12.22 (*)	12.23 (c)	12.24 (b)
12.25 (c)	12.26 (c)	12.27 (a)	12.28 (b)	12.29 (a)	12.30 (a)		

Explanations Dimensional Analysis & Model Analysis

12.1(c)

Waves in an ocean are governed by Froude number.

12.2(c)

When vertical and horizontal scales are different, the model is called distorted model.

Velocity ratio, $V_r = \sqrt{L_{rV}} = \sqrt{\frac{1}{9}} = \frac{1}{3}$

Area ratio, $A_r = L_{rV} L_{rH} = \frac{1}{9} \times \frac{1}{40}$

Discharge ratio, $Q_r = V_r A_r = Q_m / Q_p$

Discharge in the prototype,

$$Q_p = Q_m / (V_r A_r)$$
$$= 1 \times 3 \times 9 \times 40$$
$$= 1080 \text{ lps}$$

12.3(d)

$$\text{Mach number} = \frac{V}{\sqrt{E/\rho}}$$

$$\text{Euler number} = \frac{\Delta p}{\frac{1}{2}\rho V^2}$$

$$\text{Froude number} = \frac{V}{\sqrt{gy}}$$

$$\text{Reynolds number} = \frac{\rho V L}{\mu}$$

12.5(d)

For dynamic similarity. Reynolds model law will be used.

$$\text{Re} = \frac{V_1 D}{\nu_1} = \frac{V_2 D}{\nu_2}$$

$$V_2 = 2 \times \frac{0.03}{0.01} = 6 \text{ m/s}$$

12.6(c)

In this case Froude model law will be applied.

Given, $L_r = \frac{1}{25}$

Velocity ratio, $V_r = \sqrt{L_r}$

Force ratio, $F_r = V_r^2 L_r^2 = L_r^3$

Force on prototype $= 0.5 \times (25)^3 = 7812.5$ kg

12.7 (b)

The Euler number (E_u) is a dimensionless number used in fluid flow calculations. It expresses the relationship between a local pressure drop e.g. over a restriction and the kinetic energy per volume, and is used to characterize losses in the flow, where a perfect frictionless flow corresponds to an Euler number of 0.

$$E_u = \frac{\Delta P}{(\rho V^2)/2}$$

12.8(c)

Discharge ratio, $Q_r = L_f^{2.5}$

Prototype discharge = 1000 m^3/s

Model discharge $= \frac{1000}{(9)^{2.5}} = 4.11 \text{ m}^3/\text{s}$

12.9(b)

Distorted model can have vertical scale exaggeration or slope exaggeration. Therefore they are not geometrically similar. It may have either geometrical distortion, or material distortion or distortion of hydraulic quantities or a combination of these.

12.10 (c)

The Reynolds model law shall be applied in the case of fully submerged objects

$$\frac{V_m L_m}{\nu_m} = \frac{V_p L_p}{\nu_p}$$

$$\therefore \quad V_m = V_p\left(\frac{\nu_m}{\nu_p}\right)\left(\frac{L_p}{L_m}\right)$$

$$= 15 \times \frac{1.5 \times 10^{-5}}{1.02 \times 10^{-6}} \times 30$$

$$= 6661.8 \text{ km/h} = 1850.5 \text{ m/s}$$

The Reynolds model law ensures dynamic, kinematic and geometric similarities.

12.11 (a)

Models may be larger than prototypes also. e.g., model of carburettor. However in general models are smaller than the prototypes.

12.12 (a)

Weber model law is applicable when surface tension force are predominant along with inertia forces.

12.13 (c)

The Froude number is a ratio of inertial and gravitational forces. The *Euler Number* can be interpreted as a measure of the ratio of the *pressure* forces to the *inertial* forces. Reynolds is the ratio of *Inertia* force to viscous force. Mach number is ratio of *inertia force* to *elastic* force.

12.14 (c)

Froude model law will be applicable in this case.

$$Fr_m = \frac{V_m}{\sqrt{gLm}} = \frac{V_p}{\sqrt{gL_p}} = Fr_p$$

If $\quad L_r = \frac{L_m}{L_p}$

and $\quad V_r = \frac{V_m}{V_p} = \sqrt{L_r}$

$$\frac{(\text{Force})_m}{(\text{Force})_p} = \rho_r L_r^2 V_r^2$$

$$\Rightarrow \quad \frac{(\text{Force})_m}{(\text{Force})_p} = \rho_r L_r^3 \qquad [\because \rho_r = 1]$$

$$\Rightarrow \quad \frac{5}{(\text{Force})_p} = \left(\frac{1}{25}\right)^3$$

$$\Rightarrow \quad (\text{Force})_p = 5 \times 25^3$$

$$\Rightarrow \quad (\text{Force})_p = 78.125 \text{ kN}$$

12.15 (d)

Horizontal scale, $L_r = \frac{L_m}{L_p} = \frac{1}{1000}$

Vertical scale, $h_r = \frac{y_m}{y_p} = \frac{1}{100}$

By Froude model law, we have

$$\frac{V_m}{\sqrt{gy_m}} = \frac{V_p}{\sqrt{gy_p}}$$

$$\Rightarrow \quad \frac{V_m}{V_p} = \sqrt{\frac{y_m}{y_p}}$$

$$\Rightarrow \quad \frac{V_m}{V_p} = \sqrt{h_r}$$

$$\Rightarrow \quad V_r = \sqrt{h_r}$$

$\therefore$ Discharge ratio,

$$Q_r = \frac{Q_m}{Q_p} = A_r \times V_r$$

$$\Rightarrow \quad \frac{Q_m}{Q_p} = L_r h_r \times \sqrt{h_r}$$

$$\Rightarrow \quad \frac{Q_m}{Q_p} = L_r h_r^{3/2}$$

$$\Rightarrow \quad \frac{0.1}{Q_p} = \frac{1}{1000} \times \left(\frac{1}{100}\right)^{3/2}$$

$$\Rightarrow \quad Q_p = 0.1 \times 1000 \times 1000$$

$$\Rightarrow \quad Q_p = 10^5 \text{ m}^3/\text{s}$$

12.16 (c)

If gravitational and inertial forces are the only important forces, then the Froude number must be the same in the model and prototype. Thus

$$\frac{V_m}{\sqrt{gL_m}} = \frac{V_p}{\sqrt{gL_p}}$$

But g is same for both model and prototype

$$\therefore \quad \frac{V_m}{V_p} = \sqrt{\frac{L_m}{L_p}}$$

$$\Rightarrow \quad V_r = \sqrt{L_r}$$

Now, Discharge = Area × Velocity

$$\Rightarrow \quad Q_r = A_r \times V_r$$

$$\Rightarrow \quad Q_r = L_r^2 \times (L_r)^{1/2} = L_r^{5/2}$$

12.17 (d)

Power, $P \propto L_r^5 N_s^3$

$(N_s)_m = (N_s)_p$

$$\frac{P_m}{P_P} = \left(\frac{L_m}{L_p}\right)^5 \times 1 = \left(\frac{1}{2}\right)^5 = \frac{1}{32}$$

12.18 (d)

Some of the typical examples for which distorted models are required to be prepared are rivers, dams across very wide rivers, harbours, estuaries etc., for which the horizontal dimensions are large in proportion to the vertical ones.

12.19 (c)

In the case of a flow in spillway, Froude number will dominate

$$\frac{V_m}{V_p} = \sqrt{L_r}$$

$$\frac{Q_m}{Q_p} = L_r^{5/2} = \left(\frac{1}{50}\right)^{5/2}$$

$$\Rightarrow \quad Q_p = 50^{5/2}(3) = 53033 \text{ m}^3/\text{s}$$

12.20 (b)

$$\frac{F_m}{F_p} = \left(\frac{1}{100}\right)^3$$

$F_p = 100$ kN

12.21 (c)

$$\frac{T_m}{T_p} = (L_r)^{1/2}$$

$T_p = 5 \times 2 = 10$ hours

12.22 (*)

$$\frac{F_m}{F_p} = \left(\frac{1}{25}\right)^3$$

$$\Rightarrow \quad F_p = 5781.25 \text{ kgf}$$

12.23 (c)

$$\frac{Q_m}{Q_p} = (L_r)^{5/2}$$

$$\Rightarrow \quad Q_m = \frac{10^5}{100^{5/2}} = 1 \text{ m}^3/\text{s}$$

12.24 (b)

For dynamic similarity, Reynolds model law will be used.

$$\frac{\rho_P V_P L_P}{\mu_P} = \frac{\rho_m V_m L_m}{\mu_m}$$

$$\Rightarrow \frac{0.8 \times \rho_w \times Q_P \times 1}{A_P \times 2 \times 10^{-2}} = \frac{\rho_w \times Q_m \times 0.1}{A_m \times 1 \times 10^{-2}}$$

$$\Rightarrow Q_m = \frac{0.8 \times 1 \times \frac{\pi}{4}(0.1)^2 \times 2}{\frac{\pi}{4} \times 1^2 \times 2 \times 0.1}$$

$$\Rightarrow \quad Q = 0.08 \text{ m}^3/\text{sec.} = 80 \text{ } l/\text{sec.}$$

12.25 (c)

According to Reynold's Model law

$(\text{Re})_m = (\text{Re})_p$

$$\frac{\rho_r V_r L_r}{\mu_r} = \text{Constant}$$

$$\frac{\rho_w \times 1.6 \times D}{\mu_w} = \frac{\frac{\rho_w}{750} \times V \times 2D}{\mu_w / 60}$$

$$V = \frac{750 \times 1.6}{60 \times 2} = 10 \text{ m/s}$$

12.26 (c)

Flow rate, $Q_r = (L_r)_H (L_r)_V^{3/2}$

$$\therefore \quad \frac{Q_p}{Q_m} = 150 \times (25)^{3/2}$$

$$Q_m = \frac{1500}{150 \times 125} = 0.08 \text{ m}^3/\text{sec}$$

12.27 (a)

$$F_L = C_L \frac{\rho u_0^2 A}{2}$$

$$3.2 \times 9.81 = \frac{C_L \times 1.22 \times 30^2 \times 0.1}{2}$$

$$C_L = 0.572$$

$$F_L = 3.2 \times \left(\frac{160 \times 0.278}{2}\right)^2 \times \frac{10}{0.1}$$

$E = 700$ kgf

12.29 (a)

- Capillary tube depression = $\frac{4\sigma}{8d}$, dependent on surface tension density and diameter of tube.
- In modeling of flow induced drag is done invoking both Froude no. and Reynold's no.
- Flow of a fluid in a narrow pipe mainly relatable to Reynold's no. (Cauchy number is square of Mach no. and mainly used for compressible liquids.
- Flow over the downstream slope of an Ogee spillway is affected by Froude no.

12.30 (a)

- Dimension of Chezy's constant is $L^{1/2}T^{-1}$
- $\frac{H}{N^2D^2} = \frac{L}{\left(\frac{1}{T}\right)^2 \times L^2} = T^2L^{-1}$
- $\frac{Q^2}{D^5} = \frac{\left(\frac{L^3}{T}\right)^2}{(L)^5} = LT^{-2}$
- $\frac{V}{\sqrt{gL}} = \frac{\left(\frac{L}{T}\right)}{\sqrt{\left(\frac{L}{T^2} \times L\right)}} = 1$ (Non-dimensional)

■■■■

13 Notches and Weirs

13.1 An error of 0.5% in the measurement of head in a V-notch causes an error of
(a) 0.5% in the discharge
(b) 1.0% in the discharge
(c) 1.25% in the discharge
(d) 1.5% in the discharge

[ESE : 1995]

13.2 If the error in the measurement of head in a 'V' notch is 1%, then the error in the measurement of discharge will be
(a) 1% (b) 1.5%
(c) 2% (d) 2.5%

[ESE : 2000]

13.3 Consider the following measuring structures:
1. Submerged broad-crested weir
2. Free broad-crested weir
3. Free sharp-crested weir
4. Free ogee spillway

The correct sequence of the increasing order of the discharge coefficient of these structures is
(a) 1, 2, 4, 3 (b) 2, 1, 3, 4
(c) 2, 1, 4, 3 (d) 1, 2, 3, 4

[ESE : 2001]

13.4 A Cipolletti weir discharges water with the head of water over the crest being 250 mm. If the head due to velocity of approach is 0.01 m, what will be the excess percentage of flow, when corrected for velocity of approach as compared to when not so corrected?
(a) 3.2% (b) 4.2%
(c) 5.3% (d) 6.3%

[ESE : 2003]

13.5 The approximate discharge over a 4 m long rectangular weir (with suppressed end contractions) with head over the crest as 0.36 m is
(a) 4.2 litres/s (b) 2.4 m^3/s
(c) 6.1 litres/s (d) 1.6 m^3/s

[ESE : 2003]

13.6 The head on a sharp-crested rectangular weir of height 1.6 m and crest length 1.2 m was incorrectly observed to be 0.13 m when it was actually 0.15 m. What was the percentage error in the computed value of flow rate?
(a) 0.5% (b) 1.0%
(c) 2.0% (d) 1.5%

[ESE : 2009]

13.7 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Rehbock formula
B. Francis formula
C. A special trapezoidal weir
D. Linear proportional weir

List-II
1. Sutro weir
2. Rectangular suppressed weir
3. Rectangular side-contracted weir
4. Cippolletti weir

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	2	4	3	1
(c)	1	4	3	2
(d)	2	3	4	1

[ESE : 2009, 2011]

13.8 The absolute percentage error in the computed discharge over a rectangular weir corresponding to an absolute error of 1.5% in the measurement of head over the sill of the weir would be
(a) 1.5 (b) 2.25
(c) 2.5 (d) 3.75

[ESE : 2011]

13.9 Consider the following devices
1. Orifice
2. Borda's mouthpiece running free

3. Bell-mouthed orifice
4. External mouthpiece

What is the correct sequence of these devices by decreasing magnitude of coefficient of discharge?

(a) 2, 3, 1 and 4 (b) 4, 3, 1 and 2
(c) 4, 1, 3 and 2 (d) 2, 1, 3 and 4

[ESE : 2011]

13.10 A depth-discharge relationship of the canal section is maintained at a notch fall because the sill of the notches is

(a) Level with downstream canal bed
(b) Below the upstream canal bed
(c) Level with upstream canal bed
(d) Above the upstream canal bed

[ESE : 2011]

13.11 For accurate flow measurement in open channels, an arrangement for aeration under the nappe is necessary when the weir used is

(a) Contracted rectangular
(b) Suppressed rectangular
(c) Submerged contracted rectangular
(d) Triangular

[ESE : 2013]

13.12 Among weirs used in open flow metrology, critical depth of the flow is the relevant criterion in:

(a) Broad-crested weir
(b) Cippoletti weir
(c) Parabolic weir
(d) Sharp-crested weir

[ESE : 2013]

13.13 The head over a V-notch at the end of a channel is 75 cm. If an error of 0.15 cm is possible in the measurement of the head, then the percentage error in computing the discharge is

(a) 0.25 (b) 0.5
(c) 0.75 (d) 1.0

[ESE : 2015]

Answers Notches and Weirs

13.1	(c)	13.2	(d)	13.3	(d)	13.4	(c)	13.5	(d)	13.6	(*)	13.7	(d)	13.8	(b)
13.9	(b)	13.10	(d)	13.11	(b)	13.12	(c)	13.13	(b)						

Explanations Notches and Weirs

13.1(c)

Error in discharge measurement,

(i) for a *V*-notch $\frac{dQ}{Q} = 2.5\frac{dH}{H}$

$= 2.5 \times 0.5 = 1.25\%$

(ii) for rectangular notch $\frac{dQ}{Q} = 1.5\frac{dH}{H}$

13.2(d)

$$\frac{dQ}{Q} = 2.5\frac{dH}{H} = 2.5\%$$

13.3(d)

For ogee spillway $C_{d1} = 1.19\, C_{ds}$

C_{ds} is the discharge coefficient for sharp – crested weir. So 4 will come after 3.

The classification of weir is:

$H_1/B_w \le 0.1$	Long crested weir
$01 < H_1/B_w < 0.35$	Broad-crested weir
$0.35 \le H_1/B_w < 1.5$	Narrow-crested weir
$H_1/B_w \ge 1.5$	Sharp-crested weir

Further submerged weirs have lesser coefficient of discharge compared to free weirs. So 2 will come after 1.

13.4(c)

Discharge when approach velocity is neglected

$$Q = \frac{2}{3}C_d L\sqrt{2g}\,H^{3/2}$$

If velocity of approach, V_a is to be taken into consideration

$$Q_a = \frac{2}{3}C_d L\sqrt{2g}\left[(H+h_a)^{3/2} - h_a^{3/2}\right]$$

Excess percentage of flow

$$= \left(\frac{Q_a - Q}{Q}\right) \times 100$$

$$= \left(\frac{Q_a}{Q} - 1\right) \times 100$$

$$= \left[\frac{(0.25+0.01)^{3/2} - 0.01^{3/2}}{(0.25)^{3/2}} - 1\right] \times 100$$

$$= 5.3\%$$

13.5 (d)

$$Q = \frac{2}{3} C_d \sqrt{2g} L_e H^{3/2}$$

$$= 1.84\, L_e H^{3/2} \text{ (Long rectangular weir)}$$

$$L_e = (L - 0.1\, nH)$$

$$= 4 - 0.1 \times 2 \times 0.36$$

$$= 3.928 \text{ m}$$

$$\therefore Q = 1.84 \times 3.928 \times (.36)^{3/2} = 1.56 \text{ m}^3/\text{s}$$

13.6 (*)

For rectangular notch or weir

$$\frac{dQ}{Q} = \frac{3}{2}\frac{dH}{H}$$

$$\Rightarrow \frac{dQ}{Q} = 1.5 \times \left(\frac{0.15 - 0.13}{0.15}\right)$$

$$\Rightarrow \frac{dQ}{Q} = 0.2$$

$\therefore$ Percentage error in flow rate = 0.2×100
$= 20\%$

13.7 (d)

(i) Rehbock's formula is an empirical formula for calculating discharge in rectangular suppressed weir. It is given by

$$Q = \frac{2}{3}\left(0.605 + 0.08\frac{H}{Z}\right) + \frac{0.001}{H}\sqrt{2g} L H^{\frac{3}{2}}$$

Where L is the length of weir, H is head in meters and Z is the crest height in meters.

(ii) Francis' formula is one of the commonly used empirical formula for computing the discharge over sharp or narrow crested weirs with or without end contraction. Francis proposed the following formulae for the discharge over rectangular weir.

(a) When the velocity of approach is not considered

$Q = 1.84(L - 0.1\, nH)H^{3/2}$

(b) With the velocity of approach taken into account

$Q = 1.84(L - 0.1\, nH_1)(H_1^{3/2} - h_a^{3/2})$

Where $H_1 = H + h_a = H + \frac{V_a^2}{2g}$, H is height of water surface above the crest of weir, and n is the number of end contractions.

13.8 (b)

For a rectangular weir

$$Q = \left(\frac{2}{3} C_d L \sqrt{2g}\right) H^{3/2} = KH^{3/2}$$

$$dQ = \frac{2}{3} KH^{1/2} \cdot dH$$

$$\Rightarrow \frac{dQ}{Q} = \frac{\frac{3}{2}KH^{1/2}}{KH^{3/2}} \cdot dH = \frac{3}{2}\frac{dH}{H}$$

$\therefore$ For an error of 1.5% in measurement of head, corresponding error in discharge = 1.5×1.5 = 2.25%

13.9 (b)

The coefficient of discharge of a orifice varies from 0.61 to 0.65 depending on the size and the shape of the orifice, and the head of liquid under which the flow takes place. For general purposes for small sharp-edged orifices discharging water of liquids of similar viscosity, an average value of 0.62 or 0.63 may be adopted for C_d.

A Borda's mouthpiece is a short cylindrical tube attached to a circular orifice in the side of a reservoir or tank such that it projects inwardly.

Coefficient of discharge, $C_d = C_c \times C_v$.

The value of C_v for a Borda's mouthpiece running free is equal to 1 and $C_d = C_c = 0.5$

C_d for Borda's mouth piece running full = 0.707.

In a bell-mouthed orifice loss of energy as the water discharges out is less.

$\therefore$ C_d for bell-mouthed orifice is more than sharp-edged orifice.

13.10 (d)

Depth-discharge relationship of canal section is maintained at notch fall because crest (sill level)

of notches is above the upstream canal bed and there is no heading up or drawdown of water level in canal near the fall.

13.11 (b)

In a contracted weir (one who's notch does not span the full channel), the nappe is automatically aerated and springs free of the weir crest. In a suppressed weir (where the sides of the channel act as the ends of the weir notch), the nappe may, or may not, be aerated. So, here the arrangement for aeration under the nappe is necessary.

13.13 (b)

Percentage error in discharge with head, in V-notch is given by

$$\frac{dQ}{Q} = \frac{5}{2} \times \frac{dH}{H}$$

$$= \frac{5}{2} \times \frac{0.15}{75}$$

$$\therefore \quad \frac{dQ}{Q} \times 100\% = 0.5\%$$

■■■■

14 Impact of Jets and Turbines

14.1 A pumped storage plant is a
(a) high head plant (b) run-off river plant
(c) peak load plant (d) base load plant
[ESE : 1995]

14.2 If the discharge is Q in a pipe fitted with an end cap nozzle discharging a jet of water with velocity V and hitting normally a plate which is moving with a velocity $V/2$ towards the nozzle, then the jet would hit the plate with a discharge of
(a) $0.5Q$ (b) Q
(c) $1.5Q$ (d) $2Q$
[ESE : 1995]

14.3 Assertion (A): The specific speed of a Pelton wheel is generally much less than that of a reaction turbine.
Reason (R): Pelton wheels generally use more than one nozzle and the specific speed is defined for power developed per nozzle.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1996]

14.4 A turbine works at 20 m head and 500 rpm speed. Its 1 : 2 scale model to be tested at a head of 20 m should have a rotational speed of nearly
(a) 1000 rpm (b) 700 rpm
(c) 500 rpm (d) 250 rpm
[ESE : 1996]

14.5 The correct sequence, in the direction of the flow of water for installation in a hydropower plant is
(a) reservoir, surge tank, turbine, penstock
(b) reservoir, penstock, surge tank, turbine
(c) reservoir, penstock, turbine, surge tank
(d) reservoir, surge tank, penstock, turbine
[ESE : 1997]

14.6 In a 2-jet Pelton wheel working at full load, the jets are issuing from nozzles (so shaped as to avoid any further contraction of jets) of 10 cm diameter. The load is suddenly reduced to 36% of full load. The altered jet diameter shall be
(a) 1.8 cm (b) 3.0 cm
(c) 3.6 cm (d) 6.0 cm
[ESE : 1997]

14.7 Match List-I (Types of turbines) with List-II (Ranges of specific speed in MKS units) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Francis	1. 10 – 35
B. Kaplan	2. 35 – 60
C. Pelton with jet	3. 60 – 300
D. Pelton with two jet	4. 300 – 1000

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	2	1
(c)	3	4	1	2
(d)	4	3	1	2

[ESE : 1998]

14.8 Assertion (A): The inlet velocity triangle for Pelton turbine is a straight line.
Reason (R): For a Pelton turbine, the vane angle at inlet is 180°.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1999]

14.9 To generate 10,000 HP under a head of 81 m while working at a speed of 500 rpm, the turbine of choice would be

(a) Pelton (b) Kaplan
(c) Bulb (d) Francis

[ESE : 1999]

14.10 Consider the following statements:
1. Run-of-river plants can be located on any river.
2. Runaway speed of a turbine is generally 180% of normal speed.
3. Underground power stations are suited to area susceptible to landslides.
4. Higher the specific speed, higher will be the discharge and head.

Which of these statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 4 (d) 2 and 4

[ESE : 1999]

14.11 Match List-I (Turbine) with List-II (Specific speed) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Pelton	1. 25
B. Propeller	2. 75
C. Kaplan	3. 500
D. Francis	4. 800
	5. 900

Codes:

	A	B	C	D
(a)	1	4	5	2
(b)	3	4	2	5
(c)	4	1	5	3
(d)	1	5	4	2

[ESE : 1999]

14.12 Given that atmospheric pressure head = 9 m, vapour pressure head (max.) = 1 m, failure head = 40 m and cavitation coefficient $\sigma = 0.15$, the height at which the turbine can be set above the tail race level is
(a) 6 m (b) 4 m
(c) 3 m (d) 2 m

[ESE : 2000]

14.13 Consider the following statements:
1. Specific speed uniquely determines the type, shape and design of the turbine.
2. Both unit speed 'n_{11}' and unit discharge 'Q_{11}' are necessary to uniquely determine the type and design of the turbine.

Which of these statements is/are correct in respect of a hydraulic turbine?
(a) 2 alone (b) 1 alone
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2000]

14.14 The ideal efficiency of a single-jet Pelton wheel is given by

$$\frac{2}{V^2}[Vv + v(V - v)\cos\phi - v^2]$$

(symbols have their usual meanings)
If friction on the buckets reduces the relative velocity by a factor k_1 and if windage losses reduce the effectiveness of the affected parameters by a factor k_2, then the resulting efficiency multiplied by V^2 is given by
(a) $2k_1k_2[Vv + v(V - v)\cos\phi - v^2]$
(b) $2[k_1Vv + k_2 v(V - v)\cos\phi - v^2]$
(c) $2[k_2Vv + k_1k_2 v(V - v)\cos\phi - v^2]$
(d) $2[k_1Vv + k_1k_2 v(V - v)\cos\phi - k_2v^2]$

[ESE : 2001]

14.15 For a hydro-electric project with reaction turbine, the draft tube at the exit from the turbine is
(a) always immersed in water
(b) always above the water
(c) may either be above or below the water
(d) above or below the water depending on the unit speed of the turbine

[ESE : 2002]

14.16 Consider the following statements in case of impulse turbine:
1. The pressure and velocity both change as the water flows through the turbine.
2. Pressure throughout remains atmospheric and the velocity alone changes.
3. All the available energy is converted into kinetic energy.
4. Water is admitted over the entire circumference of the runner.
5. Water is admitted only through the nozzle.

Which of these statements are correct?
(a) 2, 3 and 5 (b) 2 and 3
(c) 1, 4 and 5 (d) 1 and 4

[ESE : 2002]

14.17 In case of semi-circular vanes, the theoretical maximum efficiency of the wheel can be

(a) 50% (b) 67%
(c) 75% (d) 100%
[ESE : 2002]

14.18 Without residual whirl in the flow at the entr-ance to a draft tube, the best cone angle is
(a) <6° (b) 9° to 11°
(c) 18° (d) 24°
[ESE : 2002]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

14.19 Assertion (A): Selection of turbine by specific speed criterion is more scientific.
Reason (R): Specific speed is independent of dimensions, size of both actual and specific turbine.
[ESE : 2002]

14.20 Assertion (A): The relative velocity of water of a Pelton turbine equals the difference between the absolute velocities of water and vane.
Reason (R): For a Pelton turbine, the inlet blade angle is 180°.
[ESE : 2003]

14.21 Pondage in a hydropower station is defined as
(a) impounding of considerable amount of excess water during seasons of surplus flow
(b) a regulating body of water in the form of relatively small amount of run-off to regulate flow variation in daily or weekly power requirements
(c) excess run-off to last for years
(d) excess run-off for a few hours only
[ESE : 2003]

14.22 The specific speed of a turbine under a head of 150 m to develop 2000 HP while running at 300 rpm is
(a) 10-35 (b) 35-60
(c) 60-300 (d) 300-1000
[ESE : 2003]

14.23 A pelton wheel operates at 630 rpm taking 3 m^3/s of water under a head of 256 m with a speed ratio of 0.48 (Given $\sqrt{19.62} = 4.43$) What is the diameter of the impeller?
(a) 0.90 m (b) 1.03 m
(c) 1.42 m (d) 1.80 m
[ESE : 2004]

14.24 An impulse turbine of 3 m diameter is rated at 10000 kW at 300 rpm under a head of 500 m. The turbine is operated under the head of 400 m. What is the power developed?
(a) 15000 kW (b) 14000 kW
(c) 13000 kW (d) 12000 kW
[ESE : 2004]

14.25 An impulse turbine of 3 m diameter is rated at 1000 kW at 300 rpm under a head of 500 m. The turbine is operated under the head of 400 m. What is the speed at which it would run?
(a) 324 rpm (b) 336 rpm
(c) 348 rpm (d) 364 rpm
[ESE : 2004]

14.26 A forebay in a hydel system is provided at the junction of
(a) the power channel and the tail race channel
(b) the tail race channel and the penstock
(c) the penstock and the turbine
(d) the power channel and the penstock
[ESE : 2005]

14.27 Which one of the following statements is not correct?
(a) Draft tubes decrease efficiency of a turbine.
(b) Wheels of a reaction turbine must always run full.
(c) When the load on a reaction turbine is decreased, the system reduces quantity of flow of water in an immersed flow reaction turbine and reduces the power produced.
(d) Pelton wheels are impulse turbine.
[ESE : 2006]

14.28 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Pelton	1. Draft tube is used
B. Kaplan	2. Draft tube is not used
C. Banki	3. Operates under high head and low discharge
D. Francis	4. Operates under low head and high discharge

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	3	4	2	1
(c)	2	4	3	1
(d)	3	1	2	4

[ESE : 2006]

14.29 In the selection of turbine by specific speed or head, which one of the following statements is not correct?
(a) For specific speed 10-35, Kaplan turbines
(b) For specific speed 60-300, Francis turbines
(c) For head 50-150 m, Francis turbines
(d) For head above 300 m, Pelton wheel

[ESE : 2006]

14.30 To generate 8100 kW under a head of 81 m while working at a speed of 540 rpm, what type of turbine is suitable?
(a) Pelton (b) Kaplan
(c) Bulb (d) Francis

[ESE : 2007]

14.31 Water is supplied a height of 2.8 m at the rate of 35 *l*ps to a hydraulic ram which delivers 2 *l*ps to a height of 28 m above the ram. What is the Rankine's efficiency?
(a) 58% (b) 55%
(c) 52% (d) 44%

[ESE : 2008]

14.32 Match List-I (Type of power house) with List-II (Feature) and select the correct answer using the codes given below the lists:

List-I
A. Tidal Plant
B. Storage Plant
C. Pumped Storage Plant
D. Run-of-river plant

List-II
1. Utilizes reversible turbines and improves utilization factor
2. Utilizes current flow in stream, and has pondage to improve load factor
3. Head on turbine varies with time cyclically
4. Utilizes annually average flow with storage

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	3	2	1	4
(c)	1	2	3	4
(d)	1	4	3	2

[ESE : 2008]

14.33 The shape number in the case of pumps refers to which one of the following?
(a) Ratio of sizes of suction pipe and delivery pipe
(b) Ratio of diameter and thickness of impeller
(c) Non dimensional form of specific speed
(d) Ratio of blade angle at the inlet to the blade angle at the exit

[ESE : 2008]

14.34 Match List-I (Component) with List-II (Function) and select the correct answer using the codes given below the lists:

List-I
A. Spiral casing
B. Stay ring
C. Guide vane
D. Runner

List-II
1. To allow flow of water through it to produce a torque for the rotation of the runner
2. To direct the water on the runner at an appropriate angle
3. To distribute the flow over the periphery of the runner
4. To act as column helping to support the electrical generator above the turbine

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	1	2	4	3
(c)	3	4	2	1
(d)	1	4	2	3

[ESE : 2009]

14.35 In all reaction turbines, maximum efficiency is obtained if the
(a) guide vane angle is 90°
(b) blade angle is 90° at the inlet

(c) blade angle is 90° at the outlet
(d) angle of the absolute velocity vector at the outlet is 90°

[ESE : 2010]

14.36 For attaining maximum efficiency, a Francis turbine runner is so designed as to result in radial discharge at exit. This is done by
(a) Providing runner vane angle at inlet as 90°
(b) Providing guide vane angle at inlet as 90°
(c) Providing runner vane angle at exit as 90°
(d) Designing for absolute velocity at outlet to be inclined at 90° to direction of vane there

[ESE : 2011]

14.37 Assume that water vaporizes at an absolute pressure of 1.5 m, barometric pressure head is 9.5 m, cavitation coefficient is 0.1. A turbine operates under a head of 40 m. The safe height of the runner above the tail water level, in meters, is
(a) 6 (b) 4
(c) 3 (d) 2

[ESE : 2011]

14.38 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Pelton turbine
B. Francis turbine
C. Kaplan turbine
D. Banki turbine

List-II
1. Mixed flow reaction turbine
2. Operating under low head and large discharge
3. Operating under high head and large discharge
4. No draft tube

Code:

	A	B	C	D
(a)	4	2	1	3
(b)	3	1	2	4
(c)	4	1	2	3
(d)	3	2	1	4

[ESE : 2011]

14.39 **Assertion (A):** In the case of water power plants, it is advisable to provide the surge tank as close to the turbine unit as possible.

Reason (R): Purpose of surge tank is to provide the intended protection for the portion of the penstock which lies on the upstream of it.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

14.40 A fire hose has a nozzle attached to it, and the nozzle discharges a jet of water into the atmosphere at a velocity of 20 m/s. This causes the joint of the nozzle with the hose to be in
(a) Tension (b) A state of zero stress
(c) Compression (d) Bending stress

[ESE : 2011]

14.41 Consider the following assumptions made in the analysis of a jet impinging normally on a moving plate to introduce the principle of moment of momentum:
1. Friction between jet and plate is neglected.
2. Flow is steady.
3. Impinging momentum of jet is unchanged.
4. Plate moves at a constant velocity.

Which of these statements are relevant?
(a) 1, 2 and 4 only (b) 1, 2 and 3 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2012]

14.42 Consider the following statements:
1. The specific speed for turbines is directly proportional to $H^{5/4}$.
2. The specific speed for turbines is inversely proportional to $H^{5/4}$.
3. The specific speed for pumps is directly proportional to $H^{3/4}$.
4. The specific speed for pumps is inversely proportional to $H^{3/4}$.

Which of these statements are correct?
(a) 1 and 3 (b) 2 and 4
(c) 1 and 4 (d) 2 and 3

[ESE : 2012]

14.43 A turbine discharging 10 m^3/s is to be designed so that a torque of 1600 kg-m is to be exerted on the impeller turning at 200 rpm under the

condition that the exiting liquid exerts no moment in spite of its momentum. The tangential component of the velocity at the outer periphery of the impeller of radius 1.0 m is

(a) 0.98 m/s (b) 1.57 m/s
(c) 2.10/s (d) 2.26 m/s

[ESE : 2012]

14.44 Two Pelton turbines *A* and *B* have the same specific speed and are working under the same head. Turbine *A* produces 400 kW at 1000 rpm. If turbine *B* produces 100 kW, then its rpm is

(a) 4000 (b) 2000
(c) 1500 (d) 3000

[ESE : 2012]

14.45 Consider the following types of turbines:

1. Francis
2. Pelton with a single jet
3. Kaplan

The correct sequence of these turbines in increasing order of their specific speeds is

(a) 1, 3 and 2 (b) 2, 1 and 3
(c) 1, 2 and 3 (d) 2, 3 and 1

[ESE : 2012]

14.46 A turbine develops 7000 kW power under a head of 25 m at 145 rpm. Calculate the specific speed of turbine and state the type of turbine.

(a) 485, Pelton (b) 217, Francis
(c) 217, Pelton (d) 485, Francis

[ESE : 2013]

14.47 In all reaction turbines, for maximum efficiency, the velocity of:

(a) Swirl at outlet must be zero
(b) Flow at entrance must be zero
(c) Swirl at entrance must be zero
(d) Flow at outlet must be zero

[ESE : 2013]

14.48 A turbine develops 2516 kW at 240 rpm. The torque in the shaft is approximately:

(a) 400 kNm (b) 3336 kNm
(c) 1000 kNm (d) 100 kNm

[ESE : 2013]

14.49 A Kaplan turbine has a runner of diameter 4.0 m. The diameter of the hub is 1.6 m. If the velocity of flow and the swirl velocity at the inlet side of the blade at the hub are 6.0 m/s and 10.0 m/s, respectively, the flow and swirl velocities at the inlet side of the tip are, respectively:

(a) 15.0 m/s and 10.0 m/s
(b) 6.0 m/s and 25.0 m/s
(c) 6.0 m/s and 4.0 m/s
(d) 2.5 m/s and 10.0 m/s

[ESE : 2013]

14.50 A jet of oil of relative density 0.8 and of area 0.02 m^2 issues at 10 m/s. If it strikes normally on a stationary plate, the force exerted on the plate is

(a) 1906 N (b) 15606 N
(c) 1600 N (d) 19581 N

[ESE : 2013]

14.51 A two-dimensional water jet strikes a fixed two-dimensional plate at 30° to the normal to the plate. This causes the jet to split into two streams in which the ratio of larger discharge to smaller discharge is

(a) 14.0 (b) 3.0
(c) 2.0 (d) 1.0

[ESE : 2014]

14.52 In a Francis turbine, the runner blades are radial at the inlet and the discharge leaves the runner radially at the exit. For this turbine

(a) The relative velocity is radial at the outlet
(b) The absolute velocity is radial at the outlet
(c) The guide vane angle is 90°
(d) The velocity of flow is constant

[ESE : 2014]

14.53 Statement (I): The effective head of a turbo-machine is equal to: Gross head minus the head loss in penstock and the velocity head at the turbine inlet.

Statement (II): A turbo-machine becomes susceptible to cavitation if pressure falls below the vapour pressure of the liquid.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).

(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2014]

14.54 A hydraulic turbine has an output of 6000 kW when it works under a head of 25 m runs at 100 rpm. Then the type of turbine used is
(a) Pelton wheel (b) Francis
(c) Kaplan (d) Propeller

[ESE : 2015]

14.55 The velocity heads of water at the inlet and outlet sections of a draft tube are 3.0 m and 0.20 m, respectively. The frictional and other losses in the draft tube are 0.4 m. What is the efficiency of the draft tube?
(a) 15% (b) 67%
(c) 80% (d) 86%

[ESE : 2015]

14.56 **Assertion (A):** Possibility of cavitation is an important consideration in the selection of a turbine for a given head and a range of corresponding specific speed.
Reason (R): High-speed turbines are used for high heads.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2015]

14.57 At the point of operation with maximum efficiency, a turbine indicated unit power of 12 units and unit speed of 98 units and operates with 3300 kgf/s of flow. What are the speed in rpm and the specific speed of the machine respectively when its design head is 8.5 m?
(a) 285 rpm and 339
(b) 270 rpm and 360
(c) 285 rpm and 360
(d) 270 rpm and 339

[ESE : 2016]

14.58 A hydraulic turbine develops 8000 kW when running at 300 rpm under a head of 45 m. The speed of the same turbine under a head of 60 m is
(a) 224.4 rpm (b) 346.4 rpm
(c) 424.8 rpm (d) 485.8 rpm

[ESE : 2016]

14.59 The important parameters describing the performance of a hydraulic machine are: P the power input, H the head produced across the machine and the efficiency, η. For a given geometrical design of the machine, the performance is characterized by the variables: H – the head increase across the machine, ρ – the fluid density, ω – the angular velocity of the rotor, D – the diameter of the rotor, μ – the fluid viscosity and Q – the flow rate; and both P and η are expressed through these variables. How many non-dimensional parameters are involved herein? Gravitational acceleration g has also to be considered necessarily
(a) 7 (b) 6
(c) 5 (d) 4

[ESE : 2016]

14.60 A Pelton wheel works under a head of 400 m. Frictional loss through the pipe flow is limited to 10%. The coefficient of velocity for the jet is 0.98. What is the velocity of the jet? Take, $g = 10\ m/s^2$.
(a) 83 m/s (b) 71 m/s
(c) 65 m/s (d) 56 m/s

[ESE : 2016]

14.61 Consider the following statements :
1. In an Impulse turbine, the pressure of the flowing water remains unchanged and is equal to atmospheric pressure.
2. In Impulse turbines, the water impinges on the buckets with 'pressure energy'.
3. In a Reaction turbine, the pressure of the flowing water remains unchanged and is equal to atmospheric pressure.

Which of the above statements is/are correct?
(a) 1 only (b) 2 only
(c) 3 only (d) 1,2 and 3

[ESE : 2016]

14.62 A Pelton wheel with single jet rotates at 600 rpm. The velocity of the jet from the nozzle is

100 m/s. If the ratio of the bucket velocity to jet velocity is 0.44 and the speed ratio is 0.43, what is the coefficient of velocity of the nozzle?

(a) 0.817 (b) 0.882
(c) 0.913 (d) 0.977

[ESE : 2016]

14.63 **Statement (I):** The speed of a hydraulic turbine has to be maintained constant irrespective of the load on the machine for keeping the electrical power generation frequency constant.

Statement (II): Governing of hydraulic turbines can be done by controlling the discharge through the turbines by adjusting the spear valve in Pelton turbines and the wicket in Francis or Kaplan turbines.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

14.64 Consider the following statements regarding a turbine:

1. Specific speed plays an important role in the selection of the type of turbine.
2. An increase in specific speed of the turbine is accompanied by higher maximum efficiency.
3. The runner of too high specific speed with high available head increases the cost of the turbine on account of the high mechanical strength required.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

[ESE : 2017]

14.65 In a hydraulic machine, the moment of momentum of water is reduced by 15915 N.m, when the machine is rotating to 600 rpm. The power developed is

(a) 1000 kW (b) 1500 kW
(c) 2000 kW (d) 2500 kW

[ESE : 2017]

14.66 Consider the following statements in connection with hydraulic turbines:

1. The Kaplan turbine is a radial flow turbine in which the guide vane angles as well as the runner vane angles are adjustable.
2. Francis and Kaplan turbines are provided with draft tubes which carry water from exit of runner to tailwater to increases the gross head across the turbine.
3. The parts of turbines susceptible to cavitation are the guide vanes and runner vanes - drastically reducing the turbine efficiency.
4. The specific speed of a 4-jet Pelton turbine will be 28 if the specific speed of a single -jet Pelton turbine is 14.

(a) 2 and 3 (b) 1 and 3
(c) 1 and 4 (d) 2 and 4

[ESE : 2017]

14.67 Consider the following statements:

1. Surge tanks are not substitutes for forebays.
2. Pumped storage power plants are a boon to power generation.
3. Water hammer in penstocks is not dangerous.
4. Kaplan turbines are used in low head power plants.

Which of the above statements are correct?

(a) 2 and 4 (b) 1 and 4
(c) 2 and 3 (d) 1 and 3

[ESE : 2017]

14.68 **Statement (I):** In the computations of velocity triangles, or the torque of well-encased roto-dynamic flow machines, whether of outward, or inward, flow type, the tangential component of velocity at the smaller radius flow section can be almost neglected.

Statement (II): This follows from the very concept of 'outward', or 'inward', flow—to a large extent—in visualizing the working features of the machine.

[ESE : 2017]

■■■■

Answers Impact of Jets and Turbines

14.1 (c)	14.2 (c)	14.3 (c)	14.4 (a)	14.5 (b)	14.6 (d)	14.7 (c)	14.8 (c)		
14.9 (d)	14.10 (b)	14.11 (a)	14.12 (d)	14.13 (b)	14.14 (d)	14.15 (a)	14.16 (a)		
14.17 (d)	14.18 (a)	14.19 (a)	14.20 (c)	14.21 (b)	14.22 (a)	14.23 (b)	14.24 (*)		
14.25 (*)	14.26 (d)	14.27 (a)	14.28 (b)	14.29 (a)	14.30 (d)	14.31 (b)	14.32 (a)		
14.33 (c)	14.34 (c)	14.35 (d)	14.36 (d)	14.37 (b)	14.38 (c)	14.39 (a)	14.40 (c)		
14.41 (a)	14.42 (b)	14.43 (b)	14.44 (b)	14.45 (b)	14.46 (b)	14.47 (a)	14.48 (d)		
14.49 (c)	14.50 (c)	14.51 (b)	14.52 (b)	14.53 (d)	14.54 (b)	14.55 (c)	14.56 (c)		
14.57 (a)	14.58 (b)	14.59 (d)	14.60 (a)	14.61 (a)	14.62 (d)	14.63 (a)	14.64 (b)		
14.65 (a)	14.66 (d)	14.67 (a)	14.68 (*)						

Explanations Impact of Jets and Turbines

14.1 (c)

A pumped storage plant generates power during peak hours, but during the off-peak hours water is pumped back. They are peak load plants and use reversible turbines which can be medium head or high head.

14.2 (c)

Relative velocity of plate with respect to jet

$$V_r = \frac{V}{2} + V = 1.5V$$

Force, $F = \rho A V_r . V_r = 2.25\rho V^2$

Therefore, the discharge with which water is striking plate is $1.5Q$.

14.3 (c)

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

where P = Total power developed

14.4 (a)

We know that

$$\left(\frac{DN}{\sqrt{H}}\right)_m = \left(\frac{DN}{\sqrt{H}}\right)_P$$

$$\frac{1}{2} = \frac{500}{N_m}$$

$$N_m = 1000 \text{ rpm}$$

14.5 (b)

Reservoir - Penstock - Surge tank - Turbine

The surge tank is open to atmosphere and connected to penstock. It should be as close as possible to the power house (turbine).

14.6 (d)

Power developed $P \propto Q \propto d^2$ where d is the diameter of the jet.

$$\frac{P_1}{P_2} = \frac{d_1^2}{d_2^2}$$

$$\frac{100}{36} = \frac{10^2}{d_2^2}$$

$$d_2 = 6 \text{ cm}$$

14.7 (c)

Specific speed of Kaplan > Francis > Pelton with two jets > Pelton with single jet.

14.8 (c)

For Pelton turbine, $\alpha = 0°$ and $\theta = 0°$.

14.9 (d)

Power developed in kW

$$= 10{,}000 \times 0.7355 = 7355 \text{ kW}$$

$$\text{Specific speed} = \frac{N\sqrt{P}}{H^{5/4}} = \frac{500 \times \sqrt{7355}}{(81)^{5/4}}$$

$$= 176.46 \text{ (in SI)}$$

(1 hp = 735.5 Watt)

Turbine	Specific speed (SI units)
Pelton	8-30
Francis	40-420
Kaplan and Propeller	380-950

14.10 (b)

Run of the river plants are those which utilize the flow as it comes without any storage being provided. These plants would be feasible only on such river which have minimum dry weather flow. Higher specific speed means higher discharge but lower head and smaller size of runner.

14.11 (a)

Turbine type	Specific Speed
Pelton	10-60
Francis	60-300
Kaplan	300-1000
Propeller	300-1000

14.12 (d)

Thoma's cavitation parameter,

$$\sigma = \frac{H_a - H_v - H_s}{H}$$

$$\therefore \quad H_s = (9 - 1) - 0.15 \times 40 = 2 \text{ m}$$

Thus turbine can be set 2 m above tail race level.

14.13 (b)

Unit speed and unit discharge are are used to predict the performance of turbine and specific speed uniquely determines the design and shape of turbine.

14.14 (d)

Jet velocity = V

Bucket velocity = v

Relative velocity = $V - v$

Ideal efficiency is given by

$$\eta_{ideal} = \frac{2v(V - v)(1 + \cos\phi)}{V^2}$$

$$= \frac{2}{V^2}\left[Vv - v(V - v)\cos\phi - v^2\right]$$

Loss of energy due to friction on bucket reduces relative velocity between jet and bucket by a factor k_1.

$$\therefore \quad \eta_1 = \frac{2}{V^2}\left[Vv + v(V - v)k_1\cos\phi - v^2\right]$$

Windage losses are expressed as $k_2\frac{v^2}{2g}$. So,

$$\eta_2 = \frac{2}{V^2}[k_1Vv + k_1k_2v(V - v)\cos\phi - k_2v^2]$$

14.15(a)

Draft tube must be air-tight and under all-conditions of its operation its lower end must be submerged below the level of water in the tail race. It has two purposes:

(i) Permits a negative or suction head to be established at the runner exit.

(ii) Converts a large portion of velocity energy rejected from the runner into useful pressure energy.

14.16(a)

The machine for which the change in static head in the runner is zero is known as impulse turbine. In these machines, the energy transfer in the runner takes place only by the change in the dynamic head of the fluid. All the available energy is converted into kinetic energy or velocity head by passing water through a contracting nozzle provided at the end of the penstock. Throughout its action water is at atmospheric pressure. The jet of water strikes at bucket attached on the circumference of the wheel.

In the reaction turbine, at the entrance to the runner, only a part of the available energy of water is converted into kinetic energy and a substantial part remains in the form of pressure energy. Thus pressure and velocity both change as the water flows through the turbine. For this gradual change of pressure to be possible the runner should be completely enclosed in an air tight casing and the passage is entirely full of water throughout the operation of the turbine.

14.17 (d)

Maximum Efficiency, $\eta_{max} = \left(\frac{1+\cos\theta}{2}\right)$

For $\theta = 0°$, the curved vanes will become semicircular and $\eta_{max} = 1$ or 100%.

14.18 (a)

For straight divergent type draft tube the central cone angle should not be more than 6° because if

the angle is more than 6°, the water flowing through the draft tube will not remain in contact with the inner surface, with the result that eddies are formed and the efficiency of the draft tube is reduced.

14.19 (a)

Specific speed is independent of size and dimensions of both actual and specific turbine so comparing and selecting turbines on basis of specific speed criterion is more scientific.

14.20 (c)

For Pelton turbine, $\alpha = 0°$ and $\theta = 0°$.

θ is inlet blade angle.

14.21 (b)

Pondage usually refers to the comparably small water storage body. Such regulating body has considerably less storage than the reservoirs of large dams and conventional hydroelectric stations which can store water for long periods such as a dry season or year. Ample pondage allows a power plant meet hourly load fluctuations for a period of a week or more.

14.22 (a)

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

In Metric units 1 hp = 735.5 Watt

$$N_s = \frac{300\sqrt{2000 \times 735.5}}{(150)^{5/4}}$$

$$= 21.91 \text{ (in SI)}$$

14.23 (b)

$$\text{Speed ratio} = \frac{u}{\sqrt{2gH}}$$

$$\therefore \quad u = 0.48 \times \sqrt{2 \times 9.81 \times 256}$$

$$= 0.48 \times 4.43 \times 16$$

$$= 34.02 \text{ m/s}$$

But $$u = \left(\frac{\pi DN}{60}\right)$$

$$\therefore \quad D = \frac{60 \times 34.02}{\pi \times 630} = 1.03 \text{ m}$$

14.24 (*)

The power $P \propto H^{3/2}$

$$\therefore \quad P_2 = P_1\left(\frac{H_2}{H_1}\right)^{3/2}$$

$$= 10{,}000 \times \left(\frac{400}{500}\right)^{3/2}$$

$$= 7155.4 \text{ kW}$$

The power developed will be reduced when the head is reduced.

However the answer is given by

$$P_2 = P_1\left(\frac{H_1}{H_2}\right)^{3/2} = 13975.4 \text{kW}$$

So one can choose 14000 kW as the answer although it is incorrect.

14.25 (*)

Speed, $N \propto \sqrt{H}$

$$\therefore \quad N_2 = N_1\sqrt{\left(\frac{H_2}{H_1}\right)}$$

$$= 300 \times \sqrt{\left(\frac{400}{500}\right)}$$

$$= 268.3 \text{ rpm}$$

However the answer is given by

$$N_2 = N_1\sqrt{(H_1 / H_2)} = 335.4 \simeq 336 \text{ rpm}$$

So one can choose 336 rpm as the answer although it is incorrect.

14.26 (d)

The sequence of units of hydel system are power channel – forebay – intake – short penstocks – power house (turbine) – tail race.

Thus forebay is between power channel and penstock.

14.27 (a)

Draft tube convert kinetic energy at the exit of runner into useful pressure thereby increasing the efficiency.

14.28 (b)

In impulse turbine (Pelton wheel and Banki) draft tube is not used.

Pelton wheel is suitable for high head and low discharge. Kaplan turbines operates under low head and high discharge.

14.29 (a)

Turbine type	Specific Speed	Head
Pelton	10-60	> 250 m
Francis	60-300	370 m
Kaplan	300-1000	40-50 m

14.30 (d)

Specific speed,

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

$$= \frac{540\sqrt{8100}}{81^{5/4}} = 200$$

Francis turbine is suitable.

14.31 (b)

The Rankine's efficiency may be given as

$$\eta_r = \frac{qH}{Qh}$$

where q is rate of flow of water actually lifted

H is level of water in delivery tank w.r.t. supply tank

Q is rate of flow of water flowing past the waste valve

h is level of water in supply tank

$$\therefore \quad \eta_r = \frac{2\times(28-2.8)}{(35-2)\times 2.8} = 54.54\% \approx 55\%$$

14.32 (a)

Tidal plants – These work on the principle that there is a rise in sea water during high tide period and fall during low tide period. Thus the water rises and falls twice a day. Hence head on turbine varies with time cyclically.

Pumped Storage Plant – This generates power during peak hours, but during the off-peak hours, water is pumped back from the tail water pool to head water pool. So these plants use reversible turbines which function both as turbine as well as pump.

Storage Plant – Utilizes annually average flow with storage.

Runoff River Plant – Utilizes current flow in stream and has pondage to improve load factor.

14.33 (c)

The specific speed of a pump is defined as the speed in revolution per minute of a geometrically similar pump of such a size that under corresponding conditions it would deliver 1 litre of liquid per second against a head of 1m. It is represented by N_S and expressed as

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}}$$

Where N is rotational speed in rpm for maximum.efficiency

Q is discharge in m^3/s

H is net head developed in m.

It may be noted that the specific speed N_S has the dimensions of $\left[L^{3/4}T^{-3/2}\right]$.

The non-dimensional form of specific speed is given by

$$N_S = \frac{N\sqrt{Q}}{(gH)^{3/4}}$$

This parameter n_S is known as dimensionless specific speed or shape number of the pump.

14.34 (c)

Spiral casing: The spiral casing around the runner of the turbine is known as the volute casing or scroll case. Throughout its length, it has numerous openings at regular intervals to allow the working fluid to impinge on the blades of the runner. These openings convert the pressure energy of the fluid into momentum energy just before the fluid impinges on the blades. This maintains a constant flow rate despite the fact that numerous openings have been provided for the fluid to enter the blades, as the cross-sectional area of this casing decreases uniformly along the circumference.

Stay ring or Speed ring: It directs water from spiral casing to guine wane or wicket gates and resists the load upon it by internal pressure of water

Guide or stay vanes: The primary function of the guide or stay vanes is to convert the pressure energy of the fluid into the momentum energy. It also serves to direct the flow at design angles to the runner blades.

Runner: Runner blades are the heart of any turbine. These are the centers where the fluid strikes and the tangential force of the impact

causes the shaft of the turbine to rotate, producing torque.

14.35(d)

Reaction turbine efficiency is maximum when whirling velocity at the outlet is zero and absolute velocity vector at the outlet is 90°.

14.36(d)

Francis turbine efficiency is maximum when whirling velocity at the outlet is zero and discharge is radial at exit. This is done by designing runner such that the absolute velocity vector at the outlet is inclined at 90° to direction of vane.

14.37 (b)

NPSH (Net positive suction head)

= Caviation coefficient × Manometric head

= 0.1 × 40 = 4 m

$$\text{Now, NPSH} = \frac{p_{atm} - p_v}{\rho g} - h_s - h_{f_s}$$

Safe height of runner

$$= h_s + h_{f_s} = \frac{p_{atm} - p_v}{\rho g} - \text{NPSH}$$

= 9.5 – 1.5 – 4 = 4 m

14.38 (c)

A draft tube is a pipe or passage of gradually increasing cross-sectional area which connects the runner exit to the tail race. In a pelton turbine a casing made of cast iron or fabricated steel plates is usually provided to lead water to the tail race level.

14.39 (a)

Surge Tanks: A surge tank is a cylindrical open-topped storage tank which is connected to the penstock at a suitable point. Surge tanks are provided in the case of hydroelectric developments having long penstocks. These are provided to relieve the penstocks of excess pressure caused by water hammer and to provide additional supply of water when the turbines are in need of more water on account of increased load. A surge tank however, provides protection against water hammer pressure for only that portion of the penstock which lies on the upstream of it. As such surge tank should be provided as close to the power house as is possible according to the site conditions.

14.41 (a)

After the jet impinges normally on a moving plate the direction of velocity changes. Hence the direction of momentum changes.

14.42 (b)

The specific speed for turbines is given by

$$N_S = \frac{N\sqrt{P}}{H^{5/4}}$$

The specific speed for pumps is given by

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}}$$

14.43 (b)

Given, diameter = 2 m

Power = Torque × ω = Force × Velocity

$$\therefore \text{ Velocity} = \frac{(1600 \times 9.81) \times \left(2\pi \times \frac{200}{60}\right)}{\rho Q V}$$

$$= \frac{(1600 \times 9.81) \times \left(2\pi \times \frac{200}{60}\right)}{(1000 \times 10) \times \frac{\pi \times 2 \times 200}{60}}$$

= 1.57 m/s

14.44 (b)

$$N_{S_A} = N_{S_B}$$

$$\frac{N_1\sqrt{P_1}}{H^{5/4}} = \frac{N_2\sqrt{P_2}}{H^{5/4}}$$

$$\Rightarrow \quad 1000 \times \sqrt{400} = N_2 \times \sqrt{100}$$

$$\therefore \quad N_2 = 2000 \text{ rpm}$$

14.45 (b)

The type of turbine for different specific sped is given in table as

Specific speed	*Type of turbine*
8.5 to 30	Pelton wheel with single jet
30 to 51	Peiton wheel with two or more jet
51 to 255	Francis turbine
255 to 860	Kaplan or Propeller turbine

14.46 (b)

$$N_S = \frac{N\sqrt{P}}{H^{5/4}} = \frac{145\sqrt{7000}}{(25)^{5/4}} = 217$$

Low head ⇒ Francis turbine

14.47 (a)

Efficiency of reaction turbine $\eta\% = \dfrac{V_{w_1u_1} - V_{w_2u_2}}{gH}$

V_{w_1} = velocity of whirl at inlet

V_{w_2} = velocity of whirl at outlet

To maximize efficiency $V_{w_2u_2} = 0$

Since $u_2 \neq 0$, V_{w_2} has to be zero.

i.e. to maximize efficiency swirl at outlet must be zero.

14.48 (d)

$$P = \frac{2\pi NT}{60}$$

$$\Rightarrow \quad 2516 \times 10^3 = 2\pi(240)\frac{T}{60}$$

$$\Rightarrow \quad T = 100\ \text{kNm}$$

14.49 (c)

Velocity of flow is constant at every point.

$$v_f = \frac{Q}{\frac{\pi}{4}\left(D_0^2 - D_b^2\right)}$$

D_0 = runner/outer diameter

D_b = hub diameter

$\therefore$ at tip, velocity of flow = 6 m/s

Also, $v_{w_1}u_1 = v_{w_2}u_2$

At hub, $v_{w_1} = 10$ m/s, $u_1 = \dfrac{\pi \times 1.6 \times N}{60}$

At tip, $v_{w_2} = ?$, $u_2 = \dfrac{\pi \times 4 \times N}{60}$

$$\therefore \quad v_{w_2} = \frac{10 \times 1.6}{4} = 4\ \text{m/s}$$

14.50 (c)

$\rho = 800\ \text{kg/m}^3$

$F = \rho AV(V_{w1})$

$A = 0.02\ \text{m}^2$

$= 800(0.02)10(10)$

$V = 10$ m/s

$= 1600$ N

14.51 (b)

On splitting of jet into two streams, the larger discharge would be

$$Q_1 = \frac{Q}{2}(1+\cos\theta)$$

and, smaller discharge would be

$$Q_2 = \frac{Q}{2}(1-\cos\theta)$$

$$\text{So,} \quad \frac{\text{Larger discharge}}{\text{Smaller discharge}} = \frac{\frac{Q}{2}(1+\cos\theta)}{\frac{Q}{2}(1-\cos\theta)}$$

$$= \frac{1+\cos\theta}{1-\cos\theta}$$

$$= \frac{1+\cos(90°+30°)}{1-\cos(90°-30°)} = \frac{1+\frac{1}{2}}{1-\frac{1}{2}} = \frac{3}{1} = 3$$

14.53 (d)

A turbo machine is a device in which energy transfer occurs between a flowing fluid and rotating element due to dynamic action. This results in change of pressure and momentum of the fluid.

Effective head: It is the head available at the inlet of the turbine. It is obtained by considering all head losses in penstock. If h is the total loss, then the effective head above the turbine is $H = Hg - hf$.

14.54 (b)

Specific speed,

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = \frac{100\sqrt{6000}}{25^{5/4}}$$

$$= 138.56$$

Hence, it is Francis turbine because its specific speed varies from 60-300.

14.55 (c)

Efficiency of draft tube,

$$h_d = \frac{\frac{V_i^2}{2g} - \frac{V_e^2}{2g} - h_f}{\frac{V_i^2}{2g}}$$

$$= \frac{3 - 0.2 - 0.4}{3}$$

$$= 0.8 \text{ i.e. } 80\%$$

14.56 (c)

High speed turbine like Kaplan turbine are used for low or medium head, while low speed turbine, like Pelton turbine are used for high head.

14.57 (a)

$$\frac{P}{H^{3/2}} = 12$$

$$P = 12 \times (8.5)^{3/2}$$

$$\frac{N}{\sqrt{H}} = 98$$

$$N = 98\sqrt{8.5} = 285$$

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

$$= \frac{285\sqrt{12 \times (8.5)^{3/2}}}{(8.5)^{5/4}} = 339$$

14.58 (b)

$$\frac{N}{\sqrt{H}} = \text{constant}$$

$$\frac{300}{\sqrt{45}} = \frac{N}{\sqrt{60}}$$

$$N = 346.4 \text{ rpm}$$

14.59 (d)

P and η can be expressed in terms of D, H, u, Q, g, ρ and ω i.e. 7 variables.

Number of non dimensional parameters involved are $7 - 3 = 4$.

14.60 (a)

Head at the nozzle = $0.9 \times 400 = 360$ m

Velocity of jet,

$$V = \sqrt{2gH}$$

$$= 0.98\sqrt{2 \times 9.81 \times 360}$$

$$\simeq 83 \text{ m/s}$$

14.62 (d)

$$N = 600 \text{ rpm}$$

$$V_1 = 100 \text{ m/s}$$

$$\frac{u_1}{v_1} = 0.44$$

$$\Rightarrow \quad u = 44 \text{ m/s}$$

$$\frac{u}{\sqrt{2gH}} = 0.43$$

$$\Rightarrow \quad H = 533.6658 \text{ m}$$

$$v_1 = 100$$

$$c_v = \sqrt{2gH}$$

$$100 = c_v\left(\frac{44}{0.43}\right) = 0.977$$

14.65 (a)

Power $= T\omega$

$$= 15915 \times \left(\frac{2\pi \times 600}{60}\right)$$

$$= 1000 \text{ kW}$$

15 Pumps

15.1 When two identical centrifugal pumps are operating in series on a common rising main, then
(a) the pressure in the rising main will be nearly doubled, while discharge will remains same
(b) the discharge will be nearly doubled, while the pressure remains the same
(c) discharge as well as the pressure in the rising main will be doubled
(d) discharge as well as the pressure in the rising main will increase but not become double

[ESE : 1995]

15.2 Which one of the following statements regarding reciprocating pump is correct?
(a) Friction head is mainly responsible for causing cavitation in a reciprocating pump at the beginning of the suction stroke.
(b) Effect of acceleration pressure on reciprocating pumps appears parabolic and has the maximum effect at the middle of the delivery stroke.
(c) Air vessels reduces the acceleration head and consequently reduces the effect of friction head also.
(d) The maximum permissible suction lift in a double acting reciprocating pump is independent of vapour pressure.

[ESE : 1996]

15.3 The velocity at the test section of water tunnel is controlled by varying the speed of a propeller pump to increase the speed by 50%, it would be necessary to increase power to approximately
(a) 125% (b) 275%
(c) 350% (d) 400%

[ESE : 1997]

15.4 Assertion (A): By providing air vessels on the suction and delivery side of the pump, it is possible to increase the delivery head of the pump.
Reason (R): The air vessel eliminates the acceleration head and makes discharge uniform.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

15.5 Two identical centrifugal pumps are operated in parallel so as to deliver into a common delivery pipe. Speed for both is also identical. At what total discharge (Q) and total head (H) will the system operate as compared to discharge and head of each of the pumps operated singly?
(a) Both total Q and total H would increase, each approximately by 50%.
(b) Total Q would be approximately doubled, but H would remain the same.
(c) Total H would be approximately doubled, but Q would remain the same.
(d) Total H would be doubled, but Q would be approximately halved.

[ESE : 1998]

15.6 Assertion (A): Inlet side of a pump is less susceptible to cavitation damage.
Reason (R): Cavitation occurs when the velocity is high and pressure is low.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

15.7 The maximum permissible suction lift for centrifugal pump in practice (at sea level and at 30°C) is

(a) 12 m (b) 10 m
(c) 6 m (d) 3 m

[ESE : 1999]

15.8 Consider the following statements:
1. Pumps in series operation allow the head to increase.
2. Pumps in series operation increase the flow rate.
3. Pumps in parallel operation increase the flow rate.
4. Pumps in parallel operation allow the head to increase.

Which of these statements are correct?
(a) 1 and 3 (b) 1 and 4
(c) 2 and 4 (d) 3 and 4

[ESE : 1999]

15.9 A commonly used handpump is the
(a) centrifugal pump
(b) reciprocating pump
(c) rotary pump
(d) axial flow pump

[ESE : 1999]

15.10 Match List-I (Pump) with List-II (Requirement) and select the correct answer using the codes given below the lists:

List-I
A. Multistage centrifugal pump of moderate sized impellers
B. Archimedean screw type pump
C. Simple reciprocating pump
D. Axial flow propeller pump

List-II
1. High head and low discharge
2. Low head and large discharge
3. High head and moderate discharge
4. Low head and low discharge

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	3	4	1	2
(c)	4	3	2	1
(d)	3	4	2	1

[ESE : 1999]

15.11 A pump running at 1414 rpm delivers 256 *l*ps of water against a head of 16 m. The pump is of the
(a) normal speed radial type
(b) double suction type
(c) mixed flow type
(d) axial flow type

[ESE : 2000]

15.12 Consider the following statements:
The head-discharge characteristics curve of two centrifugal pumps in
1. parallel can be obtained by doubling the ordinates.
2. series can be obtained by doubling the abscissa.

Which of these statements is/are correct?
(a) 2 alone (b) 1 alone
(c) Neither 1 nor 2 (d) Both 1 and 2

[ESE : 2000]

15.13 If the radius of the centrifugal pump impeller is reduced from 10 cm, the head developed by the pump will change from 10 m to
(a) 9 m of water (b) 8.1 m of water
(c) 9.487 m of water (d) 11.111 m of water

[ESE : 2000]

15.14 Reciprocating pumps are suitable for
(a) low discharge and high head
(b) high discharge and low head
(c) low discharge and low head
(d) high discharge and high head

[ESE : 2000]

15.15 Two geometrically similar pumps are running at the same speed of 100 rpm and lifting water against the heads of 25 m and 16 m respectively. First pump is having an impeller diameter of 300 mm. The impeller diameter of second pump shall be
(a) 192 mm (b) 240 mm
(c) 300 mm (d) 469 mm

[ESE : 2002]

15.16 Which one of the following statements is correct?
(a) Reciprocating pumps are less efficient than centrifugal pumps.
(b) Delivery from a reciprocating pump is pulsating.
(c) Reciprocating pumps are suitable for large discharges and smaller heads.

(d) For a negative slip to occur, a reciprocating pump must have a coefficient of discharge less than unity.

[ESE : 2002]

15.17 **Assertion (A):** The shape of the impeller of rotodynamic pumps is such as to force the water in a radial/mixed/ or axial flow patterns.
Reason (R): A rotodynamic pump has a wheel or a rotating element which rotates the water in a casing and, thus, imparts energy to the water.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

15.18 Consider the following statements relating to centrifugal pumps:
1. In centrifugal pumps discharge is proportional to speed of the impeller.
2. In centrifugal pumps discharge is proportional to the cube of the impeller diameter.
3. Specific speed is a criterion for selection of centrifugal pumps.
4. Cavitation in centrifugal pumps can be eliminated by avoiding sharp bends, lowering velocity in suction pipe and by lowering temperature.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 2003]

15.19 A centrifugal pump discharges 260 litres of water per second when running at 600 rpm. The impeller diameter at the outlet is 80 cm. It develops a head of 15.3 m. What is the approximate minimum starting speed?
(a) 425 rpm (b) 450 rpm
(c) 475 rpm (d) 500 rpm

[ESE : 2004]

15.20 A combination of centrifugal pumps of specific speed 20 and overall efficiency 80%, running at 800 rpm is to be used to pump 40 *l*ps of water to a height of 75 m. What should be the arrangement?
(a) 3 pumps in series
(b) 3 pumps in parallel
(c) 4 pumps in series
(d) 4 pumps in parallel

[ESE : 2004]

15.21 Match **List-I** (Machines) with **List-II** (Associated with) and select the correct answer using the codes given below the lists:

List-I
A. Centrifugal pump
B. Reciprocating pump
C. Francis turbine
D. Pelton wheel

List-II
1. Per cent slip
2. Bucket
3. Guide blade
4. Volute chamber

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	4	1	3	2
(c)	2	3	1	4
(d)	2	1	3	4

[ESE : 2004]

15.22 The function of an air vessel in a reciprocating pump is to obtain
(a) reduction of suction head
(b) rise in delivery head
(c) continuous supply of water at uniform rate
(d) increase in supply of water

[ESE : 2005]

15.23 A high efficiency pump is required for low discharge, high head and low maintenance cost. Delivery of water need not be continuous. The pump need not run at high speed. Which one of the following is the correct choice?
(a) Centrifugal pump (b) Reciprocating pump
(c) Air lift pump (d) Hydraulic ram

[ESE : 2005]

15.24 Which one of the following inferences is not drawn by studying performance curves of centrifugal pumps?

(a) Discharge increases with speed
(b) Power decreases with speed
(c) Head increases with speed
(d) Manometric head decreases with discharge

[ESE : 2006]

15.25 The centrifugal pump should be installed above the water level in the sump such that
(a) its height is not more than 10.3 m at room temperature of liquid
(b) its height is not allowed to exceed 6.7 m
(c) the negative pressure does not reach as low as the vapour pressure
(d) the negative pressure is not allowed to develop in the impeller

[ESE : 2006]

15.26 Which one of the following statements is correct?
(a) Pumps operating in series boost the discharge whereas pumps operating in parallel boost the head.
(b) Pumps operating in parallel boost the discharge whereas pumps operating in series boost the head.
(c) In both the above cases there would be a boost in discharge only.
(d) In both the above cases there would be a boost in head only.

[ESE : 2006]

15.27 At a rated capacity of 44 cumec, a centrifugal pump develops 36 m of head when operating at 725 rpm. What is its specific speed?
(a) 327 (b) 255
(c) 350 (d) 45

[ESE : 2007]

15.28 A single-acting reciprocating pump has a plunger diameter 25 cm and stroke 35 cm. The speed of the pump is 60 rpm and it delivers 16.5 litres/second of water. What is the value of the theoretical discharge?
(a) 16.8 *l*ps (b) 17.2 *l*ps
(c) 18.0 *l*ps (d) 18.4 *l*ps

[ESE : 2007]

15.29 A fast centrifugal pump impeller has which of the following?
(a) Forward facing blades
(b) Radial blades
(c) Backward facing blades
(d) Propeller type blades

[ESE : 2008]

15.30 Consider the following statements:
An air vessel is fitted on the suction side of a reciprocating pump to
1. achieve higher speed without separation
2. reduce work in overcoming frictional resistance
3. avoid excessive vibration
4. have uniform discharge

Which of these statements are correct?
(a) 1, 2 and 4 (b) 1 and 2 only
(c) 3 and 4 only (d) 2, 3 and 4

[ESE : 2008]

15.31 While selecting a centrifugal pump for your requirement of head and discharge on the basis of its performance characteristics, which one of the following criteria is to be adopted?
(a) Head, discharge and efficiency
(b) Head and discharge only
(c) Discharge only
(d) Head only

[ESE : 2009]

15.32 Consider the following statements:
The function of the impeller in a centrifugal pump is to
1. convert the pressure energy into hydraulic energy
2. convert the hydraulic energy into mechanical energy
3. convert the mechanical energy into hydraulic energy
4. transform most of the kinetic energies to pressure energy

Which of these statements is/are correct ?
(a) 1 only (b) 3 only
(c) 1, 2 and 3 (d) 2, 3 and 4

[ESE : 2009]

15.33 A centrifugal pump gives maximum efficiency when its impeller blades are
(a) bent forward (b) bent backward
(c) straight (d) wave-shaped

[ESE : 2009]

15.34 By which one of the following, a small quantity of water may be lifted to a great height?

(a) Hydraulic ram
(b) Hydraulic crane
(c) Hydraulic lift
(d) Hydraulic coupling

[ESE : 2009]

15.35 Consider the following devices as likely to concern with water hammer phenomenon in their design/operation:
1. Hydraulic ram
2. Hydraulic accumulator
3. Penstock
4. Surge tank
5. Draft tube

Which of the above devices is/are so concerned?
(a) 1, 2, 3, 4 and 5 (b) 1, 3 and 4 only
(c) 2 and 3 only (d) 3 only

[ESE : 2010]

15.36 Consider the following statements:
In reciprocating pumps, the air vessels are used
1. to get continuous supply of liquid at a uniform rate.
2. to save the power required to drive the pump.
3. to run at much higher speed without any danger of separation.

Which of these statements are correct?
(a) 1 and 2 only (b) 1 and 3 only
(c) 1, 2 and 3 (d) 2 and 3 only

[ESE : 2010]

15.37 A centrifugal pump will start delivering the liquid only when
(a) manometer head is greater than total head
(b) head developed tends to exceed the manometric head
(c) head developed in a centrifugal pump is due to pressure head only
(d) head developed is negligible

[ESE : 2010]

15.38 Consider the following statements:
1. Pumps in series operation can be the head to increase.
2. Pumps in series operation increase the flow rate.
3. Pumps in parallel operation increase the flow rate.
4. Pumps in parallel operation can be the head to increase.

Which of these statements are correct?
(a) 1 and 3 (b) 1 and 2
(c) 2 and 3 (d) 3 and 4

[ESE : 2010]

15.39 Conversion of dynamic velocity head into static pressure head in a centrifugal pump is the result of
(a) increasing area of flow between adjacent vanes from inlet to outlet
(b) difference in pressure between suction and delivery ends
(c) radial thrust in pumps
(d) stuffing box

[ESE : 2011]

15.40 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Shallow open well
B. Deep open well
C. Shallow tube
D. Deep tube well

List-II
1. Submersible pump
2. Wind power (mill)
3. Persian wheel
4. Centrifugal pump

Code:

	A	B	C	D
(a)	3	2	4	1
(b)	1	2	4	3
(c)	3	4	2	1
(d)	1	4	2	3

[ESE : 2011]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

15.41 **Assertion (A):** The efficiency of a reciprocating pump is 10-20 percent higher than that of a centrifugal pump for comparable discharge-head conditions.

Reason (R): The discharge from a reciprocating pump is dependent upon speed.

[ESE : 2011]

15.42 **Assertion (A):** In centrifugal pumps, flow takes place from low pressure zone to high pressure zone.

Reason (R): Possibility of separation occurring in pumps can be more and characterizing efficiency of pumps is less than that of turbines.

[ESE : 2011]

15.43 When a pump primes and works but not up to its capacity and pressure, the attributable reasons are as follows:

1. Speed may be too low.
2. Suction lift is too high.
3. Total static head is much higher than as designed.
4. Foot value has been removed.

Which of these reasons can be valid?

(a) 1, 2, 3 and 4 (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2 and 3 only

[ESE : 2012]

15.44 Determine the number of impellers required for a multistage pump to lift 3840 liters per minute against a total head of 80 m at a speed of 700 r.p.m., given that the limiting N_s for each impeller is 700 units.

(a) 6 (b) 5
(c) 4 (d) 3

[ESE : 2012]

15.45 A 20 cm centrifugal pump delivers 13.2 lps at a head of 45 m when running at a speed of 1350 r.p.m. A similarly designed pump of 15 cm size runs at the same speed. What are the most likely values of discharge and delivery head serviced by this second pump?

(a) 5.57 lps and 25.3 m
(b) 7.20 lps and 25.3 m
(c) 8.27 lps and 27.8 m
(d) 8.27 lps and 29.4 m

[ESE : 2012]

15.46 Consider the following statements:

Air vessels are fitted on the suction and delivery sides of a reciprocating pump to

1. Achieve higher speed without separation
2. Reduce work in overcoming frictional resistance
3. Avoid excessive vibration permanently.
4. Have nearly uniform discharge.

Which of these statements are correct?

(a) 1, 2 and 4 only (b) 1, 2 and 3 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2012]

15.47 Given below are two lists. Which of these are properly matched?

Types of pump		Head-Discharge performance
1. Propeller pump	:	Large discharges and low heads with negligible percentage variation in head
2. Single stage centrifugal pump with backward curved blades	:	Medium heads, with decreasing head as discharge increases
3. Turbine pump	:	Medium to high heads with low, but constant, discharges.

(a) 1 and 2 (b) 2 and 3
(c) 2 only (d) 3 only

[ESE : 2012]

15.48 Consider the following statements:

The total head against which a pump has to work must include, besides any other items,

1. the suction lift.
2. the delivery head
3. the head lost due to friction at entrance in the rising main
4. the head lost due to friction at exit in the rising main.

Which of these statements are correct?

(a) 1, 2 and 3 only (b) 2 and 3 only
(c) 1, 2, 3 and 4 (d) 3 and 4 only

[ESE : 2012]

15.49 **Assertion (A):** For a hydraulic ram, D'Aubuisson's efficiency is always more than Rankine's efficiency.

Reason (R): By definition, efficiency is always less than unity in any system of mechanics; and addition of a small value to both numerator and denominator in the ratio of such a case always improves the value.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2012]

15.50 Consider the following statements:
To maximize the Net Positive Suction Head Available for a reciprocating pump, one must
1. Reduce the suction pipe friction loss.
2. Increase the ambient pressure at the supply reservoir.
3. Increase the pump speed.
4. Increase the static suction head.

Which of these statements are correct?

(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

[ESE : 2013]

15.51 A hydraulic ram utilizes a supply under 4.0 m head, and delivers to an effective head of 20 m above the unit. The ratio of water wasted to the water delivered is 15. The efficiency of the pump, with neglecting frictional losses in the pipes, is:

(a) 17.5% (b) 20.0%
(c) 28.6% (d) 33.3%

[ESE : 2013]

15.52 A centrifugal pump lifts 100 *l*/s of a liquid against a net head of 150 kPa. The brake power required is 18.0 kW when the liquid is water with a specific weight of 9.8 kN/m^3. What would be the brake power if the liquid is a solvent having a relative density of 0.8 instead of water, with all other factors remaining the same as before?

(a) 14.4 kW (b) 18.0 kW
(c) 22.5 kW (d) 17.2 kW

[ESE : 2014]

15.53 A centrifugal pump has its impeller of 50 cm diameter at inlet, and it rotates at 1200 rpm. The tangential velocity of the impeller at the inlet is

(a) 16π m/s (b) 10π m/s
(c) 12π m/s (d) 100π m/s

[ESE : 2014]

15.54 The number of impellers required for a multistage pump to lift 4500 litres/minute against a total head 190 m at a speed of 750 rpm with specific speed not to exceed 700 is

(a) 6 (b) 8
(c) 10 (d) 12

[ESE : 2015]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

15.55 **Assertion (A):** In a reciprocating pump, the piston is considered to be moving with simple harmonic motion on assumption that the connecting rod is very large compared to be crank length.
Reason (R): There is acceleration at the beginning and retardation at the end of each stroke.

[ESE : 2015]

15.56 **Assertion (A):** By providing Air Vessels on the suction and delivery sides of a reciprocating pump, it is possible to increase the delivery head of the pump.
Reason (R): The Air Vessel terminates the acceleration head and contributes to the outgoing discharge becoming reasonably steady and uniform.

[ESE : 2015]

15.57 **Assertion (A):** The specific speed (N_s) of a centrifugal pump is defined as the speed (in rpm) at which it works most efficiently.
Reason (R): The specific speed is a characteristic of pumps that can be used as a

basis for comparing the performance of centrifugal pumps.

[ESE : 2015]

15.58 Two identical centrifugal pumps are connected in parallel to a common delivery pipe of a system. The pump curve of each of the pumps is represented by $H = 20 - 60Q^2$ where H is manometric head of the pump and Q is the discharge of the pump. The head loss equation when two such fully-similar pumps jointly deliver the same discharge Q will be

(a) $H = 40 - 15Q^2$ (b) $H = 20 - 60Q^2$

(c) $H = 40 - 60Q^2$ (d) $H = 20 - 15Q^2$

[ESE : 2016]

15.59 In a single-acting reciprocating pump, the acceleration head at the beginning of the suction stroke is 3.5 m. If the pump is 1.5 m below the water level in the supply reservoir, the pressure head at the cylinder at that instant, considering the atmospheric pressure as 10.0 m is

(a) 2 m(abs) (b) 4 m(abs)

(c) 8 m(abs) (d) 16 m(abs)

[ESE : 2016]

15.60 **Statement (II):** Multistage centrifugal pumps are used to produce very high delivery heads.

Statement (II): Roto-dynamic pumps must have to be centrifugal rather than centripetal, from the very basic principles of hydrodynamics. Also, the stages are in series.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

15.61 A centrifugal pump has a impeller of 30 cm diameter and runs at 1000 rpm giving best efficiency. It delivered 1.2 m^3/minute against a head of 25 m. What is its non-dimensional specific speed (based on flow expressed in *l.p.s*)?

Take $\sqrt{9.81} = 3.132$; and $\sqrt{\sqrt{9.81}} = 1.177$.

(a) 55 (b) 63

(c) 72 (d) 80

[ESE : 2017]

15.62 The approximate value of BHP of a pump to supply 1 m^3/s water to a town at RL 400 m from a source, whose water level is at RL 320 m, would be

(a) 940 (b) 1000

(c) 1070 (d) 1120

[ESE : 2017]

■■■■

Answers Pumps

15.1	(a)	15.2	(c)	15.3	(a)	15.4	(b)	15.5	(b)	15.6	(d)	15.7	(c)	15.8	(a)
15.9	(b)	15.10	(b)	15.11	(c)	15.12	(c)	15.13	(b)	15.14	(a)	15.15	(b)	15.16	(b)
15.17	(b)	15.18	(a)	15.19	(c)	15.20	(c)	15.21	(b)	15.22	(c)	15.23	(b)	15.24	(b)
15.25	(c)	15.26	(b)	15.27	(a)	15.28	(b)	15.29	(c)	15.30	(a)	15.31	(a)	15.32	(b)
15.33	(b)	15.34	(a)	15.35	(b)	15.36	(c)	15.37	(b)	15.38	(a)	15.39	(b)	15.40	(a)
15.41	(b)	15.42	(c)	15.43	(a)	15.44	(b)	15.45	(a)	15.46	(a)	15.47	(a)	15.48	(c)
15.49	(a)	15.50	(a)	15.51	(d)	15.52	(a)	15.53	(b)	15.54	(*)	15.55	(b)	15.56	(a)
15.57	(d)	15.58	(d)	15.59	(c)	15.60	(a)	15.61	(c)	15.62	(c)				

Explanations Pumps

15.1(a)

When two pumps operate in series, discharge remains same and head produced is doubled and if they operate in parallel, discharge is doubled and head remains the same.

15.2(c)

In a reciprocating pump, at the beginning of suction stroke the pressure head will be $(H_s + H_{as}) + h_{fs}$ below the atmospheric pressure. However the head loss due to friction (h_{fs}) is very small compared to sum of suction head and head due to acceleration ($H_a + H_{as}$).

Effect of acceleration pressure on reciprocating pump is linear with maximum effect at the start of suction or delivery stoke.

15.3(a)

Propeller type pump is based on the momentum theory. To increase the speed by 50% discharge should be increased by 50% at the test section because the cross-section of the tunnel remains unchanged. Therefore the rotational speed of the impeller should also be increased by 50%. The head developed ($H \propto N^2$) will be $(1.5)^2$ times the original head developed. Therefore the power should be increased by $\frac{(1.5)^2 - 1}{1} \times 100 = 125\%$ approximately (assuming 100% efficiency)

15.4(b)

Air vessels are used to obtain uniform rate of flow in both suction and delivery pipes of a reciprocating pump. It increases the delivery head but reduction of suction head increases danger of cavitation.

15.5 (b)

When two identical pumps are connected in parallel, volume flow rate(discharge) is doubled, head remains constant.

15.6(d)

As the liquid flows through the rotating impeller it receives energy from the vanes which results in an increase in both pressure and velocity energy. The cavitation is likely to occur at the inlet to the pump i.e. suction side.

15.8 (a)

Pumps in parallel: individual volume flow rates are added, head remains constant.

Pumps in series: total head is sum of individual pump heads.

15.10 (b)

Multistage centrifugal pump of moderate sized impeller can be used to produce high head if connected in series (i.e., on the same shaft) for discharging large quantity of water they can be connected in parallel.

15.11 (c)

The specific speed, $N_s = \frac{N\sqrt{Q}}{H^{3/4}}$

$$N_s = \frac{1414 \times \sqrt{256}}{(16)^{0.75}} = 2828$$

Type of pump	Specific speed
Slow speed radial flow	300-900
Medium speed radial flow	900-1500
High speed radial flow	1500-2400
Mixed flow or screw type	2400-5000
Axial flow or propeller type	3400-15,000

15.12 (c)

For parallel connection discharge will get doubled, so abscissa should be doubled.

For series connection head will get doubled, so ordinate should be doubled.

15.13 (b)

$\frac{ND}{\sqrt{H}}$ will remain same even when diameter is reduced $H_2 = \left(\frac{D_2}{D_1}\right)^2 H_1 = (0.9)^2 \times 10 = 8.1$ m of water

15.14 (a)

Reciprocating pump gives constant discharge under variable heads. It is used for low discharge under variable high heads.

15.15 (b)

Equating head coefficients, we get

$$\frac{N_1 D_1}{\sqrt{H_1}} = \frac{N_2 D_2}{\sqrt{H_2}}$$

$$\therefore \quad D_2 = \left(\frac{1000}{1000}\right) \times \sqrt{\frac{16}{25}} \times 300 = 240 \text{ mm}$$

15.16 (b)

Reciprocating pump: Suitable for less discharge and high head. More efficient than centrifugal pump. Delivery from pump is pulsating.

Slip $= (Q_{th} - Q_a)$

$Q_{th} < Q_a$ or $C_d > 1$

If coefficient of discharge is more than one, negative slip would occur.

15.17 (b)

The pumps based on the principle of fluid dynamics (angular momentum change) are called rotodynamic pump. The rotar consist of number of blades and there is relative motion between the rotar vanes and fluid. These are classified as:

(i) Centrifugal pumps with radial flow
(ii) Half axial or screw or mixed flow pumps with axial and radial flow
(iii) Axial flow or propeller pumps with axial flow.

15.18 (a)

Cavitation parameter (σ) needs to be controlled to avoid cavitation in centrifugal pumps.

15.19 (c)

Minimum starting speed,

$$\left[\left(\frac{\pi N_{min}}{60}\right)^2 \left(D_1^2 - D^2\right)\right] = 2gH_m$$

Given $D_1 = 80$ cm $= 0.8$ m
$H_m = 15.3$ m
$Q = 260$ l/s $= 0.26$ m^3/s
$N = 600$ rpm

Inner diameter of the impeller is approximately half of outer diameter

$$\therefore \quad \frac{\pi N_{min}}{60} = \sqrt{\frac{2 \times 9.81 \times 15.3}{(0.8^2 - 0.4^2)}}$$

$$\Rightarrow \quad N_{min} = 477.6 \simeq 475 \text{ rpm}$$

15.20 (c)

Specific speed, $N_s = \frac{N\sqrt{Q}}{H^{3/4}}$

For parallel arrangement, $H = 75$ m

$$Q = \left(\frac{20 \times (75)^{3/4}}{800}\right)^2$$

$= 0.405$ m^3/s $= 405$ lps.

Since the discharge of single pump is more than 40 lps so parallel arrangement is not possible.

For series arrangement, $Q = 0.04$ m^3/s

$$H^{3/4} = \frac{800 \times \sqrt{0.04}}{20}$$

$\Rightarrow \quad H = 16$ m

Therefore number of pumps required to develop 75 m head,

$n = \frac{75}{16} = 4.67 \simeq 5$ pumps in series.

The closest answer is 4 pumps in series.

15.21 (b)

Guide blades are provided in Francis tube to guide flow of water.

In Pelton wheel water jet strikes the blade.

Slip in reciprocating pump is defined as the difference between theoretical discharge and actual discharge.

Volute chamber is spiral shaped casing around the impeller in volute pump which is a centrifugal pump.

15.22 (c)

Air vessel ensure continuous supply of water at a uniform rate in a reciprocating pump. It results in saving of work against friction.

Percentage of work saved during stroke in

(i) single acting pump is 84.8%

(ii) double acting pump is 39.2%

The air vessels change the indicator diagram of the reciprocating pump.

15.23 (b)

Air lift pump, centrifugal pump and hydraulic ram have low efficiency. Centrifugal pump is suitable for low head. Reciprocating pump is correct choice.

15.24 (b)

$Q \propto N$; $P \propto N^3$; $H \propto N^2$

Power increases with cube of speed

15.25 (c)

Centifugal pump should be installed above water level in sump such that negative pressure does not reach as low as vapour pressure and thereby not cause cavitation.

15.26 (b)

Pumps in parallel: individual volume flow rates are added, head remains constant.

Pumps in series: total head is sum of individual pimp heads.

Therefore pumps in parallel boost discharge whereas pumps in series boost head.

15.27 (a)

For a centrifugal pump, the specific speed is given by

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{725\times\sqrt{44}}{(36)^{3/4}} = 327.22$$

15.28 (b)

Theoretical discharge for single acting reciprocating pump is given by

$$Q_t = \frac{ALN}{60} = \frac{\pi\times(25\times10^{-2})^2\times35\times10^{-2}\times60\times10^3}{4\times60}$$

$= 17.2$ *l*ps

15.29 (c)

Impeller of a centrifugal pump is provided with a series of backward curved blades or vanes. It is mounted on a shaft which is coupled to an external source of energy (usually an electric motor) which imparts the required energy to the impeller thereby making it to rotate.

15.30 (a)

An air vessel is a close chamber having an opening at its base through which the liquid may flow into the vessel or it may flow out from the vessel. It is obvious that the difficulty with the reciprocating pups is that the supply of liquid is quite intermittent. Air vessel is fitted to obtain a uniform rate of flow of liquid in both suction and delivery pipe of a reciprocating pump. Air vessel also makes an allowance to achieve higher speed, so that the flow rate of liquid entering cylinder may be more than the mean discharge. Also, when a pump is equipped with air vessels, the fluctuations in the velocity of flow in suction and delivery pipes are eliminated, which results in reducing the head loss due to friction in these pipes and hence certain amount of energy is saved. However, air vessels do not contribute in avoiding vibrations in the pump.

15.31 (a)

Head and discharge are based on utility and greater efficiency is good economically.

15.32 (b)

Mechanical energy is converted into hydraulic energy by impeller.

Electrical energy (Input) → MOTOR → Mechanical Energy (shaft power) → IMPELLER → Hydraulic Energy (Output)

15.33 (b)

In backward bent impeller blades the outlet tip curves in direction opposite to motion and offer less resistance helping in achieving high speed leading to higher efficiency.

15.34 (a)

The hydraulic ram is a type of pump in which the energy of large quantity of water falling through small height is utilized to lift a small quantity of this water to greater height.

15.35 (b)

Design of Hydraulic ram, Penstock and surge tank is done taking into consideration the water hammer phenomenon.

15.36 (c)

Air vessels are fitted to get continuous flow of liquid at uniform rate and to achieve higher speed. It reduces fluctuations in velocity and reduces head loss thereby saving power.

15.37 (b)

Centrifugal pump will start delivering liquid when the head developed exceeds manometric head Manometric head is the sum of the actual lift (Static head) + the frictional losses in the pipes + the discharge velocity head.

15.38 (a)

Pumps in parallel: individual volume flow rates are added, head remains constant.

Pumps in series: total head is sum of individual pimp heads.

Therefore pumps in parallel increase discharge whereas pumps in series increase head.

15.39 (b)

TOTAL DYNAMIC SUCTION HEAD (hs) is the static suction head plus the velocity head at the pump suction flange minus the total friction head in the suction line. The total dynamic suction head, as determined on pump test, is the reading of the gauge on the suction flange, converted to feet of liquid and corrected to the pump centerline, plus the velocity head at the point of gauge attachment.

TOTAL DYNAMIC DISCHARGE HEAD (hd) is the static discharge head plus the velocity head at the pump discharge flange plus the total friction head in the discharge line. The total dynamic discharge head, as determined on pump test, is the reading of a gauge at the discharge flange, converted to feet of liquid and corrected to the pump centerline, plus the velocity head at the point of gauge attachment.

TOTAL HEAD (H) or TOTAL DYNAMIC HEAD (TDH) is the total dynamic discharge head minus the total dynamic suction head or plus the total dynamic suction lift.

15.40 (a)

The Persian wheel is a mechanical water lifting device operated usually by draught animals like bullocks, buffaloes or camels. It is used to lift water from water sources typically open wells (mainly shallow open wells).

For deep tube wells, submersible pump is suitable and for Shallow tube well, centrifugal jet pump is suitable.

Wind power (mill) can be used to lift water from deep open well.

15.41 (b)

A reciprocating pump is a positive displacement pump in which the liquid is sucked and then it is actually pushed or displaced due to the thrust exerted on it by a moving member, which results in lifting the liquid to the required height. These pumps usually have one or more chambers which are alternately filled with the liquid to be pumped and then emptied again. As such the discharge of liquid pumped by these pumps almost wholly depends on the speed of the pump.

15.42 (c)

The efficiency of a pump is generally less than that of a turbine. The flow passages in a centrifugal pump are diverging (flow is decelerating) wherease those of a turbine are coverging (flow is accelerating). The losses in a pump are more because of possiblity of flow separation and formation of eddies in a diverging flow.

15.43 (a)

When a pump primes and works but not up to its capacity and pressure the reasons are

(i) Air may be leaking into pump through suction line.
(ii) Speed may be too low.
(iii) Discharge head may be higher than anticipated.
(iv) Suction lift may be too high.
(v) Foot valve or end of suction pipe may not have sufficient submergence.
(vi) Impeller may be partly clogged or too small in diameter.
(vii) Rotation may be in the wrong direction.

15.44 (b)

If H_m is the manometric head developed by each pump, then as

$$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$$

Given, $N_s = 700$ rpm, $N = 700$ rpm
$Q = 3840$ litres/minute $= 64$ lps

$$\therefore \quad 700 = \frac{700 \times \sqrt{64}}{H_m^{3/4}}$$

$$\therefore \quad (H_m)^{3/4} = 8$$
$$\therefore \quad H_m = (8)^{4/3} = 16$$

$$\therefore \text{ Number of impellers required} = \frac{80}{16} = 5$$

15.45 (a)

$H_1 = 45$ m; $Q_1 = 13.2$ lps
$D_1 = 20$ cm; $N_1 = 1350$ rpm
$D_2 = 15$ cm; $N_2 = N_1 = 1350$ rpm
$Q_2 = ?$ $H_2 = ?$

Head coefficient

$$C_H = \frac{H}{N^2D^2}$$

$$\Rightarrow \quad \frac{H_1}{N_1^2D_1^2} = \frac{H_2}{N_2^2D_2^2}$$

$$\Rightarrow \quad \frac{45}{(20)^2} = \frac{H_2}{(15)^2} \qquad (\text{As } N_2 = N_1)$$

$$\Rightarrow \quad H_2 = \frac{45 \times 225}{400}$$

$$= \frac{45 \times 9}{16} = \frac{405}{16} = 25.3 \text{ m}$$

Discharge coefficient

$$C_Q = \frac{Q}{ND^3}$$

$$\Rightarrow \quad \frac{Q_1}{N_1D_1^3} = \frac{Q_2}{N_2D_2^3}$$

$$\Rightarrow \quad \frac{13.2}{(20)^3} = \frac{Q_2}{(15)^3}$$

$$\Rightarrow \quad Q_2 = \left(\frac{15}{20}\right)^3 \times 13.2$$

$$= \frac{27}{64} \times 13.2 = 5.568 \text{ lps} = 5.57 \text{ lps}$$

15.46 (a)

An air vessel is fitted to the suction pipe and to the delivery pipe at a point close to the cylinder of a single-acting reciprocating pump.
(i) to obtain a continuous supply of liquid at a uniform rate
(ii) to save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipes, and
(iii) to run the pump at a high speed without separation.

15.47 (a)

Turbine pumps run at low speeds as they do not have backward curved blades and thus are not capable of high heads.

15.48 (c)

The total head against which a pump has to work are
(i) Static head H_s, which is the vertical distance between the liquid surfaces in the sump and the tank to which the liquid is delivered by the pump.
(ii) Velocity head ($V^2/2g$) at the point of discharge.
(iii) Head loss, H_L, which includes the head loss due to friction in suction and delivery pipes as well as head loss in valves, bends and all such appurtenances both on the suction and the delivery sides.

15.49 (a)

D' Aubuisson's efficiency $= \frac{w \times H}{W \times h}$

Rankine's efficiency $= \frac{w \times (H - h)}{(W - w) \times h}$

For hydraulic ram, D' Aubuisson's efficiency is more than Rankine's efficiency.

$$\frac{a+\Delta a}{b+\Delta b} > \frac{a}{b}$$

$$\frac{a+\Delta a}{b+\Delta b} - \frac{a}{b} > 0$$

adding small value to numerator and denominator improves the value of ratio.

15.50 (a)

Net positive suction head is the minimum pressure required at the suction port of the pump to keep the pump from cavitating.

$$\text{NPSH} = \frac{P_t}{\rho g} - \frac{P_v}{\rho g} - h_f$$

Increase in pressure at supply reservoir increases NPSH

Reduction in suction friction reduces h_f thereby increasing NPSH.

15.51 (d)

$$\frac{\text{water delivered}}{\text{water wasted}} = \frac{1}{15}$$

$$\text{Eff. of pump} = \frac{\text{Output}}{\text{Input}} = \frac{20}{4\times 15}\times 100$$

$$= 33.33\%$$

15.52 (a)

Considering all other factors constant,

Brake power $\propto$ specific weight

$\therefore$ Brake power required is 18 kW when liquid is water with a specific weight of 9.8 kN/m^3. Then brake power in liquid with solvent having specific density 0.8.

$= 18 \text{ kW} \times 0.8 = 14.4 \text{ kW}$

15.53 (b)

Tangential velocity

$$= \frac{\pi DN}{60} = \frac{\pi \times 50 \times 10^{-2} \times 1200}{60} = 10\,\pi \text{ m/sec}$$

15.54 (*)

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

For n no. of pumps,

$$N_s = \frac{N\sqrt{Q}}{\left(\frac{H}{n}\right)^{3/4}}$$

$$\frac{190}{n} = 0.1949, \quad n = 975$$

15.56 (a)

Air vessel on the suction and delivery sides of a reciprocating pump are used to:

1. Achieve higher speed without separation
2. Reduce work in overcoming frictional resistance
3. Have nearly uniform discharge
4. Increase the delivery head of the pump

15.57 (d)

The specific speed (N_s) of a pump is the speed of a geometrically similar turbine that would develop 1 kW power when working under unit head.

15.58 (d)

$H = 20 - 60$

When two pumps are joined in parallel discharge becomes half. So head loss equation now is

$$H = 20 - 60\left(\frac{Q}{2}\right)^2$$

$$H = 20 - 15Q^2$$

15.59 (c)

Suction head created by pump= –3.5 m

Available head at the entrance of cylinder = 10 + 1.5 = 11.5 m

Pressure head at cylinder = 11.5 – 3.5 = 8 m

15.61 (c)

Non-dimensional specific speed

$$N_S = \frac{N\sqrt{Q}}{(gH)^{3/4}} = \frac{100\sqrt{\frac{1.2}{60}\times 1000}}{(9.81\times 25)^{3/4}} = 72.166$$

15.62 (c)

$\gamma_w = 10 \text{ kN/m}^3 = 10000 \text{ N/m}^3$

$$\text{Power (in BHP)} = \frac{10000\times 1\times(400-320)}{746}$$

$$= 1072.386 \simeq 1070$$

16 Open Channel Flow

16.1 Match List-I (Hydraulic structure) with List-II (Water surface profile at the structure) and select the correct answer using the codes given below the lists:

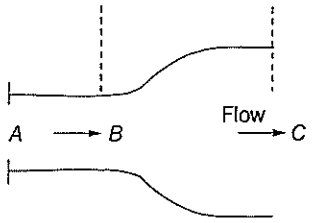
List-I	List-II
A. On a flat topped broad-crested weir	1. M_1
B. Immediately below a sluice gate on a level apron	2. M_2
C. Behind the weir on an alluvial river	3. S_1
D. In a chute spillway	4. S_2
	5. H_2
	6. H_3

Codes:

	A	B	C	D
(a)	5	6	1	4
(b)	4	6	2	1
(c)	2	5	6	4
(d)	5	4	1	3

[ESE : 1995]

16.2 The given figure shows a subcritical open channel flow expansion (*BC* in the figure) of rectangular cross-section. With respect to the water level in the flume (*A* in the figure), water level in the expansion *BC* will



(a) fall
(b) not change
(c) rise
(d) first rise and then fall

[ESE : 1995]

16.3 Which one of the following is analogous to normal shock wave?
(a) An elementary wave in a still liquid
(b) Hydraulic jump
(c) Flow of liquid through an expanding nozzle
(d) Sub-critical flow in an open-channel

[ESE : 1995]

16.4 Though Manning's formula is dimensionally non-homogeneous, it is commonly used in practice because
(a) it is in simple form
(b) it was derived from extensive field data
(c) it can be made dimensionally homogeneous
(d) it can be related to Chezy's coefficient or Darcy-Weisbach's friction factor

[ESE : 1995]

16.5 For flow under a sluice gate where the upstream depth is 1.2 m and the depth at vena-contracta is 0.3 m, the discharge per metre width would be nearly
(a) 0.36 m^3/s (b) 1.5 m^3/s
(c) 1.7 m^3/s (d) 4.0 m^3/s

[ESE : 1996]

16.6 In an open channel of wide rectangular section with constant 'n' value, the bed slope is 1.2×10^{-3}, the local friction slope at a section is 1.05×10^{-3}, the local Froude number of the flow is 0.8. The local rate of variation of depth with longitudinal distance along the flow direction is

(a) $\frac{1.2-1.05}{1-0.8}\times10^{-3}$ (b) $\frac{-1.2-1.05}{1-0.8}\times10^{-3}$

(c) $\frac{1.2+1.05}{1-0.64}\times10^{-3}$ (d) $\frac{1.2-1.05}{1-0.64}\times10^{-3}$

[ESE : 1996]

16.7 Before passage of a surge, the depth and velocity of flow at a section are 1.8 m and 3.72 m/s and,

after passage, they are 0.6 m and 7.56 m/s respectively. The speed of the surge is

(a) +1.8 m/s (b) –2.7 m/s
(c) +3.6 m/s (d) –4.5 m/s

[ESE : 1996]

16.8 A channel bed slope 0.0009 carries a discharge of 30 m^3/s when the depth of flow is 1.0 m. What is the discharge carried by an exactly similar channel at the same depth of flow if the slope is decreased to 0.0001?

(a) 10 m^3/s (b) 15 m^3/s
(c) 60 m^3/s (d) 90 m^3/s

[ESE : 1997]

16.9 At a hydraulic jump, the depths at the two sides are 0.4 m and 1.4 m. The head loss in the jump is nearly

(a) 1.0 m (b) 0.9 m
(c) 0.7 m (d) 0.45 m

[ESE : 1997]

16.10 Which one of the following pairs relating to flumes carrying open channel flow is correctly matched?

(a) Non-modular flume
... Flow is unaffected by drowning
(b) Venturi flume
... Standing wave forms at the throat
(c) Venturi flume
... Flow at the throat is at less than critical velocity
(d) Standing wave flume
... Hump is not provided at the throat

[ESE : 1997]

16.11 **Assertion (A):** A hydraulic jump cannot be expected on a long steep slope (fed by a large reservoir) when it is followed by a short reach of adverse slope termination in vertical drop into a deep and wide reservoir.

Reason (R): The terminal depth is such an adverse slope reach will be critical and the flow in the steep slope may be nearly at or at normal depth.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

16.12 Which one of the following pairs is NOT correctly matched (b = bottom width, y = depth of flow, θ = side slope with vertical)?

(a) For least perimeter of rectangular canal section
... $b = 2y$
(b) For least perimeter of trapezoidal canal section
... $b = 2y(\sec\theta - \tan\theta)$
(c) For critical flow through rectangular canal
... $v = gy$
(d) For critical flow through trapezoidal canal
... $v = \sqrt{\dfrac{gy(b + y\tan\theta)}{\beta + 2y\tan\theta}}$

[ESE : 1998]

16.13 A rectangular open channel carries a discharge of 15 m^3/s when the depth of flow is 1.5 m and the bed slope is 1 : 1440. What will be the discharge through the channel at the same depth if the slope would have been 1 : 1000?

(a) 21.6 m^3/s (b) 18 m^3/s
(c) 14.4 m^3/s (d) 12.5 m^3/s

[ESE : 1998]

16.14 A trapezoidal section of a channel is 2 m wide at base and the side slopes are 1H to $1\frac{1}{2}$V. It carries a water discharge of 7 m^3/sec at a depth of 1 m. Consider the specific force comprising $(\rho QV + \gamma A\bar{y})$. For an increase of 2 cm of depth, what would be the change in the magnitude of the second term $(\gamma A\bar{y})$?

(a) –35 kgf (b) +35 kgf
(c) +70 kgf (d) +140 kgf

[ESE : 1998]

16.15 Storage of water by impounding is required where

(a) plenty of water is available in the stream in all seasons
(b) excess of suspended and dissolved matter are present in the water
(c) there is a large variation in quantity of the river flow from time to time.
(d) the flow is uniform throughout the year but is insufficient.

[ESE : 1998]

16.16 The height of a hydraulic jump in a stilling pool was found to be 10 cm in a model with $L_p/L_m = 36$. The prototype jump height would be
(a) 0.6 m
(b) 3.6 m
(c) 21.6 m
(d) Indeterminable for want of adequate data
[ESE : 1999]

16.17 **Assertion (A):** Surges can be positive or negative.
Reason (R): Negative surges may occur when a gate at the head of a channel is suddenly opened or when a gate at tail end of a channel is suddenly closed.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2000]

16.18 Consider the following statements:
1. In an open channel flow, energy grade line is obtained by adding datum head, pressure head and velocity head.
2. In an open channel, hydraulic grade line is the free surface itself.
3. For a pipe and an open channel of source dimension, the hydraulic gradient line is located at the same height above datum.
4. Energy gradient line of an open channel is always horizontal.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4
[ESE : 2000]

16.19 For a wide rectangular channel using Manning's formula, the differential equation of gradually varied flow (with the usual notations) is given by

(a) $\frac{dy}{dx} = S_0 \frac{\left[1-\left(\frac{y_c}{y}\right)^{10/3}\right]}{\left[1-\left(\frac{y_0}{y}\right)^{3}\right]}$

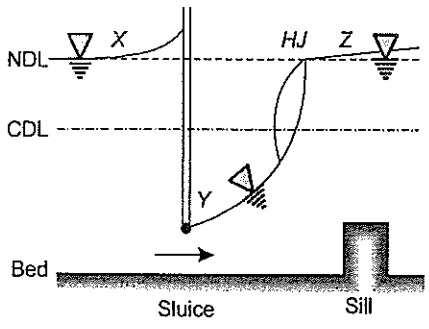
(b) $\frac{dy}{dx} = S_0 \frac{\left[1-\left(\frac{y_0}{y}\right)^{10/3}\right]}{\left[1-\left(\frac{y_c}{y}\right)^{3}\right]}$

(c) $\frac{dy}{dx} = S_0 \frac{\left[1-\left(\frac{y_0}{y}\right)^{3}\right]}{\left[1-\left(\frac{y_c}{y}\right)^{3}\right]}$

(d) $\frac{dy}{dx} = S_0 \frac{\left[1-\left(\frac{y_c}{y}\right)^{3}\right]}{\left[1-\left(\frac{y_0}{y}\right)^{3}\right]}$

[ESE : 2000]

16.20 A sluice gate opening in a canal is shown in the given figure. The shapes of water surface profiles at X, Y and Z will be respectively (NDL = Normal Depth Line, CDL = Critical Depth Line, HJ = Hydraulic Jump)



(a) M_1, M_3 and M_1 (b) M_2, M_3 and M_2
(c) S_1, S_3 and S_2 (d) H_2, S_3 and S_1
[ESE : 2000]

16.21 The stage in a river is 4.8 m, the water surface slope is 1 in 10,000 and the discharge in the stream is 600 m^3/s. If the stage remains the same and the water surface slope is 1 in 14,400, then the discharge in the stream will be
(a) 300 m^3/s (b) 400 m^3/s
(c) 600 m^3/s (d) 500 m^3/s
[ESE : 2000]

16.22 Water surface profiles that are asymptotic at one end and terminated at the other end would include
(a) H_2 and S_2 (b) H_3 and S_2
(c) M_2 and H_2 (d) M_2 and H_3
[ESE : 2001]

16.23 A hydraulic jump is always needed in case of
(a) an A_2 profile followed by an A_3 profile
(b) an A_3 profile followed by an A_2 profile
(c) an H_2 profile followed by an M_2 profile
(d) an M_1 profile followed by an M_3 profile
[ESE : 2001]

16.24 For a hydraulically efficient rectangular section, the ratio of width to normal depth is
(a) 0.5 (b) 1.0
(c) 2.0 (d) $2\sqrt{3}$
[ESE : 2002]

16.25 A rigid boundary rectangular channel having a bed slope of $\frac{1}{800}$ has its width and depth of flow equal to 2 m and 1 m respectively. If the flow is uniform and the value of Chezy's constant is 60, the discharge through the channel is
(a) 1.0 m^3/s (b) 1.5 m^3/s
(c) 2.0 m^3/s (d) 3.0 m^3/s
[ESE : 2002]

16.26 Consider the following statements in regard to the critical flow:
1. Specific energy is maximum for a given discharge.
2. Specific force is maximum for a given discharge
3. Discharge is maximum for a given specific force.
4. Discharge is maximum for a given specific energy.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1 and 2
(c) 2 and 3 (d) 3 and 4
[ESE : 2002]

16.27 Match List-I (Slope) with List-II (Description) and select the correct answer using the codes given below the lists:

List-I
A. Mild
B. Adverse
C. Limit
D. Critical

List-II
1. is when the flow is at Froude number one along the channel
2. is an example of non-sustaining slope
3. always sustains uniform subcritical flow
4. is one which has smallest critical slope for a given channel shape and roughness

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	1	4	2	3
(c)	3	4	2	1
(d)	1	2	4	3

[ESE : 2002]

16.28 If F_1 and F_2 are the Froude numbers of flow before and after the hydraulic jump occurring in a rectangular channel, then

(a) $F_2^2 = \dfrac{F_1^2}{\left(-1+\sqrt{1+8F_1^2}\right)^3}$

(b) $F_2^2 = \dfrac{8F_1^2}{\left(-1+\sqrt{1+8F_1^2}\right)^3}$

(c) $F_2^2 = \dfrac{F_1^2}{\left(-0.5+\sqrt{1+8F_1^2}\right)^3}$

(d) $F_2^2 = \dfrac{8F_1^2}{\left(-0.5+\sqrt{1+F_1^2}\right)^3}$

[ESE : 2002]

16.29 Consider the following statements about a hydraulic ram
1. Hydraulic ram does not need external power.
2. It works on the fundamental principle of water hammer.
3. The efficiency of a hydraulic ram is only of the order of 8 to 10%.
4. It can be termed as a low, intermittent discharge low-head pumping installation.

Which of these statements are correct?
(a) 2 and 3 (b) 1, 2, 3 and 4
(c) 1 and 2 (d) 1 and 3
[ESE : 2002]

16.30 Consider the following statements related to centrifugal pumps:

1. Centrifugal pumps with blades facing backward have fast runners.
2. Multistage pumps have two or more impellers installed in series so that the discharge is increased.
3. Diffusion type centrifugal pumps are called turbine pumps.
4. A centrifugal pump with rising characteristics is used when actual lift is small and the amount of flow is constant.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

[ESE : 2002]

16.31 The critical depth of water flowing through a rectangular channel of width 5 m when discharge is 12.5 m^3/s is

(a) $(2.25)^{1/2}$ m (b) $(16)^{1/2}$ m
(c) $(0.46)^{1/3}$ m (d) $(0.64)^{1/3}$ m

[ESE : 2003]

16.32 Assertion (A): At the critical state of flow, the specific force is a minimum for the given discharge.

Reason (R): For a minimum value of specific force, the first derivative of force with respect to depth should be unity.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

16.33 Assertion (A): The vertical co-ordinate of the apex of the Q-curve is $\frac{2}{3}E$.

Reason (R): The horizontal co-ordinate of the apex of E-curve is 1.5 times $\left(\frac{q^2}{g}\right)^{1/3}$.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

16.34 The steps involved in the procedure of computing length of backwater curves are given below with usual notations:

1. Insert all DH values and average value of slope in the differential equation.
2. Assume a new depth of flow y for the other end of the reach and insert corresponding values of A, P, v, R, $\frac{v^2}{2g}$, H and S.
3. Determine or assume the initial conditions of depth, channel characteristics and discharge.
4. Compute average S value and the change in specific head ΔH.
5. Repeat the process for each reach adding resulting ΔL values to obtain total required distance ΔL until the depth or distance desired is reached.

The correct sequence of these steps is

(a) 1-2-3-4-5 (b) 3-1-5-2-4
(c) 3-2-4-1-5 (d) 1-4-5-2-3

[ESE : 2003]

16.35 Consider the following statements which relate to different types of water surface profiles. Curve types conform to usual classifications y_c and y_0 (critical and normal depths):

1. Type-3 curves lie between y_c and y_0
2. All curves where $y_c < y_0$ are unaffected by upstream disturbances.
3. All curves where $y_c > y_0$ are influenced by downstream disturbances.
4. All curves approaching the 'y' line approach it asymptotically except for C curve where $y_0 = y_c$.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1 and 2

[ESE : 2003]

16.36 Flow duration curve is a plot of

(a) flow against its time of occurrence in chronological order

(b) flow in ascending order against percentage time in chronological order
(c) flow that equalled or exceeded against percentage time
(d) flow against duration of time for which it is sustained

[ESE : 2003]

16.37 The momentum correction factor for a flow through open channel is given by

(a) $\frac{1}{AV^2}\int_A v^2 dA$ (b) $\frac{1}{AV}\int_A v^2 dA$

(c) $\frac{1}{A}\int_A v^2 dA$ (d) $\frac{1}{AV^2}\int_A v dA$

[ESE : 2003]

16.38 Consider the following statements regarding the conditions to be satisfied for the maximum discharge through a trapezoidal channel section with side slope 1: n, bed width b, flow depth d and having a fixed bed slope:

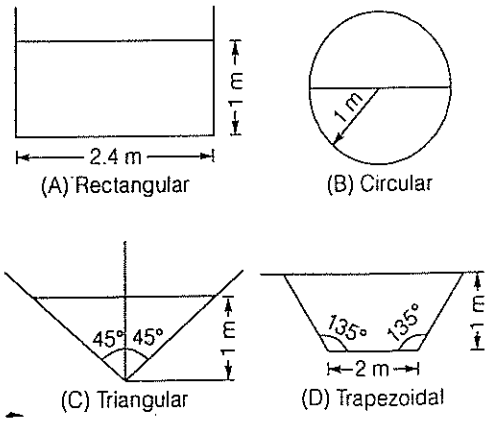
1. Sloping sides should have an angle of 30° with vertical.
2. Hydraulic mean depth equals half the flow depth.
3. Length of sloping sides should be equal to twice the bottom width.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

[ESE : 2004]

16.39 Water can flow with 1 m depth in alternatively four channels of different sections as shown below:



Which one of the following sequences shows their hydraulic radii, arranged in descending order?

(a) D-C-B-A (b) D-A-B-C
(c) A-B-C-D (d) A-B-D-C

[ESE : 2004]

16.40 In a reach of open channel flow, with $q = 2\ m^2/s$, depth of flow at section A is 1.5 m and at section B, 1.6 m. The difference in specific energies at two sections can be correspondingly taken as 0.09 m. The bed slope is 1 in 2000. The mean energy slope between the sections is given as 0.003. What is the length of reach AB?

(a) 54 m with A on the upstream
(b) 54 m with B on the upstream
(c) 36 m with A on the upstream
(d) 36 m with B on the upstream

[ESE : 2004]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

16.41 **Assertion (A):** When water flows through a long stretch of a narrow rectangular channel, the water surface at the walls is higher than that at the central axis.

Reason (R): Resistive effort of atmospheric air is felt more at the walls than away from the walls.

[ESE : 2004]

16.42 **Assertion (A):** At the critical state of flow, the specific force is a minimum for the given discharge.

Reason (R): For a minimum value of specific force, the first derivative of force with respect to depth should be unity.

[ESE : 2005]

16.43 Match List-I (Type of curve) with List-II (Flow condition) and select the correct answer using the codes given below the lists:

List-I	List-II
A. M_1	1. Slope upward in the direction of flow
B. H_3	2. Back water profile
C. S_2	3. Hydraulic jump occurs
D. A_2	4. Hydraulic drop occurs

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	2	4	3	1
(c)	1	4	3	2
(d)	2	3	4	1

[ESE : 2005]

16.44 The Froude number of a hydraulic jump is 5.5. The jump can be classified as a/an
(a) undular jump (b) oscillating jump
(c) weak jump (d) steady jump
[ESE : 2005]

16.45 Consider the following statements in respect of specific energy of flow in an open channel of fixed width:
1. There is only one specific energy curve for a given channel.
2. Alternate depths are the depths of flow at which the specific energy is the same.
3. Critical flow occurs when the specific energy is minimum.

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3
[ESE : 2006]

16.46 If the Froude number of flow in a rectangular channel at a depth of flow of y_0 is F_0, then what is y_c / y_0 equal to?
(a) $F_0^{1/3}$ (b) $F_0^{2/3}$
(c) $F_0^{3/2}$ (d) $F_0^{-1/2}$
[ESE : 2006]

16.47 A hydraulically efficient trapezoidal section of open channel flow carries water at the optimal depth of 0.6 m. Chezy coefficient is 75 and bed slope is 1 in 250. What is the discharge through the channel?
(a) 1.44 m^3/s (b) 1.62 m^3/s
(c) 1.92 m^3/s (d) 2.24 m^3/s
[ESE : 2006]

16.48 In the step methods (both direct and standard), the computations must
(a) proceed downstream in subcritical flow
(b) proceed upstream in subcritical flow
(c) always proceed upstream
(d) always start at a control section
[ESE : 2006]

16.49 Which of the following equations are used for the derivation of the differential equation for water surface profile in open channel flow?
1. Continuity Equation
2. Energy Equation
3. Momentum Equation

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1 and 3 only
(c) 1 and 2 only (d) 2 and 3 only
[ESE : 2006]

16.50 In a wide rectangular channel if the normal depth is increased by 20%, then what is the approximate increase in discharge?
(a) 25% (b) 30%
(c) 35% (d) 40%
[ESE : 2006]

16.51 A right-angled triangular channel symmetrical in section about the vertical carries a discharge of 5 m^3/s with a velocity of 1.25 m/s. What is the approximate value of the Froude number of the flow?
(a) 0.3 (b) 0.4
(c) 0.5 (d) 0.6
[ESE : 2007]

16.52 Flow depths across a sluice gate are 2.0 m and 0.5 m. What is the discharge (per metre width)?
(a) 1.0 m^2/s (b) 1.4 m^2/s
(c) 2.0 m^2/s (d) 2.8 m^2/s
[ESE : 2007]

16.53 A rectangular channel is 6 m wide and discharges 30 m^3s^{-1}. The upstream depth is 2.0 m, acceleration due to gravity is 10 ms^{-2}. Then, what is the specific energy (approximate)?
(a) 2.5 (b) 0.3
(c) 2.3 (d) None of these
[ESE : 2007]

16.54 For a smooth hump in a sub-critical flow to function as a broad crested weir, the height ΔZ of the hump above the bed must satisfy which one of the following?

(a) $\Delta Z \geq (E_1 - y_c)$ (b) $\Delta Z \geq (E_1 - E_c)$

(c) $\Delta Z \leq (E_1 - y_c)$ (d) $\Delta Z \leq (E_1 - E_c)$

(E_1 = Specific head upstream of the hump, E_c = Specific head at the critical depth y_c)

(Neglect friction effects)

[ESE : 2007]

16.55 Match List-I (Flow section type) with List-II (Critical discharge is proportional to) where y is the depth of flow and select the correct answer using the codes given below the lists:

List-I	List-II
A. Shallow parabolic	1. $y(z^{3/2})$
B. Triangular	2. $y^{3/2}$
C. Rectangular	3. $y^{5/2}$
D. Trapezoidal	4. y^2

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	2	1	4	3
(d)	4	3	2	1

[ESE : 2007]

16.56 Which one of the following statements is not correct?

A control section in an open channel is the site

(a) where the flow quantiy can be controlled

(b) at which flow is known to be critical

(c) where the discharge can be measured

(d) where the specific energy is determined

[ESE : 2007]

16.57 What is the normal depth in a wide rectangular channel carrying 0.5 m^2/s discharge at a bed slope of 0.0004 and Manning's $n = 0.01$?

(a) 0.13 m (b) 0.32 m

(c) 0.43 m (d) 0.50 m

[ESE : 2007]

16.58 Flow happens at a critical depth of 0.5 m in a rectangular channel of 4 m width. What is the value of discharge?

(a) 5.4 m^3/s (b) 5.1 m^3/s

(c) 4.9 m^3/s (d) 4.4 m^3/s

[ESE : 2007]

16.59 A hydraulic jump occurs at the top of a spillway. The depth before jump is 0.2 m. The sequent depth is 3.2 m. What is the energy dissipated in m (approximate)?

(a) 27 (b) 10.5

(c) 15 (d) 42

[ESE : 2007]

16.60 A rectangular channel 3 m wide is laid on a slope of 0.0002. When the depth of flow in the channel is 1.5 m what is the average boundary shear stress (nearly)?

(a) 0.3 N/m^2 (b) 0.15 N/m^2

(c) 3.0 N/m^2 (d) 1.5 N/m^2

[ESE : 2007]

16.61 In connection with a gradually varied flow with notations y_0 = normal depth, y_c = critical depth and y = depth in the gradually varied flow, match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. $y_c > y_0 > y$	1. M_1
B. $y_0 > y > y_c$	2. S_3
C. $y > y_c > y_0$	3. M_2
D. $y > y_0 > y_c$	4. S_1

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2007]

16.62 In a wide rectangular channel, an increase in the normal depth by 20% corresponds to how much (approximate) increase in discharge?

(a) 12% (b) 20%

(c) 36% (d) 48%

[ESE : 2007]

16.63 The sequent depth ratio of a hydraulic jump in a rectangular channel is 16.48. What is the Froude number (approximate) at the beginning of the jump?

(a) 9.0 (b) 12.0
(c) 5.0 (d) 8.0

[ESE : 2007]

16.64 When discussing most efficient section of flow into open channels, what is the perimeter P as a proportion of depth of flow h (i.e., P/h) for (i) a triangular section, and (ii) a trapezoidal section, respectively?

(a) 2.25, 2.83 (b) 2.25, 3.15
(c) 2.83, 3.15 (d) 2.83, 3.46

[ESE : 2008]

16.65 Consider the following statements:

1. Hydraulically most efficient channel section for an open channel flow will carry maximum discharge for a given area of cross section.
2. For a given cross sectional area hydraulic radius is maximum when the wetted perimeter is minimum.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2008]

16.66 The type of jump that forms when initial Froude number lies between 2.5 and 4.5 is

(a) weak jump (b) steady jump
(c) undular jump (d) oscillating jump

[ESE : 2008]

16.67 Consider the following factors:

1. The change in the shape and size of the channel cross-section
2. The change in the slope of the channel
3. The presence of obstruction
4. The change in the frictional forces at the boundaries

Which of the above factors would cause a gradually varied flow?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2 and 4 only (d) 3 and 4 only

[ESE : 2009]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

16.68 **Assertion (A):** For a hydraulically efficient channel, the hydraulic radius is equal to half the depth of flow.

Reason (R): A hydraulically efficient channel has the minimum perimeter for a given area of flow.

[ESE : 2009]

16.69 **Assertion (A):** Energy dissipation in a hydraulic jump is mainly caused by the large eddies in turbulence.

Reason (R): Large eddies transport the fluid over large distances, thus causing the mixing effect of turbulence.

[ESE : 2010]

16.70 **Assertion (A):** An economical channel section gives maximum discharge for a given cross-sectional area.

Reason (R): An economical channel section has smooth surface for reduced friction.

[ESE : 2010]

16.71 A partially open sluice gate is suddenly raised to its full opening. The resulting surge waves at the gate are

(a) a positive wave travels towards the gate from the upstream side while a negative wave travels downstream from the gate
(b) a positive wave travels from the gate onto the upstream side while a positive wave travels downstream from the gate
(c) a negative wave travels from the gate onto the upstream side while a positive wave travels downstream from the gate
(d) a negative wave travels towards the gate from the upstream side whereas a positive wave travels downstream from the gate

[ESE : 2010]

16.72 Consider the following statements regarding specific energy of the flow in an open channel:

1. There is only one specific energy curve for a given channel.

2. Alternate depths are the depths of flow at which the specific energy is the same.
3. Critical flow occurs when the specific energy is minimum for the flow rate.

Which of these statements is/are correct?

(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2010]

16.73 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

A. Sudden closure of a sluice gate
B. Hydraulic jump in a stilling basin
C. Spreading of irrigation water in a field
D. Flow in a main irrigation canal

List-II

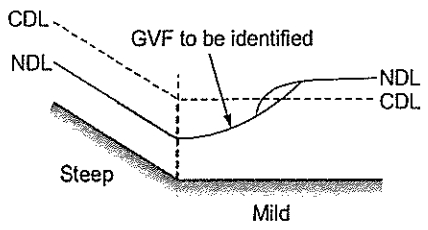
1. Uniform flow
2. Rapidly varied flow
3. Unsteady flow
4. Spatially varied flow

Code:

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	1	4	2	3
(d)	3	4	2	1

[ESE : 2011]

16.74 The water surface profile in the flow situation as shown in the figure below is



(a) S3 (b) M3
(c) S2 (d) M1

[ESE : 2011]

16.75 Best side slope for most economical trapezoidal section in open channel flow, wherein side slopes are defined by: X horizontal to 1 vertical, is when X equals

(a) 0.404 (b) 0.500
(c) 0.577 (d) 0.673

[ESE : 2011]

16.76 Consider the following statements in respect of critical flow in a wide rectangular channel:

1. The specific energy is minimum for a given discharge.
2. The discharge is maximum for a given specific energy.
3. The specific force is minimum for a given discharge.
4. The Froude number is equal to unity.

Which of these statements are correct?

(a) 1, 2 and 3 only (b) 1, 2, 3 and 4
(c) 1, 2 and 4 only (d) 2, 3 and 4 only

[ESE : 2012]

16.77 For a hydraulically efficient rectangular channel of bed width 4.0 m, the depth of flow is

(a) 4 m (b) 0.5 m
(c) 1 m (d) 2 m

[ESE : 2012]

16.78 The velocity with which an elementary surge wave can travel upstream in a channel with depth y = 1.6 m and velocity V = 2.4 m/s is (Take $g = 10\ m/s^2$)

(a) 16 m/s (b) 13.6 m/s
(c) 2.4 m/s (d) 1.6 m/s

[ESE : 2012]

16.79 Consider the following statements related to water surface profile in gradually varied flow in an open channel:

1. M_1 and S_1 curves approach Y_0 line asymptotically; and tend to be horizontal as y tends to ∞.
2. M_2 and S_2 curves meet Y_0 line horizontally, and Y_0 line asymptotically.
3. M_3 and S_3 curves meet Y_0 line normally, and also meet the channel bed normally
4. C_1 and C_2 curves will be slightly curved if Chezy's equation is used; otherwise, they may tend to be straight lines.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1 and 4 only
(c) 2 and 3 only (d) 3 and 4 only

[ESE : 2012]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these

two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

16.80 Statement-I: The best hydraulic section always has the minimum excavation.

Statement-II: The best hydraulic section gives the minimum area for a given discharge.

[ESE : 2012]

16.81 Statement-I: A given channel may be classifiable as mild for one discharge, critical for another discharge, and steep for yet another discharge.

Statement-II: Normal depth and critical depth are independent functions of the discharge along with, or without, other appropriate parameters.

[ESE : 2012]

16.82 Statement (I): An economical channel section gives maximum discharge for a given cross-sectional area.

Statement (II): An economical channel section has smooth surface with reduced friction.

[ESE : 2013]

16.83 Statement (I): In the case of an open channel flow, for a hydraulically efficient section, the hydraulic radius is equal to 50% of depth of flow in the channel.

Statement (II): Wetted perimeter is minimum for a hydraulically efficient section of an open channel.

[ESE : 2013]

16.84 A rectangular channel carries a uniform flow with a Froude number of 2.83. The ratio of critical depth to normal depth of this flow is:

(a) 1.68 (b) 2.83

(c) 2.00 (d) 4.75

[ESE : 2013]

16.85 Which of the following equations are used for the derivation of the differential equation for water surface profile in an open channel?

1. Continuity equation
2. Energy equation
3. Momentum equation

(a) 1, 2 and 3 (b) 1 and 3 only

(c) 2 and 3 only (d) 1 and 2 only

[ESE : 2013]

16.86 When flow is critical through open channels, which of the following statements are correct?

1. The specific energy is minimum for a given discharge.
2. The discharge is maximum for a given specific energy.
3. The specific force is minimum for a given discharge.
4. Froude number of the flow is equal to unity.

(a) 1, 2 and 3 only (b) 1, 2 and 4 only

(c) 1, 2, 3 and 4 (d) 2, 3 and 4 only

[ESE : 2013]

16.87 For a hydraulically efficient rectangular channel of bed width 5 m, the hydraulic radius is equal to

(a) 2.5 m (b) 1.25 m

(c) 5 m (d) 2 m

[ESE : 2014]

16.88 A triangular open channel has a vortex angle of 90° and carries flow at a critical depth of 0.3 m. The discharge in the channel is

(a) 0.41 m^3/s (b) 0.11 m^3/s

(c) 0.21 m^3/s (d) 0.31 m^3/s

[ESE : 2014]

16.89 At a hydraulic jump, the depths at the two sides are 0.3 m and 1.4. The head loss in the jump is nearly

(a) 1.0 m (b) 0.95 m

(c) 0.79 m (d) 0.45 m

[ESE : 2014]

16.90 It is expected that due to extreme cold weather, the entire top surface of canal carrying water will be covered with ice sheet for some days. If the discharge in the canal were to remain unaltered, this condition would lead to

(a) No change in the depth of flow

(b) Decrease in the depth of flow

(c) Gradually decreasing flow
(d) Increase in the depth of flow

[ESE : 2014]

16.91 Consider the following statements regarding a gradually varied flow in a prismatic open channel.
1. Total energy line remains parallel to the water surface.
2. The rate of energy loss at the section is inversely proportional to d^x where d is flow depth with index x.
3. In analyzing the flow, the energy equation of flow is not applicable.
4. Pressure distribution at every section can be assumed to be hydrostatic.

Which of the above statements are correct?
(a) 1 and 4 (b) 2 and 4
(c) 1 and 2 (d) 2 and 3

[ESE : 2014]

16.92 At a hydraulic jump, the depths at its two sides are 0.3 m and 1.2 m. The head loss in the jump is
(a) 1.0 m (b) 0.8 m
(c) 0.5 m (d) 0.45 m

[ESE : 2015]

16.93 Field observations are carried out to assess the discharge of a river. Measurements are taken in a 2000 m straight reach. Slope is approximately 1 in 4000. Bed slope is determinably to a possible accuracy of 0.4 cm; wetted perimeter is determinable within 4% of possible error; and sectional area within 6% of possible error. Using Chezy's equation, the assessed discharge will be accurate to within
(a) 9.6% (b) 10.8%
(c) 11.4% (d) 12.7%

[ESE : 2015]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

16.94 Assertion (A): Open channel flow in a channel is said to be critical when the specific force is maximum for a given discharge.
Reason (R): Direct integrating for steady non-uniform flow by Bresse's method was developed for very wide rectangular channels.

[ESE : 2015]

16.95 Assertion (A): A moving hydraulic jump is called a surge.
Reason (R): The travel of a wave is faster in the upper portion than in the lower portion in case of positive surges.

[ESE : 2015]

16.96 In a trapezoidal channel with bed width of 2 m, and side slopes of 2v on 1h, critical flow occurs at a depth of 1 m. What will be the quantity of flow and the flow velocity? Take g as 10 m/s^2.
(a) 7.22 m^3/s and 3.10 m/s
(b) 6.82 m^3/s and 2.89 m/s
(c) 7.22 m^3/s and 2.89 m/s
(d) 6.82 m^3/s and 3.10 m/s

[ESE : 2016]

16.97 A 7.5 m wide rectangular channel conveys 12 m^3/s of water with a velocity of 1.5 m/s. The specific energy head of the flow is
(a) 1.18 m (b) 1.78 m
(c) 2.18 m (d) 2.78 m

[ESE : 2016]

16.98 The sequent depth ratio in a hydraulic jump formed in a rectangular horizontal channel is 10. The Froude number of the supercritical flow is
(a) 12.2 (b) 10.4
(c) 7.42 (d) 4.21

[ESE : 2016]

16.99 A partially open sluice gate discharges water at 6 m/s with a depth of 40 cm in a rectangular horizontal channel of width 5 m. What would be the post-jump depth of flow on the downstream of the gate by taking g as 10 m/s^2?
(a) 1.51 m (b) 1.70 m
(c) 1.85 m (d) 1.95 m

[ESE : 2016]

16.100 For a hydraulically efficient rectangular channel of bed width 5 m, the hydraulic radius is

(a) 0.5 m (b) 1.25 m
(c) 2.75 m (d) 4.25 m

[ESE : 2016]

16.101 At a hydraulic jump, the flow depths are 0.4 m and 5 m at the upstream and downstream, respectively. The channel is wide rectangular. The discharge per unit width is nearly

(a) 5.8 m^2/s (b) 6.4 m^2/s
(c) 7.3 m^2/s (d) 8.3 m^2/s

[ESE : 2016]

Directions: Each of the next items consists of two statements, one labelled as the **'Statement (I)'** and the other as **'Statement (II)'**. Examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

16.102 **Statement (I):** In open channel flow, maximum velocity does not occur on the surface.

Statement (II): Three is wind drag on the free surface of an open channel.

[ESE : 2016]

16.103 **Statement (I):** Flow over sharp-crested weirs, standing wave flumes and abrupt free overfalls at ends of long straight channels are examples of rapidly varied flow.

Statement (II): The above-listed flows are all essentially local phenomena and can be utilized for flow measurement in open channels.

[ESE : 2016]

16.104 Hydraulic jump forms in a horizontal rectangular channel carrying a unit discharge of 1.019 $m^3/sec/m$ at a depth of 10.19 mm. This jump is classified as

(a) Weak jump (b) Oscillating jump
(c) Steady jump (d) Strong jump

[ESE : 2017]

16.105 In wide rectangle channel, the normal depth is increased by 20%. This would mean an increase in the discharge of the channel nearly by

(a) 20% (b) 26%
(c) 36% (d) 56%

[ESE : 2017]

16.106 At a sluice gate across a rectangle channel, the upstream flow conditions are depth of 2.0 m, velocity of flow of 1.25 m/sec. The flow conditions at the vena contracta just downstream of the gate can be taken as: depth of 0.44 m; velocity of flow of 5.68 m/sec. What is the total thrust on the gate on its upstream face (to the nearest 10 units)?

(a) 770 kgf (b) 800 kgf
(c) 825 kgf (d) 870 kgf

[ESE : 2017]

Answers Open Channel Flow

16.1 (a)	16.2 (c)	16.3 (b)	16.4 (b)	16.5 (b)	16.6 (d)	16.7 (a)	16.8 (a)		
16.9 (d)	16.10 (c)	16.11 (a)	16.12 (c)	16.13 (b)	16.14 (a)	16.15 (c)	16.16 (b)		
16.17 (b)	16.18 (a)	16.19 (b)	16.20 (a)	16.21 (d)	16.22 (c)	16.23 (d)	16.24 (c)		
16.25 (d)	16.26 (d)	16.27 (a)	16.28 (b)	16.29 (c)	16.30 (c)	16.31 (d)	16.32 (c)		
16.33 (a)	16.34 (c)	16.35 (c)	16.36 (c)	16.37 (a)	16.38 (b)	16.39 (b)	16.40 (d)		
16.41 (c)	16.42 (c)	16.43 (d)	16.44 (d)	16.45 (c)	16.46 (b)	16.47 (b)	16.48 (b)		
16.49 (c)	16.50 (b)	16.51 (b)	16.52 (d)	16.53 (c)	16.54 (d)	16.55 (d)	16.56 (b)		
16.57 (c)	16.58 (d)	16.59 (b)	16.60 (d)	16.61 (b)	16.62 (c)	16.63 (b)	16.64 (d)		
16.65 (c)	16.66 (d)	16.67 (a)	16.68 (d)	16.69 (c)	16.70 (c)	16.71 (c)	16.72 (c)		
16.73 (b)	16.74 (b)	16.75 (c)	16.76 (b)	16.77 (d)	16.78 (d)	16.79 (*)	16.80 (c)		
16.81 (c)	16.82 (c)	16.83 (d)	16.84 (c)	16.85 (d)	16.86 (c)	16.87 (b)	16.88 (b)		
16.89 (c)	16.90 (d)	16.91 (b)	16.92 (c)	16.93 (c)	16.94 (d)	16.95 (b)	16.96 (c)		
16.97 (a)	16.98 (c)	16.99 (a)	16.100(b)	16.101 (c)	16.102 (b)	16.103 (b)	16.104(d)		
16.105(c)	16.106(a)								

Explanations Open Channel Flow

16.2 (c)

By expanding the width, discharge per unit width (q) in a rectangular channel will decrease. For subcritical flow depth of flow in expansion BC will rise continuously.

16.3 (b)

The flow on upstream of the shock is supersonic having a relatively lower pressure while on the downstream of the shock it is subsonic having a high pressure. The process of formation of shock wave in a compressible fluid is analogous to the formation of hydraulic jump in open channel. In case of hydraulic jump the flow changes from supercritical to subcritical flow and is accompanied by an increase in depth and decrease in the velocity of flow.

16.4 (b)

Manning's equation $V = \frac{1}{n} R^{2/3} S_0^{1/2}$ has the dimensions of roughness coefficient n as $[L^{-1/3}T]$. Owing to its simplicity and acceptable degree of accuracy in a variety of practical applications, the formula is the most widely used uniform-flow formula in the world. It represents rough turbulent flow.

16.5 (b)

$$q = \frac{\sqrt{2g}\, y_1 y_2}{\sqrt{y_1 + y_2}} = \frac{4.43 \times 1.2 \times 0.3}{\sqrt{(1.2 + 0.3)}} = 1.30$$

This is nearly equal to 1.5 $m^3/s/m$

16.6 (d)

The equation for GVF is

$$\frac{dy}{dx} = \frac{S_0 - S_f}{\left(1 - F^2\right)}$$

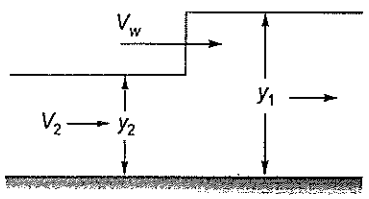
Given $S_0 = 1.2 \times 10^{-3}$

$S_f = 1.05 \times 10^{-3}$

$$\frac{dy}{dx} = \left[\frac{1.2 - 1.05}{1 - (0.8)^2}\right] \times 10^{-3}$$

16.7(a)

A surge is a moving wavefront which brings about an abrupt change in the depth of the channel.



As there is decrease in the depth and increase in depth and increase in velocity of flow after passage of surge so it means the surge is negative and travels downstream.

$$V_w = \frac{V_1y_1 - V_2y_2}{y_1 - y_2}$$

$$= \frac{3.72 \times 1.8 - 7.56 \times 0.6}{1.8 - 0.6}$$

$$= 1.8 \text{ m/s}$$

16.8(a)

Exactly similar channel means that area and wetted perimeter are same i.e.

$$\frac{Q_2}{Q_1} = \sqrt{\frac{S_2}{S_1}}$$

$$\Rightarrow Q_2 = \sqrt{\frac{0.0001}{0.0009}} \times 30 = 10 \text{ m}^3/\text{s}$$

16.9(d)

Head loss or energy loss,

$$E_L = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(1.4 - 0.4)^3}{4 \times 1.4 \times 0.4} = 0.45 \text{ m}$$

16.10 (c)

Critical depth flume is known as a standing wave flume or throated flume. In the throat section there is a hump to assist the formation of hydraulic jump. Constriction flume operating in the subcritical range are called venturi flumes.

16.11 (a)

Since the steep slope is long so flow in steep channel will be nearly at or at normal depth. When it is followed by short reach of adverse slope it will fall in deep and wide reservoir before reaching critical depth so hydraulic jump cannot be expected.

16.12 (c)

For critical flow in rectangular channel $V = \sqrt{gy}$

16.13 (b)

Area, perimeter and hydraulic radius will not change.

$$\therefore \frac{Q_2}{Q_1} = \sqrt{\frac{S_2}{S_1}}$$

$$\Rightarrow Q_2 = 15 \times \sqrt{\frac{1}{1000} \times \frac{1440}{1}} = 18 \text{m}^3/\text{s}$$

16.14 (a)

When the depth increases by 2 cm, the area of flow and centre of gravity also increases. Hence the change in magnitude of the second term will be negative.

16.15 (c)

When there is large variation in quantity of river flow from time to time, then excess water during monsoon is stored by impounding and utilized when flow is lean.

16.16(b)

$$\frac{L_p}{L_m} = 36$$

$\therefore$ Height of jump in prototype
$= 36 \times 10 = 360 \text{ cm} = 3.6 \text{ m}$

16.17 (b)

(i) When the gate is partly closed suddenly, positive surge moves upstream and negative surge moves downstream.

(ii) When the gate is opened suddenly, positive surge moves downstream and negative surge moves upstream.

16.18 (a)

In open channel flow during flow there are losses such as frictional loss, so total energy will decrease inn direction of flow. Thus energy gradient line will not be horizontal.

16.19 (b)

$$\frac{dy}{dx} = S_0 \frac{1 - (y_0/y)^N}{1 - (y_c/y)^M}$$

For Chezy's formula $N = 3$; $M = 3$

For Manning's formula $N = 10/3$; $M = 3$

N is related to conveyance $\left(\frac{1}{n}AR^{2/3}\right)$.

16.20 (a)

The surface profile is: M_1, M_3, HJ and M_1 Since NDL is above CDL so the bed slope is mild.

16.21 (d)

$$\frac{Q_2}{Q_1} = \sqrt{\frac{S_2}{S_1}}$$

$$\therefore \quad Q_2 = 6000 \times \sqrt{\frac{10{,}000}{14{,}400}} = 500 \text{ m}^3/\text{s}$$

16.22 (c)

The curves which are asymptotic at one end and terminated at the other end are M_2 and H_2

From $$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - \frac{Q^2T}{gA^3}} = S_0 \frac{1 - \left(\frac{y_n}{y}\right)^{10/3}}{1 - \left(\frac{y_c}{y}\right)^3}$$

Using Manning's equation for wide rectangular channel.

(i) As $y \to y_0$; $\frac{dy}{dx} \to 0$; i.e. the water surface approaches normal depth line asymptotically

(ii) As $y \to y_c$; $\frac{dy}{dx} \to \infty$; i.e. the water surface meets the critical depth line vertically in region 2 and 3.

(iii) As $y \to \infty$, $\frac{dy}{dx} \to 0$; i.e. the water surface meets a very large depth as horizontal asymptote in region 1.

(iv) As $y \to 0$, $\frac{dy}{dx} \to \infty$; it means that the surface profile meets the channel bed vertically in region 3.

Thus

(i) M_1, M_2, S_2 and S_3 meet y_0 line asymptotically

(ii) M_1 and S_1 curve tend to horizontal as $y \to \infty$

(iii) M_2, M_3 and S_2 meet y_c line normally

(iv) M_3 and S_3 meet channel bed normally.

The slope of:

* C_1 and C_3 curves comes out to be equal to critical slope of the bed, if Chezy's equation is used. Otherwise they are slightly curved.

16.23 (d)

A hydraulic jump is needed when supercritical flow changes ino subcritical flow or when critical depth line is to be crossed.

16.24 (c)

For hydraulically efficient rectangular section.

$$\frac{B_{em}}{y} = 2.0$$

Sl. No.	Channel shape	A	P_{em}	B_{em}	R_{em}	T_{em}
1.	Rectangle (half square)	$2y_e^2$	$4y_{em}$	$2y_{em}$	$\frac{y_{em}}{2}$	$2y_{em}$
2.	Trapezoidal (half regular hexagon)	$\sqrt{3}y_e^2$	$2\sqrt{3}y_{em}$	$\frac{2}{\sqrt{3}}y_e$	$\frac{y_{em}}{2}$	$\frac{4}{\sqrt{3}}y_e$
3.	Circular (semicircle)	$\frac{\rho}{2}y_e^2$	πy_e	–	$\frac{y_{em}}{2}$	$2y_{em}$
4.	Triangle (vertex angle = 90°)	y_e^2	$2\sqrt{2}y_{em}$	–	$\frac{y_{em}}{2\sqrt{2}}$	$2y_{em}$

16.25 (d)

Hydraulic depth,

$$R = \frac{A}{P} = \frac{2 \times 1}{2 \times 2} = 0.5\text{m}$$

$$Q = C\sqrt{RS} = 60 \times \sqrt{0.5 \times \frac{1}{800}} \times 2 \times 1$$

$$= 3.0 \text{ m}^3/\text{s}$$

16.26 (d)

At critical flow, specific energy and specific force is minimum for a given discharge. In other words for a given specific energy or specific force, discharge is maximum at critical flow.

16.27 (a)

In mild slope critical depth line (CDL) is below the normal depth line (NDL). The flow is subcritical and uniform.

For adverse slope, uniform flow can not be sustained. The CDL is defined by NDL does not exist.

The critical slope has unit Froude number and NDL coincides with CDL.

For a channel of given shape and roughness, critical slope will have a least value under conditions corresponding to a limit value.

The least value of S_c is called the limit slope.

(i) For a trapezoidal section of given geometry and roughness, a given depth of critical flow can be maintained by one and only one critical slope. However, for a given critical slope there can be more than one critical depth.

(ii) For channels of the second kind (m is negative) and for rectangular channels ($m = 0$), only one limit slope exists, Slopes flatter than this cannot be critical and the slopes steeper than this can be critical at two different depths. For a rectangular channel, the limit value of S_c is 8/3 at $\eta_c = 1/6$.

16.28 (b)

$$\frac{y_2}{y_1} = \frac{\left(-1+\sqrt{1+8F_1^2}\right)}{2} \quad ...(i)$$

and $$\frac{y_1}{y_2} = \frac{\left(-1+\sqrt{1+8F_2^2}\right)}{2} \quad ...(ii)$$

Equating the equation (i) with inverse of equation (ii) we get

$$F_2^2 = \frac{8F_1^2}{\left(-1+\sqrt{1+8F_1^2}\right)^3}$$

$$F_1^2 = \frac{8F_2^2}{\left(-1+\sqrt{1+8F_2^2}\right)^3}$$

16.29 (c)

The efficiency of hydraulic ram is about 75%. It is used when large quantity of water available at small height and small quantity of water is to be raised to greater heights.

16.30 (c)

Multistage pumps with impellers in series, increase the head while discharge is constant.

16.31 (d)

Discharge per unit width $q = 12.5/5$

$= 2.5 \text{ m}^3/\text{s/m}$

Critical depth, $y_c = (q^2/g)^{1/3} = (0.64)^{1/3}$

16.32 (c)

At critical state of flow, specific force is minimum so first derivative of force with respect to depth should be zero.

16.33 (a)

Q-curve is the graph between discharge on horizontal axis and depth of flow on vertical axis at constant specific energy Q. The apex corresponds to the critical depth.

$$h_c = \frac{2}{3}E = \left(\frac{q^2}{g}\right)^{1/3}$$

So vertical co-ordinate of Q curve is $\frac{2}{3}E$.

E-curve is the graph between specific energy on horizontal axis and depth of flow on vertical axis. The apex again corresponds to critical depth of flow.

$$E_c = \frac{3}{2}h_c$$

16.35 (c)

For $y_c < y_0$ the curves are M_1, M_2 and M_3. The control section for mild profiles is downstream so upstream disturbance does not affect them.

Similarly, for $y_c > y_0$ the curves are S_1, S_2, and S_3. The control section for steep profiles is upstream and downstream disturbance does not affect them.

Type-2 curve lie between y_c and y_0.

Type-3 curves are above y_c or y_0 whichever is large.

Type-1 curves are below y_c or y_0 whichever is smaller.

16.36 (c)

The flow duration curve or discharge frequency curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. A flow duration curve characterizes the ability of the basin to provide flows of various magnitudes. It is extremely useful for the design of structures on a stream.

16.37 (a)

Channel boundary resistances alter the velocity distribution along the cross-section, with varying influence that reduces from the wall of the channel to the water free surface. This non-uniform velocity distribution needs to be taken into consideration for appropriate design of the related structures. The energy and momentum coefficients are used to correct these effects.

$$\text{Momentum correction factor} = \frac{1}{AV^2}\int_0^A v^2 dA$$

$$\text{Kinetic Energy correction factor} = \frac{1}{AV^3}\int_0^A v^3 dA$$

16.38 (b)

Hydraulically efficient trapezoidal channel is half hexagon. Length of sloping sides will be equal to the bottom width. The sides will make 60° angle from horizontal and 30° with vertical.

16.39 (b)

Figure	Area (A)	Perimeter (P)	Hydraulic Radius
A.	2.4	4.4	0.55
B.	$\pi/2$	π	0.5
C.	1	$2\sqrt{2}$	0.35
D.	3	$2+2\sqrt{2}$	0.62

So the arrangement in descending order of hydraulic radii is $D - A - B - C$

16.40 (d)

Critical depth,

$$y_c = \left(\frac{q^2}{g}\right)^{1/3} = \left(\frac{2^2}{9.81}\right)^{1/3} = 0.74\text{m}$$

As $y_A = 1.5$ m and $y_B = 1.6$ m are more than y_c so the flow is subcritical.

$\therefore\ E_A < E_B$

Length of reach AB assuming B on the upstream will be

$$L_{AB} = \frac{E_B - E_A}{S_0 - \bar{S}_f} = \frac{0.09}{\frac{1}{2000} - 0.003} = -36\text{m}$$

Since L_{AB} is negative so B is on the upstream.

16.41 (c)

The velocity is higher in the middle so the water surface level will be lower in the middle and higher at middle.

16.42 (c)

For minimum value of specific force first derivative of force with respect to depth should be zero.

16.43 (d)

When a S_2 profile ends with a sudden drop of bed, the surface drops suddenly and it is called hydraulic drop. This can happen with any profile except A_2.

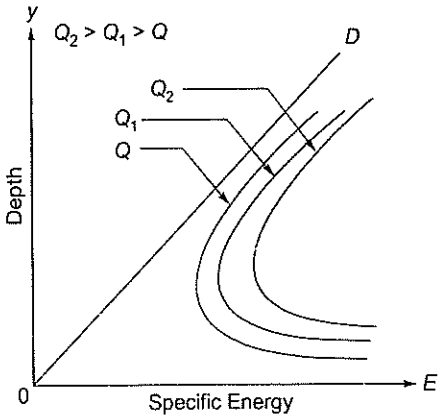
There can be no hydraulic jump in S_2 profile.

16.44 (d)

The hydraulic jumps in horizontal rectangular channels are classified into five categories based on Froude number F_1 of the super-critical flow as:

Range	Type
$1.0 < F_1 \le 1.7$	Undular jump
$1.7 < F_1 \le 2.5$	Weak jump
$2.5 < F_1 \le 4.5$	Oscillating jump
$4.5 < F_1 \le 9.0$	Steady jump
$F_1 > 9.0$	Strong or choppy jump

16.45 (c)



16.46 (b)

$$F_0 = \frac{V}{\sqrt{gy_0}} = \frac{q}{\sqrt{gy_0^3}} \text{ and } y_c^3 = \frac{q^2}{g}$$

$$\therefore\ \frac{y_c}{y_0} = F_0^{2/3}$$

16.47 (b)

$Q = CA\sqrt{RS}$

For hydraulically efficient trapezoidal section,

$A = \sqrt{3}y_e^2 = \sqrt{3} \times (0.6)^2 = 0.624\text{m}$

$R = \frac{y_e}{2} = \frac{0.6}{2} = 0.3\text{ m}$

$\therefore\ Q = 75 \times 0.624 \times \sqrt{0.3 \times \frac{1}{250}} = 1.62\ \text{m}^3/\text{s}$

16.48 (b)

The calculations must proceed upstream in subcritical flows and downstream in supercritical flows to keep the errors minimum.

16.49 (c)

Momentum equation is not used for derivation of differential equation for water surface profile in open channels.

16.50 (b)

For wide rectangular channel $R \simeq y$

Using Chezy's equation,

$$Q = C \times By \times \sqrt{yS}$$

$$\frac{dQ}{Q} = \frac{3}{2}\frac{dy}{y}$$

$$\frac{dQ}{Q} = 30\%$$

16.51 (b)

We know that

$$Q = AV$$

$$\Rightarrow \quad 5 = A \times 1.25$$

$$\Rightarrow \quad A = 4\ \text{m}^2$$

For a symmetrical right angled triangular channel,

$$m = 1$$

$$\therefore \quad A = my^2 = 1 \times y^2 = y^2$$

$$T = 2my = 2 \times 1 \times y = 2y$$

But $A = 4\ \text{m}^2$

$$\Rightarrow \quad y^2 = 4$$

$$\Rightarrow \quad y = 2\ \text{m}$$

Hydraulic depth, $D = \frac{A}{T} = \frac{4}{2 \times 2} = 1$

Froude Number $= \frac{V}{\sqrt{gD}} = \frac{1.25}{\sqrt{9.81 \times 1}} = 0.4$

16.52 (d)

If the loss of energy across the sluice gate is assumed to be negligible, then by energy equation, we have

$$y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g}$$

But discharge per unit width,

$$q = V_1 y_1 = V_2 y_2$$

$$\therefore \quad y_1 + \frac{q^2}{2gy_1^2} = y_2 + \frac{q^2}{2gy_2^2}$$

$$\Rightarrow \quad \frac{q^2}{g} = \frac{2y_1^2 y_2^2}{y_1 + y_2}$$

$$\Rightarrow \quad \frac{q^2}{9.81} = \frac{2 \times (2)^2 \times (0.5)^2}{2 + 0.5}$$

$$\Rightarrow \quad q^2 = 0.8 \times 9.81$$

$$\Rightarrow \quad q = 2.8\ \text{m}^2/\text{s}$$

16.53 (c)

We know that

$$Q = AV$$

$$\Rightarrow \quad 30 = 6 \times 2 \times V$$

$$\Rightarrow \quad V = 2.5\ \text{m/s}$$

The specific energy may be given as

$$E = y + \frac{V_1^2}{2g}$$

$$= 2 + \frac{(2.5)^2}{2 \times 9.81} = 2.3\ \text{m}$$

16.54 (d)

If the flow is subcritical, then after the introduction of hump the specific energy will decrease by ΔZ (height of hump).

$$E_c \le E_1 - \Delta Z$$

$$\Rightarrow \quad \Delta Z \le E_1 - E_c$$

16.56 (b)

A control section is defined as a section in which a fixed relationship exists between the discharge and depth of flow. Weirs, spillways, sluice gates are some typical examples of structures which give rise to control sections. Any GVF profile will have at least one control section. In the synthesis of GVF profiles occurring in serially connected channel elements, the control sections provide a key to the identification of proper profile shapes.

16.57 (c)

For a wide rectangular channel, the hydraulic radius (R) is approximately equal to the depth of flow.

By Manning's equation, we have

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2}$$

Here $A = By$

$R = y$

$$\therefore \quad Q = \frac{1}{n} \times By \times y^{2/3} S_0^{1/2}$$

$$\Rightarrow \quad \frac{Q}{B} = \frac{1}{n} \times y^{5/3} S_0^{1/2}$$

$$\Rightarrow \quad q = \frac{1}{n} \times y^{5/3} S_0^{1/2}$$

$$\Rightarrow \quad \frac{0.5 \times 0.01}{(0.0004)^{1/2}} = y^{5/3}$$

$$\Rightarrow \quad y = 0.43 \text{ m}$$

16.58 (d)

For a rectangular channel, critical depth is given by

$$y_c^3 = \frac{q^2}{g}$$

$$\Rightarrow \quad q^2 = y_c^3 g$$

$$\Rightarrow \quad q^2 = (0.5)^3 \times 9.81$$

$$\Rightarrow \quad q = 1.107 \text{ m}^2/\text{s}$$

But discharge,

$$Q = q \times B = 1.107 \times 4$$
$$= 4.4 \text{ m}^3/\text{s}$$

16.59 (b)

The energy dissipation is given by

$$E_L = \frac{(y_2 - y_1)^3}{4 y_1 y_2} = \frac{(3.2 - 0.2)^3}{4 \times 0.2 \times 3.2}$$

$$= 10.55 \text{ m}$$

16.60 (d)

The average shear stress (τ_0) at the boundary of a channel in uniform flow is given by

$$\tau_0 = \gamma R S_0$$

But $$R = \frac{A}{P} = \frac{By}{B + 2y}$$

$$= \frac{3 \times 1.5}{3 + (2 \times 1.5)} = 0.75 \text{ m}$$

$$\therefore \quad \tau_0 = 9810 \times 0.75 \times 0.0002$$
$$= 1.47 = 1.5 \text{ N/m}^2$$

16.61 (b)

The classification of flow profiles for gradually varied flow is given below:

Channel	Region	Condition	Type
	1	$y > y_0 > y_c$	M_1
Mild Slope (M)	2	$y_0 > y > y_c$	M_2
	3	$y_0 > y_c > y$	M_3
	1	$y > y_c > y_0$	S_1
Steep slope (S)	2	$y_c > y > y_0$	S_2
	3	$y_c > y_0 > y$	S_3
Critical slope (C)	1	$y > y_0 = y_c$	C_1
	3	$y < y_0 = y_c$	C_3
Horizontal bed (H)	2	$y > y_c$	H_2
	3	$y < y_c$	H_3
Adverse slope (A)	2	$y > y_c$	A_2
	3	$y < y_c$	A_3

16.62 (c)

The Manning's equation for a wide rectangular channel is given as

$$Q = \frac{1}{n} \times B \times y^{5/3} \times S_0^{1/2}$$

Therefore for same value of n, B and S_0, we get

$$Q \propto y^{5/3}$$

$$\Rightarrow \quad \frac{Q_1}{Q_2} = \left(\frac{y_1}{y_2}\right)^{5/3}$$

$$\Rightarrow \quad \frac{100}{Q_2} = \left(\frac{100}{120}\right)^{5/3}$$

$$\Rightarrow \quad Q_2 = \frac{100}{0.738}$$

$$\Rightarrow \quad Q_2 = 136$$

$\therefore$ Increase in discharge

$$= \quad Q_2 - Q_1 = 136 - 100 = 36\%$$

16.63 (b)

The sequent depth ratio for a rectangular channel is given by

$$\frac{y_2}{y_1} = \frac{1}{2}\left(-1 + \sqrt{1 + 8F_1^2}\right)$$

$$\Rightarrow \quad 16.48 = \frac{1}{2}\left(-1 + \sqrt{1 + 8F_1^2}\right)$$

$$\Rightarrow 1 + 8F_1^2 = 1153.28$$

$\Rightarrow \quad F_1 = \sqrt{144}$

$\Rightarrow \quad F_1 = 12.0$

16.64 (d)

(i) For most efficient triangular section, $m = 1$

$\therefore \quad P = 2y\sqrt{m^2+1} \quad [\because y = h]$

$\Rightarrow \quad \frac{P}{h} = 2\sqrt{2}$

$\Rightarrow \quad \frac{P}{h} = 2.83$

(ii) For most efficient trapezoidal section,

$$m = \frac{1}{\sqrt{3}} \text{ and } B = \frac{2}{\sqrt{3}}h$$

$\therefore \quad P = B + 2y\sqrt{m^2+1} \quad [\because y = h]$

$\Rightarrow \quad P = \frac{2}{\sqrt{3}}h + 2h\sqrt{\left(\frac{1}{\sqrt{3}}\right)^2 + 1}$

$\Rightarrow \quad \frac{P}{h} = \frac{2}{\sqrt{3}} + 2.31$

$\Rightarrow \quad \frac{P}{h} = 3.46$

16.65 (c)

Most economical channel carries maximum discharge for given area of cross section.

$$\text{Hydraulic radius} = \frac{\text{Cross sectional area}}{\text{Wetted parameter}}$$

Hydraulic radius is maximum when wetted parameter is minimum if area is same.

16.66 (d)

Jump	Froude number
Undular jump	$1 < Fr_1 < 1.7$
Weak jump	$1.7 < Fr_1 < 2.5$
Oscillating jump	$2.5 < Fr_1 < 4.5$
Steady jump	$4.5 < Fr_1 < 9$
Strong jump	$Fr_1 > 9$

16.67 (a)

A steady nonuniform flow in a prismatic channel with gradual changes in its water surface is termed as gradually varied flow (GVF).

16.68 (d)

Assertion is incorrect as it is not a necessary condition.

In case of triangular channel,

$$R = \frac{y}{2\sqrt{2}}$$

16.69 (c)

Large eddies transport the fluid over small distance as is the case of hydraulic jump.

So, reason is incorrect.

16.70 (c)

It is not necessary that surface is smooth in economical section for reduced friction. However if surface is smooth then it allows better discharge flow and increases efficiency. Economic section must have minimum wetted perimeter.

16.71 (c)

Positive wave travels downstream from gate as it results in increase in depth of flow and negative wave travels from gate onto upstream as it results in decrease in depth of flow.

16.72 (c)

Critical flow occurs when specific energy and specific force is minimum and discharge is maximum.

Alternative depths are depth with same specific energy.

There can be many specific energy curve for a given channel as it depends on the depth of flow.

16.73 (b)

If the flow properties, say the depth of flow, in a channel remains constant along the length of the channel it is called uniform flow. Flow in a main irrigation channel is a uniform flow.

If the change of depth in a varied flow is rapid and appreciable it is called a rapidly varied flow. In a stilling basin hydraulic jump is confined either partly or entirely for energy dissipation. Hydraulic jump is associated with rapid and significant change in depth and other flow properties.

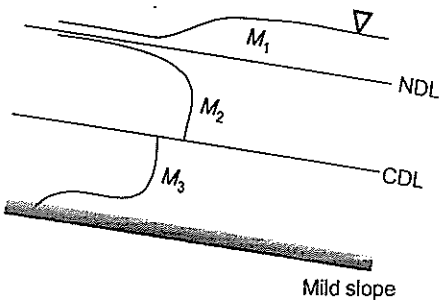
An unsteady flow occurs when the flow properties, such as the depth or discharge at a section changes with time. Sudden closure of a sluice gate creates such phenomena on the upstream of the gate.

If some flow is added to or abstracted from the varied flow it is know as a spatially varied flow.

When irrigation water spreads over a field some water percolates down into the soil creating a spatially varied flow.

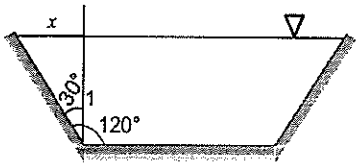
16.74 (b)

On a mild slope channel the flow below critical depth line is termed as M_3.



16.75 (c)

A most economical trapezoidal channel is half-hexagon such that its internal angle is 120°.



$$\tan 30° = \frac{x}{1}$$

or $$\frac{1}{\sqrt{3}} = \frac{x}{1}$$

or $$x = 0.577$$

16.76 (b)

At critical flow, specific energy and specific force is minimum for a given discharge. In other words for a given specific energy or specific force discharge is maximum at critical flow and Froude number is equal to unity.

16.77 (d)

For a most economical rectangular channel

$$y = \frac{b}{2} = \frac{4}{2} = 2\text{m}$$

16.78 (d)

$$C = \sqrt{gy} = \sqrt{10 \times 1.6} = 4 \text{ m/s}$$

$\therefore$ Velocity of surge wave travelling

Upwards = C – V

= 4 – 2.4 = 1.6 m/s

16.79 (*)

None of the options is correct. The correct Answer is 1 and 3 only.

16.80 (c)

Best hydraulic section gives minimum wetted perimeter for constant wetted area for a given discharge.

So, reason in incorrect.

16.81 (c)

It depends on discharge whether a given channel is mild, steep or critical. Hence Statement (I) is correct.

Critical depth is a function of discharge per unit width but not normal depth for a rectangular channel.

$$y_c = \left(\frac{q^2}{g}\right)^{1/3}$$

Normal depth is calculated from manning's or chezy's equation. Hence Statement (II) is wrong.For different discharges specific energy curve will be different for given channel.

16.82 (c)

It is not necessary that surface is smooth in economical section for reduced friction. However if surface is smooth then it allows better discharge flow and increases efficiency. Economic section must have minimum wetted perimeter.

16.84 (c)

$$F_r = 2.83$$

$$= \frac{v}{\sqrt{gy_n}} = \frac{q}{y_n\sqrt{gy_n}} \quad [\because q = vy_n]$$

$$\Rightarrow \quad (2.83)^2 = \frac{(q^2/g)}{y_n^3} = \frac{y_c^3}{y_n^3}$$

$$\Rightarrow \quad \frac{y_c}{y_n} = (2.83)^{2/3} = 2$$

16.85 (d)

Only energy and continuity equations are sufficient.

16.86 (c)

The characteristics of critical flow are

(i) The specific energy is minimum for the given discharge.

(ii) The Froude number is equal to unity.

(iii) For a given specific energy the discharge is maximum at the critical flow.

(iv) The velocity head is equal to half the hydraulic depth in a channel of small slope.

(v) Specific force is minimum for the given discharge.

(vi) Flow at the critical state is unstable.

16.87 (b)

For most efficient rectangular channel,

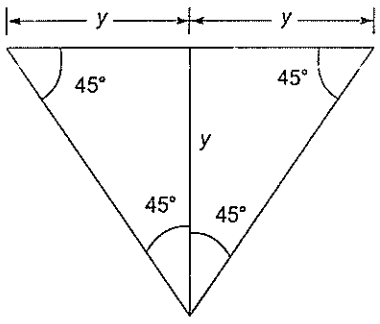
$$\text{Hydraulic radius} = \frac{y}{2}$$

$$\text{and depth, } y = \frac{B}{2}$$

$$\therefore \quad R = \frac{y}{2} = \left(\frac{B/2}{2}\right) = \frac{B}{4}$$

$$= \frac{5}{4} = 1.25 \text{ m}$$

16.88 (b)



For critical flow, $\frac{Q^2T}{gA^3} = 1$

So, $$\frac{Q^2 \times 2y}{g\left(2 \times \frac{1}{2} \times y \times y\right)^3} = 1$$

($\because$ Top width, $T = 2y$)

$$\Rightarrow \quad Q = \sqrt{\frac{gy^5}{2}} = \sqrt{\frac{9.81 \times (0.3)^5}{2}}$$

$$Q = 0.109 \text{ m}^3/\text{sec}.$$

$$Q = 0.11 \text{ m}^3/\text{sec}.$$

16.89 (c)

Head (Energy) loss in jump

$$E_L = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(1.4 - 0.3)^3}{4 \times 1.4 \times 0.3} = 0.79 \text{ m}$$

16.90 (d)

When the canal surface freezes due to cold, specific energy will decrease flow will become critical. Further decrease in icethickness (Δz), will lead to increase in depth.

16.91 (b)

The gradually varied flow in a prismatic channel, depth of flow changes over large length and specific energy is constant.

Assumption of G.V.F.:

(1) Chezy's formula and Manning's formula are used to determine energy slope.

(2) Energy correction factor (α) = 1

(3) Pressure distribution is hydrostatic.

(4) The bottom slope of the channel is very small.

(5) Flow is steady i.e. discharge is constant.

(6) Roughness coefficient of the channel is independent of depth.

16.92 (c)

Head loss,

$$E_L = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(1.2 - 0.3)^3}{4 \times 1.2 \times 0.3} = 0.50 \text{ m}$$

16.93 (c)

Given:

Length = 2000 m, Slope = 1/4000

$$\text{Percentage error in slope} = \frac{0.4}{\left(\frac{2000}{4000}\right) \times 100} \times 100$$

$$\Rightarrow \quad \frac{dS}{S} \times 100 = 0.8\%$$

From chezy's equation

$$Q = AC\sqrt{RS} = AC\sqrt{\frac{A}{P}S}$$

$$= CA^{3/2}P^{-1/2}S^{1/2}$$

$$\Rightarrow \quad \frac{dQ}{Q} \times 100 = \frac{3}{2}\frac{dA}{A} \times 100 + \frac{1}{2}\frac{dP}{P} \times 100 + \frac{1}{2}\frac{dS}{S} \times 100$$

$$\frac{3}{2}\frac{dA}{A} \times 100 + \frac{1}{2}\frac{dP}{P} \times 100 + \frac{1}{2}\frac{dS}{S} \times 100$$

$$= \frac{3}{2} \times 6 + \frac{1}{2} \times 4 + \frac{1}{2} \times 0.8$$

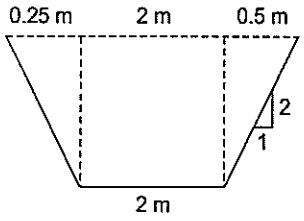
$$= 9 + 2 + 0.4 = 11.4\%$$

16.94 (d)

All critical flow, specific energy and specific force is minimum for a given discharge. In other words

for a given specific energy or specific force is maximum at critical flow.

16.96 (c)



$$E_c = y_c + \frac{v^2}{2g} = y_1 + \frac{Q^2}{2gA^2}$$

But for critical condition we know that

$$= \frac{Q^2}{g} = \frac{A^3}{T}$$

$$\Rightarrow \quad E_c = y_c + \frac{A}{2T}$$

$$= 1 + \frac{2.5}{2\times 3} = 1.416 \text{ m}$$

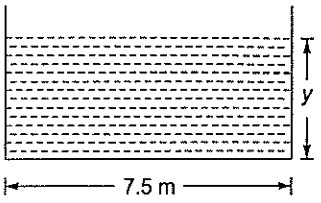
Again, $E_c = y_c + \frac{Q^2}{2gA^2}$

$$Q^2 = (1.416 - 1)\times 2g \times 2.5^2$$

$$= 7.21 \text{ m}^3/\text{s}$$

$$v = \frac{7.21}{2.5} = 2.89 \text{ m/s}$$

16.97 (a)



$Q = 12 \text{ m}^3/\text{s}$

$V = 1.5 \text{ m/s}$

$$V = \frac{Q}{A}$$

$$1.5 = \frac{12}{7.5\times y}$$

$$y = 1.067 \text{ m}$$

$$E = y + \frac{v^2}{2g}$$

$$= 1.067 + \frac{1.5^2}{2\times 9.8} = 1.18 \text{ m}$$

16.98 (c)

$$\frac{y_2}{y_1} = 10$$

$$\frac{y_2}{y_1} = \frac{1}{2}\left[-1+\sqrt{1+8F_1^2}\right]$$

$$10 = \frac{1}{2}\left[-1+\sqrt{1+8F_1^2}\right]$$

$$20 = -1+\sqrt{1+8F_1^2}$$

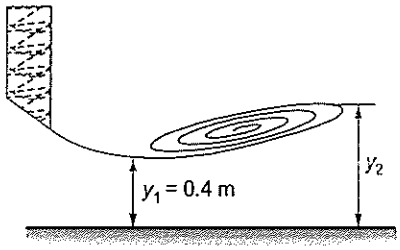
$$21 = \sqrt{1+8F_1^2}$$

$$441 = 1+8F_1^2$$

$$8F_1^2 = 440$$

$$F_2 = \sqrt{\frac{440}{8}} = 7.42$$

16.99 (a)



y_1 = Pre jump depth = Depth at vena contracta
y_2 = Post jump depth

$$q = v_1 y_1 = 6 \times 0.4 = 2.4 \text{ m}^3/\text{s}$$

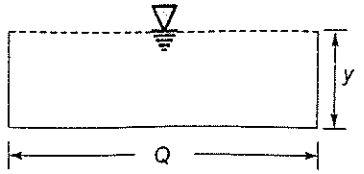
$$F_1^2 = \frac{q^2}{gz_1^3} = \frac{2.4^2}{10\times 0.4^3} = 9$$

$$\frac{y_2}{y_1} = \frac{1}{2}\left[-1+\sqrt{1+8F_1^2}\right]$$

$$= \frac{1}{2}\left[-1+\sqrt{73}\right] = 1.51 \text{ m}$$

16.100 (b)

$$R = \frac{A}{P} = \frac{B\cdot y}{B+2y}$$



For hydraulic efficient rectangular channel.

$B = 2y$

$$\therefore \quad R = \frac{2y^2}{2y+2y} = \frac{y}{2}$$

$$= \frac{B}{4} = \frac{5}{4} = 1.25$$

16.101 (c)

$$\frac{2q^2}{g} = y_1 y_2 (y_1 + y_2)$$

$$\frac{2q^2}{9.8} = 0.4 \times 5(0.4 + 5) = 2 \times 5.4 = 10.8$$

$$q = \sqrt{\frac{10.8 \times 9.8}{2}} = 7.3 \text{ m}^2/\text{s}$$

16.104(d)

$$F_1^2 = \frac{q^2}{gy^3}$$

$$\therefore \quad F_1^2 = \frac{(1.019)^2}{9.81 \times (0.1019)^3}$$

$$F_1 = 10$$

$\therefore$ $F_1 = 10$ is greater than 9 i.e. $F_1 > 9$ [Strong jump]

16.105 (c)

For very wide rectangular channel,

$$R = y$$

As per Chezy's equation

$$Q \propto y_0^{3/2}$$

$$\frac{\delta Q}{Q} \times 100 = \frac{3}{2} \times 20\% = 30\%$$

As per Manning's equation

$$Q \propto y_0^{5/3}$$

$$\frac{\delta Q}{Q} \times 100 = \frac{5}{3} \times 20\% = 33.33\%$$

Close answer is 36%.

16.106 (a)

$$F = \frac{\rho(y_1 - y_2)^3}{2(y_1 + y_2)} = \frac{1000}{2} \frac{(2 - 0.44)^3}{(2 + 0.44)}$$

$$= 762.39 \text{ kgf} \simeq 770 \text{ kgf}$$

UNIT

II

Engineering Hydrology

Syllabus

Hydrological cycle, Ground water hydrology, Well hydrology and related data analysis; Streams and their gauging; River morphology; Flood, drought and their management; Capacity of Reservoirs.

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2.	Evaporation, Transpiration and Stream Flow Measurement	159
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4.	Floods, Flood Routing & Flood Channel	181

OOOO

1 Precipitation and General Aspects of Hydrology

1.1 An accurate estimate of average rainfall in a particular catchment area can be obtained by
(a) arithmetic mean method
(b) isohyetal method
(c) normal ratio method
(d) Thiessen method
[ESE : 1995]

1.2 The percentage standard error of precipitation averages is often expressed functionally or graphically in terms of (i) precipitating gauge network density expressed as area per gauge, and (ii) total area of catchment. The percentage standard error
(a) increases with area per gauge as well as with total area
(b) decreases with area per gauge as well as with total area
(c) increases with area per gauge but decreases with total area
(d) decreases with area per gauge but increases with total area
[ESE : 1996]

1.3 If 'p' is the precipitation, 'a' is the area represented by a rain gauge, and 'n' is the number of rain gauges in a catchment area, then the weighted mean rainfall is

(a) $\frac{\Sigma ap^3}{\Sigma a^2}$ (b) $\frac{\Sigma ap}{n}$

(c) $\frac{\Sigma ap}{\Sigma a}$ (d) $\frac{\Sigma ap^5}{\Sigma a^3}$

[ESE : 1996]

1.4 Depth-Area-Duration curves of precipitation are drawn as
(a) minimizing envelopes through the appropriate data points
(b) maximizing envelopes through the appropriate data points
(c) best fit mean curves through the appropriate data points
(d) best fit mean straight lines through the appropriate data points
[ESE : 1996]

1.5 The yield of a well depends upon
(a) permeability of soil
(b) area of aquifer opening into the wells
(c) actual flow velocity
(d) all of the above
[ESE : 1996]

1.6 Mean precipitation over an area is best obtained from gauged amounts by
(a) arithmetic mean method
(b) Thiessen method
(c) linearly interpolated isohyetal method
(d) orographically weighted isohyetal method
[ESE : 1997]

1.7 Depth-Area-Duration curves would seem to resemble
(a) arcs of circle concave upwards with duration increasing outward
(b) first quadrant limbs of hyperbolae with duration increasing outward
(c) third quadrant limbs of hyperbolae with duration decreasing outward
(d) first quadrant limbs of hyperbolae with duration decreasing outward
[ESE : 1997]

1.8 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Specific yield
B. Specific capacity
C. Specific retention
D. Specific storage

List-II
1. Volume of water retained per unit volume of aquifer

2. Volume of water drained by gravity per unit volume of aquifer
3. Difference of porosity and specific storage
4. Well yield per unit drawdown
5. Volume of water released from unit volume of aquifer for unit decline in piezometric head

Codes:

	A	B	C	D
(a)	2	4	1	5
(b)	4	2	3	5
(c)	2	5	1	4
(d)	4	2	3	1

[ESE : 1998]

1.9 Water present in an artesian aquifer is usually
(a) at sub atmospheric pressure
(b) at atmospheric pressure
(c) at 0.5 times of the atmospheric pressure
(d) above atmospheric pressure

[ESE : 1998]

1.10 An aquifer confined at top and bottom by impermeable layers is stratified into three layers as follows:

Layer	Thickness (m)	Permeability (m/day)
Top layer	4	30
Middle layer	2	10
Bottom layer	6	20

The transmissivity (m^2/day) of the aquifer is
(a) 260 (b) 227
(c) 80 (d) 23

[ESE : 1998]

1.11 The following rainfall data refers to station *A* and *B* which are equidistant from station *X*:

	Station *A*	Station *X*	Station *B*
Long-term normal annual rainfall in mm	200	250	300
Annual rainfall in mm for the year 1940	140	P	270

The value of P will be
(a) 250 (b) 220
(c) 205 (d) 200

[ESE : 1998]

1.12 Specific capacity of a well is the
(a) volume of water that can be extracted by the force of gravity from a unit volume of aquifer
(b) discharge per unit drawdown of the well
(c) drawdown per unit discharge of the well
(d) rate of flow through a unit width and entire thickness of aquifer

[ESE : 2000]

1.13 **Assertion (A):** The available yield of a tubewell can be doubled by doubling the diameter of the well.

Reason (R): The yield of a tubewell varies inversely with the logarithm of the reciprocal of the diameter of the well.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

1.14 Match List-I (Equation) with List-II (Applicability or principle of equation) and select the correct answer using the codes given below the lists:

List-I
A. Theim's equation
B. Dupit's assumption
C. Bernoulli's equation
D. Continuity equation

List-II
1. is based on energy conservation principle
2. is based on mass conservation principle
3. is applicable to steady flow towards a well in a confined aquifer
4. is applicable to steady flow in an unconfined aquifer

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	2	1
(c)	4	3	1	2
(d)	3	4	1	2

[ESE : 2002]

1.15 The performance of a well is measured by its
(a) Specific capacity
(b) Specific yield
(c) Storage coefficient
(d) Permeability coefficient

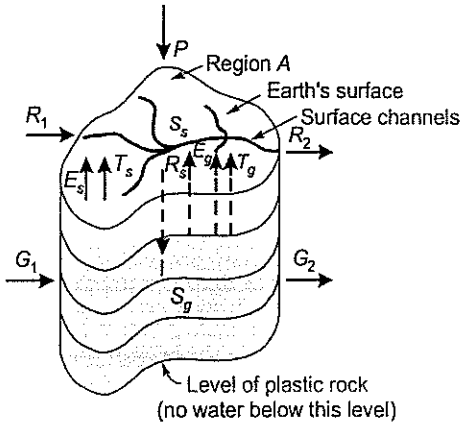
[ESE : 2002]

1.16 In a water-shed, four raingauges I, II, III and IV are installed. The depths of normal annual rainfall at these stations are 60, 75, 80 and 100 cm respectively. The rain gauge at station III went out of order during a particular year. The annual rainfall for that year, recorded at the remaining three stations was 90, 60 and 70 cm. The rainfall at station III can be considered as

(a) 60 cm (b) 70 cm
(c) 80 cm (d) 120 cm

[ESE : 2002]

1.17 Regional hydrological cycle is shown in the figure.



The correct hydrologic budget equations

(a) $P + R_1 - R_2 + R_g - E_s - T_s - I = DS_s$
(b) $I + G_1 - G_2 - R_g - E_g - T_g = DS_g$
(c) $P-(R_2-R_1)-(E_s+E_g)-(T_s+T_g)-(G_2-G_1) = D(S_s+S_g)$
(d) $P - R - G - E - T = DS_s$

[ESE : 2002]

1.18 Consider the following statements:

A well development

1. involves reversal of flow through the well screen
2. increases permeability towards the well
3. decreases permeability towards the well
4. is continued till sand/silt free water is pumped out

Which of these statements is/are correct?

(a) 1, 3 and 4 (b) 1, 2 and 4
(c) 3 only (d) 1 and 4

[ESE : 2003]

1.19 Match List-I (Well hydraulics parameters) with List-II (Definition) and select the correct answer using the codes given below the lists:

List-I

A. Specific yield
B. Safe yield
C. Specific capacity
D. Field capacity

List-II

1. Discharge per unit drawdown of well
2. Same as specific retention
3. Measure of water that can be removed by pumping
4. Limit of withdrawal from well without depletion of the aquifer
5. Water-bearing capacity of aquifer

Codes:

	A	B	C	D
(a)	4	3	2	5
(b)	3	4	1	2
(c)	4	3	1	2
(d)	3	4	2	5

[ESE : 2003]

1.20 The moving average of annual precipitation record is carried out to determine

(a) Trend
(b) Annual mean
(c) Extreme annual variation
(d) Extreme seasonal variation

[ESE : 2003]

1.21 Match List-I (Type of precipitation) with List-II (Principal causes) and select the correct answer using the codes given below the lists:

List-I

A. Convective
B. Cyclonic
C. Frontal
D. Orographic

List-II

1. Atmospheric disturbance
2. Mountain barrier
3. Pressure difference
4. Temperature difference
5. Warm and cold air masses

Codes:

	A	B	C	D
(a)	1	4	5	2
(b)	4	3	5	2
(c)	1	4	2	5
(d)	4	3	2	5

[ESE : 2003]

1.22 **Assertion (A):** The yield of a well varied from 10 m^3/day to 20 m^3/day when the aquifer area changed from 50 m^2 to 75 m^2.

Reason (R): The yield is found to be directly proportional to the area of an aquifer opening into a well.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2004]

1.23 Which one of the following correctly defines aquiclude?

(a) A saturated formation of earth material which not only stores water but also yields it in sufficient quantity.
(b) A formation through which only seepage is possible and thus the yield is insignificant compared to an aquifer.
(c) A geological formation which is neither porous nor permeable.
(d) A geological formation which is essentially impermeable to the flow of water.

[ESE : 2004]

1.24 Which one of the following defines Aridity Index (*AI*)?

(a) $AI = \frac{PET - AET}{PET} \times 100$

(b) $AI = \frac{PET}{AET} \times 100$

(c) $AI = \frac{AET}{PET} \times 100$

(d) $AI = \frac{AET - PET}{AET} \times 100$

(where AET = Actual Evapotranspiration and PET = Potential Evapotranspiration)

[ESE : 2004]

1.25 The discharge per unit drawdown at the well is known as

(a) Specific yield
(b) Specific storage
(c) Specific retention
(d) Specific capacity

[ESE : 2005]

1.26 The area between the two isohyetes 45 cm and 55 cm is 100 km^2, and that between 55 cm and 65 is 150 km^2. What is the average depth of annual precipitation over the basin of 250 km^2?

(a) 50 cm (b) 52 cm
(c) 56 cm (d) 60 cm

[ESE : 2005]

1.27 For which one of the following purposes is the double mass curve used ?

(a) Checking on the consistency of precipitation records.
(b) Prediction of annual precipitation.
(c) Defining which periods of storm should be analyzed to obtain the maximum useful information from storm rainfall records.
(d) For estimating the capacity of a reservoir.

[ESE : 2005]

1.28 Which one of the following is not a major type of storm precipitation?

(a) Frontal storm (b) Air mass storm
(c) Orographic storm (d) Continental storm

[ESE : 2006]

1.29 Double mass curves are used

(a) to check on the consistency of precipitation records
(b) as basis for storm rainfall analysis
(c) to determine average rainfall over an area
(d) to indicate rainfall distribution

[ESE : 2006]

1.30 What is the Probable Maximum Precipitation (PMP)?

(a) Projected precipitation for a 100 year return period
(b) Maximum precipitation for all past recorded storms
(c) Upper limit of rainfall, which is justified climatologically
(d) Effective precipitable water

[ESE : 2007]

1.31 Which one of the following is a method of extending the length of record for a frequency curve at a station?

(a) Double Mass Curve method
(b) The Station Year method
(c) Thiessen method
(d) Isohyetal method

[ESE : 2007]

1.32 The quantitative statement of the balance between water gains and losses in a certain basin during a specified period of time is known as which one of the following?
1. Water budget
2. Hydrologic budget
3. Groundwater budget

Select the correct answer using the codes given below:
(a) 1 only (b) 2 only
(c) 3 only (d) none of these

[ESE : 2007]

1.33 Inconsistency of rainfall data can be checked by which one of the following?
(a) Normal ratio method
(b) Mass curve method
(c) Double-mass curve method
(d) Depth duration frequency curve

[ESE : 2008]

1.34 What is the chemical symbol for ice as per UNESCO terminology?
(a) H_8O_4 (b) H_2O
(c) H_6O_3 (d) H_4O_2

[ESE : 2008]

1.35 What is 'Hydrological Cycle'?
(a) Processes involved in the transfer of moisture from sea to land
(b) Processes involved in the transfer of moisture from sea back to sea again
(c) Processes involved in the transfer of water from snowmelt in mountains to sea
(d) Processes involved in the transfer of moisture from sea to land and back to sea again

[ESE : 2009]

1.36 Consider the following with respect to 'double-mass curve':
1. Plot of accumulated rainfall with respect to two chronological orders
2. Plot for estimating multiple missing rainfall data
3. Plot for checking the consistency of the rainfall data
4. Plot of accumulated annual rainfall of a station vs. accumulated rainfall of a group of stations

Which of these statements are correct?
(a) 1 and 3 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

[ESE : 2009]

1.37 Generally to estimate PMP, $P_m = 42.16D^{0.475}$ is used (P_m is maximum depth of precipitation, D = duration). What are the units of P_m and D in the equation?
(a) mm, sec (b) cm, sec
(c) mm, hr (d) cm, hr

[ESE : 2009]

1.38 An unconfined aquifer of porosity 30%, permeability 35 m/day and specific yield of 0.20 has an area of 100 km^2. If the water table falls by 0.25 m during a drought, the volume of water lost from storage, in million cubic metres, is
(a) 2.0 (b) 5.0
(c) 1.0 (d) 4.0

[ESE : 2010]

1.39 The coefficient of variation of the rainfall for six rain gauge stations in catchments was found to be 29.54%. The optimum number of stations in the catchments for an admissible 10% error in the estimation of the mean rainfall will be
(a) 3 (b) 6
(c) 9 (d) 12

[ESE : 2010]

1.40 Ombrometer (pluviometer) is used to measure
(a) soil moisture stress of a plant
(b) rainfall depth
(c) leaf area
(d) root zone depth

[ESE : 2010]

1.41 Which of the following are pertinent to the realization of hydrological cycle?
1. Latitudinal differences in solar heating of the Earth's surface.
2. Inclination of the Earth's axis
3. Uneven distribution of land and water
4. Coriolis effect.

(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2012]

1.42 What would be the volume of water stored in a saturated column with a porosity of 0.35 with a cross-sectional area of 1 m^2 and depth of 3 m?

(a) 2.0 m^3 (b) 0.105 m^3
(c) 1.05 m^3 (d) 3.0 m^3

[ESE : 2012]

1.43 The surface joining the static levels in several non-pumping wells penetrating a continuous confined aquifer represents

(a) Water table surface
(b) Capillary fringe
(c) Piezometric surface of the aquifer
(d) Physical top surface of the aquifer

[ESE : 2012]

1.44 Which of the following statements are correct?

1. A fine sprinkle of precipitation of small and rather uniform water drops with all drop diameters below 0.10 mm is called as drizzle.
2. The precipitation of liquid water with every drop diameter less than 0.5 mm is known as rain.
3. Precipitation in the form of balls or irregular lumps of ice each over 5 mm in diameter is called as hail.
4. Dew is formed directly by condensation on the ground mainly during night when the surface has been cooled by outgoing radiation.

(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

[ESE : 2013]

1.45 The double mass curve technique is used:

(a) To find the average rainfall over a number of years
(b) To estimate the missing rainfall data
(c) To check the consistency of rain gauge records
(d) To find the minimum number of rain gauges required in a basin

[ESE : 2013]

1.46 **Statement (I):** Condensation of water vapour into droplets precedes the precipitation process.

Statement (II): Formation of precipitation droplets is predicted on the presence of condensation nuclei.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2013]

1.47 Consider the following statements:

1. The normal annual rainfall of a station is obtained as the arithmetic average of the successive annual rainfall in the last 30 years.
2. The 'normal rainfall' are updated by deleting the needful number of oldest years data from the record and adding the needful number of most recent years data to the record.
3. The standard deviation computed for the rainfall of the same 30 years of rainfall data is taken as a measure of the variability of the rainfall during the self same set of years.
4. If the observed rainfall in any year is less than the current normal annual rainfall, then that year is called a dry year.

Which of the above statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2 and 4 only (d) 1, 3 and 4 only

[ESE : 2014]

1.48 The double mass analysis is adopted to

(a) Estimate the missing rainfall data
(b) Obtain intensities of rainfall at various durations
(c) Check the consistency of data
(d) Obtain the amount of storage needed to maintain a demand pattern

[ESE : 2014]

1.49 When 3.5 million m^3 of water was pumped out from an unconfined aquifer of 6.3 km^2 areal extent, the water table was observed to go down by 2.5 m. The specific yield of the aquifer is best approximated as

(a) 32% (b) 28%
(c) 25% (d) 22%

[ESE : 2014]

1.50 An unconfined aquifer of porosity 35%, permeability 40 m/day and specific yield of 0.15 has an area of 100 km^2. If the water table falls uniformly throughout the aquifer area by 0.2 m during a drought, the volume of water lost from storage is

(a) 1.5 Mm^3 (b) 3.0 Mm^3
(c) 7.0 Mm^3 (d) 8.0 Mm^3

[ESE : 2014]

1.51 Ground water flows through an aquifer with a cross-sectional area of 1.0×10^4 m and a length of 1500 m. Hydraulic heads are 300 m and 250 m at the ground water entry and exit points in the aquifer respectively. Ground water discharge into stream at the rate of 1500 m^3/day. The corresponding hydraulic conductivity of this aquifer will be

(a) 3.5 m/day (b) 4.5 m/day
(c) 5.0 m/day (d) 5.5 m/day

[ESE : 2014]

1.52 A tubewell of 30 cm diameter penetrates fully into an artesian aquifer. The artesian length is 15 m. The yield from the well under a drawdown of 3 m through the aquifer consisting of sand of effective size of 0.2 mm and coefficient of permeability of 50 m/day, with radius of drawdown of 150 m, is nearly

(a) 240 *l*/s (b) 120 *l*/s
(c) 24 *l*/s (d) 12 *l*/s

[ESE : 2014]

1.53 The successive annual rainfall magnitudes at a place for a period of 10 years from 2001 to 2010, both inclusive, are 30.3, 41.0, 33.5, 34.00, 33.3, 36.2, 33.6, 30.2, 35.5 and 36.3 cm. The mean and median values of this annual rainfall series are respectively

(a) 33.8 cm and 34.39 cm
(b) 34.39 cm and 33.8 cm
(c) 34.39 cm and 40.2 cm
(d) 33.8 cm and 40.2 cm

[ESE : 2014]

1.54 Orographic rain occurs when the air is cooled sufficiently as a result of

(a) lifting due to flow over a mountain barrier
(b) relative movement of two large air masses
(c) violent upthrow of air arising from localized heating
(d) cyclonic conditions

[ESE : 2015]

1.55 A Double-Mass-Curve Analysis is useful in

(a) Consistency Analysis
(b) Frequency Analysis
(c) Storage Computation Analysis
(d) Guessing missing data in cases of non-homogeneous terrain

[ESE : 2015]

1.56 **Statement (I):** The deeper a lake, the lesser the evaporation in summer and the more in winter.

Statement (II): Heat storage in water bodies affects seasonal evaporation.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

1.57 Consider the following statements concerning precipitation.

1. The Isohyetal map method of determining the average precipitation is considered to be better than the Thiessen method.
2. There is no possibility of damaging the storms because of cloud seeding activity.
3. Water that percolates through the soil emerges as the dry weather flow in streams.

Which of the above statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 2017]

■■■■

Answers Precipitation and General Aspects of Hydrology

1.1 (b)	1.2 (a)	1.3 (c)	1.4 (b)	1.5 (d)	1.6 (d)	1.7 (b)	1.8 (a)	1.9 (d)	
1.10 (a)	1.11 (d)	1.12 (b)	1.13 (d)	1.14 (d)	1.15 (a)	1.16 (c)	1.17 (c)	1.18 (b)	
1.19 (b)	1.20 (a)	1.21 (b)	1.22 (d)	1.23 (d)	1.24 (a)	1.25 (d)	1.26 (c)	1.27 (a)	
1.28 (d)	1.29 (a)	1.30 (c)	1.31 (b)	1.32 (a)	1.33 (c)	1.34 (b)	1.35 (d)	1.36 (c)	
1.37 (d)	1.38 (b)	1.39 (c)	1.40 (b)	1.41 (d)	1.42 (c)	1.43 (c)	1.44 (c)	1.45 (c)	
1.46 (a)	1.47 (d)	1.48 (c)	1.49 (d)	1.50 (b)	1.51 (b)	1.52 (c)	1.53 (b)	1.54 (a)	
1.55 (a)	1.56 (a)	1.57 (b)							

Explanations Precipitation and General Aspects of Hydrology

1.1 (b)

Normal ratio method is used for estimating missing annual precipitation value at a station when the annual precipitation and normal annual precipitation at neighbouring stations are known. In calculating average rainfall in a catchment area arithmetic mean method is very crude method and it is rarely used. Thiessen-polygon method of calculating the average precipitation is superior to the arithmetic average method as some weightage is given to the various stations on a rational basis. The isohyetal method is superior to other methods (arithmetic mean and thiessen) when stations are large in number.

1.2 (a)

As the gauge network density increases (area per gauge decreases) the error of precipitation averages decreases. In other words with increase in area per gauge the standard error increases. With increase in total area of catchment, the standard error will increase.

1.3 (c)

Weighted mean rainfall can be calculated according to Theissen Polygon method also called as Weighted Area Method.

1.4 (b)

The maximum depth area curve for a given duration D is prepared by assuming the area distribution of rainfall for smaller duration to be similar to the total storm. The procedure is then repeated for different storms and the envelope curve of maximum depth area for duration D is obtained. A similar procedure for various values of D results in a family of envelope curves of maximum depth vs area, with duration as the third parameter. These curves are called DAD curves.

1.5 (d)

Yield of a well means the discharge from the well excavated through given aquifer

$$Q = nv_a A = KiA$$

where

n is porosity

v_a is actual flow velocity of ground water

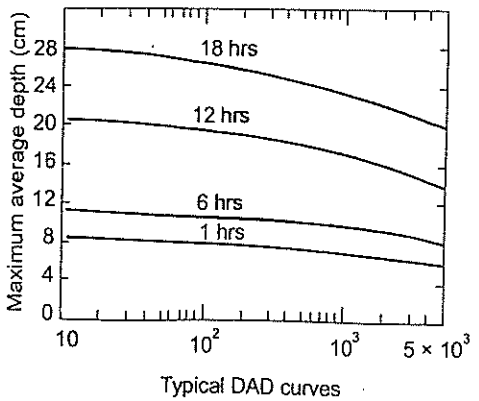
A is area of the aquifer opening into the wells

K is permeability of soil

1.6 (d)

Isohyets are contours of equal rainfall. The orographically weighted isohyets are prepared by tracing paper for mountainous areas and therefore they are more accurate than linearly interpolated isohyets.

1.7 (b)



Typical DAD curves

None of the option represents the actual DAD curves , so Option (b) – is closest.

1.8 (a)

Specific Yield + Specific Retention = Porosity

Specific Yield is the ratio of volume of water in an aquifer that can be extracted by the force of gravity to the total volume of the saturated aquifer.

Specific Capacity of a well is its yield per unit drawdown.

Specific Retention is the ratio of volume of water retained in an aquifer to the total volume of the saturated aquifer.

Specific Storage is the volume of water released from unit volume of aquifer for unit decline in piezometric head.

1.9 (d)

In Artesian aquifer or Confined aquifer the water present is usually above atmospheric pressure as it is confined between two impermeable stratas thus preventing it from any exposure to atmospheric pressure.

1.10(a)

Transmissibility, $T = \Sigma kd$

$= (4 \times 30) + (2 \times 10) + (6 \times 20)$

$= 120 + 20 + 120 = 260\ m^2/day$

1.11(d)

Since the normal annual rainfall at stations *A* and *B* does not lie within 10% of the normal annual rainfall at station *X*.

So, using normal ratio method, we get

$$P = \frac{250}{2}\left[\frac{140}{200} + \frac{270}{300}\right] = 200\ mm$$

If the normal annual rainfall at non-missing station lie within 10% of that at missing station then arithmetic average method can be used.

1.12 (b)

Volume of water than can be extracted by the force of gravity from a unit volume of aquifer is specific yield. Rate of flow through unit width and entire saturated thickness of aquifer is called transmissivity.

1.13 (d)

Yield of a well in unconfined aquifer,

$$Q = \frac{\pi K\left(d^2 - h_w^2\right)}{2.3\log_{10}\left(R / r_w\right)}$$

Yield of a well in confined aquifer,

$$Q = \frac{2\pi KH\left(D - h_w\right)}{2.3\log_{10}\left(R / r_w\right)}$$

As the yield of well is inversely proportional to the logarithm of the reciprocal of radius (diameter) of the well, so doubling the diameter will not double the yield.

1.14 (d)

- Theim's Equation – Equation of discharge for the steady flow in a confined aquifer.
- Dupit's Equation - Equation for steady flow in an unconfined aquifer.
- Bernoulli's Equation – Based on Energy Conservation principle.
- Continuity Equation – Mass Conservation principle.

1.15(a)

Specific capacity is the discharge per unit drawdown of a well and it measures efficiency of a well. All other parameters like specific yield, storage coefficient and permeability coefficient are used for water bearing formation.

1.16(c)

Since the normal annual rainfall for stations I, II and IV does not lie within 10% of that of normal annual rainfall at station III. So,

Using Normal Ratio Method

$$P_{III} = \frac{80}{3}\left[\frac{90}{60} + \frac{60}{75} + \frac{70}{100}\right] = 80\ cm$$

1.17 (c)

The hydrologic budget consists of inflows, outflows, and storage as shown in the following equation: Inflow = Outflow +/- Changes in Storage. Inflows add water to the different parts of the hydrologic system, while outflows remove water. Storage is the retention of water by parts of the system.

In the Hydrologic Budget Equation:

$P - R - E - T - G = \Delta S$

Where, P - Total Precipitation

R – Net Runoff

E – Total Evaporation

T – Total Transpiration

G – Net Ground Water Flow

ΔS – Total change in storage

1.18 (b)

Well development is a part of normal well drilling procedure after the completion of the well and before the final disinfection. It is necessary to maximize the yield of the well and to optimize the filter capacity of the gravel pack after well construction.

1.19(b)

The quantity of water retained by the material against the pull of gravity is called specific retention or field capacity.

Specific yield + Specific retention = Porosity.

So the soil is not fully saturated at field capacity.

1.20(a)

A moving average plot, in which the average value of precipitation of three or five consecutive time intervals is plotted at the mid-value of the time interval is useful in smoothening out the variations and bringing out the trend.

1.21 (b)

Convective precipitation is caused by convection where the surface layer of the atmosphere is heated causing the moisture laden air to rise. As it rises it cools to form clouds. The unequal heating of the earth's surface causes convection.

Cyclonic precipitation is caused by lifting of an air mass due to the pressure difference. Cyclonic precipitation may be either frontal or non-frontal cyclonic precipitation.

Frontal rainfall occurs when warm air is forced to rise over cold air. The moisture in the warm air condenses as it cools which causes clouds and rain.

Orographic or relief rainfall is caused when masses of air pushed by wind are forced up the side of elevated land formations, such as large mountains.

1.22(d)

Yield of a well $Q = KiA$

Where i is the hydraulic gradient at the surface of well. If i remains constant then discharge is proportional to area of an aquifer opening into the well. So the discharge should change from 10 m^3/s to 15 m^3/s when aquifer area is changed from 50 m^2 to 75 m^2.

1.23 (d)

Aquifer is a saturated formation of earth material which not only stores water but also yields it in sufficient quantity. e.g. unconsolidated deposits of sand and gravel.

Aquitard is a formation through which only seepage is possible and thus the yield is insignificant compared to an aquifer e.g. sandy clay unit.

Aquifuge is a geological formation which is neither porous nor permeable e.g. massive compact rock without any fracture.

Aquiclude is geological formation which is essentially impermeable to the flow of water although it may contain large amounts of water due to its high porosity e.g. clay.

So in terms of yield, Aquifer > Aquitard > Aquiclude > Aquifuge.

1.24 (a)

The departure of AI from its corresponding normal value is known as AI anomaly, represents moisture shortage. Based on AI anomaly, the intensity of agricultural drought is classified as follows:

AI anomaly	Severity class
1-25	mild arid
26-50	moderate arid
750	severe arid

1.25 (d)

Specific capacity is the discharge per unit drawdown of a well and it measures efficiency of a well.

1.26(c)

Average depth of annual precipitation

$$= \frac{\left(\frac{45+55}{2}\right)\times 100 + \left(\frac{55+65}{2}\right)\times 150}{100+150} = 56 \text{ cm}$$

1.27 (a)

The double-mass curve can be used to adjust inconsistent precipitation data. The graph of the cumulative data of one variable versus the cumulative data of a related variable is a straight line so long as the relation between the variables is a fixed ratio.

1.28 (d)

Orographic storm: A rain or snow event that results from, or is significantly enhanced by, lifting of an air mass over a mountain barrier.

Air Mass Storm, also called an "ordinary" thunderstorm, is a thunderstorm that is generally weak and usually not severe. The lifting source, which is a crucial factor in thunderstorm development, is usually the result of uneven heating of the surface, though they can be induced by weather fronts and other low-level boundaries associated with wind convergence.

Frontal thunderstorms occur along the boundaries of weather fronts (e.g. cold front).

1.29 (a)

The double-mass curve can be used to adjust inconsistent precipitation data. The graph of the cumulative data of one variable versus the cumulative data of a related variable is a straight line so long as the relation between the variables is a fixed ratio.

1.30 (c)

The Probable Maximum Precipitation (PMP) may be defined as the maximum depth of precipitation for a given duration that may possibly occur on a given catchment at any time of the year. Hence such a precipitation would result from the possible severest storm that may result from the worst possible combinations of hydrological conditions in the area.

Probable Maximum Flood (PMF) is the extreme flood that is physically possible in a region as a result of severe most combinations, including rare combinations of meteorological and hydrological factors. The PMF is used in situations where the failure of the structure would result in loss of life and catastrophic damage and as such complete security from potential floods is sought.

1.31 (b)

When long records are not available, records at two or more stations are combined to get one long record for the purposes of recurrence interval calculation. This method is known as station year method. In this method all the records which are available from the various stations situated in a meteorologically homogeneous area are combined together, so as to represent the record of an imaginary representative station called the station year.

1.32 (a)

A water budget equation is used to describe the flow of water in and out of a system in a specific time period. The system can be a particular basin or a catchment.

1.33 (c)

The checking for inconsistency of a record is done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent.

1.34 (d)

Most of the earth's water sources such as rivers, lakes, oceans, ground water, etc. get their supplies from rain, while the rain water in itself is derived from the evaporation from these sources. Water is infact lost to the atmosphere as vapor from the earth, which is then precipitated back in the form of rain, snow, hail, dew, sleet or frost, etc. This evaporation and precipitation continues forever and thereby, a balance is maintained between the two. This process is known as hydrologic cycle.

1.36 (c)

Double mass curve is a plot for checking the inconsistency of the rainfall data. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent. In this technique the data of the annual (or monthly mean) rainfall of any station x and also the average rainfall of the group of base stations covering a long period is arranged in reverse chronological order (i.e. the latest record as the first entry and the oldest record as the last entry in the list). The accumulated precipitation of

the station (ΣP_x) and the accumulated values of the average of the group of base stations, (ΣP_{av}) are calculated starting from the latest record values of ΣP_x are plotted against ΣP_{av} for various consecutive time periods.

1.37(d)

Based upon the rainfall records available all over the world, a list of world's greatest recorded rainfalls of various duration can be assembled. When this data is plotted upon a log-log paper, an enveloping straight line drawn to the plotted points obeys the equation

$$P_m = 42.16\, D^{0.475}$$

where P_m = extreme rainfall depth in cm and D = duration in hours. The values obtained from this equation are of use in probable maximum precipitation (PMP) estimations.

1.38(b)

The actual volume of water that can be extracted by the force of gravity from a unit volume of aquifer material is known as the specific yield (S_y).

Volume of water lost during drought

$= S_y \times$ Area $\times$ drop in water table

$= 0.2 \times 100 \times 10^6 \times 0.25$

$= 5 \times 10^6\ m^3$

1.39(c)

The number of optimum stations can be given as

$$N = \left(\frac{C_v}{\varepsilon}\right)^2 = \left(\frac{29.54}{10}\right)^2$$

$= 8.72 \approx 9$ stations

1.40(b)

Precipitation is expressed in terms of the depth to which rainfall water would stand on an area if all the rain were collected on it. The precipitation is collected and measured in a raingauge. Terms such as pluviometer, ombrometer and hyetometer are also sometimes used to designate a raingauge.

1.42 (c)

Volume of water stored

$= 0.35 \times 3 \times 1 = 1.05\ m^3$

1.44 (c)

Rain: Water drops that have a diameter of at least 0.5 mm.

It can be classified based on intensity as,

- Up to 2.5 mm/h – Light rain
- 2.5 mm/h to 7.5 mm/h – Moderate rain
- Heavy rain > 7.5 mm/h

Drizzle: Rain droplets of size less than 0.5 mm and rain intensity of less than 1mm/h.

Hail: It is a showery precipitation in the form of irregular pellets or lumps of ice of size more than 8 mm.

Dew: Water droplets condensed from the air, usually at night, onto cool surfaces near the ground. Dew forms when the temperature of the surfaces falls below the dew point of the surrounding air usually due to radiational cooling.

1.45 (c)

Double mass curve technique is used to check the consistency of rainfall data.

1.46 (a)

When water is saturated locally in the atmosphere, the water condenses and precipitates. Sufficient water nuclei must be present to aid condensation and thus cause precipitation.

1.47 (d)

The Normal rainfall is calculated as the average value of rainfall of a particular date, month or year over a specified period of 30 years. The 30 year Normal rainfall is recomputed every decade to account for factors that may affect the amount of rainfall on that area like change in land use, environment etc.

The Standard deviation shows the rainfall variability over a particular period.

1.48 (c)

The trend of the rainfall records at a station may slightly change after some years due to a change in the environment (or exposure) of a station either due to coming of new building, fence, planting of trees or cutting of forest nearby, which affect the catch of the gauge due to change in the wind pattern or exposure. The consistency of records at the station is tested by a double mass curve by plotting the cumulative annual rainfall at a station against the concurrent cumulative values of mean annual rainfall for a group of surrounding stations, for the number of year of record.

1.49 (d)

By considering volumetric approach

Water pumped = $S_y \times$ Area $\times$ drawdown

$$S_y = \frac{\text{water pumpdown}}{\text{area} \times \text{drawdown}}$$

$$= \frac{3.5 \times 10^6}{6.3 \times 10^6 \times 2.5}$$

$$= 0.2222 \simeq 22\%$$

1.50 (b)

Volume lost = $S_y \times$ Drawdown $\times$ Area

$= 0.15 \times 0.2 \times 100 \times 10^6 \text{ m}^3$

$= 3 \times 10^6 \text{ m}^3 = 3 \text{ Mm}^3$

1.51 (b)

Discharge, $Q = kiA$

$$1500 = k \times \frac{(300-250)}{1500} \times 10^4,$$

$$\therefore \quad k = 4.5 \text{ m/day}$$

1.52 (c)

$$\text{Yield of aquifer } (q) = \frac{2\pi kb(h_3 - h_1)}{ln\left(\frac{R}{r}\right)}$$

$$q = \frac{2\pi \times \left(\frac{50}{24 \times 60 \times 60}\right) \times 15 \times 3}{ln\left(\frac{150}{0.15}\right)}$$

$$q = \frac{2\pi \times 5.787 \times 10^{-4} \times 15 \times 3}{6.90775}$$

or $q = 0.02368 \text{ m}^3/\text{sec.}$

$q = 23.68 \text{ l/sec.} \simeq 24 \text{ l/sec.}$

1.53 (b)

$$\text{Mean value} = \frac{\sum x}{n}$$

$$= \frac{30.3 + 41.0 + 35.5 + 34 + 33.3 + 36.2 + 33.6 + 30.2 + 35.5 + 36.3}{10}$$

$= 34.39$ cm

If we arrange the various rainfall magnitude in increasing order, then we get,

30.2, 30.3, 33.3, 33.5, 33.6, 34, 35.5, 36.2, 36.3, 41.0

If no. of terms are even, then median will

$$= \left[\frac{\left(\frac{n}{2}\right) + \left(\frac{n}{2}+1\right)}{2}\right] = \frac{33.6 + 34}{2} = 33.8 \text{ cm}$$

1.54 (a)

Orographic precipitation, also known as relief precipitation, is precipitation generated by a forced upward movement of air upon encountering a physiographic upland. This lifting can be caused by two mechanisms:

1. The upward deflection of large scale horizontal flow by the orography.
2. The upward vertical propagation of moist air up an orographic slope caused by daytime heating of the mountain barrier surface.

1.55 (a)

The double-mass curve can be used to adjust inconsistent precipitation data. The graph of the cumulative data of one variable versus the cumulative data of a related variable is a straight line so long as the relation between the variables is a fixed ratio.

1.57 (b)

The possibility of cloud seeding not damaging the storms cannot be entirely ruled out.

■■■■

2 Evaporation, Transpiration & Stream Flow Measurement

2.1 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Anemometer	1. Humidity
B. Rain simulator	2. Evapotranspiration
C. Lysimeter	3. Infiltration
D. Hygrometer	4. Wind speed

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	3	4	1	2
(c)	4	3	2	1
(d)	3	4	2	1

[ESE : 2001]

2.2 The Penman's evapo-transpiration equation is based on

(a) water budget method
(b) energy balance method
(c) mass transfer method
(d) energy balance and mass transfer approach

[ESE : 2002]

2.3 Penman's equation is based on

(a) energy budgeting only
(b) Energy budgeting and water budgeting
(c) Energy budgeting and mass transfer
(d) Water budgeting and mass transfer

[ESE : 2006]

2.4 In the case of large rivers, a number of equidistant vertical sections of the total width of flow are identified, for the purpose of finding by numerical integration, the total discharge on any day. On each section, the mean velocity is taken as the arithmetic average of two typical depths on that section. Then the mean velocity is worked out for that section. Usually, the mean velocity of any section, corresponds to which one of the following? (V represents the point velocity at the given section and the depth such as $0.1d$, $0.2d$.... etc.)

(a) $\frac{V_{0.1d} + V_{0.9d}}{2}$ (b) $\frac{V_{0.2d} + V_{0.8d}}{2}$

(c) $\frac{V_{0.3d} + V_{0.7d}}{2}$ (d) $\frac{V_{0.4d} + V_{0.6d}}{2}$

[ESE : 2006]

2.5 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I	List-II
A. Location	1. Perennial
B. Stability	2. Degrading
C. Variation of discharge	3. Tidal
D. Plan form	4. Braided

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	3	1	2	4
(c)	4	1	2	3
(d)	3	2	1	4

[ESE : 2006]

2.6 A standard, ground-based evaporation pan, corresponding to Indian Standards, is installed at the banks of a surface reservoir. The water surface area on a particular day is 100 hectares. The recorded evaporation loss from the pan, on a certain day, is nearly 4.0 cm. What is the anticipated evaporation loss from the reservoir for that day?

(a) $(1.8 \text{ to } 2) \times 10^4$ m^3 per day
(b) $(2.5 \text{ to } 2.75) \times 10^4$ m^3 per day
(c) $(3.0 \text{ to } 3.25) \times 10^4$ m^3 per day
(d) $(3.8 \text{ to } 4.05) \times 10^4$ m^3 per day

[ESE : 2007]

2.7 How is the average velocity along the vertical in a wide stream obtained?

(a) By averaging the velocities at 0.2 and 0.8 depth from surface.
(b) By measuring velocity at 0.6 depth below the surface.

(c) By measuring velocity at half the depth.
(d) By measuring velocity at 0.1 times the depth below the surface.

[ESE : 2007]

2.8 How is the determination of aquifer parameters *S* (Storage Coefficient) and *T* (Transmissivity Coefficient) done?
1. By recording the drawdown in a pumped well at different time intervals.
2. By recording the drawdown in installed observation wells at different time intervals.

Select the correct answer using the codes given below:
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2007]

2.9 Maximum possible discharge from a small catchment corresponding to a particular rainfall intensity is independent of which one of the following?
(a) Soil moisture conditions
(b) Drainage characteristics of catchment
(c) Area of the catchment
(d) Duration of the rainstorm

[ESE : 2008]

2.10 Consider the following chemical emulsions:
1. Methyl alcohol
2. Cetyl alcohol
3. Stearyl alcohol
4. Kerosene

Which of the above chemical emulsions is/are used to minimize the loss of water through the process of evaporation?
(a) 1 only (b) 1 and 4
(c) 2 and 4 (d) 2 and 3

[ESE : 2009]

2.11 Consider the following with respect to measurement of stream flow during flood:
1. Timing of the travel of floats released in the stream
2. Use of weir formula for spillways provided on a dam
3. Calculation of flow through a contracted opening at a bridge
4. Using a current meter

Which of the above is/are reliable and accurate?
(a) 1 only (b) 4 only
(c) 3 and 4 (d) 2 and 3

[ESE : 2009]

2.12 Calibration of a current meter for use, in channel flow measurement is done in a
(a) wind tunnel (b) water tunnel
(c) towing tank (d) flume

[ESE : 2010]

2.13 A stilling well is required when the stage measurement is made by employing
(a) Bubble gauge
(b) Float gauge recorder
(c) Vertical staff gauge
(d) Inclined staff gauge

[ESE : 2011]

2.14 Consider the following statements:
1. Over the oceans there is more evaporation than precipitation.
2. On land it is more precipitation than evapo-transpiration.

Which of these statements are correct?
(a) Both 1 and 2 (b) Neither 1 nor 2
(c) 1 only (d) 2 only

[ESE : 2012]

2.15 Wading technique is used:
(a) To determine velocity of sea waves during Tsunami
(b) To determine thickness of canal lining in alluvial soils
(c) To measure the volume of dredging material in harbours
(d) To determine velocity of flow in shallow streams

[ESE : 2013]

2.16 Steep rise in the flow-mass curve during a certain period indicates:
(a) Very high evaporation losses during that period
(b) Flash floods during that period
(c) Sudden spurt in irrigation demand during that period
(d) Sudden rise in demand for water to meet hydropower generation

[ESE : 2013]

Answers Evaporation, Transpiration and Stream Flow Measurement

2.1	(c)	2.2	(d)	2.3	(c)	2.4	(b)	2.5	(d)	2.6	(c)	2.7	(b)	2.8	(c)	2.9	(d)
2.10	(d)	2.11	(b)	2.12	(c)	2.13	(b)	2.14	(a)	2.15	(d)	2.16	(b)				

Explanations Evaporation, Transpiration and Stream Flow Measurement

2.1 (c)

An anemometer is a device used for measuring wind speed, and is a common weather station instrument.

A hygrometer is an instrument used for measuring the moisture content in the atmosphere.

A lysimeter is a measuring device which can be used to measure the amount of actual evapotranspiration which is released by plants. By recording the amount of precipitation that an area receives and the amount lost through the soil, the amount of water lost to evapotranspiration can be calculated.

2.2 (d)

Penman's Equation is based on a combination of both energy balance and mass transfer approach.

2.3 (c)

Penman's Equation is based on a combination of both energy budgeting and mass transfer approach.

2.4 (b)

In shallow stream of depth up to about 3.0 m, the average velocity

$$\overline{V} = V_{0.6d}$$

This is called single point observation.

In moderately deep streams the velocity is observed at two points.

$$\therefore \quad \overline{V} = \frac{V_{0.2d} + V_{0.8d}}{2}$$

In rivers having large flood flows, only surface velocity (V_s) is measured within a depth of about 0.5 m from the surface. The average velocity $\overline{V} = kV_s$ where k is in the range of 0.85 to 0.95.

2.5 (d)

(i) A perennial stream is one which always carries some flow. There is considerable amount of groundwater flow contribution throughout the year. The discharge varies considerably throughout the year.

(ii) If the river bed is constantly getting eroded to reduce and dissipate available excess land slope, then the river is known as a degrading river. Such river is in the process of achieving stability.

(iii) Tidal rivers, undergo periodical rise and fall in its water level, depending upon the nature of the tide.

The distance up to which tidal effect is experienced depends upon various factors such as shape and configuration of the river, the tidal range, etc. Thus location of river and ocean confluence is important.

2.6 (c)

Depth of evaporation = $C_P \times$ pan evaporation

where C_P = pan coefficient = 0.8 for ISI standard pan

$\therefore$ Depth of evaporation

$= 0.8 \times 4 \times 10^{-2}$ m per day

The total volume of evaporation

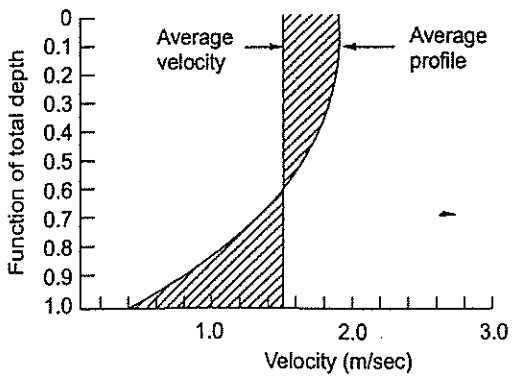
= Depth of evaporation × water surface area

$= 0.8 \times 4 \times 10^{-2} \times 100 \times 10^4$ m^3 per day

$= 3.2 \times 10^4$ m^3 per day

2.7 (b)

The velocity profile shows how the average velocity is usually at 0.6 times the total depth from the water surface, or 0.4 times the total depth from the bottom of the channel. This is why, in shallow channels (< 2.5 ft or < 0.75 m), current meter measurements are made at four tenths of the total depth (from the bottom).



2.8 (c)

Storativity or the storage coefficient is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer. Storativity is a dimensionless quantity, and ranges between 0 and the effective porosity of the aquifer.

Transmissivity is the rate of flow under a unit hydraulic gradient through a unit width of aquifer of given saturated thickness. The transmissivity of an aquifer is related to its hydraulic conductivity as follows:

$$T = Kb$$

where T is transmissivity $[L^2/T]$, K is Transmissivity Coefficient or permeability and b is aquifer thickness $[L]$.

2.10 (d)

Certain chemicals such as cetyl alcohol (hexadecanol) and stearyl alcohol (octadecanol) form monomolecular layers on a water surface. These layers act as evaporation inhibitors by preventing the water molecules to escape past them.

2.11 (b)

Quick stream flow measuring is best done with a water current meter to measure water current velocity. For larger streams, the current velocity meter may be used to measure a vertical profile of water velocity at several points across a stream channel.

Using a weir formula for Spillways provided on a dam & in case of calculation of flow through a contracted opening at a bridge causes losses.

Timing of the travel of floats released in the stream is not reliable.

2.12 (c)

The relation between the stream velocity and revolutions per second of the current meter is called the calibration equation. The calibration equation is unique to each instrument and is determined by towing the instrument in a special tank called towing tank. Towing tank is a long channel containing still water with arrangements for moving a carriage longitudinally over its surface at constant speed. The current meter to be calibrated is mounted on the carriage with the rotating element immersed to a specified depth in the water body in the tank. The carriage is then towed at a predetermined constant speed (v) and the corresponding average value of revolutions per second (N_s) of the instrument determined. This experiment is repeated over the complete range of velocities and a best-fit linear relation in the form of the equation $v = aN_s + b$ where a, b are constants of the current meter.

2.13 (b)

The Float-operated stage recorder is the most common type of automatic stage recorder in use. In this a float operating in a stilling well is balanced by means of a counterweight over the pulley of a recorder.

To protect the float from debris and to reduce the water surface wave effects on the recording stilling wells are provided in all float-type stage recorder installations.

2.14 (a)

Evaporation is more prevalent over the oceans than precipitation, while over the land, precipitation routinely exceeds evaporation. Most of the water that evaporates from the oceans falls back into the oceans as precipitation. Only about 10 percent of the water evaporated from the oceans is transported over land and falls as precipitation. Once evaporated, a water molecule spends about 10 days in the air. The process of evaporation is so great that without precipitation runoff, and groundwater discharge from aquifers, oceans would become nearly empty.

2.15 (d)

The current meter is held at the requisite depth below the surface of the stream vertically by an observer who stands in the water. This technique is known as Wading and is used to determine the velocity of flow in shallow streams.

2.16 (b)

Flow mass curve is a plot of the cumulative discharge volume against time plotted in chronological order, the slope of the mass at any point represents rate of flow at that instant, so flash flood during a period will show steep rise in the flow mass curve.

■■■■

3 Infiltration, Runoff and Hydrograph

3.1 Which one of the following constitute the basic assumption of Unit Hydrograph theory?
(a) Non-linear response and time invariance
(b) Non-linear time variance and linear response
(c) Linear response and linear time variance
(d) Time invariance and linear response
[ESE : 1995]

3.2 The following four hydrological features have to be estimated or taken as inputs before one can compute the flood hydrograph at any catchment outlet:
1. Unit hydrograph
2. Rainfall hydrograph
3. Infiltration index
4. Base flow

The correct order in which they have to be employed in the computations is
(a) 1, 2, 3, 4 (b) 2, 1, 4, 3
(c) 2, 3, 1, 4 (d) 4, 1, 3, 2
[ESE : 1996]

3.3 The following steps are involved in arriving at a unit hydrograph:
1. Estimating the surface runoff in depth.
2. Estimating the surface runoff in volume.
3. Separation of base flow.
4. Dividing surface runoff ordinates by depth of runoff.

The correct sequence of these steps is
(a) 3, 2, 1, 4 (b) 2, 3, 4, 1
(c) 3, 1, 2, 4 (d) 4, 3, 2, 1
[ESE : 1997]

3.4 If a 4-hour unit hydrograph of a certain basin has a peak ordinate of 80 m^3/s, the peak ordinate of a 2-hour unit hydrograph for the same basin will be
(a) equal to 80 m^3/s
(b) greater than 80 m^3/s
(c) less than 80 m^3/s
(d) between 40 m^3/s to 80 m^3/s
[ESE : 1998]

3.5 Match **List-I** (Name of scientists) with **List-II** (Contribution to field of hydrology) and select the correct answer using the codes given below the lists:

List-I
A. Dalton
B. Snyder
C. Blaney-Criddle
D. Sherman

List-II
1. Unit Hydrograph
2. Evaporation
3. Empirical flood formula
4. Synthetic Unit Hydrograph
5. Consumptive use equation

Codes:

	A	B	C	D
(a)	2	3	5	1
(b)	1	4	3	2
(c)	2	4	5	1
(d)	1	3	4	5

[ESE : 1998]

3.6 If the base period of a 6-hour hydrograph of a basin is 84 hours, then a 12 hours unit hydrograph derived from this 6 hour unit hydrograph will have a base period of
(a) 72 hours (b) 78 hours
(c) 84 hours (d) 90 hours
[ESE : 2000]

3.7 Which of the following principles relate to a Unit Hydrograph?
1. The hydrographs of direct runoff due to effective rainfall of equal duration have the same time base.

2. Effective rainfall is not uniformly distributed within its duration.
3. Effective rainfall is uniformly distributed throughout the whole area of drainage basin.
4. Hydrograph of direct run off from a basin due to a given period of effective rainfall reflects the combination of all the physical characteristics of the basin.

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 2001]

3.8 A 3-hour storm on a small drainage basin produced rainfall intensities of 3.5 cm/hr, 4.2 cm/hr and 2.9 cm/hr in successive hours. If the surface runoff due to the storm is 3 cm, then the value of ϕ-index will be

(a) 2.212 cm/hr (b) 2.331 cm/hr
(c) 2.412 cm/hr (d) 2.533 cm/hr

[ESE : 2001]

3.9 Consider the following statements:

1. An ephemeral stream is one which has a base-flow contribution.
2. Flow characteristics of a stream depend upon rainfall and catchment characteri-stics and also the climatic factors which influence evapo-transpiration.
3. Sequent Peak Algorithm is used for estimating run off from rainfall.

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 2 alone

[ESE : 2002]

3.10 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. ϕ-index
B. Lysimeter
C. Dilution technique
D. Snyder's equation

List-II

1. Used for measurement of evapo-transpiration for given vegetation
2. Used for flow measurement
3. Average rainfall above which the rainfall volume is equal to the runoff volume
4. Relates the basin lag to the basin characteristics

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	4	2	1	3
(c)	3	2	1	4
(d)	4	1	2	3

[ESE : 2002]

3.11 A 6-hour rainstorm with hourly intensities of 7, 18, 25, 17, 11 and 3 mm/hour produced a runoff of 39 mm. Then, the ϕ-index is

(a) 3 mm/hour (b) 7 mm/hour
(c) 8 mm/hour (d) 10 mm/hour

[ESE : 2002]

3.12 The Unit-Hydrograph theory is based on the assumption of

(a) nonlinear response and time invariance
(b) linear response and nonlinear time variance
(c) time invariance and linear response
(d) nonlinear response and nonlinear time variance

[ESE : 2002]

3.13 A two-hour storm hydrograph has 5 units of direct runoff. The two-hour unit hydrograph for this storm can be obtained by dividing the ordinates of the storm hydrograph by

(a) 2 (b) 2/5
(c) 5 (d) 5/2

[ESE : 2002]

3.14 **Assertion (A):** Unit hydrograph theory is not applicable to catchment areas larger than 5000 sq. km.

Reason (R): Rainfall is not uniformly distributed on large catchment areas.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

3.15 The following items related to hydrologic requirements in a hydropower system. Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Stream flow in order of magnitude is plotted as ordinate and per cent of time as abscissa.
B. Cumulative value of stream flow is plotted against time for whole period of record.
C. Plot of available power against per cent of time.
D. Plot of flow in a stream against time at specific interval.

List-II

1. Mass curve
2. Flow duration curve
3. Hydrograph
4. Power duration curve

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	2	1	4	3
(d)	4	3	2	1

[ESE : 2002]

3.16 Match List-I (Hydrological terms) with List-II (Relationship/Nature of curve) and select the correct answer using the codes given below the lists:

List-I

A. Theissen Polygon
B. Mass Curve
C. Hyetograph
D. DAD curve

List-II

1. Average depth of rainfall over an area
2. Relationship of rainfall intensity and time
3. Relationship of accumulated rainfall and time
4. Relationship of river run-off and time
5. Always a falling curve

Codes:

	A	B	C	D
(a)	1	3	2	5
(b)	1	5	3	2
(c)	4	3	2	5
(d)	4	5	3	2

[ESE : 2003]

3.17 Which one of the following characteristics describes a watershed system in system's parlance?

(a) Linear
(b) Non-linear
(c) Linear and time-invariant
(d) Non-linear and time-variant

[ESE : 2003]

3.18 A 6-hour storm with hourly intensities of 7, 18, 25, 12, 10 and 3 mm per hour produced a run-off of 33 mm. Then the ϕ-index is

(a) 7 mm/h (b) 3 mm/h
(c) 10 mm/h (d) 8 mm/h

[ESE : 2003]

3.19 A catchment area of 90 hectares has a run-off coefficient of 0.4. A storm of duration larger than the time of concentration of the catchment and of intensity 4.5 cm/hr creates a peak discharge rate of

(a) 11.3 m^3/s (b) 0.45 m^3/s
(c) 450 m^3/s (d) 4.5 m^3/s

[ESE : 2003]

3.20 Consider the following statements:

1. Time-area histogram method aims at developing an IUH.
2. Isochrone is a line joining equal rainfall on a map.
3. Linear reservoir is a reservoir having straight boundaries.
4. Linear channel is a fictitious channel in which an inflow hydrograph passes through with only translation and no attenuation.

Which of these statements are correct ?

(a) 1, 2 and 3 (b) 1 and 4
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

[ESE : 2003]

3.21 In Snyder's method of synthetic unit hydrograph development, basin lag is taken as

(a) the time interval between centroid of the rainfall excess and surface runoff
(b) the time interval from mid point of the unit rainfall excess to the peak of the unit hydrograph
(c) independent of rainfall duration
(d) independent of catchment characteristics

[ESE : 2004]

3.22 A storm with 14 cm precipitation produced a direct runoff of 8 cm. The time distribution of the storm is as shown in the table below:

Time from start (h)	Incremental Rainfall in cm
1	1.0
2	2.0
3	2.8
4	3.3
5	2.5
6	1.8
7	0.6

What is the value of ϕ-index of the storm?

(a) 0.5 cm/h (b) 0.7 cm/h
(c) 0.8 cm/h (d) 0.9 cm/h

[ESE : 2004]

3.23 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Rising limb of a hydrograph
B. Falling limb of a hydrograph
C. Peak rate of flow
D. Drainage density

List-II
1. Depends on intensity of rainfall
2. Function of total channel length
3. Function of catchment slope
4. Function of storage characteristics

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	1	4	3	2
(c)	3	2	1	4
(d)	1	2	3	4

[ESE : 2004]

3.24 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Unit Hydrograph
B. Synthetic unit Hydrograph
C. Darcy's law
D. Rational method

List-II
1. Design flood
2. Permeability
3. Ungauged basin
4. 1 cm runoff

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	2	1	4	3
(c)	4	3	2	1
(d)	4	1	2	3

[ESE : 2004]

3.25 Clark's method aims at which one of the following?
(a) Developing an IUH due to a instantaneous rainfall excess over catchment
(b) Developing stage-discharge relationship
(c) Measurement of infiltration
(d) Flood routing through channels

[ESE : 2004]

3.26 A 6 hour storm has 6 cm of rainfall and the resulting runoff was 3 cm. If ϕ-index remains at the same value, which one of the following is the runoff due to 12 cm of rainfall in 9 hours in the catchment?

(a) 4.5 cm (b) 6.0 cm
(c) 7.5 cm (d) 9.0 cm

[ESE : 2005]

3.27 A catchment has an area of 150 hectares and a run-off/rainfall ratio of 0.40. If due to 10 cm rainfall over the catchment, a stream flow at the catchment outlet lasts for 10 hours, what is the average stream flow in the period?

(a) 60,000 m^3/hr (b) 100 m^3/minute
(c) 3.5 m^3/s (d) 1.33 m^3/s

[ESE : 2005]

3.28 Viewing watershed as a system, which one of the following assumptions is made in the Unit Hydrograph theory?
(a) Non-linearity
(b) Both linearity and time variance
(c) Both time invariance and non-linearity
(d) Both linearity and time invariance

[ESE : 2005]

3.29 Recorded annual maximum 24-hour rainfall magnitudes at stations 'X'are as under:

Years	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Rainfall (cm)	12.0	6.0	4.8	7.9	12.0	14.2	13.6	6.0	3.7	2.9

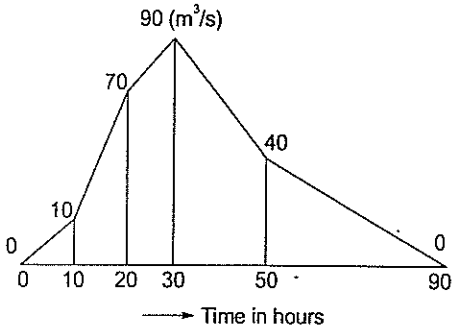
What is the return period, in years, for a 6.0 cm annual rainfall according to (i) Hazen formula and (ii) Weibull formula; respectively?

(a) $\frac{10}{7}, \frac{11}{7}$ (b) $\frac{20}{13}, \frac{22}{13}$

(c) $\frac{5}{3}, \frac{11}{7}$ (d) $\frac{20}{11}, \frac{11}{6}$

[ESE : 2006]

3.30 A DRH due to a storm over a basin has a time base of 90 hours with straight line portions of the hydrograph with flow rates of 0, 10, 70, 90, 40 and 0 m^3/s at elapsed durations of 0, 10, 20, 30, 50 and 90 hours as indicated on the above diagram, respectively. The catchment area is 300 km^2. What is the rainfall excess in the storm?



(a) 2.83 cm (b) 3.46 cm

(c) 3.87 cm (d) 4.02 cm

[ESE : 2006]

3.31 The time of concentration at the outlet in an urban area catchment of 1.5 km^2 area with a run off coefficient of 0.42 is 28 minutes. The maximum depth of rainfall with a 50 year return period for this time of concentration is 48 mm. What is the peak flow rate at the outlet for this return period?

(a) 12 m^3/s (b) 14 m^3/s

(c) 16 m^3/s (d) 18 m^3/s

[ESE : 2006]

3.32 Match List-I (Technique/Principle) with List-II (Purpose) and select the correct answer using the code given below the lists:

List-I

A. ϕ-Index

B. Slope - area method

C. Flow duration curve

D. Dilution technique

List-II

1. Dependable flow
2. Reservoir regulation
3. Steady stream discharge determination
4. Run-off volume
5. Unsteady stream discharge determination

Codes:

	A	B	C	D
(a)	3	5	1	4
(b)	4	1	2	3
(c)	3	1	2	4
(d)	4	5	1	3

[ESE : 2006]

3.33 A 252 km^2 catchment area has a 6 hr UH which is a triangle with time base of 35 hours. What is the peak discharge of the DRH due to 5 cm effective rainfall in 6 hr from that catchment?

(a) 45 cumecs (b) 115 cumecs

(c) 200 cumecs (d) 256 cumecs

[ESE : 2006]

3.34 A 4-hour unit hydrograph of a basin can be approximated as a triangle with a base period of 48 hours and peak ordinate of 300 m^3/s. What is the area of the catchment basin?

(a) 7776 km^2 (b) 5184 km^2

(c) 2592 km^2 (d) 1294 km^2

[ESE : 2006]

3.35 Assertion (A): The unit hydrograph cannot be applied for areas less than 5000 sq. km.

Reason (R): The run-off hydrograph reflects the physiographic factors of a catchment.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 2006]

3.36 Match List-I (Parameter) with List-II (Relatable Term) and select the correct answer using the codes given below the lists:

List-I

A. Rainfall Intensity

B. Rainfall Excess

C. Rainfall Averaging

D. Mass Curve

List-II

1. Isohyets
2. Cumulative rainfall
3. Hyetograph
4. Direct Runoff hydrograph

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	3	4	1	2
(c)	1	3	4	2
(d)	3	4	2	1

[ESE : 2007]

3.37 The total observed runoff volume during a 4 hour storm with a uniform intensity of 2.8 cm/hr is 25.2×10^6 m^3 from a basin of 280 km^2 area. What is the average infiltration rate for the basin?
(a) 3.6 mm/hr (b) 4.8 mm/hr
(c) 5.2 mm/hr (d) 5.5 mm/hr
[ESE : 2007]

3.38 The rainfall hyetograph shows the variation of which one of the following?
(a) Cumulative depth of rainfall with time
(b) Rainfall depth with area
(c) Rainfall intensity with time
(d) Rainfall intensity with cumulative depth of rainfall
[ESE : 2007]

3.39 In constructing a 4 hour synthetic unit hygrograph for a basin, the lag time is estimated to be 40 hours. When will the peak discharge in the Synthetic Unit Hydrograph occur from the start of the storm?
(a) 36 hours (b) 40 hours
(c) 42 hours (d) 44 hours
[ESE : 2007]

3.40 Consider the following statements:
1. Only the surface flow constitutes the flood hydrograph due to an isolated storm.
2. For a given storm, the flood peak is dependent on the drainage density.
3. Fan shaped catchments give narrow hydrograph with low peak.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 3
(c) 2 only (d) 3 only
[ESE : 2007]

3.41 A unit hydrograph for a watershed is triangular in shape with base period of 20 hours. The area of the watershed is 500 ha. What is the peak discharge in m^3/hour?
(a) 7000 (b) 6000
(c) 5000 (d) 4000
[ESE : 2007]

3.42 Kirpich equation is used to determine which one of the following?
(a) Run-off from a given rainfall
(b) Base time of a unit hydrograph
(c) Time of concentration in run-off hydrograph
(d) None of the above
[ESE : 2008]

3.43 A 4 hr storm had 4 cm of rainfall and the resulting direct runoff was 2.0 cm. If the ϕ-index remains at the same value, the runoff due to 10 cm of rainfall in 8 hr in the catchment is
(a) 6.0 cm (b) 7.5 cm
(c) 2.3 cm (d) 2.8 cm
[ESE : 2008]

3.44 A triangular direct runoff hydrograph due to a storm has a time base of 60 hr and a peak flow of 30 m^3/s occurring at 20 hr from the start. If the catchment area is 300 km^2, what is the rainfall excess in the storm?
(a) 50 mm (b) 20 mm
(c) 10.8 mm (d) 8.3 mm
[ESE : 2009]

3.45 A 3 hr unit hydrograph U_1 of a catchment of area 235 km^2 is in the form of a triangle with peak discharge 30 m^3/s. Another 3 hr unit hydrograph U_2 is also triangular in shape and has the same base width as U_1, but has a peak flow of 90 m^3/s. What is the catchment area of U_2?
(a) 117.5 km^2 (b) 235 km^2
(c) 470 km^2 (d) 705 km^2
[ESE : 2009]

3.46 A catchment area of 60 ha has a runoff coefficient of 0.40. If a storm of intensity 3 cm/h and duration longer than the time of concentration occurs in the catchment, then what is the peak discharge?
(a) 2.0 m^3/s (b) 3.5 m^3/s
(c) 4.5 m^3/s (d) 2.5 m^2/s
[ESE : 2009]

3.47 The land use of an area and the corres-ponding runoff coefficients are as follows:

Sl. No.	Land use	Area (ha)	Runoff coefficient
1.	Roads	10	0.70
2.	Lawn	20	0.10
3.	Residential area	50	0.30
4.	Industrial area	20	0.80

What is the equivalent runoff coefficient?

(a) 0.15 (b) 0.36
(c) 0.40 (d) 0.51

[ESE : 2009]

3.48 A catchment of area 200 ha has a runoff coefficient 0.5. A storm of duration larger than the time of concentration of the catchment and of intensity 3.6 cm/h causes a peak discharge of

(a) 5 m^3/s (b) 10 m^3/s
(c) 100 m^3/s (d) 360 m^3/s

[ESE : 2010]

3.49 A catchment consists of 30% area with runoff coefficient 0.40 with the remaining 70% area with runoff coefficient 0.60. The equivalent runoff coefficient will be

(a) 0.48 (b) 0.54
(c) 0.63 (d) 0.76

[ESE : 2010]

3.50 A direct-runoff hydrograph due to isolated storm was triangular in shape with a base of 80 h and peak of 200 m^3/s. If the catchment area is 1440 km^2, the effective rainfall of the storm is

(a) 20 cm (b) 10 cm
(c) 5 cm (d) 2 cm

[ESE : 2010]

3.51 The shape of the recession limb of a hydrograph depends on

(a) basin as well as storm characteristics
(b) storm characteristics only
(c) basin characteristics only
(d) base flow only

[ESE : 2010]

3.52 An S-curve hydrograph has been obtained for catchments of 270 km^2 from a 3 hour unit hydrograph. The equilibrium discharge for the S-curve is

(a) 750 m^3/s (b) 277.8 m^3/s
(c) 250 m^3/s (d) 187 m^3/s

[ESE : 2010]

3.53 The rainfall on five successive days on a catchment was 3, 6, 9, 5 and 1 cm respectively. If the ϕ-index for the storm can be assumed to be 3 cm/day, the total direct runoff from the catchment due to this storm is

(a) 11 cm (b) 24 cm
(c) 9 cm (d) 20 cm

[ESE : 2012]

3.54 The excess runoff hydrograph from a catchment area 10 km^2 due to a storm of 6 hrs duration has been observed to be triangular in shape. The peak flow is observed to be 10 m^3/s and the base length is 20 hrs. The rainfall excess in the catchment is

(a) 5.1 cm (b) 3.6 cm
(c) 4.5 cm (d) 2.5 cm

[ESE : 2012]

3.55 An urban area is located in plains having "average climatic conditions". The impervious area thereof for which drainage must be provided is 3.6 ha and the design rainfall intensity is 2.0 cm/hr. The drains will be designed for a runoff of

(a) 0.05 m^3/s (b) 0.10 m^3/s
(c) 0.20 m^3/s (d) 0.40 m^3/s

[ESE : 2012]

3.56 The theory of synthetic hydrograph based on flood routing techniques is based on the principle that rainfall impulse (net storm rain) is modified by the factors.

1. The time of travel of the flow volume in channel and overland flow
2. Storage
3. Both translation and storage

(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2013]

3.57 A mean annual runoff of 2 m^3/s from a catchment of area 10 km^2 represents an effective rainfall of nearly:

(a) 530 cm (b) 590 cm
(c) 630 cm (d) 658 cm

[ESE : 2013]

3.58 The peak magnitude of a flood hydrograph during 4 hr study duration over a catchment is 300 m^3/s. The total depth of rainfall is 6 cm, and the infiltration loss during the said 4 hr period is 2 cm. A constant uniform base flow of 20 m^3/s is premised throughout. The peak value of the corresponding 4 hr unit hydrograph is

(a) 75 m^3/s (b) 70 m^3/s
(c) 50 m^3/s (d) 40 m^3/s

[ESE : 2014]

3.59 The rainfall on 5 successive days in a catchment was 2, 7, 8, 4 and 3 cm. If the ϕ index for the storm is 3 cm/day, the total direct run-off volume generated from a 195 km^2 catchment is

(a) 19.5 M m^3 (b) 23.4 M m^3
(c) 15.6 M m^3 (d) 32.5 M m^3

[ESE : 2014]

3.60 The best estimate of runoff represented by 57 mm of runoff depth from a basin area 3300 km^2 is nearly

(a) 2300 cumec-days
(b) 2225 cumec-days
(c) 2175 cumec-days
(d) 2020 cumec-days

[ESE : 2014]

3.61 A direct runoff hydrograph due to a storm idealized into a triangular shape has a peak flow rate of 60 m^3/s occurring at 25 hours from its start. If the base width of this hydrograph is 72 hours, and the catchment area is 777.6 km^2, the run-off from the storm is

(a) 1 cm (b) 2 cm
(c) 5 cm (d) 10 cm

[ESE : 2014]

3.62 If the direction of advance of a storm is the same as the direction of the resulting runoff in the drainage basin, such runoff will generally

(a) Be more than the 'rational' run-off through a short time
(b) Result in increased infiltration through a short time
(c) Be less than the 'rational' runoff through a short time
(d) Result in increased evaporation, as also transpiration, loss

[ESE : 2014]

Directions: The following items consists of two statements; one labelled as **'Statement (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

3.63 **Statement (I):** Instantaneous unit hydrograph (IUH) is used in theoretical analysis of rainfall excess-runoff characteristics of a catchment.

Statement (II): For a given catchment, IUH, being independent of rainfall characteristics, is indicative of the catchment storage characteristics.

[ESE : 2014]

3.64 **Statement (I):** Theoretically an infinite number of unit graphs are possible for a given basin.

Statement (II): The rainfall duration and its areal distribution affect the hydrograph.

[ESE : 2014]

3.65 A 4-hour rainfall in a catchment of 250 km^2 produces rainfall depths of 6.2 cm and 5 cm in successive 2-hour unit periods. Assuming the ϕ index of the soil to be 1.2 cm/hour, the runoff volume is

(a) 1.6 ha-m (b) 16 ha-m
(c) 160 ha-m (d) 1600 ha-m

[ESE : 2015]

3.66 Consider the following steps which are involved in arriving at a unit hydrograph:

1. Separation of base flow
2. Estimating the surface runoff in volume
3. Estimating the surface runoff in depth
4. Dividing surface runoff ordinate by depth of runoff

Which is the correct sequence of these steps?

(a) 4, 3, 2 and 1 (b) 1, 2, 3 and 4
(c) 4, 2, 3 and 1 (d) 1, 3, 2 and 4

[ESE : 2015]

3.67 S-Curve Hydrograph is the hydrograph
(a) producing 1 cm of runoff over the basin
(b) of flow from a 1 cm intensity rain of infinite duration
(c) having a volume of 1 cm^3
(d) of the total storm duration in any single storm rainfall

[ESE : 2015]

3.68 Surface Runoff represents total water
(a) flowing in surface channels after the rainfall.
(b) obtained after deducting from rainfall water what has infiltrated and/or evaporated, from the total rainfall.
(c) excluding the base flow in surface channels after the rainfall.
(d) flown (or flowing) through all channels over a specified period of time.

[ESE : 2015]

3.69 A peak flow of a flood hydrograph due to a six-hour storm is 470 m^3/s. The corresponding average depth of rainfall is 8 cm. Assume infiltration loss of 0.25 cm/hour and a constant base flow of 15 m^3/s. What is the peak discharge of 6 hour unit hydrograph for this catchment?
(a) 60 m^3/s (b) 70 m^3/s
(c) 80 m^3/s (d) 90 m^3/s

[ESE : 2016]

3.70 Over a basin of area 333 km^2, there was a storm for 6h with a uniform intensity of 2 cm/h. The observed runoff was 20×10^6 m^3. The observed rate of infiltration for the basin was
(a) 5 mm/h (b) 10 mm/h
(c) 20 mm/h (d) 40 mm/h

[ESE : 2016]

3.71 In the standard SCS-CN method of modeling runoff due to daily rainfall, if CN = 75, the runoff magnitude for a one-day rainfall of 100 mm is nearly
(a) 17 mm (b) 31 mm
(c) 41 mm (d) 57 mm

[ESE : 2017]

3.72 An 8-hour storm with incremental rainfall during each successive hour is tabulated herewith. What will be the correction to total runoff when, whereas the actual φ index was 0.5 cm/hour, a wrong magnitude of 0.6 cm/hour was adopted in computing the total runoff?

Time from start (hour)	1	2	3	4	5	6	7	8
Incremental rainfall in each hour (cm)	0.4	0.8	1.2	0.9	1.8	1.0	0.3	0.8

(a) +1.0 cm (b) +0.9 cm
(c) +0.8 cm (d) +0.6 cm

[ESE : 2017]

3.73 Statement (I): Collin's method for the determination of the unit hydrograph for a multi-period storm considers residuals as attributable to the unit graph of the period of the largest rain.
Statement (II): Collin's method is *ab initio* premised on the Bernard method where a unit graph is necessarily to be proportional to the net rain.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2017]

Answers Infiltration, Runoff and Hydrograph

3.1 (d)	3.2 (c)	3.3 (a)	3.4 (b)	3.5 (c)	3.6 (d)	3.7 (d)	3.8 (d)	3.9 (c)	
3.10 (a)	3.11 (c)	3.12 (c)	3.13 (c)	3.14 (a)	3.15 (c)	3.16 (a)	3.17 (c)	3.18 (d)	
3.19 (d)	3.20 (b)	3.21 (b)	3.22 (d)	3.23 (a)	3.24 (c)	3.25 (a)	3.26 (c)	3.27 (b)	
3.28 (d)	3.29 (d)	3.30 (d)	3.31 (d)	3.32 (d)	3.33 (c)	3.34 (c)	3.35 (d)	3.36 (b)	
3.37 (d)	3.38 (c)	3.39 (c)	3.40 (c)	3.41 (c)	3.42 (c)	3.43 (a)	3.44 (c)	3.45 (d)	
3.46 (a)	3.47 (c)	3.48 (b)	3.49 (b)	3.50 (d)	3.51 (c)	3.52 (c)	3.53 (a)	3.54 (b)	
3.55 (c)	3.56 (c)	3.57 (c)	3.58 (b)	3.59 (a)	3.60 (c)	3.61 (a)	3.62 (a)	3.63 (a)	
3.64 (b)	3.65 (d)	3.66 (b)	3.67 (b)	3.68 (b)	3.69 (b)	3.70 (b)	3.71 (c)	3.72 (d)	
3.73 (d)									

Explanations Infiltration, Runoff and Hydrograph

3.1 (d)

Time invariance and linear response are the two basic assumptions of UH-theory. Other assumptions are:

(i) Rainfall excess occurs uniformly over the basin

(ii) The distribution of storm over the basin is uniform.

3.2 (c)

First determine the rainfall hydrograph and then infiltration index. The effective rainfall can be determined from the rainfall hydrograph and infiltration index. Now multiply the ordinates of unit hydrograph by effective rainfall. This will give direct runoff hydrograph (DRH). Finally add base flow to the DRH and flood hydrograph can be obtained.

3.3 (a)

The separation of base flow gives direct runoff hydrograph (DRH). The area under the DRH gives volume of surface runoff. The effective depth of precipitation can be obtained by using ϕ-index or volume of surface runoff can be divided by the catchment area. Finally the ordinates of UH can be obtained by dividing the ordinates of DRH by effective depth of precipitation.

3.4 (b)

With the reduction of unit hydrograph duration, 1 cm excess rainfall will occur in reduced period. So peak ordinate of UH will increase and time base will decrease. Thus the peak ordinate of 2 hr UH will be greater than 80 m^3/s.

3.5 (c)

$$E_L = C(e_w - e_a)$$

This equation is known as Dalton's law of evaporation after John Dalton who first recognized this law. Evaporation continuous till $e_w = e_a$. If $e_w > e_a$ Condensation takes place.

Snyder was the one to develop a synthetic UH based on a study of watersheds in the Appalachian Highlands. In basins ranging from 10 – 10,000 mi^2

Snyder relations are $t_p = C_t (L L_C)^{0.3}$

The Blaney–Criddle equation is a relatively simplistic method for calculating evapotranspiration. The equation is ideal when only air-temperature datasets are available for a site. Given the coarse accuracy of the equation, it is recommended that it should be used to calculate evapotranspiration for periods of one month or greater.

3.6 (d)

The 12-hr Unit Hydrograph will be obtained by adding the ordinates of 6-hr and ordinates of 6-hr UH lagged by 6-hr and then dividing the ordinates by 2. So the base period for 12 hr UH will be, 84 + 6 = 90 hr.

Base period of derived UH

$$T_B = t_B + \left(\frac{D}{d} - 1\right) \times d = t_B + (D - d)$$

where

t_B is base period of known UH

D is duration of derived UH

d is duration of known UH.

3.7 (d)

In a given period of effective rainfall, the hydrograph of direct runoff from a basin reflects the combination of rainfall characteristics and the physical characteristics of the basin.

Effective rainfall is assumed to be constant and uniformly distributed over the basin, i.e., if there are N rain gauges spread uniformly over the basin, then all the gauges should record almost same amount of rainfall during the specified time.

Also the hydrographs of direct runoff due to effective rainfall of equal duration have the same time base.

3.8 (d)

Total rainfall = 3.5 + 4.2 + 2.9 = 10.6 cm

Effective rainfall = 3 cm

Infiltration = 10.6 – 3 = 7.6 cm

Assuming infiltration to occur for three hours.

$\therefore \quad t_e = 3$ hrs

$$\phi\text{-index} = \frac{7.6}{3} = 2.53 \text{ cm/hr}$$

3.9 (c)

Ephemeral stream is one which does not have any base flow contribution. It does not have any well defined channel.

3.10 (a)

The rate at which water infiltrates into a ground is called the infiltration capacity. For an initially dry soil subjected to rain, the infiltration capacity curve shows an exponentially decaying trend. Initially the rate of infiltration is high but it soon decreases, as most of the soil gets moist. The rate of infiltration reaches a uniform rate after some time.

For consistency in hydrological calculations, a constant value of infiltration rate for the entire storm duration is adopted. The average infiltration rate is called the Infiltration Index and the two types of indices commonly used are ö – index and W – index.

The ϕ-index is defined as the rate of infiltration above which the rainfall volume equals runoff volume.

A lysimeter is a measuring device which can be used to measure the amount of actual evapotranspiration which is released by plants. By recording the amount of precipitation that an area receives and the amount lost through the soil, the amount of water lost to evapotranspiration can be calculated. Lysimeters are of two types: weighing and non-weighing.

Dilution technique is used for flow measurement of small and turbulent streams.

3.11 (c)

Total rainfall = 7 + 18 + 25 + 17 + 11 +3

= 81 mm

Effective rainfall = 39 mm

Infiltration = 81 – 39 = 42 mm

Assuming t_e = 6 hrs

$$\phi\text{-index} = \frac{42}{6} = 7 \text{ mm/hr}$$

This value exceeds 7 and 3 mm/hour rainfall intensity so there will be no runoff during these hours.

Net infiltration for 4 hours

$$= 42 - 10 = 32 \text{ mm}$$

$$\phi = \frac{32}{4} = 8 \text{ mm/hr}$$

3.13 (c)

The 2 hour unit hydrograph is obtained by dividing the ordinates of storm hydrograph by the direct runoff depth which is 5 units.

3.14 (a)

The size of catchment imposes upper limit and lower limit for application of UH. Above 5000 km^2 the centre of the storm can vary from storm to storm and each can give different DRHs under otherwise identical situations. The rainfall will be nonuniform in these conditions. The lower limit for UH theory is 200 ha. At this level of area, a Number of factors affect the rainfall-runoff relationship and the UH is not accurate enough for the prediction of DRH.

3.15 (c)

A flow duration curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest.

A Mass curve is the graph of the cumulative values of a hydrologic quantity (such as precipitation or runoff), generally as the Ordinate, plotted against time or date as the Abscissa.

A hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river, or other channel or conduit carrying flow.

3.16 (a)

Methods used to convert point rainfall values at different raingauge stations into an average value over a catchment include

- Arithmetical Mean Method
- Thiessen Polygon Method
- Isohyetal Method

A Mass curve is the graph of the cumulative values of a hydrologic quantity (such as precipitation or runoff), generally as the Ordinate, plotted against time or date as the Abscissa.

3.18 (d)

Total rainfall = 7 + 18 + 25 + 12 + 3 = 75 mm
Effective rainfall = 33 mm
Infiltration = 65 – 33 = 42 mm
Assuming t_e = 6 hrs

$$\phi = \frac{42}{6} = 7 \text{ mm/hr}$$

It is greater than 3 mm/hr and 7 mm/hr
So for 4 hour the infiltration would be
42 – 10 = 32 mm

$$\therefore \text{ index} = \frac{32}{4} = 8 \text{ mm/hr}$$

3.19 (d)

$Q_P = kiA/36$
where
Q_P is Peak discharge in m^3/s
i is intensity in cm/hour
A is Area in ha

$$\therefore Q_P = \frac{0.4 \times 4.5 \times 90}{36} = 4.5 \text{ m}^3/\text{s}$$

If area is in km^2 and intensity in mm/hr, then

$$Q_p(\text{m}^3/\text{s}) = \frac{kiA}{3.6}$$

3.20 (b)

Clark's method of IUH as time area histogram method is used to develop an Instantaneous unit hydrograph due to the Instantaneous rainfall excess over a catchment.

Isochrones are imaginary lines across the catchment from where water particles traveling downward take the same time to reach the catchment outlet. The concept of Isochrones is helpful for explaining the effective duration of a uniform rainfall on the shape of hydrograph.

A linear reservoir is characterized by a linear relationship between the storage and the output.

A linear channel is characterized by continuity and momentum equations. It is a fictitious channel in which the time required to translate a discharge Q through a given reach is constant, in such channels inflow hydrograph passes through with only translation and no attenuation.

3.21 (b)

Snyder was the one to develop a synthetic Unit Hydrograph based on a study of watersheds in the Appalachian Highlands. In basins ranging from 10 – 10,000 mi^2

Snyder relations are $t_p = C_t (L L_C)^{0.3}$

where t_p = basin lag (hr)

L = length of the main stream from the outlet to the divide (mi)

L_c = length along the main stream to a point nearest the watershed centroid (mi)

C_t = Coefficient usually ranging from 1.8 to 2.2

3.22 (d)

Total rainfall = 14 cm
Direct runoff = 8 cm
Infiltration = 14 – 8 = 6 cm
Assuming t_e = 7 hours

$$\phi = \frac{6}{7} = 0.86 \text{ cm/hr}$$

It is greater than 0.6 cm/hr
∴ For 6 hrs, infiltration = 6 – 0.6 = 5.4 cm

$$\therefore \quad \phi = \frac{5.4}{6} = 0.9 \text{ cm/hr}$$

3.23(a)

The rising limb of a hydrograph is also known as concentration curve and it represents the increase in discharge due to the gradual building up of storage in channels and over the catchment surface.

3.24 (c)

In India, only a small number of streams are gauged (i.e., stream flows due to single and multiple storms, are measured). There are many drainage basins (catchments) for which no stream flow records are available and unit hydrographs may be required for such basins. In such cases, hydrographs may be synthesized directly from other catchments, which are hydrologically and meteorologically homogeneous, or indirectly from other catchments through the application of empirical relationship. Unit hydrograph thus derived is called Synthetic Unit Hydrograph.

Darcy's law at constant elevation is a simple proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance. This equation for single phase fluid flow is the defining equation for absolute permeability (single phase permeability).

3.25(a)

Clark's method, also known as Time-area histogram method aims at developing an IUH due to an instantaneous rainfall excess over a catchment. It is assumed that the rainfall excess first undergoes pure translation and then attenuation. The translation is achieved by a travel time-area histogram and the attenuation by routing the results of the above through a linear reservoir at the catchment outlet.

3.26(c)

$$\phi - \text{index} = \frac{6-3}{6} = 0.5 \text{ cm/hr}$$

Infiltration for 9 hour rainfall

$$= 9 \times 0.5 = 4.5 \text{ cm}$$

Runoff due to 12 cm rainfall

$$= 12 - 4.5 = 7.5 \text{ cm}$$

3.27(b)

Runoff = $150 \times 10^4 \times 0.4 \times 0.1 = 60{,}000 \text{ m}^3$

$$\text{Average stream flow} = \frac{60{,}000}{10 \times 60} = 100 \text{ m}^3/\text{minute}$$

3.28 (d)

The primary assumption of unit hydrograph theory is that the rainfall has uniform distribution, both in space – with minimal variations across the basin – and in time; in other words, the rainfall rate does not vary much during the event.

3.29(d)

The data are arranged in descending order

Rainfall	Order (m)
14.2	1
13.6	2
12.0	3
12.0	4
7.9	5
6.0	6
6.0	7
4.8	8
3.7	9
2.9	10

$$\text{Probability, } P = \left(\frac{m-0.5}{N}\right) \text{ Hazen's formula}$$

$$= \frac{m}{N+1} \text{ Weibull's formula}$$

$$\text{Return period } T = \frac{1}{P}$$

For 6.0 cm rainfall $m = 6$

(i) $T = \frac{10}{5.5} = \frac{20}{11}$

(ii) $T = \frac{N+1}{m} = \frac{11}{6}$

3.30(d)

$$\text{Area under DRH} = \frac{1}{2} \times 10 \times 10 + \frac{(10+70) \times 10}{2} + \left(\frac{70+90}{2}\right) \times 10$$

$$+\left(\frac{90+40}{2}\right)\times 20+\frac{40}{2}\times 40$$

$= 3350\ m^3hr/s = 12.06 \times 10^6\ m^3$

$$\therefore \text{ Rainfall excess} = \frac{12.06\times 10^6}{300\times 10^6}$$

$= 0.0402\ m = 4.02\ cm$

3.31 (d)

The mean intensity of precipitation for a duration equal to time of concentration and an exceedence probability P,

$$i_{t,cp} = \frac{48}{(28/60)} = \frac{720}{7} mm/h$$

Peak discharge from Rational formula

$$Q = \frac{C\, i_{t,cp} A}{3.6} = 0.42\times\frac{720}{7}\times\frac{1.5}{3.6}$$

$= 18\ m^3/s$

3.32 (d)

Dilution technique is used for stream flow measurement. The two dilution techniques used are (1) the steady feed method and (2) the instantaneous, point - source time indigenous method.

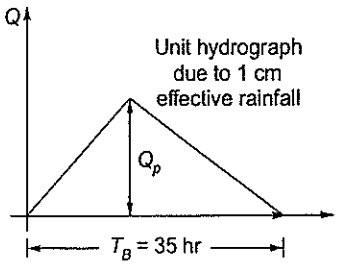
Advantages: They condense in closed conduits, such as penstocks, sewers pipe lines, where current-meter measurements are difficult, and they are fast and accurate.

Disadvantages: Expensive for measuring large stream and the special equipments required for the measurements of concentration.

When it is not possible to make direct measurement especially during floods, slope-area method is a most commonly used indirect method of measurement. In this method discharge is computed on the basis of a uniform flow equation involving channel characteristics, water surface profile and a roughness coefficient. The drop in water surface profile for a uniform reach of channel represents losses caused by bed roughness. Discharge is calculated using Manning's equation is used in this method.

A flow duration curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest.

3.33 (c)



From the unit hydrograph

$$\frac{Q_p T_B}{2} = A\times\left(\frac{1}{100}\right)$$

$$\frac{Q_p\times 35\times 3600}{2} = \frac{252\times 10^6}{100}$$

$$\therefore \quad Q_p = 40\ m^3/s$$

The peak discharge due to 5 cm effective rainfall is $5 \times 40 = 200\ m^3/s$

3.34 (c)

$$\frac{Q_P T_B}{2} = A\times\frac{1}{100}$$

$$A = \frac{300\times 48\times 3600\times 100}{2\times 10^6}$$

$$= \frac{3\times 48\times 36}{2} = 2592\ km^2$$

3.35 (d)

A unit hydrograph is applicable for an area greater than 2 km^2 and less than 5000 km^2

3.36 (b)

A hyetograph is a graphical representation of the distribution of rainfall over time.

Isohyet is a line on a map connecting points having the same amount of rainfall in a given period.

A Mass curve is the graph of the cumulative values of a hydrologic quantity (such as precipitation or runoff), generally as the Ordinate, plotted against time or date as the Abscissa.

Direct runoff hydrograph (DRH) is effective rainfall occurring uniformly over a watershed at a uniform rate over a particular period of time.

3.37 (d)

The average infiltration rate is also called W-index. Thus

$$W = \frac{P - R - I_a}{t}$$

where, P = Total storm precipitation depth
R = Total storm runoff depth
t = time of rainfall excess
I_a = Initial losses in terms of depth

$\therefore \quad P = 2.8 \times 10 \times 4 = 112$ mm

$$R = \frac{25.2 \times 10^6 \times 10^3}{280 \times 10^6} = 90 \text{ mm}$$

$t_c = 4$ hr
$I_a = 0$

$$\therefore \quad W = \frac{112 - 90}{4} = 5.5 \text{ mm/hr}$$

3.38 (c)

A rainfall hyetograph is a plot of intensity of rainfall against the time interval.

3.39 (c)

The time when the peak discharge occurs from the start of the storm may be given as

$$t_{pk} = \frac{t_R}{2} + t_P = \frac{4}{2} + 40 = 42 \text{ hours}$$

3.40 (c)

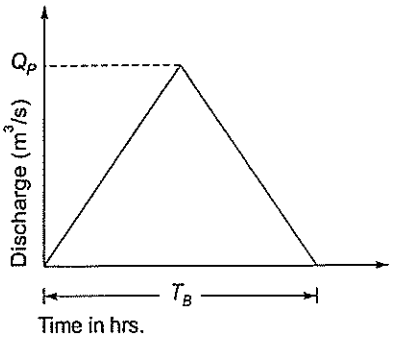
The flood hydrograph consists of flow in all the three phases of runoff, viz. surface runoff, interflow and base flow.

The factors affecting flood hydrograph are shape, size, slope and drainage density. A large drainage density creates situation conducive for quick disposal of runoff down the channels. This fast response is reflected in a pronounced peak discharge.

Fan shaped i.e. nearly semicircular shaped catchments give high peak and narrow hydrographs while elongated catchments give broad and low-peaked hydrographs.

3.41 (c)

The unit hydrograph is shown below:



From this Unit Hydrograph

$$\frac{Q_P T_B}{2} = A \times \left(\frac{1}{100}\right)$$

$$\Rightarrow \quad \frac{Q_P \times 20}{2} = 500 \times 10^4 \times \frac{1}{100}$$

$$\Rightarrow \quad Q_P = 5000 \text{ m}^3/\text{s}$$

3.42 (c)

Kirpich equation is an empirical relation used for the estimation of the time concentration. It is given as

$$t_c = 0.01947\, L^{0.77} S^{-0.385}$$

where t_c = time of concentration in minutes
L = maximum length of travel of water (m)
S = slope of the catchment = $\frac{\Delta H}{L}$
ΔH = difference in elevation between the most remote point on the catchment outlet.

3.43 (a)

$$(\phi - \text{index})_4 = \frac{P - R}{t_e} = \frac{4 - 2}{4} = 0.5 \text{ cm/hr}$$

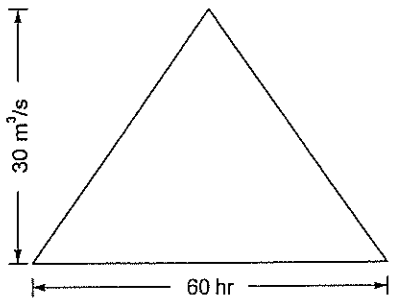
But, $(\phi\text{-index})_4 = (\phi\text{-index})_8$

$$\Rightarrow \quad 0.5 = \frac{10 - R}{8}$$

$$\Rightarrow \quad R = 10 - 4$$

$$\Rightarrow \quad R = 6 \text{ cm}$$

3.44 (c)



Area of direct runoff hydrograph
= Total volume of excess rainfall (V)

$$\Rightarrow \quad \frac{1}{2} \times 30 \times 60 \times 60 \times 60$$

= Total volume of excess rainfall (V)

$\Rightarrow$ Depth of excess rainfall

$$= \frac{V}{\text{catchment area}}$$

$$= \frac{30 \times 60 \times 60 \times 60 \times 10^3}{2 \times 300 \times 10^6} = 10.8 \text{ mm}$$

3.45(d)

Time base of both the unit hydrographs is same.

Let it be t.

$$\therefore \quad \frac{1}{2}\times 30\times t\times\frac{1}{235} = \frac{1}{2}\times 90\times t\times\frac{1}{A_2}$$

$$\Rightarrow \quad A_2 = 235\times 3$$

$$\Rightarrow \quad A_2 = 705\ \text{km}^2$$

3.46(a)

The peak discharge is given by

$$Q_p = kiA$$

$$= 0.40\times\frac{3\times10^{-2}}{60\times60}\times60\times10^4$$

$$= 2.0\ \text{m}^3/\text{s}$$

3.47(c)

$$K_{eq} = \frac{K_1A_1 + K_2A_2 + K_3A_3 + K_4A_4}{A_1 + A_2 + A_3 + A_4}$$

$$= \frac{0.70\times10 + 0.10\times20 + 0.30\times50 + 0.80\times20}{10+20+50+20}$$

$$= 0.4$$

3.48(b)

As per rational formula, the peak value of discharge is expressed as

$$Q_p = KAi$$

$$= 0.5\times200\times10^4\times\frac{3.6\times10^{-2}}{3600}$$

$$= 10\ \text{m}^3/\text{s}$$

3.49(b)

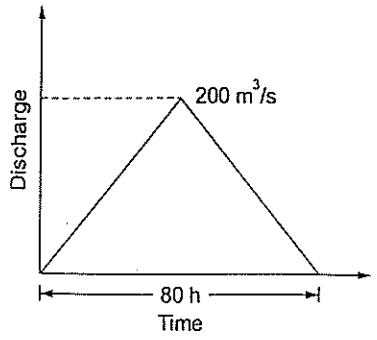
The equivalent runoff coefficient is given by

$$K = \frac{K_1A_1 + K_2A_2}{A_1 + A_2}$$

$$= \frac{0.4\times0.3 + 0.6\times0.7}{0.3+0.7}$$

$$= 0.54$$

3.50(d)



$\therefore$ Total runoff = Area of triangle

$$= \frac{1}{2}\times80\times3600\times200$$

$$= 28.8\times10^6\ \text{m}^3$$

Area of catchment = 1440 km^2

$$\therefore \text{ Effective rainfall} = \frac{\text{Total runoff}}{\text{Area of catchment}}$$

$$= \frac{28.8\times10^6}{1440\times10^6}$$

$$= 0.02\ \text{m}$$

$$= 2\ \text{cm}$$

3.51(c)

The climatic factors control the rising limb and the recession limb is independent of storm characteristics, being determined by catchment characteristics only.

3.52(c)

The equilibrium discharge is expressed as

$$Q_s = \frac{A}{D}\times10^4\ \text{m}^3/\text{h}$$

where A is area of catchment in km^2 and D is duration in hours.

$$\therefore \quad Q_s = \frac{270}{3}\times10^4$$

$$= 90\times10^4\ \text{m}^3/\text{h}$$

$$= \frac{90\times10^4}{3600}\ \text{m}^3/\text{s}$$

$$= 250\ \text{m}^3/\text{s}$$

3.53 (a)

Day	Rainfall (cm)	Runoff (cm)
1	3	0
2	6	3
3	9	6
4	5	2
5	1	0
		$\Sigma R = 11$ cm

3.54 (b)

$$\text{Total runoff in m}^3 = \left(\frac{1}{2}\times20\times60\times60\times10\right)$$

$$= 360{,}000\ \text{m}^3$$

$$\therefore \text{ Rainfall excess} = \left(\frac{360{,}000}{10\times10^6}\right)\text{m}$$

$$= 0.036\text{ m}$$

$$= 3.6\text{ cm}$$

3.55 (c)

The runoff, Q is given by

$$Q = \frac{1}{36}\text{k.p.A}$$

$$K = 1\text{ (impervious)}$$

$$\therefore \quad Q = \frac{1}{36}\times1\times2\times3.6$$

$$= 0.2\text{ m}^3\text{/sec}$$

3.56 (c)

According to Snyder the shape of synthetic unit hydrograph is likely to be affected by basin characteristics like area, topography, shape of the slope, drainage density and channel storage. So, according to the theory synthetic hydrograph is affected by:

1. The time of travel, i.e. translation time of the flow volume in channel and overland flow.
2. Both translation and storage capacity of the basin.

3.57 (c)

$$Q = 2\text{ m}^3\text{/s}$$

$$= 2\times3600\times24\times365\text{ m}^3\text{/yr}$$

$$= 63.072\times10^6\text{ m}^3\text{/yr}$$

$$A = 10\text{ km}^2 = 10\times10^6\text{ m}^2$$

$\therefore$ Annual volume

$$= 10\times10^6\text{ y} = 63.072\times10^6$$

$\Rightarrow \quad y = 6.3072\text{ m} = 630.72\text{ cm}$

3.58 (b)

Effective rainfall

$$= 6 - 2 = 4\text{ cm}$$

Peak of effective hydrograph

$$= 300 - 20 = 280\text{ m}^3\text{/sec.}$$

The peak value of 4 hr unit hydrograph

$$= \frac{280}{4} = 70\text{ m}^3\text{/sec.}$$

3.59 (a)

Total direct runoff

$$= (7-3) + (8-3) + (4-3)$$

$$= 10\text{ cm}$$

So, Volume generated

$$= \frac{10}{100}\times195\times10^6\text{ m}^3$$

$$= 19.5\times10^6\text{ m}^3 = 19.5\text{ Mm}^3$$

3.60 (c)

Best estimated runoff

$$= \frac{\text{Total volume generated}}{\text{duration}}$$

$$= \frac{\left(57\times10^{-3}\right)\times3300\times10^6}{24\times60\times60}$$

$$= 2177.083$$

$$\simeq 2175\text{ cumec - days}$$

3.61 (a)

$$\text{Total runoff} = \frac{1}{2}\times60\times72\times3600$$

$$= 7776000\text{ m}^3$$

Depth of runoff

$$= \frac{\text{Total runoff}}{\text{Catchment area}}$$

$$= \frac{7776000}{777.6\times10^6}\text{m} = \frac{1}{100}\text{m}$$

$$= 0.01\text{ m} = 1\text{ cm}$$

3.63(a)

In order to obtain the runoff hydrograph resulting from a storm of varying intensities, it is preferable to have a unit hydrograph of very short duration, theoretically, the shortest duration is zero. Accordingly if duration of effective rainfall approach, zero, the unit hydrograph is called as an instantaneous unit hydrograph, generally abbreviated as IUH.

The advantage of IUH over unit hydrograph (Sharman, 1932) is that the IUH overcomes the problem of duration of rainfall and the restriction on uniform distribution of rainfall.

3.64(b)

The unit hydrograph (UH) of a basin is defined as the hydrograph resulting from an effective rainfall of 1 unit evenly distributed over the basin during the time D. Theoretically an infinite number of unit hydrograph, are possible for a given basin. The

following hypothesis are considered while the linear unit hydrograph is used as a transfer function.

1. The unit hydrograph reflects the ensemble of the physical characteristics of the river basin.
2. The effective rainfall is uniformly distributed over the catchment.
3. The shape characteristics of the unit hydrograph are independent of time. Therefore duration of the unit hydrograph is constant regardless the effective rainfall intensity.

3.65 (d)

Net runoff depth

$= (6.2 - 2 \times 1.2) + (5 - 2 \times 1.2)$

$= 6.4$ cm $= 0.064$ m

Runoff volume of catchment

= Runoff depth × Area

$= 0.064 \times 250 \times 10^6 \times 10^{-4}$ ha-m

$= 1600$ ha-m

3.66 (b)

- The separation of base flow gives Direct Runoff Hydrograph (DRH).
- The area under the DRH gives volume of surface runoff.
- The effective depth of precipitation can be obtained by using index or volume of surface runoff divided by the catchment area.
- Finally the ordinates of UH can be obtained by dividing the ordinates or DRH by effective depth of precipitation.

3.67 (b)

S-curve hydrograph is the hydrograph of flow from a 1 cm intensity rain of infinite duration.

3.68 (b)

According to water balance,

Runoff + Evapotranspiration + Infiltration/ Recharge = Precipitation

3.69 (b)

Peak discharge of 6 hr hydrograph = 470 m^3/s

$\therefore$ Peak discharge of D.R.H

= 470 – base flow

= 470 – 15 = 455 m^3/s

Now, Rainfall excess depth

= Total rainfall – Infiltration losses

= 8 cm – 0.25 × 6

= 8 – 1.5 = 6.5 cm

$\therefore$ Peak discharge of UH

$$= \frac{455}{6.5} = 70 \text{ m}^3/\text{s}$$

3.70 (b)

$A = 333$ km^2

Storm duration is 6 hr and intensity 2 cm/hr

Let rate of infiltration be x mm/hr

$$(2 - 0.1x) \times 10^{-2} \times 6 \times 333 \times 10^6 = 20 \times 10^6$$

$x = 9.99$ mm/hr = 10 mm/hr

3.71 (c)

According to standard SCS-CN method,

$$S = \left(\frac{1000}{CN}\right) - 10$$

where, S = Potential maximum retention

CN = Curve number

$$S = \frac{1000}{75} - 10 = 3.33$$

Actual runoff,

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

P = Total rainfall in inch

$$= \frac{100}{25.4} = 3.937 \text{ in}$$

$$Q = \frac{(3.937 - 0.2 \times 3.33)^2}{3.937 + 0.8 \times 3.33}$$

= 1.62 inch = 41.17 mm

3.72 (d)

Total runoff

$= (0.8 + 1.2 + 0.9 + 1.8 + 1.0 + 0.8) - \phi\text{-index} \times T_e$

Now, total runoff as per correct value of ϕ-index, is

$\phi = (0.8 + 1.2 + 0.9 + 1.8 + 1.0 + 0.8) - 0.5 \times 6$

$= 6.5 - 3.0 = 3.5$ cm

$\therefore$ Correction = 3.5 – 2.9 = 0.6 cm

3.73 (d)

Collin's method for determination of unit hydrograph is an iterative method used for a multi-period storm.

Collins introduced a method of approximation to obtain a unique solution of set of equation by taking the assumptions:- assume a unit hydrograph and apply it to all excess rainfall blocks of the hyetograph except the largest.

4 Floods, Flood Routing & Flood Channel

4.1 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I

A. Conservation reservoirs
B. Retarding basins
C. Flood plains
D. Flood walls

List-II

1. Uncontrolled outlets
2. Flood-fighting
3. Temporary storage of flood water
4. Controlled outlets

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	1	4	2	3
(c)	4	1	3	2
(d)	4	1	2	3

[ESE : 1996]

4.2 Probability of a 10 year flood to occur at least once in the next 4 years is

(a) 25% (b) 35%
(c) 50% (d) 65%

[ESE : 1997]

4.3 The Standard Project Flood is

(a) derived from the probable maximum precipitation in the region
(b) derived from the severemost meteoro-logical conditions anywhere in the country
(c) the flood with return period of 1000 years
(d) the same as the probable maximum flood

[ESE : 1997]

4.4 Consider the following statements:

1. A 100 year flood discharge is greater than a 50 year flood discharge.
2. 90% dependable flow is greater than 50% dependable flow.
3. Evaporation from salt-water surface is less than that from fresh-water surface.

Which of these statements are correct?

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

[ESE : 1998]

4.5 In a linear reservoir, the

(a) volume varies linearly with elevation
(b) outflow rate varies linearly with storage
(c) storage varies linearly with time
(d) storage varies linearly with inflow rate

[ESE : 1998]

4.6 The trap efficiency of a reservoir is a function of

(a) inflow into the reservoir
(b) ratio of inflow to storage capacity
(c) ratio of reservoir capacity to inflow
(d) reservoir capacity

[ESE : 1998]

4.7 A culvert is designed for a peak flow Q_p on the basis of rational formula. If a storm of the same intensity as used in the design and twice the duration occurs, then the resulting peak discharge will be

(a) Q_p (b) $Q_p/2$
(c) $\sqrt{2}Q_p$ (d) $2Q_p$

[ESE : 1998]

4.8 In a flow-mass curve study, the demand line drawn from a ridge does not intersect the mass curve again. This implies that

(a) the reservoir is not full at the beginning
(b) the storage is not adequate
(c) the demand cannot be met by the inflow as the reservoir will not refill
(d) the reservoir is wasting water by spill

[ESE : 1998]

4.9 If a tangent drawn parallel to the demand line from a ridge point of a mass curve does not intersect the mass curve again it can be inferred that the
(a) frequency of the flood entering into the reservoir is less
(b) inflow into the reservoir cannot meet the demand
(c) reservoir is overflowing resulting in wastage
(d) reservoir can meet higher demand
[ESE : 2000]

4.10 The probability that a 100 year flood is equalled or exceeded, at least once in 100 years is
(a) 99% (b) 64%
(c) 36% (d) 1%
[ESE : 2001]

4.11 As a flood wave passes a given section of a river, the time of occurrence of the maximum stage and that of the maximum discharge will be such that
(a) the maximum discharge passes down before the maximum stage is attained
(b) the maximum stage is attained before the maximum discharge passes down
(c) the two events occur simultaneously
(d) no specific sequence would be universally assignable
[ESE : 2001]

4.12 The life of a reservoir is determined by its capacity (C), volume of annual inflow into the reservoir (I) and concentration of sediment in the incoming flow (C_s). Life will be more if
(a) C, I and C_s are high
(b) C and I are high but C_s is low
(c) C is high but I and C_s are low
(d) C, I and C_s are low
[ESE : 2001]

4.13 The slope area method is extensively used in
(a) development of rating curve
(b) estimation of flood discharge based on high-water marks
(c) cases where shifting control exists
(d) cases where back-water effect is present
[ESE : 2002]

4.14 **Assertion (A):** In routing a flood hydrograph through a reservoir, the peak of the outflow hydrograph will be smaller than the inflow hydrograph and it occurs after the peak of the inflow.
Reason (R): In linear reservoir routing, the storage is a function of both outflow and inflow discharges.
[ESE : 2002]

4.15 An effective storage of a flood control reservoir is
(a) the amount of water which can be supplied from it in a particular interval of time
(b) the storage between the minimum and maximum reservoir levels under ordinary operating conditions
(c) the useful storage plus the surcharge storage less the valley storage
(d) the storage volume of flood water above maximum reservoir level
[ESE : 2002]

4.16 Match List-I (Floods) with List-II (Para-meters) and select the correct answer using the codes given below the lists:

List-I
A. Standard Project Flood (SPF)
B. Maximum Probable Flood (MPF)
C. Design Flood
D. Maximum Flood

List-II
1. Includes catastrophic floods
2. Includes floods of severe conditions
3. Peak flow obtained from observed data
4. Flood of desired recurrence interval

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	1	2	3	4
(c)	2	1	3	4
(d)	1	2	4	3

[ESE : 2003]

4.17 A bridge has an expected life of 50 years and is designed for a flood magnitude of return period 100 years. What is the risk associated with this hydrologic design?
(a) $1-(0.99)^{50}$ (b) $(0.5)^{50}$
(c) $(0.99)^{50}$ (d) $(0.99)^{100}$
[ESE : 2004]

4.18 Which one of the following statements is correct in respect of the two important aspects of flood forecast – (1) reliability of the forecast, and

(2) the time available in between the forecast and the occurrence of flood?

(a) Meteorological forecast is least reliable and time available is also the least
(b) Hydrological forecast is most reliable but the time available is the least
(c) River forecast is least reliable and the time available is the maximum
(d) River forecast is most reliable but the time available is the least

[ESE : 2004]

4.19 For a given storm, other factors remaining same,

(a) basins with large drainage densities give smaller flood peaks
(b) low drainage density basins give shorter time bases of hydrographs
(c) the flood peak is independent of the drainage density
(d) basins having low drainage density give smaller peaks in flood hydrographs

[ESE : 2005]

4.20 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Storage
B. Pondage
C. Pondage factor
D. Daily load factor

List-II

1. Small storage
2. Ratio of total inflow to the total number of days power plant operates in a week
3. Large reservoirs
4. Average plant load × peak load
5. Ratio of average load to peak load

Codes:

	A	B	C	D
(a)	3	2	1	5
(b)	5	1	2	4
(c)	3	1	2	5
(d)	5	2	1	4

[ESE : 2005]

4.21 Which one of the following flood routing methods involve the concepts of wedge and prism storages?

(a) Coefficient method
(b) Muskingum method
(c) Pul's method
(d) Lag method

[ESE : 2005]

4.22 In a river carrying a discharge of 142 m^3/s, the stage at a station A was 3.6 m and the water surface slope was 1 in 6000. If during a flood, the stage at A was 3.6 m and the water surface slope was 1 in 3000, what was the flood discharge (approximately)?

(a) 284 m^3/s (b) 200 m^3/s
(c) 164 m^3/s (d) 96 m^3/s

[ESE : 2006]

4.23 Which one of the following statements is not correct?

(a) Storage and pondage can be obtained from flow duration curve.
(b) Primary or firm power corresponds to maximum stream flow condition.
(c) Secondary power is occasionally called surplus power.
(d) Often, flash boards are put on dams to augment the pondage at low flow durations.

[ESE : 2006]

4.24 The basic equation of flood routing through a reservoir can be modified for discrete successive intervals Δt by which one of the following?

(a) $\left[\frac{I_1+I_2}{2}\right]\Delta t+\left[S_1+\frac{Q_1\Delta t}{2}\right]=\left[S_2+\frac{Q_2\Delta t}{2}\right]$

(b) $\left[\frac{I_1+I_2}{2}\right]\Delta t+\left[S_1-\frac{Q_1\Delta t}{2}\right]=\left[S_2+\frac{Q_2\Delta t}{2}\right]$

(c) $\left[\frac{I_1+I_2}{2}\right]\Delta t+\left[S_1+\frac{Q_1\Delta t}{2}\right]=\left[S_2-\frac{Q_2\Delta t}{2}\right]$

(d) $\left[\frac{I_1+I_2}{2}\right]\Delta t+\left[S_1-\frac{Q_1\Delta t}{2}\right]=\left[S_2-\frac{Q_2\Delta t}{2}\right]$

[ESE : 2006]

4.25 By using Gumbel's method, the flood discharge with a return period of 500 years at a particular township neighbourhood was estimated as 18000 m^3/s with a probable error of 2000 m^3/s. What are the 95% confidence probability limits of the 500 year flood at the location?

(a) 16100 m^3/s to 19900 m^3/s
(b) 17050 m^3/s to 18950 m^3/s

(c) 14080 m^3/s to 21920 m^3/s
(d) 13600 m^3/s to 22400 m^3/s

[ESE : 2006]

4.26 During a flood in a stream of width 200 m (taken as rectangular section), the gauge reading was found to rise by 18 cm per hour. What would be the difference in discharges at two sections, each 250 m on either side of the gauge station?
(a) 10 m^3/s less at downstream section
(b) 7.5 m^3/s less at downstream section
(c) 5 m^3/s less at downstream section
(d) 5 m^3/s more at downstream section

[ESE : 2007]

4.27 From the analysis of rainfall data at a particular station, it was found that a rainfall of 400 mm had a return period of 20 years. What is the probability of rainfall equal to or greater than 400 mm occurring at least once in 10 successive years?
(a) $(0.95)^{10}$ (b) $1-(0.95)^{10}$
(c) $1-(0.05)^{10}$ (d) $(0.05)^{10}$

[ESE : 2008]

4.28 A culvert is designed for a flood magnitude of return period 100 years and has expected life of 20 years. The risk in this hydrologic design is
(a) $1-0.99^{20}$ (b) $1-0.01^{20}$
(c) $1-0.09^{20}$ (d) $1-0.10^{20}$

[ESE : 2010]

4.29 Consider the following statements.
In case of flood routing in a river channel by Muskingum method, the coefficient x represents:
1. A dimensionless constant indicating the relative importance of inflow and outflow in determining storage.
2. A storage constant having the dimension of time.
3. In natural channels, x usually varies between 0.1 and 0.3.
4. When the values of x equals 0.5, there exists the influence of both inflow and outflow on storage.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 3 and 4 only
(c) 1, 2 and 3 only (d) 2, 3 and 4 only

[ESE : 2011]

4.30 The hydrologic risk of a 100-year flood occurring during the 2-year service life of a project is
(a) 9.8% (b) 9.9%
(c) 19.9% (d) 1.99%

[ESE : 2012]

4.31 The design flood commonly adopted in India for barrages and minor dams is
(a) Probable maximum flood
(b) A flood of 50-100 years return period
(c) Peak flood
(d) Standard project flood or a 100-year flood, whichever is higher

[ESE : 2012]

4.32 The Muskingham method of flood routing is a
(a) Form of hydraulic routing of a flood
(b) Form of reservoir routing
(c) Complete numerical solution of St. Venant equations
(d) Hydrological channel routing method

[ESE : 2012]

4.33 It is proposed to design a causeway along a village road. The return period for the annual maximum flood of a given magnitude was found to be 5 years. The probability that this flood magnitude will be exceeded at least once during next 2 years is:
(a) 0.8 (b) 0.5
(c) 0.45 (d) 0.36

[ESE : 2013]

4.34 The probability of a 10 years flood to occur at least once in the next 5 years is
(a) 35% (b) 41%
(c) 60% (d) 65%

[ESE : 2014]

4.35 That extreme flood that is physically possible in a region from a severe-most combination, including rare combination of metrological and hydrological factors, is designated as the
(a) Design flood
(b) Standard project flood
(c) Probable maximum flood
(d) Flash flood

[ESE : 2014]

4.36 Return Period Refers to
(a) The Probability of Exceedance of an event
(b) The Probability of Non-Exceedance of an event
(c) The Inverse of the Probability of Exceedance of an event
(d) The Inverse of the Probability of Non-Exceedance of an event

[ESE : 2015]

4.37 Probability of a 10-year flood to occur at least once in the next 5 years is
(a) 35% (b) 40%
(c) 50% (d) 65%

[ESE : 2015]

4.38 A new reservoir has a capacity of 12 Mm^3 and its catchment area is 400 km^2. The annual sediment yield from this catchment is 0.1 ha.m/km^2 and the trap efficiency can be assumed constant at 90%. The number of years it takes for the reservoir to lose 50% of its initial capacity is, nearly
(a) 177 years (b) 77 years
(c) 17 years (d) 7 years

[ESE : 2016]

4.39 The probability of a 10 year flood to occur at least once in the next 4 years is
(a) 45% (b) 35%
(c) 30% (d) 20%

[ESE : 2017]

Directions: The following items consists of two statements; one labelled as **'Statement (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

4.40 **Statement (I):** The fundamental storage equation through a river reach considers that the total inflow is balanced by total outflow plus the change in storage in the reach over the routing period as has been considered.
Statement (II): To be adaptable for actual computations, the storage equation is recast in the form

$$\frac{1}{2}(I_1 + I_2)t + \left(S_1 - \frac{1}{2}D_1 t\right) = \left(S_2 + \frac{1}{2}D_2 t\right)$$

where suffixes 1 and 2 denote values at start and end respectively, of the routing interval t, the I's and D's denote, respectively, the inflow and outflow at the respective points of time and the S's denote the storage in the reach at the respective point of time.

[ESE : 2017]

4.41 **Statement (I):** When a loop rating curve is prepared at a gauging station when a flood wave passes, the maximum discharge occurs earlier than the maximum stage.
Statement (II): When a flood wave passes through a reach, during rising stages, some water may get into depressions on the floodplains of the river and, may be, only part of this spill returns to the channel runoff when flood levels recede.

[ESE : 2017]

4.42 **Statement (I):** The Muskingum method of routing a flood through a river reach is not a simple recast of the storage equation

$$I = D + \frac{d}{dt}(S)$$

Statement (II): The Muskingum method first develops trial storage loops considering contributions from both inflow and outflow and also the algebraic difference between them.

[ESE : 2017]

Answers Floods, Flood Routing & Flood Channel

4.1 (c)	4.2 (b)	4.3 (b)	4.4 (c)	4.5 (b)	4.6 (c)	4.7 (a)	4.8 (c)	4.9 (b)	
4.10 (b)	4.11 (a)	4.12 (d)	4.13 (b)	4.14 (c)	4.15 (c)	4.16 (a)	4.17 (a)	4.18 (d)	
4.19 (d)	4.20 (c)	4.21 (b)	4.22 (b)	4.23 (b)	4.24 (b)	4.25 (c)	4.26 (c)	4.27 (b)	
4.28 (a)	4.29 (b)	4.30 (d)	4.31 (d)	4.32 (d)	4.33 (d)	4.34 (b)	4.35 (c)	4.36 (c)	
4.37 (b)	4.38 (c)	4.39 (b)	4.40 (a)	4.41 (a)	4.42 (a)				

Explanations Floods, Flood Routing & Flood Channel

4.1 (c)

Storage or conservation reservoirs has gates and valves installed at its spillway and can retain excess flow during periods of peak flow and can release them gradually during low flows as and when need arises. Thus they have controlled outlets.

Retarding basins or retarding reservoirs has uncontrolled and ungated outlets.

Masonry structures used to confine the river in a manner similar to levees are known as flood walls. These are used to protect important structures against floods especially where the land is at a premium.

4.2 (b)

Probability corresponding to 10 year return period is

$$P = \frac{1}{10} = 0.1$$

The probability of flood occurring at least once in 4 years is

$= 1 - (1 - P)^4 = 1 - 0.9^4 = 0.3439 \approx 35\%$

4.3 (b)

The flood that would result from a severe combination of meteorological and hydrological factors that are reasonably applicable to the region. Extremely rare combinations of factors are excluded.

4.4 (c)

For a return period T, the magnitude of flood is given by equation of hydrologic frequency analysis as

$$x_T = \bar{x} + k\sigma$$

The value of k increases with higher return period. So flood magnitude for 100 year return period is more than that of 50 year return period.

% dependable flow means number of times the given discharge is equalled or exceeded.

$$\% \text{ Dependability} = \frac{100}{\text{Returnperiod}}$$

90% dependable flow has lesser return period while, 50% dependable flow has higher return period. So, 90% dependable flow is less than 50% dependable flow.

When a solute is dissolved in water, the vapour pressure is less than that of pure water and hence causes a reduction in the rate of evaporation.

4.5 (b)

For linear reservoir $S = kQ$

The storage varies linearly with outflow discharge, or outflow rate varies linearly with storage.

4.6 (c)

Trap efficiency increases with increase in ratio of reservoir capacity to inflow. Therefore to minimize sediment accumulation in a reservoir, the capacity to inflow ratio should be kept minimum possible. It implies that reservoir should be constructed in stages.

4.7 (a)

Rational formula $Q_p = kiA$.

There is no term for duration of rainfall in the rational formula so peak discharge will not change.

4.8 (c)

In case the demand line drawn from a ridge does not intersect the mass curve again, it means the

rate of inflow is less than or equal to rate of demand. So, the reservoir will not be refilled and the demand cannot be met by the inflow.

4.9 (b)

Mass-curve is the plot between cumulative inflow volume and the time.

4.10 (b)

The probability corresponding to 100 years return period

$$P = \frac{1}{100} = 0.01$$

The probability of the flood exceeding at least once in 100 years is

$$R = 1 - (1 - P)^{100} = 1 - 0.99^{100}$$
$$= 0.634 = 64\%$$

4.11 (a)

Due to storage effect maximum stage will occur after the maximum inflow discharge passes down.

4.12 (d)

In determining the life of a reservoir the following factors are considered and investigated :

- Water tightness of the basins
- Stability of the reservoir rim
- Availability of construction material in the reservoir area
- Silting
- Direct and indirect submergence of economic mineral wealth
- Seismo-tectonics

Trap efficiency (TE) is one of the most important factors affecting life of a reservoir. TE of reservoir, over a period, is the ratio of total deposited sediment to the total sediment inflow.

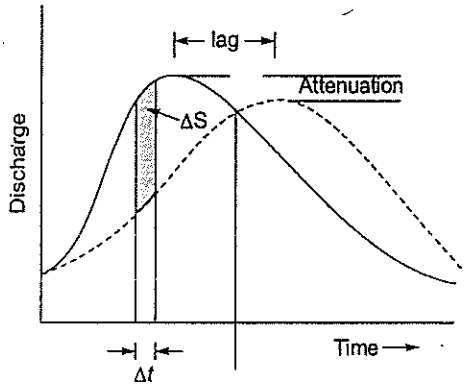
4.13 (b)

When it is not possible to make direct measurement especially during floods, slope-area method is a most commonly used indirect method of measurement. In this method discharge is computed on the basis of a uniform flow equation involving channel characteristics, water surface profile and a roughness coefficient. The drop in water surface profile for a uniform reach of channel represents losses caused by bed roughness. Discharge is calculated using Manning's equation is used in this method.

4.14 (c)

Flood routing is the technique of determining the flood hydrograph at a section of a river by utilizing the data of flood flow at one or more upstream sections. The hydrologic analysis of problems such as flood forecasting, flood protection, reservoir design and spillway design invariably include flood routing.

The peak of the outflow hydrograph will be smaller than of the inflow hydrograph because of the effects of channel/reservoir storage and resistance to flow. This reduction in the peak value is called attenuation.



4.15 (c)

Effective storage = Useful storage + Surcharge storage – Valley storage corresponding to the rate of inflow in the reservoir.

4.16 (a)

Probable Maximum Flood (PMF): This is the flood resulting from the most severe combination of critical meteorological and hydrological conditions that are reasonably possible in the region. The PMF is computed by using the Probable Maximum Storm (PMS) which is an estimate of the physical upper limit to storm rainfall over the catchment. This is obtained from the studies of all the storms that have occurred over the region and maximizing them for the most critical atmospheric conditions.

Standard Project Flood (SPF): This is the flood resulting from the most sever combination of meteorological and hydrological conditions considered reasonably characteristic of the region.

The SPF is computed from the Standard Project Storm (SPS) over the watershed considered and may be taken as the largest storm observed in the region of the watershed.

Design flood is the value of the instantaneous peak discharge adopted for the design of a particular project or any of its structures. In addition to the considerations of the flood characteristics, frequencies and potentiality of the contributing drainage area above the structure, social, economic and other non-hydrologic considerations which are likely to have influence are considered in deriving a design flood.

The term "design flood" is used to denote the maximum flood flow that could be passed without damage or serious threat to the stability of engineering structures.

4.17(a)

Risk = Probability of flood being exceeded at least once over a period of n years.

$$= 1-\left(1-\frac{1}{100}\right)^{50} = 1-(0.99)^{50}$$

4.18(d)

Meteorological forecast is long range forecast gives maximum time for advance notice but it is least reliable.

Hydrological forecast is based on rainfall-runoff relationship and gives warning 2 to 5 days in advance. Its reliability is more than meteorological forecast.

River forecast is most reliable but the advance warning is 12 to 40 hours only.

4.19 (d)

Drainage density is the ratio of total length of stream channels to the area of catchment. Large drainage density creates quick flowing off or runoff down the channel hence gives a faster response (shorter time base) and high peak discharge.

4.21(b)

Wedge and prism storage concept is used in channel routing using Muskingum method.

4.22(b)

Discharge is directly proportional to $\sqrt{S}$.

$$\therefore \quad Q_2 = Q_1 \times \sqrt{\frac{S_2}{S_1}}$$

$$= 142 \times \sqrt{\frac{1}{3000} \times 6000}$$

$$= 200.8\ m^3/s$$

4.23(b)

The firm power corresponds to minimum flow condition.

4.24(b)

The basic continuity equation for reservoir routing is

$$\left(\frac{I_1+I_2}{2}\right)\Delta t - \left(\frac{Q_1+Q_2}{2}\right)\Delta t = S_2 - S_1$$

$$\left(\frac{I_1+I_2}{2}\right)\Delta t + \left(S_1 - \frac{Q_1\Delta t}{2}\right) = S_2 + \frac{Q_2\Delta t}{2}$$

4.25(c)

For confidence probability C, the confidence interval (if variate x_T is bounded by values x_1 and x_2) is given by:

$$x_1 = x_T - f(c)\, S_e$$

$$x_2 = x_T + f(c)\, S_e$$

Given $x_T = 18000\ m^3/s$

$S_e = 2000\ m^3/s$

For 95% confidence probability $f(c) = 1.96$

$$\therefore \quad x_1 = 18000 - 1.96 \times 2000 = 14080\ m^3/s$$

$$x_2 = 18000 + 1.96 \times 2000 = 21920\ m^3/s$$

4.26(c)

$$Q_1 - Q_2 = \frac{18 \times 10^{-2}}{60 \times 60} \times (250 + 250) \times 200$$

$$\Rightarrow Q_1 - Q_2 = 5\ m^3/s$$

4.27(b)

The probability of occurrence of an event at least once over a period of 'n' successive years is called the risk, R. It is given as

$$R = 1-(1-P)^n$$

where $P = \frac{1}{T} = \frac{1}{20} = 0.05$

$$\therefore \quad R = 1-(1-0.05)^{10}$$

$$= 1-(0.95)^{10}$$

4.28 (a)

The probability of occurrence of an event at least once over a period of n successive years is called the risk, R. Thus the risk is given by

$$R = 1-\left(1-\frac{1}{T}\right)^n$$

$$= 1-\left(1-\frac{1}{100}\right)^{20} = 1-0.99^{20}$$

4.29 (b)

Muskingum equation relates the storage in a reservoir to the outflow (Q) and inflow (I)

$$S = K[x\cdot I + (1-x)\cdot Q]$$

In this the parameter x is known as weighting factor and takes a value between 0 and 0.5.

The coefficient K is known as storage-time constant and has the dimensions of time.

Normally, for natural channels, the value of x lies between 0 to 0.3. For a given reach, the values of x and K are assumed to be constant. When $x = 0$, $S = KQ$, valid for linear reservoir. When $x = 0.5$, $S = K[0.5I + 0.5\ Q]$. There exists the influence of both inflow and outflow on storage.

4.30 (d)

The risk is given by,

$$R = 1-\left(1-\frac{1}{T}\right)^n = 1-\left(1-\frac{1}{100}\right)^2$$

$$= 0.0199 = 1.99\%$$

4.31 (d)

For permanent barrages and minor dams with capacity less than 60 Mm^3 design flood recommended is SPF or flood with a return period of 100 years whichever gives higher value.

4.32 (d)

In reservoir routing, the storage is a unique function of outflow discharge, $S = f(Q)$.

However, in channel routing the storage is a function of both outflow and inflow discharge and hence a different routing method is needed from muskingum method of hydrological channel routing storage is given by

$$S = k\left[xI^m + (1-x)Q^m\right]$$

4.33 (d)

$$p = 1-q^n = 1-\left(1-\frac{1}{T}\right)^n$$

$$\Rightarrow \quad p = 1-\left(1-\frac{1}{5}\right)^2$$

$$= 1 - 0.64 = 0.36$$

4.34 (b)

Favorable probability

$$(p) = \frac{1}{10} = 0.1$$

Unfavorable probability (q)

$$= 1 - p = 1 - 0.1 = 0.9$$

Probability to flood occur atleast once in the next 5 year

$$= 1 - q^n$$
$$= 1 - (0.9)^5$$
$$= 0.40951$$
$$\simeq 0.41 \text{ or } 41\%$$

4.35 (c)

Maximum Probable Flood (MPF) differs from the Standard Project Flood (SPF) in that it includes the extremely rare and catastrophic floods and is usually confined to spillway design of very high dams. The SPF is generally around 80% of the MPF for the basin.

4.36 (c)

The estimated likelihood of an event to occur is called recurrence interval or Return Period. It is the inverse of the probability that the event will be exceeded in one year, or the inverse of the expected number of occurrences in a year.

4.37 (b)

Probability corresponding to a 10 year return period is

$$P = \frac{1}{10} = 0.1$$

The probability of flood occurring at least once in 5 year is

$$= 1 - (1 - P)^5 = 1 - (1 - 0.1)^5$$
$$= 1 - 0.5904$$
$$= 0.4095 = 40.95\%$$

4.38 (c)

Trap efficiency means 90% of sediment will be stored

Let number of years are x to till reservoir to 50%

$400 \times 0.1 \times 10^4 \times 0.90 \times x$

$= 12 \times 10^6 \times 0.5$

$x = 16.67 = 17$ years

4.39 (b)

Probability of an event occurring atleast once in 'n' successive years is called risk:

$$\text{Risk} = 1 - (q^n) = 1-\left(1-\frac{1}{T}\right)^n = 1-\left(1-\frac{1}{10}\right)^4$$

$= 0.35$ or 35%

4.40 (a)

$\frac{1}{2}(I_1 + I_2)t + \left(S_1 - \frac{1}{2}D_1 t\right) = \left(S_2 + \frac{1}{2}D_2 t\right)$ is the fundamental routing equation which says that

Total inflow – Total outflow = Change in storage

4.42 (a)

Any routing method is based on the fundamental equation i.e.,

$$I - D = \frac{d}{dt}(S)$$

(Here symbol D denotes outflow).

UNIT

III

Water Resources Engineering

Syllabus

Multipurpose uses of Water, River basins and their potential; Irrigation systems, water demand assessment; Resources - storages and their yields; Water logging, canal and drainage design, Gravity dams, falls, weirs, Energy dissipaters, barrage Distribution works, Cross drainage works and head-works and their design; Concepts in canal design, construction & maintenance; River training, measurement and analysis of rainfall.

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OOOO

1 Water Requirement of Crops

1.1 Given that the base period is 100 days and the duty of the canal is 1000 hectares per cumecs, the depth of water will be
(a) 0.864 cm (b) 8.64 cm
(c) 86.4 cm (d) 864 cm
[ESE : 1995]

1.2 The following data were recorded from an irrigated field:
1. Field capacity : 20%
2. Permanent wilting point : 10%
3. Permissible depletion of available soil moisture: 50%
4. Dry unit weight of soil : 1500 kgf/m^3
5. Effective rainfall : 25 mm

Based on these data, the net irrigation requirement per metre depth of soil will be
(a) 75 mm (b) 125 mm
(c) 50 mm (d) 25 mm
[ESE : 1997]

1.3 **Assertion (A):** Duty is an expression of the irrigating capacity of a unit volume of water.
Reason (R): Duty at the head of a distributary will be less than that at the head of a watercourse and more than that at the head of a canal.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1999]

1.4 If the depth is 8.64 cm on a field over a base period of 10 days, then the duty is
(a) 10 hectares per cum/s
(b) 100 hectares per cum/s
(c) 864 hectares per cum/s
(d) 1000 hectares per cum/s
[ESE : 2000]

1.5 10 m^3/s of water is diverted to a 32 hectare field for 4 hours. Soil probing after irrigation showed that 0.3 m of water had been stored in the root zone. Water application efficiency in this case would be
(a) 96% (b) 66.67%
(c) 48% (d) 24%
[ESE : 2001]

1.6 A canal was designed to supply the irrigation needs of 1000 ha of land growing rice of 140 days base period and having a delta of 130 cm. If the canal water is used to irrigate wheat of base period 119 days and having a delta of 50 cm, the area that can be irrigated is
(a) 452 ha (b) 904 ha
(c) 1105 ha (d) 2210 ha
[ESE : 2002]

1.7 **Assertion (A):** Sprinkler method of irrigation has a higher water application/use efficiency.
Reason (R): Sprinkler system causes less interference in cultivation and other farming operations.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2002]

1.8 Acidic soils are reclaimed by
(a) leaching of the soil
(b) using limestone as a soil amendment
(c) using gypsum as a soil amendment
(d) provision of drainage
[ESE : 2002]

1.9 The delta for a crop having base period 120 days is 70 cm. What is the duty?
(a) 2480 hectare/cumec

(b) 1481 hectare/cumec
(c) 148 hectare/cumec
(d) 1.481 hectare/cumec

[ESE : 2004]

1.10 For a culturable command area of 1000 hectare with intensity of irrigation of 50%, the duty on field for a certain crop is 2000 hectare/cumec. What is the discharge required at head of water course with 25% losses of water?
(a) 3/16 cumec (b) 1/4 cumec
(c) 1/3 cumec (d) 1/2 cumec

[ESE : 2004]

1.11 What is the moisture depth available for evapotranspiration in root zone of 1 m depth soil, if dry weight of soil is 1.5 gm/cc, field capacity is 30% and permanent wilting point is 10%?
(a) 450 mm (b) 300 mm
(c) 200 mm (d) 150 mm

[ESE : 2004]

1.12 If the sensitivity of an irrigation module is 0.5, then what percent variation in outlet discharge will be caused by 50 per cent variation in canal water depth?
(a) 100% (b) 50%
(c) 25% (d) 12.5%

[ESE : 2006]

1.13 The moisture tension for a soil is 8 atmospheres. The soil is then at
(a) permanent wilting point
(b) field capacity
(c) optimum moisture content
(d) equivalent moisture

[ESE : 2006]

1.14 Consider the following terms relating to irrigation requirements:
1. Consumptive irrigation requirement
2. Net irrigation requirement
3. Field irrigation requirement
4. Gross irrigation requirement

For a given set up, which one of the following is the correct relation?
(a) $1 > 2 > 3 > 4$ (b) $1 < 2 < 3 < 4$
(c) $(1 = 2) < 3 < 4$ (d) $1 < (2 = 3) < 4$

[ESE : 2006]

1.15 A drainage coefficient
(a) decides the choice of the method of the drainage
(b) decides the kind of crop that can be grown on the land
(c) is the depth of water that can be removed from the drainage area in unit time.
(d) is the flow of water from the soil into the tile laterals per unit time

[ESE : 2006]

1.16 A soil sample has an exchangeable sodium percentage of 16%, its electrical conductivity is 3.2 milli-Mhos/cm and pH of 9.5. How is the soil classified?
(a) Saline soil
(b) Saline-alkaline soil
(c) Alkaline soil
(d) None of the above

[ESE : 2007]

1.17 If the discharge required for different crops is 0.4 cumecs in the field and the capacity factor and time factors are 0.8 and 0.5 respectively, then what is the design discharge of the distributary at its head ?
(a) 0.80 cumecs (b) 0.16 cumecs
(c) 1.0 cumecs (d) 1.24 cumecs

[ESE : 2007]

1.18 Semi-module outlets are those outlets in which
(a) discharge gets affected by the change in water level of field channel
(b) discharge gets affected by the change in water level of the distributing channel but not with the change in water level of field channel
(c) discharge is independent of water levels in the distributing channel and the field channel
(d) None of the above

[ESE : 2008]

1.19 During a particular stage of the growth of a crop, consumptive use of water is 2·8 mm/day. If the amount of water available in the soil is 25% of 80 mm depth of water, what is the frequency of irrigation?
(a) 9 days (b) 13 days
(c) 21 days (d) 25 days

[ESE : 2009]

1.20 Consider the following statements:
Irrigation water has to be supplied to the crops when the moisture level falls
1. below field capacity
2. to wilting point
3. below wilting point
Which of these statements is/are correct?
(a) 1 (b) 2 only
(c) 3 only (d) 2 and 3
[ESE : 2009]

1.21 A groundwater basin consists of 10 km^2 area of plains. The maximum groundwater table fluctuation has been observed to be 1.5 m. Consider specific yield of the basin as 10%. What is the available groundwater storage in million cubic metres?
(a) 1.0 (b) 1.5
(c) 2.5 (d) 2.0
[ESE : 2009]

1.22 In a canal irrigation project, 76% of the culturable command area (CCA) remained without water during Kharif season; and 58% of CCA remained without water during Rabi season in a particular year. Rest of the areas got irrigated in each crop respectively. What is the intensity of irrigation for the project in the year ?
(a) 134% (b) 76%
(c) 66% (d) 58%
[ESE : 2009]

1.23 The discharge required for Rabi and Kharif crops are 0.4 m^3/s and 0.3 m^3/s respectively. The capacity and time factors are 0.8 and 0.5 respectively at each season. The design discharge of the distributary at its head is
(a) 0.8 m^3/s (b) 0.16 m^3/s
(c) 1.0 m^3/s (d) 1.24 m^3/s
[ESE : 2010]

1.24 Assertion (A): In the border strip method of irrigation, the size of the strip depends on soil characteristics, slope of the land and discharge.
Reason (R): Border strip method is a controlled type of subsurface irrigation method.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2010]

1.25 Consider the following zones:
1. Saturation zone
2. Capillary zone
3. Intermediate zone
4. Soil water zone
Which of these does not relate to the zone of aeration in the soil profile?
(a) 1 and 2 (b) 2 and 3
(c) 4 only (d) 1 only
[ESE : 2011]

1.26 An identified source of irrigation water has ion concentrations of Na^+, Ca^{++} and Mg^{++} as 20, 10 and 8 milliequivalent per litre, respectively. The SAR of this water is approximately
(a) 2.06 (b) 6.67
(c) 2.67 (d) zero
[ESE : 2011]

1.27 Flexibility of an outlet may be defined as the ratio of the rate of change of
(a) Outlet discharge to the rate of change of water level of the parent channel
(b) Outlet discharge to the rate of change of the discharge of the parent channel
(c) Parent channel discharge to the rate of change of the outlet discharge
(d) Parent channel water level to the rate of change of the outlet discharge
[ESE : 2011]

1.28 Assertion (A): The duty of water decreases as the point of its measurement moves away from the field of application.
Reason (R): Duty depends on soil characteristics.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2011]

1.29 A rice crop is to be irrigated in a field covering an area of 2400 ha, the duty and base period of rice are given as 860 ha/cumec and 120 days

respectively. The volume of water required in the field is nearly:

(a) 500 ha-m (b) 1400 ha-m
(c) 2000 ha-m (d) 2880 ha-m

[ESE : 2013]

1.30 In an irrigation project, in a certain year, 70% and 46% of the culturable command area in Kharif and Rabi, respectively, remained without water and rest of the area got irrigation water. The intensity of irrigation in that year for the project was:

(a) 116% (b) 84%
(c) 42% (d) 58%

[ESE : 2013]

1.31 The gross command area for a distributary is 5000 hectares, 80% of which is culturable irrigable. The intensity of irrigation for Rabi is 50%; and for Kharif is 30%. The average duty at the head of the distributory is 2000 hectares/cumec for Rabi season and 900 hectares/cumec for Kharif season. The discharge required at the head of the distributory from average demand considerations is

(a) 1.00 cumecs (b) 1.33 cumecs
(c) 2.33 cumecs (d) 3.33 cumecs

[ESE : 2013]

1.32 The following data were noted from an irrigation field:

1. Field capacity = 20%
2. Permanent wilting point = 10%
3. Permissible depletion of available soil moisture = 50%
4. Dry unit weight of soil = 15 kN/m^3
5. Effective rainfall = 50 mm

The net irrigation requirement per metre depth of soil will be

(a) 75 mm (b) 125 mm
(c) 50 mm (d) 25 mm

[ESE : 2014]

1.33 For an irrigated field having: Field capacity = 30%, Permanent wilting point = 10%, Permissible depletion of available moisture = 40%, Dry weight of soil = 14.70 kN/m^3, Unit weight of water = 9.8 kN/m^3 and Effective rainfall = 30 mm, what is the net irrigation requirement per meter depth of soil?

(a) 300 mm (b) 150 mm
(c) 120 mm (d) 90 mm

[ESE : 2014]

1.34 A lift irrigation scheme using a discharge of 96 m^3/hr is planned to raise a crop with an average Δ of 0.375 m. Intensity of irrigation is 60%. Assuming 3600 hours of working of the tubewell for a year, the culturable command area is

(a) 96 Ha (b) 48 Ha
(c) 144 Ha (d) 120 Ha

[ESE : 2014]

1.35 A field measures 40 hectares. When 8 cumecs of water was supplied for 6 hours, 30 cm of water was stored in the root zone. The field application efficiency is nearly.

(a) 70% (b) 80%
(c) 85% (d) 90%

[ESE : 2014]

1.36 Consumptive Use refers to the loss of water as a result of

(a) Evaporation and Transpiration
(b) Crop Water Requirement
(c) Evaporation and Infiltration
(d) Evaporation and Transpiration from the cropped area

[ESE : 2015]

1.37 The discharge capacity required at the outlet to irrigate 3000 ha of sugarcane having a kor depth of 173 mm and a kor period of 30 days is

(a) 2.0 m^3/s (b) 1.0 m^3/s
(c) 20 m^3/s (d) 0.20 m^3/s

[ESE : 2015]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

1.38 **Assertion (A):** If the soil moisture is only slightly more than the slightly more than the wilting coefficient, the plant must expend extra energy

to obtain the water and hence the plant will not grow healthily.
Reason (R): Excessive water supply retards plant growth.

[ESE : 2015]

1.39 **Assertion (A):** Duty of drip irrigation is very high.
Reason (R): Losses are least in drip irrigation.

[ESE : 2015]

1.40 Consider the following statements in connection with soil-water-crop relationship:
1. Water utilization by plants is mainly from capillary water.
2. The amount of irrigation water required to meet the evapotranspiration needs of the crop during its full growth duration is its consumptive irrigation requirements.
3. The depth of water required to bring the soil-moisture level of a given soil up to its field capacity is called hygroscopic water.
4. With continuous increase in quantity of water applied, the yield of most crops increase up to a certain limit and then is expected to be constant.

Which of the above statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

[ESE : 2017]

■■■■

Answers Water Requirement of Crops

1.1 (c)	1.2 (c)	1.3 (b)	1.4 (d)	1.5 (b)	1.6 (d)	1.7 (c)	1.8 (b)	1.9 (b)	
1.10 (c)	1.11 (b)	1.12 (c)	1.13 (a)	1.14 (b)	1.15 (c)	1.16 (c)	1.17 (c)	1.18 (b)	
1.19 (c)	1.20 (a)	1.21 (b)	1.22 (c)	1.23 (c)	1.24 (c)	1.25 (d)	1.26 (b)	1.27 (b)	
1.28 (b)	1.29 (d)	1.30 (b)	1.31 (b)	1.32 (d)	1.33 (d)	1.34 (c)	1.35 (a)	1.36 (d)	
1.37 (a)	1.38 (b)	1.39 (a)	1.40 (a)						

Explanations Water Requirement of Crops

1.1 (c)

$$\Delta \times D = 864 \times B$$

D = 1000 ha/cumec

B = 100 days

$$\Delta = \frac{864 \times 100}{1000} = 86.4 \text{ cm}$$

1.2 (c)

The readily available moisture

$= 0.5 \times (20 - 10) = 5\%$

Deficiency due to the fall of moisture is

$$= \frac{\gamma_d}{\gamma_\omega} \times d \times \text{readily available moisture}$$

$$= \frac{1500}{1000} \times 1000 \times 0.05 = 75 \text{ mm}$$

25 mm depth of water is available from precipitation so net irrigation needed is 75 – 25 = 50 mm

1.3 (b)

Due to loss of water by evaporation and percolation, the duty is less at the head of distributary than at the head of the water course and more than that at the head of the canal.

1.4 (d)

$$D \times \Delta = 864 \times B$$

$$\therefore \quad D = \frac{864 \times 10}{8.64} = 1000 \text{ ha/m}^3\text{/s}$$

1.5 (b)

The volume of water in root zone,

$V_r = 0.3 \times 32 \times 10^4 = 9.6 \times 10^4 \text{ m}^3$

The volume of water supplied,

$V_s = 10 \times 4 \times 3600 = 1.44 \times 10^5 \text{ m}^3$

Water application efficiency,

$$\eta = \frac{V_r}{V_s} \times 100 = 66.67\%$$

1.6 (d)

The discharge (Q) in canal remains same.

Duty for rice, $D_1 = \frac{1000}{Q}$ ha/cumec

Duty for wheat, $D_2 = \frac{A_2}{Q}$ ha/cumec

Now $\frac{D_1\Delta_1}{B_1} = \frac{D_2\Delta_2}{B_2}$

or $\frac{A_1\Delta_1}{B_1} = \frac{A_2\Delta_2}{B_2}$

$\therefore \quad A_2 = \frac{119}{140} \times \frac{130}{50} \times 10002$

$= 2210$ ha

1.7 (c)

Sprinkler system consists of network of pipes running across the field. Thus it will cause interference in cultivation and other operation.

1.8 (b)

The salts injurious to the health of plants are alkali salts eg. Na_2CO_3, Na_2SO_4 and NaCl. Such a salt affected soil is unproductive and is known as saline soil. If the soil is saline and the efflorescence continues for a long period, then soils become ill aerated and highly unproductive and these are called alkaline soils. These soils can be reclaimed by

(i) Leaching
(ii) Providing surface and subsurface drainage of the area.
(iii) Crop rotation
(iv) Lining of canals and water courses
(v) Reducing the intensity of irrigation.
(vi) Optimum use of water
(vii) Gypsum addition

Acidic soils, on the other hand, can be reclaimed by basic salts such as limestone.

1.9 (b)

$$\text{Duty} = \frac{864 \times 120}{70} = 1481 \text{ ha/cumec}$$

1.10 (c)

The area to be irrigated = $0.5 \times 1000 = 500$ ha

The discharge needed on field

$$= \frac{500}{2000} = 0.25 \text{ cumec}$$

For 25% loss of water at the head of water course, the discharge required at the head of water course

$$Q = \frac{0.25}{0.75} = \frac{1}{3} \text{ cumec}$$

Duty at the head of the water course

$= 2000 \times 0.75 = 1500$ ha/cumes

1.11 (b)

$$\text{Moisture depth} = \frac{\gamma_d}{\gamma_w} \times (FC - PWP) d$$

$$= \frac{1.5}{1} \times (0.3 - 0.1) \times 1$$

$= 0.3$ m $= 300$ mm

1.12 (c)

$$\text{Sensitivity, } S = \frac{(dq/q)}{(dy/y)}$$

where

q is discharge through outlet

y is depth in distributary canal.

Given $S = 0.5$

$dq/q = ?$

$$\therefore \quad \frac{dq}{q} = \frac{dy}{y} \times S = 50 \times 0.5 = 25\%$$

1.13 (a)

Soil moisture tension is the pressure which must be exerted on the soil in order to extract water from it.

It is a measure of tenacity with which the water is held by the soil. It is also known as capillary potential.

At field capacity moisture tension is about $\frac{1}{10}$ to $\frac{1}{3}$ atm. At permanent wilting point moisture tension is 7-32 atm. Moisture equivalent of the soil is the percentage of moisture retained in an initially saturated sample of soil, 1 cm thick, after it has been subjected to centrifugal force of 1000 times gravity for a period of 30 minutes.

Optimum moisture content is slightly less than field capacity. So moisture tension is approximately same.

1.14(b)

Consumptive Irrigation Requirement,

$$CIR = C_u - R_e$$

C_u is Consumptive use of crop

R_e is Effective rainfall

Net Irrigation Requirement (NIR) = CIR + Water lost as percolation in satisfying other needs such as leaching.

Field Irrigation Requirement,

$$FIR = \frac{NIR}{\text{Water application efficiency } (\eta_a)}$$

Thus,

FIR = NIR + percolation losses in field watercourses and field channels

Gross Irrigation Requirement (GIR)

$$= \frac{FIR}{\text{Efficiency of Water Conveyance } (\eta_c)}$$

∴ GIR = FIR + Conveyance losses in distributaries upto the field.

So GIR > FIR > NIR > CIR

1.15(c)

The rate at which water is removed by a drain is called drainage. It is expressed as the depth of water in cm or metres, to be removed in 24 hours from the drainage area.

1.16(c)

The classification of soils as per electrical conductivity (EC) in milli mhos/cm, Exchangeable sodium percentage (ESP) and pH values is tabulated below:

Classification	EC	ESP	pH
Saline soil or white alkali	> 4	< 15	≤ 8.5
Alkaline soil or Non-saline soil or sodic soil or Black Alkali	< 4	> 15	8.5 to 10.0
Saline-alkali soil	> 4	> 15	< 8.5

1.17(c)

Design discharge

$$= \frac{\text{Discharge required in the field}}{\text{Time factor} \times \text{capacity factor}}$$

$$= \frac{0.4}{0.5 \times 0.8} = 1.0 \text{ cumecs}$$

1.18(b)

The various available types of outlets (modules) are:

(i) Non-modular outlets are those through which the discharge depends upon the difference of head between distributary and water course. Common examples are open sluice and drowned pipe outlet.

(ii) Semi modules or flexible modules are those through which the discharge is independent of the water level of the water course but depends only upon the water level of the distributary so long as a minimum working head is available. Common examples are pipe outlet, venturi flume, open flume and orifice semi-module.

(iii) Rigid modules or modular outlets are those through which the discharge is constant and fixed within limits, irrespective of the fluctuations of the water levels of either the distributary or of the water course or of both. Common example is Gibb's module.

1.19(c)

$$\text{Water available to the soil} = \frac{25}{100} \times 80 = 20 \text{ mm}$$

Additional water required = 80 – 20 = 60 mm

$$\therefore \text{ Frequency of irrigation} = \frac{60}{2.8} = 21.43 \text{ days}$$

Thus the crop should be irrigated after every 21 days.

1.20(a)

The soil moisture is not allowed to be depleted up to the wilting point, as it would result in considerable fall in crop yield. The optimum level up to which the soil moisture may be allowed to be depleted in the root zone without fall in crop yield has to be worked out for every crop and soil by experimentation. The irrigation water should be supplied as soon as the moisture falls upto this optimum level and its quantity should be just sufficient to bring the moisture content up to its field capacity.

1.21 (b)

Available ground water storage

$$= 10 \times (10^3)^2 \times 1.5 \times \frac{10}{100}$$

$$= 1.5 \times 10^6 \text{ m}^3$$

$$= 1.5 \text{ m}^3$$

1.22 (c)

The annual intensity of irrigation is the sum total of intensities of irrigation of all the seasons of the year.

Intensity of irrigation for kharif season

$$= 100 - 76 = 24\%$$

Intensity of irrigation for rabi season

$$= 100 - 58 = 42\%$$

$\therefore$ Annual intensity of irrigation

$$= 24 + 42$$

$$= 66\%$$

1.24 (c)

Border irrigation method is a type of surface irrigation method.

1.25 (d)

(i) *Soil-water zone:* The soil-water zone extends from the ground surface down upto the major root zone. The soil in this zone becomes saturated either during irrigation or when rainfall occurs. However, the soil in this zone remains saturated only for a short duration after irrigation or rainfall, because the excess water drains through the soil under the influence of gravity. This excess water which cannot be retained by the soil is known as gravitational water.

(ii) *Intermediate zone:* The intermediate zone extends from the lower edge of soil-water zone to the upper limit of the capillary zone. This zone usually contains non-moving vadose water which is held by molecular and surface tension forces in the form of hygroscopic and capillary water.

(iii) *Capillary zone:* The capillary zone extends from the water table upto the limit of capillary rise of water. This pore space may be considered to represent a capillary tube and hence just above the water table almost all pores contain capillary water which constitute this zone.

(iv) *Saturation zone:* In the zone of saturation all the interstices are filled with water under hydrostatic pressure. The zone of saturation is bounded at the top by either a limiting surface of saturation called water table or an overlying impermeable strata and extends down to underlying impermeable strata.

1.26 (b)

SAR = Sodium Absorption Ratio

$$= \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} = \frac{20}{\sqrt{\frac{10+8}{2}}} = 6.67$$

1.27 (b)

An outlet is a sort of head regulator through which water is released from a distributing channel into a water course or field channel.

Canal outlets are of three types:

(i) Non-modular outlets

(ii) Semi-modular outlets

(iii) Modular outlets

Flexibility: It is defined as the ratio of the rate of change of discharge of an outlet to the rate of change of discharge of the distributing channel.

Proportionality: If the flexibility is equal to one then the outlet is termed as proportional outlet.

Sensitivity: It is defined as the ratio of the rate of change of discharge of an outlet to the rate of change in the level of the water surface in the distributing channel.

Efficiency: It is defined as the ratio of the head recovered to the head put in. Efficiency is a measure of conservation of head by an outlet.

Setting: It is the ratio of the depth below full supply level of the crest of an outlet to the full supply depth of the channel at that point.

Adjustability: Adjustability means capacity for modification of the outlet to take into account changed condition such as silting or scouring of the distributing channel.

1.28 (b)

Duty of water is the relation between the area of the land irrigated and the quantity of water required

to be supplied for growing a crop. It is usually defined as the area of land in hectares which can be irrigated for growing any crop if one cumec (one cubic metre per second) of water is supplied continuously to the land for the entire base period of the crop. As irrigation water flows over the agricultural land, some amount of water percolates into the soil there by decreasing the duty of soil.

1.29 (d)

$$\Delta = 8.64\frac{B}{D} = \frac{8.64\times120}{860}$$

$$= 1.2056\text{ m}$$

$\therefore$ Vol. $= 2400 \times 1.2056$ ha-m

$= 2893 \approx 2880$ ha-m

1.30 (b)

% of area under irrigation

$= (100-70) + (100-46)$

$= 30 + 54 = 84\%$

1.31 (b)

Gross Command Area= 5000 hectares

Curable Command Area = 4000 hectares

Area irrigated by Rabi = 2000 hectares

Area irrigated by Kharif = 1200 hectares

Distribution required at the head of distributory from average demand consideration

$$= \frac{1200}{900} = 1.33 \text{ cumecs}$$

1.32 (d)

Net irrigation requirement

= Consumption Use – Effective Rainfall

$$= 0.5\times(0.2-0.1)\times\frac{15}{10}\times1000$$

$$= 0.05\times\frac{15}{10}\times1000 = 75 \text{ mm}$$

Effective rainfall = 50 mm

$\therefore$ Net irrigation requirement

= 75 mm – 50 mm = 25 mm

1.33 (d)

Total irrigation water requirement

$$=0.4(0.3-0.1)\times\frac{14.7}{9.8}\times1000$$

$$=0.4\times0.2\times1.5\times1000$$

$=120$ mm

$\therefore$ Net irrigation requirement

$=120-30-90$ mm

1.34 (c)

By applying mass conservation,

$0.375\times0.6\times A = 3600\times96$

$A = 1536000\text{ m}^2$ (Where A = Area)

or $A = 153.6$ ha

So, most close is option (c).

1.35 (a)

Total water applied

$= 8\times3600\times6$

$= 172800\text{ m}^3$

Height of water applied

$$= \frac{\text{Volume of water}}{\text{Area}}$$

$$= \frac{172800}{40\times10^4} = 0.432\text{ m}$$

$= 43.2$ cm

$\therefore$ Field application efficiency

$$= \frac{30}{43.2}\times100 = 70\%$$

1.36 (d)

Crop consumptive water use is the amount of water transpired during plant growth plus what evaporates from the soil surface and fatigue in the crop area.

1.37 (a)

Required discharge capacity

$$= \frac{\text{Total volume of water}}{\text{kor period}}$$

$$= \frac{3000\times10^4\times173\times10^{-3}}{30\times24\times60\times60} = 2\text{ m}^3/\text{s}$$

1.38 (b)

Harmful effect of excessive irrigation are:

1. Too much water in the soil inhibits the process of germination of seeds. It is due to the reason that under these conditions, the seeds do not get sufficient air to respire.
2. Roots do not grow properly because excess water affects soil aeration and hence plants roots do not grow properly.

3. Excessive water in the field increases the amount of salt on the surface of soil due to evaporation.
4. The excessive irrigation may lead to lodging of the crop, may fall on the ground under the effect of strong winds.

1.39 (a)

Drip irrigation, also known as trickle irrigation, is an irrigation method that saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone.

Fertilizer and nutrient loss is minimized due to localized application and reduced leaching. Soil erosion and Weed growth is lessened.

1.40 (a)

Water mainly used by plants is from capillary water.

CIR (consumption irrigation requirement) $= C_u - P_{eff}$

C_u = Consumptive use or evapotranspiration.

From definition of CIR, it is clear that, the portion of evapotranspiration to be satisfied by irrigation is called CIR.

Hygroscopic water is water below P.W.P.

Yield of crop increases only upto optimum depth, beyond that yield starts reducing.

■■■■

2 Design of Stable Channels and Canals

2.1 Assertion (A) : Irrigation canals are constructed at a maximum grade.
Reason (R) : It is advantageous to command as much arid land as possible.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

2.2 Match List-I (Control structures) with List-II (Functions of the control structures) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Canal drop	1. Control of flow depth
B. Canal escape	2. Control of bed grade
C. Canal cross regulator	3. Control of full supply level
D. Canal outlets	4. Control of discharge

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	2	3	1	4
(c)	3	2	1	4
(d)	3	2	4	1

[ESE : 1997]

2.3 For medium silt whose average grain size is 0.16 mm, Lacey's silt factor is likely to be
(a) 0.30 (b) 0.45
(c) 0.70 (d) 1.32

[ESE : 1997]

2.4 In order to ensure that no scouring takes place in the bed of a channel of bed slope 'S' constructed on alluvial soil of particle size 'd' cm, the flow velocity should be restricted to
(a) $4.85\, d^{1/2} S^{-1/6}$ (b) $4.85\, d^{-1/2} S^{1/6}$
(c) $0.48\, d^{1/2} S^{-1/6}$ (d) $0.48\, d^{-1/2} S^{1/6}$

[ESE : 2000]

2.5 The Lacey's silt factor for a particular alluvium is 2.0. This alluvium would comprise
(a) medium sand of size 0.5 mm
(b) coarse sand of size 0.75 mm
(c) medium bajri of size 1.3 mm
(d) coarse bajri of size 2.4 mm

[ESE : 2001]

2.6 Match List-I (Surface) with List-II (Appro-ximate range of Manning's n) and select the correct answer using the codes given below the lists:

List-I
A. Gravel river bed with 50 mm diameter bed
B. Badly maintained unlined irrigation channel
C. Concrete lined channel
D. Channel with brick lining

List-II
1. 0.02 to 0.022
2. 0.025 to 0.04
3. 0.013 to 0.017
4. 0.04 to 0.08

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	4	2	3	1
(c)	1	3	2	4
(d)	1	2	3	4

[ESE : 2001]

2.7 In alluvial channels carrying clear water, the ratio of maximum tractive shear stress on the sides and that on the channel bed is approximately
(a) 0.5 (b) 1.76
(c) 0.76 (d) 1.5

[ESE : 2001]

2.8 Consider the following statements:
Garret's diagram for the design of irrigation channel is based on:
1. Kennedy's theory
2. Lacey's theory
3. Kutter's formula
4. Manning's formula
Which of these statements are correct?
(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4
[ESE : 2002]

2.9 The total number of independent equations that form the Lacey's regime theory is
(a) 2 (b) 3
(c) 4 (d) 6
[ESE : 2002]

2.10 Balanced depth of cutting of canal is
(a) half the total depth of a canal
(b) half of full supply depth
(c) the maximum cut that an excavator can take
(d) where volume of cutting is equal to volume of filling
[ESE : 2002]

2.11 Modular limit of a canal outlet is the ratio of
(a) rate of change of discharge of outlet to that of distributary.
(b) water depth above outlet crest to the full supply depth of the channel
(c) water depth above the crest on downstream to that on upstream of outlet
(d) rate of change of discharge of an outlet to the rate of change of water level of the channel.
[ESE : 2002]

2.12 A canal fall is a control structure
(a) located at a place where the country slope is flatter than the canal bed slope
(b) located most economically where the depth of cutting is less than the balancing depth
(c) the location of which is independent of the command to be served
(d) designed to secure raising of water surface on its upstream
[ESE : 2002]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

2.13 Assertion (A): With tile lining of canals, permissible velocity of flow is lower than that with concrete lining.
Reason (R): The surface of tile lining becomes rough due to loss of surface material with high velocity.
[ESE : 2003]

2.14 Assertion (A): Canal escape serves as a safety valve for a canal.
Reason (R): Canal escape discharges the excess water in the parent canal due to sudden closure of outlets by the farmers.
[ESE : 2003]

2.15 Match List-I (Theory) with List-II (Propounded by) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Exit gradient	1. G. Lacey
B. Alluvial canal	2. L.K. Sherman
C. Unit hydrograph	3. A.N. Khosla
D. Boundary layer	4. C. Inglis
	5. T.V. Karman
	6. L. Prandtl

Codes:

	A	B	C	D
(a)	1	3	2	6
(b)	6	2	3	5
(c)	3	1	2	6
(d)	3	1	4	2

[ESE : 2003]

2.16 What is the regime scour depth for a channel in soil with silt factor of unity and carrying 8 m^2/s of discharge intensity in accordance with Lacey's regime theory?
(a) 3.6 m (b) 4 m
(c) 5.4 m (d) 25. 6 m
[ESE : 2004]

2.17 The channel section can be designed on the basis of Lacey's Theory. The steps are mentioned below:
1. Finding out the perimeter
2. Finding out the velocity
3. Calculation of the silt factor
4. Finding out the area

What is the correct sequence of the steps?
(a) 4-2-3-1 (b) 3-1-4-2
(c) 4-1-3-2 (d) 3-2-4-1

[ESE : 2005]

2.18 In Lacey's regime theory, the velocity of flow is proportional to
(a) Qf^2 (b) Q/f^2
(c) $(Qf^2)^{1/6}$ (d) $(Q/f^2)^{1/6}$

[ESE : 2005]

2.19 Match List-I with List-II and select the correct answer using the codes given below the lists:
(S = bed slope, q = discharge intensity, Q = Discharge)

List-I
A. Mean velocity in a Lacey's regime channel
B. Mean velocity in a lined channel
C. Normal scour depth in an alluvial channel
D. Wetted perimeter of a Lacey regime channel

List-II
1. $S^{1/2}$
2. $S^{1/3}$
3. $q^{2/3}$
4. $q^{-2/3}$
5. $Q^{1/2}$

Codes:

	A	B	C	D
(a)	2	5	3	1
(b)	3	1	4	5
(c)	2	1	3	5
(d)	3	5	4	1

[ESE : 2006]

2.20 Which type of fall can be generally used for a moderate discharge of 40–60 cumecs and low fall heights of 1 to 1.5 m?
(a) Vertical drop fall (b) Ogee fall
(c) Glacis fall (d) Baffle fall

[ESE : 2006]

2.21 The permissible tractive force in an erodible channel depends upon which of the following?
1. Angle of the repose of the material
2. Particle size
3. Sediment content of water
4. Wetted perimeter of channel

Select the correct answer using the codes given below:
(a) 1, 2 and 4 (b) 1, 2 and 3
(c) 1 and 3 only (d) 2 and 4 only

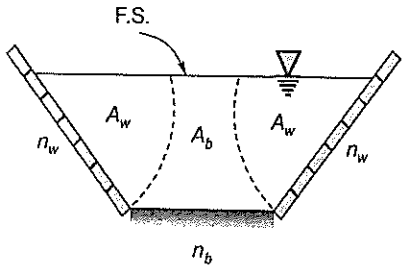
[ESE : 2008]

2.22 Consider the following statements:
Lining of irrigation canals has necessarily to be carried out in the reaches where the channel passes through
1. sandy soil
2. coarse aggregate soil
3. clay soil
4. fine silt and clay

Select the correct answer using the codes given below:
(a) 1 and 3 (b) 3 only
(c) 1 and 2 (d) 3 and 4

[ESE : 2008]

2.23 The two sides of a trapezoidal channel are lined with cement plaster, $n_w = 0.012$, while the earthen bed has $n_b = 0.025$, the area is divided into three parts as in the figure.



Consider the following assumptions to find the discharge through this section:
1. The average velocity is the same for all the 3 parts.
2. Discharge is the same in all the 3 parts.
3. Bed slope is the same for all the 3 parts.
4. Hydraulic mean radius is the same for all the 3 parts.

Which of the above assumptions are correct?
(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

[ESE : 2010]

2.24 Garret's diagrams are used to
(a) separate base flow from total runoff
(b) correct inconsistency in rainfall data
(c) determine reservoir capacity
(d) design channels

[ESE : 2010]

2.25 **Assertion (A):** Lining a canal is always beneficial and economical.
Reason (R): The seepage losses are greatly reduced and extra water is available for irrigation.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

2.26 Two different channels, *M* and *N*, in two different sites are designed based on Lacey's theory, to carry same quantum of discharge. But the bed material of *M* is found to be finer than that of *N*.
(a) Channel *M* will have steeper longitudinal slope
(b) Channel *N* will have steeper longitudinal slope
(c) Channels *M* and *N* can have same longitudinal slopes
(d) Silting is more in *M* than in *N*

2.27 The relation between suspended sediment transport Q_s and stream flow Q is often represented by an equation of the form

$$Q_s = K \cdot Q^n$$

where *n* commonly varies between:
(a) 1/3 and 1/2 (b) 0.2 and 0.3
(c) 1 and 3 (d) 0.6 and 0.8

[ESE : 2011]

2.28 Consider the following statements:
The general depth of scour calculated by Lacey's formula in a river represents the depth below the:
1. Maximum flood level in the river
2. Minimum flow water level in the river
3. Normal flow water level in the river
4. Existing river bed level

Which of these statements is/are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2, 3 and 4 only (d) 1 only

[ESE : 2011]

2.29 The local scour depth in front of a semicircular shaped rectangular pier having width equal to *W* aligned parallel to the flow below the surrounding bed is
(a) 2.0 *W* (b) 1.5 *W*
(c) 1.2 *W* (d) 1.0 *W*

[ESE : 2012]

2.30 Critical shear stress of cohesive sediment
(a) Decreases with the void ratio for a given plasticity index.
(b) Increases with the plasticity index for a given void ratio
(c) Increases with shear strength for a given clay content
(d) All of the above

[ESE : 2012]

2.31 Consider the following statements:
1. A regime channel will have side slopes of value 0.5 H : 1 V.
2. Lacey's regime formula is applicable to regime channels with sediment concentration more than 5000 ppm
3. For a Lacey regime channel the Manning roughness coefficient is estimated by Strickler's formula
4. The mean velocity in a Lacey channel is proportional to $R^{2/3}$ where R = hydraulic radius.

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 4
(c) 2 and 3 (d) 3 and 4

[ESE : 2013]

2.32 The minimum size of gravel that will not move in the bed of a wide rectangular channel of depth 0.8 m and longitudinal slope 0.0041 is
(a) 11 mm (b) 23 mm
(c) 36 mm (d) 57 mm

[ESE : 2013]

2.33 Consider a wide rigid-boundary canal with bed slope of 0.004, Manning's ρ = 0.18 and depth of flow 0.88 m. The average boundary shear stress will be
(a) 17.2 N/mm^2 (b) 18.2 N/mm^2
(c) 19.2 N/mm^2 (d) 16.2 N/mm^2

[ESE : 2014]

2.34 In a Lacey regime channel:
1. The bed load is zero.
2. The suspended load is zero.
3. The bed slope is a function of the full supply discharge and the silt size.

Which of the above statements is/are correct?
(a) 1 and 2 (b) 3 only
(c) 2 and 3 (d) 2 only

[ESE : 2014]

2.35 A regime canal carries silt of median size 0.25 mm. The Lacey's silt factor of this silt is
(a) 0.66 (b) 0.88
(c) 0.44 (d) 0.22

[ESE : 2014]

2.36 A channel designed by Lacey's theory has a velocity of 0.88 m/sec. The silt factor is 1.1. Then hydraulic mean depth will be
(a) 1.95 m (b) 1.76 m
(c) 1.63 m (d) 1.50 m

[ESE : 2014]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

2.37 Assertion (A): An alluvial channel is defined as a channel in which the flow transports sediment of the same physical characteristics as the material in the wetted surface of the channel.
Reason (R): This ensures that the channel cross-section and the channel slope do not change.

[ESE : 2015]

2.38 Assertion (A): The excavation of side slope of an irrigation canal for clayey type of soil should be made at 1 : 1 (i.e. 1 horizontal to 1 vertical) which is taken as nearly equal to the angle of internal friction of the soil.
Reason (R): The angle of internal friction represents the stable slope when the excavated soil, or soil in loose conditions, assumes when dumped in situ.

[ESE : 2015]

2.39 The conditions to be satisfied for a channel in 'Regime' as per-Lacey are
1. Constant discharge
2. Silt grade and silt concentration are constant
3. The channel is flowing in unlimited incoherent alluvium of the same alluvial character as that transported.

Which of the above statements are correct?
(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2016]

2.40 A channel designed by Lacey's theory has a mean velocity of 1.1 m/s. The silt factor is 1.1. Then hydraulic mean radius will be
(a) 1.13 m (b) 2.27 m
(c) 3.13 m (d) 4.27 m

[ESE : 2016]

Directions: Each of the next items consists of two statements, one labelled as the 'Statement (I)' and the other as 'Statement (II)'. Examine these two statements carefully and select the answers to these items using the codes given below :
Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

2.41 Statement (I) : A channel in alluvium running with constant discharge and constant sediment charge will first form its flow section and then its final longitudinal slope.

Statement (II) : If a channel in alluvium has a section too small for a given discharge and slope steeper (than required, degradation and aggradation happen and then the flow section attains final regime.

[ESE : 2016]

2.42 **Statement (I):** The shear stress exerted by the stream flow on the bed is responsible for the movement of bed sediment particles.

Statement (II): The sediment will move when the shear stress crosses a threshold limit designated as a critical shear stress τ_c.

[ESE : 2016]

2.43 Consider the following statements regarding design of channel by Lacey and Kennedy:

1. The theoretical concept of silt transportation is the same in both the theories.
2. Lacey improved upon Kennedy's formula.
3. There are no defects in either the theories of Lacey or of Kennedy.

Which of the above statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 2017]

■■■■

Answers Design of Stable Channels and Canals

2.1	(d)	2.2	(b)	2.3	(c)	2.4	(a)	2.5	(c)	2.6	(b)	2.7	(c)	2.8	(a)	2.9	(b)
2.10	(d)	2.11	(b)	2.12	(b)	2.13	(a)	2.14	(a)	2.15	(c)	2.16	(c)	2.17	(d)	2.18	(c)
2.19	(c)	2.20	(c)	2.21	(b)	2.22	(d)	2.23	(*)	2.24	(d)	2.25	(d)	2.26	(b)	2.27	(c)
2.28	(d)	2.29	(a)	2.30	(d)	2.31	(d)	2.32	(c)	2.33	(*)	2.34	(b)	2.35	(b)	2.36	(b)
2.37	(c)	2.38	(d)	2.39	(b)	2.40	(b)	2.41	(a)	2.42	(a)	2.43	(a)				

Explanations Design of Stable Channels and Canals

2.1 (d)

The slope of the channel is fixed on available country slope consistent with economy. A steeper slope governed by the maximum permissible velocity, will be most economical, but it will lower the FSL, causing less irrigation. Hence, the maximum possible irrigation would indicate flatter slope governed by minimum permissible velocity for no silting to occur. A via media between these two limits must be adopted for selecting a suitable bed slope for the channel.

2.2 (b)

Canal drop or fall is provided whenever the available natural ground slope is steeper than the designed bed slope of the channel. Thus it controls the grade of bed.

Canal escape is constructed as a side channel to remove surplus water from an irrigation channel into a natural drain. The water in the irrigation channel may become surplus due to some mistake, or difficulty in regulation at the head, or due to excessive rainfall in upper reaches. Thus it controls the full supply level to avoid breaching of canal and work as safety valve. The minimum capacity of the escape is generally kept half of the channel capacity at the point of escape.

Canal cross-regulator controls the flow depth by heading up water on the U/S when the water level in main channel is low.

Canal outlets or modules are built at the head of the water course so as to connect it with a minor or distributary channel. They control discharge to watercourse on the principle of equitable distribution of water.

2.3 (c)

Lacey's silt factor, $f = 1.76\sqrt{d_m}$

$= 1.76 \times \sqrt{0.16} = 0.704$

2.4 (a)

Flow velocity, $V = \frac{1}{n} R^{2/3} S^{1/2}$

For no scouring in the channel

$d = 11\,RS$

$$\therefore \quad R = \frac{d}{11S}$$

By Stickler's formula

$$n = \frac{d^{1/6}}{24}$$

$$\therefore \quad V = \left(\frac{24}{d^{1/6}}\right)\left(\frac{d}{11S}\right)^{2/3} S^{1/2}$$

$$= 4.8\, d^{1/2} S^{-1/6}$$

2.5 (c)

Lacey's silt factor

$$f = 1.76\sqrt{d_m}$$

$$\therefore \quad d_m = \left(\frac{f}{1.76}\right)^2 = 1.3$$

2.6 (b)

The gravel bed will be more rough than brick lined channel.

Similarly badly maintained unlined irrigation channel will have higher 'n' value than concrete lined channel.

2.7(c)

Maximum tractive shear stress on the sides and on the bed of a channel is $0.75\ \gamma y_0 s_0$ and $0.97\gamma y_0 s_0$ respectively.

2.8 (a)

Garret's diagram is graphical solution of Kennedy's and Kutter's equations to save enormous mathematical calculations in the design of irrigation channels. These have been drawn for trapezoidal channel with side slopes as $\frac{1}{2}$H : 1V on the assumption that irrigation channels adopt approximately this shape even though they were constructed on different side slopes.

2.9 (b)

A rigid bed canal has one degree of freedom i.e. for a given channel a change in discharge would cause a change in the depth only.

A man-made alluvial channel has three degrees of freedom i.e. for a given channel, change in discharge can cause changes in width, depth and bed slope. Thus three equations independent of each other are needed, as given by Lacey, to represent three degrees of freedom viz. depth, width and gradient. A natural alluvial river has four degrees of freedom as its planiform can also alter.

2.10 (d)

Balanced depth of cutting of canal is where volume of cutting = volume of filling. This reduces the transportation expenses of soil.

2.11(b)

The ratio of depth of water level over crest on the downstream of the module (H_2) to the depth of water level over crest on the upstream of the module (H_1) is called drowning ratio or submergence ratio (H_2/H_1).

The rate of change of discharge through the outlet to the rate of change of water level of the distributary or channel is called sensitivity.

The rate of change of discharge of outlet to that of distributary is called flexibility.

Modular limits are extreme values of any one or more variables, beyond which an outlet becomes incapable of acting as a module or semi-module.

The range between the lowest and highest limiting values of various such factors is known as modular range.

2.12(b)

When the available natural ground slope is steeper than the designed bed slope of the channel, the difference is adjusted by constructing canal falls or drops. The location of fall depends upon the topography, command area and the possibility of combining it with a bridge, regulator, or some other masonry work, since such combinations often result in economy and better regulation.

2.13(a)

Limiting velocities in different type of linings

	Type of lining	Safe limiting velocity
1.	Boulder lining	1.5 m/s
2.	Burnt clay tile lining	1.8 m/s
3.	Cement concrete lining	2.7 m/s

2.16(c)

Regime scour depth,

$$R = 1.35\left(\frac{q^2}{f}\right)^{1/3}$$

$$= 1.35 \times \left(\frac{8^2}{1}\right)^{1/3} = 5.4 \text{ m}$$

2.17 (d)

Design procedure of Lacey's theory:

(i) Calculate silt factor

$$f = 1.76\sqrt{d_m}$$

(ii) Find out velocity

$$V = \left(\frac{Qf^2}{140}\right)^{1/6}$$

$$= 10.8\, R^{2/3} R^{1/3}$$

(iii) Find out area $A = Q/V$

(iv) Find out perimeter $P = 4.75\sqrt{Q}$

As per Lacey's theory slope,

$$S = \frac{f^{5/3}}{3340 Q^{1/6}}$$

2.19 (c)

Mean velocity in Lacey's regime channel

$$V = 10.68\, R^{2/3} S^{1/3}$$

Mean velocity in lined channel given by Manning's

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Normal scour depth in alluvial channel

$$= 1.35\left(\frac{q^2}{f}\right)^{1/3}$$

Wetted perimeter,

$$P = 4.75$$

2.20 (c)

Ogee fall has convex and concave curves. Due to smooth transition, the kinetic energy of the flow is not at all dissipated. This causes erosion of downstream bed and banks. It is not used these days.

Well (Cylindrical or syphon well) fall is necessary in the case of falls greater than 1.8 m and for discharges greater than 0.29 m^3/s. Thus it is used for larger drop and smaller discharges.

Simple vertical drop type and Sarda type falls are used for small discharges which vary over wide range. They are suitable for discharges upto 15 cumecs and drops upto 1.5 m.

Straight Glacis falls are designed such that hydraulic jump occurs on the glacis, causing sufficient energy dissipation. They can be adopted suitably for discharges upto 60 cumecs and drops upto 1.5 m and can be even flumed.

Baffle fall (English fall) may be used for all discharges when drop is more than 1.5 m.

Note: Glacis type fall is suitable as a metering device. Baffle fall can also be flumed to measure the discharge.

2.21 (b)

Tractive force $F = W \sin\theta = \gamma AL \sin\theta$

- Angle of repose controls the shear stress between channel bed and particle.
- Tractive force exerted by water is proportional to particle size
- Sediment content controls the value of γ in the Tractive force equation

2.22 (c)

Lining of irrigation canals is necessary in reaches where channel passes through Sandy soils and coarse aggregate soils as percolation and absorption of these soils is high.

2.23 (*)

Only bed slope will be same for all the three parts.

2.24 (d)

Garret's diagram gives the graphical method of designing a channel. Basic aim is to save time. It is based on Keneddy's theorem and Kutter's formula.

2.25 (d)

Lining of a canal is always beneficial. It reduces seepage losses and extra water is available for irrigation. But it may not be economical always as cost of lining can be very expensive.

2.26 (b)

When discharge is same, channel with finer material will have less silt factor.

$$f = 1.76\sqrt{d_{mm}}$$

$$S = \frac{f3}{3340 Q^{1/6}}$$

If Q is constant

$$S \propto f^{5/3}$$

Thus channel N will have steeper longitudinal slope

2.27 (c)

$$Q_s = KQ^n$$

From Meyer-Peter and Muller formula n varies between 1 and 3.

2.28 (d)

The general depth of scour calculated by Lacey's formula in a river represents depth below maximum flood level.

2.30 (d)

Average shear stress acting on bed of channel at which sediment particles just begin to move is called Critical shear stress. Increase in plasticity index at given void ratio increases cohesion, thus increases the Critical shear stress. Increase in shear strength increases the Critical shear stress. As void ratio decreases for given Plasticity index, Critical shear stress increases.

2.31 (d)

In open channels, the Darcy–Weisbach equation is valid using the hydraulic diameter as equivalent pipe diameter. It is the only sound method to estimate the energy loss in man-made open channels. Though for various reasons, empirical resistance coefficients like Chezy, Gauckler–Manning–Strickler equations are used to calculate roughness coefficient.

2.32 (c)

$$d_{max} = 11RS_0$$

Where, $R = \frac{By}{B+2y} \simeq y \; [\because B \gg y]$

$= 11(0.8)0.0041$

$= 0.03608 \text{ m} = 36 \text{ mm}$

2.33 (*)

Average boundary shear stress

$$\tau_{av} = \gamma_w RS$$

$$= 9.81 \times 0.88 \times 0.004 \times 10^3$$

$$= 34.53 \text{ N/mm}^2$$

2.34 (b)

In Lacey's regime channel

$$f = 1.76\sqrt{d_{mm}}$$

$$S = \frac{f^{5/3}}{3340Q^{1/6}}$$

f = silt factor, Q = discharge, d = silt size.

2.35 (b)

Lacey's silt factor (f)

$$= 1.76\sqrt{d_{mm}} = 1.76\sqrt{0.25} = 0.88$$

2.36 (b)

Hydraulic mean depth,

$$R = \frac{5}{2}\frac{V^2}{f} = \frac{5}{2} \times \frac{(0.88)^2}{1.1} = 1.76 \text{ m}$$

2.37 (c)

The Cross-section and Slope of an alluvial channel changes due to silting and erosion at the wetted surface of the channel.

2.38 (d)

Angle of 1 : 1 is the angle of repose of moist clay which is the gradient of slope at which soil settles naturally when in loose state.

2.39 (b)

Conditions to be satisfied for Regime as per Lacey are:

(i) Channel should flow uniformly in "incoherent unlimited alluvium" of same character as that transported by the water;

(ii) Silt grade should be constant

(iii) Silt charge should be constant;

(iv) Discharge should be constant.

(v) Flow is uniform

2.40 (b)

Hydraulic mean radius $= R = \frac{5}{2} \cdot \frac{v^2}{f}$

v = mean velocity = 1.1 m/s

f = silt factor = 1.1

$$R = \frac{5}{2} \times \frac{1.1^2}{1.1} = 2.75 \text{ m}$$

Note: None of these answer is correct, but nearest answer is 2.27 m.

2.41 (a)

In the initial regime condition flow section is first of all formed and then longitudinal slope changes.

Finally because of change in slope degradation and aggradation happen and finally attains final regime condition.

2.43 (a)

Concept of silt transportation from both Kennedy's and Lacey's theory is weight of water. Limitations are there in both Kennedy's as well as Lacey's theory.

■■■■

3 Design & Construction of Gravity Dams

3.1 The construction of impounding reservoir is required when

(a) average annual flow in the stream is lower than average demand

(b) the rate flow in the stream, in dry season is more than the demand

(c) the rate of flow in the stream, in dry season is less than the demand

(d) the rate of flow in the stream is equal to the demand

[ESE : 1996]

3.2 If ρ is the specific gravity of the material used in the design of a masonry dam of triangular section, then the ratio between the height and base width of the dam for structural safety and stability is equal to

(a) $\sqrt{2\rho}$ (b) $\sqrt{\rho}$

(c) $\frac{1}{\rho}$ (d) $\frac{1}{\sqrt{\rho}}$

[ESE : 1997]

3.3 If the eccentricity of total self-weight W of a masonry dam at its base is equal to one-fourth of base width B, then the maximum pressure at the base is given by

(a) 2W/3B (b) 4W/3B

(c) 5W/2B (d) 8W/3B

[ESE : 1998]

3.4 The best design of an arch dam is when

(a) all horizontal water loads are transferred horizontally to the abutments

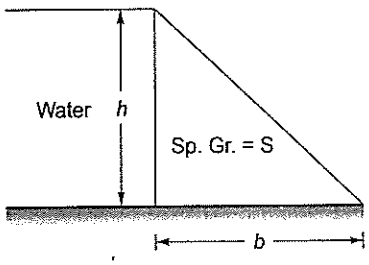
(b) the dam is safe against sliding at various levels

(c) the load is divided between the arches and cantilevers and the deflections at the conjugal points being equal

(d) the deflections of the cantilevers are equal at different points

[ESE : 1999]

3.5 Assertion (A): In the retaining wall shown in the given figure when the ratio $\frac{h}{b} = \sqrt{S}$ the eccentricity is $\frac{b}{6}$ whether the storage is nil or full.



Reason (R): The resultant force will pass through the centroid of the pressure distribution diagram on the base, for the nil or full storage if the ratio $\frac{h}{b} = \sqrt{S}$.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 1999]

3.6 Which one of the following sets is used to control the seepage through the foundations of an earth dam?

(a) Chimney drain, upstream blanket and cut-off trench

(b) Cut-off sheet piles, upstream blanket and cut-off trench

(c) Upstream blanket, cut-off sheet piles and chimney drain

(d) Relief wells, upstream blanket and chimney drain

[ESE : 2000]

3.7 A constant angle arch dam when compared to a constant radius arch dam utilizes concrete quantity of about
(a) 33% (b) 43%
(c) 73% (d) 143%
[ESE : 2002]

3.8 Assertion (A): Cut-offs are provided on the downstream base of hydraulic structures.
Reason (R): Hydraulic structures fail by overturning about the downstream base due to excessive erosion at the base caused by overflowing water.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2002]

3.9 Consider the following statements:
The function of a cut-off in an earth dam is
1. to reduce uplift pressures on the dam
2. to prevent undermining of foundation
3. to reduce loss of stored water
4. to support the dam
Which of these statements are correct?
(a) 1 and 3 (b) 2 and 4
(c) 2 and 3 (d) 3 and 4
[ESE : 2003]

3.10 A check dam is a
(a) flood control structure
(b) soil conservation structure
(c) river training structure
(d) water storage structure
[ESE : 2003]

3.11 The base width of a solid gravity dam is 25 m. The material of the dam has a specific gravity of 2.56 and the dam is designed as an elementary profile ignoring uplift. What is the approximate allowable height of the dam?
(a) 64 m (b) 40 m
(c) 164 m (d) 80 m
[ESE : 2005]

3.12 Which of the following categories best describes the Hirakud reservoir?
(a) Reservoir for irrigation and power
(b) Reservoir for flood control, power and irrigation
(c) Reservoir for irrigation and water supply
(d) Reservoir for recreation and fishery
[ESE : 2009]

3.13 What is the critical combination of vertical and horizontal earthquake accelerations to be considered for checking the stability of a gravity dam in reservoir full condition ?
(a) Vertically upward and horizontally downstream
(b) Vertically upward and horizontally upstream
(c) Vertically downward and horizontally upstream
(d) Vertically downward and horizontally downstream
[ESE : 2009]

3.14 The maximum height of a low gravity dam of elementary profile made of concrete of relative density 2.5 and safe allowable stress of foundation material 3.87 MPa without considering uplift force is about
(a) 113 m (b) 217 m
(c) 279 m (d) 325 m
[ESE : 2010]

3.15 A constant centre (in plan-view) arch dam is best suited for
(a) A V-shaped gorge
(b) A U-shaped gorge
(c) Both U-shaped and V-shaped gorges
(d) Multi-peaked gorges
[ESE : 2011]

3.16 At the base of a gravity dam section, the vertical stress at the toe was found to be 2.4 MPa. If the downstream face of the dam has a slope of 0.707 horizontal : 1 vertical, and if there is no tail water, the maximum principal stress at the toe of the dam is
(a) 1.7 MPa (b) 2.4 MPa
(c) 3.6 MPa (d) 4.8 MPa
[ESE : 2014]

3.17 The top width and the bottom width at river thalweg level of a concrete gravity dam are 6 m and 24 m respectively. The vertical section of the dam at the thalweg alignment is 38 m above the thalweg. The upstream face is vertical and the depth of water on the upstream side is 36 m. The moment of hydrostatic force about the toe at that level is
(a) 77760 kN-m (b) 25292 kN-m
(c) 6480 kN-m (d) 51840 kN-m
[ESE : 2014]

3.18 Consider the following statements related to uplift pressure in gravity dams:

1. A drainage gallery reduces the uplift pressure at all levels below the gallery.
2. A drainage gallery below upstream water level reduces the uplift pressure at all levels below the upstream water level.
3. A grout curtain near the heel reduces seepage and uplift pressure everywhere on the gravity dam whatever the upstream water level.

Which of the above statements are correct?

(a) 2 and 3 only (b) 1 and 2 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2016]

3.19 **Statement (I) :** The trap efficiency of a reservoir increases with age as the reservoir capacity is reduced by sediment accumulation.

Statement (II): The trap efficiency is a function of the ratio of reservoir capacity to the total inflow. A small reservoir on a large stream has a low trap efficiency.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

3.20 Consider the following statements in respect of dams:

1. In a gravity, dam, grout curtain is provided near the toe to reduce the exit gradient.
2. A drainage gallery with its drainage pipe system provided in gravity dam reduces the uplift pressure at all levels below the upstream water level.
3. An earthquake acceleration of 0.1 g acting vertically downward causes a decreases of 10% in the unit weight of concrete and of water in a gravity dam.
4. The Tehri dam is a gravity dam.

Which of the above statements are correct?

(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

[ESE : 2017]

3.21 Consider the following statements concerning engineering geology:

1. Dams on sedimentary impervious strata dipping upstream will be unsafe.
2. In general, igneous rocks are hard and are suitable for construction of large hydraulic structures.
3. Construction of a major dam must be preceded by thorough geotechnical investigations.
4. Construction of dams is never indicated in any active sone of seismicity.

Which of the above statements are correct?

(a) 1 and 2 only (b) 1 and 4 only
(c) 2 and 3 only (d) 3 and 4 only

[ESE : 2017]

Answers Design & Construction of Gravity Dams

3.1	(c)	3.2	(b)	3.3	(d)	3.4	(c)	3.5	(b)	3.6	(b)	3.7	(b)	3.8	(b)	3.9	(c)		
3.10	(a)	3.11	(b)	3.12	(b)	3.13	(d)	3.14	(a)	3.15	(b)	3.16	(c)	3.17	(a)	3.18	(a)		
3.19	(d)	3.20	(a)	3.21	(c)														

Explanations Design & Construction of Gravity Dams

3.1 (c)

Impounding reservoirs can store water during high flow and utilize the same during lean flow period (i.e. when flow in stream is less than demands).

3.2 (b)

$\frac{H}{b} = \sqrt{\rho}$ from stress criterion

$\frac{H}{b} = \mu\rho$ from stability or sliding criterion

3.3 (d)

Masonry cannot take tension. So maximum pressure for $e > \frac{b}{6}$ is

$$p_{max} = \frac{2W}{3\left[\frac{B}{2} - e\right]} \qquad \text{Given } e = \frac{B}{4}$$

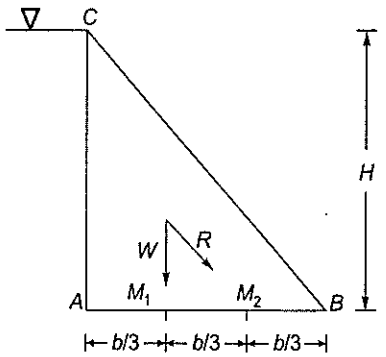
$$\therefore \quad p_{max} = \frac{8W}{3B}$$

3.4 (c)

Arch dams are solid walls curved in plan. They behave as a cantilever retaining wall standing up from its base, and partly the load will be transferred to the two ends of the arch span by horizontal action. In the trial load method of design, the load is assumed to be distributed between the arch elements and the cantilever elements. The deflection calculated at conjugal points should be the same.

3.5 (b)

When the reservoir is empty, the resultant force should pass through the inner third point (M_1) so that no tension is developed. For the reservoir full condition, the resultant must pass through the outer third point (M_2) so that no tension is developed. Taking the moment of the forces about M_2 and equating it to zero.



$$b = \frac{H}{\sqrt{\rho - c}}$$

If uplift is not considered

$$b = \frac{H}{\sqrt{\rho}}$$

3.6 (b)

For seepage control through embankments/dams following drainage filters can be provided:

(i) Rock toe filter
(ii) Horizontal blanket or filter on downstream
(iii) Chimney drain

For seepage control through foundations the following can be provided :

(i) Impervious cut-off sheet piles
(ii) Relief wells or drain trenches or cut-off trench
(iii) Upstream blanket

3.7 (b)

Arch dams can be divided into three types:

(i) Constant radius arch dams
(ii) Variable radius arch dams
(iii) Constant angle arch dams

Constant radius arch dam is simplest in design and construction, but uses the maximum concrete. A constant angle arch dam uses about 43% of concrete used by constant radius arch dam. A variable radius arch dam is an intermediate choice, using around 58% of the concrete used by constant radius arch dam.

3.8 (b)

In order to dissipate residual energy and to keep scour away from the pucca floor, loose stone talus is provided on the downstream of D/S pucca floor and upstream of U/S pucca floor. The erosion at the downstream will cause the structure to fail by overturning about downstream base.

Cut-offs on downstream prevent undermining of foundation by reducing exit gradient.

3.9 (c)

Impervious vertical cutoff made of concrete or sheet pile can be provided at the upstream end of the earthen dam. It can control seepage. The downstream cut-offs may reduce exit-gradient and thereby prevent undermining of foundation.

3.10(a)

Check dam is used for flood control.

3.11(b)

For elementary profile

$$B = \frac{H}{\sqrt{S_C - C}}$$

When uplift is ignored C = 0

$$\therefore \quad B = \frac{H}{\sqrt{S_C}}$$

Or $H = 25 \times \sqrt{2.56} = 40\ \text{m}$

3.12(d)

When the vertical acceleration is acting downward, the foundation shall try to move downward away from the dam body; thus reducing the effective weight and the stability of the dam, and hence is the worst case for designs. When the reservoir is full, the force due to horizontal acceleration would produce worst results if it is additive to the hydrostatic water pressure, thus acting towards the downstream. When the reservoir is empty, this force would produce worst results, if considered to be acting upstream.

3.13 (d)

When the vertical acceleration is acting downward, the foundation will try to move downward, i.e. away from the body of the dam; thus reducing the effective weight and stability of the dam. Thus it is the worst case from design point of view. When the reservoir is full, the force due to horizontal acceleration would produce worst results if it is additive to the hydrostatic water pressure, thus acting towards the downstream. When the reservoir is empty, this force would produce worst result, if considered acting upstream.

3.14(a)

The limiting height of a low concrete gravity dam without considering uplift force is given by

$$H_{max} = \frac{f}{\gamma_w (G+1)} = \frac{3.87 \times 10^3}{9.81(2.5+1)}$$

$$= 112.7\ \text{m} \simeq 113\ \text{m}$$

3.15 (b)

Constant Center Arch Dam (variable angle) have the following features-

- Good for U-shaped valleys
- Easy construction
- Vertical upstream face
- Appropriate for middle-high dams

3.16 (c)

$$\tan\theta = \frac{1}{0.707} = \sqrt{2}$$

$$\theta = 54.7356°$$

$$-2.4 = \frac{6}{2} + \frac{6}{2}\cos 2\left[-(90° - \theta)\right] + 0$$

$$\sigma = 3.6\ \text{MPa}$$

3.17 (a)

$$F_H = \rho g \bar{H} \times \text{Area}$$

$$= 10^3 \times 9.81 \times \frac{36}{2} \times 36 \times 1$$

$$= 6356.88\ \text{kN}$$

Moment of hydrostatic force about toe

$$= F_H \times \frac{H}{3}$$

$$= 6356.88 \times \frac{36}{3} = 7628.56\ \text{kNm}$$

3.18 (a)

At the downstream point or at the toe of the dam uplift pressure will remain same irrespective of the location of drainage gallery.

3.19 (d)

The sediment trap efficiency is the difference in the sediment yield of the reservoir inflow minus the yield of the outflow, divided by the yield of the inflow. The greater the trap efficiency, the greater the sedimentation.

The trap efficiency of reservoirs typically decreases with increasing age, as the capacity of the reservoir decreases. The trap efficiency is impacted by the type of sediments, the hydraulic characteristics of the reservoir, and how the reservoir is operated.

3.20 (a)

Tehri dam is Rock and Earth fill dam.

Drainage gallery reduces the uplift pressure at all levels except at D/s end where uplift pressure remains constant.

Grout curtain increases the length of flow thus reducing the exit gradient.

4 Water Logging, Theories of Seepage and Spillway

4.1 The following parameters relate to the design of weirs on permeable foundations:

1. Scour depth
2. Exit gradient
3. Uplift pressure
4. Unbalanced head

Design of the downstream end pile of the weir depends upon

(a) 1 and 2 (b) 1 and 4
(c) 2 and 3 (d) 3 and 4

[ESE : 1995]

4.2 **Assertion (A) :** Leaching requirement is defined as the fraction of irrigation water that must be leached through the root zone of the plant in order to prevent soil salinity exceeding a specified level.
Reason (R) : The concept of leaching requirement can be used to compute the quantity of drainage water that must be removed from an identified land spread.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

4.3 Match List-I (Main provision) with List-II (Surplussing arrangement) and select the correct answer using the codes below the lists:

List-I

A. Minor irrigation work
B. Medium irrigation project in interior area
C. Earth dam across main river
D. Masonry dam on good rock

List-II

1. Saddle spillway
2. Syphon spillway
3. Ogee spillway
4. Surplus weir

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	4	2	3	1
(c)	2	4	3	1
(d)	2	4	1	3

[ESE : 1997]

4.4 The spacing of tile drains to relieve water-logged land is directly proportional to the

(a) depth of drain below the ground surface
(b) depth of impervious strata from the drain
(c) depth of drain below the water level
(d) coefficient of permeability of the soil to be drained

[ESE : 1999]

4.5 In a barrage on pervious foundation, sheet piles are provided both upstream and downstream of the barrage to reduce uplift pressure and to prevent piping. Which one of the following statements is true in this regard?

(a) Compared to downstream sheet pile, the upstream sheet pile is more effective in reducing uplift and piping
(b) Compared to upstream sheet pile, the downstream sheet pile is more effective in reducing uplift and piping
(c) Downstream sheet pile is more effective in reducing uplift while the upstream sheet pile is more effective in reducing piping
(d) Upstream sheet pile is more effective in reducing uplift while the downstream sheet pile is more effective in reducing piping

[ESE : 2001]

4.6 Consider the following statements:
The downstream impervious flow of concrete for a barrage has ruptured. This can be due to

1. insufficient length of upstream impervious floor

2. insufficient length of downstream impervious floor
3. insufficient depth of downstream pile
4. choking of inverted filter

Which of these statements are correct?

(a) 1 and 2 (b) 1 and 4
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

[ESE : 2001]

4.7 At a certain point in the floor of weir, the uplift pressure head due to seepage is 4.5 m. If the relative density of concrete is 2.5, the minimum thickness of floor required at this point to counteract the uplift pressure is

(a) 1 m (b) 2 m
(c) 3 m (d) 4 m

[ESE : 2002]

4.8 The ideal condition for energy dissipation in the design of spillways is the one when the tail water rating curve

(a) lies above jump rating curve at all discharges
(b) coincides with the jump rating curve at all discharges
(c) lies below jump rating curve at all discharges
(d) lies either above or below the jump rating curve depending upon discharge

[ESE : 2003]

4.9 Leaching is a process

(a) by which alkali salts present in the soil are dissolved and drained away
(b) by which alkali salts in soil come up with water
(c) of draining excess water of irrigation
(d) which controls water-logging

[ESE : 2003]

4.10 Which one of the following equations represents the downstream curve of the "Ogee" spillway (where x and y are the co-ordinates of the crest profile measured from the apex of the crest, and H is the design head)?

(a) $x^{1.85} = 2H^{0.85}y$ (b) $x = 2H^{1.85}y^{0.85}$
(c) $x^{0.85} = 2H^{1.85}y$ (d) $x = 2H^{0.85}y^{1.85}$

[ESE : 2004]

4.11 For a saddle siphon, the maximum operative head is 6.25 m. The width and height of the throat of the siphon are 4 m and 2 m respectively. The coefficient of discharge is 0.90. How many units are required to pass a flood of 300 cumec? (Take $g = 10$ m/s^2)

(a) One (b) Two
(c) Three (d) Four

[ESE : 2004]

4.12 Which one of the following is the purpose of providing the downstream sheet pile in a barrage?

(a) To control failure due to piping by high value of exit gradient
(b) To control failure due to scour
(c) To stop failure due to sliding
(d) To stop failure due to uplift pressure

[ESE : 2007]

4.13 Consider the following statements:

1. Giving equal weightages to horizontal and vertical creeps for design of weir foundations is one of the drawbacks of Kennedy's theory.
2. Khosla's theory of design of foundations for weirs is based on potential theory.
3. Piping problem can be reduced by increasing the length of floor.
4. In Lane's weighted creep theory, horizontal creep is given less weightage compared to vertical creep.

Which of these statements is/are correct?

(a) 1 (b) 2, 3 and 4
(c) 2 and 4 only (d) 3 and 4 only

[ESE : 2009]

4.14 **Assertion (A):** A seepage passing through the body of an earth dam affects the weight of dam.
Reason (R): The specific weight of submerged soil is not dependent on the porosity of soil.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

4.15 Consider the following statements:
Mitra's hyperbolic transition design is based on the principle that

1. Flow depth in the canal, as well as the discharge, is constant

2. Width of the canal varies along with the discharge
3. Rate of change of velocity per unit length of transition is constant throughout the length of the transition

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2011]

4.16 A discharge of 72 m^3/s is to be allowed through siphon spillways of 2 m width and 75 cm depth with working head of 8 m. The number of spillways to be provided will be (Take coefficient of discharge for the spillways = 0.64)

(a) 2 (b) 4
(c) 6 (d) 8

[ESE : 2012]

4.17 The flip bucket energy dissipator for a spillway is suitable where:

1. The tail water depth is low.
2. The rock on the downstream is fragile and is erodible.
3. The rock on the downstream is good and non-erodible.

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2013]

4.18 Which of the following outlets are of semi-modular type?

1. Khanna's module
2. Adjustable proportional module
3. Submerged pipe outlet
4. Open flume outlet
5. Kennedy's gauge outlet

(a) 2, 4 and 5 (b) 1, 2 and 4
(c) 2, 3 and 5 (d) 3, 4 and 5

[ESE : 2014]

4.19 In a ski-jump bucket provided in an overflow spillway, the lip angle is 30°, and the actual velocity of flow entering the bucket is 30 m/s. The maximum vertical height attained by the trajectory of the jet, measured above the lip of the bucket, is nearly

(a) 45 m (b) 35 m
(c) 22 m (d) 11 m

[ESE : 2015]

4.20 By considering the channel index as 5/3, the setting of an orifice type irrigation outlet to have proportionality is

(a) 0.90 (b) 0.67
(c) 0.30 (d) 0.15

[ESE : 2015]

4.21 A 20 m long horizontal concrete floor under a barrage on a permeable foundation retains a 5 m head of water and has a 5 m deep downstream end pile. The exit gradient is

(a) 1 in 4 (b) 1 in 5
(c) 1 in 6 (d) 1 in 8

[ESE : 2016]

4.22 **Statement (I):** The ogee spillway is a control weir having an S-shaped crest profile which provides a high discharge coefficient without causing cavitations.

Statement (II): The crest profile of ogee spillway conforms to the lower nappe of flow over a ventilated sharp-crested weir and ensures a constant discharge coefficient for all heads.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

■■■■

Answers Water Logging, Theories of Seepage and Spillway

4.1	(c)	4.2	(b)	4.3	(a)	4.4	(d)	4.5	(d)	4.6	(a)	4.7	(c)	4.8	(b)	4.9	(a)
4.10	(a)	4.11	(d)	4.12	(a)	4.13	(b)	4.14	(c)	4.15	(d)	4.16	(c)	4.17	(d)	4.18	(a)
4.19	(d)	4.20	(c)	4.21	(b)	4.22	(c)										

Explanations Water Logging, Theories of Seepage and Spillway

4.1 (c)

The downstream vertical cut-off at the end of the pucca floor is used to prevent undermining of foundation. There are two considerations for this purpose :

(i) Uplift pressure

(ii) Safe exit gradient

4.2 (b)

Leaching water percolates down to join the water table or is drained away by sub-surface drains. It is needed to compute the leaching requirement so that quantity of drainage water to be removed from identified land can be estimated.

4.3 (a)

Straight drop spillway or overfall spillway may be constructed on small bunds or on thin arch dams etc.

Ogee or overflow spillway is widely used with concrete, masonry, arch and buttress dams.

For earthen and rockfill dams a separate spillway is generally constructed in a flank or a saddle away from the main valley. It is also called chute or trough spillway.

Schemes involving-cultivable command area (CCA) upto 2000 ha are minor irrigation schemes; those involving CCA between 2000 to 10,000 ha are medium irrigation schemes; and those involving CCA greater than 10,000 ha are major irrigation schemes.

A surplus weir is a masonry weir with its crest level equal to full tank level. It is used in tank irrigation (minor irrigation schemes).

Syphon spillway is provided within the body of the gravity dam in medium or major irrigation projects.

4.4 (d)

Spacing of the drains $S = \frac{4K}{q}\left(b^2 - a^2\right)$

where

K is coefficient of permeability

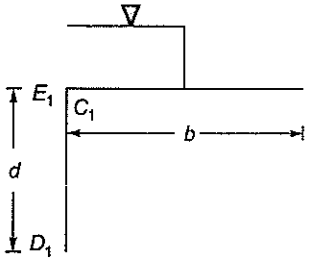
q is discharge per unit length in the drain

a is depth of impervious strata below the drain

b is maximum height of the drained water table above the impervious layer.

4.5 (d)

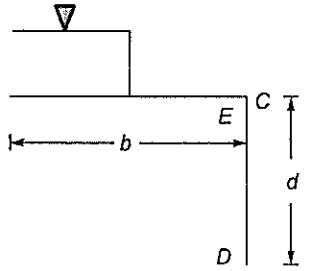
Upstream sheet pile



$\phi_{C_1} = 100 - \phi_E$

$\phi_{D_1} = 100 - \phi_D$

Downstream sheet pile



$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 2}{\lambda}\right)$$

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 1}{\lambda}\right)$$

Where $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$ and $\alpha = \frac{b}{d}$

$\phi_D < 50\%$

So $\phi_{D_1} > 50\%$ for all values of α.

For normal range of $0.4 < \alpha < 0.8$

$\phi_E = 50\%$

So $\phi_{C_1} = 50\%$

Thus upstream piles are more effective in reducing uplift pressure. While down stream piles are more effective in reducing exit gradient.

4.6 (a)

The rupturing of downstream impervious floor means that uplift pressure is very high and weight of concrete or masonry floor is not able to counter balance the same. It means that the length of upstream and downstream floor is not sufficient to reduce the uplift pressure.

4.7 (c)

To counter the uplift pressure at this point,

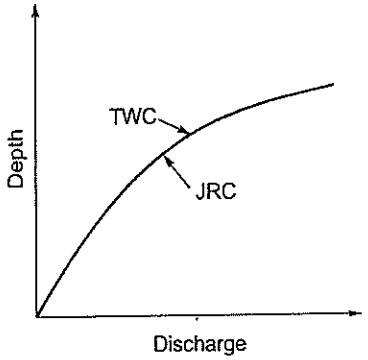
Buoyant weight of concrete=seepage force on area

$(2.5 - 1) \times t \times 1 = 4.5 \times 1$

$t = 3$ m

4.8 (b)

When tail water curve coincides with jump rating curve no extra construction cost is required to dissipate energy or to protect the basin as it is ideal condition for energy dissipation in design of spillways. When the tail water-rating curve coincides with jump curve for all values of discharge then the requirement for the sequent, depths are always satisfied and the jump forms at the same location.



4.9 (a)

Leaching is the process in which land is flooded with adequate depth of water. The alkali salts present in soil, get dissolved with this water, which percolate down to join the water table or are drained away by sub-surface drains.

Leaching requirement, $LR = \frac{D_d}{D_i}$

D_d is Depth of water drained out per unit area

D_i is Depth of irrigation water applied per unit area

$$D_i = C_u + D_d$$

C_u is Consumptive use

$$\therefore \quad LR = \frac{D_i - C_u}{D_i} = \frac{EC_i}{EC_d}$$

EC_i is Electrical conductivity of irrigation water

EC_d is Electrical conductivity of drained water.

4.10(a)

The downstream profile has following general equation.

$$x^n = KH^{n-1}y$$

Slope of upstream face of spillway	K	n
(i) Vertical	2.0	1.85
(ii) 1H : 3V	1.936	1.836
(iii) 1H : 1.5V	1.939	1.810

4.11(d)

The discharge through one unit,

$$Q = C_d A\sqrt{2gh}$$

$$= 0.90 \times (4 \times 2) \times \sqrt{2 \times 10 \times 6.25}$$

$$= 80.5 \text{ m}^3/\text{s}$$

Thus number of units needed $= \frac{300}{80.5} = 4$

4.12 (a)

Downstream sheet pile is provided to reduce high value of exit gradient. It increases the seepage path and reduces head in the end.

4.13 (b)

Giving equal weightage to horizontal and vertical creeps for design of weir foundation is one of the drawback of Bligh's theory.

4.14 (c)

- When seepage passes through the body of an earthen dam, it affects the weight of the dam.

  Effective weight = Actual weight + Seepage Force.
- Specific weight of submerged soil is given by

$$= \gamma_{sub} \times \text{Volume}$$

$$= \left(\frac{G-1}{1+e}\right)\gamma_w \times \text{Volume}$$

As e depends on porosity, hence specific weight of submerged soil also depends on porosity.

4.15 (d)

For water depth to remain constant in the transition and the trough, A.C. Mitra proposed hyperbolic transitions. The transition is designed on the basis that the rate of change of velocity per unit length of the transition is constant throughout the transition length.

It assumes that the width of the canal varies along with the velocity.

4.16 (c)

Discharge through one syphon spillway is given by

$$Q = C_d.A \times \sqrt{2gH}$$

$$= 0.64 \times 2 \times 0.75 \times \sqrt{2 \times 9.81 \times 8}$$

$$= 12.02\ m^3/s$$

$$\therefore \text{ Number of spillways} = \frac{72}{12.02} = 5.98 \cong 6$$

4.17 (d)

The flip bucket, also called ski-jump dissipator, is provided when depth is lesser than the depth required for the jump formation and river bed rock is good.

4.18 (a)

Common types of semi modulus are:-

(i) Open fume outlet

(ii) Adjustable orifice semi-module

(iii) Pipe outlet discharging freely into air

(iv) Kennedy's gauge outlet or Venturi-flume outlet.

4.19 (d)

Vertical component of velocity = $v\sin\theta = v\sin30°$

vertical velocity at top is zero, so

$$v\sin30° - gt = 0$$

$$t = \frac{v\sin30°}{g}$$

$$h = v\sin30°t - \frac{1}{2}gt^2$$

$$h = \frac{1}{2g}v^2\sin^2 30°$$

$$= \frac{30^2 \times \left(\frac{1}{2}\right)^2}{2 \times 9.81} = 11.47\ m$$

4.20 (c)

$$\text{Outlet index for orifice type outlet} = \frac{1}{2}$$

$$\text{Channel index} = \frac{5}{3}$$

$$\text{Setting} = \frac{\text{Outlet index}}{\text{Channel index}} = \frac{1/2}{5/3} = 0.3$$

4.21 (b)

$$G_E = \frac{H}{d} \times \frac{1}{\pi\sqrt{\lambda}}$$

$$\lambda = \frac{1+\sqrt{1+\alpha^2}}{2} = \frac{1+\sqrt{1+4^2}}{2} = 2.56$$

$$\left(\because \alpha = \frac{b}{d} = \frac{20}{5} = 4\right)$$

$$G_E = \frac{5}{5} \times \frac{1}{3.15 \times \sqrt{2.56}} = \frac{1}{5}$$

4.22 (c)

If the discharge is higher than the designed discharge then negative pressure will develop on the underside of the curve. Hence cavitation will occur.

■■■■

5 River Training Work, Diversion Headwork, Cross-drainage Work and Miscellaneous

5.1 The most economical method of soil conservation is to
(a) construct check dams
(b) construct contour bunds
(c) drain the soil
(d) afforest the area

[ESE : 1995]

5.2 Assertion (A): When friction blocks are provided in a stilling basin to localize and stabilize the jump formation, the downstream depth in the jump is less than that without the friction blocks.
Reason (R): The discharge per unit width at the section where the blocks are located is increased.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1996]

5.3 In the alignment of an irrigation channel wherefrom offtakes have to be provided at regular intervals, changes in the given channel parameters are made use of. The correct sequence of the decreasing order of preference of these parameters is
(a) width, slope, depth
(b) width, depth, slope
(c) depth, slope, width
(d) depth, width, slope

[ESE : 1996]

5.4 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Tailwater curve much above jump height curve
B. Tailwater curve slightly above jump height curve
C. Tailwater curve coinciding with jump height curve
D. Tailwater curve below the jump height curve

List-II
1. Basin at bed level
2. Sunk basin
3. Roller bucket
4. Sloping apron

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	1	2
(c)	4	3	1	2
(d)	3	4	2	1

[ESE : 1996]

5.5 While considering weir designs on permeable soils, the correction for mutual interference of sheet piles is NOT applicable on an intermediate pile if the outer pile
(a) goes deeper than the intermediate pile and is farther from the intermediate pile by more than twice its own length.
(b) goes only just as deep as the intermediate pile and is within a distance of one and a half times its own length.
(c) does not go as deep as the intermediate pile, no matter what the horizontal distance between them is.
(d) is safe against deleterious exit gradient.

[ESE : 1997]

5.6 When a river starts meandering, the sediment carrying capacity
(a) first decreases and ultimately increases
(b) first increases and ultimately decreases
(c) remains unaffected as the plan shape changes continuously
(d) changes erratically all the time leaving permanent braids

[ESE : 1998]

5.7 A submerged pipe outlet from a minor feeds into a well chamber across the bank. Water from the well chamber overflows a weir-like face into the field channel. The flow into the field channel
(a) will increase with any drop in the water level in the minor
(b) will not be much affected by any change in the water level in the minor
(c) will decrease with any drop in the water level in the minor
(d) will be proportional to the flow in the minor when the minor flows between set ranges

[ESE : 1998]

5.8 **Assertion (A):** In a venturi flume, the specific energy values at the normal and throat sections are always individually constant, whether the flow in the normal section is subcritical or supercritical.
Reason (R): In a canal transition formed by providing a 'hump' the total energy is constant at both the sections irrespective of the type of flow in the normal section.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

5.9 Consider the following statements:
1. In designing a hydraulic structure in permeable foundation by Khosla's theory, the slope correction is applicable to piles located at the ends of the sloped floor only in a structure with one or more sloped floors.
2. Khosla's theory can be correctly applied in alluvium of finite depth.
3. Length of flow has lesser effect on exit gradient than the depth of piles.
4. Intercepts between hydraulic gradient line and free water surface on the glacis and horizontal floor downstream is the unbalanced uplift in a structure.

Which of these statements related to the design of hydraulic structure are correct?
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 4

[ESE : 2000]

5.10 Match List-I (Energy dissipation) with List-II (Water level and slope condition) and select the correct answer using codes given below the lists:

List-I
A. Roller bucket
B. Ski-jump bucket
C. Standing wave basin with depressed floor
D. Standing wave basin with raised floor

List-II
1. TWL (tail channel water level) is slightly above JWL (jump height water level) and the slope of the channel is mild
2. TWL is considerably above JWL and the slope of the channel is mild
3. TWL is slightly below JWL and the slope of the channel is mild
4. TWL is considerably less than JWL and the slope of the channel is steep

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	2	4	1	3
(c)	2	4	3	1
(d)	4	2	3	1

[ESE : 2000]

5.11 Gibb's module is a type of outlet which ensures
(a) constant discharge even if the water levels in the supply channel and water course fluctuate
(b) variable discharge as per the need
(c) constant discharge into the water course when the water levels in the supply channel vary
(d) constant discharge for varying water levels in the water course for a given water level in the supply channel

[ESE : 2001]

5.12 The following data pertain to a natural drain crossing an irrigation canal:

Item	Canal data	Drainage data
Flow (m^3/s)	5	500
Bed level (m)	120	116
Depth of flow (m)	0.8	10

Which one of the following types of cross-drainage should be recommended in this case?
(a) Aqueduct
(b) Syphon aqueduct

(c) Syphon
(d) Super-passage

[ESE : 2001]

5.13 In curved reach of a meandering river, both deposition of sediments and erosion of bank occur. Which one of the following statements is true in this regard?
(a) Deposition of sediments occurs in the inner bank while the outer bank is subjected to erosion.
(b) Deposition of sediments occurs in the outer bank while the inner bank is subjected to erosion.
(c) In the direction of flow, the outer bank undergoes erosion first and the sediment is later deposited on the outer bank downstream.
(d) In the direction of flow, the inner bank undergoes erosion first and the sediments are subsequently deposited on the inner bank downstream.

[ESE : 2001]

5.14 In a river, silt excluder and silt ejector are constructed
(a) at a location after the head regulator and at the head of the canal, respectively
(b) at the head of the canal and at a location after the head regulator, respectively
(c) at the same location
(d) at specific locations depending upon diverse factors and their locations do not follow a set pattern

[ESE : 2001]

5.15 Which of the following pairs are correctly matched?
1. Silt factor : Average size of silt particles
2. Silt load : Volume of suspended sediments flowing with water in unit time.
3. Silt charge : Weight of silt per unit volume of water
4. Silt grade : Gradation between different silt particles

Select the correct answer using the codes given below :
(a) 1 and 4 (b) 3 and 4
(c) 2 and 3 (d) 1 and 2

[ESE : 2003]

5.16 The worst condition of uplift on the floor of a syphon aqueduct occurs when there is
(a) high flood flow in the drainage with canal dry
(b) full supply flow in the canal with drainage dry
(c) high flood flow in the drainage with canal running full
(d) Water is at drainage bed and canal is dry

[ESE : 2003]

5.17 Which one of the following is the correct sequence in the increasing order of the Froude number of flow assumed by the bed form of an alluvial stream with movable bed material?
(a) Ripple-Plane bed-Dune-Plane bed-Antidune
(b) Dune-Ripple-Plane bed-Antidune-Plane bed
(c) Plane bed-Ripple-Dune-Plane bed-Antidune
(d) Plane bed-Ripple-Antidune-Dune-Plane bed

[ESE : 2004]

5.18 Match List-I (Relative position of canal and drainage channel) with List-II (Type of cross drainage work) and select the correct answer using the code given below the lists:

List-I
A. Canal taken above the drainage channel at its grade
B. Drainage channel taken above the canal at its bed slope
C. Canal taken below the drainage channel
D. Drainage channel taken below the canal

List-II
1. Canal siphon
2. Drainage siphon
3. Aqueduct
4. Super passage

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

[ESE : 2005]

5.19 Denehy's groyne is a special type of groyne which is
(a) pointing upstream (b) pointing downstream
(c) Hockey type (d) T-headed

[ESE : 2005]

5.20 Which of the following are the purpose of a groyne as a river training structure?

1. It contracts a river channel to improve its depth.
2. It protects the river bank.
3. It does not allow silt to deposit in the vicinity.
4. It trains the flow along a certain course.

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 1, 2 and 4
(c) 1 and 3 (d) 2, 3 and 4

[ESE : 2005]

5.21 Match List-I (Factor) with List-II (Ratio) and select the correct answer using the codes given below the lists:

List-I

A. Load factor
B. Capacity factor
C. Diversity factor
D. Plant use factor

List-II

1. $\frac{\text{Sum of individual maximum demands}}{\text{Simultaneous maximum demands}}$
2. $\frac{\text{Maximum demands}}{\text{Station capacity}}$
3. $\frac{\text{Average load}}{\text{Maximum load}}$
4. $\frac{\text{Energy produced}}{\text{Installed capacity} \times \text{time in hours}}$

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	4	1	2
(c)	1	4	3	2
(d)	3	2	1	4

[ESE : 2005]

5.22 What type of cross drainage work is provided when the canal runs below the drain, with FSL of canal well below the bed of the drain?

(a) Aqueduct
(b) Super passage
(c) Level crossing
(d) Siphon aqueduct

[ESE : 2006]

5.23 **Assertion (A):** The USBR type-II stilling basin length requirement is less than that in type-III basin for similar design conditions.

Reason (R): Energy dissipation is primarily accomplished by hydraulic jump in USBR type-II stilling basin.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2006]

5.24 Groynes are adopted for river bank protection works. When it is placed inclined downstream in the direction of flow in the river, it is designated as which one of the following?

(a) Repelling groyne
(b) Attracting groyne
(c) Neither repelling nor attracting groyne
(d) Fixed groyne

[ESE : 2007]

5.25 Consider the following statements:

An aqueduct is a cross drainage work in which

1. a canal is carried over the drainage channel.
2. a drainage channel is carried over the canal.
3. both drainage channel and canal are at the same level.

Which of these statements is/are correct?

(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2007]

5.26 What are the recommended setting options of an adjustable proportional module worked with an open flume type outlet?

1. 3/10 2. 9/10
3. 1/2 4. 5/3

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 1 and 3
(c) 3 and 4 (d) 2 and 4

[ESE : 2007]

5.27 The flood plain of a river carries a discharge of 2000 m^3/s. What are the values of the meander length and dominant flow width?

(a) 160 m, 48 m (b) 180 m, 42 m
(c) 200 m, 38 m (d) 220 m, 36 m

[ESE : 2007]

5.28 During a certain week a power plant turns out 8,400,000 kW-hr and the peak load during the week is 100,000 kW. What is the load factor during the week?
(a) 40% (b) 45%
(c) 50% (d) 60%
[ESE : 2007]

5.29 For calculating the maximum flood discharge in an alluvial stream, which is the best suited relation?
(a) $v \propto R^{2/3} S^{1/3}$ (b) $v \propto R^{2/3} S^{1/2}$
(c) $v \propto R^{1/2} S^{1/2}$ (d) $v \propto D^{0.64}$
[ESE : 2008]

5.30 Under which one of the following categories is the river Ganga classified in the reach through UP and Bihar?
(a) Straight river (b) Meandering river
(c) Braided river (d) Deltaic river
[ESE : 2009]

5.31 What is the height of wave which is likely to be generated by a wind of 80 km/hr in a reservoir having a fetch of 50 km?
(a) 0.5 m (b) 1.0 m
(c) 2.0 m (d) 3.0 m
[ESE : 2009]

5.32 Consider the following statements related to undersluices provided in diversion weirs on permeable foundations :
1. They are fully gate-controlled and have crest at the same level as the weir crest when no silt excluders are provided.
2. They scour the silt deposited on the river bed in the pockets upstream of the canal head regulator.
3. It is not necessary to provide end pile line on the downstream end of the undersluice floor.
4. The discharge capacity of the undersluice is 10-15% of the maximum flood or two times the maximum discharge of the offtaking canal or maximum winter discharge, whichever is the highest.

Which of these statements is/are correct?
(a) 1 (b) 2 and 4 only
(c) 2, 3 and 4 (d) 3 and 4 only
[ESE : 2009]

5.33 Consider the following statements:
1. High water training is undertaken to protect against damage due to floods.
2. Low water training is undertaken to provide sufficient depth for navigation.
3. Mean water training is undertaken to provide efficient disposal of sediment load.

Which of these statements is/are correct?
(a) 1 and 2 only (b) 1, 2 and 3
(c) 2 and 3 only (d) 2 only
[ESE : 2010]

5.34 Consider the following statements:
The function of a launching apron at the end of downstream impervious apron of a weir is
1. to protect the downstream pile from the scour holes progressing in the upstream direction.
2. when the scour holes are formed, to provide for the stones of the falling apron to settle down in the holes and cover them.
3. to provide relief of the uplift pressure at the downstream end.
4. to provide extra length for proper formation of hydraulic jump.

Which of these statements is/are correct?
(a) 1, 2, 3 and 4 (b) 3 only
(c) 2 only (d) 1 and 2 only
[ESE : 2010]

5.35 Heavy scour at the head and shank of guide banks can lead to undermining of the stone pitching and consequent failure of the guide bank. This situation is avoided by providing
(a) spurs (b) vertical cutoffs
(c) marginal bunds (d) launching apron
[ESE : 2010]

5.36 A submerged pipe outlet is an example of
(a) semi-modular outlet
(b) non-modular outlet
(c) rigid module
(d) adjustable proportional module
[ESE : 2010]

5.37 A ski-jump bucket is generally used as an energy dissipator when the tail water
(a) is greater than 1.1 times the required conjugate depth for the formation of hydraulic jump; and the river bed rock is 'good'

(b) depth is lesser than the depth required for the jump formation; and the bed of the river channel is composed of 'sound' rock
(c) depth is equal to the depth required for the jump formation, and the river bed rock is 'good'
(d) depth is 1.3 times the required for the jump formation and the river bed is composed of 'weak' rock

[ESE : 2010]

5.38 The wave height, in metres, generated on the surface of a reservoir, having a fetch length $F = 30$ km, due to wind blowing on the surface of the reservoir at a velocity of 30 km/hr, is
(a) 0.26 m (b) 0.96 m
(c) 0.52 m (d) 1.2 m

[ESE : 2010]

5.39 Consider the following statements Morphological characteristics of a river are represented by:
1. Changes in the river form.
2. Changes in the characteristics of the river bed as a result of variation of discharge in the river.
3. No changes in the plan bed form.
4. No changes in the river bed form.

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 3 and 4

[ESE : 2011]

5.40 Consider the following situation in a flow mass curve study when demand line drawn from a ridge in the mass curve does not intersect the mass curve again. This means that
(a) The storage is not adequate
(b) The demand cannot be met by the inflow as the reservoir will not refill
(c) the reservoir was not full at the beginning
(d) The reservoir is wasting water by spill

[ESE : 2011]

5.41 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Deflector
B. Biff wall
C. Cistern
D. Baffle wall

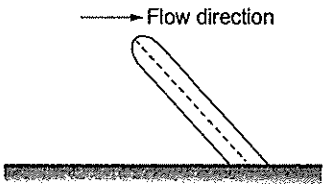
List-II
1. Low-height wall across canal down- stream of the fall
2. Vertical end wall with horizontal projection
3. Short wall at down-stream end of the fall
4. Pond level below the fall

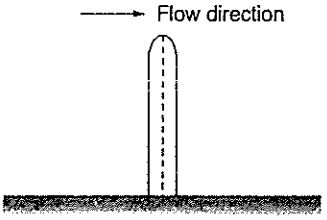
Code:

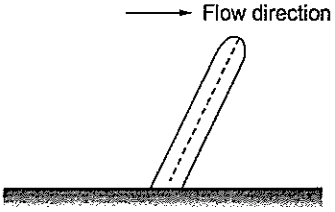
	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	1	4	2	3
(d)	3	4	2	1

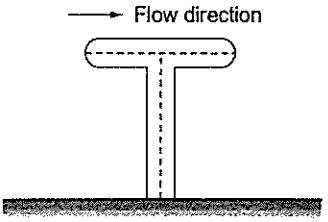
[ESE : 2011]

5.42 Which one of the groyne arrangements represents an 'attracting groyne'?

(a)


(b)


(c)


(d)


[ESE : 2011]

5.43 Consider the following statements:
1. In a super-passage, the drain runs over the canal.
2. In a siphon, the drain runs below the canal.
3. In a siphon aqueduct, type-II, the canal banks are made of RCC walls.

Which of these statements are correct?

(a) 1 only (b) 1 and 2 only

(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2011]

5.44 Consider the following statements

1. Groynes are constructed projecting from the bank into the river at the bank to be protected from flood.
2. Repelling groyne projects downstream into the river-flow from the point of its origin from the bank.
3. Attracting groyne projects upstream into the river from the point of its origin from the bank.
4. Perpendicular groyne projects normal to the river flow from the point of its origin from the bank.

Which of these statements are correct?

(a) 1 and 4 (b) 1 and 2

(c) 2 and 3 (d) 3 and 4

[ESE : 2013]

5.45 If the channel index at an irrigation outlet is 5/3, "setting" of an orifice type outlet in order to have proportionality is

(a) 0.90 (b) 0.67

(c) 0.30 (d) 0.15

[ESE : 2014]

5.46 **Statement (I):** The sharp corners in the cross-section of a canal are rounded.

Statement (II): The corners may not become zones of stagnation.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).

(c) Statement (I) is true but Statement (II) is false.

(d) Statement (I) is false but Statement (II) is true.

[ESE : 2014]

5.47 A barrage on a major river in the Gangetic plains has been design for a flood discharge 7000 m^3/s. It has been provided with a waterway of 360 m length. The looseness factor of this barrage is

(a) 1.7 (b) 1.1

(c) 0.7 (d) 0.1

[ESE : 2016]

5.48 Tortuosity of a meandering river is the ration of

(a) Meander length to width of the meander

(b) Meander length to width of the river

(c) Curved length along the river to the direct axial length of the river

(d) Direct axial length of the river to the curved length along the river

[ESE : 2017]

5.49 Objective for river training are

1. High flood discharge may pass safely through the reach.
2. Sediment load (including bed and suspended load) may be transported efficiently.
3. By making the river course unstable whereby to increase bank erosion.

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1 and 2

(c) 2 and 3 (d) 1 and 3

[ESE : 2017]

■■■■

Answers River Training Work, Diversion Headwork, Cross-drainage Work & Miscellaneous

5.1 (d)	5.2 (c)	5.3 (c)	5.4 (b)	5.5 (a)	5.6 (a)	5.7 (c)	5.8 (c)	5.9 (d)	
5.10 (c)	5.11 (a)	5.12 (b)	5.13 (a)	5.14 (b)	5.15 (c)	5.16 (a)	5.17 (c)	5.18 (d)	
5.19 (d)	5.20 (b)	5.21 (b)	5.22 (b)	5.23 (c)	5.24 (b)	5.25 (a)	5.26 (a)	5.27 (*)	
5.28 (c)	5.29 (b)	5.30 (b)	5.31 (c)	5.32 (b)	5.33 (b)	5.34 (c)	5.35 (d)	5.36 (b)	
5.37 (b)	5.38 (b)	5.39 (a)	5.40 (b)	5.41 (a)	5.42 (c)	5.43 (d)	5.44 (a)	5.45 (c)	
5.46 (a)	5.47 (*)	5.48 (c)	5.49 (b)						

Explanations River Training Work, Diversion Headwork, Cross-drainage Work & Miscellaneous

5.1 (d)

Check dam and contour bunding are mainly water harvesting techniques. Contour bunding can check erosion in hilly areas but it is not very economical as every year the bunds are to be maintained before rainy season. The afforestation of catchment area is the long lasting and economic solution for soil conservation.

5.2 (c)

Baffle piers (friction blocks) help in breaking the flow and dissipate energy mostly by impact. Therefore the length of jump is less. Although there is a increase in discharge per unit width also.

5.3 (c)

The best alignment of off-taking channel is that in which the off-taking channel makes zero angle with the parent channel initially and then separates out in transition. The depth of water should always be such that off take channel runs full. The transitions should be properly designed, so as to avoid accumulation of silt. The transition can also be used as metering flume. Thus depth, slope and width will be the correct order of preference of parameters.

5.4 (b)

When TWC is much above JHC, the jump forming at the toe will be drowned and little energy will be dissipated. In such a case roller bucket will be the most suitable choice.

If TWC is slightly above JHC, then sloping apron will be the suitable choice.

Tail water curve (TWC) coincides with jump height curve (JHC) then stilling basin at bed level with horizontal apron is provided.

A subsidiary dam below the main dam can also be provided.

When TWL is slightly below JWC, then sloping apron with depressed floor may be provided. When TWL is considerably below JHC, ski-jump bucket should be provided.

5.5 (a)

In the Khosla's theory for calculating seepage pressure under the weir, following corrections are used:

(i) Correction for mutual interference of piles
(ii) Correction for thickness of floor
(iii) Correction for the slope of the floor

The correction for mutual interference of piles is given by

$$C = 19\sqrt{\frac{D}{b'}}\left(\frac{d+D}{b}\right)$$

where

b' is distance between two pile lines.

D is the depth of the pile line, the influence of which is to be determined on the neighbouring pile of depth d. It is to be measured below the level at which interference is desired

d is the depth of pile on which the effect is considered

b is total floor length

This equation does not apply to the effect of an outer pile on intermediate pile, if the intermediate pile is equal to or smaller than the outer piles and

is at a distance greater than twice the length of the outer pile.

5.6 (a)

During floods river carries silt charge in excess of the quantity required for stability, the river starts building up its slope by depositing the silt on its bed. This accretion is the primary process, which consequently leads to meandering. The increase in slope tends to increase the width of the channel and the sediment carrying capacity decreases. Finally due to shifting of the convex bar, the width between the banks reduces, which increases the velocity and sediment carrying capacity also.

5.7 (c)

Submerged pipe outlet is non-modular type so the discharge depends upon the water level in both the minor and well chamber.

$$Q = C_d A\sqrt{2gH_L}$$

Thus discharge through outlet can be increased by increasing H_L or by increasing the depth of water in minor. If there is any drop in the water level in the minor, the H_L and discharge will decrease.

5.8 (c)

Venturi flume consists of a gradually contracting channel leading to 'throat' and a gradually expanding channel away from it. For the same discharge Q, the discharge per unit width (q) is more at throat section so the specific energy at throat is more than that at normal section for super critical flow while the reverse happens in subcritical flow. However, the specific energy at normal and throat section is individually constant.

By providing hump, some loss of energy occurs and total energy at throat will be less.

5.9 (d)

The exit gradient, $G_E = \frac{H}{d}\frac{1}{\pi\sqrt{\lambda}}$

where $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$

and $\alpha = \frac{b}{d}$

b is length of floor

d is depth of vertical cut off

With increase in b/d the factor $\frac{1}{\pi\sqrt{\lambda}}$ decreases and H/d reduces with increase in depth of vertical cutoff. Thus both 'b' and 'd' affect equally on the exit gradient.

5.10 (c)

When TWC is slightly above JWC and slope of channel is mild, standing wave basin with raised floor is constructed to match them.

When TWC is considerably above JWL and the slope of channel is mild, roller bucket is chosen for desired energy dissipation.

When TWC is slightly below JWL and slope of channel is mild, standing wave basin with depressed floor is preferred to level them.

When TWC is considerably below JWL and slope of channel is steep, ski jump bucket is used to reduce scourging potential energy of water.

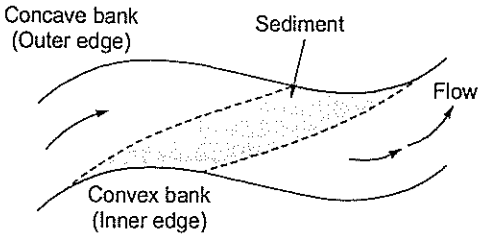
5.11 (a)

Gibb's module is a rigid module or modular outlet and the discharge through it is constant within certain limits, irrespective of the fluctuations of water level in distributary or water course or both.

5.12 (b)

The difference in bed level of the canal and drainage is 4 m while the flow depth in drainage is 10 m. Thus HFL of drain at 126 m is higher than the canal bed at 120 m. Therefore syphon aqueduct is most suitable.

5.13 (a)



The sediment scouring occurs at outer edge and deposition occurs on the inner bank at same place and at outer edge downstream.

5.14(b)

Silt excluders are constructed on the bed of the river, upstream of the head regulator. While silt ejectors are constructed on the bed of the canal and a little distance downstream from the head regulator.

Silt excluders remove silt from the water before it enters canal. Silt ejectors extract the silt from the canal water after the silted water has travelled a certain distance in the off-take canal.

5.15(c)

Silt factor $f = 1.76\sqrt{d_m}$ is related to square root of average size of silt particles (d_m) but not the average size itself.

Silt load or sediment load includes bed load and suspended load.

Silt charge is the weight of silt per unit volume of water.

Silt grade refers to the type and size of silt.

5.16(a)

Syphon aqueduct is a cross-drainage work provided when HFL of the drain is higher than the canal bed and the water passes through the syphon aqueduct (drainage) barrels under syphonic action. The worst condition of uplift will be when the drainage is flowing at HFL and canal is dry.

5.17(c)

At low flow velocities, the bed does not move at all and its form is plain. With the increase in velocity (Froude number) the bed forms change from ripples to dunes with Froude number less than one. When the Froude number is further increased the dunes are washed away and a flat surface is left. As the Froude number approaches unity, the surface waves breaks and the whole wave system moves upstream leading to formation of antidunes.

Plane bed ($\tau_0 - \tau_c$) – Ripples – Dunes –Plane bed ($\tau_0 > \tau_c$) – Antidunes

5.18 (d)

An aqueduct is a watercourse constructed to convey water, which carries canal above the drainage channel at its grade. Drainage siphon is similar to aqueduct except that stream bed is depressed locally below the canal. Super passage is reverse of aqueduct drainage channel is carried above the canal at its bed slope. Canal siphon is similar to super passage but canal is taken below drainage channel.

5.19(d)

Denehy's T-shaped groyne is a special type of groyne developed in India for protection of bank. It comprises of ordinary groyne with an extra cross groyne at the head giving it T-shape.

Hockey shaped groyne is an attracting type of groyne.

5.20(b)

Groynes are embankment type structures, constructed transverse to the river flow, extending from the bank into the river. They are constructed to protect the bank from which they are extended, by deflecting the current away from the bank. These are called repelling groynes. On the upstream side of a repelling groyne, a still water pocket is formed. where the suspended sediments carried by the river, gets deposited. For low water training or training for depth groynes can be used. Herein they contract the width of the channel to provide sufficient depth for navigation during low water periods.

In order to train the flow along a certain course guide banks are most commonly used. However groynes can also be used to deflect the flow or attract the flow.

5.22(b)

If bed level of canal is sufficiently above the HFL of the drain, an aqueduct is the right choice. Sometimes bed level of canal may be little below the HFL of drain so that water flows under syphonic action. This structure is known as aqueduct syphon.

If bed level of the drain is sufficiently above the canal FSL, a super passage may be constructed.

If the canal FSL is little above bed level of drain to allow syphonic action, the structure is called Canal Syphon. Aqueduct or super-passage type of drainage works are used when high flood discharge is large and continues for a sufficient time.

A level crossing is used when the canal water and drain water are allowed to intermingle with each other. This is adopted when high flood drainage discharge is short lived.

5.23(c)

USBR Stilling Basins

(i) **Type-I** (with froude number (F_1) between 2.5 to 4.5) has length of stilling basin from $4.3y_2$ to $6y_2$, where y_2 is post jump depth.

(ii) **Type-II** ($F_1 > 4.5$ and $V_1 < 15$ m/s). It is provided with chute blocks, baffle block and end sills. The length of stilling basin is considerably less than Type-I, because the dissipation of energy occurs by the impinging action of the incoming flow against the baffle blocks. However the baffle blocks are subjected to large impact force. They should be designed for extra force due to dynamic action against the upstream face

$F = Z\gamma_w A(y_1 + h_v)$, where $(y_1 + h_v)$ is the specific energy of the flow entering the basin.

(iii) **Type-III** ($F_1 > 4.5$, and $V_i > 15$ m/s)

In this case baffle blocks are not provided, because

(i) the blocks will be subjected to very high impact forces

(ii) there is possibility of cavitation on the downstream faces of the blocks.

The stilling basin therefore consists of chute blocks and a denoted sill. As the dissipation of energy occurs mainly due to hydraulic jump, the length of Type-III basin is greater than that in Type-II basin.

5.24(b)

A groyne pointing downstream has the property of attracting the flow towards it and is called an attracting groyne. In attracting groynes scours holes are developed nearer the bank, as compared to those in a repelling groyne. Since such attracting groynes bring the water current as well as scour holes nearer the bank and make it more susceptible to damage, they are not used generally. The groynes are therefore, generally aligned either perpendicular to the bank or pointing upstream (repelling groyne).

5.25(a)

An aqueduct and syphon aqueduct are cross drainage works in which the canal is taken over the natural drain, such that the drainage water runs below the canal either freely or under syphoning pressure. Super passage and syphon are cross drainage works in which the drain is taken over the canal such that the canal water runs below the drain either freely or under syphoning pressure.

Level crossing is a cross drainage work in which the canal water and drain water are allowed to intermingle with each other. A level crossing is generally provided when a large canal and a huge drainage (such as a stream or a river) approach each other practically at the same level.

5.26(a)

The ratio of the depth of sill level of the outlet below the FSL of the distributary to the full supply depth of the distributary, is known is setting.

$$\text{Setting} = \frac{\text{Outlet index (m)}}{\text{Channel index (n)}}$$

For a wide trapezoidal channel, the discharge is proportional to $y^{5/3}$. Therefore for such channels, $n = 5/3$. The discharge through an orifice type outlet is proportional to $H^{1/2}$ and thus for such an outlet,

$$m = \frac{1}{2}$$

$$\therefore \text{ Setting} = \frac{1/2}{5/3} = \frac{3}{10}$$

Similarly for a weir type outlet,

$$m = \frac{3}{2}$$

$$\therefore \text{ Setting} = \frac{3/2}{5/3} = \frac{9}{10}$$

The outlet is said to be proportional when the rate of change of outlet discharge equals the rate of change of channel discharge.

5.27 (*)

Meander Parameters:

River flood plains	Incided river
$M_b = 153.42\sqrt{Q}$	$M_b = 102.16\sqrt{Q}$
$M_l = 53.61\sqrt{Q}$	$M_l = 46.01\sqrt{Q}$
$W = 8.84\sqrt{Q}$	$W = 4.53\sqrt{Q}$

Here

Q – Discharge in cumecs

M_b – Meander width (m)

M_l – Meander Length (m)

W – effective width (m)

5.28 (c)

Load factor is defined as the ratio of the average load during a certain period to the maximum or peak load during that period. The load factor is thus related to a certain period and therefore, there will be daily load factors, weakly load factors, load for a given month and yearly load factors.

$$\therefore \text{Load factor} = \frac{8,400,000}{24\times7\times100,000} \times 100 = 50\%$$

5.29 (b)

$V = 0.55\text{ m } D^{0.64}$ (Kennedy's)

$V = (1/n)\, R^{2/3}\, S^{1/2}$ (Manning's)

$V = 10.8\, R^{2/3}\, S^{1/3}$ (Lacey's)

5.30 (b)

Formation of successive bends of reverse order in a river may lead to the formation of a complete S curve called meander. Such a river is called meandering river.

When a river flows in two or more channels around alluvial islands, it is known as a braided river.

Deltaic river is a river which gets divided into branches before joining the sea, thus forming a Δ shaped delta

5.31 (c)

Waves are generated on the surface of reservoir by the blowing winds, which causes a pressure towards the downstream side. Wave pressure depends upon the wave height. Wave height in metres may be given by the equation.

(i) $h_w = 0.032\sqrt{VF} + 0.763 - 0.271(F)^{3/4}$

for $F < 32$ km

(ii) $h_w = 0.032\sqrt{VF}$ for $F > 32$ km

where V is wind velocity in km/hr and F is fetch in km.

$$\therefore \quad h_w = 0.032\sqrt{80\times50}$$

$$= 2.02 \text{ m}$$

5.32 (b)

The under sluices are the openings provided at the base of the weir or barrage with their crest at low level. It is necessary to provide end pile on downstream end of undersluice to prevent undermining due to head difference.

5.33 (b)

Training type:

(i) Low water- navigational depth

(ii) Mean water- sediment disposal

(iii) High water- flood control

5.34 (c)

A launching apron is an apron of loosely packed stones. The function of a launching apron is to protect the impervious floor and the pile from the scour holes progressing towards the floor and the pile. The protection is provided by a launching apron by forming a protective covering of stones over a certain slope below the bed of the river at which the apron is originally laid to the bottom of the deepest scour likely to occur. When scour occurs, the position attained by this apron is called launched position and the apron is the known as launched apron.

5.35 (d)

To ensure the safety against undermining of stone pitching and consequent failure of guide bank and damage to the toe of well protected bank from scouring by the action of floods launching apron is provided at the toe of the bank.

5.36 (b)

Non-modular outlets are those through which the discharge depends upon the difference of head between the distributary and the water course. The discharge through such a module, therefore, varies widely with either a change in the water level of the distributary or that of the water course. The common examples of this type of outlets are (i) open sluice and (ii) drowned pipe outlet.

5.37 (b)

The ski jump bucket type of an energy dissipator can be used for energy dissipation when the tail water depth is insufficient or low at all discharges. The ski jump bucket type of an energy dissipator

requires sound and rocky river bed, because a part of the energy dissipation takes place by impact, although some of the energy is dissipated in air by diffusion and aeration.

5.38 (b)

Wave height generated on the surface of a reservoir is given by

$$h_w = 0.032\sqrt{VF}$$
$$= 0.032 \times \sqrt{30 \times 30}$$
$$= 0.96\,\text{m}$$

However, it may be noted that the above formula is applicable for $F > 32$ km in strict terms.

5.40 (b)

Demand line drawn from the ridge denotes that reservoir is full at the beginning, i.e. at another point on mass curve if demand line intersects the mass curve again, then the reservoir is assumed to be full at that point of inter section. If demand line does not meets the mass curve again, it means reservoir will not refill again as the inflow into the reservoir could not meet the demand. If mass curve meets the demand line and then moves above the demand line, reservoir gets filled and water strarts spilling off from reservoir.

5.41 (a)

Cistern: The cistern or cistern element is that portion of the fall on the downstream of the crest wall in which the surplus energy of water leaving the crest is dissipated and the subsequent flow stilled before it passes on to the lower level chanel. The object of providing a cistern are

(i) To reduce the intensity of impact of the dropping jet of water against the downstream floor.

(ii) To provide water cushion to dissipate the energy of the falling jet, and

(iii) To produce reverse flow by providing a suitable end wall to ensure an impact in the cistern.

Deflector or Deflector wall: A deflector or deflector wall may also be provided at the end of the cistern if high velocity jet persists upto the end of the cistern.It causes a reverse roller to form which causes a limited scour away from the toe where it does not endanger the structure and piling up of material against the toe.

Biff wall: A biff wall which may also be provided at the end of the cistern if high velocity jet persists upto the end of the cistern. Its function is also similar to that of a deflector.

Baffle wall: A baffle wall is a low wall which may be provided at the end of the cistern. It provides a deep pool of water behind itself in the cistern and thus help to cause dissipation of surplus energy. However, to be effective for this purpose the baffle walls should be sufficiently high.

5.42 (c)

Groynes or spurs are the structures constructed transverse to the river flow extending from the bank into the river. Groynes may be aligned either perpendicular to the bank line or at an angle pointing upstream or downstream. These are also known as spur dikes or transverse dikes, and constitute the most widely used river training works.

According to function seved by the groynes these may be classified as

(i) *Attracting groynes:* A groyne pointing downstream tends to attract the river flow towards the bank on which it is provided and hence it is called an attracting groyne. The attracting groynes safeguard the opposite bank against the attack of the current as they attract the current towards the bank adjacent to them.

(ii) *Repelling groynes:* A groyne pointing upstream tends to repel the river flow away from the bank on which it is provided and hence it is called a repelling groyne.
As compared to attracting groynes, repelling groynes are more effective and do not cause any trouble. As such repelling groynes are commonly used for the purpose of river training and bank protection.

(iii) *Deflecting groynes:* A groyne either perpendicular to the bank or pointing slightly upstream and having a relatively short length tends to only deflects the flow without repelling it and hence it is called a deflecting groyne. A deflecting groyne, however gives only local protection.

(iv) *Sedimenting groynes:* A groyne which dampens the velocity of flow and thus causes deposition of sediment carried by the river without repelling or deflecting the flow, is called a sedimenting groyne.

5.43 (d)

A super passage is just like a bridge in which the natural drain is carried over the canal. A super passage is constructed where the bed of the drain is well above the canal F.S.L.

A syphon serves the same purpose as superpassage and is constructed where the F.S.L. of the canal is higher than the bed of the drain.

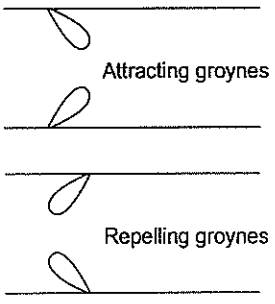
Aqueducts are of following three types

Type I: In this type the sides of the aqueduct (or syphon aqueduct) are earthen banks with complete earthern slopes.

Type II: In this type also the canal continues in its earthen section over the drain, but the outer slopes of the earthen banks are replaced by retaining walls.

Type III: In this type the earthen banks are not provided through the aqueduct (or syphon aqueduct) and the canal water is carried in a masonry or concrete trough.

5.44 (a)



5.45(c)

For orifice type outlet,

$$m = \frac{1}{2}$$

$$\therefore \quad \text{Setting} = \frac{H}{D}$$

$$\Rightarrow \quad = \frac{1}{2} \times \frac{3}{5}$$

$$\Rightarrow \quad = \frac{3}{10} = 0.3$$

5.47 (*)

$$\text{Looseness factor} = \frac{\text{Actual width}}{\text{Regime width}}$$

Actual width = 360 m (given)

Regime width = $4.75\sqrt{Q}$

Given, Q = discharge for which barrage has been designed

Regime width = $4.75\sqrt{7000} = 397.41$

$$\text{Losseness factor} = \frac{360}{397.41} = 0.9$$

5.48 (c)

Tortuosity means the sharpness of any curve.

For a meandering river it is defined as

$$\text{Tortuosity} = \frac{\text{Curved length along the river}}{\text{Direct axial length of the river}}$$

5.49 (b)

River training's purpose is to stabilise the river course and to reduce bank erosion.

■■■■

UNIT

IV

Environmental Engineering

Syllabus

Water Supply Engineering: Sources, Estimation, quality standards and testing of water and their treatment; Rural, Institutional and industrial water supply; Physical, chemical and biological characteristics and sources of water, Pollutants in water and its effects, Estimation of water demand; Drinking water Standards, Water Treatment Plants, Water distribution networks.

Waste Water Engineering: Planning & design of domestic waste water, sewage collection and disposal; Plumbing Systems. Components and layout of sewerage system; Planning & design of Domestic Waste-water disposal system; Sludge management including treatment, disposal and re-use of treated effluents; Industrial waste waters and Effluent Treatment Plants including institutional and industrial sewage management.

Solid Waste Management: Sources & classification of solid wastes along with planning & design of its management system; Disposal system, Beneficial aspects of wastes and Utilization by Civil Engineers.

Air, Noise pollution and Ecology: Concepts & general methodology.

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OOOO

1 Water Demand

1.1 When was the water (Prevention and Control of Pollution) Act enacted by the Indian Parliament?

(a) 1970 (b) 1974
(c) 1980 (d) 1985

[ESE : 1996]

1.2 Consider the following statements:
The daily per capita consumption of water apparently increases with
1. higher standard of living of people
2. availability of sewerage in the city
3. metered water supply
4. wholesome and potable quality of water

Which of these statements are correct?

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1,2 and 4

[ESE : 1999]

1.3 Match List-I (Industry and unit of production) With List-II (Water need in kL/unit/day) and select the correct answer using the codes given below the lists:

List I	List-II
A. Automobile (per vehicle)	1. 1 to 2
B. Leather (per 100 kg)	2. 4
C. Paper (per tonne)	3. 40
D. Crude petroleum refinery (per tonne)	4. 50-100
	5. 200-400

Codes:

	A	B	C	D
(a)	3	2	5	1
(b)	1	3	5	4
(c)	3	2	4	5
(d)	5	4	2	1

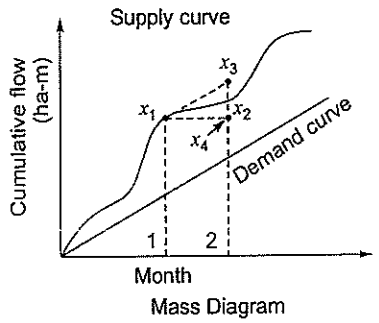
[ESE : 1999]

1.4 Assertion (A): The future population is predicted on the basis of knowledge of the city and its environment.
Reason (R): The future population depends on the trade and expansion of the city, discovery of mineral deposits, power generation etc.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

1.5 In the figure shown below, x_2x_4 represents



Mass Diagram

(a) accumulated supply
(b) storage requirement
(c) accumulated demand for the period 1 to 2
(d) surplus in the reservoir

[ESE : 2001]

1.6 The population figures in a growing town are as follows:

Year	Population
1970	40,000
1980	46,000
1990	53,000
2000	58,000

The predicted population in 2010 by Arithmetic Regression method is

(a) 62,000 (b) 63,000
(c) 64,000 (d) 65,000

[ESE : 2002]

1.7 On which of the following factors, does the population growth in a town normally depend?

1. Birth and death rates
2. Migrations
3. Probabilistic growth
4. Logistic growth

Select the correct answer using the codes given below:

(a) 1 and 4 (b) 1 and 2
(c) 1, 2 and 3 (d) 2 and 3

[ESE : 2003]

1.8 Which one of the following Acts/Rules has a provision for "No right to appeal"?

(a) Environment (Protection) Act, 1986
(b) The Hazardous Waste (Management and Handling) Rules, 1989
(c) Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989
(d) Environment (Protection) Rules, 1992

[ESE : 2004]

1.9 The present population of a community is 28000 with an average water demand of 150 Lpcd. The existing water treatment plant has a design capacity of 6000 m^3/d. It is expected that the population will increase to 48000 during the next 20 years. What is the number of years from now when the plant will reach its design capacity assuming an arithmetic rate of population growth?

(a) 8.6 years (b) 12.0 years
(c) 15.0 years (d) 16.5 years

[ESE : 2006]

1.10 For water supply to a medium town, what is the daily variation factor?

(a) 1.5 (b) 2.5
(c) 3 (d) 3.5

[ESE : 2008]

1.11 Which one of the following factors has the maximum effect on figure of per capita demand of water supply of a given town?

(a) Method of charging of the consumption
(b) Quality of water
(c) System of supply-intermittent or continuous
(d) Industrial demand

[ESE : 2008]

1.12 Population levels over 5 decades of a small town are given below.

Year	Population
1960	2,50,000
1970	2,80,000
1980	3,40,000
1990	4,20,000
2000	4,90,000

The population of the town in the year 2020 estimated by Arithmetic Increase method will be

(a) 5,10,000 (b) 5,90,000
(c) 6,10,000 (d) 6,90,000

[ESE : 2014]

1.13 The population of a city in the year 2000 was 82,300. If average percent increase in population per decade in 35%, the population of the city in the year 2020 estimated geometrical increase will nearly be

(a) 100000 (b) 125000
(c) 150000 (d) 175000

[ESE : 2015]

1.14 A water supply distribution system for an averagely-populated township to be designed for

(a) Maximum daily demand
(b) Maximum hourly demand and fire demand
(c) Average demand
(d) Maximum daily demand and fire demand, or maximum hourly demand, whichever is higher

[ESE : 2016]

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Answers Water Demand

1.1	(b)	1.2	(d)	1.3	(a)	1.4	(a)	1.5	(a)	1.6	(a)	1.7	(b)	1.8	(a)	1.9	(b)
1.10	(a)	1.11	(d)	1.12	(c)	1.13	(c)	1.14	(d)								

Explanations Water Demand

1.1 (b)

The various regulations are:

(i) The Forest Act, 1927

(ii) The Wild Life (Protection) Act, 1927

(iii) The Water (Prevention and Control of Pollution) Act, 1974

(iv) The Water (Prevention and Control of Pollution) Cess Act, 1977

(v) The Forest conservation Act, 1980

(vi) The Air (Prevention and Control of Pollution) Act, 1981

(vii) The Environment (Protection) Act, 1986

(viii) The Public Liability Insurance Act, 1991

1.2 (d)

Factors affecting per capita demand:

- **Size of the city:** Per capita demand for big cities is generally large as compared to that for smaller towns as big cities have sewered houses.
- Presence of industries.
- Climatic conditions.
- Habits of people and their economic status.
- **Quality of water:** If water is aesthetically $ medically safe, the consumption will increase as people will not resort to private wells, etc.
- Pressure in the distribution system.
- **Efficiency of water works administration:** Leaks in water mains and services; and unauthorised use of water can be kept to a minimum by surveys.
- Cost of water.
- **Policy of metering and charging method:** Water tax is charged in two different ways: on the basis of meter reading and on the basis of certain fixed monthly rate.

1.3 (a)

Demand of Water in Industrial Areas in India

Sector	Average water consumption in Indian industries	Globally Best
Thermal Power Plant	Average 80 cubic meter per megawatt (mwh)	Less than 10 cubic metre (m^3)per mwh
TextileIndustry	200-250 m^3 per tonne cotton cloth	Less than 100 m^3 per tonne cotton cloth
Paper and Pulp	• Wood base mills: 150-200 m tonne per tonne • Waste paper based mills: 10-80 m^3 per tonne	• Wood base mills: 50-75 m^3 ton per tonne • Waste paper based mills: 10-25 m^3 per tonne
Total iron and Steel Plants	10-80 m^3 per tonne of finished product (Average around 25 m^3)	5-10 m^3 per tonne of finished product best practice less than 0.1 m^3 waste water per tonne finished products
Distilleries	75-200 m^3 per tonne Alcohol produced	Figure NA
Fertilizer Industry	• Nitrogenous Fertilizer Plant 5.0-20.0 m^3 per tonne • Straight Phosphatic Plant 1.4-2.0 m^3 per tonne • Complex Fertilizer 0.2-5.4 m^3 per tonne	An effluent discharge of less than 1.5 m^3 tonne as P_2O_5

1.5 (a)

Line x_1x_3 is parallel to demand curve. Between 1 and 2 demand is more than supply.

Accumulated demand between 1 and 2 is x_3x_4.

Accumulated supply between 1 and 2 is x_2x_4.

Depletion of storage between 1 and 2 is x_2x_3.

1.6 (a)

The trade and expansion of a city, discovery of mineral deposits, power generation etc. lead to increase in number of opportunities thus resulting in migration to that city and increase in future population. Thus the future population of a city is predicted on the basis of knowledge of the city and environment.

1.7 (b)

Birth Rate: The number of live births per thousand of population per year.

Death Rate: The ratio of deaths to the population of a particular area or during a particular period of time, usually calculated as the number of deaths per one thousand people per year.

1.8 (a)

Section-22 of Environment (Protection) Act, 1986 has a provision for 'No right to appeal'.

1.9 (b)

Population after n years,

$$P_n = P_0 + n\bar{x}$$

$\bar{x}$ is arithmetic design growth rate

Given $P_0 = 28000$

For $n = 20$; $P_{20} = 48000$

$$\therefore \quad \bar{x} = \frac{48000 - 28000}{20} = 1000 \text{ per year}$$

The population when design capacity will be required,

$$P_n = \frac{6000 \times 1000}{150} = 40{,}000$$

∴ Number of years to reach the plant at design capacity,

$$n = \frac{P_n - P_0}{\bar{x}} = \frac{40000 - 28000}{1000}$$

$$= 12.0 \text{ years}$$

Note: *Since design capacity of treatment plant is done on the basis of 2 times average daily demand not maximum daily demand, but in the given question solution is done on the basis of simply average daily demand otherwise answer will not match from any of the given option (data will be improper).*

1.10 (a)

The GOI manual on water supply has recommended the following values of peak factor depending upon the population.

S.No.	Population	Peak factors
1.	Upto 50,000	3.0
2	50,001 - 2,00,000	2.5
3.	Above 2 lakh	2.0
4.	For Rural water supply scheme, where supply is effected through standpost for only 6 hr	3.0

1.11 (d)

The factors affecting per capita demand are:

(i) Size of the city
(ii) Climatic conditions
(iii) Types of gentry and habits of people
(iv) Industrial and commercial activities
(v) Quality of water supplies
(vi) Pressure in the distribution system
(vii) Development of sewerage facilities
(viii) System of supply
(ix) Cost of water
(x) Policy of metering and method of charging

Among the above factors industrial and commercial activities have the maximum effect on per capita demand. The pressure of industrial and commercial activities at a particular place increases the water consumption by large amounts. Many industries require really huge amounts of water and as such increase the water demand considerably.

1.12 (c)

Average decadel increase

$$= \frac{30{,}000 + 60{,}000 + 80{,}000 + 70{,}000}{4}$$

$$= 60{,}000$$

Increase in population over the next 2 decades

$$= 2 \times 60{,}000$$

$$= 120{,}000$$

∴ Population in year 2020 will be

$$P_{2020} = P_{2000} + 2 \times 60{,}000$$

$$= 4{,}90{,}000 + 2 \times 60{,}000$$

$$= 6{,}10{,}000$$

1.13 (c)

Estimation of population by geometrical increase method

$$P_n = P_0\left(1 + \frac{r}{100}\right)^n$$

$$P_{2020} = P_{2000}\left(1 + \frac{35}{100}\right)^2$$

Where, $P_0 = 82300$, $n = 2$, $r = 35\%$

$$= 82300\left(1 + \frac{35}{100}\right)^2$$

$$= 149991.75 \simeq 1{,}50{,}000$$

1.14 (d)

Distribution system is to be designed for greater of maximum hourly demand or maximum daily demand and fire demand.

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2 Conduits for Transporting Water

2.1 Two reservoirs at different levels are connected by two parallel pipes of diameter '$2d$' and 'd'. The ratio of the flows in the two pipes (larger: smaller) is

(a) $\sqrt{2}:1$ (b) $2:1$

(c) $4:1$ (d) $4\sqrt{2}:1$

[ESE : 1995]

2.2 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Soil pipe	1. Ventilating pipe
B. Intercepting trap	2. Wash basin
C. P-trap	3. Water closet waste
D. Cowl	4. House drainage

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	3	4	2	1
(c)	4	3	2	1
(d)	4	3	1	2

[ESE : 1995]

2.3 Which one of the following pairs is not correctly matched?

(a) Check valve: To check water flow in all directions

(b) Sluice valve : To control flow of water through pipelines

(c) Air valve : To release the accumul-ated air

(d) Scour valve : To remove silt in a pipeline

[ESE : 1996]

2.4 The entry of foul smelling gases into the house coming from the sewers can be prevented by

(a) providing water seals for all the fixtures

(b) providing water seals for all the fixtures and a vent pipe in the plumbing system

(c) providing sufficient vent pipes in the plumbing system

(d) exhaust fans

[ESE : 1996]

2.5 The following steps are involved in making a spigot and socket joint of cast iron pipes used in water supply systems:

1. Tarred gasket or hemp yarn is wrapped around the spigot.
2. The spigot end is centred into the socket end of the preceding pipe.
3. A jointing ring is placed around the barrel and against the face of the socket.
4. The gasket or hemp yarn is caulked slightly.
5. Molten pig lead is poured and then caulked.

The correct sequence of these steps is

(a) 2, 1, 4, 3, 5 (b) 2, 1, 3, 4, 5

(c) 1, 2, 4, 5, 3 (d) 1, 2, 3, 5, 4

[ESE : 1997]

2.6 Service connection consists of

(a) ferrule, stopcock and gooseneck

(b) ferrule, check valve and gooseneck

(c) stopcock, meter and sluice valve

(d) sluice valve, check valve and meter

[ESE : 1999]

2.7 The trap used for a water closet is called

(a) gully trap (b) P-trap

(c) intercepting trap (d) anti-siphon trap

[ESE : 1999]

2.8 **Assertion (A):** The leakage losses are less when the water supply is intermittent.

Reason (R): Pressure is less in intermittent water supply.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

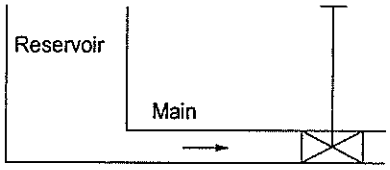
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

2.9 The usual size of residential ferrule bore varies from
(a) 1 mm to 5 mm
(b) 10 mm to 50 mm
(c) 100 mm to 500 mm
(d) 1000 mm to 5000 mm

[ESE : 2000]

2.10 The following sketch shows a water supply main from a storage reservoir provided with a sluice valve:



The type of valve most suitable for this pipeline is
(a) air valve
(b) scour valve
(c) pressure relief valve
(d) None of the above

[ESE : 2001]

2.11 Match List-I (Unit) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Leaping weir
B. Gutter inlet
C. Inverted syphon
D. Catch basin

List-II
1. To prevent grit, sand, debris, etc. from entering the storm sewer.
2. To carry the sewer below a stream or railway line
3. To drain rain water from roads to the storm sewer
4. To separate storm water and the sanitary sewage

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	3	4	1	2

[ESE : 2001]

2.12 In sanitary plumbing of buildings, a two pipe system signifies
(a) separate soil pipes and waste pipe without vent pipes
(b) a soil-cum-waste pipe and a ventilating pipe
(c) separate soil and waste pipe and a common ventilating pipe
(d) separate soil pipe and waste pipe, each with its own vent pipe

[ESE : 2001]

2.13 Which of the following are storm water regulators?
1. Side weir
2. Leaping weir
3. Syphonic spillway
4. Float actuated gates or valves
5. Inverted syphon

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 1, 3 and 5
(c) 2, 3, 4 and 5 (d) 1, 2, 4 and 5

[ESE : 2001]

2.14 Match List-I (Valves) with List-II (Uses) and select the correct answer using the codes given below the lists:

List-I
A. Sluice valve
B. Check valve
C. Air inlet valve
D. Ball valve

List-II
1. Used where gravity flow is required through pipe line
2. Used to maintain constant level of water
3. Used for reversal of flow
4. Used for isolating

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	4	2	1	3
(c)	1	2	4	3
(d)	4	3	1	2

[ESE : 2002]

2.15 Consider the following statements:
While deciding to locate an intake structure for a city situated on a river bank, intake for water supply should be located
1. in deep waters

2. sufficiently away from shore lines
3. upstream of the populated city
4. near navigational channel

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 2002]

2.16 Consider the following valves in a water distribution system:

1. Check valve
2. Pressure-reducing valve
3. Air relief valve
4. Scour valve
5. Sluice valve

Which of these work automatically?

(a) 1, 3 and 4 (b) 2, 4 and 5
(c) 3, 4 and 5 (d) 1, 2 and 3

[ESE : 2003]

2.17 Match List-I (Fixture) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I

A. Surge arrester
B. Butterfly valve
C. Scour valve
D. Check valve

List-II

1. Prevention of reversal of flow in a pipeline
2. Regulating or stopping the flow especially in large size conduits
3. Control of water hammer
4. Draining or emptying the pipeline section

Codes:

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	1	4	2	3
(d)	3	4	2	1

[ESE : 2004]

2.18 Consider the following statements:

The basic difference between water pipes and sewer pipes is

1. in the material used for the pipes
2. in the pressure of the liquid flow
3. in the suspended solids they carry

Which of these statements is/are correct?

(a) 1 and 3 (b) 1 only
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 2004]

2.19 Match List-I (Type of Pipe) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Steel pipe	1. House plumbing
B. Cast iron pipe	2. Hot water carrying
C. GI Pipe	3. Distribution main
D. PVC pipe	4. Pumping main

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	4	3	2	1
(c)	2	1	4	3
(d)	2	3	4	1

[ESE : 2004]

2.20 Match List-I (Equation/Method) with List-II (Application) and select the correct answer using the codes given below the lists:

List-I

A. Manning's Equation
B. Darcy-Weisbach
C. Hardy Cross Method
D. Rational Method

List-II

1. Frictional head loss estimation in pipe flow
2. Sanitary sewer design
3. Storm sewer design
4. Water distribution system design

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	1	4	3	2
(c)	2	1	3	4
(d)	1	4	2	3

[ESE : 2007]

2.21 Which of the following are the advantages of cast-iron pipe for its use in water supply?

1. Resistant to corrosion to a reasonable extent
2. Very easy to join the pipes
3. Easy to transport
4. Longer life

Select the correct answer using the codes given below:
(a) 1, 3 and 4 (b) 1, 2 and 3
(c) 1 and 4 only (d) 2, 3 and 4
[ESE : 2008]

2.22 Which one of the following valves is seldom used in water distribution systems because of high head loss characteristics?
(a) Butterfly (b) Globe
(c) Plug (d) Sluice
[ESE : 2008]

2.23 Sonoscope is used for which one of the following?
(a) Checking the accuracy of water meters
(b) Regulating the fire hydrants
(c) As a replacement of venturimeter for discharge measurement
(d) Detection of leakage in underground water mains
[ESE : 2008]

2.24 What is the depth of waterseal in the traps?
(a) < 2.5 cm
(b) 2.5 – 7.5 cm
(c) 7.5 – 12.5 cm
(d) Not less than 15 cm
[ESE : 2008]

2.25 Consider the following statements:
In a water supply system,
1. drain valves are provided at elevated or higher, points to remove accumulated air.
2. reflux valve allows flow in one direction only.
3. drain valves are provided at low points to remove silt and other deposits.
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 2 only
(c) 2 and 3 only (d) 3 only
[ESE : 2010]

2.26 Consider the following statements:
The disadvantages of employing steel pipes in conveyance and distribution of water are, they
1. cannot withstand high negative pressures or vacuums that may be created in them, especially the combined effects of vacuum and external loads of backfill and traffic.
2. are easily affected by acidic or alkaline waters and even atmospheric agencies may produce adverse effects on them.
3. cannot be used for high pressures. (Generally not used for pressures above 7 kg/cm^2)
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 only
[ESE : 2010]

2.27 Match List-I with List-II and select the correct answer using the code given below the lists:
List-I
A. Steel pipe
B. Concrete pipe
C. AC pipe
D. Vitrified clay
List-II
1. Highly resistant to corrosion but can break easily
2. Virtually corrosion resistant
3. Sulphide corrosion
4. Electrolyte corrosion
Code:

	A	B	C	D
(a)	2	3	1	4
(b)	4	3	1	2
(c)	2	1	3	4
(d)	4	1	3	2

[ESE : 2011]

2.28 Consider, the following statements in respect of cast iron pipes employed for water supply
1. Easy to make joints
2. Strong and durable
3. Corrosion resistant
4. Long life
Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 1, 3 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4
[ESE : 2015]

2.29 Consider the following statements regarding valves in a pipe line:
1. In long pipe lines, air will accumulate in the low point of the line and will interfere with the flow.
2. Pressure relief valves are used in pipe lines where pressure may increase beyond the maximum permissible pressure.
3. Non-return valves prevent water flowing back, i.e. in the opposite direction.

Which of the above statements are correct?

(a) 1 and 2 only (b) 2 and 3 only

(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2015]

2.30 Assertion (A): The flow in water distribution pipes takes place due to gravity.

Reason (R): The flow in sewers takes place due to gravity.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 2015]

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Answers Conduits for Transporting Water

2.1	(d)	2.2	(b)	2.3	(a)	2.4	(b)	2.5	(a)	2.6	(a)	2.7	(b)	2.8	(c)	2.9	(b)		
2.10	(c)	2.11	(b)	2.12	(d)	2.13	(a)	2.14	(d)	2.15	(b)	2.16	(d)	2.17	(b)	2.18	(d)		
2.19	(b)	2.20	(a)	2.21	(c)	2.22	(c)	2.23	(d)	2.24	(b)	2.25	(c)	2.26	(b)	2.27	(b)		
2.28	(b)	2.29	(b)	2.30	(d)														

Explanations Conduits for Transporting Water

2.1 (d)

$$h_f = f\frac{L}{D}\frac{V^2}{2g} = \frac{16f}{\pi^2}\frac{L}{D^5}\frac{Q^2}{2g}$$

Since the pipes are connected in parallel, the head loss will be same for both pipes. The length of the two pipes is same also.

$$\therefore \quad \frac{Q_1}{Q_2} = \left(\frac{D_1}{D_2}\right)^{5/2} = \left(\frac{2d}{d}\right)^{5/2} = 4\sqrt{2}$$

2.2 (b)

Soil Pipe: It is a drain pipe that carries wastes from a plumbing fixture, especially from a toilet to sewer lines.

Intercepting Trap: The trap can be defined as fittings at the end of soil pipes or waste pipes to stop foul gases (odour) coming out of the soil pipe or waste pipe. It is a part of the drainage (sanitary) system. It is developed or designed such that it retains a small quantity of waste water from the discharge of fitting to which it is attached as a barrier to prevent foul gases or air entering the building.

P-Trap: A P-trap is a plumbing fixture that traps debris that has drained from the sink and prevents it from forming a clog deep within the plumbing system, and stops sewer gases from passing into the home.

Cowl: It is used in ventilation pipe and prevents rainwater from entering the ventilation duct.

2.3 (a)

All water contains dissolved air. Normally this would be about 2% but it can vary largely depending on temperature and pressure. Air trapped in the line in pockets is continually moving in and out of solution.

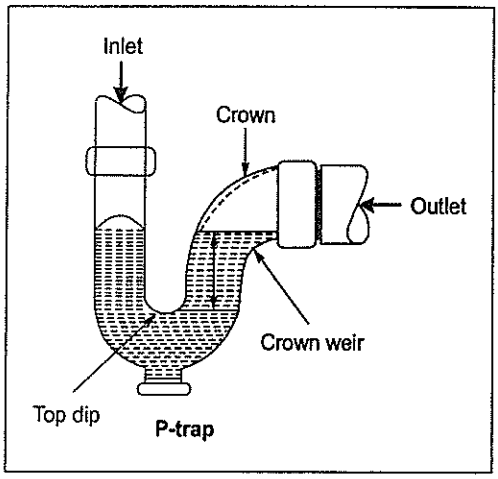
Air in the line not only reduces the flow by causing a restriction but amplifies the effects of pressure surges. **Air valves** should be placed in the line at sufficient intervals so that air can be evacuated, or, if the line is drained, air can enter the line.

Scour valves are located at low points or between valved sections of the pipeline. Their function is to allow periodic flushing of the lines to remove sediment and to allow the line to be drained for maintenance and repair work.

2.4 (b)

The entry of foul smelling gases into the house coming from the sewers can be prevented by:

- Providing water seal in all fixtures.
- Vent pipe in plumbing system.



2.5 (a)

The enlarged end of pipe is called 'socket' or 'bell' and normal end is called 'spigot'. Such questions are based on common sense and not information.

2.6 (a)

Service connection includes ferrules, stop cock, goose neck, service neck, water meters, stop cock, water taps, bib cocks, spouts, pipe fittings such as bends, crosses, tees, elbows, union, plugs, flanges etc.

2.8 (c)

As compared to continuous supply system, intermittent supply has more pressure and hence leakage losses are also less.

2.9 (b)

The usual size of residential ferrule varies from 10 mm to 50 mm. For connections of more than 50 mm diameter, a tee branch connection is used.

2.10 (c)

Water hammer phenomena will cause considerable damage to pipe when sluice valve is suddenly opened. Water hammer pressure can be reduced by providing pressure relief valve upstream of sluice valve.

2.11 (b)

Gutter inlet is used to drain rain water from roads to storm sewer. Leaping Weir is used to separate storm water and the sanitary sewage. Inverted siphon is used to carry the sewer below a stream or railway line.

2.12 (d)

The two-pipe system is the best and most improved system of plumbing. There are two sets of vertical pipes, one for excreta (night soil) as soil pipe and another for sullage as waste pipe. The soil pipes as well as waste pipes are separately ventilated, by providing, separate vent pipe or anti-siphonage pipe. This system has four vertical pipes.

2.13 (a)

The storm water regulators are :

(i) Leaping weir
(ii) Overflow weir
(iii) Siphon spillway

2.14 (d)

Sluice valve can be used to isolate any part of distribution system during repairs. Air inlet valves release high pressure and admit air during vacuum. Thus they ensure gravity flow under atmospheric pressure.

Ball valve are provided in the cistern to maintain constant level of water. They are also provided with overflow pipe to drain out excess incoming water.

2.15 (b)

Site selection for Intake structures:

- Black Iron for gas pipes.
- The site should be so selected that it may admit water even under worst condition of flow in the river. Generally, it is preferred that intake should be sufficiently below the shore line.
- Site should be very close to treatment plant as possible.
- It should be so located that it is free from the pollution. It is better to provide intake at upper stream of city so that water is not contaminated.
- It should not interfere with river traffic, if any.
- It should be located where good foundation conditions are available.
- It should be so located that it admits relatively pure water free from mud, sand and pollutants. Means it should be protected from rapid currents.

2.16 (d)

A **check valve**, clack valve, non-return valve or one-way valve is a valve that normally allows fluid (liquid or gas) to flow through it in only one direction.

A gate valve, also known as a **sluice valve**, is a valve which opens by lifting a round or rectangular gate/wedge out of the path of the fluid. The distinct feature of a gate valve is the sealing surfaces between the gate and seats are planar, so gate valves are often used when a straight-line flow of fluid and minimum restriction is desired.

The **pressure relief valve (PRV)** is a type of valve used to control or limit the pressure in a system. The pressure is relieved by allowing the pressurised fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits.

2.17 (b)

Butterfly valve is a valve consisting of a rotating circular plate or a pair of hinged semicircular plates, attached to a transverse spindle and mounted inside a pipe in order to regulate or prevent flow.

2.18 (d)

Cast iron pipes are generally used for sewer pipes. However the basic difference is pressure flow in water pipe and suspended solids carried in sewage.

2.19 (b)

Following are the most common materials used in plumbing systems:

- Steel pipes for – pumping main of distribution main
- Galvanized iron for carrying hot water in water supply lines.
- Cast iron for plumbing waste lines.
- PVC (Poly Vinyl Chloride) for plumbing waste lines.
- Chromed brass for plumbing waste lines
- Chromed copper – for water supply lines.
- Copper (rigid and flexible) for water supply lines.
- CPVC (Chlorinated Poly-Vinyl Chloride) for water supply lines.
- PEX (Cross-linked Polyethylene) for water supply lines
- Black Iron for gas pipes.

2.20 (a)

The **Mannings equation** is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope. It is extensively used in sanitary sewer design.'

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

In fluid dynamics, the **Darcy–Weisbach equation** is a phenomenological equation, which relates the head loss, or pressure loss, due to friction along a given length of pipe to the average velocity of the fluid flow for an incompressible fluid.

$$h_f = \frac{fLV^2}{2gD}$$

The **Hardy Cross method** is an iterative method for determining the flow in pipe network systems where the inputs and outputs are known, but the flow inside the network is unknown. The introduction of the Hardy Cross method for analyzing pipe flow network revolutionized municipal water supply design.

The **Rational Method** is a simple technique for estimating a design discharge from a small watershed. It was developed by Kuichling (1889) for small drainage basins in urban areas. It is used extensively in Storm sewer design.

2.21 (c)

The advantages of cast iron pipes are:

(i) Moderate in cost
(ii) Easy to join
(iii) Strong and durable
(iv) Corrosion resistant
(v) Long life
(vi) Service connections can be easily made

But if their size becomes large, then they are very heavy and uneconomical. Also they are likely to break during transportation or while making connections.

2.22(c)

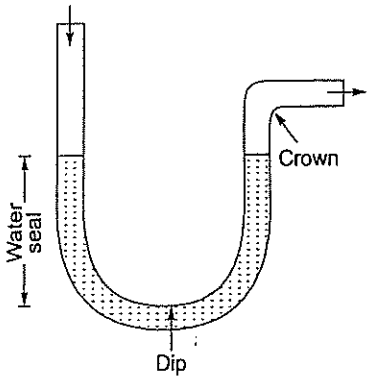
Plug valves are simple and ecomomical shut off valves which are generally not used in plumbing operations because of high head loss and throttling operational characteristics.

2.23(d)

The sonoscope/water phone is recommended by the AWWA (American Water Work Association) standards committe in its inspection and maintainace procedure for hydrants. Its regular use promots leak awareness and identifies costly leaks.

2.24(b)

Traps are the fittings placed at the ends of the soil pipes or the sullage pipes to prevent the passage of foul gases from the pipes to the outside. This is possible because traps do enclose or maintain water seal between the pipe and outside. This water depth does not allow gases to escape to the outside of pipe. The efficiency and effectiveness of a trap will depend upon the depth of water seal. Greater is this depth more effective the trap will be. This water seal generally varies from 25 mm to 75 mm; 50 mm being quite common in most of the traps.



2.25(c)

Drain valves are provided to remove the entire water from within a pipe (after closing the water supply). These are small gated off-takes which are provided at low points. These are also known as blow off valves or scour valves.

2.26 (b)

Steel pipes are comparatively expensive, but they are the strongest and most durable of all water supply systems. They can withstand high water pressure, come in convenient (longer) lengths than most other pipes and thus incur lower installation/ transportation costs. They can also be easily welded.

2.28 (b)

Cast iron pipes are most commonly used in water distribution system mainly because of the following reasons.

- They are cheaper in cost
- It has high resistance to corrosion
- It is highly durable

C.I. pipes are manufactured by following 4 methods.

1. Horizontally cast (MC ware pipes)
2. Vertical cast (pit cast in sand moulds)
3. Centrifugally cast in sand lines moulds spun type
4. Centrifugally cast in water cooled metal moulds

2.29 (b)

In long pipes, air accumulates at the top most point of the line.

2.30 (d)

The flow in water distribution pipes takes place due to water pressure and in sewer due to gravity.

3 Development of Ground Water and Well Hydraulics

3.1 Match List-I (Soil classification of an aquifer) with List-II (Values of the range of hydraulic conductivities in metre per day) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Fine gravel	1. 1 to 10
B. Very fine sand	2. 0.1 to 0.01
C. Silt	3. 100 to 1000
D. Pure clay	4. 10^{-5} to 10^{-6}

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	1	3	2	4
(c)	3	1	4	2
(d)	3	1	2	4

[ESE : 1997]

3.2 A commonly used handpump is the
(a) centrifugal pump
(b) reciprocating pump
(c) rotary pump
(d) axial flow pump

3.3 Match List-I (Pump) with List-II (Requirement) and select the correct answer using the codes given below the lists:

List-I
A. Multistage centrifugal pump of moderate sized impellers
B. Archimedean screw type pump
C. Simple reciprocating pump
D. Axial flow propeller pump

List-II
1. High head and low discharge
2. Low head and large discharge
3. High head and moderate discharge
4. Low head and low discharge

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	3	4	1	2
(c)	4	3	2	1
(d)	3	4	2	1

3.4 Match List-I (Tests) with List-II (Features) and select the correct answer using the codes given below the lists:

List-I
A. Pumping test
B. Recuperation Test
C. Pressure Test
D. Jar Test

List-II
1. The gradual rise of water level in well is observed as time progresses
2. Rate of pumping is adjusted to constant level of water in well
3. Vigorous mixing of the chemical followed by slow mixing
4. Pipeline is filled up with water, allowed to stand for sometime and then at least double the maximum pressure is applied

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	4	3
(c)	1	2	4	3
(d)	2	1	3	4

[ESE : 2003]

3.5 Consider the following statements:
1. Infiltration galleries are placed along the river beds at a depth 4 to 6 m.
2. The draw-down for the infiltration galleries is more than that for radial wells.
3. Clogging of pipe pores in infiltration galleries is less than that for radial wells.

4. The cost of extracting unit volume of water is more in case of infiltration galleries as compared to radial wells.

Which of these statements is/are correct?

(a) 1 and 2 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 4 only

[ESE : 2005]

3.6 **Assertion (A):** In a strainer type tube well, strainer pipes are surrounded by wire mesh.
Reason (R): This prevents the fine particles from entering the well pipe.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

3.7 **Statement-I :** Rainwater is collected and harvested using storage structures like underground tanks for future use and also for recharging the aquifer.
Statement-II : Rainwater harvesting pits allow the rainwater to percolate and recharge the aquifer.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

3.8 Coefficient of permeability of an underground stratum is 0.001 m/s. Discharge obtained from a well of area 20 m^2 dug into this stratum (with drawdown of 2 m) will be

(a) 2400 lpm (b) 2000 lpm
(c) 1200 lpm (d) 1000 lpm

[ESE : 2012]

3.9 **Statement-I :** When a tube well penetrates into a homogenous aquifer and is then pumped, there will occur lowering of water surface. The resultant surface is designated as 'Drawdown curve'.
Statement-II : Since the pressure on the surface of the 'Drawdown curve' is always at atmospheric level, it is called by this name.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

3.10 Due to a continuous pumping for 7 hrs from a catchment of 25 ha, having porosity of 30% and specific retention of 10%, groundwater level dropped by 1 m. The corresponding change in storage is:

(a) 7.5 ha-m (b) 0.75 ha-m
(c) 1.87 ha-m (d) 0.187 ha-m

[ESE : 2013]

3.11 As recommended by Sichardt, the radius of influence is

(a) Inversely proportional to drawndown
(b) Linearly proportional to drawdown
(c) Independent of drawdown
(d) Proportional to square root of drawdown

[ESE : 2013]

3.12 In a uniform, semi-infinite aquifer, the dependable discharge of a lone circular open well is increased most easily by

(a) increasing the diameter
(b) making it into one with a square kerb
(c) deepening the well
(d) providing coarser screening filter

[ESE : 2015]

3.13 What is the strainer length required for a deep tube well giving a discharge of 8 litres per second? Assume permissible entrance velocity of 2 cm/second. It is desired to have the strainer of slot sizes 20 mm × 0.2 mm with number of slots per cm length of the strainer as 100.

(a) 8 m (b) 1 m
(c) 12 m (d) 10 m

[ESE : 2015]

3.14 Which of the following statement are correct as regards aquifer characteristics?

1. The storage coefficient is the volume of water released from storage from the entire aquifer due to unit depression of piezometric head.
2. The storage coefficient is the same as the specific yield for water table aquifer.
3. Both the aquifer constant, viz, storage coefficient S and Transmissivity T are dimensionless numbers.

(a) 1 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

[ESE : 2016]

3.15 Consider the following statements in respect of ground water aquifers:

1. Specific storages is specific capacity per unit depth of the aquifer.
2. Specific capacity is storage coefficient per unit aquifer depth.
3. Specific capacity is a constant for a given well.
4. For one-dimensional flow in a confined aquifer between two water bodies, the piezometric head line in the aquifer is a straight line.

Which of the above statements are correct?

(a) 2 and 3 (b) 2 and 4
(c) 1 and 3 (d) 1 and 4

[ESE : 2017]

3.16 For an unconfined aquifer, the specific yield is 20%, specific retention is 15%, and permeability is 35 m/day. Consider the following statements:

1. The porosity of the aquifer is 35%.
2. The transmissibility is 35 m^2/day.
3. The volume of water lost from storage per meter drop in the water table per 100 km^2 area of the aquifer is 20 million m^3.

Which of the above statements are correct?

(a) 1 and 3 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2017]

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Answers Development of Ground Water and Well Hydraulics

3.1	(d)	3.2	(b)	3.3	(b)	3.4	(b)	3.5	(b)	3.6	(a)	3.7	(a)	3.8	(c*)	3.9	(b)		
3.10	(*)	3.11	(b)	3.12	(c)	3.13.	(d)	3.14	(b)	3.15	(b)	3.16	(d)						

Explanations Development of Ground Water and Well Hydraulics

3.1 (d)

Soil Classification of an Aquifer	Hydraulic Conductivity (m/day)	Drainage characteristics
Gravel	100-1000	Pervious
Sand	1-10	Pervious
Silt	0.1-0.01	Slightly pervious
Clay	10^{-5} to 10^{-6}	Impervious

3.2 (b)

Hand pumps are manually operated pumps; they use human power and mechanical advantage to move fluids or air from one place to another. There are many different types of hand pump available, mainly operating on a piston, diaphragm or rotary vane principle with a check valve on the entry and exit ports to the chamber operating in opposing directions. Most hand pumps have plungers or reciprocating pistons, and are positive displacement. All other pumps operate at very high rpm and hence cannot be used as hand pump.

3.4 (b)

Pumping Test: A *pumping test* is a field experiment in which a well is pumped at a controlled rate and water-level response (drawdown) is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself; response data from pumping tests are used to estimate the hydraulic properties of aquifers, evaluate well performance and identify aquifer boundaries.

Pressure Test: The purpose of pressure test is to investigate the various limits of the pipeline such as reliability, maximum capacity, leaks, fittings and pressure. It is a test in which a test pipeline is filled with water and is allowed to stand for some time and then pressure is applied.

3.5 (b)

An **Infiltration Gallery** is a structure including perforated conduits in gravel to expedite transfer of water to or from a soil aquifer.

Infiltration galleries may be used to supplement a storm sewer, by directing storm runoff from non-road areas.

Primarily, upright plastic pipes capped with simple grates are placed every 5-8 metres along the low point of a slope, to handle heavy surface runoff. The pipes proceed straight down, about two metres, to a horizontal cross-pipe; this pipe is the secondary system.

The horizontal pipe is then perforated slightly (about 10% of its surface area) and surrounded by gravel. Initially, runoff will exit the pipe and infiltrate the gravel to the soil beyond, dissipating naturally. As flow increases, the water will eventually fill the pipe and need to be dissipated more quickly. Thus, a catch basin is placed at the lowest point of the sloping ground, which is connected to the storm sewer system at large.

3.6 (a)

Strainer is a device through which liquid is passed for purification, filtering or separation from solid matter including a screen or a cloth or a wire mesh. In strainer type tube wells, strainer pipes are surrounded by wire mesh which prevents fine particles from entering the well pipe.

3.7 (a)

Rainwater harvesting can be done in a lot of ways. The rainwater can be collected in the roof and then directed to storage tanks, or it can be stored in pits in ground to recharge the aquifer and increase ground water level of the area.

3.8 (c*)

Discharge is given by

$$q = kiA = 0.001 \times 1 \times 20$$

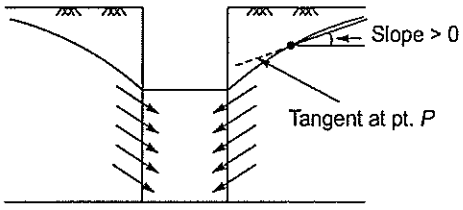
(Assuming $L = 1$ m)

$$= 0.02 \text{ m}^3/\text{sec}$$

$$= 1200 \text{ lpm}$$

3.9 (b)

Any point on drawdown curve will have pressure equal to atmospheric pressure but slope of the tangent at this point being > 0, the curve apponenitly gets lowered towards the well from where water is being drawn and thus it is called as DRAWDOWN CURVE.



3.10 (*)

$A = 25$ ha

Porosity, $n = 0.3$

Sp. retention $S_R = 0.1$

$\therefore \quad S_y = n - S_R = 0.2$

$\therefore$ Storage change $= 25 \times 0.2 \times 1$

$= 5$ ha-m

3.11 (b)

The radius of influence (R) is commonly known as radius of drawdown, is the radius measured from the centre of the wall to the point at which drawdown is measured.

It is given by $R = 3000\ S\sqrt{k}$

where,

R = radius of drawdown

S = drawdown

k = permeability of aquifer soil

3.12 (c)

Discharge of an uncofined aquifer,

$$Q = \frac{\pi K\left(H_1^2 - H_2^2\right)}{2.303 \log_{10} R/r}$$

The discharge of an aquifer can be increased by,

- Decreasing the diameter of the well
- Increasing the depth of the well

3.13 (d)

Discharge of tube well

$= 8\ l/s = 8 \times 10^{-3}\ m^3/s$

Permissible entrance velocity,

$= 2$ cm/s $= 2 \times 10^{-2}$ m/s

Let length of strainer is 'l'

$l \times (20 \times 0.2 \times 10^{-6}) \times (2 \times 10^{-2}) \times (100 \times 100) = 8 \times 10^{-3}$

$l = 10$ m

3.16 (d)

Porosity, $n = S_y + S_R$

S_y = Specific yield

S_R = Specific retention

$\therefore \quad n = 0.20 + 0.15 = 0.35$

Transmissibility of an aquifer is defined as the ability of an aquifer to pass water through unit width.

$T = KH$

$= 35$ m/d $\times$ 1 m $= 35\ m^2/d$

Volume of water lost from storage

$= S_y \times 100 \times 10^6\ m^2 \times 1$ m

$= 20 \times 10^6\ m^3 = 20\ Mm^3$

■■■■

4 Quality Control of Water Supplies

4.1 If the total hardness and alkalinity of a sample of water are 300 mg/L and 100 mg/L ($CaCO_3$ scale) respectively, then its carbonate and non-carbonate hardness (in units of mg/L) will be respectively

(a) 100 and 200 (b) 400 and 300
(c) 100 and 400 (d) 400 and zero

[ESE : 1995]

4.2 Electrical conductivity (EC) of water and total dissolved solids (TDS) are interrelated. The value of EC will

(a) decrease with increase in TDS
(b) increase with increase in TDS
(c) decrease initially and then increase with increase in TDS
(d) increase initially and then decrease with increase in TDS

[ESE : 1995]

4.3 Which one of the following would contain water with the maximum amount of turbidity?

(a) Lakes (b) Oceans
(c) Rivers (d) Wells

[ESE : 1996]

4.4 Zero hardness of water is achieved by

(a) using lime soda process
(b) excess lime treatment
(c) ion exchange method
(d) using excess alum dosage

[ESE : 1997]

4.5 Match List-I (Parameters) with List-II (Permissible concentration in drinking water) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Hardness	1. 0.1 mg/L
B. Nitrate concentration	2. 0.5 mg/L
C. Iron concentration	3. 200 mg/L
D. Fluoride concentration	4. 45 mg/L

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	3	4	1	2
(c)	4	3	2	1
(d)	4	3	1	2

[ESE : 1997]

4.6 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Absence of fluorides
B. Excess of lead
C. Presence of excess nitrates
D. Absence of iodide

List-II

1. Methaemo globinemia
2. Goitre
3. Dental caries
4. Anaemia

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	2	3	4	1
(c)	3	4	1	2
(d)	1	2	4	3

[ESE : 1997]

4.7 Which of the following determinations are NOT necessary for raw water from a lake for use as source of supply of water for boiler-feed?

1. Turbidity 2. Bacterial count
3. Iron 4. Hardness

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

[ESE : 1997]

4.8 Which of the following is/are the characteristic(s) of coliform organism?

1. Bacillus
2. Gram-negative
3. Ferments lactose
4. Spore-forming

Select the correct answer using the codes given below:

(a) 1 alone (b) 1, 2 and 4
(c) 1, 2 and 3 (d) 2, 3 and 4

[ESE : 1998]

4.9 If the methyl orange alkalinity of water equals or exceeds total hardness, all of the hardness is
(a) non-carbonate hardness
(b) carbonate hardness
(c) pseudo hardness
(d) negative non-carbonate hardness

[ESE : 1999]

4.10 Consider the following statements:
Some amount of chlorides is allowed in drinking water because
1. it helps in killing bacteria
2. small quantity of chlorides adds to the taste
3. it is not injurious to human health
4. it is not economical to remove it completely

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 1999]

4.11 **Assertion (A):** Alum is the most commonly used coagulant in water treatment.
Reason (R): Alum is very effective in killing pathogens present in water.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

4.12 The amount of bleaching powder containing 20% available chlorine needed to chlorinate a rural water supply covering a population of 10000 at 50 Lpcd at the rate of 2 ppm is

(a) 1 kg (b) 5 kg
(c) 0.2 kg (d) 20 kg

[ESE : 2001]

4.13 Which of the following statements are correct?
1. Groundwater is generally free from suspended and dissolved impurities.
2. Suspended matters often contain pathogenic bacteria.
3. Rain water is soft and tasteless.
4. Lake water may contain microscopic organisms.

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 1 and 2
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 2001]

4.14 Match List-I (Impurities) with List-II (Effects) and select the correct answer using the codes given below the lists:

List-I
A. Dissolved sulphates and chlorides of Ca and Mg
B. Dissolved bicarbonates of Ca and Mg
C. Dissolved fluorides of Na
D. Dissolved organic matter

List-II
1. Hardness and corrosion
2. Bacterial infection
3. Alkalinity and softness
4. Impairment of dental health

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	1	4	3	2
(c)	2	4	3	1
(d)	1	3	4	2

[ESE : 2001]

4.15 Match List-I (Water quality) with List-II (Method of determination) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Hardness	1. Winkler's method
B. Chlorine	2. EDTA method
C. DO	3. Orthotolidine test
D. Chloride	4. Mohr method

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	2	4	1	3
(c)	1	3	2	4
(d)	1	4	2	3

[ESE : 2001]

4.16 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Protozoa	1. Methaemog-lobinemia
B. Bacteria	2. Poliomyelitis
C. Presence of nitrate> 45 mg/L	3. Dysentry
D. Virus	4. Typhoid fever

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	1	4	3	2
(c)	3	4	1	2
(d)	1	2	3	4

[ESE : 2004]

4.17 Which one of the following organisms is responsible for enteric fever?

(a) ECHO
(b) Salmonella typhi
(c) Entamoeba histolytica
(d) Echinococcus

[ESE : 2004]

4.18 Match List-I (Water/Waste water parameter) with List-II (Test) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Potability of water	1. Mohr's method
B. Chloride	2. Orthotolidine test
C. Residual chlorine	3. EDTA method
D. Hardness of water	4. MF technique

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	2	3	4	1
(d)	4	1	2	3

[ESE : 2004]

4.19 Match List-I (Type of impurity) with List-II (Effect) and select the correct answer using the codes given below the lists:

List-I

A. Carbonates and bicarbonates of calcium and magnesium
B. Carbonates and bicarbonates of sodium
C. Sulphates and chlorides of calcium and magnesium
D. Oxides of iron and manganese

List-II

1. Permanent hardness
2. Temporary hardness
3. Alkalinity and softness
4. Colour and taste

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	2	4	1	3
(c)	1	4	2	3
(d)	2	3	1	4

[ESE : 2005]

4.20 A sample of ground water at a pH of 7.0 contains 122 mg/L of bicarbonates. What is the alkalinity of this water (in terms of $CaCO_3$)?

(a) 120 mg/L (b) 60 mg/L
(c) 100 mg/L (d) 200 mg/L

[ESE : 2005]

4.21 Which of the following are associated with alum coagulation?

1. A decrease in alkalinity of treated water
2. Formation of hydroxide flocs of aluminium
3. A slight decrease in pH of treated water
4. An increase in permanent hardness

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2, 3 and 4 (d) 2 and 4

[ESE : 2005]

4.22 What is the equivalent calcium carbonate concentration of 110 mg/L of $CaCl_2$?

(a) 50 mg/L (b) 58.5 mg/L
(c) 100 mg/L (d) 117 mg/L

[ESE : 2006]

4.23 Which of the following cations impart(s) pseudo-hardness to water?

(a) Calcium only
(b) Magnesium only
(c) Calcium and magnesium
(d) Sodium

[ESE : 2006]

4.24 Match List-I (Equipment) with List-II (Parameter) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Tintometer	1. Temperature
B. Nephelometer	2. Colour
C. Imhoff cone	3. Turbidity
D. Muffle furnace	4. Settleable solids
	5. Volatile solids

Codes:

	A	B	C	D
(a)	4	3	1	5
(b)	2	5	4	3
(c)	4	5	1	3
(d)	2	3	4	5

[ESE : 2006]

4.25 Chlorination with Cl_2 produces hypoch-lorous acid (HOCl), which may further dissociate as hypochlorite ion (OCl^-) depending upon pH of the water. The reaction is represented as:

$$HOCl \underset{}{\overset{k}{\rightleftharpoons}} H^+ + OCl^-$$

($k = 2.5 \times 10^{-8}$ moles/L at 20°C)

What is the fraction of HOCl in the water at pH 7.0?

(a) 0.95 (b) 0.80
(c) 0.20 (d) 0.05

[ESE : 2006]

4.26 After which of the following treatment units, the turbidity is maximum?

(a) Chlorination
(b) Primary sedimentation
(c) Flocculation basin
(d) Secondary sedimentation

[ESE : 2006]

4.27 What is the most common cause of acidity in water?

(a) Carbon monoxide (b) Nitrogen
(c) Hydrogen (d) Carbon dioxide

[ESE : 2006]

4.28 If total hardness and alkalinity of a water sample are 200 mg/L as $CaCO_3$ and 260 mg/L as $CaCO_3$ respectively, what are the values of carbonate hardness and non-carbonate hardness?

(a) 200 mg/L and zero
(b) Zero and 60 mg/L
(c) Zero and 200 mg/L
(d) 60 mg/L and zero

[ESE : 2006]

4.29 Hardness to water is caused by the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. Which are the least soluble forms of calcium and magnesium at normal water temperature?

(a) $CaCl_2$ and $MgCO_3$
(b) $Ca(HCO_3)_2$ and $MgCl_2$
(c) $Ca(OH)_2$ and $Mg(HCO_3)_2$
(d) $CaCO_3$ and $Mg(OH)_2$

[ESE : 2006]

4.30 Match List-I (Pathogen) with List-II (Epidemic) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Bacteria	1. Gastroenteritis
B. Virus	2. Cholera
C. Protozoa	3. Worms
D. Helminth	4. Polio

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

[ESE : 2007]

4.31 Match List-I (Parameter) with List-II (Impact) and select the correct answer using the codes given below the lists:

List-I
A. Excess sulphates
B. Lack of iodide
C. Excess hardness
D. Excess dissolved oxygen

List-II
1. Greater soap consumption
2. Laxative effect
3. Goitre
4. Corrosion of pipes

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	4	3	1	2
(c)	2	3	1	4
(d)	4	1	3	2

[ESE : 2007]

4.32 The concentration of hardness producing cations may be estimated using which one of the following?

(a) Conductivity meter
(b) pH meter
(c) Spectrophotometer
(d) Flame photometer

[ESE : 2007]

4.33 Which one of the following treatments is economically effective in the control of guinea worm disease?
(a) Chlorination
(b) Filtration
(c) Ozonation
(d) Sedimentation

[ESE : 2007]

4.34 Match List-I (Type of impurity) with List-II (Harm caused) and select the correct answer using the codes given below the lists:

List-I
A. Excess of nitrates
B. Excess of fluorides
C. Lack of iodides
D. Excess of chlorides

List-II
1. Brackish water
2. Goiter
3. Fragile bones
4. Blue babies

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	1	2	3	4
(c)	4	3	2	1
(d)	1	3	2	4

[ESE : 2009]

4.35 The concentration of OH^- ion in a water sample is measured as 17 mg/L at 25°C. What is the pH of the water sample?
(a) 10 (b) 11
(c) 12 (d) 13

[ESE : 2009]

4.36 What is the theoretical oxygen demand of 300 mg/L glucose solution?
(a) 300 mg/L (b) 320 mg/L
(c) 350 mg/L (d) 400 mg/L

[ESE : 2009]

4.37 Which one of the following tests of water/wastewater employs Erichrome Black T as an indicator?
(a) Hardness (b) COD
(c) Residual chlorine (d) DO

[ESE : 2009]

4.38 Match List-I (Parameters) with List-II (Units) and select the correct answer using the code given below the lists:

List-I	List-II
A. Turbidity	1. TON
B. Pathogen	2. TCU
C. Odour	3. JTU
D. Colour	4. MPN

Code:

	A	B	C	D
(a)	2	1	4	3
(b)	3	1	4	2
(c)	2	4	1	3
(d)	3	4	1	2

[ESE : 2011]

4.39 Assertion (A): Fluorides should always be present in drinking water upto a value 1.5 mg/l.
Reason (R): Such a water helps clean the teeth well.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

4.40 Which one of the following tests employs ferroin indicator?
(a) Chemical oxygen demand
(b) Ammonia nitrogen
(c) Nitrate nitrogen
(d) Fluoride

[ESE : 2011]

4.41 The maximum safe permissible limit of sulphates in domestic water supply is
(a) 100 mg/L (b) 200 mg/L
(c) 500 mg/L (d) 600 mg/L

[ESE : 2012]

4.42 One Nephelometry Turbidity Unit (NTU) is equal to the turbidity produced by
(a) 1 mg SiO_2 dissolved in 1l of distilled water with the test being run according to absorption principle.
(b) 1 mg SiO_2 dissolved in 1l of distilled water with the test being run according to scattering principle.
(c) 1 mg Formazin dissolved in 1l of distilled water with the test being run according to absorption principle.
(d) 1 mg Formazin dissolved in 1l of distilled water with the test being run according to scattering principle.

[ESE : 2012]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

4.43 Statement-I : Fluoride concentrations of approximately 1.0 mg/l in drinking water help to prevent dental cavities in children.
Statement-II : During formation of permanent teeth, fluoride combines chemically with tooth enamel resulting in softer and weaker teeth that are less resistant to decay.

[ESE : 2012]

4.44 Statement-I : Virus is living organisms in a natural environment including soil.
Statement-II : Virus comes to life after entering the host tissue through contamination.

[ESE : 2012]

4.45 Statement-I : The ability of water to conduct electricity, known and measured as the specific conductance, and concentration of total dissolved solids are not relatable on a one-to-one basis.
Statement-II : Many organic molecules and compounds dissolve in water without ionizing and hence are not taken into account while measuring specific conductance.

[ESE : 2012]

4.46 Statement-I: Water with heavy algal growth often has pH values as high as 9 to 10.
Statement-II: Non-utilization of the bicarbonate ion as a carbon source by algae can result in substantial accumulation of OH^- ions.

[ESE : 2012]

4.47 EDTA titration method of hardness determination of water sample uses an indicator which combines with hardness-causing divalent cations and forms a coloured complex. The name of the indicator and the colour of the formed complex respectively are
(a) Ferroin and dark blue
(b) Ferroin and wine red
(c) Eriochrome Black T and dark blue
(d) Eriochrome Black T and wine red

[ESE : 2012]

4.48 The most common constituents of alkalinity in natural water are measured by titrating the water sample with 0.02 N H_2SO_4 using.
(a) Eriochrome Black T and Ferroin indicators
(b) Ferroin and Phenolphthalein indicators
(c) Phenolphthalein and Methyl Orange indicators
(d) Methyl Orange and Eriochrome Black T indicators.

[ESE : 2012]

4.49 An approximate estimation of total dissolved solids of a given water sample is often made by measuring
(a) Electrical conductivity of the water sample
(b) Electro-magnetic conductivity of the water sample
(c) Sound conductivity of the water sample
(d) Thermal conductivity of the water sample

[ESE : 2012]

4.50 Which one of the following tests employs Ethylene Diamine Tetra Acetic Acid as a titrating agent?

(a) Chlorides (b) Dissolved oxygen
(c) Hardness (d) Residual chlorine

[ESE : 2012]

4.51 The dissolved oxygen in a water sample is generally estimated by modified Winkler method. The water sample is taken in a 300 m*l* BOD bottle and the dissolved oxygen is fixed by adding

(a) 1 ml of conc. H_2SO_4 followed by addition of 1 mnl of $MnSO_4$ reagent and contents mixed thoroughly, thereafter waiting for 5-10 minutes, and then 1 ml of alkali-iodide-azide reagent is added.
(b) 1 ml of alkali-iodide-azide reagent followed by addition of 1 ml of conc. H_2SO_4 and then the contents mixed thoroughly, thereafter waiting for 5-10 minutes, 1 ml of $MnSO_4$ regent is added.
(c) 1 ml of $MnSO_4$ followed by addition of 1 ml of alkali-iodide-azide reagents and then the contents mixed thoroughly, thereafter waiting for 5-10 minutes and then 1 ml of conc. H_2SO_4 is added.
(d) 1 ml of conc. of H_2SO_4 followed by addition of 1 ml of alkali-iodide-azide reagent and then the contents mixed thoroughly, thereafter waiting for 5-10 minutes and then 1 ml of $MnSO_4$ reagent is added.

[ESE : 2013]

4.52 Consider the following statements:

1. Typhoid fever is caused by viral infection.
2. Infectious hepatitis is caused by bacterial infection.
3. Cholera is caused by bacteria.
4. Amoebic dysentery is caused by protozoal infection.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 3 and 4 only (d) 2 and 3 only

[ESE : 2013]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

4.53 **Statement (I):** Water with heavy algal growths often has pH values as high as 9 to 10.
Statement (II): Non-utilization of the bicarbonate ion as a carbon source by algae can result in substantial accumulation of OH ions.

[ESE : 2013]

4.54 **Statement (I):** 'Environment' includes abiotic and biotic parameters.
Statement (II): Abiotic parameters include algae, bacteria, animals; and biotic parameters are air, water and soil.

[ESE : 2013]

4.55 The total hardness value obtained from the complete analysis of a water sample was found to be 120 mg/*l*. If the value of carbonate hardness is 50 mg/*l*, the non-carbonate hardness and alkalinity are, respectively

(a) 170 mg/*l* and 70 mg/*l*
(b) 170 mg/*l* and 50 mg/*l*
(c) 70 mg/*l* and 50 mg/*l*
(d) 50 mg/*l* and 70 mg/*l*

[ESE : 2014]

4.56 Consider the following statements:

1. The quality of waste water determined on the basis of DO.
2. The BOD test is based on DO.
3. Determination of DO helps in controlling corrosion.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2014]

4.57 **Statement (I):** During an epidemic of infective hepatitis, the supplied water is super chlorinated.
Statement (II): Spore-forming bacteria which cause this disease are effectively removed from water by super chlorination.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2014]

4.58 The dissolved oxygen in a water sample is generally estimated by modified Winkler method. Accordingly, approximately 200 ml volume of dissolved-oxygen fixed solution shall be titrated with
(a) Sodium thiosulphate reagent using soluble starch as an indicator
(b) Sodium thiosulphate reagent using ferroin as an indicator
(c) Ferrous ammonium sulphate reagent using soluble starch as an indicator
(d) Ferrous ammonium sulphate reagent using ferroin as an indicator

[ESE : 2014]

4.59 **Assertion (A):** Dracontiasis is transmitted by drinking contaminated water.
Reason (R): Dracontiasis can be controlled by filtration of the drinking water.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2015]

4.60 Electrical conductivity (EC) of water and total dissolved solids (TDS) are relatable as:
The value of EC will
(a) Decrease with increase in TDS
(b) Increase with increase in TDS
(c) Decrease initially and then increase with increase in TDS
(d) Increase initially and then decrease with increase in TDS

[ESE : 2016]

4.61 The waste water of a certain large colony contains $10^{-5.6}$ mmol/*l* of OH^- ions at 25°C. The pH of this sample is
(a) 8.6 (b) 7.9
(c) 5.4 (d) 4.5

[ESE : 2016]

4.62 **Statement (I):** Recarbonation of water softened by, lime-soda process results in increased hardness of the water.
Statement (II): Suspended solids, like $CaSO_4$ and $MgSO_4$, which have not settled in the sedimentation tank get dissolved due to passage of CO_2.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

4.63 The concentration of chloride ions in a water sample is estimated by titration with
(a) Sodium thiosulphate reagent using ferrion as an indicator
(b) Ferrous ammonium sulphate reagent using soluble starch as in indicator
(c) Silver nitrate reagent using potassium chromate as an indicator
(d) Silver nitrate reagent using potassium dichromate as in indicator

[ESE : 2017]

■■■■

Answers Quality Control of Water Supplies

4.1 (a)	4.2 (b)	4.3 (c)	4.4 (c)	4.5 (b)	4.6 (c)	4.7 (a)	4.8 (c)	4.9 (b)	
4.10 (b)	4.11 (b)	4.12 (b)	4.13 (c)	4.14 (d)	4.15 (a)	4.16 (c)	4.17 (b)	4.18 (d)	
4.19 (d)	4.20 (c)	4.21 (c)	4.22 (c)	4.23 (d)	4.24 (d)	4.25 (b)	4.26 (c)	4.27 (d)	
4.28 (a)	4.29 (d)	4.30 (a)	4.31 (c)	4.32 (c)	4.33 (b)	4.34 (c)	4.35 (b)	4.36 (b)	
4.37 (a)	4.38 (d)	4.39 (a)	4.40 (a)	4.41 (b)	4.42 (d)	4.43 (c)	4.44 (d)	4.45 (a)	
4.46 (c)	4.47 (d)	4.48 (c)	4.49 (a)	4.50 (c)	4.51 (c)	4.52 (c)	4.53 (c)	4.54 (c)	
4.55 (c)	4.56 (a)	4.57 (c)	4.58 (a)	4.59 (b)	4.60 (b)	4.61 (c)	4.62 (c)	4.63 (c)	

Explanations Quality Control of Water Supplies

4.1 (a)

Carbonate hardness is equal to total hardness or alkalinity, whichever is less i.e. 100 mg/L

Non-carbonate hardness

= Total hardness – Alkalinity

= 300 – 100

= 200 mg/L

4.2 (b)

An approximate analysis for TDS is often made by determining the electrical conductivity of the water. The ability of water to conduct electricity is called specific conductance and it is a function of its ionic strength. Unfortunately, specific conductance and concentration of TDS are not related on a one to one basis. Only ionized substances contribute to specific conductance. Organic molecules and compounds that dissolve without ionizing are not measured. Additionally, the magnitude of specific conductance is influenced by the valence of the ions in the solution, their mobility and their relative numbers. The temperature also has an important effect with specific conductance increasing as the water temperature increases. The ions usually accounting for majority of TDS in natural waters are Na, Ca, Mg, HCO_3^-, SO_4^{2-}, Cl^-, etc. Hence their presence increases the electrical conductivity of water.

4.3 (c)

Rivers during monsoon season have high suspended solids concentration in suspension. This causes high turbidity.

4.4 (c)

Ion exchange process is used for zero hardness water.

A variety of dissolved solids can be removed by ion exchange. For hardness removal zeolite (a naturally occurring sodium alumino-silicate material sometime called green sand) and synthetic resins are used. The removal process is based on high adsorption capacity of calcium and magnesium ions compared to sodium ions. In this process exchange sites are utilized to remove hardness. When all the exchange sites are utilized, hardness begins to appear in the effluent. This is called break through and it necessitates the regeneration of the medium by contacting it with a strong sodium-chloride solution.

4.5 (b)

Small concentrations (approximately 1.0 mg/L) of fluoride are helpful to prevent dental cavities in children. Iron concentrations of 0.3 mg/L may cause colour problem. The Indian standard have desirable limits of 0.3 mg/L for iron and 1.5 mg/L for fluoride. Nitrate concentrations above 45 mg/L may cause blue baby disease.

4.6 (c)

Fluoride or fluorine deficiency is a disorder which may cause increased dental caries (or tooth decay) is the breakdown of dental tissues by the acidic products released by the "bacterial fermentation of dietary carbohydrates.") and possibly osteoporosis (a bone disorder which

leads to a decrease in bone mass, and an increase in bone fragility).

Lead in excess is toxic to many organs and tissues including heart, kidney, bones, intestines, reproductive system and nervous system. Hence it should not be greater than 0.05 mg/*l*. Excess lead causes anaemia.

Too much of nitrates is harmful for infants and causes Methemoglobinemia or Blue Baby Disease.

Iodine deficiency causes Goitre.

4.7 (a)

Turbidity, bacterial count and iron has no significant effect on efficiency of boiler. However, hardness causes scaling.

4.8 (c)

Coliform group organisms have following characteristics.

(i) It is bacillus (straight rod like shape with square or rounded ends)
(ii) Gram negative rods will be present
(iii) Glucose (Lactose bile) fermentation and gas production within 24 ± 2 to 48 ± 3 hours of incubation.
(iv) No spores should be present.

4.9 (b)

The alkalinity is measured by titrating the water with an acid and determining the hydrogen equivalent. Alkalinity is expressed as mg/L of $CaCO_3$. Methyl orange is an indicator with pH range 2.8 to 4.4. It changes colour from red to yellow and thus indicates end of titration.

The hardness due to monovalent cations like Na^+ is called pseudo hardness.

Total alkalinity = carbonate + bicarbonate + hydroxide alkalinity

If total alkalinity is more than or equal to total hardness.

Carbonate hardness = total hardness

Non carbonate hardness = 0

4.10 (b)

Small amout of chlorine (practically 0.2 gm/*l*) of residual is ensure of the break point to safeguard the water against future recontamination, not for it is uneconomical to remove.

4.11 (b)

Alum is very effective coagulant for water treatment and is most commonly used. It is quite cheap, forms excellent stable floc and does not require any skilled supervision.

Destruction of bacteria by different treatment processes.

Process	Percent removal
Coarse screens	0 – 5
Fine screens	10 – 25
Grit chambers	10 – 25
Plain sedimentation	25 – 27
Chemical coagulation	40 – 80
Trickling filters	90 – 95
Activated sludge	90 – 98
Chlorination	98 – 99.9

4.12 (b)

Chlorine dose required

$$= 2 \times 10^{-6} \times 10{,}000 \times 50 = 1 \text{ kg/day}$$

Bleaching powder required $= \frac{1}{0.2} = 5$ kg/day

4.13 (c)

Ground water is free from suspended impurities. However dissolved gases, salts and minerals are found in groundwater.

4.14 (d)

Note: In given List-II point 3 should be Alkalinity and Hardness in place of Alkalinity and Softness.

4.15 (a)

Chlorine residuals can be tested by orthotolidine test, DPD test, Chlorotex test and Starch-Iodide test.

The dissolved oxygen of sewage is generally determined by Winkler's method which is an oxidation - reduction process carried out chemically to liberate iodine in amount equivalent to the quantity of DO originally present.

4.16 (c)

Typhoid fever is caused by bacteria (Salmonella Typhi). Presence of excess nitrates > 45mg/*l* causes blue baby disease called Methemoglobinemia. Dysentry is caused by Protozoan

(Entamoeba Histolytic). Poliomyelitis is caused by virus.

4.17 (b)

Salmonella typhi and Salmonella paratyphi (bacteria) cause enteric fever.

Enteric Cytopathogenic Human Orphan ECHO (virus) cause aseptic meningitis, epidemic exanthem, infantile diarrhoea.

Entamoeba histolytica (protozoa) cause dimebiasis (amebic dysentry, amebic enteritis, amebic colitis). Echmococcus (helminth) cause enchinococcosis (hydlatidosis, granulosis, dog tapeworm).

4.18 (d)

Potability means absence of pathogenic organisms and they can be detected by Membrane Filtration (MF) technique.

4.19 (d)

Temporary Hardness – Carbonates and bicarbonates of Ca and Mg

Permanent Hardness – Sulphates and Chlorides of Ca and Mg

Alkalinity and Softness – Carbonates and bicarbonates of Na

Oxides of Iron and Manganese impart colour and taste to water.

4.20 (c)

Alkalinity expressed in equivalents

$$= HCO_3^- + OH^- - H^+$$

Milliequivalent mass of $[HCO_3^-]$

$$= \frac{122}{61} = 2 \text{ meq/L}$$

Milliequivalent mass of $[OH^-]$

$$= \frac{10^{-7}}{17} \text{meq/L}$$

Milliequivalent mass of $[H^+]$

$$= \frac{10^{-7}}{1} \text{meq/L}$$

The milliequivalent of $[OH^-]$ and $[H^+]$ are negligible. So Alkalinity as $CaCO_3$

$$= 2 \times 50 = 100 \text{ mg/L}$$

4.21 (c)

The purpose of coagulation is to alter the colloids so that they can adhere to each other. During coagulation a positive ion is added to water to reduce the surface charge to the point where the colloids are not repelled from each other.

Aluminum can be purchased as either dry or liquid alum $[Al_2(SO_4)_3.14H_2O]$. When alum is added to a water containing alkalinity, the following reaction occurs :

$$Al_2(SO_4)_3\,14\,H_2O + 6HCO_3 \rightleftharpoons$$

$$2Al(OH)_3 + 6CO_2 + 14H_2O + 3SO_4^{2-}$$

Such that each mole of alum added uses six moles of alkalinity and produces six moles of carbon dioxide. The above reaction shifts the carbonate equilibrium and decreases the pH. However, as long as sufficient alkalinity is present and CO_2 is allowed to evolve, the pH is not drastically reduced and is generally not an operational problem. When sufficient alkalinity is not present to neutralize the sulfuric acid production, the pH may be greatly reduced :

$$Al_2(SO_4)_3 . 14\,H_2O \rightleftharpoons$$

$$2Al(OH)_3 + 8H_2O + 3H_2SO_4$$

If the second reaction occurs, lime or sodium carbonate may be added to neutralize the sulfuric acid. Two important factors in coagulant addition are pH and dose. The optimum dose and pH must be determined from laboratory tests. The optimal pH range for alum is approximately 5.5 to 6.5 with adequate coagulation possible between pH 5 to pH 8 under some conditions.

4.22 (c)

Molecular weight of $CaCl_2$

$$= 40 + 2 \times 35.0 = 110 \text{ g/mole}$$

Equivalent weight of $CaCl_2 = \frac{110}{2} = 55$

Milliequivalents of $CaCl_2$ in 110 mg/L

$$= \frac{110}{55} = 2 \text{ meq/L}$$

So $CaCl_2$ as $CaCO_3 = 2 \times 50 = 100$ mg/L

4.23 (d)

Monovalent cations impart pseudo-hardness. Hardness is the concentration of multivalent cations.

4.24 (d)

Nephelometer is based on scattering principle for measurement of turbidity. It uses formazin, a chemical compound, for standard. Formazin is more reproducible standard than SiO_2.

Tintometer is a color measuring instrument which compares colour of water in Nessler tubes which contain solutions of platinum Cobalt dissolved in water.

4.25 (b)

For pH = 7

Concentration of $[H^+] = 10^{-pH}$ moles/L

Ionization constant

$$k = \frac{[H^+][OCl^-]}{[HOCl]} = 2.5 \times 10^{-8} \text{ moles/L}$$

The total quantity of HOCl and OCl^- present in water is called free available chlorine. The relative distribution of these two species is very important because the killing efficiency of HOCl is about 40 to 80 times that of OCl^-. The percent distribution of HOCl

$$\frac{[HOCl]}{[HOCl]+[OCl^-]} = \frac{1}{1+k\,10^{pH}}$$

$$= \frac{1}{1+2.5\times10^{-8}\times10^{7}} = \frac{1}{1.25} = 0.8$$

4.26 (c)

Flocculation basin is used for formation of flocs through coagulation. After this process turbidity is highest. Primary sedimentation causes settling of particles and turbidity reduces.

4.27 (d)

CO_2 reacts with water to form carbonic acid.

4.28 (a)

Since alkalinity is more than total hardness so only carbonate hardness is present.

Carbonate hardness = 200 mg/L

Non-carbonate hardness = zero

4.29 (d)

Carbonates are less soluble than bicarbonates. Bicarbonates begin to convert to less soluble carbonates at pH values above 9.0. The least soluble forms are calcium carbonate and magnesium hydroxide. Chemical precipitation is accomplished by converting calcium hardness to calcium carbonate and magnesium hardness to magnesium hydroxide.

4.30 (a)

Cholera	:	Bacteria
Worms	:	Helminths
Polio	:	Virus
Gastroenteritis	:	Protozoan

4.32 (c)

Hardness is defined as the concentration of multivalent metallic cations in solution. The multivalent metallic ions most abundant in natural waters are calcium and magnesium. Hardness can be measured by using spectrophotometric techniques or chemical titration to determine the quantity of calcium and magnesium ions in a given sample. Hardness can be measured directly by titration with ethylenediamine tetracetic acid (EDTA) using Eriochrome Black *T* (EBT) as an indicator.

4.33 (b)

Most of the standing pond water is contaminated with Guinea Worm Disease and anyone who drinks this water stands at a risk of getting infected from it. GWD can be prevented by filtration of the water or by using water from underground sources which is free from contamination of larvae.

4.34 (c)

Concentrations of fluorine upto 1.0 mg/L in drinking water help to prevent dental cavities in children. During formation of permanent teeth, fluoride combines chemically with tooth animal resulting in harder, stronger teeth that are more resistant to decay. When concentration of fluorides exceed 2.2 mg/L, it results in discoloration of teeth called mottling. Excess fluorides also results in bone fluorosis and other skeleton abnormalities.

4.35 (b)

$pOH = -\log[OH^-]$

where $[OH^-]$ is concentration of OH^- ions in moles per litre

$$\text{Moles} = \frac{\text{Weight in gm}}{\text{Molecular mass}} = \frac{17\times10^{-3}}{17}$$

$\therefore$ Moles of $OH^- = 10^{-3}$

$\therefore$ $pOH = -\log[10^{-3}]$

$\Rightarrow$ $pOH = 3$

But $pH + pOH = 14$

$\Rightarrow$ $pH = 14 - 3$

$\Rightarrow$ $pH = 11$

4.36 (b)

The equation for the total oxidation of glucose is as follows:

$$\underset{180\ g}{C_6H_{12}O_6} + \underset{192\ g}{6O_2} \longrightarrow \underset{264g}{6CO_2} + \underset{108g}{6H_2O}$$

$\because$ 180 g of glucose require 192 g of oxygen for complete oxidation

$\therefore$ Requirement of oxygen for 300 mg of glucose

$$= 300 \times \frac{192}{180} = 320 \text{ mg}$$

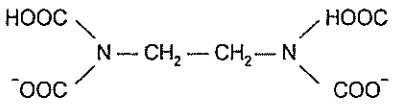
Thus the theoretical oxygen demand of 300 mg/L of glucose solution in 320 mg/L.

4.37 (a)

The ions involved in water hardness, i.e. $Ca^{2+}(aq)$ and $Mg^{2+}(aq)$, can be determined by titration with a chelating agent, ethylene diamine tetra acetic acid (EDTA), usually in the form of disodium salt (H_2Y^{2-}).

The titration reaction is:

$$Ca^{2+}(aq) + H_2Y^{2-}(aq) \longrightarrow CaY^{2-}(aq) + 2H^{+}(aq)$$



EDTA (anionic form)

Eriochrome Black T is commonly used as indicator for the above titration. The end point of titration is indicated by a sharp colour change from wine red to blue. Titration using Eriochrome Black T as indicator determines total hardness due to $Ca^{2+}(aq)$ and $Mg^{2+}(aq)$ ions. Hardness due to $Ca^{2+}(aq)$ ion is determined by a separate titration at a higher pH, by adding NaOH solution to precipitate $Mg(OH)_2(s)$, using hydroxynaphthol blue as indicator.

4.38 (d)

JTU: Jackson turbidity unit is a unit of measure turbidity on silica scale. Other turbidity units are NTU (Nephelometric turbidity unit) and FTU (Formazin Turbidity unit.

The extent of taste or odour present in a particular sample of water is measured by a term called odour intensity, which is related with the threshold odour. The threshold odour or threshold odour number, as it is generally called, represents the dilution ratio at which the odour is hardly detectable. MPN (Most Probable Number) is an index to measure the coliforms in the total water sample.

4.39 (a)

Fluorine upto (1 mg/*l* to 1.5 mg/*l*) is required for the growth of permenant teeth and to prevent dental cavity. If it is more than 1.5 mg/*l* it causes decolourisation of the teeth and result in its mottling (a disease called flourisis).

4.40 (a)

Ferroin sulfate or ferroin indicator is prepared by combining Phenanthraline to Ferrous sulphate in water. If is used for detecting COD.

4.41 (b)

The safe maximum limits in domestic water supply are:

Sulphates <= 200 mg/*l*
Chlorides <= 250 mg/*l*
Fluorides <= 1.5 mg/*l*
Nitrates <= 45 mg/*l*

4.42 (d)

Jackson's Turbidity Unit (JTU) is equal to the turbidity produced by 1 mg SiO_2 in 1 L of distilled water. Formazin, a chemical compound, provides more reproducible standards than SiO_2 and has replaced it as a reference. The term Nephelometre Turbidity Units (NTU) is often used to indicate that the test was run according to the scattering principle.

4.43 (c)

Flouride concentration of less than 0.8 – 1 ppm may be harmful and may cause dental caries due to formation of excessive cavities in the teeth of young children during calcination of their permanent teeth.

4.44 (d)

Virusus are the smallest biological structure, containing all information necessary for its reproduction. They are obligate parasites, and as such, require a host in which to live.

4.45 (a)

Specific conductance and concentration of TDS are not related on one-to-one basis, only ionized substances contribute to specific conductance. Organic molecules and compounds that dissolve without ionizing are not measured. Additionally, the magnitude of specific conductance is influenced by the valancy of the ions in solution, there mobility and relative numbers.

4.46 (c)

The alkalinity present in water may be of mineral origin. It may be present due to atmospheric carbon dioxide mixed in water or due to microbial decomposition of organic matter.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$$

Last reaction is a weak reaction but utilization of bicarbonate by algae drives the reaction to the right and hence sufficient accumulation of $[OH^-]$ takes place. Hence if algae is present in water, it becomes alkaline.

4.47(d)

In EDTA method, water is titrated with ethylene diamene tetra acetic acid using EBT (Erichrome black T) as indicator. EBT forms red colour with water and titration changes the colour to blue.

4.48(c)

Alkalinity in natural water is measured by titrating the water sample with 0.02 N H_2SO_4 using phenolphthalein and methyl orange indicators.

4.49(a)

An approximate analysis of TDS is after made by determining the electrial conductivity of water. The ability of water to conduct electricity is known as specific conductance is a function of its ionic strength.

4.51 (c)

The Winkler Method is a technique used to measure dissolved oxygen in fresh water systems. It uses titration to determine dissolved oxygen in the water sample.

Reagent List:

- 2 ml Manganese sulphate
- 2 ml alkali-iodide-azide
- 2 ml concentrated sulfuric acid
- 2 ml starch solution
- Sodium thiosulfate

Procedure:

1. A 300-mL glass Biological Oxygen Demand (BOD) stoppered bottle is filled till brim with sample water.
2. Manganese sulphate is added to the collection bottle by inserting the calibrated pipette just below the surface of the liquid.
3. Alkali-iodide-azide reagent is also added in the same manner.
4. The sample is mixed by inverting it several times. If oxygen is present, a brownish-orange cloud of precipitate or floc will appear.
5. Then concentrated sulfuric acid is added. At this point, the sample is "fixed" and can be stored for up to 8 hours if kept in a cool, dark place.
6. This sample is then titrated with sodium thiosulfate to a pale straw color.
7. Then starch solution is added so a blue color forms.
8. Titration is done until the sample turns clear.
9. The concentration of dissolved oxygen in the sample is equivalent to the number of milliliters of titrant used. Each mL of sodium thiosulphate added in steps 6 and 8 equals 1 mg/L dissolved oxygen.

4.52 (c)

Typhoid fever is caused by bacteria not by viral infection where as infectious hapatitis is caused by virus not by bacteria.

4.53 (c)

Carbonate ions (CO_3^{2-}) react with water (H_2O)to form bicarbonate ions (HCO_3^-) & Hydroxide ions (OH^-).

In case of algae presence in water, it utilizes bicarbonate ions (HCO_3^-). On depletion of bicarbonate ions (HCO_3^-), more Hydroxide ions (OH^-) will be produced thereby increasing the alkalinity of water.

4.54 (c)

Environment includes the following two factors:

1. **Abiotic** factors refer to non-living physical and chemical elements in the ecosystem. Abiotic resources are usually obtained from the lithosphere, atmosphere, and hydrosphere. Examples of abiotic factors are water, air, soil, sunlight, and minerals.
2. **Biotic** factors are living or once-living organisms in the ecosystem. These are obtained from the biosphere and are capable of reproduction. Examples of biotic factors are animals, birds, plants, fungi, and other similar organisms.

4.55 (c)

Carbonate hardness

$$= \text{Minimum of} \begin{cases} \text{Total hardness} \\ \text{Alkalinity} \end{cases}$$

Carbonate hardness is 50 mg/*l* and total hardness is 120 mg/*l*

∴ Alkalinity is 50 mg/*l*

and, Non-carbonate hardness

= Total hardness – carbonate hardness

= (120 – 50) mg/*l* = 70 mg/*l*

4.57 (c)

During an epidemic of infective hepatitis, the supplied water is super chlorinated because of avoidance of future contamination but the spore forming bacteria, which can survive with nutrients, are resistant to ultraviolet radiation, desiccation, high temperature, extreme freezing and chemical disinfectants.

4.58 (a)

The D.O. content of sewage is generally determined by the Winkler's method which is an oxidation-reduction process carried out chemically to liberate iodine in amount equivalent to the quantity of dissolved oxygen originally present. In this test, sodium thiosunphate is using as reagent and soluble starch as an indicator.

4.59 (b)

Dracontiasis, more commonly known as Guinea worm disease, is a preventable infection caused by the parasite Dracunculus medinensis. Infection affects poor communities in remote parts of Africa that do not have safe water to drink.

4.60 (b)

The EC of a solution is a measure of its ability to carry an electric current; the more dissolved ionic solutes in a water, the greater its electrical conductivity.

$$\left(EC\left(p\frac{\text{mho}}{\text{cm}}\right)\text{at } 25°C\right) \times 0.65 = \text{TDS}(\text{mg}/l)$$

4.61 (c)

$$[OH^-] = 10^{-5.6} \text{ mmole/lt.}$$
$$= 10^{-5.6} \times 10^{-3}$$
$$= 10^{-8.6} \text{ moles/lt.}$$
$$p[OH^-] = -\log[OH^-] = -\log[10^{-8.6}] = 8.6$$
$$pH + pOH = 14$$
$$\Rightarrow \quad pH = 14 - 8.6 = 5.4$$

4.62 (c)

Recarbonation of water softened by lime-soda. Process results in increased hardness of water because in this method precipitate are again made soluble in water. $CaSO_4$ and $MgSO_4$ are dissolved solids not suspended solids.

4.63 (c)

The Mohr method uses silver nitrate for titration. This corresponds to 1 m*l* of 0.0141 equals to 1 mg chloride in solution. The silver nitrate solution is standardized against standard chloride solution, prepared from sodium chloride (NaC*l*). During the titration, chloride ion is precipitated as white silver chloride.

$$Ag^+ + Cl^- \rightleftharpoons AgCl$$

The potassium chromate as indicator is added to visualize the endpoint, demonstrating presence of excess silver ions. In the presence of excess silver ions, solubility product of silver chromate exceeded and it forms a reddish-brown precipitate. This stage is taken as evidence that all chloride ions have been consumed and only excess silver ions have reacted with chromate ions.

$$2Ag^+ + CrO_4^{2-} \rightleftharpoons Ag_2CrO_4$$

■■■■

5 Water Treatment & Distribution System

5.1 The following residual chlorine compounds are formed during chlorination of water:

1. NH_2Cl 2. $NHCl_2$
3. HOCl 4. OCl^-

The correct sequence of formation of these residual chlorine compounds is

(a) 2, 1, 3, 4 (b) 1, 2, 4, 3
(c) 1, 2, 3, 4 (d) 2, 1, 4, 3

[ESE : 1995]

5.2 Match List-I (Type of water source) with List-II (Treatment to be given) and select the correct answer using the codes given below the lists:

List-I

A. Surface water (river or canal)
B. Water from infiltration gallery
C. Lake/pond water
D. Tube well water

List-II

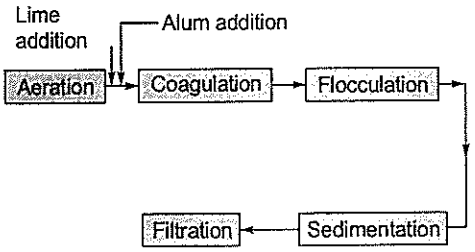
1. Aeration, coagulation, sedimentation and disinfection
2. Disinfection
3. $CuSO_4$ treatment, coagulation, sedimentation, filtration and disinfection
4. Coagulation, flocculation, sedimentation, filtration and disinfection

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	1	4	3	2
(c)	1	4	2	3
(d)	4	1	2	3

[ESE : 1995]

5.3 The flow chart of water treatment plant is shown in the following figure. If it is proposed to defluoridate the water using 'Nalgonda treatment' then it should be done



(a) after adjusting the dose of lime and alum
(b) after sedimentation
(c) after filtration
(d) before aeration

[ESE : 1995]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.4 Assertion (A): Tapered flocculation is more efficient when compared to the conventional process of flocculation.

Reason (R): In tapered flocculation, velocity gradient at the inlet is less than that at the outlet of the flocculation unit.

[ESE : 1995, 1996]

5.5 Assertion (A): Presence of E.Coli bacteria in water indicates that the water is polluted with fecal discharge.

Reason (R): E.Coli is a pathogenic bacteria.

[ESE : 1996]

5.6 Which of the following treatment reduce salinity of water?
1. Flash mixing and sedimentation
2. Electrodialysis
3. Reverse osmosis
4. Freezing
5. Filtration

Select the correct answer using the codes given below:
(a) 1, 2, 3, 4 and 5 (b) 2, 3 and 4
(c) 1, 3 and 5 (d) 1, 2 and 4

[ESE : 1996]

5.7 The cleaning of slow sand filter is done by
(a) reversing the direction of flow of water
(b) passing air through the filter
(c) passing a solution of alum and lime through the filter
(d) scraping off top layers of sand and admitting water

[ESE : 1996]

5.8 What is the correct sequence of formation of the following compounds during chlorination of water in which ammonia is present?
1. NCl_3 2. NH_2Cl
3. $NHCl_2$

Select the correct answer using the codes given below:
(a) 1, 2, 3 (b) 2, 3, 1
(c) 3, 1, 2 (d) 2, 1, 3

[ESE : 1996]

5.9 Match List-I (Name of impurity in water) with List-II (Removed by) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Fluorides	1. Activated carbon
B. Manganese	2. Activated alumina
C. Taste and odour	3. Manganese zeolite

Codes:

	A	B	C
(a)	1	2	3
(b)	2	3	1
(c)	2	1	3
(d)	3	2	1

[ESE : 1996]

5.10 Which of the following statements about design period are true?
1. It is concerned with economy of investments.
2. It takes into account aspects like life and durability and ease or difficulty in capacity increase of installations.
3. It considers the frequency of occurrence of extremes of river flow.
4. It is concerned with estimating future requirements.

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 2 and 3
(c) 1, 2, and 4 (d) 1, 3 and 4

[ESE : 1997]

5.11 A river is the source of water for water supply to a town. Its water is very turbid and polluted. The correct sequence of steps for treating the river water would be
(a) pre-sedimentation → pre-chlorination → coagulation → sedimentation → filtration → post chlorination
(b) coagulation → sedimentation → post-chlorination
(c) coagulation → filtration → sedimenta-tion → post-chlorination
(d) sedimentation → post-chlorination

[ESE : 1997]

5.12 Uniformity coefficient of filter sand is given by
(a) $\frac{D_{50}}{D_5}$ (b) $\frac{D_{50}}{D_{10}}$
(c) $\frac{D_{60}}{D_5}$ (d) $\frac{D_{60}}{D_{10}}$

[ESE : 1997]

5.13 Which of the following statement is/are true in relation to the term 'detention period' in a settling tank?
1. It may be determined by introducing a dye in the inlet and timing its appearance at the outlet.
2. Greater the detention period, greater the efficiency of removal of settleable matter.
3. It is the time taken for any unit of water to pass through the settling basin.
4. It is usually more than the flowthrough period.

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 2, 3 and 4
(c) 1 and 3 (d) 4 alone
[ESE : 1997]

5.14 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Dead-end system
B. Grid-iron system
C. Ring system
D. Radial system

List-II
1. Equal pressures and multiple flow paths
2. Both economy and reasonably equal pressures
3. Economy and simplicity
4. Zonal distribution

Codes:

	A	B	C.	D
(a)	3	2	1	4
(b)	2	4	1	3
(c)	3	1	2	4
(d)	2	1	4	3

[ESE : 1997]

5.15 Which of the following treatment(s) will be indicated for a rural water supply from a deep ground water source?
1. Sedimentation
2. Alum dosage
3. Potassium permanganate dosing
4. Bleaching powder application

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 3 and 4 (d) 4 alone
[ESE : 1997]

5.16 Which of the following pairs is/are correctly matched?
1. Eutrophication... Nutrient accumulation leading to ecosystem change occurring in impounded water
2. Autotrophism... Utilization, rearrange-ment and decom-position of complex materials predominate
3. Heterotrophism... Predominance of fixation of light energy, use of simple inorganic substances and built-up of complex substances

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1 alone
(c) 2 and 3 (d) 1 and 3
[ESE : 1997]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.17 **Assertion (A):** Ozone is not widely used in community water supplies.
Reason (R): It is not possible to maintain residual concentrations of ozone in water after the disinfection process.
[ESE : 1998]

5.18 **Assertion (A):** In the case of dual media filter, the rate of filtration is more than that of rapid sand filter.
Reason (R): The direction of flow is from fine medium to coarse medium.
[ESE : 1998]

5.19 **Assertion (A):** Chlorides should be absent in drinking water.
Reason (R): Chlorides give salty taste to water.
[ESE : 1998]

5.20 Air-binding in rapid sand filters is encountered when
(a) there is excessive negative head
(b) the water is subjected to prolonged aeration
(c) the raw water contains dissolved gases
(d) the filter bed comprises largely of coarse sand
[ESE : 1998]

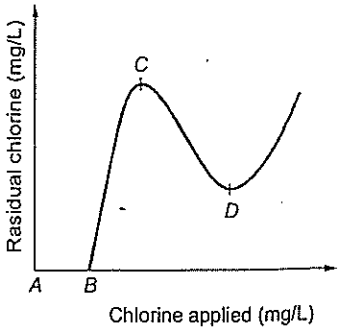
5.21 In a water treatment plant, dissolved iron and manganese can be removed from the water by
(a) aeration
(b) aeration and coagulation
(c) aeration and flocculation
(d) aeration and sedimentation
[ESE : 1998]

5.22 The various treatment processes in a water treatment plant are listed below:
1. Filtration 2. Chlorination
3. Sedimentation 4. Coagulation
5. Flocculation
The correct sequence of processes in water treatment is
(a) 1, 2, 3, 4, 5 (b) 4, 5, 3, 1, 2
(c) 2, 3, 1, 5, 4 (d) 1, 2, 5, 3, 4
[ESE : 1998]

5.23 The effective size (ES) of sand and its uniformity coefficient (UC) are the usually specified parameters for sand filters. In slow sand filters, as compared to rapid sand filters,
(a) ES is less but UC is more
(b) ES is more but UC is less
(c) both ES and UC are more
(d) both ES and UC are less
[ESE : 1998]

5.24 For proper slow mixing in the flocculator of a water treatment plant, the temporal mean velocity gradient G needs to be of the order of
(a) 5 to 10 s^{-1} (b) 20 to 80 s^{-1}
(c) 100 to 200 s^{-1} (d) 250 to 350 s^{-1}
[ESE : 1998]

5.25 If only ammonia was present in water, the only change in the diagram below would have been that the curve would



(a) be a straight line
(b) become parallel to Y-axis
(c) become parallel to X-axis after D
(d) be passing through the origin
[ESE : 1998]

5.26 Which one of the following is the purpose of providing a surge tank in a pipeline carrying water?
(a) To store water
(b) To increase the pressure throughout the pipeline
(c) To store overflowing water
(d) To protect the pipeline against water hammer
[ESE : 1998]

5.27 Match List-I (Water treatment units) with List-II (Detention time) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Rapid mixing unit	1. 1.5 hours
B. Flocculator	2. 10 seconds
C. Propeller mixing unit	3. 30 seconds
D. Sedimentation tank	4. 30 minutes

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	1	2
(c)	4	3	2	1
(d)	3	4	1	2

[ESE : 1998]

5.28 Match List-I (Nature of the solids) with List-II (Unit operation or process connected with its removal) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Dissolved solids	1. Sedimentation
B. Colloidal solids	2. Reverse osmosis
C. Volatile solids	3. Coagulation
D. Settleable solids	4. Digestion

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	3	2	4	1
(c)	2	3	1	4
(d)	3	2	1	4

[ESE : 1998]

5.29 Match List-I (Operational problems in rapid gravity filter) with List-II (Methods to overcome the problems) and select the correct answer using the codes given below the lists:

List I

A. Incrustation of filter sand media
B. Air binding and development of negative head
C. Mud ball formation
D. Slime growth on filter

List II

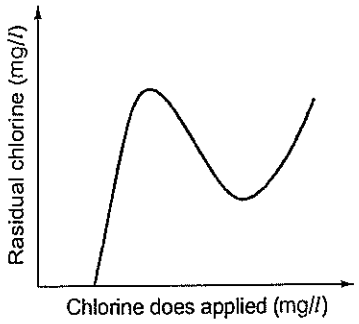
1. Compressed air scouring for about 4 minutes at the time of backwashing and manual surface raking
2. Washing the filter with sodium hydroxide or bleaching powder occasionally
3. Thorough backwashing with salt solution after soaking the filter in it
4. Increasing the depth of water during filter operation by about 15-20 cm as compared to the normal depth maintained during daily operation and more frequent backwashing

Codes:

	A	B	C	D
(a)	2	4.	3	1
(b)	4	2	1	3
(c)	2	4	1	3
(d)	4	2	3	1

[ESE : 1999]

5.30 In the plot of residual chlorine dose applied shown in the figure below, the curve will not have any (0, 0) point because



(a) of experimental error
(b) chlorine escapes into the atmosphere
(c) chlorine requires some contact time
(d) chlorine is consumed for disinfection

[ESE : 1999]

5.31 The correct sequence of processes in a water treatment plant for rural water supply is

(a) chlorination, aeration, sedimentation, rapid sand filter
(b) coagulation, sedimentation, slow sand filter, chlorination
(c) coagulation, flocculation, clarification, pressure filter
(d) aeration, plain sedimentation, slow sand filter, chlorination

[ESE : 1999]

5.32 The purpose of a proportional weir at the effluent end of a channel type grit removal unit is to

(a) provide easy passage of solid particles
(b) measure the rate of flow in the channel
(c) keep the depth of flow in the channel above a certain value
(d) maintain constant mean velocity in the channel

[ESE : 1999]

5.33 Assertion (A): At the ferrule point of a water supply distribution pipe network for Indian towns having a majority of two-storey buildings, the ideal minimum pressure head of water is 12 m.

Reason (R): This magnitude of pressure head at ferrule is necessary to reach the highest floor of the two storey buildings.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

5.34 A rural water supply scheme serves a population of 10,000 at the rate of 50 litres per capita per day. For the chlorine dose of 2 ppm, the required amount of bleaching powder with 20% available chlorine will be

(a) 0.5 kg (b) 5 kg
(c) 10 kg (d) 15 kg

[ESE : 2000]

5.35 The raw water entering an ideal horizontal settling tank contains following two types of particles:

Particle type	Settling velocity (m/h)	Concentration (mg/L)
I	3	200
II	1	300

When the surface overflow rate of the settling tank is 3 $m^3/m^2/h$, the concentration of the particles in the settled water will be

(a) 100 mg/L (b) 200 mg/L
(c) 300 mg/L (d) 400 mg/L

[ESE : 2000]

5.36 Which one of the following filters will produce water of higher bacteriological quality?

(a) Slow sand filter
(b) Rapid sand filter
(c) Pressure filter
(d) Dual media filter

[ESE : 2000]

5.37 **Assertion (A):** Break-point chlorination is required to ensure free chlorine residuals for better disinfection.

Reason (R): Free chlorine residuals have good disinfecting power and they are usually dissipated quickly in the distribution system.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

5.38 Match List-I (Unit in water treatment plant) with List-II (Impurities removed) and select the correct answer using the codes given below the lists:

List-I

A. Aerator
B. Rapid sand filter
C. Slow sand filter
D. Sedimentation tank (after coagulation and flocculation)

List-II

1. Excess CO_2 and H_2S
2. Settleable and colloidal mater
3. Suspended matter
4. Suspended, colloidal and bacterio-logical matter

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	3	1	2	4
(c)	3	1	4	2
(d)	1	3	4	2

[ESE : 2001]

5.39 Consider the following impurities:

1. CO_2 and H_2S
2. Finely-divided suspended matter
3. Disease causing bacteria
4. Excess alkalinity

The correct sequence of the removal of these impurities in a water treatment plant is

(a) 1, 2, 3, 4 (b) 1, 4, 3, 2
(c) 1, 4, 2, 3 (d) 4, 1, 3, 2

[ESE : 2001]

5.40 Which of the following are the common problems associated with the operation of rapid sand-filter?

1. Air binding
2. Cracking of sand beds
3. Bumping of filter beds
4. Mud balls

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 2 and 3
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

[ESE : 2001]

5.41 The purpose of providing a balancing reservoir in a water supply distribution system is to

(a) equalize pressures in the distribution system
(b) store adequate quantity of water to meet requirements in case of break-down of inflow
(c) store adequate fire fighting reserve
(d) take care of fluctuations in the rate of consumption.

[ESE : 2001]

5.42 Which of the following statements regarding industrial water supply is/are correct?

1. Industrial water supplies need not be disinfected.
2. Water for industrial use requires chemical treatment.
3. Standards of purity and methods of treatment of water or industrial use are often different from those for domestic water supplies.
4. It is more economical to use water from surface sources than groundwater sources for industrial water supplies.

Select the correct answer using the codes given below:

(a) 1, 2 and 4 (b) 2, 3 and 4
(c) 3 and 4 (d) 3 only

[ESE : 2001]

5.43 Match List-I (Different forms of nitrogen in water) with List-II (Inferences) and select the correct answer using the codes given below the lists:

List-I
A. Nitrate nitrogen
B. Total nitrogen
C. Nitrite nitrogen
D. Ammonia nitrogen

List-II
1. Unsatisfactory microbial activity
2. Satisfactory microbial activity
3. Eutrophication may result
4. Recent organic pollution

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	1	4	3	2
(c)	3	4	1	2
(d)	1	2	3	4

[ESE : 2002]

5.44 'Air binding' may occur in
(a) Sewers (b) Artesian well
(c) Aerator (d) Filter

[ESE : 2002]

5.45 The purpose of re-carbonation after lime-soda process of water softening is the
(a) removal of excess soda from water
(b) removal of non-carbonate hardness
(c) recovery of lime
(d) conversion of precipitates to soluble form

[ESE : 2003]

5.46 Which of the following treatment processes are necessary for removing suspended solids from water?
1. Coagulation 2. Flocculation
3. Sedimentation 4. Disinfection
Select the correct answer using the codes given below:
(a) 1 and 2 (b) 1, 2 and 3
(c) 2 and 4 (d) 1 and 4

[ESE : 2003]

5.47 Match List-I (Filter operating problems) with List-II (Effects) and select the correct answer using the codes given below the lists:

List-I
A. Air binding
B. Mud deposition
C. Cracking of bed
D. Sand incrustation

List-II
1. Changes effective size of sand
2. Mud penetrates deeper inside the bed
3. Mounds and balls of mud are formed in the bed
4. Air and gases get locked in the bed

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	1	2
(c)	4	3	1	2
(d)	3	4	2	1

[ESE : 2003]

5.48 Which of the following are removed by rapid sand filter from water?
1. Dissolved solids 2. Suspended solids
3. Bacteria 4. Helminths
Select the correct answer using the codes given below:
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 2, 3 and 4

[ESE : 2003]

5.49 If the specific gravity of a suspended particle is increased from 2 to 3, the settling velocity will
(a) not change
(b) get doubled
(c) get increased by 1.5 times
(d) get increased by 2.25 times

[ESE : 2004]

5.50 Which one of the following filters should be recommended for protected rural water supply project?
(a) pressure filter
(b) slow sand filter
(c) diatomaceous earth filter
(d) rapid sand filter

[ESE : 2004]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two

statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.51 **Assertion (A):** The fluoride content in drinking water should neither be too low nor too high.
Reason (R): Deficiency of fluoride content causes mottling of teeth and its excess causes dental cavities in children.

[ESE : 2004]

5.52 **Assertion (A):** The settling velocity of a discrete particle will become five times when its diameter doubles.
Reason (R): The settling velocity of a discrete particle is almost proportional to the square of the particle diameter.

[ESE : 2004]

5.53 Which one of the following is a not a specific criterion for calculating surface overflow rate in sedimentation tank design?

(a) Total quantity of water to be treated
(b) Total surface area available in the tank
(c) Total length of the tank
(d) Total depth of the tank

[ESE : 2004]

5.54 Which of the following remedial measures are taken to avoid negative head and air binding in a rapid sand filter?

1. Avoiding the occurrence of excessive negative head
2. Pumping in air
3. Avoiding increase in water temperature
4. Control of algae growth

Select the correct answer using the codes given below:

(a) 1, 3 and 4 (b) 2, 3 and 4
(c) 1 and 2 (d) 1, 2, 3 and 4

[ESE : 2004]

5.55 Consider the following statements:
Aeration in water treatment helps in

1. killing pathogens
2. correcting pH
3. precipitating dissolved iron and manganese
4. expelling excess CO_2 and H_2S
5. expelling volatile oils

Which of these statements are correct?

(a) 2, 4 and 5 (b) 3, 4 and 5
(c) 1, 2, 3 and 5 (d) 1, 2, 3 and 4

[ESE : 2004]

5.56 **Assertion (A):** A small quantity of ammonia is added to water before carrying out disinfection using chlorine.
Reason (R): Chloramines are persistent disinfectants, which provide continued protection against regrowth of micro-organisms in a water distribution system.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2005]

5.57 Match List-I (Equation/Law) with List-II (Related Application) and select the correct answer using the codes given below the lists:

List-I

A. Chick's law
B. Darcy-Weisbach equation
C. Stoke's equation
D. Carmen-kozeny equation

List-II

1. Discrete particle settling
2. Head loss in a pipe
3. Head loss in filters
4. Rate of bacterial kill

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	3	1	2	4
(c)	4	1	2	3
(d)	3	2	1	4

[ESE : 2005]

5.58 A flash mixer of 2.0 m^3, with a velocity gradient of mixing mechanism equal to 600 s^{-1}, and fluid absolute viscosity of 1.0×10^{-3} N-s/m^2 is continuously operated. What is the power input per unit volume?

(a) 360 W (b) 720 W
(c) 1440 W (d) 300 W

[ESE : 2005]

5.59 Consider the following statements:
In water supply distribution network,
1. the grid-iron system requires more length of pipe lines and larger number of cut-off valves.
2. the design of the grid-iron system is difficult but economical.
3. employing a grid iron system, the dead ends are completely eliminated.
4. employing a grid-iron system permits more water to be diverted towards the affected point from various directions.

Which of these statement are correct?
(a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 3

[ESE : 2005]

5.60 Which one of the following types of settling phenomenon can be analyzed by the classic sedimentation laws of Newton and Stokes?
(a) Discrete settling
(b) Flocculent settling
(c) Hindered settling
(d) Compression settling

[ESE : 2005]

5.61 Match List-I (Treatment process) with List-II (Removed matter) and select the correct answer using the codes given below the lists:

List-I
A. Plain sedimentation
B. Chemical precipitation
C. Slow Sand Filtration
D. Aeration

List-II
1. Dissolved gases
2. Dissolved solids
3. Suspended solids with specific gravity more than 1.0.
4. Floating solids
5. Bacterial cells

Codes:

	A	B	C	D
(a)	5	1	4	2
(b)	3	2	5	1
(c)	5	2	4	1
(d)	3	1	5	2

[ESE : 2005]

5.62 Among the following, which is/are not pre-treatment unit(s)?
(a) Bar-screen and grit chamber
(b) Flow equalization and proportioning tank
(c) Neutralization for pH adjustment tank
(d) Nutrient removal tank

[ESE : 2005]

5.63 According to the theory of filtration in water treatment, which of the following mechanisms come into play when water is filtered through a filter bed?
1. Mechanical straining
2. Capillary action
3. Centrifugal force
4. Electro-kinetic phenomenon
5. Osmotic force
6. Bacteriological action

Select the correct answer using the codes given below:
(a) 1, 2, 4 and 6 (b) 2, 3 and 5
(c) 3, 4, 5 and 6 (d) 1, 3, 4 and 6

[ESE : 2005]

5.64 A standard multiple-tube fermentation test was conducted on a sample of water. The results of the analysis for the confirmed test are given below:

Sample Size (mL)	No. of positive results out of 5 tubes	No. of negative results out of 5 tubes
10	4	1
1	2	3
0.1	1	4
0.01	0	5

MPN Index for combinations of positive results when 5 tubes used per dilutions (10 mL, 1.0 mL, 0.1 mL)

Combination of positives	MPN Index per 100 mL
5-4-3	280
4-3-1	33
4-2-1	26
2-1-0	7

Using the above MPN Index table, what is the most probable number (MPN) of the sample?
(a) 280 (b) 33
(c) 26 (d) 70

[ESE : 2006]

5.65 Chlorides from water are removed by
(a) Lime soda process
(b) Reverse osmosis
(c) Cation exchange process
(d) Chemical coagulation
[ESE : 2006]

5.66 In which treatment unit is *Schmutzdecke* formed?
(a) Sedimentation tank
(b) Rapid sand filter
(c) Coagulation tank
(d) Slow sand filter
[ESE : 2006]

5.67 Which one of the following chemicals is employed for dechlorination of water?
(a) Sodium sulphite
(b) Sodium bicarbonate
(c) Calcium carbonate
(d) Hydrogen peroxide
[ESE : 2006]

5.68 Which one of the following is the correct sequence of slow sand filter (SSF), rapid sand filter (RSF), dual media filter (DMF) and mixed media filter (MMF) in the decreasing order of their filtration rates?
(a) MMF ≈ DMF > RSF > SSF
(b) DMF > RSF > SSF > MMF
(c) RSF > SSF > MMF ≈ DMF
(d) SSF > MMF ≈ DMF > RSF
[ESE : 2006]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.69 **Assertion (A):** Flocculating particles settle in a curved path in a long rectangular sedim-entation tank designed for a constant flow rate.
Reason (R): The downward settling velocities of particles as well as their respective horizontal velocities remain constant during their stay in the tank.
[ESE : 2006]

5.70 **Assertion (A):** Large weir overflow rates will result in excessive velocities at the outlet of a settling basin.
Reason (R): These excessive velocities will extend backward into the settling zone, causing particles and flocs which would otherwise be removed as sludge to be drawn into the outlet.
[ESE : 2006]

5.71 Match **List-I** (Disinfectant) with **List-II** (Property) and select the correct answer using the codes given below the lists:
List-I
A. Chlorine
B. Ozone
C. Iodine
D. Ultra-violet rays
List-II
1. No carcinogenics results
2. Ineffective in the presence of suspended solids
3. Not affected by the Ammonium ion
4. Feasible residual oxygen
Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	1	2	4	3
(c)	4	2	1	3
(d)	1	3	4	2

[ESE : 2007]

5.72 What is the predominating coagulation mechanism for raw water having high turbidity and high alkalinity?
(a) Ionic layer compression
(b) Adsorption and charge neutralization
(c) Sweep coagulation
(d) Inter particle bridging
[ESE : 2007]

5.73 **Assertion (A):** A discrete particle (of diameter d_0) settling in a circular sedimentation tank follows a parabolic path.

Reason (R): The downward settling velocity (v_0) of the discrete particle (of diameter d_0) in a circular sedimentation tank does not change with time.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2007]

5.74 Match List-I (Predominance of compounds) with List-II (pH range) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Monochloramine	1. Below pH 4.4
B. Dichloramine	2. Over pH 7.5
C. Nitrogen trichloride	3. Between pH 5 to 6.5

Codes:

	A	B	C
(a)	1	2	3
(b)	2	3	1
(c)	3	1	2
(d)	3	2	1

[ESE : 2008]

5.75 Which one of the following can fix atmospheric nitrogen?

(a) Green algae (b) Blue green algae
(c) Red algae (d) Brown algae

[ESE : 2008]

5.76 What is the most important design parameter used in designing a continuous flow rectangular sedimentation tank for removal of discrete particles?

(a) Length of the tank
(b) Surface overflow rate
(c) Depth of the tank
(d) Temperature of the water to be treated

[ESE : 2009]

5.77 Which combination of surface water quality parameters will indicate sweep coagulation as the preferred mechanism of coagulation?

(a) High turbidity–low alkalinity
(b) High turbidity–high alkalinity
(c) Low turbidity–high alkalinity
(d) Low turbidity–low alkalinity

[ESE : 2009]

5.78 Which one of the following processes of water softening requires recarbonation?

(a) Lime-soda ash process
(b) Hydrogen-cation exchanger process
(c) Sodium-cation exchanger process
(d) Demineralization

[ESE : 2009]

5.79 Consider the following treatment process units in a water treatment plant:

1. Coagulation 2. Disinfection
3. Sedimentation 4. Filtration

Which is the correct sequence of the process units in the water treatment plant?

(a) 2–4–3–1 (b) 1–4–3–2
(c) 2–3–4–1 (d) 1–3–4–2

[ESE : 2009]

5.80 The correct sequence of treatment of typical turbid surface water is

(a) flocculation, coagulation, sedimentation, filtration
(b) flocculation, coagulation, filtration, sedimentation
(c) coagulation, flocculation, filtration, sedimentation
(d) coagulation, flocculation, sedimentation, filtration

[ESE : 2010]

5.81 Consider the following statements:

The appropriate method(s) for removal of fluorides from water comprise

1. addition of alum and lime followed by clarification.
2. passing through beds of activated alumina.

Which of these statements is/are correct?

(a) Neither 1 nor 2 (b) Both 1 and 2
(c) 1 only (d) 2 only

[ESE : 2010]

5.82 Consider the following statements:

In water treatment, the addition of chlorine inactivates the cells of pathogenic bacteria through

1. penetration of the chlorine species through the cell walls.
2. suffocation of the cells.
3. reaction of the chlorine species with the enzyme system of the cells.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2010]

5.83 In a water treatment, the optimum time of flocculation is usually given as 30 minutes. In case the time of flocculation is increased beyond this value, the flocs will
(a) become heavy and settle down in flocculation itself
(b) entrap air and will float in the sedimentation tank
(c) break up and defeat the purpose of flocculation
(d) stick to the paddles
[ESE : 2010]

5.84 Assertion (A): Break point chlorination ensures a residual of free available chlorine.
Reason (R): A super high chlorine dose inactivates the pathogens in a very short time.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2010]

5.85 If organic sources of carcinogenic compounds in water persist even after chlorination, then what is the correct sequence among treatment processes listed below if all these are considered compulsory?
1. Coagulation
2. Sedimentation
3. Filtration in general
4. Activated carbon bed filtration
5. Flocculation
6. Chlorination
(a) 4-5-3-2-6 and 1 (b) 1-2-3-4-5 and 6
(c) 4-2-3-1-5 and 6 (d) 1-5-2-3-4 and 6
[ESE : 2011]

5.86 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Viruses in water
B. Depletion of oxygen
C. Excess nitrates in water
D. Excess fluorides in water

List-II
1. Parasite-based disease
2. Fish extinction
3. Methemeglobinemia
4. Mottling of teeth

Code:

	A	B	C	D
(a)	1	2	3	4
(b)	4	2	3	1
(c)	1	3	2	4
(d)	4	3	2	1

[ESE : 2011]

5.87 Consider the following statements:
The role of the gravel bed in a rapid sand filter is
1. To filter out large suspended matter.
2. To support the sand bed above it.
3. To prevent the escape of sand particles.
4. To uniformly distribute the backwash water.
5. To prevent algae growth.
Which of these statements are correct?
(a) 1, 2, 3, 4 and 5
(b) 2, 3 and 4 only
(c) 3, 4 and 5 only
(d) 1, 2 and 3 only
[ESE : 2011]

5.88 Consider the following statements:
The following factors relate to the process of coagulation
1. Percentage removal is higher when turbidity is more.
2. Addition of activated silica aids in the process of coagulation.
3. pH of water is an important consideration for selecting a coagulant.
Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2011]

5.89 Which of the following methods are employed for determination of free and combined chlorine residuals in water?

1. Starch-iodide method
2. Orthotolidine method
3. Amperometric titration method
4. SNORT method
5. DPD method

(a) 1, 2, 4 and 5 (b) 1, 2 and 3 only
(c) 3, 4 and 5 only (d) 2, 3 and 4 only

[ESE : 2011]

5.90 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

A. Primary sedimentation
B. Coagulation
C. Flocculation
D. Secondary sedimentation

List-II

1. Differential settling
2. Hindered settling
3. Charge neutralization
4. Growth of flocs
5. Flow-through velocity

Code:

	A	B	C	D
(a)	2	5	4	1
(b)	1	3	4	2
(c)	2	4	3	1
(d)	5	4	3	2

[ESE : 2011]

5.91 Which of the following operational problems relate to the functioning of rapid gravity filter?

1. Inadequate media comprising filter bed
2. Sludge bulking
3. Mud balls
4. Negative head
5. Incrustation of media

(a) 1, 3, 4 and 5 only (b) 1, 2, 3 and 4 only
(c) 2, 3, 4 and 5 only (d) 1, 3, 4 and 5

[ESE : 2011]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.92 **Assertion (A):** Disinfection is the last treatment given to water before it is supplied to consumers.
Reason (R): Any other treatment after disinfection may incidentally also contaminate the water.

[ESE : 2011]

5.93 **Assertion (A):** The bottom layers of water in a deep reservoir are usually not acceptable as raw water in a water supply system.
Reason (R): The bottom water layers may contain products of anaerobic degradation.

[ESE : 2011]

5.94 Consider the following statements:

1. Carbonate hardness is due to bicarbonates.
2. Non-carbonate hardness is due to sulphates and chlorides of Ca and Mg.
3. Both the hardnesses can be removed by lime-soda method.
4. Both the hardnesses can be removed by ion-exchange method.

Which of these statements are correct.

(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2012]

5.95 Which of the following reasons are responsible for adoption of post-chlorination of water?

1. Chlorine demand is reduced.
2. Possibility of taste and odour formation is reduced.
3. Possibility of carcinogenic compounds is reduced.
4. Chloramines are formed.

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1 and 4 only (d) 2, 3 and 4 only

[ESE : 2012]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

5.96 Statement-I : Chlorides are added to kill pathogens as a disinfection process in the treatment of water.
Statement-II : It forms hypochlorous acid to oxidize the organic compounds including bacteria.
[ESE : 2012]

5.97 Statement-I : An epidemic of infective hepatitis is transmitted by drinking contaminated water.
Statement-II : Since infective hepatitis is transmitted by bacteria, it can be controlled by filtration and disinfection of water.
[ESE : 2012]

5.98 Statement (I): Rapid sand filters consisting of carefully sieved sand on top of a bed of gravel will only filter particles larger than its pore size.
Statement (II): In addition to staining, adsorption, continued flocculation and sedimentation in the pore spaces help in particles removal mechanism.
[ESE : 2013]

5.99 Statement (I): Suspended as well as colloidal particulates are removed from water by addition of 25% alum dosage.
Statement (II): The optimum dosage of alum is determined by performing the 'Jar test'.
[ESE : 2013]

5.100 Statement (I): In a rectangular baffled channel, it is easy to alter the G value.
Statement (II): In a rectangular baffled channel, the baffles are rigidity built and so cannot undergo any change.
[ESE : 2013]

5.101 Which of the following statements are the important characteristics of a slow sand filter?
1. Cleaning of filter is done by scraping and sand removal.
2. Lack of pretreatment.
3. Greater efficiency of bacterial removal as compared to rapid sand filter.
4. Efficient in colour, taste and odour removal.
(a) 1, 2, 3 and 4 (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2 and 3 only
[ESE : 2013]

5.102 Which of the reasons given below favour the use of cast iron pipe for city water supply?
1. Strong in tension; and pipe of large diameter (up to 6 m) can be made.
2. Easy to make joints
3. Durable
4. Corrosion-resistant
(a) 1, 2, 3 and 4 (b) 2, 3 and 4 only
(c) 1, 2, and 4 only (d) 1, 3 and 4 only
[ESE : 2013]

5.103 A water treatment plant treats 6000 m^3 of water per day. If it consumes 20 kg chlorine per day, then the chlorine dosage would be
(a) 3.00 mg/l (b) 3.75 mg/l
(c) 4.25 mg/l (d) 3.33 mg/l
[ESE : 2014]

5.104 When a turbid stream flows into the ocean, the ionic content of the water increases drastically. This causes coagulation and settling which leads to formation of deposits (deltas). Such coagulation mechanism is called
(a) Adsorption and charge neutralization
(b) Interparticle bridging
(c) Ionic layer compression
(d) Sweep coagulation
[ESE : 2014]

5.105 A rapid sand filter for a town with water requirement of 1 MLD is to be provided with rate of filtration at 4000 l/hr/m^2, with backwash system. What would be the size of filter and its underdrainage system to the nearest approximation?
(a) 10 and 0.032 sq.m
(b) 11 and 0.022 sq.m
(b) 12 and 0.045 sq.m
(d) 15 and 0.062 sq.m
[ESE : 2014]

5.106 Consider the following statements in respect of injecting chlorine between rapid sand filter and storage tank:
1. More contact time is available.
2. Chlorine demand is reduced.
3. $NHCl_2$ is formed which is more effective than residual chlorine.
4. Break point chlorination takes place.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1 and 2 only (d) 3 and 4 only
[ESE : 2014]

5.107 What is the settling velocity of a discrete particle in a wide body of water when the relevant Reynold's number is less than 0.5? The diameter and specific gravity of the particle are 2×10^{-3} cm and 2.65, respectively. Water temperature is 20°C. (Kinematic viscosity = 2×10^{-2} cm²/sec)
(a) 0.018 cm/sec (b) 0.025 cm/sec
(c) 0.18 cm/sec (d) 0.25 cm/sec
[ESE : 2014]

5.108 If the length dimension of a square filter bed increase to two times (while the rate of filtration remains unchanged), the amount of water filtered would become
(a) 4 times (b) 2 times
(c) 1 time (d) 16 times
[ESE : 2014]

5.109 A certain water needs alum treatment to the extent of 10 p.p.m. How much alum, in quintals per day, would be needed to treat 10 MLD of water?
(a) 10 (b) 1.0
(c) 100 (d) 1000
[ESE : 2015]

5.110 10 MLD water is to be chlorinated in a clear water reservoir (CWR) with 0.8 mg/l chlorine dose with providing contact time of 40 minutes. The required CWR capacity is nearly
(a) 220 m³ (b) 280 m³
(c) 28 m³ (d) 22 m³
[ESE : 2015]

5.111 What is the rapid sand filter surface area required for filtering of 10 MLD water assuming a filtration rate of 100000 l/m²/day?
(a) 100 m² (b) 10 m²
(c) 1 m² (d) 1000 m²
[ESE : 2015]

5.112 Consider the following statements in respect of slow sand filter and rapid sand filter:
1. The two filters differ in respect of the standards regarding non-uniformity of the sand used in their filtering media.
2. The two filters do not differ in respect of the effective size of the sand used in them.
3. The two filters differ in respect of their respective under-drainage system.
4. The two filters differ in respect of their respective rate of filtration.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 1, 3 and 4
[ESE : 2015]

5.113 How many kg of bleaching powder is needed per day to chlorinate 4 MLD of water of so that, after 40 minutes of contact, there remains residual chlorine of 0.25 mg/l, and that the bleaching powder has only 25% available chlorine.
(a) 8 kg (b) 20 kg
(c) 24 kg (d) 6.5 kg
[ESE : 2015]

5.114 **Assertion (A):** Coagulation is the process of charge neutralization on colloids.
Reason (R): Flocculation is the process to grow the chargeless colloids into settleable flocs.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2015]

5.115 Consider the following statements regarding the overflow rate of a sedimentation tank:
1. Temperature of water affects the overflow rate.
2. Size of particle intended to be removed does not affect the overflow rate.
3. Density of particle intended to be removed affects the overflow rate.

Which of the above statements are correct?
(a) 1 and 3 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3
[ESE : 2015]

5.116 The following are certain operating problems of a rapid sand filter:
1. Sand depth should never be depleted by more than 10 cm.
2. Air binding results due to development of negative head and formation of air bubbles in the filter sand.
3. Water softening with lime-soda leads to incrustation of sand.
4. Bumping of filter bed is caused due to negative head.

Which of the above statements are correct?
(a) 1, 2 and 4 only (b) 1, 2 and 3 only
(c) 3 and 4 only (d) 1, 2, 3 and 4
[ESE : 2016]

5.117 Consider the following characteristics of E.coli bacteria:
1. Gram negative
2. Spore-forming
3. Facultative anaerobic
4. Bacillus

Which of the above are correct?
(a) 1, 2 and 3 only (b) 2 and 4 only
(c) 1, 3 and 4 only (d) 1, 2, 3 and 4
[ESE : 2016]

5.118 How much bleaching powder is needed to chlorinate 5000 *l* of water whose chlorine demand is 2 mg/*l*, assuming that the bleaching powder has 25% available chlorine?
(a) 4 g (b) 40 g
(c) 140 g (d) 400 g
[ESE : 2016]

5.119 The design overflow rate of a sedimentation tank is chosen considering
(a) Flow rate through the tank
(b) Diameter of the particle intended to be removed
(c) Volume of the sedimentation tank
(d) Detention time in the tank
[ESE : 2016]

5.120 Consider the following statements regarding coagulant aids:
1. They are employed when temperature is low as they then accelerate the process of coagulation.
2. They are employed when flocs are small and water is coloured.
3. With their use, water purification capacity of the plant is increased.
4. Most widely used materials are oxidants, absorbent, weighing agents, activated carbon and polyelectrolytes.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3
(c) 1 and 4 (d) 2, 3 and 4
[ESE : 2017]

5.121 A good disinfectant
1. Should be persistent enough to prevent regrowth of organisms in the distribution system.
2. Must be toxic to micro-organism at concentrations well above the toxic thresholds of humans and higher animals.
3. Should have a fast rate of kill of micro-organisms.

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3
[ESE : 2017]

5.122 How much bleaching powder (having 20% available chlorine) is needed to disinfect 10000 litres of water whose chlorine demand is 1.0 mg/*l*? It should be ensured that, after about 1 hour contact time 0.2 mg/*l* chlorine is available.
(a) 30 g (b) 40 g
(c) 48 g (d) 68 g
[ESE : 2017]

5.123 Consider the following statements regarding removal of impurities from water:
1. Settleable solids are removed by filtration.
2. Volatile solids are removed through sedimentation.
3. Dissolved solids are removed through reverse osmosis.
4. Colloidal solids are removed by coagulation.

Which of the above statements are correct?
(a) 1 and 2 (b) 3 and 4
(c) 2 and 3 (d) 1 and 4
[ESE : 2017]

Directions: Each of the next items consists of two statements, one labelled as the 'Statement (I)' and the other as 'Statement (II)'. Examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

5.124 **Statement (I):** Softening of clear groundwater should be carried out immediately after collection by pumping out, or from springs.

Statement (II): Iron and manganese precipitates can foul the exchange medium surface if oxidation occurs in, or prior to, the ion-exchange phase.

[ESE : 2017]

5.125 **Statement (I):** Incrustation of sand occurs in rapid sand filter when water softened by lime-soda is fed in for filtration.

Statement (II): The sand gets coated with precipitates of $Ca(OH)_2$ and $Mg(OH)_2$ generated during softening of water by lime-soda process which leads to incrustation of sand.

[ESE : 2017]

Answers Water Treatment & Distribution System

5.1	(c)	5.2	(a)	5.3	(a)	5.4	(c)	5.5	(c)	5.6	(b)	5.7	(d)	5.8	(b)	5.9	(b)		
5.10	(a)	5.11	(a)	5.12	(d)	5.13	(b)	5.14	(c)	5.15	(d)	5.16	(b)	5.17	(a)	5.18	(c)		
5.19	(d)	5.20	(a)	5.21	(d)	5.22	(b)	5.23	(a)	5.24	(b)	5.25	(d)	5.26	(d)	5.27	(a)		
5.28	(a)	5.29	(a)	5.30	(d)	5.31	(d)	5.32	(d)	5.33	(a)	5.34	(b)	5.35	(b)	5.36	(a)		
5.37	(c)	5.38	(d)	5.39	(c)	5.40	(d)	5.41	(d)	5.42	(b)	5.43	(a)	5.44	(d)	5.45	(d)		
5.46	(b)	5.47	(a)	5.48	(d)	5.49	(b)	5.50	(b)	5.51	(c)	5.52	(d)	5.53	(d)	5.54	(d)		
5.55	(b)	5.56	(a)	5.57	(a)	5.58	(a)	5.59	(b)	5.60	(a)	5.61	(b)	5.62	(d)	5.63	(d)		
5.64	(d)	5.65	(b)	5.66	(d)	5.67	(a)	5.68	(a)	5.69	(c)	5.70	(b)	5.71	(a)	5.72	(c)		
5.73	(b)	5.74	(b)	5.75	(b)	5.76	(b)	5.77	(b)	5.78	(a)	5.79	(d)	5.80	(d)	5.81	(b)		
5.82	(d)	5.83	(b)	5.84	(b)	5.85	(d)	5.86	(a)	5.87	(b)	5.88	(a)	5.89	(a)	5.90	(b)		
5.91	(a)	5.92	(a)	5.93	(a)	5.94	(c)	5.95	(d)	5.96	(d)	5.97	(c)	5.98	(d)	5.99	(d)		
5.100	(d)	5.101	(d)	5.102	(b)	5.1103	(d)	5.104	(c)	5.105	(b)	5.106	(c)	5.107	(a)	5.108	(a)		
5.109	(b)	5.110	(b)	5.111	(a)	5.112	(d)	5.113	(c)	5.114	(c)	5.115	(a)	5.116	(b)	5.117	(c)		
5.118	(b)	5.119	(b)	5.120	(a)	5.121	(c)	5.122	(*)	5.123	(b)	5.124	(d)	5.125	(c)				

Explanations Water Treatment & Distribution System

5.1 (c)

First chloramines (combined residuals) will form by reaction of ammonia with chlorine. The chloramines are formed first by following reactions of ammonia and chlorine (hypochlorous acid HOCl)

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$
$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$
$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

At pH > 6.5 monochloramine will be the predominant species.

Then free residual chlorine compounds (HOCl and OCl^-) will form as follows:

$$Cl_2 + H_2O \rightarrow HOCl + H^+$$
$$HOCl \rightleftharpoons H^+ + OCl^-$$

Thus correct sequence is $NH_2Cl - NHCl_2 - HOCl - OCl$

5.2 (a)

Surface water contains inorganic suspended matter, organic suspended matter and pathogens mainly. They are generally soft and less corrosive than ground water. So coagulation, flocculation, sedimentation, filtration and disinfection shall be the treatment.

Ground water has no suspended matter and it can be used after disinfection.

Lake water will have odour, taste and colour due to heavy algal growth. Some turbidity will also be there due to mixing of layers. So $CuSO_4$ treatment for colour, odour and taste followed by coagulation, sedimentation, filtration and disinfection is needed.

5.3 (a)

Defluoridation using Nalgonda technique uses alum with prior mixing of lime (CaO) or sodium carbonate (Na_2CO_3). The added lime helps to ensure adequate alkalinity required for effective hydrolysis of alum, so that residual alum does not remain in the treated water.

5.4 (c)

Large *G* value with short times tend to produce small, dense flocs, while low *G* values and long time produce larger, lighter flocs. Since large, dense flocs are more easily removed in the settling basin, it will be advantageous to have high *G* values at inlet compared to the outlet end.

5.5 (c)

E-coli is a nonpathogenic bacteria of Fecal coliform group of organisms. These are believed to have long survival time outside the animal body than most pathogens have because the die-off rate of fecal coliform (E-coli) is logarithmic. The number of surviving organisms may be an indication of the time lapse since contamination.

5.6 (b)

Chlorides are generally present in water in the form of sodium chloride and may be due to leaching of marine sedimentary deposits, pollution from sea water, brine, or industrial and domestic wastes, etc. Their concentrations above 250 mg/L produce brackish taste which is objectionable. It is measured by potentio-metric method using titration with silver nitrate solution. In Argentometric method, of chloride measurement, silver nitrate titration in the presence of potassium chromate indicator is used. The red precipitate of silver chromate indicates end of titration.

Brackish taste of chlorides can be removed by:

(i) Evaporation and distillation
(ii) Electrodialysis method
(iii) Reverse osmosis method
(iv) Freezing process
(v) Solar distillation method.

Lime soda process and cation exchange process are used for hardness removal. Chemical coagulation is used for colloidal particle removal.

5.7 (d)

The cleaning of slow sand filters is not done by backwashing as is done for rapid gravity filters, but is done by scrapping and removing the 1.5 to 3 cm of top sand layer. The top surface is finally racked, roughened, cleaned and washed with good water.

5.8 (b)

Chlorine immediately reacts with NH_3 present in the water, resulting in the formation of Chloramines

which are termed as combined form of chlorine. The various reactions involved in chlorination are as follows:

(i) $Cl_2 + NH_3 \xrightarrow{pH>7.5} NH_2Cl + HCl$
(Ammonia) (Monochloramine)

(ii) $NH_2Cl + Cl_2 \xrightarrow{pH>(5\text{-}6.5)} NHCl_2 + HCl$
(Dichloramine)

(iii) $NHCl_2 + Cl_2 \xrightarrow{pH<4.4} NHCl_3 + HCl$
(Nitrogentrichloride)

5.9 (b)

Fluoride can be removed by:

(i) Nalgonda technique
(ii) Activated alumina
(iii) Bone char

Nalgonda technique uses aluminium salt (alum) for removing fluoride.

Manganese and iron can be removed by aeration or manganese zeolite (a natural green sand coated with manganese dioxide).

Taste and odour can be removed by:

(i) Aeration
(ii) Activated carbon
(iii) Copper sulphate

Copper sulphate is an algicide also.

5.10 (a)

Design period considers the useful life of any structure. Further hydrological analysis for design of the structure considers the frequency of occurrence of extremes of river flow.

5.11 (a)

For highly turbid and polluted water pre-chlorination before coagulation–sedimentation reduces load on filter and also reduces the taste, odour, algae and other organisms.

5.12 (d)

Uniformity coefficient $C_u = D_{60}/D_{10}$ should be 1.65 for rapid sand filter.

5.13 (b)

The flow through period (actual average time for batch of water) is always less than the detention period.

5.14 (c)

Dead end system is economic and simple, and can be extended or expanded easily.

In grid-iron system, the water reaches at different places through more than one route. The discharge to be carried by each pipe, the friction loss, and the size of the pipe therefore, get reduced.

However, more length of pipe lines, a large number of sluice valves and loops make the design difficult and costlier.

The ring system has lesser number of valves and smaller pipe lengths. The peripheral main pipe maintains reasonably equal pressures at all points.

In radial system water flow occurs from distribution reservoirs (centre) to branches (periphery and radial) in a radial manner. This ensures high pressure and efficient water distribution to various zones. The calculations for design of sizes are also simple.

5.15 (d)

Ground water sources do not have turbidity so sedimentation, alum doses or oxidant like potassium permanganate is not needed.

5.16 (b)

Organisms that use organic carbon for the formation of new biomass are called heterotrophs, while organisms that derive cell carbon from carbon dioxide are called Autotrophs. The conversion of CO_2 to cellular complex compounds requires a reductive process, which requires a net input of energy. Therefore autotrophic organisms must spend more of their energy for synthesis, than do heterotrophs, resulting in generally lower yield of cell mass and growth rates. Eutrophication is caused by nutrients like carbon, nitrogen and phosphorous. It is a natural process of algal production and siltation of water body. The water body becomes shallower.

5.17 (a)

Ozone is the allotropic form of oxygen.

Ozone is a powerful oxidant which reacts with reduced inorganic compounds and with organic material. It reacts vigorously with bacteria and

viruses. It is more effective than chlorine in activating resistant strains of bacteria and viruses. It does not form carcinogenic compounds like chlorine by reacting with organic acids etc.

However it is chemically unstable and so it must be produced on site and used immediately. The cost of ozonation is two to three times higher than the cost of chlorination. Since no residual remains, it will be necessary to use small amounts of chlorine after ozonation to provide continued protection against regrowth of pathogens in the distribution system.

5.18 (c)

The dual media filter have filtration rate between 10 to 20 $m^3/h/m^2$. It is approxi-mately 4 times higher than that in rapid sand filter.

The dual media filter has anthracite coal and silica sand as medium. The density of coal is less than sand so coal is on top and the flow occurs from coarse medium to fine medium (silica sand).

	Coal	Sand
Depth (m)	0.3	0.3
Specific gravity	1.4-1.6	2.65
Effective size (mm)	0.9-1.0	0.5- 0.55
Uniformity coefficient	< 1.8	< 1.65

5.19 (d)

Some amount of chlorides is needed for maintaining salt balance of body. The permissible limit for chlorides is 250 mg/L.

5.20 (a)

The negative pressure in filter media tends to release the dissolved air and other gases present in water. The gas bubbles gets attached to the sand grains and seriously affects the working of the filter. This is called air binding. Algae may also produce oxygen and cause air binding. So algae growth should be controlled by using algicides.

Increase in water temperature reduces solubility of dissolved air and it gets released to cause air binding. So this should be avoided.

The filter should be cleaned as soon as loss of head exceed the optimum allowable values. Herein compressed air and water can be used.

5.21 (d)

Aeration will oxidize the iron and manganese and then they can be separated by sedimentation.

5.22 (b)

The sequence of treatment in a water treatment plant:

Coagulation → Flocculation → Sedimentation → Filtration → Chlorination

5.23 (a)

	Slow sand filter	Rapid sand filter
Effective Size	0.2 mm to 0.4 mm	0.35 to 0.55 mm
Uniformity Coefficient	1.8 to 2.5	1.2 to 1.8

Thus in slow sand filters ES is less but UC is more than that in rapid sand filter.

5.24 (b)

For mixing basins Gt should be 30,000 to 60,000 where t is the detention period or mixing periods (usually 60 to 120 sec). For flocculator the G value ranges between 20 to 80 s^{-1} and detention period 20 to 60 minutes.

5.25 (d)

If only ammonia is present then first chloramines will be formed. Thus there will be no destruction of chlorine residual by reducing compounds, which is represented by AB. So curve will pass through origin.

5.26 (d)

Surge tanks are provided at the end of the line where water hammer is created by rapid closing of a valve.

5.27 (a)

Rapid Mixing Unit – 30 Seconds

Flocculator – 30 minutes

Propeller Mixing Unit – 10 seconds

Sedimentation Tank – 1.5 hours

5.29 (a)

Common Operational Troubles in Rapid Gravity Filters

Air Binding :

- When the filter is newly commissioned, the loss of head of water percolating through the filter is generally very small. However, the loss of head goes on increasing as more and more impurities get trapped into it.
- A stage is finally reached when the frictional resistance offered by the filter media exceeds the static head of water above the and bed. Most of this resistance is offered by the top 10 to 15 cm sand layer. The bottom sand acts like a vacuum, and water is sucked through the filter media rather than getting filtered through it.
- The negative pressure so developed, tends to release the dissolved air and other gases present in water. The formation of bubbles takes place which stick to the sand grains. This phenomenon is known as Air Binding as the air binds the filter and stops its functioning.
- To avoid such troubles, the filters are cleaned as soon as the head loss exceeds the optimum allowable value.

Formation of Mud Balls: The mud from the atmosphere usually accumulates on the sand surface to form a dense mat. During inadequate washing this mud may sink down into the sand bed and stick to the sand grains and other arrested impurities, thereby forming mud balls.

Cracking of Filters: The fine sand contained in the top layers of the filter bed shrinks and causes the development of shrinkage cracks in the sand bed. With the use of filter, the loss of head and, therefore, pressure on thesand bed goes on increasing, which further goes on widening these cracks.

Remedial Measures to Prevent Cracking of Filters and Formation of Mud Balls

- Breaking the top fine mud layer with rakes and washing off the particles.
- Washing the filter with a solution of caustic soda.
- Removing, cleaning and replacing the damaged filter sand.

5.30 (d)

In the initial dose of chlorine there is no residual because chlorine, being a strong oxidant, reacts with almost any matter in a reduced state such as Fe^{2+}, Mn^{2+}, H_2S and organics.

Thus there is no exact answer but closest answer will be (d).

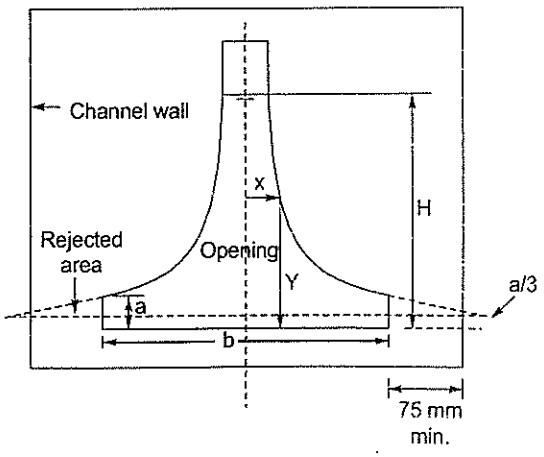
5.31 (d)

Disinfection using chlorine is necessary part of water treatment for rural water supply. Therefore (a) and (c) can not be the answer. Before slow sand filter, coagulation is not suitable. Therefore (b) is not possible.

5.32 (d)

With variation in sewage flow received at treatment plant, it is important that velocity of the wastewater in the grit chamber should be maintained nearly constant. Otherwise when flow is lower, deposition of not only inorganic solids but also organic solids will occur in grit chamber due to lowering of velocity. With flow higher than average, when the velocity will exceed the critical velocity, scouring of already deposited grit particles will occur leading to failure of performance. Hence for proper functioning, the velocity should not be allowed to change in spite of change in flow in the grit chamber. This can be achieved by provision of proportional weir or Parshall flume at the outlet end of grit chamber.

PROPORTIONAL WEIR:



5.33 (a)

Ferrule point is the connecting point from the main supply line to the domestic connection. The

pressure at this point should be such that water can reach the highest floor of the two storey building. Also as per government manuals, for towns where two-storeyed buildings are common, the minimum residual pressure at ferrule point should be 12m.

5.34 (b)

Chlorine dose required

$= 2 \times 10^{-6} \times 10{,}000 \times 50$

$= 1$ kg/day

Bleaching powder required $= \frac{1}{0.2} = 5$ kg/day

5.35 (b)

All particles having settling velocity equal to or greater than surface overflow rate will be completely removed while particles having settling velocity lower than SOR will be partially removed.

Total removal $= 200 + \frac{1}{3} \times 300 = 300$ mg/L

The concentration of particles in settled water $= (200 + 300) - 300 = 200$ mg/L

5.36 (a)

Slow sand filter can remove upto 98-99% of bacteria present in water and thus has maximum bacteria removal efficiency. In case the water is pre-chlorinated, the efficiency can go upto 99.5% - 99.9%.

5.37 (c)

The addition of chlorine beyond break point is called break point chlorination. It ensures a residual of 0.2 to 0.3 mg/L of free chlorine. This residual of free chlorine, appearing after break point, is not easily removed except by sunlight and therefore it takes care of the future contamination of water in the distribution system. The chloramines formed by reaction of chlorine and ammonia before break point are called combined residual chlorine. These chloramines are less effective disinfectants than free residuals. Chloramines are persistent and provide continued protection against regrowth of pathogens in distribution system.

5.38 (d)

Aerator is used to remove gases like CO_2 and H_2S. Sedimentation tank (after coagulation and flocculation) can remove settleable as well as colloidal particles. Slow sand filter and rapid sand filter both remove suspended matter but slow sand filter is more effective in removing bacteriological matter.

5.39 (c)

First aeration is done to remove gases CO_2 and H_2S and pathogens (disease causing bacteria) will be removed in the last.

5.40 (d)

Common problems associated with filtration of waste water are:

(i) Air binding
(ii) Turbidity break through cracking of sand bed
(iii) Mudball formation
(iv) Buildup of emulsified grease
(v) Loss of filter medium due to backwashing
(vi) Gravel moulding or bumping of filter beds.

5.41 (d)

Total storage

= Balancing storage + Breakdown storage + Fire storage

5.42 (b)

The disinfection of industrial water supplies is necessary in food processing, distillery (alcohol), etc.

5.43 (a)

Eutrophication is caused due to excessive nutrients in the water (nitrates, phosphates etc). The presence of total nitrogen indicates satisfactory microbial activity. Nitrite nitrogen indicates partly decomposed condition i.e. unsatisfactory microbial activity. Ammonia nitrogen presence indicates recent organic pollution.

5.44 (d)

The filtration process causes blocking of filter media due to impurities arrested in them. The downward flow of water is resisted by sand grains and impurities arrested in them. A stage may

reach when the frictional resistance exceeds the static head of water above the sand bed most of this resistance is caused by the top 10 to 15 cm sand layer. The bottom sand acts like a vacuum and the water is sucked through the filter media without cleaning. The dissolved air and gases from water are released and they stick to sand grains. This phenomena is called air binding and seriously affects the efficiency of filter.

5.45 (d)

Lime-soda process converts all types of hardness into precipitate of $CaCO_3$ and $Mg(OH)_2$. These precipitate may not be removed completely and will continue settling slowly resulting in deposits in water lines and storage facilities. It is therefore necessary to 'stabilize' the water by converting the supersaturated $CaCO_3$ back to the soluble form. This can be done by recarbonation.

5.46 (b)

In **sedimentation** process the coarser suspended particles are removed by letting the waste water settle in sedimentation basins.

The effectiveness of sedimentation may however be increased by mixing certain chemicals with the water. So as to form flocculent precipitate, the process is known as **flucculantion.**

These flocculent precipitate carries the suspended particles as it settles. The process is called chemical coagulation or simply **coagulation.**

But **disinfection** is used for process of killing of germs, by addition of certain chemicals.

5.48 (d)

Dissolved solids cannot be removed in rapid sand filter. Helminth eggs, which range in size from about 10 mm to more than 100 mm, can be removed by many commonly used waste water-treatment processes such as sedimentation, filtration and stabilization ponds. However, some helminth eggs are extremely resistant to environmental stresses and may survive usual waste water and sludge disinfection procedure. Chlorine disinfection and mesophilic anaerobic digestion, for example, are not effective at inactivating many helminth eggs.

5.49 (b)

Settling velocity, $v = \frac{g}{18} \times \frac{(S_s - 1)}{\nu} d^2$

As specific gravity changes from 2 to 3, the settling velocity will change from v to $2v$.

5.50 (b)

Slow sand filter will be able to remove suspended particles and up to 99% pathogenic organisms. So small amount of supplies for rural areas can be ensured by slow sand filters.

5.51 (c)

Concentrations of fluoride approximately 1.0 mg/L in drinking water help to prevent dental cavities in children. Excessive intake of fluoride (> 2 mg/L) may be noticeable discoloration of teeth called mottling.

5.52 (d)

Settling velocity of discrete particles is given by Newton or Stoke's equation. It is propor-tional to square of the particle diameter.

5.53 (d)

Surface overflow rate $= \frac{Q}{A_s} = \frac{Q}{LB}$

A_s is surface area

SOR does not depend upon total depth of the tank.

5.54 (d)

To avoid negative head and air binding, filter is cleaned when the head loss is more than the static head of water over sand bed. Another remedy is to pump in air to reduce the suction effect created due to negative head.

5.55 (b)

Aeration can not kill pathogens and correct pH of water. Although volatile liquids such as humic acids and phenols can be removed from water by aeration. The removal rates are too low for the process to be practical except in extreme cases where excessive quantities must be reduced to more manageable levels.

5.56 (a)

The chloramines prevent the formation of compounds formed by reaction of free chlorine

with the organics or phenol. The chloramines are predominant species above pH 6.5. Chloramines are persistent and provide continued protection against regrowth of micro-organisms in distribution system.

5.57 (a)

One of the most important variables in the disinfection is contact time. Harriet Chick observed that for a given concentration of disinfectant, the longer the contact time, the greater the kill. In differential form, Chick's law is

$$\frac{dN_t}{dt} = -kN_t$$

$\frac{dN_t}{dt}$ is rate of kill of pathogens with time

k is inactivation rate constant

N_t is number of pathogens at time t.

Carmen-Kozeny equation for head loss in filter is

$$h_f = \frac{f'L(1-e)V_s^2}{e^3 g d_p}$$

h_f is frictional head loss through bed of particles of uniform size d_p in metre.

e is porosity of bed

V_s is filtering velocity $= \frac{Q}{A_s}$ m/s

d_p is diameter of filter media grains, m

Friction factor, $f' = 150\frac{(1-e)}{\text{Re}} + 1.75$

$\text{Re} = \frac{\phi \rho_w V_s d_p}{\mu}$ where ϕ is the shape factor

5.58 (a)

Velocity gradient, $G = \sqrt{\frac{P}{\mu V}}$

Power input per unit volume,

$$P = \mu G^2 V$$
$$= 1 \times 10^{-3} \times (600)^2 \times 1$$
$$= 360 \text{ W}$$

5.59 (b)

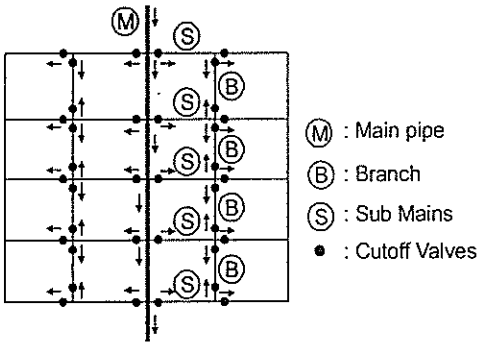
Grid Iron System: It is suitable for cities with rectangular layout, where the water mains and branches are laid in rectangles.

Advantages:

1. Water is kept in good circulation due to the absence of dead ends.
2. In the cases of a breakdown in some section, water is available from some other direction.

Disadvantages

1. Exact calculation of sizes of pipes is not possible due to provision of valves on all branches.



Grid-iron System

5.60 (a)

In **Discrete particle settling** (Type I), the particles settle individually without interaction with neighboring particles. This is in accordance to the classic sedimentation laws of Newton and Stokes.

Key features:

- Size, shape and specific gravity of the particles do not change with time.
- Settling velocity remains constant.

5.61 (b)

In plain sedimentation tank, suspended solids with specific gravity more than1 are removed. Chemical precipitation removes dissolved solids. Slow sand filtration removes 98-99% of the bacteria. Aeration removes dissolved gases (CO_2 and H_2S)

5.62 (d)

Nutrient Removal Tank removes the nitrogen and phosphorus present as nutrients in waste water. This is not a part of Preliminary treatment.

5.63 (d)

Principal mechanisms and phenomenon contributing to removal of material within a granular medium depth filter are: (i) Straining

(mechanical and chance contact), (ii) Sedimentation, (iii) Impaction, (iv) Interception, (v) Adhesion, (vi) Flocculation, (vii) Chemical adsorption (bonding and chemical interaction), (viii) Physical adsorption (electrostatic forces, electrokinetic forces and vaander Walls forces), (ix) Biological growth.
(x) Centrifugal force in disc filter.

5.64 (d)
First select 10, 1 and 0.1 sample size. For this series the MPN = 26
Now select 1,0.1, and 0.01 sample size. The positive tubes 2–1–0 are giving. MPN index is 7. Because the series of sample used is one tenth of the 10, 1 and 0.1 sample sizes used in the table, so multiply by 10 in the value. Therefore, the MPN of the sample is 70.

5.65 (b)
Chlorides are generally present in water in the form of sodium chloride and may be due to leaching of marine sedimentary deposits, pollution from sea water, brine, or industrial and domestic wastes, etc. Their concentrations above 250 mg/L produce brackish taste which is objectionable. It is measured by potentiometric method using titration with silver nitrate solution. In Argentometric method, of chloride measurement, silver nitrate titration in the presence of potassium chromate indicator is used. The red precipitate of silver chromate indicates end of titration.
Brackish taste of chlorides can be removed by:
(i) Evaporation and distillation
(ii) Electrodialysis method
(iii) Reverse osmosis method
(iv) Freezing process
(v) Solar distillation method
Lime soda process and cation exchange process are used for hardness removal. Chemical coagulation is used for colloidal particle removal.

5.66 (d)
The biological layer formed by microbial decomposition of harmless compounds is called *schmutzdecke* or dirty skin. This helps in absorbing and straining out impurities. This layer is formed in slow sand filter.

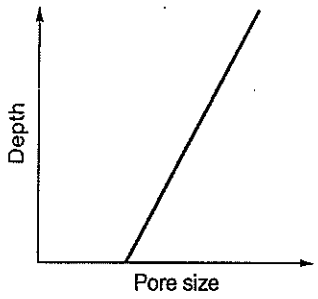
5.67 (a)
Dechlorination means removing the chlorine from water. This is generally required when super-chlorination has been practised. The common dechlorinating agents are:
(i) SO_2 gas
(ii) Sodium thiosulphate ($Na_2S_2O_3$)
(iii) Activated carbon
(iv) Sodium metabisulphate ($Na_2S_2O_5$)
(v) Ammonia as NH_4OH
(vi) Sodium sulphite (Na_2SO_3)
(vi) Sodium bisulphite ($NaHSO_3$)

5.68 (a)

S.L.	Filter	Medium				Rate of filtration
(i)	Slow sand filter	Fine sand effective size 0.2mm				0.12 to 0.32 m/h
(ii)	Rapid sand filter	Coarse sand effective size 0.45 to 0.55 mm and Coefficient of uniformity 1.65				2.5 to 5 m/h
(iii)	Dual media filter	Effective size (mm) Uniformity coefficient	Sand 0.5-0.55 < 1.65		Coal 0.9-1.0 < 1.8	10 to 20 m/h
(iv)	Mixed media filter	Percentage Effective size (mm)	Silica sand 30%	Garnet sand 10% > 0.15mm	Anthracite 60% < 1.0mm	10 to 20 m/h

The gradation of mixed media filter is such that the depth to pore size graph is close to ideal filter as shown in figure below.

Dual and mixed media filters make possible the direct filtration of water of low turbidity without settling operation.



Ideal Filter Gradation

5.69 (c)

Flocculating particles have type-2 settling. The Stoke's equation cannot be used because flocculating particle are continuously changing in shape, size and, if a large aggregate of particles collect, specific gravity because also change of entrapped water in interstitial space. The batch analysis of type-2 settling is represented by plotting isoremoval line.

The slope at any point on isoremoval line is the instantaneous velocity of the fraction of particles represented by that line. The velocity of setting increases with depth due to increase in particle size by continued collision and aggregation with other particle.

The horizontal flow velocity remains constant.

5.70 (b)

The large weir overflow rates cause short circuiting and this causes particles to get removed without setting.

5.72 (c)

The coagulation of metallic salts releases hydrogen ions as well as coagulant species. These hydrogen ions neutralize alkalinity. In water with high turbidity and high alkalinity the pH will be relatively unaffected by coagulant addition. Because of the high alkalinity, absorption and charge neutralization will be less effective than in waters of low alkalinity. Higher coagulant dosage should be used to ensure sweep coagulation.

5.73 (b)

When the flow in circular sedimentation tank enters at the centre and is baffled to flow radially towards the perimeter, the horizontal velocity of the water is continually decreasing as the distance from the centre increases. Thus, a discrete particle with a settling velocity (v_0) is continually undergoing a change in its absolute velocity due to the decrease in horizontal velocity. Thus, the particle path in a circular basin is a parabola as opposed to the straight particle path line in the long rectangular tank.

5.74 (b)

During chlorination, the chlorine (in the form of HOCl) immediately reacts with ammonia present in water to form various chloramines as given below:

$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$

Monochloramine

$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$

Dichloramine

$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$

Nitrogen trichloramine

The monochloramine predominates at pH value of over 7.5; dichloramine at pH ranges of 5 to 6 5 and nitrogen trichloramine at pH below 4.4. These chloramines so formed are stable and are found to possess disinfecting properties.

5.72 (b)

Blue Green algae is also called cyanobacteria. Cyanobacteria are oxygenic photosynthetic bacteria that are widespread in marine, freshwater and terrestrial environments, and many of them are capable of fixing atmospheric nitrogen.

5.76 (b)

Surface overflow rate is the most important design parameter in designing a continuous flow rectangular sedimentation tank. If the discharge through the tank is Q, width of tank is B and length of the tank is L, then surface overflow rate is given by

$$v_0 = \frac{Q}{BL}$$

The surface overflow rate can be said to be representing the setting velocity of the slowest setting particles which are 100% removed. Thus, particles having setting velocity greater than or equal to surface overflow rate are 100% removed. Particles having setting velocity less than surface overflow rate are not 100% removed. If a particle

enters the tank at a height 'h' with a setting velocity v which is less than v_0, then it will be removed if

$$v = \frac{h}{H} \times v_0$$

where H is the height of the tank.

5.77 (b)

Higher alkalinity provides higher concentration of OH^- ions which helps in forming insoluble compounds which can be removed easily. High turbidity and high alkalinity in water makes it unaffected by the addition of coagulant. Higher coagulant dosage should be used to ensure sweep coagulation.

High Turbidity: Low Alkalinity a Low doses of coagulants.

Low Turbidity: Low Alkalinity a Addition of both turbidity and alkalinity.

Low Turbidity: High Alkalinity a High doses of coagulants.

5.78 (a)

When hard water is treated with lime [$Ca(OH)_2$] and soda ash [Na_2CO_3], calcium and magnesium salts present in it react with lime and soda ash to form insoluble precipitates of calcium carbonate and magnesium hydroxide. These precipitates can be sedimented out in a sedimentation tank. However, a little quantity may remain as finely divided particles and may cause troubles by getting deposited on the filter to cause enlargement of the sand grains called incrustation of the filter media or in the pipe of distribution system. To prevent this, it is generally necessary that the water be recarbonated by passing carbondioxide gas through it, as it leaves the sedimentation tank. In the recarbonation process, the insoluble carbonates combine with the CO_2 to again form the soluble bicarbonates, as given below:

(i) $CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$

(ii) $Mg(OH)_2 + CO_2 \longrightarrow MgCO_3 + H_2O$

(iii) $MgCO_3 + CO_2 + H_2O \longrightarrow Mg(HCO_3)_2$

By the recarbonation process, even though the water regains some of its hardness yet recarbonation is advisable.

5.81 (b)

The appropriate method for removal of fluorides from water is de-fluoridation. It can be achieved by the addition of any of the following $Ca_3(PO_4)_2$, Bone charcoal, Lime, Activated carbon and Reagents.

5.82 (d)

At low concentrations, chlorine probably kills micro-organisms by penetrating the cell and reacting with the enzymes and protoplasm. At higher concentrations, oxidation of the cell wall will destroy the organism.

5.85 (d)

Filtration is employed after coagulation, flocculation and sedimentation to remove the finer particles in suspension, which may avoid settling in sedimentation basins even after using chemical coagulation.

Activated carbon is a specially treated carbon, which possesses the property of absorbing and attracting impurities, such as gases, liquid, and finely divided solids. Because of its excellent property of absorbing impurities, it is widely used for removing tastes and odours from public supplies.

5.86 (a)

The presence of too much of nitrate in water may adversely affect the health of infants, causing a disease technically called "methemoglobinemia" (commonly called "blue baby disease". The nitrate concentration in domestic water supplies is generally limited to 45 mg/*l*.

A fluoride concentration of less than 0.8-1.0 ppm may be harmful and may cause dental caries (tooth decay) due to the formation of excessive cavities in the teeth of young children during calcination of their permanent teeth. Higher fluoride concentrations, greater than 1.5 ppm or so, may again be harmful, causing spotting and discoloration of teeth, (a disease called fluorosis), which with continued excessive consumption of fluorides, may even cause deformation of bones. Depletion of oxygen from water is related to fish extinction.

5.87 (b)

The bed of a rapid sand filter consists of stratified layer with smallest size in the top most layer.

The sand used being bigger in sizes, the penetration of impurities will be deeper and the greater depth of bed is effective.

The gravel below sand supports the filtering media. Gravel helps in uniform distribution of wash water up through the filter media. It also prevents sand from entering into drains and then causing them to choke. The depth of gravel varies from 45 to 60 cm. The size of the gravel will vary from 5 to 25 mm the smallest size layers being at the top.

5.88 (a)

The amount of a coagulant required for coagulation depends on the turbidity and colour of the raw water. High turbidity aids in formation of thick and dense flocs leading to effective removal.

Selection of type of coagulant is dependent on pH value of raw water. Alum is used for pH range of 6.5 to 8.5. For pH range of 8.5 and above copperas is used. Ferric sulphate is quite effective in the pH range of 4 to 7 and above 9, whereas Ferric chloride is quite effective in the pH range of 3.5 to 6.5 and above 8.5.

5.89 (a)

The amount of residual chlorine left in the chlorinated water after the required contact period, can be experimentally determined by using any of the following tests:

1. Orthotolidine test
2. D.P.D. test
3. Chlorotex test
4. Starch-iodide test

Amperometric titration method is used for the determination of total chlorine concentrations in natural water.

5.90 (b)

Coagulation is a chemical technique which is directed towards the destabilisation of the charged colloidal particles. Flocculation, on the other hand, is the slow mixing technique which promotes the agglomeration of the stabilised particles to form flocs.

5.91(a)

The operational troubles which are generally encountered during the operation of rapid gravity filters are.

Air binding: Development of negative pressure in the bottom sand layer of rapid sand filter leads to air binding. The negative pressure so developed, tends to release the air dissolved in water. It causes the formation of bubbles, which stick to the sand grains, and affects the working of filter.

Mud balls: The mud from the atmosphere usually accumulates on the sand surface, so as to form a dense mat. During inadequate washing of the filter, this mud may sink down into the sand bed. This mud then sticks to the sand grains and other arrested impurities, thereby forming mud balls. The fine sand contained in the top layers of the filter bed, shrinks and causes the development of shrinkage cracks in the sand bed.

5.92 (a)

The disinfection not only removes the existing bacteria from the water at the plant, but also ensures their immediate killing even afterwards, in the distribution system. The contamination of water during its transit from the treatment plant to the place of its consumption is also thus, prevented by the disinfectants. The chemical which is used as a disinfectant must, therefore, be able to give this residual sterilizing effect for a long period, thus affording some protection against recontamination.

5.94 (c)

By the use of ion-exchange method zero hardness can be obtained.

5.96(d)

Chlorine in its various forms is invariably and almost universally used for disinfecting public water supplies. When chlorine is added to water, it forms hypochlorous acid which has an immediate and disastrous effect on most forms of microscopic organism.

5.97 (c)

Hepatitis is transmitted by virus.

5.98 (d)

Particles smaller in size than pore size can pass through.

5.101 (d)

Advantages of Slow Sand Filter

- Very effective removal of bacteria, viruses, protozoa, turbidity and heavy metals in contaminated fresh water
- Simplicity of design and high self-help compatibility: construction, operation and maintenance only require basic skills and knowledge and minimal effort
- If constructed with gravity flow only, no (electrical) pumps required
- Local materials can be used for construction
- High reliability and ability to withstand fluctuations in water quality
- No necessity for the application of chemicals
- Easy to install in rural, semi-urban and remote areas, Simplicity of design and operation
- Long lifespan (estimated >10 years)

5.102 (b)

Advantages of Cast iron pipes

- The main advantage of cast iron pipe fittings are that they are indeed highly resistant to abrasion making them the ideal choice for anyone wanting to drain materials such as sand, dishwasher water and garbage disposal.
- They are highly durable and practically indestructible.
- They do not react with most chemicals and won't melt or burn even in extreme conditions.
- They have a long lifespan which minimizes the need for replacements and repairs.
- Cast iron pipe fittings are very well constructed and as such have fantastic sound-proofing qualities when compared to other materials. So, there is minimal noise and vibration between the fittings and the pipes.
- Their versatility is another great advantage of choosing cast iron pipe fittings. There is a wide range of joining methods available for the fittings and that also allows for simple and efficient installation in all situations.
- Cast iron pipe fittings are cheap to install in comparison to other materials. They are cheaper to buy than many other pipe fittings and they are also one of the easiest types to use and install with minimal fuss.

Disadvantages of Cast iron pipes

- These pipes are very heavy and it requires specific means of transportations.
- It is also not advisable to use cast iron pipes in inaccessible places.
- Because of their heavy load, these pipes are made in shorter lengths. This equates to more jointing and a more complicated layout.

5.103 (d)

Chlorine dosage

$$= \frac{20 \times 10^6}{6000 \times 10^3} \text{mg}/l = 3.33 \text{ mg}/l$$

5.104 (c)

Large numbers of ions are present in Sea water/ Salty water. So, when a turbid stream flows into an ocean, then turbidity and the ions together lead to coagulation by ionic layer compression.

5.105 (b)

$$\text{Size of filter} = \frac{Q}{\text{Rate of filtration}}$$

$$= \frac{1\text{MLD}}{4000\, l/\text{hr}/\text{m}^2} = \frac{10^6}{4000 \times 24}\text{m}^2$$

$$= 10.42\ \text{m}^2$$

Use 11 m^2 filter

Size of under drainage system

= 0.2% of filter area = 0.022 m^2

5.107 (a)

For Re < 5, we apply Stoke's law equation

$$V_s = \frac{g}{18}(G-1)\frac{d^2}{\nu}$$

$$= \frac{9.81}{18}(2.65-1) \times \frac{\left(2 \times 10^{-3}\right)^2}{2 \times 10^{-2}} \frac{\text{m}}{\text{sec}^2} \times \frac{\text{cm}^2/\text{cm}^2}{\text{sec}}$$

$$= \frac{9.81}{18}(1.65) \times \frac{4 \times 10^{-6}}{2 \times 10^{-2}}$$

= 0.018 cm/sec.

5.108 (a)

Assume rate of filtration = q l/d/m^2

Given as a square filter, if length (l) dimension of filter becomes two times, the area will become ($l' \times l' = 2l \times 2l) = 4l^2$) four times.

So, amount of water filtered = Rate of filteration × Area

$= q \times 4A = 4 \times (q \times A)$

= 4 times the initial amount of water filtered.

5.109 (b)

Alum needed

= 10 MLD × 10 ppm

= 10×10^6 L/day × 10 mg/L

= 100×10^6 mg/day = 100 kg/day

= 1 quintal/day

5.110 (b)

Required CWR capacity

$$= \left(10 \times 10^6\right) \times \left(\frac{40}{24 \times 60}\right) \times 10^{-3} \text{ m}^3$$

$= 280 \text{ m}^3$

5.111 (a)

Required filtering water = 10 MLD = 10×10^6 *l*/d

Filtration rate = 100,000 *l*/m²/day

Now, surface area required

$$= \frac{\text{Required filtering water}}{\text{Filteration rate}} = \frac{10 \times 10^6}{100{,}000} = 100 \text{ m}^2$$

5.112 (d)

Difference between Slow Sand and Rapid Sand filters

S. No	Item	Slow Sand Filters	Rapid Sand Filters
1.	Rate of filtration	$3 m^3/m^2/d$	$125 m^3/m^2/d$
2.	Size of bed	Large, 200 m^2	Small, 200-400 m^2
3.	Depth of bed	0.3 m of gravel, 1.2 m of sand usually reduced to not less than 0.6 m by scraping.	0.5 m of gravel, 0.7 m of sand or less not, reduced by washing.
4.	Size of sand	Effective size 0.25 to 0.3 to 0.35 mm, uniformity coefficient 2 to 2.5 to 3.	0.45 mm and higher uniformity coefficient 1.5 and lower depending on under-drainage system.
5.	Grain size distribution of sand in filter	Unstratified	Stratified with smallest or lightest grains at top and coarsest or heaviest at bottom.
6.	Under-drainage system	Split tile laterals laid in coarse stone and discharging into tile o fconcrete main drain	1. Perforated pipe laterals discharging into pipe mains. 2. Porous plates above inlet box 3. Porous blocks with included channels
7.	Loss of head	0.15 m initial to 1 m final	0.3 m initial to 2.5 m final
8.	Length of run between cleanings	20 to 60 days	12 to 72 hours
9.	Penetration of suspended matter	Superficial	Deep
10.	Method of cleaning	1. Scraping off surface layer of sand and washing and storing cleaned sand for periodic re-sanding of bed 2. Washing surface sand in Place by washer traveling over sand bed.	Dislodging and removing suspended matter by upward flow or backwashing which fluidises the bed. Possible use of water or air jets or mechanical rakers to improve scour.
11.	Amount of wash water used in cleaning sand	0.2 to 6% of water filtered	1 to 4-6% of water filtered
12.	Preparatory treatment of water	Generally none	Coagulation, flocculation and sedimentation

5.113 (c)

Required chlorine dose

= Chlorine demand + Residual chlorine

= 1.25 + 0.25 = 1.5 mg/*l*

∴ Total required chlorine per day

$= 4 \times 10^6 \times 1.5 \times 10^{-6}$ kg = 6 kg

Available chlorine in bleaching powder = 25%

∴ Bleaching powder required per day

5.114 (c)

$$= \frac{\text{Total required chlorine per day}}{\text{Available chlorine in beaching per day}}$$

$$= \frac{6}{0.25} = 24 \text{ kg}$$

5.115 (a)

Stoke's law states that denser and larger particles have a higher settling velocity, thus a higher overflow rate. Hence size and density of particle affects the overflow rate.

When the temperature decreases, the rate of settling becomes slower. When the water is colder, the flow in the plant is at its lowest and the detention time in the plant is increased so the floc has time to settle out in the sedimentation basins.

5.116 (b)

- Expansion of sand bed during back washing should be kept within limits to avoid carry over of sand to wash water through. Sand bed should never be depleted more than 10 cm from original thickness for this purpose.
- Air binding is caused due to negative head and formation of air bubbles.
- In lime-soda method, hardness is removed in the form of precipitate which get coated over sand particles and leads to incrustation.
- Sometimes careless or indifferent operation of the filter, bumping or lifting of the filter beds takes plate when switching on the back wash cycle is adopted.

5.117 (c)

E.coli is

- Gram negative bacteria i.e. it leave a red strain in a staining technique which is performed to identify cell components.
- Non spore forming bacteria
- Facultative anaerobic i.e. can work both in presence or absence of oxygen.
- Bacillus i.e. they have straight rod shape with square or rounded ends.

5.118 (b)

Quantity of 100% pure bleaching powder required

$= 2 \times 5000 \times 10^{-3} = 10$ gm

Quantity of 25% pure bleaching powder required

$$= \frac{10}{0.25} = 40 \text{ gm}$$

5.119 (b)

Design overflow rate of a sedimentation tank is the setting velocity of the particle intended to be removed, which is chosen considering the diameter of the particle intended to be removed.

5.121 (c)

A good disinfectant must be toxic to micro-organism at concentrations will below the toxic threshold of humans and higher animals.

5.122 (*)

Total dosage of chlorine (mg/*l*) = Total demand (mg/*l*) + Residual (mg/*l*)

Total dosage = (1 + 0.2) mg/*l* = 1.2 mg/*l*

For 10000 *l* of water, chlorine required

= 10000 *l* × 1.2 mg/*l* = 12000 mg = 12 g

This chlorine has to come from bleaching powder which has 20% available chlorine

Hence, bleaching powder required

$$= \frac{12}{0.2} \text{g} = 60 \text{g}$$

Note: *Since no answer is matching. We can take nearest as correct answer i.e., 68g.*

5.123 (b)

Settleable solids are removed by sedimentation volatile solids which get segregated from fixed solids by heating at 600°C in muffle furnace.

5.124 (d)

Softening of ground water may or may not be done, depending upon the quality of ground water.

5.125 (c)

Incrustation of sand occurs in rapids sand filter when water softened by lime soda is fed in for filtration. During lime soda process, ppt of calcium carbonate (and not calcium hydroxide) is formed along with magnesium hydroxide which leads to incrustation.

6 Design of Sewer

6.1 In transition of sewers from smaller diameter sewers to larger diameter sewers, the continuity of sewers is maintained at the
(a) bottom of the concrete bed of sewers
(b) inverts of the sewers
(c) crowns of the sewers
(d) hydraulic gradients of the sewers
[ESE : 1995]

6.2 The slope of a 1.0 m diameter concrete sewer laid at a slope of 1 in 1000, develops a velocity of 1 m/s, when flowing full. When it is flowing half-full, the velocity of flow through the sewer will be
(a) 0.5 m/s (b) 1.0 m/s
(c) 2 m/s (d) 2.0 m/s
[ESE : 1995]

6.3 **Assertion (A):** While laying a sewer line, the socket end of a sewer is kept facing the downward slope in the trench.
Reason (R): The socket end being heavy will slide down the slope if it faces the downward slope.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1996]

6.4 Self-cleansing velocity is
(a) the minimum velocity of flow required to maintain a certain amount of solids in the flow
(b) the maximum velocity of flow required to maintain a certain amount of solids in the flow
(c) such flow velocity as would be sufficient to flush out any deposited solids in the sewer
(d) such flow velocity as would be sufficient to ensure that sewage does not remain in the sewer
[ESE : 1997]

6.5 The following steps are involved in laying a sewer in a trench:
1. Transferring the centre line of the sewer to the bottom of a trench.
2. Setting sight rails over the trench.
3. Driving pegs to the level of the invert line of the sewer.
4. Placing the sewer in the trench.
The correct sequence of these steps is
(a) 1, 2, 3, 4 (b) 2, 3, 4, 1
(c) 4, 2, 3, 1 (d) 2, 3, 1, 4
[ESE : 1997]

6.6 In the design of storm sewers, "time of concentration" is relevant to determine the
(a) rainfall intensity
(b) velocity in the sewer
(c) time of travel
(d) area served by the sewer
[ESE : 1997]

6.7 The maximum flow occurs in an egg shaped sewer when the ratio of flow to vertical diameter is
(a) 0.33 (b) 0.50
(c) 0.95 (d) 1.00
[ESE : 1998]

6.8 In a design of storm sewers, if the time taken by rain-water to flow from the farthest point of the watershed to the sewer inlet is 't_i' and the time of flow of water from the sewer inlet to the point in the sewer that is under consideration is 't_f' then the time of concentration will be
(a) t_i
(b) t_f
(c) $t_i + t_f$
(d) t_i or t_f whichever is greater
[ESE : 1999]

6.9 A circular sewer of diameter 1 m carries storm water to a depth of 0.75 m. The hydraulic radius is approximately

(a) 0.3 m (b) 0.4 m
(c) 0.5 m (d) 0.6 m

[ESE : 1999]

6.10 For the design of a storm sewer in a drainage area, if the time of concentration is 20 minutes, then the duration of rainfall will be taken as
(a) 10 min (b) 20 min
(c) 30 min (d) 40 min

[ESE : 2000]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

6.11 **Assertion (A):** Sewers are not allowed to flow full.
Reason (R): Reserve space in the sewer takes care of fluctuations in the sewage flow.

[ESE : 2000]

6.12 **Assertion (A):** The design of all non-circular sections is based upon getting a "hydraulically equivalent section".
Reason (R): The chart of hydraulic elements is very useful in sewer design.

[ESE : 2001]

6.13 **Assertion (A):** Most important activity in sewer line construction is to start constructing it from the tail end and to check levels with a boning rod.
Reason (R): Construction of sewer line from tail end is recommended because required number of pumping stations may be incorporated in sewer network design.

[ESE : 2003]

6.14 A sewer is commonly designed to attain self-cleansing velocity at
(a) peak hourly rate of flow
(b) average hourly rate of flow
(c) minimum hourly rate of flow
(d) sewer running half full

[ESE : 2003]

6.15 Consider the following statements:
1. The velocity of flow in the rising main should be less than 0.8 m/s at any time.
2. Maximum velocity of flow is generally limited to 1.8 m/s and never allowed to exceed 3.0 m/s.

In the design of large sewage pumping stations, which of the above conditions must be satisfied?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2004]

6.16 If a sewer *X* is to be designed to generate equivalent self-cleansing action as in sewer *Y*, then
(a) velocity in sewer *X* must be equal to velocity in sewer *Y*
(b) slope of sewer *X* must be equal to slope of sewer *Y*
(c) tractive force intensity generated in sewer *X* must be same as that in sewer *Y*
(d) the roughness coefficient of *X* sewer material should be same as that of *Y* sewer material

[ESE : 2004]

6.17 Consider the following statement regarding building manholes:
1. They must be provided at every change of alignment, gradient or diameter.
2. They must be provided at the head of all sewers.
3. They must be provided at every junction of two or more sewers.
4. They must be provided at every 100 m along straight runs of sewers.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 3 (d) 2 and 4

[ESE : 2004]

6.18 Which of the following statements is correct?
A combined sewer is one which transports domestic sewage and
(a) storm water
(b) industrial waste
(c) overhead flow
(d) industrial wastes and storm water

[ESE : 2004]

6.19 In the design consideration of sewerage system, the sewers must have which one of the following?

(a) Maximum velocity of flow
(b) Only 50 per cent of maximum velocity of flow
(c) Minimum velocity of not less than cleansing velocity of flow
(d) High pressure at all times

[ESE : 2008]

6.20 **Assertion (A):** Laterals of minimum specified diameter in sewerage system have to be laid at slopes designed for self-cleaning velocity.

Reason (R): For the specified minimum lateral diameter at specified slopes, a minimum flow rate is not essential to maintain self-cleansing velocity.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

6.21 A sewer of 400 mm diameter and slope 1 in 400, running half-full, has a flow velocity of 0.82 m/sec. What velocity of flow will be obtained if the slope is made 1 in 100?

(a) 3.28 m/s (b) 1.64 m/s
(c) 0.82 m/s (d) 0.41 m/s

[ESE : 2012]

6.22 A sewer has a diameter of 300 mm and slope of 1 in 400. While running full it has a mean velocity of 0.7 m/s. If both the diameter and slope are doubled (to respectively be 600 mm and 1 in 200), what will be the changed mean velocity when running half-full ? Use Manning's formula.

(a) 1.59 m/s (b) 2.80 m/s
(c) 0.90 m/s (d) 1.00 m/s

[ESE : 2012]

6.23 At the same mean velocity of flow, the ratio of head loss per unit length for a sewer pipe running full to that for the same pipe flowing half-full is:

(a) 2.0 (b) 1.67
(c) 1.0 (d) 0.67

[ESE : 2013]

6.24 The self-cleansing velocity in a sewer depends on:

1. BOD (soluble)
2. Slope of the sewer
3. Ratio of depth of flow sewage to sewer diameter ratio

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2013]

6.25 One sewer has a dia. of 300 mm and another one has a dia. of 600 mm. When both run half-full, what will be the ratio of velocities in the two pipes if the slope of both pipes is the same?

(a) 1 (b) $\frac{1}{2}$
(c) $\left(\frac{1}{2}\right)^{2/3}$ (d) $\left(\frac{1}{2}\right)^{3/2}$

[ESE : 2013]

6.26 If the slope of sewer A is 1/100 and that of sewer *B* is 1/400, the velocity of flow in the two sewers will have a ratio of (size of both the sewers being same)

(a) $\frac{1}{2}$ (b) 1
(c) $(2)^{2/3}$ (d) 2

[ESE : 2013]

6.27 As per Manual on Sewerage and Sewage Treatment, Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, Government of India, when a sewer connects with another sewer having a difference of 600 mm in level between the water lines (peak flow levels) of main line and the invert level of branch line, the connection may be provided using

(a) Side entrance manhole
(b) Junction manhole
(c) Flushing manhole
(d) Drop manhole

[ESE : 2014]

6.28 A combined sewage system is more appropriate for developed areas where

(a) Rainfall occurs for a very few days in a year
(b) Rainfall occurs almost uniformly throughout the year
(c) Air temperatures are nearly uniform throughout the year
(d) Air temperatures through the year include extremes during certain runs of days

[ESE : 2016]

6.29 **Statement (I):** The invert of the lower (outgoing) larger size sewer is depressed suitably so as to match with the crowns of the upper (incoming) and the smaller size sewers.

Statement (II): It ensures that the smaller sewer runs full by backwater effect from the larger sewer even if the larger sewer does not run full.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

[ESE : 2017]

■■■■

Answers Design of Sewer

6.1	(c)	6.2	(b)	6.3	(d)	6.4	(c)	6.5	(d)	6.6	(a)	6.7	(c)	6.8	(c)	6.9	(a)
6.10	(b)	6.11	(a)	6.12	(b)	6.13	(c)	6.14	(c)	6.15	(c)	6.16	(c)	6.17	(a)	6.18	(d)
6.19	(c)	6.20	(b)	6.21	(b)	6.22	(a)	6.23	(c)	6.24	(c)	6.25	(c)	6.26	(d)	6.27	(d)
6.28	(b)	6.29	(c)														

Explanations Design of Sewer

6.2 (b)

For $\frac{d}{D} = 0.5$; $\frac{v}{V} = 1.0$

where, d is depth of flow
v is flow velocity at depth d
D is diameter of sewer
V is flow velocity at full flow

$\therefore$ $v = 1.0$ m/s

6.3 (d)

Socket end face upstream slope.

6.5 (d)

First sight rails are set over the trench. Then pegs can be driven to the level of invert line and centre line of the sewer marked on sight rails can be transferred to the bottom of the trench. Finally, sewers should be placed in the trench.

6.6 (a)

Time of concentration (t_c) is the time taken by water droplet to reach the catchment outlet from farthest part. So whole catchment contributes to runoff only when the time of rainfall is greater than 't_c'. It is used to determine critical rainfall intensity.

6.9 (a)

Hydraulic radius of sewer flowing full

$$R = \frac{D}{4} = \frac{1}{4} = 0.25\text{m}$$

At 0.75 m depth of flow

$$\frac{r}{R} \simeq 1.2$$

$\therefore$ $r \simeq 1.2 \times 0.25 = 0.3$ m

At 0.5 m depth of flow

$$\frac{r}{R} = 1.0$$

$\therefore$ $r = 0.25$ m

6.10 (b)

Maximum runoff will be obtained from the rain having a duration equal to the time of concentration, and this is called the critical rainfall duration. Therefore duration of rainfall should be 20 min.

6.11 (a)

Generally sewers run half to three-fourth full at maximum discharge. The extra space thus left above is provided:

- To account for fluctuations in flow.
- Large scale infiltration of storm water
- Unforeseen increase in population or water consumption and consequent increase in sewage production.

6.12 (b)

Hydraulically equivalent section means that two sections can carry same discharge, while flowing full, on the same grade.

6.13 (c)

The construction of sewer line is started from the tail end so that sewers of tail length may be utilized even during the initial periods of its construction, thus ensuring that the functioning of sewerage scheme need not to wait till the completion of entire scheme.

6.15 (c)

Rising main may be of cast iron or asbestos cement pressure pipe. The velocity of flow in the rising main should not be less than 0.75 m/s at any time of flow to avoid settling of particles. The maximum velocity limitation is due to continuous abrasion caused by the suspended particles.

6.16 (c)

Velocity and discharge are functions of tractive force intensity which depends upon friction coefficient as well as flow velocity. For equal self cleansing tractive force intensity should be same in both sewers.

6.19 (c)

The velocity which will even scour the deposited particles of a given size, must be developed in the sewers, at least once a day, so as not to allow any deposition in the sewers is called self-cleansing velocity. The generation of such a minimum self-cleansing velocity in the sewer, at

least once a day, is important, because if certain deposition takes place and is not removed, it will obstruct free flow causing further deposition and finally leading to the complete blocking of the sewer.

6.21 (b)

Velocity of flow is given by Manning's formula

$$v = \frac{1}{n}R^{2/3}S^{1/2}$$

$$\therefore \quad v \propto S^{1/2}$$

$$\therefore \quad v_1 = \frac{1}{n}(R)^{2/3}\left(\frac{1}{400}\right)^{1/2}$$

$$v_2 = \frac{1}{n}(R)^{2/3} \times \left(\frac{1}{100}\right)^{1/2}$$

$$\therefore \quad \frac{v_2}{v_1} = \left(\frac{400}{100}\right)^{1/2}$$

$$\therefore \quad v_2 = 2 \times 0.82 = 1.64 \text{ m/s}$$

6.22 (a)

According to Manning's formula

$$V_1 = \frac{1}{n}(R_1)^{2/3}(S_1)^{1/2} = 0.7$$

$$\Rightarrow \quad V_1 = \frac{1}{n}\left(\frac{D_1}{4}\right)^{2/3}(S_1)^{1/2} = 0.7$$

Now, $D_2 = 2D_1$; $S_2 = 2S_1$

$$\therefore \quad V_2 = \frac{1}{n}\left(\frac{2D_1}{4}\right)^{2/3}(2S_1)^{1/2}$$

$$\therefore \quad V_2 = 2.24\, V_1 = 1.57 \text{ m/s} \cong 1.59 \text{ m/s}$$

6.24 (c)

Self-cleaning velocity does not depend on BOD.

6.25 (c)

$$V = \frac{1}{n}R^{2/3}\sqrt{S}$$

$$\frac{V_1}{V_2} = \left(\frac{R_1}{R_2}\right)^{2/3}$$

$$= \frac{(A_1/P_1)^{2/3}}{(A_2/P_2)} = \left[\frac{\frac{\pi}{8}D_1^2 \Big/ \frac{\pi D_1}{2}}{\frac{\pi}{8}D_2^2 \Big/ \frac{\pi D_2}{2}}\right]^{2/3}$$

$$= \left(\frac{D_1}{D_2}\right)^{2/3} = \left(\frac{1}{2}\right)^{2/3} \quad [\because D_2 = 2D_1]$$

6.26 (d)

$$\frac{V_1}{V_2} = \sqrt{\frac{S_1}{S_2}} = \sqrt{\frac{1}{100} \times \frac{400}{1}} = 2$$

6.27 (d)

A manhole which is constructed to connect the high level branch sewer (> 0.6 m) to the low level main sewer by vertical dropping pipe is known as drop manhole.

6.28 (b)

If rainfall occurs almost uniformly throughout the year, single sewer would be appropriate as its advantage will be available for entire year.

6.29 (c)

The invert of the lower larger size sewer is depressed suitably so as to match with the crowns of the upper and the smaller size sewers as it prevents backing up of sewage.

7 Quality and Characteristics of Sewage

7.1 An industrial waste water enters a stream having a BOD concentration of 10 mg/L and a flow of 20 m^3/s. If the flow of wastewater is 1.5 m^3/s and its BOD concentration is 250 mg/L, then the BOD concentration in the stream at a point downstream of the point of confluence of wastewater with the stream will be

(a) 2.67 mg/L (b) 12.09 mg/L
(c) 13.00 mg/L (d) 26.74 mg/L

[ESE : 1995]

7.2 Which of the following pairs is not correctly matched?

(a) BOD : Strength of sewage
(b) Methane : Product of anaerobic decomposition
(c) COD : Biodegradability of waste-water
(d) Nitrate : Methaemoglobinemia

[ESE : 1996]

7.3 The following data pertain to a sewage sample:
Initial DO = 10 mg/L
Final DO = 2 mg/L
Dilution to 1%
The BOD of the given sewage sample is

(a) 8 mg/L (b) 10 mg/L
(c) 100 mg/L (d) 800 mg/L

[ESE : 1997]

7.4 Sewage sickness occurs when

(a) sewage contains pathogenic organisms
(b) sewage enters the water supply system
(c) sewers get clogged due to accumulation of solids
(d) voids of soil clogged due to continuous application of sewage on a piece of land

[ESE : 1997]

7.5 Consider the following statements:
Ventilation of sewer lines is necessary to
1. avoid building up of sewer gases
2. ensure atmospheric pressure in the waste water surface
3. ensure the safety of sewer maintenance people
4. provide oxidation facility to sewage

Which of these statements are correct?

(a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 3

[ESE : 1999]

7.6 For a colony of 10,000 persons having sewage flow rate of 200 L/capita/day, BOD of applied sewage of 300 mg/L and organic loading of 300 kg/day/hectare, the area of an oxidation pond required for treating the sewage of the colony is

(a) 0.2 hectares (b) 1 hectare
(c) 2 hectares (d) 6 hectares

[ESE : 1999]

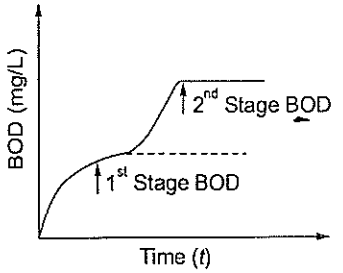
7.7 Consider the following statements associated with water pollution parameters:
1. One of the primary indicators of the degree of water pollution is the concentration of organic matter.
2. Total organic carbon (TOC), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are important parameters of water pollution.
3. Generally TOC > COD > BOD.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

[ESE : 1999]

7.8 The second stage BOD as shown in the figure is due to



(a) experimental error
(b) increased activity of bacteria
(c) nitrification demand
(d) interference by certain chemical reactions

[ESE : 1999]

7.9 Sewage sickness is a term used for
(a) persons who become sick after drinking polluted water
(b) a treatment plant which does not function properly
(c) a stream where the flora and fauna die due to sewage inflow
(d) the condition of land where sewage is applied continuously for a long period

[ESE : 1999]

7.10 A 2% solution of a sewage sample is kept at an incubation temperature of 20°C. If initial DO (Dissolved Oxygen) and final DO values after 5 days' incubation period are 8.5 mg/L and 5.5 mg/L respectively, then the BOD will be
(a) 50 mg/L (b) 150 mg/L
(c) 250 mg/L (d) 350 mg/L

[ESE : 2000]

7.11 For a waste, the 5-day BOD at 20°C is found to be 200 mg/L. For the same waste, 5-day BOD at 30°C will be
(a) less than 200 mg/L
(b) more than 200 mg/L
(c) 200 mg/L
(d) zero, as the bacteria cannot withstand such a high temperature

[ESE : 2000]

7.12 The ultimate BOD value of a waste
(a) increases with temperature
(b) decreases with temperature
(c) remains the same at all temperatures
(d) doubles with every 10°C rise in temperature

[ESE : 2000]

7.13 A certain waste has a BOD of 162 mg/L and its flow is 1000 cubic metres per day. If the domestic sewage has a BOD of 80 gram per capita, then the population equivalent of the waste would be
(a) 20.25 (b) 1296
(c) 2025 (d) 12960

[ESE : 2001]

7.14 The correct statement of comparison of ultimate BOD, COD, Theoretical Oxygen Demand (ThOD) and 5-day BOD (BOD_5) is
(a) $BOD_u > COD > ThOD > BOD_5$
(b) $COD > ThOD > BOD_u > BOD_5$
(c) $ThOD > COD > BOD_u > BOD_5$
(d) $COD > BOD_u > BOD_5 > ThOD$

[ESE : 2002]

7.15 Match List-I (Standards of sewage effluents for the discharge in surface water sources) with List-II (Tolerance limits in mg/L) and select the correct answer using the codes given below the lists:

List-I	List-II
A. BOD_5	1. 250
B. COD	2. 30
C. Oil and grease	3. 20
D. Total suspended solids	4. 10

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	2	4	1	3
(c)	3	1	4	2
(d)	2	1	4	3

[ESE : 2002]

7.16 Sewage sickness signifies
(a) diseases caused by sewage
(b) soil pores getting clogged and preventing free circulation of air when sewage is continuously applied on land
(c) raw sewage is applied and used for irrigating vegetables which are eaten raw
(d) disposal of septic sewage on land

[ESE : 2003]

7.17 Which one of the following pairs is not correctly matched?
(a) BOD/COD = 0 : Waste-water is toxic
(b) BOD/COD ≤ 0.2 : Acclimatization of seed is necessary
(c) BOD/COD ≥ 0.6 : Waste-water is non-biodegradable
(d) BOD = COD = 0 : Waste-water is devoid of organic matter

[ESE : 2004]

7.18 A waste water sample of 2 mL is made upto 300 mL in BOD bottle with distilled water. Initial

DO of the sample is 8 mg/L and after 5 days it is 2 mg/L. What is its BOD?

(a) 894 mg/L (b) 900 mg/L
(c) 300 mg/L (d) 1200 mg/L

[ESE : 2004]

7.19 A municipal sewage has BOD_5 of 200 mg/L. It is proposed to treat it and dispose off into a marine environment. For what minimum efficiency should the sewage treatment plant be designed?

(a) 85% (b) 60%
(c) 50% (d) 33.67%

[ESE : 2005]

7.20 Match List-I (Parameter) with List-II [General standard for discharge into the inland surface water in mg/L (max)] and select the correct answer using the codes given below the lists:

List-I	List-II
A. BOD (5 day 20°C)	1. 250
B. COD	2. 100
C. Oil and grease	3. 20
D. Suspended solids	4. 10
	5. 30

Codes:

	A	B	C	D
(a)	2	1	4	5
(b)	5	4	3	2
(c)	2	4	3	5
(d)	5	1	4	2

[ESE : 2005]

7.21 What is 5 days 20°C BOD equal to?

(a) 3 days 27°C BOD (b) 4 days 30°C BOD
(c) 6 days 32°C BOD (d) 7 days 35°C BOD

[ESE : 2005]

7.22 Presence of nitrogen in a waste water sample is due to the decomposition of

(a) carbohydrates (b) proteins
(c) fats (d) vitamins

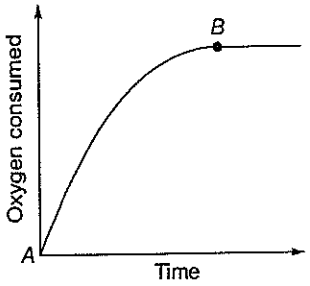
[ESE : 2005]

7.23 In context of water polluted with sewage, what does BOD signify?

(a) Biological oxygen demand
(b) Bacteriological oxygen demand
(c) Biochemical oxygen demand
(d) Biology of degradation

[ESE : 2006]

7.24 The figure below shows, BOD curve when the experiment was conducted at 20°C. If the experiment is conducted at 30°C, then the portion AB of the curve



(a) shifts to the left
(b) shifts to the right
(c) remains unchanged
(d) shrinks

[ESE : 2010]

7.25 A sample of sewage is estimated to have a 5 day 20° C BOD of 250 mg/*l*. If the test temperature be 30°C, in how many days will the same value of BOD be obtained?

(a) 1.5 days (b) 2.5 days
(c) 3.3 days (d) 7.5 days

[ESE : 2012]

7.26 Consider the following statements:

The time of BOD assimilation in a stream can be affected by

1. Ratio of stream depth to flow width.
2. Stream BOD value.
3. BOD rate constant.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

7.27 Statement-I : The BOD test is conducted for 5 days at 20°C.

Statement -II : The amount of oxygen utilized by microorganisms anaerobically is called BOD.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

7.28 Consider the following statements:
1. Grease data is a measure of effectiveness of primary settling tanks.
2. Volatile acid data provide information concerning anaerobic degradation of organic matter.
3. Total and volatile solids data are indispensable in the design and operation of sludge digestion, vacuum filter and incineration units.
4. Ammonia and organic nitrogen data are helpful in controlling aerobic treatment costs to a minimum.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1, 2 and 4 only (d) 2, 3 and 4 only

[ESE : 2013]

7.29 If the average sewage from a city is 95×10^6 *l*/day and the average 5 day BOD is 300 mg/*l* against a standard of 75 mg/day per capita at 20°C, then the population equivalent of the city will be
(a) 28,500 (b) 285×10^6
(c) 3,80,000 (d) 380×10^6

[ESE : 2014]

7.30 **Statement (I):** Dilution of the wastewater sample with organic-free, oxygen-saturated water is necessary to measure 5-day 20°C BOD values greater than 7 mg/*l*.

Statement (II): The saturation for oxygen in water at 20°C is approximately 9 mg/*l*.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2014]

7.31 Consider the following statements regarding biochemical oxygen demand (BOD) of river water.
1. The BOD rate constant varies with river water temperature.
2. The BOD rate constant does not depend on the BOD of the river water.
3. The BOD rate constant is often different for different river waters.
4. The BOD rate constant cannot be determined in a laboratory.

Which of the above statements are correct?
(a) 1 and 4 (b) 1 and 3
(c) 2 and 3 (d) 2 and 4

[ESE : 2015]

7.32 **Statement (I) :** Dilution of the wastewater sample with organic-free, oxygen-saturated water is necessary to measure 5-day 20°C BOD values greater than 7 mg/*l*.

Statement (II): Saturation concentration of oxygen in water at 20°C is approximately 9 mg/*l*.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2017]

■■■■

Answers Quality and Characteristics of Sewage

7.1	(d)	7.2	(c)	7.3	(d)	7.4	(d)	7.5	(d)	7.6	(c)	7.7	(a)	7.8	(c)	7.9	(d)						
7.10	(b)	7.11	(b)	7.12	(c)	7.13	(c)	7.14	(b)	7.15	(c)	7.16	(b)	7.17	(c)	7.18	(b)						
7.19	(c)	7.20	(d)	7.21	(a)	7.22	(b)	7.23	(c)	7.24	(a)	7.25	(c)	7.26	(c)	7.27	(c)						
7.28	(d)	7.29	(d)	7.30	(b)	7.31	(b)	7.32	(b)														

Explanations Quality and Characteristics of Sewage

7.1 (d)

$$BOD_{stream} = \frac{Q_1y_1 + Q_2y_2}{Q_1 + Q_2} = \frac{20\times10 + 1.5\times250}{20+1.5}$$

$$= 26.74 \text{ mg/L}$$

7.2 (c)

COD (Chemical oxygen demand) includes oxygen demand of:

(i) Biodegradable organic matter
(ii) Inorganic matter that can be oxidized easily.
(iii) BOD_5/COD ratio greater than 0.63 denotes biodegradability of water.
(iv) Nitrate concentrations above 45 mg/l may case methaemoglobinemia or blue baby disease.

7.3 (d)

BOD = [Initial DO – Final DO] × Dilution Factor

Where Dilution Factor

$$= \frac{\text{Volume of diluted sample}}{\text{Volume of undiluted sample}}$$

$$= (10-2)\times\frac{100}{1} = 800 \text{ mg/L}$$

7.4 (d)

When sewage is applied continuously on a piece of land, the soil pores or voids may get filled up and clogged with sewage matter retained in them. Thus free circulation of air will be prevented and anaerobic conditions will develop within the pores. Sewage sickness is the condition when soil pores get filled up and clogged with sewage matter due to continuous application of waste water effluents. This develops anaerobic conditions and foul gases like methane, carbon-dioxide and hydrogen sulphide are evolved.

In order to prevent sewage sickness:

(i) Sewage should be given primary treatment
(ii) The soil chosen for effluent irrigation/sewage farming should be sandy or loamy.
(iii) A proper under drainage system (open jointed drains) should be designed.
(iv) Land should be given rest for some time and ploughed thoroughly.
(v) Rotation of crops to be followed.
(vi) Shallow depths of water should be applied.

7.5 (d)

Ventilation in sewers is needed to avoid

(i) the danger of asphyxiation of sewer maintenance employees
(ii) the buildup of odourous gases such as hydrogen sulphide, ammonia etc.
(iii) the development of explosive mixture of sewer gases principally methane and oxygen

Another reason for ventilating sewers is to ensure a continuous flow of sewage inside the sewer.

7.6 (c)

The daily BOD generated

$= 10{,}000 \times 200 \times 300 \times 10^{-6} = 600$ kg/day

Thus area requirement $= \frac{600}{300} = 2$ ha

7.7 (a)

$\left(\frac{COD}{TOC}\right)$ ratio may vary from zero for an organic material resistant to dichromate oxidation to 5.33 for methane. However generally wastewater from houses and industries contain non-biodegradable (refractory) organics so TOC > COD > BOD.

7.8 (c)

The carbonaceous stage, or first stage BOD, represents that portion of oxygen demand involved in the bacterial conversion of organic carbon to carbon dioxide. The nitrogenous stage, or second stage BOD, represents a combined carbonaceous plus nitrogenous demand, when organic nitrogen, ammonia, and nitrite are converted to nitrate by bacteria, a process that also consumes DO.

7.10 (b)

BOD = (Initial DO – Final DO) × Dilution Factor

$$= (8.5 - 5.5) \times \left(\frac{100}{2}\right) = 150 \text{ mg/L}$$

7.11 (b)

The effect of temperature on BOD can be approximately given by the van't Hoff-Arrhenius models :

$$K_T = K_{20}(1.047)^{T-20}$$

At $T = 30°C$, $K_T > K_{20}$

$$BOD_{5,30°C} = L_0\left(1 - e^{-k_T t}\right)$$

$\therefore$ $BOD_{5,30°C} > BOD_{5,20°C} = 200$ mg/L

7.12 (c)

Ultimate BOD represents the biode-gradable organic matter, so it will remain unchanged.

7.13 (c)

Daily BOD contributed by waste

$$= 162 \times \frac{1000 \times 1000}{10^3}$$

$$= 162{,}000 \text{ g/day}$$

Population equivalent

$$= \frac{162{,}000}{80} = 2025$$

7.14 (b)

The biochemical oxygen demand (BOD_u or BOD_5) will always be less than Chemical oxygen demand (COD) i.e.

$COD > BOD_u > BOD_5$

Theoretical oxygen demand is calculated from the chemical formula of the organic matter. This is applicable for organic matter of animal and vegetable origin. The COD determines the oxygen demand by both organic and inorganic matter except the non-biodegradable organics. So ThOD <COD. However ThOD is the oxygen demand for final conversion of organic matter to their natural form. The BOD is the oxygen demand by micro organism to consume organic matter. Thus in BOD final conversion to natural form (elements) is not complete.

$ThOD > BOD_u$

So final order is $COD > ThOD > BOD_u > BOD_5$

7.17 (c)

$BOD_5/COD \geq 0.63$ means waste water is biodegradable

7.18 (b)

BOD_5 = [initial DO – Final D O] × dilution factor

$$= (8 - 2) \times \frac{300}{2} = 900 \text{ mg/L}$$

7.19 (c)

The tolerance limit for BOD_5 in marine environment disposal is 100 mg/L

Minimum efficiency needed,

$$\eta_{min} = \frac{200 - 100}{100} \times 100 = 50\%$$

7.20 (d)

- **BOD:** Biochemical oxygen demand (BOD, also called biological oxygen demand) is the amount of dissolved oxygen needed (i.e., demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period.
- Chemical oxygen demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite.

7.21 (a)

$BOD_t = L_0\left(1 - e^{-kt}\right)$

and $k_T = k_{20}(1.047)^{T-20}$

BOD_5 at 20°C will be equal to a BOD_t for given temperature when $k_T t$ is equal to $k_{20} \times 5$.

$$k_T t = k_{20} \times 5$$

or $$\frac{k_T}{k_{20}} = \frac{5}{t} = (1.047)^{T-20}$$

$$t = \frac{5}{(1.047)^{T-20}}$$

T	t(days)
27°C	3.63
30°C	3.16
32°C	2.88
35°C	2.51

There is no correct answer but (a) is closest

7.22 (b)

The nitrogen compounds from organisms are eliminated in the form of urea, uric acid and ammonia. All of these substances are produced from protein metabolism.

7.24 (a)

The BOD of water at any time t is expressed as

$$y_t = L_o (1 - e^{-kt})$$

The value of k is temperature dependent. Because micro-organisms are more active at higher temperatures, the value of k increases with increasing temperatures. The value of y_t approaches L_o asymptotically indicating that the total, or ultimate, BOD (y_u) is equal to the initial oxygen equivalent of the water L_o. Thus, at higher temperatures the value of y_t approaches to ultimate BOD earlier, shifting point B on the curve towards the left.

7.25 (c)

$$BOD_{5,\,20°C} = L\left(1 - 10^{-K_D \times t}\right)$$

The effect of temperature on BOD can be given by

$$K_{D_{T°C}} = K_{D_{20°C}} (1.047)^{T-20}$$

$$\therefore \quad K_{D_{30°C}} = K_{D_{20°C}} (1.047)^{10}$$

$$K_{D_{30°C}} = 1.583 K_{D_{20°C}}$$

$$\therefore \quad L\left(1 - 10^{-K_D \times 5}\right) = L\left(1 - 10^{-1.583 \times K_D \times t}\right)$$

$$\Rightarrow \quad 10^{-K_D \times 5} = 10^{-1.583 \times K_D \times t}$$

$$\therefore \quad t = \frac{5}{1.583} = 3.16 \text{ days}$$

7.27 (c)

If sufficient oxygen is present in water the useful aerobic bacteria will flourish and cause the biological decomposition of waste and organic matter, thereby reducing the carbonaceous material from water. The amount of oygen required in the process until oxidation gets completed is known as BOD. Polluted waters will continue to absorb oxygen for many months and it is not practically possible to determine this ultimate oxygen demand. Hence, the BOD of water during the first five days at 20°C is generally taken as standard demand.

7.28 (d)

Grease data is associated with skimming tanks.

7.29 (d)

Population equivalent of city

$$= \frac{\text{BOD produced per day in city}}{\text{Standard BOD per capital}}$$

$$= \frac{95 \times 10^6 \times 300}{75} = 380 \times 10^6$$

7.31 (b)

BOD rate constant (k_D) varies with temperature (T) as,

$$k_{D_{T°C}} = k_{D_{20°C}} [1.047]^{T-20}$$

k_D is computed from BOD values measured at various times as it depends upon the nature of the organic matter present in sewage.

8 Disposing of the Sewage Effluents

8.1 Which one of the following solid waste disposal methods is ecologically most acceptable?
(a) Sanitary landfill (b) Incineration
(c) Composting (d) Pyrolysis
[ESE : 1995]

8.2 A polluted stream undergoes self-purification in four distinct zones:
1. Zone of clear water
2. Zone of active decomposition
3. Zone of degradation
4. Zone of recovery
The correct sequence of these zones is
(a) 3, 4, 2, 1 (b) 2, 3, 4, 1
(c) 2, 4, 3, 1 (d) 3, 2, 4, 1
[ESE : 1995]

8.3 The formation for BOD assimilation in a stream should include
(a) BOD rate constant
(b) sedimentation of organic matter
(c) BOD rate constant and sedimentation of organic matter
(d) pathogenic bacterial decay coefficient
[ESE : 1996]

8.4 Eutrophication of water bodies is caused by the
(a) discharge of toxic substances
(b) excessive discharge of nutrients
(c) excessive discharge of suspended solids
(d) excessive discharge of chlorides
[ESE : 1996]

8.5 Non-disposal of solid waste may cause the spread of
(a) malaria
(b) rodents related plague
(c) typhoid
(d) dysentery
[ESE : 1996]

8.6 Which of the following materials are used as landfill sealants for the control of gas and leachate movements?
1. Lime 2. Sand
3. Bentonite 4. Fly ash
5. Butyl rubber
Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 4 and 5
(c) 3 and 5 (d) 1, 2 and 4
[ESE : 1997]

8.7 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Sludge disposal	1. Seeding
B. Sludge digestion	2. Biofilters
C. Aerobic action	3. Lagooning
D. Recirculation	4. Contact bed

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	3	1	2	4
(c)	1	3	2	4
(d)	1	3	4	2

[ESE : 1997]

8.8 Which one of the following would help prevent the escape of foul sewer gases from a water closet?
(a) Air gap (b) Vent pipe
(c) Gully trap (d) none of these
[ESE : 1997]

8.9 Self purification of running streams may be due to
(a) sedimentation, oxidation and coagulation
(b) dilution, sedimentation and oxidation
(c) dilution, sedimentation and coagulation
(d) dilution, oxidation and coagulation
[ESE : 1997]

8.10 The typical density in kg/m^3 (in situ) of well-compacted municipal solid waste in landfill is in the range of
(a) 100 to 300 (b) 310 to 500
(c) 550 to 850 (d) 900 to 1100
[ESE : 1997]

8.11 The following zones are formed in a polluted river
1. Zone of clear water
2. Zone of active decomposition
3. Zone of recovery
4. Zone of pollution
The correct sequence in which these zones occur progressively downstream in a polluted river is
(a) 4, 2, 1, 3 (b) 4, 2, 3, 1
(c) 2, 4, 3, 1 (d) 2, 4, 1, 3
[ESE : 1998]

8.12 Which one of the following methods can be employed for plastic and rubber waste disposal?
(a) Composting (b) Incineration
(c) Sanitary landfill (d) Pyrolysis
[ESE : 1998]

8.13 For fish habitat in a river, the minimum dissolved oxygen required is
(a) 2 mg/L (b) 4 mg/L
(c) 8 mg/L (d) 10 mg/L
[ESE : 1999]

8.14 **Assertion (A):** Sanitary landfills can no longer be used for the disposal of solid wastes in India.
Reason (R): The leachates from sanitary landfills may pollute the ground water.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1999]

8.15 When a sewage is disposed off in a river, the rate of depletion of dissolved oxygen of the river mainly depends on
(a) biochemical oxygen demand of the sewage
(b) chemical oxygen demand of the sewage
(c) total organic carbon present in the sewage
(d) dissolved oxygen present in the sewage
[ESE : 2000]

8.16 From ecological considerations, the minimum level of Dissolved Oxygen (DO) necessary in the rivers and streams is
(a) 1 mg/L (b) 2 mg/L
(c) 4 mg/L (d) 8 mg/L
[ESE : 2000]

8.17 Which one of the following sets of processes is a part of self-purification of streams?
(a) Settling, bio-degradation and desalination
(b) Settling, bio-degradation and aeration
(c) Floatation, ion exchange and desalination
(d) Desalination, ion exchange and reverse osmosis
[ESE : 2000]

8.18 When sewage enters a flowing river, the rapid depletion of dissolved oxygen is due to
(a) change in temperature in river water
(b) the suspended particles in river and waste
(c) respiratory activity of aquatic plants in the river
(d) microbial activity
[ESE : 2000]

8.19 When wastewater is disposed of into a running stream, four zones are formed. In which one of the following zones will the minimum level of dissolved oxygen be found?
(a) Zone of degradation
(b) Zone of active decomposition
(c) Zone of recovery
(d) Zone of clear water
[ESE : 2001]

8.20 Which one of the following methods would be best suited for disposal of plastic and rubber waste?
(a) Composting (b) Incineration
(c) Pyrolysis (d) Sanitary landfill
[ESE : 2001]

8.21 Which one of the following comprehensive classifications is used for different types of solid wastes?
(a) Residential, commercial and treatment plant wastes
(b) Food, demolition and construction wastes
(c) Municipal, industrial and hazardous wastes
(d) Rubbish, special wastes and wastes from open areas
[ESE : 2001]

8.22 The least expensive and most suitable excreta disposal unit for rural areas would be the
(a) soak pit
(b) pit privy
(c) leaching cesspool
(d) septic tank

[ESE : 2001]

8.23 The least expensive and most suitable excreta disposal unit for rurual areas would be the
(a) soak pit (b) pit privy
(c) leaching cesspool (d) septic tank

[ESE : 2001]

8.24 **Assertion (A):** U.K. Royal Commission on Sewage Disposal of 1898-1915 classified British rivers on the basis of 65° F, 5-day BOD.
Reason (R): British rivers do not have flow time to open sea more than 5 days.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

8.25 The description of solid waste collected is as follows:

Night soil	:	35 t
Rubbish	:	40 t
Debris	:	25 t
Garbage	:	40 t

The organic solids in the above composition is
(a) 35 t (b) 60 t
(c) 100 t (d) 75 t

[ESE : 2002]

8.26 The term 'Refuse' generally does not include
(a) putrescible solid waste
(b) excreta
(c) non-putrescible solid waste
(d) ashes

[ESE : 2003]

8.27 In dissolved oxygen sag curve, the sag curve results because
(a) it is a function of rate of addition of oxygen to the stream
(b) it is a function of rate of addition of oxygen from the stream
(c) it is a function of both addition and depletion of oxygen from the stream
(d) the rate of addition of oxygen is linear but the rate of depletion is non-linear

[ESE : 2004]

8.28 In which type of lakes, does a perfect ecological equilibrium among the producers, decomposers and consumer groups of organisms exist?
(a) Senescent lakes
(b) Mesotrophic lakes
(c) Oligotrophic lakes
(d) Eutrophic lakes

[ESE : 2005]

8.29 What is eutrophication of lakes primarily due to?
(a) Multiplication of bacteria
(b) Excessive inflow of nutrients
(c) Increase in benthic organisms
(d) Thermal and density currents

[ESE : 2007]

8.30 Which among the following brings about the Hazardous Waste Management and Handling Rules in India?
(a) Central Pollution Control Board
(b) Ministry of Environment and Forests
(c) Ministry of Urban Development
(d) Ministry of Rural Development

[ESE : 2007]

8.31 The daily cover of MSW landfills consists of which one of the following?
(a) Compacted soil (b) Geomembrane
(c) Geotextile (d) Geocomposite

[ESE : 2007]

8.32 What does the presence of excess nitrates in river water indicate?
(a) Recent pollution of water with sewage
(b) Past pollution of water with sewage
(c) Intermittent pollution of water with sewage
(d) No pollution of water with sewage

[ESE : 2008]

8.33 Shallow ponds in which dissolved oxygen is present at all depths are called
(a) aerobic lagoons
(b) aerobic ponds

(c) facultative lagoons
(d) facultative ponds

[ESE : 2010]

8.34 In the facultative pond systems, the aerobic zone may get extended downwards due to
(a) calm waters along with weak sunlight
(b) mixing by wind action along with weak sunlight
(c) mixing by wind action along with penetration by sunlight
(d) calm waters along with penetration by sunlight

[ESE : 2010]

8.35 Deep ponds, in which oxygen is absent except, perhaps, across a relatively thin surface layer, are called
(a) aerobic ponds
(b) anaerobic ponds
(c) facultative ponds
(d) polishing ponds

[ESE : 2011]

8.36 Assertion (A): The BOD gets removed at a very fast rate immediately after sewage is discharged into a river.

Reason (R): A part of the BOD in the sewage is due to settleable organic matter therein.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

8.37 Statement-I : Municipal Solid Waste is disposed off in the Transport Safe Disposal Facility (TSDF) to convert it into organic compost.

Statement-II : The organic Municipal Solid Waste is converted into compost by worms; and the process is called 'Vermicomposting'.

[ESE : 2012]

8.38 Which of the following help to prevent water pollution due to land-disposal of waste?
1. Proper consolidation of waste to reduce pore space and permeability.
2. Disposal over impervious strata.
3. Layer of impervious soil of the top and the sides of the deposited solid waste.

(a) 1 and 2 only (b) 1 and 3 only
(c) 1, 2 and 3 (d) 2 and 3 only

[ESE : 2015]

8.39 Consider the following statements regarding excreta disposal without water carriage system:
1. Pit-Privy is a pit in the ground with the toilet seat located directly over it.
2. Bore-Hole Latrines do not cause nuisance due to files and odour.
3. Aqua-Privy works on the same principle as a septic tank.
4. In the context of a Bore-Hole Latrine, a pit of about 30 cm to 40 cm diameter is dug to a depth of 4 m to 8 m.

Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 2 and 4 only
(c) 1, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2015]

8.40 Assertion (A): Composting is basically a treatment method for inorganic waste from a community.

Reason (R): In the incineration method of refuse disposal, the refuse is burnt off and the volume is much reduced.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2015]

8.41 Sewage sickness relates to
(a) Toxicity of sewage interfering with 'response' to treatment
(b) Destruction of aquatic flora and fauna due to gross pollution of receiving bodies of water by the sewage
(c) Reduction in the waste purifying capacity of the soil
(d) Clogging of pores in soil due to excessive application of sewage leading to obstruction of land aeration thereby leading to septic conditions in land.

[ESE : 2016]

Answers Disposing of the Sewage Effluents

8.1	(c)	8.2	(d)	8.3	(a)	8.4	(b)	8.5	(c)	8.6	(c)	8.7	(a)	8.8	(d)	8.9	(b)
8.10	(d)	8.11	(b)	8.12	(d)	8.13	(b)	8.14	(d)	8.15	(a)	8.16	(c)	8.17	(b)	8.18	(d)
8.19	(b)	8.20	(c)	8.21	(c)	8.22	(d)	8.23	(b)	8.24	(a)	8.25	(d)	8.26	(b)	8.27	(c)
8.28	(c)	8.29	(b)	8.30	(b)	8.31	(a)	8.32	(b)	8.33	(b)	8.34	(c)	8.35	(b)	8.36	(d)
8.37	(b)	8.38	(c)	8.39	(c)	8.40	(d)	8.41	(d)								

Explanations Disposing of the Sewage Effluents

8.1 (c)

The leachate from sanitary landfill tend to pollute ground water. Incineration and pyrolysis release air pollutants. Composting does not has any harmful effect.

8.2 (d)

Zones in polluted water	Minimum DO Levels
(i) Zone of clear water	100% saturation
(ii) Zone of degradation	40% saturation
(iii) Zone of active decomposition	0% saturation
(iv) Zone of recovery	40% saturation

8.3 (a)

In a stream the natural purification processes are:

(i) Dilution
(ii) Sedimentation and resuspension
(iii) Filtration
(iv) Gas transfer i.e., aeration
(v) Heat transfer
(vi) Chemical conversions i.e., oxidation, reduction and precipitation
(vii) Metabolic processes

The BOD (dissolved and suspended) gets diluted when a point/line source discharges waste water into a water body. The suspended organic matter gets settled and resuspended due to eddies. The microorganism consume BOD by metabolic processes and it depends upon BOD rate.

8.4 (b)

Eutrophication is caused by undesired increase in the concentration of nutrients in an ecosystem.

Increased nutrient enrichment can arise from both point and non-point sources:

- **Point source pollution:** Pollution that comes from contaminants that enter a waterway from a single identifiable source such as stationary locations or fixed facilities. Examples are discharges from a sewage treatment plant or industrial plants and fish farms.
- **Non-point source pollution:** Pollution from widespread including human activities with no specific point of discharge or entry into receiving watercourses. Examples are leaching out of nitrogen compounds from fertilized agricultural lands and losses from atmospheric deposition.

8.5 (c)

Non-disposal of solid waste will result in biodegradation of organic matter. This will cause obnoxious odour and attract flies which are the chief agents of diseases like typhoid, dyphtheria, diarrhoea, etc.

8.6 (c)

Sealants are used of control for gas and leachate movement

Classification types	Representative
(i) Compacted clay	: Bentonites, illites, kaolinites.
(ii) Inorganic chemicals	: Sodium carbonate, silicate or pyrophosphate
(iii) Synthetic chemicals	: Polymers, rubber latex
(iv) Synthetic membrane	: PVC, butyl rubber, hypalon, poly-thene, nylon reinforced liners.

(v) Asphalt : Modified asphalt, asphalt-covered polypropylene fabric, asphalt concrete.

(vi) Others : Gunite concrete, soil cement, plastic soil cement.

The sealant material should be more impermeable than the soil. So sand will not be a suitable material. Flyash and lime themselves produce pollutants which dissolve in water. Therefore, these materials cannot be used as sealants.

8.7 (a)

Raw sludge can be disposed of without digestion using lagoons.

Seeding is the process of introducing micro-organism from an already functioning plant into a newly constructed plant. Due to seeding, the micro-organisms take some time to acclimatize themselves to the new environment and this is called lag phase. This is true for all type of plants (Activated Sludge, trickling filter, sludge digestion, etc.) based on biological treatment. However it is more important factor in anaerobic sludge digestion process.

Biofilters are high rate trickling filters based on recirculation of effluent from trickling filter to primary clarifier.

Contact beds for filtration of sewer is based on aerobic decomposition.

8.8 (d)

Gully trap is provided at the junction of the room or a roof drain and the other drain coming from bath, kitchen, etc. It may be P-trap or S-trap.

Intercepting trap is provided at the junction of a house sewer and a municipal sewer.

Water closets are fitted with P or S-trap.

8.9 (b)

The major physical processes involved in self purification of watercourses are dilution, sedimentation and resuspension, gas transfer, and heat transfer. Gas transfer includes oxidation.

8.10 (d)

When compacting a broad range of municipal solid wastes the typical density obtained is about 1100 kg/m^3 irrespective of the starting density and applied pressure.

8.12 (d)

When Waste is burnt in absence of oxygen, then this method of solid waste disposal is called Pyrolysis. It is the second best option after recycling. The solids are separated from the volatile liquid and gaseous compounds that can be used as fuel. Thus it helps in reducing dependency on fossil fuel and geo-extraction.

8.13 (b)

The amount of DO an aquatic organism needs depends upon its species, the temperature of the water, pollutants present, and the state of the organism itself (adult or young, active or dormant).

The generally accepted minimum amount of DO that will support a large population of various fishes is from 4 to 5 mg/l. When the DO drops below 3 mg/l, even the hardy fish die.

8.14 (d)

Leachate movement should be controlled by well designed drainage system. So that ground water may not get polluted.

8.15 (a)

Rate of depletion of dissolved oxygen, coincides with the rate of BOD exertion.

$$\therefore \quad \frac{dy}{dt} = -\frac{dC}{dt}$$

where C is the concentration of DO

$$y_t = L_0 - L_t$$

$$\frac{dC}{dt} = \frac{dL_t}{dt} = -kL_0e^{-kt}$$

y_t is BOD at any time t

L_0 is ultimate BOD

L_t is oxygen equivalent of the organics at time t

8.16 (c)

The generally accepted minimum amount of DO that will support a large population of various fishes is from 4 to 5 mg/l. When the DO drops below 3 mg/l, even the hardy fish die.

8.17 (b)

Self purification of streams include physical, chemical and biological process.

A. Physical processes:
Dilution; sedimentation and resuspension; filtration; gas transfer; and heat transfer.

B. Chemical Processes:
Chemical conversion (oxidation and reduction)

C. Biological process:
Metabolic processes in micro-organisms.

8.18 (d)

The biodegradable matter present in sewage is consumed by microorganisms through aerobic respiration. This decreases the dissolved oxygen in river.

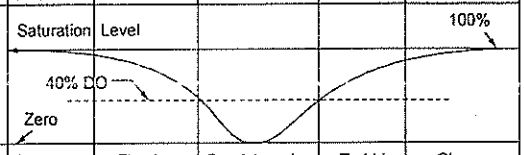
8.19 (b)

When a single large charge of sewage is poured into a clean stream, the water becomes turbid, sunlight is shut out of the depths, and green plants, which by photosynthesis remove carbon dioxide from the water and release oxygen to it, die off. Depending on the stream velocity, the water soon turns nearly black. Odorous sulfur compounds are formed and solids settle to the bottom, forming sludge. The settled solids soon decompose, forming gases such as ammonia, carbon dioxide, and methane or marsh gas. Scavenging organisms increase in number until they match the food supply. The oxygen resources are drawn upon heavily and, when overloaded, become exhausted. Life in such waters is confined to anaerobic bacteria (which exist when no oxygen is available), larvae of certain insects such as mosquitoes, and a few worms. There are no fish; turtles are generally the only forms of higher life present. This condition is known as the **zone of degradation.**

In a second zone, or **zone of decomposition,** more solids settle out, the water becomes somewhat clearer, and sunlight penetrates the surface. Oxygen is absorbed from the atmosphere at the air-water interface permitting the establishment of aerobic (oxygen available) conditions. The aerobic bacteria continue the conversion of organic matter into nitrates, sulfates, and carbonates. These, together with the carbon dioxide produced by decomposition as well as by bacteria and plant life, are food sources. With sunlight now penetrating the water, and with abundant food, algae begin to flourish and form a green scum over the surface.

In the third zone, or **zone of recovery,** algae become more numerous and self-purification proceeds more rapidly. Green plants utilizing carbon dioxide and oxygen will liberate in the say time more oxygen than is consumed, thus hastening the recovery of the stream. Simultaneously, the fish that require little oxygen such as catfish are also found. As the dissolved oxygen increases, more types of fish appear.

After recovery, in the **zone of clearer water,** fish find the stream highly favorable, as the algae support various aquatic insects and other organisms on which fish feed. The water is clear or turbid according to concentration of algae, and may have odour for the same reason.

Parti-cular	Zones of Pollution				
	Clear Water	Zone of Degradation	Zone of active decomposition	Zone of Recovery	Zone of Clearer water
1. DO SAG Curve					
2. Physical Indices	Clear Water No Bottom Sludges	Floating Solids, Bottom Sludge Colour, Turbidity	Grenish and Darker colour, CH_4, H_2S, CO_2 N_2 Gases Evolution, Black Scum at Top	Turbid with Bottom Sludge	Clearer water with no bottom sludge

8.20 (c)

Pyrolysis is a form of treatment that chemically decomposes organic materials by heat in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above 430°C (800°F). In practice, it is not possible to achieve a completely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. If volatile or semi-volatile materials are present in the waste, thermal desorption will also occur.

Organic materials are transformed into gases, small quantities of liquid, and a solid residue containing carbon and ash. The off-gases may also be treated in a secondary thermal oxidation unit. Particulate removal equipment is also required. Several types of pyrolysis units are

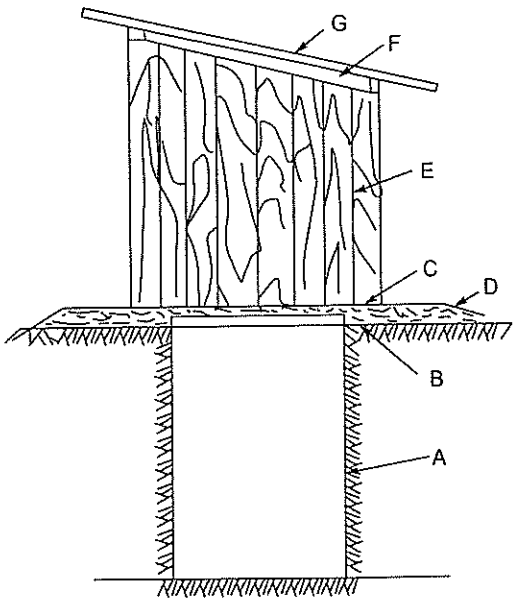
available, including the rotary kiln, rotary hearth furnace, and fluidized bed furnace. These units are similar to incinerators except that they operate at lower temperatures and with less air supply.

8.21 (c)

Three general categories of solid waste and their sub classification are as follows:

1. Municipal wastes:
   (i) Food wastes
   (ii) Rubbish
   (iii) Ashes and residues
   (iv) Demolition and construction wastes
   (v) Special wastes
   (vi) Treatment-plant wastes
2. Industrial wastes :
   (i) Rubbish, ashes, demolition and construction wastes, special wastes
3. Hazardous wastes :
   (i) Radioactive substances
   (ii) Chemicals (corrosive, reactive, toxic)
   (iii) Biological wastes
   (iv) Flammable wastes
   (v) Explosives

8.23 (b)



A = PIT
B = BASE
C = FLOOR
D = MOUND
E = ENCLOSURE INCLUDING DOOR
F = VENTILATION
G = FLOOR

Measurements shown are in cms

Various Parts of a Pit Privy

The pit privy consists of a hole-dug in the ground covered with either a squatting plate or a slab provided with riser and seat. A super structure is built around it. The function of the pit is to isolate and store human excreta in such a way that no harmful bacteria can be carried further to the new host.

8.24 (a)

British rivers were classified by Royal Commission on Sewage Disposal of 1898-1915 on basis of 65°F, 5 day BOD because at that time their rivers did not have flow time to open sea more than 5 days.

8.25 (d)

Night soil, and garbage are organic wastes
Debris is waste from demolition and construction.
Rubbish includes all non-putrescible wastes except ashes.
Thus organic solids = 35 + 40 = 75 t.

8.26 (b)

Refuse density is 300 to 600 kg/m^3.
Density of rubbish < garbage < ashes

8.27 (c)

The rate of change of deficit

$$\frac{dD}{dt} = k_1 L_t - k_2 D$$

k_1, k_2 are reaction rate constants for oxygen removal and addition respectively.
L_t is BOD at time t
D is oxygen deficit

8.28 (c)

A perfect ecological system means that there are producers, consumers, and decomposers present in the system in such a manner that food and energy flows from one level to the other. The pollutants (nitrogen and phosphorous) disturb this equilibrium by increasing productivity of a lake. As the productivity of a lake increases, its water quality reduces and equilibrium is disturbed. Oligotrophic lakes have low level of productivity so they can be considered to be perfect ecological system.

8.29 (b)

Eutrophication is a natural process under which lakes get infested with algae and silt up gradually

to become shallower and more productive through the entry and cycling of nutrients like carbon, nitrogen and phosphorous. This natural process of eutrophication in fact can always get its carbon and nitrogen requirements from the atmospheric gases like CO_2 and NO_2; while the requirement of phosphorous is met by its presence in natural run off due to disintegration of rocks, which produce phosphorous. The increased phosphorous in lake water, will cause accelerated eutrophication of lakes and is called cultural eutrophication.

8.31 (a)

The municipal solid waste (MSW) is simply brought and dumped on the ground, spread in layers of about 0.5 m thickness, and compacted. Another layer of 0.5 m thickness is then placed on top of the previous layer and also compacted. Layering and compacting are repeated until a height of about 1.5 m is reached. At this point and at the end of a working day, a cover of earth of about 0.15 to 0.3 m thickness is compacted on the top and side slopes of the compacted heap, which is called a cell. This cover is called the daily cover.

8.32 (b)

The presence of nitrogen in sewage indicates the presence of organic matter and may occur in form of free ammonia, albuminoid nitrogen, nitrites and nitrates. The free ammonia indicated the very first stage of decomposition of organic matter (thrust indicating recently staled sewage); albuminoid nitrogen indicates quantity of nitrogen present in sewage before the decomposition of organic matter is started; the nitrites indicate the presence of partly decomposed (not fully oxidized) organic matter; and nitrates indicate the presence of fully oxidized matter.

8.33 (b)

Shallow ponds in which dissolved oxygen is present at all depths are called aerobic ponds. Although some oxygen is provided by diffusion from the air, the bulk of the oxygen in ponds is provided by photosynthesis. Lagoons are distinguished from ponds in that oxygen for lagoons is provided by artificial aeration.

When sufficient energy is supplied to keep the entire contents, including the sewage solids, mixed and aerated, the reactor is called an aerobic lagoon. When only enough energy is supplied to mix the liquid portion of the lagoon, solids settle to the bottom in areas of low velocity gradients and proceed to degrade anaerobically. This facility is called a facultative lagoon, and the process differs from that in the facultative pond only in the method by which oxygen is supplied.

8.34 (c)

Aerobic conditions are maintained in the upper portions of the facultative pond by oxygen generated by algae, and, to a lesser extent by penetration of atmospheric oxygen. Stagnant conditions in the sludge along the bottom prevent oxygen transfer to that region and anaerobic conditions prevail there. The boundary between the aerobic and anaerobic zones is not stationary. Mixing by wind action and penetration by sunlight may extend the aerobic area downward. Conversely calm waters and weak lighting result in the anaerobic layer rising toward the surface.

8.35 (b)

Stabilisation ponds may be classified as aerobic, facultative or anaerobic, depending upon the mechanism of purification.

In a totally aerobic pond, the stabilisation of water is brought about by aerobic bacteria, which flourish in the presence of oxygen.

In an anaerobic pond, however, the stabilisation of waste is mainly brought about by the usual anaerobic conversion of organic wastes to carbon dioxide, methane, and gaseous end products, with eruption of foul odours and pungent smells.

In a facultative pond, the upper layers work under aerobic conditions, while the anaerobic conditions prevail in the bottom layers. The upper aerobic layer of the pond acts as a good check against the evolution of the foul odours from such a pond.

Aerobic ponds are usually of depth of 0.5 m

Facultative ponds are usually of depth of 1 to 1.5 m

Anaerobic ponds are usually of depth of 2.5 to 4 m

8.36 (d)

Below the point where sewage is discharged into the river-stream zone of degradation or zone of pollution is found. This zone is characterised by

water becoming dark and turbid with formation of sludge deposits at the bottom. DO is reduced to about 40% of the saturation value. There is an increase in carbon dioxide content; reoxygenation (i.e., reaeration occurs but is slower than deoxygenation.

8.37 (b)

Vermicompost is the end product of the breakdown of organic matter by earthworms and is generally used in Municipal Solid Waste Management.

8.39 (c)

- A Pit Privy is a small structure, separate from a main building, which covers a pit in the ground with a toilet seat located directly over it.
- A Bore-Hole Latrine is a hole of 30 cm to 40 cm diameter drilled into the ground to a depth of 4m to 8m to receive and store the excreta. The disadvantage of this type of latrine is that it causes odour, attracts flies and may lead to groundwater contamination.
- An aqua privy is like a single chamber septic tank, except the toilet is located directly over the tank.

8.40 (d)

The organic material, excluding plastics, rubber and leather are separated from municipal solids wastes and are subjected to bacterial decomposition, the end product remaining after dissimilatory and assimilatory bacterial activity is humus or compost. The entire process involving both separation and bacterial conversion of the organic solid wastes is known as composting.

8.41 (d)

Sewage sickness relates to clogging of pore in soil due to excessive application of sewage leading to obstruction of land aeration thereby leading to septic condition in land.

■■■■

9 Treatment of Sewage

9.1 Match List-I (Process) with List-II (Biological agent) and select the correct answer using the codes given below the lists:

List-I

A. Oxidation ditch
B. Waste stabilization pond
C. Imhoff tank
D. Rotating Biological Contractor (RBC)

List-II

1. Facultative bacteria
2. Anaerobic bacteria
3. Aerobic bacteria (suspended culture)
4. Aerobic bacteria (attached culture)

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	3	1	2	4
(c)	1	2	3	4
(d)	3	4	1	2

[ESE : 1995]

9.2 One litre of sewage, when allowed to settle for 30 minutes gives a sludge volume of 27 cm^3. If the dry weight of this sludge is 3.0 grams, then its sludge volume index will be

(a) 9 (b) 24
(c) 30 (d) 81

[ESE : 1995]

9.3 **Assertion (A):** In waste-water treatment, waste stabilisation ponds are more successful in sunny tropical regions.

Reason (R): The bacterial action of purification is achieved through photo-synthetic bacteria.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1995]

9.4 The waste stabilization ponds can be

(a) aerobic (b) anaerobic
(c) facultative (d) any of the above

[ESE : 1996]

9.5 The following are the sewage treatment processes:

1. Primary sedimentation
2. Screening
3. Grit removal
4. Secondary sedimentation

When only preliminary treatment is to be given for sewage, select the required treatment processes including their correct sequence from the codes below:

(a) 2, 3 (b) 2, 3, 1
(c) 1, 2, 3, 4 (d) 3, 1, 2, 4

[ESE : 1996]

9.6 A grit chamber of dimensions 12.0 m × 1.50 m × 0.80 m liquid depth has a flow of 720 m^3/hr. Its surface loading rate and detention time are, respectively

(a) 4000 $m^3/hr/m^2$ and 1.2 minute
(b) 40000 Lph/m^2 and 40 minutes
(c) 40 $m^3/hr/m^2$ and 12 minutes
(d) 40000 Lph/m^2 and 1.2 minutes

[ESE : 1997]

9.7 Match List-I (Impurities to be removed from sewage) with List-II (Treatment unit used) and select the correct answer using the codes given below the lists:

List-I

A. Large floating matter
B. Suspended inorganic matter
C. Suspended organic matter
D. Dissolved organic matter

List-II

1. Trickling filter
2. Primary clarifier

3. Grit chamber
4. Screens

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	3	4	1	2
(c)	4	3	2	1
(d)	4	3	1	2

[ESE : 1997]

9.8 Which of the following are claimed advantageous in respect of aerobic sludge digestion as compared to anaerobic sludge digestion?
1. Lower BOD concentration in super-natant liquor.
2. Production of a sludge with excellent dewatering propensity.
3. Greater production of methane.
4. Lesser operating cost.
5. Lesser capital cost.

Select the correct answer using the codes given below:
(a) 1, 2 and 4 (b) 2, 3, 4 and 5
(c) 3, 4 and 5 (d) 1, 2 and 5

[ESE : 1997]

9.9 Which of the following waste disposal tasks are achieved by a septic tank with its dispersion trench?
1. Aerobic sludge digestion
2. Settling and anaerobic sludge digestion
3. Anaerobic sewage stabilization
4. Bio-oxidation of effluent

Select the correct answer using the codes given below:
(a) 1 and 3 (b) 3 and 4
(c) 2 and 4 (d) 1 and 4

[ESE : 1997]

9.10 Assertion (A): Horizontal velocity of flow through grit chambers is maintained between 24 to 30 cm/sec.
Reason (R): Removal of organic and inorganic particles larger than 0.1 mm diameter is very essential.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

9.11 The following three stages are known to occur in the biological action involved in the process of sludge digestion:
1. Acid fermentation
2. Alkaline fermentation
3. Acid regression

The correct sequence of these stages is
(a) 1, 2, 3 (b) 2, 3, 1
(c) 3, 1, 2 (d) 1, 3, 2

[ESE : 1998]

9.12 Fresh sludge has moisture content of 99% and, after thickening, its moisture content is reduced to 96%. The reduction in volume of sludge is
(a) 3% (b) 5%
(c) 75% (d) 97%

[ESE : 1998]

9.13 In the oxidation ditch, the excess sludge is taken to
(a) anaerobic digestor
(b) aerobic digester
(c) drying beds
(d) incinerator

[ESE : 1998]

9.14 The flow sheet of the liquid stream of a sewage treatment scheme consists of
1. Trickling filter
2. Primary settling tank
3. Grit chamber
4. Screen chamber
5. Secondary settling tank

The correct sequence of these units in the sewage treatment scheme of a liquid stream is
(a) 3, 4, 1, 2, 5 (b) 3, 4, 2, 1, 5
(c) 4, 3, 1, 2, 5 (d) 4, 3, 2, 1, 5

[ESE : 1998]

9.15 Which one of the following pairs is NOT correctly matched?
(a) Activated sludge...aeration
(b) Trickling filters...attached growth system
(c) Oxidation ditch...algae
(d) Channel grit chamber...proportional weir

[ESE : 1998]

9.16 The two main gases liberated from an anaerobic sludge digestion tank would include
(a) ammonia and carbon dioxide
(b) carbon dioxide and methane
(c) methane and hydrogen sulphide
(d) ammonia and methane
[ESE : 1998]

9.17 Which one of the following sewage treatment units has a Parshall flume?
(a) Trickling filter (b) Oxidation ditch
(c) Grit chamber (d) Aerated lagoon
[ESE : 1998]

9.18 Which one of the following principal types of reactors is related to trickling filter?
(a) Plug flow (b) Complete-mix
(c) Packed-bed (d) Fluidized-bed
[ESE : 1998]

9.19 Which one of the following is LEAST important in the activated sludge process?
(a) Proper proportion of the return sludge from the secondary settling tank
(b) Adequate aeration in the biological reactor, so as to maintain certain minimum dissolved oxygen
(c) Proper food to micro-organisms (F : M) ratio
(d) The sludge volume index of the return sludge to be less than 200
[ESE : 1998]

9.20 Sludge bulking can be controlled by
(a) chlorination (b) coagulation
(c) aeration (d) denitrification
[ESE : 1998]

9.21 The correct sequence of the sludge digestion steps is
(a) acid formation, hydrolysis, methane formation
(b) methane formation, acid formation, hydrolysis
(c) hydrolysis, methane formation, acid formation
(d) hydrolysis, acid formation, methane formation
[ESE : 1999]

9.22 Consider the following statements about waste stabilization ponds:
1. The pond has a symbiotic behaviour of waste stabilization through algae on one hand and bacteria on the other.
2. The oxygen in ponds is provided by algae through photosynthesis.
3. The detention period for waste stabilization pond is of the order of two to three days.
4. The bacteria, which develop in the pond, are aerobic bacteria.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2 and 4 (d) 1 and 2
[ESE : 1999]

9.23 Match List-I (Methods of solid wastes disposal) with List-II (Terms pertaining to the methods) and select the correct answer using the codes given below the lists:

List I
A. Incineration
B. Sanitary landfill
C. Composting
D. Salvage by sorting

List-II
1. Requires presorting, grinding and turning
2. Limited to special wastes and selected materials
3. High operational and maintenance cost
4. Tractor
5. Rat and fly breeding

Codes:

	A	B	C	D
(a)	2	5	4	3
(b)	1	4	2	3
(c)	3	4	1	2
(d)	3	5	4	2

[ESE : 1999]

9.24 **Assertion (A):** Vent should be provided over both the septic tank and the seepage pit.
Reason (R): The vent pipes remove the gases that are generated due to bacterial action and avoid building up of pressure.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1999]

9.25 In which one of the following tests is the organic matter in the waste water used as food by micro-organisms?
(a) BOD
(b) Most probable number
(c) COD
(d) Chlorine demand
[ESE : 2000]

9.26 The function of algae in an oxidation pond is to
(a) provide a mat over the surface of the oxidation pond so as to prevent evaporation of water
(b) provide oxygen for bacteria to degrade organic matter
(c) provide a greenish appearance to the pond
(d) prevent the odour nuisance
[ESE : 2000]

9.27 Consider the following pairs of treatment units and impurities removed:
1. Grit chamber : Sand and silt
2. Detritus tank : Organic matter
3. Primary sedimentation tank : Suspended impurities
4. Aeration tank of activated sludge process plant : Oil and grease
Which of these pairs are correctly matched?
(a) 1 and 2 (b) 1, 2, 3 and 4
(c) 2, 3 and 4 (d) 1 and 3
[ESE : 2000]

9.28 Aerobic method of composting practiced in India is called
(a) Bangalore method (b) Nagpur method
(c) Delhi method (d) Indore method
[ESE : 2000]

9.29 Consider the following advantages:
1. Lower BOD concentration in supernatant liquor.
2. Production of a sludge with excellent dewatering capacity.
3. Recovery of methane gas.
4. Lower operation cost.
Which of these are the advantages of anaerobic digestion over aerobic digestion?
(a) 1 and 4 (b) 1 and 2
(c) 2, 3 and 4 (d) 1, 2 and 3
[ESE : 2000]

9.30 The MLSS concentration in the aeration tank of extended aeration activated sludge process is 4000 mg/L. If one litre of sample settled in 30 minutes and the measuring cylinder showed a sludge volume of 200 mL, then the sludge volume index would be nearly
(a) 200 (b) 150
(c) 100 (d) 50
[ESE : 2000]

9.31 Match List-I (Treatment units) with List-II (Type of processes) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Trickling filter	1. Symbiotic
B. Activated sludge process	2. Extended aeration
C. Oxidation ditch	3. Suspended growth
D. Oxidaton pond	4. Attached growth

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	1	2
(c)	3	4	1	2
(d)	4	3	2	1

[ESE : 2001]

9.32 If the moisture content of a sludge is reduced from 98% to 96%, the volume of sludge will decrease by
(a) 2% (b) 20%
(c) 25% (d) 50%
[ESE : 2001]

9.33 In a high rate trickling filter, the problem of ponding can be solved by
(a) flooding and raking
(b) chlorination and supply of air
(c) raking and chlorination
(d) flooding and supply of air
[ESE : 2001]

9.34 Consider the following statements:
The process of activated sludge can be explained as
1. a physical action whereby the finer suspended particles of sewage form a sublayer for a bacterial film at the surface

2. a chemical action whereby the finer suspended particles and colloidal solids are combined into masses of large bulk
3. a biochemical action whereby the sludge flocs so formed act as vehicles for aerobic bacteria oxidizing the organic matter

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

[ESE : 2001]

9.35 Sewage may be disposed of without treatment into a water body if the available dilution is
(a) less than 150 (b) more than 150
(c) more than 300 (d) more than 500

[ESE : 2001]

9.36 Which one of the following terms, correctly describes 'Biomagnification'?
(a) Reproduction of micro-organisms
(b) Observation of micro-organisms under a microscope
(c) Ability of micro-organisms to form zo-ological film
(d) Concentration of toxic materials in the food chain

[ESE : 2001]

9.37 Assertion (A): Settled sewage is subjected to biological treatment.
Reason (R): Any biological treatment is preceded by a settling tank.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

9.38 At a sewage treatment plant for a flow of 3 m^3/s, the cross-sectional area of grit chamber will be about
(a) 3 m^2 (b) 10 m^2
(c) 25 m^2 (d) 30 m^2

[ESE : 2002]

9.39 In the preliminary treatment of wastewater skimming tanks are often included in the treatment scheme. Various features of skimming tanks are that these
1. can remove general floating matter
2. can remove oily and greasy matter
3. have detention time of 30 min
4. employ compressed air blown through diffusers

Which of these statements are correct?
(a) 1 and 3 (b) 2 and 4
(c) 2 and 3 (d) 1 and 2

[ESE : 2002]

9.40 In a sanitary landfill, decomposition and chemical changes within organic content of the solid waste goes on. Consequential changes within landfill can be
1. temperature changes within landfill
2. production of gases like H_2S, CO, CO_2 and CH_4
3. destruction of pathogens
4. production of other gases like SO_2 and NO_2

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3
(c) 1 and 4 (d) 2 and 3

[ESE : 2002]

9.41 Bangalore method and Indore method of disposing solid wastes are
(a) identical
(b) different as Bangalore method is an anaerobic method
(c) different as Bangalore method does not contain human excreta
(d) different as Indore method is an incineration method

[ESE : 2003]

9.42 Consider the following data in the design of grit chamber:
1. Specific gravity of grit = 2.7
2. Size of grit particle = 0.21 mm
3. Viscosity of water = 1.0×10^{-2} cm^2/s

The settling velocity (cm/s) of the grit particle will be
(a) 1 to 2.5 (b) 2.6 to 5.0
(c) 5.1 to 7.8 (d) > 7.8

[ESE : 2003]

9.43 Amongst the various sewage treatment methods, for the same discharge, the largest area is needed for

(a) trickling filter
(b) anaerobic pond
(c) oxidation ditch
(d) oxidation pond

[ESE : 2003]

9.44 Consider the following treatment steps in a conventional wastewater treatment plant:
1. Primary sedimentation
2. Grit removal
3. Disinfection
4. Secondary sedimentation
5. Screening
6. Secondary treatment unit

The correct sequence of these steps is
(a) 5-2-1-6-4-3 (b) 1-2-4-5-3-6
(c) 2-3-4-5-6-1 (d) 6-5-4-3-2-1

[ESE : 2003]

9.45 In an activated sludge process, the sludge volume index can be controlled by
(a) aeration
(b) adding chlorine
(c) reducing recycling ratio
(d) increasing the depth of aeration tank

[ESE : 2003]

9.46 A primary sedimentation tank is not required for
(a) activated sludge system
(b) extended aeration system
(c) trickling filtration system
(d) tapered activated sludge process using pure oxygen for aeration

[ESE : 2003]

9.47 Match List-I (Parameter) with List-II (Treatment unit or process) and select the correct answer using the codes given below the lists:

List-I
A. F/M ratio
B. Solar energy
C. Effluent recirculation
D. Volatile fatty acids

List-II
1. Anaerobic digester
2. Detritus tank
3. Waste stabilization pond
4. Trickling filter
5. Activated sludge process

Codes:

	A	B	C	D
(a)	2	3	5	4
(b)	5	3	4	1
(c)	5	1	4	3
(d)	4	1	2	3

[ESE : 2004]

9.48 In aerobic conditions, the microbial decomposition of organics results in the formation of which one of the following?
(a) Stable and objectionable end products
(b) Unstable and objectionable end products
(c) Unstable and acceptable end products
(d) Stable and unobjectionable end products

[ESE : 2004]

9.49 An industry manufacturing urea produces waste water, which largely contains urea and ammonia. The treatment plant consists following units for effective control of nitrogen:
1. Nitrification followed by denitrification
2. Hydrolysis unit
3. Ammonia stripping by air
4. Lime dosing and mixing unit

Which one of the following is the correct sequence of above unit operations in the treatment plant?
(a) 3-2-1-4 (b) 2-3-1-4
(c) 2-4-3-1 (d) 4-2-3-1

[ESE : 2004]

9.50 Which one of the following reactors can create a problem of short circuiting due to density currents?
(a) Batch (b) Complete mix
(c) Plug flow (d) Fluidized bed

[ESE : 2004]

9.51 **Assertion (A):** Composting is the most commonly used process for the decomposition of the organic components of municipal solid wastes.
Reason (R): Bangalore method is a common anaerobic method used for biological conversion of organic components of municipal solid wastes.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2005]

9.52 Match List-I (Treatment process) with List-II (Related terms) and select the correct answer using the codes given below the lists:

List-I
A. Lagoons
B. Trickling filter
C. Oxidation ponds
D. Activated sludge process

List-II
1. Attached growth system
2. Algae-bacteria symbiotic relationship
3. Extended aeration
4. Low cost treatment method

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2005]

9.53 Which one of the following statements is not correct?
(a) Settling and sludge digestion occurs in septic tanks in one compartment.
(b) Settling and sludge digestion occurs in imhoff tank in different compartments.
(c) Septic tank is a low-rate anaerobic unit whereas an imhoff tank is a high rate anaerobic unit.
(d) The rate of sludge accumulation in septic tank is approximately 40-70 litres/ capita/year.

[ESE : 2005]

9.54 Consider the following statements in regard to aerobic and anaerobic treatment processes:
1. Biomass production in the aerobic treatment process is more as compared to the anaerobic treatment process.
2. Start-up period is more in the aerobic treatment process as compared to the anaerobic treatment process.
3. Energy consumption and production is more in the aerobic treatment process as compared to the anaerobic treatment process.

Which of these statements is/are correct?
(a) 1 and 2 (b) 2 and 3
(c) Only 2 (d) Only 1

[ESE : 2005]

9.55 When the recirculation ratio in a high rate trickling filter is unity, then what is the value of the recirculation factor?
(a) 1 (b) > 1
(c) < 1 (d) Zero

[ESE : 2005]

9.56 Match List-I (Process/Bacteria) with List-II (Energy/Material) and select the correct answer using the codes given below the lists:

List-I
A. Anabolism
B. Autotrophs
C. Catabolism
D. Heterotrophs

List-II
1. Providing energy for the synthesis of new cells and maintenance of other cell functions
2. Obtaining energy and material for growth from organic sources
3. Providing the material necessary for cell growth
4. Obtaining energy and material for growth from inorganic sources

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	3	2	1	4
(c)	1	2	3	4
(d)	3	4	1	2

[ESE : 2006]

9.57 Match List-I (Physical properties of filtering material for trickling filters) with List-II (Limiting value) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Crushing strength N/mm^2	1. 12.0
B. Hardness	2. 100.0
C. Per cent wear	3. 4.0
D. Specific gravity	4. 2.6

Codes:

	A	B	C	D
(a)	2	1	2	4
(b)	2	4	3	1
(c)	3	4	2	1
(d)	2	1	3	4

[ESE : 2007]

9.58 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Suspended solids
B. Nutrients
C. Heavy metals
D. Dissolved inorganic solids

List-II

1. May cause eutrophication
2. Toxic, may interfere with effluent reuse
3. May interfere with effluent reuse
4. Cause sludge deposits

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2007]

9.59 Which one of the following methods of solid waste management conserves energy most efficiently in the form of gas or oil?
(a) Incineration with heat recovery
(b) Combusting
(c) Fluidized-bed incineration
(d) Pyrolysis

[ESE : 2007]

9.60 In conventional activated sludge process, MLSS is generally kept in which range?
(a) < 100 mg/L (b) 1000 – 2000 mg/L
(c) 2000 – 3000 mg/L (d) 3000 – 5000 mg/L

[ESE : 2007]

9.61 Which one of the following is considered as the thermophilic range of sludge digestion?
(a) 60°C to 70°C (b) 50°C to 57°C
(c) 29°C to 40°C (d) 20°C to 30°C

[ESE : 2008]

9.62 Consider the following statements:
In the context of sludge volume index (SVI),
1. the SVI is expressed as the volume (in cc) of the activated sludge for one gram of dry weight of the sludge.
2. a higher value of SVI indicates a light and fluffy sludge which is not easily settleable.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2008]

9.63 An industry has a sewage treatment plant which produces sludge with a moisture content of 98%. With the solid content remaining the same, the sludge is thickened so that the moisture content now is 96%. If the original quantity of sludge is P, what is the quantity of the thickened sludge?
(a) 0.98P (b) 3P/4
(c) 2P/3 (d) P/2

[ESE : 2008]

9.64 In a well operating activated sludge process unit, what is the value of sludge volume index?
(a) < 50 (b) 100-150
(c) 200-300 (d) > 300

[ESE : 2008]

9.65 Bangalore and Indore process of composting are which of the following?
(a) Both anaerobic processes
(b) Both aerobic processes
(c) Anaerobic process and aerobic process, respectively
(d) Aerobic process and anaerobic process, respectively

[ESE : 2008]

9.66 A solid waste sample has been segregated and one of the components has been subjected to elemental analysis. The result of analysis in per cent by mass revealed C (40%), H (6.0%) O (44%), N (0.3%). What is the likely waste component?
(a) Food waste (b) Paper and cardboard
(c) Plastic waste (d) Leather waste

[ESE : 2008]

9.67 Which of the following pollutants are generally not removed in a sewage treatment plant?
(a) Inorganic suspended solids
(b) Dissolved organic solids
(c) Oil and grease
(d) Dissolved inorganic solids

[ESE : 2009]

9.68 Effluent from a wastewater treatment plant (flow rate = 8640 m^3/d, temperature = 25°C) is discharged to a surface stream (flow rate = 1.2 m^3/s, temperature = 15°C). What is the temperature of the stream after mixing?

(a) 10°C (b) 15.77°C
(c) 20°C (d) 24.99°C

[ESE : 2009]

9.69 Match List-I (Water/Wastewater treatment) with List-II (Operating problem) and select the correct answer using the codes given below the lists:

List-I
A. Trickling filter
B. Activated sludge process
C. Rapid gravity filter
D. Anaerobic sludge digester

List-II
1. Negative head
2. Fly-breeding
3. Sludge bulking
4. pH reduction

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	2	3	1	4
(c)	4	1	3	2
(d)	2	1	3	4

[ESE : 2009]

9.70 Which one of the following types of samples is relevantly employed for the design of wastewater treatment plant?

(a) Grab sample
(b) Composite sample
(c) Integrated sample
(d) Any sample

[ESE : 2009]

9.71 A drain carrying sewage of BOD = 200 mg/L and flow rate of 50 m^3/s joins a river whose upstream BOD is 8 mg/L and flow rate is 500 m^3/s. Assume immediate and complete mixing of drain with the river. What is the estimated downstream BOD of the river flow?

(a) 20.4 mg/L (b) 25.4 mg/L
(c) 104.4 mg/L (d) 70.4 mg/L

[ESE : 2009]

9.72 A 12.5 mL sample of treated waste-water requires 187.5 mL of odor-free distilled water to reduce the odor to a level that is just perceptible. What is the threshold odor number (TON) for the wastewater sample?

(a) 0.07 (b) 1.07
(c) 15 (d) 16

[ESE : 2009]

9.73 Which one of the following parameters is not included in the routine characterization of solid waste for its physical composition?

(a) Moisture content
(b) Density
(c) Particle size analysis
(d) Energy value

[ESE : 2009]

9.74 **Assertion (A):** The rate of biomass production will be always lower than the rate of food utilization in a biological system having a mixed culture of micro-organism.

Reason (R): Catabolism converts part of the food into waste products.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2009]

9.75 In an aerobic attached-culture system, the biomass at the biofilm-medium surface interface experiences

(a) aerobic and endogenous metabolism
(b) anaerobic and endogenous metabolism
(c) anaerobic and exogenous metabolism
(d) aerobic and exogenous metabolism

[ESE : 2010]

9.76 Secondary clarifier of an activated sludge process must be designed for effluent clarification and solids thickening, both of which relate directly to the

(a) surface area
(b) transport velocity due to sludge withdrawal
(c) gravity settling of solids relative to the water
(d) underflow solids concentration

[ESE : 2010]

9.77 Consider the following statements:
In a sewage treatment process
1. detention time required for anaerobic decomposition is more as compared to that for aerobic decomposition.
2. Anaerobic decomposition is more energy-consuming as compared to aerobic decomposition.
3. Anaerobic decomposition is a more sensitive process as compared to aerobic decomposition.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 2 only
(c) 3 only (d) 1 and 3 only
[ESE : 2010]

9.78 Consider the following statements:
Activated sludge process can be said to comprise:
1. Conversion of dissolved organic matter into biological flocs
2. Removal of dissolved BOD of the waste water
3. Digestion of the sludge

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2011]

9.79 During sewage treatment, effluent from which one of the following treatment units has minimum wt/vol amount of suspended solids?
(a) Detritus channel
(b) Primary sedimentation tank
(c) Secondary sedimentation tank
(d) Activated sludge process aeration tank
[ESE : 2011]

9.80 The group of micro-organisms involved in production of methane from acetic acid (or acetate) in anaerobic waste water treatment processes is:
(a) Methanothrix and Methanobacterium
(b) Methanobacterium and Methanosarcina
(c) Methanosarcina and Methanospirillum
(d) Methanothrix and Methanosarcina
[ESE : 2011]

9.81 When sufficient energy through mechanical mixing is supplied to keep the entire contents, including the sewage solids, mixed and aerated, the reactor is termed
(a) an aerobic lagoon
(b) an aerobic pond
(c) a facultative lagoon
(d) a facultative pond
[ESE : 2011]

9.82 The manufacturer of aeration devices reports the oxygen transfer rate of the device obtained through laboratory tests carried under standard conditions. Such standard conditions are
(a) wastewater at zero DO, 25°C and 760 mm Hg
(b) Tapwater at zero DO, 0°C and 700 mm Hg
(c) Tapwater at zero DO, 20°C and 760 mm Hg
(d) Wastewater at zero DO, 0°C and 700 mm Hg
[ESE : 2011]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:
Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

9.83 **Assertion (A):** In the secondary sedimentation tank of a sewage treatment plant the settling particles form a blanket which descends and captures more particles.

Reason (R): The particles are flocculant and in very high concentration whenever there is an efficient working activated sludge, or trickling filter, process.
[ESE : 2011]

9.84 **Assertion (A):** The sludge processing utilizes the aerobic digestion in which it is converted to CO_2 and methane.

Reason (R): The acid-forming bacteria convert the complex organics such as fats, proteins and carbohydrates into organic fatty acids. The methane-forming bacteria convert organic acids to CO_2 and CH_4.
[ESE : 2012]

8.85 **Statement-I :** Chlorophyll-bearing plants take water and carbondioxide to synthesize carbohydrates.
Statement-II : Wasted food ultimately leads to production of various natural resources like water and sunlight energy.
[ESE : 2012]

9.86 What is the correct sequence of the following treatment units employed in a conventional sewage treatment plant?
1. Screen chamber
2. Primary settling tank
3. Trickling filter
4. Grit chamber
5. Secondary settling tank
(a) 5, 4, 2, 3 and 1 (b) 1, 4, 2, 3 and 5
(c) 5, 2, 3, 4 and 1 (d) 1, 4, 3, 2 and 5
[ESE : 2013]

9.87 Which of the following parameters are employed in the design of trickling filter?
1. Hydraulic loading rate
2. Organic loading rate
3. Detention time
4. Weir loading rate
(a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 2 and 3 only (d) 3 and 4 only
[ESE : 2013]

9.88 In activated sludge process, 1 MLD (by volume) of secondary sludge has to be returned to keep the required MLSS concentration in the aeration tank. This sludge has a water content of 99%. If the sludge water content is reduced to 98%, what volume of the sludge will be needed to be recycled?
(a) 0.25 MLD (b) 0.5 MLD
(c) 0.75 MLD (d) 1.00 MLD
[ESE : 2013]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below :
Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

9.89 **Statement (I):** Plastic media of 25 to 100 mm size are employed in super-rate trickling filters for treatment of waste-water having a very high BOD.
Statement (II): Plastic media have high specific surface area, high void space and low weight. Hydraulic loading rate and organic loading rate are 30 to 90 $m^3/d/m^2$ and 1000 to 2000 $g/d/m^3$ respectively, which are much higher than in stone media trickling filter.
[ESE : 2013]

9.90 **Statement (I):** The cross-section of grit channel is designed for a uniform velocity at all flow rates.
Statement (II): A U-type of cross-section maintains a uniform velocity at all flow rates.
[ESE : 2013]

9.91 **Statement (I):** For aerobic composting of refuse, it is mandatory to maintain the C/N ratio between 50 and 60.
Statement (II): C/N ratio is one of the important factors in composting. It is an important constituent as loss of nitrogen is to be prevented and maximum proportion of the nitrogen in compost is to be preserved.
[ESE : 2013]

9.92 In an aerobic attached culture system, the biomass present at the biofilm-medium surface interface experiences
(a) Aerobic and endogenous metabolism
(b) Anaerobic and exogenous metabolism
(c) Anaerobic and endogenous metabolism
(d) Aerobic and exogenous metabolism
[ESE : 2014]

9.93 A sewage sludge has a water content of 99%. What will be the concentration of suspended solids in the sludge?
(a) 10 mg/l (b) 100 mg/l
(c) 1000 mg/l (d) 10,000 mg/l
[ESE : 2014]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).

(c) Statement (I) is true but Statement (II) is false.

(d) Statement (I) is false but Statement (II) is true.

9.94 **Statement (I):** When waste water is treated at an oxidation ditch, anaerobic sludge digester is not required.

Statement (II): Oxidation ditch admits an extended aeration process whereby sludge gets mineralized.

[ESE : 2014]

9.95 **Statement (I):** The rate of biomass production will always be lower than the rate of food utilization in a biological system having a mixed culture of microorganisms.

Statement (II): Catabolism converts part of the food into waste products.

[ESE : 2014]

9.96 A sludge had 100 m^3 volume when its moisture content was 95%. What would be its volume if its moisture content changed to 90%?

(a) 200 m^3 (b) 50 m^3

(c) 94.7 m^3 (d) 105.5 m^3

[ESE : 2015]

9.97 The Sludge Volume Index for mixed liquor having suspended solids concentration of 2000 mg/l and showing a settled volume of 200 ml from a one litre sample would be

(a) 0.1 (b) 1000

(c) 100 (d) 10

[ESE : 2015]

9.98 The different actions that take place in anaerobic decomposition process are

1. Alkaline fermentation
2. Acid fermentation
3. Acid regression
4. Methane formation

What is the correct sequence of these actions (from earlier to later)?

(a) 4, 3, 1 and 2 (b) 2, 3, 1 and 4

(c) 4, 1, 3 and 2 (d) 2, 1, 3 and 4

[ESE : 2015]

9.99 Consider the following statements:

1. Ammonia nitrogen is a measure of nitrogen present as ammonium hydroxide and ammonium salts. It will progressively decrease as sewage gets treated.
2. Organic nitrogen is the total nitrogenous matter in sewage excepting that present as ammonia nitrogen, nitrites and nitrates. It becomes ammonia in anaerobic decomposition and nitrites or nitrates in aerobic decomposition.

Which of the above statements is/are correct?

(a) 1 only (b) Both 1 and 2

(c) 2 only (d) Neither 1 nor 2

[ESE : 2015]

9.100 What is the required plan size of a square sedimentation tank (as the primary sedimentation tank in sewage treatment), given that its effect depth is 3 m, and the flow rate is 40 MLD with admissible surface loading of 1000,000 l/m^2/day?

(a) 23.5 m × 23.5 m (b) 30 m × 30 m

(c) 20 m × 20 m (d) 15 m × 15 m

[ESE : 2015]

9.101 **Assertion (A):** Anaerobic digestion of sewage is unsuitable in the vicinity of a crowded locality.

Reason (R): Aerobic digestion of sewage is costly but is suitable at a crowded locality.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 2015]

9.102 100 m^3 of sludge holds a moisture content of 95%. If its moisture content changes to 90%, the volume of this sludge will then be

(a) 40.5 m^3 (b) 50 m^3
(c) 75 m^3 (d) 94.7 m^3

[ESE : 2016]

9.103 Consider the following statements in respect of flow equalization in a waste-water treatment plant:
1. Biological treatment is enhanced because shock loadings are eliminated or minimized.
2. Flow equalization is an attractive option for upgrading the performance of overloaded treatment plants.
3. Inhibiting substances can be diluted and pH can be stabilized.
4. Thickening performance of primary sedimentation tanks following grit removal is improved.

Which of the above statements are correct?
(a) 1, 2, 3 and 4
(b) 1, 2 and 3 only
(c) 1, 2 and 4 only
(d) 3 and 4 only

[ESE : 2016]

9.104 A drain carrying 5 m^3/s of wastewater with its BOD of 100 mg/*l* joins a stream carrying 50 m^3/s flow with it BOD of 5 mg/*l*. What will be the value of the BOD of the combined flow after complete mixing?
(a) 3.6 mg/*l* (b) 13.6 mg/*l*
(c) 33.6 mg/*l* (d) 53.6 mg/*l*

[ESE : 2016]

9.105 Consider the following statements in respect of aerated grit chamber:
1. The grit accumulates at the bottom in advancing spiral-flow aeration tanks, locationally preceded by grit chambers, led to the eventual development of aerated grit chambers.
2. The excessive wear on grit handling equipment is a major factor for the popularity of aerated grit chambers.
3. Aerated grit chambers are designed to provide detention period of 1 minute at maximum rate of flow.
4. Diffusers are located at 0.45 m to 0.6 m above the bottom of the chamber.

Which of the above statements are correct?
(a) 1, 2 and 3 only
(b) 3 and 4 only
(c) 1, 2 and 4 only
(d) 1, 2, 3 and 4

[ESE : 2016]

9.106 Consider the following statements in respect of anaerobic sludge digester:
1. It is less expensive compared to several other methods available.
2. Processing of separable solids impacts the environment to a minimum.
3. Quantity of separated solids requiring disposal is minimal.
4. Digested sludge is very readily dewaterable.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 3 and 4 only (d) 1, 2 and 4 only

[ESE : 2016]

9.107 Consider the following statements as regards a Septic Tank:
1. The size required is large and uneconomical when serving more than roughly 100 persons.
2. It can remove around 90% of BOD and 80% of suspended solids.
3. As compared to the sludge holding of a plain sedimentation tank, a septic tank can hold about 90% less of sludge volume.
4. Frequent removal of sludge is not required.

Which of the above statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

[ESE : 2016]

Directions: Each of the next items consists of two statements, one labelled as the **'Statement (I)'** and the other as **'Statement (II)'**. Examine these two statements carefully and select the answers to these items using the codes given below :

Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

9.108 **Statement (I) :** Aerobic condition in composting of refuse can be confirmed by temperature measurements.

Statement (II): Aerobic reactions are exothermic.

[ESE : 2016]

9.109 **Statement (I):** The rate of biomass production will be always lower than the rate of food utilization in a biological system having a mixed culture of micro-organisms.

Statement (II): Catabolism converts part of the food into waste products.

[ESE : 2017]

9.110 Consider the following statements regarding contact stabilization process:
1. Primary settling tank is not required in some cases.
2. BOD removal occurs in two stages.
3. Aeration volume requirements are approximately 50% of those of a conventional - or tapered - aeration plant.
4. Returned sludge is aerated for 30 min to 90 min in sludge aeration tank.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1 and 4
(c) 1, 2 and 3 (d) 2, 3 and 4

[ESE : 2017]

9.111 Consider the following statements regarding pyrolysis:
1. It is an irreversible chemical change brought about by the action of heat in oxygen free atmosphere.
2. Range of temperature is 500°C to 1000°C.
3. Internal heating causes organic matter to decompose physically and chemically rather than burn.
4. It is highly exothermic process.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 3 and 4
(c) 2 and 4 (d) 1, 2 and 3

[ESE : 2017]

Answers Treatment of Sewage

9.1	(b)	9.2	(a)	9.3	(c)	9.4	(d)	9.5	(a)	9.6	(d)	9.7	(c)	9.8	(d)	9.9	(c)
9.10	(c)	9.11	(d)	9.12	(c)	9.13	(c)	9.14	(b)	9.15	(c)	9.16	(b)	9.17	(c)	9.18	(c)
9.19	(d)	9.20	(a)	9.21	(d)	9.22	(d)	9.23	(c)	9.24	(d)	9.25	(a)	9.26	(b)	9.27	(d)
9.28	(d)	9.29	(c)	9.30	(d)	9.31	(d)	9.32	(d)	9.33	(c)	9.34	(a)	9.35	(d)	9.36	(d)
9.37	(c)	9.38	(b)	9.39	(b)	9.40	(b)	9.41	(b)	9.42	(b)	9.43	(d)	9.44	(a)	9.45	(c)
9.46	(b)	9.47	(b)	9.48	(d)	9.49	(d)	9.50	(c)	9.51	(b)	9.52	(c)	9.53	(c)	9.54	(d)
9.55	(b)	9.56	(a)	9.57	(d)	9.58	(a)	9.59	(d)	9.60	(c)	9.61	(b)	9.62	(c)	9.63	(d)
9.64	(b)	9.65	(c)	9.66	(a)	9.67	(d)	9.68	(b)	9.69	(b)	9.70	(a)	9.71	(b)	9.72	(d)
9.73	(d)	9.74	(a)	9.75	(b)	9.76	(a)	9.77	(d)	9.78	(b)	9.79	(d)	9.80	(d)	9.81	(a)
9.82	(c)	9.83	(a)	9.84	(d)	9.85	(c)	9.86	(b)	9.87	(b)	9.88	(b)	9.89	(a)	9.90	(c)
9.91	(d)	9.92	(c)	9.93	(d)	9.94	(a)	9.95	(a)	9.96	(b)	9.97	(c)	9.98	(b)	9.99	(b)
9.100	(c)	9.101	(b)	9.102	(b)	9.103	(a)	9.104	(b)	9.105	(c)	9.106	(a)	9.107	(c)	9.108	(a)
9.109	(a)	9.110	(c)	9.111	(d)												

Explanations Treatment of Sewage

9.1 (b)

Imhoff tank and septic tanks have anaerobic bacteria for BOD removal and waste stabilization.

9.2 (a)

Sludge volume index is the volume occupied in mL by one gm of solids in the mixed liquor after settling for 30 minutes. It indicates the physical state of sludge produced in a biological aeration system. It is used to decide the rate of recycle of sludge (Q) required to maintain the desired Mixed Liquor Suspended Solids (MLSS) and Food to Micro organism (F/M) ratio in the aeration tank to achieve the desired degree of purification. So by reducing recycling ratio SVI can be controlled.

The settled sludge volume

$$V_{ob} = 27 \text{ cm}^3/\text{lit} = 27 \text{ mL/lit}$$

The concentration of suspended solids in mixed liquor, $X_{ob} = 3$ g/lit

$$\therefore \quad \text{SVI} = \frac{V_{ob}}{X_{ob}} = \frac{27}{3} = 9 \text{ mL/gm}$$

9.3 (c)

The aerobic zone in stabilization pond gives complete purification by symbiotic relationship between algae and bacteria. The bacteria use oxygen as an electron acceptor to oxidize the waste water organics to stable end products such as CO_2, PO_4^{3-}. The algae in turn use these compounds as a material source and with sunlight as energy source, produce oxygen as an end product.

9.4 (d)

Waste Stabilization Ponds (WSPs) are large, man-made water bodies in which blackwater , greywater or faecal sludge are treated by natural occurring processes and the influence of solar light, wind, microorganisms and algae. The ponds can be used individually, or linked in a series for improved treatment.

9.5 (a)

Preliminary treatment units are:

(i) Screening and communitor

(ii) Grit chamber

(iii) Flow equalization tank and flow meter constant.

9.6 (d)

$$\text{Surface Loading rate} = \frac{720}{12 \times 1.5}$$

$$= 40 \text{ m}^3/\text{hr}/\text{m}^2 = 40000 \text{ ltr}/\text{hr}/\text{m}^2$$

$$\text{Detention time} = \frac{V}{Q} = \frac{12 \times 1.5 \times 0.8}{720} \times 60$$

$$= 1.2 \text{ minutes}$$

9.7 (c)

Trickling filter is used to remove the dissolved organic matter from waste water.

Suspended solids that pass through screens and grit chambers are removed from the sewage in sedimentation tanks. These tanks, called primary clarifiers, provide about two hours of detention time for gravity settling to take place.

Grit chambers are long narrow tanks that are designed to slow down the flow so that suspended inorganic solids will settle out of the water.

9.8 (d)

Aerobic digestion is an endogenous respiration process. Methane is not produced in this process.

Advantages of aerobic digestion compared to anaerobic digestion are:

(i) Volatile solids reduction is approximately equal to that obtained anaerobically.
(ii) Lower BOD concentrations in supernatant liquor.
(iii) Production of an odourless, humus like, biologically stable end product.
(iv) Recovery of more of the basic fertilizer value in the sludge
(v) Operation is relatively easy

Major disadvantages are:

(i) High power cost associated with supplying oxygen.
(ii) Digested biosolids have poorer settling characteristics (dewatering propensity).

9.9 (c)

Septic tanks are based on anaerobic process.

Stabilization means :

(i) Reduction of pathogens
(ii) Elimination of offensive odours and
(iii) Inhibitation, reduction or elimination of potential for putrefaction.

The principal methods for stabilization are:

(i) Alkaline stabilization
(ii) Anaerobic digestion
(iii) Aerobic digestion and
(iv) Composting.

In septic tanks digestion of settled solids reduces the sludge compared to that obtained from primary settling tank.

The dispersion trenches oxidize the effluent from septic tanks to reduce BOD.

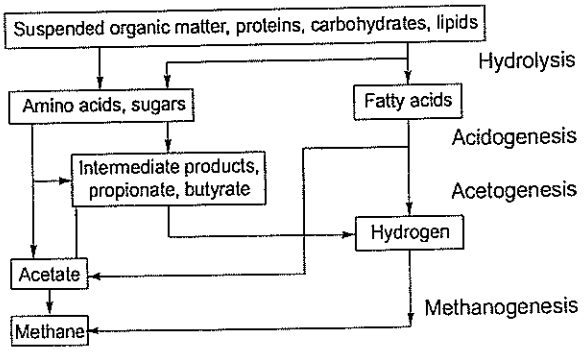
9.10 (c)

The horizontal flow velocity is maintained within 24 to 30 cm/s, so as not to cause scouring.

9.11 (d)

The factors that determine the removal efficiency of biodegradable organic matter are:

- The nature and composition of the organic matter to be removed.
- Suitability of environmental factors.
- Sludge retention time in the reactor.
- The intensity of mixing, hence contact between bacterial biomass and organic matter.
- Specific loading of organic matter with respect to bacterial sludge mass, and retention time.



Different steps are necessary for the anaerobic digestion of proteins, carbohydrates, and lipids. Four different phases can be distinguished in the overall conversion process of organic matter to biogas as (1) Hydrolysis, (2) Acidogenesis, (3) Acetogenesis and (4) Methanogenesis.

9.12 (c)

$$V_1(100 - p_1) = V(100 - p)$$

$$\Rightarrow \quad \frac{V_1}{V} = \frac{100-99}{100-96} = \frac{1}{4} = 0.25$$

$$\text{Volume reduction} = \frac{V - V_1}{V} \times 100 = 75\%$$

9.13 (c)

Oxidation ditch is based on extended aeration process. There is no need of separate sludge digester as the detention time is very large. So sludge can be directly taken to sludge drying beds.

9.14 (b)

The general flow sheet of liquid stream of a sewage treatment scheme consists of:

Screen Chamber → Grit Chamber → Primary Settling Tank → Trickling Filter → Secondary Settling Tank.

9.15 (c)

Oxidation pond is based on algae-bacteria symbiotic relationship.

9.16 (b)

Anaerobic digestion is a process by which microorganisms break down biodegradable material in the absence of oxygen.

9.17 (c)

Parshall flumes are proportioning weirs and they maintain constant flow velocity in grit chamber for settling (Type-I) of inorganic particles.

9.18 (c)

Type reactor	Applications in wastewater treatment
1. Batch	Activated sludge process
2. Complete-mix	Aerated lagoons, aerobic sludge digestion
3. Plug flow	Chlorine contact basin, natural treatment system
4. Packed bed	Non-submerged and submerged trickling filter, depth filtration, air stripping
5. Fluidized bed	Upflow sludge blanket.

9.19 (d)

Food to micro-organism ratio, and consequently proper proportion of return sludge from the secondary settling tank are important parameters. The return of sludge will be necessary to maintain adequate Mixed Liquor Suspended Solids (MLSS) concentration to achieve desired degree of treatment. Sludge volume index is calculated to evaluate the sludge settling characteristics. SVI values below 100 are desired and SVI values above 150 are typically associated with filamentous growth. The other measure of quantifying settling characteristics of activated sludge is zone settling rate. Oxygen is required in the activated sludge process in the aeration tank for oxidation of part of the influent organic matter, and also for endogenous respiration of the micro-organisms in the system. It should maintain specified level of DO in the waste-water i.e., 0.1-1.0 mg/L for conventional activated plants, 1-2 mg/L for extended aeration and above 2 mg/L for nitrification in the activated sludge plant.

9.20 (a)

Sludge bulking is caused by filamentous micro-organisms and sludge settling characteristics are very poor in this case.

It can be controlled by

(i) adjusting food to microorganism ratio
(ii) raising or lowering DO
(iii) using disinfectant (chlorine)

The problem of rising sludge is caused by denitrification in the secondary clarifier.

9.21 (d)

There are three stages in sludge digestion:

(i) **Hydrolysis:** Particulate material is converted to soluble compounds that can be hydrolysed further to simple monomers.
(ii) **Fermentation (Acidogenesis):** Amino acids, sugars and some fatty acids are degraded further. Final products of fermentation (acetate, hydrogen and CO_2) are precursors of methane formation.
(iii) **Methanogenesis**

9.22 (d)

Stabilization (facultative) ponds are based on symbiotic relationship of bacteria in anaerobic zone and algae in the aerobic zone. The bacteria uses oxygen as an electron acceptor to oxidize the waste water organics to stable end products

such as CO_2, NO_3^- and PO_4^{3-}. The algae in turn use these compounds as a material source and with sunlight as an energy source, produce oxygen as an end product.

The usual detention time is 7 to 30 days in facultative pond. The bacteria are facultative.

9.23 (c)

Presorting, grinding and turning are required in composting. Salvage by sorting can be adopted for non-biodegradable non-combustible material only.

9.24 (d)

Seepage pit is an absorption system for septic tank effluent. It does not have any vent pipe.

9.25 (a)

Biochemical oxygen demand is the amount of oxygen required for microbial metabolism of organic compounds in water. This demand occurs over some variable period of time depending on temperature, nutrient concentrations, and the enzymes available to indigenous microbial populations. The amount of oxygen required to completely oxidize the organic compounds to carbon dioxide and water through generations of microbial growth, death, decay, and cannibalism is total biochemical oxygen demand (total BOD).

9.26 (b)

Algae are autotrophic, photosynthetic organism and, even though they do not utilize organic compounds directly, yet play significant role in the natural purification process. In the presence of sunlight, algae metabolize the waste products of hetero-trophic bacteria (CO_2, NO_3^-, PO_4^{3-}, etc.) while obtaining energy from sunlight.

9.27 (d)

Detritus tanks are grit chambers designed for flow with smaller flow velocity and longer detention periods so as not only the grit, etc. is separated but also very fine sand particles settle. The organic matter settled in this tank is separated from the grit by currents through baffles.

9.28 (d)

Indore method is aerobic while Bangalore method is anaerobic for composting.

9.29 (c)

The advantages of anaerobic digestion over aerobic digestion are:

- Recovery of energy in the form of methane. This leads to lower operation cost.
- Anaerobically digested sludge contains nutrients and organic matter which improves the fertility of soil. It also has excellent dewatering capacity.

9.30 (d)

Sludge volume index (SVI)

$$= \frac{V_{0b}(\text{mL/L})}{X_{0b}(\text{mg/L})} \times 1000 = \frac{200}{4000} \times 1000$$

$= 50$ mL/gm

9.31 (d)

Suspended culture systems are:

(i) Activated sludge process and its variants like extended aeration.
(ii) Aerated lagoons and oxidation ponds
(iii) Aerobic digestion with aeration.

Attached culture systems are:

(i) Trickling filters
(ii) Rotating biological contractors
(iii) Packed bed reactors
(iv) Anaerobic packed and fluidized beds

9.32 (d)

$$(100 - p_1)\, V_1 = (100 - p_2)\, V_2$$

$$\Rightarrow \quad \frac{V_2}{V_1} = \left(\frac{100 - p_1}{100 - p_2}\right)$$

$$\Rightarrow \quad \frac{V_2}{V_1} = \frac{100 - 98}{100 - 96} = \frac{2}{4} = 0.5$$

$\therefore$ Decrease in volume is 50%

9.33 (c)

Ponding is caused by clogging of filter media due to heavy growth of fungi and algae. This can be controlled by raking and chlorinating. Chlorination kills the algae. Other algicide like copper sulphate can be added to the sewage and bed should be left resting for some time.

Facultative bacteria are the predominating organisms in trickling filters. In the lower reaches of the filter nitrifying bacteria will also be present. The fungi are also responsible for waste

stabilization under low pH-conditions or with certain industrial wastes. At time fungi growth can be so rapid that the filter clogs and ventilation becomes restricted.

Algae can grow only in the upper reaches of the filter where sunlight is available. Generally algae do not take part in waste degradation. The algae may cause clogging of filter surface which may cause odours.

9.34 (a)

Unit operations involve contaminant removal by physical forces, while unit processes involve biological and/or chemical reactions. A wastewater treatment system is composed of a combination of unit operations and unit processes designed to reduce certain constituents to an acceptable level.

In secondary treatment, biological and chemical processes are used to remove most of the organic matter.

9.35 (d)

Dilution factor	Purification needed
(i) Between 300-500	Primary treatment such as plain sedimentation. The effluent SS $\not>$150 ppm
(ii) Between 150-300	Screening, sedimen-tation, and chemical precipitation. The effluent SS $\not>$ 600 ppm
(iii) Less than 150	Complete treatment The effluent SS $\not>$ 30 ppm BOD_5 at 18.3°C $\not>$ 20 ppm

9.36 (d)

Biomagnification is the increasing concentration of a substance, such as a toxic chemical, in the tissues of organisms at successively higher levels in a food chain. This increase can occur as a result of:

- Persistence – where the substance cannot be broken down by environmental processes
- Food chain energetics – where the substance concentration increases progressively as it moves up a food chain
- Low or non-existent rate of internal degradation or excretion of the substance – often due to water-insolubility

Biological magnification often refers to the process whereby certain substances such as pesticides or heavy metals move up the food chain, work their way into rivers or lakes, and are eaten by aquatic organisms such as fish, which in turn are eaten by large birds, animals or humans. The substances become concentrated in tissues or internal organs as they move up the chain. Bioaccumulants are substances that increase in concentration in living organisms as they take in contaminated air, water, or food because the substances are very slowly metabolized or excreted.

9.37 (c)

Almost all biological treatments are preceded by a settling tank except in case of oxidation ponds. So reason is wrong.

9.38 (b)

The flow velocity in grit chamber is about 0.25 to 0.3 m/s. Therefore cross-sectional area $= \frac{3}{0.3} = 10\ m^2$

9.39 (b)

Skimming tanks are used for removal of oily and greasy matter. A detention time of 3 to 5 minutes is usually sufficient. The rise of oil and greasy matter is brought about by allowing compressed air into the sewage from diffusers. The oily and greasy matter should be removed because they interfere in secondary treatment process.

9.40 (b)

Gases found in landfills include air, ammonia, carbon dioxide, carbon monoxide, hydrogen, sulfide, methane, nitrogen and oxygen. Carbon dioxide and methane are the principal gases produced from the anaerobic decomposition of the organic solid waste components.

The landfilling operation is biological method of waste treatment, since the waste is stabilized by aerobic as well as anaerobic processes. During initial phase aerobic bacteria and fungi deplete the available oxygen. As a result of aerobic respiration, the temperature in the fill increases.

9.41 (b)

Bangalore method: This method of composting is an anaerobic method and was developed at Bangalore in India in 1939. It is recommended where night soil and refuse are used for preparing the compost. The method overcomes many of the disadvantages of the Indore method, such as the problem of heap protection from adverse weather, nutrient losses from high winds and strong sun, frequent turning requirements, and fly nuisance. However, the time required for the production of finished compost is much longer. The method is suitable for areas with scanty rainfall.

Indore method: This method of composting is an aerobic method through passive aeration and was made at Indore in India in mid 1920s.

9.42 (b)

Particle size (0.21 mm) is between 0.1 mm and 1 mm so the settling velocity in transition region will be given by Newton's law

$$v^2 = \frac{4}{3} g \frac{(\rho_p - \rho_w) d}{C_D \rho_w}$$

where $C_D = \frac{24}{Re}$ (laminar) when $Re < 1$

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34$$

(transition) when $1 < Re < 10^4$

$C_D = 0.4$ (turbulent) when $Re > 10^4$

Finding the settling velocity in transition region is a trial and error process. However, the velocity of particle can be calculated by assuming laminar flow and the velocity in transition region will be less than the calculated value.

$$v = \frac{g}{18}(S_s - 1)\frac{d^2}{v}$$

$$= \frac{9.81}{18} \times (2.7 - 1) \times \frac{(0.21 \times 10^{-3})^2}{10^{-2} \times 10^{-4}}$$

$$= 0.0408 \text{ m/s} = 4.08 \text{ cm/s}$$

Therefore settling velocity will line in range 2.6 to 5.0 cm/s.

9.43 (d)

Oxidation Ponds are also known as stabilization ponds or lagoons. They are used for simple secondary treatment of sewage effluents. Within an oxidation pond heterotrophic bacteria degrade organic matter in the sewage which results in production of cellular material and minerals.

9.44 (a)

Screening – Grit removal – Primary sedimentation – Secondary treatment unit – Secondary sedimentation – Disinfection will be the correct sequence.

If flow meter is also given then it will come after grit removal.

9.45 (c)

Sludge volume index is used to indicate the physical state of the sludge produced in a biological aeration system. It is defined as the volume occupied in ml by one gram of solids in the mixed liquor after settling for 30 minutes. The usual adopted range of SVI is between 50-150 ml/gm and such a value indicates good sludge. It can be controlled by reducing recycling rate.

9.46 (b)

In extended aeration system long detention times are provided with low F/M ratio and high MLSS concentration to maintain culture in endogenous phase. Primary sedimentation tank is frequently avoided in this process, but grit chamber or communitor is often provided for screening.

9.47 (b)

The F/M ratio is a process control number that helps to determine the proper number of microorganisms for the system. To do this calculation, the following information will be needed:

- Influent Flow into your activated sludge system (Flow MGD)
- Influent CBOD (mg/l) concentration into your aeration tank.
- Mixed Liquor Volatile Suspended Solids Concentration (mg/l)
- Volume (in gallons) of your aeration system

The term Food to Microorganism Ratio (F/M) is actually a measurement of the amount of incoming food (Lbs of Influent CBOD) divided by the Lbs of Microorganisms in the system. If case of an activated sludge system, F/M ratio is determined regularly.

9.48 (d)

In aerobic conditions, the microbial activity results in stable and unobjectionable end products. In anaerobic conditions, methane and carbondioxide (CO_2) are produced which are objectionable.

9.49 (d)

The waste from fertilizer manufacturing unit consists of:

(i) Very high nitrogen content as Ammonia and Urea
(ii) High Phosphates and Fluorides
(iii) High Arsenic
(iv) Oils

Removal of wastes:

(i) Oils are removed in a gravity separator.
(ii) Arsenic is segregated by hydrolysis. (water removal and concentration)
(iii) Phosphates and fluorides are segregated and chemically coagulated by lime and settled down in a settling tank.
(iv) Ammonia is removed by Lagooning or air stripped tower packed with red wool stakes.
(v) Nitrification and denitrification can be used for urea removal.

9.50 (c)

In Batch reactor flow is neither entering nor leaving the reactor i.e. flow enters is treated and then is discharged and the cycle repeats. The liquid content of the reactor are mixed completely. For example, the BOD test in BOD bottle is a batch reactor. These reactors are used for activated-sludge process with sequence batch reactors and mixing of concentrated solutions into working solutions.

In complete-mix reactor, it is assumed that complete mixing occurs instantaneously and uniformly throughout the reactor as fluid particles enter the reactor. Fluid particles leave the reactor in proportion to their statistical population. They are used in aerated lagoons, aerobic sludge digestion. Complete-mix reactor with recycle are used in activated sludge treatment.

In plug flow reactors fluid particles passes through the reactor in the same sequence in which they entered. The particles retain their identity and they remain in the reactor for a time equal to the theoretical retention time.

Fluidized-bed reactor is similar to the packed-bed reactor in many respects, but the packing material is expanded by the upward movement of fluid through the bed.

Non ideal flow is defined as short circuiting that occurs when a portion of arrives at the outlet before the bulk of the flow that entered the reactor during the same period arrives. This condition can occur incompletely mix or plug flow reactor. Mixing will break the layer of different density in completely mixed reactor. So density current short circuiting will occur in plug flow reactor.

9.51 (b)

Indore method is aerobic while Bangalore method is anaerobic and is hence more clean than the Indore method.

9.52 (c)

A **trickling filter** is a fixed-bed biological reactor that operates under aerobic conditions. Pre-settled wastewater is continuously 'trickled' or sprayed over the filter. As the water migrates through the pores of the filter, organics are aerobically degraded by the biofilm covering the filter material.

An **activated sludge process** refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required.

9.53 (c)

Both septic tank and imhoff tank are anaerobic units having same rate of anaerobic process.

9.54 (d)

Aerobic processes are more efficient than anaerobic processes with respect to biomass conversion and thus have a greater value of yield. Upon the addition of biomass, the organisms require time to acclimatize to their new environment before significant cell division and biomass production. The anaerobic bacteria are very sensitive to pH, salinity and temperature.

So their acclimatization period is more in anaerobic treatment process.

Although energy consumption for aeration is more in aerobic process but energy production is more in anaerobic process.

9.55 (b)

Recirculation factor,

$$F = \frac{1+\left(\frac{R}{I}\right)}{\left(1+0.1\frac{R}{I}\right)^2} = \frac{2}{(1.1)^2} > 1$$

9.56 (a)

Metabolic processes are of two types:

(i) Catabolism provides energy for synthesis of new cells as well as for maintenance of other cell functions.

(ii) Anabolism provides the material necessary for cell-growth. When an external food source is interrupted the organism will use stored food for maintenance energy in a process called endogenous catabolism. Enzymes play major role in biochemical reactions.

The chemical formula for bacterial cell is assumed to be $C_5H_7O_2N$. Organisms that derive energy and material from inorganic sources are called autotrophs, while bacteria that obtain both energy and material from organic compounds are called heterotrophs. Phototrophs, bacteria which utilize sunlight for an energy source and inorganic substances for a material source, play important role in natural water purification processes.

9.57 (d)

The ideal filter material is low-cost and durable, has a high surface to volume ratio, is light, and allows air to circulate. Whenever it is available, crushed rock or gravel is the cheapest option. The particles should be uniform and 95% of them should have a diameter between 7 and 10 cm. A material with a specific surface area between 45 and 60 m^2/m^3 for rocks and 90 to 150 m^2/m^3 for plastic packing is normally used. Larger pores are less prone to clogging and provide for good air circulation. Primary treatment is also essential to prevent clogging and to ensure efficient treatment.

9.58 (a)

Eutrophication is the depletion of oxygen in a water body, which kills aquatic animals. It is a response to the addition of excess nutrients, mainly phosphates, which induces explosive growth of plants and algae, the decaying of which consumes oxygen from the water. One example is the "bloom" or great increase of phytoplankton in a water body as a response to increased levels of nutrients. Eutrophication is almost always induced by the discharge of phosphate-containing detergents, fertilizers, or sewage, into an aquatic system.

9.59 (d)

Upon heating in an oxygen free atmosphere, most organic substances can be split through a combination of thermal cracking and condensation reactions into gaseous, liquid and solid fractions. This process is called pyrolysis. In contrast to the combustion process, which is highly exothermic the pyrolytic process is highly endothermic. Hence pyrolysis is also called destructive distillation. The converted products derived from solid wastes through pyrolysis like gas and oil possess a high energy content. Thus, these products can be stored and used for energy production by an additional conversion step.

9.60 (c)

Process	MLSS Range in mg/L
Conventional ASP	1500-3000
Completely mixed ASP	3000-6000
Extended Aeration ASP	3000-6000

9.61 (b)

The process of sludge digestion is greatly influenced by temperature, i.e. rate of sludge digestion is more at higher temperatures and vice versa. There are two distinct temperature zones:

(i) **Thermophilic digestion:** In this zone of high temperature, digestion is brought about by heat loving thermophilic organisms. The temperature in this zone ranges between 40° to 60°C with 54°C being optimum.

(ii) **Mesophilic digestion:** In this zone of moderate temperature, digestion is brought about by common mesophilic organisms. The temperature in this zone ranges between 25° to 40°C with 29°C being optimum.

9.62 (c)

Sludge Volume Index (SVI) is defined as the volume occupied in mL by one gram of solids in the mixed liquor after settling for 30 minutes. The usual adopted range of SVI is 50-150 mL/gm and such a value indicates good settling sludge.

9.63 (d)

If the sludge with volume V_1 and moisture content p_1 reduces to volume V and moisture content p, then

$$V = V_1\left[\frac{100-p_1}{100-p}\right] = P\left[\frac{100-98}{100-96}\right] = \frac{P}{2}$$

9.64 (b)

Sludge Volume Index is a calculation that indicates the tendency of activated sludge solids (aerated solids) to thicken or to become concentrated during the sedimentation/thickening process. SVI is calculated in the following manner: (1) allow a mixed liquor sample from the aeration basin to settle for 30 minutes; (2) determine the suspended solids concentration for a sample of the same mixed liquor; (3) calculate SVI by dividing the measured (or observed) wet volume (mL/L) of the settled sludge by the dry weight concentration of MLSS in grams/L.

9.66 (a)

Higher percentage of carbon and oxygen indicate that it is food waste.

9.67 (d)

Pollutants removed:

- Inorganic suspended solids
- Dissolved organic solids
- Oil and grease

Process of treatment:

- Primary sedimentation tank
- Trickling filter, Activated Sludge Process
- Skimming Tank

Dissolved inorganic solids are not removed in water treatment process.

9.68(b)

Temperature of the mix

$$T = \frac{Q_wT_w + Q_sT_s}{Q_w + Q_s}$$

$$= \frac{8640\times25 + 1.2\times24\times60\times60\times15}{8640 + 1.2\times24\times60\times60}$$

$$= 15.77°C$$

9.70(a)

The physical and chemical characteristics of sewage vary from top to bottom of sewage depth as well as with time as from morning to evening. Samples are taken at a point beneath the surface where the turbulence is thoroughly mixing up the sewage particles. This is called a grab sample. Such grab samples are collected at regular intervals during a day.

9.71(b)

$$BOD_{mix} = \frac{Q_SBOD_S + Q_RBOD_R}{Q_S + Q_R}$$

$$= \frac{50\times200 + 500\times8}{50+500}$$

$$= 25.45\ mg/L$$

9.72(d)

Threshold odour number is given as

$$TON = \frac{A+B}{A}$$

where A is the volume of odorous water (mL) and B is the volume of odor-free water required to produce a 200 mL mixture.

$$\therefore \quad TON = \frac{12.5+187.5}{12.5} = 16$$

9.73(d)

The parameters which are included in the routine characterization of solid waste for its physical composition are particle size analysis, moisture content and density.

Energy content, chemical content are the parameters used in chemical composition.

9.74(a)

If all the food were converted to biomass, then the rate of food utilization would equal the rate of biomass production. But, since catabolism

converts part of the food into waste products, the rate of food utilization will be greater than the rate of biomass production.

9.75 (b)

Attached-culture systems employ reactors in which waste water is contacted with microbial films attached to surfaces. Surface area for biofilm growth is increased by placing a porous medium in the reactor. The organisms attach themselves to the medium and grow into dense films of a viscous, jellylike nature. Waste water passes over this film in thin sheets with dissolved organics passing into the biofilm due to concentration gradients within the film. Suspended particles and colloids may be retained on the sticky surfaces where they are decomposed into soluble products. Oxygen from the wastewater and from air in the void spaces of the medium provide oxygen for aerobic reactions at the biofilm surface. Waste products from the metabolic processes diffuse outward and are carried away by the water or air currents moving through the voids of the medium. Growth of the biofilm is restricted to one direction-outward from the solid surface. As the film grows thicker, concentration gradients of both oxygen and food develop. Eventually, both anaerobic and endogenous metabolism occur at the biofilm-medium surface interface. The attachment mechanism is a weakened and the shearing action of the wastewater flowing across the film pulls it from its mooring and washes it away. This process known as sloughing, is function of both the hydraulic and organic loading rate. Biofilm is quickly reestablished in places cleared by sloughing.

9.76 (a)

Secondary clarifiers for activated sludge must accomplish two objectives. First, they must produce an effluent sufficiently clarified to meet discharge standards. Secondly, they must concentrate the biological solids to minimize the quantity of sludge that must be handled. Thus, secondary clarifiers must be designed for effluent clarification and solids thickening, both of which relate directly to the surface area.

9.78 (b)

Activated sludge plant involves:

1. wastewater aeration in the presence of a microbial suspension,
2. solid-liquid separation following aeration,
3. discharge of clarified effluent,
4. wasting of excess biomass, and
5. return of remaining biomass to the aeration tank.

In activated sludge process wastewater containing organic matter is aerated in an aeration basin in which micro-organisms metabolize the suspended and soluble organic matter. Part of organic matter is synthesized into new cells and part is oxidized to CO_2 and water to derive energy. In activated sludge systems the new cells formed in the reaction are removed from the liquid stream in the form of a flocculent sludge in settling tanks. A part of this settled biomass, described as activated sludge is returned to the aeration tank and the remaining forms waste or excess sludge.

9.79 (d)

The sludge obtained from the sludge digestion plant of activated sludge process contains too much of moistuse (98% to 99%) and is very bulky. Detritus tanks are nothing but grit chambers designed to flow with a smaller flow velocity (of about 0.09 m/sec) and longer detention periods (about 3 to 4 minutes) so as to separate out not only the larger grit, etc., but also to separate out the very fine sand particles.

9.80 (d)

For the biomass converting acetal to methane, there are two classes of methanogens Methanothrix and Methanosarcina. The first class has a low specific activity and a low half velocity constant which causes it to predominate in systems with low steady state acetate concentrations. This is true of most operating systems because they are lowly loaded. The second class-Methanosarcina have relatively high half velocity constants and specific activities. In addition the nutritional requirements of methanosarcina is more than Methanothrix.

9.81 (a)

Aerated lagoons are common in small communities. These systems use aerators to mix the contents of the pond and add oxygen to the wastewater. They are sometimes referred to as partial-mix or complete-mix lagoons depending on the extent of aeration.

9.82 (c)

760 mm of Hg is standard atmospheric pressure.

9.83 (a)

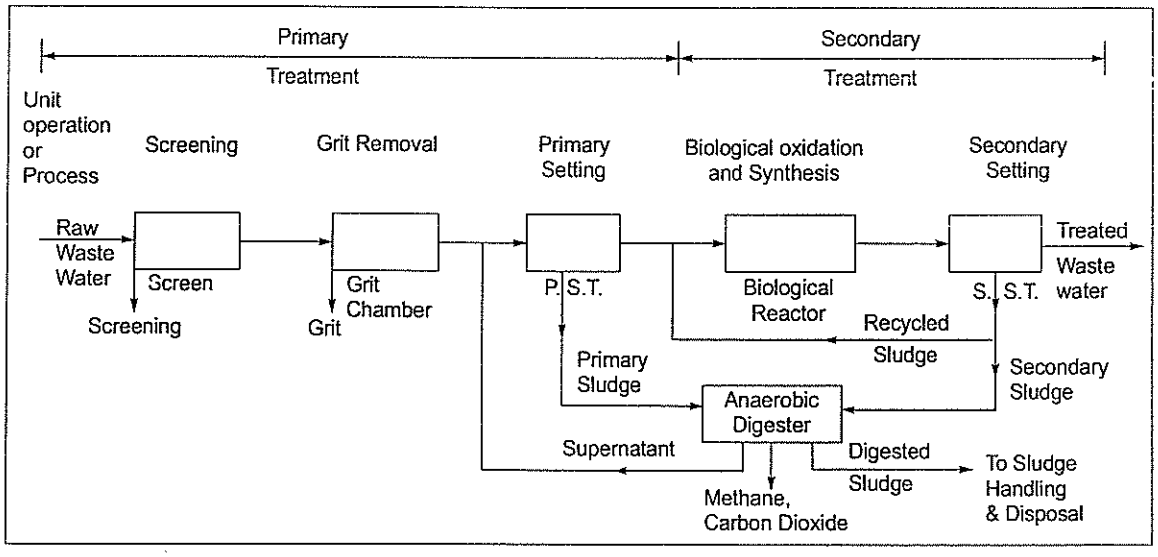
The secondary sedimentation facility is provided after the biological reactor to facilitate the sedimentation of the cells produced during biological oxidation of organic matter. If these cells produced are not removed, complete treatment will not be achieved as these cells will represent about 30 to 60% of the organic matter present in untreated wastewater in aerobic treatment. Depending on the type of reactor used fraction of these settled cells is returned back to the reactor and remaining cells are wasted as excess sludge for further treatment.

9.84 (d)

Sludge digestion can be achieved both under aeroboic as well as anaerobic conditions. Of these anaerobic sludge digestion is most common and normally adopted in conventional treatment. As sludge contains much of solid materials proper aeration by agitation with air is difficult. The aerators themselves will likely to get choked by solid particles. Moreover sludge reduction in terms of volume is less in aerobic digestion. In anaerobic digestion organic acids are converted into CO_2 and CH_4.

9.86 (b)

Process Flow-sheet of Conventional Domestic Sewage Treatment Plant.



8.85 (c)

Sunlight is not produced from wasted food.

$$\text{Carbon Dioxide + Water} \xrightarrow{\text{Light}} \text{Glucose + Oxygen}$$

$$6CO_2 + 6H_2O \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

9.87 (b)

The design of trickling filter primarily involves finding out diameters and depth of the tank, which is based on the values of the filter loadings that are:

- Hydraulic Loading Rate
- Organic Loading Rate

9.88 (b)

$$V_1(100-p_1) = V_2(100-p_2)$$

$$\Rightarrow \quad V_2 = (1\,\text{MLD})\left(\frac{100-99}{100-98}\right)$$

$$= 1\left(\frac{1}{2}\right) = 0.5\ \text{MLD}$$

9.89 (a)

Super rate trickling filter: It is also called as 'Roughing filter' or 'Biotower'. Plastic media is used in this filter. Since the power required in Bio-filter per unit of BOD removal is less as compared to ASP, these are becoming popular these days. They are used ahead of the existing trickling filter or ASP and are generally constructed above ground. The walls of the biotower can be made from RCC or when modular plastic media is used the walls can be made from the plastic, since there is no hydrostatic pressure on the walls. Air blower may be provided in addition to natural air draft in biotower to enhance oxygen resources of the system to handle higher organic loading rates.

9.90 (c)

Uniform velocity section is and not the U-type section.

9.91 (d)

Optimum C/N ratio is 30-50 and it is one of the most important factors affecting composting process. Hence assertion is false.

9.94 (d)

Moisture content

$$= 99\%$$

$$= \frac{\text{weight of water}}{\text{weight of solid}}$$

Hence, 100 kg wet sludge makes

$$\frac{100\,\text{kg}}{1\times 100\,\text{kg/m}^3} = 0.1\ \text{m}^3$$

$\therefore$ Concentration of suspended solid

$$= \frac{1\text{kg}}{0.1\text{m}^3} = \frac{1\times 10^6\,\text{mg}}{0.1\times 10^3\,l}$$

$$= 1\times 10^4\ \text{mg}/l$$

9.95 (a)

The rate of food utilization would be equal to rate of biomass production if all food were converted to biomass. Catabolism provides the chemical energy necessary for the maintenance and growth of cells. Since energy is obtained from food, therefore a part of food gets used up in catabolism and the rest of the food gets converted into biomass.

9.96 (b)

$$V_1(100-p_1) = V_2(100-p_2)$$

$$\Rightarrow \quad 100(100-95) = V_2(100-90)$$

$$\therefore \quad V_2 = 50\ \text{m}^3$$

9.97 (c)

Sludge volume index is the volume occupied in mL by one gm of solids in the mixed liquor after settling for 30 minutes.

$$\therefore \quad \text{SVI} = \frac{200\,mL}{2000\times 10^{-2}\ \text{gm}} = 100\ \text{mL/gm}$$

9.100 (c)

Required surface area

$$= \frac{40\times 10^6}{10{,}000} = 400\ \text{m}^2$$

(Square sedimentation tank)

$\therefore \quad B^2 = 400$

$\Rightarrow \quad B = L = 20\ \text{m}$

9.101 (b)

Aerobic digestion of sewage is costly but suitable for big cities because in aerobic digestion system end products are an odourless, humus like, biological stable end product.

9.102 (b)

$$V_1(100-P_1) = V_2(100-P_1)$$

$$V_1 = 100\ \text{m}^3$$

$$P_1 = 95\%$$

$$P_2 = 90\%$$

$$100(100-95) = V_2(100-90)$$

$$100\times 5 = V_2(10)$$

$$\Rightarrow \quad V_2 = 50\ \text{m}^3$$

9.103 (a)

Flow equalization basin is located after screening and grit removal and before primary sedimentation.

9.104 (b)

$$\text{BOD mix} = \frac{Q_S BOD_S + Q_R BOD_R}{Q_S + Q_R}$$

$$= \frac{5 \times 100 + 50 \times 5}{5 + 50} = \frac{750}{55}$$

$$= 13.6 \text{ mg/}l$$

9.105 (c)

An aerated grit chamber consists of a standard spiral flow aeration tank provided with air diffusion tubes placed on one side of the tank. The grit particles tend to settle down to the bottom of the tank at rates dependent upon the particle size and the bottom velocity of roll of the spiral flow, which in turn depends on the rate of air diffusion through diffuser tubes and shape of aeration tank. The heavier particles settle down whereas the lighter organic particles are carried with roll of the spiral motion.

9.107 (c)

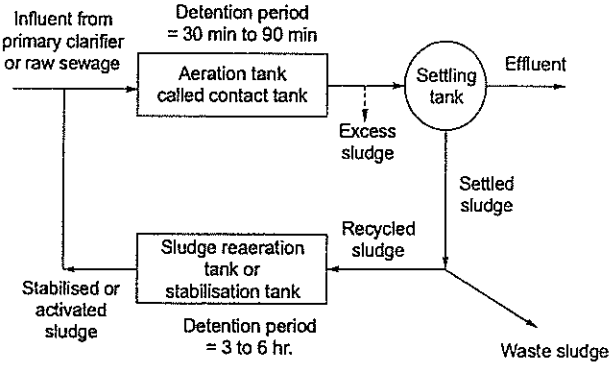
A septic tank is a watertight chamber made of brick work, concrete, fiberglass, PVC or plastic, through which blackwater from cistern or pour-flush toilets and greywater through a pipe from inside a building or on outside toilet flows for primary treatment. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate. Effluent is infiltrated into the ground or transported via a sewer to a centralized treatment plant. Accumulating faecal sludge needs to be dug out of the chamber regularly and correctly disposed off.

9.110 (c)

Contact Stabilisaton Process or Biosorption Process:

This process has been designed for treating colloidal wastewaters.

In this process, the sewage and returned sludge are mixed and aerated for a comparatively shorter period of 30 to 90 hour in a special mixing tank, called contact tank. This mixing will allow the suspended and dissolved organic matter to be sorbed to the activated sludge floc. The sorbed organics and flocs are removed in the secondary settling tank, where the effluent from the contact tank enters. These settled sorbed organics and flocs are then transferred to a sludge aeration tank or stabilisation tank where the organics are stabilised over a period of about 3 to 6 hours before it is fed back into the contact aeration tank. The stabilised sludge is then mixed with the influent wastewater again, and the process is repeated. The flow diagram for this process is shown in figure.



9.111 (d)

Pyrolysis is a highly endothermic process.

10 Air and Sound Pollution

10.1 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. CO	1. Greenhouse effect
B. CO_2	2. Acid rains
C. SO_2	3. Acute toxicity
D. NO_x	4. Ozone liberation at ground level

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	2	3	4	1
(c)	3	1	2	4
(d)	4	1	2	3

[ESE : 1995]

10.2 The atmosphere extends upto a height of 10,000 km. It is divided into the following four thermal layers:

1. Mesosphere
2. Stratosphere
3. Thermosphere
4. Troposphere

The correct sequence of these starting from the surface of the earth upwards is

(a) 2, 4, 1, 3 (b) 4, 2, 1, 3
(c) 4, 2, 3, 1 (d) 2, 4, 3, 1

[ESE : 1995]

10.3 Which of the following air pollutants is/are responsible for photochemical smog?

1. Oxides of nitrogen
2. Ozone
3. Unburnt hydrocarbons
4. Carbon monoxide

Select the correct answer using the codes given below:

(a) 1 alone (b) 2, 3, and 4
(c) 1, 3 and 4 (d) 1 and 3

[ESE : 1997]

10.4 Match List-I (Equipment) with List-II (Pollutants removed) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Electrostatic precipitators	1. Coarse particles
B. Cyclones	2. Fine dust
C. Wet scrubbers	3. Gas
D. Adsorbers	4. Sulphur dioxide

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	3	4
(c)	2	1	4	3
(d)	1	2	4	3

[ESE : 1997]

10.5 Two sources generate noise levels of 90 dB and 94 dB respectively. The cumulative effect of these two noise levels on the human ear is

(a) 184 dB (b) 95.5 dB
(c) 94 dB (d) 92 dB

[ESE : 1997]

10.6 Match List-I (Pollutants) with List-II (Sources) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Acid water	1. Volcanoes
B. SO_2	2. Automobiles
C. CO	3. Thermal power station
D. Fly ash	4. Mining

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	4	1	3	2
(c)	1	4	3	2
(d)	1	4	2	3

[ESE : 1998]

10.7 Aerosol is
(a) carbon particles of microscopic size
(b) dispersion of small solid or liquid particles in gaseous media
(c) finely divided particles of ash
(d) diffused liquid particles

[ESE : 1998]

10.8 Match List-I (Air pollutant) with List-II (Environmental effect) and select the-correct answer using the codes given below the lists:

List I
A. Carbon monoxide
B. Particulate matter
C. Nitrogen oxides
D. Sulphur dioxide

List-II
1. Respiratory distress for living beings
2. Chemical reaction with haemoglobin in blood
3. Reduction in visibility and aeroallergens carrier
4. Photochemical smog in atmosphere

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	3	2	4	1
(c)	2	3	4	1
(d)	3	2	1	4

[ESE : 1999]

10.9 If carbon monoxide is released at the rate of 0.03 m^3/min from a gasoline engine and 50 ppm is the threshold limit for an 8 hour exposure, the quantity of air which dilutes the contaminant to a safe level will be
(a) 60 m^3/min (b) 600 m^3/min
(c) 60 m^3/s (d) 600 m^3/s

[ESE : 1999]

10.10 The sound pressure level for a jet plane on the ground with sound pressure of 2000μ bar should be
(a) 60 decibel (b) 100 decibel
(c) 140 decibel (d) 180 decibel

[ESE : 1999]

10.11 **Assertion (A):** In recent years, there has been a progressive increase in the percentage of solar ultraviolet rays reaching the earth's surface.

Reason (R): In the last few years, there has been a progressive increase in the percentage of carbon dioxide in the earth's atmosphere.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

10.12 Which one of the following plume behaviours occurs when atmospheric inversion begins from the ground level and continues?
(a) Looping (b) Fumigation
(c) Coning (d) Fanning

[ESE : 2000]

10.13 Which one of the following pollutants or pairs of pollutants is formed due to photochemical reactions?
(a) CO alone (b) O_3 and PAN
(c) PAN and NH_3 (d) NH_3 and CO

[ESE : 2000]

10.14 In the context of basic concept of an ecological system, the most appropriate definition of ecology is that it is a study of the
(a) inter-relationship between organisms and the environment
(b) relationship of human species with the industry
(c) relationship of human species with natural resources
(d) relationship of human species with air

[ESE : 2000]

10.15 Organisms that mineralize organic matter in an ecosystem are called
(a) producers (b) consumers
(c) decomposers (d) carnivorous

[ESE : 2000]

10.16 Which of the following statements related to C/N (Carbon/Nitrogen) ratio is not correct?
(a) Lower initial C/N ratio leads to loss of nitrogen and slows down the rate of decomposition
(b) Higher initial C/N ratio leads to cell destruction to obtain nutrition

(c) Higher initial C/N ratio leads to lower conservation of nitrogen in the finished compost
(d) An initial C/N ratio of 30 to 50 is optimal for composting

[ESE : 2000]

10.17 The role of the bed material in a "packed tower" used for removing particulate matter from gaseous emissions is to
(a) act as a filter bed to capture the particulates within the pores
(b) provide a large surface area on which the particulate matter can be collected
(c) reduce the flow of gas
(d) uniformly distribute the spray of water

[ESE : 2000]

10.18 Which of the following air pollutants are responsible for the greenhouse effect?
1. Methane
2. Carbon dioxide
3. Chlorofluorocarbons
4. Nitrogen oxides

Select the correct answer using the codes given below:
(a) 2 and 3 (b) 1 and 2
(c) 1, 3 and 4 (d) 1, 2, 3 and 4

[ESE : 2001]

10.19 Which of the following pairs are correctly matched?
1. Ringelmann chart : To grade density of smoke
2. Pneumoconiosis : Disease caused due to coaldust
3. PAN : Secondary air pollutant

Select the correct answer using the codes given below:
(a) 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 1, 2 and 3

[ESE : 2001]

10.20 Which of the following pairs are correctly matched?
1. Reverberation time : Time required to reduce noise by 60 dB
2. NIPTS : Responsible for permanent hearing loss
3. Sound foci : Formed when sound waves are reflected from convex surface
4. TTS : Responsible for temporary hearing loss

Select the correct answer using the codes given below:
(a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 1, 2 and 3

[ESE : 2001]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

10.21 **Assertion (A):** The surface of sea water is on the rise.
Reason (R): A thick layer of gases enveloping the earth does not allow heat to pass into space from the earth at a rate which is as much as the rate at which the heat coming from space penetrates it towards the earth.

[ESE : 2002]

10.22 **Assertion (A):** Wet scrubber removes particulates from a gaseous stream.
Reason (R): In the wet scrubber water droplets come into contact with the particulates.

[ESE : 2002]

10.23 The following is a well known formula for estimating the plume rise:

$$\Delta h = \frac{V_s d}{u}\left(1.5 + 0.0096\frac{Q_h}{V_s d}\right)$$

where the letters have their usual meaning.
The estimated plume rise (by the above formula) with a stack gas having heat emission rate 2000 kJ/s, the wind speed 4 m/s, stack gas speed 8 m/s inside a stack diameter of 1 m at the top is

(a) 7.8 m (b) 8.7 m

(c) 3.15 m (d) $\frac{8000}{\pi}(1.5+0.0024\pi)$

[ESE : 2002]

10.24 In sampling of stack gases for measurement of concentration of Suspended Particulate Matter (SPM), the flue gases are sucked in the instrument at

(a) any rate of flow from mid diameter of chimney
(b) any point of chimney cross-section and at any rate of flow
(c) a constant rate of flow but at four equidistant points along the diameter
(d) controlled positions and controlled velocities along the chimney diameter to get isokinetic conditions

[ESE : 2002]

10.25 Match List-I (Air pollutants) with List-II (Harmful effects) and select the correct answer using the codes given below the lists:

List-I	List-II
A. SPM	1. Blood haemoglobin
B. NO	2. Vegetation
C. CO	3. Respiratory system
D. SO_2	4. Building materials

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	1	2	3	4
(c)	3	2	1	4
(d)	1	4	3	2

[ESE : 2002]

10.26 Match List-I (Air pollutants) with List-II (Emitted mainly by) and select the correct answer using the codes given below the lists:

List-I
A. Hydrocarbons
B. Particulates and gases
C. Sulphur dioxide
D. Carbon monoxide

List-II
1. Coal burning
2. Gasoline fuel
3. Tyres
4. Carburettor

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	2	1
(c)	3	4	1	2
(d)	4	3	1	2

[ESE : 2002]

10.27 Which one of the following statements explains the term pyrolysis?

(a) Solid waste is heated in closed containers in oxygen-free atmosphere
(b) Solid waste is incinerated in presence of oxygen
(c) Wastewater is treated with oxygen
(d) Dissolved solids from water are removed by glass distillation

[ESE : 2003]

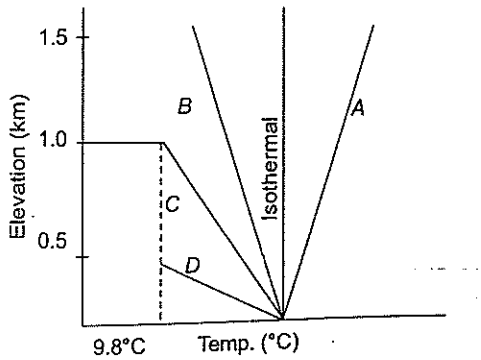
10.28 In urban air pollution, the most poisonous gas is supposed to be carbon monoxide. It is hazardous because it

(a) affects our sense of smell
(b) is carcinogenic in nature
(c) combines with haemoglobin
(d) causes blindness

[ESE : 2003]

10.29 The graph shows the relationship of ambient lapse rates to the dry adiabatic lapse rate under different conditions of stability. Match stability situations A, B, C and D (as given in the graph) with the classes of stability as follows:

1. Super adiabatic 2. Dry adiabatic
3. Sub adiabatic 4. Inversion



Select the correct answer using the codes given below:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	4	3	1	2

[ESE : 2003]

10.30 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Test with sound waves in the audible frequency range
B. Fire flow tests
C. Hydraulic gradient tests
D. Coefficient tests

List-II

1. To determine the ability of a distribution system to transmit water with adequate residual pressure
2. Location and isolation of leaks
3. To determine the efficiency and adequacy of a distribution system during days of high demand
4. To determine the internal condition of pipeline with respect to friction loss

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	2	3	1	4
(c)	4	1	3	2
(d)	4	3	1	2

[ESE : 2004]

10.31 Which one of the following procedures is used for sampling of the flue gas in a chimney for SPM?

(a) Isothermal sampling
(b) Isokinetic sampling
(c) Adiabatic condition
(d) Variable rate of sampling

[ESE : 2004]

10.32 Acoustics of an auditorium is considered to be excellent when its reverberation time is between

(a) 0.50 and 1.50 s (b) 1.50 and 2.00 s
(c) 2.00 and 3.00 s (d) 3.00 and 5.00 s

[ESE : 2004]

10.33 Which one of the following units is employed for the removal of particulate matter above 50 μm in size?

(a) Gravity settling chamber
(b) Cyclone
(c) Fabric filter
(d) Electrostatic precipitator

[ESE : 2004]

10.34 Which type of light energy is effectively absorbed by CO_2 in the lower boundary of the troposphere?

(a) X-rays (b) UV-rays
(c) Visible light (d) Infra-red rays

[ESE : 2005]

10.35 Which one of the following is the correct sound intensity expression with usual notations?

(a) $dB = 10 \log_{10}(I/I_0)^2$
(b) $dB = 10 \log_{10}(I/I_0)$
(c) $dB = 10 \log_{10}(I - I_0)^2$
(d) $dB = 10 \log_{10}(I - I_0)$

[ESE : 2005]

10.36 What type of noise can be abated by providing lining on walls and ceiling with sound absorbing materials?

(a) Source noise
(b) Reflection noise
(c) Structural noise
(d) Direct air-borne noise

[ESE : 2005]

10.37 Which one of the following pairs is not correctly matched?

Plume Behaviour		Atmospheric Condition
(a) Looping	:	Stable
(b) Fumigation	:	Inversion above and lapse below the stack
(c) Fanning	:	Inversion
(d) Trapping	:	Inversion above and below the stack with lapse in between

[ESE : 2005]

10.38 Which is the major pollutant present in photochemical smog?

(a) PAN (b) SO_2
(c) HC (d) NO_2

[ESE : 2005]

10.39 Consider the following statements:
In solid waste management
1. density separation of solid wastes can be accomplished by air classifiers.
2. iron recovery from solid wastes can be done by magnetic separators.
3. aluminium separation from solid wastes can be accomplished by eddy current separators.

Which of these statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3.

[ESE : 2005]

10.40 Which one of the following is the range of ozonosphere in atmosphere?
(a) Troposphere to Stratosphere
(b) Tropopause to Stratopause
(c) Tropopause to Mesosphere
(d) Stratosphere to Mesosphere

[ESE : 2006]

10.41 Which one of the following pairs is not correctly matched?
(a) Coriolis effect : The effect of earth's rotation on wind direc-tion and velocity
(b) PAN : Found during photo-chemical smog
(c) Cyclone : Employed for parti-culate matter removal
(d) Wind rose : Employed in forecast of pollutant dispersion in ambient air

[ESE : 2006]

10.42 Match List-I (Air pollutant) with List-II (Impact on human health) and select the correct answer using the codes given below the lists:
List-I
A. Particulates
B. Carbon monoxide
C. Sulphur oxides
D. Photochemical oxidants
List-II
1. Impairs transport of O_2 in bloodstream
2. Irritation of mucous membranes of respiratory tract
3. Causes coughing, shortness of breath, headache, etc.
4. Causes respiratory illness

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	2	1	4	3
(d)	4	3	2	1

[ESE : 2007]

10.43 Which type of plume may occur during winter nights?
(a) Looping (b) Inversion
(c) Coning (d) Lofting

[ESE : 2007]

10.44 A machine in a steel plate fabricating industry is found to be producing a sound level of 50 dB. In the expansion plans one more such machine needs to be added. What will be the combined noise level?
(a) 80 – 100 dB (b) 101 – 150 dB
(c) 51 – 70 dB (d) 40 – 50 dB

[ESE : 2007]

10.45 A heterotroph is an organism that obtains
(a) its cell carbon from an inorganic source
(b) its energy from the oxidation of simple inorganic compounds
(c) its cell carbon as well as its energy from organic matter
(d) its energy from a natural ecosystem

[ESE : 2007]

10.46 The term 'biological magnification' indicates which one of the following?
(a) Likelihood of increasing size of animals during evolution
(b) Magnification pertaining to microscopy
(c) Accumulation of pollutants in soil
(d) Accumulation of pollutants in successive consumers

[ESE : 2007]

10.47 Pneumoconiosis is caused due to inhalation of which one of the following?
(a) Silica (b) NO_x
(c) Lead (d) Cadmium

[ESE : 2008]

10.48 Which one of the following conditions of automobile gives maximum unburned hydrocarbons?

(a) Idling (b) Cruise
(c) Acceleration (d) Deceleration

[ESE : 2008]

10.49 Electrostatic precipitator is most useful for which one of the following industries?
(a) Tannery
(b) Hydroelectric power generation
(c) Thermal power generation
(d) Textile factory

[ESE : 2008]

10.50 What will be the resultant decibel level when two sources make noise of equal decibels?
(a) Decibel level will the same
(b) Decibel level will increase by 3 decibels
(c) Decibel level will decrease by 3 decibels
(d) Decibel level will be equal to the sum of decibels of the two sources

[ESE : 2008]

10.51 Match List-I (Air pollutant) with List-II (Effect) and select the correct answer using the codes given below the lists:

List-I	List-II
A. CO	1. Acid rain
B. CO_2	2. Acute toxicity
C. SO_2	3. Ozone liberation
D. NO_x	4. Greenhouse effect

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	4	3	2	1
(c)	2	4	1	3
(d)	3	4	1	1

[ESE : 2008]

10.52 Biological magnification of pesticides takes place through which of the following?
(a) Population pyramids
(b) Hydrologic cycle
(c) Food chains
(d) Air cycle

[ESE : 2008]

10.53 Which one of the following toxic gases has physiological action as asphyxiant?
(a) SO_2 (b) NO_2
(c) Cl_2 (d) CO

[ESE : 2009]

10.54 Assuming annual travel for each vehicle to be 20000 km, what is the quantity of NO_x produced from 50000 vehicles with emission rate of 2.0 g/km/vehicle?
(a) 1800 tonnes (b) 1900 tonnes
(c) 2000 tonnes (d) 2100 tonnes

[ESE : 2009]

10.55 What are the air pollutants responsible for acid rain within and downwind areas of major industrial emissions?
(a) Hydrogen sulfide and oxides of nitrogen
(b) Sulfur dioxide and oxides of nitrogen
(c) Carbon dioxide and hydrogen sulfide
(d) Methane and hydrogen sulfide

[ESE : 2009]

10.56 Consider the following air pollutants:
1. NO_x 2. PAN
3. CO_2 4. CO

Which of the above air pollutants is/are present in an auto exhaust gas?
(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1, 3 and 4

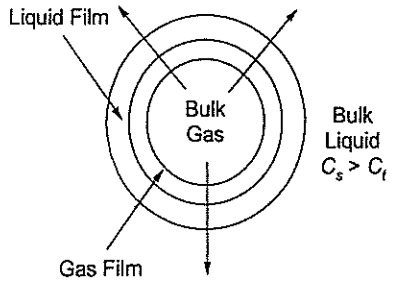
[ESE : 2009]

10.57 Noise pollution in a road-side building can be reduced by
(a) providing a ditch around the building and filling it with water
(b) providing a steel mesh around the building
(c) providing a thick bush around the building
(d) planting tall trees around the building and fencing them with barbed wires

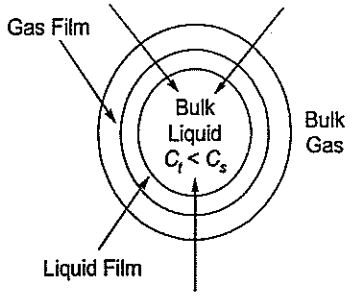
[ESE : 2010]

10.58 In a liquid-gas system, when the water is dispersed in air, the absorption of gas is represented by

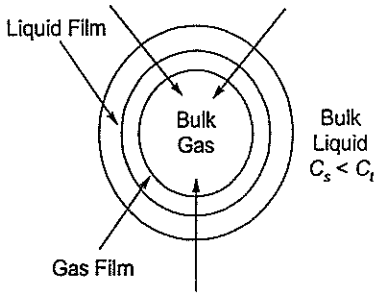
(a)



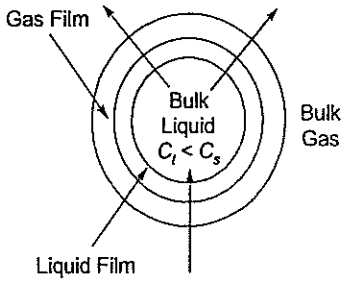
(b)



(c)



(d)



[ESE : 2010]

10.59 **Assertion (A):** Traffic 'Smog' is likely to occur in regions where vehicle mileage is considerable and there is a low incidence of sunlight.
Reason (R): Traffic 'Smog' is caused by the reaction of oxides of nitrogen and some of the hydrocarbons in presence of bright sunlight.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

10.60 Which of the following are responsible for the formation of photochemical smog?
1. Light intensity
2. Ratio of hydrocarbons to nitric oxide
3. CO_2
4. Hydrocarbon reactivity
5. SO_2

(a) 1, 2, 3, 4 and 5 (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 2, 3 and 5 only

[ESE : 2011]

10.61 Which of the following factors contribute to formation of photochemical smog?
1. Stable atmospheres
2. NO_x
3. Solar insolation
4. CO

(a) 1, 2, 3 and 4 (b) 2, 3 and 4 only
(c) 1 and 4 only (d) 1, 2 and 3 only

[ESE : 2012]

10.62 For noise measurement, formula for sound pressure level (SPL) is $20 \log \frac{P}{P_{ref}}$. What will be the resultant noise in dB if P is 0.0002 μ bar ?
(a) 0 (b) 60
(c) 90 (d) 100

[ESE : 2012]

10.63 Environmental impact assessment includes
(a) Environmental statement
(b) Environmental management plan
(c) Risk and hazard assessment and mitigation
(d) All of the above

[ESE : 2012]

10.64 **Statement-I :** Air pollutant concentration and time of retention increase due to inversion.
Statement-II : During winter, the heavy cold layer in the atmosphere retains the hot toxic pollutants for a longer period in the atmosphere.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

10.65 Consider the following statements:
1. Particulates have irregular shapes.
2. Size can be determined by an equivalent aerodynamic diameter by comparing with a perfect sphere.

3. Particulates larger than 10 μ are said to settle relatively quickly since their settling velocity is not less than 10 cm/min.
4. The particles roughly the size of bacteria have aerodynamic diameter of 0.1 μm to 10 μm.

Which of the statements is/are correct?

(a) 1, 2, 3 and 4 (b) 1 and 3 only
(c) 1, 2 and 4 only (d) 2, 3 and 4 only

[ESE : 2012]

10.66 Consider the following statements in regard to an electrostatic precipitator:

1. Power requirement is small compared to other devices.
2. Immune to variable particulate loadings and flow rates.
3. 99+ percent efficiency is obtainable. Very small particles can be collected, wet or dry.
4. Can handle both gases and mists at high volume of flow.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 3 and 4 only
(c) 1, 2 and 3 only (d) 2, 3 and 4 only

[ESE : 2013]

10.67 Consider the following statements:

1. Noise pollution can be reduced using double-glass window panes.
2. Glass absorbs the noise.
3. The air trapped in the double-glass system acts as an insulator and reduces the noise.
4. The noise totally reflects back due to the two layers of glass.

Which of these statements are correct?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1 and 3 only (d) 2 and 4 only

[ESE : 2013]

10.68 Consider the following statements:

1. Sound is a form of mechanical energy from a vibrating substance, transmitted by a cyclic series of compressions and rarefactions of the molecules of the material through which it passes.
2. In a pure tone, the wave pattern of the alternating positive and negative sound pressure is of ideal sinusoidal form with fixed wave length, frequency and amplitude.
3. The speed of transmission of sound is a function of the transmitting medium and its temperature.
4. The audible range of 200 to 25000 Hz is considered normal for young adults.

Which of these statements are correct in respect of sound transmission?

(a) 1, 2, 3 and 4 (b) 1, 2 and 4 only
(c) 1, 2 and 3 only (d) 2, 3 and 4 only

[ESE : 2013]

10.69 The major source of 'Carbon monoxide' in the urban atmosphere is due to

(a) Decomposition of organics
(b) Chemical reaction between VOC and NO_x
(c) Incomplete combustion of fuel
(d) Incomplete combustion in the presence of sunlight

[ESE : 2014]

10.70 Consider the following statements relating zones of atmosphere to altitude:

1. Temperature decreases with altitude in troposphere.
2. Speed of sound decreases with altitude in troposphere.
3. Temperature increases with altitude to stratosphere.
4. Ozone is present in stratosphere which protects people from harmful effects of solar radiation.

Which of the above statements are correct?

(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2014]

10.71 The principle involved in collection and sampling of particulate matter in which the particles are drawn through a device by deflecting them from their original paths is called

(a) Filtration
(b) Electrostatic precipitation
(c) Impaction
(d) Gravitational settling

[ESE : 2014]

10.72 **Statement (I):** Electrostatic precipitators (ESP) can remove particles of sub-micron size.

Statement (II): Due to high voltage supply, ESPs attract any charged particle.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2014]

10.73 Consider the following statements in respect of electrostatic precipitators:
1. Power requirement is very small compared to other air pollution control devices and so they are cheaper to perform than other devices.
2. Can handle both gases and mists for high volume flow.
3. Very small particles can be collected, either wet or dry.

Which of the above statements are correct?
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2015]

10.74 Consider the following statements related to ozone:
1. Tropospheric ozone is harmful
2. Stratospheric ozone is beneficial
3. During prevalence of photochemical smog, O_3 is formed

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2015]

10.75 Consider the following statements related to noise:
1. The range of sound power and sound pressures produced is from 0.0002 μ to 10000 μ bars.
2. Human ears do not respond linearly to increase in sound pressure.
3. Regular exposure to moderate noise makes the human ear more resistant to occasional exposures of high-intensity noise.

Which of the above statements are correct?
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2015]

10.76 Consider the following statements in respect of effect of air pollutants on vegetation:
1. Necrosis refers to killing to tissue.
2. Chlorosis refers to loss or reduction of green plant pigment.
3. Leaf abscission refers to the dropping of leaves.
4. Leaf epinasty refers to a downward curvature of a leaf due to a higher rate of growth on the upper surface.

Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 1, 2, 3 and 4
(c) 2, 3 and 4 only (d) 1, 2 and 4 only

[ESE : 2015]

10.77 Consider the following statements regarding ecology:
1. Climax ecosystem is a stage in the evolution of an ecosystem, at which all the species are in dynamic equilibrium among themselves as also with the environment.
2. Ecological niche means all the physical, chemical and biological factors that a species needs in order to live and reproduce exist.
3. Edge effect refers to the presence of rich and unique biological diversity found in an ecotone.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2015]

10.78 **Assertion (A):** Gases are normally formless fluids and can be changed to liquid or solid states by change of temperature and pressure.
Reason (R): Smog refers to the occurrence of a heavy, cloudy, hazy floating layer in the atmosphere formed by a mixture of smoke, dust, fog and mist.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false
(d) A is false but R is true

[ESE : 2015]

10.79 Consider the following properties of fluorine:
1. It is a member of the halogen family.
2. It is a greenish yellow diatomic gas.
3. Chlorine, iodine, bromine and helium are members of the halogen family.
4. Even fireproof asbestos burns in the ambience of fluorine.

Which of the above are correct?
(a) 1, 2 and 3 only (b) 3 and 4 only
(c) 1, 2 and 4 only (d) 1, 2, 3 and 4

[ESE : 2016]

10.80 Consider the relevance of the following features for causing photochemical smog
1. Air stagnation.
2. Abundant sunlight.
3. High concentration of NO_x in atmosphere.
4. High concentration of SO_2 in atmosphere.

Which of the above features are correct?
(a) 1, 2 and 4 only (b) 3 and 4 only
(c) 1, 2 and 3 only (d) 1, 2, 3 and 4

[ESE : 2016]

10.81 Consider the following statements related to ecology
1. All the physical, chemical and biological factors that a species needs in order to live and reproduce is called ecological niche.
2. The boundary zone between two ecosystems is known as ecotone.
3. The forests in the Arctics are known as tundra.
4. A biome usually has a distinct climate and life forms adapted to that climate. Biome is more extensive and complex than an ecosystem.

Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2016]

10.82 Consider the following laws of ecology suggested by Barry Commoner:
1. Everything is connected to every thing else.
2. Everything must go somewhere.
3. Nature knows best.
4. There is no such thing as a free lunch.

Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2016]

10.83 Consider the following statements regarding air pollution:
1. The pollutant caused by incomplete combustion or organic matter is carbon monoxide.
2. Depletion of ozone in outer atmosphere may trigger skin cancer.
3. Acid rains are caused by SO_2 and NO_x.
4. The permissible standard for SO_2 in air for residential areas in India is 80 $\mu g/m^3$.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 3 and 4
(c) 2 and 4 (d) 1, 2 and 3

[ESE : 2017]

10.84 **Statement (I):** Tiny quantities of over 30 rare gases would warm the atmosphere over the Earth more rapidly than CO_2.
Statement (II): A single molecule of some CFCs, methane and nitrous oxide absorbs as much heat as 15,000 molecules, 25 molecules and 230 molecules of CO_2, respectively.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2017]

Answers Air and Sound Pollution

10.1 (c)	10.2 (b)	10.3 (d)	10.4 (b)	10.5 (b)	10.6 (a)	10.7 (b)	10.8 (c)		
10.9 (b)	10.10 (c)	10.11 (b)	10.12 (d)	10.13 (b)	10.14 (a)	10.15 (c)	10.16 (c)		
10.17 (b)	10.18 (d)	10.19 (d)	10.20 (c)	10.21 (a)	10.22 (a)	10.23 (a)	10.24 (d)		
10.25 (c)	10.26 (d)	10.27 (a)	10.28 (c)	10.29 (b)	10.30 (a)	10.31 (b)	10.32 (a)		
10.33 (a)	10.34 (d)	10.35 (b)	10.36 (b)	10.37 (a)	10.38 (c)	10.39 (d)	10.40 (d)		
10.41 (d)	10.42 (b)	10.43 (b)	10.44 (c)	10.45 (c)	10.46 (d)	10.47 (a)	10.48 (a)		
10.49 (c)	10.50 (b)	10.51 (c)	10.52 (c)	10.53 (d)	10.54 (c)	10.55 (b)	10.56 (d)		
10.57 (c)	10.58 (b)	10.59 (d)	10.60 (b)	10.61 (d)	10.62 (a)	10.63 (d)	10.64 (a)		
10.65 (a)	10.66 (b)	10.67 (c)	10.68 (a)	10.69 (c)	10.70 (d)	10.71 (b)	10.72 (a)		
10.73 (b)	10.74 (a)	10.75 (a)	10.76 (b)	10.77 (a)	10.78 (b)	10.79 (c)	10.80 (c)		
10.81 (d)	10.82 (d)	10.83 (a)	10.84 (a)						

Explanations Air and Sound Pollution

10.1 (c)

Carbon monoxide affect human aerobic metabolism by forming carboxyhaemoglobin (COHb).

Oxides of nitrogen (NO_x) includes – nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), nitrogen sesquioxide (N_2O_3), Nitrogen tetroxide (N_2O_4) and nitrogen pentoxide (N_2O_5). NO and NO_2 are of primary concern as air pollutants. NO_2 plays major role in the production of secondary air pollutant ozone (O_3).

SO_2 is responsible for acid rains as it combines with water vapour to form secondary pollutants like H_2SO_4 which cause acidity.

10.2 (b)

Scientists divided the atmosphere into four layers according to temperature: troposphere, stratosphere, mesosphere, and thermosphere. The temperature drops as we go up through the troposphere, but it rises as we move through the next layer, the stratosphere. The farther away from earth, the thinner the atmosphere gets.

Troposphere: This is the layer of the atmosphere closest to the Earth's surface, extending up to about 10-15 km above the Earth's surface. It contains 75% of the atmosphere's mass. The troposphere is wider at the equator than at the poles. Temperature and pressure drops as you go higher up the troposphere.

Stratosphere: This layer lies directly above the troposphere and is about 35 km deep. It extends from about 15 to 50 km above the Earth's surface.

Mesosphere: Directly above the stratosphere, extending from 50 to 80 km above the Earth's surface, the mesosphere is a cold layer where the temperature generally decreases with increasing altitude. Here in the mesosphere, the atmosphere is very rarefied nevertheless thick enough to slow down meteors hurtling into the atmosphere, where they burn up, leaving fiery trails in the night sky.

Thermosphere: The thermosphere extends from 80 km above the Earth's surface to outer space. The temperature is hot and may be as high as thousands of degrees as the few molecules that are present in the thermosphere receive extraordinary large amounts of energy from the Sun. However, the thermosphere would actually feel very cold to us because of the probability that these few molecules will hit our skin and transfer enough energy to cause appreciable heat is extremely low.

10.3 (d)

Photochemically, the hydrocarbons and NO_x are the necessary ingredients to produce photochemical smog.

Unburnt Hydrocarbons

$$+NO_x \xrightarrow[\text{(Oxides of nitrogen)}]{\text{sunlight}} \text{smog}$$

The end product of these photochemical reactions is photochemical smog consisting of air contaminants such as O_3, PAN, aldehydes, ketones, alkyl nitrates and carbon monoxide.

Thus, oxides of nitrogen and unburnt hydrocarbons are responsible for causing photochemical smog.

10.4 (b)

(i) Electrostatic precipitator (High voltage) is used for > 1 mm but can collect submicron particles also.

(ii) Cyclone collector (based on centrifugal force) is used for 5 to 25 μm size particle

(iii) Wet scrubber are used for gaseous pollutants

(iv) Adsorbers are specific to gases. A reactive liquid adsorbent (water or limestone) may be used to remove SO_2 from flue gases.

10.5 (b)

For noise level of 90 dB

$$P_{rms_1} = 20\left\{\text{antilog}\left(\frac{90}{20}\right)\right\}$$

$$= 632455.53$$

For noise level of 94 dB

$$P_{rms_2} = 20\left\{\text{antilog}\left(\frac{94}{20}\right)\right\}$$

$$= 1002374.47$$

$$P_{rms,equiv.} = \sqrt{P_{rms_1}^2 + P_{rms_2}^2}$$

$$= 1185223.429$$

Cumulative effect

$$= 20 \log \frac{1185223.43}{20}$$

$$= 95.46 \text{ dB}$$

10.6 (a)

Carbon Monoxide (CO)

- Fuel combustion from vehicles and engines.
- Reduces the amount of oxygen reaching the body's organs and tissues; aggravates heart disease, resulting in chest pain and other symptoms.

Ground-level Ozone (O_3)

- Secondary pollutant formed by chemical reaction of volatile organic compounds (VOCs) and NOx in the presence of sunlight.
- Decreases lung function and causes respiratory symptoms, such as coughing and shortness of breath, and also makes asthma and other lung diseases get worse.

Lead (Pb)

- Smelters (metal refineries) and other metal industries; combustion of leaded gasoline in piston engine aircraft; waste incinerators (waste burners), and battery manufacturing.
- Damages the developing nervous system, resulting in IQ loss and impacts on learning, memory, and behavior in children. Cardiovascular and renal effects in adults and early effects related to anaemia.

Nitrogen Dioxide (NO_2)

- Fuel combustion (electric utilities, big industrial boilers, vehicles) and wood burning.
- Worsens lung diseases leading to respiratory symptoms, increased susceptibility to respiratory infection.

Particulate Matter (PM)

- This is formed through chemical reactions, fuel combustion (e.g., burning coal, wood, diesel), industrial processes, farming (plowing, field burning), and unpaved roads or during road constructions.
- Short-term exposures can worsen heart or lung diseases and cause respiratory problems. Long-term exposures can cause heart or lung disease and sometimes premature deaths.

Sulfur Dioxide (SO_2)

- SO_2 comes from fuel combustion (especially high-sulfur coal); electric utilities and industrial processes as well as natural occurrences like volcanoes.

- Aggravates asthma and makes breathing difficult. It also contributes to particle formation with associated health effects.

10.7 (b)

Aerosols or particulates or suspended particulate matter is defined as the liquid or solid particles when they are suspended in gaseous medium. The term aerosol is used during the time it is suspended in air. After the particle is settled down, the term ceases to be valid.

10.9 (b)

$$\text{Quantity of air} = \frac{10^6}{50} \times 0.03 = 600 \text{ m}^3/\text{min}$$

10.10 (c)

$$\text{Sound pressure level (dB)} = 20 \log_{10}\left(\frac{P}{P_0}\right)$$

P is sound pressure in N/m^2

P_0 is reference pressure (2×10^{-5} N/m^2)

For given sound pressure

$P = 2000\ \mu$ bar $= 200$ N/m^2

$$\therefore \text{SPL} = 20 \log\left(\frac{200}{2\times10^{-5}}\right) = 140 \text{ dB}$$

10.11 (b)

Depletion of ozone layer (in stratosphere and mesosphere) has led to increased exposure of earth's surface to ultraviolet radiation. The ozone depleting substances are chlorofluoro carbons (CFCs).

Increased percentage of carbon dioxide has led to global warming (greenhouse effect).

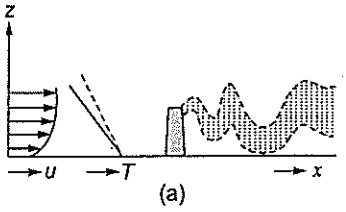
10.12 (d)

1. When the ambient lapse rate is super-adiabatic (greater than the adiabatic), the turbulence of the air itself causes the atmosphere to serve as an effective vehicle of dispersion. As indicated in **fig-a**, the resultant plume is designated as a **looping plume**. In this highly unstable atmosphere, the stream of emitted pollutants undergoes rapid mixing, and any wind causes large eddies which may carry the entire plume down to the ground, causing high concentrations close to the stack before dispersion is complete. In areas where conditions make looping plumes likely, higher stacks may be needed to prevent premature contact with the ground.
2. When the ambient lapse rate is equal to or very near the dry adiabatic lapse rate, the plume issuing from a single chimney or smokestack tends to rise directly into the atmosphere until it reaches air of density similar to that of the plume itself. This type emission, called a **neutral plume**, is seen in **fig-b**.

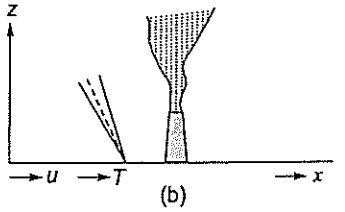
   However, this neutral plume tends to cone (see **fig-c**) when wind velocity is greater than 20 mi/h and when cloud cover blocks solar radiation by day and terrestrial radiation by night.
3. When the ambient lapse rate is sub-adiabatic (less than the dry adiabatic), the atmosphere is slightly stable. Under such conditions, there is limited vertical mixing, and the probability of air pollution problems in the area is increased. The typical plume in such a situation is said to be **coning**, since it assumes a cone like shape about the plume line, as shown in **fig-c**. While the dispersion rate is faster for a looping plume, the distance at which a coning plume first reaches the ground is greater.
4. When the lapse rate is negative, as in the presence of an inversion, the dispersion of stack gas is minimal, because of lack of turbulence. In the extremely stable air, a plume spreads horizontally, with little vertical mixing, and is said to be **fanning (fig-d)**, and in flat country such a plume may be visible for miles downwind of its source. In areas where radiation inversions are common, construction of stacks high enough to allow for discharge of emissions above the inversion layer is recommended. This solution is not practical for subsidence inversions, since they usually extend to much greater heights.
5. Extenuating circumstances can often alleviate or aggravate the pollution possibilities accompanying negative lapse rate conditions.

For instance, when the lapse rate is super-adiabatic above the emission source and inversion conditions exist below the source, the plume is said to be **lofting**. As shown in **fig-e**, a lofting plume has minimal downward mixing, and the pollutants are dispersed downwind without any significant ground-level concentrations.

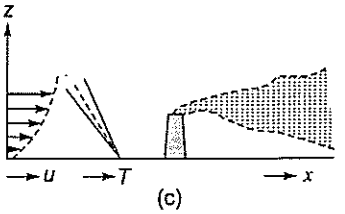
6. When an inversion layer occurs at a short distance above the top of the stack and super adiabatic conditions prevail below the stack, then plume is said to be **fumigating** (fig-f). In such a case, the pollutants cannot escape above the top of the stack because of inversion layer, and they will be brought down near the ground due to turbulence in the region above the ground and below the inversion , caused by strong lapse rate. This represents quite a bad case of atmospheric conditions for dispersion.
7. When inversion layer exists above the emission source, as well as below the source, then naturally, the emitted plume will neither go up, nor will it go down and would remain confined between the two inversion (fig-g). Such a plume is called a **trapping** plume and is considered a bad condition for dispersion, as the dispersion cannot go above a certain height.



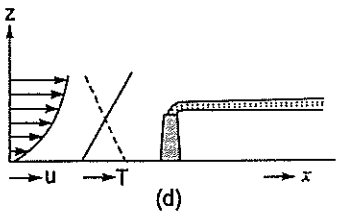
(a)



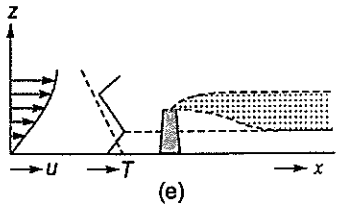
(b)



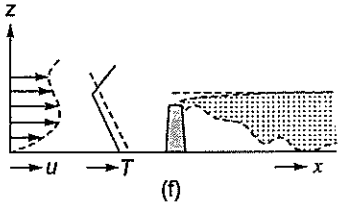
(c)



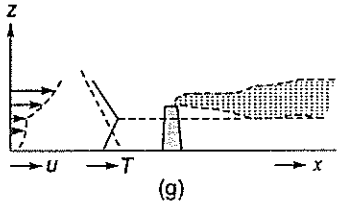
(d)



(e)



(f)



(g)

SYMBOLS:

---------- Adiabatic lapse rate

———— Environmental lapse rate

10.13 (b)

Photochemical reactions form O_3, PAN, formaldehyde, etc.

10.14 (a)

The scientific study of interaction among organisms and their environment is called ecology.

10.15 (c)

Decomposer class includes saprophytic organisms that help in nutrients and element recycling process. These are bacteria, fungi and protozoans. They reduce organic matter to simple compounds and elements.

10.16 (c)

Initial Carbon-Nitrogen ratios (by mass) between 30 to 50 are optimum for aerobic composting. At lower ratio (C/N) nitrogen in the form of ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios nitrogen may be

a limiting nutrient and cell destruction becomes necessary to obtain nutrients.

10.17 (b)

In the packed tower, packing material (bed material) is used to increase the contact time between vapour and liquid. The material chosen for packing has a large surface to volume ratio and a large void ratio that offers minimum resistance to gas flow.

10.18 (d)

Carbon dioxide is considered to be major greenhouse gas, as it is responsible for about 60% of the total greenhouse effect caused by all the greenhouse gases. Other green-house gases are CH_4, NO_x and chlorofluoro carbons.

10.19 (d)

The **Ringelmann scale** is a scale for measuring the apparent density of Smoke. It has 5 levels of density inferred from a grid of black lines on a white surface which, if viewed from a distance, merge into known shades of grey.

Pneumoconiosis is an occupational lung disease and a restrictive lung disease caused by the inhalation of dust, often in mines and from agriculture.

Peroxyacetyl nitrate (PAN) is a component of photochemical smog, which is a mixture of air pollutants that includes both gases and particulates, some of which react with sunlight.

10.20 (c)

Reverberation time is the time required to reduce the intensity to one-millionth of its initial value.

$$\text{Sound level (dB)} = 10 \log \left(\frac{I_1}{I_2}\right)$$

$$= 10 \log (10^6) = 60 \text{ dB}$$

TTS (Temporary Threshold Shift) is temporary impairment of hearing acuity as indicated by change in the threshold of audibility PTS (Permanent Threshold Shift) is related to permanent hearing loss. The sound foci are formed when sound waves are reflected from concave surface.

10.21 (a)

Entrapping of infrared radiation emitted from earth's surface by greenhouse gases results in increase of temperature. This causes melting of polar ice caps and high mountains. The melted ice flows to oceans and the surface of sea water is on rise due to this.

10.22 (a)

Wet scrubber removes gaseous pollutant and particulate matter. The particulate matter by incorporating them into liquid droplets directly on contact efficiency for well designed wet collectors of all types is a function of the energy consumed in the air-to-water contact process.

10.23 (a)

Wind Speed $u = 4$ m/s

Stack gas speed $V_s = 8$ m/s

Diameter $d = 1$ m

Heat rise $Q_h = 2000$ kJ/s

We know that effective height of stack,

$$\Delta h = \frac{V_s \times d}{u}\left[1.5 + 0.0097 \times \frac{Q_h}{V_s \times d}\right]$$

$$\Delta h = \frac{8 \times 1}{4}\left[1.5 + 0.0097 \times \frac{2000}{8 \times 1}\right] = 7.8 \text{ m}$$

10.24 (d)

To obtain representative samples, selection of sampling site and the number of sampling point are the most important factors. The gas stream in the stack is normally under turbulent flow condition and any flow disturbance would result in non-uniform and unstable gas flow profiles and non-uniform particle concentration patterns. The other important factor in stack sampling is high temperature and high velocities of the gases encountered inside the stack. Therefore isokinetic technique is adopted for particulate laden gas stream. In this technique a sample is drawn into the probe such that the condition at the tip of the probe is same as those in the free gas stream at the sampling point. It can be carried out in two ways :

1. By computing point velocity of free stream by Pitot tube and adjusting sampling velocity.

2. By using a hull type of sampling probe, in which the static pressures measured between the inner and outer probe walls is balanced.

10.26 (d)

Aromatic hydrocarbons are biochemically and biologically active, and some are potentially carcinogenic. All aromatics are derived from or related to benzene. Transportation, including incomplete combustion from car engines, along with evaporative emissions from fuel tanks, crankcases and carburettors contributed the largest percentage of hydrocarbons.

10.27 (a)

Upon heating in an oxygen free atmosphere during pyrolysis, most organic substances can be split through a combination of thermal cracking and condensation reactions in gaseous liquid and solid fractions.

10.28 (c)

Carbon monoxide (CO) combines with haemoglobin (Hb) of blood to give carboxy-haemoglobin (COHb), thus reducing the capability of the blood to carry oxygen. Since the affinity of haemoglobin for carbon monoxide is more than 200 times as great as its affinity for oxygen, CO can seriously impair the transport of O_2, even when present at low concentrations.

10.29 (b)

$$\text{Lapse rate} = \frac{\text{Temperature difference}}{\text{Elevation difference}} = \frac{\Delta T}{\Delta h}$$

Curve	ΔT	Δh	$\Delta T/\Delta h$
A	– ive	—	– ive
B	9.8°C	> 1.5 km	< 6.53°C/km
C	9.8°C	1 km	9.8°C/km
D	9.8°C	0.5 km	17.6°C/km

Dry adiabatic lapse rate is 9.8°C/km and wet adiabatic lapse rate is 6°C/km. The actual adiabatic lapse rate is between 6°C/km to 9.8°C/km.

If ambient lapse rate is more than actual adiabatic lapse rate then it is super-adiabatic. If ambient lapse rate is 9.8°C/km then dry adiabatic condition prevail. If ambient lapse rate is less than actual adiabatic lapse rate then it is sub-adiabatic. For negative rate the condition is said to be inversion.

Therefore

A represents	Inversion	(4)
B represents	Sub-adiabatic	(3)
C represents	Dry adiabatic	(2)
D represents	Super adiabatic	(1)

10.30(a)

Leakage can be detected in the distribution system by

(i) direct observations
(ii) using sounding rods which work in audible frequency range.
(iii) plotting hydraulic gradient line
(iv) using waste detection meters like Deacon's water waste detection meter.

10.31 (b)

Isokinetic conditions exist when the velocity in the stack 'V_s' equals the velocity at the top of the probe nozzle 'V_n' at the sample point. Sampling in these conditions provides a uniform, unbiased sample of the pollutants being emitted by the source.

10.32 (a)

Reverberation time is the time required to reduce the intensity to one millionth of its initial value. When this time is between 0.5 to 1.5 seconds, acoustics are considered to be excellent.

10.33 (a)

Name of mechanical device		Minimum particle size that can be removed	Efficiency
(i)	Gravity settling chamber	> 50 μm	< 50%
(ii)	Centrifugal collectors including cyclone collectors	> 5-25 μm	50-90%
(iii)	Electrostatic precipitator	> 1 μm	95-99%
(iv)	Fabric filters	< 1μm	> 99%

10.34 (d)

CO_2 is major greenhouse gas and absorbs long wave radiations like infrared radiation.

10.35 (b)

Sound energy is conveyed by means of a wave motion through some medium (gas, liquid, or

solid). The common method used in gauging this energy transport is to measure the rate at which energy is passing a certain point. This concept involves sound intensity. Sound intensity is the power per square meter. Sound intensity is measured as a relative ratio to some standard intensity, I_o.

10.36 (b)

Linings and sound absorbing materials are most commonly used in theatres, concert arena and movie halls because they abate reflection noises.

10.37 (a)

Looping Plume:

- High degree of convective turbulence
- Superadiabatic lapse rate – strong instabilities.
- Associated with clear daytime conditions accompanied by strong solar heating and light winds.
- High probability of high concentrations sporadically at ground level close to stack.
- Occurs in unstable atmospheric conditions.

10.38 (c)

Photochemically, the NO_x and hydrocarbons are two groups of chemical compounds which are the necessary ingredients for the production of photochemical smog.

$$HC + NO_x \xrightarrow{\text{sunlight}} \text{Smog}$$

The end product of photochemical reactions is photochemical smog consisting of air contaminants such as O_3, PAN, aldehydes, ketones, alkyl nitrates and carbon monoxide.

10.39 (d)

Processing techniques used to recover materials and to prepare wastes for further processing		
Processing technique	**Function**	**Representative equipment and/or facilities and applications**
Mechanical size & shape alteration	Alteration of the size and shape of solid-waste components	Equipment used to reduce the size of solid waste includes hammermills, shredders, roll crushers, grinders, chippers, jaw crushers, rasp mills, and hydropulpers.
Mechanical component separation	Separation of recoverable materials, usually at a processing facility	Trommels and vibrating screens are used for unprocessed and processed wastes; disk screens for processed wastes; zigzag, vibrating air, rotary air, and air knife classifiers for processed wastes. Jig, pneumatic, sink/float, inertial, inclined or shaking table flotation, and optical sorting are used to separate the light and heavy materials in solid wastes.
Magnetic and electro-mechanical separation	Separation of ferrous & non-ferrous materials from processed solid wastes	Magnetic separation is used for ferrous materials; eddy current separation for aluminum; electrostatic separation for glass in wastes free of ferrous and aluminum scrap; magnetic fluid separation for nonferrous materials from processed wastes.
Drying and dewatering	Removal of moisture from solid wastes	Convection, conduction, and radiation dryers have been used for solid wastes and sludge. Centrifugation and filtration are used to dewater treatment plant sludge.

10.40 (d)

From the earth surface atmosphere to the outer periphery of the planet, there are several layers of gaseous clouds which are - Troposphere, Stratosphere, Mesosphere and Thermosphere with increasing height from the surface.

Height (km)	Layer	Sub-layer	Water Vapour	Temperature	Gases
40000	Thermo-sphere		None	Slowly increases with height	Rarified
500		Iono-sphere		Rapidly increases with height	Atomic H, O, N, Ne
80	Meso-sphere		None	Decreases with height	
50	Strato-sphere		Little		Ozone layer
			Moist with vapour	Increases with height	Diatomic O_2
12	Tropo-sphere		Cloud	Decreases with height	N_2, O_2, CO_2, O_2, Kr, He, Ne, Ar

Earth Surface

10.41 (d)

Wind rose diagram represents direction, frequency and velocity of the winds in a particular location. The direction of wind is characteristically from high pressure to low, but the Coriolis force tends to deflect air currents out of these expected patterns. Wind speed is measured by an anemometer, an instrument typically consisting of three or four hemispherical cups arranged on a vertical axis.

A pollution rose is used for plotting the data necessary to determine the source direction of specific air contaminants. The velocity of wind determines the travel time of a particulate to a receptor and also the dispersion rate of air contaminants.

Cyclone is a low pressure system in the northern hemisphere. Horizontal air movement is anticlockwise and the vertical movement is upward. Low pressure systems are usually

associated with cloudy skies, gusty winds and atmospheric instability, and the formation of fronts. Under such unstable conditions dispersion of pollutants is likely, and air pollution problems are minimal.

Cyclone collectors are centrifugal collectors used for removal of 5–25 μm size particulate matter.

10.42 (b)

During extreme winter nights, under extreme inversion conditions, the emission spreads horizontally due to extremely stable environment. Such a plume is called fanning plume. The negative environmental lapse rate from the ground causes these extreme inversion conditions.

10.43 (c)

The sound pressure level in dB is given by

$$L_p = 20\log_{10}\left(\frac{p_{rms}}{20\,\mu Pa}\right)$$

Sound level of 1st machine = 50 dB

$$\therefore \quad 50 = 20\log_{10}\left(\frac{p_{rms}}{20\,\mu Pa}\right)$$

$$\Rightarrow \quad \frac{p_{rms}}{20\,\mu Pa} = \text{Antilog}\left(\frac{50}{20}\right)$$

$$\Rightarrow \quad p_{rms} = 6324.55\,\mu Pa$$

Since the sound level of 2nd machine is also 50 dB, therefore p_{rms} of 2nd machine will also be 6324.55 μPa.

∴ Resultant sound level in rms

$$= \sqrt{(6324.55)^2 + (6324.55)^2}$$

$$= 8944.26\,\mu Pa$$

$$\therefore \quad L_p = 20\log_{10}\left(\frac{8944.26}{20}\right)$$

$$= 53.01\text{ dB}$$

10.44 (c)

Organisms that derive both energy and material from inorganic sources are called autotrophs, while that obtain both energy and material from organic compounds are called heterotrophs. Phototrophs are organisms which utilize sunlight for an energy source and inorganic substances for a material source.

10.47 (a)

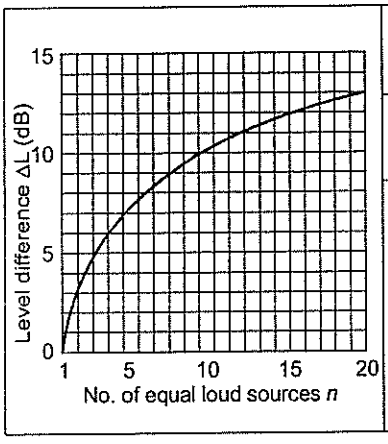
Pneumoconiosis is an occupational lung disease and a restrictive lung disease caused by the inhalation of silica and coal dust, often in mines and from agriculture.

10.49 (c)

An **electrostatic precipitator (ESP)** is a filtration device that removes fine particles, like dust and smoke, from a flowing gas using the force of an induced electrostatic charge minimally impeding the flow of gases through the unit.

10.50 (b)

Adding of equal loud incoherent sound sources



Level increase ΔL for n equal loud sound sources	
No. of n equal loud sound sources	Level increase ΔL in dB
1	0
2	3.0
3	4.8
4	6.0
5	7.0
6	7.8
7	8.5
8	9.0
9	9.5
10	10.0
2	10.8
16	12.0
20	13.0

10.54 (c)

NO_x emitted by 50000 vehicles

$= 2.0 \times 50000$

$= 100000$ g/km

NO_x produced by 50000 vehicles for a distance of 20000 km

$= 100000 \times 20000 \times 10^{-6}$ tonnes

$= 2000$ tonnes

10.55 (b)

Acid rain is caused by a chemical reaction that begins when compounds like sulfur dioxide and nitrogen oxides are released into the air. These substances can rise very high into the atmosphere, where they mix and react with water, oxygen, and other chemicals to form more acidic pollutants, known as acid rain.

10.56 (d)

PAN (peroxyacetyl nitrate) is a secondary pollutant which is formed in the atmosphere by a

photochemical reaction or by hydrolysis or oxidation. Alkenes like ethylene in the presence of sunlight react which nitrogen dioxide at high concentrations to form PAN and Ozone (O_3). This ethylene is produced in automobile exhausts and not PAN which is a secondary pollutant.

10.57 (c)

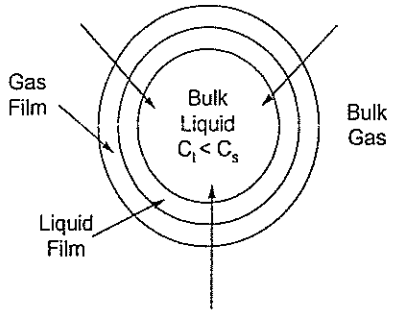
Methods to reduce Noise Pollution:

- Proper Town planning technique
- Raising of obstructions and barriers in between noise sources (automobiles) and residences.
- Raising of thick and high vegetation and growing trees.

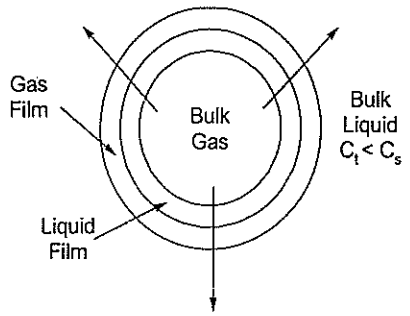
10.58 (b)

Liquid Gas systems:

- Water dispersed in Air



- Air dispersed in Water



10.59 (d)

Smog is formed when NOx and hydrocarbons react photochemically in presence of intense sunlight. The end products of photochemical reactions is photochemical smog consisting of air contaminants such as O_3, PAN, Aldehydes, Ketones etc.

10.60 (b)

Photochemically the NOx and hydrocarbons are two groups of chemical compounds which are necessary for production of photochemical smog. The end products of photochemical reaction are photochemical smog consisting of air contaminants such as O_3, PAN, Aldehydes, Ketones etc.

10.61 (d)

Photochemically, NO_x and hydrocarbons are two groups of chemical compounds which are the necessary ingredients for the production of photochemical smog.

$$\text{Hydrocarbons} + NO_x \xrightarrow{\text{sunlight}} \text{Smog.}$$

10.62 (a)

$$SPL = 20\log_{10}\left(\frac{P}{P_{ref}}\right)$$

$$P_{ref} = 20\,\mu Pa$$

$$P = 0.0002\,\mu\,bar$$

$$= 0.0002 \times 10^5\,\mu Pa$$

$$\therefore \quad SPL = 20\log_{10}\left(\frac{0.0002\times10^5}{20}\right)$$

$$= 20\log_{10}(1) = 0$$

10.63 (d)

Environmental Impact Assessment (EIA) is the process by which the anticipated effects on the environment of a proposed development or project are measured. If the likely effects are unacceptable, design measures or other relevant mitigation measures can be taken to reduce or avoid those effects.

10.64 (a)

The most common form of surface-based inversion is the *radiational inversion*. It occurs whereever, the surface of the earth can become cooler during the night and winters by the thermal radiation of energy. As a result of a decrease in temperature of the ground, the lower atmosphere in contact with it loses sensible heat through conduction, conversion, and more importantly, radiation. Consequently a temperature inversion, is setup between the cool low-level air and the warmer air above. This type of inversion is most

pronounced during the late night and early morning hours and is sometimes called a *nocturnal inversion.* The effects of stable low-level air are evident early in the day when the smoke from chimney's and small fires is confined close to the ground.

10.67 (c)

Glass doesn't reflect sound waves. Sound waves require a medium to travel and they travel faster in glass than in air. Double glass window panes have air in between which is a poor conductor than glass and hence reduces noise.

10.69 (c)

Chief source of Carbon monoxide in urban atmosphere is incomplete combustion of fuel, i.e. especially due to automobile exhaust.

10.71 (b)

In electrostatic precipitators , the emitted gas is passed through a highly ionised atmosphere i.e. in high voltage field, and in that zone particulates, get electrically charged with the result that they got separated out from the gaseous stream with the help of electrostatic forces.

10.72 (a)

Electrostatic Precipitators (ESP) can remove particles of very small size (> μm). In electrostatic precipitators, the flue gas is made to pass through a highly ionised zone, where the particals get electrically charged and are separated out from the gas, with help of electrostatic forces in the powerful electric field.

They are widely used in thermal power plants, pulp and papers industries, mining and steel plants.

10.73 (b)

Due to high voltage, power requirement is very high in electrostatic precipitator as compared to other devices viz-a-viz cyclone collector, wet scrubber, adsorbers, etc.

10.74 (a)

Ground level ozone (i.e. tropospheric ozone), though less concentrated than ozone aloft, is more of a problem because of its health effects and is also a green house gas.

Ozone is a powerful oxidizing agent readily reacting with other chemical components to make many possibly toxic oxides and hence can cause severe diseases like asthma, chronic bronchitis, etc. Whereas, stratospheric ozone stops UV radiations from reaching the earth.

Ozone is the largest constituent of photochemical smog along with PAN.

10.75 (a)

Most cases of noise-induced hearing loss are caused by repeated exposure to moderate levels of noise over many years, not by a few cases of very loud noise. Wearing hearing protectors can help prevent damage from both moderate and loud noise.

10.76 (b)

Necrosis is the name given to unprogrammed death of cells and living tissue.

Chlorosis is a condition in which leaves produce insufficient chlorophyll. As chlorophyll is responsible for the green colour of leaves, chlorotic leaves becomes pale, yellow or yellow-white.

10.79 (c)

- Fluorine is a member of the halogen family.
- It is pale yellow diatomic gas.
- Chlorine, iodine and bromine are member of halogen family but helium is not, it is a noble gas.
- Fluorine in combination with chlorine forms chlorine trifluoride which can burn highly fire-retardant material line sand, asbestos etc.

10.80 (c)

Photochemical smog is formed in the presence of high concentration of hydrocarbons, nitrogen oxides, air stagnation as not to cause disperses of air and abundant sunlight.

10.81 (d)

A Biome is a formation of plants and animals that have common characteristics due to similar climates and can be found over a range of continents. Spanning continents, biomes are distinct biological communities that have formed in response to a shared physical climate. Biomes

are distinct from habitats, because any biome can comprise a variety of habitats.

An **Ecotone** is a transition area between two biomes. It is where two communities meet and integrate. It may be narrow or wide, and it may be local (the zone between a field and forest) or regional (the transition between forest and grassland ecosystems). An ecotone may appear on the ground as a gradual blending of the two communities across a broad area, or it may manifest itself as a sharp boundary line.

An **Ecological niche** is the role and position a species has in its environment; how it meets its needs for food and shelter, how it survives, and how it reproduces. A species' niche includes all of its interactions with the biotic and abiotic factors of its environment.

10.82 (d)

Barry commoners four laws of ecology.

- Everything is connected to everything else.
- Everything must go somewhere.
- Nature knows best.
- There is no such thing as a free lunch.

UNIT

V

Soil Mechanics and Foundation Engineering

Syllabus

Soil Mechanics: Soil exploration - planning & methods, Properties of soil, classification, various tests and inter-relationships; Permeability & Seepage, Compressibility, consolidation and Shearing resistance, Earth pressure theories and stress distribution in soil; Properties and uses of geo-synthetics.

Foundation Engineering: Types of foundations & selection criteria, bearing capacity, settlement analysis, design and testing of shallow & deep foundations; Slope stability analysis, Earthen embankments, Dams and Earth retaining structures: types, analysis and design, Principles of ground modifications.

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OOOO

1 Properties of Soils

1.1 Match List-I (Type of soil) with List-II (Mode of transportation and deposition) and select the correct answer using the codes given below the lists:

List-I

A. Lacustrine soils
B. Alluvial soil
C. Aeolian soils
D. Marine soils

List-II

1. Transportation by wind
2. Transportation by running water
3. Deposited at the bottom of lakes
4. Deposited in sea water

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	2	1	4
(c)	3	2	4	1
(d)	1	3	2	4

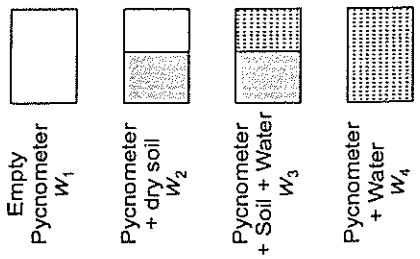
[ESE : 1995]

1.2 The liquid limit and plastic limit of sample are 65% and 29% respectively. The percentage of the soil fraction with grain size finer than 0.002 mm is 24. The activity ratio of the soil sample is

(a) 0.50 (b) 1.00
(c) 1.50 (d) 2.00

[ESE : 1995]

1.3 The given figure indicate the weights of different pycnometers:



The specific gravity of the solids is given by

(a) $\frac{W_2}{W_4 - W_2}$

(b) $\frac{W_1 - W_2}{(W_3 - W_4) - (W_2 - W_1)}$

(c) $\frac{W_2}{W_3 - W_4}$

(d) $\frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$

[ESE : 1995]

1.4 A soil sample has a shrinkage limit of 10% and specific gravity of soil solids as 2.7. The porosity of the soil at shrinkage limit is

(a) 21.2% (b) 27%
(c) 73% (d) 78.8%

[ESE : 1995]

1.5 **Assertion (A):** If the water table is very near to the subgrade of the road, it will ultimately cause cracking of the road surface.

Reason (R): The consistency of the soil will change from plastic to liquid state leading to its volumetric decrease.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1995]

1.6 In a wet soil mass, air occupies one-sixth of its volume and water occupies one-third of its volume. The void ratio of the soil is

(a) 0.25 (b) 0.5
(c) 1.00 (d) 1.50

[ESE : 1995]

1.7 Lacustrine soils are soils
(a) transported by rivers and streams
(b) transported by glaciers
(c) deposited in sea beds
(d) deposited in lake beds

[ESE : 1996]

1.8 A soil sample is having a specific gravity of 2.60 and a void ratio of 0.78. The water content in percentage required to fully saturate the soil at that void ratio would be
(a) 10 (b) 30
(c) 50 (d) 70

[ESE : 1996]

1.9 A dry soil has mass specific gravity of 1.35. If the specific gravity of solids is 2.7, then the void ratio will be
(a) 0.5 (b) 1.0
(c) 1.5 (d) 2.0

[ESE : 1996]

1.10 A clay sample has a void ratio of 0.50 in dry state and specific gravity of solids = 2.70. Its shrinkage limit will be
(a) 12% (b) 13.5%
(c) 18.5% (d) 22%

[ESE : 1996]

1.11 A soil has liquid limit of 60% plastic limit of 35% and shrinkage limit of 20% and it has a natural moisture content of 50%. The liquidity index of soil is
(a) 1.5 (b) 1.25
(c) 0.6 (d) 0.4

[ESE : 1996]

1.12 Consider the following statements in relation to the given table:

Volume (cc)	Content	Weight (g)
0.2	Air	0
0.3	Water	0.3
0.5	Solids	1.0

1. Soil is partially saturated at degree of saturation = 60%
2. Void ratio = 40%
3. Water content = 30%
4. Saturated unit weight = 1.5 g/cc

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 4

[ESE : 1996]

1.13 Consider the following statements in the context of aeolian soils:
1. The soil has low density and low compressibility.
2. The soil is deposited by wind.
3. The soil has large permeability.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 3 (d) 1 and 2

[ESE : 1997]

1.14 The dry density of a soil is 1.5 g/cc. If the saturation water content were 50% then its saturated density and submerged density would, respectively, be
(a) 1.5 g/cc and 1.0 g/cc
(b) 2.0 g/cc and 1.0 g/cc
(c) 2.25 g/cc and 1.25 g/cc
(d) 2.50 g/cc and 1.50 g/cc

[ESE : 1997]

1.15 The moisture content of a clayey soil is gradually decreased from a large value. What will be the correct sequence of the occurrence of the following limits?
1. Shrinkage limit
2. Plastic limit
3. Liquid limit

Select the correct answer using the codes given below:
(a) 1, 2, 3 (b) 1, 3, 2
(c) 3, 2, 1 (d) 3, 1, 2

[ESE : 1997]

1.16 A fill having a volume of 1,50,000 cum is to be constructed at a void ratio of 0.8. The borrow pit soil has a void ratio of 1.4. The volume of soil required (in cubic meters) to be excavated from the borrow pit will be
(a) 1,87,500 (b) 2,00,000
(c) 2,10,000 (d) 2,50,000

[ESE : 1997]

1.17 Given that Plasticity Index (*PI*) of local soil =15 and *PI* of sand = zero, for a desired *PI* of 6, the percentage of sand in the mix should be

(a) 70 (b) 60
(c) 40 (d) 30

[ESE : 1997]

1.18 A clayey soil has liquid limit = w_L; plastic limit = w_P and natural moisture content = w. The consistency index of the soil is given by

(a) $\frac{W_L - W}{W_L - W_P}$ (b) $\frac{W_L - W_P}{W_L - W}$

(c) $\frac{W_P - W}{W_L - W_P}$ (d) $\frac{W_L - W_P}{W_P - W}$

[ESE : 1998]

1.19 A soil has mass unit weight γ, water content 'w' (as ratio). The specific gravity of soil solids = G, unit weight of water = γ_w; S the degree of saturation of the soil is given by

(a) $S = \frac{1+w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$

(b) $S = \frac{w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$

(c) $S = \frac{(1+w)}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$

(d) $S = \frac{w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{wG}}$

[ESE : 1998]

1.20 If an unconfined compressive strength of 4 kg/cm^2 in the natural state of clay reduces by four times in the remoulded state, then its sensitivity will be

(a) 1 (b) 2
(c) 4 (d) 8

[ESE : 1999]

1.21 The saturated and dry densities of a soil are respectively 2000 kg/m^3 and 1500 kg/m^3. The water content (in percentage) of the soil in the saturated state would be

(a) 25 (b) 33.33
(c) 50 (d) 66.66

[ESE : 1999]

1.22 If a soil sample of weight 0.18 kg having a volume of 10^{-4} m^3 and dry unit weight of 1600 kg/m^3 is mixed with 0.02 kg of water then the water content in the sample will be

(a) 30% (b) 25%
(c) 20% (d) 15%

[ESE : 1999]

1.23 Match List-I (Terms) with List-II (Formulae) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Void Ratio	1. $\frac{V_V}{V}$
B. Porosity	2. $\frac{W_W}{W_S}$
C. Degree of saturation	3. $\frac{V_W}{V_V}$
D. Water content	4. $\frac{W}{V}$
	5. $\frac{V_V}{V_S}$

Codes:

	A	B	C	D
(a)	4	3	5	1
(b)	5	4	3	1
(c)	4	1	5	2
(d)	5	1	3	2

[ESE : 1999]

1.24 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Loess	1. Deposited from suspe-nsion in running water
B. Peat	2. Deposits of marine origin
C. Alluvial soil	3. Deposits by wind
D. Marl	4. Organic soil

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	1	2
(c)	4	3	2	1
(d)	3	4	1	2

[ESE : 2000]

1.25 The value of porosity of a soil sample in which the total volume of soil grains is equal to twice the total volume of voids would be

(a) 75% (b) 66.66%
(c) 50% (d) 33.33%

[ESE : 2000]

1.26 A soil has a liquid limit of 40% and plasticity index of 20%. The plastic limit of the soil will be
(a) 20% (b) 30%
(c) 40% (d) 60%

[ESE : 2000]

1.27 A sample of saturated sand has a dry unit weight of 18 kN/m^3 and a specific gravity of 2.7. If density of water is 10 kN/m^3, the void ratio of the soil sample will be
(a) 0.5 (b) 0.6
(c) 0.4 (d) 0.9

[ESE : 2000]

1.28 **Assertion (A):** Black cotton soils are clays and they exhibit characteristic property of swelling.
Reason (R): These clays contain Montmorillonite which attracts external water into its lattice structure.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

1.29 A dry soil sample has equal amounts of solids and voids by volume. Its void ratio and porosity will be

	Void ratio	Porosity (%)
(a)	1.0	100%
(b)	0.5	50%
(c)	0.5	100%
(d)	1.0	50%

[ESE : 2001]

1.30 The plasticity index and the percentage of grain size finer than 2 microns of a clay sample are 25 and 15, respectively. Its activity ratio is
(a) 2.5 (b) 1.67
(c) 1.0 (d) 0.6

[ESE : 2001]

1.31 A soil sample having a void ratio of 1.3, water content of 50% and a specific gravity of 2.60, is in a state of
(a) partial saturation
(b) full saturation
(c) over saturation
(d) under saturation

[ESE : 2001]

1.32 The natural void ratio of a sand sample is 0.6 and its density index is 0.6. If its void ratio in the loosest state is 0.9, then the void ratio in the densest state will be
(a) 0.2 (b) 0.3
(c) 0.4 (d) 0.5

[ESE : 2001]

1.33 Which one of the following phase diagrams represents a clay at its shrinkage limit?

(a)
AIR
WATER
SOLIDS

(b)
WATER
SOLIDS

(c)
AIR
SOLIDS

(d)
WATER
AIR
SOLIDS

[ESE : 2001]

1.34 Which one of the following correctly represents the dry unit weight of a soil sample which has a bulk unit weight of γ_t at a moisture content of w%?

(a) $\frac{w\gamma_t}{100}$ (b) $\gamma_t\left(1+\frac{w}{100}\right)$
(c) $\gamma_t\left(\frac{100}{100+w}\right)$ (d) $\frac{\gamma_t(100-w)}{100}$

[ESE : 2001]

1.35 Which one the following represents relative density of saturated sand deposit having moisture content of 25%, if maximum and minimum void ratio of sand are 0.95 and 0.45 respectively and specific gravity of sand particles is 2.6?
(a) 40% (b) 50%
(c) 60% (d) 70%

[ESE : 2002]

1.36 The correct sequence of plasticity of minerals in soil in an increasing order is
(a) silica, kaolinite, illite, montmorillonite
(b) kaolinite, silica, illite, montmorillonite
(c) silica, kaolinite, montmorillonite, illite
(d) kaolinite, silica, montmorillonite, illite

[ESE : 2002]

1.37 **Assertion (A):** A soil is at its liquid limit if the consistency index of the soil is equal to zero.
Reason (R): The consistency index of a soil is defined as ratio of (liquid limit minus the natural water content) to (natural water content minus plastic limit).
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2002]

1.38 Consider the following statements:
A dispersed structure is formed in clay when
1. the net electrical forces between adjacent soil particles at the time of deposition are repulsive
2. remoulding and compacting of clays have high void ratio
3. there is concentration of dissolved minerals in water
4. platelets have face to face contact in more or less parallel arrays
Which of these statements are correct?
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 2 and 4 (d) 1, 3 and 4
[ESE : 2003]

1.39 The collapsible soil is associated with
(a) dune sands (b) laterite soils
(c) loess (d) black cotton soils
[ESE : 2003]

1.40 Consistency as applied to cohesive soils is an indicator of its
(a) density (b) moisture content
(c) shear strength (d) porosity
[ESE : 2003]

1.41 While computing the values of limits of consistency and consistency indices, it is found that liquidity index, has a negative value.
Consider the following comments on this value:
1. Liquidity index cannot have a negative value and should be taken as zero.
2. Liquidity index can have a negative value.
3. The soil tested is in semisolid state and stiff.
4. The soil tested is in medium soft state.
Which of these statements are correct?
(a) 1 and 4 (b) 1 and 3
(c) 2 and 4 (d) 2 and 3
[ESE : 2003]

1.42 The predominant mineral responsible for shrinkage and swelling in black cotton soils is
(a) illite (b) kaolinite
(c) mica (d) montmorillonite
[ESE : 2003]

1.43 Two soil sample A and B have porosities $n_A = 40\%$ and $n_B = 60\%$ respectively. What is the ratio of void ratios $e_A : e_B$?
(a) 2 : 3 (b) 3 : 2
(c) 4 : 9 (d) 9 : 4
[ESE : 2004]

1.44 Match **List-I** (Densities) with **List-II** (Expressions) and select the correct answer using the codes given below the lists:
(Symbols G, e, γ_w and S stand for specific gravity of soil grains, void ratio, unit weight of water and degree of saturation respectively)

List-I	List-II
A. Dry density	1. $\gamma_w(G + Se)/(1 + e)$
B. Moist density	2. $\gamma_w G/(1 + e)$
C. Submerged density	3. $\gamma_w(G + e)/(1 + e)$
D. Saturated density	4. $\gamma_w(G - 1)/(1 + e)$

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	2	3	4	1
(c)	4	1	2	3
(d)	4	3	2	1

[ESE : 2004]

1.45 What are the respective values of void ratio, porosity ratio and saturated density (in kN/m^3) for a soil sample which has saturation moisture content of 20% and specific gravity of grains as 2.6? (take density of water as 10 kN/m^3)
(a) 0.52, 1.08, 18.07 (b) 0.52, 0.34, 18.07
(c) 0.77, 1.08, 16.64 (d) 0.52, 0.34, 20.14
[ESE : 2004]

1.46 Embankment fill is to be compacted at a density of 18 kN/m^3. The soil of the borrow area is at a density of 15 kN/m^3. What is the estimated number of trips of 6 m^3 capacity truck for hauling the soil

required for compacting 100 m^3 fill of the embankment? (Assume that the soil in the borrow area and that in the embankment are at the same moisture content)

(a) 14 (b) 18
(c) 20 (d) 23

[ESE : 2004]

1.47 Match List-I (Unit/Test) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Casagrande's apparatus
B. Hydrometer
C. Plate load test
D. Oedometer

List-II
1. Determination of grain size distribution
2. Consolidation characteristics
3. Determination of consistency limits
4. Determination of safe bearing capacity of soil

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	1	3	4	2
(c)	3	1	2	4
(d)	3	1	4	2

[ESE : 2004]

1.48 A clay sample has a void ratio 0.54 in dry state. The specific gravity of soil solids is 2.7. What is the shrinkage limit of the soil?

(a) 8.5% (b) 10.0%
(c) 17.0% (d) 20.0%

[ESE : 2005]

1.49 Consider the following clay minerals:
1. Kaolinite
2. Illite
3. Montmorillonite

Which one of the following is the correct sequence of the minerals given above in the increasing order of their grain size?

(a) 3-2-1 (b) 1-3-2
(c) 1-2-3 (d) 3-1-2

[ESE : 2006]

1.50 Consider the following statements:
1. Mica is a clay mineral.
2. Rock dust particles, even of clay size are non-plastic.
3. A particle of kaolinite is electrically charged.

Which of these statements are correct?

(a) 1, 2 and 3 (b) Only 1 and 2
(c) Only 2 and 3 (d) Only 1 and 3

[ESE : 2006]

1.51 Which one of the following relation gives the value of degree of saturation S, in terms of unit weight γ, water content w (as ratio) and specific gravity of soil solids G_s, γ_w is unit weight of water?

(a) $S = \dfrac{w}{(\gamma / \gamma_w)(1+w) - 1/G_s}$

(b) $S = \dfrac{w}{(\gamma / \gamma_w)(1+w) + 1/G_s}$

(c) $S = \dfrac{w}{(\gamma_w / \gamma)(1+w) + 1/G_s}$

(d) $S = \dfrac{w}{(\gamma_w / \gamma)(1+w) - 1/G_s}$

[ESE : 2006]

1.52 **Assertion (A):** The water content of inorganic soils is determined by heating the soil in an oven at a temperature of 105° to 110°C.

Reason (R): The free water, absorbed water and structural water are all completely removed from the soil by heating it at 105° to 110°C.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2007]

1.53 In comparison to Atterberg limits of normal soils, the expansive soils have which of the following?
1. More liquid limit
2. Less plastic limit
3. Less shrinkage limit
4. More volumetric shrinkage

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 1, 3 and 4 only
(c) 2 and 3 only (d) 1, 2 and 4 only

[ESE : 2008]

1.54 For a sandy soil with soil grains spherical in shape and uniform in size, what is the theoretical void ratio ?
(a) 0.61 (b) 0.71
(c) 0.91 (d) 0.81
[ESE : 2009]

1.55 A soil has liquid limit = 35, plastic limit = 20, shrinkage limit = 10 and natural moisture content = 25%. What will be its liquidity index, plasticity index and shrinkage index?
(a) 0.67, 15 and 25 (b) 0.33, 15 and 10
(c) 0.67, 25 and 15 (d) 0.33, 20 and 15
[ESE : 2009]

1.56 A cohesive soil yields a maximum dry density of 16 kN/m^3 during a standard Proctor Compaction test. If the specific gravity is 2.65, what would be its void ratio?
(a) 0.552 (b) 0.624
(c) 0.712 (d) 0.583
[ESE : 2009]

1.57 Consider the following properties for clays *X* and *Y*:

Sl. No.	Properties	Clay X (%)	Clay Y (%)
1.	Liquid limit	42	56
2.	Plastic limit	20	34
3.	Natural water content	30	50

Which of the clays, *X* or *Y*, experiences larger settlement under identical loads; is more plastic; and is softer in consistency?
(a) *X*, *Y* and *X* (b) *Y*, *X* and *X*
(c) *Y*, *X* and *Y* (d) *X*, *X* and *Y*
[ESE : 2009]

1.58 Consider the following clay minerals:
1. Kaolinite
2. Montmorillonite
3. Illite
What is the correct sequence in an increasing order of their plasticity index?
(a) 1–2–3 (b) 3–2–1
(c) 1–3–2 (d) 3–1–2
[ESE : 2009]

1.59 Consider the following statements:
1. Each year, black cotton soil appreciably shrinks during dry season and swells during rainy season. This alternate cycle of shrinking and swelling causes severe stresses in structures supported directly by such soil.
2. Black cotton soil contains predominantly a clay mineral called kaolinite, which is responsible for causing appreciable shrinking and swelling.
3. Shrinking and swelling of black cotton soils are observed only upto a certain depth below the ground level. Below that level, there is neither shrinking nor swelling.
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 3 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2010]

1.60 In a wet soil mass, air occupies one-sixth of its volume and water occupies one-third of its volume. The void ratio of the soil is
(a) 0.25 (b) 0.50
(c) 0.75 (d) 1.0
[ESE : 2010]

1.61 Consider the following statements:
1. Peat and muck are organic soils.
2. Peat is an inorganic soil whereas muck is an organic soil.
3. Indurated clay is a type of clay which does not soften under prolonged wetting.
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 2 only
(c) 3 only (d) 1 and 3 only
[ESE : 2010]

1.62 A specimen of clayey silt contains 70% silt size particles. Its liquid limit = 40 and plastic limit = 20. In liquid limit test, at moisture content of 30%, required number of blows was 50. Its plasticity index, activity and consistency index will respectively be
(a) 20, 0.67 and 0.5 (b) 20, 1.5 and 2.0
(c) 30, 1.5 and 0.72 (d) 20, 0.286 and 0.38
[ESE : 2010]

1.63 Liquefaction of foundation soil during an earthquake shall not be the reason for cracking of

(a) only floors in the building
(b) walls and roof in the building
(c) beams and columns in the building
(d) only balcony in the building

[ESE : 2010]

1.64 Consider the following statements:
1. Mica is a clay mineral.
2. The shape of clay particle is usually flaky.
3. A particle of kaolinite is electrically charged.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 3 only
(c) 2 and 3 only (d) 2 only

[ESE : 2010]

1.65 Match List-I (Deposit) with List-II (Soil structure) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Coarse grained soil	1. Flocculated
B. Silt deposit	2. Cohesive matrix
C. Clay deposit	3. Honeycomb
D. Composite soil	4. Single-grained

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	4	3	1	2
(c)	2	1	3	4
(d)	4	1	3	2

[ESE : 2010]

1.66 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Plate load
B. Pycnometer
C. Core cutter
D. Mechanical sieve

List-II
1. Specific gravity
2. Bearing capacity
3. Grain size analysis
4. Field density

Code:

	A	B	C	D
(a)	3	1	4	2
(b)	2	1	4	3
(c)	3	4	1	2
(d)	2	4	1	3

[ESE : 2011]

1.67 The natural water content of the soil sample was found to be 40%, specific gravity is 2.7 and void ratio 1.2; then the degree of saturation of the soil will be
(a) 100% (b) 69%
(c) 87% (d) 90%

[ESE : 2012]

1.68 The porosity of a soil sample having its void ratio equal to unity would be
(a) 33.34% (b) 50.0%
(c) 66.66% (d) 75.0%

[ESE : 2012]

1.69 The porosity of a certain soil sample was found to be 80% and its specific gravity was 2.7; the critical hydraulic gradient will be estimated as
(a) 0.34 (b) 0.92
(c) 1.0 (d) 1.5

[ESE : 2012]

1.70 The field density and field moisture content of a soil can be determined by
1. Core cutter method
2. Sand replacement method
3. Proctor compaction test
4. Modified proctor compaction test

(a) 1, 2, 3 and 4 (b) 1 and 2 only
(c) 2 and 3 only (d) 2 and 4 only

[ESE : 2012]

1.71 Consider the following statements:
1. Relative density is a meaningful parameter for all types of soils.
2. Relative density is a meaningful parameter only for cohesionless soils.
3. Relative density is a better indicator of the denseness of an in-situ granular soil deposit than the void ratio.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

1.72 Consider the following statements:
1. Activity is a property typical of clay soils.
2. An activity value of 7 in a clay soil is indicative of the presence of montmorillonite mineral.
3. An activity value of 7 in a clay soil is indicative of the presence of illite mineral.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only
[ESE : 2013]

1.73 In a wet soil mass, air occupies one-fourth of its volume and water occupies one-half of its volume. The void ratio of this soil is:
(a) 1 (b) 2
(c) 3 (d) 4
[ESE : 2013]

1.74 Consider the following statements:
1. If the soil is not black in colour, it is unlikely to be a swelling soil.
2. The swelling pressure of a fine-grained soil depends on its initial water content and density.
3. The swelling pressure of a fine-grained soil depends on the nature of the pore fluid.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only
[ESE : 2013]

1.75 A soil sample has a void ratio of 0.5; its porosity will be
(a) 50% (b) 66%
(c) 100% (d) 33%
[ESE : 2014]

1.76 A saturated specimen of clay was immersed in mercury and displaced volume was 21.8 cc. The weight of the sample was 32.2 gm. After oven drying for 48 hours, weight reduced to 20.2 gm while volume came down to 11.6 cc. The shrinkage limit of the soil is
(a) 7.9% (b) 8.0%
(c) 8.9% (d) 9.8%
[ESE : 2014]

1.77 Statement (I): Clays exhibit more hygroscopicity than sands.

Statement (II): Clays are colloidal and consequently their specific surface is very high.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.
[ESE : 2014]

1.78 The specific gravity of a soil sample is 2.7 and its void ratio is 0.945. When it is fully saturated the moisture content of the soil will be
(a) 25% (b) 30%
(c) 35% (d) 40%
[ESE : 2015]

1.79 Arrange the following soils with respect to increasing order of realizable friction ratio:
1. Loose gravel fill
2. Sands or gravels
3. Clay sand mixtures and silts
4. Clays and peats
(a) 1, 2, 3 and 4 (b) 4, 2, 3 and 1
(c) 1, 3, 2 and 4 (d) 4, 3, 2 and 1
[ESE : 2015]

1.80 A soil sample has shrinkage limit of 6% and the specific gravity of the soil grains is 2.6. The porosity of soil at shrinkage limit is
(a) 7.5% (b) 9.5%
(c) 13.5% (d) 16.5%
[ESE : 2016]

1.81 What is the dry unit weight of a clay soil when the void ratio of a sample there of is 0.50, the degree of saturation is 70% and the specific gravity of soil grains is 2.7? Take the value of γ_w to be 9.81 kN/m^3.
(a) 13.65 kN/m^2 (b) 19.95 kN/m^2
(c) 23.65 kN/m^2 (d) 29.95 kN/m^2
[ESE : 2016]

1.82 A fill having volume of 150000 m^3 is to be constructed at a void ratio of 0.8. The borrow pit solid has a void ratio of 1.4. The volume of soil required to be excavated from the borrow pit will be
(a) 150000 m^3 (b) 200000 m^3
(c) 250000 m^3 (d) 300000 m^3
[ESE : 2016]

1.83 The ratio of dry unit weight to unit weight of water represents
(a) specific gravity of soil solids
(b) specific gravity of soil mass

(c) specific gravity of dry soil
(d) shrinkage ratio

[ESE : 2016]

1.84 Proctor's compaction test for the maximum dry density of a certain soil gave the results as : 1.77 gm/cc and OMC 14.44%. The specific gravity of the clay soil grain was 2.66. What was the saturation degree for this soil?
(a) 44% (b) 55%
(c) 66% (d) 77%

[ESE : 2016]

1.85 The value of porosity of a soil sample in which the total volume of soil grams is equal to twice the total volume of voids would be
(a) 30% (b) 40%
(c) 50% (d) 60%

[ESE : 2016]

1.86 Consider the following statements:
1. Illite the mineral largely responsible for the swelling and shrinkage behaviour of clayey coils.
2. A differential free swell value of 55% indicates a soil with low degree of expansiveness.
3. Higher the plasticity index of a soil, greater its swelling potential.
4. A low shrinkage limit of a soil indicates possibility of swelling at low water content.

Which of the above statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 4 (d) 3 and 4

[ESE : 2017]

1.87 Consider the following effects as indicative of complete saturation of a soil sample:
1. Pore water pressure is positive.
2. Volume of water to volume of voids is equal to 1..
3. Relative density is equal to 1.

Which of the above statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 2017]

1.88 **Statement (I):** At shrinkage limit, the soil is fully saturated.
Statement (II): Montmorillonite clay minerals are non-expansive.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2017]

■■■■

Answers Properties of Soils

1.1 (b)	1.2 (c)	1.3 (d)	1.4 (a)	1.5 (c)	1.6 (c)	1.7 (d)	1.8 (b)	1.9 (b)	
1.10 (c)	1.11 (c)	1.12 (b)	1.13 (b)	1.14 (c)	1.15 (c)	1.16 (b)	1.17 (b)	1.18 (a)	
1.19 (b)	1.20 (c)	1.21 (b)	1.22 (b)	1.23 (d)	1.24 (d)	1.25 (d)	1.26 (a)	1.27 (a)	
1.28 (a)	1.29 (d)	1.30 (b)	1.31 (b)	1.32 (c)	1.33 (b)	1.34 (c)	1.35 (c)	1.36 (a)	
1.37 (c)	1.38 (c)	1.39 (c)	1.40 (c)	1.41 (d)	1.42 (d)	1.43 (c)	1.44 (a)	1.45 (d)	
1.46 (c)	1.47 (d)	1.48 (d)	1.49 (a)	1.50 (c)	1.51 (d)	1.52 (c)	1.53 (a)	1.54 (c)	
1.55 (b)	1.56 (b)	1.57 (c)	1.58 (c)	1.59 (d)	1.60 (d)	1.61 (d)	1.62 (a)	1.63 (d)	
1.64 (d)	1.65 (b)	1.66 (b)	1.67 (d)	1.68 (b)	1.69 (a)	1.70 (b)	1.71 (c*)	1.72 (b)	
1.73 (c)	1.74 (d)	1.75 (d)	1.76 (c)	1.77 (a)	1.78 (c)	1.79 (d)	1.80 (c)	1.81 (b)	
1.82 (b)	1.83 (d)	1.84 (d)	1.85 (a)	1.86 (d)	1.87 (a)	1.88 (c)			

Explanations Properties of Soils

1.1 (b)

Alluvial soil is a fine grained fertile soil deposited by water flowing over flood plains or in river beds.

Lacustrine Soil is deposited at bottom of lakes. The soil material consists of a clay and silt mixture.

Aeolian soils are wind deposited materials that consist primarily of sand or silt-sized particles. These materials tend to be extremely well sorted and free of coarse fragments.

Marine soils are sediments that accumulate in a marine (ocean or sea) environment. These sediments are later exposed and subjected to soil development because either the ocean floor was uplifted or the water receded.

1.2 (c)

$$\text{Activity} = \frac{\text{Plasticity Index}}{\%\text{ of clay fraction}}$$

$$= \frac{65-29}{24} = \frac{36}{24}$$

$$= 1.5 > 1.25$$

$\therefore$ The soil is active.

1.3 (d)

Specific Gravity of solids is given by

$$G_s = \frac{W_2 - W_1}{(W_2 - W_1)(W_3 - W_4)}$$

1.4 (a)

$$\text{Shrinkage limit, } w_s = \frac{e}{G} \times 100$$

$$\therefore \quad e = 0.1 \times 2.7 = 0.27$$

$$\text{Porosity, } \quad n = \frac{e}{1+e} \times 100$$

$$= \frac{0.27}{1+0.27} \times 100 = 21.2\%$$

1.5 (c)

The volume of soil increases from plastic limit to liquid limit. The cracking in soil is due to reduction in bearing capacity and consequent failure and heaving.

1.6 (c)

$$\text{Void ratio, } \quad e = \frac{V_V}{V_S}$$

V_v = air void + water filled voids

$$= \frac{1}{6}V + \frac{1}{3}V = \frac{V}{2}$$

$$V_s = V - V_v = \frac{V}{2}$$

$$\therefore \quad e = \frac{V/2}{V/2} = 1.0$$

1.7 (d)

Lacustrine soils are silt and clays which have been deposited in still, fresh water of lakes.

1.8 (b)

Given, $S = 100\%$

$$\therefore \quad w = \frac{Se}{G} = \frac{100 \times 0.78}{2.60} = 30\%$$

1.9 (b)

$$G_m = G_s(1-n) = \frac{G_s}{1+e}$$

G_m is mass specific gravity

G_s is specific gravity of solids

$$\therefore \quad e = \frac{G_s}{G_m} - 1$$

$$\Rightarrow \quad e = \frac{2.7}{1.35} - 1 = 1$$

1.10 (c)

At shrinkage limit, soil is fully saturated.

$$\therefore \quad w_s = \frac{e}{G} \times 100 = \frac{0.5}{2.7} \times 100 = 18.5\%$$

1.11 (c)

Liquidity Index

$$= \frac{w - w_P}{w_L - w_P} = \frac{50 - 35}{60 - 35}$$

$$= \frac{15}{25} = 0.6$$

Consistency Index = 1 – 0.6 = 0.4

1.12 (b)

Degree of saturation,

$$S = \frac{V_w}{V_V} \times 100$$

$$= \frac{0.3}{0.2 + 0.3} \times 100 = 60\%$$

$$\text{and void ratio} = \frac{V_v}{V_s} = \frac{0.2 + 0.3}{0.5}$$

$$= 1 \times 100 = 100\%$$

1.13 (b)

Aeolian soils are deposited by winds. It consist of uniformly graded particles. The void ratio and permeability of soil are high. They are non-plastic and can withstand deep vertical cuts due to slight cementation between particles. These soils have high compressibility and density is low in natural states.

Example: Fine sand in dunes; loess.

1.14 (c)

$$\gamma_{sat} = \gamma_d(1 + w) = 1.5 \times 1.5$$

$$= 2.25 \text{ g/cc}$$

$$\gamma_{sub} = \gamma_{sat} - \gamma_w = 2.25 - 1.0$$

$$= 1.25 \text{ g/cc}$$

1.15 (c)

As the moisture content of a clayey soil is reduced from a large value, the alterberg limits are encountered in following sequence.

Liquid limit → Plastic limit → Shrinkage limit

1.16 (b)

The volume of soil solids from borrow pit soil and from fill should be equated.

$$V_s = \frac{V_1}{1+e_1} = \frac{V_2}{1+e}$$

$$\therefore \quad V_1 = V_2 \times \frac{1+e_1}{1+e_2}$$

$$= 150000 \times \frac{1+1.4}{1+0.8}$$

$$= 200{,}000 \text{ m}^3$$

1.17 (b)

Let percentage of sand is x. So plasticity of mix is

$x \times 0 + (1 - x) \times 15 = 6$

$$x = \frac{9}{15} = 0.6 \text{ or } 60\%$$

1.18 (a)

The consistency index indicates the consistency (firmness) of a soil. Soil at the liquid limit will have a consistency index of 0, while soil at the plastic limit will have a consistency index of 1.

1.19 (b)

$$\gamma = \frac{G(1+w)}{1+e}\gamma_w$$

$$1 + e = \frac{G(1+w)\gamma_w}{\gamma}$$

and $\quad Gw = Se$

$$\frac{Gw}{S} = \frac{G(1+w)\gamma_w}{\gamma} - 1$$

Dividing both sides by G, we get

$$\Rightarrow \quad \frac{w}{S} = (1+w)\frac{\gamma_w}{\gamma} - \frac{1}{G}$$

$$S = \frac{w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$$

1.20(c)

$$\text{Sensitivity} = \frac{(UCC)_{\text{natural}}}{(UCC)_{\text{remoulded}}} = \frac{4}{(4/4)} = 4$$

1.21(b)

$$\gamma_d = \frac{\gamma_{sat}}{\left(1+\frac{w}{100}\right)}$$

$$1+\frac{w}{100} = \frac{2000}{1500}$$

$$\therefore \quad w = 33.33\%$$

1.22(b)

Dry weight of sample

$= 1600 \times 10^{-4} = 0.16$ kg

Weight of water in soil before mixing additional quantity

$= 0.18 - 0.16 = 0.02$ kg

After mixing water the total quantity of water

$= 0.02 + 0.02$

$= 0.04$ kg water

Thus, water content $= \frac{0.04}{0.16} \times 100 = 25\%$

1.23(d)

Degree of saturation,

$$S = \frac{V_w}{V_v} \times 100 = \frac{W_w}{V_V} \times 100$$

Density of water is 1 gm/cc.

1.24 (d)

Loess is a loosely compacted wind-blown sediment typically in the 20–50 micrometer size range.

Peat is a brown material consisting of partly decomposed vegetable matter (humus) forming a deposit in a water saturated environment and in the absence of oxygen.

Marl is a fine grained calcium-carbonated soil of marine origin.

1.25(d)

Given, $V_s = 2V_v$

Void ratio, $e = \frac{V_v}{V_s} = 0.5$

Porosity, $n = \frac{e}{1+e} = \frac{05}{1.5} = \frac{1}{3}$

or 33.33%

1.26(a)

Plastic limit, $w_P = w_L - PI$

$= 40 - 20 = 20\%$

1.27(a)

$$\gamma_d = \frac{G}{1+e}\gamma_w$$

$$\Rightarrow \quad e = \frac{G\gamma_w}{\gamma_d} - 1 = \frac{2.7 \times 10}{18}$$

$= 0.5$

1.28(a)

For black cotton soil:

(i) Liquid limit – 40 to 100%

(ii) Plasticity Index – 20 to 60%

(iii) Shrinkage limit – 10 to 15%

(iv) Optimum Moisture content – 25 to 30%

1.29(d)

Void ratio, $e = \frac{V_v}{V_s} = 10$

Porosity, $n = \frac{e}{1+e} \times 1 = \frac{1}{1+1} \times 10$

$= 50\%$

1.30(b)

Activity

$$= \frac{\text{Plasticity Index}}{\text{Per cent of clay particles finer than 2 } \mu\text{m}}$$

$$= \frac{25}{15} = 1.67$$

As activity is more than 1.25 so it is active soil.

1.31(b)

$$Gw = Se$$

$$S = \frac{2.60 \times 50}{1.3} = 100\%$$

Therefore soil is fully saturated.

Remember	$S \leq 100\%$ always
	w can be more than 100%
	e can be more than 1.0.

1.32(c)

Relative Density Index

$$= \frac{e_{max} - e}{e_{max} - e_{min}} = 0.6$$

Void ratio in loosest state,

$$e_{max} = 0.9$$

Void ratio in natural state,

$$e = 0.6$$

$$\therefore \quad 0.9 - e_{min} = \frac{0.9 - 0.6}{0.6}$$

$$e_{min} = 0.9 - 0.5 = 0.4$$

1.33(b)

At shrinkage limit, there is no air and degree of saturation is 100%.

1.34(c)

$$\gamma_d = \frac{\gamma_t}{\left(1 + \frac{w}{100}\right)} = \frac{100\gamma_t}{(100 + w)}$$

1.35(c)

At saturated moisture content void ratio is

$$e = \frac{Gw}{S} = \frac{2.6 \times 25}{100} = 0.65$$

Relative density,

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

$$= \frac{0.95 - 0.65}{0.95 - 0.45} = 0.6$$

$$D_r = 60\%$$

1.36(a)

Silica has least plasticity while Montmo-rillonite has highest plasticity.

1.37(c)

For $w = w_L$

$$\text{Consistency index} = \frac{w_L - w}{w_L - w_P} = 0$$

1.38 (c)

- Dispersed structure is formed when there is net repulsive force.
- Remoulding and compaction converts the edge to face orientation to face to face orientation (dispersed structure)
- Concentration of dissolved mineral decreases the charge of clay particle, thus stabilizing them to form flocculated structure.

1.39 (c)

Loess is predominantly a silt-sized sediment that is formed by the accumulation of wind-blown dust. It covers about 10% of the Earth's surface. It is usually homogeneous and highly porous and is traversed by vertical capillaries that permit the sediment to fracture and form vertical bluffs.

1.40(c)

Consistency of soil refers to the resistance offered by it against forces that tend to deform or rupture the soil aggregate. It is related to strength.

1.42 (d)

Montmorillonites expand considerably more than other clays due to water penetrating the interlayer molecular spaces and concomitant adsorption. The amount of expansion is due largely to the type of exchangeable cation contained in the sample. The presence of sodium as the predominant exchangeable cation can result in the clay swelling to several times its original volume. Also the water content of montmorillonite is variable and it increases greatly in volume when it absorbs water.

1.43(c)

$$e_A = \frac{n_A}{1 - n_A} = \frac{0.4}{0.6} = \frac{2}{3}$$

$$e_B = \frac{n_B}{1 - n_B} = \frac{0.6}{0.4} = \frac{3}{2}$$

$$\therefore \quad \frac{e_A}{e_B} = \frac{4}{9}$$

1.44(a)

Moist density,

$$\gamma = \left(\frac{G + Se}{1 + e}\right)\gamma_w$$

For dry density put $S = 0$

For saturated density put $S = 1$

Submerged density

= saturated density – density of water

1.45(d)

Given $w = 20\%$, $G = 2.6$, $S = 100\%$

$$\therefore \quad e = \frac{Gw}{S} = \frac{2.6 \times 20}{100} = 0.52$$

$$n = \frac{e}{1+e} = 0.34$$

$$\gamma_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_w$$

$$= \frac{2.6+0.52}{1+0.52} \times 10$$

$$= 20.53 \text{ kN/m}^3$$

If density of water is taken as 9.81 kN/m^3

$$\gamma_{sat} = 20.14 \text{ kN/m}^3$$

1.46 (c)

In problems of fill and borrow pit, the volume of soil solids shall be equated.

$$V_s = \frac{V}{1+e} = \frac{V\gamma}{G(1+w)\gamma_w}$$

As the moisture content of borrow area and that of embankment are same.

$$V_1\gamma_1 = V_2\gamma_2$$

For 100 m fill at embankment, the volume required from borrow pit

$$V_2 = \frac{100 \times 18}{15} = 120 \text{ m}^3$$

$$\text{Number of trips of truck} = \frac{120}{6} = 20$$

1.47 (d)

Cassagrande apparatus is used to determine the liquid limit of soils. Liquid Limit is defined as the water content at which the soil changes from liquid state to plastic state.

Hydrometer method is used to determine the particle size distribution of fine-grained soils passing 75 μ sieve. The hydrometer measures the specific gravity of the soil suspension at the centre of its bulb. The specific gravity depends upon the mass of solids present, which in turn depends upon the particle size.

Plate Load Test is a field test for determining the ultimate bearing capacity of soil and the likely settlement under a given load. The Plate Load Test basically consists of loading a steel plate placed at the foundation level and recording the settlements corresponding to each load increment.

An **oedometer test** is a test that measures a soil's consolidation properties. Oedometer tests are performed by applying different loads to a soil sample and measuring the deformation response. The results from these tests are used to predict how a soil in the field will deform in response to a change in effective stress.

1.48 (d)

At shrinkage limit the soil remains fully saturated,

$$w_s = \frac{e_{min}}{G} \times 100$$

$$= \frac{0.54}{2.7} \times 100 = 20\%$$

1.49 (a)

	Thickness (Å)	Lateral dimension (Å)
Kaolinite	100-1000	1000-20,000
Montmorillonite	10-50	1000-5000
Illite	50-500	1000-5000

Thus size of kaolinite > Illite > Montmorillonite

1.50 (c)

Feldspars are the most common rock minerals which account for the abundance of clays derived from the feldspars on the earth's surface. Quartz comes next in order of frequency. Most sands are composed of quartz.

Mica constitute very small fraction of original igneous rocks and thus it can not be said to be clay mineral.

Rock flour (rock dust particles) generally consists of more or less uniform size grains of quartz and they are least plastic varieties.

Electrical charge on kaolinite is responsible for plastic behaviour of soils and cohesion in clays.

1.51 (d)

Unit weight,

$$\gamma = \frac{G_s(1+w)}{(1+e)}\gamma_w$$

$$1 + e = \frac{G_s(1+w)\gamma_w}{\gamma}$$

Using $G_s w = Se$

$$1+\frac{G_s w}{S} = \frac{G_s(1+w)\gamma_w}{\gamma}$$

Dividing both sides by G_s and rearranging, we get

$$S = \frac{w}{(\gamma_w/\gamma)(1+w)-1/G_s}$$

1.52(c)

The drying of soil is recommended at a temperature of 105°-110°C as temperature higher than 110°C may break the crystalline structure of clay particles and result in the loss of chemically bound water of crystallization.

1.55(b)

Plasticity index, $I_P = w_L - w_P$
$= 35 - 20 = 15\%$

Liquidity index, $I_L = \frac{w_N - w_P}{I_P} = \frac{25-20}{15} = 0.33$

Shrinkage Index, $I_S = w_P - w_S = 20 - 10 = 10\%$

1.56(b)

The maximum dry density of the cohesive soil is given by

$$\gamma_d = \frac{G\gamma_w}{1+e}$$

$$\Rightarrow \quad 16 = \frac{2.65\times 9.81}{1+e}$$

$$\Rightarrow \quad e = 0.625$$

1.57 (c)

Plasticity Index (I_P) is the numerical difference between liquid limit and plastic limit. The soil with higher value of I_P will be more plastic.

$(I_P)_X = 42 - 20 = 22$
$(I_P)_Y = 56 - 34 = 22$

But if plasticy index is same for both soils, then the soil with larger difference in liquid limit and natural water content is more plastic.

Consistency Index,

$$I_C = \frac{\text{Liquid limit} - \text{Natural water content}}{I_P}$$

$$\therefore \quad (I_C)_X = \frac{42-30}{22} = 0.545$$

$$(I_C)_Y = \frac{56-50}{22} = 0.273$$

Soil which has low value of consistency index is softer. Thus the softer soil will undergo large settlements under identical loads.

1.58(c)

The values of plasticity index of kaolinite, Illite and montmorillonite are 15, 30 and 300 respectively.

1.59(d)

Black cotton soils contain predominantly a clay mineral called montmorillonite, which is responsible for causing appreciable shrinking and swelling. Clay soils containing other clay minerals do not exhibit the volume change characteristics to the same degree as those containing montmorillonite mineral.

1.60(d)

If V is the volume of wet soil mass, then

Volume of air, $V_a = \frac{V}{6}$

Volume of water $V_w = \frac{V}{3}$

But void ratio is given by

$$e = \frac{V_v}{V_s}$$

where V_v = Volume of voids
$= V_a + V_w$
$= \frac{V}{6} + \frac{V}{3} = \frac{V}{2}$

Also, $V_s = V - V_v = V - \frac{V}{2} = \frac{V}{2}$

$$\therefore \quad e = \frac{V/2}{V/2} = 1$$

1.61(d)

Peat is a highly organic soil, consisting almost entirely of vegetable matter in varying stages of decomposition. It is brown to black in colour and possess a strong organic odour. Peat in general is highly compressible and hence one should be cautious while using it for supporting foundations of structures.

Muck is a mixture of fine particled, inorganic solid and black decomposed organic matter. It is usually found accumulated under conditions of imperfect drainage e.g. in swamps or is deposited by overflowing rivers.

Indurated clay is a soil that had been hardened by extremes of climate.

1.62 (a)

Plasticity Index, $I_P = W_L - W_P$

$= 40 - 20 = 20$

Activity of clay,

$$A_C = \frac{\text{Plasticity index}}{\text{Per cent finer than } 2\mu}$$

$$= \frac{\text{Plasticity index}}{\text{Per cent of clay size particles in the soil}}$$

$$= \frac{20}{100-70} = 0.67$$

Consistency Index,

$$I_C = \frac{W_L - W_N}{I_P} = \frac{40-30}{20}$$

$= 0.50$

1.64 (d)

Clay soils have flaky particles to which water adheres, thus imparting the property of plasticity.

Kaolinite: This clay mineral is the weathering product of feldspars. It has a white, powdery appearance. Because kaolinite is electrically balanced, its ability of adsorb ions is less than that of other clay minerals.

1.65 (b)

Single grained structure is formed by the settlement of coarse grained soils in suspension in water. A flocculent structure is formed by the deposition of fine soil fraction (like clay particles) in water. The particles oriented in flocculent structure will have edge to face contact.

Honeycomb structure is formed by the disintegration of flocculent structure under superimposed load. The particles oriented in honeycomb structure will have face to face contact.

1.66 (b)

Allowable bearing pressure is determined by conducting a plate load test at the site. It is also used for determining the settlement for a given intensity of loading.

Pycnometer can be used to determine specific gravity as well as water content of soil sample.

Core cutter method is a field method for determination of mass density.

1.67 (d)

$$e = \frac{wG_S}{S}$$

$\therefore$ Degree of saturation,

$$S = \frac{wG_S}{e} = \frac{0.4 \times 2.7}{1.2}$$

$= 0.9 = 90\%$

1.68 (b)

$$n = \frac{e}{1+e} = \frac{1}{2} = 50\%$$

1.69 (a)

$$i_c = \frac{G-1}{1+e}$$

Given, $n = 80\%$, using $n = \frac{e}{1+e}$

We get, $e = 4$

$\therefore$ $$i_c = \frac{2.7-1}{1+4} = 0.34$$

1.70 (b)

Core cutter method: One method of examining the in-situ density of the soil is the core cutter method. This method involves pushing steel rings in the soil to determine the wet and dry volume weight including the water content.

Sand Replacement Method: Determination of field density of cohesion less soil is not possible by core cutter method, because it is not possible to obtain a core sample. In such situation, the sand replacement method is employed to determine the unit weight.

Proctor test: The Proctor test is used to determine the maximum density that can be practically achieved for a soil. The Proctor soil compaction test is performed by measuring the density of the soil being tested at different moisture content points. The aim of the Proctor test is to determine the optimum moisture content for the soil.

1.71 (c*)

The term relative density is used to express the relative compactness of a natural cohesionless

soil deposit. Relative density is the ratio of the difference between the voids ratio of soil in its loosest state e_{max}, and its natural state, e to the difference between the void ratios in the loosest and densest states.

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

This term is used for cohesionless soils only. This term is not applicable to cohesive soil because of uncertainities in the laboratory determination of the voids ratio in the loosest state of the soil (e_{max}).

Note: In point no. 2 soil mentioned should be cohesionless.

1.73 (c)

$$V_a = V/4, \quad V_w = V/2$$

$$\therefore \quad V_v = \frac{V}{4} + \frac{V}{2} = \frac{3V}{4}$$

$$\therefore \quad e = \frac{V_v}{V_s} = \frac{\frac{3V}{4}}{V - \frac{3}{4}V} = \frac{\frac{3V}{4}}{\frac{V}{4}} = 3$$

1.74 (d)

There are a lot of swelling soils which are brown or light coloured, even though most expansive soils are dark in colour.

Swelling pressure of a soil depends on lots of factors such as initial dry density, method of compaction, moisture content, height of specimen, surcharge pressure and nature of pore fluid.

1.75 (d)

$$\text{Porosity,} \quad n = \frac{e}{1+e} = \frac{0.5}{1+0.5} = 33\%$$

1.76 (c)

Mass of water in initial condition

$$= 32.2 - 20.2 = 12 \text{ gm}$$

Loss of water from original to shrinkage limit

$$= (21.8 - 11.6) \times 1 = 10.2 \text{ gm}$$

Shrinkage limit

$$= \frac{32.2 - 20.2 - 10.2}{20.2} \times 100 = 8.91 \simeq 8.9\%$$

1.77 (a)

Since clays are colloidal in nature and consequently their specific surface is very high.

Due to very high specific surfaces of clay, the hygroscopicity of clay is more than sands.

1.78 (c)

$$wG = Se$$

$$w \times 2.7 = 1 \times 0.945$$

$$w = 0.35 \text{ i.e. } 35\%$$

1.80 (c)

$$w_s = 6\%; \quad G = 2.6$$

$\Rightarrow$ At shrinkage limit, soil is fully saturated.

$$se = wG$$

$$1.e = 0.06 \times 2.6$$

$$\Rightarrow \quad e = 0.156$$

$$n = \frac{e}{1+e} = \frac{0.156}{1+0.156}$$

$$= 0.1349 = 13.49\%$$

1.81 (b)

Bulk unit weight

$$\gamma_b = \frac{(G + Se)\gamma_w}{1+e}$$

$$= \frac{2.7 + 0.4 \times 0.5}{1+0.5} \times 9.81$$

$$= 19.947 \text{ kN/m}^3$$

$$\Rightarrow \quad Se = wG$$

water content

$$w = \frac{0.7 \times 0.5}{2.7} = 0.12962$$

$$\gamma_d = \frac{\gamma_b}{1+w} = \frac{19.947}{1+0.12962}$$

$$= 17.658 \text{ kN/m}^3$$

Note: Dry unit weight has been asked but no answer is matching. But bulk unit weight is matching.

1.82 (b)

Volume of solids will remain same.

$$(V_s)_{fill} = (V_s)_{Borrowpit}$$

$$\left(\frac{V_T}{1+e}\right)_{fill} = \left(\frac{V_T}{1+e}\right)_{Borrowpit}$$

$$\frac{150000}{1+0.8} = 200000 \text{ m}^3$$

1.83 (d)

$$\text{Shrinkage ratio, } R = \frac{\gamma_d}{\gamma_w}$$

1.84 (d)

$(\gamma_d)_{max} = 1.77$ g/cc

OMC = 14.44%

$G = 2.66$

$$\gamma_d = \frac{G \cdot \gamma_w}{1+e}$$

$$\Rightarrow \quad 1.77 = \frac{2.66 \times 1}{1+e}$$

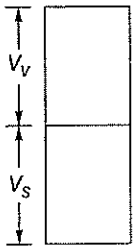
$$e = 0.5028$$

$$\Rightarrow \quad Se = wG$$

$$S = \frac{wG}{e} = \frac{0.1444 \times 2.66}{0.5028}$$

$$= 0.7639 = 76.39\%$$

1.85 (a)



$V_s = 2V_V$ (given)

$$n = \frac{V_V}{V_T}$$

$$V_T = V_S + V_V = 2V_V + V_V = 3V_V$$

$$n = \frac{V_V}{3V_V} = \frac{1}{3} = 33.33\%$$

1.86 (d)

- Montmorillonite is the mineral largely responsible for swelling and shrinkage. Activity of montmorillonite is 1 to 7 and activity of Illite is 0.5 – 1.
- Differential free swell value more then 50 indicates highly expansiveness.

1.87 (a)

Degree of saturation of saturated soil is 1.

$$S = \frac{V_w}{V_v} = 1$$

hence, $V_w = V_v$

Relative density $I_D = \dfrac{e_{max} - e}{e_{max} - e_{min}} = 1$

i.e., $e = e_{min}$

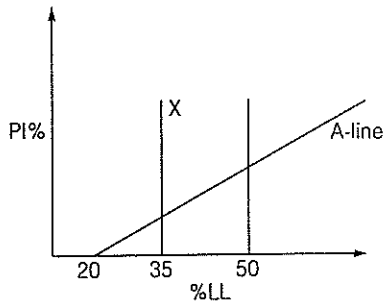
Hence soil is in densest condition.

1.88 (c)

Montmorillonite clay mineral is expansive having activity 1 to 7. Soil containing high Montmorillonite show more swelling and shrinkage.

2 Classification of Soils

2.1 The standard plasticity chart to classify fine grained soils is shown in the given figure.



The area marked *X* represents
(a) silt of low plasticity
(b) clay of high plasticity
(c) organic soil of medium plasticity
(d) clay of intermediate plasticity

[ESE : 1996]

2.2 A soil has a liquid limit of 45% and lies above the *A*-line when plotted on a plasticity chart. The group symbol of the soil as per IS soil Classification is
(a) CH (b) CI
(c) CL (d) MI

[ESE : 1997]

2.3 Consider the following statements:
A well-graded sand should have
1. uniformity coefficient greater than 6
2. coefficient of curvature between 1 and 3
3. effective size greater than 1 mm
Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

[ESE : 1998]

2.4 If the proportion of soil passing 75 micron sieve is 50% and the liquid limit and plastic limit are 40% and 20% respectively, then the group index of the soil is
(a) 3.8 (b) 6.5
(c) 38 (d) 65

[ESE : 1999]

2.5 Match List-I (Soils) with List-II (Group symbols) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Clayey gravel	1. SM
B. Clayey sand	2. OH
C. Organic clay	3. SC
D. Silty sand	4. GC

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	1	2
(c)	4	3	2	1
(d)	3	4	1	2

[ESE : 2000]

2.6 Based on grain distribution analysis, the D_{10}, D_{30} and D_{60} values of a given soil are 0.23 mm, 0.3 mm and 0.41 mm respectively. As per IS code, the soil classification will be
(a) SW (b) SP
(c) SM (d) SC

[ESE : 2001]

2.7 Given that coefficient of curvature = 1.4,
D_{30} = 3 mm, D_{10} = 0.6 mm.
Based on this information of particle size distribution for use as subgrade, this soil will be taken to be
(a) uniformly-graded sand
(b) well-graded sand
(c) very fine sand
(d) poorly-graded sand

[ESE : 2001]

2.8 In a soil specimen, 70% of particles are passing through 4.75 mm IS sieve and 40% of particles are passing through 75 μ IS sieve. Its uniformity coefficient is 8 and coefficient of curvature is 2. AS per IS classification, this soil is classified as

(a) SP (b) GP
(c) SW (d) GW

[ESE : 2002]

2.9 The laboratory tests on a sample yielded the following results:

Plasticity index : 32%
Liquidity index : 0.15
Activity number : 1.58

Which of the following inferences can be drawn?

1. The soil is very stiff.
2. The soil is medium soft.
3. The soil is highly plastic.
4. The soil is medium plastic.
5. The soil is active.

Select the correct answer using the codes given below :

(a) 1, 3 and 5 (b) 1, 3, and 4
(c) 2, 3 and 5 (d) 1, 2 and 4

[ESE : 2005]

2.10 Match List-I (Soil classification symbol) with List-II (Soil property) and select the correct answer using the codes given below the lists:

List-I	List-II
A. GW	1. Soil having uniformity coefficient > 6
B. SW	2. Soil having uniformity coefficient > 4
C. ML	3. Soil have low plasticity
D. CL	4. Soil have low compressibility

Codes:

	A	B	C	D
(a)	1	2	4	3
(b)	2	1	3	4
(c)	2	1	4	3
(d)	1	2	3	4

[ESE : 2008]

2.11 Match List-I (Soil) with List-II (Type) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Fine sand	1. Expansive soil
B. Silt	2. Coarse grained soil
C. Peat	3. Fine grained
	4. Organic soil

Codes:

	A	B	C
(a)	3	2	1
(b)	4	3	1
(c)	3	1	2
(d)	2	3	4

[ESE : 2008]

2.12 Match List-I (Symbol) with List-II (Soil) and select the correct answer using the codes given below the lists:

List-I	List-II
A. *ML*	1. Silty sand
B. *SM*	2. Inorganic silt with large compressibility
C. *Pt*	3. Inorganic silt with small compressibility
D. *MH*	4. Soil with high organic content with high compressibility

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	4	1	3	2
(c)	3	1	4	2
(d)	4	2	3	1

[ESE : 2008]

2.13 Consider the following statements:

1. Poorly graded or uniform sands compact to low dry unit weights.
2. Heavy clays with high plasticity have very low maximum dry unit weight.
3. In clay soils, the maximum dry weight tends to decrease as plasticity increases.

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 3 only

[ESE : 2010]

2.14 Match List-I (Measuring device) with List-II (Soil parameter) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Pycnometer	1. Compressibility
B. Hydrometer	2. Permeability
C. Oedometer	3. Specific gravity
D. Permeameter	4. Particle size analysis

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

[ESE : 2010]

2.15 Consider the following statements:

1. The minimum value of group index for a soil can be taken as zero.

2. The maximum possible value of group index for a soil is twenty.

Which of these statements is/are correct?

(a) Both 1 and 2 (b) 1 only
(c) 2 only (d) Neither 1 nor 2

[ESE : 2010]

2.16 Consider the following statements:

1. For a well graded sand, the coefficient of curvature should lie between 1 and 3.
2. A soil having uniformity coefficient smaller than about 2.0 is considered uniform.

Which of these statements is/are correct?

(a) Both 1 and 2 (b) Neither 1 nor 2
(c) 1 only (d) 2 only

[ESE : 2010]

2.17 On analysis of particle size distribution of a soil, it is found that $D_{10} = 0.1$ mm, $D_{30} = 0.3$ mm and $D_{60} = 0.8$ mm. The uniformity coefficient and coefficient of curvature, as given by the particle size distribution curve, are respectively

(a) 3 and 3 (b) 2.67 and 1.125
(c) 2.67 and 3 (d) 8 and 1.125

[ESE : 2011]

2.18 Which one of the following statements is correct?

(a) Grain size is the primary criterion for classification of coarse, as well as fine-grained soil
(b) Grain size is the primary criterion for classification of coarse-grained soils
(c) Plasticity curve classifies coarse grained soils
(d) Plasticity characteristics relate to classification of coarse-grained soils

[ESE : 2013]

2.19 Consider the following statements:

1. A conspicuous break in the continuity of a grain size distribution curve indicates a mixture of soil from two different layers.
2. A steep grain size distribution curve indicates prevalence of nearly uniform grain size.
3. A flat grain size distribution curve indicates certain range of missing grain sizes.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 2 and 3 only
(c) 1 and 3 only (d) 1 and 2 only

[ESE : 2013]

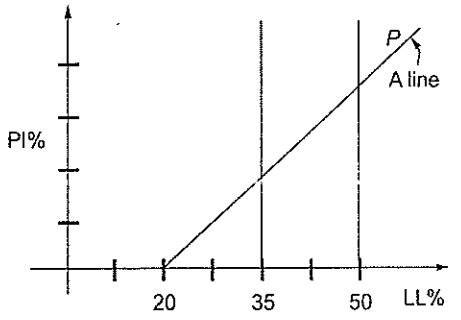
2.20 **Statement (I):** A semi-log plot is used to represent the grain size distribution of a soil sample.

Statement (II): In a semi-log plot, a wide range of grain sizes can be accommodated.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2014]

2.21 The standard plasticity chart by Casagrande to classify fine-grained soils is shown in the figure.



The area marked *P* represents

(a) Inorganic clays of high plasticity
(b) Organic clays and highly plastic organic silts
(c) Organic and inorganic silts and silt-clays
(d) Clays

[ESE : 2016]

2.22 Consider a soil sample, for which test yield the following results:

Passing 75 micron sieve 62%
Liquid limit 35%
Plasticity index 14%

As per the group index classification of soil, what is the soil condition of the above soil sample?

(a) Poor (b) Fair
(c) Good (d) Excellent

[ESE : 2016]

■■■■

Answers Classification of Soils

2.1	(d)	2.2	(b)	2.3	(b)	2.4	(b)	2.5	(c)	2.6	(b)	2.7	(b)	2.8	(d)	2.9	(a)
2.10	(b)	2.11	(d)	2.12	(c)	2.13	(a)	2.14	(d)	2.15	(a)	2.16	(a)	2.17	(d)	2.18	(b)
2.19	(a)	2.20	(a)	2.21	(a)	2.22	(b)										

Explanations Classification of Soils

2.1 (d)

% LL (Liquid Limit)	Plasticity
< 35	Low
35 – 50	Intermediate
> 50	High

Soils above *A*-line are clays and soils below A-line are silts and organic soils.

Equation of *A*-line is

$$PI = 0.73(w_L - 20)$$

2.2 (b)

Liquid limit 45% lies between 35% to 50% for intermediate plasticity. The soil above *A* line should be given symbol CI.

2.3 (b)

For well graded sand $C_u > 6$ and $1 < C_c < 3$

For well graded gravel $C_u > 4$ and $1 < C_c < 3$

2.4 (b)

Group Index, $GI = 0.2a + 0.005ac + 0.01bd$

a = %passing 75 mm sieve greater than 35 but not exceeding 75 (between 0 to 40)

b = %passing 75 mm sieve greater than 15 but not exceeding 55 (between 0 to 40)

c = Liquid limit greater than 40 not exceeding 60 (between 0 to 20)

d = Plasticity index greater than 10 and not exceeding 30 (between 0 to 20)

$a = 50 - 35 = 15 < 40$

$b = 50 - 15 = 35 < 40$

$c = 40 - 40 = 0$

$d = 20 - 10 = 10 < 20$

$\therefore$ G.I. $= 0.2 \times 15 + 0.005 \times 40 \times 0 + 0.01 \times 35 \times 10$

$= 3 + 0 + 3.5$

$= 6.5$

2.5 (c)

The Unified Soil Classification System (USCS) is a soil classification system used to describe the texture and grain size of a soil. The classification system can be applied to most unconsolidated materials, and is represented by a two-letter symbol. Each letter is described below (with the exception of Pt):

First and / or Second Letters

Letter	Definition
G	gravel
S	sand
M	silt
C	clay
O	organic

Second Letters

Letter	Definition
P	poorly graded (uniform particle sizes)
W	well-graded (diversified particle sizes)
H	high plasticity
L	low plasticity

2.6 (b)

Coefficient of uniformity,

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.41}{0.23} = 1.78$$

Coefficient of curvature,

$$C_c = \frac{D_{30}}{D_{60} \times D_{10}} = \frac{0.3^2}{0.41 \times 0.23} = 0.95$$

For well graded sand $1 < C_c < 3$ and $C_u > 6$ as per IS classification. So it is a poorly graded sand.

2.7 (b)

Coefficient of curvature,

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

$$\Rightarrow \quad D_{60} = \frac{D_{30}^2}{C_c \times D_{10}}$$

Coefficient of uniformity,

$$C_u = \frac{D_{30}^2}{C_c \times D_{10}^2} = \left(\frac{3}{0.6}\right)^2 \times \frac{1}{1.4} = 17.9$$

As $1 < C_c < 3$ and $C_u > 6$ so it is well graded sand.

2.8 (d)

As less than 50% are passing through 75 μ IS Sieve, it is coarse grained soil. As % Sand (30%) = % Gravel (30%) willbe classified as Gravelly soil.

Also C_u (8) > 6 and C_c (2) is between 1 and 3 so it is well graded (W). So symbol will be GW as per IS.

2.9 (a)

Since the liquidity index of soil is negative so soil is in semi-solid state or very stiff.

Consistency index (CI)	Liquidity index (LI)	Consistency
1.00 - 0.75	0.00 - 0.25	Stiff
0.75 - 0.50	0.25 - 0.50	Medium soft
0.50 - 0.25	0.50 - 0.75	Soft
0.25 - 0.00	0.75 - 1.00	Very soft

$$CI = \frac{w_L - w}{PI}$$

and $$LI = \frac{w - w_P}{PI}$$

where

w is natural water content

w_L is liquid limit

w_p is plastic limit

PI is plasticity index

$$CI + LI = 1.00$$

If $CI > 1$ or $LI < 0$, then soil is very stiff.

If $CI < 0$ or $LI > 1$ soil behaves as liquid.

Activity number	Classification
0.75	Inactive
0.75 - 1.25	Normal
> 1.25	Active

So soil is active

Liquid limit	Plasticity
0 - 30 %	Low
35 - 50%	Medium
> 50%	High

Plasticity Index	Plasticity
0	Non plastic
1 - 5	Slight
5 - 10	Low
10 - 20	Medium
20 - 40	High
> 40	Very high

So soil is high plastic

2.10 (b)

GW is well graded gravel for which coefficient of uniformity (C_u) > 4.

SW is well graded sand for which coefficient of uniformity (C_u) > 6

ML is silt with low plasticity (< 35%)

CL is clay with low plasticity (< 35%). It also possess low compressibility.

2.11 (d)

Sand (both fine and coarse – Coarse grained soil

Silt – Fine grained soil

Peat – Organic soil

2.13 (a)

Poorly graded or uniform sand compact to low dry unit weights while well graded sand compact to high dry weights because in well graded soil, smaller particle can be fitted in voids of large size particle, so voids are less and this results into a dense mass.

As the plasticity increases, smaller size clay particles increases. This results in decrease in maximum dry unit weight and increase in OMC.

2.14 (d)

The Pycnometer is used for determination of both the specific gravity of soil particles and water content of soil. The specific gravity of soil is determined using the relation:

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

Water content is determined by using the relation

$$w = \left[\frac{(M_2 - M_1)}{(M_3 - M_4)} \times \left(\frac{G-1}{G}\right) - 1\right] \times 100$$

Where M_1= mass of empty Pycnometer,

M_2 = mass of the Pycnometer with dry soil

M_3 = mass of the Pycnometer and soil and water

M_4 = mass of Pycnometer filled with water only.

G = Specific gravity of soils.

Hydrometer method is used to determine the particle size distribution of fine-grained soils passing 75 μ sieve. The hydrometer measures the specific gravity of the soil suspension at the centre of its bulb. The specific gravity depends upon the mass of solids present, which in turn depends upon the particle size.

An oedometer test is a test that measures a soil's consolidation properties. Oedometer tests are performed by applying different loads to a soil sample and measuring the deformation response. The results from these tests are used to predict how a soil in the field will deform in response to a change in effective stress.

The constant head **permeameter** is a test used to measure the permeability wherein the head causing flow through the specimen remains constant throughout the test.

2.15 (a)

For qualitative evaluation of the desirability of a soil as a highway subgrade material, a number referred to as the group index has been developed. It varies from a value of 0 to 20, lower the value higher is the quality of the sub-grade and greater the value, poor is the sub-grade.

2.16 (a)

For a soil to be well graded coefficient of curvature (C_c) must lie between 1 and 3. In addition to this coefficient of uniformity (C_u) must be greater than 4 for gravels and greater than 6 for sands.

A soil is said to be very uniform, if $C_u < 5$; it is said to be of medium uniformity, if $C_u = 5$ to 15; and it is said to be very non-uniform or well graded, if $C_u > 15$

2.17 (d)

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.8}{0.1} = 8$$

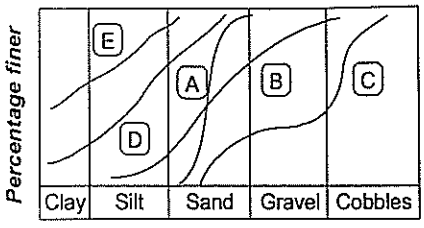
$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} = \frac{(D_{30})^2}{0.8 \times 0.1} = 1.125$$

2.18 (b)

Coarse grained soils are classified based on grain size and fine grained soils are classified based on Atterberg's limits.

2.19 (a)

Both the position and the shape of the grading curve for a soil can aid in establishing its identity and description. Some typical grading curves are shown.

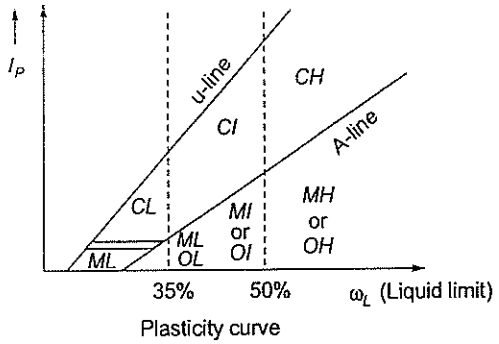


Curve A - a poorly-graded medium SAND
Curve B - a well-graded GRAVEL-SAND (i.e. having equal amounts of gravel and sand)
Curve C - a gap-graded COBBLES-SAND
Curve D - a sandy SILT
Curve E - a silty CLAY (i.e. having little amount of sand)

2.20 (a)

In view of large range of particles sizes, a logarithmic scale becomes necessary. Further a semilogarithmic plot has the merit that soils of equal uniformity exhibit the same shape of grain size curve, irrespective of the particles size frictions present in the soil.

2.21 (a)



Plasticity curve

CH = High plastic inorganic clay

2.22 (b)

$p = 62\%$
$LL = 35\%$
$I_P = 14\%$
$GI = 0.2a + 0.005ac + 0.01bd$
$a = p - 35$
$= 62 - 35$
$= 27 \not> 40 = 27$
$b = p - 15$
$= 62 - 15$
$= 47 \not> 40 = 40$
$c = LL - 40 = 0$
$d = I_P - 10 = 14 - 10 = 4$
$GI = 0.2 \times 27 + 0.005 \times 27 \times 0 + 0.01 \times 40 \times 4$
$= 5.4 + 1.6 = 7$

3 Effective Stresses and Permeability

3.1 If during a permeability test on a soil sample with a falling head permeameter, equal time intervals are noted for drop of head from 'h_1' to 'h_2' and again from 'h_2' to 'h_3', then which one of the following relations would hold good?

(a) $h_3^2 = h_1 h_2$ (b) $h_1^2 = h_2 h_3$

(c) $h_2^2 = h_1 h_3$

(d) $(h_1 - h_2) = (h_2 - h_3)$

[ESE : 1995]

3.2 If the saturated density of a given soil is 2.1 t/m^3, then the total stress (T in t/m^2) and the effective stress (E in t/m^2) of a saturated soil stratum at a depth of 4 m will be

	T	E
(a)	4.4	2.4
(b)	5.4	3.4
(c)	7.4	4.0
(d)	8.4	4.4

[ESE : 1995]

3.3 Assertion (A): At depth z below the surface of a submerged soil, water pressure is $\gamma_w z$ and it is the stress caused by the water which is called the "neutral stress".

Reason (R): The water pressure acts equally in all directions and transmits the same fully in grain to grain contact causing compression in the soil.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 1995]

3.4 A bed of sand consists of three horizontal layers of equal thickness. The value of Darcy's 'k' for the upper and lower layers is 1×10^{-2} cm/sec and that for the middle layer is 1×10^{-1} cm/sec. The ratio of the permeability of the bed in the horizontal direction to that in the vertical direction is

(a) 10.0 to 1 (b) 2.8 to 1

(c) 2.0 to 1 (d) 1 to 10

[ESE : 1996]

3.5 Due to rise in temperature, the viscosity and unit weight of percolating fluid are reduced to 70% and 90% respectively. Other things being constant, the change in coefficient of permeability will be

(a) 20.0% (b) 28.6%

(c) 63.0% (d) 77.8%

[ESE : 1996]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

3.6 Assertion (A): Constant-head permeability test is not used for fine-grained soils.

Reason (R): The lesser the permeability of the soil, lesser is the discharge.

[ESE : 1997]

3.7 Consider the following statements:

1. Constant head permeameter is best suited for determination of coefficient of permeability of highly impermeable soils.
2. Coefficient of permeability of a soil mass decreases with increase in viscosity of the pore fluid.

3. Coefficient of permeability of soil mass increases with increase in temperature of the pore fluid.

Which of these statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 1998]

3.8 Match List-I (Processes) with List-II (Governing laws/equations) and select the correct answer using the codes given below the lists:

List-I

A. Flow of water in soil
B. Flow of water through pipe
C. Sedimentation of soil particles in water

List-II

1. Boussinesq's equation
2. Darcy's law
3. Poiseuille's equation
4. Skempton's equation
5. Stoke's law

Codes:

	A	B	C
(a)	2	4	5
(b)	2	3	5
(c)	1	3	5
(d)	2	3	4

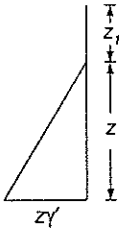
[ESE : 1999]

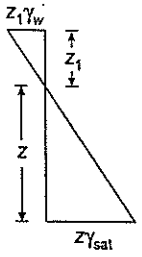
3.9 In a two-layer soil system, the top soil and bottom soil are of same thickness but the coefficient of permeability of the top soil is twice that of the bottom soil of coefficient of permeability 'k'. When horizontal flow occurs, the equivalent coefficient of permeability of the system will be

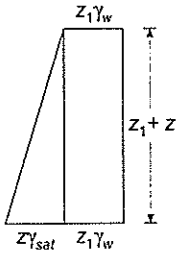
(a) 2 k (b) 1.5 k
(c) 1.25 k (d) 1.2 k

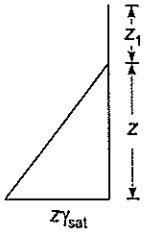
[ESE : 2000]

3.10 Which one of the following diagrams represents the effective pressure distribution for a saturated soil mass of depth 'z' submerged under water of height 'z_1' above its top level (γ' = submerged density of soil, γ_{sat} = saturated density of soil and γ_w = unit weight of water)?

(a) 

(b) 

(c) 

(d) 

[ESE : 2000]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

3.11 **Assertion (A):** Effective vertical stress at some depth below a river bed is unaffected by the water depth in the river.

Reason (R): Equal amounts of increase in total stress and pore pressure will not change the effective stress.

[ESE : 2001]

3.12 **Assertion (A):** Permanent lowering of GWT results in settlements.

Reason (R): Increase in effective stress results in settlement of soils.

[ESE : 2001]

3.13 The following data were obtained when a sample of medium sand was tested in a constant head permeameter:

Cross-section area of sample : 100 cm^2
Hydraulic gradient : 10
Discharge collected : 10 cc/s
The coefficient of permeability of the sand is
(a) 0.1 m/s (b) 0.01 m/s
(c) 1×10^{-4} m/s (d) 1×10^{-8} m/s
[ESE : 2001]

3.14 The total, neutral and effective vertical stresses (in t/m^2) at a depth of 5 m below the surface of a fully saturated soil deposit with a saturated density of 2 t/m^3 would, respectively, be
(a) 5, 5 and 10 (b) 5, 10 and 5
(c) 10, 5 and 10 (d) 10, 5 and 5
[ESE : 2001]

3.15 A stratified soil deposit has three layers of thicknesses : $z_1 = 4$, $z_2 = 1$, $z_3 = 2$ units and the corresponding permeabilities of $k_1 = 2$, $k_2 = 1$ and $k_3 = 4$ units, respectively. The average permeability perpendicular to the bedding planes will be
(a) 4 (b) 2
(c) 8 (d) 16
[ESE : 2003]

3.16 Match List-I (Soil description) with List-II (Coefficient of permeability, mm/s) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Gravel	1. > 1
B. Clay silt admixtures	2. 10^{-2} to 10^{-4}
C. Loess	3. < 10^{-6}
D. Homogeneous clays	4. 10^{-4} to 10^{-6}

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	1	4	3	2
(c)	4	1	2	3
(d)	1	4	2	3

[ESE : 2003]

3.17 Consider the following statements:
1. Coarse sand is more than a million times permeable than a high plasticity clay.
2. The permeability depends on the nature of soil and not on properties of liquid flowing through soil.
3. If a sample of sand and a sample of clay have the same void ratio, both samples will exhibit the same permeability.
4. Permeability of soil decreases as the effective stress acting on the soil increases.

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 1 and 4 (d) 2 and 3
[ESE : 2004]

3.18 In a falling head permeability test on a soil, the time taken for the head to fall from h_0 to h_1 is t. The test is repeated with same initial head h_0, the final head h' is noted in time $t/2$. Which one of the following equations gives the relation between h', h_0 and h_1?
(a) $h' = h_0/h_1$ (b) $h' = \sqrt{h_0 / h_1}$
(c) $h' = h_0 h_1$ (d) $h' = \sqrt{h_0 h_1}$
[ESE : 2004]

3.19 Assertion (A): The drained tests using triaxial test apparatus are useful in the study of drainage of water through the soil sample and hence the permeability of the soil sample.
Reason (R): The permeability of soil is an important property useful in estimation of loss of imponded water through permeable soil layers below the earth dams.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2004]

3.20 The installation of sand drains in clayey soil causes the soil adjacent to the sand drains to undergo which one of the following?
(a) Increase in porosity
(b) Increase in compressibility
(c) Decrease in horizontal permeability
(d) Decrease in shear strength
[ESE : 2004]

3.21 A soil deposit has three layers having same thickness each but the permeabilities of the layers are in the ratio of 1 : 2 : 4 from top to bottom.

What is the ratio of average permeability in the horizontal direction to that in the vertical direction?
(a) 7 : 2 (b) 14 : 6
(c) 28 : 24 (d) 49 : 36
[ESE : 2005]

3.22 Consider the following statements:
1. Organic matter increases the permeability of a soil.
2. Entrapped air decreases the permeability of a soil.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2007]

3.23 Consider the following statements:
1. Permeability of a soil decreases as the effective stress acting on the soil increases.
2. The presence of organic matter in the soil increases its permeability.
3. Entrapped air decreases the permeability of a soil.

Which of these statements is/are correct?
(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1 and 3
[ESE : 2009]

3.24 Consider the following statements
The coefficient of permeability k depends upon
1. void ratio of the soil.
2. duration of flow.
3. equivalent diameter of the soil grains.
4. shape of the particle.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 1, 3 and 4 only (d) 3 and 4 only
[ESE : 2010]

3.25 A soil has discharge velocity of 5×10^{-7} m/s and a void ratio of 0.50. Its seepage velocity will be
(a) 15×10^{-7} m/s (b) 10×10^{-7} m/s
(c) 20×10^{-7} m/s (d) 30×10^{-7} m/s
[ESE : 2010]

3.26 Consider the following statements:
1. Organic matter decreases the permeability of a soil.
2. Entrapped air decreases the permeability of a soil.

Which of these statements are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2012]

3.27 Two observation wells penetrating into a confined aquifer are located 1500 m apart in the direction of flow. Heads of 50 m and 25 m are indicated at these two observation wells. If the coefficient of permeability for the aquifer is 30 m/day and its porosity is 0.25, the time of travel of an inert tracer from one well to another is
(a) 75 days (b) 750 days
(c) 1200 days (d) 3000 days
[ESE : 2012]

3.28 Consider the following statements:
1. Presence of moisture in sand does not affect the magnitude of friction angle.
2. Moisture introduces capillary effect in a sandy soil leading to apparent increase in angle of internal friction.
3. Moisture introduces capillary effect in a sandy soil leading to development of apparent cohesion.
4. The capillary film is broken by drying or submergence leading to loss in the apparent cohesion.

Which of these statements are correct?
(a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 2 and 4 only (d) 3 and 4 only
[ESE : 2013]

3.29 Consider the following statements:
1. Knowledge about moisture content is necessary to determine permeability.
2. Some typical marine clay may have moisture content as high as 400%.
3. Sand-bath method of moisture content determination is not suitable for soils containing organic matter.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2014]

3.30 The void ratio of a given soil *A* is twice that of another soil *B*, while the effective size of particles of soil *A* is one-third of that of soil *B*. The ratio of

height of capillary rise of water in soil *A* to that in soil *B* will be

(a) 0.67 (b) 1.0
(c) 1.5 (d) 2.0

[ESE : 2014]

3.31 A stratum of soil consists of three layers of equal thickness. The permeability of both the top and the bottom layers is 10^{-4} cm/s; and that of the middle layer is 10^{-3} cm/s; then the value of the horizontal coefficient of permeability for the entire composite of the soil layers is

(a) 2×10^{-4} cm/s (b) 3×10^{-4} cm/s
(c) 4×10^{-4} cm/s (d) 5×10^{-4} cm/s

[ESE : 2015]

3.32 Consider the following statements:

1. Effective stress in a sand layer below a lake with standing water does not alter as the water level fluctuates.
2. Regarding water table below the ground surface, any rise in the water table causes equal changes in both pore pressure and effective stress.
3. Capillary saturation will cause the effective stress in increase.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2015]

3.33 **Assertion (A):** Permanent lowering of ground water table results in settlement of foundations.
Reason (R): Increase in effective stress does not result in settlement of strata.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2015]

3.34 Consider the following assumptions as regards field permeability test:

1. The flow is laminar and Darcy's law is valid.
2. The flow is horizontal and uniform at all points in the vertical section.
3. The velocity of flow is proportional to the 'tangent magnitude' of the hydraulic gradient.

Which of the above assumptions are correct?

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2016]

3.35 In a three-layered soil system, the thicknesses of the top and bottom layers each are half the thickness of the middle layer. The coefficients of permeability of top and bottom layers each are double the coefficients of permeability k of the middle layer. When horizontal flow occurs, the equivalent coefficient of permeability of the system will be

(a) 1.5 k (b) 3.0 k
(c) 4.5 k (d) 6.0 k

[ESE : 2016]

3.36 An extended layer of soil with homogeneous rounded grains has 10% of the material finer than 0.07 mm. The constant to be adopted to determine its permeability has been recommended as 750. What is its permeability?

(a) 2.583 m/day (b) 2.857 m/day
(c) 3.244 m/day (d) 3.675 m/day

[ESE : 2017]

3.37 Consider the following statements regarding permeability of soils:

1. Permeability of coarse grained soil is inversely proportional to the specific surface at a given porosity.
2. Direct measurement of permeability of a soil specimen at any stage of loading in odometer test can be made only in fixed-ring type oedometer.
3. The permeability of an aquifer increased with decreases in temperature of water moving through it.

Which of the above statements is/are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 2017]

3.38 Consider the following statements in the context of capillary pressure in soils:

1. Pore water pressure is negative in capillary zone.
2. Water is in tension in capillary zone.

3. Capillary pressure is more in coarse grained soils.

Which of the above statements are correct?

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2017]

Directions: Each of the next items consists of two statements, one labelled as the **'Statement (I)'** and the other as **'Statement (II)'**. Examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

3.39 Statement (I): Fine-grained soils are difficult to drain.

Statement (II): Capillary forces act on pore water.

[ESE : 2017]

3.40 Statement (I): Saturated fine, as well as medium, sands of uniform particle size are most susceptible to liquefaction.

Statement (II): Fine particles reduce the permeability which is a prime factor for liquefaction.

[ESE : 2017]

■■■■

Answers Effective Stresses and Permeability

3.1 (c)	3.2 (d)	3.3 (c)	3.4 (b)	3.5 (b)	3.6 (a)	3.7 (c)	3.8 (b)	3.9 (b)	
3.10 (a)	3.11 (a)	3.12 (a)	3.13 (c)	3.14 (d)	3.15 (b)	3.16 (d)	3.17 (c)	3.18 (d)	
3.19 (b)	3.20 (c)	3.21 (d)	3.22 (b)	3.23 (d)	3.24 (c)	3.25 (a)	3.26 (c)	3.27 (b)	
3.28 (d)	3.29 (a)	3.30 (c)	3.31 (c)	3.32 (d)	3.33 (c)	3.34 (d)	3.35 (a)	3.36 (d)	
3.37 (a)	3.38 (a)	3.39 (a)	3.40 (a)						

Explanations Effective Stresses and Permeability

3.1 (c)

$$k = \frac{2.3aL}{At}\log\left(\frac{h_1}{h_2}\right)$$

$$= \frac{2.3aL}{At}\log\left(\frac{h_2}{h_3}\right)$$

$$\therefore \quad \frac{h_1}{h_2} = \frac{h_2}{h_3}$$

$$\Rightarrow \quad h_2^2 = h_1 h_3$$

3.2 (d)

Total stress $= \gamma_{sat} Z = 2.1 \times 4$
$= 8.4\ t/m^2$

Pore pressure $= \gamma_w Z = 1 \times 4 = 4\ t/m^2$

Effective stress $= 8.4 - 4 = 4.4\ t/m^2$

3.3 (c)

The pore pressure prevents the compression of the soil mass. Pore water pressure is known as neutral pressure because it cannot resist shear stress.

3.4 (b)

$$\frac{k_{ex}}{k_{ez}} = \frac{(k_1h_1 + k_2h_2 + k_3h_3)}{(h_1 + h_2 + h_3)^2}\left(\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}\right)$$

for $h_1 = h_2 = h_3$

$$\frac{k_{ex}}{k_{ez}} = \frac{(k_1 + k_2 + k_3)}{9}\left(\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}\right)$$

$k_1 = k_3 = 1 \times 10^{-2}$ cm/s

$k_2 = 10 \times 10^{-2}$ cm/s

$$\frac{k_{ex}}{k_{ez}} = \frac{(1+10+1)}{9}\left(\frac{1}{1}+\frac{1}{10}+\frac{1}{1}\right)$$

$$= \frac{12\times 2.1}{9} = 2.8$$

3.5 (b)

Taylor's equation based on Poiseuille's law for laminar flow through circular tube is given by

$$k = \frac{\gamma}{\mu}\frac{e^3}{1+e}CD_s^2$$

∴ Change in coefficient of permeability,

$$k' = \frac{0.9\gamma}{0.7\mu}\frac{e^3}{1+e}CD_s^2$$

$$\therefore \quad \frac{k'}{k} = \frac{0.9}{0.7}\times 100 = 128.57\%$$

Change = 28.57%

3.6 (a)

Constant head-permeability is used for coarse grained soil and not for fine-grained soils, because the discharge through the fine soils will be very small.

3.7 (c)

Constant head permeameter is best suited for high permeability soils.

3.8 (b)

Darcy's law states that there is a linear relationship between flow velocity (v) and hydraulic gradient (*i*) for any given saturated soil under steady laminar flow conditions

Stoke's Law – Sedimentation of soil particles in water with a constant velocity is known as terminal velocity. It is applicable to spheres of diameter between 0.2 mm and 0.0002 mm.

Poiseuille's equation relates pressure drop between two points to the discharge in a pipe flow system.

3.9 (b)

Equivalent horizontal permeability,

$$k_{ex} = \frac{k_1h_1 + k_2h_2}{h_1 + h_2} = \frac{2kh + kh}{h+h} = 1.5\ k$$

3.10 (a)

Total stress at any point in the soil

$= \gamma_w Z_1 + \gamma_{sat} Z$

3.11 (a)

Effective stress = Total stress – pore pressure

Effective stress remains unaffected by water depth in river.

3.12 (a)

Permanent lowering of Ground Water Table (GWT) reduces pore pressure and thereby increases effective stress so settlement occurs.

3.13 (c)

$$k = \frac{Q}{iA} = \frac{10}{100\times 10}\times 10^{-2}$$

$$= 1\times 10^{-4}\ \text{m/s}$$

3.14 (d)

Total stress, $\sigma = 2\times 5 = 10\ \text{t/m}^2$

Neutral stress, $u = 1\times 5 = 5\ \text{t/m}^2$

Effective stress, $\sigma' = \sigma - u = 10 - 5 = 5\ \text{t/m}^2$

3.15 (b)

$$k_{ev} = \frac{z_1 + z_2 + z_3}{\frac{z_1}{k_1} + \frac{z_2}{k_2} + \frac{z_3}{k_3}}$$

$$= \frac{4+1+2}{\frac{4}{2}+\frac{1}{1}+\frac{2}{4}} = \frac{7}{3.5} = 2$$

3.16 (d)

Gravel has maximum permeability and clays have minimum permeability. Loess deposit has a loose structure and permeability is more than clay silt admixture.

3.17 (c)

Coarse sand is more than million times permeable than a high plasticity clay.

$$k = CD_s^2\frac{e^3}{(1+e)}\frac{\gamma}{\mu}$$

Permeability depends upon

(i) Grain size
(ii) Properties of pore fluid
(iii) Void ratio of soil
(iv) Structural arrangement of the soil particles
(v) Entrapped air and foreign matter
(vi) Adsorbed water in clayey soils.

It means that a sample of sand and clay having same void ratio may not have same permeability

due to structural arrangement of particles and adsorbed water.

Increase in effective stress causes compression of soil and rearrangement of particles. So permeability decrease.

3.18(d)

In falling head permeability test

$$k = 2.3\frac{aL}{At}\log_{10}\left(\frac{h_0}{h_1}\right)$$

$$= 2.3\frac{aL}{A(t/2)}\log_{10}\left(\frac{h_0}{h'}\right)$$

$$\therefore \quad \log_{10}\left(\frac{h_0}{h_1}\right) = 2\log\left(\frac{h_0}{h'}\right)$$

$$\Rightarrow \quad \frac{h_0}{h_1} = \left(\frac{h_0}{h'}\right)^2$$

$$\Rightarrow \quad h' = \sqrt{h_0 h_1}$$

3.19 (b)

Triaxial test is used to measure the permeability of low permeable soils. Test involves the establishment of a steady-state flow condition in a cylindrical condition housed in triaxial permeability cell.

3.20(c)

The installation of sand drains causes peripheral smear (i.e., wiping action caused by casing or hollow mandrel used to form the well as it is driven down into the soil and then pulled out after it has been filled with sand). For a soil originally having a greater permeability in the horizontal than that in the vertical direction, the smeared zone forms a barrier to the horizontal flow of water, thereby slowing down the process of consolidation considerably.

3.21(d)

Average permeability in horizontal direction,

$$k_{ex} = \frac{k_1h_1 + k_2h_2 + k_3h_3}{h_1 + h_2 + h_3}$$

Average permeability in vertical direction,

$$k_{ev} = \frac{h_1 + h_2 + h_3}{\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}} = \frac{12}{7}$$

$$\frac{k_{ex}}{k_{ev}} = \frac{49}{36}$$

3.22(b)

Organic matter and entrapped air obstruct the flow in the soil voids, and hence reduce the permeability.

3.23 (d)

- As the effective stress increases, void ratio decreases. Hence permeability decreases.
- Entrapped air decreases the permeability of soil.
- Organic matter has the tendency to move towards flow channel and choke them. Thus the permeability is reduced.

3.24(c)

Since permeability is the property governing the ease with which a fluid flows through the soil, it depends on the characteristics of the fluid or permeant as well as those of the soil. Mathematically,

$$k = CD_s^2.\frac{\gamma}{\mu}.\frac{e^3}{1+e}$$

where k is coefficient of permeability, D_s is effective particle size, γ is unit weight of permeant, μ is viscosity of permeant, e is void ratio and C is shape factor.

3.25(a)

Porosity is expressed as

$$n = \frac{e}{1+e} = \frac{0.5}{1+0.5} = \frac{1}{3}$$

Seepage velocity,

$$v_s = \frac{v}{n} = \frac{5\times10^{-7}}{1/3}$$

$$= 15 \times 10^{-7} \text{ m/s}$$

3.26 (c)

The permeability is greatly reduced if air is entrapped in the voids thus reducing its degree of saturation. Organic foreign matter also has the tendency to move towards critical flow channels and choke them up, thus decreasing the permeability.

3.27 (b)

Let the inert tracer travel by a distance 'dx' in time 'dt'

$$\therefore \quad V_s = \frac{dx}{dt} = \text{Actual vel. of flow}$$

$$V_s = \frac{v}{n} = \frac{dx}{dt}$$

Now, $V = ki$

$$\Rightarrow \quad V_s.n = ki$$

$$\Rightarrow \quad \frac{dx}{dt}.n = ki$$

$$\Rightarrow \frac{1500}{t}0.25 = 30 \times \frac{(50-25)}{1500}$$

$$\Rightarrow \quad t = 750 \text{ days}$$

3.28 (d)

- Presence of moisture in sand does have some effect on friction angle. However, this is not usually taken into account in practice.
- Moisture introduces capillary effects in sand, leading to development of apparent cohesion and capillary film is broken by drying or submergence leading to loss of apparent cohesion.

3.30 (c)

Ther empirical formula for capillary height is

$$h = \frac{C}{eD_{10}}$$

$$\Rightarrow \quad \frac{h_A}{h_B} = \frac{e_B(D_{10})_B}{e_A(D_{10})_A} = \left(\frac{e_B}{e_A}\right) \times \left(\frac{D_{10B}}{D_{10A}}\right)$$

$$= \frac{1}{2} \times 3 = 1.5$$

3.31 (c)

$$k_H = \frac{k_1H + k_2H + k_3H}{3H}$$

$$= \frac{10^{-4} + 10^{-3} + 10^{-4}}{3}$$

$$= \frac{12 \times 10^{-4}}{3} = 4 \times 10^{-4} \text{ cm/s}$$

3.32 (d)

When water level fluctuation takes place above a lake, total stress (σ) and pore water pressure (u) changes with same value in a sand layer below a lake, hence effective stress does not change.

But when the WT is below the ground level, any rise or fall in the WT causes different and unequal changes in both σ & u.

Capillary saturation leads to development of negative pore pressure (i.e. $-u$)

Effective stress, $\bar{\sigma} = \sigma - (-u) = \sigma + u$

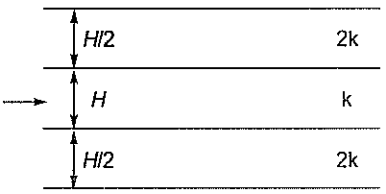
$\therefore$ Increment is observed in $\bar{\sigma}$.

3.33 (c)

Permanent lowering of ground water table results in settlement of foundation and it is due to increase in effective stress in settlement strata.

3.35 (a)

$$K_{avg} = \frac{\Sigma k_i z_i}{\Sigma z_i}$$



$$= \frac{2k\ H/2 + k \cdot H + 2k\ H/2}{\frac{H}{2} + H + \frac{H}{2}}$$

$$= \frac{3kH}{2H} = 1.5\ k$$

3.36 (d)

$k = CD_{10}^2$

$k = 750 \times (0.07)^2 = 3.675$ m/day

Note: As per Allen Hazen

$k = CD_{10}^2$

Where $C = 100$

D_{10} is in cm

and k is in cm/sec

Similarly if we solve this equation

then $k = 750 \times (0.007 \text{ cm})^2$

$= 0.03675$ cm/sec

$= 0.03675 \times 10^{-2}$ m/day $\times 24 \times 3600$

$= 31.752$ m/day

Answer is not matching hence option 'd' is correct.

3.37 (a)

As per Kozney-Carman equation

$$k = \left(\frac{\gamma_w}{\mu}\right)\frac{e^3}{1+e}\times\frac{1}{S_s^2}$$

$$k \propto \frac{1}{S_s^2}$$

Dynamic viscosity (μ) is inversely proportional to temperature hence permeability is directly proportional to the temperature.

In consolidation test, two types of consolidation cell, the floating ring cell and the fixed ring cell are commonly used. A falling head permeability test can be performed on the consolidation specimen attaching a stand pipe to fixed ring consolidometer, hence the coefficient of permeability can be determined only in fixed ring test.

3.39 (a)

Fine grained soils are more difficult to drain than coarse grained soils because the voids in the former are so small that the contained water is strongly held by capillary attraction, while in soil with large grains this force does not act so strongly.

3.40 (a)

Prime factor for liquefaction is "Decrease in effective stress, due to development of excess pore pressure which is caused due to dynamic or seismic loading.

4 Seepage Analysis

4.1 A flownet is drawn to obtain
(a) seepage, coefficient of permeability and uplift pressure
(b) coefficient of permeability, uplift pressure and exit gradient
(c) exit gradient, uplift pressure and seepage quantity
(d) exit gradient, seepage and coefficient of permeability

[ESE : 1995]

4.2 A uniform sand stratum 2.5 m thick has a specific gravity of 2.62 and a natural void ratio of 0.62. The hydraulic head required to cause quick sand condition in the sand stratum is
(a) 0.5 m (b) 1.5 m
(c) 2.5 m (d) 3.5 m

[ESE : 1995]

4.3 A soil has a discharge velocity of 6×10^{-7} m/s and a void ratio of 0.5. Its seepage velocity is
(a) 18×10^{-7} m/s (b) 12×10^{-7} m/s
(c) 6×10^{-7} m/s (d) 3×10^{-7} m/s

[ESE : 1995]

4.4 **Assertion (A):** Quick sand is not a type of sand but it is a condition arising in a sand mass.
Reason (R): When the upward seepage pressure becomes equal to the pressure due to submerged weight of a soil, the effective pressure becomes zero.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1996]

4.5 An upward hydraulic gradient i of a certain magnitude will initiate the phenomenon of boiling in granular soils. The magnitude of this gradient is
(a) $0 \le i \le 0.5$ (b) $0.5 \le i \le 1.0$
(c) $i \simeq 1.0$ (d) $1 < i \le 2$

[ESE : 1996]

4.6 A deposit of fine sand has a porosity n and specific gravity of soil solids is G. The hydraulic gradient of the deposit to develop boiling condition of sand is given by
(a) $i_c = (G-1)(1-n)$
(b) $i_c = (G-1)(1+n)$
(c) $i_c = \dfrac{G-1}{1-n}$
(d) $i_c = \dfrac{G-1}{1+n}$

[ESE : 1996]

4.7 Match List-I (Flow type) with List-II (Flow characteristics) and select the correct answer using the codes given below the lists:

List-I
A. Transient flow
B. Turbulent flow
C. Steady-state flow
D. Laminar flow

List-II
1. Seepage flow is a function of time
2. Hydraulic gradient varies with square of velocity
3. Flow at low velocity
4. Governing equation in 2-D is

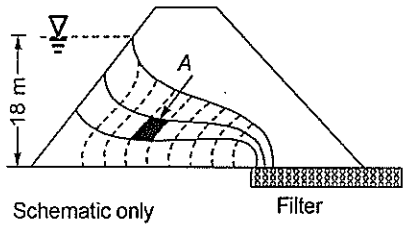
$$k_x \frac{\partial^2 h}{\partial x^2} + k_y \frac{\partial^2 h}{\partial y^2} = 0$$

Codes:

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	1	4
(c)	1	2	3	4
(d)	2	1	4	3

[ESE : 1996]

4.8 In the schematic flownet shown in the given figure, the hydraulic potential at point *A* is



(a) 5 m of water (b) 12 m of water
(c) 15 m of water (d) 25 m of water

[ESE : 1996]

4.9 Which one of the following equations correctly gives the relationship between the specific gravity of soil grains (G) and the hydraulic gradient (i) to initiate 'quick' condition in a sand having a void ratio of 0.5?

(a) $G = 0.5i + 1$ (b) $G = i + 0.5$
(c) $G = 1.5i + 1$ (d) $G = 1.5i - 1$

[ESE : 1997]

4.10 A sand deposit has a porosity of 1/3 and its specific gravity is 2.5. The critical hydraulic gradient to cause sand boiling in the stratum will be

(a) 1.5 (b) 1.25
(c) 1.0 (d) 0.75

[ESE : 1997]

4.11 A flownet constructed to determine the seepage through an earth dam which is homogeneous but anisotropic, gave four flow channels and sixteen equipotential drops. The coefficients of permeability in the horizontal and vertical directions are 4.0×10^{-7} m/s and 1×10^{-7} m/s respectively. If the storage head was 20 m, then the seepage per unit length of the dam (in m^3/s) would be

(a) 5×10^{-7} (b) 10×10^{-7}
(c) 20×10^{-7} (d) 40×10^{-7}

[ESE : 1997]

4.12 To make certain that the backfill material is more pervious than the soil to be drained, the relationship used is

(a) $(D_{15})_{filter} \leq 5 (D_{85})_{protected\ soil}$
(b) $(D_{15})_{filter} \geq 5 (D_{85})_{protected\ soil}$
(c) $(D_{15})_{filter} \leq 5 (D_{15})_{protected\ soil}$
(d) $(D_{15})_{filter} \geq 5 (D_{15})_{protected\ soil}$

[ESE : 1997]

4.13 The configuration of flow nets depends upon

(a) the permeability of the soil
(b) the difference in the head between upstream and downstream sides
(c) the boundary condition of flow
(d) the amount of seepage that takes place

[ESE : 1998]

4.14 Consider the following statements:
Phreatic line in an earth dam is

1. elliptical in shape
2. an equipotential line
3. the topmost flow line with zero water pressure
4. approximately a parabola

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 3 and 4 (d) 1 alone

[ESE : 1998]

4.15 A sand deposit has a porosity of 0.375 and a specific gravity of 2.6, the critical hydraulic gradient for the sand deposit is

(a) 2.975 (b) 2.225
(c) 1 (d) 0.75

[ESE : 1999]

4.16 A flownet for an earth dam on impervious foundation consists of 4 flow channels and 15 equipotential drops. The full reservoir level is 15 m above the downstream horizontal filter. Given that horizontal permeability is 9×10^{-6} m/s and vertical permeability is 1×10^{-6} m/s, the quantity of seepage through the dam will be

(a) 36 mL/s/m (b) 25 mL/s/m
(c) 20 mL/s/m (d) 12 mL/s/m

[ESE : 1999]

4.17 A strata of 3.5 m thick fine sand has a void ratio of 0.7 and G of 2.7. For a quick sand condition to develop in this strata, the water flowing in upward direction would require a head of

(a) 7 m (b) 5.56 m
(c) 5 m (d) 3.5 m

[ESE : 2000]

4.18 A flownet of a coffer dam foundation has 6 flow channels and 18 equipotential drops. The head of water lost during seepage is 6 m. If the coefficient of permeability of foundation is 4×10^{-5} m/min, then the seepage loss per metre length of dam will be
(a) 2.16×10^{-2} m³/day
(b) 6.48×10^{-2} m³/day
(c) 11.52×10^{-2} m³/day
(d) 34.56×10^{-2} m³/day

[ESE : 2000]

4.19 **Assertion (A):** The possibility of quicksand condition occurring is more on the downstream of a weir on permeable foundation.
Reason (R): Seepage lines are directed upwards at the downstream of such a weir.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

4.20 Consider the following statements:
1. Quick condition and liquefaction of saturated sands are based on similar phenomenon.
2. Quick condition is associated with only earth dams.
3. Liquefaction is possible in dry sand.
4. Liquefaction is associated with increase in pore water pressure due to vibrations.

Which of these statements are correct?
(a) 2 and 4 (b) 1 and 4
(c) 1 and 2 (d) 1, 3 and 4

[ESE : 2002]

4.21 Match List-I (Protective measure) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Inverted filter
B. Riprap
C. Clay core
D. Sand columns

List-II
1. To protect river banks from erosion by river flow
2. To prevent escape of fine soils by seepage water
3. To reduce damage due to liquefaction of saturated granular soils during earthquakes
4. To reduce seepage of water through the body of the earth dams

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	3	4	1
(c)	4	1	2	3
(d)	2	1	4	3

[ESE : 2004]

4.22 Match List-I (Unit) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Graded filter
B. Lime treatment
C. Impervious clay core
D. Curtain grouting

List-II
1. To reduce seepage of water through body of earth dam
2. To reduce water seepage through foundation below dam
3. To stabilize black cotton soils
4. To drain water without losing fines from the soil

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	1	2	4	3
(c)	4	2	1	3
(d)	1	3	4	2

[ESE : 2005]

4.23 A soil mass under seepage has a downward flow of water. Which of the following statements are correct with regard to stresses at any point in the soil mass?
1. Effective stress is decreased by an amount equal to the seepage force
2. Effective stress is increased by an amount equal to the seepage force

3. Total stress will change
4. Total stress will be unaltered

Select the correct answer using the codes given below:

(a) 1 and 3 (b) 2 and 3
(c) 1 and 4 (d) 2 and 4

[ESE : 2006]

4.24 From a flow net which of the following information can be obtained?

1. Rate of flow 2. Pore water pressure
3. Exit gradient 4. Permeability

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2, 3 and 4 only (d) 1 only

[ESE : 2007]

4.25 Consider the following statements:

1. Quicksand is a special variety of sand.
2. Quicksand is not a material but a hydraulic condition.
3. In nature, quicksand condition is observed usually in coarse silt or fine sand.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2009]

4.26 In a 6 m thick stratum of fine sand having submerged density of 11 kN/m^3, quicksand condition occurred at a depth of 4.2 m of excavation. What is the depth of lowering of groundwater table required for making an excavation 5 m deep ? Take density of water as 10 kN/m^3.

(a) 3.85 m (b) 1.68 m
(c) 1.1 m (d) 0.897 m

[ESE : 2009]

4.27 For a sheet pile wall constructed in a soil having effective grain size = 0.1 mm, the difference of the upstream and downstream water levels is 3 m. If the flow net drawn for the problem yields 2 as the ratio of number of head drops to number of flow channels, then what is the discharge in unit of m^3/s/m length of sheet pile wall?

(a) 3.0×10^{-4} (b) 3.0×10^{-2}
(c) 1.5×10^{-4} (d) 1.5×10^{-2}

[ESE : 2009]

4.28 A homogeneous earth dam is 43 m high with 3 m as free board and a 30 m long horizontal filter at the downstream end. The flownet drawn in the dam section consists of 5 flow channels and 15 potential drops. If the dam is 500 m long and the permeability of the material of the dam is uniformly 3×10^{-3} m/s, the total discharge permeating through the body of the dam will be

(a) 0.0004 m^3/s (b) 0.0036 m^3/s
(c) 0.0039 m^3/s (d) 0.20 m^3/s

[ESE : 2010]

4.29 Consider the following statements:

1. The hydraulic head at a point in the soil includes piezometric head as well as datum head.
2. Piping in soil occurs when effective pressure becomes equal to zero.
3. Piping in soil occurs when soil is highly porous.

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 2 only

[ESE : 2010]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

4.30 **Assertion (A):** The possibility of piping failure in earth dams is more if black cotton soil is the foundation material.

Reason (R): The highly expansive black cotton soils are the most common soils wherever basalt rock is present.

[ESE : 2010]

4.31 **Assertion (A):** Flow net is dependent on the permeability of soil through which flow is taking place.

Reason (R): The flow net is useful in finding the discharge.

[ESE : 2010]

4.32 A flow net for seepage under a sheet pile wall has $n_f = 4$, $n_d = 8$ and the permeabilities of the soil in the horizontal and vertical directions are: $K_h = 8 \times 10^{-5}$ m/sec and $K_v = 2 \times 10^{-5}$ m/sec. If the head loss through the soil is 2 m, the quantity of seepage per meter length of the wall will be

(a) 2×10^{-5} m^3/sec (b) 4×10^{-5} m^3/sec
(c) 8×10^{-5} m^3/sec (d) 16×10^{-5} m^3/sec

[ESE : 2011]

4.33 Statement-I : In a flownet, each field must be a (curvilinear) square:

Statement-II : Each flow channel in a flownet has the same rate of flow.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

4.34 Consider the following statements:

1. Quantity of seepage in each flow channel of a flow-net is independent of the size of field.
2. Drop in head between adjacent equipotential lines of a flow-net is dependent on upstream head.
3. With increase in the length of a flow path, the corresponding exit gradient will decrease.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2013]

4.35 A sand sample has a bulk density of 20 kN/m^3 and a degree of saturation of 70%. If the specific gravity of soil grains is 2.65, the value of critical hydraulic gradient for the soil will be

(a) 1.02 (b) 1.05
(c) 1.10 (d) 1.15

[ESE : 2014]

4.36 Statement (I): The possibility of quicksand condition occurring is more on the downstream of a weir on a permeable foundation than on the upstream end with an upward component of seepage velocity.

Statement (II): Seepage lines end with an upward component of seepage velocity at the downstream reaches of such a weir.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

4.37 A uniform collapsible sand stratum, 2.5 m thick, has specific gravity of its sand as 2.65, with a natural void ratio of 0.65. The hydraulic head required to cause quick collapsible sand condition is

(a) 2.50 m (b) 2.75 m
(c) 3.25 m (d) 3.50 m

[ESE : 2016]

4.38 Consider the following statements regarding flow net:

1. It helps determine the quantity of seepage.
2. It helps determine the upward lift below a hydraulic structure.
3. It is applicable to rotational flow only.

Which of the above statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 2017]

■■■■

Answers Seepage Analysis

4.1 (c)	4.2 (c)	4.3 (a)	4.4 (a)	4.5 (c)	4.6 (a)	4.7 (a)	4.8 (b)	4.9 (c)	
4.10 (c)	4.11 (b)	4.12 (d)	4.13 (c)	4.14 (c)	4.15 (c)	4.16 (d)	4.17 (d)	4.18 (c)	
4.19 (a)	4.20 (b)	4.21 (d)	4.22 (a)	4.23 (d)	4.24 (b)	4.25 (c)	4.26 (b)	4.27 (c)	
4.28 (*)	4.29 (d)	4.30 (d)	4.31 (d)	4.32 (b)	4.33 (d)	4.34 (a)	4.35 (c)	4.36 (a)	
4.37 (a)	4.38 (a)								

Explanations Seepage Analysis

4.1 (c)

Once a flow net is constructed, its graphical properties can be used to obtain solutions for many seepage problems such as the estimation of seepage losses from reservoirs, determination of seepage pressures, uplift pressures below dams, to check against the possibility of piping and many others.

4.2 (c)

Critical hydraulic gradient,

$$i_c = \frac{G-1}{1+e} = \frac{2.62-1}{1+0.62} = 1.0$$

Head required

$= i_c \times$ thickness of sand stratum

$= 1 \times 2.5 = 2.5$ m

4.3 (a)

$$\text{Porosity} = \frac{e}{1+e} = \frac{0.5}{1.5} = \frac{1}{3}$$

$$\text{Seepage velocity} = \frac{\text{Discharge velocity}}{\text{Porosity}}$$

$$= \frac{6\times10^{-7}}{(1/3)} = 18\times10^{-7} \text{ m/s}$$

4.4 (a)

Quick sand condition corresponds to zero effective pressure due to upward seepage.

4.5 (c)

Critical hydraulic gradient, $i_{cr} = \frac{G-1}{1+e}$

$G = 2.65$, $e = 0.7$

So on solving $i_{cr} \simeq 1$

4.6 (a)

$$i_c = \frac{G-1}{1+e} = (G-1)(1-n)$$

4.7 (a)

Transient flow, is flow where the flow velocity and pressure are changing with time. When changes occur to a fluid systems such as the starting or stopping of a pump, closing or opening a valve, or changes in tank levels, then transient flow conditions exist: otherwise the system is steady state.

Turbulent flow, type of fluid flow in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction.

Steady-state flow refers to the condition where the fluid properties at any single point in the system do not change over time. These fluid properties include temperature, pressure, and velocity.

Laminar flow (or streamline flow) occurs when a fluid flows in parallel layers, with no disruption between the layers. At low velocities, the fluid tends to flow without lateral mixing, and adjacent layers slide past one another.

4.8 (b)

The number of equipotential drops are 9.

Drop in head per drop $= \frac{18}{9} = 2$ m of water.

The point A is after three drops so head at point A is $h_A = 18 - 3 \times 2 = 12$ m of water

4.9 (c)

Critical hydraulic gradient,

$$i_c = \frac{G-1}{1+e} = \frac{G-1}{1+0.5}$$

$$\therefore \quad G = 1.5\,i + 1$$

4.10 (c)

$$i_c = (G-1)(1-n)$$

$$= (2.5-1)\times\left(1-\frac{1}{3}\right) = 1.0$$

4.11 (b)

Seepage is given by

$$q = \sqrt{k_x k_z} \times \frac{N_f}{N_d} \times H$$

$$= \sqrt{4\times10^{-7}\times1\times10^{-7}} \times \frac{4}{16} \times 20$$

$$= 10 \times 10^{-7}\ \text{m}^3/\text{s/m}$$

4.12 (d)

The filter material should be coarse enough to allow easy passage for percolating water which can move easily without any build up of water pressure in the filter. For the filter to provide full drainage,

$$k_{\text{filter}} \geq 25\,k_{\text{protected soil}}$$

Where k is the permeability and it is proportional to square of particle size. So,

$$D_{15\ \text{filter}} \geq 5D_{15\ \text{protected soil}}$$

4.13 (c)

A flow net is a graphical solution to the equations of steady groundwater flow. A flow net consists of two sets of lines which must always be orthogonal (perpendicular to each other): flow lines, which show the direction of groundwater flow, and equipotentials lines (lines of constant head), which show the distribution of potential energy.

4.14 (c)

Phreatic line is the top flow line which separates saturated zone from unsaturated zone and below which positive hydrostatic pressure exists in the dam section. Along the phreatic line, the atmospheric pressure exists. It's shape is approximately of a parabola.

4.15 (c)

Critical hydraulic gradient,

$$i_c = \frac{G-1}{1+e} = (G-1)(1-n)$$

$$= (2.6-1)\times(1-0.375)$$

$$= 1.0$$

4.16 (d)

Equivalent permeability,

$$k_e = \sqrt{k_x k_z}$$

$$= \sqrt{9\times10^{-6}\times1\times10^{-6}}$$

$$= 3\times10^{-6}\ \text{m/s}$$

Seepage, $$q = k_e \times \frac{N_f}{N_d} \times H$$

$$= 12\times10^{-6}\ \text{m}^3/\text{s/m}$$

$$= 12\ \text{mL/s/m}$$

4.17 (d)

The critical hydraulic gradient,

$$i_c = \frac{G-1}{1+e} = 1.0$$

For quick sand condition

$$i = i_c = \frac{h}{L}$$

$$h = 1.0 \times 3.5 = 3.5\ \text{m}$$

4.18 (c)

Seepage loss per metre length,

$$q = k \times \frac{N_f}{N_d} \times H$$

Given, $$k = 4\times10^{-5}\ \text{m/min}$$

$$= 4\times10^{-5}\times24\times60\ \text{m/day}$$

$$= 0.0576\ \text{m/day}$$

$$\therefore \quad q = 0.0576\times\frac{6}{18}\times6$$

$$= 0.1152\ \text{m}^3/\text{day}$$

$$= 11.52\times10^{-2}\ \text{m}^3/\text{day}$$

N_f is number of flow channels = 6.0

N_d is number of equipotential drops = 18

4.19 (a)

On the upstream side the seepage lines (streamlines) are directed downwards and increase the effective stress. While on the downstream side seepage line are directed upwards and reduce the effective stress.

4.20 (b)

When the effective stress is zero soil looses its strength and behave as a liquid. The phenomenon of quick condition is due to flow of water through the soil. While liquefaction occurs due to vibration

caused by earthquake, explosion, volcanic eruption etc. However, in both cases effective stress becomes zero.

4.21 (d)

Sand columns increase the permeability and therefore drainage of water occurs easily and faster. During earthquake conditions, the excess pore pressure will be quickly dissipated and thus liquefaction of sands can be reduced.

Riprap protect river banks from erosion.

4.22 (a)

Lime treatment reduces liquid limit slightly and increases plastic limit immensely. So there is reduction in plasticity index.

4.23 (d)

In the case of downward flow of water the pore pressure is decreased and effective stress increased. Total stress remains unaltered in the flow.

4.24 (b)

Seepage pressures, uplift pressures, exit gradient and pore-water pressure can be obtained from a flownet.

4.25 (c)

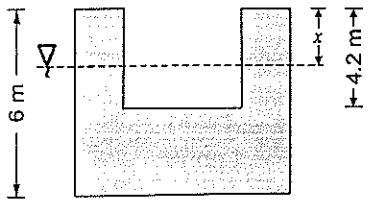
Quicksand is a condition and not a soil type. This condition is created in saturated thick layers of loose fine sandy soils when disturbed either due to vibration, such as, from pile driving in the neighbourhood, or due to pressure of flowing water.

4.26 (b)

Let x be the depth of ground water table initially.

Total upward water force on the sand stratum at the bottom of excavation

$$= (6 - x) \times \gamma_w$$



Total downward force at the bottom of excavation

= Weight of soil in saturated condition

$$= \gamma_{sat} \times (6 - 4.2)$$

$$= (\gamma_{sub} + \gamma_w) \times 1.8$$

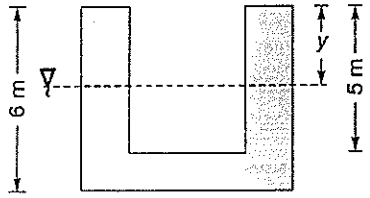
When quicksand condition occurs, then total upward water force becomes equal to total downward force i.e.

$$(6 - x) \times \gamma_w = (\gamma_{sub} + \gamma_w) \times 1.8$$

$$\Rightarrow (6 - x) \times 10 = (11 + 10) \times 1.8$$

$$\Rightarrow x = 6 - \frac{21 \times 1.8}{10}$$

$$\Rightarrow x = 2.22 \text{ m}$$



Similarly, if the depth of displaced ground water table is y from the surface, then

$$(6 - y) \times \gamma_w = (6 - 5) \times (\gamma_{sub} + \gamma_w)$$

$$\Rightarrow (6 - y) \times 10 = 1 \times (11 + 10)$$

$$\Rightarrow y = 6 - 2.1$$

$$\Rightarrow y = 3.9 \text{ m}$$

$\therefore$ Lowering of water table $= y - x$

$$= 3.9 - 2.2$$

$$= 1.68 \text{ m}$$

4.27 (c)

The permeability of a soil as per Hazen equation is given by

$$k = 100\, D_{10}^2 \text{ in cm/s}$$

where D_{10} is Hazen's effective grain size in cm.

$$\therefore k = 100 \times \left(\frac{0.1}{10}\right)^2$$

$$= 0.01 \text{ cm/s}$$

$$= 10^{-4} \text{ m/s}$$

The discharge per unit length is given by

$$q = k \times H \times \frac{n_f}{n_d}$$

$$= 10^{-4} \times 3 \times \frac{1}{2}$$

$$= 1.5 \times 10^{-4} \text{ m}^3/\text{s/m}$$

4.28 (*)

The discharge per unit length of the dam is given by

$$q = k \times \frac{N_f}{N_d} \times H$$

$$= 3\times10^{-3}\times\frac{5}{15}\times(43-3)$$

$$= 40\times10^{-3}\ m^2/sec$$

$\therefore$ Total discharge permeating through the body of the dam is given by

$$Q = q\times L$$
$$= 40\times10^{-3}\times500$$
$$= 20\ m^3/s$$

None of the options is correct.

4.29 (d)

- Piezometric head = Pressure Head + Datum Head. Piezometric head already includes datum head.
- When effective pressure becomes zero this leads to erosion of the soil, this begins near the downstream toe but may lengthen progressively towards the upstream. This phenomenon is known as piping, because erosion occurs in the form of a pipe or closed channel underneath the structure.
- Highly porous refers to gravel in which large discharge is required for piping. But piping can also occur in sands which are comparatively lesser porous and require lesser discharge.

4.30 (d)

Black cotton soils are held together even at critical hydraulic gradient due to inherent cohesion that holds the grains together. Possibility of piping failure is less because the cohesion component of shear strength is an independent quantity.

4.31 (d)

Flow net depends upon boundary condition, and not on the permeability of soil. Flow net is useful in finding the seepage discharge, uplift pressure, exit gradient etc.

4.32 (b)

For a sheet pile the quantity of seepage per unit length of wall is given by

$$q = K'\cdot H\cdot\frac{n_f}{n_d}$$

$$K' = \sqrt{K_h\times K_v} = 4\times10^{-5}$$

$$\Rightarrow\quad q = \left(4\times10^{-5}\right)\times2\times\frac{4}{8}$$

$$= 4\times10^{-5}\ m^3/s$$

4.33 (d)

All fields in a flow net are drawn as "elementary squares", meaning that average distances between opposite sides are equal. Therefore each flow channel in a flow net has same rate of flow.

4.34 (a)

Drop between equipotential line $= \frac{H}{n}$

Where, H = Upstream head

4.35 (c)

Hydraulic Gradient, $i_c = \frac{G-1}{1+e}$

$$\text{Bulk density} = \frac{(G+Se)\gamma_w}{1+e}$$

$$20 = \frac{(2.65+0.7e)}{1+e}\times10$$

$$20+20e = 26.5+7e$$

$$e = 0.5$$

$$\Rightarrow\quad 6.5 = 13e$$

So, $$i_c = \frac{2.65-1}{1+0.5} = \frac{1.65}{1.5}$$

$$i_c = 1.1$$

4.36 (a)

Upward seepage reduces effective stress and downward seepage increases effective stresses.

4.37 (a)

Critical hydraulic gradient,

$$i_{cr} = \frac{G-1}{1+e} = \frac{2.65-1}{1+0.65} = 1$$

Hydraulic gradient,

$$i_{cr} = \frac{\text{Head}}{\text{Length}} = \frac{H}{2.5} = 1$$

Hydraulic head

$$= 2.50\ m$$

5 Compaction of Soil

5.1 For conducting a Standard Proctor Compaction Test, the weight of hammer (P in kg), the fall of hammer (Q in mm), the number of blows per layer (R) and the number of layers (S) required are respectively

	P	Q	R	S
(a)	5.89	550	50	3
(b)	4.89	450	25	3
(c)	3.60	310	35	4
(d)	2.60	310	25	3

[ESE : 1995]

5.2 Sheep-foot rollers are recommended for compacting

(a) granular soils (b) cohesive soils
(c) hard rock (d) any type of soil

[ESE : 1996]

5.3 Consider the following statements:

1. 'Relative compaction' is not the same as 'relative density'.
2. Vibrofloatation is not effective in the case of highly cohesive soils.
3. 'Zero air void line' and 100% saturation line are not identical.

Which of these statements is/are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 3 alone

[ESE : 1998]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.4 **Assertion (A):** Permeability continues to decrease with the increase in dry density of a compacted soil.

Reason (R): Soil particles in water surroundings may be mutually attracted or repulsed.

[ESE : 1998]

5.5 **Assertion (A):** For a given soil, the optimum moisture content increases with the increase in compactive effort.

Reason (R): Higher the compactive effort, higher is the dry density at the same moisture content.

[ESE : 2000]

5.6 Match List-I (Roller type) with List-II (Soil type) and select the correct answer using the codes given below the lists:

List-I

A. Pneumatic roller
B. Smooth wheeled roller
C. Sheep foot roller
D. Vibratory roller

List-II

1. Cohesive and granular soils
2. Plastic soils of moderate cohesion
3. Cohesionless soils
4. Silty soils of low plasticity

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	3	1	2	4
(c)	4	1	2	3
(d)	3	2	1	4

[ESE : 2002]

5.7 In a compaction test if the compacting effort is increased, it will result in

(a) increase in maximum dry density and OMC

(b) increase in maximum dry density but OMC remains unchanged
(c) increase in maximum dry density and decrease in OMC
(d) no change in maximum dry density but decrease in OMC

[ESE : 2003]

5.8 Match List-I (Equipment) with List-II (Use) and select the correct answer using the codes given below the lists:

List-I
A. Vibratory rollers
B. Sheep foot rollers
C. Frog hammers
D. Vibrofloats

List-II
1. To compact soils in confined areas and at corners
2. To compact road and railway embank-ments of sandy soils
3. To densify sandy soils over a large area and to a larger depth
4. To compact clayey soil fills

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	4	2	3	1
(c)	2	4	1	3
(d)	2	4	3	1

[ESE : 2004]

5.9 Soil is compacted at which one of the following when a higher compactive effort produces highest increase in dry density?
(a) Optimum water content
(b) Dry side of the optimum moisture content
(c) Wet side of the optimum moisture content
(d) Saturation moisture content

[ESE : 2004]

5.10 Assertion (A): The clay core of an earth dam is usually compacted on the wet side of OMC.
Reason (R): Compaction on the wet side of OMC reduces permeability and prevents cracking in core.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2005]

5.11 Match List-I (Equipment) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Sheep foot roller
B. Frog hammer
C. Vibratory roller

List-II
1. To densify cohesionless soils to relatively larger depths
2. To compact lumpy cohesive soil fills
3. To compact soils at corners and places which bigger rollers cannot access
4. To compact cohesionless soils of shallow depth

Codes:

	A	B	C
(a)	4	1	2
(b)	2	1	4
(c)	4	3	2
(d)	2	3	4

[ESE : 2005]

5.12 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Smooth wheel rollers
B. Sheep foot rollers
C. Pneumatic tyred rollers
D. Rammers

List-II
1. Most suitable for compacting cohesive soils
2. Most suited for compacting coarse grained soils
3. Used for compacting soils in confined places
4. Suitable for both cohesionless and cohesive soils

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2006]

5.13 Match List-I (Type of soil) with List-II (Compaction equipment) and select the correct answer using the codes given below the lists:

List-I

A. Wet clays and silts
B. Crushed rock
C. Fill soils
D. Sands

List-II

1. Smooth wheel rollers
2. Vibrators
3. Pneumatic tyred rollers
4. Grid rollers

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	3	1	4	2
(c)	4	1	3	2
(d)	3	2	4	1

[ESE : 2006]

5.14 The following soils are compacted at the same compactive effort in the field. Which one of the following is the correct sequence in the increasing order of their maximum dry density?

(a) Silty clay – Clay – Sand – Gravel sand clay mixture
(b) Sand – Gravel sand clay mixture – Silty clay – Clay
(c) Clay – Silty clay – Sand – Gravel sand clay mixture
(d) Sand – Gravel sand clay mixture – Clay – Silty clay

[ESE : 2007]

5.15 Consider the following statements:

On addition of lime to a clay soil, generally

1. MDD and strength both increase
2. MDD decreases but strength increases
3. MDD and OMC both increase

Which of these statements is correct ?

(a) 1 only (b) 2 only
(c) 3 only (d) None of these

[ESE : 2007]

5.16 An increase in compaction effort will lead to which of the following?

(a) Decrease in both the optimum moisture content (OMC) and maximum dry density.
(b) Decrease in the optimum moisture content (OMC) and increase in the maximum dry density.
(c) Increase in the optimum moisture content (OMC) and decreases in the maximum dry density.
(d) Increase in both the optimum moisture content (OMC) and maximum dry density.

[ESE : 2007]

5.17 In laboratory compaction tests, the optimum moisture content of soil decreases

(a) with increase of compaction energy and with decrease of coarse grains in the soil
(b) with decrease of compaction energy and with increase of coarse grains in the soil
(c) with increase of both compaction energy and coarse grains in the soil
(d) with decrease of both compaction energy and coarse grains in the soil

[ESE : 2008]

5.18 Consider the following:

1. Increase in shear strength and bearing capacity
2. Increase in slope stability
3. Decrease in settlement of soil
4. Decrease in permeability

Which of the above with respect to compaction of soil is/are correct?

(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2, 3 and 4

[ESE : 2009]

5.19 Consider the following statements:

1. In clay soils, the maximum dry unit weight tends to decrease as plasticity increases.
2. In clay soils, the maximum dry unit weight tends to increase as plasticity increases.
3. Heavy clays with high plasticity have the minimum dry unit weight and high OMC.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2010]

5.20 When the compaction energy increases the compaction of soils:

(a) Both of OMC and maximum dry density decrease

(b) Both of OMC and maximum dry density increase
(c) OMC decreases but maximum dry density increases
(d) OMC increases but maximum dry density decreases

[ESE : 2011]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

5.21 **Assertion (A):** The efficiency of the sheeps foot roller depends on the weight of the roller and the number of 'feet' in contact with the ground at a time.
Reason (R): Sheep foot rollers are considered most suitable for compacting clayey soils.

[ESE : 2011]

5.22 **Assertion (A):** In a compaction test at $\gamma_{d_{max}}$ and OMC, the degree of saturation is never 100%.
Reason (R): It is not possible to expel all the air entrapped in soil by compaction.

[ESE : 2011]

5.23 Consider the following statements:
1. Swelling is greater and shrinkage is less for clay compacted on the dry side of optimum.
2. Clays compacted on the dry side of optimum are characterized by larger strength.
3. An increase in organic content of clay soils causes an increase in optimum moisture content value.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2013]

5.24 Consider the following statements:
1. Cohesionless soils experience relatively quicker compression under load.
2. Clays compacted dry-of-optimum compress more rapidly.
3. Clays compacted wet-of-optimum consolidate more under low stress range.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2013]

5.25 A sample of sand has a volume of 1000 ml in its natural state. Its minimum volume when compacted is 750 ml. When gently poured into a measuring cylinder, its possible maximum volume is 1320 ml. What is the relative density?
(a) 56 (b) 52
(c) 58 (d) 60

[ESE : 2014]

5.26 **Statement (I):** The zero-air void curve is non-linear.
Statement II: The dry density at 100% saturation is a non-linear function of void ratio.

[ESE : 2014]

5.27 **Statement (I):** For a given soil, optimum moisture content increases with the increase in compactive effort.
Statement (II): Higher the compactive effort higher is the dry density at the same moisture content.

[ESE : 2016]

Answers Compaction of Soil

5.1 (d)	5.2 (b)	5.3 (a)	5.4 (a)	5.5 (d)	5.6 (c)	5.7 (c)	5.8 (c)	5.9 (b)	
5.10 (a)	5.11 (d)	5.12 (b)	5.13 (c)	5.14 (c)	5.15 (b)	5.16 (b)	5.17 (c)	5.18 (d)	
5.19 (d)	5.20 (c)	5.21 (b)	5.22 (a)	5.23 (a)	5.24 (a)	5.25 (a)	5.26 (a)	5.27 (d)	

Explanations Compaction of Soil

5.1 (d)

The Indian Standard Equivalent of the Standard Proctor Test is called the light compaction test (IS : 2720 Part VII-1974). The values of the respective parameters of this test are :

P = 2.6 kg,

Q = 310 mm,

R = 25, S = 3

The Indian Standard Equivalent of the Modified Proctor Test is called the heavy compaction test (IS : 2720 Part VIII-1983). The values of the respective parameters of this test are :

P = 4.9 kg,

Q = 450 mm,

R = 25, S = 5

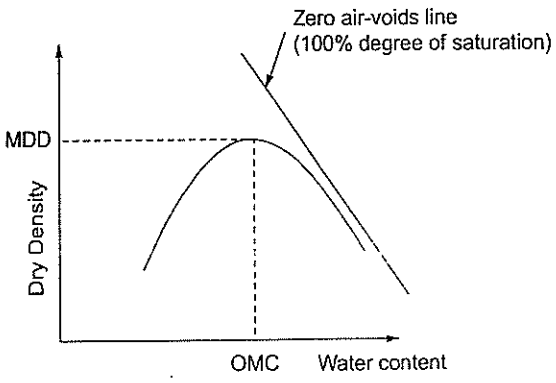
5.2 (b)

Sheepsfoot rollers are used for compacting fine grained soils such as heavy clays and silty clays. Sheepsfoot rollers are used for compaction of soils in dams, embankments, subgrade layers in pavements and rail road construction projects. These are of static and vibratory types. Vibratory types rollers are used for compaction of all fine grained soils and also soil with sand-gravel mixes. Generally this roller is used for compaction of subgrade layers in road and rail projects.

5.3 (a)

Relative compaction is defined as the ratio of the in-situ, wet density of a soil or aggregate to the test maximum wet density of the same soil or aggregate when **compacted** by a specific test method.

Soil densification techniques are used for reducing liquefaction hazards is to avoid large increases in pore water pressure during earthquake shaking. **Vibrofloatation** involves the use of a vibrating probe that can penetrate granular soil to depths of over 100 feet. The vibrations of the probe cause the grain structure to collapse thereby densifying the soil surrounding the probe. To treat an area of potentially liquefiable soil, the vibroflot is raised and lowered in a grid pattern. The relation between moisture content and dry unit weight for a saturated soil is the **zero air-voids line.**



5.4 (a)

The structure of soil changes from flocculated (attraction force) to dispersed (repulsive force) as the moisture content increases up to optimum moisture content. In this case the permeability decreases and dry density increases due to change of structure.

5.5 (d)

The optimum moisture content decreases and maximum dry density increases with increase in compactive effort. At the same time dry density increases at any moisture content with increase in compactive effort. This is due to increase in the dispersed orientation of particles at same moisture content.

5.6 (c)

Pneumatic tyred rollers are also called as rubber tyred rollers. These rollers are used for compaction of coarse grained soils with some

fines. These rollers are least suitable for uniform coarse soils and rocks. Generally pneumatic tyred rollers are used in pavement subgrade works both earthwork and bituminous works.

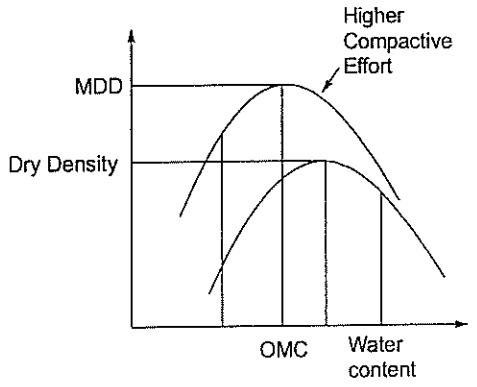
Smooth wheeled roller are the most suitable soils for these roller type are well graded sand, gravel, crushed rock, asphalt etc. where crushing is required. These are used on soils which does not require great pressure for compaction. These rollers are generally used for finishing the upper surface of the soil. These roller are not used for compaction of uniform sands.

Sheepsfoot rollers are used for compacting fine grained soils such as heavy clays and silty clays. Sheepsfoot rollers are used for compaction of soils in dams, embankments, subgrade layers in pavements and rail road construction projects.

Vibratory rollers compact the soil through impact forces. These forces result in compaction greater than the equivalent static load. Vibratory rollers are suitable for coarse grained soil. Vibratory rollers can be used for all types of soil except for plastic clays.

5.7 (c)

The effect of increasing the amount of compactive effort is to increase the maximum dry density and to decrease the optimum water content (OMC).



5.8 (c)

Frog hammers are used to compact soils in confined areas and at corners e.g., back of retaining wall, etc.

Soil densification techniques are used for reducing liquefaction hazards is to avoid large increases in pore water pressure during earthquake shaking. **Vibrofloatation** involves the use of a vibrating probe that can penetrate granular soil to depths of over100 feet. The vibrations of the probe cause the grain structure to collapse thereby densifying the soil surrounding the probe. To treat an area of potentially liquefiable soil, the vibroflot is raised and lowered in a grid pattern.

5.9 (b)

With increase in compactive effort, the optimum moisture content decrease and dry density increases. Thus soil is to be compacted on the dry side of the optimum moisture content of original (lower compactive effort) Proctor curve.

5.10 (a)

To avoid large expansions and swelling pressure under pavements and the floors, cohesive soils are generally compacted at a water content more than the optimum moisture content (OMC) with the resulting dry density less than the maximum dry density. The clayey soil in the impervious core of an earth dam is also compacted to the wet side of the optimum to reduce swelling pressure and to achieve low permeability. On the other hand, the highway embankment of cohesive soils are generally compacted of a water content lower than OMC to achieve higher shear strength and low compressibility. Likewise, the soil in the outer shells of the earth dams is compacted on dry side of the optimum to obtain higher shear strength, high permeability and low pore pressure.

5.11 (d)

By sheep foot roller the compaction is achieved by a combination of tamping and kneading. It is suitable for cohesive soils.

Frog hammers are pneumatic rammers. They are used for cohesionless soils, especially in small restricted and confined areas such as beds of drainage trenches and backfills of bridge abutments.

Vibratory rollers or drum have a separate motor drive i.e., an arrangement of eccentric weights so as to produce high frequency, low amplitude vertical oscillation. Layers of the order of 1 m deep could be compacted to high densities.

Vibrofloat can be used for compacting cohesionless soils up to 12 m depth (i.e., relatively larger depths.)

5.12 (b)

Rammers are used for compacting small areas by providing impact load to the soil. This equipment is light and can be hand or machine operated. Rammers are suitable for compacting cohesive soils as well as other soils. This machine is used in areas with difficulty of access.

5.13 (c)

Grid rollers are used for compaction of weathered rocks, well graded coarse soils. These rollers are not suitable for clayey soils, silty clays and uniform soils. The main use of these rollers are in subgrade and sub-base in road constructions.

5.14 (c)

A well graded sand attains a much higher dry density than a poorly graded sand for same compactive effort.

Cohesive soil has high air voids. This soil attains a relatively lower maximum dry density as compared to the cohesionless soil. It also requires more water than cohesionless soil and so the optimum water content is high. Heavy clay of very high plasticity has very low dry density and very high optimum water content.

5.15 (b)

- Lime decreases the plasticity index of highly plastic soils and make them friable and more easily handled in the field.
- It increases the optimum moisture content and decreases the maximum compacted density however there will be an increase in strength.
- About 5-10% lime is required for cohesive soils.

5.16 (b)

For a given type of compaction, the higher the compactive effort, the higher the maximum dry unit weight and lower the optimum moisture content.

5.17 (c)

As the grain size increases, specific surface area of solids decreases so less water is required to make lubricating water layer around soil particles hence OMC decreases. As compactive effort increases the OMC decreases.

5.18 (d)

Compaction is the application of mechanical energy to a soil so as to rearrange its particles and reduce the void ratio.

It is applied to improve the properties of an existing soil or in the process of placing fill such as in the construction of embankments, road bases, runways, earth dams, and reinforced earth walls. Compaction is also used to prepare a level surface during construction of buildings. There is usually no change in the water content and in the size of the individual soil particles.

The objectives of compaction are:

- To increase soil shear strength and therefore its bearing capacity.
- To reduce subsequent settlement under working loads.
- To reduce soil permeability making it more difficult for water to flow through.

5.19 (d)

As plasticity increases in clay soils, the maximum dry unit weight decreases. Heavy clays of very high plasticity have very low dry unit weight and a very high OMC.

5.20 (c)

The effect of increasing the amount of compactive effort is to increase the maximum dry density and to decrease the optimum water content. At a water content less than the optimum, the effect of increased compaction is more predominant. At a water content more than the optimum, the volume of air voids becomes almost constant and the effect of increased compaction is not significant.

But, the maximum dry density does not go on increasing with an increase in the compactive effort.

5.21 (b)

The sheep-foot roller consists of a hollow drum with a large number of small projections (known as feet) on its surface. These projections penetrate the soil layers during the rolling operations and cause compaction.

The sheep-foot rollers are ideally suited for compaction of cohesive soils. The rollers compact the soil by a combination of tamping and kneading

action. When the roller is passed for the first time, the projections penetrate the soil layer and the lower portion of the layer is compacted. In successive passes, compaction is obtained in the middle and the top portion of the layer. This continually rising effect of the compaction is called walking-out of the roller.

5.22 (a)

The water content corresponding to the maximum dry density is known as the optimum water content (O.W.C.) or the optimum moisture content (O.M.C.).

For a given water content, theoretical maximum density, $(\rho_d)_{theomax}$, is obtained corresponding to the condition when there are no air voids (i.e. degree of saturation is equal to 100%). The theoretical maximum dry density is also known as saturated dry density $(\rho_d)_{sat}$. In this condition, the soil becomes saturated by reduction in air voids to zero but with no change in water content. It may be mentioned that compaction methods cannot remove all the air voids, and, therefore, the soil never becomes fully saturated. Thus, the theoretical maximum density is only hypothetical. The line indicating the theoretical maximum density can be plotted along with the compaction curve. It is also known as zero air void line or 100% saturation line.

5.24 (a)

- In cohesionless soils, compression is relatively quicker because settlement is mainly immediate.
- Due to large permeability, clays are compacted more rapidly thus leading to quicker consolidation process on dry side.
- Clays compacted wet of optimum is more compressible than the flocculated soil on dry side of optimum, at relatively low stress levels. This is because the strong interparticle bonds in a flocculated structure do not allow the particles to be displaced.

5.25 (a)

$$V = 100\text{ ml},$$
$$V_{min} = 750\text{ ml},$$
$$V_{max} = 1320\text{ ml}$$

$$e = \text{Void ratio} = \frac{V_V}{V_S}$$

Hence, V_s = constant for all condition only V_V changes.

Let, $V_s = x$

$$e = \frac{V_V}{V_s} = \frac{V - V_s}{V_s} = \frac{V}{V_s} - 1$$

For natural state, $e = \frac{100}{x} - 1$

For maximum compacted state,

$$e_{max} = \frac{1320}{x} - 1$$

For minimum compacted,

$$e_{min} = \frac{750}{x} - 1$$

$$\Rightarrow \text{Relative density} = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100\%$$

$$= \frac{\left(\frac{1320}{x} - 1\right) - \left(\frac{1000}{x} - 1\right)}{\left(\frac{1320}{x} - 1\right) - \left(\frac{750}{x} - 1\right)} \times 100$$

$$= \frac{\frac{320}{x}}{\frac{570}{x}} \times 100 = \frac{320}{570} \times 100 = 56.14\%$$

5.27 (d)

Optimum moisture content decreases with compactive effort.

■■■■

6 Compressibility and Consolidation

6.1 The natural void ratio of a saturated clay strata, 3 m thick is 0.90. The final void ratio of the clay at the end of consolidation is expected to be 0.71. The total consolidation settlement of the clay strata is

(a) 30 cm (b) 25 cm
(c) 20 cm (d) 15 cm

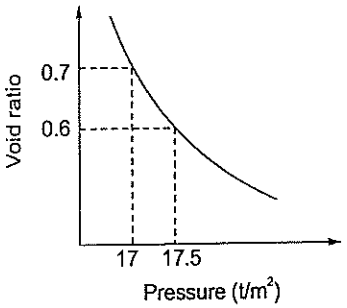
[ESE : 1995]

6.2 The identical clay samples of the same size, designated as *A* and *B* are subjected to consolidation test under identical loading conditions. Drainage takes place through one face in sample *A* and through both the faces in sample *B*. 50% consolidation of sample *A* occurs in 10 minutes. The time required for 50% consolidation to occur in sample *B* will be

(a) 40 minutes (b) 10 minutes
(c) 5 minutes (d) 2.5 minutes

[ESE : 1995]

6.3 The void ratio-pressure diagram is shown in the given figure. The coefficient of compressibility is



(a) 0.0050 m^2/t (b) 0.073 m^2/t
(c) 0.20 m^2/t (d) 0.25 m^2/t

[ESE : 1995]

6.4 A clay layer 5 m thick in field takes 300 days to attain 50% consolidation with condition of double drainage. If the same clay layer is underlain by hard rock then the time taken to attain 50% consolidation will be

(a) 300 days (b) 600 days
(c) 900 days (d) 1200 days

[ESE : 1996]

6.5 The change that take place during the process of consolidation of a saturated clay would include

(a) an increase in pore water pressure and an increase in effective pressure
(b) an increase in pore water pressure and a decrease in effective pressure
(c) a decrease in pore water pressure and a decrease in effective pressure
(d) a decrease in pore water pressure and an increase in effective pressure

[ESE : 1997]

6.6 Match List-I (Property) with List-II (Slope of the curve) and select the correct answer using the codes given below the lists:

List-I
A. Coefficient of compressibility
B. Compression index
C. Coefficient of subgrade modulus

List-II
1. Stress-deformation
2. Stress-void ratio
3. Volume-pressure
6. Log stress-void ratio

Codes:

	A	B	C
(a)	4	2	1
(b)	4	3	2
(c)	2	4	1
(d)	3	4	1

[ESE : 1997]

6.7 The initial and final void ratios of a clay sample in a consolidation test are 1 and 0.5, respectively. If initial thickness of the sample is 2.4 cm, then its final thickness will be

(a) 1.3 cm (b) 1.8 cm
(c) 1.9 cm (d) 2.2 cm

[ESE : 1997]

6.8 Match List-I (Effect) with List-II (Reason) and select the correct answer using the codes given below the lists:

List-I
A. Excessive settlement
B. High expansivity
C. Reduction of bearing capacity
D. Acceleration of consolidation

List-II
1. Rise of water table
2. High compressibility
3. Montmorillonite
6. Sand drains

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	1	3	2
(d)	2	3	1	4

[ESE : 1997]

6.9 Which one of the following soils has stress-strain response similar to that of dense sand? (OCR stands for over consolidation ratio)
(a) Over consolidated clays having high OCR
(b) Over consolidated clays having low OCR
(c) Normally consolidated clays
(d) Unconsolidated clays

[ESE : 1998]

6.10 In the consolidated drained test on a saturated soil sample, pore water pressure is zero during
(a) consolidation stage only
(b) shearing stage only
(c) both consolidation and shearing stages
(d) loading stage

[ESE : 1998]

6.11 Consider the following statements:
1. The degree of saturation of a saturated soil mass subjected to pressure remains unchanged during the process of consolidation.
2. Secondary consolidation is due to the plastic deformation of the soil when the pore fluid is not subjected to any excess pressure.
3. Primary consolidation is independent of the coefficient of permeability of the soil but depends on the decrease in void volume due to air escape.

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 1998]

6.12 Terzaghi's consolidation theory is applicable to one-dimensional consolidation test
(a) for small load increment ratios
(b) for large load increment ratios
(c) for a load increment ratio of nearly one
(d) in situations where there is no excess pore pressure

[ESE : 1998]

6.13 **Assertion (A):** For a fully saturated soil, the pore pressure parameter is equal to zero.
Reason (R): The compressibility of water is much smaller than the coefficient of volume compressibility.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

6.14 Which one of the following pairs of parameters and expression is NOT correctly matched?
(a) Coefficient of consolidation ... $\frac{T_v H^2}{t}$
(b) Coefficient of volume compressibility ... $\frac{e_0 - e}{(1+e_0)(p - p_0)}$
(c) Over consolidation ratio ... $\sqrt{\frac{\text{Maximum previous effective pressure}}{\text{Existing effective pressure}}}$
(d) Modulus of volume change ... $\frac{a_v}{1+e_0}$

[ESE : 1999]

6.15 Consider the following:
1. Initial consolidation
2. Primary consolidation

3. Secondary consolidation
4. Final consolidation

The three stages which would be relevant to consolidation of a soil deposit includes

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

[ESE : 1999]

6.16 **Assertion (A):** Terzaghi's theory of consolidation considers only primary consolidation.

Reason (R): Secondary consolidation takes place only at the end of the primary consolidation.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

6.17 Match List-I with List-II and select the correct answer using the codes given below the lists (notations have their usual meaning):

List-I	List-II
A. Coefficient of compressibility	1. m_v
B. Compression index	2. $C_v t/H^2$
C. Time factor	3. a_v
D. Coefficient of volume compressibility	4. C_c

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	1	2	4	3
(c)	1	4	2	3
(d)	3	4	2	1

[ESE : 2000]

6.18 Reduction in volume of soil primarily due to squeezing out of water from the voids is called

(a) primary consolidation
(b) plastic flow
(c) creep
(d) secondary consolidation

[ESE : 2000]

6.19 The settlement analysis for a clay layer draining from top and bottom shows a settlement of 2.5 cm in 4 years and an ultimate settlement of 10 cm. However detailed subsurface investigation reveals that there is no drainage at the bottom. The ultimate settlement in this condition will be

(a) 2.5 cm (b) 5 cm
(c) 10 cm (d) 20 cm

[ESE : 2000]

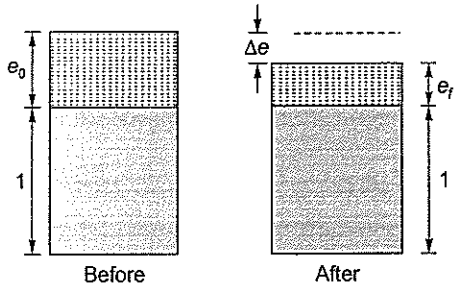
6.20 **Assertion (A):** The rates of settlement of building structures on sandy clay soils are faster compared to those of buildings constructed on clayey soils.

Reason (R): The rate of consolidation is dependent on the permeability of soils and the permeability of sandy clay is more than that of clayey soil.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

6.21 The figure given shows the state of a sample of clay before and after consolidation. Based on these figures, the settlement of a clay layer of initial thickness H will be

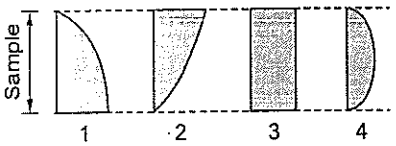


(a) $\frac{a_v}{1+e_0}$ (b) $\frac{H\Delta e}{(1+e_f)}$

(c) $\frac{\Delta e}{(1+e_f)}$ (d) $\frac{H\Delta e}{(1+e_0)}$

[ESE : 2001]

6.22 Excess pore pressure distributions within the thickness of a soil sample tested in oedometer sometime after loading is shown in the figure below labelled 1, 2, 3 and 4. Which one of these figures, refers to a situation where the operator forgot to put on the porous stones at the top and bottom of the sample before the test?



(a) 1 (b) 2
(c) 3 (d) 4

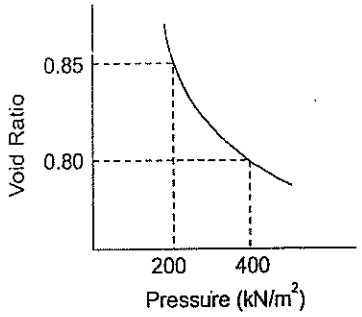
[ESE : 2001]

6.23 In soil consolidation process, the following events take place after loading:
1. Decrease in excess pore pressure.
2. Increase in total stress.
3. Development of excess pore pressure.
4. Increase in effective stress.

The correct sequence of these events is
(a) 3, 2, 1, 4 (b) 2, 3, 1, 4
(c) 2, 3, 4, 1 (d) 3, 2, 4, 1

[ESE : 2001]

6.24 The e-p curve for a soil is shown in the figure below. The coefficient of compressibility (in m^2/kN) of the soils is



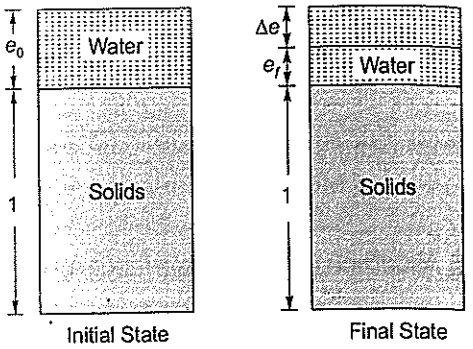
(a) 4000 (b) 2000
(c) 2.5×10^{-4} (d) 1.25×10^{-4}

[ESE : 2001]

6.25 A saturated clay layer with double drainage takes 5 years to attain 90% degree of consolidation under a structure. If the same layer were to be single drained, what would be the time (in years) required to attain the same consolidation under the same loading conditions?
(a) 10 (b) 15
(c) 20 (d) 25

[ESE : 2001]

6.26 In the phase diagrams given the change due to initial state changing into final state is shown due to consolidation. Depth of soil layer undergoing consolidation is H; e_0 is initial void ratio; e_f is final void ratio; Δe is change in void ratio.



Indicate which of the following expressions gives settlement of the layer.

(a) $H\log_{10}\left(\frac{\Delta e}{1+e_0}\right)$ (b) $\log_{10}\left(H\frac{\Delta e}{1+e_0}\right)$

(c) $\frac{\Delta e}{1+e_0}$ (d) $H\frac{\Delta e}{1+e_0}$

[ESE : 2002]

6.27 Which one of the following statements regarding coefficient of consolidation C_v is correct?

(a) $C_v \propto k$ (b) $C_v \propto \frac{1}{k}$

(c) $C_v \propto m_v$ (d) $C_v \propto a_v$

[ESE : 2002]

6.28 **Assertion (A):** A clay layer of thickness. H, with single drainage suffers an ultimate settlement of S under increase in pressure of Δp. When a thin sand layer is present at its mid depth, the layer, under otherwise identical conditions, will have no change in ultimate settlements.

Reason (R): The path of travel of water for the clay layer is H under single drainage. When a thin sand layer is present at mid depth of clay layer, the path of travel in lower half of the layer gets reduced to $H/2$ and that in upper half of the layer gets reduced to $H/4$. This considerably reduces the time required to realize ultimate settlement.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

6.29 Consider the following statements:
Theory of consolidation predicts settlement due to primary consolidation; it cannot include settlement due to initial compression nor due to secondary consolidation. This happens because of the following assumptions made by the theory:
1. Soil grains and water are incompressible.
2. Soil is fully saturated.
3. Compression takes place in vertical direction only.
4. Time lag in consolidation is entirely due to low permeability of soil.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 3 and 4 (d) 1, 2 and 4
[ESE : 2002]

6.30 For a certain loading condition, a saturated clay layer undergoes 40% consolidation in a period of 178 days. What would be the additional time required for further 20% consolidation to occur?
(a) 89 days (b) 222.5 days
(c) 329.5 days (d) 400.5 days
[ESE : 2004]

6.31 The one dimensional theory of consolidation proposed by Terzaghi derives its name due to the fact that
(a) only vertical dimension of the soil sample is used for consolidation test and lateral dimensions are neglected
(b) water in the soil sample in conventional consolidometer escapes in the lateral directions resulting into settlements only in vertical direction
(c) normal stress on the sample is applied in only one (vertical) direction
(d) lateral movements of soil grains are not permitted across any vertical boundary resulting into only vertical settlements to account for the decrease in volume due to escape of water from soil sample
[ESE : 2004]

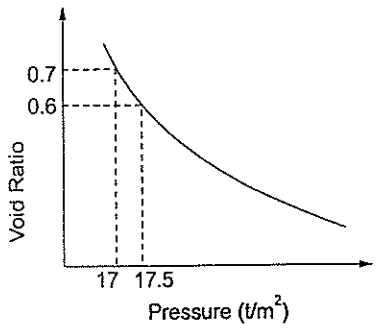
6.32 Consider the following statements:
1. A recovery ratio of less than 1 implies that the soil has compressed.
2. A recovery ratio greater than 1 implies that the soil has swelled.
3. A recovery ratio of less than 1 implies that the soil has swelled
4. A recovery ratio greater than 1 implies that the soil has compressed.

Which of these statements is/are correct?
(a) 1 and 2 (b) 1 only
(c) 3 and 4 (d) 4 only
[ESE : 2005]

6.33 If the time required for 60% consolidation of a remoulded soil sample of clay with single drainage is 't', then what is the time required to consolidate the same sample of clay with the same degree of consolidation but with double drainage?
(a) $4t$ (b) $2t$
(c) $t/2$ (d) $t/4$
[ESE : 2005]

6.34 If Δp is increment of pressure on a normally consolidated saturated soil mass, as per Terzaghi's theory at the instant of application of pressure increment i.e., when time $t = 0$, what is the pore pressure developed in the soil mass?
(a) Zero
(b) Very much less than Δp
(c) Equal to Δp
(d) Greater than Δp
[ESE : 2005]

6.35 The void ratio-pressure diagram is shown below. What is the coefficient of compressibility?



(a) 0.5 m^2/t (b) 0.73 m^2/t
(c) 0.20 m^2/t (d) 0.25 m^2/t
[ESE : 2005]

6.36 Match List-I (Term) with List-II (Definition) and select the correct answer using the codes given below the lists (where 'e' is void ratio, 'p' is effective vertical stress, 'k' is permeability and γ_w is unit weight of water):

List-I

A. Compression index, C_c
B. Coefficient of volume change, m_v
C. Coefficient of compressibility, a_v
D. Coefficient of consolidation, C_v

List -II

1. Slope of the e-p curve defined as $\Delta e/\Delta p\,(1+e_0)$
2. Slope of e-log p curve given by $[-\Delta e/\Delta(\log p)]$
3. Term defined as $k/(m_v\gamma_w)$
4. Slope of the e-p curve defined as $-\Delta e/\Delta p$

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	4	3	2	1
(c)	2	3	4	1
(d)	4	1	2	3

[ESE : 2005]

6.37 A clay layer 3 m deep is sandwiched by a pervious material. The soil reaches 90% consolidation in 3 years. At another site, the same clay layer is bounded by impervious boundary at the bottom and sand at the top. What is the time taken by this layer to reach 90% settlement?

(a) 9 years (b) 12 years
(c) 15 years (d) 21 years

[ESE : 2005]

6.38 In a consolidation test void ratio decreased from 0.80 to 0.70 when the load was changed from 40 kN/m^2 to 80 kN/m^2. What is the compression index?

(a) 0.14 (b) 0.16
(c) 0.33 (d) 0.66

[ESE : 2006]

6.39 In a consolidation test the sample tested has height H; water content is w, specific gravity of solids G. After increasing the loading by an increment Δp, the height decrease is ΔH. Which one of the following expresses the corresponding change in void ratio Δe?

(a) $\Delta e = \dfrac{\Delta H}{H(1+wG)}$

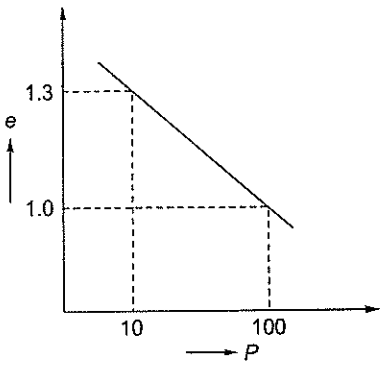
(b) $\Delta e = \dfrac{\Delta H(1+wG)}{H}$

(c) $\Delta e = \dfrac{H(1+wG)}{\Delta H}$

(d) $\Delta e = \dfrac{H}{\Delta H(1+wG)}$

[ESE : 2006]

6.40 The virgin compression curve for a soil is shown in figure below. What is the compression index of the soil?



(a) 0.3 (b) 0.5
(c) 1.5 (d) 15

[ESE : 2007]

6.41 Consider the following statements:

1. Coefficient of consolidation normally increases with decreasing liquid limit of clay.
2. The larger the value of coefficient of consolidation, the longer it takes for full consolidation to occur.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2008]

6.42 During the consolidation of a clay layer, if instead of double drainage, the drainage is allowed at single face only, the rate of compression will be

(a) 4 times slower (b) 4 times faster
(c) 2 times slower (d) 2 times faster

[ESE : 2008]

6.43 A clay sample, originally 26 mm thick at a void ratio of 1.22, was subjected to a compressive load. After the clay sample was completely consolidated, its thickness was measured to be 24 mm. What is the final void ratio?

(a) 1.322 (b) 1.421
(c) 1.311 (d) 1.050

[ESE : 2009]

6.44 A 1 m thick layer of saturated clay, drained at both faces, settles by 10 cm in one year. If a thin layer of pervious soil is introduced in the middle of this layer, then what will be the period during which the settlement of 10 cm will be completed?

(a) 4 years (b) 0.5 year
(c) 0.25 year (d) 2 years

[ESE : 2009]

6.45 **Assertion (A):** At the same voids ratio desiccated clay is stronger than saturated clay.

Reason (R): Desiccation impacts (induces) pre-compressive forces in the soil structure.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

6.46 During consolidation process of clayey soils, indicate the sequence of occurrence of the following events in the order from first to last

1. Load being taken up by the pore-water
2. Load being taken up by the soil grains
3. Drainage of water from the pores of the soil

(a) 1, 2 and 3 (b) 2, 3 and 1
(c) 1, 3 and 2 (d) 2, 1 and 3

[ESE : 2011]

6.47 If, instead of single drainage, the number of drainage faces is increased to two in responding soils, the rate of compression will be

(a) 4 times slower (b) 2 times slower
(c) 4 times faster (d) 2 times faster

[ESE : 2011]

6.48 Settlement due to creep in soils is contingent on

(a) Primary consolidation
(b) Secondary consolidation
(c) Initial settlement
(d) Compaction settlement

[ESE : 2011]

6.49 **Assertion (A):** In non-cohesive soils, settlement occurs immediately after application of load.

Reason (R): The settlement is attributed to volume changes caused by lateral yielding or shear strains occurring in the soil.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

6.50 Consider the following statements:

1. Mathematically speaking, the time taken for 100% consolidation is infinite.
2. The time factor for a particular average degree of consolidation depends upon the distribution of initial excess hydrostatic pressure.
3. Secondary consolidation obeys Terzaghi's one-dimensional theory of consolidation.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

6.51 Consider the following statements:

1. Consolidation time increases with increasing compressibility.
2. Consolidation time decreases with increasing permeability.
3. Consolidation time is dependent on the magnitude of stress increase.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

6.52 Consider the following statements:

1. The maximum possible over-consolidation ratio of normally consolidated soil is unity.
2. The compressibility of a field deposit is slightly greater than that shown by a laboratory sample.
3. In Terzaghi's theory of one-dimensional consolidation, only hydrodynamic lag is considered whereas plastic lag is ignored.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2013]

6.53 Compression index developed by Casagrande is

(a) $C_V = 0.009(LL + 10\%)$
(b) $C_V = 0.009(LL - 10\%)$

(c) $C_V = 0.0009(LL + 10\%)$
(d) $C_V = 0.0009(LL - 10\%)$

[ESE : 2014]

6.54 When a structural load is applied on a soil stratum, which of the following soil types will have the minimum settlement?
(a) Over-consolidated clay stratum
(b) Clayey silt stratum
(c) Normally consolidated clay stratum
(d) Sandy clay stratum

[ESE : 2014]

6.55 **Statement (I):** In a consolidation test, pressure on the soil specimen is doubled at each step.

Statement (II): It is intended that the soil always remains in a normally consolidated condition.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

[ESE : 2014]

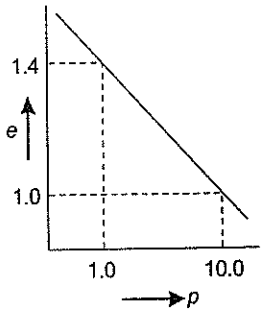
6.56 If the coefficient of permeability is doubled and the coefficient of volume compressibility in simultaneously halved, the coefficient of consolidation
(a) increase by 2 times
(b) decrease by 2 times
(c) increase by 4 times
(d) decrease by 4 times

[ESE : 2015]

6.57 In a 7 m thick soil stratum, with its initial void ratio of 0.40, the void ratio decreases to 0.30 when the effective pressure on the stratum is increased by 1.0 kg/cm^2. The consolidation settlement of the stratum will be
(a) 5 cm (b) 50 cm
(c) 100 cm (d) 150 cm

[ESE : 2015]

6.58 The virgin compression curve for a particular soil is as shown in the below figure on the standard graphical format. The compression index of the soil is



(a) 0.3 (b) 0.4
(c) 0.5 (d) 0.6

[ESE : 2015]

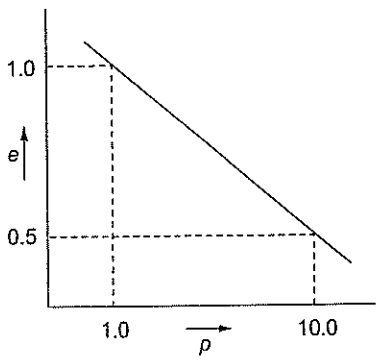
6.59 The time taken to construct a building was from April 1992 to September 1993. In September 1996, the average settlement was found to be 5.16 cm. If the ultimate settlement is estimated to be 25 cm, then the settlement in January 1997 would have been
(a) 6 cm (b) 7 cm
(c) 8 cm (d) 9 cm

[ESE : 2015]

6.60 A soil deposit has a void ratio of 1.0. If the void ratio is reduced to 0.60 by compaction, the percentage volume loss is
(a) 10% (b) 20%
(c) 30% (d) 40%

[ESE : 2015]

6.61



The virgin compression curve with axes adopted as per convention in this regard for a clay soil is shown in the figure. The compression index of the soil is
(a) 0.25 (b) 0.50
(c) 1.00 (d) 1.25

[ESE : 2016]

Directions: Each of the next items consists of two statements, one labelled as the **'Statement (I)'** and

the other as **'Statement (II)'**. Examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

6.62 **Statement (I)** : Rate of settlement of a consolidating layer depends upon its coefficient of consolidation, which is directly proportional the permeability and number of drainage paths available.

Statement (II): The excess hydrostatic pore pressure is relieved fast in soil of higher permeability, in turn, depending on the number of drainage paths available in the consolidating layer.

[ESE : 2016]

6.63 **Statement (I):** Consolidation is the process of expulsion of pore water by applying steady load for a long time.

Statement (II): Volume change occurs immediately after the action of the load in case of consolidation tests.

[ESE : 2017]

6.64 Consider the following statements:

1. Secondary consolidation of soil follows Terzaghi's one-dimensional theory of consolidation.
2. Consolidation is a function of total stress.
3. Even after complete dissipation of excess pore pressure, the soil undergoes a little more consolidation.

Which of the above statements is/are correct?

(a) 3 only (b) 1 and 2

(c) 2 and 3 (d) 1 only

[ESE : 2017]

6.65 Consider the following statements:

1. Immediate settlement takes place as soon as the load is placed.
2. Secondary settlement is significant in the case of organic soil.
3. Secondary settlement is estimated based on the 'void ratio versus time curve' for a particular load under consolidation test.

Which of the above statements are correct?

(a) 1 and 2 (b) 1, 2 and 3

(c) 2 and 3 (d) 1 and 3

[ESE : 2017]

■■■■

Answers Compressibility and Consolidation

6.1 (a)	6.2 (d)	6.3 (c)	6.4 (d)	6.5 (d)	6.6 (c)	6.7 (b)	6.8 (d)	6.9 (a)	
6.10 (c)	6.11 (a)	6.12 (a)	6.13 (d)	6.14 (c)	6.15 (a)	6.16 (b)	6.17 (d)	6.18 (a)	
6.19 (c)	6.20 (a)	6.21 (d)	6.22 (c)	6.23 (b)	6.24 (c)	6.25 (c)	6.26 (d)	6.27 (a)	
6.28 (b)	6.29 (d)	6.30 (b)	6.31 (d)	6.32 (a)	6.33 (d)	6.34 (c)	6.35 (c)	6.36 (a)	
6.37 (b)	6.38 (c)	6.39 (b)	6.40 (a)	6.41 (a)	6.42 (a)	6.43 (d)	6.44 (c)	6.45 (a)	
6.46 (c)	6.47 (c)	6.48 (b)	6.49 (c)	6.50 (b)	6.51 (a)	6.52 (a)	6.53 (b)	6.54 (a)	
6.55 (b)	6.56 (c)	6.57 (b)	6.58 (b)	6.59 (a)	6.60 (b)	6.61 (b)	6.62 (a)	6.63 (c)	
6.64 (a)	6.65 (b)								

Explanations Compressibility and Consolidation

6.1 (a)

Total consolidation,

$$\Delta H = \frac{H(e_0 - e_f)}{1+e_0}$$

$$= \frac{3\times10^{-2}\times(0.9-0.71)}{1+0.9}$$

$$= 30\text{ cm}$$

6.2 (d)

The sample A is single drained and sample B is double drained. The sample B will take only $\frac{1}{4}$ of time that required in sample A.

6.3 (c)

Coefficient of compressibility,

$$a_v = -\frac{\Delta e}{\Delta\sigma} = -\left(\frac{0.6-0.7}{17.5-17}\right)$$

$$= 0.2\text{ m}^2/\text{t}$$

6.4 (d)

Since $T_v = \frac{C_v t}{d^2}$, therefore for same values of T_v and C_v, t is proportional to d^2 where d is length of drainage path. Therefore the time taken in single drainage will be four times that in the double drainage.

6.5 (d)

When stresses are increased, the excess pore pressure is equal to stress increment at $t = 0$. Naturally effective stresses decrease by the same stress increment. With the onset of consolidation excess pore pressure starts dissipating and effective stresses increase. Finally at the end of consolidation the stress increment is completely transferred to soil grains and only hydrostatic pore pressure exists. So effective stress is maximum at the end of consolidation.

6.6 (c)

Coefficient of compressibility,

$$a_v = -\frac{\Delta e}{\Delta\sigma}$$

$$= \frac{\text{Change in void ratio}}{\text{Change in stress}}$$

Compression index,

$$C_c = \frac{e_0 - e}{\log(\sigma/\sigma_0)}$$

6.7 (b)

$$\frac{H_f}{H_i} = \frac{1+e}{1+e_0}$$

$$H_f = \left(\frac{1+0.5}{1+1}\right)\times 24$$

$$= 1.5 \times 1.2 = 1.8\text{ cm}$$

6.8 (d)

- Sand drains reduce the length of drainage path resulting in acceleration of consolidation.
- High compressibility leads to excessive settlement.

- Rise of water table reduces the bearing capacity of soil.
- High volume change (expansivity and shrinkage) in clay is due to Montmorillonite.

6.9 (a)

Normally consolidated clays behave in a manner similar to loose sand. Heavily over consolidated soils behave similar to dense sand.

6.10 (c)

Consolidated means drainage is allowed in first stage. Drained means drainage is allowed in second stage. So in case of consolidated drained test, drainage is allowed in both stages so pore pressure is zero.

6.11 (a)

During primary consolidation degree of saturation = 100% and void ratio reduces. There are no air voids in the soil i.e., it does not depend on the decrease in void volume due to air escape. During secondary consolidation only plastic deformation occurs.

6.12 (a)

Terzaghi's theory considers that certain soil properties such as permeability and modulus of volume change are constant. The pressure versus void ratio relationship is linear. These assumptions hold good for small load increments only.

6.13 (d)

The pore pressure parameter B is equal to one for fully saturated condition because the compressibility of water is small compared to coefficient of volume compressibility of soil sample.

$$B = \frac{1}{1+n(C_v / C_s)}$$

6.14 (c)

Coefficient of consolidation,

$$C_v = \frac{k}{\gamma_w m_v} = \frac{T_v H^2}{t}$$

Coefficient of volume compressibility or modulus of volume change,

$$m_v = \frac{a_v}{1+e_0} = \frac{(e_0 - e)}{(1+e_0)(p - p_0)}$$

Over consolidation ratio,

$$= \frac{\text{Maximum previous effective pressure}}{\text{Existing effective pressure}}$$

6.15 (a)

Initial consolidation or elastic compression due to expulsion of pore air or rapid dissipation of pore water with application of stress. This is significant in non-saturated clays, silts and granular soils.

Primary consolidation due to slow expulsion of excess pore pressure over a period of time.

Secondary consolidation due to viscous layer around particles resulting in rearrangement of particles.

6.18 (a)

After initial consolidation, further reduction in volume occurs due to expulsion of water from the voids. When a saturated soil is subjected to a pressure, initially all the applied pressure is taken up by water as an excess pore water pressure. A hydraulic gradient will develop and the water starts flowing out and a decrease in volume occurs. This reduction in volume is called as the primary consolidation of soil.

6.19 (c)

Ultimate settlement does not depend upon drainage condition.

6.20 (a)

Rate of settlement depends upon permeability, drainage conditions (single drained or double drained) and coefficient of volume change as

$$\text{Time factor, } T_v = \frac{C_v t}{d^2}$$

6.21 (d)

$$\text{Settlement, } \Delta H = \frac{H \Delta e}{1+e_0}$$

6.22 (c)

	Top plate	Bottom plate
Sample-1	Yes	No
Sample-2	No	Yes
Sample-3	No	No
Sample-4	Yes	Yes

6.23 (b)

- Initial Consolidation : When a load is applied to a partially saturated soil, a decrease in

volume occurs due to expulsion and compression of air in the voids. A small decrease in volume occurs due to compression of solid particles. The reduction in volume of the soil just after the application of the load is known as initial consolidation or initial compression. For saturated soils, the initial consolidation is mainly due to compression of solid particles.

- **Primary Consolidation** : After initial consolidation, further reduction in volume occurs due to expulsion of water from the voids. When a saturated soil is subjected to a pressure, initially all the applied pressure is taken up by water as an excess pore water pressure. A hydraulic gradient will develop and the water starts flowing out and a decrease in volume occurs. This reduction in volume is called as the primary consolidation of soil.
- **Secondary Consolidation** : The reduction in volume continues at a very slow rate even after the excess hydrostatic pressure developed by the applied pressure is fully dissipated and the primary consolidation is complete. The additional reduction in the volume is called as the secondary consolidation.

6.24 (c)

Coefficient of compressibility,

$$a_v = -\frac{\Delta e}{\Delta \sigma}$$

$$= -\left(\frac{0.8-0.85}{400-200}\right) = \frac{0.05}{200}$$

$$= 2.5 \times 10^{-4}\ m^2/kN$$

6.25 (c)

$$\frac{t_2}{t_1} = \left(\frac{d_2}{d_1}\right)^2$$

But $d_2 = 2d_1$

$\therefore \quad \frac{t_2}{t_1} = 4$

d_2 is drainage path for single drained

d_1 is drainage path for double drained

$\therefore \quad t_2 = 5 \times 4 = 20$ years

6.26 (d)

Settlement, $\Delta H = H\left(\frac{e_0 - e_f}{1+e_0}\right) = \frac{H\Delta e}{1+e_0}$

6.27 (a)

Coefficient of consolidation,

$$C_v = \frac{k}{m_v \gamma_w}$$

6.28 (b)

The ultimate settlement is given by

$$S = m_v \Delta p\, H$$

It does not depend upon type of drainage (single or double drainage) conditions. Therefore A is correct. The presence of thin sand layer reduces drainage path and settlement becomes fast.

6.29 (d)

Since the assumption of compression in vertical direction only is required to compute settlement due to volumetric change so it has no relation with primary and secondary compression.

6.30 (b)

Time factor, $T = \frac{\pi}{4}U^2$ for $U < 60\%$

For same clay layer at different times t_1 and t_2 the relationship reduces to

$$\frac{t_2}{t_1} = \left(\frac{U_2}{U_1}\right)^2$$

$$\Rightarrow \quad t_2 = \left(\frac{60}{40}\right)^2 \times 178$$

$$= 400.5 \text{ days}$$

Thus additional time needed $= t_2 - t_1$

$$= 400.5 - 178$$

$$= 222.5 \text{ days}$$

6.31 (d)

Assumptions of Terzaghi's Theory:

1. The soil is homogenous (uniform in composition throughout) and isotropic(show same physical property in each direction).
2. The soil is fully saturated (zero air voids due to water content being so high).
3. The solid particles and water are incompressible.
4. Compression and flow are one-dimensional.
5. Strains in the soil are relatively small.
6. Darcy's Law is valid for all hydraulic gradients.

7. The coefficient of permeability and the coefficient of volume compressibility remain constant throughout the process.
8. There is a unique relationship, independent of time, between the void ratio and effective stress

6.32(a)

$$\text{Recovery ratio}, R_r = \frac{L_a}{L_t}$$

L_a = actual length of sample in tube
L_t = total length of the sampling tube driven below the bottom of the bore hole

It represents degree of disturbance of soil during extraction in open drive sampler like Shelby tube.

$R_r = 1$ indicates no disturbance to the sample
$R_r < 1$ indicates that the sample is compressed
$R_r > 1$ indicates that there is expansion of sample within the tube.

6.33(d)

For same degree of consolidation,

$$\frac{t_1}{t_2} = \left(\frac{d_1}{d_2}\right)^2$$

Single drainage $t_1 = t$; $d_1 = H$
Double drainage $t_2 = ?$; $d_2 = H/2$

$$\therefore \quad t_2 = t \times \left(\frac{H/2}{H}\right)^2 = \frac{t}{4}$$

6.34(c)

A $t = 0$ the pore pressure increment or pore pressure developed will be Δp. At any time $t > 0$ excess pore pressure dissipates and reduces.

6.35(c)

Coefficient of compressibility,

$$a_v = -\frac{\Delta e}{\Delta \sigma} = -\left(\frac{0.6-0.7}{17.5-17}\right)$$
$$= 0.20\ \text{m}^2/\text{t}$$

6.37(b)

For same degree of consolidation,

$$t_2 = t_1\left(\frac{d_2}{d_1}\right)^2$$
$$= 4t_1 = 4 \times 3 = 12 \text{ years}$$

6.38(c)

Compression Index

$$C_c = \frac{e_0 - e_f}{\log(\sigma_f / \sigma_0)}$$
$$= \frac{0.80 - 0.70}{\log(80/40)} = 0.33$$

6.39(b)

$$\frac{\Delta H}{H} = \frac{\Delta e}{1+e_0}$$

Using $e_0 = G\,w$ (for full saturation)

$$\Delta e = \frac{\Delta H(1+Gw)}{H}$$

6.40(a)

Compression index is given by the equation,

$$C_c = \frac{e_1 - e_2}{\log_{10}(\bar{\sigma}_2/\bar{\sigma}_1)}$$
$$= \frac{1.3 - 1.0}{\log_{10}(100/10)} = 0.3$$

6.41(a)

From Taylor's formula, we have

$$T_v = \frac{C_v t}{d^2}$$

For full consolidation i.e. $U = 100\%$. T_v will more or less be a constant.

$$\therefore \quad C_v t = \text{constant}$$

$$\Rightarrow \quad C_v \propto \frac{1}{t}$$

Thus, larger the value of coefficient of consolidation, smaller it takes for full consolidation to occur.

6.42(a)

From Taylor's formula, we have

$$T_v = \frac{C_v t}{d^2}$$

$$\Rightarrow \quad t \propto d^2$$

$$\Rightarrow \quad \frac{t_d}{t_s} = \left(\frac{d_d}{d_s}\right)^2 = \left(\frac{H/2}{H}\right)^2$$

$$\Rightarrow \quad t_s = 4\,t_d$$

Thus the time taken by the clay in single drainage is four times more than in double drainage.

6.43(d)

$$\frac{\Delta H}{H} = \frac{\Delta e}{1+e}$$

$$\Rightarrow \quad \frac{26-24}{26} = \frac{\Delta e}{1+1.22}$$

$$\Delta e = 0.171$$

But $e_1 - e_2 = \Delta e$

$$\Rightarrow \quad e_2 = 1.22 - 0.171$$

$$\Rightarrow \quad e_2 = 1.05$$

6.44(c)

For a particular soil

$$t \propto d^2$$

$$\Rightarrow \quad \frac{t_1}{t_2} = \left(\frac{d_1}{d_2}\right)^2$$

$$\Rightarrow \quad \frac{1}{t_2} = \left(\frac{1}{0.5}\right)^2$$

$$\Rightarrow \quad t_2 = 0.25 \text{ years}$$

6.45 (a)

Desiccation in clay soils can result in shrinkage of the soil and subsidence of the ground. As the soil re-hydrates, it can swell, resulting in ground heave. One of the reasons of preconsolidation is desiccation of the clay deposit. During drying due to rise in temperature, tension develops in pore water and effective stress increases.

6.46 (c)

Consolidation of soil deposit has three stages:

1. **Initial Consolidation:** When a load is applied to a partially saturated soil, a decrease in volume occurs due to expulsion and compression of air in the voids.
2. **Primary Consolidation:** After initial consolidation, further reduction in volume occurs due to expulsion of water from voids. When a saturated soil is subjected to a pressure, initially all the applied pressure is taken up by water as an excess pore water pressure, as water is almost incompressible as compared with solid particles. A hydraulic gradient develops and the water starts flowing out and a decrease in volume occurs. The decrease depends upon the permeability of the soil and is, therefore, time dependent. This reduction in volume is called primary consolidation.
3. **Secondary consolidation:** It occurs due to the plastic readjustment of the solid particles and the adsorbed water to the new stress system.

6.47 (c)

Coefficient of consolidation,

$$C_v = \frac{T_v d^2}{t}$$

for two drainage path, rate of compression becomes 4 times faster.

6.48 (b)

Creep is prolonged deformation under the action of constant applied stress. In secondary consolidation drainage of water from the pores of the soil due to development of pore water pressure causes compression of the soil layer.

6.49 (c)

In non-cohesive soils, immediate settlement occurs due to expulsion and compression of pore air and expulsion of pore water after the load is applied. Thus, volume of soil also reduces.

6.50 (b)

Secondary consolidation continues much beyond primary consolidation and occurs at a much slower rate. It occurs at a constant effective stress and is not associated with the dissipation of excess pore water pressure. It does not obey Terzaghi's $1 - D$ theory.

6.52 (a)

The **over consolidation ratio** or OCR is defined as the highest stress experienced divided by the current stress. A soil which is currently experiencing its highest stress is said to be normally consolidated and to have an OCR of one. Even though the consolidation is 100% complete due to the phenomenon of **hydrodynamic lag** that means the entire load increment that has been applied to the soil has been transferred to the soil grains, yet the settlement of soil continues. This phenomenon is due to a number of reasons but primarily due to what is known as **plastic lag** that these solid particles go on adjusting themselves even at constant stresses they continue to undergo some deformation even at

constant stress and readjust themselves. And this gradual movement of the particle and readjustment even under the constant stress is what is called **secondary compression behavior** or **secondary consolidation.**

6.53 (b)

The compression index, C_c is sometimes approximately estimated by empirical equations relating C_c to some simple index property of the soil.

One of the most widely used equations with ±30 percent error, is the one proposed by Terzaghi and Peck (1967) for undisturbed clays of low to medium sensitivity.

$$C_c = 0.009\,(W_L - 10)$$

in which W_L is the liquid limit expressed in percent.

This equation can be used only for clays which are not very sensitive ($s_t < 4$)

For remoulded clays, the following equations is used

$$C_c = 0.007(W_L - 7)$$

Some of the other equations that have been proposed are:

$$C_c = 1.15(e_0 - 0.35)$$

for all clays

$$C_c = 0.30\,(e_0 - 0.27)$$

for inogranic cohesive soil

$$C_c = 1.15 \times 10^{-12}\, W_n$$

for organic soils

Where, W_n is the natural water content of the soil.

6.54 (a)

The compression index for the over consolidated clay stratum (called recompression index) is smaller as compared to other given soils , thus it will have minimum settlement.

6.55 (b)

In consolidation test, pressure on the soil specimen is doubled at each step. The pressure commonly used are 25, 50, 100, 200, 400 and 800 kN/m^2. In this test, it is intended that the soil always remains in a normally consolidated condition.

6.56 (c)

$$C_v = \frac{k}{\gamma_w m_v}$$

$$\frac{C_{v_1}}{C_{v_2}} = \frac{k_1}{k_2} \times \frac{m_{v_2}}{m_{v_1}} = \frac{1}{2} \times \frac{1}{2}$$

$$C_{v_2} = 4C_{v_1}$$

6.57 (b)

$$\Delta H_c = H_0 m_v \Delta\sigma$$

$$= H_0 \times \left(\frac{\frac{\Delta e}{1+e_o}}{\Delta\sigma} \right) \times \Delta\sigma$$

$$= 700 \times \left(\frac{0.40 - 0.30}{1 + 0.40} \right)$$

$$= 700 \times \frac{0.1}{1.4} = 50 \text{ cm}$$

6.58 (b)

Compression Index,

$$C_c = \frac{e_1 - e_2}{\log_{10}\left(\frac{\bar{\sigma}_2}{\bar{\sigma}_1}\right)} = \frac{1.4 - 1}{\log\left(\frac{10}{1}\right)} = 0.4$$

6.59 (a)

From September 1993 to September 1996 i.e. in 3 years, the average settlement is 5.16 cm

i.e., $t_1 = 3$ years

$\Delta h_1 = 5.16$ cm

Then settlement in January 1997 i.e., in 3.25 year will be Δh_2

Consolidation in 3 year $= \frac{5.16}{25} = 0.2064$

$$\therefore \quad T_V = \frac{\pi}{4} U^2 = 0.0334$$

$$\therefore \quad \frac{C_V t}{H^2} = T_V = 0.0334$$

$$\frac{C_V}{H^2} = \frac{0.0334}{3} = 0.0113$$

Now in 3.25 year

$$T_V = \frac{\pi}{4} U^2 = -\frac{C_v t}{H^2}$$

$$= 0.0113 \times 3.25 = 0.03618$$

$$U = 0.2146$$

$$\therefore \quad U = \frac{\Delta h_2}{H}$$

$$0.2146 = \frac{\Delta h_2}{25}$$

$$\therefore \quad \Delta h_2 = 5.37 \text{ cm}$$

6.60 (b)

Volume of soil (V_s) remains constant

$$V_s = \frac{V}{1+e} = \text{Constant}$$

$$\therefore \quad \frac{V_1}{1+e_1} = \frac{V_2}{1+e_2}$$

$$\frac{V_1}{1+1} = \frac{V_2}{1+0.6}$$

$$\frac{V_2}{V_1} = \frac{1.6}{2} = \frac{4}{5}$$

% volume loss

$$= \left(\frac{V_1 - V_2}{V_1}\right) \times 100\% = \left(1 - \frac{V_2}{V_1}\right) \times 100$$

$$= \left(1 - \frac{4}{5}\right) \times 100 = 20\%$$

6.61 (b)

Compression index,

$$C_c = \frac{\Delta e}{\log\left(\frac{\sigma_2}{\sigma_1}\right)} = \frac{1.0 - 0.5}{\log\left(\frac{10}{1}\right)} = 0.50$$

6.62 (a)

$$T_V = \frac{C_v \cdot t}{d^2} = \frac{k}{m_v d_w} \cdot \frac{t}{d^2}$$

6.64 (a)

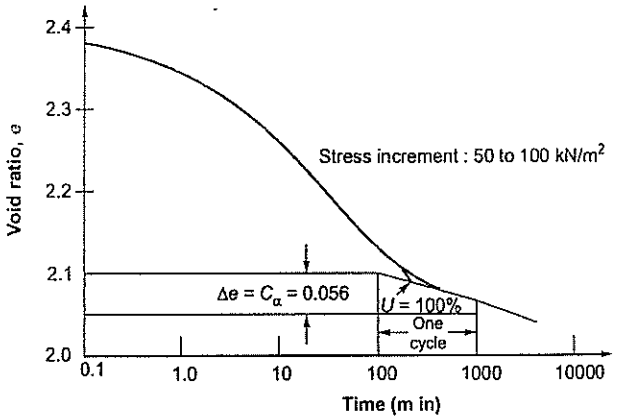
- Terzaghi's one dimensional theory of consolidation is valid for primary consolidation.
- Consolidation is function of effective stress.
- After complete dissipation of excess pore pressure, secondary consolidation may occur.

6.65 (b)

Secondary consolidation becomes important for certain types of soil, such as peat, soft organic clay and some loosely deposited clays.

Secondary compression index (C_s) can be calculated as

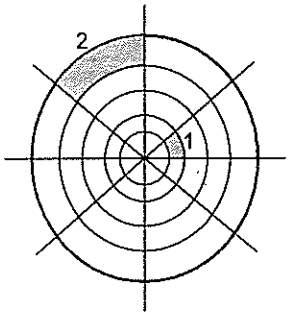
$$C_s = \frac{\Delta e}{\Delta \log(t)}$$



Determination of the rate of secondary compression , C_α

7 Stress Distribution in the Soil

7.1 Standard Newmark's influence chart is shown in the given figure. If loaded equally the areas marked 1 and 2 will yield pressures at the centre such that



(a) 1 yield more than 2
(b) 2 yield more than 1
(c) 1 and 2 yield the same
(d) 1 yield exactly half of that of 2

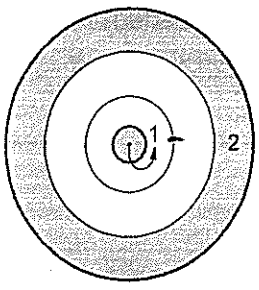
[ESE : 1995]

7.2 A concentrated load of 50 t acts vertically at a point on the soil surface. If Boussinesq's equation is applied for computation of stress, then the ratio of vertical stresses at depths of 3 m and 5 m respectively vertically below the point of application of load will be

(a) 0.36 (b) 0.60
(c) 1.66 (d) 2.77

[ESE : 1995]

7.3 A part of the Newmark's influence chart with four concentric circles is shown in the figure below. If the hatched areas 1 and 2 are loaded separately with the same intensity of loading, then the intensity of pressure yielded



(a) by 1 will be more than that yielded by 2
(b) by 2 will be more than that yielded by 1
(c) by 1 and 2 will be equal
(d) at the centre will be inversely proportional to the radii of the two circles

[ESE : 1997]

7.4 For a vertical concentrated load acting on the surface of a semi-infinite elastic soil mass, the vertical normal stress at depth 'z' is proportional to

(a) z (b) $1/z$
(c) z^2 (d) $1/z^2$

[ESE : 1997]

7.5 With a vertical point load on the surface when considering the vertical plane passing through the load, the stress gets reduced by 52.3% at a depth of

(a) 0.25 of unit length (b) 0.5 of unit length
(c) 0.75 of unit length (d) 1 of unit length

[ESE : 1999]

7.6 In the case of stratified soil layers, the best equation that can be adopted for computing the pressure distribution is

(a) Prandtl's (b) Skempton's
(c) Westergaard's (d) Boussinesq's

[ESE : 2000]

7.7 In a Newmark's influence chart for stress distribution, there are 10 concentric circles and 50 radial lines. The influence factor of the chart is

(a) 0.0002 (b) 0.002
(c) 0.02 (d) 0.2

[ESE : 2001]

7.8 σ_z is the vertical stress at a depth equal to Z in the soil mass due to a surface point load Q. The vertical stress at depth equal to $2Z$ will be

(a) $0.25\sigma_z$ (b) $0.50\sigma_z$
(c) $1.0\sigma_z$ (d) $2.0\sigma_z$

[ESE : 2002]

7.9 The change in the vertical stress in the soil mass estimated by Boussinesq's equation when Poisson's ratio of soil changes from 0.3 to 0.5 will be
(a) reduction by 30% (b) increase by 50%
(c) reduction by 20% (d) no change
[ESE : 2002]

7.10 In a Newmark's chart for stress distribution, there are 10 concentric circles and 20 radial lines. The influence factor for the chart would be
(a) 0.1 (b) 0.05
(c) 0.01 (d) 0.005
[ESE : 2003]

7.11 A footing of 3 m × 3 m size transmits a load of 1800 kN. The angle of load dispersion in soil $\alpha = \tan^{-1} 0.5$. What is the stress created by the footing load at a depth of 5 m?
(a) 26.12 kN/m^2 (b) 27.12 kN/m^2
(c) 28.12 kN/m^2 (d) 29.12 kN/m^2
[ESE : 2004]

7.12 Match List-I (Situation) with List-II (Stress Path) and select the correct answer using the codes given below the lists:

List-I
A. Embankment construction
B. Excavation of a pit
C. Hydrostatic loading
D. Lateral expansion of a backfill

List-II
1. Stress path moves in left side upward direction
2. Stress path moves in left side downward direction
3. Stress path moves in right side upward direction
4. Stress path moves along the horizontal axis

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	3	2	4	1
(c)	2	3	4	1
(d)	2	3	1.	4

[ESE : 2004]

7.13 Stresses obtained from Boussinesq's theory are considered reasonably satisfactory in foundation engineering because
(a) they represent stress distribution in inhomogeneous soils below loaded area
(b) they account for anisotropy of soil property
(c) they give due regard to plastic behaviour of soils, particularly for settlement analysis
(d) they consider elastic soil medium, and the intensity of allowable stresses below foundations in most cases are quite small and justify elastic solutions
[ESE : 2005]

7.14 Westergaard's formula for vertical stress gives greater value of stress than that by the Boussinesq's formula, when r/z exceeds
(a) 1.5 (b) 2.5
(c) 3.5 (d) 4.0
[ESE : 2005]

7.15 A point load of 650 kN is applied on the surface of a thick layer of clay. Using Boussinesq's elastic analysis, what is approximate value of the estimated vertical stress at a depth 2 m and a radial distance of 1.0 m from the point of application of load?
(a) 55 kN/m^2 (b) 44 kN/m^2
(c) 41 kN/m^2 (d) 37 kN/m^2
[ESE : 2006]

7.16 A line load of infinite length has an intensity q per unit length. What is the vertical stress σ_z at a depth z below the earth at the centre of the load?
(a) $\sigma_z = \frac{2qz}{\pi}$ (b) $\sigma_z = \frac{2q}{\pi z}$
(c) $\sigma_z = \frac{2qz^2}{\pi}$ (d) $\sigma_z = \frac{2q}{\pi z^2}$
[ESE : 2008]

7.17 Consider the following statements:
1. Westergaard's theory of stress distribution is more appropriate for soil deposits which exhibit large lateral strain.
2. Newmark's influence chart can be used for the determination of vertical stress under any shape of a loaded area.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2010]

7.18 An isobar is a line which connects all points below the ground surface at which

(a) The local ground elevation is same
(b) The settlement is same
(c) The vertical stress is the same
(d) The ground elevation is varying

[ESE : 2012]

7.19 A concentrated load of 50 kN acts on the surface of ground. The increase in vertical stress directly below the load at a depth of 4 m will be (Value of influence factor is 0.48)

(a) 1.5 kN/m^2 (b) 15 kN/m^2
(c) 150 kN/m^2 (d) 0.15 kN/m^2

[ESE : 2013]

7.20 Consider the following statements:

1. The bulb of pressure under strip-footing forms in the lengthwise direction.
2. The bulb of pressure under a strip-footing forms in the width-wise direction.
3. Contact pressure at the edges of a rigid footing in a saturated clay is theoretically infinite.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 2 and 3 only
(c) 1 and 2 only (d) 1 and 3 only

[ESE : 2013]

7.21 Assertion (A): Boussinesq equation is not suitable for sedimentary deposits.

Reason (R): Sedimentary deposits do not represent an iso-tropic-cum-homogeneous system.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2015]

7.22 Which of the following statements are correct?

1. Stress Isobar can be prepared using Boussinesq's stress distribution theory.
2. Equivalent point load method yield accurate results.
3. Newmark's method relates the vertical stress with the help of influence chart.
4. Westergaard's method helps in determination of stress distribution for layered soils.

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 2, 3 and 4

[ESE : 2017]

7.23 Statement (I): The stresses and strains in a soil mass depend on the stress-deformation characteristics, anisotropy and non-homogeneity of the soil and also on the boundary conditions.

Statement (II): Boussinesq's theory of stress distribution in soils deals with layered soils only.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2017]

■■■■

Answers Stress Distribution in the Soil

7.1	(c)	7.2	(d)	7.3	(c)	7.4	(d)	7.5	(d)	7.6	(c)	7.7	(b)	7.8	(a)	7.9	(d)
7.10	(d)	7.11	(c)	7.12	(b)	7.13	(d)	7.14	(a)	7.15	(b)	7.16	(b)	7.17	(b)	7.18	(c)
7.19	(a)	7.20	(b)	7.21	(a)	7.22	(b)	7.23	(c)								

Explanations Stress Distribution in the Soil

7.1 (c)

Any sub area of Newmark's chart has same influence value. Therefore 1 and 2 will yield same pressure at the centre.

7.2 (d)

Vertical stress below point load,

$$\sigma_z = 0.4775\frac{Q}{z^2}$$

$$\therefore \quad \frac{\sigma_3}{\sigma_5} = \left(\frac{5}{3}\right)^2 = 2.77$$

7.3 (c)

In Newmark's chart each annular area will have same influence value. Therefore both area 1 and 2 will produce same intensity of pressure.

7.4 (d)

According to Boussinesq's theory,

$$\sigma_z = \frac{3Q}{2\pi z^2}\left[\frac{1}{1+(r/z)^2}\right]^{5/2} = K_B\frac{Q}{z^2}$$

7.5 (d)

For the vertical plane passing through the load, the vertical stress is

$$\sigma_z = 0.4775\frac{Q}{z^2}$$

z (unit length)	σ_z	% reduction
0.25	$7.64Q$	more than Q
0.5	$1.91Q$	more than Q
0.75	$0.84Q$	16% reduction
1.0	$0.4775Q$	52.25% reduction

7.6 (c)

Westergaard's equation is applicable for non-isotropic condition commonly encountered in sedimentary stratified deposits.

7.7 (b)

$$\text{Influence factor} = \frac{1}{10\times 50} = 0.002$$

7.8 (a)

Under the point load, the vertical stress is given by

$$\sigma_z = \frac{0.4775Q}{z^2}$$

(From Boussinesq's equation at $r/z = 0$)

$$\therefore \quad \sigma_{2z} = \frac{0.4775Q}{4z^2} = 0.25\sigma_z$$

The depth at which $\sigma_z = 0.1$ per unit area is

$z = \sqrt{4.775} = 2.185$ units under the load.

Thus isobar extends up to 2.185 units of depth under the load to dissipate 90% of stresses.

7.9 (d)

Vertical stress at a point due to a point load Q is

$$\therefore \quad \sigma_z = \frac{3Q}{2\pi z^2}\left[\frac{1}{\left(1+(x/z)^2\right)}\right]^{5/2}$$

It depends only on r/z and is independent of poisson's ratio. So, there wont be any change in vertical stress.

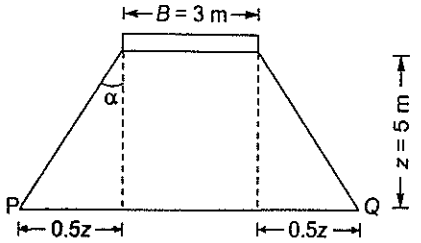
7.10 (d)

Influence factor

$$= \frac{1}{\text{No. of concentric circles} \times \text{No. of radial lines}}$$

$$= \frac{1}{10\times 20} = 0.005$$

7.11(c)



$$PQ = B + z = 3 + 5 = 8 \text{ m}$$

Stress at $z = 5$ m is $\sigma = \dfrac{1800}{8 \times 8}$

$= 28.125 \text{ kN/m}^2$

7.12(b)

In hydrostatic loading $\Delta\sigma_h = \Delta\sigma_v$. So stress path moves along a horizontal axis. Lateral expansion of backfill means $\Delta\sigma_h < 0$ and $\Delta\sigma_v = 0$ so stress path moves in left side upward direction. During embankment construction $\Delta\sigma_h = 0$ and $\Delta\sigma_v > 0$ so stress path moves in right side upward direction. During excavation of a pit $\Delta\sigma_h = 0$ and $\Delta\sigma_v < 0$ so stress path moves in left side downward direction.

7.13(d)

Boussinesq's theory is based on the following assumptions :

(i) The soil medium is elastic, homoge-neous, isotropic and semi infinite medium.
(ii) The medium obeys Hooke's law.
(iii) The self weight of the soil is ignored.
(iv) The soil is initially unstressed.
(v) The change in volume of the soil upon application of the loads on to it is neglected i.e., it is non-dilatant.
(vi) The top surface of the soil medium is free from shear stresses and is subjected to only point loads.
(vii) The stresses are distributed symme-trically with respect to vertical axis.

7.14(a)

The Boussinesq's equation gives vertical stress

$$\sigma_z = K_B \frac{Q}{z^2}$$

where $$K_B = \frac{3/2\pi}{\left[1+(r/z)^2\right]^{5/2}} \quad \text{...(i)}$$

For $\mu = 0$, the Westergaard's solution is

$$\sigma_z = K_W \frac{Q}{z^2}$$

$$K_w = \frac{1/\pi}{\left[1+2(r/z)^2\right]^{3/2}} \quad \text{...(ii)}$$

Equating (i) and (ii), we get,

$$r/z = 1.524$$

for $r/z < 1.524$; $K_W < K_B$

Westergaard's formula gives lesser value of vertical stress. For $r/z > 1.524$, $K_W > K_B$ i.e., Westergaard's formula gives greater value of stress.

7.15(b)

According to Boussinesq's theory,

$$\sigma_z = \frac{3Q}{2\pi z^2} \frac{1}{\left[1+(r/z)^2\right]^{5/2}}$$

$$= \frac{3 \times 650}{2\pi \times 2^2 \left[1+\left(\frac{1}{2}\right)^2\right]^{5/2}}$$

$= 44.4 \text{ kN/m}^2$

7.16 (b)

Vertical stress at a point P due to a line load of intensity q/unit length.

$$\therefore \quad \sigma_z = \frac{2q}{\pi z}\left[\frac{1}{\left(1+(x/z)^2\right)}\right]^2$$

where,
x = distance of point from centreline of load
z = depth of point below the centre of load

7.17(b)

Westergaard assumed an elastic soil to be laterally reinforced by numerous closely spaced, horizontal sheets of negligible thickness but of infinite rigidity that allow only vertical movement but prevent the mass as a whole from undergoing any lateral strain. Newmark has constructed a circular influence chart to compute the vertical stress at any point at a depth (z) under a circular footing, carrying a uniform load of intensity q. This chart incidentally can be used not only for circular areas but for all other types of footings like square, rectangular or any other shape.

7.18 (c)

An isobar or pressure bulb is a stress contour or a line which connects all points below the ground surface at which the vertical pressure is the same. In fact, an isobar is a spatial curved surface and resembles a bulb in shape; this is because the vertical pressure at all points in a horizontal plane at equal radial distances from the load is the same.

7.19 (a)

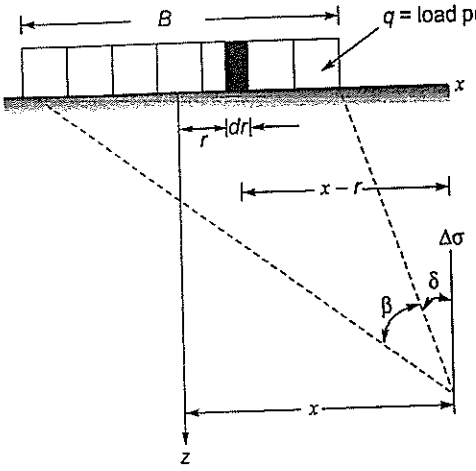
$$\sigma_z = \frac{Q}{Z^2}.I_B = \frac{Q}{Z^2}(0.48)$$

$$= \frac{50}{4^2}(0.48) = 1.5 \text{ kN/m}^2$$

7.20 (b)

At a given depth and for some distance from center line of footing, pressure remains constant along the length of strip footing, hence pressure bulb forms in the width wise direction and along the length.

According to theory of elasticity, contact pressure at the edges of a rigid footing on saturated clay assuming clay to be perfectly elastic and homogenous and extending to a great depth increases from a value less than 0.7 q at the center line to an infinite value at the edges.



$$\Delta\sigma = \frac{q}{\pi}\left[\beta + \sin\beta\cos(\beta + 2\delta)\right]$$

7.21 (a)

In Boussinesq's Equation, it is assumed that the soil must be elastic, isotropic and also a homogeneous mass extending infinitely on all sides from the level surface.

7.22 (b)

Equivalent point load method is in approximate method.

7.23 (c)

Boussinesq's assumed soil as isotropic medium and layered soils is a non-isotropic medium hence Boussinesq's is not valid for layered soil.

8 Shear Strength of Soil

8.1 In an unconfined compression test on a saturated clay, the undrained shear strength was found to be 6 t/m^2. If a sample of the same soil is tested in an undrained condition in triaxial compression at a cell pressure of 20 t/m^2, then the major principal stress at failure will be

(a) 48 t/m^2 (b) 32 t/m^2

(c) 24 t/m^2 (d) 12 t/m^2

[ESE : 1995]

8.2 A laboratory vane shear test apparatus is used to determine the shear strength of a clay sample and only one end of the vane takes part in shearing the soil. If T = applied torque, H = height of vane and D = diameter of the vane, then shear strength of the clay is given by

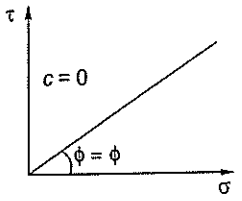
(a) $\dfrac{T}{\pi D^2\left(H+\dfrac{D}{6}\right)}$ (b) $\dfrac{T}{\pi D^2\left(\dfrac{H}{2}+\dfrac{D}{12}\right)}$

(c) $\dfrac{T}{\pi D^2\left(H+\dfrac{D}{10}\right)}$ (d) $\dfrac{T}{\pi D^2\left(H+\dfrac{D}{12}\right)}$

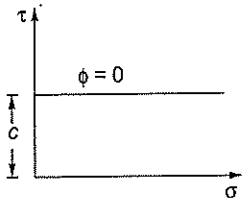
[ESE : 1995]

8.3 Which one of the following figure gives the failure envelope for a normally consolidated saturated clay sample tested in triaxial test under drained conditions?

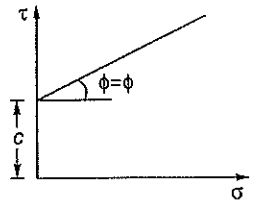
(a)



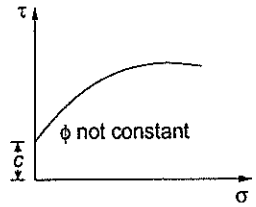
(b)



(c)



(d)



[ESE : 1996]

8.4 Match List-I (Type of shear tests) with List-II (Mohr circle and its envelope) and select the correct answer using the codes given below the lists:

List-I

A. Undrained test on normally consolidated saturated clays

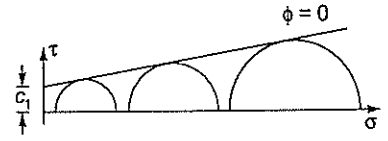
B. Consolidated undrained test on normally consolidated saturated clays

C. Drained tests on saturated cohesive soil

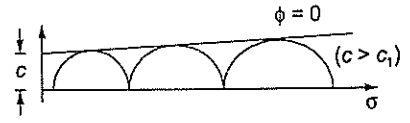
D. Unconfined test on clays

List-II

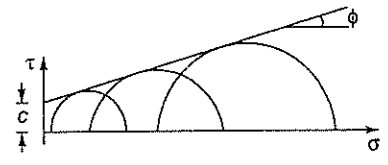
1.



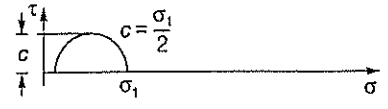
2.



3.



4.



Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	1	2	3	4
(c)	4	3	2	1
(d)	3	2	1	4

[ESE : 1996]

8.5 A soil fails under an axial vertical stress of 100 kN/m^2 in unconfined compression test. The failure plane makes an angle of 50° with the horizontal. The shear parameters 'c' and 'ϕ' respectively will be

(a) 41.9 kN/m^2, 0° (b) 50.0 kN/m^2, 0°
(c) 41.9 kN/m^2, 10° (d) 50.0 kN/m^2, 10°

[ESE : 1996]

8.6 A and B are Skempton's pore pressure coefficients. For saturated normally consolidated soils,

(a) $A > 1$ and $B > 1$ (b) $A > 1$ and $B < 1$
(c) $A < 1$ and $B > 1$ (d) $A < 1$ and $B = 1$

[ESE : 1997]

8.7 A clay soil specimen when tested in unconfined condition gave an unconfined compressive strength of 100 kN/m^2. A specimen of the same clay with the same initial condition is subjected to a UU triaxial test under a cell pressure of 100 kN/m^2. Axial stress (in kN/m^2) at failure would be

(a) 150 (b) 200
(c) 250 (d) 300

[ESE : 1997]

8.8 If 's' is the shear strength, 'c' and ϕ are shear strength parameters, and 'σ_n' is the normal stress at failure, then Coulomb's equation for shear strength of the soil can be represented by

(a) $c = s + \sigma_n \tan\phi$ (b) $c = s - \sigma_n \tan\phi$
(c) $s = \sigma_n + c \tan\phi$ (d) $s = c - \sigma_n \tan\phi$

[ESE : 1997]

8.9 A dry sand specimen is put through a triaxial test. The cell pressure is 50 kPa and the deviator stress at failure is 100 kPa, the angle of internal friction for the sand specimen is

(a) 15° (b) 30°
(c) 37° (d) 45°

[ESE : 1997]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

8.10 **Assertion (A):** In box shear test, the failure plane is predetermined and is horizontal.

Reason (R): The shear stress is applied in the vertical direction.

[ESE : 1997]

8.11 **Assertion (A):** In the case of unconfined compression test, Mohr's circle passes through the origin.

Reason (R): The major principal stress is zero.

[ESE : 1997]

8.12 Shear failure of soils takes place when

(a) the angle of obliquity is maximum
(b) maximum cohesion is reached in cohesive soils
(c) ϕ reaches its maximum value in cohesionless soils
(d) residual strength of the soil is exhausted

[ESE : 1998]

8.13 A triaxial test was conducted on a granular soil. At failure $\frac{\sigma_1}{\sigma_3} = 4$. The effective minor principal stress at failure was 100 kPa. The values of approximate ϕ and the principal stress difference at failure are, respectively

(a) 45° and 570 kPa (b) 40° and 400 kPa
(c) 37° and 300 kPa (d) 30° and 200 kPa

[ESE : 1998]

8.14 In a Mohr's diagram, a point above Mohr's envelope indicates

(a) imaginary condition
(b) safe condition
(c) imminent failure condition
(d) condition of maximum obliquity

[ESE : 1998]

8.15 Which one of the following is the reason for the likelihood of erroneous results of a Direct Shear Test on a saturated clay sample?
(a) The test amounts to undrained test
(b) Failure plane is predetermined
(c) Progressive failure might take place
(d) Drainage conditions are not controllable
[ESE : 1998]

8.16 Which one of the following tests CANNOT be done without undisturbed sampling?
(a) Shear strength of sand
(b) Shear strength of clay
(c) Determination of compaction parameters
(d) Atterberg limits
[ESE : 1998]

8.17 Match List-I (Field problems) with List-II (Type of laboratory shear test) and select the correct answer using the codes given below the lists:

List-I
A. Stability of a clay foundation of an embankment, whose rate of construction is such that some consolidation occurs
B. Initial stability of a footing on saturated clay
C. Long-term stability of a slope in stiff, fissured clay
D. Foundation on soft marine clay deposits.

List-II
1. Undrained triaxial test
2. Drained triaxial test
3. Consolidated undrained test
4. Quick vane shear test

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	1	3	2	4
(c)	3	1	2	4
(d)	3	1	4	2

[ESE : 1999]

8.18 In a direct shear test, the shear stress and normal stress on a dry sand sample at failure are 0.6 kg/cm^2 and 1 kg/cm^2 respectively. The angle of internal friction of the sand will be nearly
(a) 25° (b) 31°
(c) 37° (d) 43°
[ESE : 1999]

8.19 Match List-I (Investigator) with List-II (Equation) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Skempton	1. $v = ki$
B. Coulomb	2. $\sigma' = \sigma - u$
C. Stokes	3. $v = \frac{D^2(\gamma_s - \gamma_w)}{18\eta}$
D. Terzaghi	4. $s = c + \sigma \tan\phi$
	5. $u = B[\sigma_3 + A(\sigma_1 - \sigma_3)]$

Codes:

	A	B	C	D
(a)	4	5	3	2
(b)	5	4	3	2
(c)	4	5	1	3
(d)	5	4	2	3

[ESE : 1999]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

8.20 **Assertion (A):** Shear parameters 'c' and ϕ vary with drainage conditions of shear test.
Reason (R): Shear parameter 'c' and ϕ are dependent on water content of soil.
[ESE : 1999]

8.21 **Assertion (A):** Stress paths can be plotted for stress conditions during triaxial test.
Reason (R): It is not possible to control drainage in a triaxial test.
[ESE : 2000]

8.22 Consider the following features of direct shear test:
1. Failure takes place on the predetermined plane.
2. It is a quick test.
3. Drainage conditions cannot be changed.
4. Failure of the sample is progressive.

Which of these are the disadvantages of direct shear test?

(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 3 and 4

[ESE : 2000]

8.23 Which one of the following soil types is most likely to be subjected to liquefaction under seismic forces?

(a) Soft saturated clays
(b) Loose saturated sands
(c) Murum
(d) Fractured rocky strata

[ESE : 2000]

8.24 A soil sample tested in a triaxial compression apparatus failed when the total maximum and minimum principal stresses were100 kPa and 40 kPa, respectively. The pore pressure measured at failure was 10 kPa. The effective principal stress ratio at failure is

(a) 2.5 (b) 3.0
(c) 2.75 (d) 2.0

[ESE : 2001]

8.25 In a triaxial test at failure, major principal stress was 180 kPa, minor principal stress was 100 kPa, and pore pressure was 20 kPa. The tangent of the angle of shearing resistance of the sandy soil tested is

(a) 1/3 (b) 2/7
(c) 1/2 (d) 1/6

[ESE : 2002]

8.26 Laboratory vane shear test can also be used to determine

(a) shear parameters of silty sand
(b) shear parameters of sandy clay
(c) liquid limit of silty clay
(d) plastic limit of clayey silt

[ESE : 2002]

8.27 A wooden bridge in Assam failed and was observed to have arched up in the middle after the earthquake. The right abutment settled 40 cm and left abutment 30 cm. The bridge was supported on wooden piles, which floated up during the earthquake. The most probable cause of failure is

(a) shear failure of soil below abutments.
(b) excessive settlement below abutments due to increased forces.
(c) liquefaction of foundation soil below abutments and piles.
(d) failure of abutments due to dynamic earth pressure behind abutments.

[ESE : 2002]

8.28 **Assertion (A):** The ultimate strength of soil material is determined by the stresses in the potential failure plane.

Reason (R): The critical shear stress causing failure depends upon the properties of soil as well as on the normal stress in the failure plane.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

8.29 A *CD* triaxial test was conducted on a granular soil. At failure $\frac{\sigma_1'}{\sigma_3'}$ was 3.0. The effective minor principal stress of failure was 75 kPa. The principal stress difference at failure will be

(a) 75 kPa (b) 150 kPa
(c) 225 kPa (d) 300 kPa

[ESE : 2003]

8.30 On which of the following factors does the behaviour of sand mass to cause liquefaction during an earthquake depend largely?

1. The number of stress cycles
2. The frequency and amplitude of vibrations of the earthquake shock
3. Angle of internal friction of sand
4. Relative density of sand

Select the correct answer using the codes given below:

(a) 1, 2, 3 and 4 (b) 2, 3 and 4
(c) 1 and 3 (d) 4 only

[ESE : 2003]

8.31 Consider the following statements:

1. All soils can experience liquefaction under vibrations.

2. Liquefaction is generally associated with sandy soils.
3. Liquefaction is not possible in normal clays.
4. Highly sensitive clays may undergo liquefaction under vibrations.

Which of these statements are correct?

(a) 1 and 3 (b) 2 and 4
(c) 2 and 3 (d) 2, 3 and 4

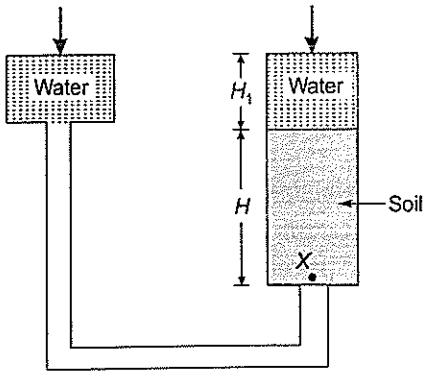
[ESE : 2003]

8.32 A shear test was conducted on a soil sample. At failure the ratio of $\frac{\sigma_1-\sigma_3}{2}$ to $\frac{\sigma_1+\sigma_3}{2}$ is equal to unity. Which one of the following shear tests represents this condition?

(a) Drained triaxial compression test
(b) Undrained triaxial compression test
(c) Undrained triaxial compression test
(d) Unconfined compression test

[ESE : 2004]

8.33 Which one of the following expressions represents the shear strength of soil at point *X*? Angle of shear resistance of soil is ϕ and symbols γ_w, γ_{sat}, γ_{sub}, γ_{dry} stand for unit weights of water, saturated soil, submerged soil and dry soil respectively.



(a) $\gamma_{dry} H \tan\phi$
(b) $[\gamma_{sat} H-(H+H_1)\gamma_w]\tan\phi$
(c) $\gamma_{sub} H \tan\phi$
(d) $(\gamma_{dry} H-H_1\gamma_w)\tan\phi$

[ESE : 2004]

8.34 Which one of the following is the appropriate triaxial test to assess the immediate stability of an unloading problem, such as an excavation of a clay slope?

(a) UU test
(b) CU test
(c) CD test
(d) Unconsolidated drained tests

[ESE : 2005]

8.35 Well-graded dense saturated sands have high shear strength because

(a) such sands have a better grade (superior type) of sand grains resulting in higher strength
(b) such sands have lower water content, which increases shear strength
(c) such sands have better interlocking of grains, higher inter-particle contacts and higher inter-particle frictional resistance resulting in higher strength
(d) presence of water in such sands induces capillary pressure generating higher inter granular stresses, which generate apparent cohesion and hence higher shear strength

[ESE : 2005]

8.36 A footing is resting on a fully saturated clayey strata. For checking the initial stability, shear parameters are used from which one of the following?

(a) Consolidated non-drained test
(b) Unconsolidated drained test
(c) Unconsolidated non-drained test
(d) Unconsolidated non-drained test with pore pressure measurement

[ESE : 2005]

8.37 In a shear test on cohesionless soils, if the initial void ratio is less than critical void ratio, the sample will

(a) increase in volume
(b) initially increase in volume and then remain constant
(c) decrease in volume
(d) initially decrease and then increase in volume

[ESE : 2005]

8.38 As the state of strain of an element of dense sand changes from plain strain to trivial strain condition, the effective angle of internal friction

(a) increases
(b) decreases
(c) remains constant
(d) first increases and then remains constant

[ESE : 2005]

8.39 Which one of the following factors are associated with the behaviour of sand mass during earthquake to cause liquefaction?
1. Number of stress cycles
2. The frequency and amplitude of vibration of waves generated by an earthquake.
3. Characteristics of sand
4. Relative density

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1, 2, 3 and 4
(c) 2 and 4 (d) 3 and 4
[ESE : 2005]

8.40 Which one of the following different types of submerged soils is susceptible to liquefaction under earthquake shocks?
(a) Dense sand (b) Soft clay
(c) Loose silt (d) Fissured clay
[ESE : 2005]

8.41 Consider the following statements:
1. A sand with its void ratio higher than its critical void ratio increases in volume when sheared.
2. A sand with its void ratio less than its critical void ratio increases in volume when sheared.
3. For a sand at critical void ratio, the volume change during shear is minimum.

Which of these statements are correct?
(a) 1, 2 and 3 (b) Only 1 and 2
(c) Only 2 and 3 (d) Only 1 and 3
[ESE : 2006]

8.42 Consider the following statements about the shearing resistance as a function of effective stress:
1. Effective stress on the failure plane governs the shearing resistance and not the total stress.
2. Two soils equally dense, consolidated to same effective stress will show different shear resistance with drainage and undrained condition.
3. The post peak drop off in shearing resistance is less pronounced in over consolidated clays and more in normally consolidated clays at same effective stress.

Which of these statements are correct?
(a) 1, 2 and 3 (b) Only 1 and 3
(c) Only 1 and 2 (d) Only 2 and 3
[ESE : 2006]

8.43 Consider the following statements:
1. Stress path is a locus of stress points developed by stress changes in the soil and can be obtained from Mohr's Stress Circle.
2. Stress path can be used to determine the intensity of stress at a point due to the application of uniformly applied circular loaded area.
3. Stress path has a value in giving insight into probable soil response-particularly if a part of the previous history stress path can be reproduced.

Which of these statements are correct?
(a) 1, 2 and 3 (b) Only 1 and 2
(c) Only 2 and 3 (d) Only 1 and 3
[ESE : 2006]

8.44 What does the confining pressure used in triaxial compression tests on an undisturbed soil sample represent?
(a) The in-situ total normal stress
(b) The in-situ total lateral stress
(c) The in-situ effective principal stress
(d) The in-situ shear stress
[ESE : 2007]

8.45 Consider the following statements:
Liquefaction is a phenomenon
1. observed in fine sands
2. associated with development of positive pore pressure

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2007]

8.46 Assertion (A): Shear strength parameters of sand can be estimated by conducting unconfined compression test.
Reason (R): The effective angle of shearing resistance of sand is nearly the same for dry and saturated sands, in drained condition.
(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2007]

8.47 Consider the following statements:
1. Pore pressure parameter A is a constant for a soil.
2. The shear strength of soil is a function of the effective stress in the soil and not of the total stress in the soil.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2008]

8.48 Which one of the following conditions is valid in case of unconfined compression test in comparison to triaxial test?
(a) Minor principal stress = 0
(b) Minor principal stress = 0.5 × major principal stress
(c) Minor principal stress = major principal stress
(d) Major principal stress = 3 × minor principal stress

[ESE : 2009]

8.49 In an unconfined compression test on stiff clay, if the failure plane made an angle of 52° to the horizontal, what would be the angle of shearing resistance?
(a) 16° (b) 14°
(c) 12° (d) 13°

[ESE : 2009]

8.50 Considerable loss of shear strength due to shock or disturbance is exhibited by
(a) under-consolidated clays
(b) normally consolidated clays
(c) over-consolidated clays
(d) organic soil

[ESE : 2010]

8.51 Consider the following statements:
1. Sensitivity of a natural soil deposit cannot be less than 1.0.
2. A saturated loose sand deposit liquefies when water flows through it in upward direction under critical hydraulic gradient.
3. A quick clay has very high sensitivity.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2010]

8.52 Liquefaction of foundation soil during an earthquake shall not be the reason for cracking of
(a) only floors in the building
(b) walls and roof in the building
(c) beams and columns in the building
(d) only balcony in the building

[ESE : 2010]

8.53 Consider the following statements:
Apparent cohesion in sands is exhibited mainly due to
1. reduction in density.
2. increase in density.
3. capillary moisture in pores.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 3 only
(c) 2 and 3 only (d) 2 only

[ESE : 2010]

8.54 Unconfined compression test is most suitable for determining the
1. Sensitivity of clays
2. Settlement of embankments
3. 'Strength' of partially saturated clay sample
4. 'Strength' of fully saturated clay sample

(a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 3 and 4 only (d) 1 and 4 only

[ESE : 2011]

8.55 Consider the following statements:
1. For a saturated soil, Skempton's B-parameter is nearly equal to unity.
2. For an undisturbed sensitive clay, the stress-strain curve shows a peak.
3. Interlocking contributes significantly to the shearing strength in case of dense sand.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

8.56 For the determination of shear strength parameters, c and ϕ, of soil in the laboratory, the test to be conducted will be

(a) Triaxial compression test
(b) Sieve analysis
(c) Compaction test
(d) Relative density test

[ESE : 2012]

8.57 Consider the following statements:
For pure clay, the shear strength parameters will be
1. Cohesion $c = 0$; and angle of internal friction ϕ will be maximum.
2. Cohesion c is maximum; and angle of internal friction ϕ is also maximum.
3. Angle of internal friction ϕ is zero, with some value of cohesion c.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 only
(c) 3 only (d) 2 only

[ESE : 2012]

8.58 Statement-I : A curved, or straight, line connecting the relevant stress points is called the stress path.
Statement-II : All the total stress paths and the effective stress paths for the drained tests are straight lines at a slope of 45°.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2012]

8.59 Consider the following statements:
1. Brittle behaviour of soils can be obtained when the soil is heavily over-consolidated clay.
2. Remoulded cohesive clays show a tendency towards progressive failure.
3. Undisturbed sensitive clays show a tendency towards progressive failure.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 3 only
(c) 1 and 2 only (d) 2 and 3 only

[ESE : 2013]

8.60 Consider the following statements:
1. The water content of a soil remains unchanged during the entire duration of a 'quick' test.
2. Effective stress cum shear parameters of clay can be obtained from drained triaxial shear test.
3. Strain-controlled shear test is a good option since this test procedure maintains better control on the rate of loading than other tests.

Which of the above statements is/are correct?
(a) 1, 2 and 3 (b) 1 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2014]

8.61 In a triaxial compression test, the major principal stress was 90 kPa and the minor principal stress was 30 kPa, at failure. The pore pressure at failure was observed to be 10 kPa. The tangent of the angle of shearing resistance of the sandy soil that was tested was
(a) 1/2 (b) 1/3
(c) 2/3 (d) 3/4

[ESE : 2015]

8.62 A cylindrical soil specimen of saturated clay, 3.50 cm diameter and 8 cm length, is tested in an unconfined compression testing machine. The specimen failed under a vertical load of 50 kg together with an accompanying additional deformation of 8 mm. What is the unconfined compressive strength of this clay?
(a) 4.67 kg/cm^2 (b) 5.0 kg/cm^2
(c) 5.5 kg/cm^2 (d) 6.0 kg/cm^2

[ESE : 2015]

8.63 An undrained triaxial compression test is carried out on a saturated clay sample under a cell pressure of 50 kN/m^2. The sample failed at a deviator stress of 100 kN/m^2. The cohesion of this clay sample would be
(a) 25 kN/m^2 (b) 50 kN/m^2
(c) 75 kN/m^2 (d) 100 kN/m^2

[ESE : 2017]

8.64 Statement (I): Cohesion and angle of internal friction are shear strength parameters of soils.
Statement (II): Cohesion is zero for pure sand and angle of internal friction is zero for pure clay.

[ESE : 2017]

Answers Shear Strength of Soil

8.1 (b)	8.2 (b)	8.3 (a)	8.4 (b)	8.5 (c)	8.6 (d)	8.7 (b)	8.8 (b)	8.9 (b)		
8.10 (c)	8.11 (c)	8.12 (a)	8.13 (c)	8.14 (a)	8.15 (b)	8.16 (b)	8.17 (c)	8.18 (b)		
8.19 (b)	8.20 (b)	8.21 (c)	8.22 (b)	8.23 (b)	8.24 (b)	8.25 (a)	8.26 (c)	8.27 (c)		
8.28 (a)	8.29 (b)	8.30 (a)	8.31 (d)	8.32 (d)	8.33 (c)	8.34 (a)	8.35 (c)	8.36 (d)		
8.37 (d)	8.38 (a)	8.39 (b)	8.40 (c)	8.41 (c)	8.42 (c)	8.43 (d)	8.44 (b)	8.45 (c)		
8.46 (d)	8.47 (b)	8.48 (a)	8.49 (b)	8.50 (a)	8.51 (d)	8.52 (d)	8.53 (b)	8.54 (d)		
8.55 (a)	8.56 (a)	8.57 (c)	8.58 (c)	8.59 (c)	8.60 (a)	8.61 (d)	8.62 (a)	8.63 (b)		
8.64 (b)										

Explanations Shear Strength of Soil

8.1 (b)

Major principal stress in undrained test
= cell pressure + undrained shear strength × 2
= 20 + 6 × 2 = 32 t/m^2

8.2 (b)

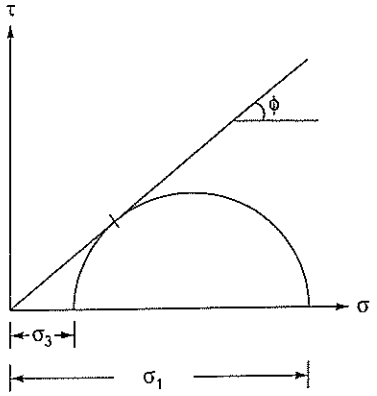
For vane shear test with one end in shearing,

$$\tau = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{12}\right)}$$

When both ends take part in shearing,

$$\tau = \frac{T}{\pi D^2\left(\frac{H}{2}+\frac{D}{6}\right)}$$

8.3 (a)



For drained condition, ϕ will be mobilized, for normally consolidated clay failure envelope passes through origin so $C = 0$.

8.4 (b)

UU (unconsolidated undrained) test: In this, cell pressure is applied without allowing drainage. Then keeping cell pressure constant, deviator stress is increased to failure without drainage.

CU (consolidated undrained) test: In this, drainage is allowed during cell pressure application. Then without allowing further drainage, deviator stress is increased keeping cell pressure constant.

CD (consolidated drained) test: This is similar to CU test except that as deviator stress is increased, drainage is permitted. The rate of loading must be slow enough to ensure no excess pore water pressure develops.

8.5 (c)

The angle of failure from horizontal,

$$\alpha = 45° + \frac{\phi}{2}$$

$$\Rightarrow \quad \phi = (50° - 45°) \times 2$$

$$\Rightarrow \quad \phi = 10°$$

In this case $\sigma_1 = 100$ kN/m^2 and $\sigma_3 = 0$

But $$\sigma_1 = 2c \tan\left(45 + \frac{\phi}{2}\right)$$

$$\Rightarrow \quad c = \frac{100}{2\tan 50°} = 41.9 \text{ kN/m}^2$$

8.6 (d)

For saturated normally consolidated soil

$$B = 1,\ A < 1.$$

For heavily over-consolidated soil A can be less than zero. For saturated fine sand in loose condition A may be as high as 2 to 3.

8.7 (b)

Unconfined compressive strength

$$q_u = 100\ \text{kN/m}^2$$

For UU test,

$$\sigma_1 - \sigma_3 = q_u$$

$$\therefore \quad \sigma_1 = 100 + 100 = 200\ \text{kN/m}^2$$

8.8 (b)

$$s = c + \sigma_n \tan\phi \quad \text{[Coulomb's equation]}$$

$$\therefore \quad c = s - \sigma_n \tan\phi$$

8.9 (b)

For sand cohesion, $c = 0$

$$\sigma_1 = \sigma_3 N\phi$$

$$N\phi = \tan^2\left(45 + \frac{\phi}{2}\right)$$

$$\sigma_1 = 100 + 50 = 150\ \text{kPa}$$

$$\sigma_3 = 50\ \text{kPa}$$

Now $150 = 50 N\phi$

$$\Rightarrow \quad N\phi = 3$$

$$\Rightarrow \quad \tan\left(45 + \frac{\phi}{2}\right) = \sqrt{3}$$

$$\Rightarrow \quad 45 + \frac{\phi}{2} = 60°$$

$$\Rightarrow \quad \phi = 30°$$

8.10 (c)

Normal stress is in vertical direction and shear stress is applied in horizontal direction.

8.11 (c)

In unconfined compression test minor principal stress $\sigma_3 = 0$.

8.12 (a)

When the Mohr's circle touches the failure envelope, the soil fails by shearing. This failure may occur at one point only along the failure plane or at all the points on failure plane. It means that shear strength may or may not be fully mobilized. So the maximum angle of obliquity is correct answer.

8.13 (c)

$$\sigma'_{3f} = 100\ \text{kPa}$$

$$\therefore \quad \sigma'_{1f} = 4\sigma'_{3f} = 400\ \text{kPa}$$

Principal stress difference

$$= \sigma'_{1f} - \sigma'_{3f} = 300\ \text{kPa}$$

and $$\sin\phi = \frac{\sigma'_{1f} - \sigma'_{3f}}{\sigma'_{1f} + \sigma'_{3f}} = \frac{300}{500} = 0.6$$

$$\phi = 36.86° \simeq 37°$$

8.14 (a)

Point above Mohr's Envelope indicates that shear stress is more than shear strength of soil which is an imaginary condition.

8.15 (b)

In the case of saturated clay sample, the quick test condition of box shear test will not allow drainage so $\phi = 0$. It means that the weakest plane will lie at an angle 45° from the horizontal plane. However in this case failure plane is pre-determined which is not the weakest plane.

8.16 (b)

- Clay is more sensitive on remoulding and strength changes drastically. Thus for calculating the shear strength of clay, undisturbed sample is required.
- Compaction parameters, i.e, optimum moisture content and dry density are calculated on disturbed sample.
- Shear strength of soil is not affected by remoulding.
- For atterberg limit, we take the soil sample and mix with water so the sample is disturbed.

8.17 (c)

For initial stability → Undrained Test

Long term Stability → Drained Test

For Soft Marine Clay → Vane Shear Test

8.18 (b)

$$\tau = \sigma \tan\phi;\ \tan\phi = \frac{0.6}{1} = 0.6$$

$$\tan 30° = \frac{1}{\sqrt{3}} = 0.577$$

as $\tan\phi > \tan 30°$

$$\therefore \quad \phi > 30°;\quad \phi = 31°$$

8.19(b)

Terzaghi gave effective stress principle. Effective stress,

$$\sigma' = \sigma - u$$

where σ is total stress and u is pore pressure.

8.20(b)

The shear parameters c and ϕ are empirical. They depend upon the effective stress in soil and vary with drainage conditions of the test. The pore pressure in the soil specimen depends upon degree of saturation during first stage of the test. Thus water content also affects the parameters c and ϕ. However drainage conditions and water content are two independent factors affecting shear parameters.

8.21 (c)

The triaxial compression test consists of two stages:

- *First stage:* In this, a soil sample is set in the triaxial cell and confining pressure is then applied.
- *Second stage:* In this, additional axial stress (also called deviator stress) is applied which induces shear stresses in the sample. The axial stress is continuously increased until the sample fails.

During both the stages, the applied stresses, axial strain, and pore water pressure or change in sample volume can be measured. Drainage can be very much controlled in Triaxial Test.

8.22 (b)

The most important limitation of direct shear test is that the failure plane is predetermined and this may not be the weakest plane.

There is virtually no control of drainage of soil specimen as the water content of saturated soil changes rapidly with stress.

The stress conditions across the soil sample are very complex because of nonuniform distribution of normal and shear stress on the potential surface of sliding. The stress is more at edge and less at centre. Due to this there is progressive failure of the specimen i.e., the entire strength of soil is not mobilised simultaneously.

8.23 (b)

Soil liquefaction describes a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition, causing it to behave like a liquid. It is more likely to occur in sandy or non-plastic silty soils.

8.24(b)

Effective principal stress ratio

$$= \frac{\sigma_1 - u}{\sigma_3 - u} = \frac{100-10}{40-10} = 3.0$$

8.25 (a)

Major principal stress:

$\bar{\sigma}_1 = \sigma_1 - u = 180 - 20 = 160$ kPa

Minor principal stress:

$\bar{\sigma}_3 = \sigma_3 - u = 100 - 20 = 80$ kPa

For sand,

$c = 0$

$$\sigma_1 = \sigma_3 \tan^2\left(45° + \frac{\phi}{2}\right)$$

Thus on solving $\phi = 19.47°$

And $\tan\phi = 0.353$

So, nearest option is (a)

8.26(c)

Vane shear test is used to determine the cohesion or shear strength of sensitive soft clays because their cylindrical specimen cannot be easily prepared. It is necessary that the soil mass should be saturated completely because the angle of shearing resistance will not be zero for partially saturated soils. This method should be used when:

(i) Clay is deep, normally consolidated and sensitive

(ii) Only the undrained shear is required.

The test cannot be conducted on the fissured clay or the clay containing sand or silt laminations.

It can be also be used for determination of liquid limit of soils because the shear strength at liquid limit is about 2.7 kN/m^2.

8.27(c)

The differential settlement of abutments and subsequent rotation results in arching up of the

bridge. It is given that wooden piles floated up during the earthquake. So liquefaction is the main cause of settlement and failure.

8.28(a)

$$\tau = c + \sigma \tan \phi$$

where σ is the normal stress on the failure plane.

8.29(b)

$$\sigma_3' = 75 \text{ kPa}; \sigma_1' = 3\sigma_3'$$

Principal stress difference

$$= \sigma_1' - \sigma_3' = 2\sigma_3' = 2 \times 75$$
$$= 150 \text{ kPa}$$

8.30(a)

Although all the factors are responsible for liquefaction of soils. However, relative density is the most important factor as liquefaction can occur in loose sandy soils.

8.31(d)

Cohesive soils generally do not show liquefaction due to cohesion between particles. However highly sensitive clays when subjected to vibration may change their structure and start flowing like a liquid.

8.32(d)

When ratio of $\frac{\sigma_1 - \sigma_3}{2}$ to $\frac{\sigma_1 + \sigma_3}{2}$ is equal to unity

$$\frac{\sigma_1 - \sigma_3}{2} = \frac{\sigma_1 + \sigma_3}{2}$$

$\sigma_3 = 0$ (Confining pressure zero)

This case is represented by unconfined compression test.

8.33(c)

As the free water surface on both sides is same so there is no flow occurring through soil. Thus effective stress at X,

$\sigma' = \gamma_w H_1 + \gamma_{sat} H - \gamma_w (H + H_1) = \gamma_{sub} H$

$\therefore$ Shear strength,

$$\tau = \sigma' \tan\phi = \gamma_{sub} H \tan\phi$$

8.34(a)

For problems of short term-stability of foundations; excavations and earth dams UU (Unconsolidated Undrained) tests are appropriate. For problems of long-term stability either UU test or CD test is appropriate, depending upon the drainage conditions of soil.

8.35 (c)

Well grade sands have higher shearing resistance as they have high inter-particle contacts. Dense sands have better interlocking of particles. Saturated sands have higher frictional resistance. Also, loose, saturated, uniformly graded fine grain sands are very susceptible to liquefaction.

8.36 (d)

UU (unconsolidated undrained) test: In this, cell pressure is applied without allowing drainage. Then keeping cell pressure constant, deviator stress is increased to failure without drainage.

CU (consolidated undrained) test: In this, drainage is allowed during cell pressure application. Then without allowing further drainage, deviator stress is increased keeping cell pressure constant.

CD (consolidated drained) test: This is similar to CU test except that as deviator stress is increased, drainage is permitted. The rate of loading must be slow enough to ensure no excess pore water pressure develops.

8.37(d)

If initial void ratio is less than critical void ratio then the sample is dense sand. So in this case the volume will decrease initially to get fully compacted and then to achieve critical void ratio the volume will increase.

If initial void ratio is more than critical void ratio then the sample is loose sand. In this case volume initially decreases and then remains constant.

8.38(a)

Trivial strain condition means zero strain in all directions. This condition gives higher angle of internal friction compared to plane strain condition.

8.39(b)

The phenomenon when the sand loses its shear strength due to oscillatory motion is known as liquefaction. The structures resting on such soils sink. The soils most susceptible to liquefaction are the saturated, fine and medium sands of uniform particle size. When such a deposit has void ratio greater than the critical void ratio i.e. loose sand is subjected to sudden shearing stresses, the volume decreases and pore pressure

increases. The effective stresses in soil decrease and sand behaves as a dense liquid. If the deposits are compacted to a void ratio. Smaller than the critical void ratio, the chances of liquefaction reduces.

The liquefaction can occur due to explosion, heavy vibration of waves generated by an earthquake and number of stress cycles.

8.40 (c)

In loose silt, under earthquake shocks the volume decreases and positive pore water pressure is generated due to which effective stress decreases. When effective stress becomes zero, soil looses all of its shear strength and this phenomenon is called liquefaction.

8.41 (c)

Loose sands have initial void ratio more than critical void ratio. When this sand is sheared the final void ratio reaches critical void ratio i.e., the void ratio decreases and therefore volume of soil also decreases.

Dense sands have initial void ratio less than critical void ratio when this sand is sheared, the void ratio decreases first to achieve 100% relative density (minimum void ratio) and then volume increases to achieve critical void ratio. The sand at critical void ratio have minimum change in volume during shearing. The critical void ratio at ultimate or critical state is a function of either effective all round pressure or normal stress.

8.42 (c)

The effective stress principle given by Terzaghi states that:

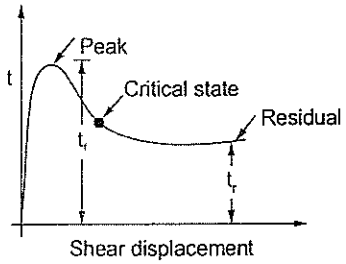
(a) The effective stress is equal to total stress minus pore pressure

(b) The effective stress controls certain aspects of soil behaviour, notably compressibility and shear strength.

Thus according to Terzaghi, it is the effective stress on the failure plane that governs the shearing strength and not the total stress.

Further undrained conditions reduce the effective stress due to development of pore pressure. Thus two soils equally dense consolidated to same effective stress in the confining pressure stage and sheared under drained and undrained conditions will show different shear resistance.

Over consolidated clays behave similar to dense sands and they show pronounced peak during shearing. Normally consolidated clays show less pronounced peak or no peak during shearing. Both the soils finally show same strength at large value of strain due to rolling and translation of bulky particles. This final strength is called residual strength and can be determined by ring shear apparatus.



(Ring shear test)

8.43 (d)

The successive states of stress in a test specimen or an in-situ element of soil can be represented by a series of Mohr's circles or in a less confusing way, by series of stress points (p, q).

$$p = \frac{\sigma_1 + \sigma_3}{2} \text{ and}$$

$$q = \frac{\sigma_1 - \sigma_3}{2}$$

The curve or straight line connecting the relevant stress points is called the stress path, giving a clear representation of states of stress. The horizontal distance between effective and total stress path is the value of pore pressure at any particular state. In general the horizontal distance between the two stress paths is the sum of the pore water pressure due to change in total stress and the static pore water pressure.

8.44 (b)

The triaxial cell contains soil sample which is subjected to an all round pressure. This is called the cell pressure or confining pressure. It acts radially on the vertical surface of the specimen and axially at the top and bottom.

8.45 (c)

Due to development of excessive pore water pressure, the effective stress of soil becomes

zero and it tends to behave like liquid and loses its shear strength.

8.46(d)

Unconfined compression test is a special case of triaxial test carried out at zero cell pressure. This test is applicable only to soils for which $\phi_u = 0$ i.e. fully saturated, non-fissured clays.

8.47(b)

Pore water parameters are empirical coefficients which are used to express the response of pore pressure to changes in total stress under undrained conditions. Pore pressure parameter A is not a constant and is different for different soils and stress conditions. For a given soil, A depends upon the strain, anisotropy, sample disturbance and the over consolidation ratio.

8.48(a)

Unconfined compression test is a special case of triaxial test in which the confining pressure is zero. This test may be conducted on undisturbed or remoulded cohesive soils. It cannot be conducted on coarse-grained soils such as sands and gravels as these cannot stand without lateral support.

8.49(b)

If the failure plane makes an angle α with the horizontal, then

$$\alpha = 45° + \frac{\phi}{2}$$

where ϕ is the angle of shearing resistance

$$\therefore \quad 52° = 45° + \frac{\phi}{2}$$

$$\Rightarrow \quad \phi = 14°$$

8.50 (a)

Under-consolidated clays when undergo shock or disturbance, remoulding occurs which leads to considerable loss of shear strength.

8.51 (d)

Natural soils generally have a sensitivity value of 1 or more than 1. However, stiff clays having fissures and cracks sometimes exhibits a sensitivity value of less than 1, since these weaknesses i.e. fissures and cracks present in an undisturbed sample, will be removed upon remoulding.

$$\text{Sensitivity,} \quad S_t = \frac{(q_u)\ \text{undisturbed}}{(q_u)\ \text{remoulded}}$$

8.53(b)

Bulking in sands is manifestation of capillary moisture. The capillary menisci surrounding the soil grains produces apparent cohesion which holds the particle together in clusters. The increase in volume known as bulking occurs only in moist sands, thereby decreasing the density of sand.

8.54 (d)

The unconfined compression test is a special form of a triaxial test in which the confining pressure is zero. The test can be conducted only on clayey soils which can stand without confinement.

8.55 (a)

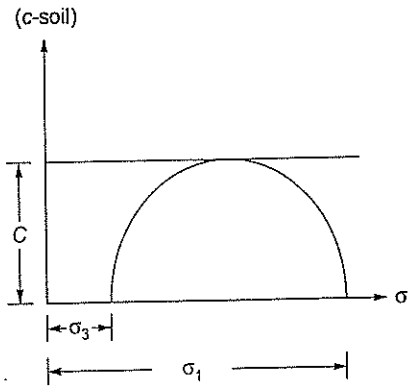
Dense sands derive their shear strength from interlocking and friction whereas clays derive their shear strength from cohesion. For a saturated soil, skempton's B parameter = 1.

8.56 (a)

The triaxial test is the most versatile of all shear testing method, to determine c and ϕ of the soil. Drainage conditions can be controlled, whatever be the type of soil. In the triaxial test, pore water pressure measurements can be made accurately. Volume changes can also be measured. The specimens can fail on any weak plane. The stress distribution on the failure plane is fairly uniform.

8.57 (c)

For pure clay, failure envelope ($\phi = 0$)



8.58 (c)

Progressive changes in the state of a particular load application can be represented by a series

of Mohr circles. The locus of points on the Mohr diagram whose coordinates represent the maximum shear stress and the associated principal stress for the entire stress history is defined as a stress path. For given principal stresses σ_1 and σ_3, the coordinates of a point on the stress path are

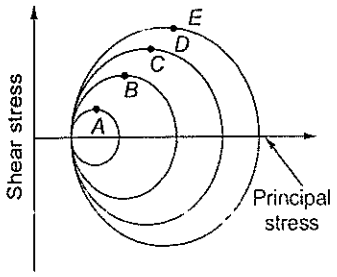
$$p = \frac{\sigma_1 + \sigma_3}{2}$$

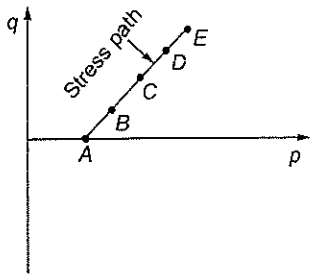
and

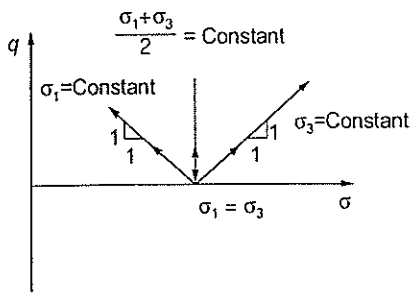
$$q = \frac{\sigma_1 - \sigma_3}{2}$$

Such a plot is referred to as p-q diagram.

The stress path for σ_3 = constant and σ_1 increasing is a 45° line. Figure shows stress paths for different variations of σ_1 and σ_3. A stress path diagram may be constructed for total or effective stress conditions.







8.59 (c)

- In case of heavily over consolidated clays, the stress strain curve has a sharp peak. Hence it shows brittle behaviour.
- Remoulded clays or soft clays show constant failure at similar values of stress hence it has a plastic failure. This is the reason for progressive failure.
- Undisturbed sensitive clay shows a sharp peak which occurs at relatively low strain in stress-strain curve.

8.61 (d)

$$\sin\phi = \frac{\bar{\sigma}_1 - \bar{\sigma}_3}{\bar{\sigma}_1 + \bar{\sigma}_3}$$

$$= \frac{(90-10)-(30-10)}{(90-10)+(30-10)} = \frac{60}{100}$$

$$\sin\phi = \frac{3}{5}$$

$$\therefore \quad \tan\phi = \frac{3}{4}$$

8.62 (a)

$$A_0 = \frac{\pi}{4} \times (3.50)^2 = 9.621\ \text{cm}^2$$

$$A_f = \frac{A_o}{1-\epsilon_0} = \frac{9.62}{1-\frac{0.8}{8}}$$

$$= 10.69\ \text{cm}^2$$

$$\therefore \quad q_u = \frac{50}{10.69} = 4.677\ \text{kg/cm}^2$$

8.63 (b)

Undrained triaxial compression

saturated clays ($\phi = 0$)

$\sigma_3 = 50\ \text{kN/m}^2$

$\sigma_d = 100\ \text{kN/m}^2$

$\sigma_1 = \sigma_3 + \sigma_d = 50 + 100$

$= 150\ \text{kN/m}^2$

From stress relationship

$$\sigma_1 = \sigma_3 \tan^2\left(45 + \frac{\phi}{2}\right) + 2c\tan\left(45 + \frac{\phi}{2}\right)$$

$$150 = 50 + 2c$$

$$c = \frac{100}{2} = 50\ \text{kN/m}^2$$

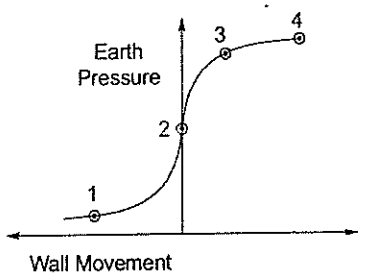
9 Retaining Wall/ Earth Pressure Theories

9.1 A retaining wall retains a sand strata with $\phi = 30°$ up to its top. If a uniform surcharge of 12 t/m^2 is subsequently put on the sand strata, then the increase in the lateral earth pressure intensity on the retaining wall will be

(a) 1 t/m^2 (b) 2 t/m^2
(c) 4 t/m^2 (d) 8 t/m^2

[ESE : 1995]

9.2 The variation of earth pressure with wall movement is shown in the figure by the points labelled



(a) 1 and 2 (b) 2 and 3
(c) 2 and 4 (d) 1 and 4

[ESE : 1995]

9.3 No tension should develop at the base of the rectangular well foundation or at any horizontal section within the well. For no tension at the base, the resultant of P_a (Total active thrust) and W (Weight of soil and well above the base) must pass through middle

(a) half of the base
(b) third of the base
(c) quarter of the base
(d) of the base

[ESE : 1995]

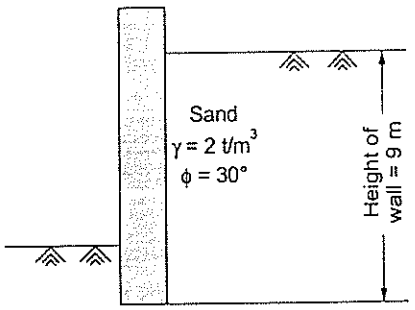
9.4 Assertion (A): The safe height ($2z_0$) to which an unsupported vertical cut in clay can be made is $4c/\gamma$.

Reason (R): Active earth pressure of cohesive backfill shows that the negative pressure (tension) is developed at top level. This tension decrease to zero at depth z_0 and total net pressure up to a depth $2z_0$ is zero.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1996]

9.5 Active earth pressure per metre length on the retaining wall with a smooth vertical back as shown in the given figure will be



(a) 81 t (b) 27 t
(c) 2 t (d) 1 t

[ESE : 1996]

9.6 A retaining wall with vertical back retains a cohesionless dry backfill at an inclination of β with the horizontal. The backfill has an angle of internal friction ϕ, unit weight γ and height of the wall is H. The passive earth pressure on the wall is given by (where P_p = Total passive earth pressure)

(a) $P_p = \frac{1}{2}\gamma H^2 \cos\beta \left[\frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\beta}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\beta}}\right]$

(b) $P_p = \frac{1}{2}\gamma H^2 \cos\beta \left[\frac{\cos\beta - \sqrt{\cos^2\beta + \cos^2\beta}}{\cos\beta + \sqrt{\cos^2\beta + \cos^2\beta}}\right]$

(c) $P_p = \frac{1}{2}\gamma H^2 \cos\beta\left[\frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}\right]$

(d) $P_p = \frac{1}{2}\gamma H^2 \cos\beta\left[\frac{\cos\beta + \sqrt{\cos^2\beta + \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta + \cos^2\phi}}\right]$

[ESE : 1996]

9.7 In the following figures, if

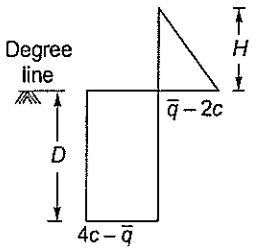
H = height of wall above dredge line,

$\bar{q}$ = effective vertical stress at any depth,

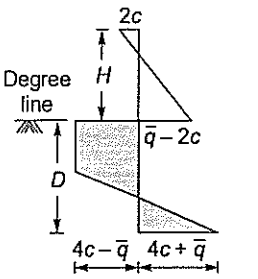
c = unit cohesion,

and passive pressure is shown hatched in the figures, then the earth pressure distribution diagram used for analysis of a cantilever sheet pile embedded to a depth D in a purely cohesive soil will be as in

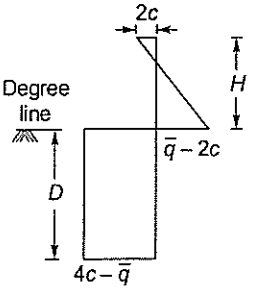
(a)



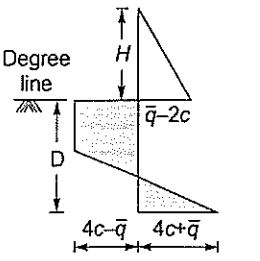
(b)



(c)

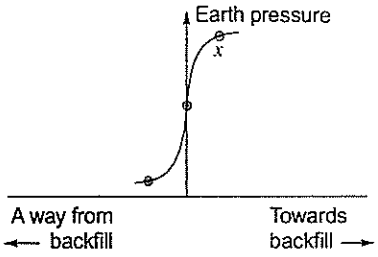


(d)



[ESE : 1996]

9.8 Earth pressure and resultant possibilities of wall movement are shown in the diagram below.



Lateral movement of retaining wall

The point marked X in the diagram denotes

(a) earth pressure at rest

(b) active earth pressure

(c) arching active pressure

(d) passive earth pressure

[ESE : 1997]

9.9 In a cohesionless soil deposit having a unit weight of 1.5 t/m^3 and an angle of internal friction of 30°, the active and passive lateral earth pressure intensities (in t/m^2) at a depth of 10 m will, respectively, be

(a) 15 and 5 (b) 5 and 15

(c) 10 and 20 (d) 20 and 10

[ESE : 1997]

9.10 Given that for a soil deposit,

K_o = earth pressure coefficient at rest

K_a = active earth pressure coefficient

K_p = passive earth pressure coefficient

μ = Poisson's ratio.

The value of $(1 - \mu)/\mu$ is given by

(a) K_a/K_p (b) K_o/K_a

(c) K_p/K_a (d) $1/K_o$

[ESE : 1997]

9.11 Consider the following statements:

Rankine's theory and Coulomb's theory give same values of coefficients of active and passive earth pressures when

1. the retaining wall has a vertical back
2. the backfill is cohesionless
3. angle of slope of backfill is equal to the angle of internal friction
4. angle of slope of backfill is 0°
5. angle of wall friction δ is 0°
6. angle of wall friction δ is equal to ϕ

Which of these statements is/are correct?
(a) 1, 2, 3 and 5
(b) 1, 2, 4 and 5
(c) 2, 3, and 6
(d) 1, 4 and 6

[ESE : 1998]

9.12 Consider the following statements:
1. Coulomb's earth pressure theory does not take the roughness of wall into consideration.
2. In case of non-cohesive soils, the coefficients of active earth pressure and earth pressure at rest are equal.
3. Any movement of retaining wall away from the fill corresponds to active earth pressure condition.

Which of these statements is/are correct?
(a) 1 alone (b) 1 and 2
(c) 2 alone (d) 3 alone

[ESE : 1998]

9.13 Match List-I (Type of structure) with List-II (Type of pressure exerted by sandy back fill) and select the correct answer using the codes given below the lists:

List-I
A. A masonry retaining wall founded on compressible clay
B. Pressure on the back of a cantilever sheet pile wall near the embedded end
C. A masonry retaining wall founded on rock

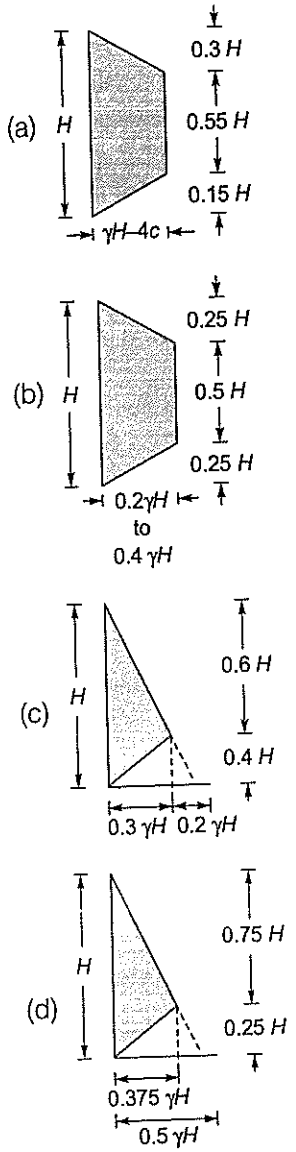
List-II
1. Active pressure
2. Earth pressure at rest
3. Passive earth pressure

Codes:

	A	B	C
(a)	1	3	2
(b)	3	2	1
(c)	3	1	2
(d)	2	3	1

[ESE : 1999]

9.14 Which one of the following typical pressure distribution diagrams represents the lateral pressure distribution on braced sheeting in stiff clay with temporary support, as given by Tschebotarioff?



[ESE : 1999]

9.15 Given that $c = 2$ t/m^2, $\phi = 0°$ and $\gamma = 2$ t/m^3, the depth of tension crack developing in a cohesive soil backfill would be
(a) 1 m (b) 2 m
(c) 3 m (d) 4 m

[ESE : 1999]

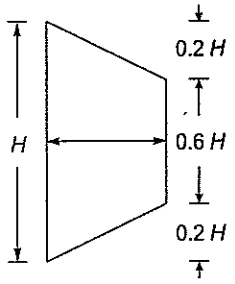
9.16 The correct sequence of the given parameters in descending order of earth pressure intensity is
(a) active, passive, at rest
(b) passive, active, at rest
(c) passive, at rest, active
(d) at rest, passive, active

[ESE : 2000]

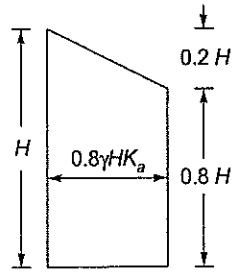
9.17 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Dense sand
B. Loose sand
C. Plastic clay

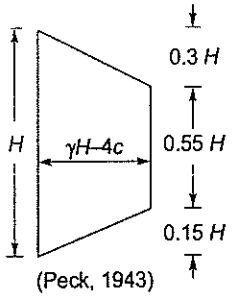
List-II

1.


(Terzaghi-Peck, 1948)

2.


(Terzaghi-Peck, 1948)

3.


(Peck, 1943)

Codes:

	A	B	C
(a)	3	2	1
(b)	2	1	3
(c)	1	3	2
(d)	1	2	3

[ESE : 2000]

9.18 An earth-retaining structure may be subjected to the following lateral earth pressures:
1. Earth pressure at rest
2. Passive earth pressure
3. Active earth pressure

The correct sequence of the increasing order of the magnitudes of these pressures is
(a) 3, 2, 1 (b) 1, 3, 2
(c) 1, 2, 3 (d) 3, 1, 2

[ESE : 2001]

9.19 For a sand having an internal friction of 30°, the ratio of passive to active lateral earth pressure will be
(a) 1 (b) 3
(c) 6 (d) 9

[ESE : 2001]

9.20 When movement of a wall under the earth pressures from the backfill was prevented the coefficient of earth pressure was recorded as 0.5. The ratio of the coefficient of passive and active earth pressure of the backfill is
(a) 1/3 (b) 3
(c) 1/9 (d) 9

[ESE : 2002]

9.21 **Assertion (A):** Passive earth pressure is always greater than the earth pressure at rest and active earth pressure.
Reason (R): In passive state the structure becomes the actuating element and soil becomes the resisting element to maintain the stability.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

9.22 The wall friction of the retaining wall
(a) decreases active earth pressure but increases passive earth pressure
(b) decreases passive earth pressure but increases active earth pressure
(c) decrease both active and passive earth pressure
(d) increase both active and passive earth pressure [ESE : 2005]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false
(d) A is false but R is true

9.23 Assertion (A): Basement walls and bridge abutments are usually designed for earth pressure at rest.
Reason (R): These are usually not restrained by the floor slab and by the deck structure at their bases.
[ESE : 2005]

9.24 Assertion (A): The earth pressure at rest is greater than active pressure but less than passive earth pressure.
Reason (R): When the wall moves away from backfill from the rest condition, the mobilization of the internal resistance of soil occurs; on the other hand, if the wall moves towards the fill, the shearing resistance build up.
[ESE : 2005]

9.25 Assertion (A): The state of earth pressure at rest is the state of equilibrium with zero strain condition.
Reason (R): In rest condition neither the wall nor the soil moves.
[ESE : 2006]

9.26 In a braced vertical excavation of 5 m height and 2.50 m width in a cohesive soil having undrained cohesion equal to 20 kN/m^2 and bulk unit weight of 20 kN/m^3, what is the factor of safety against heave failure at its base?
(a) 1.0 (b) 1.20
(c) 1.40 (d) 2.0
[ESE : 2006]

9.27 If the coefficient of active earth pressure is 1/3, then what is the value of the coefficient of passive earth pressure?
(a) 1/9 (b) 1/3
(c) 3 (d) 1
[ESE : 2007]

9.28 Why are weep holes provided at the back of retaining walls?
(a) To reduce the active earth pressure on the walls.
(b) To reduce the build-up of hydrostatic pressure.
(c) To provide better compaction.
(d) To increase the passive earth pressure.
[ESE : 2007]

9.29 Assertion (A): Rankine's earth pressure theory should not be used for concrete retaining walls and Coulomb's theory should not be used for estimating passive earth pressures.
Reason (R): Rankine assumed that the retaining wall has a vertical back and Coulomb assumed that the resultant reaction due to earth pressure acts at one-third the height of the wall.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2008]

9.30 A vertical cut is to be made in saturated clay with c = 15 kN/m^2, $\phi = 0°$, and γ = 20 kN/m^3. What is the theoretical depth to which the clay can be excavated without side collapse?
(a) 6 m (b) 2 m
(c) 2.5 m (d) 3 m
[ESE : 2008]

9.31 What is the intensity of active earth pressure at a depth of 10.0 m in dry sand with an angle of shearing resistance of 30° and unit weight of 18 kN/m^3?
(a) 50 kN/m^2 (b) 60 kN/m^2
(c) 70 kN/m^2 (d) 80 kN/m^2
[ESE : 2009]

9.32 When a vertical face excavation was made in a clayey silt, having density of 20 kN/m^3, it failed at a depth of excavation of 4 m. What is the cohesive strength (in kN/m^2) of the soil, if its angle of internal friction was 30°?
(a) 23.1 (b) 20.0
(c) 11.6 (d) 10.2
[ESE : 2009]

9.33 Consider the following statements:
1. The yield of a retaining wall required to reach plastic equilibrium in active case is more than that in positive case.

2. Culman's graphical method is simplified version of the more general trial wedge method.
3. For a masonry gravity retaining wall coulomb's theory of earth pressure is preferred for designing.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 3 only
[ESE : 2010]

9.34 The lateral earth pressure coefficient of a soil, K_a for active state, K_p for passive state and K_0 for at-rest condition, compare as
(a) $K_0 < K_a < K_p$ (b) $K_a < K_0 < K_p$
(c) $K_a < K_p < K_0$ (d) $K_p < K_0 < K_a$
[ESE : 2011]

9.35 Consider the following statements regarding Coulomb's theory of earth pressure:
1. It is based on wedge theory of earth pressure.
2. It assumes the wall surface to be rough.
3. It may or may not satisfy the static equilibrium condition occurring in nature.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2012]

9.36 A wall with smooth vertical back and 10 meters height retains cohesionless material with a horizontal surface. The cohesionless material weighs 4.91 kN/m^3 and has an angle of internal friction of 30°. The total active earth pressure is
(a) 81.585 kN/m length of wall
(b) 91.585 kN/m length of wall
(c) 40.743 kN/m^2
(d) 8.158 kN/m^2
[ESE : 2012]

9.37 The earth pressure behind a bridge abutment is:
(a) Active
(b) Passive
(c) At rest
(d) Constant always and everywhere
[ESE : 2013]

9.38 Consider the following statements:
1. According to Terzaghi, the average angle of wall friction may be taken equal to two-thirds of the respective angle of internal friction.
2. Wall friction increases the active earth pressure and also decreases the passive earth resistance of the soil.
3. Wall friction decreases the active earth pressure and increases the passive earth resistance of the soil.

Which of the above statements is/are correct?
(a) 1,2 and 3 (b) 1 and 2 only
(c) 3 only (d) 1 and 3 only
[ESE : 2014]

9.39 Consider the following statements:
1. Uniform surcharge increases active earth pressure even as it decreases passive resistance.
2. For analyzing the conditions at a masonry gravity wall, application of Coulomb's theory of earth pressure is preferred.
3. Culmann's method is applicable to a stratified backfill; whereas Poncelet's method is not.

Which of the above statements are correct ?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) I, 2 and 3
[ESE : 2014]

9.40 **Statement (I):** For a cantilever retaining wall, Rankine's theory of earth pressure may be used.

Statement (II): For a retaining wall with smooth vertical back, Rankine's theory is appropriate.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.
[ESE : 2014]

9.41 Consider the following statements:
1. The required yield of a retaining wall to reach equilibrium in the active case in less than for the passive case.
2. The active pressure caused by a cohensionless backfill on a smooth vertical retaining wall may be reduced by compacting the backfill.
3. Given a choice, one should prefer a cohesive soil for a backfill vis-a-vis a non-chhesive soil.

Which of the above statements is/are correct?

(a) 1,2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only
[ESE : 2015]

9.42 A rigid retaining wall of 6 m height has a saturated backfill of soft clay soil. What is the critical height when the properties of the clay soil are γ_{sat} = 17.56 kN/m^3 and cohesion c = 18 kN/m^2
(a) 1.1 m (b) 2.1 m
(c) 3.1 m (d) 4.1 m
[ESE : 2016]

9.43 In a certain sea shore, the height of a retaining wall with smooth vertical back is 4.4 m. The foundation is over an expansive collapsible soil and has a horizontal surface at the level of the top of the wall and carries a UDL of 197 kPa. The unit weight and angle of internal friction are 19 kN/m^3 and 30°, respectively. What is the nearest magnitude of the total active pressure per metre length of this sea shore wall?
(a) 270 kN/m (b) 360 kN/m
(c) 450 kN/m (d) 640 kN/m
[ESE : 2016]

Answers Retaining Wall/Earth Pressure Theories

9.1	(c)	9.2	(d)	9.3	(b)	9.4	(a)	9.5	(b)	9.6	(c)	9.7	(b)	9.8	(d)	9.9	(b)
9.10	(d)	9.11	(b)	9.12	(d)	9.13	(a)	9.14	(c)	9.15	(b)	9.16	(c)	9.17	(d)	9.18	(d)
9.19	(d)	9.20	(d)	9.21	(a)	9.22	(a)	9.23	(c)	9.24	(a)	9.25	(a)	9.26	(c)	9.27	(c)
9.28	(b)	9.29	(b)	9.30	(d)	9.31	(b)	9.32	(c)	9.33	(c)	9.34	(b)	9.35	(a)	9.36	(a)
9.37	(c)	9.38	(d)	9.39	(c)	9.40	(a)	9.41	(b)	9.42	(d)	9.43	(b)				

Explanations Retaining Wall/Earth Pressure Theories

9.1 (c)
Increase in lateral earth pressure

$$\Delta\sigma_h = K_a q$$

Active earth pressure coefficient,

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30}{1+\sin 30} = \frac{1}{3}$$

$$\therefore \quad \Delta\sigma_h = \frac{1}{3}\times 12 = 4 \text{ t/m}^2$$

9.2 (d)
Point 1 represents active earth pressure due to wall movement away from soil and point 4 represents passive earth pressure due to wall movement towards the fill.

9.3 (b)
For no tension to develop at base of foundation,

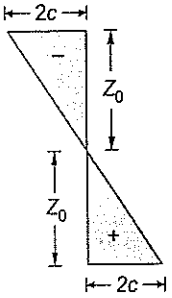
$\sigma_{min} > 0$

$$\frac{P}{B^2}\left[1-\frac{6e}{B}\right] > 0$$

$$e > \frac{B}{6}$$

So point load must lie within $\left(\frac{B}{6}+\frac{B}{6}\right) = \frac{B}{3}$ i.e within middle third of base.

9.4 (a)
Tension is shown as negative and compression as positive.



For pure clay K_a = 1.0

$\therefore$ Lateral pressure $= \gamma z - 2c$.

At $z_0 = \dfrac{2c}{\gamma}$ lateral pressure will be zero.

9.5 (b)

Active earth pressure coefficient

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30°}{1+\sin 30°}$$

$$= \frac{1}{3}$$

Active earth pressure per unit length

$$= \frac{1}{2}K_a\gamma H^2$$

$$= \frac{1}{2}\times\frac{1}{3}\times 2\times 9\times 9$$

$$= 27 \text{ t/m}$$

9.7 (b)

Cantilever sheet piling walls depend on the passive resisting capacity of the soil below the depth of excavation to prevent overturning. The depth of sheet piling walls below the bottom of the excavation is determined by using the difference between the passive and active pressures acting on the wall. The theoretical depth of pile penetration below the depth of excavation is obtained by equating horizontal forces and by taking moments about an assumed bottom of piling. The theoretical depth of penetration represents the point of rotation of the piling. Additional penetration is needed to obtain some fixity for the piling. Computed piling depths are generally increased 20% to 40% to obtain some fixity and to prevent lateral movement at the bottom of the piling.

9.8 (d)

When wall moves towards the earthfill, then maximum earth pressure acting on wall before failure is known as passive earth pressure.

9.9 (b)

Maximum active pressure,

$$p_A = K_A\sigma_z$$

where $K_A = \dfrac{1-\sin\phi}{1+\sin\phi}$

Maximum passive pressure,

$$p_P = K_P\sigma_z$$

where $k_P = \dfrac{1+\sin\phi}{1-\sin\phi}$

For $\phi = 30°$, $K_A = \dfrac{1}{3}$

and $K_P = 3$

$\sigma_z = 1.5 \times 10 = 15$ t/m^2

$\therefore$ $p_A = \dfrac{1}{3} \times 15 = 5$ t/m^2

$p_P = 3 \times 15 = 45$ t/m^2

In the case of passive pressure full strain mobilization may not take place and so actual passive pressure will be less than maximum value.

9.10 (d)

$$K_o = \frac{\mu}{1-\mu}$$

$$\Rightarrow \quad \frac{1}{K_o} = \frac{1-\mu}{\mu}$$

9.11 (b)

From Couiomb's theory

$$K_a = \frac{\sin^2(\alpha+\phi)}{\sin^2\alpha\sin(\alpha-\delta)\left[1+\sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\phi-\delta)\sin(\phi+\beta)}}\right]}$$

For smooth vertical wall retaining a backfill with horizontal surface

$$\alpha = 90°, \delta = 0, \beta = 0$$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi}$$

Rankine's active earth pressure coefficient

Same can be shown for passive case also.

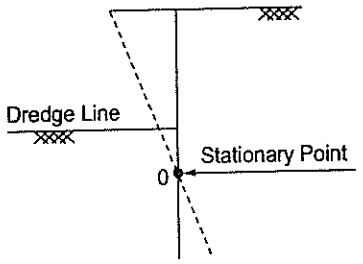
9.12 (d)

By considering the wall friction, the Coulomb's theory eventually considers the wall to be rough. The relative movement of the wall and the soil on the back develops frictional forces that influence the direction of the resultant pressure.

In Coulomb's theory, the failure surface is assumed to be plane surface which pases through heel of the wall. This assumption introduces only a negligibel error in teh case of active pressure. However in the case of passive

pressure, the error involved remains small only for values of δ less then $\phi/3$.

9.13(a)



Above the dredge line, the pressure is active on the back of the wall. Near the embedded end the pressure on the back of the wall will be passive as the wall moves towards the fill.

The retaining wall made of masonry is gravity retaining wall. If the wall is founded on rock there will not be any stretching of soil mass so earth pressure conditions will be at rest. Similarly on a compressible clay active earth pressure conditions will develop.

9.14 (c)

Fig.	Case	Proposed by
(a)	Braced sheeting in clay	Terzaghi & Peck
(b)	Apparent pressure diagram for braced cuts in firm clay	Peck, Hanson and Thornburn
(c)	Braced pile with temporary support in stiff clay	Tschebotarioff
(d)	Braced pile with permanent support in medium clay	Tschebotarioff

9.15(b)

Depth of tension crack,

$$Z_c = \frac{2c}{\gamma\sqrt{K_a}}$$

For $\phi = 0; \quad K_a = 1$

$$\therefore \quad Z_c = \frac{2\times 2}{2} = 2\,\text{m}$$

The unsupported depth, $H_c = 2Z_c$

9.16(c)

Passive pressure is maximum.

Active pressure is minimum.

9.17(d)

List-II gives the lateral pressures on braced sheet pile walls. The pressure distribution on the wall is non-hydrostatic. Based on the measurements on actual job sites, empirical pressure diagram have been proposed by Terzaghi and Peck, and Tschebotarioff depending upon the type of soil.

9.18 (d)

Pressure at rest: When the wall is at rest and the material is in its natural state then the pressure applied by material is known as Earth Pressure at Rest.

Active earth pressure: When the wall moves away from the backfill, there is a decrease in the pressure on the wall and this decrease continues until a minimum value is reached after which there is no reduction in the pressure and the value will become constant. This kind of pressure is known as active earth pressure.

Passive earth pressure: When the wall moves towards the backfill, there is an increase in the pressure on the wall and this increase continues until a maximum value is reached after which there is no increase in the pressure and the value will become constant. This kind of pressure is known as passive earth pressure.

9.19(d)

$\frac{K_p}{K_a}$ will be the ratio of passive to active earth pressure.

$$\frac{K_p}{K_a} = \left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2 = \left(\frac{1+\sin 30^\circ}{1-\sin 30^\circ}\right)^2 = 9$$

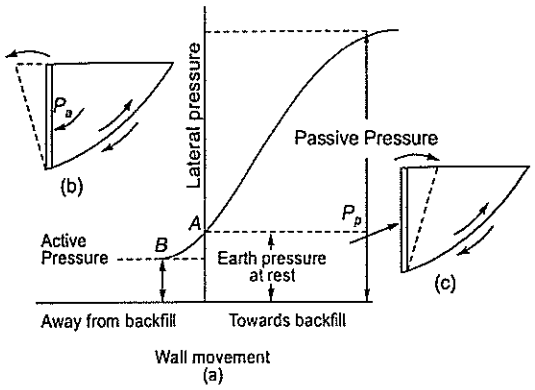
9.20(d)

Coefficient of earth pressure at rest,

$$1-\sin\phi = K_0$$
$$\sin\phi = 1-0.5$$
$$\sin\phi = 0.5$$

$$\therefore \quad \frac{K_p}{K_a} = \left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2 = \left(\frac{1.5}{0.5}\right)^2 = 9$$

9.21 (a)



9.22 (a)

The angle of friction (δ) between the soil and the wall can be determined from direct shear test. The value of δ may range from $\frac{1}{2}\phi$ to $\frac{3}{4}\phi$ in most cases and it can be assumed as $\frac{2}{3}\phi$ in the absence of precise data.

The wall friction decreases active earth pressure and increases passive earth pressure.

From Coulomb's theory,

$$K_p = \frac{\sin^2(\alpha-\phi)}{\sin^2\alpha\sin(\alpha+\delta)\left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi+\beta)}{\sin(\phi+\delta)\sin(\phi+\beta)}}\right]}$$

$$K_a = \frac{\sin^2(\alpha+\phi)}{\sin^2\alpha\sin(\alpha-\delta)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi+\beta)}{\sin(\phi-\delta)\sin(\phi+\beta)}}\right]^2}$$

9.23 (c)

Both basement walls and bridge abutments are designed for earth pressure at rest.

9.24 (a)

$$K_a < K_0 < K_p$$

9.25 (a)

$$K_0 = \frac{\mu}{1-\mu}$$

Where μ is the Poisson's ratio $\simeq 1-\sin\phi'$ where ϕ' is the angle of shearing resistance

9.26 (c)

Factor of safety,

$$F = \frac{C_u N_c}{\gamma H}$$

Given $C_u = 20\ \text{kN/m}^2$, $\gamma = 20\ \text{kN/m}^3$

Bearing capacity factor N_c from Skempton's analysis is

$$N_c = 5\left(1+0.2\frac{D_f}{B}\right),$$

for $\frac{D_f}{B} < 2.5$

$= 7.5$ for $\frac{D_f}{B} > 2.5$

Thus $N_c = 5\times\left(1+0.2\times\frac{5}{2.5}\right) = 7.0$

$\therefore$ $F = \frac{20\times7}{20\times5} = 1.4$

9.27 (c)

The relation between K_a and K_p is given by

$$K_aK_p = 1$$

$$\Rightarrow \frac{1}{3}\times K_p = 1$$

$$\Rightarrow K_p = 3$$

9.28 (b)

Weep holes at the base of retaining walls are intended to bleed off excess moisture that collects behind the wall. Due to rise of water table, the pore pressure develops and it causes excessive hydrostatic pressure on the wall. To reduce the development of excessive lateral pressure, weep holes are provided.

9.29 (b)

The **Rankine's theory** assumes that there is no wall friction, the ground and failure surfaces are straight planes, and that the resultant force acts parallel to the backfill slope

For higher values of δ, the error becomes unacceptable because of pronounced curvature of slip surface.

9.30 (d)

The critical (theoretical) depth of vertical cut in a cohesive soil is given by

$$H_c = \frac{4c}{\gamma\sqrt{K_a}}$$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin0°}{1+\sin0°} = 1$$

$\therefore$ $H_c = \frac{4\times15}{20\times\sqrt{1}} = 3\ \text{m}$

9.31 (b)

The intensity of active earth pressure is given by

$$p_a = K_a \times \gamma \times H$$

$$= \left(\frac{1-\sin 30^\circ}{1+\sin 30^\circ}\right) \times 18 \times 10$$

$$= 60\ \text{kN/m}^2$$

9.32 (c)

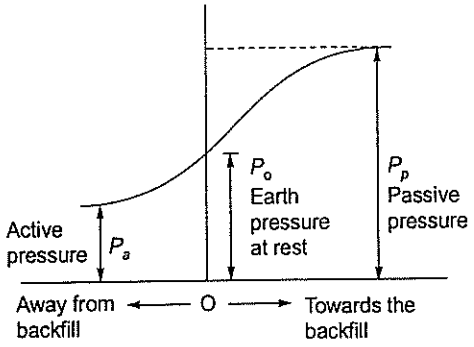
$$H_c = \frac{4c}{\gamma\sqrt{K_a}}\ ;\ \text{But}\ K_a = \frac{1-\sin 30^\circ}{1+\sin 30^\circ} = \frac{1}{3}$$

$$\therefore \quad 4 = \frac{4 \times c \times \sqrt{3}}{20}$$

$$\Rightarrow \quad c = 11.6\ \text{kN/m}^2$$

9.33 (c)

The yield of a retaining wall required to reach plastic equilibrium in active case is less than that in passive case. Active pressures are accompanied by movements of the retaining wall directed away from the soil and passive resistances are accompanied by movements towards the soil.



Culmann gave the graphical method to evaluate the earth pressure from Coulomb's trial wedge method. Culmann's method permits one to determine graphically the magnitude of the earth pressure and to locate the most dangerous rupture surface according to Coulomb's trail wedge method. Culmann's method is in fact a simplified version of the more general trial wedge method. It may be conveniently used for ground surface of any shape, for different types of surcharge loads, and for layered backfill with different unit weights for different layers.

For cantilever and counterfort walls, Rankine's theory is used; for gravity and semi-gravity retaining walls, Coulomb's theory is preferred.

9.34 (b)

$$K_a = \frac{1-\sin\phi}{1+\sin\phi}, K_p = \frac{1+\sin\phi}{1-\sin\phi}$$

and $\quad K_o = 1 - \sin\phi$

$$K_p > K_o > K_a$$

9.35 (a)

The Coulomb theory provides a method of analysis that gives the resultant horizontal force on a retaining system for any slope of wall, wall friction, and slope of backfill provided. This theory is based on the assumption that soil shear resistance develops along the wall and failure plane. Since wall friction requires a curved surface of sliding to satisfy equilibrium, the Coulomb formula will give only approximate results as it assumes planar failure surfaces. The accuracy for Coulomb will diminish with increased depth. For passive pressures the Coulomb formula can also give inaccurate results when there is a large back slope or wall friction angle.

9.36 (a)

$$P_a = \frac{1}{2} K_a \gamma h^2$$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30^\circ}{1+\sin 30^\circ} = \frac{1}{3}$$

$$\therefore \quad P_a = \frac{1}{2} \times \frac{1}{3} \times 4.91 \times 10^2$$

$$= 81.83\ \text{kN/m}$$

Length of wall.

9.37 (c)

In bridge abutment, there is no tendency of wall movement.

$\Rightarrow$ At rest earth pressure.

9.39 (c)

Uniform surcharge increases both active and passive earth pressure.

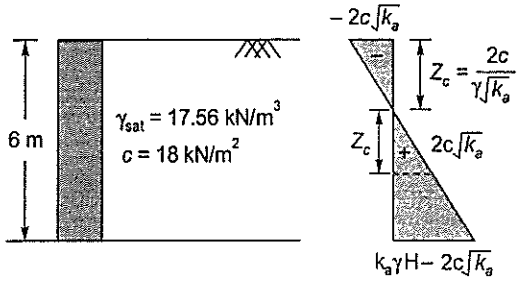
9.40 (a)

Retaining walls are designed for active earth pressure. Rankine's earth pressure theory over estimates the active earth pressure. So it is safe to design the retaining wall using this theory.

9.41 (b)

On compaction, of cohesionless backfill, active earth pressure decreases and passive earth pressure increases.

9.42 (d)



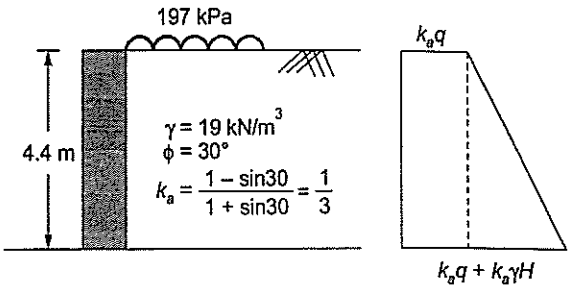
Critical height of unsupported cut

$$H_c = \frac{4c}{\gamma\sqrt{k_a}}$$

$$k_a = \frac{1-\sin 0^\circ}{1+\sin 0^\circ} = 1$$

$$H_c = \frac{4c}{\gamma} = \frac{4\times 18}{17.56} = 4.1\text{ m}$$

9.43 (b)



$$P_a = k_a q \cdot H + \frac{1}{2}k_a \gamma H^2$$

$$= \frac{1}{3}\times 197 \times 4.4 + \frac{1}{2}\times\frac{1}{3}\times 19 \times 4.4^2$$

$$= 350.24\text{ kN/m}$$

10 Stability Analysis of Slopes

10.1 Consider the following assumptions for slope stability analysis:

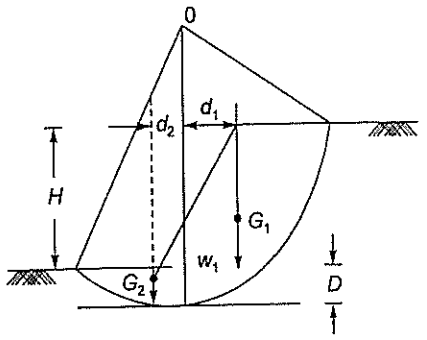
1. Friction is fully mobilized.
2. Effective stress analysis is adopted.
3. Total stress analysis is used.
4. Resultant 'R' passes through the centre of the circle.
5. Resultant 'R' is tangential to the friction circle.

The assumptions necessary for friction circle method of analysis would include

(a) 1, 3 and 4 (b) 1, 3 and 5
(c) 2 and 4 (d) 2 and 5

[ESE : 1995]

10.2 The depth factor D_f in slope failure in the situation shown in the figure will be



(a) greater than one (b) less than one
(c) equal to one (d) equal to zero

[ESE : 1999]

10.3 If an infinite slope of clay at a depth 5 m has cohesion of 1 t/m^2 and unit weight of 2 t/m^3, then the stability number will be

(a) 0.1 (b) 0.2
(c) 0.3 (d) 0.4

[ESE : 1999]

10.4 Consider the following statements associated with stability of slope:

1. Stability number is inversely proportional to cohesion and directly proportional to height.
2. Swedish method of analysis is based on circular failure surfaces.
3. The Culmann method assumes that rupture will occur in a plane.

Which of these statements are correct?

(a) 2 and 3 (b) 1 and 3
(c) 1 and 2 (d) 1, 2 and 3

[ESE : 2000]

10.5 Taylor's stability number S_n is given by which one of the following expressions? (c is cohesion, F_c is factor of safety, γ is density of soil and H, the height of the slope).

(a) $\frac{c}{F_c\gamma}$ (b) $\frac{c}{\gamma H}$

(c) $\frac{c}{F_c\gamma H}$ (d) $\frac{c}{F_c(\gamma + H)}$

[ESE : 2002]

10.6 Consider the following statements:

Dewatering increases the slope stability of a cohesionless soil mainly because

1. it causes change in pH
2. it reduces pore water pressure

Which of the statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2007]

Answers Stability Analysis of Slopes

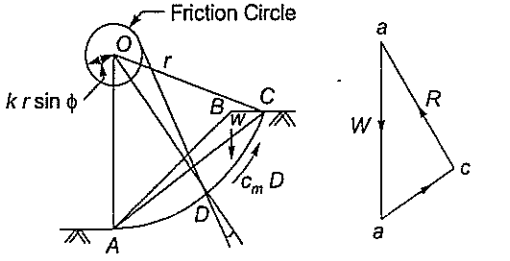
10.1 (b) 10.2 (a) 10.3 (a) 10.4 (a) 10.5 (c) 10.6 (b)

Explanations Stability Analysis of Slopes

10.1 (b)

The friction circle method of stability analysis of slope is applicable to c - ϕ soils. Following are the assumptions:

- Method is based on total stress analysis.
- Enables the angle of shearing resistance to be taken into account.
- Slip surface is circular.
- Frictional resistance is fully mobilized along the slip surface.
- Resultant R is tangential to the friction circle.



(a) (b) Force triangle

10.2(a)

Depth factor,

$$D_f = \frac{D+H}{H}$$

$D_f = 1.0$ for toe failure, $D_f > 1$ for base failure

10.3(a)

$$\text{Stability number} = \frac{C}{\gamma H} = \frac{1}{2\times 5} = 0.1$$

10.4(a)

Taylor's stability number, $S = \dfrac{C_m}{\gamma H}$

where, C_m is unit cohesion mobilised, γ is unit weight of soil, H is height of slope

Thus, stability number is directly proportional to cohesion and inversely proportional to height. The culmann's graphical method of earth pressure determination is based on Coulomb's wedge theory. It is better than Ponclet's method and can be used for ground surface of any shape, for different types of surcharge loads, and for layered backfill with different unit weights for different layers.

10.5 (c)

A dimensionless parameter called a Taylor's stability number is often useful for the analysis of slopes of $c-\phi$ soils and can be defined by the following equation:

$$S_n = \frac{C_m}{\gamma H} = \frac{C}{F_c \gamma H} = \cos^2 i\left(\tan i - \tan\phi\right)$$

10.6 (b)

Dewatering in cohesionless soil reduces pore water pressure. This leads to increase in effective stress and which in result increases the shear strength of soil. Hence slope stability increases.

11 Shallow Foundation and Bearing Capacity

11.1 Bearing capacity of a soil strata supporting a footing of size 3 m x 3 m will not be affected by the presence of ground water table located at a depth which is

(a) 1.0 m below the base of the footing
(b) 1.5 m below the base of the footing
(c) 2.5 m below the base of the footing
(d) 3 m below the base of the footing

[ESE : 1995]

11.2 **Assertion (A):** Terzaghi's bearing capacity theory is not applied to deep foundations.
Reason (R): Shear strength is mobilized on the sides of deep foundations.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1995]

11.3 A raft foundation is to be constructed on a sandy soil. The maximum differential settlement and limiting maximum settlement as recommended by Indian Standard code are:

	Max. differential settlement	Limiting max. settlement
(a)	40 mm	65 mm to 100 mm
(b)	40 mm	40 mm to 65 mm
(c)	25 mm	65 mm to 100 mm
(d)	25 mm	40 mm to 65 mm

[ESE : 1996]

11.4 A rectangular footing 1 m x 2 m is placed at a depth of 2 m in a saturated clay having an unconfined compressive strength of 100 kN/m^2. According to Skempton, the net ultimate bearing capacity is

(a) 420 kN/m^2 (b) 412.5 kN/m^2
(c) 385 kN/m^2 (d) 350 kN/m^2

[ESE : 1996]

11.5 If the actual observed value of standard penetration resistance, N, is greater than 15 in a fine sand layer below water table, then the equivalent penetration resistance will be

(a) $15+\left(\frac{N+15}{2}\right)$ (b) $15-\left(\frac{N+15}{2}\right)$

(c) $15+\left(\frac{N-15}{2}\right)$ (d) $15+\left(\frac{15-N}{2}\right)$

[ESE : 1997]

11.6 Match List-I (Field test) with List-II (Parameters measured) and select the correct answer using the codes given below the lists:

List-I
A. Plate Load Test
B. Standard Penetration Test
C. Static Dutch Cone Penetration Test
D. Dynamic Penetration Test

List-II
1. Total and frictional resistances
2. Load intensity and settlement values
3. N_{CD} values
4. SPT values

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	4	2	3	1
(c)	2	4	1	3
(d)	4	2	1	3

[ESE : 1997]

11.7 In standard penetration test, the split spoon sampler is penetrated into the soil stratum by giving blows from a drop weight whose weight (in kg) and free fall (in cm) are, respectively

(a) 30 and 60 (b) 60 to 30
(c) 65 to 75 (d) 75 to 65

[ESE : 1997]

11.8 **Assertion (A):** In the case of sand deposits with uniform density, N values are found to increase with depth.

Reason (R): Overburden pressure increases with depth below ground level.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

11.9 A rectangular footing $L \times B$ is to be placed at a depth D below ground level such that $\frac{D}{B} < 2.5$.

The factor N_C to be used in deciding of the allowable bearing capacity for the footing as given by Skempton is calculated using the equation

(where $N_{CR} = N_C$ for rectangular footing, $N_{CS} = N_C$ at surface)

(a) $N_{CR} = 1.4\, N_{CS}$

(b) $N_{CR} = \left(1 + 0.2\frac{D}{B}\right) N_{Cs}$

(c) $N_{CR} = \left(1 + 0.2\frac{B}{L}\right) N_{Cs}$

(d) $N_{CR} = \left(1 + 0.2\frac{B}{L}\right)\left(1 + 0.2\frac{D}{B}\right) N_{Cs}$

[ESE : 1998]

11.10 Consider the following statements associated with local shear failure of soils:

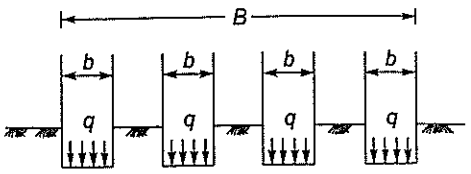
1. Failure is sudden with well-defined ultimate load.
2. This failure occurs in highly compressible soils.
3. Failure is preceded by large settlement.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

[ESE : 1998]

11.11 Four square footings, $b \times b$, each carrying a loading intensity of q are spaced close enough as shown in the given figure:



The significant depth D_s, i.e., depth of vertical stress contour, having a value of $0.2q$ will be

(a) $1.5\,b$ (b) $6.0\,b$
(c) $1.5\,(B - 4b)$ (d) $1.5\,B$

[ESE : 1998]

11.12 Rafts resting on sands can be allowed double of the allowable soil pressure when

(a) permissible settlement is doubled
(b) length is doubled
(c) depth factor is increased
(d) water table is lowered

[ESE : 1998]

11.13 Consider the following statements:

The Standard Penetration Test (SPT) in soils is the most commonly used field test. SPT is used to determine

1. consistency of clay
2. undrained shear strength of soft sensitive clays
3. relative density of sands
4. drained shear strength of fine loose sand

Which of these statements are correct?

(a) 1 and 2 (b) 2 and 4
(c) 1 and 3 (d) 3 and 4

[ESE : 1998]

11.14 Consider the following statements:

1. Dynamic cone penetration test for site investigation is based on the principle that elastic shock waves travel in different materials at different velocities.
2. Electrical resistivity method of subsurface investigation is capable of detecting only the strata having different electrical resistivity.
3. In-situ vane shear test is useful for determining the shear strength of very soft soil and sensitive clays and is unsuitable for sandy soil.

Which of these statements is/are correct?

(a) 1 and 2 (b) 1 and 3

(c) 2 and 3 (d) 2 alone

[ESE : 1998]

11.15 As per IS:1904-1986 the permissible angular distortion with respect to steel structures in isolated foundations resting on plastic clay is

(a) $\frac{2}{3000}$ (b) $\frac{1}{3000}$

(c) $\frac{1}{300}$ (d) $\frac{2}{300}$

[ESE : 1999]

11.16 Influence factor for immediate settlement of footing depends on its

(a) size and shape

(b) rigidity alone

(c) location and size

(d) size, shape, rigidity and location

[ESE : 1999]

11.17 As per Terzaghi's equation, the bearing capacity of strip footing resting on cohesive soil (c = 10 kN/m^2) for unit depth and unit width (assume N_c as 5.7) is

(a) 47 kN/m^2 (b) 57 kN/m^2

(c) 67 kN/m^2 (d) 77 kN/m^2

[ESE : 1999]

11.18 A raft of 6 m × 9 m is founded at a depth of 3 m in a cohesive soil having c = 120 kN/m^2. The ultimate net bearing capacity of the soil using the Terzaghi's theory will be nearly

(a) 820 kN/m^2 (b) 920 kN/m^2

(c) 1036 kN/m^2 (d) 1067 kN/m^2

[ESE : 1999]

11.19 The standard penetration resistance N of a granular deposit is found to be 20. The soil can be classified approximately in terms of ϕ and density index respectively as

(a) 20° and 10% for very loose condition

(b) 32° and 50% for medium condition

(c) 32° and 30% for loose condition

(d) 38° and 65% for dense condition

[ESE : 1999]

11.20 Match List-I (In-situ test) with List-II (Measurement) and select the correct answer using the codes given below the lists:

List-I

A. SPT test

B. Plate load test

C. Field vane shear test

D. CPT test

List-II

1. Penetration resistance (N value)
2. Load settlement data
3. Point resistance and skin friction
4. In situ shear strength

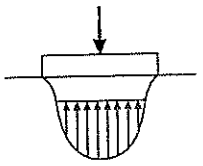
Codes:

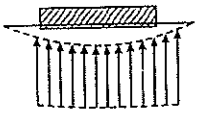
	A	B	C	D
(a)	1	2	4	3
(b)	1	2	3	4
(c)	2	1	3	4
(d)	2	1	4	3

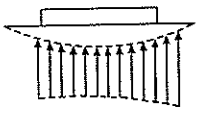
[ESE : 2000]

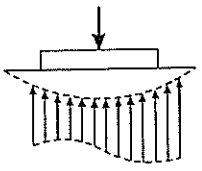
11.21 Match List-I (Contact pressure distribution diagrams) with List-II (Description of footings) and select the correct answer using the codes given below the lists:

List-I

A. 

B. 

C. 

D. 

List-II

1. Rigid footing on cohesive soil
2. Flexible footing on cohesive soil
3. Rigid footing on cohesion-less soil at ground level
4. Flexible footing on cohesionless soil at ground level

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	4	2	3	1
(c)	3	2	4	1
(d)	4	1	3	2

[ESE : 2000]

11.22 Assertion (A): Larger footings settle more than the smaller footings under the same load intensity.

Reason (R): Size of the pressure bulb depends upon the size of the footing.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

11.23 Depth of foundation depends upon

(a) scour depth, minimum grip length and Rankine depth
(b) scour depth, minimum grip length and depth of bearing stratum
(c) scour depth, Rankine depth and depth of bearing stratum
(d) minimum grip length, Rankine depth and depth of bearing stratum

[ESE : 2000]

11.24 Match List-I (Test) with List-II (Property) and select the correct answer using the codes given below the lists:

List-I
A. Proctor Test
B. Vane Test
C. Penetration Test
D. Hydrometer Test

List-II
1. Grain Size Analysis
2. Shear Strength
3. Bearing Capacity
4. Compaction

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	4	2	1	3
(c)	4	2	3	1
(d)	2	4	3	1

[ESE : 2001]

11.25 Two circular footings of diameters D_1 and D_2 are resting on the surface of a purely cohesive soil. The ratio $D_1/D_2 = 2$. If the ultimate load carrying capacity of the footing of diameter D_1 is 200 kN/m^2, then the ultimate bearing capacity (in kN/m^2) of the footing of diameter D_2 will be

(a) 100 (b) 200
(c) 314 (d) 571

[ESE : 2001]

11.26 The minimum bearing capacity of a soil under a given footing occurs when the groundwater table at the location is at

(a) the base of the footing
(b) the ground level
(c) a depth equal to one-half the width of footing
(d) a depth equal to the width of footing

[ESE : 2001]

11.27 Match List-I (Field test) with List-II (Property) and select the correct answer using the codes given below the lists:

List-I
A. Pumping test
B. Plate load test
C. Pile load test

List-II
1. Bearing capacity
2. Load carrying capacity
3. Permeability

Codes:

	A	B	C
(a)	1	2	3
(b)	3	1	2
(c)	2	3	1
(d)	3	2	1

[ESE : 2001]

11.28 A rigid strip footing subjected to vertical central load fails under general shear failure. The rupture surface developed is

(a) circular one sided rotational failure
(b) plane surface of failure originating at the edge of footing and extending downwards with orientation of Rankine passive state equilibrium
(c) symmetrical failure surface consisting of segment of spiral and Rankine's passive state failure surface
(d) symmetrical failure surface consisting of segments of log spiral and plane failure surface as per Rankine active state of equilibrium

[ESE : 2002]

11.29 In a plate load test on sandy soil, the test plate of 60 cm × 60 cm undergoes a settlement of 5 mm at a pressure of 12×10^4 N/m^2. What will be the expected settlement of 3 m × 3 m footing under same pressure?
(a) 25 mm (b) 20 mm
(c) 15 mm (d) 9 mm

[ESE : 2002]

11.30 Assertion (A): Terzaghi's bearing capacity theory overestimates the bearing capacity of footings.
Reason (R): Terzaghi's theory neglects the shearing resistance of rupture surface in the soil above the foundation level.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

11.31 If two foundations, one narrow and another wide, are resting on a bed of sand carrying the same intensity of load per unit area, then which one is likely to fail early?
(a) Narrow foundation
(b) Wider foundation
(c) Both will fail simultaneously
(d) Difficult to judge since other conditions are unknown

[ESE : 2003]

11.32 The contact pressure distribution under a rigid footing on a cohesionless soil would be
(a) uniform throughout
(b) zero at centre and maximum at edges
(c) zero at edges and maximum at centre
(d) maximum at edges and minimum at centre

[ESE : 2003]

11.33 A strip footing having 1.5 m width founded at a depth of 3 m below ground level in a clay soil having $c = 20$ kN/m^2, $\phi = 0°$ and unit weight $\gamma = 20$ kN/m^3. What is the net ultimate bearing capacity using Skempton's analysis?
(a) 30 kN/m^2 (b) 60 kN/m^2
(c) 100 kN/m^2 (d) 140 kN/m^2

[ESE : 2004]

11.34 When a load test was conducted by putting a 60 cm square plate on top of a sandy deposit, the ultimate bearing capacity was observed as 60 kN/m^2. What is the ultimate bearing capacity for a strip footing of 1.2 m width to be placed on the surface of the same soil?
(a) 75 kN/m^2 (b) 120 kN/m^2
(c) 150 kN/m^2 (d) 160 kN/m^2

[ESE . 2004]

11.35 A plate load test is conducted on a cohesionless soil with a test plate having width B_p(cm) and settlement of this plate S_p(cm) is obtained at the same load intensity as a foundation. A footing having a width B_f(cm) is to be constructed as foundation. What is the settlement S_f(cm) experienced by this footing?
(a) $S_f = S_p \{[B_f(B_p + 30)]/[B_p(B_f + 30)]\}^2$
(b) $S_f = S_p \{[B_p(B_f + 30)]/[B_f(B_p + 30)]\}^2$
(c) $S_f = S_p [B_f/B_p]$
(d) $S_f = S_p [B_p/B_f]$

[ESE : 2004]

11.36 Match List-I (Type of strata below foundation) with List-II (Type of foundation movement) and select the correct answer using the codes given below the lists:

List-I
A. Sand
B. Heterogeneous landfill
C. Black cotton soil
D. Hard rock

List-II

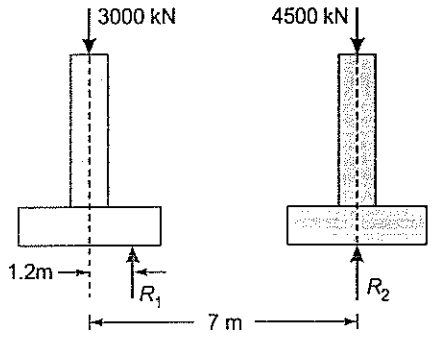
1. Practically no movements
2. Immediate settlements
3. Large relative settlements
4. Heaving of foundations

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	2	3	4	1
(c)	3	2	1	4
(d)	3	2	4	1

[ESE : 2004]

11.37 A strap footing is to be provided for the two columns shown in the diagrams given below.



What is the length L of the left footing? Take width of both the footings as 3.5 m and safe bearing capacity of soil as 350 kN/m^2.

(a) 2.0 m (b) 2.5 m
(c) 3.5 m (d) 2.95 m

[ESE : 2004]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

11.38 **Assertion (A):** Raft foundations are the best type of shallow foundations to support heavy structures.

Reason (R): Raft foundations has the ability to redistribute load coming on weak pockets of soil below raft to the adjacent soils where the stresses are less severe for the soil at that place. This reduces the chances of differential settlements and increases the bearing capacity.

[ESE : 2004]

11.39 **Assertion (A):** Plate load test carried out at the site gives field test data which is useful in evaluation of bearing capacity and settlements. It is normally conducted at the level of the proposed foundation.

Reason (R): Plate load test is reliable because it reflects the true behaviour of foundation stratum below the proposed level of foundation and extending up to large depth below.

[ESE : 2004]

11.40 Consider the following statements:

1. The standard penetration test is a reliable method for measuring the relative density of granular soils.
2. For a sand having the same relative density, N-values remain the same at all depths.
3. For a sand having the same relative density, N-values are different at different depths.

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 1 and 2
(c) 3 only (d) 1 and 3

[ESE : 2005]

11.41 Which one of the following states of field compaction of sand deposit truly represents the corrected standard penetration test value: N (corrected) = 27?

(a) Loose (b) Medium dense
(c) Dense (d) Very dense

[ESE : 2005]

11.42 In case of footing on the surface or shallow depth in very dense sand which one of the following types of failure is likely to occur?

(a) Punching shear failure
(b) Local shear failure
(c) General shear failure
(d) Any of the above three

[ESE : 2005]

11.43 The bearing capacity factors N_c, N_q and N_γ are functions of
(a) width and depth of footing
(b) density of soil
(c) cohesion of soil
(d) angle of internal friction of soil
[ESE : 2005]

11.44 Assertion (A): The bearing capacity of a footing always gets affected by the location of ground water table.
Reason (R): Water in soil affects the shear strength parameters as well as the unit weight.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2005]

11.45 In a plate load test, how is the ultimate load estimated from the load settlement curve on a log-log graph?
(a) Directly
(b) By drawing tangents to the curve at the initial and final points
(c) By the secant method
(d) At 0.2 per cent of the maximum settlement
[ESE : 2005]

11.46 In which one of the following zones is a logarithmic spiral shape of failure surface assumed in the case of bearing capacity analysis of c-ϕ soils?
(a) Active zone
(b) Passive zone
(c) Radial shear zone
(d) Surcharge zone
[ESE : 2005]

11.47 A test plate 30 cm square, settles by 12 mm under a load of 4.5 kN in a sandy soil. By how much will a footing 2 m × 2 m subjected to a load of 200 kN settle?
(a) 36.3 mm (b) 20.87 mm
(c) 75.75 mm (d) 18.15 mm
[ESE : 2006]

11.48 The contact pressure distribution below rigid footing on the surface of a clay soil is
(a) uniform for the full width
(b) maximum at the centre and minimum at the edges
(c) maximum at the edges and minimum at the centre
(d) of an irregular shape
[ESE : 2007]

11.49 Consider the following statements:
1. The bearing capacity of a footing on clay does not significantly get altered by the presence of water table.
2. The bearing capacity of a footing on saturated clay ($\phi = 0$) is a function of its size.
Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2007]

11.50 Consider the following statements:
Criteria for satisfactory performance of footings are that the
1. soil supporting the footing must be safe against shear failure
2. footing must not settle more than a pre-specified value
3. footing must be rigid
4. footing should be above water table.
Which of these statements are correct?
(a) 3 and 4 (b) 1 and 2
(c) 1 and 3 (d) 2 and 4
[ESE : 2007]

11.51 The observed N-value from a standard penetration test conducted in saturated sandy strata is 30; the N-value corrected for dilatancy may be taken as
(a) 18 (b) 23
(c) 28 (d) 36 [ESE : 2007]

11.52 Assertion (A): Estimation of settlement of foundations on sandy soils can be done by using SPT values .
Reason (R): Sampling in cohesionless soils without disturbing the structure is difficult.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false
(d) A is false but R is true [ESE : 2007]

11.53 Match List-I (Equipments) with List-II (Use) and select the correct answer using the codes given below the lists:

List-I
A. Hydrometer
B. Plate load test set up
C. Pycnometer
D. Direct shear apparatus

List-II
1. Determination of shear parameters
2. Determination of specific gravity
3. Determination of bearing capacity of soils
4. Grain size distribution tests for clays

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	4	3	2	1
(c)	2	3	4	1
(d)	4	1	2	3

[ESE : 2008]

11.54 Consider the following statements in respect of static cone penetration test:
1. The cone used has an apex angle of 60° and base area of 10 cm^2.
2. This test give a continuous record of cone resistance.

Which of these statements is/are correct?
(a) 1 only
(b) 2 only
(c) Both 1 and 2
(d) Neither 1 nor 2 [ESE : 2008]

11.55 Which factors influence the bearing capacity of a purely cohesionless soil?
1. Relative density of soil
2. Width and depth of footing
3. Unit weight of soil

Select the correct answer using the codes given below:
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3
[ESE : 2008]

11.56 Match List-I (Field test) with List-II (Suitability) and select the correct answer using the codes given below the lists:

List-I
A. Plate load test
B. Standard penetration test
C. Vane shear test
D. Dilatancy test

List-II
1. To estimate bearing capacity of granular soil
2. To estimate in situ strength of soft clay
3. To identify silt from clay
4. To estimate bearing capacity for permissible settlement in clays

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2008]

11.57 Match List-I (Test) with List-II (Utility) and select the correct answer using the codes given below the lists:

List-I
A. Field density test
B. Plate load test
C. CBR

List-II
1. Stress deformation characteristics
2. Compaction characteristics
3. Design of pavement
4. Safe load bearing capacity of soil

Codes:

	A	B	C
(a)	2	4	1
(b)	4	2	1
(c)	4	2	3
(d)	2	4	3

[ESE : 2008]

11.58 For a proposed building, raft foundation, isolated footings and combined footings are being considered. These foundations are to be listed in the decreasing order of preference in terms of performance. Which one of the following is the correct order of listing?
(a) Raft foundation – Combined footings –Isolated footings
(b) Isolated footings – Raft foundation –Combined footings

(c) Combined footings – Raft foundation –Isolated footings
(d) Combined footings – Isolated footings –Raft foundation

[ESE : 2008]

11.59 Consider the following statements:
Foundation design in expansive soil can be done by
1. isolating the foundation from the swelling soil
2. taking measures to prevent the swelling
3. employing measures to make the structure withstand the movement

Which of these statements is/are correct?
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2008]

11.60 Assertion (A): Foundation on expansive soils must be designed for as high a bearing pressure as possible consistent with the bearing capacity and settlement requirement.
Reason (R): Lightly loaded single and two storeyed buildings experience maximum damage when built on expansive soils.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2008]

11.61 On which of the following soils is the standard penetration test useful?
1. Cohesionless soils
2. Medium clays
3. Gravelly soils
4. Very stiff clays

Select the correct answer using the codes given below:
(a) 1 only (b) 1 and 3
(c) 1 and 2 (d) 3 and 4

[ESE : 2009]

11.62 Consider the following statements:
1. Standard penetration test (SPT) is conducted by pushing a cone into soil at the rate of 2 cm/s.
2. Standard penetration test results are unreliable in deposits containing large number of boulders.
3. Dutch cone is a static penetrometer.

Which of these statements is/are correct:
(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 3 only

[ESE : 2009]

11.63 Consider the following statements:
Increasing width of footing results in
1. increase in settlement of a consolidating clay layer
2. Increase in bearing capacity of sandy soils
3. decrease in bearing capacity of clays

Which of these statements is/are correct?
(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2009]

11.64 If an SPT test gave the average blow count of 32 in fine sand below water table, then what is the corrected value of blow count?
(a) 22.1 (b) 23.5
(c) 24.2 (d) 24.8

[ESE : 2009]

11.65 The standard penetration resistance value obtained in a deep deposit of sand at a depth of 6.0 m was 28. The unit weight of sand is 18.0 kN/m^3. What is the corrected value of number of blows for overburden pressure?
(a) 60 (b) 57
(c) 59 (d) 55

[ESE : 2009]

11.66 The net ultimate bearing capacity of a purely cohesive soil
(a) depends on the width of the footing and is independent of the depth of the footing
(b) depends on the width as well as the depth of the footing
(c) depends on the depth, but is independent of the width, of the footing
(d) is independent of both the width and the depth of the footing

[ESE : 2009]

11.67 A soil has a low allowable bearing capacity. The soil deposit contains compressible loess. A foundation is to be provided for a structure

carrying a heavy load. Which one of the following foundation types is to be adopted?
(a) Strap footing
(b) Continuous footing
(c) Raft foundation
(d) Combined spread foundation

[ESE : 2009]

11.68 The observed *N*-value from a standard penetration test conducted in saturated sandy strata is 30; the *N*-value corrected for dilatancy may be taken as
(a) 15 (b) 20
(c) 23 (d) 39

[ESE : 2011]

11.69 Two footings, one circular and the other square, are founded on the surface of a purely cohesionless soil. The diameter of the circular footing is the same as that of the side of the square footing. The ratio between their ultimate bearing capacities will be
(a) 1.0 (b) 1.3
(c) 1.33 (d) 0.75

[ESE : 2011]

11.70 Consider the following statements:
1. Standard penetration test is commonly used for cohesionless soils.
2. Standard penetration test results in respect of a cohesionless soil are correlated to its density index and friction angle.
3. Use of *N*-value not corrected for overburden pressure leads to highly conservative design of footings at shallow depths.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

11.71 If water table is encountered in the standard pit while conducting plate load test
(a) The load test should be abandoned
(b) The pit is considered unsafe
(c) Test should be conducted with complete dewatering continuously throughout the test duration.
(d) The bearing capacity of soil cannot be determined in this condition

[ESE : 2012]

11.72 Consider the following statements relating to foundations on expansive soils:
1. Strength should be improved and compressibility should be reduced.
2. Compressibility should be increased.
3. No stabilization should be done.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 2 only
(c) 1 only (d) 3 only

[ESE : 2012]

11.73 Consider the following statements
1. The benefit of surcharge and depth of foundation is only marginal in case of footings on purely cohesive soils.
2. The bearing capacity of a footing in pure clay increases with increase in size of the footing.
3. Size effects in plate load tests are more important in case of cohesionless soils.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

11.74 The mean unconfined compressive strength of a purely cohesive soil was found to be 50 kN/m^2. The ultimate bearing capacity of a square footing calculated by Terzaghi's concept (bearing capacity factor $NC = 5.7$) will be
(a) 185.25 kN/m^2 (b) 390.5 kN/m^2
(c) 285 kN/m^2 (d) 142.5 kN/m^2

[ESE : 2012]

11.75 The ultimate bearing capacity of a square footing on surface of a saturated clay having unconfined compression strength of 50 kN/m^2 (using Skempton's equation) is
(a) 250 kN/m^2 (b) 180 kN/m^2
(c) 150 kN/m^2 (d) 125 kN/m^2

[ESE : 2013]

11.76 Consider the following statements:
1. In the case of footings on purely cohesive soils, the benefit due to surcharge or depth of foundation is only marginal.
2. The bearing capacity of a footing in pure clay may be increased by increasing its size.
3. Factor of safety should be applied only to the net ultimate bearing capacity.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3
[ESE : 2014]

11.77 The gross bearing capacity of a footing is 450 kN/m^2. If the footing is 1.5 m wide and is at a depth of 1 m in a clayey soil which has a unit weight of 20 kN/m^3, then the net bearing capacity is
(a) 410 kN/m^2 (b) 420 kN/m^2
(c) 430 kN/m^2 (d) 440 kN/m^2
[ESE : 2014]

11.78 A footing 1 m × 1 m in size rests on the surface of an infinite layer of soil. It is subjected to a load of 600 kN. What is the immediate settlement of the soil by considering Eu = 2.0 MPa, N = 0.5 and influence factor = 0.95?
(a) 22.5 mm (b) 25.5 mm
(c) 27.5 mm (d) 30.0 mm
[ESE : 2015]

11.79 Consider the following statements:
1. The proportioning of footing in sand is more often governed by settlement rather than by bearing capacity.
2. The pressure bulb profiles under a strip footing form as co-axially imaginable bulbs under its length.
3. Friction piles are also called floating piles.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only
[ESE : 2015]

11.80 Which of the following factors affect the bearing capacity of cohesive soils?
1. Density of the soil
2. Angle of shearing resistance of the soil
3. Depth of the footing
4. Width of the footing
(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4
[ESE : 2015]

11.81 Consider the following statement:
1. The ultimate bearing capacity of a footing on sand increases.
2. The settlement of the footing on sand increases with increase in its width.

Which of the above statements are correct?
(a) 1 only (b) Both 1 and 2
(c) 2 only (d) Neither 1 nor 2
[ESE : 2015]

11.82 **Assertion (A):** In cohesive soils, the ultimate bearing capacity is independent of foundation width.
Reason (R): The ultimate bearing capacity of cohesive soils increases with depth below ground level.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2015]

11.83 In a plate load test on a soil, at a particular magnitudes of the settlement, it was observed that the bearing pressure beneath the footing is 100 kN/m^2 and the perimeter shear is 25 kN/m^2. Correspondingly, the load capacity of a 2 m square footing at the same settlement will be
(a) 200 kN (b) 300 kN
(c) 400 kN (d) 600 kN
[ESE : 2017]

11.84 Consider the following statements:
1. According to Terzaghi, a foundation is shallow if its depth is equal to or less than its width.
2. Spread footing, strap footing and raft footing are types of shallow foundations.
3. Combined footing may be trapezoidal if the two columns carry unequal loads; and rectangular if both columns carry equal loads.
4. For water tanks, providing raft foundations will avoid unequal settlements.

Which of the above statements are correct?
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1, 2 and 4 only (d) 3 and 4 only
[ESE : 2017]

11.85 Consider the following statements:
For a rigid footing placed at the ground surface on sand, the contact pressure
1. is maximum at the edges.
2. is zero at the edges.
3. distribution is parabolic.
4. is uniform throughout the base of the footing.

Which of the above statements are correct?
(a) 1 and 3 only (b) 1 and 4 only
(c) 2 and 3 only (d) 2 and 4 only
[ESE : 2017]

11.86 Consider the following statements as suggestive of the bearing capacity of soil:
1. The maximum net loading intensity at which neither the soil fails in shear nor is there excessive settlement detrimental to the structure.
2. The maximum net pressure which the soil can carry without shear failure.
3. The net ultimate bearing capacity of the soil divided by a factor of safety.

Which of the above statements is/are correct?
(a) 1, 2 and 3 (b) 1 only
(c) 2 only (d) 3 only
[ESE : 2017]

■■■■

Answers Shallow Foundation and Bearing Capacity

11.1 (d)	11.2 (a)	11.3 (d)	11.4 (c)	11.5 (c)	11.6 (c)	11.7 (c)	11.8 (a)	
11.9 (d)	11.10 (c)	11.11 (d)	11.12 (a)	11.13 (c)	11.14 (c)	11.15 (c)	11.16 (d)	
11.17 (b)	11.18 (a)	11.19 (b)	11.20 (a)	11.21 (c)	11.22 (a)	11.23 (a)	11.24 (c)	
11.25 (b)	11.26 (b)	11.27 (b)	11.28 (c)	11.29 (d)	11.30 (d)	11.31 (a)	11.32 (c)	
11.33 (d)	11.34 (c)	11.35 (a)	11.36 (b)	11.37 (d)	11.38 (a)	11.39 (c)	11.40 (c)	
11.41 (b)	11.42 (c)	11.43 (d)	11.44 (d)	11.45 (a)	11.46 (c)	11.47 (a)	11.48 (c)	
11.49 (d)	11.50 (b)	11.51 (b)	11.52 (b)	11.53 (b)	11.54 (c)	11.55 (d)	11.56 (c)	
11.57 (d)	11.58 (a)	11.59 (d)	11.60 (a)	11.61 (a)	11.62 (c)	11.63 (b)	11.64 (b)	
11.65 (d)	11.66 (d)	11.67 (c)	11.68 (c)	11.69 (d)	11.70 (a)	11.71 (c)	11.72 (c)	
11.73 (d)	11.74 (a)	11.75 (c)	11.76 (d)	11.77 (c)	11.78 (*)	11.79 (a)	11.80 (a)	
11.81 (b)	11.82 (b)	11.83 (d)	11.84 (a)	11.85 (c)	11.86 (c)			

Explanations Shallow Foundation and Bearing Capacity

11.1 (d)

When the water table is B depth below the base of the footing there is no effect of ground water table on bearing capacity. (B is the width of footing)

11.2 (a)

Terzaghi's bearing capacity theory is for general shear failure. While the load capacity of piles is sum of shaft resistance (friction) and end bearing resistance.

11.3 (d)

For Raft foundation on sand maximum permissible settlement is 40 to 65 mm. The permissible differential settlement is 25 mm.

For raft foundation on clay, limiting maximum settlement 65 to 100 mm. Maximum differential settlement 40 mm.

11.4 (c)

$$q_{net,\,ult} = cN_c$$

$$N_c = 5\left(1+0.2\frac{B}{L}\right)\left(1+0.2\frac{D_f}{B}\right)$$

for $\frac{D_f}{B} < 2.5$

$$= 5\times\left(1+0.2\times\frac{1}{2}\right)\left(1+0.2\times\frac{2}{1}\right) = 7.7$$

$$c = q_u/2 = 100/2$$

$$= 50\ \text{kN/m}^2$$

$$\therefore \quad q_{net,ult} = 50 \times 7.7 = 385\ \text{kN/m}^2$$

11.5 (c)

Saturated fine or silty dense or very dense sand deposits below water table have a tendency to dilate during shear under undrained conditions. Therefore the observed N value is more than actual value and dilatancy correction should be applied as

$$N' = 15+\left(\frac{N-15}{2}\right) = \frac{N+15}{2}$$

It is based on the assumption that critical void ratio occurs at $N = 15$.

11.6 (c)

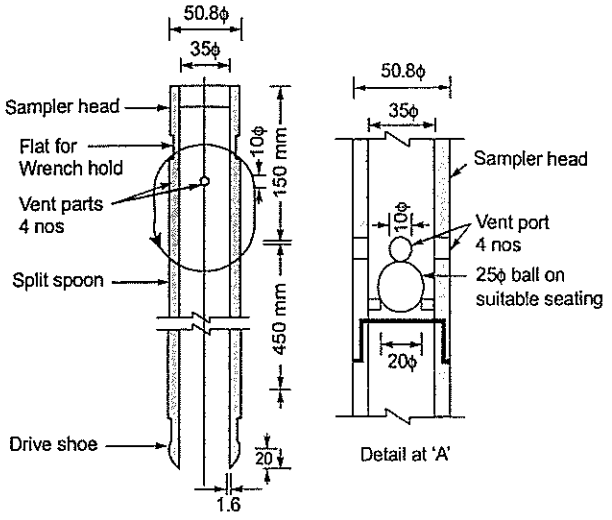
Plate Load Test is a field test for determining the ultimate bearing capacity of soil and the likely settlement under a given load. The Plate Load Test basically consists of loading a steel plate placed at the foundation level and recording the settlements corresponding to each load increment.

The Standard Penetration Test (SPT) provides a disturbed sample of soil and a blow count which approximately correlates to density/strength of soil, by driving a hollow split spoon sampler into the ground.

Static Cone Penetration Test – Also known as Dutch Cone for CPT, it gives a continuous record of variation of both cone resistance and friction resistance with depth. CPT however does not yield any sample. It is suitable for soft clay and silts & fine to medium sand deposits.

11.7 (c)

A standard split spoon sampler consists of a thick wall tube having outer diameter of 50.8 mm and internal diameter of 35 mm and a length of 600 mm. The tube has a drive shoe attached to its bottom and coupling head at top to accommodate the drill rod, used for testing. The drill rod is coupled to sampler head and the sampler is lowered into the clean hole, made in the ground in advance. The sampler is driven into the undisturbed soil at the bottom of the hole, with the help of a driving weight assembly consisting of a driving head and a 650 N weight with 750 mm free fall. The blows from the driving weight fall on the drill rod which drives the sampler into the soil. The sampler is first driven through 150 mm in the hole. This is known as seating drive. The sampler is then driven further through 300 mm and the number of blows required for 300mm penetration are recorded. This number of blows is termed as penetration resistance of soil and is represented by symbol N.



11.8 (a)

With the increase of overburden pressure with increasing depth, the *N* value also increase.

11.9 (d)

According to Skempton's analysis of cohesive soils, it has been shown that the bearing capacity factors in Terzaghi's equation tends to increase with depth for a cohesive soil.

For $\left(\frac{D_f}{B}\right) < 2.5$, (where D_f is the depth footing and B is the base width)

(N_c) for rectangular footing

$$= 5\left(1+\frac{0.2D_f}{B}\right)\left(1+\frac{0.2B}{L}\right) \le 9$$

(N_c) for circular and rectangular footing

$$= 6\left(1+\frac{0.2D_f}{B}\right)\left(1+\frac{0.2B}{L}\right) \le 9$$

For $\left(\frac{D_f}{B}\right) < 2.5$, (N_c) for rectangular footing

$$= 7.5\left(1+\frac{0.2B}{L}\right) \le 9$$

11.10 (c)

Sudden and well defined failure occurs in dense sand having relative density (> 70%)

Foundations on sand of relative density between 35 to 70 % do not show sudden failure. As the settlements are about 15% of the foundation width, a visible boundary of sheared zones appear at the surface. However, the peak of the base resistance may never be reached. This type of failure is called as local shear failure.

11.11 (d)

Significant depth = 1.5 *B*

The region within the 0.20 *q* - isobar is called by Terzaghi the "seat of settlement". The depth below centre of footing in active zone (i.e., in "seat of settlement") is 1.5*B*. For a larger footing more area will be affected so the settlement will be more.

11.12 (a)

According to Terzaghi and Peck the allowable soil pressure in cohesionless soils is directly proportional to allowable settlement. So to double the allowable soil pressure, permissible settlement should be doubled.

11.13 (c)

Standard Penetration Test (SPT) gives N-value which can be corrected for energy, overburden pressure and dilatancy in sequence. The corrected *N*-value is correlated with relative density and angle of shearing resistance for cohesionless soils; and unconfined compressive strength and consistency of cohesive soils.

11.14 (c)

Dynamic cone penetration test is used to obtain continuous record of soil resistance by driving the cone using 65 kg falling weight and counting the number of blows for every 10 cm penetration.

11.15 (c)

As per IS:1904-1986

Type of footing	MS (mm)	DS (mm)	AD
A. Isolated footing on plastic clay			
(i) for steel structures	50	0.0033L	$\frac{1}{300}$
(ii) for RCC structures	75	0.0015L	$\frac{1}{666}$
B. Raft foundation on plastic clay			
(i) for steel structures	100	0.0033L	$\frac{1}{300}$
(ii) for RCC structures	100	0.002L	$\frac{1}{500}$

MS: Maximum Settlement
DS: Differential Settlement
AD : Angular Distortion

11.16 (d)

Influence factor for immediate settlement depends upon the shape of the loaded area and the distribution of contact pressure. Thus following factors can be listed :

(i) Shape of footing

(ii) Size of rectangular footing

(iii) Location of point

(iv) Rigidity of footing

For a perfectly flexible square footing immediate settlement at centre is 2 times the immediate settlement at the corners.

11.17 (b)

Bearing capacity,

$$q_{ult} = cN_c + qN_q + \frac{\gamma B}{2}N_\gamma$$

For cohesive soil,

$$N_q = 1.0 \text{ and } N_\gamma = 0$$

$$\therefore \quad q_{net,ult} = q_{ult} - q$$

$$= cN_c = 10 \times 5.7$$

$$= 57 \text{ kN/m}^2$$

11.18 (a)

$$q_{net,ult} = s_c\, c\, N_c$$

where shape factor,

$$s_c = 1 + 0.3\, B/L$$

$$= 1 + 0.3 \times \frac{6}{9} = 1.2$$

$$\therefore \quad q_{net,\,ult} = 1.2 \times 120 \times 5.7$$

$$= 820.8 \text{ kN/m}^2$$

11.19 (b)

N-Value	Density Index	Condition	ϕ
0 – 4	0 – 15%	Very loose	< 28°
4 –10	15 – 35%	Loose	28° – 30°
10 – 30	35 – 65%	Medium dense	30° – 36°
30 – 50	65 – 85%	Dense	36° – 42°
> 50	> 85%	Very Dense	> 42°

$N = 20$ means medium condition soils with

$$\phi = 32°$$

$$D_r = 50\%$$

11.20 (a)

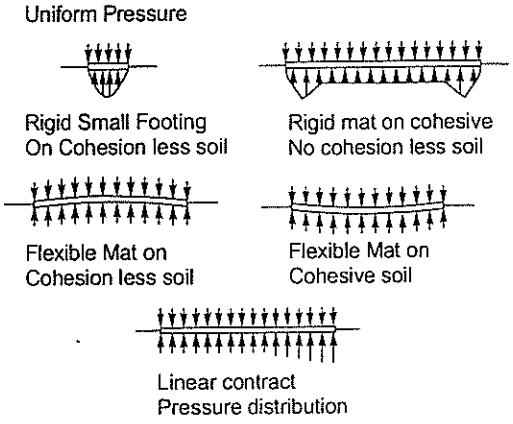
The vane shear test is an in-situ geotechnical testing methods used to estimate the undrained shear strength of fully saturated clays without disturbance.

11.21 (c)

Factor Influencing Contact Pressure:

The actual distribution of contact pressure depends upon a number of factors such as

- Elastic properties of footing
- Elastic properties of soil
- Thickness of footing



11.22 (a)

The region within the 0.20 q - isobar is called by Terzaghi the "seat of settlement". The depth below centre of footing in active zone (i.e., in "seat of settlement") is 1.5B. For a larger footing more area will be affected so the settlement will be more.

11.23 (a)

For well foundations, the depth of foundation depends upon

(i) maximum scour level

(ii) grip length

For shallow foundations, the minimum depth of footing is

$$D_{f,min} = \frac{q_f}{\gamma}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

$D_{f,min}$ is called Rankine depth

11.24 (c)

The Proctor compaction test is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density

Standard Penetration Test is a field test which is basically meant of determine the relative density of the sandy grounds; but has been empirically extended to be used for determining the allowable bearing pressure for a given settlement, and also to approximate shear parameters of the ground.

In case of fine grained soil, sieve analysis test does not give reliable test result. This because a fine grained soil consist of different sizes of particles starting from 0.075 mm to 0.0002 mm. and it is not practicable to design sieve having so smaller screen size. Also there is a chance of lost of sample during sieving. Therefore **hydrometer analysis** is done for grain size analysis of fine grained soils.

11.25 (b)

For footings on purely cohesive soils, the bearing capacity does not depend upon the size of the footing. So the bearing capacity for diameter D_2 will be 200 kN/m^2.

11.26 (b)

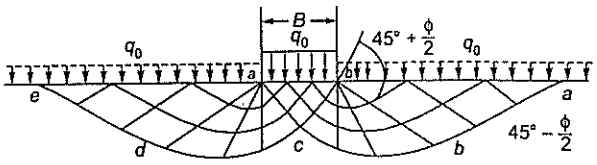
When the water table is at ground level,the surcharge depth D_f and soil below foundation base will be submerged. Thus minimum bearing capacity will occur for this condition.

11.27 (b)

A field **permeability test** consists of pumping out water from a main well and observing the resulting drawdown surface of the original horizontal water table from at least two observation wells. When a steady state of flow is reached, the flow quantity and the levels in the observation wells are noted.

Plate Load Test is a field test for determining the ultimate bearing capacity of soil and the likely settlement under a given load. The Plate Load Test basically consists of loading a steel plate placed at the foundation level and recording the settlements corresponding to each load increment.

11.28 (c)



Failure under a strip footing

11.29 (d)

$S_p = 5.0$ mm; $B_p = 0.6$ m;
$B_f = 3$ m

$$S_f = S_p \times \left(\frac{B_f(B_p + 0.3)}{B_p(B_f + 0.3)} \right)$$

$$\therefore \quad S_f = 5 \times \left(\frac{3(0.6+0.3)}{0.6(3+0.3)} \right)^2$$

$$= 9.3 \text{ mm}$$

11.30 (d)

Terzaghi's theory neglects the shearing resistance of rupture surface in the soil above the foundation level so this theory underestimates the bearing capacity of footing.

Terzaghi considered a continuous footing of width B placed at a depth of D below the ground surface. In the derivation of the equation the following assumptions were made.

- The soil is homogeneous, isotropic and Coulumb's law of shear strength is valid.
- The footing is continuous and has a rough base.
- Failure zone does not extend above the base of the foundation.
- Shear resistance of the soil above the base of the foundation is neglected.
- The soil above the base of the foundation is replaced by a uniform surcharge.
- Principle of superposition holds good.

11.31 (a)

For foundation on sand, the bearing capacity increases with width of the foundation. So narrow foundation will have lesser bearing capacity and it may fail.

11.32 (c)

A rigid footing settles uniformly. So contact pressure will be maximum at centre and zero at edge in cohesionless soils. The distribution is close to parabolic.

11.33 (d)

Net ultimate bearing capacity,

$$q_{nu} = c\,N_c$$

$$N_c = 5(1 + 0.2\,D_f/b)$$

for strip footing

$$= 5(1 + 0.2 \times 3/1.5) = 7$$

$$q_{nu} = 20 \times 7 = 140\ \text{kN/m}^2$$

For square footing or circular footing,

$$N_c = 6(1 + 0.2\,D_f/b)$$

For rectangular footing,

$$N_c = 5(1 + 0.2\,D_f/b)\,(1 + 0.2\,b/L)$$

11.34 (c)

According to Terzaghi,

$$q_{nu} = 0.5\gamma B\,N_\gamma$$

for strip footing

$$= 0.4\,\gamma B\,N_\gamma$$

for square footing

Using the above equations,

$$\gamma N_\gamma = \frac{60}{0.4 \times 0.6} = 250\ \text{kN/m}^3$$

For strip footing,

$$q_{nu} = 0.5 \times 1.2 \times 250$$

$$= 150\ \text{kN/m}^2$$

11.35 (a)

The size effect of footing has been considered by empirically evolving the equation:

$$\frac{S_f}{S_p} = \left(\frac{B_f(B_p + 30)}{B_p(B_f + 30)}\right)^2$$

This equation is applicable for dense sands having general shear failure.

11.36 (b)

Sand shows immediate settlements. Heterogeneous landfill shows uneven or relative settlements. Black cotton soil is highly compressible (shows large volume change) so it can lead to heaving of foundation. Hard rock shows practically no movements/settlements.

11.37 (d)

Taking moment about R_2

$$\text{Reaction } R_1 = \frac{3000 \times 7}{(7 - 1.2)} = 3620.69\ \text{kN}$$

Thus $R_2 = 3000 + 4500 - R_1 = 3879.31\ \text{kN}$

For left footing, $L_1 = \dfrac{3620.69}{350 \times 3.5} = 2.95\ \text{m}$

For right footing, $L_2 = \dfrac{3879.31}{350 \times 3.5} = 3.17\ \text{m}$

11.38 (a)

A raft or mat foundation is a thick reinforced concrete slab which supports all the load bearing walls and column loads of a structure or a large portion of structure. A mat is required where load is heavy and the soil is very weak or highly compressible.

11.39 (c)

The plate load test reflect the characteristics of soil located only within a depth of about twice the width of the plate.

11.40 (c)

SPT is not considered to be a refined and completely reliable method of investigation. The N values give useful information about relative density of cohesionless soils. Thus it does not measure relative density rather correlate N values with relative density.

N values increases with depth due to overburden pressure for sand having same relative density.

Therefore overburden pressure correction are applied.

11.41 (b)

According to Terzaghi and Peck, the following correlation between correct N value and compactness are useful:

N-value	Compactness
0 – 4	Very loose
4 – 10	Loose
10 – 30	Medium dense
30 – 50	Dense
> 50	Very dense

$N = 27$ corresponds to medium dense sands.

11.42 (c)

At shallow depth or surface

Relative Density	Type of failure
< 35	Punching shear
35 – 70	Local shear
> 70	General shear

Very dense sands have high relative density so general shear failure is most likely.

11.43 (d)

Terzaghi's bearing capacity factors N_c, N_q and N_γ are function of angle of friction only.

$N_c > N_q > N_\gamma$ for $\phi < 30°$

$N_c > N_\gamma > N_q$ for $30° < \phi < 40°$

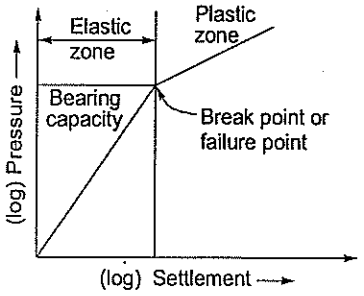
$N_\gamma > N_c > N_q$ for $\phi < 40°$

11.44 (d)

The position of ground water has a significant effect on the bearing capacity of soil. Only if it is present at a depth less than the width of the foundation from the foundation bottom. At depths greater than this, there is no effect on bearing capacity.

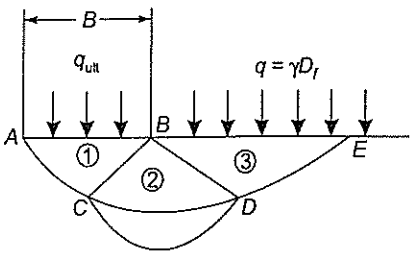
11.45 (a)

The log-log graph of load versus settlement distinctly shows, the failure point. The pressure corresponding to the point is taken as the bearing capacity.



11.46 (c)

According to Terzaghi there are three zones:



Zone-1: Elastic zone of wedge shape located beneath the loaded strip wherein the major principal stress are vertical. This remains in elastic equilibrium and behaves as if it were a part of footing itself and $\angle CAB = \angle CBA = \phi$.

Zone-2: Radial shear zone where arc CD is logarithmic spiral. (Circular when $\phi = 0$).

Zone-3: It is called Rankine passive zone. An overburden pressure $q = \gamma D_f$ acts as a surcharge on this zone.

11.47 (a)

Load intensity for 4.5 kN load on 30 cm square plate will be

$$q = \frac{4.5}{(0.3)^2} = 50 \text{ kN/m}^2$$

Load intensity for 200 kN load on 2 m x 2 m footing will be

$$q' = \frac{200}{4} = 50 \text{ kN/m}^2$$

Since load intensity is same so,

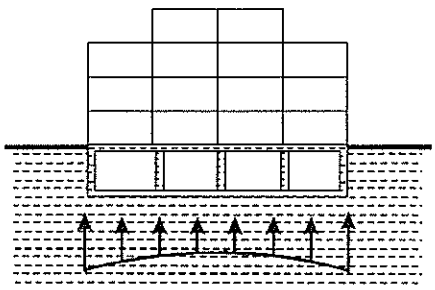
$$S_f = S_p \times \left(\frac{B_f(B_p + 0.3)}{B_p(B_f + 0.3)}\right)^2$$

$$= 12 \times \left(\frac{2 \times 0.6}{0.3 \times 2.3}\right)^2$$

$$= 36.3 \text{ mm}$$

11.48 (c)

Rigid footing on surface of clay, contact pressure is maximum at edges and minimum at centre.



11.49 (d)

The bearing capacity of a footing on saturated clay ($\phi = 0$) is given by

$$q_u = 5.7\, C_u + \gamma D_f$$

11.50 (b)

If footing is satisfying shear criteria and settlement criteria then it does not matter if footing is flexible or rigid, below or above the water table.

11.52 (b)

Sampling in cohensionless soils without disturbing the structure is difficult because there is no cohesion to keep individual grains together and grains may read just among themselves due to slight impacts also while extracting.

11.54 (c)

Static Cone Penetration Test – Also known as Dutch Cone for CPT, it gives a continuous record of variation of both cone resistance and friction resistance with depth. CPT however does not yield any sample. It is suitable for soft clay and silts and fine to medium sand deposits.

11.55 (d)

The bearing capacity of soil is influenced by various factors. The physical features of foundation such as type of foundation, size of foundation, depth of foundation and shape of foundation significantly affect the bearing capacity. The amount of total and differential settlement is one of the main controlling factors for the bearing capacity of the soil. The relative density in the case of granular soil and consistency in the case of cohesive soil play a decisive role in influencing the bearing capacity. The physical as well as engineering properties of soils such as density, cohesion and friction, position of water table and original stresses are the other factors governing the soil bearing capacity.

11.56 (c)

The distinction between silt & clay cannot be based on particle size because the significant physical properties of the two materials are related only indirectly to the size of particles. Furthermore, since both are microscopic, physical properties other than particle size must be used as criteria for field identification. Thus **Dilatancy or Shaking test** is used to distinguish between silts and clays.

11.57 (d)

Field density Test is used to determine in situ density of natural or compacted soils. The in situ density of natural soil is needed for the determination of bearing capacity of soils, for the purpose of stability analysis of slopes, for the determination of pressures on underlying strata for the calculation of settlement and the design of underground structures.

The **california bearing ratio test** is penetration test meant for the evaluation of subgrade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers.

11.58 (a)

- Isolated foundation is provided to support an individual column.
- Combined footing is used when two columns are so close to each other that their individual footings would overlap each other.
- Raft foundation is a large slab supporting a number of columns and walls under the entire structure or a large part of the structure.

11.59(d)

Expansive soil is a very common cause of foundation problems. Depending upon the supply of moisture in the ground, shrink-swell soils will experience changes in volume of up to thirty percent or more. Foundation soils which are expansive will "heave" and can cause lifting of a building or other structure during periods of high moisture. Conversely during periods of falling soil moisture, expansive soil will "collapse" and can result in building settlement. Either way, damage can be extensive.

In order for expansive soil to cause foundation problems, there must be fluctuations in the amount of moisture contained in the foundation soils. If the moisture content of the foundation soils can be stabilized, foundation problems can often be avoided.

11.60 (a)

Foundation on expansive soils must be designed for as high bearing pressure as possible so that they can counteract the swelling pressure generated by the swelling of the expansive soil. However it must be consistent with the bearing capacity and settlement requirement.

11.61 (a)

Vane shear test is more useful for clays.

11.62 (c)

Standard Penetration Test (SPT) is conducted by pushing a split spoon sampler into the soil through a borehole 55 to 150 mm in diameter at the desired depth.

11.63 (b)

Changing the width of footing does not affect the bearing capacity of clays.

11.64 (b)

Corrected SPT value

$$N = 15 + \frac{1}{2}(N' - 15)$$

$$= 15 + \frac{1}{2}(32 - 15)$$

$$= 15 + 8.5 = 23.5$$

11.65 (d)

The effect of overburden pressure on SPT value may be approximated by the equation

$$N = N' \times \left(\frac{350}{\sigma + 70}\right)$$

where σ is effective overburden pressure in kN/m^2 not exceeding 280 kN/m^2

But $\sigma = \gamma H = 18 \times 6 = 108$ kN/m^2

$$\therefore \quad N = 28 \times \left(\frac{350}{108 + 70}\right) = 55$$

11.66 (d)

As per Terzaghi's bearing capacity equation,

$$q_{ult} = cN_c + \gamma D_f N_q + 0.5\,\gamma B N_\gamma$$

For a purely cohesive soil, $N_q = 1$ and $N_\gamma = 0$

$$\therefore \quad q_{ult} = cN_c + \gamma D_f$$

But $q_{net,ult} = q_{ult} - \gamma D_f$

$$\Rightarrow \quad q_{net,ult} = cN_c + \gamma D_f - \gamma D_f$$

$$\Rightarrow \quad q_{net,ult} = cN_c$$

11.67 (c)

Raft or mat foundation is a combined footing which covers the entire area beneath of a structure and supports all the walls and columns. This type of foundation is most appropriate and suitable when the allowable soil pressure is low, or the loading is heavy.

Also, when the soil contains lenses of compressible strata which are likely to cause considerable differential settlement, a raft foundation is well suited.

11.68 (c)

$$N_c = 15 + \frac{1}{2}(N_R - 15)$$

$$= 15 + \frac{1}{2}(30 - 15)$$

$$= 22.5 \approx 23$$

11.69 (d)

Utimate bearing capacity is given by

Circular footing:

$$Q_{uc} = 1.3\,cN_c + \gamma D_f N_q + 0.3\,b\gamma N_\gamma$$

Square footing:

$$Q_{us} = 1.3\,cN_c + \gamma D_f N_q + 0.4\,b\gamma N_\gamma$$

For cohesionless soil : c = 0

For footing on surface of soil: $D_f = 0$

$$\therefore \quad \frac{Q_{uc}}{Q_{us}} = \frac{0.3}{0.4} = 0.75$$

11.70 (a)

The N-value in a granular soil is influenced by the over burden pressure. If two granular soil possesing the same relative density but having different confining pressure are tested, one with a higher confining pressure gives a higher N value. Since the confining pressure increases with depth, the N values at shallow depths are underestimated and the N values at larger depths are overestimated.

11.71 (c)

If water table is encountered while conducting plate load test, it has to be lowered by pumping before placing the plate. Throughout the test duration complete dewatering is to be carried out.

11.72 (c)

Expansive soils have high compressibility and low strength. Hence, strength should be improved and compressibility should be reduced.

11.73 (d)

$$q_u = cN_C + qN_q + 0.5\,\gamma B N_\gamma$$

For pure clay,

$$N_C = 5.7,\ N_q = 1 \text{ and } N_\gamma = 0$$

$$\therefore \quad q_u = 5.7\,c + q$$

$\therefore$ Bearing capacity of a footing in pure clay is independent of size of the footing.

11.74 (a)

For a square footing

$$q_{nu} = 1.3\, cN_C$$

where $c = \frac{50}{2} = 25\ \text{kN/m}^2$

$\therefore$ $q_{nu} = (1.3 \times 25 \times 5.7)\ \text{kN/m}^2$

$= 185.25\ \text{kN/m}^2$

11.75 (c)

$$q_{nu} = c_u N_c$$

where $c_u = \frac{50}{2} = 25\ \text{kN/m}^2$

$N_c = 6(1 + 0.2\, D_f/b)$

for $D_f = 0$, we get $N_c = 6$

$\therefore$ $q_{nu} = 25 \times 6 = 150\ \text{kN/m}^2$

11.76(d)

In case of footings on purely cohesive soils

$q_{nu} = CN_C$

Therefore the benefit due to surcharge or depth of foundation is only marginal. Moreover, the bearing capacity is independent of the size of footing.

11.77 (c)

Gross bearing capacity

$q_g = 450$

Net bearing capacity $= q_g - \gamma \times D_f$

$= 450 - 20 \times 1$ 430 kN/m^2

11.78 (*)

$B = 1000$ mm, $E = 2$ N/mm^2, $I_f = 0.95$, $\mu = 0.5$

$$q = \frac{600 \times 10^3}{(1000)^2} = 0.6\ \text{N/mm}^2$$

Immediate settlement

$$S_i = \frac{qB}{E}\left(1-\mu^2\right) I_f$$

$$= \frac{0.6 \times 1000}{2}\left(1-0.5^2\right) \times 0.95$$

$= 213.75$ mm

11.80 (a)

The bearing capacity of cohesive soil is given by

$$q_u = cN_c + \gamma D_f$$

So, the bearing capacity of cohesive soil will be affected by depth of footing, density of soil, angle of shearing resistance of the soil and not affected by width of footing.

11.81 (b)

Following equation is used from Plate load test data for sands.

$$q_f = q_p \frac{B_f}{B}$$

Settlement of footing (S_f) on sand increases with increase in its width (B_f), can be explained as

$$\frac{S_{f_1}}{S_p} = \left[\frac{B_{f_1}\left(B_p + 0.3\right)}{B_p\left(B_{f_1} + 0.3\right)}\right]^2 \text{ (for 1st footing)}$$

$$\frac{S_{f_2}}{S_p} = \left[\frac{B_{f_1}\left(B_p + 0.3\right)}{B_p\left(B_{f_2} + 0.3\right)}\right]^2 \text{ (for 2nd footing)}$$

$$\therefore \quad \frac{S_{f_1}}{S_{f_2}} = \left[\frac{B_{f_1}\left(B_{f_2} + 0.3\right)}{B_{f_2}\left(B_{f_1} + 0.3\right)}\right]^2 = \left(\frac{1+\frac{0.3}{B_{f_2}}}{1+\frac{0.3}{B_{f_1}}}\right)^2$$

If $B_{f_2} > B_{f_1}$; $\frac{S_{f_1}}{S_{f_2}} < 1$

$\therefore$ $S_{f_2} > S_{f_1}$

Hence settlement increases.

11.82 (b)

In cohesive soil, the ultimate bearing capacity q_u is defined as

$$q_u = cN_c + \gamma D_f N_q$$

So, bearing capacity of cohesive soil is dependent on angle of shearing friction, density of soil and depth of footing only.

11.83 (d)

By an empirical equation given by Housel ,

$$Q = Aq + pS$$

Q = Total load on bearing area

q = Bearing pressure beneath the footing

S = Perimeter shear

A = Area of plate (2×2 m^2)

p = Perimeter of plate ($2 \times 4 = 8$ m)

$Q = (2)^2 (100) + (8)(25)$

$= 400 + 200 = 600$ kN

11.84 (a)

As per Terzaghi, footing is shallow if $\frac{D_f}{B} \leq 1$.

12 Deep Foundation, Sheet Pile Walls and Machine Foundation

12.1 Consider the following statements regarding negative skin friction in piles:

1. It is developed when the pile is driven through a recently deposited clay layer.
2. It is developed when the pile is driven through a layer of dense sand.
3. It is developed due to a sudden drawdown of the water table.

Which of these statements is/are correct?

(a) 1 alone (b) 2 alone
(c) 2 and 3 (d) 1 and 3

[ESE : 1995]

12.2 Efficiency of a pile group is defined as

(a) $\frac{\text{Load carried by the largest pile in the group}}{\text{Load carried by the smallest pile in the group}}$

(b) $\frac{\text{Maximum load carried by a pile in the group}}{\text{Minimum load carried by a pile in the group}}$

(c) $\frac{\text{Minimum load carried by a pile in the group}}{\text{Maximum load carried by a pile in the group}}$

(d) $\frac{\text{Average load carried by a pile in the group}}{\text{Load carried by a single pile}}$

[ESE : 1995]

12.3 Match List-I (Soil property measured) with List-II (In-situ test) and select the correct answer using the codes given below the lists:

List-I

A. Modulus of subgrade reaction
B. Relative density and strength
C. Skin friction and point bearing
D. Elastic constants

List-II

1. Cyclic pile load test
2. Pressuremeter test
3. Plate load test
4. Standard penetration test

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	1	2	4	3
(c)	2	4	1	3
(d)	3	4	1	2

[ESE : 1995]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

12.4 Assertion (A): Bearing capacity of an under-reamed pile is less than that of a straight bored pile of the same diameter.

Reason (R): Under-reamed piles have enlarged bulbs.

[ESE : 1995]

12.5 Assertion (A): Franki pile has an enlarged base of mushroom shape which gives the effect of spread footing.

Reason (R): The Franki pile is best suited for granular soil.

[ESE : 1995]

12.6 Assertion (A): Negative skin friction will act on piles in filled up soils, which should be considered in design of pile foundations.

Reason (R): The filled up soils start consolidating and develop a drag force on the pile.

[ESE : 1996]

12.7 A 30 cm diameter friction pile is embedded 10 m into a homogeneous consolidated deposit. Unit adhesion developed between clay and pile shaft is 4 t/m^2 and adhesion factor is 0.7. The safe load for factor of safety 2.5 will be

(a) 21.50 t (b) 11.57 t
(c) 10.55 t (d) 6.35 t

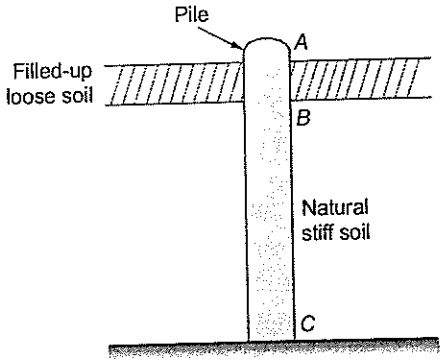
[ESE : 1996]

12.8 In case of well foundation, grip length is defined as the

(a) length below the top of the well cap to the cutting edge
(b) length between the bottom of the well cap to the cutting edge
(c) depth of the bottom of the well below the minimum scour level
(d) depth of the bottom of the well below the maximum scour level

[ESE : 1996]

12.9 Which of the following statements are true for the pile shown in the figure?



1. Frictional resistance acts upwards throughout the length of the pile.
2. Negative skin friction acts over the length AB.
3. Frictional resistance acts upwards over the length BC.
4. There is point resistance at level C.

Select the correct answer using the codes given below:

(a) 1, 3 and 4 (b) 2, 3 and 4
(c) 1 and 2 (d) 2 and 3

[ESE : 1997]

12.10 Consider the following statements regarding under reamed piles:

1. They are used in expansive soils.
2. They are of precast reinforced concrete.
3. The ratio of bulb to shaft diameters is usually 2 to 3.
4. Minimum spacing between the piles should not be less than 1.5 times the bulb diameter.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 4

[ESE : 1997]

12.11 Minimum centre to centre spacing of friction piles of diameter (D) as per BIS code is

(a) 1.5D (b) 2D
(c) 2.5D (d) 3D

[ESE : 1998]

12.12 Consider the following statements:

1. In case of pile groups in cohesive soil, block failure occurs for smaller spacing between the piles.
2. According to Feld's rule for determining pile group efficiency, the load carrying capacity of each pile is increased by 1/16 owing to the effect of the nearest pile.
3. In medium dense sand, settlement of a pile group is more than settlement of single pile.

Which of these statements is/are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1,2 and 3

[ESE : 1998]

12.13 For four free standing pile group having arc tan value of 18.3, the efficiency as per Converse Labarre formula, would be

(a) 76% (b) 78%
(c) 80% (d) 82%

[ESE : 1999]

12.14 Ratio of bearing capacity of double Under Reamed (UR) pile to that of single reamed pile is nearly

(a) 2 (b) 1.5
(c) 1.2 (d) 1.7

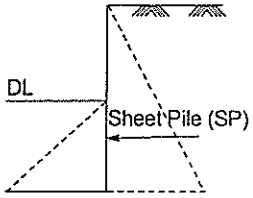
[ESE : 1999]

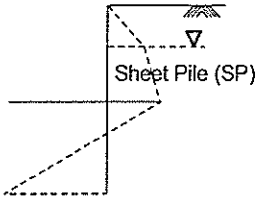
12.15 Match List-I (Sheet piles with various conditions and methods of analysis) with List-II (Earth pressure distribution) and select the correct answer using the codes given below the lists:

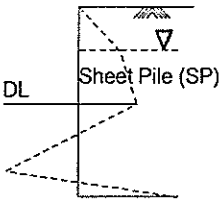
List-I

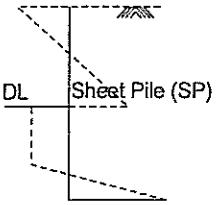
A. Cantilever sheet pile, granular soil and approximate analysis
B. Anchored sheet pile, granular soil and fixed method
C. Anchored sheet pile, granular soil and free earth method
D. Cantilever sheet pile, cohesive soil and approximate analysis

List-II

1. 

2. 

3. 

4. 

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	3	2	1
(c)	4	2	3	1
(d)	1	3	2	4

[ESE : 1999]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

12.16 **Assertion (A):** Anchored sheet pile wall is supported near its top by rods or cables anchored in soil.
Reason (R): The anchor system reduces the depth of penetration and the thickness of section of pile.

[ESE : 1999]

12.17 **Assertion (A):** Pile driving formulae have very limited use in the case of cohesive soils.
Reason (R): Pile driving in cohesive soils results in liquefaction of clays.

[ESE : 2000]

12.18 Match List-I (Suitable condition) with List-II (Foundations) and select the correct answer using the codes given below the lists:

List-I

A. When structural load is uniform and soil is soft clay, made up of marshy land.
B. When structural load is heavy and/or soil having low bearing capacity for considerable depth.
C. When soil is having good bearing capacity at shallow depth and structural load is within permissible limit.
D. When structural load of bridge is to be transferred through sandy soil to bed rock.

List-II

1. Footings
2. Piles
3. Rafts
4. Wells or piers

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	4	1	2	3
(c)	4	2	1	3
(d)	3	2	1	4

[ESE : 2000]

12.19 The nature of earth pressure above dredge line behind a cantilever sheet pile wall is
(a) active
(b) passive
(c) at rest
(d) active and passive

[ESE : 2000]

12.20 A machine foundation weighs 39.24 kN and has a spring constant k = 10000 kN/m. The system will be critically damped if the damping coefficient C_c is (acceleration due to gravity, $g = 9.81\ m^2/s$)
(a) 100 kN-s/m (b) 200 kN-s/m
(c) 400 kN-s/m (d) 800 kN-s/m

[ESE : 2000]

12.21 In the Engineering News Record formula for determining the safe load carrying capacity of a pile, the factor of safety used is
(a) 2.5 (b) 3
(c) 4 (d) 6

[ESE : 2001]

12.22 In the case of a pile foundation, negative skin friction may occur at a load which is
(a) lower than the designed load
(b) higher than the designed load
(c) equal to the designed load
(d) of any magnitude

[ESE : 2001]

12.23 In under-reamed pile construction, the ratio of shaft diameter to bulb diameter is
(a) 1/1.5 (b) 1/2
(c) 1/2.5 (d) 1/4

[ESE : 2001]

12.24 A single pile, 50 cm in diameter and 15 m long is driven in clay having an average un-confined compressive strength of 100 kN/m^2. The ultimate bearing capacity of the pile, neglecting end bearing, if any, and assuming shear mobilization factor of 0.8 around the pile is
(a) 942 kN (b) 1884 kN
(c) 1177.5 kN (d) 1334.5 kN

[ESE : 2002]

12.25 Match List-I (Method of estimating pile capacity) with List-II (Parameter to be estimated) and select the correct answer using the codes given below the lists:

List-I
A. Dynamic formulae
B. Static formulae
C. Pile load test
D. Cyclic pile load test

List-II
1. Bearing capacity of cast-in-situ concrete pile
2. Separating end-bearing and friction-bearing powers of a pile
3. Bearing capacity of a timber pile
4. Settlement of a friction bearing pile

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	4	2	3	1
(c)	3	2	4	1
(d)	4	1	3	2

[ESE : 2002]

12.26 Which one of the expressions given below correctly relates natural frequency f_n, spring stiffness 'k', mass 'm' of the machine foundation vibrating system with C_u, the coefficient of elastic uniform compression of the foundation soil?

(a) $f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \sqrt{\frac{C_u A}{m}}$

(b) $f_n = \sqrt{\frac{k}{m}} = 2\pi\sqrt{\frac{C_u A}{m}}$

(c) $f_n = \sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{C_u A}{m}}$

(d) $f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{C_u A}{m}}$

[ESE : 2002]

12.27 For designing end bearing piles of square cross-section in clays having average unconfined compressive strength of 6 t/m^2, the net ultimate bearing capacity may be taken as
(a) 15 t/m^2 (b) 18 t/m^2
(c) 20 t/m^2 (d) 27 t/m^2

[ESE : 2002]

12.28 Assertion (A): In a machine foundation subjected to vibrations, frequency of vibrations with

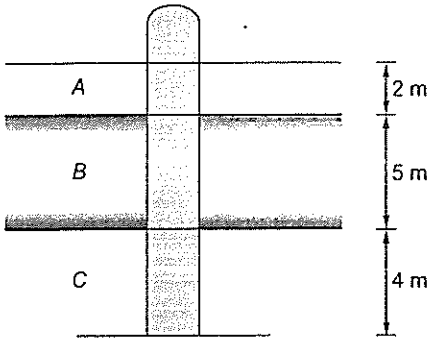
damping is less than the natural frequency of vibrations of the system.

Reason (R): The frequency of vibrations with damping ω_d and natural frequency of vibrations ω_n are related by expression $\omega_d = \omega_n(1 - d^2)$ where d is the damping ratio.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

12.29 Skin frictional capacities of a 40 cm diameter driven concrete pile for the portions *A*, *B* and *C* are 17 kN, 63 kN and 503 kN respectively, and point load capacity is 11000 kN/m^2. Total pile load capacity will be



(a) 3743 kN (b) 2864 kN
(c) 1965 kN (d) 1529 kN

[ESE : 2003]

12.30 Sinking effort in well foundation is the ratio of weight of well steining to that of skin friction developed on the sides and should preferably be

(a) < 1.0 (b) = 1.0
(c) > 1.0 (d) > 2.0

[ESE : 2003]

12.31 Match List-I (Type of Foundation) with List-II (Type of Soil) and select the correct answer using the codes given below the lists:

List-I
A. Floating piles
B. Micro Piles
C. Combined footing
D. Under-reamed piles

List-II
1. Closed spaced columns resting on compressible soil
2. Expansive soils
3. Deep soft clays
4. Loose sands

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	2	4	1	3
(c)	3	1	4	2
(d)	3	4	1	2

[ESE : 2004]

12.32 A square pile of section 30 cm × 30 cm and length 10 m penetrates a deposit of clay having $c = 5$ kN/m^2 and the mobilizing factor $m = 0.8$. What is the load carried by the pile by skin friction only?

(a) 192 kN (b) 75 kN
(c) 60 kN (d) 48 kN

[ESE : 2004]

12.33 Consider the following statements:

1. Pile foundations are usually provided when loads coming on the foundation are quite large. Such piles may often extend up to a large depth below ground level.
2. Precast piles inserted into the holes bored at the site do not get damaged while they are driven into the ground.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2004]

12.34 Match List-I (Type of foundation) with List-II (Use of the foundation) and select the correct answer using the codes given below the lists:

List-I
A. Point bearing piles
B. Sheet piles
C. Compaction piles
D. Batter piles

List-II
1. To retain soil filling
2. To transfer heavy loads to strong stratum below a weak stratum
3. To resist lateral loads
4. To densify loose soils

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	3	4	1	2
(c)	2	1	4	3
(d)	2	4	1	3

[ESE : 2004]

12.35 The load carrying capacity of an individual friction pile is 200 kN. What is the total load carrying capacity of a group of 9 such piles with group efficiency factor of 0.8?

(a) 1800 kN (b) 1640 kN
(c) 1440 kN (d) 900 kN

[ESE : 2005]

12.36 Match List-I (Type of soil) with List-II (Suitable foundation) and select the correct answer using the codes given below the lists:

List-I

A. Strong soil in surface layer
B. Weak surface layer followed by rock at shallow depth below ground
C. Swelling soil in surface layer extending up to a few meters below ground level
D. Weak heterogenous surface soil layer

List-II

1. Raft foundation
2. Isolated footing
3. End bearing pile
4. Under-reamed piles

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	2	3	4	1
(c)	1	3	4	2
(d)	2	4	3	1

[ESE : 2005]

12.37 Match List-I (Type of pile) with List-II (Situation for use) and select the correct answer using the codes given below the lists:

List-I

A. End bearing pile
B. Pedestal pile
C. Friction pile
D. Sand piles

List-II

1. When weak foundation soil is to be compacted
2. When foundation soil is granular
3. When foundation soil is relatively weak
4. When hard formation or rock is at a shallow depth

Codes:

	A	B	C	D
(a)	4	2	3	1
(b)	1	3	2	4
(c)	4	3	2	1
(d)	1	2	3	4

[ESE : 2005]

12.38 While driving a large number of piles in loose sand

(a) it is advantageous to follow a sequence of pile driving such that the inner piles are driven first and then proceed outwards
(b) it is advantageous to follow a sequence of pile driving such that the piles near the periphery are driven first and inner piles are driven later
(c) it is advantageous to follow a sequence of pile driving such that alternately inner and outer piles are driven
(d) driving of piles can be done in any random order

[ESE : 2005]

12.39 Match List-I (Type of foundations) with List-II (Suitability) and select the correct answer using the codes given below the lists:

List-I

A. Spread footings
B. Under reamed piles
C. Raft foundation
D. Deep foundation

List-II

1. Soft clay for 20 m followed by hard rock stratum
2. Up to 3 m black cotton soil followed by medium dense sand
3. Compact sand deposit extending to great depth
4. Loose sand extending to great depth

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	3	2	4	1
(c)	4	2	3	1
(d)	3	1	4	2

[ESE : 2006]

12.40 Consider the following statements:
1. The proportioning of a footing is more often governed by its bearing capacity.
2. Friction piles are also called 'floating piles'.

Which of these statements is/are correct?
(a) Only 1 (b) Only 2
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2006]

12.41 Consider the following statements:
1. Initial load tests and routine tests are carried out on test piles and working piles, respectively.
2. A cyclic load test is performed to determine a pile's skin resistance and base resistance separately.
3. In a pile load test, the safe load is taken as half the final load at which the settlement equals 10% of pile-diameter.

Which of these statements are correct?
(a) 1, 2 and 3 (b) Only 1 and 2
(c) Only 2 and 3 (d) Only 1 and 3

[ESE : 2006]

12.42 A machine and its foundation weigh 981 kN and has a spring constant $k = 10{,}000$ kN/m. What is the value of the damping coefficient C_c if the system is to be critically damped?
(Acceleration due to gravity $g = 9.81$ m/s^2)
(a) 1000 kN-s/m (b) 4000 kN-s/m
(c) 2000 kN-s/m (d) 8000 kN-s/m

[ESE : 2007]

12.43 Which of the following types of piles is likely to have the highest load capacity in compression?
(a) Driven pre-cast concrete pile
(b) Pre-cast pile placed in a pre-drilled bore
(c) Driven steel pipe pile
(d) Steel pipe pile placed in a pre-drilled bore

[ESE : 2007]

12.44 What is the value of negative skin friction for a group of piles of 30 cm diameter, 5 m long and spaced at 80 cm c/c and having cohesive strength of soil as 25 kN/m^2? (Neglect bottom contribution in bearing capacity)
(a) 925 kN (b) 950 kN
(c) 975 kN (d) 1000 kN

[ESE : 2007]

12.45 A static cone penetration test is usually conducted when the structure is likely to be founded on which of the following?
(a) Shallow foundations
(b) Pile foundations
(c) Drier foundation
(d) Improved ground

[ESE : 2007]

12.46 Match List-I (Foundation) with List-II (Demanding situation) and select the correct answer using the codes given below the lists:

List-I
A. Under-reamed piles
B. Floating rafts
C. Combined footing
D. Strap footing

List-II
1. To restrict settlement of soft clays/silts
2. To transfer the moment in between two adjacent footings
3. To restrict damages due to volume changes of swelling soils
4. When columns are very close to the property line

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	4	1	3	2
(c)	4	2	3	1
(d)	3	1	4	2

[ESE : 2008]

12.47 Match List-I (Method) with List-II (Suitability) and select the correct answer using the codes given below the lists:

List-I
A. Static formulae
B. Dynamic formulae
C. Static pile load test
D. Cyclic pile load test

List-II

1. To estimate allowable load for permis-sible settlement for a pile
2. To separate point bearing and friction bearing capacities of a pile
3. To estimate allowable load for driven piles in granular soils
4. To estimate allowable load for bored piles in clays

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	1	3	4	2
(c)	4	3	1	2
(d)	1	2	4	3

[ESE : 2008]

12.48 Consider the following statements about the under-reamed pile in swelling soils:

1. Its bulb provides anchor against movement due to volume changes of soil.
2. It is a driven pile.
3. Its bulb diameter is 2.5 times its shaft diameter.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2008]

12.49 Consider the following statements:

1. Piles are provided in groups, which are connected together by a pile cap. The structure rests on top of the pile cap. The pile cap is situated below the ground level.
2. For situations where pile is subjected to upward pull, pedestal piles or under-reamed piles are more suitable type of foundations.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2008]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

12.50 **Assertion (A):** Generally driven piles are adopted in granular soils and not in clays.
Reason (R): Vibratory loading helps in densification of sands but it has adverse effects in clays.

[ESE : 2008]

12.51 **Assertion (A):** Under-reamed piles are suitable for loose filled up sites and black-cotton soils.
Reason (R): Black cotton soils have expansive montmorillonite clay minerals.

[ESE : 2008]

12.52 Consider the following statements with respect to an anchored sheet pile wall:

1. Failure occurs due to bulging.
2. Failure occurs due to rotation.
3. Large yield is observed above the anchor rod.
4. Large yield is observed below the anchor rod and above the dredge line.

Which of these statements is/are correct?

(a) 1 only (b) 2 and 3
(c) 1 and 4 (d) 3 and 4

[ESE : 2009]

12.53 Consider the following statements:

1. Underreamed piles are precast piles with one or more underreams in each pile.
2. The ratio of pile shaft size to bulb size in an underreamed pile may be 0.33 to 0.50.
3. In a multibulb underreamed pile, the load-carrying capacity is a function of the area of cross-section of the lowest bulb.

Which of these statements is/are correct?

(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2009]

12.54 Consider the following statements:

1. Underreamed piles are designed as bearing piles.
2. In multiple-bulb underreamed piles, the bulbs are spaced at 1.5 to 2.0 times the diameter of the underream, the centre of the first

underream being at a minimum depth of 1.75 m.

3. The length of traditional undereamed pile ranges from 3 m to 4 m.

Which of these statements is/are correct?

(a) 2 and 3 (b) 1 and 2
(c) 2 only (d) 1 and 3

[ESE : 2009]

12.55 **Assertion (A):** Batter piles are provided to resist lateral load coming onto structures.
Reason (R): The batter of batter piles is helpful in converting a part of the applied lateral load into axial compressive load on the batter piles.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

12.56 Match **List-I** with **List-II** and select the correct answer using the code given below the lists:

List-I
A. Large diameter piles
B. Drilled pier
C. Open caisson
D. Box caisson

List-II
1. Heavy loads in water structures, but foundation strata at shallow depth
2. Heavy loads in water structures with horizontal loads
3. Heavy but isolated loads
4. Very heavy loads

Code:

	A	B	C	D
(a)	3	2	4	1
(b)	1	2	4	3
(c)	3	4	2	1
(d)	1	4	2	3

[ESE : 2011]

12.57 Consider the following statements:

1. Friction piles are also called floating piles
2. Minimum number of piles to qualify as a pile group is three
3. The group efficiency of a pile group may be either less than 100% or more than 100%.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2012]

Directions: Each of the next items consists of two statements, one labeled as the **'Statements (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

12.58 **Statement-I :** Different types of piles are used in construction work depending on the type of load to be carried, the sub-soil conditions and the ground water table.
Statement-II: The load transfer mechanism from a pile to the soil is selfsame in all cases.

[ESE : 2012]

12.59 **Statement-I :** Different types of piles are used in construction work depending on the type of load to be carried, the sub-soil conditions and the ground water table.
Statement-II: The load transfer mechanism from a pile to the soil is selfsame in all cases.

[ESE : 2012]

12.60 A single pile, 50 cm in diameter and 16 m long, is driven in clay having an average unconfined compressive strength of 100 kN/m^2. The ultimate load carrying capacity of the pile, neglecting end bearing if any, and assuming shear mobilization of 0.75 around the pile, is nearly:

(a) 840 kN (b) 900 kN
(c) 940 kN (d) 1000 kN

[ESE : 2013]

12.61 A drop hammer is used to drive a wooden pile. The hammer weight is 25 kN and its free falling height is 0.8 m. The penetration in the last blow

is 12 mm. What is the nearest approximation to the load carrying capacity of the pile according to the Engineering News Formula?

(a) 125 kN (b) 110 kN
(c) 3000 kN (d) 90 kN

[ESE : 2014]

12.62 Consider the following statements:

1. Initial load test and routine load tests are carried out on test piles and working piles, respectively.
2. In a pile load test, the allowable load can be taken equal to half the ultimate load at which the total settlement amounts to one-tenth of the pile diameter.
3. In a pile load test, the allowable load can be taken equal to two-thirds of the total load which causes a plastic settlement of 6 mm.

Which of the above statements are correct ?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2014]

12.63 Consider the following statements:

Problems regarding foundations to be constructed in expansive soils are solved by

1. Resorting to light foundation pressure.
2. Using under-reamed piles for light loads.
3. Making the structure rigid enough so that settlement and uplift would not affect them.
4. Providing a well-designed basement with the foundation below the neutral point.

Which of the above statements are correct?

(a) 1 and 2 (b) 2 and 4
(c) 2 and 4 (d) 2 and 3

[ESE : 2015]

12.64 Consider the following statements:

1. Dynamic resistance of a soil is not much different from its static resistance.
2. The most comprehensive pile driving formula is Hiley' formula.
3. Pile driving formulae are more useful if the subsoil consists of coarse grained soils.

Which of the above statements are correct?

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2015]

12.65 The Engineering News Record Formula, $Q_a = \frac{Wh}{6(s+0.25)}$, is used for the case of

1. Drop hammer
2. Single-acting hammer
3. Double-acting hammer

Which of the above is/are correct?

(a) 1 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

[ESE : 2016]

12.66 **Statement (I):** Negative skin friction will act on the piles of a group in filled-up reclaimed soils or peat soil.

Statement (II): The filled-up or peat soils are not fully consolidated but start consolidating under their own overburden pressure, developing a drag on the surface of the piles.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

12.67 Consider the following statements?

1. A braced cofferdam is used in shallow trench excavation as well as in deep excavation exceeding 6 m in depth.
2. Cofferdams, braced or un-braced, are temporary structures either on land or in water bodies.
3. When sheet piling is used for retaining soil, or soil and water, without any bracing, it is called a bulkhead.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2017]

Answers Deep Foundation, Sheet Pile Walls and Machine Foundation

12.1 (d)	12.2 (d)	12.3 (d)	12.4 (d)	12.5 (b)	12.6 (a)	12.7 (c)	12.8 (d)	
12.9 (b)	12.10 (b)	12.11 (d)	12.12 (b)	12.13 (c)	12.14 (b)	12.15 (d)	12.16 (a)	
12.17 (c)	12.18 (d)	12.19 (a)	12.20 (c)	12.21 (d)	12.22 (d)	12.23 (c)	12.24 (a)	
12.25 (a)	12.26 (d)	12.27 (d)	12.28 (c)	12.29 (c)	12.30 (d)	12.31 (d)	12.32 (d)	
12.33 (a)	12.34 (c)	12.35 (c)	12.36 (b)	12.37 (c)	12.38 (a)	12.39 (b)	12.40 (b)	
12.41 (a)	12.42 (c)	12.43 (a)	12.44 (*)	12.45 (b)	12.46 (d)	12.47 (c)	12.48 (d)	
12.49 (b)	12.50 (a)	12.51 (a)	12.52 (c)	12.53 (c)	12.54 (a)	12.55 (a)	12.56 (c)	
12.57 (a)	12.58 (c)	12.59 (c)	12.60 (c)	12.61 (d)	12.62 (b)	12.63 (b)	12.64 (d)	
12.65 (b)	12.66 (a)	12.67 (d)						

Explanations Deep Foundation, Sheet Pile Walls and Machine Foundation

12.1 (d)

Pile installed in freshly placed fills of soft compressible deposits (clays) are subjected to a downward drag, a consequence of the consolidation of the strata after the piles are installed. This downward drag on the pile surface, when the soil moves down relative to the pile, adds to the structural loads and is called negative skin friction. This is in contrast to the usual shaft friction which is mobilized when the pile moves down relative to the soil. Thus negative skin friction has an effect of reducing the allowable load on the pile. Negative skin friction may also develop if the fill material is a loose sand deposit. It can also occur due to the lowering of the ground water table which increases the effective stress, thus causing consolidation of the soil with the resultant down drag of piles.

12.2 (d)

The efficiency of pile group depends on the following factors:

1. Spacing of piles
2. Total number of piles in a row and number of rows in a group, and
3. Characteristics of pile (material, diameter and length)

The efficiency of the pile group can be calculated by using the following formula:

$$\eta_g = \frac{Q_{g(u)}}{NQ_u} \times 100$$

Thus, the pile group efficiency is equal to the ratio of the average load per pile in the group at which the failure occurs to the ultimate load of a comparable single pile.

12.3 (d)

Pressuremeter can be used for in-situ measurement of shear modulus (G) of the soil. In this pressure is applied to water by compressed gas (usually nitrogen) in a control cylinder at the surface.

12.4 (d)

The bearing capacity of under-reamed pile is more than driven or bored pile of the same diameter.

12.5 (b)

Franki pile is uncased cast-in-situ pile. Franki pile has enlarged base of mushroom shape which gives the effect of a spread footing. This pile is more useful where a bearing stratum of limited thickness is reached at reasonable depth. Also, this type of pile is best suited to granular soil.

12.6(a)

When the rate of consolidation of filled up soil or weak soil is more than the rate of settlement of pile, a downward drag force acts on the pile. This is called negative skin friction and reduces load carrying capacity of pile. It should be considered in the design of pile foundation.

12.7(c)

The friction load capacity,

$$q_f = \alpha \times c_u \times PL$$

Given $\alpha = 0.7$; $c_u = 4$ t/m^2

$P = \pi \times 0.3$ m; $L = 10$ m

$$\therefore \quad q_f = 0.7 \times 4 \times \pi \times 0.3 \times 10 = 26.4$$

$$\text{Safe load} = \frac{26.4}{2.5} = 10.55 \text{ t}$$

12.8 (d)

A well needs to be embedded or sunk below the maximum scour level to a required depth so that the resistance from the sides of well is able to withstand the lateral forces acting on the well. The depth of the bottom portion of well from the scour level is called the grip length. At the time of the selection of depth of foundation, the grip length and bearing capacity of soil strata must be considered. The maximum and minimum base pressures during the drastic or critical loading conditions have to remain under the permissible range.

12.9(b)

Negative skin friction will act over *AB* length and it is in the downward direction. In part *BC* the frictional resistance is in upward direction. At point *C* the end resistance develops. So 2, 3 and 4 are correct.

12.10 (b)

Under reamed piles are bored cast-in-situ concrete piles having one or more number of bulbs formed by enlarging the pile stem. These piles are best suited in soils where considerable ground movements occur due to seasonal variations, filled up grounds or in soft soil strata. Provision of under reamed bulbs has the advantage of increasing the bearing and uplift capacities. It also provides better anchorage at greater depths. These piles are efficiently used in machine foundations, over bridges, electrical transmission tower foundation sand water tanks. According to the code the diameter of under reamed bulbs may vary from 2 to 3 times the stem diameter depending upon the feasibility of construction and design requirements. The code suggests a spacing of 1.25 to 1.5 times the bulb diameter for the bulbs.

12.11 (d)

IS:2911 (Part–I)–1979 recommends a minimum spacing of 2.5 times the shaft diameter for point bearing piles, 3 times the shaft diameter for friction piles, whereas in loose sands or fill deposits, a minimum spacing of 2 times the diameter of the shaft is suggested. In the case of piles of non-circular cross-section, the diameter of the circumscribing circle shall be adopted.

12.12 (b)

The mode of failure of pile groups in cohesive soils depends primarily upon spacing of piles. For smaller spacings 'block failure' may occur. In other words the group capacity as a block will be less than sum of individual pile capacities.

For larger spacings failure of individual piles may occur.

For medium dense sand the settlement of pile group is more than settlement of single piles and group settlement ratio (settlement of group to settlement of individual pile) increases with increase in B/d where B is the width of the pile group and d is the diameter of the pile.

12.13 (c)

Efficiency by Converse Labarre formula

$$\eta_g = 1 - \frac{\phi}{90}\left[\frac{m(n-1)+n(m-1)}{mn}\right]$$

Given $m = n = 2$

For four free standing pile group

$$\phi = \arctan\left(\frac{d}{s}\right) = 18.3$$

$$\eta_g = 1 - \frac{18.3}{90}\left[\frac{2\times1+2\times1}{2\times2}\right]$$

$$= 0.797 \simeq 80\%$$

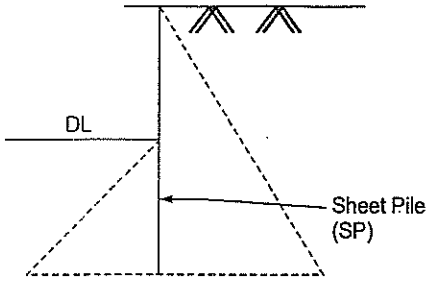
12.14 (b)

According to IS. 2911 : Part III 1973, the ratio of bearing resistance for double under-reamed pile

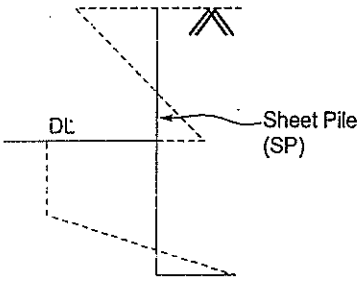
to that of single under-reamed pile is 1.5 for sandy and clayey soils including black cotton soils.

12.15 (d)

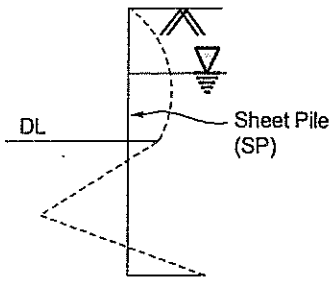
Cantilever Sheet Pile, Granular Soil – Approximate analysis



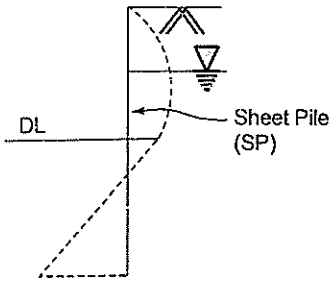
Cantilever Sheet Pile, Cohesive Soil – Approximate analysis



Anchored Sheet Pile, Granular Soil – Fixed Method

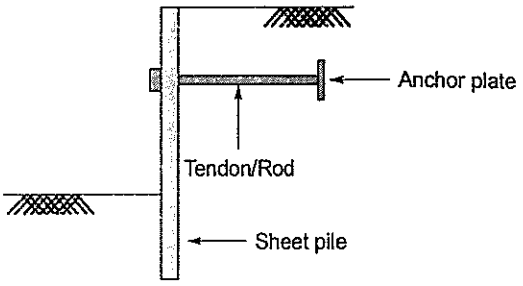


Anchored Sheet Pile, Granular Soil – Free Earth Method



12.16 (a)

Anchored sheet pile walls are held above the driven depth by anchors provided at suitable level. The anchors provide forces for the stability of the sheet pile, in addition to the lateral passive resistance of the soil into which the sheet piles are driven.



12.17 (c)

In general, the dynamic pile driving formulae appear to be more appropriate to piles driven in cohesionless soils. If the pile is driven into saturated loose silt and sand, liquefaction might reduce the pile capacity. Dynamic pile driving formulae are not considered to be applicable to piles driven into cohesive soils. This is because there may be apparent increase in driving resistance due to development of pore pressures, while there may be a tendency for it to decrease later due to dissipation of pore pressure. Pile driving in cohesive soil disturbs the soil structure and consequently the resistance tends to decrease due to remoulding in sensitive clays although there might be some regaining of strength with passage of time, due to thixotropy.

12.19 (a)

The pile tends to point of rotation, deflecting away from the backfill. Above the point of rotation, the sheet pile wall deflects away from the backfill, thus generating active conditions on the back of the wall. At the same time, between the dredge line and the point of rotation, as the wall tends to move towards the soil in front of the wall, passive conditions are generated in this side.

12.20 (c)

For critical damping $C_c = 2\sqrt{kM}$

Mass (M) should be in kg.

$$\therefore\ C_c = 2 \times \sqrt{\frac{10{,}000 \times 39.24}{9.81}}$$

$$= 400 \text{ kN-s/m}$$

12.21 (d)

The Engineering News formula is largely an empirically developed formula. It has a factor of safety of six. The intent of the factor of safety was to produce a load that could be used as an applied load of the structure the pile supported.

12.22 (d)

Negative skin friction is related to the relative rate of settlement of pile and soil surrounding the pile. It has no relation with load.

12.23 (c)

Under reamed piles are bored cast-in-situ concrete piles having one or more number of bulbs formed by enlarging the pile stem. These piles are best suited in soils where considerable ground movements occur due to seasonal variations, filled up grounds or in soft soil strata.

12.24 (a)

The skin friction resistance,

$$f_s = \alpha c_u$$

$$c_u = 100/2 = 50 \text{ kN/m}^2$$

Ultimate bearing capacity $= \alpha\, c_u PL$

$$= 0.8 \times 50 \times (\pi \times 0.5) \times 15$$

$$= 942.5 \text{ kN}$$

12.26 (d)

Natural circular frequency of the system

$$\omega_n = \sqrt{k/m}$$

where m is mass of the system

$$f_n = \frac{\omega_n}{2\pi}$$

and $k = C_u A$

12.27(d)

End bearing resistance,

$$q_b = 9c_u$$

$$c_u = \frac{6}{3} = 3 \text{ t/m}^2$$

$$\therefore \quad q_b = 9 \times 3 = 27 \text{ t/m}^2$$

12.28 (c)

The correct relationship is

$$\omega_{dn} = \omega_n \sqrt{1 - D^2}$$

12.29 (c)

Total pile capacity

$$= 17 + 63 + 503 + 11{,}000 \times \left(\frac{\pi \times 0.4^2}{4}\right)$$

$$= 1965.3 \text{ kN}$$

12.31 (d)

The pile resisting load by skin friction only is called floating pile.

The swelling pressure in expansive soils like black cotton soils can be resisted by under-reamed pile.

Micro pile resists the vertical load largely by end bearing resistance. Therefore they will be suitable in loose sands.

12.32 (d)

The load carried by skin-friction only

$$= m \times c \times P \times L$$

$$= 0.8 \times 5 \times 0.3 \times 4 \times 10$$

$$= 48 \text{ kN}$$

12.33 (a)

The precast concrete piles are generally used for a maximum in load of 80 tonnes approximately. They must be reinforced to withstand handling stresses. They are driven into the ground without any holes bored at the site.

12.34 (c)

Point Bearing Piles - If a bedrock or rocklike material is present at a site within a reasonable depth, piles can be extended to the rock surface. In this case, the ultimate bearing capacity of the pile depends entirely on the underlying material; thus the piles are called end or point bearing piles. In most of these cases the necessary length of the pile can be fairly well established.

Batter pile shall be used to transfer inclined load and horizontal forces. Free standing batter piles are subjected to bending moment due to their own weight, or external forces from other sources. Batter pile in loose fill or consolidating deposits may become laterally loaded due to settlement of the surrounding soil. In consolidating clay, special precautions, like provision of permanent casing, shall be taken.

Sheet piling is an earth retention and excavation support technique that retains soil, using steel

sheet sections with interlocking edges. **Sheet piles** are installed in sequence to design depth along the planned excavation perimeter or seawall alignment. The interlocked sheet piles form a wall for permanent or temporary lateral earth support with reduced groundwater inflow. Anchors can be included to provide additional lateral support if required.

12.35 (c)

Load carrying capacity of pile group
= Group efficiency factor × Number of piles × Individual pile capacity
= 0.8 × 9 × 200 = 1440 kN

12.36 (b)

Raft foundations (sometimes known as Mat Foundations) are a large concrete slab which can support a number of columns and walls. The slab is spread out under the entire building or at least a large part of it which lowers the contact pressure compared to the traditionally used strip or trench footing.

Isolated footings are independent footings which are provided for each column. This type of footing is used when. Columns are not closely spaced. Loads on footings are less. The Safe bearing capacity of soil is generally high.

In **End bearing piles**, the bottom end of the pile rests on a layer of especially strong soil or rock. The load of the building is transferred through the pile onto the strong layer. In a sense, this pile acts like a column.

12.37 (c)

Pedestal pile is used to bypass weak soil stratum below which thin bearing stratum is reached with reasonable depth. The pedestal of pile gives the effect of spread footing on this comparatively thin bearing.

12.38 (a)

For piles driven in loose and medium dense cohesionless soils, the group efficiency is high. The soil around and between the piles is compacted due to vibration caused during the driving operation. For better results, it is essential to start driving the piles at the centre and then proceed outwards.

12.39 (b)

In the case of loose sand there may be loose pockets causing differential settlements. Raft foundations reduce the differential settlements and higher allowable soil pressure may be used for design of rafts on loose sands.

Under-reamed piles are suitable to bear the swelling pressure caused by black cotton soil.

12.40 (b)

The proportioning of footing is governed by 'Service load' criterion to ensure equal settlement of footing for various columns. For ordinary buildings,
Service load = Dead load + 0.5 × Live Load.
Friction piles are called floating piles also.

12.41 (a)

Initial load tests can be carried out on test piles or working piles. The routine tests are carried out on working piles only.

12.42 (c)

Damping coefficient is given by

$$C_c = 2\sqrt{km}$$

$$= 2\sqrt{10000 \times \frac{981}{9.81}}$$

$$= 2000 \text{ kN-s/m}$$

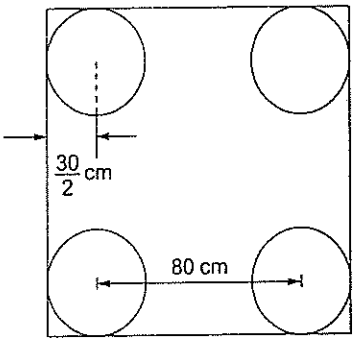
12.43 (a)

Driven pile has more load carrying capacity than bored pile because value of lateral earth pressure coefficient is more in case of driven pile, so skin friction is more.

12.44 (*)

Diameter of pile = 30 cm
Spacing = 80 cm c/c
For group action of piles, minimum spacing required = 2.5D = 2.5 × 30 = 75 cm
Hence negative skin friction of group is to be calculated
Assuming 4 number of piles
Neglecting point bearing capacity
$Q_g(u) = \alpha . C . P_g . D$
For cohesive soil, assuming $\alpha = 1$
Given, $C = 25 \text{ kN/m}^2$
P_g = Perimeter of block = 4 × 110 cm
Depth of block = 5 m

$$Q_g(u) = 1.0 \times 25 \times \left(\frac{4 \times 110}{100} \times 5\right) = 550 \text{ kN}$$



12.45(b)

Static Cone Penetration Test: Also known as Dutch Cone for CPT, it gives a continuous record of variation of both cone resistance and friction resistance with depth. CPT however does not yield any sample. It is suitable for soft clay and silts & fine to medium sand deposits.

12.46 (d)

- Under reamed piles are used to restrict damages due to volume change of swelling soils (as it causes uplift pressure).
- Combined footing is used when a foundation is built close to an existing building or the property line, there may not be sufficient space for equal projections on the sides of the exterior column.
- Strap footing consists of two spread (isolated) footings joined by a rigid beam known as strap. Its main function is to transfer the moment from the exterior footing to the interior footing.
- An exact balance of weight removed against weight imposed, the result is zero settlement of the building. This is the principle of floating foundations. Such a foundation is very useful for weak soils.

12.47 (c)

Initial Tests on piles:

This test is performed to confirm the design load calculations and to provide guidelines for setting up the limits of acceptance for routine tests. It also gives an idea of the suitability of the piling system. Initial Test on piles are to be carried out at one or more locations depending on the number of piles required.

Load applied for the initial (cyclic) load test is 2.5 times the safe carrying capacity of the pile. Loading for Initial Tests is conducted as per Appendix 'A' Clause 6.3of IS-2911 Part IV.

Routine Tests on piles:

Selection of piles for the Routine Test is done based on number of piles required subject to maximum of ½% of total number of piles required. The number of tests may be increased to 2% depending on the nature / type of structure. The test load applied is 1½ times the safe carrying capacity of the pile. The Maintained load method as described in Clause 6.2 of IS-2911 (Part IV) – 1985 shall be followed for loading for the Routine Tests.

This test will be performed for the following purposes:

(a) To ensure the safe load capacity of piles

(b) Detection of any unusual performance contrary to the findings of the Initial Test.

12.48 (d)

Under-reamed pile is a special type of bored pile which is provided with a bulb/pedestal at the end. The usual size of such piles are 150 to 200 mm shaft diameter, 3 to 4 m long. The diameter of under-reamed portion is usually 2 to 3 times the shaft diameter.

12.49 (b)

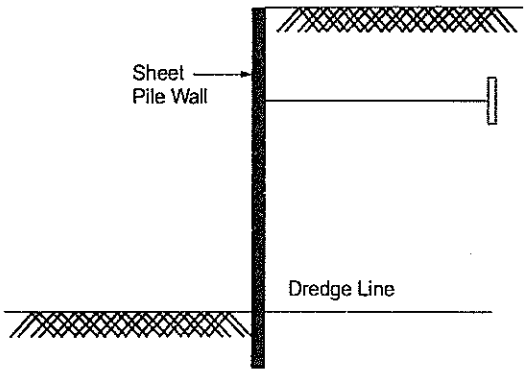
A pile cap may or may not be situated below the ground level. In case of free standing pile group, the pile cap stands above the ground. In case it rests on the soil, partially or fully buried below the ground it is called piled foundation. So statement 1 is incorrect.

12.50 (a)

Driven piles may be of concrete, steel or timber. These piles are driven into the soil strata by the impact of a hammer. Generally boring is not used in these cases. When pile is driven into granular soils it densifies the soil and increases stiffness (strength) of soil. But in case of clays, driven piles remould the soil to a distance of about two times diameter of pile

12.52 (c)

In anchored sheet pile wall large yield is observed below the anchor rod and above the dredge line, not above the anchor rod.



12.53 (c)

Under-reamed piles are cast-in-situ piles which may be installed both in sandy and in clayey soils.

12.54 (a)

Under Reamed piles are designed for both skin friction resistance and point bearing resistance.

12.55 (a)

Piles are sometimes subjected to lateral loads due to wind pressure, water pressure, earth pressure, earthquakes, etc.

If the horizontal load is large, inclined piles, known as raking piles or batter piles, are provided to take the horizontal load. These piles have a high resistance to lateral loads, as a large portion of the horizontal component of the load is carried axially by the pile. Batter piles, along with vertical piles, are provided in situations where the horizontal loads are significant, such as wharves, jetties, bridge piers, trestles, retaining wall and tall chimneys.

12.56 (c)

Drilled Pier: A drilled pier is a large diameter concrete cylinder built in the ground. A drilled pier is a type of deep foundation constructed to transfer heavy axial or lateral loads to a deep stratum below the ground surface.

Caisson: A caisson is a type of foundation of the shape of a hollow prismatic box, which is built above the ground level and then sunk to the required depth as a single unit. It is a watertight chamber used for laying foundations under water, as in rivers, lakes, harbours, etc. The caissons are of three types: (i) Open caissons, (ii) Pneumatic caissons, and (iii) Floating caissons.

Open caissons are hollow chambers, open both at the top and the bottom. The bottom of the caisson has a cutting edge. The caisson is sunk into place by removing the soil from the inside of the shaft (chamber) until the bearing stratum is reached. Well foundations are special type of open caissons.

Pneumatic caissons are closed at the top, but open at the bottom. A pneumatic caisson has a working chamber at its bottom in which compressed air is maintained at the required pressure to prevent entry of water into the chamber.

Floating caissons are open at the top but closed at the bottom. These caissons are constructed on land and then transported to the site, and floated to the place where these are to be finally installed.

12.57 (a)

The ratio of the ultimate load capacity of the pile group, Q_{ug} to the sum of the individual load capacities of the piles in the group, is called group efficiency η.

$$\eta = \frac{Q_{ug}}{nQ_u}$$

Disturbance of soil during installation of piles and overlap of stresses between adjacent piles may cause the group capacity become less than the sum of the individual capacities, that is $\eta < 1$. Generally, for smaller spacings between piles, $\eta < 1$. For larger spacings, the effect of pile interaction diminishes and η approaches unity. In driven piles where the soil around the piles gets densified, as in loose to medium sand, η may be even more than 1.

12.58 (c)

In case of friction piles, load is a transferred through friction along the length of pile. In case of end bearing piles load is transferred through bearing at the end of pile.

12.59 (c)

In case of friction piles, load is a transferred through friction along the length of pile. In case of end bearing piles load is transferred through bearing at the end of pile.

12.60 (c)

$$P = \alpha(\pi dL)C_u$$

$$= (0.75)\pi(0.5)16\left(\frac{100}{2}\right)$$

$$= 942 \text{ kN} \approx 940 \text{ kN}$$

12.61 (d)

As per Engineering News Formula

$$Q_{allowable} = \frac{W.h}{FOS(S+C)}$$

Where, $C = 2.5$ cm for drop hammer

weight, $W = 25$ kW

$h = 0.8$ m $= 80$ cm

$S = 12$ mm $= 1.2$ cm

FOS $= 6$

$$\therefore \quad Q_{allowable} = \frac{25 \times 80}{6 \times (1.2 + 2.5)}$$

$$= 90.090 = 90 \text{ kN}$$

12.62 (b)

As per IS – 2911, Part IV the allowable load on a single pile will be minimum of the following two cases :

1. $\frac{2}{3}$rd of the load at which total settlement is 12 mm.
2. 50% of the ultimate load at which total settlement is equal to the $\frac{1}{10}$ of the diameter of pile.
3. $\frac{1}{2}$ to $\frac{2}{3}$rd of the load which gives a net settlement of 6 mm.

12.64 (d)

Due to various energy losses occurring during dynamic resistance test, the static resistance and dynamic resistance of soil is different.

12.65 (b)

For drop hammer

$$Q_a = \frac{Wh}{6(s+2.5)}$$

For single acting steam hammer

$$Q_a = \frac{Wh}{(s+0.25)}$$

12.67 (d)

- Braced cofferdams are economical for small to moderate height only for earth embankment type
- In cofferdam there is no height limitation.
- Sheet piles are used as bulkhead or as impervious cutoff to reduce seepage and uplift under hydraulic structure.

■■■■

13 Soil Stabilization and Soil Exploration

13.1 Consider the following properties for a soil sampler:

1. Area ratio should be low.
2. Cutting edge should be thick.
3. Inside clearance should be high.
4. Outside clearance should be low.

The properties necessary for a good quality soil sampler would include

(a) 1 and 4 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 1, 3 and 4

[ESE : 1995]

13.2 Consider the following statements:

In subsoil exploration programme the term "significant depth of exploration" is up to

1. the width of foundation
2. twice width of foundation
3. the depth where the additional stress intensity is less than 20% of overburden pressure
4. the depth where the additional stress intensity is less than 10% of the overburden pressure
5. hard rock level

Which of these statements is/are correct?

(a) 1, 3 and 5 (b) 2, 3 and 5
(c) 1 and 4 (d) 2 and 4

[ESE : 1996]

13.3 A good quality undisturbed soil sample is one which is obtained using a sampling tube having an area ratio of

(a) 8% (b) 16%
(c) 24% (d) 32%

[ESE : 1998]

13.4 Consider the following statements:

1. Increase in volume of a soil sample without external constraints on submergence in water is termed as the 'free swell of soil.'
2. Clay soil rich in montmorillonite exhibits very low swelling characteristic.
3. Generally, free swell of soil sample ceases when its water content reaches the plastic limit.

Which of these statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

[ESE : 1998]

13.5 **Assertion (A):** Wash boring is recommended to obtain undisturbed soil sample above ground water table.

Reason (R): In wash boring, water pumped through the hollow drill rods emerges through the ports of the chopping bit carrying disintegrated soil fragments.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

13.6 A wet, cohesive subgrade is most effectively stabilized by the addition of

(a) cement (b) fly ash
(c) bitumen (d) lime

[ESE : 2000]

13.7 A soil sampler has inner and outer radii of 25 mm and 30 mm, respectively. The area ratio of the sampler is

(a) 24% (b) 34%
(c) 44% (d) 54%

[ESE : 2001]

13.8 The correct sequence of the increasing order of the disturbance to soil samples obtained from chunk, piston, split spoon and remoulded sampler is

(a) piston sampler, chunk sampler, split spoon sampler, remoulded sampler
(b) chunk sampler, piston sampler, split spoon sampler, remoulded sampler
(c) piston sampler, chunk sampler, remoulded sampler, split spoon sampler
(d) chunk sampler, piston sampler, remoulded sampler, split spoon sampler

[ESE : 2002]

13.9 Match List-I (Sampler) with List-II (Use) and select the correct answer using the codes given below the lists:

List-I
A. Split spoon sampler
B. Stationary piston sampler
C. Rotary sampler
D. Compressed air sampler

List-II
1. To obtain representative samples in all types of soil
2. To obtain undisturbed samples of sands below water table
3. To obtain undisturbed samples in clay and silts
4. To obtain approximately undisturbed samples of hard cemented cohesive soils

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	3	1	4	2
(c)	1	3	4	2
(d)	3	1	2	4

[ESE : 2003]

13.10 Consider the following statements:
Prevention or elimination of swelling can be brought by
1. providing an impervious apron around the structure
2. pre-wetting the ground to a moisture content equal to equilibrium moisture content
3. packing downward loads large enough to exceed swelling pressures
4. chemically stabilizing the soil with lime

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2, 3 and 4

[ESE : 2004]

13.11 Match List-I (Type of exploration) with List-II (Soil profile) and select the correct answer using the codes given below the lists:

List-I
A. Diamond core drilling
B. Uncased wash boring
C. Open pit excavation
D. Cased boring

List-II
1. Medium strong cohesive soils
2. Rocky formation
3. Soft cohesive soils and cohesionless soils. Exploration up to relatively large depths
4. Exploration up to a shallow depth below ground level

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2005]

13.12 Consider the following statements:
1. Obtaining reliable properties of soil is very important in geotechnical engineering. Chunk samples obtained from the field are the best for this purpose.
2. Chunk samples may easily be obtained at all depths below ground level and for all types of soils.
3. Undisturbed soil samples are enclosed in rugged containers. As such, they do not get disturbed easily during transportation and handling.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 only
(c) 2 and 3 (d) 1 and 3

[ESE : 2005]

13.13 A sampling tube with a cutting edge is used for extracting the samples. The sampling tube has the following dimensions:
Inner diameter of cutting edge = D_c
Outer diameter of cutting edge = D_w
Inner diameter of the sampling tube = D_s
Outer diameter of the sampling tube = D_t

What is the area ratio A_r of the sampling tube?

(a) $A_r = \frac{D_w^2 - D_c^2}{D_c^2} \times 100\%$

(b) $A_r = \frac{D_t^2 - D_c^2}{D_c^2} \times 100\%$

(c) $A_r = \frac{D_t^2 - D_w^2}{D_w^2} \times 100\%$

(d) $A_r = \frac{D_t^2 - D_s^2}{D_s^2} \times 100\%$

[ESE : 2006]

13.14 During a sampling operation, the drive sampler is advanced 600 mm and the length of the sample recovered is 525 mm. What is the recovery ratio of the sample?

(a) 0.125 (b) 0.140
(c) 0.875 (d) 0.143

[ESE : 2006]

13.15 A differential free swell test on a soil gives a value of differential free swell of 40%. What is the degree of swelling?

(a) Low (b) Medium
(c) High (d) Very high

[ESE : 2008]

13.16 Consider the following statements:
On addition of lime to swelling soils,
1. their liquid limit increases
2. their plastic limit increases
3. their shrinkage limit increases
4. their swelling potential decreases

Which of these statements are correct?

(a) 1 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2008]

13.17 In seismic exploration method, velocities V_1 and V_2 were 600 m/s and 4000 m/s. The distance corresponding to the break point of velocities was 30 m. Based on this detail, what is the depth of overburden?

(a) 11.5 m (b) 12.5 m
(c) 12.9 m (d) 13.2 m

[ESE : 2008]

13.18 Consider the following statements:
1. The soil obtained from wash boring is a representative sample.
2. Recovery ratio will be high during drilling in sound rock.
3. Hollow stem augers are sometimes used to drill holes in silty sand.

Which of these statements is/are correct?

(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 3 only

[ESE : 2009]

13.19 Consider the following statements:
1. A differential free swell value of 40% indicates a soil with a high degree of expansiveness.
2. A swelling pressure of less than 20 kN/m^2 is not of much consequence.
3. The swelling pressure is a unique parameter for a swelling soil and is not influenced by other factors.

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 only

[ESE : 2010]

13.20 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Geophysical methods
B. SPT
C. DCPT
D. Piston-type sampler

List-II
1. Primarily for cohesive soils
2. Clays and silts
3. Reconnaissance covering large area and large depth
4. Suitable for sandy soils

Code:

	A	B	C	D
(a)	2	1	4	3
(b)	3	1	4	2
(c)	2	4	1	3
(d)	3	4	1	2

[ESE : 2011]

13.21 Consider the following statements:
1. Buried service lines should be avoided in an expansive soil region.

2. A swelling pressure less than 20 kN/m^2 is not of much consequence.
3. If soil is not black in colour, it is unlikely to be an expansive soil.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2012]

13.22 Consider the following statements:
1. Undisturbed samples may be obtained with the help of augers.
2. Auger drilling is most effective in clayey soils.
3. Hollow stem augers are sometimes used to drill holes in silty sand.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2013]

13.23 Consider the following statements:
1. The static cone penetration test is unsuitable for layered deposits of sands, silts and clays.
2. The results of groundwater investigation are recorded as water-table contours over the site.
3. Closed piezometers are used to measure pore water pressure in soils having low permeability.

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2014]

13.24 Consider the following statements:
Lime stabilization of soil leads to
1. Decrease in shrinkage limit.
2. Increase in plastic limit.
3. Decrease in liquid limit.
4. Flocculation of clay particles

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1, 2 and 3
(c) 1, 3 and 4 (d) 2, 3 and 4
[ESE : 2015]

13.25 Consider the following statements related to the properties of a good quality soil sample:
1. Area ratio should be low
2. Cutting edge should be thick
3. Inside clearance should be low
4. Outside clearance should be low

Which of the above statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4
[ESE : 2015]

13.26 Which of the following tests are essential for designing a foundation on expansive soils?
1. Swelling pressure test
2. Free swell test
3. Estimation of differential free swell
4. Shrinkage limit test

Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 1, 2, 3 and 4 (d) 2, 3 and 4 only
[ESE : 2015]

13.27 Which technique of stabilization for the sub-base is preferred for a heavy plastic soil?
(a) Cement stabilization
(b) Mechanical stabilization
(c) Lime stabilization
(d) Bitumen stabilization
[ESE : 2016]

13.28 Consider the following statements:
1. Functions of reinforcement in reinforced soil and in reinforced concrete are comparable.
2. The design of a geotextile reinforced wall is similar in principle to that of a reinforced earth wall.

Which of the above statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2017]

■■■■

Answers Soil Stabilization and Soil Exploration

13.1 (a)	13.2 (d)	13.3 (a)	13.4 (b)	13.5 (d)	13.6 (d)	13.7 (c)	13.8 (b)	
13.9 (c)	13.10 (d)	13.11 (b)	13.12 (c)	13.13 (a)	13.14 (c)	13.15 (c)	13.16 (c)	
13.17 (c)	13.18 (c)	13.19 (b)	13.20 (d)	13.21 (b)	13.22 (c)	13.23 (a)	13.24 (a)	
13.25 (d)	13.26 (c)	13.27 (c)	13.28 (c)					

Explanations Soil Stabilization and Soil Exploration

13.1 (a)

Area ratio is the most critical factor which affects sample disturbance. It indicates the ratio of displaced volume of soil to that of the soil sample collected. If A_r is less than 10%, the sample disturbance is supposed to be small. Inside clearance should be 1 to 3%. Outside clearance should not be much greater than inside clearance and its value should lie between 0 to 2%.

13.2 (d)

Twice the width of foundation corresponds to additional stress intensity less than 10% of the overburden pressure. The additional stress intensity as 20% of the overburden pressure corresponds to 1.5 times the width of foundation.

13.3 (a)

Undisturbed Sample retains as closely as practicable the true in-situ structure and water content of the soil. For undisturbed sample the stress changes cannot be avoided. The following requirements are looked for:

- No change due to disturbance of the soil structure,
- No change in void ratio and water content,
- No change in constituents and chemical properties.

13.4 (b)

Free swell or differential free swell, also termed as free swell index, is the increase in volume of soil without any external constraint when subjected to submergence in water. It is determined as per IS: 2720 (Part XL) - 1977.

13.5 (d)

Wash boring gives unrepresentative and disturbed soil sample which are almost valueless for interpreting the correct geotechnical properties of soil. Wash boring is commonly used for exploration below ground water table for which auger method is unsuitable. This method can be used in all kinds of soils except those mixed with gravel and boulders.

13.6 (d)

Granular soils with sufficient fines are ideally suited for cement stabilization. Such soils can be easily pulverized and mixed. They require least amount of cement.

Lime stabilization is useful for clayey soils. The plasticity of the soil decreases and material is more suitable as a subgrade material.

Bitumen stabilization is very effective in stabilizing sandy soils having little or no fines. It can be used for desert soils, (Loess).

13.7 (c)

$$\text{Area ratio} = \frac{D_0^2 - D_i^2}{D_i^2} \times 100$$

$$= \frac{(30)^2 - (25)^2}{(25)^2} \times 100 = 44\%$$

13.8 (b)

Piston sampler is a thin type sampler used in case of soft sensitive clays for obtaining very fine undisturbed samples. **Chunk samples** are considered equivalent to undisturbed samples.

Split Spoon sampler gives disturbed but representative samples and can be used in all soil types.

Stationary Piston Sampler is ideal in case of soft and saturated soils.

13.9 (c)

Rotary samplers are double walled samplers. It consists of a cutting bit in its outer tube which is

used in case of hard cemented cohesive soils and rocks.

13.10 (d)

Treatment of expansive soils

- Pre-wetting a site to increase the moisture content can eliminate an expansive soil problem if the high moisture content can be maintained.
- Vertical or horizontal moisture-loss barriers are installed in only a few cases in the past, but their use is becoming more frequent. The combined effect of a moistened sub-grade and moisture barriers, when applied correctly, can be very successful. The application of moisture treatment coupled with proper degrees of compaction has been utilized extensively.

13.11 (b)

In **diamond core drilling**, the drill uses a diamond encrusted drill bit to drill through the rock.

Cased boring is done for larger depths in cohesive or cohesionless soils. Casing prevents the falling of soil into bore.

13.12 (c)

Chunk samples fall in the category of undisturbed samples. They are obtained from bottom of the test pits for all type of soils. Including those containing pebbles and cobbles. Thus reliable properties of soil can be obtained by testing chunk samples.

However, the depth of test pit is limited. Chunk samples can be obtained from exposed soil in a shaft or tunnel also. Thus they can be obtained from all the depths.

Chunk samples are not the best for obtaining the engineering properties. Piston sampler and compressed air sampler cause least disturbance to sensitive soils.

Finally special care is required in the handling, transportation, and storage of samples prior to testing.

So rugged containers are used to enclose samples. Thus 2 and 3 are correct and 1 is partially correct only.

13.13 (a)

$A_r = \frac{(D_w^2 - D_c^2)}{D_c^2} \times 100$ = Ratio of displaced volume of soil to that of the sample collected.

Area ratio is the most critical factor that affects sample disturbance. If $A_r < 10\%$, the sample disturbance is considered to be small.

13.14 (c)

Recovery ratio is defined as

$$R_r = \frac{\text{Actual length of sample in the tube}}{\text{Total length of the sampling tube driven below the bottom of the bore hole}}$$

$$R_r = \frac{525}{600} = 0.875 < 1$$

This indicates ($R_r < 1$) that the sample is compressed.

13.15 (c)

Degree of swelling for different differential free swell (DFS) are tabulated below

Degree of swelling	DFS, per cent
Low	Less than 20
Moderate	20 to 35
High	35 to 50
Very high	Greater than 50

13.16 (c)

Lime has been found to be the most effective and economical of all additives. Addition of lime to expansive soils reduces swell potential and increases workability and strength. Liquid Limit is decreased and Plastic Limit is increased with increasing lime content resulting in decreased Plasticity Index. Flocculation takes place when lime is mixed with clays.

13.17 (c)

The depth of the boundary between the two strata can be given by

$$D = \frac{d}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}} = \frac{30}{2}\sqrt{\frac{4000 - 600}{4000 + 600}} = 12.9 \text{ m}$$

13.18 (c)

Soil samples obtained from auger borings and wash borings are non-representative samples. Non-representative samples consist of mixture of materials from various soil or rock strata or are

samples from which some mineral constituents have been lost or got mixed up.

13.19 (b)

Degree of expansiveness and differential free swell are tabulated below:

Degree of expansiveness	DFS percent
Low	< 20
Moderate	20 to 35
High	35 to 50
Very high	> 50

The swelling pressure is not a unique parameter for a swelling soil. It is significantly influenced by several factors, the more important of them being the initial moisture content (moulding water content for remoulded soils), initial dry density, method of compaction, confining surcharge and the height of the soil specimen. For a given dry density, lower the initial moisture content, greater the water thirst and higher the swelling pressure.

13.20 (d)

Piston samplers are used for getting undisturbed soil samples from soft and sensitive clays and silts.

SPT (Standard penetration test) is an in-situ test used especially for cohesionless soils e.g. sandy soils. The test is useful for determining the relative density and the angle of shearing resistance of cohesionless soils. It can also be used for unconfined compressive strength test of cohesive soils.

Geophysical method is used for soil exploration and testing in large areas and large depth.

13.21 (b)

There are a lot of swelling soils which are brown or light coloured, even though most expansive soils are dark in colour.

Swelling pressure of a soil depends on lots of factors such as initial dry density, method of compaction, moisture content, height of specimen, surcharge pressure and nature of pore fluid.

A swelling pressure of less than 20 kN/m^2 is not of much consequence.

13.22 (c)

Auger obtained samples are highly disturbed. Auger boring is most effective in soft soils which can stand unsupported and have some stickiness so that they do not fall back into the hole during lifting operation. Thus it is most effective in case of silts and clays.

13.23 (a)

Water table measurements that are taken at the same time of year can be used to develop a water table contour map to show the direction of ground water flow.

13.24 (a)

Lime stabilization is used to improve the strength, stiffness and durability of fine-grained soils. Addition of lime to soils produces a maximum density under a higher optimum moisture content than in the untreated soil, thus leads to flocculated or aggregated larger particle groups which are fairly stable. Lime produces a decrease in plasticity index and swelling potential and an increase in shrinkage limit. For this reason, lime stabilization has extensively been used for stabilizing highly unstable plastic and swelling clayey soils, such as blackcotton soils.

13.25 (d)

For a good quality soil sample (undisturbed samples), the sampler should have low value of area ratio (less than 10% or so). In order to keep A_r less, thin cutting edge is therefore preferred in a soil sampler.

Inside clearance is meant to reduce the friction between the soil sample and the sampler when the soil enters the tube, by allowing for the elastic expansion of the soil. Thus if inside clearance is high, there will be too much of lateral expansion. IS recommends that the outside clearance should not be much greater than the inside clearance.

13.27 (c)

Hydrated (or slaked) lime is very effective in treating heavy plastic clayey soils.

13.28 (c)

The basic principles of incorporating reinforcement members into a soil mass are much the same as those utilised in the design of reinforced concrete.

The design of reinforced earth wall is based on assumption that "The pressure acting of the wall facing element without the reinforcements is the same as that acts on a rigid vertical retaining wall under active state".

UNIT

VI

Surveying and Geology

Syllabus

Surveying: Classification of surveys, various methodologies, instruments & analysis of measurement of distances, elevation and directions; Field astronomy, Global Positioning System; Map preparation; Photogrammetry; Remote sensing concepts; Survey Layout for culverts, canals, bridges, road/railway alignment and buildings, Setting out of Curves.

Geology: Basic knowledge of Engineering geology & its application in projects.

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OOOO

1 Fundamental Concepts of Surveying & Linear Measurement

1.1 It is required to produce a small-scale map of an area in magnetic zone by directly plotting and checking the work in the field itself. Which one of the following surveys will be most appropriate for purpose?

(a) Chain (b) Theodolite
(c) Plane Table (d) Compass

[ESE : 1995]

1.2 A 30 m metric chain is found to be 0.1 m too short throughout the measurement. If the distance measured is recorded as 300 m, then the actual distance measured will be

(a) 300.1 m (b) 301.0 m
(c) 299.0 m (d) 310.0 m

[ESE : 1995]

1.3 Offsets are

(a) lateral measurements made with respect to main survey lines
(b) perpendiculars erected from chain lines
(c) taken to avoid unnecessary walking between stations
(d) measurements which are not made at right angles to the chain line

[ESE : 1995]

1.4 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Correction for sag	1. Tacheometer
B. Least count 30′	2. Aerial photograph
C. Overlap	3. Base line
D. Additive constant	4. Prismatic compass

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	2	1
(c)	1	2	3	4
(d)	3	4	1	2

[ESE : 1995]

1.5 The number of observations required of an operation to produce results having a specified accuracy

(a) varies inversely with the square of the confidence interval
(b) varies directly with the square of the confidence interval
(c) increases with the possible magnitude of the average expected value
(d) increases with the range of observed values, namely, the difference between the maximum and the minimum values of the observations

[ESE : 1996]

1.6 The following steps are necessary to obtain sufficient accuracy with the tape:

1. Keeping uniform tension on tape for each measurement.
2. "Breaking" tape on slopes are necessary to keep the tape level.
3. Keeping accurate count of the stations.
4. Keeping the tape on the line being measured.

The correct sequence of these steps is

(a) 4, 2, 1, 3 (b) 2, 3, 4, 1
(c) 4, 1, 2, 3 (d) 3, 2, 1, 4

[ESE : 1997]

1.7 The true length of a line is known to be 200 m. When this is measured with a 20 m tape, the length is 200.80 m. The correct length of the 20 m tape is

(a) 19.92 m (b) 19.98 m
(c) 20.04 m (d) 20.08 m

[ESE : 1998]

1.8 A line of true length 500 m when measured by a 20 m tape is reported to be 502 m long. The correct length of the tape is

(a) 19.92 m (b) 20.08 m
(c) 20.80 m (d) 21 m

[ESE : 1999]

1.9 Match List-I (Corrections) with List-II (Name) and select the correct answer using the codes given below the lists:

List-I

A. $\pm L\left(1-\frac{h}{R}\right)$

B. $-\frac{l}{24}\left(\frac{W}{P}\right)^2$

C. $\pm\alpha(T_f-T_s)L$

D. $\pm\frac{(P_f-P_s)L}{AE}$

List-II

1. Sag correction
2. Pull correction
3. Temperature correction
4. Mean sea level correction

Codes:

	A	B	C	D
(a)	4	1	3	2
(b)	1	4	3	2
(c)	4	1	2	3
(d)	1	4	2	3

[ESE : 2002]

1.10 Match List-I (Type of survey) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I

A. Topographical survey
B. Reconnaissance survey
C. Cadastral survey
D. Archaeological survey

List-II

1. To determine boundaries of fields, houses, etc.
2. To find relics of antiquity
3. To determine natural features of a country
4. To determine possibility and rough cost of the surveying system to be adopted

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	3	1	4	2
(c)	2	4	1	3
(d)	2	1	4	3

[ESE : 2004]

1.11 Which of the following figures are equal to one acre?

1. 43560 sq.ft.
2. 40 gunthas
3. 10 sq. Gunter's chain
4. 4850 sq. yds.

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 2 and 4 (d) 1, 3 and 4

[ESE : 2006]

1.12 What is the slope correction for a length of 30.0 m along a gradient of 1 in 20?

(a) 3.75 cm (b) 0.375 cm
(c) 37.5 m (d) 0.0375 cm

[ESE : 2006]

1.13 A 30 m metric chain is found to be 10 cm too short throughout a measurement. If the distance measured is recorded as 300 m, what is the actual distance?

(a) 300.1 m (b) 301.0 m
(c) 299.0 m (d) 310.0 m

[ESE : 2006]

1.14 A 20 m chain was found to be 10 cm too long after chaining a distance of 2000 m. It was found to be 18 cm too long at the end of the day's work after chaining a total distance of 4000 m. What is the true distance if the chain was correct before the commencement of the day's work?

(a) 3962 m (b) 4019 m
(c) 3981 m (d) 4038 m

[ESE : 2007]

1.15 A scale of 1 inch = 50 ft. is mentioned on an old map. What is the corresponding equivalent scale?

(a) 1 cm = 5 m (b) 1 cm = 6 m
(c) 1 cm = 10 m (d) 1 cm = 12 m

[ESE : 2008]

1.16 An invar tape, 50 m in length, standardized at 20°C temperature and 10 kg pull, is used to measure a base line. The correction per tape length, if at the time of measurement the temperature was 30° and the coefficient of linear expansion of the tape was 1×10^{-6} per °C, will be

(a) 0.0200 m (b) 0.0050 m
(c) 0.0005 m (d) 0.0001 m

[ESE : 2011]

1.17 A rectangular plot of 16 km^2 in area is shown on a map by a similar rectangular area of 1 cm^2. R.F. of the scale to measure a distance of 40 km will be

(a) $\frac{1}{1600}$ (b) $\frac{1}{400000}$

(c) $\frac{1}{400}$ (d) $\frac{1}{16000}$

[ESE : 2011]

1.18 The magnitude of 'sag correction' during measurement of lengths by taping is proportional to the

(a) Cube of the weight of the tape, in kg per m run
(b) Cube root of the weight of the tape, in kg per m run
(c) Square of the weight of the tape in kg per m run
(d) Square root of the weight of the tape, in kg per m run

[ESE : 2011]

1.19 If the original scale of a negative is 1 : 10,000 the ground resolution, considering that we get nearly 20 lines pair per mm, will be

(a) 50 mm (b) 20 cm
(c) 2 m (d) 25 cm

[ESE : 2011]

1.20 If L is the length of the chain, W is the weight of the chain and T is the tension, the sag correction for the chain line is

(a) $\frac{W^2L^2}{24T^3}$ (b) $\frac{W^2L}{24T^2}$

(c) $\frac{W^2L^2}{24T^2}$ (d) $\frac{W^2L^3}{24T^3}$

[ESE : 2012]

1.21 In an inclined terrain, if the elevation difference between the two ends of a line is h and the inclined length of the line is L, the correction for slope is

(a) $\frac{h^2}{L^2}$ (b) $\frac{h^2}{2L^2}$

(c) $\frac{2h^2}{L^2}$ (d) $\frac{h^2}{2L}$

[ESE : 2012]

1.22 Which one of the following statements is correct?

(a) In a retrograde vernier, $(n-1)$ divisions on the primary scale are divided into n divisions on the vernier scale.
(b) A double vernier consists of two simple verniers placed end-to-end forming one scale with the zero in the centre.
(c) In an extended vernier, $(2n+1)$ primary divisions are divided into n divisions on the vernier.
(d) In a direct vernier, $(n+1)$ primary divisions are divided into n equal divisions on the vernier scale.

[ESE : 2013]

1.23 The length of a survey line when measured with a chain of 20 m nominal length was found to be 841.5 m. If the chain used is 0.1 m too long, the correct length of the measured line is

(a) 845.7 m (b) 837.39 m
(c) 843.6 m (d) 839.4 m

[ESE : 2014]

1.24 Consider the following statements:
The general principles of surveying are

1. To work from part to whole.
2. To locate a new station by measurements from at least two fixed reference points already established and/or identifiable.

Which of the above statements are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2015]

1.25 The side of a square land was measured as 150 m and is in error by 0.05 m. What is the corresponding error in the computed area of the land?

(a) 5 m^2 (b) 10 m^2
(c) 15 m^2 (d) 20 m^2

[ESE : 2016]

1.26 Which of the following statements are rightly associated with the laws of weights in the theory of errors?

1. If an equation is multiplied by its own weight, then the weight of the resulting equation is equal to the reciprocal of the weight of the original equation.

2. The weight of the algebraic sum of two or more quantities is equal to the reciprocal of the sum of the individual weights.
3. If the quantity of a given weight is multiplied with a factor, then the weight of the resulting quantity is obtained by dividing the original weight by the square root of that factor.
4. If the quantity of a given weight is divided by a factor, then the weight of the resulting quantity is obtained by multiplying the original weight by the square of that factor.

(a) 2 and 3 (b) 2 and 4
(c) 1 and 4 (d) 1 and 3

[ESE : 2016]

1.27 Hypotensuall allowance is given by the expression (adopting standard conventions)
(a) $(1 - \sec\theta) \times$ measured distance
(b) $(1 - \cos\theta) \times$ measured distance
(c) $(\sec\theta - 1) \times$ measured distance
(d) $(\cos\theta - 1) \times$ measured distance

[ESE : 2016]

1.28 The clogging of chain rings with mud introduces (with 'error' defined in the standard way)
1. Negative cumulative error.
2. Positive cumulative error.
3. Compensating error.

(a) 1 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

[ESE : 2016]

1.29 Survey of India was publishing toposheets using a scale of
(a) 1 : 1000 (b) 1 : 5000
(c) 1 : 10000 (d) 1 : 50000

[ESE : 2016]

■■■■

Answers Fundamental Concepts of Surveying and Linear Measurement

1.1 (c)	1.2 (c)	1.3 (b)	1.4 (b)	1.5 (a)	1.6 (c)	1.7 (a)	1.8 (a)	1.9 (a)	
1.10 (a)	1.11 (a)	1.12 (a)	1.13 (c)	1.14 (b)	1.15 (b)	1.16 (c)	1.17 (b)	1.18 (c)	
1.19 (*)	1.20 (b)	1.21 (d)	1.22 (b)	1.23 (a)	1.24 (b)	1.25 (c)	1.26 (c)	1.27 (c)	
1.28 (b)	1.29 (d)								

Explanations Fundamental Concepts of Surveying and Linear Measurement

1.1 (c)
Chain survey is used for moderately small areas and measurement of ill defined details e.g. edge of a marsh or for filling in details between already established points. Chain is used to measure the length of the line and tape is employed for measurement of offsets.
Compass survey is conducted mainly for angular measurements. It is done for large areas with rough ground having many details. However, magnetic zone affects the accuracy of compass by introducing local attraction errors. The details can be plotted in the office only.
Theodolite can be used for horizontal and vertical angle measurement.
Plane table survey is most suitable for small and medium scale mapping. The observations and plotting of details can be done simultaneously. The errors and mistakes in plotting can be checked by drawing check lines.

1.2 (c)
Actual length of chain
$= 30 - 0.1 = 29.9$ m

$$\text{Actual distance} = \frac{29.9}{30} \times 300 = 299 \text{ m}$$

1.3 (b)
The distance measured right or left of the chain line to locate details like boundaries, culverts etc. are called offsets. These are of two types:

(i) Perpendicular offsets at right angles to the chain line
(ii) oblique offsets not at right angles to the chain line

1.4 (b)

In triangulation base line is measured very precisely. Sag correction is used for base line measurement. Temperature correction is applied by measuring the temperature at least at three places. Finally slope correction is also needed on steep slopes.

The overlap of the photographs is maintained to ensure complete coverage of the area. The overlap in the direction of flight is known as longitudinal or forward overlap (about 60%). The overlap between the adjacent flights is known as side overlap (about 30%). It is used to:

(i) Orient points so as to form a continuous flight strip
(ii) View the photographs by stereoscope.

1.5 (a)

Probable error of single observation of unit weight

$$E_s = \pm 0.6745\sqrt{\frac{\Sigma e^2}{(n-1)}}$$

where

e is residual error

n is number of observations

So number of observations (n) vary inversely with square of confidence interval (E_s)

$$n = \left(\frac{0.6745}{E_s}\right)^2 \Sigma e^2 + 1$$

1.6 (c)

The correct sequence to obtain sufficient accuracy with tapes is:

(i) Keeping the tape on line being measured
(ii) Keeping uniform tension on tape for each measurement.
(iii) "Breaking" tape on slopes to keep tape level.
(iv) Keeping accurate count of stations.

1.7 (a)

$$\frac{\text{Correct length of tape}}{\text{Designated length of tape}} = \frac{\text{Correct length of line}}{\text{Length of line observed with the tape}}$$

$$\therefore \text{Correct length of tape} = \frac{200}{200.80} \times 20$$

$$= 19.92\ \text{m}$$

1.8 (a)

$$\text{Correct length of the tape} = \frac{\text{Actual length of the tape}}{\text{Nominal length of the tape}} \times \text{Measured length}$$

$$500 = \frac{l}{20} \times 502$$

$$l = 19.92\ \text{m}$$

1.10 (a)

Topographic Surveys are used to identify and map the contours of the ground and existing features on the surface of the earth or slightly above or below the earth's surface (i.e. trees, buildings, streets, walkways, manholes, utility poles, retaining walls, etc. It helps determine natural features of a country.

The **reconnaissance survey** is an study of an entire area that might be used for a road or airfield. It helps determine possibility and rough cost of surveying system to be adopted.

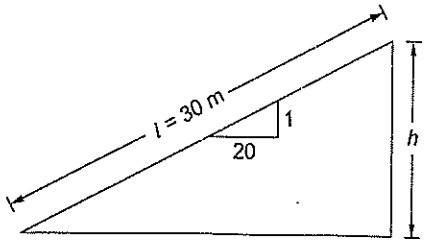
Cadastral surveying is concerned with land management, and more specifically with issues of land ownership, measurement and delineation of property boundaries.

In an **archaeological survey**, the archaeologists collect information about the location, distribution and organization of past human cultures and about old and relic structures.

1.11 (a)

1 acre = 4840 sq. Yard
1 sq. Yard = 9 sq feet
1 acre = 43560 sq ft.
1 acre = 10 x (Gunter's chain)^2
1 acre = 40 Guntha

1.12(a)



$$\text{Slope correction} = \frac{h^2}{2l}$$

Difference in elevation between points,

$$h = \frac{1}{\sqrt{(20)^2+1}} \times 30$$

$$\simeq 1.50\text{ m}$$

$$\therefore \text{Slope correction} = \frac{(1.50)^2}{2\times 30}$$

$$= 0.0375\text{ m} = 3.75\text{ cm}$$

1.13 (c)

$$\text{Actual distance} = \frac{(30-0.1)}{30} \times 300$$

$$= 299.0\text{ m}$$

1.14 (b)

For the first 2000 m, average error is

$$e = \frac{0+10}{2} = 5\text{ cm}$$

$$= 0.05\text{ m}$$

$\therefore$ Incorrect length of chain,

$$L' = 20 + 0.05 = 20.05\text{ m}$$

Measured length, $l' = 2000$ m

$$\therefore \text{ True length, } l_1 = \left(\frac{L'}{L}\right) \times l'$$

$$= \left(\frac{20.05}{20}\right) \times 2000$$

$$= 2005\text{ m}$$

For the next 2000 m, average error is

$$e = \frac{10+18}{2} = 14\text{ cm}$$

$$= 0.14\text{ m}$$

$$\therefore \quad L' = 20 + 0.14 = 20.14\text{ m}$$

$$l' = 2000\text{ m}$$

$$\therefore \text{ True length, } l_2 = \left(\frac{L'}{L}\right) \times l'$$

$$= \left(\frac{20.14}{20}\right) \times 2000 = 2014\text{ m}$$

Hence, true distance,

$$l = l_1 + l_2$$

$$= 2005 + 2014$$

$$= 4019\text{ m}$$

1.15 (b)

$$1\text{ inch} = 2.54\text{ cm}$$

$$1\text{ feet} = 0.3048\text{ m}$$

Given that 1 inch = 50 ft.

$$\Rightarrow \quad 2.54\text{ cm} = 50 \times 0.3048\text{ m}$$

$$\Rightarrow \quad 1\text{ cm} = \frac{15.24}{2.54}\text{m}$$

$$\Rightarrow \quad 1\text{ cm} = 6\text{ m}$$

1.16 (c)

Correction for temperature.

$$C_t = \alpha(T_m - T_0)L$$

where α = coefficient of thermal expansion

T_m = mean temperature in the field during measurement

T_0 = the standard temperature for the tape

L = measured length

$$C_t = 1 \times 10^{-6}(30-20) \times 50$$

$$= 0.0005\text{ m}$$

1.17 (b)

R.F. is ratio of two measurements with common unit.

$$\text{R.F.} = \left[\frac{1\text{ cm}^2}{16 \times (10^3)^2 \times (10^2)^2\text{ cm}^2}\right]^{1/2}$$

$$= \frac{1}{400000}$$

1.18 (c)

The sag correction C_s is given by

$$C_s = \frac{l(wl)^2}{24P^2}$$

where l = the length of the tape (in metres) suspended between the supports

P = pull applied in kg or N

w = weight of the tape in kg or N per metre run

C_s = sag correction in metres for length l

wl = weight of tape suspended between the supports.

1.19 (*)

Original scale of negative is 1 : 10000 and we get 20 lines per mm then ground resolution is

$$\frac{10000}{20}\text{mm} = 500\text{ mm or } 50\text{ cm.}$$

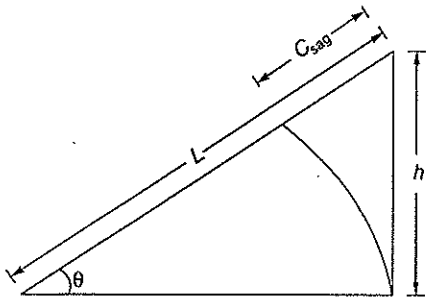
1.20 (b)

When a tape is suspended from each end, it forms a curve called a catenary . Because the curve is longer than the straight-line distance between the ends of the tape, the tape always reads longer than the actual distance. It is corrected by sag correction.

1.21 (d)

Correction due to slope

$$C_s = \frac{h^2}{2L} \text{ (Subtractive)}$$



where,

h = difference in elevation between the ends

L = Inclined length measured

l = Horizontal length

C_s = Correction due to sag

1.22 (b)

1. For Direct Vernier
   $(n-1)$ division on main scale = n division on vernier.
2. For retrograde vernier
   $(n+1)$ division on main scale = n division on vernier.
3. For double vernier
   Combination of the direct vernier
4. For inextended vernier
   $(2n-1)$ division on main scale = n division on vernier.

1.23 (a)

$$L \times l = L_1 \times l_1$$

$\Rightarrow$ $L = 841.5$ m, $l = 20.1$ m,

$l_1 = 20$ m

$$\Rightarrow \quad L_1 = \frac{841.5 \times 20.1}{20}$$

$$L_1 = 845.7 \text{ m}$$

1.24 (b)

The general principle of surveying is to work from whole to part.

1.25 (c)

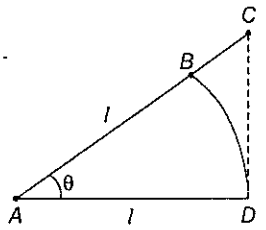
$$A = a^2$$

$$\partial A = 2a.\,\partial a$$

$$= 2 \times 150 \times 0.05$$

$$= 15 \text{ m}^2$$

1.27 (c)



$c_h = BC = AC - AB$

$= (l\sec\theta - l) = l(\sec\theta - 1)$

1.28 (b)

Length of chain is reduced

Measured length= Less

Noted down value = More

Error = (+)ve

Correction = (–)ve

Positive Cumulative Error

1.29 (d)

Topographical maps were printed on 1: 2,50,000 1: 50,000 and 1: 25,000 scales by survey of India before the adoption of nation mapping policy in 2005.

2 Compass Surveying, Theodolites and Traverse Surveying

2.1 If fore bearing of a line is $S49°52'E$ (assuming there is no local attraction), the back bearing of the line will be

(a) $S52°49'E$ (b) $S49°52'E$

(c) $N49°08'E$ (d) $N49°52'W$

[ESE : 1995]

2.2 **Assertion (A):** The vertical angles cannot be measured by the method of repetition.

Reason (R): There is only one rotation that is possible in the vertical plane.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 1996]

2.3 In a closed traverse, the sum of south latitudes exceeds the sum of north latitudes and the sum of east departures exceeds the sum of west departures. The closing line will lie in the

(a) N-W quadrant (b) N-E quadrant

(c) S-E quadrant (d) S-W quadrant

[ESE : 1997]

2.4 The direction of the magnetic meridian is established at each traverse station and the direction of the line is determined with reference to the magnetic meridian. This method of traversing is called

(a) fast needle method

(b) loose needle method

(c) bearing method

(d) fixed needle method

[ESE : 1998]

2.5 The true bearing of a line is 34°20′40″ and the magnetic declination at the place of observation is 2°00′20″W on the date of observation. The magnetic bearing of the line is

(a) 36°21′00″ (b) 34°20′20″

(c) 32°20′20″ (d) 32°00′20″

[ESE : 1999]

2.6 Consider the following assumptions of Bowditch method:

1. Angular measurements are more precise than linear measurements.
2. Linear measurements are more precise than angular measurements.
3. Errors in linear measurements are proportional to $\sqrt{L}$.
4. Correction to latitude or departure of any side

$$= \frac{\text{Total error in } L \text{ (or } D)}{} \times \frac{\text{Length of that side}}{\text{Perimeter of traverse}}$$

Which of these statements are correct?

(a) 1 and 4 (b) 1, 2 and 3

(c) 2, 3 and 4 (d) 3 and 4

[ESE : 1999]

2.7 If the declination is 5°40′W, which one of the following magnetic bearing would represent the true bearing of $S25°20'E$?

(a) $S19°20'E$ (b) $S31°0'E$

(c) $S20°0'E$ (d) $S19°20'W$

[ESE : 2000]

2.8 Consider the following steps:

1. Calculation of ΣL and ΣD.
2. Correction of latitudes and departures.
3. Calculation of bearings.
4. Calculation of interior angles.
5. Calculation of independent angles.

The correct sequence of these steps in Gale's traverse table calculations is

(a) 3, 4, 5, 2, 1 (b) 4, 3, 1, 2, 5

(c) 2, 1, 3, 4, 5 (d) 4, 3, 5, 2, 1

[ESE : 2001]

2.9 In a closed traverse with five sides, the error found from the fore bearing and back bearing of the last line is + 2°. The correction to the third line will be

(a) 0°24′ (b) 0°48′
(c) 1°12′ (d) 1°36′

[ESE : 2001]

2.10 **Assertion (A):** Whole circle bearing of a line is preferred to a quadrantal bearing.
Reason (R): Bearing is completely specified by an angle.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

2.11 The magnetic needle in a prismatic compass is placed

(a) at the bottom of the graduated aluminium ring
(b) above the graduated aluminium ring
(c) below the brass box
(d) below the needle lifter, but above the bottom inside the compass

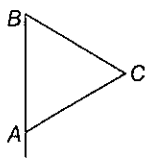
[ESE : 2003]

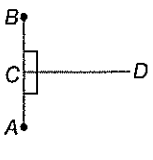
2.12 **Assertion (A):** In a theodolite if the lower clamp is not properly clamped or the instrument is not firmly tightened on the tripod head, the error introduced is known as 'slip'.
Reason (R): If the shifting head is loose, the error 'slip' will be introduced.

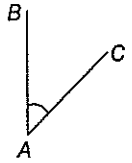
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

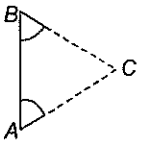
[ESE : 2003]

2.13 Which one of the following figures indicates the principle of traversing?

(a) 

(b) 

(c) 

(d) 

[ESE : 2003]

2.14 Which one of the following pairs is not correctly matched?

(a) Declination : Horizontal angle between magnetic meridian and true meridian
(b) Bowditch's rule : Employed to adjust closing error of a closed traverse
(c) Deflection angle : Measured in case of open traverse instead of measuring included angle
(d) Reconnaissance survey : Employed for detailed and precise survey

[ESE : 2005]

2.15 What is the angle between two plane mirrors of an optical square?

(a) 30° (b) 60°
(c) 45° (d) 90°

[ESE : 2006]

2.16 The magnetic bearing of a line *AB* is *S* 30°*E*. If the declination is 6° West, then what is the true bearing?

(a) S 36° E (b) N 36° W
(c) S 24° E (d) N 24° W

[ESE : 2006]

2.17 Diurnal variation is greater

(a) in winter than in summer
(b) at smaller latitudes than at higher latitudes
(c) at magnetic equator points
(d) in summer than in winter

[ESE : 2006]

2.18 The whole circle bearings of lines *AB* and *BC* are 30° 15′ and 120° 30′. What is the included angle *ABC* between the lines *AB* and *BC*?

(a) 229° 45′ (b) 89° 45′
(c) 269° 45′ (d) 90° 15′

[ESE : 2008]

2.19 What is $\angle ABC$ if *FB* of line *AB* is 40° and *BB* of line *BC* is 280°?

(a) 90° (b) 120°
(c) 240° (d) 320°

[ESE : 2008]

2.20 Which one of the following is carried out by two theodolite method?
(a) Circular curve ranging
(b) Tacheometric survey
(c) Geodetic survey
(d) Astronomical survey

[ESE : 2008]

2.21 The whole circle bearings of lines *OP* and *OQ* are 18° 15′ and 335° 45′ respectively. What is the value of the included angle *QOP*?
(a) 307° 30′ (b) 42° 30′
(c) 354° 00′ (d) 177° 00′

[ESE : 2009]

2.22 If L is the perimeter of a closed traverse, ΔD is the closing error in departure, the correction for the departure of a traverse side of length L_1, according to Bowditch rule, is

(a) $\Delta D\frac{L}{L_1}$ (b) $\Delta D\frac{L_1^2}{L}$

(c) $\frac{LL_1}{\Delta D}$ (d) $\Delta D\frac{L_1}{L}$

[ESE : 2010]

2.23 Consider the following statements about theodolites:
1. Transit theodolite is a theodolite in which the telescope can be transited.
2. EDMI is a theodolite fitted with a micrometer for measurements.
3. A double reading theodolite is one in which diametrically opposite segments of the graduated circle are brought into view and the readings are averaged.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 3 only
(c) 1 and 2 only (d) 2 and 3 only

[ESE : 2010]

2.24 In a transit theodolite, error due to eccentricity of verniers is eliminated by reading
(a) both verniers
(b) both right swing and left swing
(c) right and left faces
(d) different parts of main scale

[ESE : 2010]

2.25 Consider the following pairs in the context of a theodolite:

1. Plunging	:	The process of turning the telescope over its supporting axis through 180° in a vertical plane.
2. Face left	:	When the vertical circle of the theodolite is on the left of the observer while taking the reading.
3. Telescope normal	:	It implies 'bubble up' and face of the vertical circle left.
4. Swinging the telescope	:	It implies turning the telescope in a vertical plane.

Which of these pairs are correctly matched in case of theodolite?
(a) 1, 2 and 4 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 3

[ESE : 2010]

2.26 Consider the following in the context of variations in magnetic declination:
1. Secular 2. Diurnal
3. Annual 4. Regular

Which of these are relevant?
(a) 1, 2 and 3 (b) 1, 2 and 4
(c) 2 and 3 only (d) 3 and 4 only

[ESE : 2010]

2.27 Consider the following:
1. Line ranger
2. Reciprocal ranging
3. Random line method
4. Optical square

Which of these are the correct methods of ranging employed to solve the problem of vision obstructed but with chaining free?
(a) 1, 2, 3 and 4 (b) 2 and 3 only
(c) 2 and 4 only (d) 3 and 4 only

[ESE : 2010]

2.28 In a closed traverse *ABC*, following readings were taken

Line	Fore Bearing	Back Bearing
AB	20°	201°
BC	101°	278°
CA	278°	50°

Station *A* is free from local attraction. Correct bearing of *CB* is

(a) 275° (b) 276°
(c) 281° (d) 280°

[ESE : 2011]

2.29 Working from the whole to the part is followed as the fundamental principle of surveying so as to

1. Distribute errors
2. Improve ease of working
3. Prevent accumulation of errors
4. Compensate errors in a way
5. Refer to a common datum, say MSL

(a) 1, 2 and 4 (b) 1, 3 and 5
(c) 3 and 4 (d) 2 and 5

[ESE : 2011]

2.30 Assertion (A): The angle made by the lines of the magnetic force with the earth's surface is called dip

Reason (R): In the northern hemisphere, the south end of the needle dips downwards; and in the southern hemisphere, the north end of the needle dips downwards.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

2.31 Which one of the following statements is not correct?

(a) A surveyor's compass has two sight vanes
(b) A prismatic compass has an object vane and an eye vane
(c) A trough compass is an accessory to a plane table
(d) In a prismatic compass the graduations on the aluminimum disc rotate and the index remains stationary

[ESE : 2011]

2.32 If the whole circle bearing is 315° 20′, its quadrantal bearing would be

(a) *S* 36° 30′ *W* (b) *N* 44° 40′ *W*
(c) *N* 57° 24′ *W* (d) *S* 60° 40′ *W*

[ESE : 2012]

2.33 If the observed fore bearing of a line *xy* is 16° 26′, the back bearing of this line is

(a) 103° 26′ (b) 118° 36′
(c) 196° 26′ (d) 206° 26′

[ESE : 2012]

2.34 The needle of a magnetic compass is generally supported on a

(a) Bush bearing (b) Ball bearing
(c) Needle bearing (d) Jewel bearing

[ESE : 2012]

2.35 The length of a line measured with a 30 m chain was found to be 734.6 m. It was afterwards found that the chain was 0.05 m too long. The true length of the line was:

(a) 630.82 m (b) 680.82 m
(c) 735.82 m (d) 780.92 m

[ESE : 2013]

2.36 The bearing of line *AB* is 150° and the angle *ABC* is 124°. Bearing of line *BC* is

(a) 94° (b) 98°
(c) 198° (d) 90°

[ESE : 2013]

2.37 Which of the following set of terms does not relate to operation of a theodolite?

(a) Transiting and inverting
(b) Face left and face right
(c) Right swing and left swing
(d) Gauging and sounding

[ESE : 2013]

2.38 A theodolite was set up at *P* and the angle of elevation to the top of a mobile tower *ST* was 30°. The staff reading held at a station of *RL* 110 m was 2.555 m, the telescope being horizontal. The horizontal distance between the foot of the tower and the instrument station is 810 m. The *RL* of the top of the tower is

(a) 578.25 m (b) 579.50 m
(c) 580.25 m (d) 582.40 m

[ESE : 2014]

2.39 The magnetic bearing of a line is 55° 30' and the magnetic declination is 4° 30' east. The true bearing of a line will be
(a) 60° (b) 34°30'
(c) 49°30' (d) 51°
[ESE : 2014]

2.40 In a transit theodolite, any incidental error due to eccentricity of verniers is primarily counteracted by
(a) Reading both the verniers
(b) Reading different parts of main scale
(c) Reading right and left faces
(d) Taking both right swing readings
[ESE : 2014]

2.41 The Whole Circle Bearing of line *AB* is 50° and of line *BC* is 120°. The deflection angle at *B* at *AB* to *BC* is
(a) 50° (b) 70°
(c) 110° (d) 120°
[ESE : 2015]

2.42 Regarding a Prismatic Compass, which one of the following statements in correct?
(a) The object is sighted first. The observer then moves to the side of the object vane to take the reading.
(b) Sighting and reading are done simultaneously.
(c) The readings are taken from the north end.
(d) The compass has an edge bar needle.
[ESE : 2015]

2.43 For minor adjustments of horizontal angles measured using a theodolite, the tangential screw is adjusted after
(a) both the plates are unclamped
(b) the lower plate in clamped and the upper plate is unclamped
(c) the upper plate is clamped and the lower plate is unclamped
(d) both the plates are clamped
[ESE : 2015]

2.44 Consider the following statements:
1. The component of the distance between two points measured in the north-south direction is called the latitude of the line, between the points.
2. The component of the distance between two points measured in the east-west direction is called the departure of the line, between the points.
3. The latitude is considered as positive when reckoned southward.
4. The departure is considered as negative when reckoned westward.
Which of the above statements are correct?
(a) 1, 2 and 3 only (b) 2, 3 and 4
(c) 1, 2 and 4 only (d) 1, 2, 3 and 4
[ESE : 2015]

2.45 The magnetic bearing of a line (on full-circle mensuration basis) is 55° 30′ and the magnetic declination is 5° 30′ East. The true magnetic bearing of the line will be
(a) 61°00′ (b) 55°30′
(c) 40°00′ (d) 50°00′
[ESE : 2016]

2.46 In any closed traverse, if the survey work is error free, then
1. The algebraic sum of all the latitudes should be equal to zero.
2. The algebraic sum of all the departures should be equal to zero.
3. The sum of the northings should be equal to the sum of the southings.
Which of the above statements are correct?
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3
[ESE : 2016]

2.47 Turning of the theodolite telescope in vertical plane by 180° about the horizontal axis is known as
(a) Setting (b) Centering
(c) Transiting (d) Swinging
[ESE : 2016]

2.48 Which of the following are among the fundamental lines of a theodolite?
1. The vertical and horizontal axes.
2. The lines of collimation and axis of the plate levels.
3. The bubble line of the altitude level.
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3 only
[ESE : 2016]

2.49 A line PQ in an old map had magnetic bearing of N 57° E when the local magnetic declination was 2° E. If the magnetic declination is now 4° W, what will be the magnetic bearing of the line PQ now

(a) N 52° W (b) N 63° E
(c) N 54° E (d) N 52° E
[ESE : 2017]

Answers Compass Surveying, Theodolites and Traverse Surveying

2.1	(d)	2.2	(a)	2.3	(c)	2.4	(b)	2.5	(a)	2.6	(d)	2.7	(b)	2.8	(b)	2.9	(c)
2.10	(a)	2.11	(b)	2.12	(b)	2.13	(a)	2.14	(d)	2.15	(c)	2.16	(a)	2.17	(d)	2.18	(b)
2.19	(b)	2.20	(a)	2.21	(b)	2.22	(d)	2.23	(a)	2.24	(a)	2.25	(d)	2.26	(a)	2.27	(b)
2.28	(d)	2.29	(c)	2.30	(c)	2.31	(d)	2.32	(b)	2.33	(c)	2.34	(d)	2.35	(c)	2.36	(a)
2.37	(d)	2.38	(c)	2.39	(a)	2.40	(a)	2.41	(b)	2.42	(b)	2.43	(d)	2.44	(c)	2.45	(a)
2.46	(d)	2.47	(c)	2.48	(d)	2.49	(b)										

Explanations Compass Surveying, Theodolites and Traverse Surveying

2.1 (d)

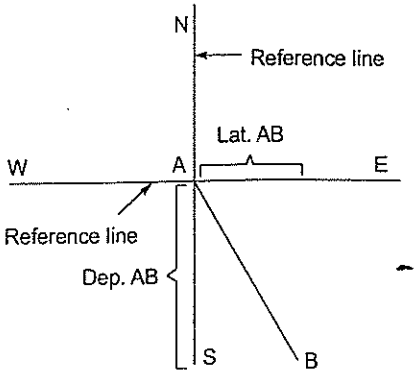
If the fore bearinssg of a line is given as the quadrantal bearing, then back bearing is numerically equal to the fore bearing. However *N* changes to *S* and *E* changes to *W* and vice versa.

2.2 (a)

Method of repetition is preferred for the measurement of a single angle and when the accuracy is desired beyond the least count of the instrument with a coarsely graduated circle. It is used for horizontal angles.

In the case of vertical angles face left and face right readings are taken.

2.3 (c)



Closing error is given by:

$\Sigma L_{south} - \Sigma L_{north} = 0$

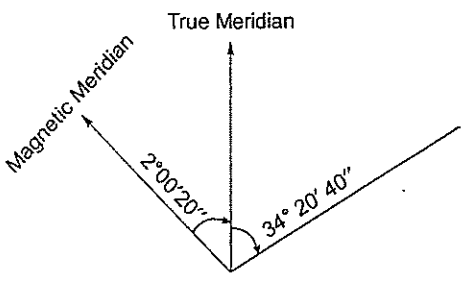
$\Sigma D_{east} - \Sigma D_{west} = 0$

Closing error will lie in south east quadrant.

2.4 (b)

In the loose needle method, the direction of the magnetic meridian is established at each traverse station and the direction of the line is determined with reference to the magnetic meridian. In other words, the magnetic bearing of each line is determined directly. A theodolite fitted with a compass is used for determining the magnetic bearing of the traverse line. The loose needle method is also known as free needle method.

2.5 (a)



When magnetic declination is west, then

True bearing = Magnetic bearing − Magnetic declination

$\Rightarrow$ 34° 20′ 40″ = Magnetic bearing − 2° 00′ 20″

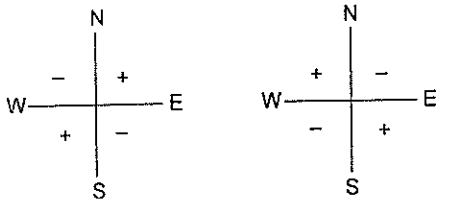
$\Rightarrow$ Magnetic bearing = 36°21′ 00″

2.6 (d)

Bowditchs rule is used to balance a traverse when the linear and angular measurements are equally precise. It is assumed that angular and linear measurement errors are proportional to $\frac{1}{\sqrt{L}}$ and $\sqrt{L}$ respectively.

2.7 (b)

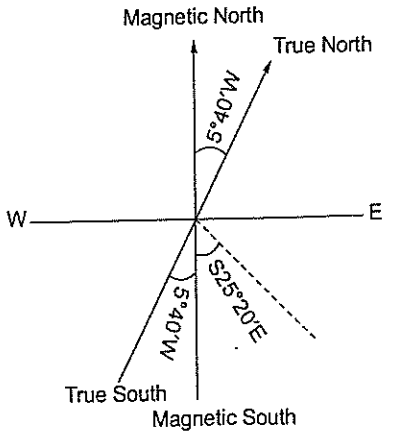
Note that negative (W) declination should be added to quadrantal bearing in second and fourth quadrant i.e. $N\ \theta W$ or $S\ \theta E$ and it should be subtracted from quadrantal bearing in first and third quadrant i.e., $N\theta E$ and $S\theta W$. Reverse should be done for positive (E) declination.



For Positive Declination For Negative Declination

True bearing = $S\ 25°\ 20'\ E + 5°\ 40'$

$= S\ 31°\ 0'\ E$



2.8 (b)

The sequence of steps in Gale's traverse table are:

(i) Writing names of traverse station.
(ii) Calculation of interior angles of traverse.
(iii) Correction of angle of disclosure (if any) to obtain correct interior angles.
(iv) Calculation of bearing of all lines with help of initial line bearing and corrected angles.
(v) calculation of latitude and departure of each line.
(vi) Calculation of closing error.
(vii) Determination of correct latitude and departure after applying correction for closing error.
(viii) Calculation of independent coordinates.

2.9 (c)

Number of sides, $n = 5$

Correction to the first line = $e/n = 0°24'$

Correction to the second line = $2e/n = 0°48'$

Correction to the third line = $3e/n = 1°12'$

Correction to the fourth line = $4e/n = 1°36'$

Correction to the fifth line = $5e/n = 2°0'$

2.10 (a)

Whole circle bearing's value ranges from 0° to 360° and is simple to measure. Therefore it is preffered to quadrantal bearing.

2.11 (b)

The *magnetic needle* is attached to a *graduated aluminium ring. The ring is graduated from* 0° to 360°. Degrees are subdivided into half degrees.

2.12 (b)

Slip is an *error which* is introduced *if* the lower *clamp* is *not* properly *clamped*, the shifting head is loose and the instrument is *not* firmly *tightened* on the tripod head.

2.13 (a)

The principles of traversing say that, a traverse should consist of a series of straight lines connected together to form an open or a closed polygon. The points defining the ends of the traverse lines are called traverse stations or traverse points.

2.14 (d)

Reconnaissance survey is done to examine the general character of the area for the purpose of determining the most feasible arrangements. It is preliminary inspection, done to have idea of terrain and features of ground. It is not detailed and precise.

2.15 (c)

Optical square is an instrument which is used for setting out right angles. It is more convenient and more accurate than a cross-staff. There are two mirrors placed vertically above the base. The mirrors are inclined at 45° to each other. One mirror is called horizon glass and it is unsilvered at the bottom and silvered on the top. Other mirror is called index glass and it is fully silvered. The horizon glass is fixed in position where as index glass can be adjusted.

2.16(a)

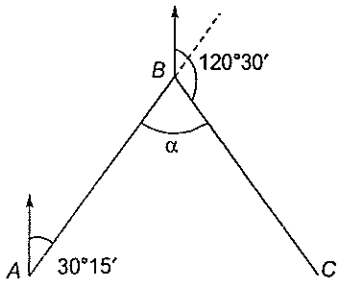
$$\text{True bearing} = S\,30°\,E + 6°\,W$$
$$= S\,36°\,E$$

2.17(d)

Diurnal variation of magnetic declination is due to

(i) geographical position of the place (lesser near equator and increases towards the pole)
(ii) the time of day (more in day)
(iii) season of the year (more in summer)
(iv) the year of the cycle of the secular variation

2.18(b)

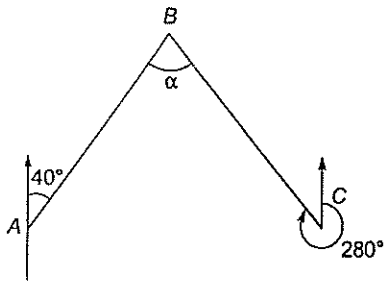


The included angle

$$\alpha = BB \text{ of } AB - FB \text{ of } BC$$
$$= (FB \text{ of } AB + 180°) - FB \text{ of } BC$$
$$= (30°15' + 180°) - 120°\,30'$$
$$= 89°\,45'$$

2.19(b)

$$BB \text{ of } BC = FB \text{ of } BC + 180°$$
$$\Rightarrow \quad FB \text{ of } BC = 280° - 180°$$
$$\Rightarrow \quad FB \text{ of } BC = 100°$$



$$BB \text{ of } AB = FB \text{ of } AB + 180°$$
$$= 40° + 180° = 220°$$

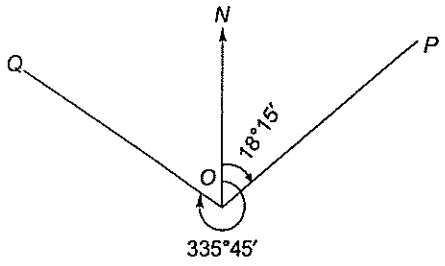
$\therefore$ Included angle, α

$$= BB \text{ of } AB - FB \text{ of } BC$$
$$= 220° - 100° = 120°$$

2.20 (a)

Circular curve ranging is carried out by two theodolite method. Only angular measurements (no linear measurements) are done in two theodolite method. This gives very accurate results even in rough terrains.

2.21(b)



$$\angle NOQ = 360° - 335°\,45'$$
$$= 24°\,15'$$

$\therefore$ Included angle,

$$QOP = 24°15' + 18°15'$$
$$= 42°30'$$

2.22 (d)

According to Bowditch rule

Correction for departure of length = Closing error in departure $\times \dfrac{\text{Length of traverse side}}{\text{Perimeter of transverse}}$

$$= \Delta D \times \frac{L_1}{L}$$

2.23 (a)

A theodolite is a precision instrument used for measuring angles both horizontally and vertically. Theodolites can rotate along their horizontal axis as well as their vertical axis. A transit is a surveying instrument that also takes accurate angular measurements. Transits use vernier scales and external graduated metal circles for angular readings.

A double reading theodolite is one in which images of diametrically opposite parts of the graduated circle are brought into the field of view by a suitable optical arrangement, and are read and averaged in one stroke.

2.24 (a)

If the zeros of the verniers *A* and *B* are not at the ends of the same diameter and exactly 180° apart, the error occurs. In that case the difference between the two vernier readings will be constant but slightly different from 180°. The error can be eliminated by taking the readings of both the verniers and taking the mean of the two readings. It may be noted that if the vernier is eccentric, no error is introduced in the angle so long as the same vernier is used for the initial and final reading. It is clear from the above discussions that by taking the mean of the two vernier readings, the error due to eccentricity of the centres and that due to eccentricity of verniers both are eliminated.

2.25 (d)

Swinging the telescope is the process of turning the telescope about the vertical axis in a horizontal plane. The swing is called right swing when the telescope is turned clockwise from the previous position. The swing is called left swing when the telescope is turned counter-clockwise.

2.26 (a)

Magnetic declination can be categorized as:

- Daily *declination*
- Annual *declination*
- Secular *declination*
- Irregular declination

2.28 (d)

In a closed traverse with no local attraction

$$FB \sim BB = 180°.$$

Since station *A* is free of local attraction thus

$$FB_{AB} = 20°$$

But, $BB_{AB} - FB_{AB} = 180°$

∴ *A* correction of –1° is applied at station *B*.

∴ $FB_{BC} = 101° - 1° = 100°$

But, $BB_{BC} - FB_{BC} = 178°$.

Therefore a correction of +2° is applied at station *C*.

∴ Correct bearing of *CB* is 280°.

2.29 (c)

Two basic principles of surveying are:

1. Location of a point by measurement from two points of reference.
2. Working from whole to part: The second ruling principle of surveying, whether plane or geodetic, is to work from whole to part.

   The idea of working in this way is to prevent the accumulation of errors and to control and localise minor errors which, otherwise, would expand to greater magnitudes if the reverse process is followed, thus making the work uncontrollable at the end.

2.30 (c)

The lines of force of earth's magnetic field run generally from south to North. Near the equator, they are parallel to the earth's surface. The horizontal projections of the lines of force define the magnetic meridian. The angle which these lines of force make with the surface of the earth is called the angle of dip or simply the dip of the needle. In elevation, these lines of force (i.e. the North end of the needle), are inclined downward towards the north in the Northern hemisphere and downward towards South in Southern hemisphere. At a place near 70° North latitude and 90° West longitude, it will dip 90°. This area is called North magnetic pole. A similar area in Southern hemisphere is called the South magnetic pole. Since the lines of force are parallel to the surface of the earth only at equator, the dip of the needle will be zero at equator and the needle will remain horizontal.

2.31 (d)

Both prismatic and surveyor's compass has two vanes. The object vane consist of a metal vane with a vertical hair and the eye vane consists of a metal vane with a fine slit.

In prismatic compass the graduated aluminium ring is attached with the needle. The ring does not rotate along with the line of sight.

The compass used with a plane table is a trough compass in which the longer sides of the trough are parallel and flat so that either side can be used as a ruler or lid down to coincide with a straight line drawn on the paper. Trough compass is used for orienting the plane table to magnetic north.

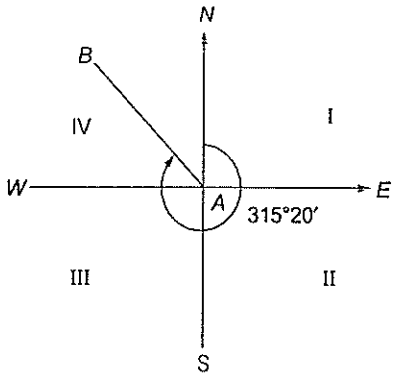
2.32 (b)

The given line lies in IVth quadrant

$\therefore$ quadrantal bearing

$= 360° - 315°\,20'$

$= 44°40' = N44°\,40'\,W$



2.33 (c)

$$B.B. = F.B. \pm 180°$$

The + sign is used when $F.B. < 180°$

$\therefore$ $B.B. = 16°\,26' + 180°$

$= 196°\,26'$

2.34 (d)

The compass needle is made of a slender symmetrical bar of magnetised steel or iron. It is hung from a conical jewel bearing supported on a sharp, hardened steel pivot.

2.35 (c)

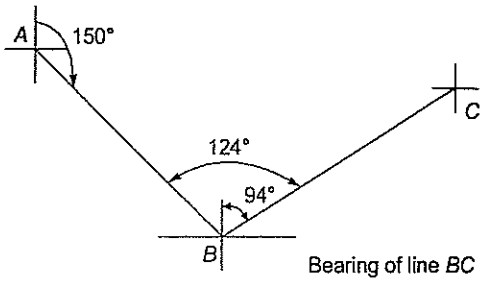
Correct length of chain

$= 30 + 0.05\ m = 30.05\ m$

$\therefore$ True length of the line

$$= \frac{734.6 \times 30.05}{30} = 735.82\ m$$

2.36 (a)



2.37 (d)

Transiting is the process of rotating the telescope over the horizontal axis through 180 in the vertical plane. The directions of the objective end and eyepiece are reversed, and the telescope points exactly in the opposite direction. It is also known as **plunging** or reversing.

If the vertical circle is on the right side of observer, the thodolite is in face right condition. If the vertical circle is on the left side of observer, the thodolite is in face left condition.

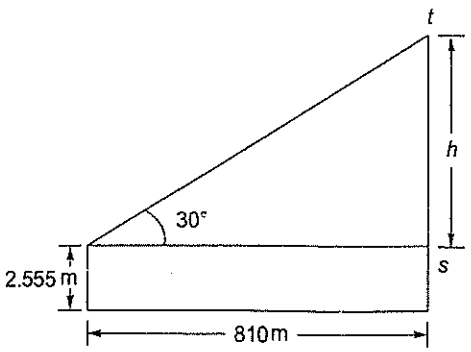
Swinging is the process of turning the telescope about the vertical axis in a horizontal plane.

The swing is called right swing when the telescope is turned clockwise from the previous position. The swing is called left swing when the telescope is turned anticlockwise from the previous position.

Sounding is the process of determination of bed depth of water body in hydrographic surveying.

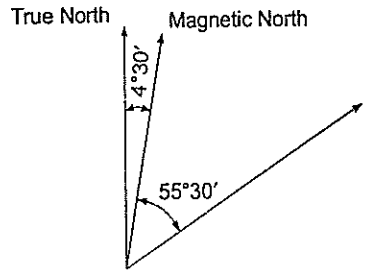
Gauges are instruments used to determine the water level and variation with time.

2.38 (c)



RL of top of tower
= *RL* of station + staff reading + *h*
= 110 + 2.555 + 810 tan 30°
= 580.208 m

2.39 (a)

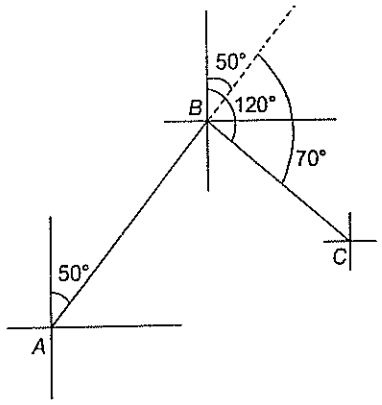


∴ True bearing
= Magnetic bearing + Magnetic declination (East)
= 55°30′ +4° 30′
= 60°

2.40 (a)

In transit theodolite, any incidental error due to eccentricity of verniers is primarily countracted by reading both the verniers.

2.41 (b)



∴ Deflection angle = 120° – 50° = 70°

2.42 (b)

In a prismatic compass, the sighting of the object and the reading of the dial are done simultaneously, whereas in a surveyor's compass, first the object is sighted and then reading of the ring is taken by moving round and looking down the glass cover.

2.43 (d)

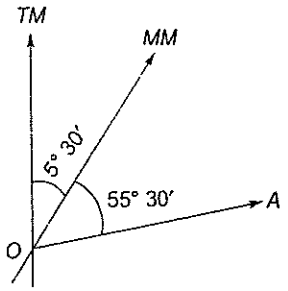
For minor adjustment of horizontal angles, measured using a theodolite, the tangential screw is adjusted after both the plates are clamped.

2.44 (c)

The latitude is considered as positive when reckoned northward and negative when reckoned southward. Similarly, the departure is considered positive and negative when reckoned on eastward and westward respectively.

2.45 (a)

$\delta_E = 5°\ 30'E$



$MB = 55°\ 30'$
$TB = MB + \delta_E$
$= 55°\ 30' + 5°\ 30'$
$= 61°\ 00'$

2.47 (c)

Transiting the Telescope : It is the process of rotating the telescope over the horizontal axis through 180° in the vertical plane. The directions of the objective end and eyepiece are reversed, and the telescope points exactly in the opposite direction. It is also known as **plunging** or reversing.

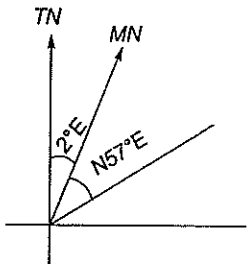
Swinging the Telescope : It is the process of turning the telescope about the vertical axis in a horizontal plane. The swing is called right swing when the telescope is turned clockwise from the previous position. The swing is called left swing when the telescope is turned anticlockwise from the previous position

2.48 (d)

Fundamental lines of theodolite and as follows:
(i) Vertical axis
(ii) Axis of plate levels
(iii) Axis of telescope

(iv) Line of collimation
(v) Horizontal axis
(vi) Axis of altitude bubble

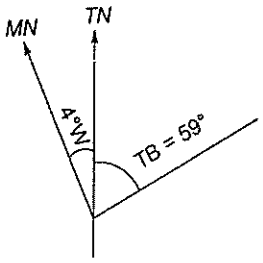
2.49 (b)



As per old map

$$TB = MB + 2°E$$
$$= 57° + 2°$$
$$= N59°E$$

When magnetic declination becomes 4°W,



$$TB = MB - 4°W$$
$$\Rightarrow \quad MB = TB + 4°W$$
$$= 59° + 4° = N63°E$$

■■■■

3 Levelling, Contouring and Plane Table Surveying

3.1 For locating an inaccessible point with the help of only a Plane table, one should use
(a) traversing (b) resection
(c) radiation (d) intersection
[ESE : 1995]

3.2 To find the *RL* of a roof slab of building, staff readings were taken from a particular set-up of the levelling instrument. The readings were 1.050 m with staff on the Bench Mark and 2.300 m with staff below the roof slab and held inverted. Taking the *RL* of the Bench Mark as 135.15 m, the *RL* of the roof slab will be
(a) 129.800 (b) 131.900
(c) 134.400 (d) 138.500
[ESE : 1995]

3.3 The method of plane tabling commonly used for establishing the instrument station is the method of
(a) radiation (b) intersection
(c) resection (d) traversing
[ESE : 1996]

3.4 The three-point problem in hydrographic surveying considers the data on the location of three shore signals *A*, *B* and *C* and the angles α and β subtended by *AB* and *BC* at the boat *P*; and then proceeds to plot the position of *P*. The problem may become indeterminate in special cases when
(a) *B* and *P* are on opposite sides of the line *AC*
(b) both *B* and *P* are on the same side of the line *AC*
(c) *P* is within the triangle *ABC*
(d) *P* is very close to the extension of one of the edges of the triangle *ABC*
[ESE : 1997]

3.5 The combined correction of curvature and refraction for a distance of 1400 m is
(a) 0.153 m (b) 0.132 m
(c) 0.094 m (d) 0.021 m
[ESE : 1997]

3.6 An observer standing on the deck of a ship just sees the top of a lighthouse which is 30 m above the sea level. If the height of the observer's eye is 10 m above the sea level, then the distance of the observer from the lighthouse will be nearly
(a) 22.5 km (b) 24.3 km
(c) 33.3 km (d) 59.7 km
[ESE : 1998]

3.7 Match List-I (Statement) with List-II (Situation) and select the correct answer using the codes given below the lists:
List-I
A. Accurate centering in plane table surveying is necessary for
B. Exact orientation is more important than accurate centering for
C. The intersection method of plane table surveying is particularly employed for
D. Plane table survey is useful for
List-II
1. Inaccessible points
2. Open country with good intervisibility
3. Large scale maps
4. Small scale maps
5. Hilly regions
Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	2	5
(c)	5	4	3	1
(d)	3	1	4	2

[ESE : 1998]

3.8 Assertion (A): When a contour survey of a steeply sloping area is envisaged, tacheometric methods are often used.

Reason (R): Stadia tacheometry leads to more accurate computation of lengths compared to steel tapes measured in however cautious and careful manner.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

3.9 Two points *A* and *B* are 1530 m apart across a river. The reciprocal levels measured are:

Level at	Readings on (in m)	
	A	B
A	2.165	3.810
B	0.910	2.355

The true difference in level between *A* and *B* would be

(a) 1.255 m (b) 1.355 m
(c) 1.545 m (d) 1.645 m

[ESE : 1999]

3.10 A lighthouse is visible just above the horizon at a certain station at the sea level. The distance between the station and the lighthouse is 40 km. The height of the lighthouse is approximately

(a) 187 m (b) 137.7 m
(c) 107.7 m (d) 87.3 m

[ESE : 1999]

3.11 The arithmetical check for the computation of *RL* by "rise and fall" method is given by

(a) $\Sigma FS - \Sigma BS = RL$ of last station point $- RL$ of first station point = ΣFall – ΣRise
(b) $\Sigma BS - \Sigma FS = RL$ of first station point $- RL$ of last station point = ΣRise – ΣFall
(c) $\Sigma BS - \Sigma FS = RL$ of last station point $- RL$ of first station point = ΣRise – ΣFall
(d) $\Sigma BS - \Sigma FS = RL$ of first station point $- RL$ of last station point = ΣRise – ΣFall

[ESE : 2000]

3.12 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Vertical cliff
B. Steep slope
C. Hill
D. Overhanging cliff

List-II
1. Contour lines of different elevations unite to form one line
2. Contour lines of different elevations cross one another
3. Contour lines are closely spaced
4. Closed contour lines with higher values inside them

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	1	3	4	2
(c)	1	2	4	3
(d)	4	2	1	3

[ESE : 2000]

3.13 The method of orienting a plane table with two inaccessible points is known as

(a) intersection
(b) resection
(c) back sighting
(d) two-point problem

[ESE : 2000]

3.14 The sensitiveness of a bubble tube in a level would decrease if

(a) the radius of curvature of the internal surface of the tube is increased
(b) the diameter of the tube is increased
(c) the length of the vapour bubble is increased
(d) the viscosity of the liquid is increased

[ESE : 2001]

3.15 Theory of errors and adjustments deals with minimizing the effects of

(a) instrumental errors
(b) mistakes
(c) systematic errors
(d) personal and accidental errors

[ESE : 2001]

3.16 Which one of the following surveys is employed for collecting sufficient data in connection with sewage disposal and water supply works?

(a) Topographic survey
(b) Cadastral survey
(c) Geodetic survey
(d) Cross-sectioning and profile levelling

[ESE : 2002]

3.17 The following readings were taken with a Dumpy level and a 4 m levelling staff on a continuously sloping ground at 30 m intervals: 0.680 m, 1.455 m, 1.855 m, 2.330 m, 2.885 m, 3.380 m, 1.055 m. The *RL* of the fourth point was calculated to be 79.100 m. The *RL* of the point that was read 0.680 m is

(a) 80.750 m (b) 79.780 m
(c) 78.420 m (d) 77.740 m

[ESE : 2002]

3.18 The object of chain and cross-staff survey is to

1. locate the boundaries of an area
2. plot the figure to a scale
3. find the area of the plot
4. find the reduced levels of the plot

Which of these statements is/are correct?

(a) 1, 2, 3 and 4 (b) 1, 2 and 3
(c) 1 and 2 (d) 4 alone

[ESE : 2002]

3.19 Match List-I (Methods) with List-II (Procedures) and select the correct answer using the codes given below the lists:

List-I

A. Traversing
B. Resection
C. Intersection
D. Radiation

List-II

1. Rays are drawn to locate the station on which the table is set-up
2. At least two rays are drawn from two different stations to the details to be located
3. Rays are drawn in the direction of details through the station point on which the table is set-up
4. Rays are drawn on the map by setting up the table over each of the stations towards the subsequent station

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2002]

3.20 The process of determining the location of the station (on the map) occupied by the plane table is called as

(a) intersection (b) three-point problem
(c) traversing (d) resection

[ESE : 2002]

3.21 Match List-I (Terms) with List-II (Description) and select the correct answer using the codes given below the lists:

List-I

A. Contour
B. Line of collimation
C. Tie line
D. Magnetic meridian

List-II

1. Line joining magnetic North and South
2. Line joining subsidiary station on the main line
3. Line joining points of same elevation
4. Line joining optical centre of the objective lens with point of intersection of cross-wires

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	2	1
(c)	3	4	1	2
(d)	4	3	1	2

[ESE : 2003]

3.22 Which one of the following methods of levelling eliminates the error due to curvature and refraction?

(a) Fly levelling
(b) Levelling by equalizing the distances of back sight and foresight
(c) Check levelling
(d) Precise levelling

[ESE : 2003]

3.23 Consider the following statements:

Reciprocal levelling eliminates the effect of

1. errors due to earth's curvature
2. errors due to atmospheric refraction
3. mistakes in taking levelling staff readings
4. errors due to line of collimation

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 4

[ESE : 2004]

3.24 **Assertion (A):** A series of closed contours indicate either a valley or a hill without any outlet, when their elevations, respectively, increase or decrease towards the centre.
Reason (R): Contour lines of different elevations can unite to form one line only at a vertical cliff.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2004]

3.25 Match List-I with List-II and select the correct answer using the codes given below the lists:
List-I
A. Satellite station
B. Gales traverse-method
C. Invar steel tape
D. Intervisibility of adjacent stations
List-II
1. Measurement of baseline
2. Characteristic of triangulation station
3. Auxiliary theodolite station near an inaccessible main triangulation station
4. Computation of co-ordinates of traverse/ triangulation stations.
Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	2	1	4	3
(c)	3	4	1	2
(d)	2	4	1	3

[ESE : 2004]

3.26 How high should a helicopter pilot rise at a point A just to see the horizon at point B, if the distance AB is 40 km?
(a) 101.75 m (b) 110.50 m
(c) 107.75 m (d) 105.50 m
[ESE : 2005]

3.27 What is the angle of intersection of a contour and a ridge line?
(a) 30° (b) 0°
(c) 180° (d) 90°
[ESE : 2006]

3.28 A level when set up 25 m from peg *A* and 50 m from peg *B* reads 2.847 m on staff held on *A* and 3.462 m on staff held on *B*, keeping bubble at its centre while reading. If the reduced levels of *A* and *B* are 283.665 m and 284.295 m respectively, what is the collimation error per 100.0 m?
(a) 0.015 m (b) 0.30 m
(c) 0.045 m (d) 0.060 m
[ESE : 2006]

3.29 There are ten instrument stations occupied in succession during a traverse survey. An observer makes equal error in each station, the magnitude of which is $\delta\theta$ in each instance at all the stations. What is the probable error of the final bearing at the end of the traverse?
(a) $\pm 10\,\delta\theta$ (b) $+ 100\,(\delta\theta)^2$
(c) $\pm 10\sqrt{\delta\theta}$ (d) $+ 10\sqrt{\delta\theta}$
[ESE : 2007]

3.30 A sailor, standing on the deck of a ship, just sees the light beam from a lighthouse on the shore. If the height of the sailor's eye and of the light beam at the lighthouse, above the sea level, are 9 m and 25 m respectively, what is the distance between the sailor and the lighthouse?
(a) 29.8 km (b) 31.1 km
(c) 31.9 km (d) 33.2 km
[ESE : 2007]

3.31 Which one of the following statements is correct?
(a) The axis of plate level should be parallel to the vertical axis.
(b) The axis of striding level must be parallel to the horizontal axis.
(c) The axis of the altitude level must be perpendicular to the line of collimation.
(d) The line of collimation must be perpendicular to the plate level axis.
[ESE : 2007]

3.32 Which one of the following statements is not correct?
(a) Change point is a point denoting shifting of level.
(b) For levelling work both centering and levelling of a dumpy level are prerequisite.
(c) Bench mark is a point whose RL is always known.
(d) None of the above
[ESE : 2008]

3.33 Consider the following statements about the characteristics of contours:
1. Closed contour lines with higher values inside show a lake.
2. Contour is an imaginary line joining points of equal elevations.
3. Closely spaced contours indicate steep slope.
4. Contour lines can cross each other in case an overhanging cliff.

Which of these statements are correct?
(a) 2,3 and 4 (b) 1 and 2 only
(c) 1 and 4 (d) 1, 2 and 3
[ESE : 2008]

3.34 Which one of the following surveys employs alidade?
(a) Contour survey
(b) Archeological survey
(c) Plane table survey
(d) Reconnaissance survey
[ESE : 2008]

3.35 Consider the following statements:
In surveying operations, the word 'reciprocal' can be associated with
1. ranging
2. levelling
3. contouring

Which of these statements is/are correct?
(a) 1 only (b) 1 and 2 only
(c) 2 and 3 only (d) 1, 2 and 3
[ESE : 2009]

3.36 Which of the following sights will be applicable for a change point?
(a) Back sight
(b) Intermediate sight and fore sight
(c) Fore sight
(d) Back sight and fore sight
[ESE : 2009]

3.37 Consider the following statements:
Reciprocal levelling is a method of levelling adopted when
1. the difference of levels between two points at a considerable distance apart is to be determined with great precision.
2. it is not possible to set up the level midway between two points as in the case of a deep valley or a river
3. error due to improper centering of level is to be eliminated

Which of these statements is/are correct?
(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1 and 3
[ESE : 2009]

3.38 Consider the following statements:
Errors eliminating by taking both face observations are those due to
1. horizontal axis not being perpendicular to the vertical axis
2. non-parallelism of the axis of telescope level and line of collimation
3. imperfect adjustment of vertical circle vernier

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only
[ESE : 2009]

3.39 If everyone of the three angles of a triangle has a probable error of ±1″, then what will be the probable error in the sum of the so-measured internal angles of the triangle?
(a) ±1″ (b) ±3″
(c) ±9″ (d) $\pm\sqrt{3}''$
[ESE : 2009]

3.40 Which one of the following errors is more severe in plane-table surveying?
(a) Defective sighting
(b) Defective orientation
(c) Movement of board between sights
(d) Non-horizontality of board when points sighted are at large differences of their elevation
[ESE : 2009]

3.41 Assertion (A): The solution of a three-point problem in plane-table surveying is aided by Lehmann's rules.
Reason (R): The application of Lehmann's rules reduces the triangle of error and is a controlled trial-and-error technique.
(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2009]

3.42 A light-house is visible just above the horizon at a certain station at the sea level. Distance between the station and the light-house is 60 km. The height of the light-house is
(a) 243.5 m (b) 4.0 m
(c) 287.5 m (d) 5.4 m

[ESE : 2010]

3.43 Error due to inclination of line of collimation in levelling across a river can be eliminated by
(a) reversion
(b) reciprocal ranging
(c) reciprocal levelling
(d) keeping level in middle

[ESE : 2010]

3.44 Assertion (A): In plane table photogrammetry, the areas to be mapped are taken from either end of a base line.
Reason (R): The position of the detail point with reference to the base line is obtained by intersection of rays drawn to it from each end of the base.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

3.45 An object on the top of a hill 100 m high is just visible above the horizon from a station at sea level. The distance between the station and the object is
(a) 38.53 km (b) 3.853 km
(c) 3853 km (d) 385.3 km

[ESE : 2011]

3.46 Which one of the following statements is not correct?
(a) Parallax error is eliminated when there is no change in the staff reading when eye is moved up and down
(b) The objective lens is to be focused towards a white or bright background for clear visibility of cross-hairs
(c) Temporary adjustments of the dumpy level are to be performed at every set up
(d) The eyepiece need not be adjusted after the first set up when the same surveyor is taking readings

[ESE : 2011]

3.47 In a solution of the three-point problem in plane table surveying, the converging of error is attained through
(a) Concyclic concept
(b) Bessel's method
(c) Triangle of error
(d) Tracing paper method

[ESE : 2011]

3.48 Assertion (A): Reciprocal levelling is adopted to decide the precise difference of level between two points at a considerable distance apart.
Reason (R): Reciprocal levelling eliminates errors due to:
(i) Curvature
(ii) Refraction, and
(iii) Line of collimation not being exactly parallel to bubble line.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

3.49 R.L. of floor at a building is 74.4 m, staff reading on the floor is 1.625 and staff reading when it is held inverted with bottom touching the ceiling of a hall is 2.870; then the height of the ceiling above the floor is
(a) 3.593 m (b) 3.953 m
(c) 4.495 m (d) 4.594 m

[ESE : 2012]

3.50 Following observations were taken during a reciprocal levelling:

Instrument near	P	Q
Staff reading at P	1.824	0.928
Staff reading at Q	2.748	1.606

If reduced level of *P* is 140.815 m, the reduced level of *Q* is

(a) 138.014 m (b) 139.616 m
(c) 140.014 m (d) 141.616 m

[ESE : 2012]

3.51 A contour may be defined as an imaginary line passing through

(a) Points on the longitudinal section
(b) Points of equal elevation
(c) Point of equal local ground slope
(d) Points of transverse section surveys

[ESE : 2012]

3.52 A closed contour line with two or more higher contours inside it will represent a

(a) Depression (b) Hill
(c) Cave (d) Well

[ESE : 2012]

3.53 Regarding plane-table survey, which of the following statements does *not* hold?

(a) All the plotting work including contouring can be done in the field.
(b) It is quite suitable for small scale surveys
(c) Less number of control points are required
(d) It can be done in all seasons

[ESE : 2012]

3.54 In a plane-table survey, the process of determining the plotted position of a station occupied by the plane-table by means of sights taken towards known points, the locations of which have already been plotted, is known as

(a) Radiation (b) Resection
(c) Intersection (d) Traversing

[ESE : 2012]

3.55 The plotting of inaccessible points in a plane-table survey can be done by the method of

(a) Interpolation
(b) Radiation
(c) Intersection
(d) Traversing

[ESE : 2012]

3.56 In case of levelling, backsight is

(a) A fixed point of known elevation
(b) The last staff reading taken before shifting the instrument.
(c) The first staff reading taken after setting the instrument.
(d) Any staff reading taken on a point of unknown elevation

[ESE : 2012]

3.57 The following observations were taken during testing of a dumpy level:

Instrument at	Staff reading on	
	P	Q
P	1.475 m	2.205 m
Q	1.440 m	2.060 m

The collimation error in the instrument was:

(a) +0.055 m (b) +0.005 m
(c) –0.055 m (d) –0.005 m

[ESE : 2013]

3.58 R.L. of a floor level is 200.490 m. Staff reading on the floor is 1.695 m. Reading on the staff held upside down against the bottom of the roof is 3.305 m. Height of the ceiling is:

(a) 3.5 m (b) 4.0 m
(c) 5.0 m (d) 6.0 m

[ESE : 2013]

3.59 Which of the following terms related to levelling are correctly defined?

1. Line of collimation — Line joining the intersection of the crosshairs to the optical centre of the object glass and its continuation.
2. Back-sight — First staff reading taken after the level is set up
3. Fore-sight — Last staff reading prior to shifting of level, or termination of the process of levelling
4. Height of instrument — Height of centre of telescope above the ground where the level is set up.

(a) 1, 2, 3 and 4
(b) 1, 2 and 4 only
(c) 1, 2 and 3 only
(d) 2, 3 and 4 only

[ESE : 2013]

3.60 Two stations P and Q are on the opposite banks of a river. Following observations were taken in reciprocal levelling.

Instrument near	Staff reading at	
	P	Q
P	1.400	3.500
Q	0.600	2.200

R.L. of P is 200.000 m, and then R.L. of Q is nearly

(a) 199.3 (b) 201.7
(c) 200.0 (d) 198.2

[ESE : 2013]

3.61 In lavelling between two points A and B on the opposite sides of a river, the level was first set up near A and the staff readings on A and B were 2.645 m and 2.30 m respectively. The level was then moved near B and set up; the respective staff readings then were 1.085 m and 1.665 m on A and B respectively. What is the true difference of level between A and B?

(a) A and B are at same level
(b) A is 0.5825 m below B
(c) A is 0.4825 m below B
(d) B is 0.5825 m below A

[ESE : 2014]

3.62 A plane, which is perpendicular to the plumb line through a point and is tangential to the level surface at that point is called a

(a) Tangential plane (b) Vertical plane
(c) Level plane (d) Horizontal plane

[ESE : 2014]

3.63 Staff reading on the floor of a verandah of a school building is 1.815 m and staff reading when held with bottom of staff touching the ceiling over the verandah is 2.870 m R.L. of the floor is 74.500 m. Height of the ceiling above floor is

(a) 4.270 m (b) 4.685 m
(c) 3.955 m (d) 4.920 m

[ESE : 2014]

3.64 In setting up the plane table at a station P, the corresponding point on the plan was not accurately centred above P. If the displacement of P was 50 cm in a direction perpendicular to the ray, how much on the plan would be the consequent displacement of a point from its true position if the scale was 1 cm = 10 m?

(a) 5 mm (b) 1 mm
(c) 0.5 mm (d) 0.05 mm

[ESE : 2014]

3.65 The levelling staff held at a distance of 200 m is read at 4.54 m with the bubble out of centre by 2 divisions towards the observer. If the sensitiveness of the bubble is 25 secs/division, and 1 division = 2 mm, then actual staff reading must have been

(a) 4.5 m (b) 4.492 m
(c) 4.54 m (d) 4.62 m

[ESE : 2015]

3.66 In a levelling survey, the summation of all backsights and the summation of all foresights are 7.475 m and 7.395 m, respectively. The reduction level of the initial benchmark is 1000.000 m. The reduced level of the of point where the staff is held will be

(a) 100.000 m (b) 100.080 m
(c) 107.395 m (d) 107.475 m

[ESE : 2015]

3.67 The rise and fall method for obtaining the reduced levels of points provides is check on

1. Foresight
2. Backsight
3. Intermediate sight

Which of the above statements are correct?

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

[ESE : 2016]

3.68 Consider the following characteristics of contours:

1. A uniform slope is indicated when contour lines are uniformly spaced.
2. Contour lines cannot and anywhere but can close on themselves.
3. A set of closed contours indicates a depression or a summit, according to the lower or higher values being respectively inward.

Which of the above statements are correct?

(a) 1 and 2 only (b) 1, 2 and 3
(c) 1 and 3 only (d) 2 and 3 only

[ESE : 2017]

3.69 The type of levelling operations carried out for laying a railway track are

1. Longitudinal levelling (LS)
2. Fly levelling
3. Barometric levelling
4. Cross-sectioning

Select the correct answer using the codes given below:

(a) 1, 2 and 3 only (b) 1, 3 and 4 only
(c) 2, 3 and 4 only (d) 1, 2 and 4 only

[ESE : 2017]

Directions: Each of the next items consists of two statements, one labelled as the **'Statement (I)'** and the other as **'Statement (II)'**. Examine these two statements carefully and select the answers to these items using the codes given below :

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is ***not*** the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

3.70 **Statement (I):** Reciprocal levelling is adopted to decide the difference of level between two points, a considerable distance apart, with great precision.

Statement (II): Reciprocal levelling eliminates errors due to curvature, refraction and collimation.

[ESE : 2017]

3.71 **Statement (I):** Curvature correction must be applied when the sights are long.

Statement (II): Line of collimation is not a level line but is tangential to the level line.

[ESE : 2017]

■■■■

Answers Levelling, Contouring and Plane Table Surveying

3.1 (d)	3.2 (d)	3.3 (c)	3.4 (d)	3.5 (b)	3.6 (c)	3.7 (a)	3.8 (a)	3.9 (c)	
3.10 (c)	3.11 (c)	3.12 (b)	3.13 (d)	3.14 (d)	3.15 (d)	3.16 (d)	3.17 (a)	3.18 (b)	
3.19 (c)	3.20 (d)	3.21 (a)	3.22 (b)	3.23 (d)	3.24 (d)	3.25 (c)	3.26 (c)	3.27 (d)	
3.28 (d)	3.29 (a)	3.30 (b)	3.31 (b)	3.32 (b)	3.33 (a)	3.34 (c)	3.35 (b)	3.36 (d)	
3.37 (b)	3.38 (b)	3.39 (d)	3.40 (b)	3.41 (a)	3.42 (a)	3.43 (c)	3.44 (a)	3.45 (a)	
3.46 (d)	3.47 (c)	3.48 (a)	3.49 (c)	3.50 (c)	3.51 (b)	3.52 (b)	3.53 (d)	3.54 (b)	
3.55 (c)	3.56 (c)	3.57 (d)	3.58 (c)	3.59 (a)	3.60 (d)	3.61 (c)	3.62 (d)	3.63 (b)	
3.64 (c)	3.65 (b)	3.66 (b)	3.67 (d)	3.68 (b)	3.69 (d)	3.70 (a)	3.71 (a)		

Explanations Levelling, Contouring and Plane Table Surveying

3.1 (d)

(i) Radiation method is suitable only when the area to be surveyed is small and all the stations are visible and accessible from the instrument station.

(ii) Traversing is most suited when a narrow strip of terrain is to be surveyed e.g. survey of roads, railway etc.

(iii) Intersection method is preferred when the distance between stations is large or the stations are inaccessible or the ground is undulating.

(iv) Resection is used when some important details can be plotted easily by choosing any station other than the triangulation station.

3.2 (d)

RL of roof slab = *RL* of *BM* + Staff reading with Staff on *BM* + Inverted Staff reading

= 135.15 + 1.050 + 2.300

= 138.500 m

3.3 (c)

There are three methods of orienting plane table :

(i) By trough compass: It is a crude method and cannot be used where local attraction is suspected.

(ii) By back sighting: It is the most accurate method of orientation.

(iii) By resection

3.5 (b)

Correction due to curvature and refraction,

$C = 0.0673\,D^2$

but $D = 1400\text{ m} = 1.4\text{ km}$

$\therefore\quad C = 0.0673 \times (1.4)^2$

$= 0.132\text{ m}$

3.6 (c)

The distance of the observer from the light-house is given by

$$D = D_1 + D_2$$

$$= \sqrt{\frac{h_1}{0.0673}} + \sqrt{\frac{h_2}{0.0673}}$$

$$= \sqrt{\frac{30}{0.0673}} + \sqrt{\frac{10}{0.0673}}$$

$$= 21.11 + 12.19$$

$$= 33.3\text{ km}$$

3.7 (a)

Accurate orientation is more important in small scale maps whereas accurate centering is required for large scale maps. Plane table is useful in open area having good intervisibility between points. Method of intersection is employed for plotting of inaccessible points.

3.8 (a)

The primary object of a tacheometric survey is the preparation of a contoured plan. It is particularly suitable for filling in details on topographical maps, preliminary location survey and surveying steep grounds, broken boundaries and water stretches, etc. Also in surveys of higher accuracy it may be used to provide a ready check on distances measured with a chain or tape.

3.9 (c)

True difference in levels,

$$h = \frac{(3.810 - 2.165) + (2.355 - 0.910)}{2}$$

$= 1.545$ m

Error in collimation adjustment,

$$e = \frac{(3.810 - 2.165) - (2.355 - 0.910)}{2}$$

$= 0.1$ m

When the level is at *A*, the reading on the staff at *A* is correct. While reading on the staff at *B* is incorrect. When the level is at *B*, the reading on the staff at *B* is correct while reading on the staff at *A* is incorrect.

Correct readings are:

Level at	Readings on (in m)	
	A	B
A	2.165	3.710
B	0.810	2.355

3.10 (c)

Height of lighthouse

$= 0.0673 \times D^2$

$= 0.0673 \times (40)^2$

$= 107.68\text{ m}$

3.11(c)

Two arithmetic checks in collimation method.

$\Sigma BS - \Sigma FS$ = Last RL – First RL

Three arithmetic checks in rise and fall method.

$\Sigma BS - \Sigma FS$ = Last RL – First RL

= ΣRise – ΣFall

3.13 (d)

Resection is a method of plane table surveying in which location of station occupied by plane table is unknown and it is determined by sighting any two or three known points or plotted points. It is also called method of orientation and it can be conducted by two field conditions as follows:

- The three-point problem
- The two-point problem

3.14(d)

Sensitiveness of a bubble tube depends upon

(i) The radius of curvature of the internal surface i.e. larger the radius greater is the sensitiveness.

(ii) The diameter of the bubble tube i.e. larger the diameter, greater the sensitiveness.

(iii) The length of the bubble i.e. larger the length greater is the sensitiveness.

(iv) The viscosity and surface tension of the liquid i.e. lesser the viscosity more is its sensitiveness.

(v) Smoothness of the finish of the internal surface of the tube i.e. greater the smoothness more is the sensitivity.

(vi) Length of one division i.e. greater the length of one division more is the sensitiveness.

3.15(d)

Systematic or cumulative errors which occurs from well understood causes can be reduced by adopting suitable methods. It follows some definite mathematical or physical law and a correction can be determined and applied.

Accidental errors are those which remain after mistakes and systematic errors have been eliminated and are caused by a combination of reasons beyond the ability of the observer to control.

Personal errors arise from the limitations of the human senses such as sight, touch and hearing.

Both accidental and personal error represent the limit of precision in the determination of a value. They obey the law of probability and therefore theory of errors and adjustments applies to them.

3.16 (d)

Cross sectioning is done to determine elevation of point in direction perpendicular to centre line and Profile levelling is done to determine elevation of points along the centre line. Cross sectioning and Profile levelling is used for projects related to sewers, pipelines, highways, railways, canals etc.

3.17(a)

BS	IS	FS	Rise	Fall	RL
0.680					80.750
	1.455			0.775	79.975
	1.855			0.400	79.575
	2.330			0.475	79.100
	2.885			0.555	78.545
1.055		3.380		0.495	78.050

RL of the point that was read as 0.680

= 79.100 + total fall up to 2.330 reading

= 79.100 + (0.475 + 0.400 + 0.775)

= 80.750

3.18 (b)

Chain surveying is used for securing data for exact description and marking of the boundaries of a piece of land or for preparing the maps of the area to show various details. It is generally used for plans of estates, fields, etc. on a large scale when the area is small in extent and the ground is fairly level and open.

The cross-staff survey is a special type of chain survey conducted to locate the boundaries of a field for the purpose of determining the area of the field.

3.22(b)

Levelling by balancing backsight and fore-sight distances can eliminate collimation error.

Error due to curvature and refraction can be eliminated by equalizing FS and BS distances or by reciprocal levelling.

3.23 (d)

Reciprocal levelling is used to determine the correct difference of elevations of two points

which are quite apart and when it is not possible to set up the instrument midway between the points to balance the foresight and backsight. It eliminates the error due to curvature of the earth and refraction and the collimation error.

3.24(d)

A series of closed contour line with one or more higher ones inside represents a hill. Similarly, a series of closed contour line with one or more lower ones inside it indicates a depression without an outlet (i.e. a lake).

Contour lines cross a valley line at right angles. They form sharp curves of V-shape across it with convex side of the curve towards the higher ground.

3.25 (c)

Satellite station is an auxiliary theodolite station taken near an inaccessible main station.

Gale transverse method is used for computation of coordinates of transverse/triangulation station.

Invar steel tape is a precise tape which is used in measurement of length of baseline in traversing.

The main characteristic of adjacent triangulation stations is that they should be inter-visible from each other.

3.26(c)

The height of rise $= 0.0673\,D^2$

$= 0.0673 \times (40)^2$

$= 107.68$ m

3.27 (d)

Contour lines cross a ridge line (watershed) valley line at right angles. However, they form curves of U-shape round the ridge line with the concave side of the curve towards the higher ground. Contour lines form sharp curves of V-shape across valley line with convex side of the curve towards the higher around.

3.28(d)

Let the collimation error per 100 m is e.

True staff reading at A

$= 2.847 + \frac{25}{100}e$

$= 2.847 + 0.25e$

True staff reading at B

$= 3.462 + \frac{50}{100}e$

$= 3.462 + 0.5e$

Difference in elevation

$= 3.462 + 0.5e - (2.847 + 0.25e)$

$= 0.615 + 0.25e$

From RL of A and B difference in elevation

$= 284.295 - 283.665$

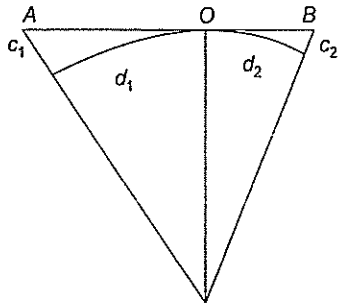
$= 0.630$ m

$\therefore \quad 0.615 + 0.25e = 0.630$

$e = 0.060$ m per 100 m

3.30(b)

Let A be the position of the top of light house and B be the position sailor's eye.



Let AB be tangential to water surface at O.

The distances d_1 and d_2 are given by

$d_1 = 3.853\sqrt{c_1}$ km

$= 3.853\sqrt{25} = 19.265$ km

$d_2 = 3.853\sqrt{c_2}$

$= 3.853\sqrt{9} = 11.559$ km

$\therefore$ Distance between A and $B = d_1 + d_2$

$= 19.265 + 11.559$

$= 30.824$ km

3.31(b)

The following relationship should exist:

(i) The axis of the plate level should be perpendicular to the vertical axis.

(ii) The axis of the altitude level must be parallel to the line of collimation.

(iii) The axis of the striding level (if provided) must be parallel to the horizontal axis.

(iv) The line of collimation must be parallel to the plate level axis.

(v) The line of collimation must be perpendicular to the horizontal axis at its intersection with the vertical axis.

(vi) The horizontal axis must be perpendicular to the vertical axis.

3.32 (b)

In levelling, change point or turning point is the point denoting shifting of level. During leveling, temporary adjustments are prerequisite for every setting of instrument.

- Centering
- Levelling
- Focussing

Benchmark is the point whose R.L. is always known.

3.33 (a)

Closed contour lines with higher values inside represents a hill. Closed contour lines with lower values insides represents a depression without an outlet i.e. a lake.

3.34 (c)

An alidade also called turning board is a device in plane table surveying that allows one to sight a distant object and use the line of sight to perform a task such as to draw a line on a plane table in the direction of the object or to measure the angle to the object from some reference point. Angles measured can be horizontal, vertical or in any chosen plane.

3.35 (b)

Reciprocal Ranging or indirect ranging is used when the end stations are not intervisible due to high ground or a hill or if the ends are too long. In such cases, intermediate points can be fixed on the survey line by a process known as reciprocal ranging.

Differential levelling is method of levelling in which the difference in elevation between two points which are at considerable distance is to be determined accurately and when it is not possible to set up the level midway between the two points. It eliminates the errors due to atmospheric refraction, inclination of line of collimation and the curvature of the earth.

3.36 (d)

A change point is the point selected on the route before shifting the instrument. The change point is also called a turning point. The staff is kept on the turning point and a foresight is taken before shifting the instrument. The staff should not be moved when the instrument is being shifted. After the instrument has been shifted and set up at the new location, a back sight is taken on the staff still held at the change point.

3.37 (b)

Reciprocal levelling is method of levelling in which the difference in elevation between two points which are at considerable distance is to be determined accurately and when it is not possible to set up the level midway between the two points. Reciprocal levelling eliminates the errors due to

- refraction
- inclination of line of collimation
- curvature

3.38 (b)

Errors eliminated by both face readings are:

1. Error due to line of collimation not being perpendicular to the horizontal axis.
2. Error due to horizontal axis not being perpendicular to the vertical axis.
3. Error due to line of collimation not being parallel to axis of altitude level.

3.39 (d)

$$\sigma_A = \pm\sqrt{(\sigma_a)^2 + (\sigma_b)^2 + (\sigma_c)^2}$$

$$= \pm\sqrt{(1)^2 + (1)^2 + (1)^2} = \pm\sqrt{3}''$$

3.40 (b)

If the orientation is defective the plotted work at successive station cannot be connected to plotted work of previous stations.

3.41 (a)

In three point problem, if the orientation of the plane table is not proper, the intersection of the resectors through the three points will not meet at a point but will form a triangle, known as triangle of error. The size of the triangle of error depends upon the amount of angular error in the orientation.

The trial and error method of three point problem, also known as Lehman's method minimises the triangle of error to a point iteratively. The iterative operation consists of drawing of resectors from known points through their plotted position and the adjustment of orientation of the plane table.

3.42 (a)

Height of light house

$= 0.0673 \times D^2$

$= 0.0673 \times (60)^2$

$= 242.28$ m

3.43 (c)

Reciprocal levelling eliminates :

- refraction error
- inclination of line of collimation
- curvature error

3.45 (a)

Distance,

$$d = \sqrt{\frac{H}{0.06735}} = \sqrt{\frac{100}{0.06735}} \text{ km}$$

$= 38.53$ km

3.46 (d)

Temporary adjustments or Station adjustments are those which are made at every instrument setting and preparatory to taking observations with the instrument. Permanent adjustments need be made only when the fundamental relations between some parts or lines are disturbed.

3.47 (c)

The trial and error method of three point problem, also known as Lehman's method minimises the triangle of error and converge the error to a point iteratively. The iterative operation consists of drawing of resectors from known points through their plotted position and the adjustment of orientation of the plane table.

3.48 (a)

When it is necessary to carry levelling across a river, ravine or any obstacle requiring a long sight between two points so situated that no place for the level can be found from which the lengths of foresight and backsight will be even approximately equal, special method i.e., reciprocal levelling is used to obtain accuracy and to eliminate the following :

1. Error in instrument adjustment;
2. Comnined effect of earth's curvature and the refraction of the atmosphere and
3. Variations in the average refraction.

3.49 (c)

Given

$RL = 74.4$ m, $BS = 1.625$ m

$HI_1 = RL + BS = 74.4 + 1.625$

$HI_2 = RL - FS = 74.4 - 2.870$

$\therefore$ Height of Ceiling $= HI_1 - HI_2$

$= 1.625 + 2.870$

$= 4.495$ m

3.50 (c)

$h_p = 1.824$; $h_Q = 2.748$

$h_p' = 0.928$; $h_Q' = 1.606$

Correct difference of elevation between P and Q is

$$h = \frac{\left(h_Q' - h_P'\right) + \left(h_Q - h_P\right)}{2}$$

$$= \frac{(1.606 - 0.928) + (2.748 - 1.824)}{2}$$

$= 0.801$ m

$\therefore$ The reduced level of Q

$= (140.815 - 0.801)$

$= 140.014$ m

3.51 (b)

A contour line is an imaginary line which connects points of equal elevation. Such lines are drawn on the plan of an area after establishing reduced levels of several points in the area. The contour lines in an area are drawn keeping difference in elevation of between two consecutive lines constant.

3.52 (b)

A closed contour line with two or more higher contours inside it will represent a Hill. Similarly a closed contour line with one or more lower ones inside it indicates a depression.

3.53 (d)

Plane table surveying cannot be done in rainy season and wet climatic conditions.

3.55 (c)

Intersection method can be used for plotting inaccessible points in plane table surveying. In this method, the positions of the object on the

plan are fixed by the intersection of rays drawn from two instrument stations. The line joining these instrument stations are called baseline.

3.56 (c)

The first staff reading taken after setting the instrument is known as backsight. The last staff reading taken after which the position of instrument station is changed is known as foresight. A fixed point of known elevation is called Benchmark.

3.57 (d)

Using reciprocal levelling,

$$h = \frac{(Q_1 - P_1) + (Q_1 - P_2)}{2}$$

$$= \frac{(2.205 - 1.475) + (2.060 - 1.440)}{2}$$

$= 0.675$ m

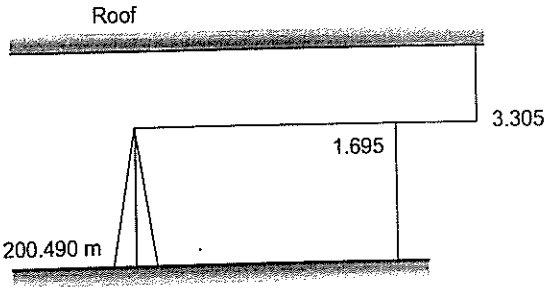
If instrument is kept at P reading at Q will be erroneous

$h = (2.205 - e) - 1.475$

$0.675 = (2.205 - e) - 1.475$

$e = 0.055$m

3.58 (c)



Height of the ceiling

$= 1.695 + 3.305 = 5.0$ m

3.59 (a)

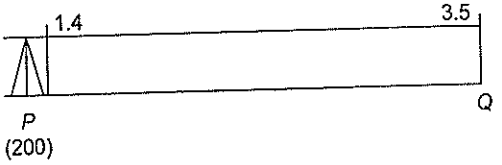
Line of Collimation: In a surveying telescope, the imaginary line through the optical center of the object glass and the cross-hair intersection in the diaphragm.

Back Sight: short for "back sight reading", the first staff reading taken by the surveyor after the levelling instrument is set up and levelled. B.S is generally taken on the point of known reduced level as on the benchmark or a change point.

Fore sight: short for "fore sight reading", the last staff reading taken before changing the instrument to the other position. It is the staff reading taken on point whose RL is to determined. This sight is considered as negative and deduced from Height of Instrument to determine RL of the point.

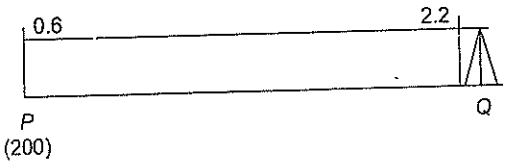
Height of Instrument: In survey leveling, it is the height of the line of collimation of the instrument over the station above which it is centered, or above a specified datum level.

3.60 (d)



$200 + 1.4 - 3.5 = RL$ of Q

$\Rightarrow$ RL of $Q = 197.9$ m



RL of $Q = 200 + 0.6 - 2.2$

$= 198.4$ m

$\therefore$ Avg. RL of $Q = \frac{197.9 + 198.4}{2}$

$= 198.15 \approx 198.2$ m

3.61 (c)

True difference of level between A and B

$$= \frac{(2.645 - 2.3) + (-1.085 + 1.665)}{2}$$

$= 0.4625$

So, A is below B by 0.4625 m.

Most close option is (c).

3.62 (d)

Horizontal plane: Horizontal plane through a point is a plane tangential to the level surface at that point. It is, therefore, perpendicular to the plumb line through the point.

3.63 (b)

Height of the ceiling above floor

= staff reading on the floor + Reading of inverted staff

$= 1.815 + 2.87$

$= 4.685$ m

3.64 (c)

In given scale, 1 cm = 10 m

i.e. 10 m on ground = 1 cm on plan

10 × 100 cm on ground = 1 × 10 mm on plan

$$1 \text{ cm on ground} = \frac{1\times10}{10\times100}\text{mm on plan}$$

∴ 50 cm on ground

$$= \frac{1\times10}{10\times100}\times 50\text{ mm on plan}$$

$$= 0.5 \text{ mm on plan}$$

3.65 (b)

Sensitivity,

$$\alpha = \frac{S}{nD}\times 206265$$

$$25'' = \frac{S}{2\times200}\times 206265$$

$$S = 0.0484\text{ m}$$

Now, Staff reading

$$= 4.54 - 0.0484 = 4.492\text{ m}$$

3.66 (b)

$\because$ ΣBS – ΣFS = RL of last point – RL of initial point

$\Rightarrow$ 7.45 – 7.395 = RL of last point – 100

∴ RL of last point = 100 + 7.45 – 7.395

= 100.08 m

3.67 (d)

Reduced levels of points on back sight and fore sight is checked along with the intermediate sight in rise and fall method.

3.68 (b)

The principal characteristics of contour lines which help in plotting or reading a contour map are as follows:

1. The variation of vertical distance between any two contour lines is assumed to be uniform.
2. The horizontal distance between any two contour lines indicates the amount of slope and varies inversely on teh amount of slope. Thus contours are spaced equally for uniform slope; closely for steep slope contours and widely for moderate slope.
3. The steepest slope of terrain at any point on a contour is represented along the normal of the contour at that point. They are perpendicular to ridge and valley lines where they cross such lines.
4. Contours do not pass through permanent structures such as buildings.
5. Contours of different elevations cannot cross each other (caves and overhanging cliffs are the exceptions).
6. Contours of different elevations cannot unite to form one contour (vertical cliff is an exception).
7. Contour lines cannot begin or end on the plan.
8. A contour line must close itself but need not be necessarily within the limits of the map.
9. A closed contour line on a map represents either depression or hill. A set of ring contours with higher values inside, depicts a hill whereas the lower value inside, depicts a depression (without an outlet).
10. Contours deflect uphill at valley lines and downhill at ridge lines. Contour lines in U-shape cross a ridge and in V-shape cross a valley at right angles. The concavity in contour lines is towards higher ground in the case of ridge and towards lower ground in the case of valley.
11. Contours do not have sharp turnings.

■■■■

4 Calculation of Area and Volume

4.1 In a mass-haul diagram, the distance (D) of the centre of mass of excavation or embankment from the line representing the volume to be hauled over is given by

(a) D = Area × Horizontal scale × Vertical scale/ Volume ordinate

(b) D = Area × Volume ordinate/(Horizontal scale × Vertical scale)

(c) D = Area × Volume ordinate

(d) D = Area × Horizontal scale/Vertical scale

[ESE : 1996]

4.2 Which one of the following methods estimates best the area of an irregular and curved boundary?

(a) Trapezoidal method

(b) Simpson's method

(c) Average ordinate method

(d) Mid-ordinate method

[ESE : 1998]

4.3 Which one of the following is measured by the area between the balancing line and the mass-haul curve?

(a) Haul between the balancing points

(b) Earthwork accumulated up to that point

(c) Excess of excavation

(d) Excess of filling

[ESE : 2004]

4.4 What is the volume of a 6 m deep tank having rectangular shaped top 6 m × 4 m and bottom 4 m × 2 m (computed through the use of prismoidal formula)?

(a) 96 m^3 (b) 94 m^3

(c) 92 m^3 (d) 90 m^3

[ESE : 2005]

4.5. Which one of the following methods of computing area assumes that the short lengths of the boundary between the ordinates are parabolic arcs?

(a) Average ordinate rule

(b) Middle ordinate rule

(c) Simpson's rule

(d) Trapezoidal rule

[ESE : 2009]

4.6 Following offsets were taken from a survey line to a hedge:

Distance (in m)	0	5	10	15	20	30	40
Offsets (in m)	3	4	5.5	5	6	4	4.5

The area between survey line and the hedge is (by trapezoidal method):

(a) 185.5 m^2 (b) 187.5 m^2

(c) 189.5 m^2 (d) 289.5 m^2

[ESE : 2013]

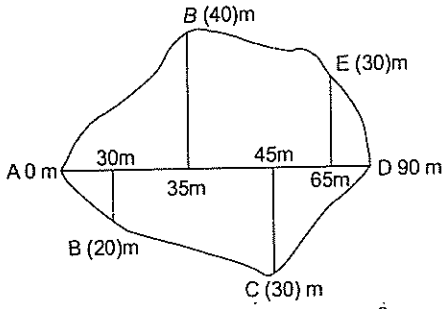
4.7 The measured radius of a circle is 80 m with a possible error of 0.05 m in its diameter. The error in the computed area will nearly be

(a) + 6.5 m^2 (b) – 0.65 m^2

(c) ± 12.6 m^2 (d) ± 8.2 m^2

[ESE : 2014]

4.8 In a cross staff survey, the perpendicular offsets are taken on right and left of the chain line AD as shown in figure – all values are in 'metres'. The area enclosed by $ABCDEFA$, computed by trapezoidal method is



(a) 3650 m^2 (b) 3200 m^2

(c) 3475 m^2 (d) 3500 m^2

[ESE : 2014]

Answers Calculation of Area and Volume

4.1 (a) 4.2 (b) 4.3 (a) 4.4 (c) 4.5 (c) 4.6 (b) 4.7 (c) 4.8 (c)

Explanations Calculation of Area and Volume

4.1 (a)

The mass-haul diagram is a curve plotted on a distance base with the ordinate at any point on the curve representing the algebraic sum of the volume of earthwork up to that point.

4.2 (b)

Mid-ordinate and Average ordinate methods are used with the assumption that the boundaries between the extremities of the ordinates are straight lines.

Trapezoidal method is based on the assumption that the figures are trapezoids. The method is more accurate than the above two methods.

Simpson's method assumes that the short iengths of the boundaries between the ordinates are parabolic arcs. This method is more useful when the boundary line departs considerably from the straight line. The results obtained by use of Simpson's method in all cases are more accurate.

4.3 (a)

In the mass-haul curve, the maximum ordinate of any loop represents the total quantity of earthwork to be moved from cut to fill. The area bounded by a loop of the mass diagram and the base line/balance line measure the haul in that section.

4.4 (c)

Prismoidal formula is also known as Simpson's rule for volumes.

Given, $2L = 6$ m; $L = 3$ m

$$A_1 = 6 \times 4 = 24 \text{ m}^2$$

$$A_2 = 4 \times 2 = 8 \text{ m}^2$$

$$A_m = \left(\frac{6+4}{2}\right) \times \left(\frac{4+2}{2}\right) = 15 \text{ m}^2$$

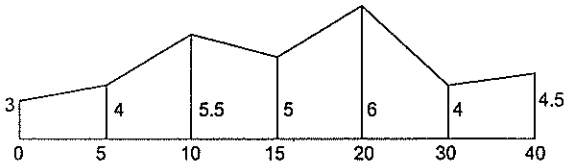
$$\therefore \quad V = \frac{L}{3}(A_1 + 4A_m + A_2)$$

$$= 24 + (4 \times 15) + 8 = 92 \text{ m}^3$$

4.5 (c)

Simpson's one third rule is a numerical method of integration used to determine area of tracts having irregular boundary. It assumes that short lengths of boundary between ordinates are parabolic. *Simpson's rule* is sometimes called as *parabolic rule*.

4.6 (b)



For area as given by Trapezoidal method is

$$A = d\left[\left(\frac{O_0 + O_n}{2}\right) + O_1 + O_2 \ldots O_{n-1}\right]$$

Now, since 'd' is not constant

$$\therefore \quad A_1 = .5\left[\frac{3+6}{2} + 4 + 5.5 + 5\right] = 95 \text{ m}^2$$

$$A_2 = 10\left[\frac{6+4.5}{2} + 4\right] = 92.5 \text{ m}^2$$

Total area,

$$A = A_1 + A_2$$

$$= 95 + 95.5 = 187.5 \text{ m}^2$$

4.7 (c)

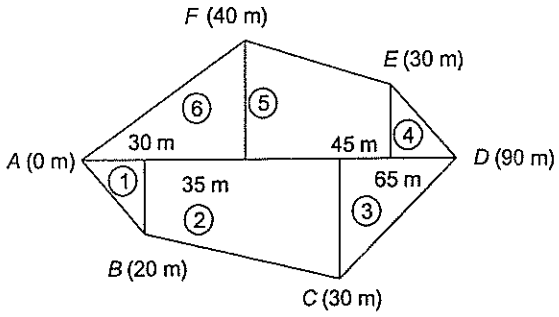
$$\text{Area } A = \pi r^2$$

$$\frac{\partial A}{A} = 2\pi r \cdot \frac{\partial r}{r}$$

$$\frac{\partial A}{A} = 2\pi \times 80 \times 0.05$$

$$\text{Error} = \pm 12.56 \text{ m}^2$$

4.8 (c)



$$\text{Area} = \frac{1}{2}\left[\begin{matrix} 20 \times 30 + (20+30) \times 15 + 30 \times 45 \\ +25 \times 30 + (40+30) \times 30 + 30 \times 40 \end{matrix}\right]$$

$$= 3475 \text{ m}^2$$

5 Engineering Instruments

5.1 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Clinometer
B. Pantagraph
C. Tellurometer
D. Ghat tracer

List-II

1. Area measuring instrument
2. Gradient finding instrument
3. Angle measuring instrument
4. Plan enlarging instrument
5. Microwave instrument

Codes:

	A	B	C	D
(a)	1	2	5	3
(b)	1	5	4	3
(c)	3	4	1	2
(d)	3	4	5	2

[ESE : 1995]

5.2 **Assertion (A):** The weight of a quantity indicates the relative precision of a quantity within a set of observations.

Reason (R): The weights are generally taken as directly proportional to the variance of the standard errors.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1996]

5.3 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Sextant
B. Sounding
C. Fathometer
D. Range

List-II

1. Measurement of depth below the water surface
2. The line on which soundings are taken
3. The lines which are usually used for depths above about 6 m
4. Instrument used for measuring angles from a boat
5. Instrument used for measuring depth in ocean

Codes:

	A	B	C	D
(a)	5	1	4	2
(b)	4	2	5	3
(c)	5	3	4	1
(d)	4	1	5	2

[ESE : 1997]

5.4 Which of the following pairs are correctly matched?

1. *Telemeter:* Measurement of distance
2. *Price meter:* Measurement of difference in elevation between points
3. *Sounding sextant :* Measurement of horizontal angles
4. *Clinometer :* Measurement of vertical angles

Select the correct answer using the codes given below:

(a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 1, 2 and 3

[ESE : 2001]

5.5 The standard measurement of the Geodimeter 510 is

(a) ± 1 cm (b) ± 5.1 mm
(c) $\sqrt{5.1}$ mm (d) ± 1 mm

[ESE : 2003]

5.6 On which one of the following are the third generation electro-optical instruments based?

(a) Microwave (b) Infra-red
(c) UV light (d) He-Laser light

[ESE : 2004]

5.7 Match List-I (Measurements) with List-II (Instruments) and select the correct answer using the codes given below the lists:

List-I
A. Displacement measurement from photograph
B. Electronic distance measurement
C. Base line measurement
D. Horizontal angle measurement

List-II
1. Box sextant
2. Subtense bar
3. Tellurometer
4. Parallax bar

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	1	3	2	4
(c)	4	2	3	1
(d)	1	2	3	4

[ESE : 2004]

5.8 Which one of the following verniers is employed in Abney Level?
(a) Retrograde vernier
(b) Double vernier
(c) Double folded vernier
(d) Extended vernier

[ESE : 2006]

5.9 For air borne application and materialization of GPS receiver and easy construction, which is the most frequently used antenna?
(a) Microstrip (b) Micropole
(c) Spiral helix (d) Choke ring

[ESE : 2006]

5.10 Which of the following instruments have both horizon glass and index glass?
1. Optical square 2. Line ranger
3. Box sextant 4. Pedometer

Select the correct answer using the codes given below:
(a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1 and 3 only (d) 2 and 4 only

[ESE : 2007]

5.11 Which one of the following instruments can be used as clinometer?
(a) Prism square (b) Line ranger
(c) Abney level (d) Optical square

[ESE : 2007]

5.12 Match List-I (Instrument) with List-II (Use) and select the correct answer using the code given below the lists:

List-I
A. Subtense bar
B. Sextant
C. Tangent clinometer
D. Range finder

List-II
1. To determine difference in elevation between points
2. To determine horizontal distance
3. To measure angles
4. To establish right angles

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	1	3	2	4
(c)	2	3	1	4
(d)	1	4	2	3

[ESE : 2007]

5.13 Electronic theodolites of various ranges in which measured angles are displayed originally on display board are based on which one of the following?
(a) Special optical technology
(b) Introduction of Microprocessor technology
(c) Electro-optical technology
(d) Special gearing

[ESE : 2008]

5.14 Consider the following equipments:
1. Tacheometer 2. Odometer
3. Passometer 4. Perambulator

Which of the above equipments can be employed for measurement of horizontal distance?
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2, 3 and 4

[ESE : 2009]

5.15 Altimetry may be depicted most accurately by
(a) hachures (b) relief shading
(c) layer tinting (d) contour lines

[ESE : 2010]

5.16 For setting out right angles, the instrument used is
(a) Optical square (b) Abney level
(c) Alidade (d) Ceylon ghat tracer
[ESE : 2010]

5.17 The angle between the index glass and the horizon glass of a box sextant is 40°; the horizontal angle between the two points sighted by the instrument is
(a) 20° (b) 60°
(c) 40° (d) 80°
[ESE : 2011]

5.18 Consider the following parameters in respect of RADAR principle:
1. It is an active sensing system.
2. Electromagnetic radiation of wavelength is in centimeter range.
3. It operates in visible region.
4. It comprises Radio detection and ranging.
Which of the above statements are correct ?
(a) 1,2 and 3 (b) 2, 3 and 4
(c) 1, 2 and 4 (d) I, 2, 3 and 4
[ESE : 2014]

5.19 Which of the following minor instruments are used for setting out right angles in chain surveying?
1. Cross square 2. Optical square
3. Prism square 4. Auto level
(a) 1 and 2 only (b) 2 and 3 only
(c) 1, 2 and 3 (d) 2, 3 and 4 only
[ESE : 2015]

5.20 Which of the following options increase the sensitivity of a bubble tube?
1. Using a liquid of greater surface tension
2. Increasing the diameter of the tube
3. Increasing the length of the tube
4. Decreasing the diameter of the tube
Select the correct answer using the codes given below:
(a) 1 and 2 only (b) 2 and 3 only
(c) 3 and 4 only (d) 1 and 4 only
[ESE : 2017]

Answers Engineering Instruments

5.1	(d)	5.2	(c)	5.3	(d)	5.4	(b)	5.5	(b)	5.6	(b)	5.7	(a)	5.8	(d)	5.9	(a)		
5.10	(c)	5.11	(c)	5.12	(c)	5.13	(c)	5.14	(d)	5.15	(d)	5.16	(d)	5.16	(a)	5.17	(d)		
5.18	(c)	5.19	(c)	5.20	(b)														

Explanations Engineering Instruments

5.1 (d)
Pantagraph is used for enlarging, reducing or reproducing the plans. Its working is based on principle of similar triangles. Planimeter is used for measurement of area of cross-sections for the highways and railways, and checking computed areas in property surveys and property divisions. The area determined with a planimeter is more accurate when the area is larger and particularly when the plotting scale is large.

5.2 (c)
The weight of an observation is a measure of its relative trustworthiness. The more reliable the result, the higher its weight. The weights of the measurement results are assumed to be inversely proportional to the square of their respective mean square error.

5.3 (d)
A sextant is an instrument used for measurement of the horizontal and vertical angles. The distinguishing feature of a sextant is the arrangement of two mirrors which enables the observer to sight two different objects simultaneously. There are two types of sextants viz. Nautical sextant and Box sextant.
The process of determination of the bed depth of a water body is called sounding. In other words, sounding is the measurement of depth of bed below the water surface.

Fathometer (also called Echo-sounder) is an instrument which is used for sounding in an ocean where the depth of water is great.

Range line is a line along which the sounding are taken. The range lines are generally marked perpendicular to the shore line. However, if the shore is irregular, the range lines are usually marked radiating from some prominent object shore signal.

5.4 (b)

Telemeter is a special device which is attached to the objective end of the telescope to measure directly the horizontal distance.

Price meter is a type of current meter which is used to determine the velocity of water.

Sounding sextant is an instrument used for measurement of horizontal and vertical angels. It is similar to a nautical sextant. However, the index glass of a sounding sextant is generally much larger as compared to that of nautical sextant. It is generally used in hydrographic surveying.

5.5 (b)

Geodimeter is a medium range (less than 25 km) electronic distance measuring equipment. It has a range of 5 km in daylight and about 25 km in the night using a mercury lamp.

5.6 (b)

According to the electromagnetic waves that carries the measuring signal, the EDM (Electronic Distance Measurement) instruments may be classified into two groups:

1. Microwave EDM instruments employing radiowaves.
2. Electro-optical instrument

5.7 (a)

The subtense bar is generally used for the measurement of horizontal distances in the following situations:

(i) In rough country, across water, river or swamps, where direct chaining is very difficult.

(ii) For measurement of the traverse lines in rough country.

(iii) For measurement of base lines of small triangulations.

(iv) To fix control points in aerial photogrammetry.

(v) For measurement of long distance where great accuracy is not required.

The Tellurometer was invented by Dr. T.L. Wadley of the South African National Institute for Telecommunication Research. The Tellurometer was the first instrument which used microwaves in the measurement of distances for surveying purposes.

5.8 (d)

There are five types of verniers in practice:

(i) **Direct Vernier:** It has divisions which are slightly shorter than those of the main scale.

(ii) **Retrograde Vernier:** It has divisions which are slightly longer than those of the main scale.

(iii) **Double Vernier:** It is used when the graduations on the main scale are numbered in both the directions. The double vernier extends in both the directions with the index mark in the centre. Infact a double vernier is a combination of two direct verniers.

(iv) **Double Folded Vernier:** It is a special type of double vernier whose total length is one-half of the combined length of the corresponding double vernier. It is used when it is required to keep the length of the vernier short.

(v) **Extended Vernier:** In this type of vernier n divisions of the vernier scale are equal in length to $(2n-1)$ divisions of the main scale. An abney level has an extended type of vernier with a least count of 5′ or 10′.

5.9 (a)

Microstrip antennas(also known as patch antennas) have added advantage for airborne application, materialization of GPS receiver, easy construction, low fabrication cost. They are mostly used at microwave frequencies and find application in satellite communication, mobile, GPS, military etc.

5.10(c)

The box sextant is a small pocket instrument used for measuring horizontal and vertical angles, measuring chain angles and locating inaccessible points. By setting the vernier to 90°, it may be used as an optical square. Optical square is an

instrument used for setting out a line at right angles to another line. Both these instruments have two sets of mirrors, one being fixed (horizon glass) and other being movable (index glass).

5.11 (c)

Abney level Can be used as clinometers for measuring slope and as hand level for levelling. It is improved modification of hand level.

Line ranger is used for ranging whereas prism square and optical square for setting out offsets at right angles.

5.13 (c)

Liquid crystal diode is used for display in electronic theodolites. It is based on electro-optical technology and is made up of segments filled with liquid.

5.14 (d)

Perambulator Passometer, Pedometer, Tacheometer, measuring wheel, speedometer, Pacing, odometer etc are used in reconnaissance surveying for measuring horizontal distance.

5.15 (d)

The measurement of altitude is called altimetry. Contour lines can be best for altimetry of steep risings, cliffs etc as it gives complete picture of earth's surface.

5.16 (a)

Abney level is an improved version of the hand level. It can be used as a hand level for levelling and as a clinometer for measuring slopes.

An alidade is a straight-edge ruler having some sighting device. It is used for sighting the objects and drawing the lines.

The Ceylon ghat tracer is a simple instrument used for measuring the slopes. It is specially useful for setting out a grade contour on a given gradient in the preliminary survey of a road in hilly area.

5.17 (d)

The sextant is based on the principle that when a ray of light is reflected successively from two mirrors, the angle between the first and last directions of ray is twice the angle between the planes of the two mirror.

$\therefore$ The horizontal angle between the two points sighted by the instrument $= 2 \times 40° = 80°$

5.18 (c)

The acronym of radar is radio detection and Ranging, which is used to determine the range, direction or speed of the object. It is an active sensing system.

5.19 (c)

For setting out right angles in chain surveying, the minor instruments used are cross staff, optical square and prism square.

Auto level, a levelling instrument, is an optical instrument used to established or check points in the same horizontal plane. It is used in surveying and building with a vertical staff to measure height difference and so transfer, measure and set heights.

5.20 (b)

The factor which govern the sensitivity of bubble tube are:

1. Viscosity of liquid
2. Radius of circle, larger the radius better will be bubble.
3. Internal fraction, if inside walls are very smooth it will give better sensitivity.

6 Tacheometric, Curve, Hydrographic Survey, Tides & Triangulation

6.1 Consider the following operations in a spire test:
1. Depress telescope and sight a point on the ground nearer to the instrument.
2. Clamp horizontal plates.
3. Sight a well-defined high point on a high building.
4. Change face and repeat the procedure.

The correct sequence of these operations is
(a) 1, 2, 3, 4 (b) 3, 1, 2, 4
(c) 3, 2, 1, 4 (d) 2, 1, 3, 4

[ESE : 1996]

6.2 Match List-I with List-II and select the correct answer using the codes given below the lists: (adopting standard notations)

List-I
A. Cubic parabola equation
B. Shifting transition curve
C. Valley curve
D. Summit curve

List-II
1. $\frac{NS^2}{4.4}$ 2. $\frac{L^2}{24R}$
3. $\frac{NS^2}{1.50+0.035S}$ 4. $\frac{x^3}{6RL}$
5. $\frac{v^2}{gR}$

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	4	1	2
(c)	1	5	2	4
(d)	4	2	3	1

[ESE : 1996]

6.3 A parabolic vertical curve is to be set out connecting two uniform grades of + 0.6% and +1.0%. The rate of change of grade is to be 0.06% per 30 m. The length of the curve will be
(a) $66\frac{2}{3}$m (b) $133\frac{1}{3}$m
(c) 200 m (d) $266\frac{2}{3}$m

[ESE : 1997]

6.4 In an external focussing tacheometer, the fixed interval between stadia hairs is 5 mm, the focal length of the objective is 25 cm, and the distance of the vertical axis of the instrument from the optical centre of the objective is 15 cm. Which one of the following is the set of constants of the tacheometer?
(a) 30, 0.15 (b) 30, 0.40
(c) 50, 0.25 (d) 50, 0.40

[ESE : 1997]

6.5 A lemniscate curve between the tangents is transitional throughout, if the polar deflection angle of its apex is equal to (ϕ is the deflection angle between the initial and final tangents)
(a) $\phi/2$ (b) $\phi/4$
(c) $\phi/6$ (d) ϕ

[ESE : 1997]

6.6 For a chord of 60 m, the mid-ordinate for a circular curve of 50 m radius will be
(a) 10 m (b) 12.5 m
(c) 15 m (d) 18.75 m

[ESE : 1998]

6.7 Triangulation station selected close to the main station for avoiding intervening obstruction is called
(a) eccentric station (b) pivot station
(c) satellite station (d) tie station

[ESE : 2000]

6.8 From the probability equation it is found that the most probable values of a series of errors arising out of observations of equal weightage are those for which the sum of their squares is
(a) zero (b) infinity
(c) minimum (d) maximum
[ESE : 2003]

6.9 Match List-I (Type of transition curves) with List-II (Characteristics) and select the correct answer using the codes given below the lists:
List-I
A. Glover's spiral
B. Cubic spiral
C. Froude's transition curve
D. Bernoulli's lemniscate
List-II
1. An autogenous curve of an automobile
2. Radius of curvature at any point varies inversely as the distance from the beginning of the curve
3. $\sin\phi = \phi$
4. $x = l, \cos\phi = 1$
Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	3	2	1	4
(c)	2	3	1	4
(d)	3	2	4	1

[ESE : 2003]

6.10 If 'g_1' and 'g_2' are the two gradients, 'r' is the rate of change of grade (%) per chain, the length of the vertical curve will be
(a) $\left(\frac{g_1 + g_2}{r^2}\right)$ (b) $\left(\frac{g_1 - g_2}{\sqrt{r}}\right)$
(c) $\left(\frac{g_1 - g_2}{r}\right)$ (d) $\frac{\sqrt{g_1 + g_2}}{r^3}$
[ESE : 2003]

6.11 What is the minimum number of satellites required from which signals can be recorded to enable a global positioning system receiver to determine latitude, longitude and altitude?
(a) One (b) Two
(c) Three (d) Four
[ESE : 2004]

6.12 If two triangulation signals of 6.75 m height each, are to be just visible over ground mutually, what is the maximum distance between their locations on the ground surface?
(a) 10 km (b) 20 km
(c) 30 km (d) 40 km
[ESE : 2005]

6.13 Match List-I with List-I and select the correct answer using the codes given below the lists:
List-I
A. Adjustment of surveying instruments
B. Bowditch rule
C. Triangulation
D. Bessel's method
List-II
1. Bringing the various fixed parts of the instruments into proper relations with one another
2. Solution of three point problem
3. Measuring all the angles and base line
4. Balancing the latitudes and departures
Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	3	4	1	2
(c)	1	4	3	2
(d)	3	2	1	4

[ESE : 2006]

6.14 What ratio do the versines of a circular curve when measured at the quarter point of a full chord and, when measured at the same point on half chord bear?
(a) 100 : 1 (b) 60 : 1
(c) 3 : 1 (d) 1 : 1
[ESE : 2006]

6.15 Match List-I (Triangulation station) with List-II (Deflection) and select the correct answer using the code given below the lists:
List-I
A. Main stations
B. Subsidiary stations
C. Satellite Stations
D. Pivot Stations
List-II
1. Control points of triangulation network
2. Points not for observation but for continuation of triangulation network
3. Points to provide additional rays to intersected points

4. Points close to main stations to avoid intervening obstructions

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	1	3	2	4
(c)	3	1	4	2
(d)	3	1	2	4

[ESE : 2007]

6.16 If the weight of an angle A (= 40° 24′ 24″ say) is 2, then the weight of the angle $A/3$ (= 13° 28′ 08″) will be

(a) 4 (b) $\pm\sqrt{3}$

(c) 9 (d) 18

[ESE : 2008]

6.17 **Assertion (A):** Triangulation networks are to be formed by well conditioned triangles.

Reason (R): Triangulation signals should be conspicuous and centred accurately over the stations.

(a) both A and R are individually true and R is the correct explanation of A

(b) both A and R are individually true but R is not the correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 2008]

6.18 Which one of the following linear methods of setting out a circular curve needs reference of the centre of the curve?

(a) Offset from chord produced

(b) Radial offset

(c) Perpendicular offset

(d) Successive bisection of arcs

[ESE : 2009]

6.19 In accordance to 'Gauss rule', weights to be assigned are proportional to

(a) 1/(Sum of the residual errors of observations

(b) 1/(Sum of the square of the residual errors of observations)

(c) Sum of the square roots of the residual errors of observations

(d) Sum of the cube roots of the residual errors of observations

[ESE : 2010]

6.20 Refraction error is the least in case of

(a) stadia tacheometry

(b) tangential tacheometry

(c) subtense bar tacheometry

(d) omnimeters

[ESE : 2010]

6.21 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

A. Traverse surveying

B. Geodetic surveying

C. Plane table surveying

D. Hydrographic surveying

List-II

1. Weddel's sounding machine

2. Alidade

3. Chain and compass

4. Theodolite

Code:

	A	B	C	D
(a)	3	4	2	1
(b)	1	4	2	3
(c)	3	2	4	1
(d)	1	2	4	3

[ESE : 2011]

6.22 The purpose of a 'satellite station' in triangulation can be served by

(a) *A* 'Church spire' in order to secure a well-shaped triangle

(b) *A* 'Flag pole' in order to secure a well shaped triangle

(c) *A* 'Steeple' in order to secure a well-shaped triangle

(d) An 'Eccentric station' near the true station whereon the instrument cannot be setup

[ESE : 2011]

6.23 The sum of the three interior angles of a triangle, the vertices of which lie on the surface of the earth, covering a vast area of several hundreds of sq kms, is

(a) Less than 180°

(b) Equal to 180°

(c) More than 180° but not less than 270°

(d) More than 180° but not more than 225°

[ESE : 2011]

6.24 The subtense tacheometry method is adopted when the ground is

(a) Flat (b) Inclined
(c) Undulating (d) A waterbody

[ESE : 2012]

6.25 Consider the following pre-conditions for correct use of a theodolite:

1. The vertical axis need not be perpendicular to the plane of the plate level bubble.
2. The line of sight must be perpendicular to the horizontal axis.
3. The axis of the level tube attached to the telescope need not be parallel to the line of sight.
4. The vertical axis, the horizontal axis and the line of sight should all pass through a point known as stadia centre.

Which of these conditions is/are necessary?

(a) 1, 2, 3 and 4 (b) 2 only
(c) 3 only (d) 1 and 4 only

[ESE : 2012]

6.26 Following observations were taken with a transit fitted with stadia wires. The line of sight was horizontal and the staff was held vertical.

	Reading on staff (m)
Top hair	1.726
Middle hair	2.278
Bottom hair	2.830

The tacheometric constants k and C are 100 and 0.4 m respectively. The horizontal distance between staff and instrument is

(a) 90.8 (b) 100.8
(c) 110.8 (d) 120.8

[ESE : 2012]

6.27 If the angle of deflection of a simple curve is θ and its radius is R, then the length of the chord is

(a) $2R \sin \theta$ (b) $2R \sin \frac{\theta}{2}$
(c) $2R \cos \theta$ (d) $2R \tan \frac{\theta}{2}$

[ESE : 2012]

6.28 If the radius of a simple curve is R, then the length of the chord for calculating the offsets by the "method of chords produced" should not exceed.

(a) $R/5$ (b) $R/10$
(c) $R/20$ (d) $R/25$

[ESE : 2012]

6.29 In an instrument, the bubble tube with divisions of 1 mm and a radius of 0.9 m has the sensitivity of

(a) $\frac{1}{2}$ (b) $\frac{1}{70}$
(c) $\frac{1}{90}$ (d) $\frac{1}{900}$

[ESE : 2012]

6.30 With regard to Trigonometric Levelling, which one of the following statements is correct at its simplest applications?

(a) Determination of the elevations of stations is based on the observed vertical angles and the horizontal distance.
(b) Determination of the horizontal distance is based on the observed vertical angles.
(c) Determination of the vertical angles is based on the observed horizontal distances.
(d) Determination of the horizontal distance

[ESE : 2015]

6.31 For better accuracy in measuring and plotting the sides of a triangle by triangulation, the angles of the triangle

(a) should not be more than 30°
(b) should not be less than 30° or more than 120°
(c) are not restricted in magnitude
(d) should not be less than 120°

[ESE : 2015]

Answers Tacheometric, Curve, Hydrographic Survey, Tides and Triangulation

6.1	(c)	6.2	(d)	6.3	(c)	6.4	(d)	6.5	(c)	6.6	(a)	6.7	(a,c)	6.8	(c)	6.9	(a)
6.10	(c)	6.11	(d)	6.12	(b)	6.13	(c)	6.14	(c)	6.15	(a)	6.16	(d)	6.17	(b)	6.18	(b)
6.19	(b)	6.20	(c)	6.21	(a)	6.22	(d)	6.23	(d)	6.24	(a)	6.25	(d)	6.26	(c)	6.27	(b)
6.28	(c)	6.29	(d)	6.30	(a)	6.31	(b)										

Explanations Tacheometric, Curve, Hydrographic Survey, Tides and Triangulation

6.1 (c)

Spire test is known as the test for the adjustment of standards. The horizontal axis should be perpendicular to the axis. First the theodolite is set up and levelled carefully at about 50 m from a high building. A point on the building is bisected with a vertical angle greater than 30°. The telescope is then lowered and a point is set near the ground. Before lowering the telescope, the horizontal plates should be clamped so that the ground point may fall exactly below the building point.

6.3 (c)

Change of grade = 1 – 0.6 = 0.4%

$$\text{Length of the curve} = \frac{0.4}{0.06} \times 30 = 200 \text{ m}$$

6.4 (d)

Tacheometric distance equation

$$D = ks + C$$

where

k is multiplying constant $= \frac{f}{i}$

C is additive constant $= f + d$

k is also known as stadia interval factor

f is focal length of the object glass

i is stadia interval

d is distance between the vertical axis of the tacheometer and the optical centre

Given, $f = 25$ cm; $i = 5$ mm; $d = 15$ cm

$$\therefore \quad k = \frac{25}{0.5} = 50$$

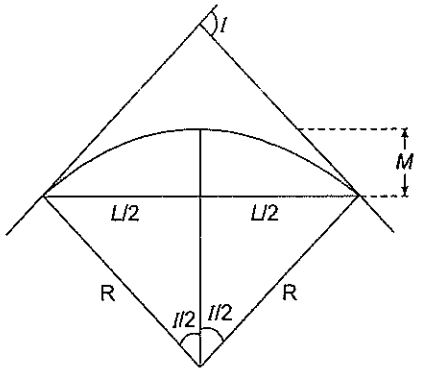
$$\text{and} \quad C = \frac{25+15}{100} = 0.40 \text{ m}$$

6.5 (c)

$$\alpha_n = \frac{\phi}{6}$$

For the curve to be transitional throughout, the maximum polar deflection angle must be equal to $\frac{1}{6}$ of the deflection angle between the initial tangents.

6.6 (a)



$$\text{Mid ordinate, } M = R - \sqrt{R^2 - (L/2)^2}$$

$$= 50 - \sqrt{(50)^2 - (60/2)^2}$$

$$= 10 \text{ m}$$

Alternatively,

Length of long chord,

$$L = 2R \sin \frac{I}{2}$$

$$\Rightarrow \quad 60 = 2 \times 50 \sin \frac{I}{2}$$

$$\Rightarrow \quad \sin \frac{I}{2} = 0.6$$

$$\Rightarrow \quad \frac{I}{2} = 36.87°$$

$$\text{Mid ordinate, } M = R\left(1 - \cos \frac{I}{2}\right)$$

$$= R \text{ versin } \frac{I}{2}$$
$$= 50 \times (1 - \cos 36.87°)$$
$$= 50 \times 0.2$$
$$= 10 \text{ m}$$

6.7 (a, c)

To secure well conditioned triangles or to have good visibility, objects such as chimneys, church spires, flag poles, towers, etc. are selected as triangulation stations. Such stations can be sighted from other stations, but instruments cannot be set up at such stations for sighting other stations for measuring horizontal angles. In such cases, a subsidiary station is selected near the main stations from the subsidiary station. The subsidiary station is known as the satellite station, false station or eccentric station.

6.8 (c)

If the measurements are of equal weight, the most probable value is that which makes the sum of the squares of the residual (v) a minimum. This is called the theory of least squares. Mathematically,

$$\Sigma v^2 = \text{minimum}$$

If the measurements are of unequal weights, the most probable value is that which makes the sum of the products of the weight 'w' and the squares of residuals a minimum. Mathematically,

$$\Sigma w(v)^2 = \text{minimum}$$

6.9 (a)

Cubic parabola is also known as Froude's transition curve.

$$y = \frac{x^3}{6RL}$$

by putting $x = l$

The assumption is $\cos\phi = 1$ and $\sin\phi = \phi$

Clothoid or Glover's spiral has the property that radius of curvature (R) at any point varies inversely with the distance.

The cubic spiral has equation,

$$y = \frac{x^3}{6RL}$$

The approximation made here is $\sin\phi = \phi$

Cubic spiral is superior to a cubic parabola.

Bernoulli's lemniscate curve is used on highways and it is preferred to the spiral for the following reasons :

(i) Its radius of curvature decreases more gradually.

(ii) Its rate of increase of curvature diminishes towards the transition curve, thus fulfilling an essential condition.

(iii) It corresponds to an autogenous curve of an automobile i.e. the path actually traced by an automobile when turning freely.

6.10 (c)

Length of vertical curve

$$= \frac{\text{Total change of grade}}{\text{Permissible rate of change of grade per chain length}}$$

Total change of grade = Difference of gradients

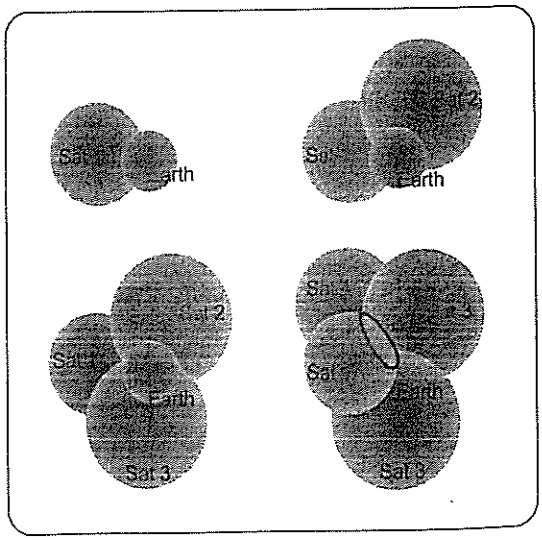
$= g_1 - g_2$

r = Permisible rate of change of grade/chain length

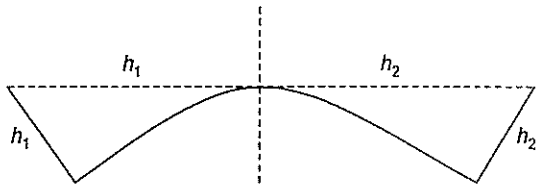
$$\text{Length of vertical curve} = \frac{g_1 - g_2}{r}$$

6.11 (d)

This method is called **trilateration**. The first satellite locates you somewhere on a sphere (top left of Figure). The second satellite narrows your location to a circle created by the intersection of the two satellite spheres (top right). The third satellite reduces the choice to two possible points (bottom left). Finally, the forth satellite helps calculate a timing and location correction and selects one of the remaining two points as your position (bottom right).



6.12 (b)



Distance of visible horizon,

$$d = d_1 + d_2$$

$$d = 2 \times 3.855 \sqrt{6.75}$$

$$d = 20.03 \text{ km}$$

6.14 (c)

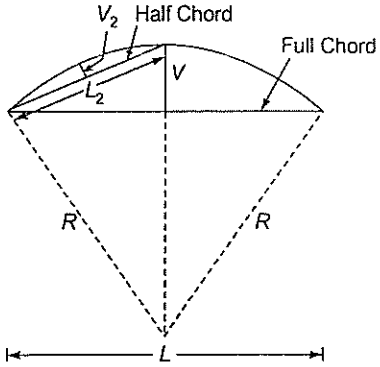
Versine of full chord, $V = \frac{L^2}{8R}$

Versine at quarter point

$$= \left(\frac{L}{4}\right)^2 + (R - V)^2 = (R - V_1^2)$$

$$V_1 = \frac{3L^2}{32}$$

(neglecting V^2 and V_1^2)



Versine for half chord,

$$L_2 = \frac{L}{2}$$

$$V_2 = \frac{L_2^2}{8R} = \frac{L^2}{32R}$$

$$\therefore \quad \frac{V_2}{V_1} = \frac{3}{1}$$

6.15 (a)

Main stations are the main control points of the network and command boundary of area to be surveyed. The station where observations are not made, but the angles at the station are used in triangulation series, is known as pivot station. When setting up instrument at triangulation station is difficult then satellite station is selected near main station. This helps avoid intervening obstructions. Subsidiary stations provide additional rays to intersected points.

6.16 (d)

If a quantity of given weight is divided by a factor, the weight of the result is obtained by multiplying its given weight by the square of that factor.

Angle a has weight of 2

$$\therefore \text{ Weight of } \frac{A}{3} = 2 \times (3)^2 = 18$$

6.17 (b)

Triangulation network should form well conditioned triangles and should be intervisible. Triangulation signals should be conspicuous and clearly visible over ground so that exact position of station can be observed from other station.

6.18 (b)

Radial offsets from tangents require reference of centre of curve for setting out a simple circular curve by linear methods.

6.20 (c)

In subtense bar method, a bar of fixed length, called a subtence bar is placed in horizontal position. The angle subtended by two target points, corresponding to fixed distance on subtense bar, at the instrument station is measured. The distance between the subtence bar and the instrument is computed from the known distance between the targets and the measured horizontal angle. So there will be no refraction error.

6.21 (a)

Sounding Machines are used to measure depth below the water surface. Sounding machines may be hand driven or machine driven. Weddel's sounding machine is hand driven.

A plane table alidade is a straight edge used for sighting with some form of sighting device. Two types of alidade are used: Plain alidade and telescopic alidade.

Geodetic surveying is that type of surveying in which the shape of the earth is taken into account.

The theodolite is the most precise instrument designed for the measurement of horizontal and vertical angles and has wide applicability in surveying especially long distance surveying such as laying off horizontal angles, locating

points on line, prolonging survey lines, establishing grades, determining difference in elevation, setting out curves etc.

In traverse surveying compass is used to establish angles between two stations while a chain is used to measure ground distance between stations.

6.22 (d)

Chimneys, church spires, flag poles, towers, lighthouses, etc., are selected as triangulation stations because of their good visibility and forming well-conditioned triangles. Such stations can be sighted from other stations but it is not possible to occupy them directly below such excellent stations for making passivations on other stations. The problem is solved as by taking another station in the vicinity of the main triangulation station from where the other stations are visible. Such stations are called the satellite stations.

6.23 (d)

Properties of spherical triangle:

- If a circle is drawn on a sphere so that the radius of the circle is the same as the radius of the sphere it is called a great circle. Any other circle is a small circle.
- An infinite number of great circle can pass through one point , but only one great circle can pass through tow points , unless they are diametrically opposite.
- A spherical triangle is a triangle each of whose sides is a great circle.
- The length of the arc of a circle can be measured by the angle which the arc subtends at the center of the circle. The sides of a spherical triangle are measured in degree , minutes , and seconds.
- No sides of a spherical triangle can therefore exceed 180°.
- The three angles of a spherical triangle must together be more than 180° and less than 540°.
- The greater side is opposite the greater angle , if tow sides are equal their opposite angles are equal.
- If one angle of the triangle is 90° it is called a right-angle triangle , and if one side of the triangle 90° it is called a quadrantal triangle .

6.24 (a)

In the subtense bar method, the horizontal angle subtended by two targets fixed on a horizontal bar at a known distance apart is measured at instrument station by theodolite.

6.26 (c)

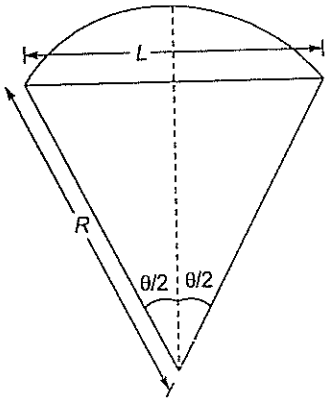
$$D = kS + C$$

$$S = 2.830 - 1.726 = 1.104$$

$$\therefore \quad D = 100 \times 1.104 + 0.4 = 110.8 \text{ m}$$

6.27 (b)

$L = 2R \sin \theta/2$



6.28 (c)

Length is selected such that there is not much difference between arc length and chord length. For the error to be within limit the length of full chord should be limited to R/20.

6.29 (d)

Sensitivity of a bubble tube

$$S = \frac{nl}{R}$$

Now, $n = 1$

$$\therefore \quad S = \frac{1 \times 10^{-3}}{0.9} = \frac{1}{900}$$

6.30 (a)

In Trigonometric Levelling, determination of the elevations of station is based on the observed vertical angles and the horizontal distances.

6.31 (b)

For better accuracy in measuring and plotting the sides of a triangle by triangulation, the angles of triangle

(i) should not be less than 30°

(ii) should not be more than 120°

7 Field Astronomy, Photogrammetic Survey, Remote Sensing & Geology

7.1 The standard time meridian in India is 82°30′ *E*. If the standard time at any instant is 20 hours 10 minutes, the local mean time for the place at a longitude of 20°*E* would be

(a) 4 h PM (b) 4 h10 m PM
(c) 1 h 20 m PM (d) 0 h 20 m PM

[ESE : 1996]

7.2 In a tilted aerial photograph, if the swing is 230°, then the rotation angle is equal to

(a) 140° (b) 130°
(c) 50° (d) 25°

[ESE : 1996]

7.3 An image of the top of the hill is 96 mm from the principal point of the photograph. The elevation of the top of the hill is 500 m and the flying height is 4000 m above the datum. The relief displacement will be

(a) 768 mm (b) 88 mm
(c) 12 mm (d) 8 mm

[ESE : 1997]

7.4 Which one of the following methods would give accurate results in determining the direction of the observer's meridian?

(a) Observation of circumpolar stars on the same vertical
(b) Observation of circumpolar stars at culmination
(c) Extra-meridian observation of a circumpolar star
(d) Observation of the Sun at equal altitudes

[ESE : 1997]

7.5 If an overlapping pair of vertical photo-graphs taken with a 150 mm focal length camera has an air base of 2100 m and the elevation of the control point A on it is 900 m above MSL and the parallax of the point is 75 mm, then the flying height above MSL of the stereopair will be

(a) 3000 m (b) 3150 m
(c) 5100 m (d) 5250 m

[ESE : 1998]

7.6 Given that δ denotes declination, θ the latitude of the place of observation and α the altitude of a star at the prime vertical, then

(a) $\sin\theta = \sin\delta \cos\alpha$
(b) $\sin\theta = \sin\delta \operatorname{cosec}\alpha$
(c) $\cos\alpha = \cos\delta \sin\theta$
(d) $\sin\delta = \sin\alpha \cos\theta$

[ESE : 1998]

7.7 The declination of a star is 21°15′N at a latitude of 43°30′N. The zenith distance at the upper culmination is

(a) 22°15′ (b) 21°15′
(c) 64°45′ (d) 43°30′

[ESE : 1999]

7.8 Which one of the following surveys is required in observations of stars?

(a) Astronomical survey
(b) Cadastral survey
(c) Aerial survey
(d) Photogrammetric survey

[ESE : 2000]

7.9 If the equation of time is – 13′28.5″, then the Greenwich Apparent Time corresponding to zero hour Greenwich Mean Time on a day is

(a) 13′ 28.5″
(b) 46′ 31.5″
(c) 23h 46′ 31.5″ of same day
(d) 23h 46′ 31.5″ of previous day

[ESE : 2000]

7.10 A vertical photograph was taken at an altitude of 1500 m above MSL. If the focal length of the camera is 20 m, the scale of photograph for a terrain lying at an elevation of 500 m is

(a) 1 : 50 (b) 1 : 100
(c) 1 : 1000 (d) 1 : 25

[ESE : 2000]

7.11 **Assertion (A):** In a spherical triangle, the sum of the three sides is always less than the circumference of the great circle.
Reason (R): The sum of the three angles of a spherical triangle is greater than two right angles, but less than six right angles.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

7.12 A road section of length 1 km scales 8 cm on a vertical photograph. The focal length of the camera is 160 mm. If the terrain is fairly level, then the flying height will be
(a) 20 m (b) 2000 m
(c) 20 km (d) 200 km

[ESE : 2001]

7.13 At a given place of observation, the declination of a circumpolar star is
(a) greater than the latitude
(b) equal to the latitude
(c) less than the co-latitude
(d) greater than the co-latitude

[ESE : 2001]

7.14 A tower appears in two successive photo-graphs taken at an altitude of 4000 m above datum. The focal length of the camera is 160 mm. The length of the air base is 300 m. The parallax for the top and bottom of the pole are 72 mm and 63 mm respectively. The height of the top of the tower above its bottom is nearly
(a) 63 m (b) 72 m
(c) 95 m (d) 135 m

[ESE : 2001]

7.15 Which one of the following is the angular distance between the observer's meridian and the vertical circle passing through a star measured along the celestial horizon?
(a) Right ascension (b) Azimuth
(c) Declination (d) Hour angle

[ESE : 2002]

7.16 A vertical photograph of a chimney was taken from an elevation of 500 m above MSL The elevation of the base of the chimney was 250 m. If the relief displacement of the top of chimney was 51.4 mm and the radial distance of the image of the top of the chimney was 110 mm, the height of the chimney is
(a) 233.64 m (b) 133.2 m
(c) 116.82 m (d) 58.41 m

[ESE : 2002]

7.17 **Assertion (A):** At a given station, a celestial body can be fixed by its co-altitude and co-declination.
Reason (R): In the astronomical triangle ZPS, ZP is constant for the given place and S is the intersection of the vertical circle and declination of circle.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

7.18 The relationship between the air-base B, photographic base 'b', flying height H and focal length 'f' of lens in a vertical photograph is given by
(a) $B = \frac{bH}{f}$ (b) $B = \frac{f}{bH}$
(c) $B = \frac{b}{fH}$ (d) $B = \frac{b}{H - f}$

[ESE : 2003]

7.19 Setting off the 'proper principal distance' in the projectors of projection stereoplotters is a procedure for which one of the following?
(a) Finding the focal length of the camera used
(b) Evaluating the digital terrain model
(c) Carrying out the interior orientation
(d) Filling the quotation for the purchase of A_7 stereoplotters

[ESE : 2004]

7.20 Consider the following statements:
IRS series satellites are

1. Low orbiting satellites
2. Geostationary satellites
3. Meteorological satellites
4. Resource survey satellites

Which of these statements are correct?

(a) 1 and 4 (b) 2 and 3
(c) 1, 2 and 4 (d) 2, 3 and 4

[ESE : 2004]

7.21 **Assertion (A):** A mosaic is large photomap assembled from two or more aerial photographs of an area.

Reason (R): Photomap and mosaic are true planimetric representations of the area.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2004]

7.22 Which one of the following represents a circumpolar star?

(a) Upper culmination above horizon, lower culmination below horizon
(b) Both upper and lower culminations below horizon
(c) Both upper and lower culminations above horizon
(d) Altitude at upper culmination is minimum

[ESE : 2005]

7.23 In an aerial photogrammetric survey, if the exposure interval is 20 seconds to cover ground distance of 1000 m between exposures, what would be the ground speed of the aircraft?

(a) 90 km/hour (b) 120 km/hour
(c) 150 km/hour (d) 180 km/hour

[ESE : 2005]

7.24 Match List-I (Phenomenon) with List-II (Method of survey) and select the correct answer using the code given below the lists:

List-I

A. Crab and drift
B. Stadia intercept
C. Culmination and elongation
D. Baseline measurement

List-II

1. Triangulation
2. Astronomical survey
3. Aerial photogrammetry
4. Tacheometric survey

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	2	4	3	1
(c)	3	4	2	1
(d)	2	1	3	4

[ESE : 2005]

7.25 What is the actual ground area covered by a 20 cm × 20 cm size vertical aerial photograph, at an average scale of 1 cm = 200 m having 60% forward overlap and 30% side overlap?

(a) 1.92 km^2 (b) 4.48 km^2
(c) 6.72 km^2 (d) 2.88 km^2

[ESE : 2005]

7.26 If the mean temperature of Sun's surface 6000 K and λ_m of its radiation is 0.5 μm, what is the mean temperature of earth's surface for which λ_m is 10.0 μm, according Wien's Displacement Law in Remote Sensing Concept?

(a) 25°C (b) 28°C
(c) 27°C (d) 30°C

[ESE : 2007]

7.27 Match List-I (Term) with List-II (Definition) and select the correct answer using the code given below the lists:

List-I

A. Apparent solar day
B. Sidereal day
C. Tropical year
D. Sidereal year

List-II

1. The time interval between two successive upper transits of the first point of Aries over the same meridian
2. The interval between two successive lower transits of the centre of the Sun across the same meridian
3. Time interval between two successive passages of the Sun over the meridian of any one of the fixed stars
4. Time interval between two successive vernal equinoxes

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	4	3
(c)	2	1	3	4
(d)	1	2	4	3

[ESE : 2007]

7.28 Which of the following can be used as a map substitute?
(a) Terrestrial photographs
(b) Vertical aerial photographs
(c) Oblique aerial photographs
(d) Vertical aerial photo-mosaics

[ESE : 2008]

7.29 Flamsteed gave numbers to stars observed by him in each constellation according to their
(a) Brilliance (b) Altitudes
(c) Co-declinations (d) Right ascensions

[ESE : 2008]

7.30 If δ is the declination of a star and ϕ is the latitude of the place of observation, then for a circumpolar star
(a) $\delta \leq \phi$ (b) $\delta \geq \phi$
(c) $\delta \leq (90° - \phi)$ (d) $\delta \leq (90° - 2\phi)$

[ESE : 2008]

7.31 A particular runway measures 6 cm on a vertical photograph, whereas the same runway measures 4 cm on a map plotted on a scale of 1/24000. The scale of the photograph at the runway elevation is
(a) 1/36000 (b) 1/24000
(c) 1/3600 (d) 1/16000

[ESE : 2008]

7.32 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Visual Interpretation
B. Geographical Information System
C. National Remote Sensing Agency
D. Supervised Image Classification

List-II
1. Creation of data bank of multi-information for a project area
2. Visual identification of objects from image characteristics
3. Computer classification of digital image data
4. Supplier of aerial and satellite based remote sensing data products in India

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	2	1	4	3
(c)	1	3	2	4
(d)	1	4	2	3

[ESE : 2008]

7.33 Which one of the following is **not** strictly a method of remote sensing?
(a) Thermal and multi spectral scanning
(b) Microwave sensing
(c) Earth resource satellite
(d) Stereoscopy

[ESE : 2008]

7.34 Which one of the following conditions requires geodetic surveying?
(a) Horizontal curve ranging
(b) Vertical curve ranging
(c) Survey of a country
(d) Reconnaissance survey

[ESE : 2009]

7.35 Which of the following coordinate systems is the most convenient way to specify the position of the star on celestial sphere?
(a) Latitude and longitude
(b) Altitude and azimuth
(c) Declination and right ascension
(d) Declination and hour angle

[ESE : 2009]

7.36 How many sidereal days are there in a solar year?
(a) 365.2840 (b) 366.2422
(c) 360.2500 (d) 365.0000

[ESE : 2009]

7.37 Consider the following statements:
A sidereal year can be defined as the time interval
1. between two successive transits of the sun through the meridian of any of the fixed stars
2. between two successive vernal equinoxes
3. between two successive passages of the sun through perigee

Which of these statements is/are correct?
(a) 3 only (b) 1 and 2
(c) 2 and 3 (d) 1 only

[ESE : 2009]

7.38 **Assertion (A):** Remote sensing is mostly quantitative in nature.

Reason (R): Remote sensing involves the subjective interpretation of the imagery.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2009]

7.39 Consider the following statements:
In aerial photogrammetry the 'filter' is placed in front of the lens to
1. reduce the effect of atmospheric haze.
2. protect the lens from dust.
3. provide uniform light distribution over the format

Which of these statements is/are correct?
(a) 1 and 2 only (b) 2 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2010]

7.40 'Iso-centre' is the point
(a) in which the tilted axis of the camera meets the vertical photograph
(b) in which the bisector of the angle of tilt meets the vertical photograph
(c) in air space, the location of the optical centre of the lens of the camera at the time of exposure
(d) where the perpendicular from the nodal point meets the photograph

[ESE : 2010]

7.41 The declination of a celestial body is the arc of the declination circle intercepted between that body and the
(a) prime vertical through that body
(b) azimuth of the body
(c) equinoxes of the Earth
(d) equator of the Earth

[ESE : 2010]

7.42 The difference between the apparent solar time and mean solar time is known as
(a) real time (b) average time
(c) equation of time (d) sidereal time

[ESE : 2010]

7.43 If a 'vertical aerial photograph', (20 cm × 20 cm) in size, on a R.F.1: 10,000 has 60% longitudinal overlap and 40% side overlap, the actual ground length covered by each photograph in the longitudinal direction of the flight will be
(a) 4 km (b) 6 km
(c) 0.8 km (d) 0.4 km

[ESE : 2011]

7.44 **Assertion (A):** The diurnal variation is the variation of the declination in a year from the mean position during the year.

Reason (R): The diurnal variation is greater in summer than in winter.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

7.45 When compared with the co-latitude of the place of observation, the declination of a circumpolar star is always.
(a) Lesser
(b) Greater
(c) Equal
(d) Either lesser or equal

[ESE : 2012]

7.46 When H is the flight height, R is the appropriate radial measure and d is the relief displacement, the vertical height of an object appearing on an aerial photograph is

(a) $\frac{R}{dH}$ (b) $\frac{dH}{R}$
(c) $\frac{H}{dR}$ (d) $\frac{RH}{d}$

[ESE : 2012]

Directions: The following items consists of two statements; one labelled as **'Statement (I)'** and the other as **'Statement (II)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

7.47 **Statement-I** : Present usage of GPS for positioning includes personal navigation, aircraft, navigation, offshore survey, vessel navigation, etc.

Statement-II : GPS is a satellite navigation system designed to provide information about instantaneous velocity and time almost anywhere on the globe at any time and in any weather.

[ESE : 2012]

7.48 **Statement (I):** Microwave bands are composed of radiation with wavelength between 1 mm and 1 m.

Statement (II): Microwaves are capable of penetrating through the atmosphere under almost all conditions.

[ESE : 2014]

7.49 **Statement (I):** The regions of the electromagnetic spectrum in which the atmosphere is transparent are called atmospheric windows.

Statement (II): The atmosphere is practically transparent in the visible region of the electromagnetic spectrum.

[ESE : 2014]

7.50 **Statement (I):** Scattering is more in lower wavelengths than in higher wavelengths.

Statement (II): Scattering effect decreases the signal value.

[ESE : 2014]

7.51 **Statement (I):** Multistage imaging refers to viewing a given area in several narrow bands.

Statement II: Multistage imaging is also called spatial resolution.

[ESE : 2014]

7.52 **Statement (I):** Spectral reflectance curves describe the spectral response of a target.

Statement II: Every object on the Earth has its unique spectral reflectance.

[ESE : 2014]

7.53 **Statement (I):** The process by which the geometry of an image area is made planimetric is called rectification.

Statement (II): It is the most precise geometric correction.

[ESE : 2014]

7.54 The observations made over the same area on different dates to monitor ground features like crop growth is called
(a) Temporal resolution
(b) Radiometric resolution
(c) Spatial resolution
(d) Spectral resolution

[ESE : 2014]

7.55 To uniquely determine the position of the user using GPS, one needs to receive signals from at least
(a) 1 satellite (b) 2 satellites
(c) 3 satellite (d) 4 satellites

[ESE : 2015]

7.56 Which one of the following Remote Sensing Systems employs only one detector?
(a) Scanning
(b) Framing
(c) Electromagnetic spectrum
(d) All of the above

[ESE : 2015]

7.57 The magnitude azimuth of one end of a runway is 80° measured clockwise from the magnetic north. The other end of runway will be numbered as
(a) 16 (b) 24
(c) 26 (d) 8

[ESE : 2015]

7.58 Local mean time of a place of longitude of 42°36′ W is 8h 42m 15s AM. The corresponding Greenwich Mean Time is
(a) 10h 32m 40s AM (b) 11h 32m 39s PM
(c) 0h 32m 39s PM (d) 11h 32m 39s AM

[ESE : 2016]

7.59 A vertical photograph of a flat area having an average elevation of 250 m above mean sea level was taken with a camera of focal length 25 cm. A section line AB 300 m long in the area measures 15 cm on the photograph; a tower BP in the area also appears on the photograph. The distance between images of top and bottom of

the tower measures 0.5 cm on the photograph. The distance of the image of the top of the tower is 10 cm. The actual height of the tower is

(a) 10 m (b) 15 m
(c) 20 m (d) 25 m

[ESE : 2016]

7.60 Cleavage is a mode of folding:

1. It is a process wherein all internal movements are along shear planes which do not change their position during the entire process.
2. It is a process wherein all internal movements are along shear planes which change their position during the process.
3. The process involves dilation in the vertical direction.
4. The process involves compression in a lateral direction.

Which of the above statements are correct?

(a) 1, 2 and 3 only (b) 1, 3 and 4 only
(c) 1, 2 and 4 only (d) 2, 3 and 4 only

[ESE : 2017]

7.61 Statement (I): All old systems of surveying can be completely replaced by remote sensing system basing on INSAT data.

Statement (II): Reference data in-situ is essential in interpreting satellite imageries.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is *not* the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

[ESE : 2017]

■■■■

Answers Field Astronomy and Photogrammetic Survey

7.1 (a)	7.2 (c)	7.3 (c)	7.4 (b)	7.5 (c)	7.6 (b)	7.7 (a)	7.8 (a)	7.9 (d)	
7.10 (a)	7.11 (a)	7.12 (b)	7.13 (d)	7.14 (c)	7.15 (b)	7.16 (c)	7.17 (d)	7.18 (a)	
7.19 (b)	7.20 (a)	7.21 (c)	7.22 (c)	7.23 (d)	7.24 (c)	7.25 (b)	7.26 (c)	7.27 (b)	
7.28 (d)	7.29 (d)	7.30 (*)	7.31 (d)	7.32 (b)	7.33 (c)	7.34 (c)	7.35 (b)	7.36 (b)	
7.37 (b)	7.38 (d)	7.39 (d)	7.40 (b)	7.41 (d)	7.42 (c)	7.43 (c)	7.44 (d)	7.45 (c)	
7.46 (b)	7.47 (a)	7.48 (b)	7.49 (b)	7.50 (b)	7.51 (d)	7.52 (b)	7.53 (b)	7.54 (a)	
7.55 (d)	7.56 (a)	7.57 (c)	7.58 (d)	7.59 (d)	7.60 (d)	7.61 (c)			

Explanations Field Astronomy and Photogrammetic Survey

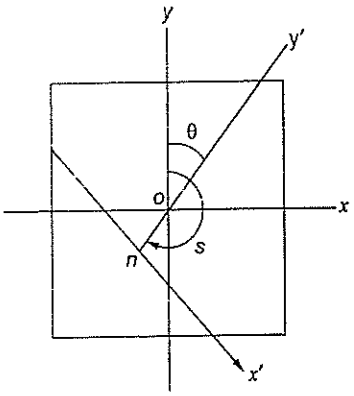
7.1 (a)

Difference in longitude = 82°30′ – 20°
= 62°30′
1 h = 15°; 1 m = 15′
and 1 s = 15″
∴ 62° = 4 h 8 m
30′ = 2 m
∴ 62°30′ = 4 h 10 m

Local mean time (LMT)
= Standard time – Difference in longitude
= 20 h 10 m – 4 h 10 m
= 16 h = 4 h PM

7.2 (c)

The swing angle (s) is the clockwise angle measured in the plane of photograph from the positive *y*-axis the photographic nadir point (*n*).



Thus, the rotation angle,

$$\theta = s - 180°$$
$$= 230° - 180° = 50°$$

7.3 (c)

Relief displacement,

$$d = \frac{r_t h_t}{H} = \frac{96 \times 500}{4000}$$
$$= 12 \text{ mm}$$

7.4 (b)

Terrestrial meridian (observer's meridian) is the great circle that passes through the terrestrial poles and point of observation.

Stars having polar distances less than the latitude of the place of observation are called circumpolar star. They are always above the horizon and therefore do not set.

When a celestial body crosses the observer's meridian, it is said to culminate or transit.

7.5 (c)

Given $f = 150 \text{ mm}$

$B = 2100 \text{ m}$; $h = 900 \text{ m}$;

$p = 75 \text{ mm}$

$$\frac{p}{f} = \frac{B}{H - h}$$

$$\Rightarrow \quad H - 900 = \frac{2100 \times 150}{75}$$

$$\therefore \quad H = 5100 \text{ m}$$

7.6 (b)

A vertical circle which is at right angles to the meridian is called prime vertical. It intersects the horizon in the east and west points.

$$\sin\delta = \cos(90 - \theta)\cos(90 - \alpha)$$
$$= \sin\theta\sin\alpha$$
$$\therefore \quad \sin\theta = \sin\delta \operatorname{cosec}\alpha$$

7.7 (a)

At upper culmination

zenith distance $= \delta - \theta = 90 - \alpha$

At lower culmination

zenith distance $= 180 - (\delta + \theta) = 90 - \alpha$

Given declination,

$$\delta = 21° 15'\text{N}$$

When $\delta < \theta$, it means that the upper culmination occurs the south of the zenith.

Zenith distance $= \theta - \delta = 43°30' - 21°15'$

$= 22°15'$

7.8 (a)

Cadastral survey is used to plot the details such as boundaries of fields, houses and property lines in rural and urban areas. These are also known as public land surveys.

Photogrammetry is used to produce a mosaic or map by compiling the photographs. Aerial survey covers photogrammetry and photo-interpretation both.

7.9 (d)

The difference between apparent and mean solar times at any instant is known as the equation of time (ET)

$$ET = GAT - GMT$$

where

GAT is Greenwich Apparent Time

GMT is Greenwich Mean Time

$$ET = -13' 28.5''$$
$$GMT = 0 \text{ h on a day}$$
$$\therefore \quad GAT = 23 \text{ h } 46' 31.5'' \text{ of previous day}$$

7.10 (a)

Scale, $S = \frac{f}{H - h} = \frac{20}{1500 - 500}$

$$= \frac{20}{1000} = \frac{1}{50}$$

7.11 (a)

Properties of spherical triangle:

(i) Any angle is less than two right angles or π radians.

(ii) The sum of three angles is less than six right angle or 3π radians and greater than two right angles or π radians.

(iii) The sum of any two sides is greater than the third.

(iv) If the sum of any two sides is equal to two right angles or π radians, the sum of the angles opposite to them is equal to two right angles or π radians.

(v) The smaller angle is opposite to the smaller side and vice versa.

(vi) If two angles are equal the sides opposite to them are also equal.

(vii) The sum of the three sides of a spherical triangle is less than circumference of great circle.

7.12(b)

Scale of photograph,

$$S = \frac{8\text{ cm}}{1\text{km}} = \frac{80\text{ mm}}{1\text{km}} = \frac{f}{H}$$

Given $f = 160\text{ mm}$

$\therefore$ $H = 2\text{ km} = 2000\text{ m}$

7.13 (d)

Circumpolar stars have polar distance less than latitude of the place or greater than co-latitude.

The star is circumpolar if $\theta + \delta$ is greater than 90° where δ is star's declination and θ is latitude of the place

Polar distance $= 90 - \delta$

$$\theta + \delta > 90°$$

$$\delta > 90° - \theta$$

$90° - \theta$ is the Co-latitude

7.14 (c)

Parallax for bottom,

$$p_b = \frac{fB}{H - h_b}$$

$$\Rightarrow \quad h_b = H - \frac{fB}{p_b}$$

$$\Rightarrow \quad h_b = 4000 - \frac{160 \times 300}{63}$$

$$\Rightarrow \quad h_b = 3238.09\text{ m}$$

Parallax difference,

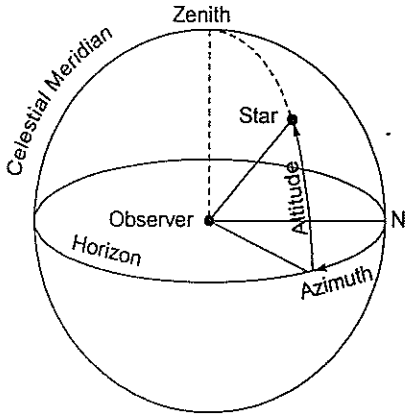
$$\Delta p = \frac{\Delta h \times p_t}{H - h_b}$$

$$\Rightarrow \quad 72 - 63 = \frac{\Delta h \times 72}{4000 - 3238.09}$$

$$\Rightarrow \quad \Delta h = 95.2\text{ m}$$

7.15 (b)

Azimuth is the direction of a celestial object from the observer, expressed as the angular distance from the north or south point of the horizon to the point at which a vertical circle passing through the object intersects the horizon.



7.16(c)

Given, $H = 500\text{ m}$

$h_1 = 250\text{ m}$

If h is the height of chimney then elevation of top of chimney, $h_2 = h_1 + h$

Relief displacement,

$$d = r_2 - r_0 = \frac{r_2 h}{H - h_1}$$

$$\therefore \quad h = \frac{51.4 \times (500 - 250)}{110}$$

$$= 116.82\text{ m}$$

7.17(d)

The position of celestial body on a celestial sphere can be stated in one of the three ways:

(i) The altitude and azimuth system

(ii) The declination and right ascension system

(iii) The declination and hour angle system

The co-altitude is also known as zenith distance. It is the complement of the altitude (α) and is written as $90 - \alpha$. From co-altitude, the altitude can be known and from co-declination, the declination can be known. However the position of body can not be determined except in specific circumstances.

7.18 (a)

Airbase is the distance covered by aircraft between two successive exposures

$$B = \frac{bH}{f}$$

7.19 (b)

A stereoplotter, also known as a multiplex, is an optical and mechanical apparatus used for preparing maps of high precision from aerial photographs. Its function is to create a precise three dimensional scale optical model and provide a means to view the spatial model and provide a means for measuring the model and plotting its orthographic or map projection.

7.20 (a)

Sun-synchronous orbit satellites which operates in a near circular polar orbit running nearly north to south at a fixed attitude ranging from 500-1000 km. Every time the satellite passes from north to south, it has a consistent and constant sunlight view of a swath (around 150 km) of earths surface. Indian Remote sensing satellite (IRS) launched by PSLV come under this kind.

7.21 (c)

An assembly of individual overlapping aerial photographs, all on approximately the same scale, which are adjusted along the edges of one another by cutting the overlapping portion is called mosaic.

Photographic maps are classified as below:

(i) Index maps in which photograph of the assembled prints arranged in the order of exposure.

(ii) Planimetric map shows natural and cultural features in plan.

(iii) Topographic map shows contour line in addition to the planimetric data.

(iv) Stereotopographic maps.

7.22 (c)

The circumpolar stars are always above the horizon and therefore they do not set. At upper culmination their altitude is maximum and at lower culmination their altitude is minimum.

7.23 (d)

Ground speed

$$= \frac{1000}{20} = 50 \text{ m/s} = 50 \times \frac{18}{5} = 180 \text{ km/h}$$

7.24 (c)

Crab of photograph is angle between flight line and edge of photograph in direction of flight. Drift is lateral shifting of photograph.

Stadia survey is a tacheometric form of distance measurement that relies on a fixed-angle intercept made by stadia hair.

Baseline is a line between two points on the earth's surface and the direction and distance between them. In a triangulation network, at least one baseline needs to be measured to calculate the size of the triangles by trigonometry.

In astronomical surveying when the star is on the observer's meridian, it is said to be at culmination. The star is said to be at elongation when it is at its farthest point from the observer's meridian.

7.25 (b)

$$L = (1 - P_l)Sl$$

and $$W = (1 - P_w)Sl$$

where

l is length of photograph

P_l is forward overlap

P_w is side overlap

$\therefore$ $$L = (1 - 0.6) \times 200 \times 20$$

$$= 1600 \text{ m} = 1.6 \text{ km}$$

$$W = (1 - 0.3) \times 200 \times 20$$

$$= 2800 \text{ m} = 2.8 \text{ km}$$

Area covered by one photograph

$$= LW = 1.6 \times 2.8 = 4.48 \text{ km}^2$$

7.26 (c)

$$\lambda_m \propto \frac{1}{T}$$

$$\Rightarrow \quad \lambda_m = \frac{a}{T}$$

where a is a constant

In case of sun, we have

$$0.5 = \frac{a}{6000}$$

$$\Rightarrow \quad a = 3000 \text{ μm-K}$$

In case of earth, we have

$$\lambda_m = \frac{a}{T}$$

$$\Rightarrow \quad 10 = \frac{3000}{T}$$

$$\Rightarrow \quad T = 300 \text{ K}$$

∴ Temperature of earth's surface in °C
$= 300 - 273 = 27°$

7.28 (d)

Photomaps are the aerial photographs which are used as a substitute for maps. The photomap may consist of one photograph, but usually photomaps are obtained by assembling two or more photographs to form a large map. The large photomaps from two or more photographs are called mosaics. To a varying degree of accuracy, a mosaic is a map substitute. The mosaic has an overall average scale comparable to the scale of a planimetric map.

7.29 (d)

A Flamsteed designation is a combination of a number and constellation name that uniquely identifies stars. *Flamsteed designations* were assigned to 2554 stars. The numbers were originally assigned in order of increasing *right ascension* within each constellation.

7.30 (*)

A star is called a circumpolar star if it always remains above the horizon, and therefore it does not set. A circumpolar star appears to describe a circle about the pole. For a circumpolar star, $\delta > 90° - \phi$

7.31 (d)

Scale of photograph

$$= \frac{\text{Photograph distance}}{\text{Map distance}} \times \text{Scale of map}$$

$$= \frac{6}{4} \times \frac{1}{24,000} = \frac{1}{16,000}$$

7.33 (c)

Remote sensing utilizes satellite and/or airborne based sensors to collect information about a given object or area. Remote sensing data collection methods can be passive or active. Passive sensors (e.g., spectral imagers) detect natural radiation that is emitted or reflected by the object or area being observed. In active remote sensing (e.g., radar) energy is emitted and the resultant signal that is reflected back is measured.

7.34 (c)

Geodetic surveying is the type of surveying in which the curvature of the earth is taken into consideration and a very high standard of accuracy is maintained. It is used for large areas like survey of a country.

7.35 (b)

Altitude and Azimuth are used to describe the location of a star on celestial system as viewed from a particular location at a particular time.

The altitude is the distance an object appears to be above the horizon. The angle is measured up from the closest point on the horizon. The azimuth of an object is the angular distance along the horizon to the location of the object. By convention, azimuth is measured from north towards the east along the horizon.

7.36 (b)

The time interval taken by one apparent revolution of the sun about the earth is called a solar day. The time interval taken by the vernal equinox in one apparent revolution about the earth is called a sidereal day. Because the time period for 366·2422 sidereal days is equal to that for 365·2422 solar days, a sidereal day is shorter than a solar day.

∵ 365·2422 solar days = 1 solar year
∴ 1 solar year = 366·2422 sidereal days

7.37 (b)

It equals 365.25636 SI days. The sidereal year differs from the tropical year, the time interval between vernal equinoxes in successive years, due to the precession of the equinoxes.

7.38 (d)

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on-site observation.

7.39 (d)

Lens cone assembly contains the following:
(a) Lens
(b) filter
(c) Shutter and diaphragm

Filter is placed in front of lens and it:
(a) reduces the effect of atmospheric haze,
(b) helps provide uniform light distribution over the entire format
(c) protects the lens from damage and dust.

7.40 (b)

Isocentre is the point on the aerial photo platform that falls on a line half-way between the Principal point and the Nadir point. It is the point at which bisector of angle of tilt meets vertical photograph.

7.41 (d)

Declination of celestial body is angular distance of body above or below celestial equator. Declination is one of the two angles that locate a point on the celestial sphere in the equatorial coordinate system, the other being hour angle. Declination's angle is measured north or south of the celestial equator, along the hour circle passing through the point in question. It is same as latitude of a station on earth.

7.42 (c)

Two types of *solar time* are apparent *solar time* (sundial *time*) and *mean solar time* (clock *time*). The apparent sun is the true sun as seen by an observer on Earth. Apparent solar time or true solar time is based on the apparent motion of the actual Sun. mean solar time is the time as calculated by the motion of the mean sun (such as is shown by an ordinary clock). The equation of time which is this difference between apparent and mean solar time, is cyclical and does not accumulate from year to year.

7.43 (c)

Actual ground length covered

$$L = (1 - P_l)l \times s$$

$$= (1 - 0.6) \times 20 \times \frac{10{,}000}{100 \times 10^3} = 0.8 \text{ km}$$

7.44 (d)

Types of variation in declination are:

(a) Durnal Variation: The diurnal variation or daily variation is the systematic departure of the declination from its mean value during a period of 24 hours. The extent of daily variations depend upon the following factors:
   (i) The locality: More at magnetic poles and less at equator.
   (ii) Season of the year: Considerably more in summer than in winter.
   (iii) Time: More in day and less in night. The rate of variation during 24 hours is variable.
   (iv) The amount of daily variation changes from year to year.

(b) Annual Variation: The variation which has a yearly period is known as annual variation.

(c) Secular variation follows a sine-curve pattern. It swings like a pendulum. For a given place, the compass needle after moving continuously for a period of years in one direction with respect to the true North, gradually comes to a stand still and then begins to move in opposite direction.

(d) Irregular Variation: The irregular variations are due to what are known as 'magnetic stroms', earthquakes and other solar influences.

7.47 (a)

The global positioning system is a space based satellite navigation system that provides location and time information in all weather, anywhere or near the earth. It is maintained by the United States Government and is freely accessible to anyone. The GPS program provides critical capabilities to military, civil and commercial users around the world. In addition, GPS is the backbone for modernizing the global air traffic system.

7.48 (b)

Microwaves are a form of electromagnetic radiation with wavelengths ranging from 1 mm to 1 m longer than those of infrared radiation but shorter than that of normal radio wave. They are able to penetrate atmosphere under almost all conditions.

7.49 (b)

Atmospheric windows is that portion of the electromagnetic spectrum that can be transmitted through the *atmosphere* without any distortion or absorption. Light in certain wavelength regions can penetrate the *atmosphere* well. These regions are called *atmospheric windows*. The *atmosphere* is *practically transparent* to a substantial *portion* of the *visible spectrum*.

7.50 (b)

Scattering is caused by pollen, dust, smoke, water droplets, and other particles in atmosphere. Scattering of light depends on the wavelength or frequency of the light being scattered. Shorter

wavelengths scatter more than longer wavelengths. Scattering effect decreases signal value.

7.51 (d)

The useful magnification of a light optical microscope is reached by multistage imaging. The total magnification M of multistage imaging with single magnification steps M_1, M_2 ... M_n is given by, $M = M_1 M_2 \ldots M_n$.

7.52 (b)

Remote sensing is based on the measurement of reflected or emitted radiation from different bodies. Objects having different surface features reflect or absorb the sun's radiation in different ways. This emitted radiation is known as Spectral Reflectance.

7.53 (b)

Rectification is process by which geometry of an image is made planimetric by referencing to some standard map projection.

Rectification is a precise geometric correction and is used when accurate direction, area or distance measurement is required.

7.54 (a)

Temporal resolution refers to the precision of a measurement with respect to time. Observations are made over same area on different dates. This is useful during crop growth, deforestation, floods etc.

7.55 (d)

This is a high-tech version of triangulation, called trilateration. The first satellite locates you somewhere on a sphere. The second satellite narrows your location to a circle created by the intersection of the two satellite spheres. The third satellite reduces the choice to two possible points. Finally the fourth satellite helps to calculate a timing and location correction and selects one of the remaining two points as your position.

7.56 (a)

Scanning system employs detectors with a narrow field of view which sweeps across the terrain to produce an image. When photons of EM energy radiated or reflected from earth surface feature encounter the detector, an electrical signal is produced that varies in proportion to the number of photons.

7.57 (c)

Numbering of the runway is

$$= \frac{\text{Magnetic azimuth from Magnetic North}}{10}$$

Other end of the runway will be at 180° difference from a given end i.e.

$80° + 180° = 260°$

$\therefore$ Number of other end = 26

7.58 (d)

Local mean time difference

$$= \frac{42°36'}{15} = 2 \text{ hr } 50 \text{ min } 24 \text{ sec}$$

Since local place is west of greenwich, LMT is less than GMT.

LMT = GMT − 2 hr 50 min 24 sec

GMT = LMT + 2 hr 50 min 24 sec

= 8 hr 42 min 15 sec + 2 hr 50 min 24 sec

= 11 hr 32 min 39 sec AM

7.59 (d)

$$h_{avg} = 250 \text{ m}$$

$$f = 25 \text{ cm}$$

$$\text{Scale} = \frac{15 \text{ cm}}{30000 \text{ cm}} = \frac{1}{2000}$$

$$r = 10 \text{ cm}$$

$$d = 0.5 \text{ cm}$$

$$\text{scale} = \frac{f}{H - hav} = \frac{1}{200}$$

$$\frac{0.25}{H - 250} = \frac{1}{200}$$

$$H = 750 \text{ m}$$

$$rh = d(h - \text{hav})$$

$$h = \frac{0.5 \times (750 - 250)}{10}$$

$$= 25 \text{ m}$$

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UNIT

VII

Highway Engineering

Syllabus

Planning & construction methodology, Alignment and geometric design; Traffic Surveys and Controls; Principles of Flexible and Rigid pavements design.

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OOOO

1 Highway Development & Planning

1.1 **Assertion (A):** Level grades may be used in fill sections for roads in rural areas.
Reason (R): On fill sections in rural areas, crowned pavements and sloping shoulders can take care of surface drainage.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1997]

1.2 Which one of the following is the chronological sequence in regard to road construction/design/development?
(a) Telford, Tresaguet, CBR, Macadam
(b) Tresaguet, Telford, Macadam, CBR
(c) Macadam, CBR, Tresaguet, Telford
(d) Tresaguet, Macadam, Telford, CBR
[ESE : 1998]

1.3 The length of National Highways as per 3rd 20 year (Lucknow) road plan is given by
(a) area of the country/75
(b) area of the country/50
(c) area of the country/40
(d) area of the country/25
[ESE : 2000]

1.4 In which one of the following location surveys of the road, soil profile sampling is done up to a depth of 1 m to 3 m below the existing ground level?
(a) Preliminary survey
(b) Final location survey
(c) Construction survey
(d) Material location survey
[ESE : 2003]

1.5 Under the Nagpur Road Plan, which of the following are NOT relevant in planning the road development programme in a backward district?
1. Existing agriculture drainage network of drain canals.
2. Existing number of Panchayat unions.
3. Existing length of mud-track roads.
4. Number of villages with population of 10000 and above.
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 1, 2 and 4 only (d) 2, 3 and 4 only
[ESE : 2013]

■■■■

Answers Highway Development & Planning

1.1 (a) 1.2 (b) 1.3 (b) 1.4 (a) 1.5 (a)

Explanations Highway Development & Planning

1.1 (a)

The main concern in surface drainage is the fast disposal of precipitation on road surface so as to minimize danger to moving vehicles. This is achieved by proper geometric design of the road, i.e. by crowning the carriageway or side cross fall, giving proper cross slope to the shoulders and verges, providing requisite longitudinal gradient.

1.2 (b)

Tresaguet construction was started in 1764 AD in France. Telford construction was started in 1803 AD in London (England). Macadam construction was started in 1815 AD in England. CBR construction was started in 1928 AD in USA

1.3 (b)

(i) Length of National Highways (NH)
= Area of the country/50

(ii) Length of State Highways (SH)
= Area of the state/25
= 62.5 × number of towns in the state – Area of the state/50

(iii) Length of the Major District Roads (MDR)
= Area of the State/12.5
= 90 × number of towns in the state

(iv) Total length of all categories of roads in a district i.e.
NH + SH + MDR + ODR + VR
= Area of District × 0.82

1.4 (a)

Soil survey is done as a part of preliminary survey to check the suitability of proposed location and details collected are used for comparative study of alternate projects. In this, sample of soil upto depth of 1 to 3 m below ground level or finished road level is taken.

1.5 (a)

Nagpur road plan formula were prepared by radial or star and grid pattern. Villages with population of 501-5000 only were considered. Agricultural area and non agricultural areas were considered. There were no consideration mentioned for existing Panchayat union, existing mud track records or existing drainage network.

2 Highway Geometric Design

2.1 The maximum super elevation to be provided on a road curve is 1 in 15. If the rate of change of super elevation is specified as 1 in 120 and the road width is 10 m, then the minimum length of the transition curve on either end will be

(a) 180 m (b) 125 m
(c) 80 m (d) 30 m

[ESE : 1995]

2.2 A summit curve is formed at the intersection of a 3% up gradient and 5% down gradient. To provide a stopping distance of 128 m, the length of summit curve needed will be

(a) 271 m (b) 298 m
(c) 322 m (d) 340 m

[ESE : 1995]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

2.3 **Assertion (A):** For mixed traffic conditions, the super elevation should fully counteract the centrifugal force for the full design speed.

Reason (R): Super elevation needed to maintain the design speed in full may exceed the limiting value of 0.07. Further, as it is not possible to increase the radius, the speed has to be restricted.

[ESE : 1995]

2.4 **Assertion (A):** Rotating parts of the surface of the road with the crown as the pivot is not generally preferred for achieving the needful cant at horizontal curves.

Reason (R): Lowering of the lower edge interferes with the drainage system of the road.

[ESE : 1996]

2.5 Which of the following are the criteria associated with the design of sag vertical curve?

1. Provision of minimum stopping distance during day time.
2. Adequate drainage.
3. Comfortable operation
4. Pleasant appearance.

Select the correct answer using the codes given below:

(a) 1, 2 and 4 (b) 2 and 3
(c) 2, 3 and 4 (d) 1 and 3

[ESE : 1996]

2.6 Assuming the safe stopping sight distance to be 80 m on a flat highway section and with a setback distance of 10 m, what would be the radius of the negotiable horizontal curve?

(a) 800 m (b) 160 m
(c) 80 m (d) 70 m

[ESE : 1996]

2.7 A vehicle was stopped in two seconds by fully jamming the breaks. The skid marks measured 9.8 metres. The average skid resistance coefficient will be

(a) 0.7 (b) 0.5
(c) 0.4 (d) 0.25

[ESE : 1997]

2.8 Which of the criteria given below are used for the design of valley vertical curves on roads?

1. Rider comfort
2. Headlight sight distance
3. Drainage

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 and 2

[ESE : 1998]

2.9 **Assertion (A):** It is general practice to provide cant to the road surface with inner edge forming the pivot point.
Reason (R): It does not change centre line levels which have already been fixed at the design stage.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1998]

2.10 For a circular curve of radius 200 m, the coefficient of lateral friction of 0.15 and the design speed is 40 kmph. The equilibrium super elevation (for equal pressure on inner and outer wheel) would be

(a) 21.3 (b) 7
(c) 6.3 (d) 4.6

[ESE : 1999]

2.11 If a descending gradient of 1 in 25 meets an ascending gradient of 1 in 40, then the length of valley curve required for a headlight sight distance of 100 m will be

(a) 30 m (b) 130 m
(c) 310 m (d) 630 m

[ESE : 1999]

2.12 An ascending gradient of 1 in 100 meets a descending gradient of 1 in 50. The length of summit curve required to provide overtaking sight distance of 500 m will be

(a) 938 m (b) 781 m
(c) 470 m (d) 170 m

[ESE : 1999]

2.13 Which one of the following expressions gives intermediate sight distance as per IRC standards?

(a) 2 SSD (b) $\frac{(SSD + OSD)}{2}$

(c) $\frac{(OSD - SSD)}{2}$ (d) 2 OSD

[ESE : 1999]

2.14 Brake is applied on a vehicle which then skids a distance of 16 m before coming to stop. If the developed average coefficient of friction between the tyres and the pavement is 0.4, then the speed of the vehicle before skidding have been nearly

(a) 20 kmph (b) 30 kmph
(c) 40 kmph (d) 50 kmph

[ESE : 1999]

2.15 Total reaction time of a driver does not depend upon

(a) perception time
(b) brake reaction time
(c) condition of mind of the driver
(d) speed of vehicle

[ESE : 2000]

2.16 A horizontal curve of 480 m for 7.5 m two-lane road is to be designed for a speed of 80 kmph. The raising of the outer edge of the pavement with respect to the inner edge to cater to the mixed traffic condition is

(a) 0.14 m (b) 0.22 m
(c) 0.24 m (d) 0.27 m

[ESE : 2000]

2.17 While driving at a speed of 30 kmph (with available friction 0.4) down the grade, the driver requires a braking distance twice that required for stopping the vehicle when he travels up the same grade. The grade is

(a) 7% (b) 10.6%
(c) 13.3% (d) 33.3%

[ESE : 2001]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

2.18 **Assertion (A):** When a sharp horizontal curve is to be introduced on a road which already has the

maximum permissible gradient, the gradient should be decreased.
Reason (R): The gradient should be decreased to compensate for the loss of tractive effort due to the introduction of sharp horizontal curve on the road.

[ESE : 2001]

2.19 Assertion (A): The centrifugal ratio decreases along the length of the transition curve.
Reason (R): The superelevation increases along the length of the transition curve.

[ESE : 2001]

2.20 Assertion (A): A skilful highway designer 'builds in' speed control at critical locations on horizontal curves rather than increase the superelevation.
Reason (R): A driver slows down on horizontal curve due to feeling of discomfort because of increase in side friction with reduced superelevation.

[ESE : 2002]

2.21 Consider the following factors:
1. Reaction time
2. Speed
3. Coefficient of longitudinal friction
4. Gradient

Which of these factors are taken into account for computing braking distance?
(a) 1 and 3 (b) 1, 2 and 4
(c) 2, 3 and 4 (d) 2 and 3

[ESE : 2002]

2.22 The camber provided on a sloping road is 1 in 48. Which one of the following is the ruling gradient?
(a) 1 in 15 (b) 1 in 20
(c) 1 in 24 (d) 1 in 30

[ESE : 2003]

2.23 Which of the following are the accepted criteria for design of valley curve for highways?
1. Headlight sight distance
2. Passing and non-passing sight distance
3. Aesthetic consideration
4. Motorist comfort
5. Drainage control

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 1, 3, 4 and 5
(c) 2, 3, 4 and 5 (d) 1 and 5

[ESE : 2003]

2.24 For a given road, safe stopping sight distance is 80 m and passing sight distance is 300 m. What is the intermediate sight distance?
(a) 220 m (b) 190 m
(c) 160 m (d) 150 m

[ESE : 2004]

2.25 Consider the following statements:
A transition curve is provided on a circular curve on a highway to provide
1. gradual introduction of centrifugal force
2. minimum stopping sight distance
3. gradual introduction of super elevation
4. comfort and security to passengers

Which of these statements are correct?
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 4 (d) 1, 2 and 4

[ESE : 2004]

2.26 What will be the ruling radius of a horizontal curve on a National Highway for a design vehicle speed of 100 km/h, assuming allowable super elevation to be 7% and lateral friction as 0.13?
(a) 405 m (b) 395 m
(c) 385 m (d) 375 m

[ESE : 2004]

2.27 A summit curve is formed at the intersection of a 3% upgrade and a 5% downgrade. What is the length of the summit curve in order to provide a stopping distance of 128 m?
(a) 271 m (b) 298 m
(c) 322 m (d) 340 m

[ESE : 2005]

2.28 Which of the following are requirements for the design of a transition curve for a highway system?
1. Rate of change of grade
2. Rate of change of radial acceleration
3. Rate of change of super elevation
4. Rate of change of curvature

Select the correct answer using the codes given below:

(a) 1, 2 and 3 (b) 2, 1 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

[ESE : 2005]

2.29 What is the minimum length of a transition curve for a design speed of 80 kmph in a horizontal curve of 240 m radius?

(a) 32 m (b) 42 m
(c) 52 m (d) 72 m

[ESE : 2006]

2.30 The design speed of a highway is 80 km/hr and the radius of circular curve is 150 m in plain topography. Which one of the following is the minimum length of transition curve?

(a) 115 m (b) 85 m
(c) 64 m (d) 43 m

[ESE : 2006]

2.31 A rising gradient of 1 in 50 meets a falling gradient of 1 in 30. Which one of the following is the length of vertical curve if the stopping sight distance is 120 m?

(a) 174 m (b) 158 m
(c) 140 m (d) 120 m

[ESE : 2006]

2.32 If a road surface is adequately superelevated on horizontal curve, which one of the following is the proper distribution of pressure on the vehicle wheels?

(a) Pressure on both outer and inner wheels is equal.
(b) Pressure on inner wheels is more than the outer wheels.
(c) Pressure on inner wheels is less than the outer wheels.
(d) Pressure on front wheel is thrice the pressure on rear wheels.

[ESE : 2007]

2.33 **Assertion (A):** Road camber helps in surface drainage..

Reason (R): In a curved road alignment, super elevation serves the purpose of camber.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2008]

2.34 If super-elevation is not provided on a horizontal curve of a highway, then on which portion of the road, are pot holes likely to develop?

(a) Outer edge of road
(b) Inner edge of road
(c) Centre of road
(d) Shoulder of road

[ESE : 2010]

2.35 Full amount of super-elevation on a horizontal curve is provided at the

(a) beginning of the transition curve
(b) centre of the circular curve
(c) end of the transition curve
(d) centre of the transition curve

[ESE : 2010]

2.36 With all other relevant conditions remaining the same, the speed of a vehicle negotiating a curve is proportional to

(a) $\sqrt{\text{Weight of the vehicle}}$
(b) Weight of the vehicle
(c) $\frac{1}{\text{Weight of the vehicle}}$
(d) $\frac{1}{\sqrt{\text{Weight of the vehicle}}}$

[ESE : 2011]

2.37 A 3% downgrade curve is followed by a 1% upgrade curve and rate of change of grade adopted is 0.1% per 20 m length. The length of the respective vertical curve is

(a) 800 m (b) 200 m
(c) 100 m (d) 400 m

[ESE : 2011]

2.38 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

A. Lateral friction
B. Cut-off lagoons
C. Skid
D. Sight distance

List-II

1. Disparity between relevant travel distances
2. Vehicle movement on a curve
3. Summit curves
4. Prevention of flooding

Code:

	A	B	C	D
(a)	2	1	4	3
(b)	3	1	4	2
(c)	2	4	1	3
(d)	3	4	1	2

[ESE : 2011]

2.39 Assertion (A): IRC has recommended a minimum coefficient of friction in the longitudinal direction on wet pavements after allowing a suitable factor of safety in the range 0.15-0.30.

Reason (R): When the longitudinal coefficient of friction of 0.40 is allowed for stopping the vehicle, the resultant retardation is 3.93 m/sec^2,

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2011]

2.40 An ideal horizontal transition curve is a

(a) Parabola (b) Circle
(c) Clothoid spiral (d) Hyperbola

[ESE : 2012]

2.41 The transitional property of a lemniscate curve is disrupted when its deflection angle is around

(a) 30° (b) 45°
(c) 60° (d) 90°

[ESE : 2012]

2.42 If R is the radius of the curve and L is the length of the long chord, the shift of the curve is (all in meter units)

(a) $\frac{L^2}{R}$ (b) $\frac{L^2}{2R}$
(c) $\frac{L^2}{24R}$ (d) $\frac{L^2}{6R}$

[ESE : 2012]

2.43 The ratio between the adopted centrifugal ratios for roads and railways is

(a) 3 : 1 (b) 4 : 1
(c) 2 : 1 (d) 5 : 1

[ESE : 2012]

2.44 For a bituminous carriageway surface having 2% camber and design speed of 100 kmph, Radius beyond which super-elevation is not essential is nearly:

(a) 1100 m (b) 1500 m
(c) 1800 m (d) 2200 m

[ESE : 2013]

2.45 A road passes through a cut with impervious strata at a depth of 1.25 m from the sub-grade level. To intercept seepage flow, a longitudinal pipe drain in trench filled with filter material and clay seal is constructed. What will be the required depth of the trench?

(a) 2.5 m (b) 1.5 m
(c) 1.25 m (d) 0.5 m

[ESE : 2013]

2.46 What is the value of the resultant retardation in m/s^2 when a longitudinal friction coefficient of 0.4 is allowed for stopping the vehicle on road?

(a) 0.98 (b) 1.95
(c) 2.93 (d) 3.93

[ESE : 2013]

2.47 The rate of super-elevation for a horizontal curve of radius 500 m in a national highway for a design speed of 100 kmph is

(a) 0.04 (b) 0.063
(c) 0.07 (d) 0.70

[ESE : 2013]

2.48 If a vehicle travelling at 40 kmph was stopped within 1.8 sec after the application of the brakes, then the average skid resistance coefficient is

(a) 0.63 (b) 0.73
(c) 0.83 (d) 0.93

[ESE : 2014]

2.49 While aligning a hill road with a ruling gradient of 6%, a horizontal curve of 75 m radius is encountered. The compensated gradient at the curve will be

(a) 1% (b) 2%
(c) 3% (d) 5%

[ESE : 2014]

2.50 An electric locomotive running at 60 kmph on a curved track of 1.68 m gauge laid at 800 m radius should be provided with superelevation of the rail by an amount of

(a) 50.5 mm (b) 55.5 mm
(c) 59.5 mm (d) 65.5 mm

[ESE : 2014]

2.51 The maximum superelevation to be provided on a road curve is 1 in 15. If the rate of change of superelevation is specified as 1 in 120 and the road width is 10 m, then the minimum length of the transition curve on each end will be

(a) 120 m (b) 100 m
(c) 80 m (d) 180 m

[ESE : 2015]

2.52 A four-lane divided highway, with each carriageway being 7.0 m wide, is to constructed in a zone of high rainfall. In this stretch, the highway has a longitudinal slope of 3% and is provided a camber of 2%. What is the hydraulic gradient on this highway in this stretch?

(a) 4.0% (b) 3.6%
(c) 4.5% (d) 3.0%

[ESE : 2015]

2.53 In an area of heavy rainfall, a State Highway of high-type bituminous surface with four lanes (14.0 m wide) is to be constructed. What will be the height of the crown of the road relative to the edges for a composite camber (i.e. middle half as parabolic and the rest as straight lines)?

(a) 14 cm (b) 21 cm
(c) 28 cm (d) 7 cm

[ESE : 2015]

2.54 A descending gradient of 4% meets an ascending grade of 1 in 40 where a valley curve of length 200 m is to be formed. What will be the distance of the lowest point on the valley curve from its first tangent point?

(a) 100 m (b) 111 m
(c) 125 m (d) 118 m

[ESE : 2015]

2.55 What will be the non-passing sight distance on a highway for a design speed of 100 kmph when its ascending gradient is 2%? Assuming coefficient of friction as 0.7 and brake efficiency as 50%.

(a) 176 m (b) 200 m
(c) 150 m (d) 185 m

[ESE : 2015]

2.56 Which one of the following items of hill road construction does not help in the prevention of landslides during the monsoon season?

(a) Breast walls
(b) Hair-pin
(c) Catch-water drains
(d) Retaining walls

[ESE : 2015]

2.57 The radius of a horizontal circular curve is 480 m and design speed therein 70 kmph. What will be the equilibrium superelevation for the pressures on the inner and the outer wheels to be equal?

(a) 5% (b) 6%
(c) 7% (d) 8%

[ESE : 2015]

2.58 The following purposes served by a transition curve in a highway alignment include:

1. Gradual introduction of the centrifugal force on moving vehicles from zero on the straight alignment to a constant final value on the circular curve.
2. Enabling the gradual introduction of superelevation on the roadway.

Select the correct answer using the codes given below:

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2017]

Answers Highway Geometric Design

2.1 (c)	2.2 (b)	2.3 (d)	2.4 (a)	2.5 (c)	2.6 (c)	2.7 (b)	2.8 (a)	2.9 (c)
2.10 (c)	2.11 (b)	2.12 (b)	2.13 (a)	2.14 (c)	2.15 (c)	2.16 (*)	2.17 (c)	2.18 (a)
2.19 (d)	2.20 (c)	2.21 (c)	2.22 (d)	2.23 (b)	2.24 (c)	2.25 (b)	2.26 (b)	2.27 (b)
2.28 (d)	2.29 (d)	2.30 (a)	2.31 (a)	2.32 (a)	2.33 (b)	2.34 (a)	2.35 (c)	2.36 (d)
2.37 (a)	2.38 (c)	2.39 (d)	2.40 (c)	2.41 (c)	2.42 (c)	2.43 (c)	2.44 (d)	2.45 (c)
2.46 (d)	2.47 (c)	2.48 (a)	2.49 (d)	2.50 (c)	2.51 (c)	2.52 (a)	2.53 (a)	2.54 (b)
2.55 (a)	2.56 (b)	2.57 (d)	2.58 (c)					

Explanations Highway Geometric Design

2.1 (c)

Length of transition curve,

$$L = eWN$$

Given, $e = \frac{1}{15}; \frac{1}{N} = \frac{1}{120};$

$W = 10\text{ m}$

$$\therefore \quad L = \frac{1}{15} \times 10 \times 120 = 80\text{ m}$$

2.2 (b)

Deviation angle,

$$N = n_1 - (-n_2) = n_1 + n_2$$
$$= 3\% + 5\% = 8\%$$

For $L > SSD$,

$$L = \frac{NS^2}{4.4} = \frac{8}{100} \times \frac{(128)^2}{4.4}$$
$$= 298\text{ m}$$

2.3 (d)

Design of superelevation for mixed traffic conditions:

To superelevate the pavement up to the maximum limit so that it can counteract the centrifugal force fully neglecting the lateral friction is safer for fast moving vehicles. But for low moving vehicles this may be quite inconvenient. On the contrary to provide low value of superelevation thus relying more on lateral friction would be unsafe for fast moving vehicles.

As a compromise, the superelevation should be provided to fully counteract the centrifugal force due to 75% of the design speed (by neglecting the friction developed) and limited the maximum superelevation to 0.07.

2.4 (a)

To attain the superelevation (i) crown of the cambered section is eliminated first and (ii) pavement is rotated to attain full superelevation.

Rotation of the pavement section to attain full superelevation is carried out in two ways as follows :

(i) Rotating about centre line (crown) has the advantage in balancing earth work. However the disadvantage of this method is the drainage problem due to depression of the inner edge below the general level. Therefore it is not preferred in high rainfall areas.

(ii) Rotating about the inner edge is preferable in very flat terrain in high rainfall area, when the road is not taken on the embankment, in order to avoid the drainage problem.

2.5 (c)

The criteria for sag vertical curve are:

(i) Comfort condition

(ii) Head light sight distance

(iii) Drainage at lowest point

(iv) Aesthetic consideration

2.6 (c)

When $L_C > S$, the formula for set back distance is

$$M = R - (R - d)\cos\left(\frac{\alpha}{2}\right)$$

Where $\alpha = \dfrac{180S}{\pi(R-d)}$

S is stopping sight distance (SSD)

d is distance between centre line of road and the centre line of the inside lane

L_c is length of the curve

However, this formula is difficult in calculation so approximate equation can be formulated by assuming that the length of chord is equal to SSD.

Given, $M = 10\text{ m}$ $S = 80\text{ m}$

$$\therefore \quad R = \frac{M}{2} + \frac{S^2}{8M}$$

$$= \frac{10}{2} + \frac{(80)^2}{8\times 10} = 85\text{ m}$$

The most close option is (c) i.e. 80 m

2.7 (b)

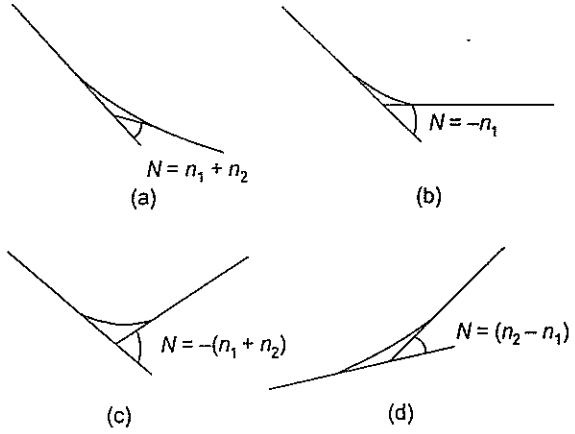
Initial speed of vehicle

$$v = fgt$$

$$s = \frac{v^2}{2fg} = \frac{f^2g^2t^2}{2fg}$$

$$\therefore \quad f = \frac{2s}{gt^2} = \frac{2\times 9.8}{9.8\times 2^2} = 0.5$$

2.8 (a)



1. Impact-free movement of vehicles at design speed
2. Availability of stopping sight distance under headlight of vehicles for night driving as during night sight distance decreases.
3. Comfort of passengers
4. Lowest point in valley curve may be located from consideration of cross drainage
5. Appearance or aesthetics

2.9 (c)

Vertical alignment and centre line change when cant is provided by raising the outer edge of the pavement with inner edge forming the pivot point.

2.10 (c)

Equilibrium superelevation,

$$e = \frac{V^2}{127R} = \frac{40^2}{127\times 200}$$

$$= 0.0629 \simeq 6.3\%$$

2.11 (b)

Deviation angle,

$$N = \frac{1}{25} + \frac{1}{40} = 0.065$$

Assuming $L > S$, where S is headlight sight distance,

$$L = \frac{NS^2}{(1.5 + 0.035S)}$$

$$= \frac{0.065\times 100^2}{1.5 + 0.035\times 100} = 130\text{ m}$$

2.12 (b)

Deviation angle,

$$N = \frac{1}{100} + \frac{1}{50} = 0.03$$

Assuming $L > S$;

$S = 500\text{ m}$

$$L = \frac{NS^2}{9.6} = \frac{0.03\times 500^2}{9.6}$$

$$= 781.25\text{ m}$$

2.13 (a)

As per IRC 66:1976,

Intermediate sight distance = 2 × stopping sight distance.

2.14 (c)

$$V = \sqrt{2gfs}$$

$$= \sqrt{2\times 9.8\times 0.4\times 16}$$

$$= 11.2\text{ m/s} = 40.32\text{ kmph}$$

2.15 (c)

Total reaction time

= Perception time + Brake reaction time

Perception time varies from driver to driver and also depends upon several other factors such as speed of the vehicle, distance of object and other environmental conditions.

According to PIEV (Perception, Intellection, Emotion and Volition) theory, the total reaction time depends upon several factors such as physical and psychological characteristics of the driver, type of the problem involved, environmental condition and temporary factors (e.g. motive of the trip, travel speed, fatigue, consumption of alcohol, etc.).

2.16(*)

Equilibrium superelevation for mixed traffic condition,

$$e = \frac{V^2}{225R} = \frac{(80)^2}{225 \times 480}$$
$$= 0.0593 < 0.07$$

Raising of outer edge with respect to inner edge

$$= eW = 0.0593 \times 7.5$$
$$= 0.44 \text{ m}$$

Raising of outer edge with respect to centre

$$= \frac{We}{2} = 0.22 \text{ m}$$

The answer should be 0.44 m, but no such option exists.

2.17(c)

Braking distance for travelling upgrade,

$$S_1 = \frac{V^2}{254(f + 0.01n)}$$

Braking distance for travelling downgrade

$$S_2 = \frac{V^2}{254(f - 0.01n)}$$

Given, $S_2 = 2S_1$

$$\Rightarrow \frac{1}{(f - 0.01n)} = \frac{2}{(f + 0.01n)}$$

$$\Rightarrow f + 0.01n = 2f - 0.02n$$

$$\therefore n = \frac{f}{0.03} = \frac{0.4}{0.03} = 13.3\%$$

2.18(a)

For $R > 45$ m, grade compensation $= \frac{75}{R}\%$

The grade compensation in per cent is $\frac{30 + R}{R}$

subject to maximum $75/R$.

In other words,

for $R \leq 45$ m grade compensation

$$= \frac{30 + R}{R}\%$$

2.19(d)

$$\text{Centrifugal ratio} = \frac{P}{W} = e + f$$

On transition curve 'e' increases from zero to full value so centrifugal ratio increases. The centrifugal force increase on transition curve gradually.

2.20 (c)

Reducing the super-elevation will not affect the side friction. Too much super-elevating friction is dangerous for slow moving vehicles as they can topple so a skilful highway designer will build speed controls at critical locations.

2.21(c)

Stopping sight distance = Lag distance + Braking distance.

For lag distance, reaction time and speed is taken into consideration.

$$\text{Lag distance} = 0.278\, Vt$$

$$\text{Braking distance} = \frac{V^2}{254(f \pm 0.01n)}$$

2.22 (d)

As per IRC 52:1981, ruling gradient values should be

1 in 30: plain and rolling terrain

1 in 20: mountainous terrain

1 in 16.7: Steep terrain

Thus for sloping road it is 1 in 30.

2.24 (c)

Safe stopping distance = 80 m

Passing sight distance = 300 m

Intermediate sight distance

$$= 2 \times \text{SSD} = 2 \times 80 = 160$$

2.25 (b)

Transitional curve is provided between a circular curve and straight road. It provides gradual introduction of centrifugal force, gradual

introduction of super elevation and comfort and security to passengers.

2.26(b)

$$R_{ruling} = \frac{V^2}{127(e+f)}$$

$$= \frac{(100)^2}{127\times(0.07+0.13)} \simeq 395\,m$$

2.27(b)

Deviation angle,

$$N = 3 + 5 = 8\% = 0.08$$

Assuming $L > S$

$$L = \frac{NS^2}{4.4} = \frac{0.08\times(128)^2}{4.4} \simeq 298\,m$$

2.28(d)

The function of transition curve is to gradually introduce the centrifugal force between the tangent point and the beginning of the circular curve. So rate of change of centrifugal acceleration (radial acceleration) should be small constant and consistent. This means that radius of the transition curve should consistently decrease from infinity (zero curvature) at tangent point to the radius R $\left\{\text{curvature } \left(\frac{1}{R}\right)\right\}$ at the beginning of the circular curve.

The other function of transition curve is to introduce the designed superelevation gradually. The extra widening of pavement at the start of circular curve should also be introduced gradually.

2.29(d)

Rate of change of centrifugal acceleration,

$$C = \frac{80}{75+V} = \frac{80}{75+80}$$

$$= 0.516\ m/s^3$$

Length of transition curve,

$$L_s = \frac{0.0215V^3}{CR}$$

$$= \frac{0.0215\times(80)^3}{0.516\times240}$$

$$= 88.9 \simeq 89\,m$$

For plain and rolling terrain,

$$L_s = \frac{2.7V^2}{R} = 72\,m$$

For mountainous and steep terrains,

$$L_s = \frac{V^2}{R} \simeq 27\,m$$

Since 72 m is one option so it should be chosen.

2.30(a)

Length of transition curve in plain or rolling terrain:

$$L_s = \frac{2.7V^2}{R} = \frac{2.7\times80^2}{150}$$

$$= 115.2\,m$$

For mountainous and steep terrains,

$$L_s = \frac{V^2}{R}$$

2.31(a)

Deviation angle,

$$N = \frac{1}{50}+\frac{1}{30} = \frac{4}{75}$$

Assuming $L > S$

$$L = \frac{NS^2}{4.4} = \frac{4}{75}\times\frac{120^2}{4.4}$$

$$= 174.5\,m$$

2.32(a)

If the road surface is kept horizontal across the alignment, the pressure on the outer wheels will be higher due to the centrifugal force acting outwards and hence the reaction at the outer wheel would be higher. In order to counteract this centrifugal force and to reduce the tendency of the vehicle to overturn or skid, superelevation is provided.

2.33 (b)

Road camber helps in proper drainage and protects the sub-grade. Super-elevation in curved roads is provided by rotating the inner edge or centre line and helps in drainage, thus serving the purpose of camber.

2.34 (a)

When a vehicle negotiates a horizontal curve on a highway, without super-elevation the pressure on the tyres on outer edge is more than on the

inner ones. Thus the chances of appearing of potholes is more on the outer edge of the road.

2.35 (c)

The full amount of super-elevation is attained by the end of transition curve or at the beginning of circular curve.

2.36 (d)

For a vehicle negotiating a curve the relation between weight of vehicle, W, centrifugal fore, P, velocity, V, and radius of the curve, R, is given by

$$P = \frac{Wv^2}{gR}$$

$\therefore$ With all other relevant conditions remaining same,

$$V = \frac{1}{\sqrt{\text{Weight of vehicle}}}$$

2.37 (a)

$$n = -3\%, n = +1\%$$

$$\text{Rate of change of grade} = \frac{0.01\%}{20\text{ m}}$$

$$N = -3 - (+1) = -4\%$$

$$L_c = \frac{N \times 20}{0.1\%} = 800\text{ m}$$

2.38 (c)

When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle. This centrifugal force is counteracted by the transverse frictional resistance developed between the tyres and the pavement which enables the vehicle to change the direction along the curve and to maintain the stability of the vehicle.

Summit curves are designed so as to provide adequate sight distance.

Cut-off lagoons are structures created along the important roadways to protect it from flooding.

2.39 (d)

The coefficient of friction reduces considerably when the pavement surface is smooth or wet. For the calculation of stopping distance, the longitudinal friction coefficient values of 0.35 to 0.40 have been recommended by the Indian Roads Congress, depending upon speed. These values have been suggested keeping in view the minimum coefficient of friction in the longitudinal direction on wet pavements and after allowing a suitable factor of safety. Further, when a longitudinal friction coefficient of 0.40 is allowed for stopping the vehicle, the resultant retardation is 3.93 m/sec^2 which is not too uncomfortable to the passengers.

In the case of horizontal curve design, the Indian Roads Congress has recommended the lateral coefficient of friction of 0.15.

2.40 (c)

The Indian Road Congress recommends the use of spiral as transition curve in the horizontal alignment of highways due to the following reasons.

(i) The spiral curve satisfies the requirements of an ideal transition.

(ii) The geometric property of spiral is such that the calculations and setting out the curve in the field is simple and easy.

2.42 (c)

$$\text{Shift, } S = \frac{L^2}{24R}$$

R = Radius of the curve

L = Length of long chord

2.43 (c)

Centrifugal ratio is the ratio of centrifugal force and weight and is given by:

$$\frac{P}{W} = \frac{V^2}{gR}$$

Maximum centrifugal ratio value

For road: $\frac{1}{4}$

For railway: $\frac{1}{8}$

$$\text{Ration between these two} = \frac{1/4}{1/8} = 2:1$$

2.44 (d)

The given camber will serve as superelevation,

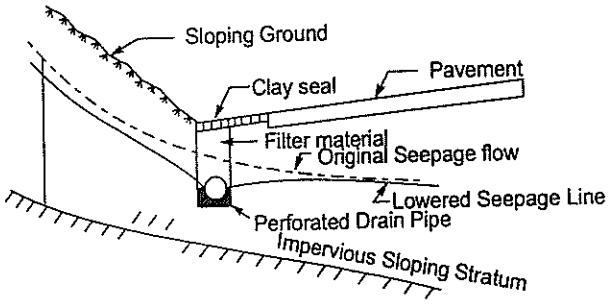
$$e = \frac{V^2}{225R}$$

$$\Rightarrow \quad 0.02 = \frac{100^2}{225 \times R}$$

$$\Rightarrow \quad R = 2222.22\,\text{m} \cong 2200\,\text{mm}$$

2.45 (c)

The maximum depth of trench can be equal to depth impervious strata below the subgrade level of the pavement which is equal to 1.25 m here. To intercept the seepage flow, longitudinal pipe drain in trench filled with filler material and clay seal is constructed.



Interception of Sewage Flow by Surface drains

2.46 (d)

Longitudinal friction coefficient

$$f = \frac{a}{g}$$

$$\Rightarrow \quad 0.4 = \frac{a}{9.81}$$

$$\Rightarrow \quad a = -3.93\,\text{m/s}^2$$

2.47 (c)

$$e = \frac{V^2}{225R} = \frac{(100)^2}{225 \times 500} = 0.088$$

Now, limit $e = 0.07$

$$e + f = \frac{V^2}{127R}$$

$$\Rightarrow \quad f = \frac{100^2}{127 \times 500} - 0.07 = 0.087\,(\text{OK}) < 0.15$$

Provide, $e = 0.07$

2.48 (a)

Data given, $u = 40$ kmph,

$V = 0$, $t = 1.8$ sec.

$\therefore \quad V = u - at$

$$u = at$$

$$a = \frac{u}{t} = \frac{40 \times 18^5}{1.8}$$

$$= 6.1728\,\text{m/sec}^2$$

$\Rightarrow$ Avg. skid resistance,

$$\mu = \frac{6.1728}{9.81} = 0.6292$$

$$\mu \simeq 0.63$$

2.49 (d)

Radius of Horizontal curve = 75 m

$$\text{Grade compensation} = \frac{30 + R}{R} \le \frac{75}{R}$$

$$= \frac{30 + 75}{75} = 1.4$$

and $$\frac{75}{R} = \frac{75}{75} = 1\%$$

So, Grade compensation = 1%

$\therefore$ Compensated gradient

= Ruling gradient – grade compensation

= 6% – 1% = 5%

2.50 (c)

Data given

$V = 60$ kmph

$R = 800$ m

$$e = \frac{V^2}{127R} = \frac{(60)^2}{127 \times 800}$$

$$= 0.03543$$

and $$e = \tan\theta = \frac{y}{x}$$

$$\therefore \quad \frac{y}{x} = e = 0.3543$$

$$y = 0.3543 \times 1680\,\text{mm}$$

$$y = 59.527\,\text{mm}$$

(Where $x = 1680$ mm)

2.51 (c)

Length of transition curve based on rate of change of superelevation is,

$$L = eNw$$

$$L = \frac{1}{15} \times 120 \times 10 = 80\,\text{m}$$

2.52 (a)

Hydraulic gradient is twice of camber.

Given, camber = 2%

$\therefore$ Gradient = 2 × 2% = 4%

2.53 (a)

Camber to be provided for state highway is 1 in 50.

$\therefore$ Height of the crown

$$= \left(\frac{14}{2}\right) \times \frac{1}{50} \times 100 \text{ cm} = 14 \text{ cm}$$

2.54 (b)

$$x = L\left(\frac{n_1}{2N}\right)^{1/2}$$

x = Horizontal distance from end of first tangent point to the lowest point in metres.

n_1 = Natural tangent of first tangent

$$N = n_1 + n_2$$

$$= \left|-\frac{4}{10} - \frac{1}{40}\right| = 0.065$$

$$x = 200\left(\frac{0.04}{2 \times 0.065}\right)^{1/2}$$

$$= 110.94 \simeq 111 \text{ m}$$

2.55 (a)

$$\text{SSD} = 0.278Vt + \frac{V^2}{254(kf + S\%)}$$

$$= 0.278 \times 100 \times 2.5 + \frac{100^2}{254(0.5 \times 0.7 + 0.02)}$$

$$= 175.9 \text{ m}$$

2.56 (b)

A hairpin turn or hairpin bend or hairpin corner is a bend in a road with a very acute inner angle, making it necessary for an oncoming vehicle to turn almost 180° to continue on the road. It does not help in prevention of landslides.

2.57 (d)

Equilibrium superelevation

$$e = \frac{V^2}{127R} = \frac{70^2}{127 \times 480}$$

$$= 0.08 \text{ i.e. } 8\%$$

3 Traffic Engineering

3.1 In desire-line diagram
(a) width of desire-line is proportional to the number of trips in one direction
(b) length of the desire-line is proportional to the number of trips in both directions
(c) width of desire-line is proportional to the number of trips in both directions
(d) both length and width of desire-line are proportional to the number of trips in both directions

[ESE : 1995]

3.2 Consider the following situations:
1. Traffic volume entering from all roads is less than 3000 vehicles per hour.
2. Pedestrian volume is high.
3. Total right turning traffic is high.
4. A road in a hilly region.

A rotary will be more suitable than control by signals, in situations listed against
(a) 1 and 3 (b) 1 and 4
(c) 2 and 4 (d) 2 and 3

[ESE : 1995]

3.3 Ratio of the width of the car parking area required at kerb for 30° parking relative to 60° parking is approximately
(a) 0.5 (b) 0.7
(c) 0.8 (d) 2.0

[ESE : 1996]

3.4 For the relationship $u = 55 - 0.44k$, where 'u' is the speed in kmph and 'k' is the density in vpkm, what will be the maximum flow in vph?
(a) 1718 (b) 1250
(c) 625 (d) 125

[ESE : 1996]

3.5 Consider the following statements:
Collision diagram is used to
1. study accident pattern
2. eliminate accidents
3. determine remedial measures
4. make statistical analysis of accidents

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 3 and 4 (d) 2 and 4

[ESE : 1996]

3.6 In which one of the following grades of a highway is an emergency escape ramp provided?
(a) 1 in 200 (b) Zero grade
(c) Down grade (d) Up grade

[ESE : 1996]

3.7 Consider the following parameters related to a rotary intersection:
1. Width of the weaving section.
2. Length of the weaving section.
3. Proportion of weaving traffic.
4. Weaving angle.
5. Width of the carriageway at entry.

Capacity is generally expressed in terms of
(a) 1, 2, 3 and 4 (b) 1, 2, 3 and 5
(c) 1, 2 and 3 (d) 4 and 5

[ESE : 1997]

3.8 It is a common practice to design a highway to accommodate the traffic volume corresponding to
(a) 30th hour (b) peak hour
(c) ADT (d) 15 min-peak period

[ESE : 1998]

3.9 It was noted that on a section of road, the free speed was 80 kmph and the jam density was 70 vpkm. The maximum flow in vph that could be expected on this road is
(a) 800 (b) 1400
(c) 2800 (d) 5600

[ESE : 1998]

3.10 If the normal flows on two approach roads at an intersection are respectively 500 pcu per hr and 300 pcu per hr, the saturation flows are 1600 pcu per hr on each road and the total lost time per signal cycle is 16 s, then the optimum cycle time by Webster's method is

(a) 72.5 s (b) 58 s
(c) 48 s (d) 19.3 s

[ESE : 1999]

3.11 When two roads with two-lane, two-way traffic, cross at an uncontrolled intersection, the total number of potential major conflict points would be

(a) 32 (b) 24
(c) 16 (d) 4

[ESE : 1999]

3.12 Assertion (A): IRC suggest that the maximum volume of traffic of 3000 vehicles per hour entering from all legs of the rotary intersection can be handled efficiently.

Reason (R): Traffic rotaries may be provided where the intersecting traffic is about 50% of the total traffic or fast turning traffic is at least 30% of the total traffic.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

3.13 Consider the following factors:

1. Length of vehicle
2. Width of vehicle
3. Approach speed
4. Stopping time for approaching vehicle
5. Passing sight distance

Which of these factors are taken into consideration for determining yellow time of a traffic signal at an inter section?

(a) 1, 2 and 5 (b) 2, 3 and 4
(c) 1, 3 and 5 (d) 1, 3 and 4

[ESE : 2000]

3.14 An observer travelling at a constant speed of 70 kmph with the traffic stream over a 5 km stretch is passed by 17 vehicles more than what he passes. When the observer travels against the stream at the same speed, the number of vehicles he meets is 303. The flow of the traffic stream is

(a) 4480 vph (b) 4160 vph
(c) 2240 vph (d) 2002 vph

[ESE : 2001]

3.15 If the total seven-day traffic volume for the week is 3625 and the traffic volume for Monday is 650, then the monthly expansion factor for Monday would be

(a) 5.6 (b) 1.25
(c) 0.8 (d) 0.25

[ESE : 2001]

3.16 Which one of the following is the purpose of divisional island?

(a) To divert the traffic into definite travel path at the intersection.
(b) To reduce the speed of traffic entering the intersection.
(c) To divert traffic from obstacles and expedite the flow of traffic.
(d) To segregate opposing flow of traffic in a multi-lane highway.

[ESE : 2001]

3.17 Based on '30th hour volume' for how much per cent time during the year can the designer willingly tolerate the unfavourable operating conditions?

(a) 30 (b) 29
(c) 2.5 (d) 0.33

[ESE : 2002]

3.18 A journey from work to home made by walking to the bus, travelling by bus to the station and completing the journey by train is regarded as

(a) 4 trips (b) 3 trips
(c) 2 trips (d) 1 trip

[ESE : 2002]

3.19 Which one of the following is taken into consideration for computing traffic capacity per lane of the highway?

(a) Passenger cars and light vehicles
(b) Trucks and buses
(c) Two-wheelers
(d) Equivalent of passenger cars

[ESE : 2003]

3.20 Match List-I (Method of traffic volume counts) with List-II (Equipment used) and select the correct answer using the codes given below the lists:

List-I

A. Manual count
B. Combination of manual and mechanical methods
C. Automatic devices
D. Photographic method

List-II

1. Video-recorder
2. Pneumatic tube
3. Watch
4. Multiple pen recorder

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	3	4	2	1
(c)	4	3	2	1
(d)	3	4	1	2

[ESE : 2003]

3.21 Match List-I (Type of study) with List-II (Data collected) and select the correct answer using the codes given below the lists:

List-I

A. Public transport inventory study
B. Public transport O-D study
C. Public transport usage study
D. Public transport operator's study

List-II

1. Starting and destination of riders
2. Available routing and scheduling
3. Vehicle-km, earning per km
4. Passenger-km, IVTT, walking time, waiting time

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	3	4
(c)	1	2	4	3
(d)	2	1	4	3

[ESE : 2003]

3.22 Match List-I (Type of traffic signals) with List-II (Advantages) and select the correct answer using the codes given below the lists:

List-I

A. Pre-timed signals
B. Vehicle-Actuated signals
C. Semi-vehicle actuated signals
D. Linked traffic signals

List-II

1. Useful for junction of a side street having low traffic volume with a main street having heavy flow
2. Overall optimization of traffic flow
3. Delay is held to a minimum, and maximum lane capacity is achieved
4. Most successfully used in linked system

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	1	2
(c)	3	4	2	1
(d)	4	3	2	1

[ESE : 2003]

3.23 **Assertion (A):** Prohibitory signs are part of regulatory signs which give a definite negative instruction regarding movement prohibition, restriction on weight, or speed of vehicles.

Reason (R): According to the IRC Standards, prohibitory signs are of octagonal shape with side being 900 mm and with a white border and red background for the standard size.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

3.24 The lost time due to starting delay on a traffic signal approach is noted to be 3 seconds, the actual green time is 25 seconds and amber time is 3 seconds. How much is the effective green time?

(a) 19 sec (b) 25 sec
(c) 27 sec (d) 31 sec

[ESE : 2004]

3.25 Match List-I (Study) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Primary road system
B. Economic studies
C. Engineering studies
D. Road use studies

List-II
1. Population distribution
2. Expressways
3. Traffic volume
4. Topographic details

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	4	3	2	1
(c)	2	3	4	1
(d)	4	1	2	3

[ESE : 2005]

3.26 Match List-I (Traffic survey) with List-II (Method) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Spot speed	1. By video tape
B. Traffic volume	2. By road side interview
C. O-D survey	3. By doppler radar
D. Parking survey	4. By pneumatic tube

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	2	4	3	1
(c)	3	4	2	1
(d)	2	1	3	4

[ESE : 2005]

3.27 Match List-I (Unit) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Clover leaf interchange
B. Traffic studies
C. Rotary island
D. Road junction approach sign

List-II
1. Informatory sign
2. Traffic control device
3. Traffic flow characteristics
4. Grade - separation

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2005]

3.28 On a road the free speed was 65 kmph and the space headway at jam density was 6.25 m. What is the maximum flow which could be expected on this road?

(a) 2600 vph (b) 1625 vph
(c) 1300 vph (d) 406 vph

[ESE : 2006]

3.29 Match List-I (Speed) with List-II (Application) and select the correct answer using the code given below the lists:

List-I
A. Space mean speed
B. Journey speed
C. Running speed
D. Spot speed

List-II
1. Road conditions studies
2. Regulatory measures
3. Traffic flow studies
4. Delay studies

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	1	4	3	2
(c)	3	4	1	2
(d)	1	2	3	4

[ESE : 2007]

3.30 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Traffic Volume
B. Traffic Density
C. Traffic Regulations
D. Rotary Intersection

List-II
1. Number of vehicles occupying a unit length of road at a given instant of time.
2. Number of vehicles passing a given point on road in a given unit of time in a given direction

3. Where all converging vehicles are forced to move in one direction around a large central traffic island
4. Rules covering all aspects of control of vehicles, drivers and all other road users

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

[ESE : 2008]

3.31 Which of the following factors are **not** strictly related to design of traffic rotary intersections?
1. Radius of central island
2. Weaving length
3. Ramps and interchanges
4. Acceleration lanes

Select the correct answer using the codes given below:
(a) 1 and 2 (b) 1 and 4
(c) 2 and 3 (d) 3 and 4

[ESE : 2008]

3.32 In urban transportation planning, the 'Modal Split' is the process of which one of the following?
(a) Staggering of working hours
(b) Segregation of fast and slow modes
(c) Separation of traffic streams by flyovers
(d) Deciding the choice for a mode

[ESE : 2008]

3.33 Which one of the following geometric features requires the magnitudes of weaving angle and weaving distance for its design?
(a) Rotary design
(b) Right-angle intersection
(c) Roundabout
(d) Grade-separated junction

[ESE : 2009]

3.34 Which set of traffic studies is needed for functional design as well as for 'highway capacity' design?
(a) Origin and destination studies
(b) Parking and accident studies
(c) Speed and volume studies
(d) Axle load studies

[ESE : 2009]

3.35 Which one of the following traffic survey schemes is most relevant when deciding on locating major 'routes' in a city?
(a) Traffic volume survey
(b) Origin and destination survey
(c) Speed survey
(d) Traffic capacity survey

[ESE : 2009]

3.36 Which one of the following equipments is useful in determining spot speed in traffic engineering?
(a) Enoscope (b) Periscope
(c) Radar (d) Tachometer

[ESE : 2009]

3.37 Which one of the following traffic signal systems is useful when there is continuous operation of group of vehicles along the main road?
(a) Simultaneous system
(b) Alternate system
(c) Simple progressive system
(d) Flexible progressive system

[ESE : 2010]

3.38 Match List-I (Type of survey) with List-II (Method/ Instrument) and select the correct answer using the codes given below the lists:

List-I
A. Traffic volume study
B. Speed and delay study
C. Spot-speed study
D. Multiple character studies

List-II
1. Workspot interview method
2. Doppler radar
3. Floating car method
4. Automatic vehicle counter and classifier
5. Electronic detector

Codes:

	A	B	C	D
(a)	5	3	2	4
(b)	1	3	2	5
(c)	5	2	3	4
(d)	1	2	3	4

[ESE : 2010]

3.39 Light reflecting devices used to guide the driver along the proper alignment are called
(a) rumble strips (b) delineators
(c) attenuators (d) litter bin

[ESE : 2010]

3.40 **Assertion (A):** In an intersection design, the relative speed is dependent on the absolute speed of intersecting vehicles and the angles between them.
Reason (R): When the angle of merging is small, the relative speed will be high.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2010]

3.41 Traffic capacity is the:
(a) Ability of roadway to accommodate traffic volume in terms of vehicles/hr
(b) Number of vehicles occupying a unit length of roadway at a given instant expressed as vehicles/km
(c) Capacity of lane to accommodate the vehicles widthwise (across the road)
(d) Maximum attainable speed of vehicles
[ESE : 2013]

3.42 The design speed of a traffic lane is 70 kmph. What is the theoretical capacity per hour taking the total reaction time to be 2 seconds and average length of vehicles as 8 m?
(a) 828 (b) 728
(c) 628 (d) 428
[ESE : 2014]

3.43 The duration of green time of a traffic signal depends on
(a) traffic density (b) traffic volume
(c) traffic speed (d) All of the above
[ESE : 2015]

3.44 What will be the theoretical maximum capacity (to nearest 10 units) for a single lane of highway given that the speed of the traffic stream is 40 kmph?
(a) 3000 veh/h (b) 2860 veh/h
(c) 2010 veh/h (d) 2510 veh/h
[ESE : 2015]

3.45 What will be the initial traffic after construction, in the commercial vehicles per day (CVD) for the following data?
Annual average daily traffic at last count = 400 CVD
Rate of traffic growth per annum = 7%
The road is proposed to be completed in 3 years.
(a) 500 (b) 421
(c) 490 (d) 449
[ESE : 2015]

3.46 Overspeed and delay studies on a preselected section of a Highway are conducted by
(a) Fast moving car method
(b) Enoscope
(c) Radar
(d) Traffic contours
[ESE : 2016]

3.47 International Traffic Intelligent Survey Data are related with
(a) Origin and destination studies
(b) Speed and delay studies
(c) Classified traffic volume studies
(d) Accident profiling studies
[ESE : 2016]

3.48 A transportation trip survey was undertaken between private car, and public car transportation. The proportion of those using private cars is 0.45. While using the public transport, the further choices available are Metro Rail and Mono Rail, out of which commuting by a Mono Rail has a proportion of 0.55. In such a situation, the choice of interest in using a Metro Rail, Mono Rail and private car would be respectively
(a) 0.25, 0.3 and 0.45
(b) 0.45, 0.25 and 0.3
(c) 0.25, 0.45 and 0.3
(d) 0.3, 0.25 and 0.45
[ESE : 2016]

3.49 The type of signalling system in which it is possible to vary the length of cycle, cycle division and the time schedule at each signal point is called
(a) Simultaneous system
(b) Alternate system
(c) Simple progressive system
(d) Flexible progressive system
[ESE : 2017]

Answers Traffic Engineering

3.1 (c)	3.2 (a)	3.3 (c)	3.4 (a)	3.5 (b)	3.6 (c)	3.7 (b)	3.8 (a)	3.9 (b)
3.10 (b)	3.11 (b)	3.12 (b)	3.13 (d)	3.14 (c)	3.15 (b)	3.16 (d)	3.17 (d)	3.18 (d)
3.19 (d)	3.20 (b)	3.21 (d)	3.22 (a)	3.23 (c)	3.24 (b)	3.25 (a)	3.26 (c)	3.27 (a)
3.28 (a)	3.29 (c)	3.30 (c)	3.31 (d)	3.32 (d)	3.33 (a)	3.34 (c)	3.35 (b)	3.36 (a)
3.37 (c)	3.38 (a)	3.39 (b)	3.40 (c)	3.41 (a)	3.42 (b)	3.43 (b)	3.44 (b)	3.45 (c)
3.46 (a)	3.47 (c)	3.48 (a)	3.49 (d)					

Explanations Traffic Engineering

3.1 (c)

Desire lines are graphical representation of Origin and Destination survey. These are straight lines connecting the origin points with destinations, summarized into different area groups. The width of such desire lines is drawn proportional to the number of trips in both directions.

3.2 (a)

Construction of a traffic rotary needs large area which may be available in rural areas at reasonable cost.

Other points when traffic rotary is justified are:

(i) Lower limit of traffic volume about 500 vehicles per hour.

(ii) Maximum value of traffic that a rotary can handle efficiently is 3000 vehicles per hour as per IRC.

(iii) If large proportion of traffic is turning right, provision of rotary even beyond these limits is justified.

(iv) IRC further specifies that rotaries may be provided where intersecting traffic is about 50% or more of the total traffic on all intersecting roads or where fast traffic turning right is at least 30% of the total traffic.

3.3 (c)

30° parking require 4.9 m width, while 60° parking require 6.0 m parking width. So ratio is given by

$$\frac{4.9}{6.0} = 0.82$$

3.4 (a)

Flow, $q = ku = 55k - 0.44k^2$

For maximum flow,

$$\frac{dq}{dk} = 0$$

$$\Rightarrow \quad 55 - 0.88k = 0$$

$$\Rightarrow \quad k = 62.5 \text{ veh/km}$$

$$\therefore \quad q_{max} = 55 \times 62.5 - 0.44 \times 62.5^2$$

$$= 1718.75 \text{ veh/hour}$$

For $v = A - Bk$ the maximum flow occurs at about half the mean free speed and is equal to $A^2/4B$. So directly

$$q_{max} = (55)^2/(4 \times 0.44)$$

$$= 1718.75 \text{ vph}$$

3.5 (b)

Collision diagrams are diagrams showing approximate paths of vehicles and pedestrians involved in accidents. They are used to:

(i) Compare and study the accident pattern

(ii) Determine the remedial measures.

3.6 (c)

The provision of emergency escape ramp on long, descending grades is appropriate for slowing or stopping out-of-control vehicles away from the main stream of traffic. Loss of breaking ability through overheating or mechanical failure results in the driver loosing the control of vehicles. Four basic types of emergency escape ramps are commonly used. They are:

(i) Sandpile

(ii) Descending grade

(iii) Horizontal grade

(vi) Ascending grade

3.7 (b)

The practical capacity (Q_p) of the rotary is dependent on the minimum capacity of the individual weaving section.

$$Q_p = \frac{280W(1+e/W)(1-p/3)}{(1+W/L)}$$

where,

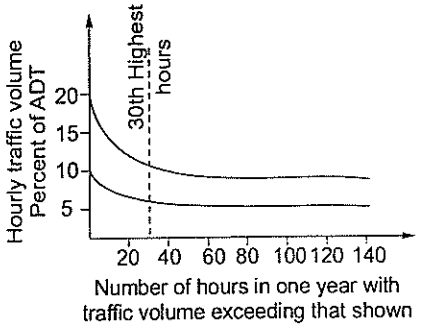
W is width of weaving section

e is average width of entry e_1 and width of nonweaving section e_2 for the range $e/W = 0.4$ to 1.0

L is length of the weaving section

p is proportion of weaving traffic

3.8 (a)



Highway design to accommodate the traffic volume is according to 30th highest hourly traffic volume from economy point of view as peak hourly traffic is too high and designing facilitates according to it will be too costly.

3.9 (b)

$$\text{Maximum flow} = \frac{\text{Free speed} \times \text{Jam Density}}{4}$$

$$= \frac{80 \times 70}{4} = 1400 \text{ veh/hour}$$

3.10 (b)

Optimum cycle time,

$$C_0 = \frac{1.5L + 5}{1 - Y}$$

L = Total lost time per cycle

= 16 sec

$Y = y_1 + y_2$

$$y_1 = \frac{500}{1600} \text{ and } y_2 = \frac{300}{1600}$$

$$\therefore \quad Y = \frac{500+300}{1000} = 0.5$$

$$C_0 = \frac{1.5 \times 16 + 5}{1 - 0.5} = 58 \text{ s}$$

3.11 (b)

Point of potential conflicts depend on the number of lanes on intersecting lanes.

For two way traffic on a right angled road intersection, the conflict points are 24 whereas for two way traffic on T-intersection the conflict point are 18 only.

3.12 (b)

As per IRC's suggestion maximum volume of traffic that rotary can handle is 3000 vehicles per hour entering from all legs of rotary intersection.

As per IRC 65:176, traffic rotaries may be provided where intersecting traffic is about 50% of total traffic or fast turning traffic is atleast 30% of total traffic.

3.13 (d)

Amber or yellow time,

$$Y = \frac{S + W + 1}{V}$$

where,

S is safe stopping distance

W is distance from stop line until vehicle (rear) is clear

l is length of the vehicle

V is approach speed

$\frac{S}{V}$ is the stopping time for approaching vehicle

3.14 (c)

This is floating car method for speed and delay studies which gives flow of vehicles,

$$q = \frac{n_a + n_y}{t_a + t_w}$$

n_a is average number of vehicles counted in the direction of the stream when test vehicle travels in the opposite direction

n_w is the average number of vehicles overtaking the test vehicle minus the number of vehicles overtaken when the test vehicle is in the direction of stream

t_w, t_a are average journey times when the test vehicle is travelling with stream and against stream respectively.

Given $n_a = 303$ vehicle

$n_w = 17$ vehicles

$$t_a = t_w = \frac{5}{70}\text{hrs}$$

$$\therefore \quad q = \frac{17+303}{\frac{5}{70}+\frac{5}{70}} = 2240 \text{ vph}$$

3.15 (b)

$$\text{Monthly expansion factor} = \frac{650\times 7}{3625} = 1.25$$

It is similar to peak hour factor (PHF)

3.16 (d)

Divisional Islands are type of traffic islands constructed as channels to divide opposing or same direction traffic streams, usually through movements in multilane. These alert the drivers about the intersection, reduce the night glare and help prevent accidents.

3.17 (d)

Only for 29 hours in a year the traffic volume exceeds the design hourly volume. Therefore, per

$$\text{cent time} = \frac{29\times 100}{365\times 24} = 0.33$$

3.18 (d)

As per definition of trip, in this case it is a single trip only as the journey is being made to reach the office. It is a one way movement and has a single purpose using different modes of transport.

3.19 (d)

Passenger Car Equivalent (PCE) or Passenger Car Unit (PCU) is a metric used in Transportation Engineering, to assess traffic-flow rate on a highway. A Passenger Car Equivalent is essentially the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car. For example, typical values of PCE (or PCU) are:

- private car (including taxis or pick-up) 1
- motorcycle 0.5
- bicycle 0.2
- bus, tractor, truck 3.5

Highway capacity is measured in PCE/hour daily

3.20 (b)

Pneumatic tube is automatic device used for counting vehicles. Video recording is a photographic method. Watch measures traffic volume with manual count. Multiple pen recorder is combination of manual and mechanical methods.

3.21 (d)

The O-D survey is an initiative to collect current and reliable information about trip patterns and travel choices of residents which is again classified into the following:

- Home Interview Survey for Internal Movements and internal-external movements.
- Road Side O-D Surveys for through movement, external-Internal movements and also internal-External movement. These are also called non-house hold surveys.

3.22 (a)

Pre-timed signals are fixed signals. Linked system means alternate system.

3.23 (c)

Prohibitory signs are circular in shape and white in colour with a red border.

3.24 (b)

The effective green time denotes that in the given total time (green time and amber time) saturation flow occurs only for small length of time. The initial delay for start of first vehicle and clearance of vehicles in the amber time causes flow to be reduced. Thus

Effective green time $(G_e) = G + A - L$

Actual green time $(G) = 25$ sec

Amber time $(A) = 3$ sec

Total lost time (L) = Initial lost time (L_i) + Final lost time (L_f)

$L_i = 3$ sec $\quad L_f \leq A$

In the absence of any data on the final lost time, it can be taken to be equal to amber time

$\therefore \quad G_e = 25 + 3 - (3 + 3)$

$= 22$ sec

But there is no such choice. So (b) can be chosen as the answer.

3.28 (a)

$$\text{Jam density} = \frac{1000}{\text{Space headway(H)}}$$

$$= \frac{1000}{6.25} = 160 \text{ veh/km}$$

$$\text{Maximum flow} = \frac{\text{Jam density} \times \text{Free speed}}{4}$$

$$= \frac{160 \times 65}{4} = 2600 \text{ vph}$$

3.31 (d)

Design factors considered in design of rotary are:

(i) Design speed
(ii) Width of rotary roadway
(iii) Radius and shape of central island
(iv) Weaving length and weaving angle
(v) Camber and super-elevation
(vi) Capacity of rotary.
(vii) Traffic signs and lighting
(viii) Radius of entry and exit curves

3.32 (d)

A modal share (also called mode split, mode-share, or modal split) is the percentage of travellers using a particular type of transportation or number of trips using said type. In freight transportation, this may be measured in mass.

Modal share is an important component in developing sustainable transport within a city or region. In recent years, many cities have set modal share targets for balanced and sustainable transport modes, particularly 30% of non-motorized (cycling and walking) and 30% of public transport. These goals reflect a desire for a modal shift, or a change between modes, and usually encompasses an increase in the proportion of trips made using sustainable modes.

3.33 (a)

Length of rotary roadway between two channelizing islands of adjacent intersecting legs is known as weaving length and angle between path of vehicle entering rotary and path of vehicle leaving rotary is known as weaving angle.

3.34 (c)

Speed and volume studies are used for highway capacity design and functional design. Spot speed studies and speed and delay study etc are used for such design. *Traffic volume studies* are mainly carried out to obtain factual data concerning the movement of vehicles at selected point on the street or highway system.

3.35 (b)

Origin and destination survey are useful:

- in locating major routes of city
- locate intermediate stops of public transport
- to understand travel patterns and characteristics
- provide input to travel demand model development,
- forecasting, and planning for area wide transportation infrastructure needs and services
- monitor progress in implementing transportation policies

3.36 (a)

Enoscope consists of a simple open housing containing a mirror mounted on a tripod at the side of the road in such a way that an observer's line of sight turned through 90°. The observer stands at one end of section at the other end enoscope is placed and measure the time taken by vehicle to cross the section which gives the spot speed.

3.37 (c)

When there is continuous operation of group of vehicles simple progressive system is useful which permit vehicle operation according to a time schedule along the main road at a reasonable speed.

3.39 (b)

Delineators are light-retro-reflecting devices mounted by the side of the roadway to indicate the roadway alignment, especially for night driving. The three broad types of delineators are roadway indicator, hazard markers and object markers.

3.40 (c)

Relative speed is the vector difference in the velocities of two vehicles in the same flow and is

the sum of the speeds of approaching vehicles in the opposite direction. Relative speed is dependent upon the absolute speed of intersecting vehicles and the angles between then. When the angle of merging is small, the relative speed will also be low. If there is a collision between two vehicles at small angle at about the same speed or at low relative speed, the impact would be much less than when vehicle collide at high relative speed. As relative speed increases, the judgement of drivers regarding time and distance is likely to be more inaccurate, thus increasing the possibility and severity of accidents. Thus, in intersection design care has to be taken to keep the relative speed low.

3.41 (a)

Traffic capacity is expressed as the maximum number of vehicle in a lane or a road that can pass a given point in unit time, usually an hour, i.e., vehicles per hour per lane or roadway. Traffic capacity and traffic volume has same units, difference between the two is that traffic volume represents the actual rate of flow of the traffic and responds to the variation in the traffic demand, while capacity indicates a capability or maximum rate of flow with a certain level of service characteristics that can be carried by the road.

3.42 (b)

Theoretical capacity

$$C = \frac{1000V}{S}$$

$$S = SSD + L$$

$$= 0.278 \times V \times t + \frac{(0.278 \times V)}{2\mu g} + L$$

$$= 0.278 \times 70 \times 2 + \frac{(0.278 \times 70)^2}{2 \times 0.4 \times 9.81} + 8$$

(Assume $\mu = 0.4$)

$$= 95.1736 \text{ m}$$

$$\therefore \quad \text{Capacity} = \frac{1000V}{S}$$

$$= \frac{1000 \times 70}{95.1736} = 735.5$$

3.44 (b)

Theoretical maximum capacity,

$$C = \frac{1000V}{S} \text{ veh/hr}$$

V = 40 kmph

S = Minimum clear distance between two vehicles

$S = 0.2\,V + 6$

$= 0.2 \times 40 + 6 = 14$ m

$$C = \frac{1000 \times 40}{14} = 2857.14 \text{ Veh/hr}$$

3.45 (c)

Initial traffic,

$$A = P\left(1 + \frac{r}{100}\right)^n$$

P = 400 commercial veh./day

r = Rate of traffic growth = 7%

n = 3 years completion time

$$A = 400\left(1 + \frac{7}{100}\right)^3$$

$= 490$ CVD

3.47 (c)

An Intelligent Traffic Management System aims at managing traffic effectively during emergencies through the use of cutting-edge communication and processing technologies and appropriate intelligent system algorithms. It is related with Classified traffic volume studies.

3.48 (a)

Metro : Mono : Private Car

$$(0.55 - 0.55 \times 0.55) : (0.55 \times 0.55) : (0.45)$$

$$0.25 : 0.30 : 0.45$$

4 Pavement Design

4.1 Given that
r = radius of load distribution
E = modulus of elasticity of concrete
K = modulus of subgrade reaction
μ = Poisson's ratio of concrete
h = thickness of slab
P = wheel load
The combination of parameters required for obtaining the radius of relative stiffness of cement concrete slab is
(a) E, K, μ, r (b) h, K, μ, r
(c) E, h, K, μ (d) P, h, K, μ
[ESE : 1995]

4.2 Assertion (A): Most flexible design procedures are based on Bankelman beam deflection measurements.
Reason (R): Elastic deflection is a practical non-destructive measure of pavement stiffness which relates well to fatigue failure.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 1996]

4.3 The plasticity index of the fraction passing 425 micron IS sieve in case of sub-base/base course should be
(a) less than 6
(b) greater than 6
(c) greater than 9
(d) between 15 and 30
[ESE : 1996]

4.4 Effect of impact on the design of rigid pavements is accounted for by
(a) increasing the thickness as would be calculated with static wheel load
(b) providing a base course
(c) adopting a reduced flexural strength of concrete through a factor of safety
(d) adopting an increased stress relative to that produced by static wheel load
[ESE : 1996]

4.5 Consider the following statements with reference to pavements:
1. Flexible pavements are more suitable than rigid pavements in regions where subgrade strength is uneven.
2. Load carrying capacity of rigid pavements depends more on the properties of concrete than the strength of subgrade.
3. Compared to flexible pavements, rigid pavements are more affected by temperature variations.
Which of these statements is/are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 3 alone
[ESE : 1996]

4.6 If the CBR value obtained at 5 mm penetration is higher than that at 2.5 mm, then the test is repeated for checking; and if the check test reveals a similar trend, then the CBR value is to be reported as the
(a) mean of the values for 5 mm and 2.5 mm penetration
(b) higher value minus the lower value
(c) lower value corresponding to 2.5 mm penetration
(d) higher value obtained at 5 mm penetration
[ESE : 1997]

4.7 The number of load cycles (N_f) to cause the failure of a pavement is proportional to (P is the respective applied load)

(a) P^4 (b) P^{-4}
(c) P^2 (d) P^{-1}

[ESE : 1997]

4.8 Assertion (A): Load stresses added to warping stresses are considered while determining the thickness of pavement.
Reason (R): Joints and sealing devices are used to relieve and/or take care of warping stresses, and the design for thickness is accordingly based upon load alone.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

4.9 The general requirement in constructing a reinforced concrete road is to place a single layer of reinforcement
(a) near the bottom of the slab
(b) near the top of the slab
(c) at the middle
(d) equally distributed at the top and bottom

[ESE : 1998]

4.10 The corrected characteristic rebound deflection on a pavement, using Bankelman beam study is 2 mm. The equivalent granular overlay thickness required for an allowable deflection of 1 mm as per original IRC guidelines is
(a) 33 mm (b) 66 mm
(c) 133 mm (d) 166 mm

[ESE : 1999]

4.11 Consider the following:
1. *LL* of soil
2. *PL* of soil
3. *SL* of soil
4. Annual average rainfall
5. Temperature of the soil

As per the latest IRC guidelines, the set of essential data required to determine moisture correction factor of clayey subgrade soil in Bankelman beam study would include
(a) 1, 2 and 4 (b) 1, 2, 3 and 4
(c) 2, 3 and 4 (d) 4 and 5

[ESE : 1999]

4.12 As per latest IRC guidelines for designing flexible pavement of CBR method, the load parameter required is
(a) number of commercial vehicles per day
(b) cumulative standard axles in msa
(c) equivalent single axle load
(d) number of vehicles (all types) during design life

[ESE : 1999]

4.13 If the load, warping and frictional stresses in a cement concrete slab are 210 N/mm^2, 290 N/mm^2 and 10 N/mm^2 respectively, the critical combination of stresses during summer mid-day is
(a) 290 N/mm^2 (b) 390 N/mm^2
(c) 490 N/mm^2 (d) 590 N/mm^2

[ESE : 1999]

4.14 In cement concrete pavements, tie bars are installed in
(a) expansion joints (b) contraction joints
(c) warping joints (d) longitudinal joints

[ESE : 1999]

4.15 Which one of the following is useful in functional evaluation of pavement?
(a) PCU (b) PSI
(c) PIEV (d) Bankelman beam

[ESE : 2000]

4.16 If the modulus of subgrade reaction of a soil is 10 kg/cm^3 when tested with a 30 cm diameter plate, the corrected modulus of subgrade reaction for the standard diameter plate will be
(a) 4 (b) 15
(c) 20 (d) 25

[ESE : 2000]

4.17 Assertion (A): The critical combination of stresses on a cement concrete pavement during summer is given by: load stress – warping stress + frictional stress.
Reason (R): The critical combination of stresses in a cement concrete pavement during winter is given by: load stress+ warping stress + frictional stress.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

4.18 Modulus of subgrade reaction using 30 cm diameter plate is obtained as 200 N/cm^3. The value of the same (in N/cm^3) using the standard plate will be
(a) 500 (b) 200
(c) 85 (d) 80

[ESE : 2001]

4.19 Consider the following statements regarding soil stabilization:
1. Subgrade should be treated if it has a soaked CBR of 5 or less.
2. Sub-base, after treatment, should have plasticity index not less than 5.
3. Base courses after treatment should have plasticity index of not more than 2 and a CBR in excess of 100.

Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 and 3
(c) 2 and 3 (d) 1 alone

[ESE : 2001]

4.20 Consider the following factors:
1. Period of construction, winter/summer
2. Degree of foundation roughness
3. Slab thickness
4. Reinforced/unreinforced

Which of these factors are considered as per IRC for obtaining the maximum expansion joint spacing in rigid pavements?
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 2 and 3 (d) 1 and 4

[ESE : 2002]

4.21 With addition of lime in soil
(a) *LL* increases and *PL* decreases
(b) Plasticity Index increases
(c) *LL* change very slightly and *PL* increases
(d) *LL* and *PL* both decrease

[ESE : 2002]

4.22 On a National Highway pavement section mean value of Bankelman beam deflection was obtained as 1.45 mm with standard deviation σ of 0.107 mm. Pavement temperature measured was 37°C and moisture correction was obtained as 1.6. What is the value of characteristic deflection considering the value of 2σ?
(a) 2.72 mm (b) 2.69 mm
(c) 2.63 mm (d) 1.94 mm

[ESE : 2002]

4.23 Match List-I (Tests) with List-II (Properties) and select the correct answer using the codes given below the lists:

List-I
A. CBR test
B. Plate bearing test
C. Triaxial test
D. Stabilometer and Cohesion-meter test

List-II
1. Modulus of sub-grade reaction
2. Arbitrary soil strength
3. Exudation and expansion pressure
4. Shear parameters

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	3	4
(c)	1	2	4	3
(d)	2	1	4	3

[ESE : 2003]

4.24 California Bearing Ratio (CBR) is a
(a) measure of soil strength
(b) method of soil identification
(c) measure to indicate the relative strengths of paving materials
(d) measure of shear strength under lateral confinement

[ESE : 2005]

4.25 Which of the following factors have to be considered for the design of the flexible pavement for a highway?
1. Design wheel load
2. Strength of pavement component material
3. Expansion joints
4. Climatic factors

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

[ESE : 2005]

4.26 Match List-I (Method of design for flexible pavement) with List-II (Principle) and select the correct answer using the codes given below the lists:

List-I
A. Group Index Method
B. CBR Method
C. US Navy Method
D. Asphalt Institute Method

List-II
1. Semi-theoretical
2. Quasi-rational
3. Empirical method using soil classifi-cation test
4. Empirical method using soil strength test

Codes:

	A	B	C	D
(a)	3	1	4	2
(b)	2	4	1	3
(c)	3	4	1	2
(d)	2	1	4	3

[ESE : 2006]

4.27 What are the maximum value of CBR and minimum value of *GI* of any material, respectively?
(a) 100, 0 (b) 100, 20
(c) 50, 5 (d) 10, 0
[ESE : 2007]

4.28 Which one of the following criteria is used for obtaining the value of modulus of subgrade reaction from the plate bearing test data?
(a) Slope of pressure settlement graph.
(b) Pressure corresponding to the settlement of 1.25 mm.
(c) Pressure corresponding to a pressure of 1.25 kg/cm^2.
(d) Pressure corresponding to the settlement of 1.50 mm.
[ESE : 2007]

4.29 Which of the following factors are used for calculating temperature stress at the critical edge region in rigid pavement design?
1. Maximum temperature difference between summer and winter
2. Coefficient of thermal expansion of concrete
3. Slab length
4. Slab width

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1 and 2 only (d) 1 and 3 only
[ESE : 2007]

4.30 IRC code No. 37-1985 deals with which one of the following?
(a) Design of rigid pavements, taking ESWL and CBR into account.
(b) Design of rigid pavements, taking axle load and CBR into account.
(c) Design of flexible pavement, taking ESWL and CBR into account.
(d) Design of flexible pavement taking cumulative axle loads and CBR into account.
[ESE : 2008]

4.31 **Assertion (A):** California Bearing Ratio Test is carried out to evaluate the stability of soil sub grade and other flexible pavement materials.
Reason (R): It is essential that at no time are the soil sub grade as well as other flexible pavement materials over stressed.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2008]

4.32 Which one of the following methods is used in the design of rigid pavements?
(a) CBR method
(b) Group index method
(c) Westergaard's method
(d) McLeod's method
[ESE : 2009]

4.33 Radius of relative stiffness of cement concrete pavement does not depend upon which one of the following?
(a) Modulus of subgrade reaction
(b) Wheel load
(c) Modulus of elasticity of cement concrete
(d) Poisson's ratio of concrete
[ESE : 2009]

4.34 For conditions prevailing in India, at which location in a cement concrete pavement will the combined

stresses due to traffic wheel load and temperature have to be critically checked during design?
(a) Corner
(b) Corner and interior
(c) Corner and edge
(d) Corner, edge and interior

[ESE : 2009]

4.35 Which one of the following sets of factors is related to design of thickness rigid pavement by Westergaard method?
(a) CBR value and stiffness index of soil
(b) Deflection factor and traffic index
(c) Swelling index and bulk modulus
(d) Radius of relative stiffness and modulus of subgrade reaction

[ESE : 2009]

4.36 Consider the following in relation to group index of soil:
1. Liquid limit
2. Sandy loam
3. Plasticity index
4. Percent passing 75 microns sieve

Which of the above is/are used for estimating the group index?
(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1, 3 and 4

[ESE : 2009]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

4.37 **Assertion (A):** Dowel bars are provided at expansion joints and sometimes also at contraction joints in cement concrete slabs.
Reason (R): Longitudinal joints in cement concrete pavements are constructed with tie bars.

[ESE : 2009]

4.38 **Assertion (A):** Worn out (smooth) tyres offer higher friction factors on dry pavements than new tyres with treads well intact.
Reason (R): Reduced pneumatic pressure is held in tubes which carry smooth tyres over them.

[ESE : 2010]

4.39 **Assertion (A):** Tie bars are used in cement concrete slabs across the longitudinal joints.
Reason (R): Tie bars are designed to act as load transfer devices.

[ESE : 2010]

4.40 In a concrete pavement, during summer at and soon after mid-day, the combined stress at the interior of the slab is equal to
(a) Wheel load stress + Temperature warping stress + Sub grade resistant stress
(b) Wheel load stress + Temperature warping stress – Sub grade resistant stress
(c) Wheel load stress – Temperature warping stress + Sub grade resistant stress
(d) Wheel load stress – Temperature warping stress – Sub grade resistant stress

[ESE : 2011]

4.41 Which of the following correspond to the recommendations of IRC for pavement thickness determination by CBR method?
1. CBR tests are to be conducted in-situ
2. Static compression is best adopted
3. The top 50 cm of subgrade should be compacted to as near the proctor density as possible

(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

[ESE : 2011]

4.42 The corrected modulus of sub-grade reaction for standard diameter plate is 6.0 kg/cm^3. What would be the modulus of sub-grade reaction of the soil when tested with a 30 cm diameter plate?
(a) 15 kg/cm^3 (b) 25 kg/cm^3
(c) 30 kg/cm^3 (d) 60 kg/cm^3

[ESE : 2013]

4.43 What is the deflection at the surface of a flexible pavement due to a wheel load of 40 kN and a tyre pressure of 0.5 MPa? The value of E for pavement and subgrade is 20 MPa.

(a) 15 mm (b) 11 mm
(c) 9 mm (d) 6 mm

[ESE : 2014]

4.44 In a flexible pavement
(a) Vertical compressive stresses decrease with depth of the layer
(b) The vertical compressive stress is the maximum at the lowest layer
(c) Tensile stresses get developed
(d) Maximum stress induced by a given traffic load is dependent on the location of the load on the pavement surface

[ESE : 2014]

4.45 Bankleman beam deflection method is used for design of
(a) Rigid overlays on rigid pavements
(b) Rigid overlays on flexible pavements
(c) Flexible overlays on flexible pavements
(d) Flexible overlays on rigid pavements

[ESE : 2014]

4.46 A collapsible soil sub-grade sample was tested using Standard California Bearing Ratio apparatus; and the observations are given below:

S.I. No.	Load	Penetration
1.	60.55 kg	2.5 mm
2.	80.55 kg	5.0 mm

Taking the standard assumptions regarding the load penetration curve, CBR value of the sample will be taken as
(a) 3.9% (b) 4.0%
(c) 4.4% (d) 5.5%

[ESE : 2016]

4.47 What is the critical thickness of a prestressed concrete pavement (using Westergaard's Corner Load Formula) to support a maximum wheel load of 4200 kg? Allow 10% for impact. Tyre pressure may be taken as 7 kg/cm^2. Assume flexural strength of concrete as 50 kg/cm^2, factor of safety as 2, subgrade reaction for plastic mix road as 6 kg/cm^3. and modulus of elasticity as 3×10^5 kg/cm^2.
(a) 19.6 cm (b) 21.6 cm
(c) 23.6 cm (d) 25.6 cm

[ESE : 2016]

4.48 In revised CBR design method recommended by the IRC for the design of flexible pavement, the total thickness depends upon
(a) Only the CBR value of the soil
(b) The CBR value of the soil and magnitude of wheel load
(c) The CBR value of the soil and cumulative standard axle loads
(d) The CBR value of the soil and number of commercial vehicles passing per day

[ESE : 2017]

4.49 Consider the following statements regarding pavements:
1. Rigid pavements are more suitable than flexible pavements for stage construction.
2. Rigid pavements are more affected by temperature variations than flexible pavements.
3. In a flexible pavement, any deformation in the top layers is transferred to underlaid layers; but, in rigid pavements, there is slab or beam action due to which any deformation is only in the top layer of the concrete slab.

Which of the above statements are correct?
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2017]

Answers Pavement Design

4.1 (c)	4.2 (d)	4.3 (a)	4.4 (a)	4.5 (c)	4.6 (d)	4.7 (d)	4.8 (a)	4.9 (c)	
4.10 (d)	4.11 (a)	4.12 (b)	4.13 (c)	4.14 (d)	4.15 (b)	4.16 (a)	4.17 (d)	4.18 (d)	
4.19 (b)	4.20 (a)	4.21 (c)	4.22 (c)	4.23 (d)	4.24 (c)	4.25 (d)	4.26 (c)	4.27 (a)	
4.28 (b)	4.29 (b)	4.30 (d)	4.31 (c)	4.32 (c)	4.33 (b)	4.34 (c)	4.35 (d)	4.36 (d)	
4.37 (b)	4.38 (b)	4.39 (c)	4.40 (b)	4.41 (c)	4.42 (a)	4.43 (d)	4.44 (a)	4.45 (c)	
4.46 (c)	4.47 (a)	4.48 (c)	4.49 (a)						

Explanations Pavement Design

4.1 (c)

Pressure deformation characteristics of rigid pavement are a function of relative stiffness of slab to that of subgrade. The term radius of relative stiffness was coined by Westergaard. It is given by

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4}$$

4.2 (d)

The Benkelman Beam Deflection Method is thus widely used for Evaluation of Structural Capacity of Existing Flexible Pavements and also for Estimation and Design of flexible overlays for Strengthening of any weak pavement for Highways. The Benkelman Beam measures the deflection of a flexible pavement under moving wheel loads.

4.3 (a)

According to IS:2720 the Plasticity Index (*PI*) of binding material in WBM for base/subbase should be less than 6%.

4.4 (a)

The load carrying capacity of rigid pavement is due to the rigidity and high modulus of elasticity of the slab. The impact load will produce stresses higher than that by the static wheel load. However it is difficult.

4.5 (c)

In regions where sub-grade strength is uneven, rigid pavements are more suitable than flexible pavements due to

- rigidity of slab
- high modulus of elasticity of the slab

4.6 (d)

The average CBR value of three test specimens is reported to the first decimal place, as the CBR value of the test specimen. If the maximum variation in the CBR values of these specimens exceeds specified limits (3% for CBR up to 10%; 5% for CBR 10 to 30% and 10% for CBR 30-60%), then the design CBR should be the average of at least six specimens.

4.7 (d)

PN_f = Constant as given by McLeod.

where

P is wheel load

N_f is number of cycles for failure

4.8 (a)

Combination of load stress and warping stress is recommended (IRC 58:1976) to determine thickness. During summer, frictional stress is added and during winter, frictional stress is subtracted from sum of Load stress and Warping stress while determining critical stress combination in case joints and sealing devices are used.

4.9 (c)

The greater quantity of reinforcement should be placed in the longitudinal direction. Further the reinforcement should either be placed in the mid depth or towards the top of the pavement for better functioning.

4.10 (d)

Corrected rebound deflection,

$$D_c = 2\text{ mm}$$

Allowable deflection,

$$D_a = 1 \text{ mm}$$

Overlay thickness,

$$h = 550 \log_{10}\left(\frac{D_c}{D_a}\right)$$

$$= 550 \log_{10} 2 = 166 \text{ mm}$$

4.11(a)

The seasonal variations cause variation in subgrade moisture. The plasticity index ($LL - PL$) and annual average rainfall are the data required to determine moisture correction factor.

Temperature correction is separately applied.

4.12 (b)

As per the revised guidelines (IRC: 37-1984) design of flexible pavements should be based on the concept of cumulative standard axle loads (MSA) instead of number of commercial vehicles which was done earlier.

4.13(c)

Critical combination of stresses

(i) During summer mid-day at bottom of slab (Load stress + warping stress – friction stress), at edge region

$$= 210 + 290 - 10$$

$$= 490 \text{ N/mm}^2$$

(ii) During winter mid-day at bottom of slab (Load stress + warping stress + friction stress), at edge region

$$= 210 + 290 + 10$$

$$= 510 \text{ N/mm}^2$$

(iii) At top of slab during midnights (Load stress + warping stress), at corner region.

4.14 (d)

Longitudinal joints in cement concrete pavements are constructed with tie bars. Tie bars are either deformed steel bars or connectors used to hold the faces of slabs in contact. They are designed to withstand tensile stress and ensure that two slabs remain together.

4.15 (b)

Present serviceability index (PSI) values are used for functional evaluation of pavement surface conditions. Physical measurements are made on pavement surface and mathematical models

4.16(a)

Standard plate is of 75 cm diameter.

$$K_1 d_1 = K_2 d_2$$

$$10 \times 30 = K_2 \times 75$$

$$\Rightarrow \quad K_2 = 4 \text{ kg/cm}^3$$

K_1, K_2 are modulus of subgrade reaction for diameter 'd_1' and 'd_2' respectively.

4.17 (d)

During summer: Critical combination of stresses in concrete pavement = Load stress + Warping stress- Frictional stress

During winter: Critical combination of stresses in concrete pavement = Load stress + Warping stress+ Frictional stress

4.18(d)

$$K_1 d_1 = K_2 d_2$$

$$\therefore \quad K_2 = \frac{30}{75} \times 200 = 80 \text{ N/cm}^3$$

4.19 (b)

Following criteria were given for soil stabilisation in design process of flexible pavements by Dunlop:

(i) Sub-grades are only stabilized if they have a soaked CBR of 5 or less and amount of cement used is limited to keep the final CBR below 50.

(ii) Base courses after treatment should have plasticity index of 2 or less and CBR in excess of 100.

(iii) Sub-bases after treatment should have plasticity index of 5 or less.

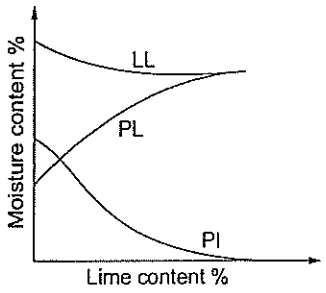
4.20(a)

Expansion joint spacing is designed based on the maximum temperature variation expected and the width of the joint. The width or the gap in expansion joint depends upon the length of the slab. The maximum spacing recommended for 25 mm wide expansion joints is 140 m when the foundation is rough for all slab thicknesses. When the foundation surface is smooth, the maximum spacing may be 90 m for slab thicknesses up to 20 cm and spacing of 120 m for slab thickness up to 25 cm, when the pavement is constructed in summer. However, when the pavement is constructed in winter, the

above spacings may be restricted to 50 m and 60 m respectively.

4.21 (c)

With addition of lime to clayey soil there is slight decrease in liquidity limit and considerable increase in plastic limit which reduces plasticity index.



First the rate of increase of plastic limit is rapid which then slows down after lime fixation point.

4.22 (c)

Characteristic deflection = $\bar{D} + 2\sigma$

$= 1.45 + 2 \times 0.107$

$= 1.664$ mm

Since temperature is above 35°C, so temperature correction

$= (37 - 35) \times 0.0065$

$= 0.013$ mm

Deflection after temperature correction

$= 1.664 - 0.013$

$= 1.651$ mm

Corrected deflection for subgrade moisture

$= 1.651 \times 1.6 = 2.64$ mm

4.24 (c)

CBR test is used to evaluate the stability of soil subgrade and other flexible pavement materials. It is an arbitrary strength test and hence can not be used to evaluate the shear strength parameters. In essence it is a measure to indicate relative strengths of paving materials and not the absolute strength.

4.25 (d)

some factors to be considered for design of pavement are:

(i) Design wheel load

(ii) Strength of pavement component material

(iii) Climatic factors

(iv) Subgrade soil

(v) Environmental factors

4.26 (c)

Various approaches of flexible pavement design are classified as:

(a) Empirical method,

(b) Semi-empirical or semi theoretical methods,

(c) Theoretical methods.

4.28 (b)

The modulus of sub-grade reaction(K) in plate bearing test may be defined as pressure sustained per unit deformation of sub-grade as specified deformation using specified plate size.

$$K = \frac{P}{0.125} \text{ kg/cm}^3$$

where P is the pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm.

IRC specifies that the K value be measured at 1.25 mm settlement.

4.29 (b)

For calculating temperature stress factors considered are:

(i) Maximum temperature difference between top and bottom of slab

(ii) Slab width

(iii) Slab length

(iv) Coefficient of thermal expansion of concrete per degree Celsius

(v) Modulus of elasticity of concrete

(vi) Poisson's ratio

4.31 (c)

Mainly it is essential that at no time, soil subgrade is over stressed as should it be over-stressed, it will deform and loose its ability to properly support axle loads.

4.32 (c)

CBR method, Group Index method, McLeod method and Burmister method are some of the methods which are used in the design of flexible pavements.

4.33 (b)

Radius of relative stiffness is given by

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4}$$

4.34 (c)

The cumulative effect of different stress gives rise to the following three critical cases :

- **Summer, mid-day:** The critical stress is for edge region given by $\sigma_{critical} = \sigma_e + \sigma_{te} - \sigma_f$ (at bottom)
- **Winter, mid-day:** The critical combination of stress is for the edge region given by $\sigma_{critical} = \sigma_e + \sigma_{te} + \sigma_f$ (at bottom)
- **Mid-nights:** The critical combination of stress is for the corner region given by $\sigma_{critical} = \sigma_e + \sigma_{te}$ (at bottom)

where; σ_e is stress due to wheel load, σ_{te} is warping stress and σ_f is frictional stresses.

4.35 (d)

While deciding thickness of rigid pavement by Westergaard method factors such as Poisson's ratio, radius of relative stiffness, modulus of sub-grade reaction etc are considered.

4.36 (d)

Group Index is a number assigned to the soil based on its physical properties. It is based on percentage material passing 75 micron sieve, Liquid limit and plasticity index. It varies from a value of 0 to 20, lower the value higher is the quality of the sub-grade and greater the value, poor is the sub-grade.

Group index, GI= 0.2a +0.005ac+ 0.01bd

a= percentage of soil passing 0.075 mm sieve in excess of 35 per cent, not exceeding 75; $0 \le a \le 40$

b= percentage of soil passing 0.075 mm sieve in excess of 15 per cent, not exceeding 55; $0 \le b \le 40$

c= value of liquid limit in excess of 40 and less than 60; $0 \le c \le 20$

d=value of plasticity index exceeding 10 and not more than 30; $0 \le d \le 10$

4.37 (b)

Dowel bars are short steel bars that provide a mechanical connection between slabs without restricting horizontal joint movement. In cement concrete slabs, dowel bars are provided at expansion joints and sometimes at contraction joints.

Longitudinal joints in cement concrete pavements are constructed with tie bars. Tie bars are either deformed steel bars or connectors used to hold the faces of slabs in contact. They are designed to withstand tensile stress and ensure that two slabs remain together.

4.38 (b)

The main factors affecting the friction coefficient are road surface texture and condition and tire composition.

Condition of the roadway refers to the presence of snow, ice, sand and other lubricants. The presence of any of these will make the surface more slippery, which reduces the coefficient of friction.

Texture of the road surface refers to the natural roughness of the asphalt. A relatively new asphalt roadway has a "sharper" surface with a high coefficient of friction. An older well-travelled asphalt roadway has a smoother, slicker surface with a lower coefficient of friction.

Tire composition and wear plays a role in determining the coefficient. Tests show that on a clean, dry surface, bald; worn out tires actually will skid to a stop more quickly than newer, treaded tires. However, on a wet roadway, treaded tires are preferred.

4.39 (c)

Tie bars used across the longitudinal joints of cement concrete pavements. Tie bars ensure two adjacent slabs to remain firmly together. These bars are not designed to act as load transfer devices. Tie bars are thus designed to withstand tensile stresses, the maximum tensile force in tie bars being equal to the force required to overcome frictional force between the bottom of the adjoining pavement slab and the soil subgrade.

4.40 (b)

(i) During Summer: Critical combination of stresses = load stress + warping stress – frictional stress, at edge region.

(ii) During winter: The critical stress combination = load stress + warping sress + frictional stress, at edge region.

(iii) At corner region: The critical stress combination = load stress + warping stress, at corner regions.

4.41 (c)

Some of the important points recommended by the IRC for the CBR method of design (IRC : 37-1970) are:

(a) The CBR tests should be performed on remoulded soils in the laboratory. In-situ tests are not recommended for design purposes. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction. The standard test procedure should be strictly adhered to.

(b) For the design of new roads, the subgrade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment is available to achieve this density in the field. In the case of existing roads, the sample should be field density of subgrade soil (at OMC or at a field moisture content).

(c) In new constructions the CBR test samples may be soaked in water for four days period before testing.

(d) Atleast three samples should be tested on each type of soil at the same density and moisture content. The specified limits of maximum variation in CBR are 3% for CBR values upto 10% 5% for values 10 to 30 and 10% for values 30 to 60%.

(e) The top 50 cm of subgrade should be compacted atleast upto 95 to 100 percent of Proctor density.

4.42 (a)

$k = 6\ \text{kg/cm}^3$

When, $a = 75\ \text{cm}$

$$k_1 = \frac{6(75)}{30}$$

$$= 15\ \text{kg/cm}^3$$

4.43 (d)

$$\text{Deflection}, \Delta = \frac{1.5Pa}{E_s}\ \text{(For flexible plate)}$$

Where, P = Contact pressure due to wheel load = 0.5 MPa

a = Radius of contact area

Now,

$$\text{Contact area} = \frac{\text{Wheel load}}{\text{Tyre pressure}} = \frac{40\times10^3\ \text{N}}{0.5\ \text{N/mm}^2}$$

$$= 80\times10^3\ \text{mm}^2$$

and, area,

$$\pi \times a^2 = 80\times10^3$$

$$a = \sqrt{\frac{80\times10^3}{\pi}} = 159.615\ \text{mm}$$

$$E_s = 250\ \text{MPa}$$

So, $$\Delta = \frac{1.5\times0.5\times159.617}{20} = 6\ \text{mm}$$

4.45 (c)

The Benkelman Beam Deflection Method is thus widely used for Evaluation of Structural Capacity of Existing Flexible Pavements and also for Estimation and Design of flexible overlays for Strengthening of any weak pavement for Highways. The Benkelman Beam measures the deflection of a flexible pavement under moving wheel loads.

4.46 (c)

$$\text{CBR}_{@2.5\,\text{mm}} = \frac{60.55}{1370}\times100 = 4.4\,\%$$

$$\text{CBR}_{@5.0\,\text{mm}} = \frac{80.55}{2055}\times100 = 3.9\,\%$$

Consider higher value.

4.47 (a)

Assume h = 20 cm and compute l

$$l = \left[\frac{Eh^3}{12k\left(1-\mu^2\right)}\right]^{1/4}$$

$$= \left[\frac{3\times10^5\times20^3}{12\times6\left[1-0.15^2\right]}\right]^{1/4}$$

$$l = 76.41\ \text{cm}$$

$$S_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$a = \sqrt{\frac{P}{p\pi}} = 13.82 \text{ cm}$$

$$\frac{50}{2} = \frac{3\times 4200}{h^2}\left[1-\left(\frac{13.82\sqrt{2}}{76.41}\right)^{0.6}\right]$$

$h = 16.78$ cm

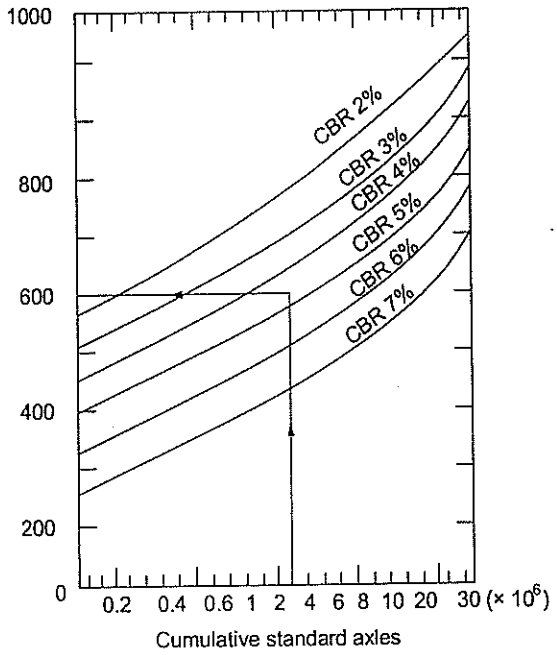
Increase 10% of h to consider impact

$\therefore$ Thicker = 16.78 + 1.678

= 18.45

$\therefore$ Approx answer is h = 19.6 cm

4.48 (c)



5 Highway Materials, Maintenance and Properties

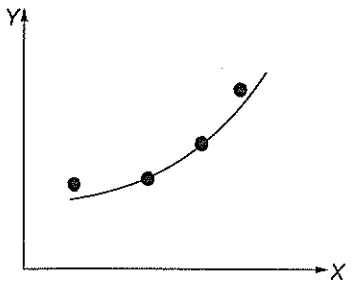
5.1 In the Los Angeles Abrasion Test on aggregate, if the speed of the drum is increased to 50 rpm, then the abrasion value will
(a) increase
(b) decrease
(c) remain unchanged
(d) be unpredictable

[ESE : 1995]

5.2 Which one of the following causes ravelling in bituminous pavement?
(a) Use of soft bitumen
(b) Excessive bitumen content
(c) Low bitumen content
(d) Use of open-graded aggregates

[ESE : 1995]

5.3 A typical Marshall test graph is shown in the given figure. The variable on the *X*-axis is % binder content by weight of total mix. The variable on the *Y*-axis for the given graph will be



(a) stability value
(b) flow value
(c) percentage of voids
(d) unit weight

[ESE : 1995]

5.4 Which one of the following items of hill road construction does not help in the prevention of landslides in the monsoon season?
(a) Retaining walls
(b) Catch water drains
(c) Breast walls
(d) Hair-pin bends

[ESE : 1995]

5.5 Consider the following types of roads in the same rainfall region:
1. Water Bound Macadam roads
2. Cement Concrete roads
3. Bituminous high-speed roads
4. Gravel roads

The correct sequence of the ascending order of steepness of camber of these roads is
(a) 4, 1, 2, 3 (b) 4, 1, 3, 2
(c) 1, 4, 3, 2 (d) 1, 4. 2. 3

[ESE : 1995]

5.6 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. Disintegration of aggregates due to weathering
B. The removal of material from the surface of the road by grinding action
C. Mutual rubbing or grinding within the mass under the action of traffic
D. Breaking up of road surface layer through cracking into irregular shaped areas

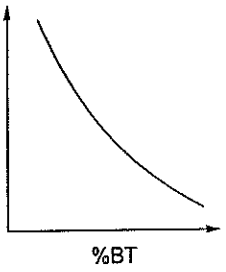
List-II
1. Attrition
2. Crazing
3. Soundness
4. Abrasion
5. Disintegration

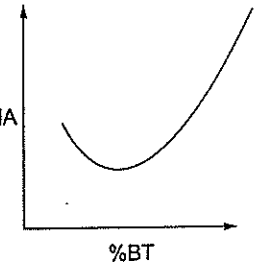
Codes:

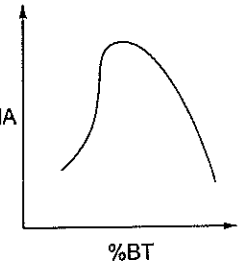
	A	B	C	D
(a)	3	1	5	2
(b)	2	5	1	4
(c)	3	4	1	2
(d)	1	4	3	5

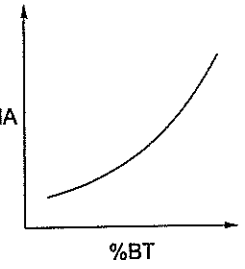
[ESE : 1996]

5.7 Which one of the following diagrams illustrates the relationship between VMA and % bitumen content (BT) in Marshall test?

(a) 

(b) 

(c) 

(d) 

[ESE : 1996]

5.8 In which one of the following bituminous constructions, compaction by pneumatic roller also is specified?
(a) Premix carpet
(b) Bituminous macadam
(c) Bituminous concrete
(d) Surface dressing

[ESE : 1996]

5.9 For an aggregate-soil mixture with maximum size of aggregate as 60 mm, the percentage of material between 6 mm and 75 micron sizes for obtaining Fuller's maximum density criterion shall be nearly
(a) 37 (b) 35
(c) 28 (d) 15

[ESE : 1997]

5.10 **Assertion (A):** Bituminous roads disintegrate even with light traffic, but such road failures are not due to any wrong use of surface treatment.
Reason (R): Improper preparation of the subgrade and the foundation are responsible for this disintegration.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

5.11 A road is passing in cut with impervious strata at a depth of 0.5 m from the subgrade level. To intercept seepage flow, a longitudinal pipe drain in trench filled with filter material and clay seal is constructed. What shall be the depth of the trench?
(a) 1.75 m (b) 1.5 m
(c) 1.0 m (d) 0.5 m

[ESE : 1998]

5.12 The amount of mechanical energy imposed on the aggregate during the aggregate impact test is of the order of
(a) 5320 kg-cm (b) 6750 kg-cm
(c) 7980 kg-cm (d) 11400 kg-cm

[ESE : 1998]

5.13 Which one of the following binders is recommended for a wet and cold climate?
(a) 80/100 penetration asphalt
(b) Tar
(c) Cutback (d) Emulsion

[ESE : 1998]

5.14 With reference to the Marshall mix design criteria for highways, which one of the following parts is NOT correctly matched?
(a) Stability value : 340 (minimum)
(b) Flow value : 8-16
(c) VFB : 50-75
(d) % Air voids : 3-5

[ESE : 1998]

5.15 Match List-I (Pavement deficiency) with List-II (Explanation) and select the correct answer using the codes given below the lists:

List-I

A. Bird baths
B. Pot holes
C. Ravelling
D. Subsidence

List-II

1. A step-sided, bowl shaped cavity caused by loss of surfacing as well as base course erosion
2. Deformation which may be caused by localized or variable subgrade failure
3. Irregular deformations which may be the result of differential settlement
4. Removal of larger surface aggregates leaving craters
5. Abrupt lowering of the road surface due to poor drainage

Codes:

	A	B	C	D
(a)	1	4	5	3
(b)	2	1	3	5
(c)	5	2	4	3
(d)	2	1	4	5

[ESE : 1998]

5.16 Which one of the following pairs is NOT correctly matched?

(a) Horizontal curves – Superelevation
(b) *O* and *D* studies – Desire lines
(c) Los Angeles test – Hardness of aggregates
(d) Soundness test – Purity of bitumen

[ESE : 1999]

5.17 For carrying out bituminous patch work during the rainy season, the most suitable binder is

(a) road tar
(b) hot bitumen
(c) cutback bitumen
(d) bituminous emulsion

[ESE : 1999]

5.18 Assertion (A): In bituminous mixes, the minimum voids requirement provides space for densification under traffic movements and expansion of bitumen at high temperature.

Reason (R): Insufficient voids in the bituminous mix causes bleeding of the bituminous surface and skidding.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1999]

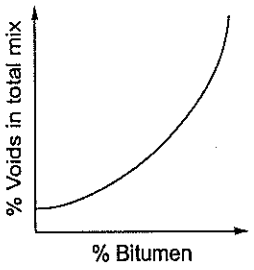
5.19 Bitumen grade 80/100 indicates that under the standard test conditions, penetration value of bitumen would vary from

(a) 0.8 mm to 1 mm
(b) 8 mm to 10 mm
(c) 8 cm to 10 cm
(d) 0.08 mm to 0.1 mm

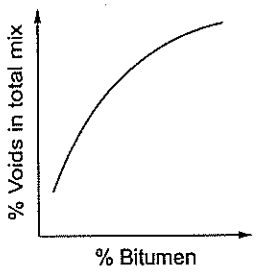
[ESE : 2000]

5.20 Which one of the following curves illustrates the correct relation between % voids in total mix and % bitumen?

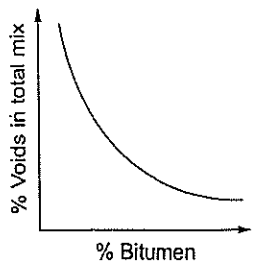
(a)



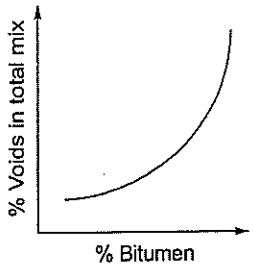
(b)



(c)



(d)



[ESE : 2000]

5.21 **Assertion (A):** The prime coat is an interface bituminous treatment when the existing base course has a pervious texture like water bound macadam.

Reason (R): The primer has to get into the capillary voids in the existing base and it should be of low viscosity. Bituminous emulsion is generally used as a prime coat.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

5.22 Match List-I (Distress) with List-II (Meaning) and select the correct answer using the codes given below the lists:

List-I
A. Settlement
B. Subsidence
C. Depression
D. Distortion

List-II
1. A localized, rather abrupt lowering of the road surface
2. A general lowering of the road surface
3. Irregular deformation of the road
4. Dished localized deformations

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	1	2	4	3
(c)	2	1	3	4
(d)	1	2	3	4

[ESE : 2001]

5.23 Consider the following stages in the construction of concrete roads:

1. Preparing the subgrade and the base course.
2. Mixing and placing the concrete.
3. Placing the framework and watering the prepared base.
4. Curing.
5. Compaction and floating.

The correct sequence of these stages is

(a) 1, 2, 3, 4, 5 (b) 1, 3, 2, 5, 4
(c) 1, 2, 3, 5, 4 (d) 1, 3, 2, 4, 5

[ESE : 2001]

5.24 Match List-I (Type of construction) with List-II (% Bitumen content) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Bituminous macadam	1. 3-3.5%
B. Dense bituminous macadam	2. $\leq$ 4%
C. Bituminous concrete	3. 14-17%
D. Bituminous mastic	4. Min. 4.5%

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	1	2	4	3
(c)	4	3	1	2
(d)	1	3	4	2

[ESE : 2002]

5.25 **Assertion (A):** The Marshall test, being a confined compression test has a correlation with deformation as it occurs on the road.

Reason (R): In road, loaded area is confined by the tyre, the surrounding surfacing and the road base.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

5.26 Match List-I (Test) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Impact test	1. Bitumen adhesion
B. Los-Angeles abrasion test	2. Toughness

C. Crushing test 3. Hardness
D. Stripping test 4. Strength

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2004]

5.27 Which one of the following defects indicates progressive disintegration of bituminous premix carpet surfacing by loss of aggregates?
(a) Pot holes (b) Ravelling
(c) Edge breaking (d) Rutting
[ESE : 2004]

5.28 In 500 gm sample of coarse aggregate, there are 100 gm flaky particles and 80 gm elongated particles. What are the flakiness and elongation indices (total) as per IS?
(a) 40% (b) 36%
(c) 18% (d) 4%
[ESE : 2004]

5.29 Match List-I (Road drainage system) with List-II (Location) and select the correct answer using the codes given below the lists:

List-I
A. Vertical sand drains
B. Causeways and culverts
C. Scuppers and catch water drains
D. Inlets and gratings

List-II
1. Urban road drainage
2. Hill roads
3. High embankments in soft soils
4. Cross drainage in road alignments

Codes:

	A	B	C	D
(a)	3	2	4	1
(b)	1	4	2	3
(c)	3	4	2	1
(d)	1	2	4	3

[ESE : 2004]

5.30 Consider the following statements:
1. Mastic asphalt is a mixture of hard grade bitumen or blown bitumen, minerals filler and fine aggregates.
2. % of binder content in the mastic asphalt is 17-20 per cent by weight of the aggregates.

Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2005]

5.31 Match List-I (Type of binder) with List-II (Uses) and select the correct answer using the codes given below the lists:

List-I
A. 80/100 penetration grade bitumen
B. 85/25 blown-bitumen
C. MC-70 cutback
D. RT-5 road tar

List-II
1. Mastic-asphalt
2. Bituminous roads
3. Grouting works
4. Prime-coat

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	2	1	4	3
(c)	3	1	4	2
(d)	2	4	1	3

[ESE : 2006]

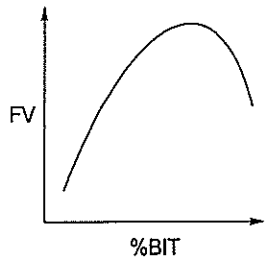
5.32 What are the standards for testing of road macadam in Aggregate Impact Test?
(a) 14 kg wt, 38 cm drop, 15 blows
(b) 14 kg wt, 35 cm drop, 20 blows
(c) 18 kg wt, 35 cm drop, 15 blows
(d) 18 kg wt, 30 cm drop, 20 blows
[ESE : 2006]

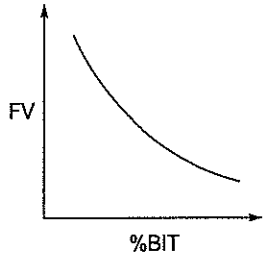
5.33 Which one of the following is the set of physical requirements of coarse aggregates for construction of WBM roads as per IRC recommendation?

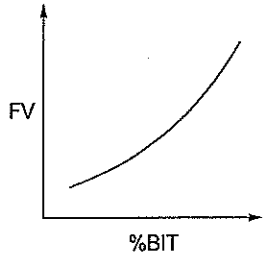
	LAV(%)	AIV(%)	FI(%)
(a)	<50	<40	<15
(b)	<50	<30	<15
(c)	<40	<30	<20
(d)	<40	<30	<15

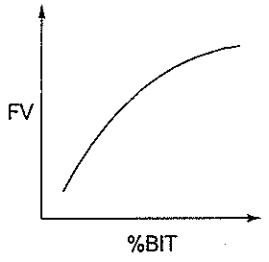
[ESE : 2006]

5.34 Which one of the following diagrams illustrates the relationship between flow value (FV) and percentage bitumen (%BIT)?

(a) 

(b) 

(c) 

(d) 

[ESE : 2006]

5.35 Match List-I (Type of construction) with List-II (Binder content) and select the correct answer using the code given below the lists:

List-I	List-II
A. Bituminous macadam	1. 8-15%
B. Dense bituminous macadam	2. 3-3.5%
C. Bituminous concrete	3. 4-4.5%
D. Bitumen mastic	4. 4.5-6.0%

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	4	3	2	1
(c)	2	3	4	1
(d)	4	1	2	3

[ESE : 2007]

5.36 Based on Fuller's maximum density criterion, for 4 mm maximum size of soil particles what is the percentage of particles between 4 mm and 2 mm by weight?

(a) 80 (b) 50
(c) 30 (d) 20

[ESE : 2007]

5.37 Consider the following statements related to Los Angeles Abrasion test on aggregates:

1. It evaluates hardness of source-rock.
2. It has a coefficient of variation of about 30 per cent.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2007]

5.38 A road surface is corrected by spreading a layer of dry sand in a thickness varying from 5 mm to 10 mm and rolling the surface by heavy rollers. Which one of the following maintenance works does it apply to?

(a) Repair of ruts and patches
(b) Repairing of blow ups
(c) Repair of bleeding surface
(d) Sealing of joints and cracks

[ESE : 2007]

5.39 The weight of aggregate having specific gravity 2.65, completely filled into a cylinder of volume 0.003 m^3 is 5.2 kg. What is the value of the angularity index of aggregate (approximately) as given by Murdock?

(a) 1 (b) 0.34
(c) 0.15 (d) 0.05

[ESE : 2007]

5.40 Match List-I (Type of wall) with List-II (Feature) and select the correct answer using the code given below the lists:

List-I

A. Parapet wall
B. Check wall
C. Breast wall
D. Gabion wall

List-II

1. Constructed with dry stone masonry encased in wire mesh
2. To add the overall stability to the hill face
3. To buttress the uphill slopes of the road cross-section
4. To give protection to the motorists

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	4	2	1	3
(c)	4	2	3	1
(d)	2	4	3	1

[ESE : 2007]

5.41 Emulsion is used as a binder in which of the following stages of construction?
1. Surface dressing work
2. Sealing open textured surfacing
3. Filling cracks in pavement
4. Prime coat
5. Pre-coating of aggregates

Select the correct answer the using the codes given below:
(a) 1, 2, 3, and 5 (b) 2, 3, 4 and 5
(c) 1, 2 and 4 (d) 1 and 3 only

[ESE : 2007]

5.42 Consider the following bituminous surfacings:
1. SDBM
2. PMC
3. AC
4. SD
5. Mastic Asphalt (MA)

Which one of the following is the correct sequence in increasing order with respect to their performance and wearing qualities?
(a) 4, 1, 2, 3, 5 (b) 2, 4, 1, 5, 3
(c) 4, 2, 1, 3, 5 (d) 1, 4, 3, 2, 5

[ESE : 2008]

5.43 Consider the following statements with reference to Water Bound Macadam (WBM) and Wet Mix Macadam (WMM):
1. WBM is a road mix and WMM is a plant mix.
2. WBM usually has plastic filler, while WMM has non-plastic filler.
3. WBM is a modern road mix and WMM is a traditional road mix.

Which of these statements is/are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 only (d) 2 only

[ESE : 2008]

5.44 Which one of the following tests is performed in the laboratory to determine the extent of weathering of aggregates for roadworks?
(a) Soundness test (b) Crushing test
(c) Impact test (d) Abrasion test

[ESE : 2009]

5.45 Hot bitumen is sprayed over freshly constructed bituminous surface followed by spreading of 6.3 mm coarse aggregates and rolled. Which one of the following is indicated by this type of construction?
(a) Surface dressing
(b) Gravel-bitumen mix
(c) Liquid seal coat
(d) Seal coat

[ESE : 2009]

5.46 **Assertion (A):** In water-bound macadam construction, grade I has better load dispersion characteristics as compared to grade III aggregates.

Reason (R): The plasticity index of the binding material should be less than 6%.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2009]

5.47 Which one of the following is not a desirable property of the subgrade soil as a highway material?
(a) Stability (b) Ease of compaction
(c) Good drainage (d) Bitumen adhesion

[ESE : 2009]

5.48 The consistency and flow resistance of a sample of bitumen can be determinated through which of the following tests?
(a) Viscosity test (b) Penetration test
(c) Ductility test (d) Softening point test

[ESE : 2016]

5.49 Flexible concrete is a mix comprising of
(a) Gravel, filler and 30/40 bitumen
(b) Sand, filler and 30/40 bitumen only
(c) Gravel, sand, filler and 60/70 bitumen
(d) Sand, filler and 60/70 bitumen only

[ESE : 2016]

5.50 Consider the following statements regarding ductility of bitumen:

1. Ductility is the property which does not permit bitumen to undergo large deformation without breaking
2. Bitumens with high ductility are generally adhesive but do not have good cementing properties
3. Ductility must be ascertained at two different temperatures in order to pronounce on the suitability of the material

(a) 3 only (b) 2 only
(c) 1 only (d) 1, 2 and 3

[ESE : 2016]

■■■

Answers Highway Materials, Maintenance and Properties

5.1 (a)	5.2 (d)	5.3 (b)	5.4 (d)	5.5 (b)	5.6 (c)	5.7 (b)	5.8 (a)	5.9 (c)	
5.10 (a)	5.11 (d)	5.12 (c)	5.13 (d)	5.14 (c)	5.15 (d)	5.16 (d)	5.17 (d)	5.18 (a)	
5.19 (b)	5.20 (c)	5.21 (c)	5.22 (a)	5.23 (b)	5.24 (b)	5.25 (d)	5.26 (a)	5.27 (a)	
5.28 (a)	5.29 (c)	5.30 (a)	5.31 (b)	5.32 (a)	5.33 (a)	5.34 (c)	5.35 (c)	5.36 (c)	
5.37 (a)	5.38 (b)	5.39 (*)	5.40 (c)	5.41 (a)	5.42 (c)	5.43 (a)	5.44 (a)	5.45 (a)	
5.46 (d)	5.47 (d)	5.48 (a)	5.49 (c)	5.50 (a)					

Explanations Highway Materials, Maintenance and Properties

5.1 (a)

The drum is normally rotated at a speed of 30-33 rpm. By increasing the speed to 50 rpm, there will be greater rubbing between the aggregate and steel balls. So abrasion value $\left(\frac{W_1}{W} \times 100\right)$ will increase.

where

W is weight of aggregate specimen

W_1 is weight of abraded aggregate passing 1.7 mm IS sieve

5.2 (d)

The removal of materials from base course is called ravelling. The loss of base course materials is only possible when either the base course is not covered by a wearing course or the wearing course has completely worn out. Due to the fast moving vehicles plying on road, there is a suction caused between the exposed base course material and pneumatic tyres. This causes removal of binding materials in WBM base and the stone aggregates are left in a loose state. Thus, in such a state if the stone aggregates are open graded, they cause ravelling.

5.3 (b)

Flow value is the deformation of specimen in 0.25 mm units up to the maximum load. It should be between 8 to 16.

Marshall stability value is the maximum load in kg before failure. Its minimum specified value is 340 kg. The stability first increases and then decreases with increase in bitumen content.

Unit weight also increases initially and then decreases.

Percentage of voids in total mix always decrease with increase in bitumen content.

The percentage of voids filled with bitumen increase with increase in bitumen content. But the graph is convex upward.

5.4 (d)

Because of precipitous work, deep valley, steep ascend to obligatory points and presence of innumerable gorges, hair pin bends (sharp 180° bend) are unavoidable on hill roads. It is located

on hill sides having the minimum slope and maximum stability. The cutting of slopes for construction of such bends often leaves them prone to land slides during monsoon. The minimum design speed for hair pin bends is 20 kmph.

5.5 (b)

Camber is provided to drain rain water from the surface of pavement. Therefore higher the absorbing capacity of surface, higher will be the camber required to drain water quickly. So correct sequence in order of steepness of camber is :

Cement Concrete roads < Bituminous high speed roads < WBM roads < Gravel roads.

5.7 (b)

Curve (a) → % air voids in total mix (V_v)

Curve (b) → VMA (% voids in mineral agg.)

Curve (c) → unit weight (g/cc)

Curve (d) → Flow value

5.8 (a)

In surface dressing rolling is done with tandem roller of 6 to 8 tonnes weight.

For premix carpet rolling is done by tandem or pneumatic roller of 6 to 9 tonnes. In bituminous concrete and bituminous macadam initial or breakdown rolling shall be done with 8 to 10 tonnes dead weight smooth wheeled rollers. The intermediate rolling shall be done with 8 to 10 tonnes dead weight or vibratory roller or with a pneumatic tyred roller of 12–15 tonnes weight having nine wheels, with a tyre pressure of at least 5.6 kg/cm^2. The finish rolling shall be done with 6-8 tonnes smooth wheeled tandem rollers.

5.9 (c)

The theoretical gradation for maximum density is given by

$$P = 100\left(\frac{d}{D}\right)^n$$

where,

P is percent finer than diameter 'd' (mm) in the material

D is diameter of the largest particle, mm

n is gradation index which depends upon the shape of particles

For spherical particles,

$$n = 0.5$$

Per cent finer than 6 mm

$$= 100\sqrt{\frac{6}{60}} = 100\sqrt{0.1}\%$$

$$= 31.6\%$$

Percent finer than 0.075 mm

$$= 100\sqrt{\frac{0.075}{60}}\% = 3.5\%$$

Percentage of material between 6 mm and 75 μm = 31.6 – 3.5 = 28.1%

5.10 (a)

Bituminous roads disintegrate even with light traffic when subgrade soil undergoes excessive deformation. It is due to improper preparation of subgrade which results in insufficient bearing capacity or shear failure in subgrade soil.

5.11 (d)

The depth of trench should be equal to depth of impervious strata below the subgrade level of pavement i.e 0.5 m

5.12 (c)

A metal hammer of weight 13.5-14.0 kg having a free fall from a height 38 cm is dropped 15 times in aggregate impact test. So energy imparted = 14 × 38 × 15 = 7980 kg-cm

5.13 (d)

Bituminous Cold Mix consists of a mixture of unheated mineral aggregate and emulsified or cutback bitumen. Emulsions are used in maintenance and patch repair works. It can be used in wet weather even when it is raining.

5.14 (c)

VFB should be between 75 to 85.

5.16 (d)

Los Angeles test is based on abrasion and it measures hardness property of aggregates.

Solubility test is used to measure purity of bitumen. Pure bitumen is completely soluble in solvents like carbon disulphide and carbon tetrachloride.

5.17 (d)

Bituminous emulsion has advantage that it can be used even in rainy weather. It is used in bituminous construction especially in maintenance and patch repair work.

5.18 (a)

The role of voids in compacted mix is to provide reserve space for compaction/densification under traffic movements and expansion of bitumen at high temperature. It also helps to avoid flushing, bleeding of bituminous surface and skidding of vehicles.

5.19 (b)

$$\text{Penetration} = \frac{1}{10} \times \text{reading on scale}$$

5.20 (c)

Curve (a) or (d) → For flow value

Curve (b) → Percent voids filled with bitumen (VFB)

Curve (c) → Percent voids in total mix

5.21 (c)

Usually MC (medium curing) or SC (slow curing) cutbacks of suitable grade or viscosity is chosen depending upon the porosity of the surface to be treated.

5.24 (b)

According to MORST specifications bitumen content are as follows:

(i) Bituminous mastic, 14-17%

(ii) Dense bituminous macadam for nominal aggregate size 40 mm minimum 4% and for nominal aggregate size 25 mm minimum 4.5%.

(iii) Bituminous macadam for nominal aggregate size 40 mm, 3.1-3.4% and for nominal aggregate size 19 mm, 3.3-3.5%.

(iv) Bituminous concrete for nominal aggregate size 19 mm, 5-6% and for nominal aggregate size 13mm, 5-7%.

5.25 (d)

Marshall test is unconfined compression test.

5.26 (a)

Impact test evaluates the toughness of stone i.e its ability to absorb energy under repeated impact.

Ductility test or stripping test is used to measure the adhesive property of bitumen and its ability to stretch.

Abrasion test is carried to test the hardness property of aggregates.

Crushing test tests the crushing strength under applied compressive load.

5.27 (a)

Bituminous premixed carpet is a surfacing course.

5.28 (a)

$$\text{Flakiness index} = \frac{100}{500} \times 100 = 20\%$$

$$\text{Elongation index} = \frac{80}{400} \times 100 = 20\%$$

$$\text{Total} = 20 + 20 = 40\%$$

5.29 (c)

The vertical sand drains increase the effective permeability of soil. This results in faster dissipation of excess pore pressure in high embankment in soft soils.

For urban road surface drainage surface consists of inlets and gratings. The limitation of land width and presence of foot paths, dividing islands and other road facilities necessitates under ground longitudinal drains.

In order to intercept and divert water from the hill slope, catch water drains are provided, running parallel to the roadways. Water from catch water drains is diverted by sloping drain and carried across the road by means of causeways and culverts.

Beside catch water drains, road side drains on one side of hill road are provided. They are angle, saucer, and kerb and channel drain types.

In hill roads where rainfall is heavy, the culverts are needed at 60 to 90 m to facilitate drainage of water across the roads. This may be quite costly. Hence often 8 to 10 scuppers (cross-drainage structures) are provided in addition to the bridges and regular culverts.

5.30 (a)

The % binder content in the mastic asphalt is 14-17%.

Mastic asphalt is an intimate homogeneous mixture of selected well graded aggregates as to yield a plastic, voidless and impermeable mass. The paving grade bitumen 30/40, 60/70 and 80/100 may be chosen depending upon the climatic conditions. Hard bitumen 180/200 type are used in surface dressing.

5.31 (b)

80/100 penetration grade bitumen is used for bituminous road construction. Mastic-asphalt is a mixture of blown bitumen, filler and fine aggregates in suitable proportions which yields voidless and impermeable mass. 85/25 bitumin-blow is basically finest quality oxidized bitumen which is known for its high boiling point and accurate composition. Rt-5 road tar is used in grouting works. Cutback MC 70 containing minimum 55% Bitumen is commonly used as a Prime Coating and Maintenance Mixing.

5.32 (a)

Impact test evaluates the toughness of material i.e its ability to absorb energy under repeated impact. A metal hammer of weight 13.5 kg-14 kg having free fall from height of 38 cm is arranged to drop through vertical guides and 15 blows are given to the test specimen.

5.33 (a)

For WBM the prescribed value of LAV, AIV and FI for

(i) Base course are < 50%, < 40% and < 15% respectively.

(ii) Surface course are < 40%, < 30% and < 15% respectively.

where,

LAV is Los-Angeles Abrasion Value

AIV is Aggregate Impact Value

FI is Flakiness Index

5.34 (c)

Fig (a) → Marshall stability or unit weight

Fig (b) → Percent voids in total mix (V_v)

Fig (c) → Flow value

Fig (d) → Percent voids filled with bitumen (VFB)

5.35 (c)

Dense bituminous macadam for nominal aggregate size 40 mm -minimum 4%- and for nominal aggregate size 25 mm-minimum 4.5%. Bituminous concrete for nominal aggregate size 19 mm -5 % to 6% and for nominal aggregate size 13 mm-5% to 7%. Bituminous macadam for nominal aggregate size 40 mm -3.1 % to 3.4% and for nominal aggregate size 19 mm-3.3% to 3.5%.

5.36 (c)

According to Fuller's maximum density criterion, the gradation is given by

$$p = 100\left(\frac{d}{D}\right)^n$$

where,

p is per cent finer than diameter 'd' (mm) in the material

D is diameter of largest particle, mm

n is gradation index (taken as 0.5 by Fuller)

$$\therefore \quad p = 100\left(\frac{2}{4}\right)^{0.5}$$

$$\Rightarrow \quad p = 70.71$$

Thus, the percentage of particles between 4 mm and 2 mm will be given by

$$100 - 70.71 = 29.29 \simeq 30\%$$

5.37 (a)

The Los Angeles abrasion value of good aggregates acceptable for cement concrete, bituminous concrete and other high quality pavement materials should be less than 30 percent. Values up to 50 percent are allowed in base courses like water bound and bituminous macadam.

5.38 (b)

In the case of blow-ups, road surface is corrected by spreading a layer of dry sand in thickness varying from 5 mm to 10 mm and rolling the surface by heavy rollers.

5.39 (*)

Angularity index depends on the grading of the coarse and fine aggregates as well as on the relative amounts of coarse and fine aggregates in the final mixed concrete. These of course, are the things which are known only after the mix has been proportioned. It is necessarly, therefore,

to make preliminary estimates of the probable value of angularity index. Where the tests are carried out, the value of angularity index, F_a can be determined, as given by Murdock as,

$$F_a = 11.05 - \frac{15W}{VG}$$

where, W is weight of aggregate in gm
= 5200 gm
V is volume of cylinder
= 3000 ml
G is specific gravity = 2.65

$$\text{So, } F_a = 11.05 - \frac{15 \times 5200}{3000 \times 2.56} = 1.239$$

5.40 (c)
Parapet walls which are extensions at the edge are used to give protection to motorcyclists on roads with steep slopes and for protecting vehicles from falling into the valley. Breast walls are constructed to buttress the uphill slope of the road cross section. Check walls are Small retaining structures provided in series to arrest landslides and to add stability to hill face. Gabion walls are provided for retaining fill portion, and constructed with dry stone masonry encased in wire mesh or geo-grid cages.

5.41 (a)
Emulsions are used in bituminous road constructions, especially in maintenance and patch repair works. Three types of bituminous emulsions are prepared viz. Rapid Setting (RS), Medium Setting (MS) and Slow Setting (SS) types. RS type emulsion is suitable for surface dressing and penetration macadam type of construction. MS type is used for premixing with coarse aggregates and SS type emulsion is suitable for fine aggregate mixes.

5.42 (c)
Increasing order of performance and wearing qualities of various bituminous surfacings

Surface dressing < Pre mixed carpet < semi-dense bituminous macadam < asphaltic concrete <Mastic asphalt

5.43 (a)
WBM is a traditional road mix and WMM is a modern road mix.

5.44 (a)
Soundness test is performed in the laboratory to study the resistance of aggregates to weathering action by conducting accelerated weathering test cycle. The chemicals used in the laboratory for conducting this test are sodium sulphate and magnesium sulphate.

5.45 (a)
Surface dressing serves as thin wearing coat over existing pavement. It consists of application of hot bituminous material followed by spreading of aggregate cover and rolling.

5.46 (d)
Aggregates are divided into 3 grades according to their size.

Grade 1 - particles of size 90 mm to 40 mm.

Grade 2 - particles of size 63 to 40 mm.

Grade 3 - particles of size 50 to 20 mm.

Load dispersion of grade 3 > grade 2> grade 1.

5.47 (d)
Bitumen adhesion test is carried out in order to decide the suitability of the road aggregates for use in road construction.

5.50 (a)
Bitumen with high ductility generally are adhesive and have good cementing property. Ductility test may be required at two different temperature to obtain some indication of the tendency of the material to change in temperature.

■■■■

UNIT

VIII

Railway Engineering

Syllabus

Terminology, Planning, designs and maintenance practices; track modernization.

Contents

Sl.	Topic	Page No.
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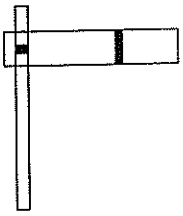
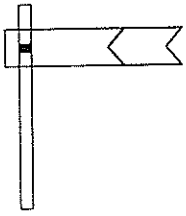
3.	Geometric Design of the Track	645
4.	Points and Crossing	650
5.	Track Stresses, Traction and Tractive Resistance	653

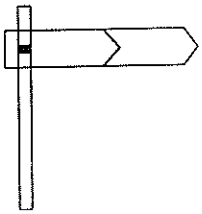
OOOO

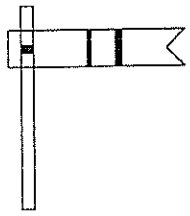
1 Rail Joints, Welding of Rails & Signals

1.1 Which one of the following figures represents a 'Warner signal' in railways?

(a) 

(b) 

(c) 

(d) 

[ESE : 1995]

1.2 A Treadle bar is used for
(a) interlocking points and signals
(b) setting points and crossings
(c) setting marshalling yard signals
(d) track maintenance

[ESE : 1997]

1.3 A railway yard in which wagons are received, sorted and new trains are formed is called a
(a) goods yard (b) station yard
(c) marshalling yard (d) shunting yard

[ESE : 2000]

1.4 Which one of the following signals is provided beyond the trailing points and switches in a railway yard?
(a) Repeater signal (b) Departure signal
(c) Advance starter (d) Routing signal

[ESE : 2000]

1.5 Which one of the following is installed as the second signal on the main signal post for better visibility?
(a) Routing signal (b) Calling on signal
(c) Co-acting signal (d) Repeating signal

[ESE : 2001]

1.6 Breathing length of LWR is the
(a) end portion which gets affected by temperature variation
(b) end portion which does not get affected by temperature variation
(c) central portion which gets affected by temperature variation
(d) central portion which does not get affected by temperature variation

[ESE : 2003]

1.7 Match List-I (Type of signals) with List-II (Characteristics) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Detonating signal	1. Locational
B. Coloured light signal	2. Operational
C. Home signal	3. Special
D. Calling on signal	4. Functional

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	4	2	1	3
(c)	4	2	3	1
(d)	2	4	1	3

[ESE : 2004]

1.8 Match List-I (Signal) with List-II (Function) and select the correct answer using the codes given below lists:

List-I	List-II
A. Outer signal	1. Departure signal
B. Starter signal	2. Reception signal
C. Repeater signal	3. Shunting signal
D. Disc signal	4. Co-acting signal

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	2	1	4	3
(c)	3	1	4	2
(d)	2	4	1	3

[ESE : 2006]

1.9 Which of the following are related to maintenance of railway track?
1. Jim crow and gauge bar
2. Through packing and boxing
3. Buffer stop and sand hump
4. Creep adjustment

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 2, 3 and 4

[ESE : 2008]

1.10 In which one of the following yards, are reception, sorting and dispatch of railway wagons done?
(a) Loco yard
(b) Marshalling yard
(c) Goods yard
(d) Passenger yard

[ESE : 2010]

1.11 A rail which is tapered to a toe at one end and has a heel at the other end is called as
(a) Stock rail (b) Tongue rail
(c) Wing rail (d) Lead rail

[ESE : 2011]

1.12 Match List-I with List-II and select the correct answer using the code given below the lists:

List-I
A. Rails
B. Sleepers
C. Ballast
D. Fish Plates

List-II
1. Connect one section of rail to next
2. Convert line load into uniformly distributed load
3. Convert point load into uniformly distributed load
4. Convert rolling loads into point load(s)

Code:

	A	B	C	D
(a)	4	3	2	1
(b)	1	2	3	4
(c)	4	2	3	1
(d)	1	3	2	4

[ESE : 2011]

1.13 A 45 kg rail on BG tracks in Indian conditions is expected to carry approximate axle loads of:
(a) 21 t (b) 22 t
(c) 23 t (d) 24 t

[ESE : 2013]

1.14 Fish plates are used in rail joints to:
1. Maintain the continuity of rails
2. Provide for any expansion or contraction
3. Transfer the load to the ballast
4. Maintain correct alignment

(a) 1, 2, 3 and 4 (b) 1, 2 and 3 only
(c) 2, 3 and 4 only (d) 1, 2 and 4 only

[ESE : 2013]

Answers Rail Joints, Welding of Rails and Signals

1.1	(b)	1.2	(a)	1.3	(c)	1.4	(c)	1.5	(c)	1.6	(a)	1.7	(d)	1.8	(b)	1.9	(c)	
1.10	(b)	1.11	(b)	1.12	(a)	1.13	(c)	1.14	(d)									

Explanations Rail Joints, Welding of Rails and Signals

1.1 (b)

Fig (a) → Calling on signal

Fig (b) → 2-Aspect warner signal

Fig (c) → Automatic signal

1.2 (a)

Treadle bar or lock bar is provided for the purpose that the point may not be operated while train is on it i.e., for interlocking points and signals.

1.3 (c)

Station yard is a system of tracks laid usually on a level within defined limit. The types of yards are:

(i) **Goods yard :** The main function is to provide facilities for receiving, loading, unloading and delivery of goods and the movement of goods vehicle.

(ii) **Marshalling yard :** The main function is breakup, reform and despatch of trains onwards. i.e., reception, sorting and departure.

(iii) **Locomotive yard :** Locomotive yard for housing locomotive. All the facilities for oil filing, watering repairing, cleaning, etc. are provided.

(iv) **Passenger bogie yard :** Passenger bogie yard provide facilities for safe movement of passenger and vehicles for the passengers.

1.4 (c)

Departure signals control the despatch of trains from the stations. They are of two types (i) Starter signals (ii) Advance starter signals. Starter signals mark the limit up to which trains stopping at a station should come to a stand.

Advance starter is provided beyond the trailing points or switches.

1.5 (c)

Routing signals are provided at the point of diversion where a number of lines exist at the station taking off different locations from the main line besides one main Home signal.

Repeating or co-acting signals are provided when the driver's vision is obstructed by (i) an overbridge between the signals or (ii) sharp curvature in the alignment or due to any other reason. It repeats the indication of the signal ahead

Repeating and co-acting signals serve the same purpose of providing visibility. But co-acting signal is provided on the same post at a lower level at which main signal exists.

Calling-on-signals consists of small arms below and parallel to Home signal fixed on the same post. When a train stops with the Home signal indication, then a calling on signal permits the train to proceed cautiously by keeping this signal arm at "PROCEED" position.

1.6 (a)

Due to variation in temperature and inability of the resisting force offered by the ballast and sleeper fastening etc. to the rail, the longitudinal movement of the long welded rail takes place. The portion of the long welded rail at each end, which under goes changes in its length due to temperature variation is called breathing length. For B.G. track in Indian conditions this length is about 125 m.

$$L = \frac{AE\alpha\Delta T}{r}$$

where

L is breathing length

A is cross-section area of rail. It is 76.86 cm^2 for 60 kg rail.

E is modulus of elasticity

$= 2.15 \times 10^6$ kg/cm^2

α is coefficient of thermal expansion

$= 1.152 \times 10^{-5}$ per°C

ΔT is temperature change

= 38°C for Zone I, 40°C for Zone II, 45°C for Zone III and 48°C for Zone IV

r is resistance of sleeper, 870 kg for ST sleeper and 640 kg for wooden sleeper

1.7 (d)

Operating signals: Detonating; Hand and Fixed signals.

Functional signals: Stop or semaphore type; Warner; Shunting; Coloured light signals.

Locational signals – Reception (Outer and Home); Departure (Starter and Advance Starter) signals.
Special signals – Repeater or co-acting; Routing; Calling on; Point indicators; Modified lower quadrant semaphoric signal etc.

1.8 (b)
Reception signal – Outer signal and Home signal
Departure signal – Starter signal and Advance starter signal
Shunting signal – Disc or ground signal
CO-ACTING signal – Repeater signal

1.9 (c)
The dead end of a railway line is provided with a barrier erected across the track to prevent the vehicles running off the track. It is called buffer stop.
Sand hump is a method to prevent the vehicles from running off the track at the end of siding. A hump of sand with rising gradient at the dead end of siding is provided.

1.10 (b)
Marshalling yard is a place where trains are received sorted, reformed and dispatched to their destinations.
Important functions of Marshalling yards are reception, sorting and departure. Places meant for these functions are called sidings. The various sidings are reception siding, sorting siding and departure siding. These sidings are provided in Marshalling yard.

1.11 (b)
Stock Rail: The position of the straight alignment against which the tongue rail fits is known as the stock rail.
Wing Rails: Wing rails help in channelising the wheels in their proper routes and direction meant for their movement. These rails guide the wheel path for movement of trains.
Tongue Rail: A tongue rail is tapered having toe at one end and heel at the other end. It is fixed at heel end and can move or rotate about this point.
Lead Rails: In a turnout, lead rails are the length of rails from the heel of the tongue rail to the toe of the crossing. These rails are of the normal rail sections

1.12 (a)
The rails on the track can be considered as steel girders for the purpose of carrying axle loads. Rails transmit the loads to sleepers and consequently reduce pressure on ballast and formation below.

Sleepers are members generally laid transverse to the rails on which the rails are supported and fixed, to transfer the loads from rails to the ballast and subgrade below:

Ballast is the granular material usually broken stone or brick, gravel or sand placed and packed below and around the sleepers to transmit load (due to the wheels of the train)from sleepers, to formation and at the same time allowing drainage of the track.

Fish Plates: These plates, resembling in shape to a fish, are used to provide the continuity between the two rails at the rail-joints. They also provide the required gap for expansion and contraction of rails due to temperature variations. They are made of steel.

1.13 (c)
BG lines on Indian Railways are classified into various categories. Among these categories a minimum rail section of 44.5 kg can be adopted in group '*D*' and group '*E*' categories if the sections have traffic density of less then 10 GMT. According to Indian Railways, a maximum axle load of 22.5 shall be taken for locomotive, a train load of 7.67 tonnes per meter behind the locomotives and a maximum axle load of 22.9 tonnes shall be taken as train load.

1.14 (d)
Load from rails to ballast is transferred through sleepers and not fish plates.

2 Ballast, Formation and Sleepers

2.1 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Shovel
B. Crow bars
C. Rail tongs
D. Claw bars

List-II

1. To lift rail
2. To remove dog spikes out of sleepers
3. To correct track alignment
4. To handle the ballast

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	4	3	1	2
(c)	4	3	2	1
(d)	3	4	1	2

[ESE : 1995]

2.2 Consider the following statements about concrete sleepers:

1. They improve the track modulus.
2. They have good scrap value.
3. They render transportation easy.
4. They maintain the gauge quite satisfactorily.

Which of these statements are correct?

(a) 1 and 2 (b) 2 and 3
(c) 2 and 4 (d) 1 and 4

[ESE : 1997]

2.3 For a sleeper density of (n + 5), the number of sleepers required for constructing a broad gauge (BG) railway track of length 650 m is

(a) 975 (b) 918
(c) 900 (d) 880

[ESE : 1999]

2.4 **Assertion (A):** Coning of wheels in railways does not cause wear and tear of the wheels.

Reason (R): The rails are tilted at an angle of 1 in 20 to reduce the wear and tear on the rails as well as on the tread of the wheels.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

2.2 Squaring of sleepers through packing consists of

(a) adjusting the sleepers to be perpen-dicular to the rails
(b) adjusting the ballast under sleepers to space them parallel to each other
(c) cutting the edges of the sleepers to a square shape
(d) adjusting the rails to be perpendicular to the sleepers

[ESE : 2001]

2.6 Match List-I (Device) with List-II (Used for) and select the correct answer using the codes given below the lists:

List-I

A. Pandrol clip
B. Densometer
C. Viseur's mire
D. Cotters

List-II

1. Fixing the tie bars with the CI sleepers
2. Measurement of 'packing voids' under the sleeper ends
3. Measurement of unevenness of rail top and rectification of alignment
4. Elastic rail fastening

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	4	2	3	1
(c)	1	2	3	4
(d)	4	3	2	1

[ESE : 2002]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

2.7 **Assertion (A):** Packing is the method of forcing and packing stone ballast below the sleepers by ramming with a beater-cum-pick axe.

Reason (R): At points and crossings, packing is carried out by lifting the track by means of track jack and requisite quantity of stone chips is evenly spread below the sleepers by shovel and the ships are allowed to consolidate by running trains.

[ESE : 2003]

2.8 **Assertion (A):** CST-9 sleeper is a type of metal sleeper, has been extensively used by Indian Railways due to its uniform strength, economical and satisfactory performance.

Reason (R): Metal sleeper is an inverted channel with folded ends. The folded edges which form a bulb resist the damage caused by the packing of ballast.

[ESE : 2003]

2.9 'Composite Sleeper Index' is employed to determine

(a) Sleeper density requirement
(b) Number of fixtures required for a certain type of sleeper
(c) Durability of sleeper
(d) Mechanical strength of wooden sleeper whereby its suitability for use is assessed

[ESE : 2014]

2.10 Which of the following types of Elastic fastenings can be used on all types of sleepers (like Wooden, Cast-Iron or Concrete) on Indian Railways?

(a) Sigma clip
(b) IRN-202 clip
(c) LG-20 Lock spike
(d) Pandrol clip

[ESE : 2014]

2.11 What will be the optimum depth of ballast cushion required for a *BG* railway track below the sleepers with sleeper density of $(M + 5)$ and bottom width of 22.22 cm?

(a) 25 cm (b) 21 cm
(c) 28 cm (d) 30 cm

[ESE : 2015]

■■■■

Answers Ballast, Formation and Sleepers

2.1 (b) 2.2 (d) 2.3 (b) 2.4 (a) 2.5 (b) 2.6 (b) 2.7 (b) 2.8 (a) 2.9 (d)
2.10 (d) 2.11 (a)

Explanations Ballast, Formation and Sleepers

2.1 (b)
Crow bar is used to raise sleeper to a desired height

2.2 (d)
The scrap value of concrete sleepers is nil.

2.3 (b)
Length of BG rail = 12.8 m

$$\text{Number of BG rails in 650 m} = \frac{650}{12.8} \simeq 51$$

Sleeper density = 13 + 5 = 18 per rail
Number of sleepers = 18 × 51 = 918

2.4 (a)
The surface of wheels are made in cone shape at an inclination of 1 in 20 and the same slope is provided in the rails, this is known as coning of wheels.

Advantages of conning of wheels:

(i) Reduces the wear the tear of the wheel flanges and rails.
(ii) To provide possibility of lateral movement of the axle with its wheels.
(iii) Prevents slipping of the wheels.

2.5 (b)
In through packing the sleepers are squared and brought to specified spacing at straight lengths and on curves i.e., the ballast under the sleepers is adjusted to space them parallel to each other.

2.6 (b)
Pandrol clips are elastic fasteners. They are responsible for attaching the rail to the base plate so the rail cannot move vertically or horizontally with respect to the base plate.

Densometer measures the depression of sleeper under a passing train.

Cotters are used to fix the tie bars with the CI sleepers. The different types of cotters are central split cotters, side split cotter, solid end split cotter and bent plate cotter.

Viscur's mire is helpful in measuring of uneveness of the rail and also used for rectification of track alighment.

2.7 (b)
Running trains causes the ballast under the sleepers to get loose and thus the depressions are farmed in the plane of rails. Therefore, regular packing of ballast under sleeper is done generally through beater-cum-pick-axe methods of packing of ballast are through packing, scissor packing and shovel packing.

At points and crossings, shovel packing is adopted where the use of beater cum-pick-axe is difficult because of less space.

Beater-pick-axe rammer is used in through packing.

2.8 (a)
The rail seat of a CST-9 has sleeper has narrow bearing tends to reduce the rocking of the sleeper under the wave motion of the rail. The sleeper is designed to provide a firm support to the rail and provides fairly good lateral and longitudinal stability to the rails. Also the inverted channel with folded edges forms a bulb to resist damage caused by packing of ballast. That's why it is one of the most extensively used sleepers by Indian Railways.

2.11 (a)
Length of BG rail = 12.8 m
Sleeper density = 12.8 + 5 = 17.8
∴ Spacing,

$$S = \frac{12.8}{17.8} \times 100 \text{ cm} = 71.91 \text{ cm}$$

∴ Optimum depth of Ballast Cushion

$$D_b = \frac{S - W}{2} = \frac{71.91 - 22.22}{2}$$

$$= 24.84 \text{ cm}$$

3 Geometric Design of the Track

3.1 The grade compensation on a 4° curve on a Broad Gauge railway track is

(a) 0.20% (b) 0.16%

(c) 0.12% (d) 0.08%

[ESE : 1995]

3.2 Consider the following situations:

1. Soil is soft.
2. Volume of existing surface traffic on the alignment is heavy.
3. Track is at a deeper level.
4. Water table is high.

In the construction of Metro Railways, "Cut and Cover" method of construction is suitable in situations listed as

(a) 1 and 2 (b) 1 and 3

(c) 1 and 4 (d) 2 and 3

[ESE : 1995]

3.3 Which one of the following types of transition curves is mostly used in Indian Railways?

(a) Euler's spiral (b) Cubic spiral

(c) Lemniscate (d) Cubic parabola

[ESE : 1998]

3.4 Consider the following surveys:

1. Reconnaissance survey
2. Preliminary survey
3. Traffic survey
4. Location survey

The correct sequence in which these surveys are conducted before the alignment of a track is finalized, is

(a) 1, 3, 2, 4 (b) 1, 3, 4, 2

(c) 3, 1, 4, 2 (d) 3, 1, 2, 4

[ESE : 1998]

3.5 In a BG railway track, the specified ruling gradient is 1 in 250. The horizontal curve of 3° on a gradient of 1 in 250 will have the permissible compensated gradient of

(a) 1 in 257 (b) 1 in 357

(c) 1 in 457 (d) 1 in 512

[ESE : 1999]

3.6 **Assertion (A):** Gradient much steeper than the ruling gradient are provided in a hilly terrain and they are negotiated with the help of a pusher engine.

Reason (R): Restricting the gradient to the ruling gradient in hilly terrains would mean increasing the length of the track resulting considerably in heavy excavation.

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

[ESE : 2001]

3.7 Grade compensation on curves in Indian Railways for BG is

(a) 0.40% per degree of curve

(b) 0.06% per degree of curve

(c) 0.04% per degree of curve

(d) 0.02% per degree of curve

[ESE : 2003]

3.8 Which one of the following is the correct expression for the versine (h) of a curve?

(l = length of rail on the curve and r = radius of curvature)

(a) $h = \frac{l^2}{r}$ (b) $h = \frac{l^2}{2r}$

(c) $h = \frac{l^2}{8r}$ (d) $h = \frac{l^2}{4r}$

[ESE : 2005]

3.9 What is the value of the steepest gradient to be provided on a 2° curve for BG line having ruling gradient of 1 in 200?
(a) 1 in 238 (b) 1 in 227
(c) 1 in 202 (d) 1 in 198
[ESE : 2006]

3.10 The ruling gradient on BG section of railway is 1 in 150 and a 4° curve is also there on it. What is the allowable ruling gradient?
(a) 1 in 146 (b) 1 in 154
(c) 1 in 196 (d) 1 in 232
[ESE : 2006]

3.11 **Assertion (A):** The super elevation provided on a curve of a railway track is less than the equilibrium cant.
Reason (R): Subject to a maximum value depending on speed and gauge, cant deficiency is allowed and therefore actual cant provided is less than the equilibrium cant.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true
[ESE : 2006]

3.12 What is the steepest gradient permissible on a 2° Curve for BG line having ruling gradient of 1 in 200?
(a) 1 in 250 (b) 1 in 238
(c) 1 in 209 (d) 1 in 198
[ESE : 2007]

3.13 Which of the following factors help in ensuring track modulus, in a railway track?
(a) Gauge and formation width
(b) Track materials and sleeper density
(c) Degree of curvature and super elevation
(d) Length of rail and flange width
[ESE : 2008]

3.14 If the ruling gradient is 1 in 150 on a particular section of a broad gauge track, the allowable ruling gradient on a 4° curve in the track will be
(a) 0.51% (b) 0.53%
(c) 0.61% (d) 0.67%
[ESE : 2011]

3.15 For a railway track in hilly terrain, the type of gradient provided is:
(a) Pulling gradient (b) Momentum gradient
(c) Helper gradient (d) Minimum gradient
[ESE : 2013]

3.16 Two parallel railway tracks are to be connected by a reverse curve, both segments having the same radius. If the centre lines of the tracks are 8 m apart and the maximum adaptable distance between the tangent points is 32 m, the allowable radius for the curve is
(a) 4 m (b) 8 m
(c) 32 m (d) 64 m
[ESE : 2014]

3.17 The steepest gradient on a 2° curve on a Broad Gauge line with a stipulated ruling gradient of 1 in 200, given that grade compensation is 0.04% per degree of curve, is
(a) 1 in 200 (b) 1 in 150
(c) 1 in 238 (d) 1 in 283
[ESE : 2014]

3.18 What would be the admissible gradient for a BG track when the grade resistance coupled with a 4° curve resistance shall equal the resistance due to a ruling gradient of 1 in 200?
(a) 0.30% (b) 0.40%
(c) 0.24% (d) 0.34%
[ESE : 2015]

3.19 In the layout of an MG track, the versine of a horizontal circular curve is measured over a 11.8 m chord length. What would be the radius of the curve if the value of the versine was 2 cm?
(a) 900 m (b) 800 m
(c) 870 m (d) 850 m
[ESE : 2015]

3.20 The maximum speed of a train on B.G. track having a curvature of 3° and a cant of 10 cm with allowable cant deficiency of 76 mm, for conditions obtaining in India, as
(a) 87.6 km/h (b) 99.6 km/h
(c) 76.6 km/h (d) 65.6 km/h
[ESE : 2016]

3.21 The gradient for a B.G. railway line such that grade resistance together with curve resistance

due to a 4° curve which will be equivalent to a simple ruling gradient of 1 in 150 is

(a) 1 : 180 (b) 1 : 200

(c) 1 : 300 (d) 1 : 400

[ESE : 2016]

3.22 Consider the following statements concerning railways:

1. A level stretch equal to the maximum train length is to be provided between the gradient reaches where s rising gradient is followed by a falling gradient.
2. Vertical curves in railway tracks are not set out as parabolas.
3. Diamond crossing can be laid on curves also.
4. Curves should be avoided at the top level segment of bridges.

Which of the above statements are correct?

(a) 1 and 3 only (b) 2 and 3 only

(c) 1 and 4 only (d) 2 and 4 only

[ESE : 2017]

Answers Geometric Design of the Track

3.1	(b)	3.2	(c)	3.3	(d)	3.4	(d)	3.5	(b)	3.6	(a)	3.7	(c)	3.8	(c)	3.9	(a)
3.10	(c)	3.11	(a)	3.12	(b)	3.13	(b)	3.14	(a)	3.15	(c)	3.16	(c)	3.17	(c)	3.18	(d)
3.19	(c)	3.20	(a)	3.21	(b)	3.22	(a)										

Explanations Geometric Design of the Track

3.1 (b)

For BG track grade compensation is 0.04% per degree of curve. For 4° curve grade compensation will be

$= 4 \times 0.04 = 0.16\%$.

3.2 (c)

Cut and Cover Method is a method of shallow tunnel construction wherein a trench is excavated and roofed over with an overhead support system, strong enough to support the load that the tunnel is expected to carry in the future.

Loose Soils with High water table table have very low shear strength. So this method is employed in these cases so that the required depth is cut out and then refilled. Direct tunneling is not preferred as it may lead to collapse of soil.

Also in case track is at a deeper level or in case there is heavy traffic then direct tunneling is preferred over Cut and Cover Method.

3.3 (d)

Cubic parabola (Froude's curve) is the most widely used. Its equation is $y = Cx^3$

where $C = \dfrac{1}{6RL}$

R is radius of circular curve

L is total length of transition curve

3.4 (d)

Preliminary survey is called initial location survey. Detailed survey is called final location survey.

3.5 (b)

Grade compensation = $0.04 \times 3 = 0.12\%$

Permissible gradient = $\dfrac{1}{250} - \dfrac{12}{10000} = \dfrac{1}{357}$

3.6 (a)

In hilly regions, it becomes uneconomical to provide ruling gradient as the track length will be increased resulting in more excavation.

So pusher gradient is provided for steeper gradient. In that portion, a pusher engine is used for pulling the load.

3.7 (c)

Grade compensation on curves in Indian railways:

- 0.04% per degree of curve - BG track

- 0.03% per degree of curve - MG track
- 0.02% per degree of curve - NG track

3.9 (a)

Grade compensation for 2° curve

$= 0.04 \times 2 = 0.08\%$

Steepest gradient (maximum permissible gradient)

$$= \frac{1}{200} - \frac{8}{10000} = \frac{1}{238}$$

3.11 (c)

Allowable ruling gradient

$$= \frac{1}{150} - \frac{0.04 \times 4}{100} = \frac{1}{197}$$

3.12 (b)

Grade compensation of BG line

$= 0.04\%$ per degree of curve

$\therefore$ Grade compensation of 2° curve

$= 2 \times 0.04 = 0.08\%$

Ruling gradient = 1 in 200 $= \frac{1}{200} \times 100 = 0.5\%$

$\therefore$ Maximum allowable gradient

$= 0.5 - 0.08 = 0.42\%$

$$= \frac{1}{100/0.42} = \frac{1}{238}$$

3.13 (b)

The track modulus depends upon the gauge, the type of rails, the type and density of sleepers, the type of section of ballast and subgrade.

3.14 (a)

The ruling gradient is the maximum gradient on a particular section, but if a curve lies on a ruling gradient, the resistance due to gradient is increased by that due to curvature and this further increass the resistance beyong the ruling gradient. In order to avoid resistances beyond the allowable limits, the gradients are reduced on curves and this reduction in gradients is known as grade compensation for curves.

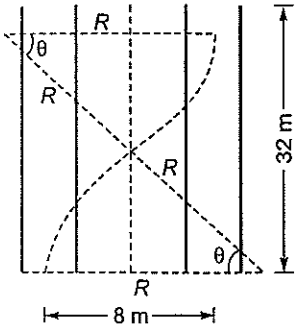
In India compensation for curvature is given at 0.04% per degree of curve for B.G., 0.03% for M.G. and 0.02% for N.G.

$\therefore$ Allowable ruling gradient after grade compensation is

$$= \frac{1}{150} - \frac{0.04}{100} \times 4$$

$= 0.0051 = 0.51\%$

3.16 (c)



Let the radius of the curves be R.

Now, as shown in the figure above we have,

$$2R\sin\theta = 32 \text{ and}$$

$$2R(1 - \cos\theta) = 8$$

$$\Rightarrow \quad \sin\theta = \frac{8}{17}$$

$$\text{So} \quad 2 \times R \times \frac{8}{17} = 32$$

$$\Rightarrow \quad R = 34 \text{ m}$$

3.17 (c)

Grade provided

= Ruling gradient - Grade compensation

= 1 in 200 – 0.04% × 2

$$= \frac{21}{5000} = 1 \text{ in } 238$$

3.18 (d)

Grade provided

= Ruling gradient – Grade compensation

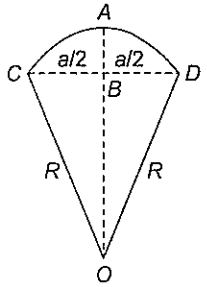
= 1 in 200 – 0.04% × 4°

$$= \frac{1}{200} - \frac{0.16}{100}$$

$= 0.34\%$

3.19 (c)

Given: Versine = $V = AB = 2$ cm, $a = 11.8$ m



$AB \times (2AO - AB) = CB \times BD$

(Property of triangle)

$$V \times (2R - V) = \frac{a}{2} \times \frac{a}{2}$$

$$2RV - V^2 = \frac{a^2}{4}$$

$$2RV = \frac{a^2}{4} \qquad (\because\ V << R)$$

$$V = \frac{a^2}{8R}$$

$$R = \frac{(11.8)^2}{8 \times 0.02} = 870.25 \text{ m}$$

3.20 (a)

$$R = \frac{1720}{3^\circ} = 573 \text{ m}$$

$$V_{max} = \sqrt{\frac{127 R\, e_{th}}{G}}$$

$$= \sqrt{\frac{127 \times 573 \times 0.176}{1.676}}$$

$$= 87.6 \text{ kmph}$$

3.21 (b)

Grade resistance + Curve resistance = Gradient resistance

$$w \tan\theta + 0.0004 \times 4^\circ \times w = \frac{w}{150}$$

$$\tan\theta = \frac{1}{150} - 0.0004 \times 4^\circ = \frac{1}{197}$$

3.22 (a)

Vertical curves in Railway tracks are set out as parabolic.

■■■■

4 Points and Crossing

4.1 Which of the following pairs are correctly matched?

1. Distance between adjoining face of running rail and check rail — Flangeway clearance
2. Distance through which the tongue rail moves laterally at the toe of switch for the movement of trains — Heel divergence
3. Distance between the gauge faces of the stock rail and tongue rail at the heel — Throw of switch
4. Angle between the gauge face of stock rail and tongue rail — Switch angle

Select the correct answer using the codes given below:

(a) 1 and 4 (b) 2 and 4
(c) 3 and 4 (d) 1, 2, 3 and 4

[ESE : 1995]

4.2 What will be the curve lead for a 1 in $8\frac{1}{2}$ turnout taking off from a straight broad gauge track?

(a) 28.49 m (b) 21.04 m
(c) 14.24 m (d) 7.45 m

[ESE : 1997]

4.3 If 'A' is the angle formed by two gauge faces, the crossing number will be

(a) tan A (b) cot A
(c) sec A (d) A rad

[ESE : 1999]

4.4 A cross-over of 1 in 10 exists between two broad gauge parallel tracks with centres at 5 m apart, the length of the straight track is

(a) 16.4 m (b) 18.4 m
(c) 19.2 m (d) 19.92 m

[ESE : 2000]

4.5 If the curve lead of a broad gauge railway turnout is 16.76 meters, the angle of crossing of the turnout will be given by

(a) $\tan^{-1} 10$ (b) $\tan^{-1} 5$
(c) $\tan^{-1} \frac{1}{10}$ (d) $\tan^{-1} \frac{1}{5}$

[ESE : 2002]

4.6 The distance between the running faces of the stock-rail and gauge face of tongue rail measured at the heel of the switch is known as

(a) flangeway clearance
(b) throw of switch
(c) heel divergence
(d) flare

[ESE : 2003]

4.7 Assertion (A): A turn-out is a combination of points and crossings, which enable a branch line to take off from another main line railway track.
Reason (R): Turn-outs are in great use in railway marshalling yards.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2005]

4.8 Consider the following statements related to interchanges:

1. In diamond interchange there is the possibility of illegal wrong-way turns.
2. Diamond interchange is far superior to cloverleaf design.

Which of these statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

[ESE : 2007]

4.9 The vertical wear on tongue rail should not exceed which one of the following?

(a) 6 mm (b) 10 mm
(c) 12 mm (d) 15 mm

[ESE : 2008]

4.10 The purpose of check rail is:
(a) To aid the flange of the opposite wheel passing through the crossing to steer clear of the nose
(b) To avoid derailment per se
(c) To help control the running speed
(d) To minimize the laying cost of long distances of trades

[ESE : 2013]

Answers Points and Crossing

4.1 (a) 4.2 (a) 4.3 (b) 4.4 (a) 4.5 (d) 4.6 (c) 4.7 (b) 4.8 (a) 4.9 (b)
4.10 (a)

Explanations Points and Crossing

4.1 (a)

Heel divergence : Distance between running faces of stock (running) rail and gauge faces of tongue rail measured at the heel of the switch.

Flangeway clearance : Distance between adjacent face of running faces of running rail and check rail.

Switch angle : Angle between the running faces of stock rail and tongue rail.

Throw of switch : Distance through which the toe of the tongue rail moves side ways.

4.2 (a)

Curve lead, $CL = 2\,GN$

$G = 1.676$ m

$\therefore \quad CL = 2 \times 1.676 \times 8.5 = 28.49$ m

4.3 (b)

There are three methods of calculating crossing number:

(i) Right Angle or Cole's Method

$N = \cot A$

This method is adopted by Indian railways.

(ii) Centre Line Method

$$N = \frac{1}{2}\cot(A/2)$$

(iii) Isosceles Triangle Method

$$N = \frac{1}{2}\operatorname{cosec}(A/2)$$

This method is important for layouts of tramways. The value of angle of crossing obtained from the right angle method is the least and hence it is the best method.

4.4 (a)

Length of track, l

$$= (D - G)\,N + G\,(4N - \sqrt{1+N^2}$$

Given $N = 10$; $D = 5$ m, $G = 1.676$ m

$$l = (5 - 1.676) \times 10 + 1.676\,(4 \times 10 - \sqrt{1+10^2})$$

$$= 83.44 \text{ m}$$

The length of straight distance $= l - 4GN$

$= 83.44 - (4 \times 1.676 \times 10) = 16.4$ m

4.5 (d)

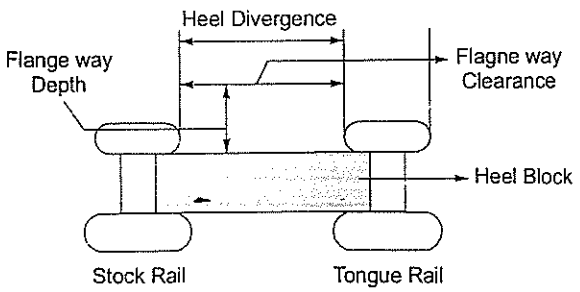
Curve lead, $CL = 2GN$

$$\therefore \quad N = \frac{16.76}{2 \times 1.676} = 5 = \cot\alpha$$

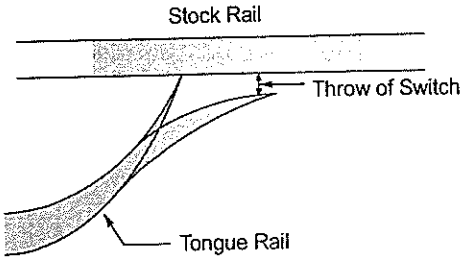
$$\therefore \text{ Angle of crossing, } \alpha = \tan^{-1}\left(\frac{1}{5}\right)$$

4.6 (c)

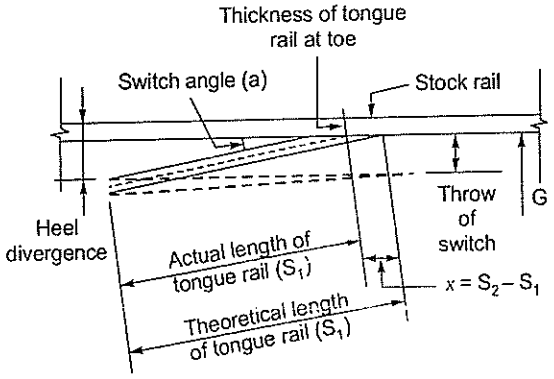
Flangeway Clearance: Distance between adjacent face of stock rail and check rail.



Heel Divergence: Distances between gauge faces of stock rail and tongue rail at the heel of the switch.



Switch angle: Angle between running faces of stock rail and tongue rail when tongue rail touches the stock rail.



Throw of Switch: Maximum distance by which the toe of tongue rail moves side way.

4.7 (b)

Marshalling yards are said to be a "Machine to receive, break up, reform and despatch trains onwards". The important functions of a Marshalling yard are as follows:

(i) Reception (ii) Sorting (iii) Departure

Since there are many sidings, so number of turnouts are provided.

4.8 (a)

Cloverleaf interchange is far superior than diamond interchange or rotary interchange. Of all the interchanges complete clover leaf interchange fulfils all the requirements of turning traffic involving the simplest traffic manoeuvers viz. diverging to the left and merging from the left by providing four indirect ramps.

■■■■

5 Track Stresses, Traction and Tractive Resistance

5.1 A train is hauled by 2-8-2 locomotive with 22.5 tonnes load on each driving axle. Assuming the coefficient of rail-wheel friction to be 0.25, what would be the hauling capacity of the locomotive?

(a) 15.0 tonnes
(b) 22.5 tonnes
(c) 45.0 tonnes
(d) 90.0 tonnes

[ESE : 1996]

5.2 The load on each axle of a locomotive is 22 tonnes. If the coefficient of friction is 0.2 then the hauling capacity due to 3 pairs of driving wheels will be

(a) 26.4 t (b) 19.8 t
(c) 13.2 t (d) 6 6 t

[ESE : 1999]

5.3 What is curve resistance for a 50 tonnes train on a BG track on a 4° curve?

(a) 0.05 tonne (b) 0.06 tonne
(c) 0.08 tonne (d) 0.10 tonne

[ESE : 2005]

5.4 A mucking operation is to be carried out by hauling trucks of 6 m^3 capacity. Further,

1. Volume of muck per blast = 60 m^3.
2. Time allotted for mucking is 60 minutes with operating efficiency = 50 minutes per hour.
3. Effective cycle time of hauling truck = 25 min.

What is the number of hauling trucks required for mucking?

(a) 3 (b) 4
(c) 5 (d) 6

[ESE : 2006]

5.5 The 'track modulus' is an index of measure of which of the following?

(a) Resistance due to friction
(b) Resistance due to shear
(c) Resistance due to deformation
(d) Resistance due to rolling

[ESE : 2008]

5.6 What is the hauling capacity of a railway locomotive, carrying an axle load of 24 tonnes each? (Assume 0.166 as the coefficient of friction)

(a) 16.5 tonnes (b) 16.0 tonnes
(c) 15.5 tonnes (d) 17.0 tonnes

[ESE : 2008]

5.7 According to the wave action for creep of rails, the pitch and depth of wave depend upon:

1. Section of rails
2. Track modulus
3. Stiffness of track
4. Stability of foundation
5. Weight of the train

Which of these are correct?

(a) 1 and 2 only (b) 1, 2 and 3
(c) 2, 3 and 4 (d) 3, 4 and 5

[ESE : 2014]

■■■■

Answers Track Stresses, Traction and Tractive Resistance

5.1 (b) 5.2 (c) 5.3 (c) 5.4 (c) 5.5 (c) 5.6 (b) 5.7 (c)

Explanations Track Stresses, Traction and Tractive Resistance

5.1 (b)

2-8-2 means 2 bogie carriers, 8 central or driving or coupled wheels and 2 rear or trailing wheels.

Thus, number of axles $= \frac{2+8+2}{2} = 6$

Number of driving axles $= \frac{8}{2} = 4$

Hauling capacity = 0.25 × 4 × 22.5 = 22.5

5.2 (c)

Hauling capacity = 0.2 × 22 × 3 = 13.1 t

5.3 (c)

Curve resistance $= \frac{0.04}{100} \times W \times D$

$= \frac{0.04}{100} \times 50 \times 4$

= 0.08 tonne

5.4 (c)

Number of cycle in one hour $= \frac{50}{25} = 2$

Volume of muck to be removed per cycle,

$= \frac{60}{2} = 30\ m^3$

Number of hauling trucks needed,

$= \frac{30}{6} = 5$

5.5 (c)

Track modulus is a measure of stiffness of the track and is defined as load per unit length of the rail, required to produce a unit depression in the track.

5.6 (b)

Hauling capacity = $\mu \times W \times n$

= 0.166 × 24 × 4

= 15.936

≈ 16 tonnes

5.7 (c)

Pitch and depth of wave is controlled the wave action. It depends upon:

- Track modulus
- Track stiffness
- Track stability

UNIT

IX

Airport, Dock , Harbour & Tunnelling Engineering

Syllabus

Airport : Layout, planning & design.

Harbour : Terminology, layouts and planning.

Tunnelling : Alignment, methods of construction, disposal of muck, drainage, lighting and ventilation.

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1 Airport, Dock, Harbour & Tunnelling Engineering

1.1 In "full face" method of constructing tunnel, the first operation relates to
(a) removal of bottom portion
(b) excavation of one drift in the centre
(c) removal of top portion
(d) excavation being done along the perimeter
[ESE : 1996]

1.2 Match List-I (Shape of tunnel) with List-II (Suitable for) and select the correct answer using the codes given below the lists:

List-I
A. Circular section
B. Horse-shoe section
C. Egg-shaped
D. Segmental-roof section

List-II
1. soft rock
2. hard rock
3. carrying water
4. sewers
5. subways

Codes:

	A	B	C	D
(a)	3	4	2	1
(b)	3	1	4	5
(c)	2	1	4	3
(d)	1	2	3	5

[ESE : 1997]

1.3 Which one of the following is considered to be an advantage of the heading and benching method of tunnel construction?
(a) It is suitable for construction in unstable rocks.
(b) In this method, it is easy to install timber support.
(c) Tunnelling can be continuous and the work can be expedited.
(d) In case of excessive water, it is easy to take corrective steps.
[ESE : 1997]

1.4 A ship is berthed in a chamber and lifted by principles of buoyancy. Such a chamber is called
(a) dry dock (b) wet dock
(c) floating dock (d) refuge dock
[ESE : 1997]

1.5 Maximum gross take-off weight of an aircraft is
(a) equal to the maximum structural landing weight
(b) less than the maximum structural landing weight
(c) more than the maximum structural landing weight
(d) equal to the empty operating weight plus the payload
[ESE : 1997]

1.6 Consider the following statements:
Wind rose diagram is used for the purpose(s) of
1. runway orientation
2. estimating the runway capacity
3. goemetric design of holding apron
Which of these statements is/are correct?
(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1 alone
[ESE : 1997]

1.7 Which of the following factors are taken into account for estimating the runway length required for aircraft landing?
1. Normal maximum temperature
2. Airport elevation
3. Maximum landing weight
4. Effective runway gradient
Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 1, 3 and 4
(c) 2 and 3 (d) 1, 2 and 4
[ESE : 1997]

1.8 **Assertion (A):** Solid fill type of wharf structure provides adequate resistance to the impact of mooring vessels, besides other advantages.
Reason (R): Solid fill structures are stable and inexpensive (except in deep water) and require little maintenance.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 1997]

1.9 Match List-I (Description) with List-II (Structure) and select the correct answer using the codes given below the lists:

List-I
A. Constructed approximately perpendicular to the shore to retard erosion of an existing beach
B. Structures that are placed parallel to the shoreline to separate the land from the water
C. Built roughly perpendicular to the shore for maintaining an entrance channel
D. Built generally parallel to the shoreline to protect a shore area

List-II
1. Jetties 2. Breakwaters
3. Seawalls 4. Groynes
5. Wharves

Codes:

	A	B	C	D
(a)	4	3	1	5
(b)	5	2	4	3
(c)	1	4	5	3
(d)	4	3	1	2

[ESE : 1998]

1.10 How many hectares of anchorage area will be required by a 181 m long ship anchored by a single anchor in a harbour of 15 m depth?
(a) 12 (b) 16
(c) 18 (d) 20

[ESE : 1998]

1.11 On which of the following factors will the selection of the type of Groyne depend?
1. Availability of material
2. Foundation condition
3. Presence or absence of marine borers
4. Topography of the beach
5. The height, period and angle of attack of approaching waves

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 2, 3, 4 and 5
(c) 1 and 2 (d) 5 alone

[ESE : 1998]

1.12 Match List-I (Shape of tunnel) with List-II (Attribute for preference) and select the correct answer using the codes given below the lists:

List-I
A. Horse-shoe section
B. Circular
C. Egg-shaped
D. Segmental roof section

List-II
1. Gives self-cleaning velocity even in dry weather flow
2. Suitable for soft rocks
3. Best suited for non-cohesive soils
4. Suitable for soft materials
5. Suitable for sub-bays

Codes:

	A	B	C	D
(a)	2	3	4	5
(b)	5	4	1	3
(c)	3	2	4	1
(d)	2	3	1	5

[ESE : 1998]

1.13 In an airport, if 4 groups of 5 gates each located well-separated are considered for traffic and the future-to present traffic ratio is 3, then the total requirement of future gates will be
(a) 32 (b) 36
(c) 44 (d) 68

[ESE : 1998]

1.14 Castor angle is defined as the angle
(a) formed by the longitudinal axis of the aircraft and the direction of movement of the nose gear.
(b) between the direction of wind and the longitudinal axis of the runway.
(c) between the true speed of the aircraft and the crosswind component.
(d) between the horizontal and the fuselage axis.

[ESE : 1998]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A

(b) both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

1.15 **Assertion (A):** The open type of wharf substructure is expensive in deep-water locations where, however, a low-level super-structure is required.

Reason (R): Open type of wharf substructure offers little restriction to water movements; hence it can be used to support piers in rivers and coastal areas alike.

[ESE : 1998]

1.16 **Assertion (A):** Wind data are reported with the true north as the reference, while the runway orientation is cited relative to the magnetic azimuth.

Reason (R): The true azimuth obtained from the wind rose analysis should be changed to the corresponding magnetic azimuth.

[ESE : 1998]

1.17 Consider the following factors:

1. Size and type of ship served
2. Availability of materials
3. Wharf configuration
4. Mooring procedures

The spaces required alongside a wharf for berthing would depend upon factors

(a) 1, 2 and 4 (b) 2, 3 and 4

(c) 1, 2 and 3 (d) 1, 3 and 4

[ESE : 1999]

1.18 Which one of the following is a component of a shield for tunnelling?

(a) Liner plate (b) Trench jack

(c) Stiffener (d) Cutting edge

[ESE : 1999]

1.19 The runway length after correcting for elevation and temperature is 2845 m. If the effective gradient on runway is 0.5 per cent, the revised runway length will be

(a) 2845 m (b) 2910 m

(c) 3030 m (d) 3130 m

[ESE : 1999]

1.20 The phenomenon of movement and deposition of sand in a zig-zag style due to drifting of sand in the vicinity of coast is called

(a) littoral drift (b) sedimentation

(c) beach drift (d) trough action

[ESE : 2000]

1.21 Match List-I (Structure) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I

A. Breakwater

B. Wharf

C. Fender system

D. Revetments

List-II

1. Separates the land from sea water
2. Lays vessels alongside, receives and discharges cargo and passengers
3. Protects a seashore
4. Absorbs the energy of the moving vessel
5. Retards erosion of an existing beach

Codes:

	A	B	C	D
(a)	5	2	4	3
(b)	3	4	2	1
(c)	3	2	4	1
(d)	1	4	3	5

[ESE : 2000]

1.22 The lowest tide which occurs in half lunar month is called

(a) spring tide (b) neap tide

(c) lunar tide (d) tidal bore

[ESE : 2000]

1.23 Which one of the following methods of tunneling is used in hard rock?

(a) Forepoling method

(b) Needle beam method

(c) Heading and benching method
(d) Shield tunnelling method

[ESE : 2000]

1.24 Match List-I with List-II with reference to airport engineering and select the correct answer using the codes given below the lists:

List-I	List-II
A. PNB	1. Noise level
B. LCN	2. Visual range
C. STOL	3. Airport pavement evaluation
	4. Type of aircraft

Codes:

	A	B	C
(a)	1	3	4
(b)	1	4	3
(c)	4	2	1
(d)	2	3	4

[ESE : 2000]

1.25 For a runway at an elevation of 1000 m above MSL and airport reference temperature of 16°C, the rise in temperature to be taken into account as per ICAO is
(a) 24.5°C (b) 15°C
(c) 7.5°C (d) 6°C

[ESE : 2000]

1.26 **Assertion (A):** Scissor crossing is provided where space does not permit provision of two separate crossovers.
Reason (R): A scissor crossing consists of four pairs of switches, six acute angle crossings and four obtuse angle crossings and check rails.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2000]

1.27 Tunnel alignment is carried out by
(a) surface theodolite traverse
(b) triangulation
(c) compass traverse
(d) aerial photography

[ESE : 2001]

1.28 With reference to tunnelling, which of the following factors are to be considered for deciding the size of the shaft?
1. System used for hoisting
2. Size of the muck car
3. Quantity of muck to be lifted
4. Eventual use of the shaft

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 1 and 4
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

[ESE : 2001]

1.29 In deep water waves, individual particles
(a) are translated
(b) are translated and rotated in a vertical plane about a horizontal axis
(c) are not translated, but they rotate in a vertical plane about a horizontal axis
(d) do not rotate in a vertical plane about a horizontal axis

[ESE : 2001]

1.30 A surface longitudinally centered on the extended runway centre line and extending outward and upward is called
(a) primary surface
(b) conical surface
(c) horizontal surface
(d) approach surface

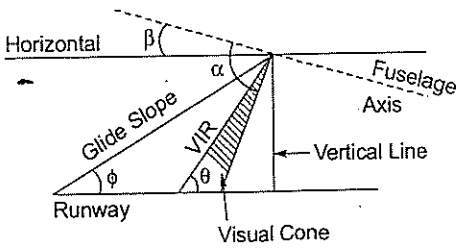
[ESE : 2001]

1.31 Which of the following factors are to be taken into consideration while designing the taxiway system?
1. Volume of air traffic
2. Runway configuration
3. Location of terminal building
4. Location of hangars

Select the correct answer using the codes given below:
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 4 (d) 1, 2, 3 and 4

[ESE : 2001]

1.32 In the figure shown below, "cockpit cut-off angle" is the angle labelled



(a) α (b) β
(c) ϕ (d) θ

1.33 Assertion (A): The most common approach for control of beach erosion is to build groynes.
Reason (R): Groynes are constructed parallel to the shore.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2001]

1.34 Consider the following factors:
1. Mass of ships to be berthed
2. Overall transit time
3. Speed of berthing
4. Environmental conditions of the port

Which of these factors are taken into account while selecting the type of fender system?
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1 and 4

[ESE : 2002]

1.35 Which one of these methods of Tunnel Construction is not suitable in rocks?
(a) Full face method
(b) Compressed air method
(c) Heading and benching method
(d) Drift method

[ESE : 2002]

1.36 Consider the following factors:
1. Air traffic control measures
2. Aircraft traffic composition
3. VFR/IFR operation
4. Runway configuration

Which of these factors affect the capacity of a runway?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 4 (d) 1, 2, 3 and 4

[ESE : 2002]

1.37 Match List-I (Imaginary surface) with List-II (Characteristic) and select the correct answer using the codes given below the lists:

List-I
A. Conical
B. Approach
C. Primary
D. Transitional

List-II
1. Longitudinally centered on a runway
2. Longitudinally centered on the extended runway
3. Extending outward and upward from the periphery of the horizontal surface
4. Extending outward and upward at right angles to the runway center line

Codes:

	A	B	C	D
(a)	3	1	2	4
(b)	4	2	1	3
(c)	3	2	1	4
(d)	4	1	2	3

[ESE : 2002]

1.38 Assertion (A): The principal advantage of the solid fill type of wharf substructure is that its great mass provides adequate resistance to the impact of mooring ships.
Reason (R): Solid fill substructures are inexpensive (except in deep water) and require little maintenance.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2002]

1.39 Match List-I (Track parameter) with List-II (Equipments used) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Unevenness	1. Track recording car
B. Gauge	2. Amsler car
C. Superelevation	3. Feeler and spring
D. Alignment	4. Gyroscopic pendulum

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	3	2	1	4
(c)	2	3	4	1
(d)	3	2	4	1

[ESE : 2003]

1.40 Match List-I (Tunnel construction methods) with List-II (Advantages) and select the correct answer using the codes given below the lists:

List-I

A. Full face method
B. Heading and Benching method
C. Drift method
D. Compressed air method

List-II

1. Helps in ventilation of tunnel
2. Useful in soft and water-bearing soil
3. Simultaneous drilling and mucking is possible
4. Tunnelling is continuous

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	3	4	1	2
(c)	4	3	1	2
(d)	3	4	2	1

[ESE : 2003]

1.41 The monthly mean of maximum daily temperature and monthly mean of average daily temperature of the hottest month of the year are 49°C and 40°C respectively. Then airport reference temperature is

(a) 43°C (b) 69.6°C
(c) 37°C (d) 52°C

[ESE : 2003]

1.42 Which one of the following imaginary surface in airport is circular in plan with centre located at an elevation of 150 m above the airport reference point?

(a) Conical surface
(b) Transitional surface
(c) Inner horizontal surface
(d) Outer horizontal surface

[ESE : 2003]

1.43 Consider the following four components in an Instrumental Landing System:

1. Threshold lights
2. Glide slope antenna
3. 'Z' markers
4. Localizer antenna

These components are installed in the direction of landing in the sequence

(a) 4-2-3-1 (b) 1-4-3-2
(c) 3-1-2-4 (d) 2-3-4-1

[ESE : 2003]

1.44 Assertion (A): Wet docks are enclosed or partially enclosed basins provided with locks and entrance gates to keep the water at fairly constant level for allowing vessels to come in, berth or leave at all times.

Reason (R): Wet docks require expensive arrangements like lock gate and the walls are designed to withstand backfill pressure when the dock is full.

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2003]

1.45 The orientation of preferential runway in an airport is influenced by

(a) direction of prevailing wind, adequate length, obstruction-free landing and take-off zones
(b) adequate waiting and service facilities
(c) convenience of terminal and control facilities
(d) stable ground and adequate turning space

[ESE : 2004]

1.46 Consider the following aircraft operations:

1. Normal landing
2. Normal take-off with all engines
3. Engine failure at take-off
4. Emergency landing with all engines shut
5. Landing with maximum payload with the help of ILS

Which of the above aircraft operations are taken into consideration in deciding the basic runway length required for an aircraft?

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 3, 4 and 5 (d) 1 and 5

[ESE : 2004]

1.47 Match List-I (Method) with List-II (Suitability) and select the correct answer using the codes given below the lists:

List-I

A. Full face method
B. Heading and Bench method
C. Drift method
D. American method

List-II

1. For tunneling of large cross-section area through soft ground driving a top drift and then widening the sides
2. For rock tunneling carried out first in smaller section of the proposed tunnel and then widened.
3. For driving the top portion in advance of the bottom portion for very large tunnel section in unstable rocks.
4. For tunneling of small cross-section area in stable rock attacking the whole section at a time.

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	4	3	2	1
(c)	4	1	2	3
(d)	2	3	4	1

[ESE : 2004]

1.48 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Dynamometer car
B. Crossing station
C. Ruling gradient
D. Turn table

List-II

1. Arrangement for turning the direction of an engine
2. Information about condition of railway track
3. Station on a single railway track system where Up and Down trains can pass each other
4. Maximum rising gradient of railway track depending on engine power.

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	2	3	4	1
(c)	3	2	4	1
(d)	3	2	1	4

[ESE : 2004]

Directions: The following items consists of two statements; one labelled as 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

1.49 Assertion (A): Open cut is economical than tunnelling for depths of over burden less than 20 metres.

Reason (R): Heading and Bench method is suitable for tunnelling in soft soils.

[ESE : 2004]

1.50 Assertion (A): Breakwaters are common in natural harbours.

Reason (R): Breakwaters help in controlling wave action and sand movement into the harbour area.

[ESE : 2004]

1.51 Which one of the following is the best method for locating soundings to estimate the dredged material form the harbours?

(a) Two angles from shore
(b) Two angles from boat
(c) One angle from shore and other from the boat
(d) Fixed intersecting ranges

[ESE : 2005]

1.52 Which one of the following gives the number of gate positions in an airport?

(a) $\frac{\text{Capacity of runway}}{60\times 2}\times$ average gate occupancy time

(b) $\frac{\text{Capacity of apron}}{60\times 2}\times$ number of aircraft movements

(c) $\frac{\text{Capacity of taxiway}}{60\times 2}\times$ average gate occupancy time

(d) $\frac{\text{Capacity of holding apron}}{60\times 2}\times$ average gate occupancy time

[ESE : 2005]

1.53 Match List-I (Unit) with List-II (Purpose) and select the correct answer using the code given below the lists:

List-I

A. Width and length of safety area of airport
B. Engine failure case

C. Location of exit taxiways
D. Grading of airport size

List-II
1. Basic runway length
2. Runway geometric design
3. Airport drainage
4. Runway capacity

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

[ESE : 2005]

1.54 Why are moorings provided?
(a) For anchoring of ships
(b) For towing the ships to the sea
(c) For repair of ships
(d) For washing of ships and ship boards
[ESE : 2005]

1.55 What is the use of a station pointer?
(a) For making soundings in water bodies
(b) For plotting of soundings in harbour area
(c) For marking sunken shipping hazards
(d) For making tidal observations
[ESE : 2005]

1.56 Consider the following statements:
1. Dock is a marine structure for mooring up vessels, loading and unloading of passengers and/or cargo.
2. Dry dock is generally used only for carrying out repairs, inspections and painting.
3. Wet dock is an enclosed or partially enclosed basin provided with locks and entrance gate to keep the water level at a fairly constant level.

Which of these statements are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 2 (d) 1 and 3
[ESE : 2005]

1.57 The percentage of time in a year during which the cross wind component remains within the limit, is
(a) wind coverage (b) head wind
(c) prevailing wind (d) cross wind
[ESE : 2005]

1.58 At a certain station, the mean of the average temperature is 25°C and mean of the maximum daily temperature is 40°C. What is the airport reference temperature (ART)?
(a) 46.6°C (b) 45°C
(c) 35°C (d) 30°C
[ESE : 2005]

1.59 Consider the following statements with respect to tunnelling methods:
1. Full face excavation is suitable for small size tunnel of short length in competent rock. It is not suitable in urban areas.
2. Heading and benching method is suitable for soft rock tunneling of medium size.
3. Drift method is suitable for large tunnels in difficult or incompetent rock.

Which of these statements are correct?
(a) 1 and 3 (b) 1, 2 and 3
(c) 2 and 3 (d) 1 and 2
[ESE : 2005]

1.60 A runway is located 450 m above the mean sea level. If the aeroplane reference field is 1800 m, what is the approximate corrected runway length for elevation?
(a) 1849 m (b) 1889 m
(c) 1987 m (d) 2013 m
[ESE : 2006]

1.61 For design of a runway length, match List-I (Factor) with List-II (Correction) and select the correct answer using the codes given below the list:

List-I
A. Standard basic length
B. Elevation
C. Temperature
D. Effective gradient

List-II
1. 7% for every 303 metres
2. 0.5%
3. 20% for each 1% gradient
4. Depends upon aircraft and obtained from ICAO Standard Tables

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

[ESE : 2006]

1.62 If M_i = Proportion of i^{th} type of aircraft in the mix,
T_i = "Gate occupancy time" of the i^{th} type of aircraft,
G = Number of gates (considering that all the available gates can be used by all aircrafts).
Which one of the following equations gives the ultimate gate capacity C?

(a) $C = \dfrac{\sum_{i=1}^{n} G \times M_i}{\sum_{i=1}^{n} T_i}$ (b) $C = \dfrac{G \times 60}{\sum_{i=1}^{n} M_i T_i}$

(c) $C = \sum_{i=1}^{n} \left(\dfrac{M_i}{G}\right) \times T_i$ (d) $C = \dfrac{G}{\sum_{i=1}^{n} M_i \times T_i}$

[ESE : 2006]

1.63 The total correction percentage for altitude and temperature, in calculating the runway length from basic runway length, normally does not exceed
(a) 7 (b) 14
(c) 28 (d) 35
[ESE : 2006]

1.64 Which one of the following methods is generally considered the best for tunnel ventilation?
(a) Driving a drift through the tunnel
(b) 'Blow in' method
(c) 'Blow out' method
(d) Combination of 'Blow in' and 'Blow out' methods
[ESE : 2007]

1.65 Which one of the following is not related to theories of creep of rails?
(a) Wave theory
(b) Percussion theory
(c) Drag theory
(d) Reversal theory
[ESE : 2007]

1.66 Which one of the following is not correct for container ports?
(a) The berth capacity is great
(b) Overall transit time is less
(c) There is minimal damage to cargo
(d) Minimal land is required for the marshalling area
[ESE : 2007]

1.67 Consider the following statements associated with groynes:
1. Hydraulic behaviour of a system of groynes is influenced by the characteristics of particles that constitute the littoral drift.
2. Groyne is constructed approximately parallel to shore.
Which of these statements is/are correct?
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2
[ESE : 2007]

1.68 What is the wave velocity for a uniform train of wave beyond the storm centre for a wave length of 20 m in 14 m deep water?
(a) 5.5 m/s (b) 11.2 m/s
(c) 4.5 m/s (d) 9 m/s
[ESE : 2007]

1.69 As the elevation increases, the runway length has to be changed at what rate?
(a) Decreased @ 5% per 300 m rise in elevation above MSL
(b) Increased @ 7% per 300 m rise in elevation above MSL
(c) Decreased @ 9% per 300 m rise in elevation above MSL
(d) Increased @ 15% per 300 m rise in elevation above MSL
[ESE : 2007]

1.70 Which one of the following methods of tunnelling is employed if the strata is sub-aqueous?
(a) Shield tunnelling
(b) Drift system
(c) Liner plate method
(d) Pilot tunnel method
[ESE : 2008]

1.71 Weisbach Triangle method may be used for which one of the following?
(a) To carry out surface alignment of a tunnel
(b) To transfer levels underground for a tunnel
(c) To connect surface and underground tunnel surveys
(d) To connect two ends of an underground tunnel
[ESE : 2008]

1.72 How can additional access, quick removal of muck and natural ventilation in long tunnels be achieved?

(a) By providing jumbos and pumps
(b) By providing scaffolding and liner plates
(c) By providing adits and shafts
(d) By providing pilot tunnels and well points

[ESE : 2008]

1.73 Match List-I (Harbour structure) with List-II (Purpose) and select the correct answer using the codes given below the lists:

List-I
A. Dolphins
B. Groynes
C. Fenders
D. Slipways

List-II
1. To protect the beach or retained earth
2. To cushion to absorb shock of ship during loading and un-loading
3. Mooring structure in combination with loading platform
4. Repairing and building ship

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	3	1	2	4
(c)	2	1	3	4
(d)	3	4	2	1

[ESE : 2008]

1.74 What is the minimum turning radius for a passenger ship?
(a) 2 × ship length
(b) 3 × ship length
(c) (1.5 × ship length) + water depth
(d) (2 × ship length) + (1.5 × draft)

[ESE : 2008]

1.75 Which of the following pairs are correctly matched?
1. Vishakhapatnam and Plymouth—Seminatural harbour
2. Paradip and Mangalore —Lagoon harbour
3. New York—Natural harbour

Select the correct answer using the codes given below:
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

[ESE : 2008]

1.76 Echo-sounding machine is used for which of the following?
1. Locating objects on sea-shore
2. Measuring sea-surface levels
3. Determining depth of sea-bed below sea surface
4. Locating sunken objects below sea surface

Select the correct answer using the codes given below:
(a) 1 and 3 only (b) 1, 2 and 3
(c) 2 and 4 (d) 3 and 4

[ESE : 2008]

1.77 Match List-I (Components) with List-II (Function) and select the correct answer using the codes given below the lists:

List-I
A. Keel and Bilge blocks
B. Capstons and Bolards
C. Fenders
D. Buoys

List-II
1. Impact absorbers of quay walls
2. Floating indicators
3. Supports for ships in dry docks
4. Anchorage devices for ships

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	1	2
(c)	4	3	2	1
(d)	3	4	2	1

[ESE : 2008]

1.78 Mean sea level at Indian ports and harbours has generally been established based on the analysis of tidal sea level fluctuations over which period?
(a) 10 years (b) 16 years
(c) 19 years (d) 25 years

[ESE : 2008]

1.79 The orientation of runway is decided by which factors?
1. Maximum wind coverage and least cross winds
2. Landing characteristics of aircrafts
3. Scope for future expansion
4. Obstruction-free approaches

Select the correct answer using the codes given below:
(a) 1 and 2 only (b) 1, 2 and 3
(c) 1, 3 and 4 (d) 2, 3 and 4
[ESE : 2008]

1.80 The size of hangar in airport is guided by which of the following?
(a) Speed and direction of wind and visibility
(b) Weight of aircraft and turning needs
(c) The fuelling capacity and storage space
(d) The length, wingspan and height of aircraft
[ESE : 2008]

1.81 Match List-I (Component) with List-II (Design feature) and select the correct answer using the codes given below the lists:

List-I
A. Taxiways
B. Control tower
C. Hangar
D. Apron

List-II
1. Large span structures
2. Visibility allround and sound-proof
3. Turning radius
4. Waiting capacity for aircraft

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	3	2	1	4
(c)	1	2	3	4
(d)	3	4	1	2

[ESE : 2008]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

1.82 **Assertion (A):** Wind Rose Diagrams, showing wind direction, duration and intensity are an essential requirement for planning the best direction of main runway of the airport.
Reason (R): Corrections for elevation temperature and gradient have to be applied to determine the length of the main runway of an airport, as per ICAO recommendations.
[ESE : 2008]

1.83 **Assertion (A):** Runway capacity will be more in airport operating under VFR than IFR.
Reason (R): VFR gives more clear visual reference of airport during good weather conditions.
[ESE : 2008]

1.84 **Assertion (A):** When a turnout is taken off from a curved track, it is called gauntlet track.
Reason (R): When a turnout from a curved track turns away in the opposite direction, the curves are said to be of contrary flexure.
[ESE : 2009]

1.85 **Assertion (A):** In case of airports, the innermost portion of approach zone, where any obstruction is to be critically viewed, is known as the clear zone.
Reason (R): The area of airport, other than the approach zone, which is used for turning of aircrafts, is called the turning zone.
[ESE : 2009]

1.86 **Assertion (A):** Helipads are usually located in close proximity to traffic-generating areas.
Reason (R): A helicopter cannot ascend or descend exactly vertically.
[ESE : 2009]

1.87 With a bit rate of 50 bps and a cycle time of 30 seconds the total information content of a navigation data set is
(a) 80 bits (b) 20 bits
(c) 100 bits (d) 1500 bits
[ESE : 2009]

1.88 Zigzag deposition and movement of sand on sea beach is called
(a) littoral drift (b) beach drift
(c) trough action (d) sedimentation
[ESE : 2010]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the

other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

1.89 **Assertion (A):** The pandrol clip is a fit and forget type of fastening and is made from silicon manganese spring steel bar and heat treated.
Reason (R): The pandrol clip has a point contact and causes indentation on the rail due to heavy toe load and small contact area.
[ESE : 2010]

1.90 **Assertion (A):** In the overall design and layout of a harbour (or port), differentiation is made between 'entrance' and 'channel' depths.
Reason (R): The 'scend' (or pitching) of a vessel may be larger at the entrance to the channel than within the channel.
[ESE : 2010]

1.91 **Assertion (A):** The paved area adjacent to the terminal building and hangers used for loading and unloading, servicing and parking of aircraft is called as apron.
Reason (R): The size of the apron depends on the size and number of gate positions and the way the gate positions are arranged.
[ESE : 2010]

1.92 Wind-rose diagram is useful in deciding on the orientation of
(a) Taxiway (b) Hanger
(c) Apron (d) Runway
[ESE : 2011]

1.93 Which of the following complete sets do not recommend the siting of a harbour layout in that vicinity?
1. Submarine canyon
2. Lee of an island
3. Closely located promontories
4. Indentation coves on the coastline
5. Hooked bays with not-so-rugged rocky bottom

(a) 2, 3, 4 and 5 (b) 1, 4 and 5 only
(c) 2, 3 and 4 only (d) 3, 4 and 5 only
[ESE : 2011]

1.94 For safe landing and take-off, the following factors need to be carefully considered:
1. Cross-wind
2. Runway grade
3. Runway width and side clearance
4. Obstructions

(a) 1, 2 and 3 only (b) 1, 2, 3 and 4
(c) 1, 3 and 4 only (d) 2, 3 and 4 only
[ESE : 2011]

1.95 Overland flow drainage on and from the tarmac of an airport invokes, in its design principles involving:
(a) Spatially varied flow without hydraulic jumps
(b) Backwater flow
(c) Subcritical flow throughout
(d) Attention to rolling flows within spatially varied flows and possibly to moving hydraulic jumps
[ESE : 2011]

1.96 **Statement (I):** The actual payload, particularly in passenger aircraft, is normally less than the maximum structural payload even when the aircraft is completely full.
Statement (II): There are limitations in the use of space when passengers are carried in an aircraft.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true
[ESE : 2013]

1.97 The lowest height above the runway where the pilots make the decision to continue the landing manoeuvre to cut it short is called the
(a) Runway height
(b) Decision height
(c) Threshold height
(d) Runway visual range
[ESE : 2015]

1.98 The runway length for an airport located at 460 m above MSL, corrected for elevation, is 3670 m. The monthly means of maximum and mean daily temperatures for the hottest month of the year are 27°C and 18°C, respectively. What will be the final corrected length of the runway with correction incorporated also due to temperature effects?

(a) 4500 m (b) 4000 m
(c) 3750 m (d) 3400 m

[ESE : 2015]

1.99 What shall be the radius of an exit taxiway with design exit speed of 90 kmph and coefficient of friction 0.13?

(a) 550 m (b) 500 m
(c) 475 m (d) 449 m

[ESE : 2015]

■■■■

Answers Airport, Dock , Harbour and Tunnelling Engineering

1.1 (d)	1.2 (b)	1.3 (a)	1.4 (c)	1.5 (c)	1.6 (d)	1.7 (d)	1.8 (b)	1.9 (a)	
1.10 (d)	1.11 (a)	1.12 (d)	1.13 (d)	1.14 (a)	1.15 (b)	1.16 (b)	1.17 (c)	1.18 (d)	
1.19 (d)	1.20 (a)	1.21 (c)	1.22 (a)	1.23 (c)	1.24 (a)	1.25 (c)	1.26 (c)	1.27 (b)	
1.28 (d)	1.29 (d)	1.30 (d)	1.31 (d)	1.32 (a)	1.33 (c)	1.34 (c)	1.35 (b)	1.36 (d)	
1.37 (c)	1.38 (b)	1.39 (c)	1.40 (c)	1.41 (a)	1.42 (d)	1.43 (c)	1.44 (b)	1.45 (a)	
1.46 (a)	1.47 (b)	1.48 (b)	1.49 (c)	1.50 (d)	1.51 (d)	1.52 (a)	1.53 (c)	1.54 (a)	
1.55 (b)	1.56 (a)	1.57 (a)	1.58 (d)	1.59 (d)	1.60 (c)	1.61 (a)	1.62 (d)	1.63 (d)	
1.64 (d)	1.65 (d)	1.66 (a)	1.67 (a)	1.68 (b)	1.69 (b)	1.70 (c)	1.71 (d)	1.72 (c)	
1.73 (b)	1.74 (a)	1.75 (d)	1.76 (d)	1.77 (a)	1.78 (c)	1.79 (c)	1.80 (d)	1.81 (b)	
1.82 (b)	1.83 (a)	1.84 (d)	1.85 (b)	1.86 (c)	1.87 (d)	1.88 (a)	1.89 (b)	1.90 (a)	
1.91 (b)	1.92 (d)	1.93 (d)	1.94 (c)	1.95 (a)	1.96 (b)	1.97 (d)	1.98 (b)	1.99 (b)	

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1.1 (d)

Excavation of small sized heading (drift) is done centrally at top or bottom of the face in the drift method.

In heading and benching method the top portion is driven in advance of the bottom portion.

In full face method the whole section is excavated once for all. It is suitable for tunnels of small cross-sections area say up to 3 m diameter.

1.2 (b)

Circular section can withstand pressure caused by water, water bearing soils or soft grounds. It is best suitable for sewers and water carrying purposes.

Horse-shoe section has a semi circular roof together with arched sides and a curved invert. It also is suitable for carrying water or sewage. The section is found to be most suitable for soft rocks. This shape is commonly used for highways and railway tunnels.

Egg shaped section is commonly used for carrying sewage because it gives self cleansing velocity even in dry weather flow.

D-section or segmental roof section is suitable in hard rock for sub-ways or navigation channels.

1.3 (a)

Heading and benching method is used when the tunnel section is very large and quality of rock is

not very satisfactory i.e., the rock is unstable. In self supporting rocks, the top heading advance are round ahead of the bottom heading. In unstable (broken or non self supporting rocks), the bench provides platform for timber supports to the heading.

1.4 (c)

Docks or wet docks or tidal basins are enclosed and are shut off by entrances or locks to maintain a uniform level of water and basins are partially enclosed areas of water.

Dry docks are repair docks. These are long, excavated chamber, having side walls, a semi circular end wall and a floor.

A floating dry clock is a floating vessel which can lift a ship out of water and retain it above water by means of its own buoyancy.

1.5 (c)

Maximum gross take off weight is the maximum load that the aircraft is certified to carry during take off and the airport pavement are designed for this weight.

Maximum structural landing weight is the difference between the gross take off weight and the weight of fuel consumed during the trip. The main gear of an aircraft is designed to support the maximum structural weight because such situations rarely occur. Operating empty weight includes the weight and all necessary gear required for flight.

Payload is the total revenue producing load. Thus it includes the weight of passengers and their baggage, mail and cargo.

Operating empty weight + Aircraft weight
= Payload + Trip fuel + Fuel reserve

The weight of an aircraft on landing
= Operating empty weight + Payload
+ Fuel reserve

This should not exceed maximum structural landing weight.

Take off weight = Landing weight + Trip fuel

This should not exceed the maximum gross take off weight of the aircraft.

1.6 (d)

The runway is usually oriented in the direction of the prevailing winds. During landing it provides breaking effect and the aircraft comes to a stop in a short length of the runway. During take off, it provides greater lift on the wings of the aircraft.

1.7 (d)

The basic runway length is determined from the performance characteristics of the aircraft using the airport. The following cases are usually considered :

(i) Normal landing case requires that aircraft should come to a stop within 60% of the landing distance.
(ii) Normal take-off case requires a clearway
(iii) Engine failure case may require either a clearway or a stopway or both.

The basic length is corrected for (in the same order):

(i) Elevation at the rate of 7% for every 300 m rise in elevation of airport above the MSL.
(ii) Temperature at the rate of 1% for every 1°C rise in airport reference temperature above the standard atmospheric temperature at that elevation.
(iii) Gradient at the rate of 20% for every 1% of the effective gradient.

1.8 (b)

A wharf or quay is a structure on the shore of a harbor or on the bank of a river or canal where ships may dock to load and unload cargo or passengers. Solid fill type provides bearing strength and stability and offers adequate resistance impact mooring vehicles but in deep water construction is difficult as well as expensive.

1.9 (a)

Groynes are structures built to protect beach or retard erosion of an existing or resorted beach by trapping of littoral drift. They are usually made perpendicular to shoreline.

Sea-walls, bulkheads and revetment are the structures constructed parallel to shore-line to develop a demarcating line between land area and water area.

Jetties are piled projection and they are built out from the shore to deep water. They are provided at places where harbour entrance is affected by littoral drift or the sea is shallow for a long distance.

1.10(d)

Anchorage area is a place where ships may be held for quarantine inspection, await docking space or await favourable weather condition. The water area required for an anchorage depends upon number, type and size of vessels.

The anchorage area is calculated as the area of the circle having radius

$R = 4 \times$ depth of water + length of ship + safe clearance to adjacent ship

$= 4 \times 15 + 181 + 12 = 253$ m

So area $= \pi R^2 \simeq 20$ ha

1.11 (a)

Type of groynes does not depend on height, period or angle of attack of approaching wave.

1.12 (d)

Circular section: best suitable for non-cohesive soils and for tunnels driven by shield-method.

Horse shoe section: When lined, this cross section offers good resistance external ground pressure and serves to combine the advantages of both the D-shaped and circular sections. This section is found to be most suitable for soft rocks.

Egg shaped section is used in sewage flow because it gives self cleansing velocity even in dry weather flow.

Segmental roof section is suitable for sub-bays.

1.13(d)

Gate is the parking space for an aircraft.

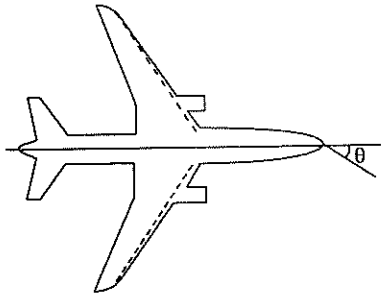
Number of Gate positions

$$= \frac{\text{Capacity of runway}}{60 \times 2} \times \text{average gate occupancy time}$$

For the present traffic $4 \times 5 = 20$ gates are needed. Therefore for future traffic (three times present traffic) 60 gates will be required. In addition some aircrafts will have higher occupancy time in future as they will be very big compared to the present traffic composition. Therefore 68 gates will be the correct choice.

1.14 (a)

Castor angle is the angle formed between the longitudinal axis of aircraft and direction of movement of nose gear.



1.15(b)

There are two types of wharf structures:

(i) Vertical face structures or closed on solid structures.
   (a) Block wall
   (b) Caisson
   (c) Cellular bulk head
   (d) Sheet pile walls

(ii) Open structures with decks supported by piles or cylinders.
   (a) High level docks
   (b) Relieving type platforms in which structural slab is below finished deck and space between is filled to provide additional weight for stability.

Solid type structures are quite commonly used where the depth of water does not exceed 16 m and the bottom conditions are suitable for the support of gravity type structures.

Open type wharf structures are used for deep water and the wharf structures are used for deep water and they have more favourable overall stability properties because of the lack of fill near its front.

1.16 (b)

Wind direction is measured with true north as reference and runway orientation is cited relative to magnetic azimuth.

True azimuth should be changed to magnetic azimuth by taking into account magnetic variation for airport location.

1.17 (c)

Mooring procedures involve many complexities and careful consideration will need to be made for safe berthing and unberthing from ports. These are irrelevant while determining spaces required alongside wharf for berthing.

1.18 (d)

The cutting edge grinds the hard rock or slice into soil in the tunnel face by chisel-shaped cutting teeth. Other components of shield are: skin plate, hood, port holes, tail and propelling jack.

1.19 (d)

For every 1% effective gradient, runway length should be increased by 20%. For 0.5% gradient the increase should be 10%.

So runway length = 2845 × 1.1

= 3129.5 = 3130 m.

1.20 (a)

Littoral drift is a geographical process that consists of the transportation of sediments (clay, silt, sand and shingle) along a coast at an angle to the shoreline in a zig-zag style, which is dependent on prevailing wind direction, swash and backwash. This process occurs in the littoral zone, and in or close to the surf zone. The process is also known as longshore drift, longshore current or longshore transport.

1.21 (c)

Breakwaters are structures constructed on coasts as part of coastal defense or to protect an anchorage from the effects of both weather and longshore drift wharf is a structure built on the shore of or projecting into a harbor, stream, etc., so that vessels may be moored alongside and cargos and passengers can be received and discharged.

Fender is a bumper used to absorb the kinetic energy of a boat or vessel berthing against a jetty, quay wall or other vessel.

Revetments are usually built to separate land from sea water, to preserve the existing uses of the shoreline and to protect the slope, as defense against erosion.

1.22 (a)

Spring tides occur usually at new and full moon or rather a day or two after (or twice in each lunar month). At new moon, the sun and moon have the same celestial longitude and cross a meridian of the earth at the same instant. The sun and moon are on same side of the earth. The high water level of the resulting tide is above the average, whereas the low water level is below the average.

During neap tide, the moon falls behind the sun. High water level is below the average, whereas the low water level is above the average.

1.23 (c)

Methods of tunneling in hard rock

(i) Drift method
(ii) Heading and benching method
(iii) Full face method
(iv) Cantilever car dump method
(v) Pilot tunnel method
(vi) Perimeter method or German method.

Methods of tunneling in soft soil

(i) Forepoling method
(ii) Needle beam method
(iii) Army method or case method
(iv) American method
(v) English method
(vi) Belgian method
(vii) German method
(viii) Austrian method
(ix) Linear plates method
(x) Shield tunnelling method

1.24 (a)

PNB: Perceived Noise Level Intensity
LCN: Load Classification Number
STOL: Short Take off and Landing

1.25 (c)

The standard temperature at the airport site can be determined by reducing the standard mean sea level temperature of 15°C at the rate of 6.5°C per thousand metre rise in elevation.

Standard temperature = 15 – 6.5 = 8.5°C

Rise in temperature = 16 – 8.5 = 7.5°C

1.26 (c)

The scissor crossing consists of 4 pair of points (switches), six acute angle crossings; two obtuse angle crossings, check rails and straight lengths.

1.27 (b)

When the length of the tunnel is small, the centre line can be located by theodolite.

When the length of the tunnel is sufficient, elaborate and very accurate methods are used. In this case, micrometer transit theodolite is used and the centre line is located by means of triangulation method.

1.28(d)

Size of shaft depends upon the following factors:

(i) Quantity of muck to be handled
(ii) Nature of hoisting system
(iii) Nature of equipment used in tunnelling
(iv) Number of labourers needed for tunnelling
(v) Space required to carry pipes and wires
(vi) Eventual use of the shaft.

1.29 (d)

When a wave is in deep water, the motion of individual particle at the surface follows a circular orbital pattern and orbital radius falls off quickly with depth. Also the particles move forward along with waves so there will be translation as well as rotation.

1.30(d)

Approach surface is trapezoidal in shape and it is longitudinally centred on the extended centre-line of the runway.

Conical surface extends upwards and outwards from the outer circular edge of the horizontal surface to a point which is at some height above the horizontal surface.

1.31 (d)

A taxiway is a path for aircraft at an airport connecting runways with aprons, hangars, terminals and other facilities. Taxiway is designed considering volume of air traffic, runway configuration, location of terminal building, location of facilities like hanger etc.

1.32(a)

$\alpha \rightarrow$ Cockpit cutoff angle
$\beta \rightarrow$ Pitch angle
$\phi \rightarrow$ Glide slope angle
$\theta \rightarrow$ Angle formed by visual range with horizontal

1.33 (c)

Groynes are constructed perpendicular to the shore to control beach erosion.

1.34(c)

The fenders are installed:

(i) To prevent direct contact between quay vessel while the vessel is moored alongside the berth (rubbing or protection fenders)
(ii) To reduce the risk of a mooring vessel moving in resonance with waves.
(iii) To absorb berthing impact energy.

The fender system controls the relative motion between the dock and ship caused by wind and waves. The maximum amount of impact depends upon weight of the ship, angle of strike and velocity of approach or speed of berthing.

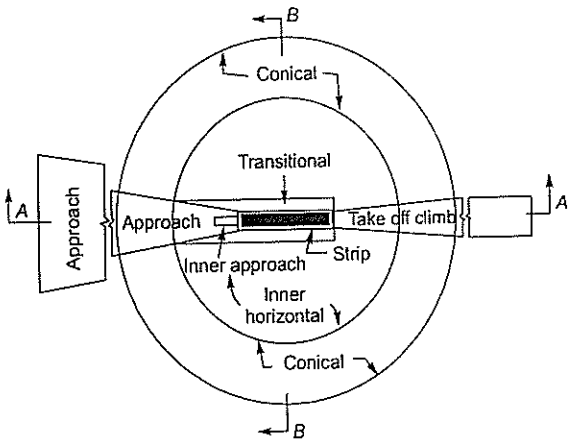
1.35 (b)

Methods for tunneling in rock areas:

(i) Full face method
(ii) Heading and beaching method
(iii) Drift method

Compressed air method is done for loose and very soft soil.

1.37 (c)



Primary Surface: A surface longitudinally centered on a runway.

Conical Surface: A surface, which extends upward and outward from the outer limits of the Horizontal Surface for a horizontal distance of 4,000 feet. The slope of the conical surface is 20-1 (5 percent) measured in a vertical plane.

Transitional Surface: A surface extending outward and upward, at right angles to the runway centerline and runway centerline extended, from the sides of the Primary Surface and the Approach Surfaces. The slope is 7-1 (14.3 percent) and the

surface extends until it intersects the Horizontal or Conical Surface.

Approach Surface: A surface longitudinally centered, on the extended centerline of the PIR runway, beginning at the end of the Primary Surface and extending outward and upward at a slope of 50:1 (2.0 percent) for a horizontal distance of 10,000 feet and at a slope of 40:1 (2.5 percent) for an additional 40,000 feet.

1.38 (b)

Solid fill type of wharf substructures consist of earth, concrete or rock partly confined by bulkhead or retaining wall. These are heavy so they resist impact of mooring ships. These are inexpensive and require little maintenance except in deep water where the construction cost and maintenance cost rises.

1.41 (a)

Airport Reference temperature,

$$T = \frac{2}{3} \times T_{av} + \frac{1}{3} \times T_{max}$$

$$= \frac{2}{3} \times 40 + \frac{1}{3} \times 49 = 43°C$$

1.42 (d)

Outer horizontal surface (OHS) is not established for the aerodromes having runway of length less than 900 m. The height of OHS is 150 m above the airport reference point (ARP) elevation.

1.43 (c)

In the direction of landing:

Outer marker – Middle marker – Threshold lights – Glide slope antenna – Localizer antenna are provided.

Z– type markers are provided just above the tower of the radio range station on airway.

So the correct sequence is 3 – 1 – 2 – 4.

1.44 (b)

Wet docks are the docks in which water is maintained at a level at which a ship is able to float. They are classified into:- Wet docks in tidal basin and Wet docks in mounted/enclosed basin.

Wet docks or harbor docks are enclosed or partially enclosed basins provided with lock and entrance gates to keep water at fairly constant level. This helps keep water level constant and allows vessels to come in and leave. But the arrangements like lock gate and walls which are designed to withstand backfill pressure are quite expensive.

1.45 (a)

Runways are always orientated in the *direction* of the prevailing *winds*, so that the force of the *wind can be utilized* during take-off and *landing* operations. The length of runway should be adequate for landing and takeoff operations and should be free from any obstruction.

1.46 (a)

Factors affecting Basic runway length are:

(i) Normal landing

(ii) Normal take off with all engines.

(iii) Engine failure at take off.

1.49 (c)

Heading and benching method is used for tunneling in hard rocks.

1.50 (d)

They are protective barrier constructed to form artificial harbor. These provide safe accommodation for shipping and protect from effect of sea waves.

1.51 (d)

Locating sounding by intersecting range is best suited for harbours, reservoirs, etc. where it is desired to determine the character of changes in the bed due to scour silting, or to measure the dredged material.

1.52 (a)

The number of gates depend on the following two factors:

(i) Estimated peak hourly volume which should not exceed the capacity of runway for balanced airport design

(ii) Gate occupancy time

$\therefore$ Number of Gates

$$= \frac{\text{Capacity of runway}}{60 \times 2} \times \text{Avg. occupancy time}$$

1.53(c)

The items to be considered in the geometric design of a runway are as follows:

(i) Length
(ii) Longitudinal and effective gradient
(iii) Rate of change of longitudinal gradient
(iv) Safety area
(v) Sight distance
(vi) Transverse gradient
(vii) Width

1.54 (a)

Mooring is provided for anchoring a boat or ship. A ship is secured to a mooring to forestall free movement of the ship on the water. An anchor mooring fixes a vessel's position relative to a point on the bottom of a waterway without connecting the vessel to shore. There are various kinds of moorings such as wing mooring, pile mooring etc.

1.55(b)

Station pointer is a three-armed protractor and consists of a graduated circle with a fixed arm and two movable arms to the either side of the fixed arm. It is used for plotting of soundings.

1.56 (a)

Docks are maritime structures used for loading and unloading of passengers and for mooring up vessels. They can be classified into two types : Dry docks and Wet docks. Dry docks are used for repairs, inspections etc whereas Wet docks or harbor docks are enclosed or partially enclosed basins provided with lock and entrance gates to keep water at fairly constant level.

1.57(a)

The cross wind component should not exceed 25 kmph. The percentage of time in a year during which the cross wind component remains within the limit of 25 kmph is called wind coverage of the runway. The orientation of the runway should be such that the minimum wind coverage of about 95% is obtained.

Head wind indicates the wind from the opposite direction of the head or nose of the aircraft while it is landing or taking off.

1.58(d)

Airport reference temperature,

$$T = \frac{2}{3}\times 25 + \frac{1}{3}\times 40 = 30^{\circ}C$$

1.59(d)

In the drift method, a small tunnel usually of size 300 cm x 300 cm is driven through the full length manually so method cannot be used for difficult or incompetent rocks.

1.60(c)

The elevation correction is 7% per 303 m rise in elevation of airport above MSL.

For 450 m elevation the correction will be

$$= \frac{450}{303}\times 7 = 10.4\%$$

So the corrected runway length will be

$$= 1800 + \frac{10.4}{100}\times 1800 = 1987.2 \text{ m}$$

1.61 (a)

Standard basic length of runway depends upon type of aircraft and are obtained from ICAO tables.

Elevation correction to basic runway length is 7% for every 300 m. Temperature correction is 1% and effective gradient correction is 20% for each 1% gradient.

1.62(d)

Gate occupancy time x Gate Capacity
= Number of Gates (G).

$$\text{Gate occupancy time} = \sum_{i=1}^{n} M_i T_i$$

$$\therefore \quad C = \frac{G}{\sum_{i=1}^{n} M_i T_i}$$

1.63 (d)

As per ICAO's recommendation if the total correction for elevation plus temperature exceeds 35% of basic runway, further checking needs to be done by conducting specific studies through model tests.

1.64(d)

'Blow in' method has the advantage of supplying of fresh air right near the working face, but the

disadvantage lies in that the foul air, smoke and dust slowly, move out, fogging the atmosphere inside the tunnel, especially in long tunnels. 'Blow out' method has the special advantage of quick removal of dust and smoke from the working face. But the drawback of this method is that the fresh air has to travel a long distance before it reaches the working face and it is quite likely that is may absorb during this time moisture, heat and foul gases of the hauling equipment resulting in an unpleasant working condition at face. Both these methods are used in combination to incorporate their advantages.

1.65 (d)

Wave theory states that wave motion is set up by moving of wheels. A vertical reverse curve is formed in the rails ahead of the wheels, resulting from the rail deflection under the load, is the chief cause of creep.

Percussion theory states that the creep is due to impact of wheels at the rail end ahead at joints. Though the creep is very small in single impact but cumulative effect of number of wheels in quick succession results in sufficient creep.

Drag theory states that backward thrust on driving wheels of the locomotive of train has got a tendency to push the sail off the track backward while the other wheels of the locomotive and the vehicles push the rail in the direction of travel. This results in creep of rails in the direction of movement of trains.

1.66 (a)

Container ports have limited berth capacity due to which there is minimal damage to cargo and overall transit time is small. Also, they occupy the minimum land for marshalling area.

1.67 (a)

Groyne is connected perpendicular to the shore to prevent erosion. Littoral drift is a geographical process that consists of the transportation of sediments (clay, silt, sand and shingle) along a coast at an angle to the shoreline in a zig-zag style. This movement affects hydraulic behavior of groynes.

1.68 (b)

(i) When the depth of water is great compared to the length of wave, the wave velocity is given by

$$v = 1.25\sqrt{l}$$

where l is length of wave

(ii) In shallow water, if the depth of water is 'd', the wave velocity is given by

$$v = 3.16\sqrt{d}$$

$$= 3.16\sqrt{1.4}$$

$$= 11.82 \text{ m/s}$$

1.69 (b)

As per ICAO's recommendation, the runway length should be increased @ 7% per 300 m rise in elevation above the mean sea level. Basic runway length is usually corrected for elevation, gradient and temperature.

1.70 (c)

Liner plate method grants an absolute control of running ground water. It is an excellent and positive method of minimizing ground subsidence in urban areas.

1.71 (d)

Since line joining two underground points gives the direction of centre line, accurate setting can be achieved only if the theodolite can be set out exactly in line with the points. The operation is quite difficult and time consuming so an alternate method known as Weisbach triangle method may be used to connect two ends of an underground tunnel.

1.72 (c)

For the purpose of ventilation, additional access, removal of muck and escape of people from tunnel passage provisions in form of adits and shafts are provided during construction.

1.74 (a)

Turning radius = 2 × ship length

Minimum dimension of turning basin should not be less than twice the length of largest ship so that ship can turn a complete circle without help of tugs.

1.75 (d)

A natural harbor is a landform where a part of a body of water is protected and deep enough to furnish anchorage. Well known natural harbours are New York City, Rio de Janeiro, San Francisco, Tokyo etc

Semi natural harbour requires artificial protection only at entrance. Vishakhapatnam and Plymouth are semi natural harbours. Lagoon harbor lies where shallow body of water is separated from large body by reefs or barrier island. Paradip and Mangalore are well known lagoon harbours.

1.76 (d)

Echo sounding is a type of SONAR used to determine the depth of water by transmitting should pulses into water. Echo sounding Machines are used comonly to determine depth of sea bed below sea surface, aid in navigation, locating objects below sea surface, etc.

1.78 (c)

The term Mean Sea Level (MSL) can also refer to a tidal datum, or frame of vertical reference defined by a specific phase of the tide. MSL as a tidal datum is computed as a mean of hourly water level heights observed over 19-years.

1.79 (c)

Generally runways are oriented in direction of prevailing winds which helps in takeoff and landing operation. Obstruction free approaches are essential for orientation of runway. There should for scope for future expansion so orientation of runway is decided accordingly.

1.80 (d)

Hangar in airport useful for servicing, overhauling and repairing aircrafts. Its size depends on turning radius and size of aircraft(its length, height and wingspan)

1.82 (b)

A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. Using a polar coordinate system of gridding, the frequency of wind direction, with color bands showing wind speed ranges. The direction of the longest spike shows the wind direction with greatest frequency.

1.83 (a)

Visibility is lower than prescribed in instrumental flight rules(IFR) so rigid traffic control is applied in this. In Visual flight rules (VFR) air traffic control is not practically requires as pilot can maintain separation with visual aids. Runway capacity will be more in airport operating under VRF than IFR. Thus VFR can give more clear visual reference of airport during good weather conditions.

1.86 (c)

The general considerations in the choice of a suitable site for a helipad are:

(i) It should be located in close proximity to the traffic generating areas.

(ii) It should have a convenient access by ground transportation, e.g. roadway or railway.

(iii) The ambient noise level should be considered.

(iv) The site for helipad should provide unobstructed approach departure paths for helicopters.

A helicopter can ascend or descend exactly vertically. However, it is not practicable, within economic limits that helicopter can ascend and descend exactly vertically.

1.87 (d)

Total information content

= bit rate × cycle time

= 50 × 30 = 1500 bits

1.88 (a)

Littoral drift is a geographical process that consists of the transportation of sediments (clay, silt, sand and shingle) along a coast at an angle to the shoreline in a zig-zag style, which is dependent on prevailing wind direction, swash and backwash. This process occurs in the littoral zone, and in or close to the surf zone. The process is also known as longshore drift, longshore current or longshore transport.

1.90 (a)

Depth and width required at entrance are more than those required in channel as entrance is more

exposed to waves. Due to more exposure to waves, scending or pitching of a vessel may be larger at entrance to the channel than within the channel.

1.91 (b)

The pavement area adjacent to terminal building and hangers used for loading and unloading , servicing and parking of aircraft is called as apron. Apron size depends of:

(i) Size and number of gate positions

(ii) Positioning of gates

(iii) Aircraft parking system

(iv) Size of loading area for aircraft

1.92 (d)

The wind data, i.e., direction, duration and intensity are graphically represented by a diagram called wind rose. The wind data should usually be collected for a period of at least 5 years and preferably of 10 years, so as to obtain an average data with sufficient accuracy. It helps in analysing the wind data and obtaining the most suitable direction of the runway.

1.94 (c)

The runway surface made of asphalt or cement concrete will not have irregularities that would result in the loss of frictional characteristics that would otherwise adversely affect the take-off or landing of an aircraft.

The portion of a strip at the end of a runway is prepared to resist blast erosion, in order to protect a landing airplane from the danger of an exposed edge.

1.96 (b)

Payload is the carrying capacity of an aircraft usually measured in terms of weight; depending on the nature of the flight, the payload of a vehicle may include cargo, passengers, flight crew, munitions, scientific instruments or experiments, or other equipment. Extra fuel, when optionally carried, is also considered part of the payload. In an airline or air freight carrier, payload may refer only to revenue-generating cargo or paying passengers.

1.98 (b)

Final corrected length of runway

= Given runway length + Length incorporated due to temp. effect

$= 3670 + L$

$$L = \frac{\text{Runway length}}{100} \times (\text{Airport ref. temp} - \text{Std. temp.})$$

$$\text{Airport ref. temp} = T_a + \frac{(T_m - T_a)}{3}$$

$$= 18 + \left(\frac{27-18}{3}\right) = 21°C$$

$$\text{Std. temp.} = 15 - 0.0065 \times 460 = 12.01°C$$

$$L = \frac{3670}{100}(21 - 12.01) = 329.93 \text{ cm}$$

Final corrected length

$= 3670 + 329.93$

$\simeq 4000$ m

1.99 (b)

Radius of exit taxiway,

$$R = \frac{V^2}{127f} = \frac{90^2}{127 \times 0.13} = 500 \text{ m}$$

■■■■

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