Civil Engineering

Railway, Airport, Dock, Harbour & Tunnelling Engineering

Comprehensive Theory

with Solved Examples and Practice Questions

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Railway, Airport, Dock, Harbour & Tunnelling Engineering

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Railway, Airport, Dock, Harbour & Tunelling Engineering

Section-A: Railway Engineering

Section - A CHAPTER 01

Railway Track

1.1 Introduction

- Railway track is a combination of rails, fitted on sleepers and resting on ballast and subgrade.
- Essential function of railway track is to support and guide the vehicles that run over it.
- The conventional railway track consists of two rails located at fixed distance apart. The pressure exerted over by the rails is in turn transmitted to the formation with the help of sleepers and ballast.
- Railway track is also known as permanent way.
- The name permanent way is given to distinguish the final layout of the track from temporary tracks. Temporary tracks are laid for conveyance of earth and materials during construction works.
- In a permanent way, rails are joined in series by fish plates and bolts and then they are fixed to sleepers by different types of fastenings.

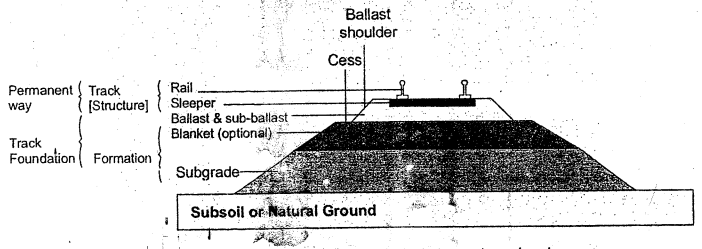


Fig. 1.1 Typical cross-section of a permanent way on embankment

- The sleepers properly spaced, resting on ballast, are suitably packed and fixed with ballast.
- This layer of ballast rests on the prepared subgrade called the formation.

1.2 Requirements of an Ideal Permanent Way

Following are the basic requirements of an ideal permanent way

(i) The gauge should be uniform and correct.
(ii) Both the rails should be at the same level in a straight track.
(iii) On curves, proper superelevation should be provided to the outer rail.
(iv) Track should have enough lateral strength.

(v) Track must have certain amount of elasticity.
(vi) Radii and superelevation, provided on curves, should be properly designed.
(vii) All joints, points and crossings should be properly designed.
(viii) Drainage system should be perfect.
(ix) It should have adequate provision of easy renewals and repairs.
(x) The components of track i.e., rail, fittings, sleepers, ballast must fully satisfy requirement for which they are provided.

1.3 Gauge of Railway Track

The gauge of a railway track is the clear distance between the running or gauge faces of the two rails.

NOTE: These running faces are the inner faces of the rails in India, we have three types of gauges

(i) Broad Gauge (BG) → 1676 mm (5 ft. 6 inches)
(ii) Metre Gauge (MG) → 1000 mm (3 ft. 3.375 inches)
(iii) Narrow Gauge (NG) → 762 mm (2 ft. 6 inch) 610 mm (2 ft.)
A larger gauge has the advantage of greater traffic capacity, speed and safety.
However, it requires flatter gradients and curves.

NOTE
(i) 610 mm is for feeder track gauge.
(ii) Small lengths of standard gauge (1435 mm) are used in India for individual projects and short line lengths.
For example: Delhi Metro Rail Corporation.

Factors responsible for selection of gauge:
(i) Cost of construction
(ii) Volume and nature of traffic
(iii) Development of under developed area
(iv) Physical features of the country
(v) Speed of vehicle movement

NOTE
(i) On important section in India, Broad Gauge is preferred.
(ii) Gauge should be uniform throughout as far as possible in a country.
(iii) Because transhipping passengers and goods from vehicles of one gauge to another is a cumbersome task.

1.4 Load Transfer on a Railway Track

- All the components of a P-way are required to transfer the rolling load to the subgrade while maintaining the proper position.
- Rail acts as girders to transmit wheel load to sleeper.
- Sleeper holds the rail in correct alignment and transmit the load to ballast.
- Ballast distributes load over formation known as subgrade and finally to natural soil on ground.

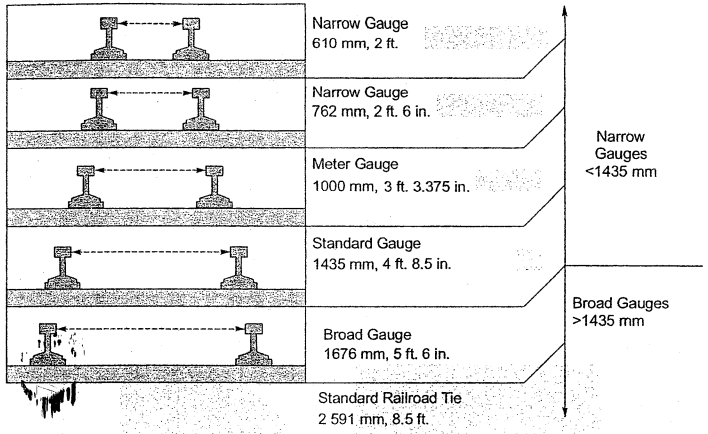
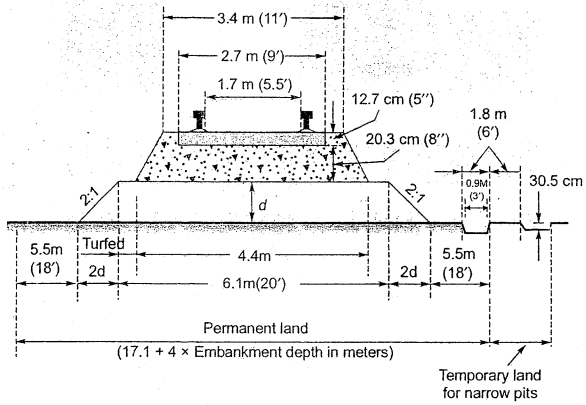


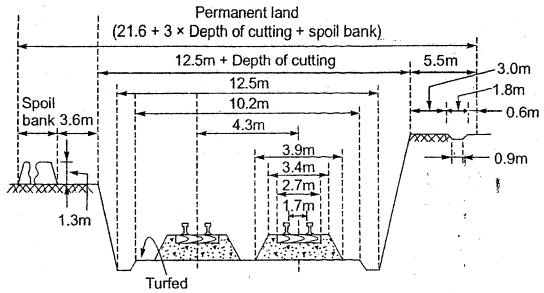
Fig. 1.2

1.5 Railway Track Cross-section

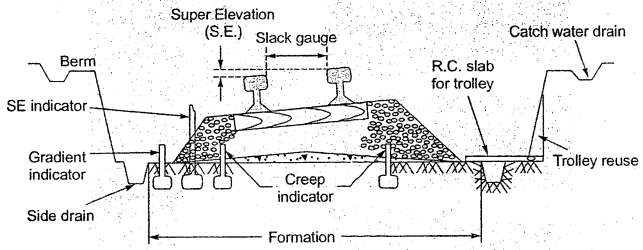
The typical cross-section of a railway track have been shown in the figure given below:



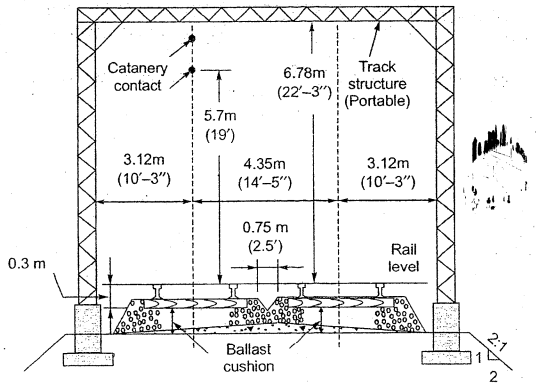
The cross-section of a B.G. Track in Embankment (On straight track)



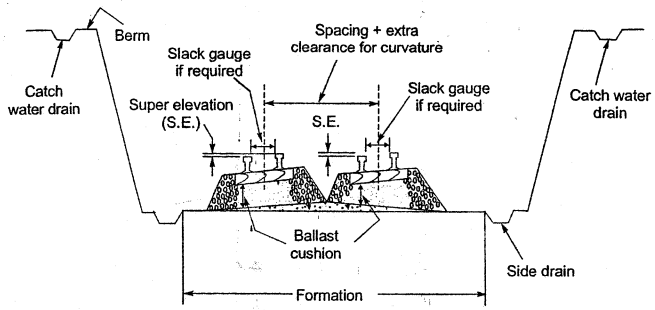
The cross-section of a B.G. Track in cutting for double line (On straight track)



The cross-section of a B.G. track for a single Line (curved track)



The cross-section of a B.G. Track for double line with electric-traction



The cross-section of a B.G. Track for double line in Cutting (On Curved Track)

Fig. 1.3

1.6 Coning of Wheels and Canting of Rails

1.6.1 Coning of Wheels

(i) The tread or rim of railway vehicles are not made flat but are sloped and this sloping surface along the circumference forms part of a cone (with a slope of about 1 in 20). This is known as coning of wheels.

(ii) On straight and level track, the wheel remains central and circumference of treads of both wheels are equal.

(iii) On the level track as the axle moves towards one rail, the diameter of wheel tread over the rail increase while it decreases over the other rail. This prevents the further movement of axle retreat back to original position with equal diameters and equal pressure on both rails.

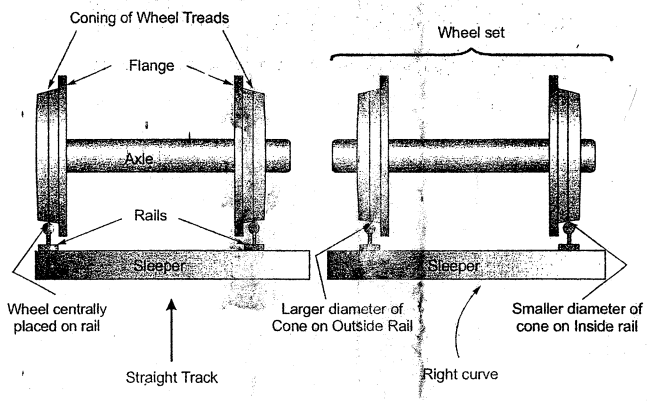


Fig. 1.4

(iv) On curved track, outer wheel has to travel greater length than the inner wheel.

Vehicle on a curve has the tendency to move sideways towards the outer rail, so the circumference of the tread on the outer rail towards inner edge of the wheel becomes greater than that on the inner rail. This helps outer rail to cover a greater distance than the inner rail.

(v) Conicity of wheel = angle between wheel tread and horizontal axis of axle.

1.6.2 Advantages of Coning of Wheel

- It helps vehicle to negotiate curves smoothly.
- To keep the train just in central position in a level track.
- To provide for possibility of lateral movement of axle with its wheels.
- To prevent wheels from slipping to some extent.
- It reduces wear and tear of the wheel flanges.

1.6.3 Disadvantages of Coning of Wheel

- The pressure of the horizontal component of the force near the inner edge of the rail has a tendency to wear the rail quickly.
- The horizontal component of the force tends to turn the rail outwards and hence the gauge is widened sometimes.
- If no base plates are provided, sleepers under the outer edge of the rail may get damaged.

1.6.4 Canting of Rails

- In order to minimize the disadvantages due to coning of wheels, canting of rails is done which means that rails are not laid flat but are tilted inwards.
- This reduces wear on the rail as well as on the tread of the wheel.
- The slope of the base plate is 1 in 20 which is also the slope of the wheel flange.
- Tilting of rails can be achieved by
  - (i) Adzing of sleepers
  - (ii) Use of canted base plate

1.6.5 Adzing of Sleepers

- A groove (having angle of 1 in 20) is being cut on the top of the sleepers. The rail is being seated into this groove in such a manner that it remains fixed in this location.
- This sort of angle making in sleepers so as to seat the rail is known as adzing of sleepers.

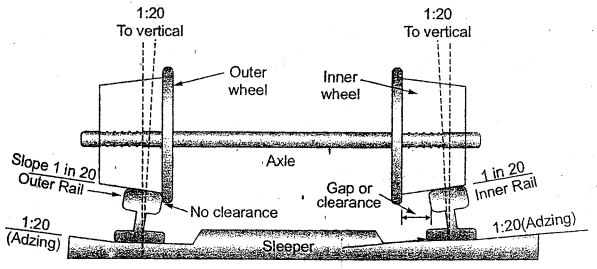


Fig. 1.5

Summary

- Railway track is a combination of rails fitted on sleepers and resting on ballast and subgrade.
- Gauge of a railway track is the distance between the inner faces of the two rails.
- Dimension of broad gauge, metre gauge and narrow gauge are 1676 mm, 1000 mm, 762 mm (also 610 mm) respectively.
- 610 mm narrow gauge is for feeder track gauge.
- Standard gauges are 1435 mm length.
- Coning of wheels is a method of levelling the wheels to avoid depreciation to the wheels and rim caused by friction between rims and inner faces of the rail top.
- Canting of rails is done in order to minimize the disadvantages due to coning of wheels.
- Tilting of rails can be achieved by either adzing of sleepers or the use of canted base plate.
- Adzing of sleepers is a sort of groove making in sleepers so as to seat the rail.

Objective Brain Teasers

Q.1 Which of the following factors govern the choice of the gauge?
(i) volume and nature of traffic
(ii) speed of train
(iii) physical features of the country
The correct answer is
(a) only (i) (b) both (i) and (ii)
(c) both (ii) and (iii) (d) (i), (ii) and (iii)

Q.2 For developing thinly populated areas, the correct choice of gauge is
(a) Broad Gauge (b) Metre Gauge
(c) Narrow Gauge (d) any of the above

Q.3 The formation width for a single line metre gauge track in embankment as adopted on Indian Railways is
(a) 4.27 m (b) 4.88 m
(c) 5.49 m (d) 6.10 m

Q.4 The side slope of embankments for a railway track is generally taken as
(a) 1 : 1 (b) 1.5 : 1
(c) 2 : 1 (d) 1 : 2

Q.5 The formation width for a double line Broad Gauge track in cutting (excluding drains) as adopted on Indian Railways is
(a) 6.10 m (b) 8.84 m
(c) 10.21 m (d) 10.82 m

Q.6 The tread of wheels is provided an outward slope of
(a) 1 in 10 (b) 1 in 15
(c) 1 in 20 (d) 1 in 25

Q.7 Wheels of rolling stock are provided flanges on
(a) outer side (b) inner side
(c) both sides (d) neither side

Q.8 Coning of wheels is provided
(a) to check lateral movement of wheels
(b) to avoid damage to inner faces of rails
(c) to avoid discomfort to passengers
(d) All the above

Q.9 For providing the required tilt of rails, adzing of wooden sleepers, is done for
(a) bull headed rails
(b) double headed rails
(c) flat footed rails
(d) any type of rails

Q.10 Check rails are provided on inner side of inner rails if sharpness of a B.G. curve, is more than
(a) 3° (b) 5°
(c) 6° (d) 8°

Q.11 The rail section which is not used on Indian Broad Gauge tracks, is
(a) 35 R (b) 40 R
(c) 45 R (d) 55 R

Q.12 The rail section which is not used on Indian metre gauge tracks, is
(a) 25 R (b) 30 R
(c) 35 R (d) 40 R

Q.13 In India the rails are manufactured by
(a) open hearth process
(b) duplex process
(c) both (a) and (b)
(d) neither (a) nor (b)

Q.14 In Indian railways, the ratio of axle load and weight of rail, is
(a) 312 (b) 412
(c) 512 (d) 600

Q.15 Match List-I (Railway zone) with List-II (Headquarters) and select the correct answer by using codes given below the lists:

List-I	List-II
A. N.E.R.	1. Calcutta
B. E.R	2. Gorakhpur
C. S.C.R	3. Maligaon (Guwahati)
D. N.E.F.R	4. Secunderabad

Codes:

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

Answers

1. (d)	2. (c)	3. (b)	4. (c)	5. (c)
6. (c)	7. (b)	8. (d)	9. (c)	10. (d)
11. (b)	12. (d)	13. (c)	14. (c)	15. (b)

CHAPTER 02

Rails

2.1 Introduction

- Rails on the track can be considered as steel girders for the purpose of carrying axle load.
- Rails are made of high carbon steel to withstand wear and tear.
- Rails are member of a railway track laid in two parallel lines.

2.1.1 Functions of Rails

Rails serves the following purpose

(i) Provides a continuous and levelled surface (for movement of heavy axle loads, in order to avoid hazardous condition due to induction of stresses or moments).

(ii) Provides a smooth surface (to keep friction between the rails and wheels to a minimum).

(iii) Bears the stresses due to heavy vertical loads, lateral forces, breaking forces and thermal effect (rails should be able to bear the stresses without failure).

(iv) Should transmit load to a greater area below (load is transmitted from rail to sleeper and consequently reduces pressure on ballast and formation below).

(v) Provides a material which resist wearing out and failure.

2.1.2 Composition of Rail Steel

- Rails are generally made by open hearth process.
- Rail steel is composed of C, Mn, Si, S, P
- For ordinary rail, high cabon steel is used.
- For rails on points and crossings, medium carbon steel is used.

2.1.3 Requirements of Rails

Rail should meet the following requirements:

(i) Proper composition of steel

(ii) Sufficient vertical and lateral stiffness.

(iii) Deep and hard wearing surface of head.

(iv) Sufficient web thickness.

(v) Sufficient foot thickness and foot width.

(vi) Balanced distribution of material of rail in head, web and foot.

(vii) Centre of gravity of rail section should be approximately at mid-height.

(viii) Sufficient fillet radii.
(ix) Tensile strength of rail piece > 72 kg/m^2
(x) Rail specimen should satisfy "Falling Weight Test" or "Tup Test".

2.2 Rail Sections

2.2.1 Types of Rail Sections

The types of rail section which have been tried so far for constructing railway tracks are as follows:

(i) Double headed rails (D. H. Rails)
(ii) Bull headed rails (B. H. Rails)
(iii) Flat footed rail (F. F. Rails)

(i) Double headed rails (D. H. Rails)

- These rails indicate the early stage of development.
- It mainly consists of three parts (a) Upper table (b) Web (c) Lower table
- Both upper tables and lower tables were identical
- When upper table gets worn out, then the rails can be inverted and reused.
- This type of rail is practically out of use in Indian Railways.

(ii) Bull headed rails (B. H. Rails)

- The next evolution was that of B.H. rails.
- It mainly consits of three parts (a) Head (b) Web (c) Foot
- Head has larger size then foot. So that even after wear, it can withstand stresses.
- Foot is designed only to furnish necessary strength and stiffness to rails.
- Bull headed rails are especially used for making points and crossing.

(iii) Flat footed rail (F. F. Rails)

- These rails are also called Vignole's rails after the name of inventor.
- It consists of three parts (a) Head (b) Web (c) Foot
- The foot is spread out to form a base (as the name "Flat Footed" suggests)
- About 90% of the railway tracks in the world are laid with this form of rails.
- In India, flat footed rails are most commonly used.

Types of Rail Sections

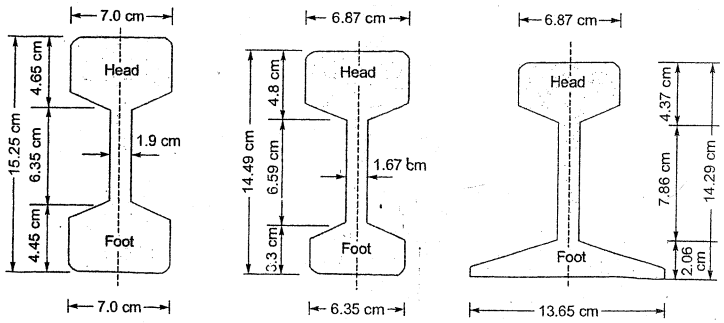


Fig. 2.1

Advantages of Flat Footed Rails:

- No requirement of chairs or keys (as the foot of the rail is directly spiked to the sleepers)
- This form of rail is stiffer both vertically and laterally then the full headed rail of equal weight.
- Less liable to develop kinks (maintain a more regular top surface than the full headed rails)
- More cheaper than the B.H. Rails
- Distributes the train load over a large number of sleepers (this results in greater track stability)

Disadvantage of Flat Footed Rails:

- Due to impact of rolling wheel loads, fitting get loosened more frequently.

NOTE: In India, standard lengthof rails are 12.80 m for B.G. and 11.89 m for meter gauge.

2.2.2 Details of Standard Rail Section

Types of sections in use

(i) British Railways (RBS sections–Revised British Standard specification)
  (a) 75R (75 lbs/yd) (b) 90R (90 lbs/yd)
  (c) 115R (115 lbs/yd)
(ii) Indian Railways
  (a) 60 kg/m (UIC section–Union Internationale des Chemins de fer or International Union of Railways) — suitable for speed upto 160 kmph.
  (b) 52 kg/m (IRS section–Indian Railway Standard) — suitable for speed upto 130 kmph.

Types of sections in use in India

(i) Rail section in use on BG
  (a) 60 kg/m [UIC] (b) 52 kg/m [IRS]
  (c) 90R (90 lb/yd ~ 45 kg/m) [RBS] (d) Length-13 m
(ii) Rail section in use on MG
  (a) 90R (90 lb/yd) (b) 75R (75 lb/yd)
  (c) 60R (60 lb/yd) (d) Length-12 m (13 m in case of 90R rails)
(iii) Rail Section in use on NG
  (a) 50R (50 lb/yd) (b) Length-12 m

NOTE: Rails of larger length are preferred to smaller length of rails as it gives more strength economy and lesser number of joints between two rails.

2.2.3 Selection of Rails

Various considerations in selection of a rail section

(a) Gauge of track
(b) Heaviest axle load
(c) Maximum permissible speed
(d) Type and spacing of sleepers
(e) Depth of ballast cushion
(f) Maximum permissible wear on top of rails (5% of weight of rails is allowed)

Thumb Rule: The relationship between weight of rail and heaviest axle load, which rails have to carry
Maximum axle load = 560 x sectional weight of rail (in lbs/yd or kg/m)

Calculate maximum axle load in tonnes

(a) For 60 kg/m (b) For 90R

2.3 Wear in Rails

- Wear is one of the prominent defects of the rail.
- Wear of the surface of the rail means either the top of the rail head or side of the rail head or end of the rail head gets removed.

2.3.1 Major Reasons of the Wear

- Extraordinarily large load
- High speed trains
- Concentrated load which are exceeding the elastic limits of the rail section.
- Gap at the rail joints.
- Slipping, skidding or striking of flanges on curves.

2.3.2 Classification of Wear

Classification of wear can be done on the following basis:

(i) Based on location through which rail passes.

(ii) Based on position of wear.

(i) Based on location through which rail passes

Following are certain specific location along the track which may induce the wearing of the rail section.

(a) Sharp curves (due to application of centrifugal force in the outward direction)

(b) Steep gradients (when train is going up, extra effort is required in pulling while in going down, extra effort is required in pushing)

(c) Approaches to station (due to braking or acceleration)

(d) In tunnels and coastal areas (due to humidity and weather effect)

(e) Weak foundations (deformations of rails due to heavy load)

(ii) Based on position of wear

On the basis of position, wear can be at the top of the rail head, or side of the rail head or end of the rail head.

(a) Wear at the top of the rail head

- Flow of metal
  (concentrated stress exceeds the elastic limit and hence the plastic flow)
- Rubbing action on the top of the rail head
  (because of movement of rolling stock at that section)
- Abrasive action/corrosive action
  (abrasive → due to rubbing action of different types of material)
  (corrosion→ more related towards the effect of weather or chemicals)

- Improper superelevation/centrifugal force
  (due to unbalanced forces on the inner and the outer rail section, there will be more stress at one location compared to another location, leading to wearing)
- Slipping of wheels on curves.
- Fluctuations in tracks
  (creates surface irregularities leading to discontinuity in the contact between wheel and rail and hence wearing occurs)
- Lack of provisions of adzing of sleepers
  (leads to striking behaviour at the point of contact between wheel and the rail section)

(b) Wear at the side of the rail head

- Rigidity of wheel base
  (due to striking of the wheel flange on the inner side of the outer rail and inner side of the inner rail at the leading section or the trailing section leading to wear)
- Slipping/skidding of wheel on curves
  (wheel tries to slip to the equilibrium condition towards average diameter of the wheel leading to wear)
- Greater thrust on inner rail
  (due to speed lesser than the equilibrium speed)

(c) Wear at the end of the rail head

- Loose fish plates, fish bolts
  (due to relative movement of the rail sections, there is a striking behaviour of wheel on rail head)
- Heavy load at high speed
  (impact transferred at the end of the rail head will be high)
- Effect of wide joints and openings
  (there is more contact between the wheel and the forward rail leading to wearing)
- Difference in rail heights at joints
  (hogging effect when wheel moves from higher level to lower level; while from lower level to higher level, movement of the rail section is in forward direction due to horizontal component of the force)

2.3.3 Permissible Limits of Vertical Wear

Table 2.1

Section	Gauge	Category of track	Lateral wear (mm)
Curves	BG	Group A & B	8
	BG	Group C & D	10
	MG	Q & R	9
Straight	BG	Group A & B	6
	BG	Group C & D	8
	MG	Q	6
	MG	R	8

Measured at a distance of 13-15 mm below the rail top table. Profile of worn-out rail is recorded and superimposed over a new profile to determine lateral wear

2.3.4 Prevention of Wear

Following are the ways of preventing wear:

- Better maintenance of track
- Use of heavier and higher UTS rail sections
- Lubricating gauge face
- Track renewal
- Welding or dehogging of battered ends
- Reducing number of joints
- Use of bearing plates (adzing of sleepers)
- Using check rails on sharp curves
- Interchanging inner and outer rails
- Maintenance of correct gauge

2.4 Hogged Rails

(i) Due to battering action of wheels over the end of the rails, the rails get bent down and get deflected at the ends.

(ii) This hogging at ends is due to loose packing under the joints and/or loose fish plate.

Remedial Measures:

(i) Hogged ends are cut-off and fresh holes for fixing fish plates are provided — cropping.
Hogged rails are entirely replaced.

(ii) Deflected ends are brought to level by welding

2.5 Buckling of Rails

- It means track has gone out of its original alignment.
- It happens when expansion of rails due to temperature variations is prevented.

Remedial Measures:

- Ballast, sleeper and rail sections must be checked for design.
- Providing steel sleeper
- Provision of expansion gap
- Not very strong tightening of fish bolts.

2.6 Welding of Rails

The welding of rails is carried out in a depot of the "Flash butt welding" process and at site by the "Thermit Welding" process.

In general, there are four welding method:

(i) Gas pressure welding
(ii) Electric arc welding (or metal arc welding)
(iii) Flash butt welding
(iv) Thermit welding

2.6.1 Types of Welded Track

Welded tracks can be classified as short welded rails, long welded rails and continuous welded rails.

(i) Short Welded Rails (SWR)

- It is a welded rail that contracts and expands throughout its length; thus producing excessive thermal stresses.
- Normally 3, 5 or 10 rail lengths are welded together.

- Short welded rails of more than 3 rail lengths produces higher thermal stresses, so these have been limited to 3 rail lengths.
- It has a length upto 130 metres.

(ii) Long Welded Rail (LWR)

- It is a welded rail the central part of which does not undergo any longitudinal movement due to temperature changes.
- A long welded rail continues to expand at its end for a particular length till adequate resisting forces gets developed towards the centre.
- A stage is reached when at a particular length of the rail from its ends, the resistance offered by track structure becomes equal to thermal changes.
- There is no movement of rail beyond this point.
- A length greater than 250 m on B.G. and 500 m on M.G. will normally function as LWR.
- The maximum length of LWR under Indian conditions shall normally be restricted to one block section.
- The length at each end of the LWR (or CWR) which is subjected to expansion/contraction on account of temperature changes is called breathing length.
- An expansion joint installed at each end of LWR (or CWR) to permit expansion/contraction of the adjoining breathing lengths due to temperature changes is called switch expansion joint (SEJ).
- Buffer rails are sometimes provided in place of SEJ at the end of LWR (or CWR).
- It has a length upto 1000 metre.

(iii) Continuously Welded Rails (CWR)

- It is a higher category of LWR.
- It may be of a length greater than 1000 m.
- It continues through station yards including points and crossings.
- It requires heavy maintenance.

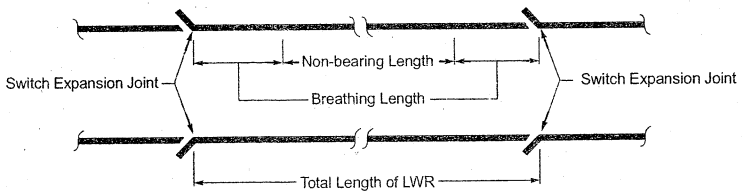


Fig. 2.2

Summary

- Rails are actually the steel girder for the purpose of carrying axle load.
- Rails provide a continuous and levelled surface, bears stresses due to forces along various plane and due to thermal effects.
- Rails are made up of C, Mn, Si, S, P.
- High carbon steel is used in case of ordinary steel while medium carbon steel is used for rails on points and crossing.

- Double headed, bull headed and flat footed are the three types of rail section tried so far for constructing railway tracks.
- Wear of the surface of rail means wear at the top, side or end of rail-head.
- Wear can be prevented by reducing number of joints, use of bearing plates, using check rails on sharp curves, interchanging inner and outer rails, dehogging of battered ends etc..
- LWR is a welded rail whose central portion does not exhibit any longitudinal movement on account of temperature change.
- SWR expands and contracts throughout its lengths.
- CWR is higher category of LWR. It continues to station yard including points and crossing.
- Battering over ends result in hogged rails.
- Track goes out of alignment if no expansion gap provided.

Objective Brain Teasers

Q.1 Two important constituents in the composition of steel used for rail are
(a) carbon and silicon
(b) manganese and phosphorous
(c) carbon and manganese
(d) carbon and sulphur

Q.2 The standard length of rail for Broad Gauge and Metre Gauge are respectively
(a) 12 m and 12 m
(b) 12 m and 13 m
(c) 13 m and 12 m
(d) 13 m and 13 m

Q.3 The following tests are conducted for rails:
(i) falling weight test
(ii) tensile test
(iii) hammer test
The compulsory tests are
(a) only (i) (b) (i) and (ii)
(c) (ii) and (iii) (d) (i) and (iii)

Q.4 Largest percentage of material in the rail is in its
(a) head (b) web
(c) foot (d) heat and foot both

Q.5 The purpose of providing fillet in a rail section is to
(a) increase the lateral strength
(b) increase the vertical stiffness
(c) avoid the stress concentration
(d) reduce the wear

Q.6 52 kg rails are mostly used in
(a) Broad Gauge (b) Metre Gauge
(c) Narrow Gauge (d) both (a) and (b)

Q.7 Tensile strength of steel used in rails should not be less than
(a) 450 MPa (b) 500 MPa
(c) 700 MPa (d) 850 MPa

Q.8 Head width of 52 kg rail section is
(a) 61.9 mm (b) 66.7 mm
(c) 67 mm (d) 72.33 mm

Q.9 Ordinary rails are made of
(a) mild steel (b) cast iron
(c) wrought iron (d) high carbon steel

Q.10 The main function of a fish plate is
(a) to join the two rails together
(b) to join rails with the sleeper
(c) to allow rail to expand and contract freely
(d) none of the above

Q.11 Number of fish bolts per fish plate is
(a) 2 (b) 4
(c) 5 (d) 6

Q.12 Due to battering action of wheels over the end of the rails, the rails get bent down and are deflected at ends. These rails are called
(a) roaring rails (b) hogged rails
(c) corrugated rails (d) buckled rails

Q.13 The slipping of driving wheels of locomotives on the rails surface causes
(a) wheel burns (b) hogging of rails
(c) scabbing of rails (d) corrugation of rails

Q.14 The width of foot for 90 R rail section is
(a) 100 mm (b) 122.2 mm
(c) 136.5 mm (d) 146.0 mm

Q.15 The height of the rail for 52 kg rail section is
(a) 143 mm (b) 156 mm
(c) 172 mm (d) 129 mm

Q.16 The total gap on both sides between the inside edges of wheel flanges and gauge faces of the rail is kept as
(a) 10 mm (b) 13 mm
(c) 16 mm (d) 19 mm

Q.17 On a single rail track, goods trains loaded with heavy iron material run starting from A to B and then empty wagons run from B to A. The amount of creep in the rails.
(a) will be more in the direction of B to A
(b) will be more in the direction of A to B
(c) will be maximum at the middle of A and B
(d) cannot be determined from the given data.

Q.18 Which one of the following rail failures is caused by loose fish bolts are expansion joints?
(a) crushed head
(b) angular break
(c) split head
(d) transverse fissures

Q.19 Wear of rails is maximum in
(a) tangent track (b) sharp curve
(c) tunnels (d) coastal area

Q.20 Rail section first designed on Indian railways, was
(a) double headed
(b) bull headed
(c) flat footed
(d) (a) & (b) simultaneously.

Q.21 Width of the top portion of a flat footed, rail, is
(a) 69.85 mm (b) 63.50 mm
(c) 66.77 mm (d) 136. 52 mm

Q.22 Bull headed rails are generally provided on
(a) points and crossing
(b) straight tangents
(c) curved tracks
(d) metre gauge tracks

Q.23 Weight and cross section of the rails are decided on
(a) gauge of tracks
(b) speed of trains
(c) spacing of sleepers
(d) All the above

Q.24 On Broad Gauge main lines with maximum traffic loads, the rail section preferred to, is
(a) 29.8 to 37.3 kg/m
(b) 32.5 to 42.5 kg/cm
(c) 44.7 to 56.8 kg/m
(d) None of these

Q.25 On Indian Railways standard length of rails for B.G. track, is
(a) 33 ft (10.06 m) (b) 36 ft (10.97 m)
(c) 39 ft (11.89 m) (d) 42 ft (12.8 m)

Q.26 On Indian Railways standard length of rails for M.G. track, is
(a) 33 ft (10.06 m) (b) 36 ft (10.97 m)
(c) 39 ft (11.89 m) (d) 42 ft (12.8 m)

Q.27 On Indian Railways, the approximate weight of a rail section is determined from the formula
(a) $\frac{\text{weight of the rail}}{\text{axial load of locomotive}} = \frac{1}{10}$
(b) $\frac{\text{weight of the rail}}{\text{axial load of locomotive}} = \frac{1}{410}$
(c) $\frac{\text{weight of the rail}}{\text{axial load of locomotive}} = \frac{1}{560}$
(d) $\frac{\text{weight of the rail}}{\text{axial load of locomotive}} = \frac{1}{610}$

Q.28 The rails get out of their original positions due to insufficient expansion gap. This phenomenon is known as
(a) hogging (b) buckling
(c) creeping (d) None of these

Q.29 Match **List-I** with **List-II** and select the correct answer by using codes given below the lists:

List-I

A. Corrugated rails
B. Burrs
C. Wear of rails
D. Flange bitten rails

List-II

1. The top surface gets worn out
2. The projection of rail on gauge side
3. The top surface develops alternate ridges and hollows
4. Inner side of outer rail on the curve.

Codes:

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

Answers

1. (c)	2. (c)	3. (a)	4. (a)	5. (c)
6. (a)	7. (c)	8. (c)	9. (d)	10. (a)
11. (b)	12. (b)	13. (a)	14. (c)	15. (b)
16. (d)	17. (b)	18. (a)	19. (b)	20. (a)
21. (c)	22. (a)	23. (d)	24. (c)	25. (d)
26. (c)	27. (c)	28. (b)	29. (d)	

CHAPTER 03

Sleepers

3.1 Function of Sleepers

Main functions of sleepers are as follows:

(i) It holds the rail to correct gauge and alignment.
(ii) It gives firm and even support to the rails.
(iii) It transfer the load in a uniform way from rails to area of ballast.
(iv) It acts as an elastic medium between rails and the ballast to absorb the blows and vibrations of moving load.
(v) It provides longitudinal and lateral stability to the permanent way.

NOTE

(i) If rail sections are not being supported evenly and firmly, then they will sink into the ballast cushion.
(ii) If sleepers are not elastic then the deformation will keep on increasing and finally the track will become irregular in shape.

3.2 Requirements of Sleepers

(i) Initial cost as well as maintenance cost should be minimum.
(ii) It should be of moderate weight.
(iii) Fixing and removing fastenings should be easy.
(iv) There should be sufficient bearing area for all the sleepers. So as to resist crushing due to rail seat.
(v) Maintenance should be easy.
(vi) Track circuiting should be possible.
(vii) Anti-theft and anti-sabotage qualities should be present.
(viii) It should be capable of resisting shocks and vibrations due to heavy loads.

3.3 Sleeper Density and Spacing of Sleepers

- Sleeper density is the number of sleepers per unit rail length.
- It is specified as $N + x$ or $M + x$

  where, N or M is length of rails in metres or yards, x is the number varying according to the factors F

- F is a funciton of axle load and speed, type and section of rails, type and strength of sleepers, type of ballast and ballast cushion and nature of formation.
- Spacing of sleeper is based on the sleeper density.
- Spacing of sleeper is kept uniform at location away from the rail joints whereas closer at location near the rail joints.

NOTE
(i) There is a limitation to the close spacing of sleepers as enough space is required for working the beaters to pack the joint sleepers.
(ii) Though more number of sleeper assures more lateral stability yet number of sleepers is restricted as certain minimum space between sleeper ensure good packing of ballast.

Example 3.1 A BG track has a sleeper density of $n + 6$. If the track is laid with welded rails of 26 m length. Find out the no. of sleepers required for constructing a railway track of 1690 m.

Solution:

$$\text{Length of each rail} = \frac{26\text{m}}{2} = 13 \text{ m}$$

Given, sleeper density $= n + 6$

Where n is the length of the rails in metres.

$$\text{Sleeper density} = 13 + 6 = 19$$

$$\text{Total no. of rail required} = \frac{1690}{13} = 130$$

$$\text{Total no. of sleepers} = \text{No. of rails} \times \text{Sleeper density}$$

$$= 130 \times 19 = 2470$$

Sleeper density = 19 implies 19 sleepers per rail length

3.4 Types of Sleepers

The sleeper which are mostly used in Indian Railways are

(i) Wooden sleepers
(ii) Steel sleepers
(iii) Cast iron sleepers
(iv) Concrete sleepers

3.4.1 Wooden Sleepers

- It is the most ideal type of sleeper and with passage of time its utility has not decreased.
- There are two categories of wooden sleepers
  (i) Hardwood sleepers → Sal, Teak etc.
  (ii) Soft wood sleepers → Deodar, Chir etc.
- Advantages of wooden sleeper
  (i) Cheap and easy to manufacture
  (ii) Very useful for heavy loads and high speed trains
  (iii) Absorbs shocks and dampens vibrations properly

  (iv) Can be handled easily without damage
  (v) Alignment can be corrected easily
  (vi) Can be used with or without ballast
  (vii) Most suitable for track circuiting
  (viii) Suitable in the areas having yielding formation
- Disadvantages of wooden sleepers
  (i) Do not maintain the gauge accurately
  (ii) Easily develop cracks with beater packing
  (iii) Susceptible to fire hazards
  (iv) It has lesser life due to wear, decay and attack by vermins
  (v) Scrap value is low
- The size of sleepers for B.G, M.G., N.G. as well as bearing area per sleeper is as follows:

Gauge	Size (in cms)	Bearing area per sleeper (in sq.ft.)
B.G	275 × 25 × 13	5.00
M.G	180 × 20 × 11.5	3.33
N.G	150 × 18 × 11.5	2.25

- Wooden sleepers required for bridges and points and crossings are of thicker section. viz. 10″ × 6″ or 10″ × 7″

NOTE: Untreated wooden sleepers should be laid with sapwood side upwards and heartwood side downwards.

3.4.1.1 Composite Sleeper Index (CSI)

- CSI is used to look at the strength characteristics and the suitablity of the particular timber used in wooden sleepers.
- CSI is given by following formula

$$\text{CSI} = \frac{S + 10H}{20}$$

Where, S = General strength figure both for green and dry timber at 12% moisture content
H = General hardness figure both for green and dry timber at 12% moisture content.

- Minimum CSI precribed on Indian Railways is as follows:
  (i) Track sleeper → 783
  (ii) Crossing sleeper → 1352
  (iii) Bridge sleeper → 1455

3.4.2 Steel Sleepers

About 20% of track on Indian Raiways is laid on steel sleepers.

They are in the form of steel trough on which rails are fixed by keys or nuts or bolts.

Advantages of steel sleepers:

(i) Easy maintainance and adjustment of gauge compared to other sleeper
(ii) Easy to handle (as they are light in weight compared to other sleepers)
(iii) Simple process of manufacturing

(iv) Longer life
(v) Better lateral rigidity
(vi) Free from decay and attack by vermins
(vii) Not susceptible to fire hazards
(viii) Good scrap value

Disadvantages of steel sleepers:
(i) Prone to corrosion
(ii) Develop cracks at rail seat or near lugs
(iii) Unsuitable for track circuiting
(iv) Can only be used for type of rails for which it is manufactured
(v) Develop the tendency to become centre bound (because of slope at both ends)

3.4.2.1 Key Type Steel Sleepers

In this type of sleepers, lugs or jaws are pressed out of metal and keys are used for holding the rails. These are of two types:

(i) Lug type (ii) Loose jaw type

Lugs are formed by pressing out the metal of the channel section while loose jaw type is an improvement on pressed lug type.

3.4.2.2 Clip and Bolt Type Sleepers

- Clips and bolts are used for holding the rails.
- Cracks are not developed in the sleepers as the holes for the bolt are small and circular.
- Requires four clips and four bolts for holding each rail.

3.4.3 CI Sleepers (Cast Iron Sleepers)

CI sleepers are either of pot type or plate type

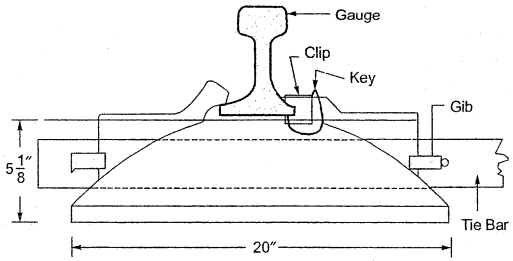
Advantages of CI sleeper over steel trough sleepers
(i) Lesser corrosion
(ii) Lesser liable to crack at rail seat
(iii) Easier to manufacture
(iv) Higher scrap value
(v) Retain alignment well due to keel at the bottom

Disadvantages of CI sleepers over steel trough sleepers
(i) Gauge maintenance is difficult (as tie bar gets bent)
(ii) Afford lesser lateral stability
(iii) Unsuitable for track circuited lines
(iv) More susceptible to breakage

They are of following types:
(i) Pot sleepers
(ii) Plate sleepers
(iii) CST 9 sleepers
(iv) Duplex rail free joint sleepers

3.4.3.1 CI Pot Sleepers

- These consists of two hollow bowls or pots of circular or elliptical shape, placed inverted on the ballast section.
- Two pots are connected with the help of cotter and gib (the projecting arm).
- Rail is placed on the top of the pot in a rail seat with a cant of 1 in 20 and is held in position with the help of a key.



C.I. Pot sleeper

Fig. 3.1

- It cannot be used on curves sharper than 4° on BG.
- Most of the fittings are hidden and then inspection and maintenance is quite difficult.
- This has become obsolete now.

3.4.3.2 Plate Sleepers

- It consists of a plate with dimension of about 88.4 cm × 30.5 cm.
- It provides an effective bearing area of 0.232 sqm under each rail.
- The plate is provided with a projecting rib underneath to have a grip in the ballast.
- Vertical stiffners are provided diagonally on the top of the plate.
- The plates are connected across the track by means of a tie rod.

3.4.3.3 CST9 Sleeper (Central Standard Trial-9)

- It is a combination of plate, pot and box sleeper.
- CST 9 stands for central standard 9 sleepers.
  This name comes from the different number of test which has been carried out in the laboratories of railways where different type of sections on different types of designs related to cast iron sleeper has been tried.
  So, in this section, this is the 9th trial which has been successful.
- It has a triangular inverted pot on the either side of the rail seat, a plate with the projecting rib and a box on the top of the plate.
- The pieces are connected across the track by means of a rod.
- A rail seat or chair is provided to hold the flat footed or bull headed rail respectively with 1 in 20 cant.
- Salient features of CST 9 sleepers are:
  (i) The tie bar is fastened to the plate by means of four standard cotters.
  Small variation in gauges is corrected by means of cotters.
  (ii) The rail seat has 1 in 20 cant and is only 11.4 cm wide.
  This narrow bearing tends to reduce the rocking of the sleeper plate under the wave motion of the rail.
  (iii) A single two way key is provided by keying of the ballast in the two packets.

(iv) Lateral stability is provided by keying up of the ballast in the two packets. Additional anchorage is provided by a keel provided centrally along the rail.

(v) Its bearing area is approximately equal to the bearing area of wooden sleepers.

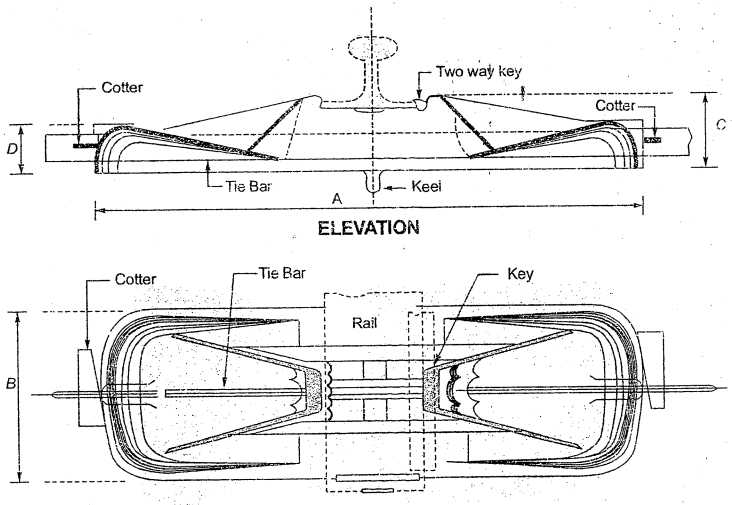


Fig. 3.2

3.4.3.4 Duplex Rail Free Joint Sleepers

- Duplex rail free joint sleepers have been provided under the rail joints in track laid with CST-9 sleepers.
- This is done to prevent cantilever action between the two supports of the sleepers at the joint.

3.4.4 Concrete Sleepers

There are two types of concrete sleepers

(i) Reinforced concrete sleepers

(ii) Pre-stressed concrete sleepers

Reinforced concrete sleepers are of two types

(i) Through type sleepers

(ii) Composite tie type sleepers

Prestressed concrete sleepers can eliminate the drawbacks of reinforced concrete sleepers.

In this type, concrete is put under vey high initial compression.

The design of prestressed concrete sleeper is based on

(i) The maximum permissible compressive strength of 211 kg/cm^2

(ii) Minimum cube crushing strength of concrete in the sleeper is 422 kg/cm^2 at 28 days

(iii) Prestressed wires are stressed to an initial stress of 8.82 kg/cm^2

A shock absorbing pad is provided at the rail seat to prevent concrete sleeper to disintegrate, and also to prevent hard riding.

3.4.4.1 Through Type RCC Sleeper

- Also known as one piece or mono block sleeper.
- Cracks develop on the tension side when stressed.

3.4.4.2 Composite Tie Type Sleepers

- It consists of two RCC blocks connected by a metal tie of inverted T-section.
- These sleepers are not subjected to any degree of tensile stress as in through type.

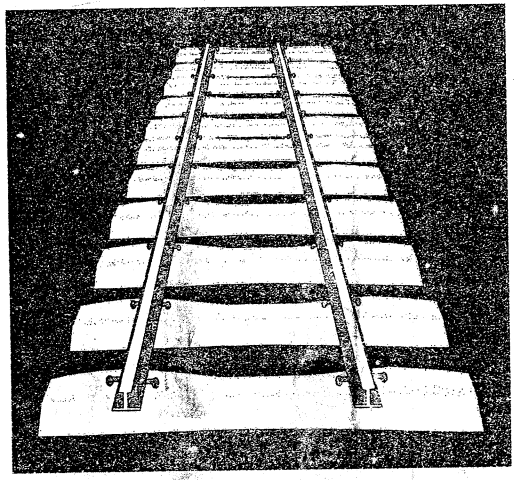


Fig. 3.3

Example 3.2 The sleeper density for a BG track is N+5. Find the number of sleepers required for 1 km of track length.

Solution:

Length of a rail for a BG track = 12.8 m or say 13 m

Sleeper density is $N + 5$

So, number of sleepers under each rail = 13 + 5 = 13

13 m of track length requires 18 numbers.

So, no. of sleepers required for 1 km (1 km = 1000 m) of track length = $\frac{18 \times 1000}{13} = 1384.6 \simeq 1385$

Summary

- Sleeper is a support for rails and a medium for load transfer from rail to ballast.
- Sleeper provides longitudinal as well as lateral stability to the permanant way.
- Sleeper density is the no. of sleepers per unit length It is specified as $N+x$ or $M+x$. (N or M is length of rails in metre or yards, x is no. varying according to axle load and speed, types of rails, sleepers and ballast, ballast cushion, nature of formation etc.)

- The major four types of sleepers are wooden, steel, cast iron concrete sleepers.
- The size of sleepers for B.G., M.G., N.G. are 275 × 25 × 13 cm, 180 × 20 × 11.5 cm, 150 × 18 × 11.5 cm.
- Untreated wooden sleepers should be laid with sapwood side upwards and heart wood side downwards.
- Composite sleeper index is used to look at the strength characteristics and suitabilityof timber.
- Minimum CSI prescribed on Indian Railways for track sleeper, crossing sleeper and bridge sleeper are 783, 1352 and 1455 respectively.
- CST9 sleeper is a combination of plate, pot and box sleepers.
- Duplex rail free joint sleepers are provided under the rail joints in tracks laid with CST-9 sleepers.
- Breathing length is that length of LWR (or CWR) which is subjected to expansion/contraction on account of temperature change.
- Switch expansion joint is installed at each end of LWR (or CWR) to permit expansion/contraction of the adjoining breathing length.
- Buffer rails are a set of rails provided in place of SEJ at the ends of LWR (or CWR).

Objective Brain Teasers

Q.1 Which of the following types of sleepers is preferred on joints?
(a) CST–9 sleeper
(b) steel trough sleeper
(c) wooden sleeper
(d) concrete sleeper

Q.2 Sleeper density in India is normally kept as
(a) $M + 2$ to $M + 7$
(b) M to M + 2
(c) $M + 5$ to $M + 10$
(d) M

Q.3 For a Broad Gauge route with M+7 sleeper density, number of sleepers per rail length is
(a) 18 (b) 19
(c) 20 (d) 21

Q.4 Standard size of wooden sleeper for Broad Gauge track is
(a) 275 × 25 × 13 cm
(b) 180 × 20 × 11.5 cm
(c) 225 × 23 × 13 cm
(d) 250 × 26 × 12 cm

Q.5 Composite sleeper index is the index of
(a) hardness and strength
(b) strength and toughness
(c) toughness and wear resistance
(d) wear resistance and hardness

Q.6 Minimum composite sleeper index prescribed on Indian Railways for a track sleeper is
(a) 552 (b) 783
(c) 1352 (d) 1455

Q.7 At points and crossings, the total number of sleepers for 1 in 12 turnouts in Broad Gauge is
(a) 51 (b) 42
(c) 70 (d) 78

Q.8 Metal sleepers are superior to wooden sleepers with respect to
(a) cost (b) lift
(c) track circuiting (d) fastening

Q.9 Consider the following statements about concrete sleepers.
(1) they improver the track modulus
(2) they have good scrap value
(3) they render transportation easy
(4) they maintain the gauge quite satisfactorily
(a) 1 and 2 are correct (b) 2 and 3 are correct
(c) 3 and 4 are correct (d) 1 and 4 are correct

Q.10 For a sleeper density of $(n + 5)$, the number of sleeper required for constructing a broad gauge railway track of length 650 m is
(a) 975 (b) 918
(c) 900 (d) 880

Q.11 Best wood for wooden sleepers is
(a) chir (b) deodar
(c) sal (d) teak

Q.12 If n is length of a rail in metres, the number of sleepers per rail length generally varies from
(a) n to $(n + 2)$ (b) $(n + 2)$ to $(n + 4)$
(c) $(n + 3)$ to $(n + 6)$ (d) $(n + 4)$ to $(n + 5)$

Q.13 Minimum packing space provided between two sleepers, is between
(a) 20 to 25 cm (b) 25 to 30 cm
(c) 30 to 35 cm (d) 35 to 40 cm

Q.14 The standard dimensions of a wooden sleeper for a B.G. railway track are
(a) 2.74 m × 25 cm × 13 cm
(b) 1.83 m × 20 cm × 11 cm
(c) 1.52 m × 15 cm × 10 cm
(d) 1.75 cm × 20 cm × 12 cm

Q.15 The standard dimensions of a wooden sleeper for M.G. railway track are
(a) 2.74 m × 25 cm × 13 cm
(b) 1.83 m × 20 cm × 11 cm
(c) 1.52 m × 15 cm × 10 cm
(d) 1.75 m × 20 cm × 12 cm

Q.16 If S and H are strength and hardness index of a timber at 12% moisture content, the composite sleeper index, is
(a) $\frac{H + 10S}{20}$ (b) $\frac{S + 10H}{20}$
(c) $\frac{20S + H}{10}$ (d) $\frac{S + 20H}{10}$

Q.17 Composite sleeper index determines
(a) number of sleepers per rail length
(b) suitability of wooden sleepers
(c) permissible stresses in steel sleeper
(d) None of these

Q.18 Minimum composite sleeper index for wooden sleepers used over bridge girders, is
(a) 1455 (b) 1355
(c) 1255 (d) 1155

Q.19 Minimum composite sleeper index for wooden sleepers used in crossovers, is
(a) 1152 (b) 1252
(c) 1352 (d) 1452

Q.20 For inspection and packing of ballast, each pot sleeper is provided with
(a) one hole (b) two holes
(c) three holes (d) four holes

Q.21 By interchanging gibs and cotters of a pot sleeper, gauge may be slackened by
(a) 1.2 mm (b) 2.2 mm
(c) 3.2 mm (d) 4.2 mm

Answers

1. (c)	2. (a)	3. (c)	4. (a)	5. (a)
6. (b)	7. (c)	8. (b)	9. (d)	10. (c)
11. (d)	12. (c)	13. (c)	14. (a)	15. (b)
16. (b)	17. (b)	18. (a)	19. (c)	20. (b)
21. (c)				

CHAPTER 04

Ballast and Formation

4.1 Ballast and it's Functions

Ballast is a layer of broken stones, gravel or sand kankar etc. laid and packed below and around sleeper.

Function of ballast:

(i) Distributes the load from the sleepers to the formation
(ii) Provides a suitable foundation for the sleepers
(iii) Protects the top surface of formation by providing coarse aggregates with plenty of voids
(iv) Holds the sleeper in position and prevents the lateral and longitudinal movement due to dynamic and vibrating load of moving train.
(v) Provides elasticity to the track
(vi) Provides easy means of correcting track levels and alignment.
(vii) Provides good drainage of the track.

4.2 Characteristics of Good Ballast

(i) Should resist crushing under dynamic loads (it should not be brittle)
(ii) Should have resistance to abrasion and weathering (non-porous particles are usually more durable)
(iii) Should provide longitudinal and lateral stability (stones should be angular and not flat)
(iv) Water that enters the ballast must drain off and voids should be big enough to prevent capillarity (maintains uniform stability and elasticity of track)
(v) Should be capable of being cleaned of all dust that gets formed to provide good drainage
(vi) Should be chosen from nearby quarries (to have reduced cost of supply)

NOTE

Different types of ballast used in India are:
(a) Broken stone (b) Gravel
(c) Sand (d) Cinder or Ashes
(e) Soft aggregates like moorum, kankar and brick ballast
(f) Selected earth

4.3 Specification of Ballast

4.3.1 Specification based on Quality

(i) Should be hard and durable
(ii) Should not wear out due to physical reasons
(iii) Should be free from inorganic and organic residues

4.3.2 Specification based on Top Width and Depth of Cusion

- The depth of ballast is an important factor for load bearing capacity and uniformity of load distribution.
- The width of ballast layer influences the lateral strength of track.

NOTE

Minimum depth of ballast section.
(i) Assume load dispersion at 45° to the vertical.
(ii) Depth should be such that dispersion lines do not overlap.

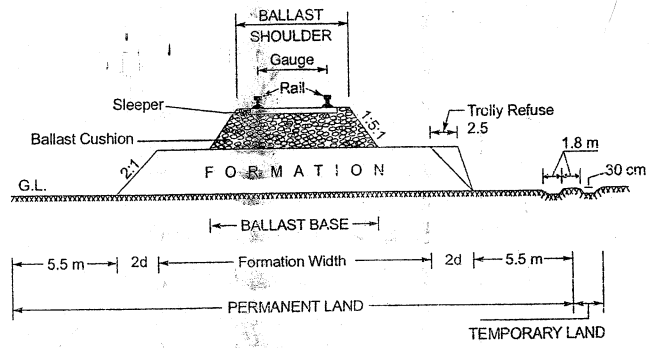
4.3.2.1 Specification

(i) Top width varies between 3350 mm to 1830 mm for broad gauge and narrow gauge.
(ii) In the case of broad gauge, there is a classification as A, B, C, D and E whereas in the case of metre gauge, the classification is Q, R_1, R_2 and S.
In the case of A and Q, min. depth of cushion is 300 mm.
In the case of B, C and R_1, it is 250 mm.
In the case of D and R_2, it is 200 mm.
In the case of E and S, it is 150 mm.

Standard size of ballast for sleepers	
Size of Ballast	Type of Sleeper
50 mm	Wooden and CI pot sleeper
40 mm	CST9 and through sleeper
25 mm	Points and crossings

4.3.3 Specification based on Physical Properties

(i) Abrasion test value at the maximum can be 30%
(ii) Impact value at the maximum can be 20%
(iii) Elongation index and Flakiness index at the maximum can be 50%
(iv) Specific gravity at a minimum level can be 2.65
(v) Maximum water absorption can be 10%



A typical cross-section of a permanent track

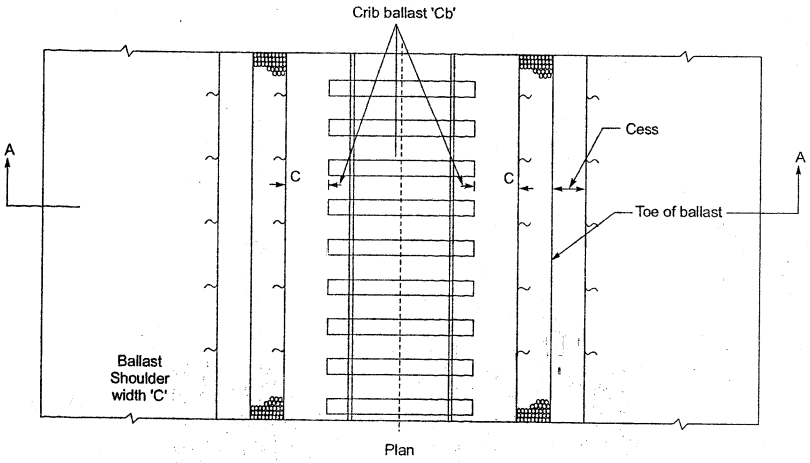
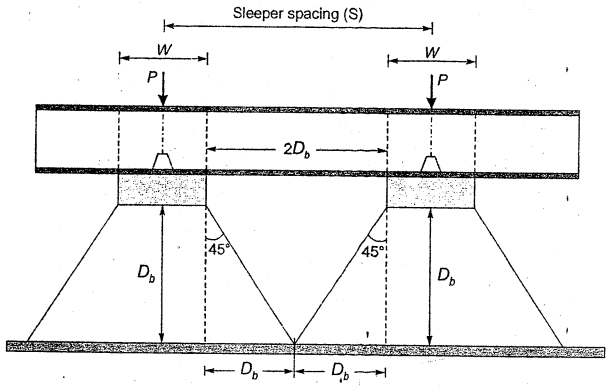


Fig. 4.1 Cross-section of a railway track

Example 4.1 Wooden sleepers are used in track laying with sleepers density as $n + 7$, the sleeper spacing is 65 cm and width of sleeper is 25 cm. Calculate minimum depth of ballast required.

Solution:

Dispersion diagram:



where,

D_b = Depth of ballast

S = Sleeper spacing

W = Width of sleeper

From figure

$$S = 2D_b + W$$

$$D_b = \frac{S - W}{2} = \frac{65 - 25}{2} = 20 \text{ cm}$$

So, minimum depth of ballast required is 20 cm.

4.4 Keywords Related to Ballast

(i) Packing → It is the compact ballast cushion laid below the sleeper as per gradation.

(ii) Boxing → It is relatively loose ballast which is placed on the side of the sleepers to provide lateral stability.

(iii) Screening → It is the process of renewing the ballast section which has degraded.

(iv) Ballast Crib → Loose ballast between the two adjacent sleepers in the track.

4.5 Formation and its Function

- Formation is the term used to denote the surface formed at the top of embankment or the bottom of the cutting for a railway or road line.
- It is also called subgrade.
- Width of the formation depends on
  - (i) The number of gauges to be laid side by side
  - (ii) Gauge type
- The Indian standard have made following recommendations for formation width as given in table:

S.No.	Particulars	Dimensions in meters			
		BG	MG	NG	Slope
1.	Embankment:				
	Width of bank:				
	(a) Single line	6.10	4.88	3.70	—
	(b) Double line	10.67	8.53	7.32	2 : 1
2.	Cutting:				
	Width excluding side drains				
	(a) Single line	5.49	4.27	3.35	—
	(b) Double line	10.06	7.93	7.01	1.5 : 1

- Functions of formation are as follows:
  - (i) Provides a smooth and uniform bed on which railway track can be laid.
  - (ii) Bears the load transmited to it from the sleeper through the section of the ballast.
  - (iii) To facilitate drainage.
  - (iv) To provide stability to the track.
  - (v) To prevent ballast from puncturing into formation.
- The height of the embankment or the depth of cutting depends upon the ground contours and the gradient adoted.

4.6 Subgrade Improvement

Method adopted for subgrade improvement are:

(i) Blanketing (ii) Sand pilling
(iii) Grouting (iv) Precast concrete mats

NOTE: Subgrade improvement is needed if subgrade consists of heavy clay, peat soils, loamy soils containing clay etc.

4.6.1 Blanketing

- Blanket of noncohesive soils between the subgrade and ballast section improve the bearing and drainage properties.

4.6.2 Sand Piling

- Holes about 30 cm in diameter and 1.8 m to 3 m in depth are driven vertically into the subgrade by driving wooden piles and then taking them out.
- Holes are then filled with sand.
- These sand piles provides mechanical support and drainage.
- Inverted filters are provided below the ballast layer as subbase for effective drainage from sand piles.

4.6.3 Grouting

- Consists of cement and sand mixed with water to make a slurry.
- Stabilizes the weak fills
- Used to stabilise and strengthen the entire subgrade.
- The ratio of cement to sand may vary from 1 : 1 to 1 : 12 and even more.
- The injection points are placed at 1.5 m to 1.8 m in staggered position at both ends of the sleepers.

4.6.4 Pre-cast Concrete Mats

- Have been used between the ballast section and top of subgrade to obtain an even distribution of load from the ballast to the subgrade.

Summary

- Ballast is a layer of broken stone, gravel or sand, kankar etc. laid and packed below and around sleeper.
- Ballast distributes the load from sleeper to formation.
- Top width of ballast varies between 3350 mm to 1850 mm for BG and NG.
- Packing is the compacted ballast cushion laid below the sleeper as per gradation.
- Boxing is the loose ballast placed on the sides of the sleepers to provide lateral stability.
- Ballast crib is the loose ballast betwen the two adjacent sleepers in the track.
- Formation is the term used to denote the surface formed at the top of the embankment or the bottom of the cutting.
- Formation is also called sugbrade.
- Methods adpoted for subgrade improvement are blanketing, sand pilling, grouting, precast concrete mats.

Objective Brain Teasers

Q.1 The formation width for a railway track depends on the
(i) type of gauge
(ii) number of tracks to be laid side by side
(iii) slope of sides of embankment or cutting
The correct answer is
(a) only (i) (b) both (i) and (ii)
(c) both (i) and (iii) (d) (i), (ii) and (iii)

Q.2 Minimum depth of ballast cushion for a Broad Gauge wooden sleeper of size 275 × 25 × 13 cm with 75 cm sleeper spacing is
(a) 15 cm (b) 20 cm
(c) 25 cm (d) 30 cm

Q.3 The nominal size of ballast used for points and crossings is
(a) 25 mm (b) 40 mm
(c) 50 mm (d) 10 mm

Q.4 Width of ballast section for Broad Gauge is
(a) 1.83 m (b) 2.25 m
(c) 3.35 m (d) 4.30 m

Q.5 Which of the following statements regarding ballast materials are correct?
1. Brick ballast has poor drainage characteristics.
2. Coal ash is not used as ballast with steel or cast iron sleepers.
3. Gravel ballast gives better performance on soft formation.
4. Sand ballast causes excessive wear on top of rail.

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

Q.6 Packing of ballast is done
(a) near the ends of sleepers
(b) on the shoulders
(c) under sleepers
(d) between two rails

Q.7 Boxing of ballast is done
(a) under rails
(b) at the rails
(c) in between two rails
(d) in between two sleepers

Q.8 For flat bottom sleepers, maximum size of ballast, is
(a) 50 mm (b) 40 mm
(c) 33 mm (d) 25 mm

Q.9 For metal sleepers with rounded edges, maximum size of ballast, is
(a) 50 mm (b) 40 mm
(c) 30 mm (d) 25 mm

Q.10 For points and crossings, maximum size ballast, is
(a) 50 mm (b) 40 mm
(c) 30 mm (d) 25 mm

Q.11 Sand may be used as ballast for
(a) wooden sleepers (b) steel sleepers
(c) cast iron sleepers (d) all the above

Q.12 Best ballast contains stones varying in size from
(a) 1.5 cm to 3 cm (b) 2.0 cm to 4 cm
(c) 2.0 cm to 5 cm (d) 2.5 cm to 6 cm

Q.13 If w is width of sleepers, s is sleeper spacking and d is depth of ballast then
(a) $d = \frac{s-w}{2}$ (b) $d = \frac{s-w}{3}$
(c) $d = \frac{s-w}{10}$ (d) $d = \frac{s-w}{5}$

Q.14 Minimum depth of ballast prescribed for B.G. trunk lines of Indian Railways, is
(a) 20 cm (b) 15 cm
(c) 25 cm (d) 30 cm

Q.15 For even distribution of load through ballast, load dispersal is assumed as
(a) 30° to the vertical (b) 45° to the vertical
(c) 60° to the vertical (d) None of these

Q.16 If sleeper density is $M + 7$ for 13 m rails, the minimum depth of ballast under wooden sleepers (25 cm × 13 cm), is
(a) 15 cm (b) 20 cm
(c) 25 cm (d) 30 cm

Q.17 The standard width of ballast for B.G. track in Indian Railways, is kept
(a) 3.35 m (b) 3.53 m
(c) 2.30 m (d) 2.53 m

Q.18 The standard width of ballast for M.G. track in Indian Railways, is kept
(a) 3.35 m (b) 3.53 m
(c) 2.30 m (d) 2.50 m

Q.19 Match **List-I** (Ballast portion) with **List-II** (Function) and select the correct answer by using codes given below the lists:

List-I
A. Ballast cushion
B. Shoulder ballast
C. Crib ballast
D. Extra ballast on

List-II
1. Stability against centrifugal forces
2. Provides resistance to the longitudinal track movement
3. Provides resistance to the lateral movement of the track
4. For distribution of curves load on the formation

Codes:

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

Answers

1. (b)	2. (c)	3. (a)	4. (c)	5. (d)
6. (c)	7. (b)	8. (a)	9. (b)	10. (d)
11. (c)	12. (c)	13. (a)	14. (d)	15. (b)
16. (b)	17. (a)	18. (c)	19. (c)	

CHAPTER 05

Tracks Fastenings

5.1 Rail to Rail Fastening

- A rail joint is the weakest link in the track.
- There is a break in the continuity of the rails in horizontal as well as vertical plane because of the expansion gap and difference in the rail heads at the joints.
- Two types of railway joints are normally used on Indian Railways.
  (i) Supported joints
  (ii) Suspended joints
- In supported joints, the ends of the rails are supported directly on a single sleeper. E.g. Duplex sleeper
- In suspended joints, the ends of the rails are suspended between the two sleepers and the load on the sleepers gets distributed.
- Rail to rail fastenings fish plate, bolts and nuts.

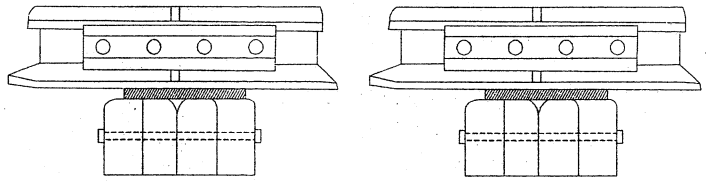


Fig. 5.1 Supported joint

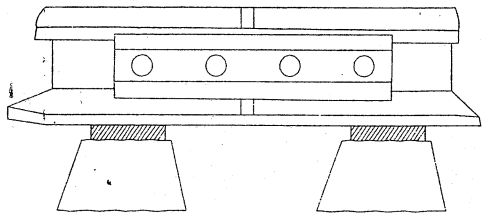


Fig. 5.2 Suspended joint

5.1.1 Fish Plates

These are used in rail joints to maintain the continuity of the rail.

- The main objective of fish plates are to keep the adjoining ends of the rail in correct position both in horizontal and vertical planes.
- Fish plates should be designed for the following purposes
  - (i) bear the stresses due to lateral and vertical bending without getting distorted. (the usual section designed for this purpose is the bone shaped on lipped fish plate).
  - (ii) to allow for the expansion and contraction of rail (area of contact between fish plates and the rail should be minimum possible with due regards to strength and other requirement of rail joints).
  - (iii) to resist wear (the section of fish plate is so designed that the irregularities at the surface of contact caused by wear can be adjusted by further tightening of fish bolt).
- This fish plate is designated as IRST dash 1 oblige 57.
- The minimum ultimate tensile strength (UTS) of the fish plate should be between 57 to 68 kg/mm^2.
- They should allow easy renewal and replacement of rails in case of wear and damage.

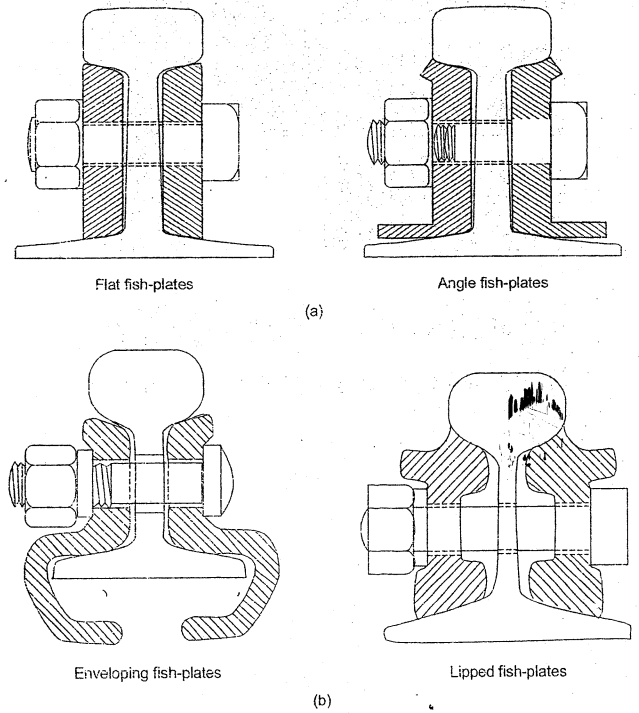


Fig. 5.3 A few designs of fish-plates

5.1.1.1 Combination Fish Plates

- There are certain locations where the two rail section which have been joined together are not of same size or cross-sectional area.
- Gives additional thickenings of joint.
- Eliminates expansion gap.
- Fish plates are marked right in/out, left in/out depending upon direction from lighter rail to heavier rail.

5.1.2 Fish Bolts and Nuts

- They are made of medium or high carbon steel (to withstand shear due to heavy transverse stresses)
- For 90 lbs rail, a bolt of 1 inch diameter and 5 inch length is used.
- Too much tightening of bolts is prohibited. (to prevent free expansion and contraction of rails)
- For this, we use lock nuts and washers.

NOTE: At one particular joint, there will be two fish plates, four bolts and four nuts.

5.2 Ways of Fastenings

Laying of the rail on a sleeper and fixing the two together can be done in following four ways:

(a) Direct laying and direct fixing
(b) Direct laying and indirect fixing
(c) Indirect laying and direct fixing
(e) Indirect laying and indirect fixing

5.2.1 Direct Laying and Direct Fixing

- Rail is laid as well as fixed directly on to the sleepers with spikes, screws or clips.
- Bearing plates between rail foot and the sleeper is absent.
- Stresses caused in the sleeper are high and the pressure on the ballast is also high.

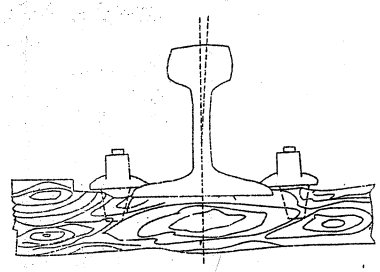


Fig. 5.4 Direct laying and direct fixing

5.2.2 Direct Laying and Indirect Fixing

- Rail is directly laid on the sleeper without a bearing plate.
- Separate fastenings fix the rail to the sleeper but a special shoulder or plate is fixed to the sleeper on either side of the rail foot by means of spikes or inserts.
- Lateral forces on the rail are transmitted to the shoulder or plate.

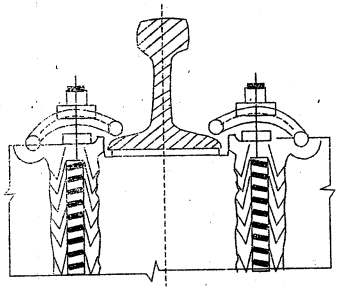


Fig. 5.5 Direct laying and indirect fixing

5.2.3 Indirect Laying and Direct Fixing

- Rail is indirectly laid on the sleeper with a bearing plate in between.
- Only one fastening fixes the bearing plate to the sleepers body and the rail to the bearing plate.

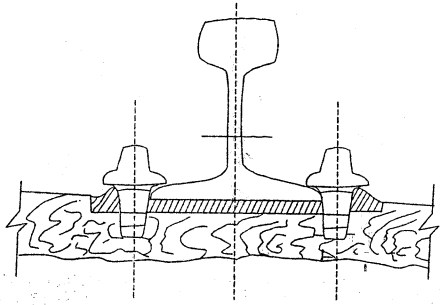


Fig. 5.6 Indirect laying and direct fixing

5.2.4 Indirect Laying and Indirect Fixing

- Rail is laid on the sleeper with a bearing plate in between.
- Bearing plate is fixed to the sleepers with rail screws but the rail is fixed to the bearing plate by separate fastenings.
- Fastenings fixing the rail to the bearing plate is tightened in-situ and it can be adjusted, loosened or taken out without touching fixtures fixing the bearing plate to sleepers.

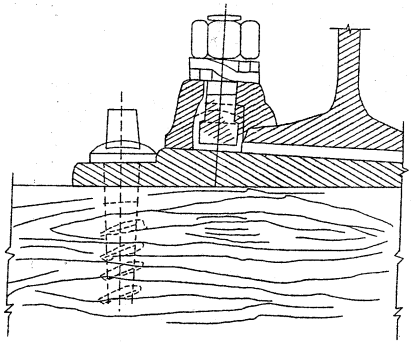


Fig. 5.7 Indirect laying and indirect fixing

NOTE

(i) A bearing plate serves to distribute the load on the rail over a large area of the sleeper which limits the stresses in the sleeper.

(ii) A bearing plate is essential for soft wood sleepers.

5.3 Rail to Wooden Sleeper Fastenings

- Rail to wooden sleeper fastenings. Dog spikes, fang bolts or screw spikes, bearing plates.
- Main functions of the spike is to keep the rail in gauge.

5.3.1 Dog Spike, Round Spike or Elastic Spike

- Spikes are means by which chairs for rails are fixed to the sleepers (all three types).
- The holding power of dog spikes is half that of screw spikes.
- Dog spikes are still preferred highly because of their economy, easy fixing and removing and better gauge maintenance.

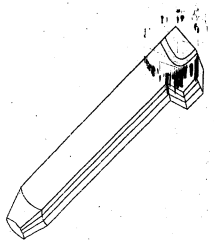


Fig. 5.8 Dog Spike

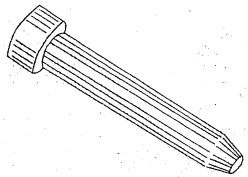


Fig. 5.9 Round spike

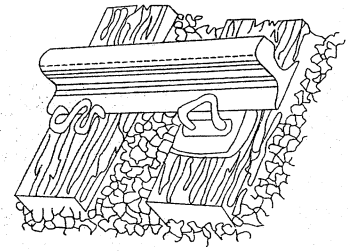


Fig. 5.10 Elastic Spike

- Dog spikes permits creep to some extent.
- Spikes offers considerable resistance to lateral deflection of the rail but little to longitudinal movement.
- The pull out strength of the spike depends on the elastic grip of the timber around the spike and the coefficient of friction.
- Round spike is similar to dog spike with only difference that top is being provided with a cap. (an alternative to bolt)
- Elastic spikes are used with flat bottomed rail, base plates and wooden sleepers, the elastic spikes holds the rail down and prevents tripping and also secures base plates to the sleepers. E.g. Macbeth Spike.
- Elastic spikes are sometimes used to overcome the difficulty of creep.
- A dog spike is square in horizontal section and has a pointed penetrating bottom and the top has two lugs on either side giving the impression of dog's head.

5.3.2 Screw Spikes

- Screw spikes are available in two types
  Plate screw, rail screw
- A screw spike is a large metal screw used to fix a tie plate or fasten rails
- It can be used in combination with spring washer.
- Screw spikes are best suited for high speed trunk routes (because of screwing nature they have a tendency to remain in position and they do not move in and out of the hole again and again.)

- In a plate screw, we used a plate along with the screw spike whereas in a rail screw, screw spike is directly fitted with the rail section just through its hole.
- In plate screw, friction offered by the plate also helps in arresting the lateral deformation and longitudinal movement of the rail.

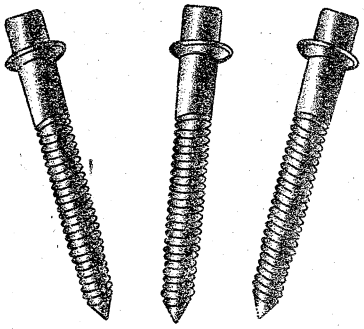


Fig. 5.11

5.3.3 Fang Bolts

- Mostly used for fixing rails or slide chair to the sleeper.
- Round spikes or screw spikes are used as an alternative to fang bolt.
- Fang bolt is a bolt inserted through a hole in the sleeper.
- They are considered effective than spikes and screws and hence are used in positions such as switches (point), tie plates and on sharp curves.
- More resistant to loosening by vibrations and movement of the rail.

NOTE: Fang bolt is a bolt which has for a nut, a triangular plate with sharp fangs projecting from its corners.

5.3.4 Bearing Plates

Functions of bearing plates:

(i) Absorbs the shocks under moving load.
(ii) Damp and absorbs high frequency vibrations and dissipates energy.
(iii) Resists lateral deformation (specially on curves) of the rails.
(iv) Resists longitudinal movement of the rail.
(v) Prevent abrasion of the bottom of the rail and the rail seat of the sleepers.
(vi) Resists crushing of the material of the sleeper just below the rail.
(vii) Provides electrical insulation between rails in a track circuited or electrified section.

Bearing plates can be categorised as follows:

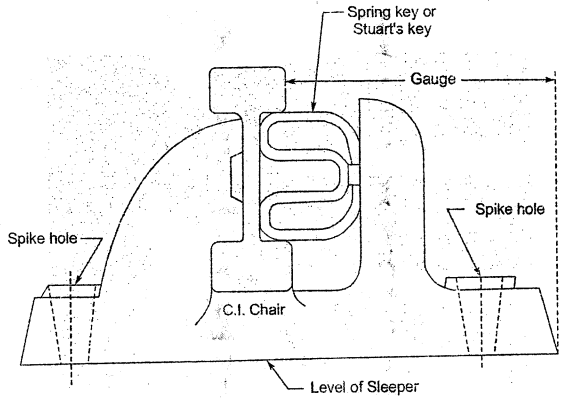
(i) M.S. canted bearing plates.
(ii) Flat mild steel bearing plates.
(iii) C.I. anticreep bearing plates.
(iv) Special CI bearing plate for BH rail (with spring key)
- MS canted bearing plates are only meant for use in turn out track.
- Canted bearing plate has a provision of 1 in 20 slope.
- Flat mild steel bearing plates are used in points and crossing (where turning of track is allowed) and they are provided with dog spikes.

5.4 Rail to Steel Sleeper Fastenings

- Rail to steel sleeper fastening ⇒ Loose jaws, keys and liners.

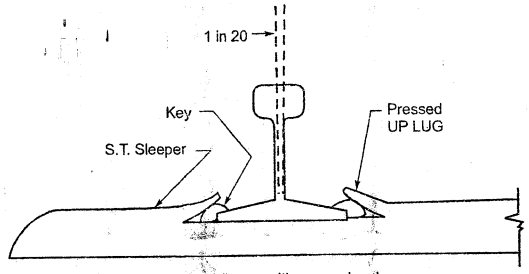
5.4.1 Loose Jaws and Keys

- Loose jaws are provided with one way keys or two way keys.
- There is no problem of damage, crack or deformation.
- Loose jaws goes below the rail surface and at this level, it is trying to provide the lateral stabilities so that rail section is not falling away.
- Keys are used to fasten the rails to the sleeper through jaws.
- Jaws may be of the following types:
  (i) jaws of anticreep bearing plates on wooden sleepers.
  (ii) loose spring jaws of the steel sleeper
  (iii) C.I. jaws of the CST9 sleepers.



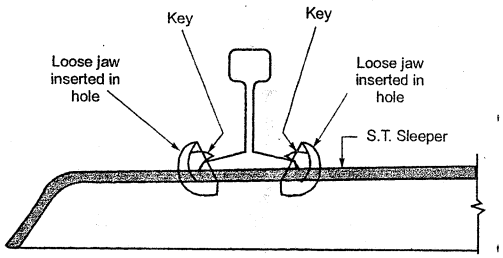
SECTIONAL VIEW

Fig. 5.12



S.T. sleeper with pressed up lugs

Fig. 5.13



S.T. sleeper with loose jaws inserted in holes

Fig. 5.14

5.4.2 Liners

- Liner tries to fasten or keep the connectivity of rail steel sleepers in position.
- Mota Singh, an employee of the Indian Railway on the basis of his experience devised a liner which came to be known as Mota Singh Liner.
- They are valued for features like high durability, dimensional stability and ability to withstand different weather conditions.

5.5 Rail to CI Sleeper Fastening

Rail to CI sleeper fastenings ⇒ Tie bars or cotters

5.5.1 Cotters

- Cotters are used to connect the CI sleeper plate to the tie bar.
- A cotter is a wedge shaped plate with a split in the horizontal and vertical plane.
- Cotters are of following types:
  - (i) Central split cotter
  - (ii) Side split cotter
  - (iii) End split cotter

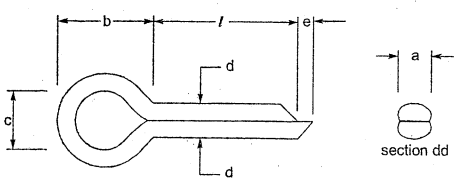


Fig. 5.15

5.5.2 Tie Bars

- Tie bars consists of flat plates with four holes for the cotters.
- The length of the tie bar to be used depends on the types of sleepers and the gauge.

NOTE: (i) Cotters and tie bars are only fastenings peculiar to C.I. sleeper.
(ii) Most commonly used cotter is the side split cotters.

5.6 Elastic Fastenings

Elastic fastenings ⇒ Elastic or pandrol clips, IRN 202 clip, rubber pads, HM fastenings, MCI insert, nylon liner.

5.6.1 Pandrol Clips

- The pandrol clips or elastic clip has different numbers. The one for our use in PR401 clips. (Pandrol 401 clips).
- It is applied parallel to the rails and is driven and removed with an ordinary hammer.
- This clip is fit and forget type.
- This can be used at any locations with any type of connectivity.
- They use two fixtures ⇒ base plates and C.I. inserts.
- Base plate is similar to bearing plate.
- CI inserts are used to connect these clips to the sleepers at the bottom.
- Toe load 710 kg for nominal deflection of 11.4 mm
- Point contact cause indentation on rail foot.
- Gauge adjustment is difficult.
- Pandrol clip can be used with advantage on wooden, steel, concrete and CI sleepers.
- Panorol rail fastenings assembly for wooden sleepers ⇒ Pandrol rail clips, rubber pads, steel on CI base plates.

NOTE: Base plates are fastened to the sleeper by normal means such as dog spikes or screw spikes.

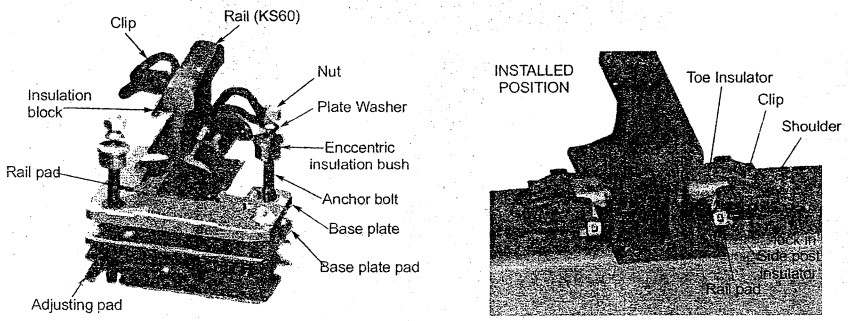


Fig. 5.16

5.6.2 IRN 202 Clip

- Devised by Indian Railways.
- Mostly used for two block RCC sleepers.
- Toe load has been increased to 1000 kg from 710 kg for the pandrol clip.
- Deflection limit has been increased to 18.5 mm from 11.5 mm for the pandrol clip.
- Removal of rail is easy in this case.
- Creep resistance is 50% of the toe load.
- Not fit or forget type.

5.6.3 Rubber Pad

- Elastic rubber pad generally forms an integral part of all elastic fastenings used with other than wooden sleepers.
- It performs following functions:
  - (i) Absorbs shocks and dampens vibrations.
  - (ii) Increased frictional resistance to the longitudinal and lateral movement of the rail.
  - (iii) Helps to distribute the loads uniformly over the sleeper and prevents crushing of the sleeper material.
  - (iv) Provides electrical insulation between rail and sleeper at the rail seat.
- Grooved rubber pads of 4 to 5 mm thickness are used on Indian Railways to serve the above given functions.
- Rubber under compression expands in lateral direction and the groove helps in accommodating the lateral expansion of rubber under load.

Summary

- Rail joint is the weakest link in the track.
- Two types of railway joint normally used in Indian railway are supported joints and suspended joints.
- Fish plates keeps the adjoining ends of rail in correct position both in horizontal and vertical planes.
- The minimum tensile strength of the fish plate should be between 57 to 68 kg/mm^2.
- There are four ways of fastenings.
  - (i) Direct laying and direct fixing
  - (ii) Direct laying and indirect fixing
  - (iii) Indirect laying and direct fixing
  - (iv) Indirect laying and indirect fixing
- A bearing plate is essential for wooden sleepers.
- Elastic spikes are used with flat bottomed rail, base plates and wooden sleepers.
- Rail to steel sleeper fastenings : Loose jaws, keys and liners.
- Rail to CI sleeper fastenings : Tie bars or cotters.
- Rail to wooden sleepers fastenings : Dog spikes, fang bolts or screw spikes, bearing plates.
- Elastic fastening : Elastic or pandrol clips, IRN 202 clips, rubber pads, HM fastenings, MCI inserts, Nylon liners.

Objective Brain Teasers

Q.1 Match List-I and 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 bar

List II
1. To lift rail
2. To remove dog spikes out of sleepers
3. To correct track alignment
4. To handle ballast

Codes :

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

Q.2 Pandrol clips cannot be used with
(a) wooden sleepers
(b) concrete sleepers
(c) CST-9 sleepers
(d) steel trough sleepers

Q.3 Number of cotters used in CST-9 sleepers is
(a) 2 (b) 3
(c) 4 (d) 5

Q.4 Loose jaws of steel trough sleepers are made of
(a) cast steel (b) mild steel
(c) cast iron (d) spring steel

Q.5 The type of spike used for fixing chairs of bull headed rails to wooden sleepers is
(a) dog spike (b) rail screw
(c) elastic spike (d) round spike

Q.6 Flat mild steel bearing plates are used
(a) for points and crossings in the lead portion
(b) with wooden sleepers at locations where creep is likely to be developed
(c) on all joints and curves
(d) on all the above

Q.7 The type of bearing plate used in all joints and on curves to give better bearing area to the rails is
(a) flat mild steel bearing plate
(b) mild steel canted bearing plate
(c) cast iron anticreep bearing plate
(d) none of the above

Q.8 Dog spikes are used for fixing rail to the
(a) wooden sleepers
(b) CST-9 sleepers
(c) steel trough sleepers
(d) concrete sleepers

Q.9 When the rail ends rest on a joint sleeper, the joints is termed as
(a) supported rail joint
(b) suspended rail joint
(c) bridge joint
(d) base joint

Q.10 Anticreep bearing plates are provided on
(a) bridges and approaches
(b) joints
(c) both (a) and (b)
(d) none of the above

Q.11 At a rail joint, the ends of adjoining rails, are connected with a pair of fish plates and
(a) 2 fish bolts (b) 4 fish bolts
(c) 6 fish bolts (d) 8 fish bolts

Q.12 Anti-creep anchors are fixed to rails by
(a) wedging (b) spring grip
(c) clamping (d) all the above

Q.13 Rails are fixed on steel sleepers
(a) by bearing plates
(b) by dog spikes
(c) by keys in lugs or jaws
(d) None of these

Q.14 To prevent creep in rails, the steel sleepers are fixed with rails by clips, bolts and
(a) one key (b) two keys
(c) three keys (d) four keys

Q.15 Overall depth of a dog spike, is
(a) 120.6 mm (b) 155.90 mm
(c) 135 mm (d) 150 mm

Q.16 Bearing plates are used to fix
(a) flat footed rails to the wooden sleepers
(b) double headed rails to the wooden sleepers
(c) bull headed rails to the wooden sleepers
(d) flat footed rails to the cast iron sleepers

Answers

1. (c)	2. (c)	3. (c)	4. (d)	5. (d)
6. (a)	7. (b)	8. (a)	9. (a)	10. (d)
11. (b)	12. (d)	13 (c)	14. (d)	15. (a)
16. (a)				

CHAPTER 06

Points and Crossings

On roads, the facilities of turning of a vehicle from one path to another does not require any special arrangement while on railways, special arrangements are necessary (the reason being flanged wheels). To facilitate movement of vehicles from one route to another, points and crossing assemblies are provided (switch)

6.1 Turnout

- A turnout is provided on a railway track to provide facilities for turning of vehicles from one track to another.
- It consists of a pair of points (switches), four lead rails, two check rails and a crossing as shown in figure.
- Turnout enables either a branch line or siding to take off from another track.

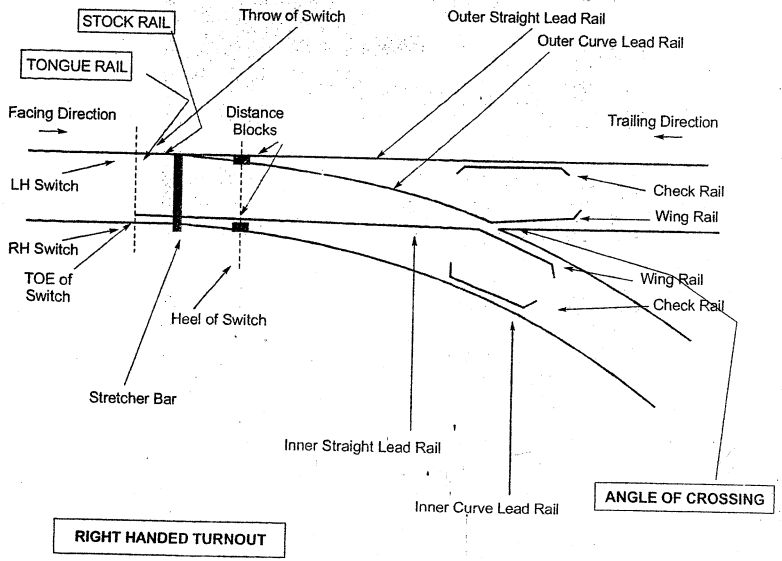


Fig. 6.1

6.1.1 Types of Turnout

- These are defined based on the direction of movement from the main track.
  - (i) Right hand turnout ⇒ Facilities are provided for turning on the right
  - (ii) Left hand turnout ⇒ Facilities are provided for turning on the left
- Turnouts are required for yards, sidings or similar sort of conditions.
- Turnouts are the weakest points on the track due to joints and movable fastenings.
- They retard the movement of the trains.

6.2 Points (or Switch Assembly)

- A set of switch consists of four lead rails, the outer two known as stock rails and the inner two as switch or tongue rails.
- A pair of tongue rails with thin stock rails are commonly known as points.
- In switch, the thicker end of tapered rail known as heel remains fixed to the main track whereas the thinner end known as toe remains movable by means of which the flanged wheels are diverted.
- It consists of the following:

(i) A pair of stock rails

- They are made of ordinary steel and have the same dimensions as for other rails in the track.

(ii) A pair of tongue rails

- They are also called point rails or switch rails.
- They are made of high carbon or manganese steel to stand wear.
- They lie between the stock rails and are tapered to a point
- The tapered end is called the toe and the untapered end as the heel.
- Heel is fixed while the toe can turn with heel on centre

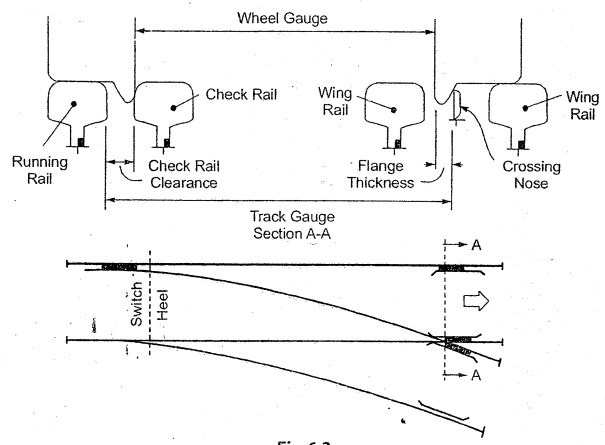


Fig. 6.2

- The tongue rail is so tapered on both the sides, so as to obtain a proper fit on the stock rail, when the tongue rail is moved towards the stock rail.
- Longer the length of tongue rail, lesser will be the jointing effect (because with a given heel divergence, the switch angle will decrease with an increase in the length of the tongue rail.)

(iii) Sliding Plates
- Sliding plates of steel are provided over which the stock rail remains fixed while the tongue rail is able to slide.

(iv) Heel Block
- Heel of the tongue rail is connected to stock rail by means of a CI heel block, thus providing a gap for the wheel flange.
- Heel block is same as distance block, the object of which is to provide a flange way between the running rail and check rail.

(v) Stretcher Bar
- The toes of both the tongue rails are connected together by means of a stretcher bar (so that each tongue moves through the same distance or gap when changing points)
- It may consist of one, two or three bars.

(vi) Gauge Tie Bar or Plate
- It is provided to hold the track rigidity to the gauge at the toe of the switches.
- It is placed on the sleeper under the toe of the switches and holds the two rails in position.

(vii) Flangeway Clearance
- The distance between the adjacent faces of the running rail and the guard or the check rails which provides a clearance for passage of wheel flanges.

(viii) Flangeway Depth
- The vertical distance between the top of the running surface of the running rail to the top of the distance block (or heel block) used between the running rail and check rail.

(ix) Heel Clearance or Heel Divergence
- It is the distance between the running faces of the switches rail and the stock rail measured perpendicular to the latter at the heel of the switch.
- Indian standard specify heel clearance for BG track as 13.7-16.8 cm.

(x) Flare
- It is a gradual tapering of the flangeway by bending or splaying the end of a check rail or using rail (at the heel of the crossing) away from the gauge line.

(xi) Throw of Switch
- Gap through which the toe of the gauge rail moves sideways to provide a path for the required direction over the turnout.
- Throw of switch according to Indian standard:
  BG = 9.5 cm, MG/NG = 8.9 cm

(xii) Switch Angles
- Angle between the running faces of the stock rail and tongue rail.
- It is a function of heel divergence and length of the tongue rail.

Do You Know?

(i) When thickness of tongue rails at toe = 0

then, $\text{angle}(\alpha) = \sin^{-1}\left(\frac{d}{S}\right)$

(ii) When thickness of tongue rails at toe = t

then, $\text{angle}(\alpha) = \sin^{-1}\left(\frac{d-t}{S_1}\right)$

or $\alpha' = \sin^{-1}\left(\frac{d}{S_2}\right)$

where d = heel divergence, S_1 = actual length of tongue rail, S_2 = Theoretical length of tongue rail.

6.2.1 Toe of Switches

The toe of the switches may be of the following types:

(i) **Undercut switch:** This is the type of switch in which the foot of the stock rail is planed to accommodate tongue rail.

(ii) **Over riding switch:** In this case, the stock rail has the full section and the tongue rail is planed to 1/4″ thick edge and over rides the foot of the stock rail.

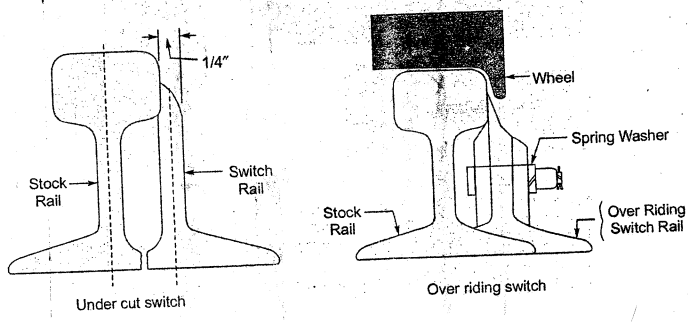


Fig. 6.3

6.3 Crossings

- It is the portion of the track where two tracks crosses each other at an angle.
- Provides two flangeways through which the flange may move.
- In the crossing, the flanged wheels of the train jump over the gap from 'throat' to 'nose'.

6.3.1 Types of Crossings

Crossings are classified based on the following:

(i) Shape of crossing

(ii) Assembly of crossing

6.3.1.1 Based on Shape of Crossing

There are three types of crossings:

(i) "V" or acute angle crossings (also termed as a "frog")

(ii) Obtuse angle or diamond crossing

(iii) Square crossing

(i) Acute Angle Crossing

- The crossing is obtained when a right hand rail of one track crosses left hand rail of another track or vice verse.
- It is used in turnouts.
- It consists of:
  - (i) Two rails joined together to form an acute angle. The joint may be formed by a point rail and a splice rail or by two point rails. These rails are made of high carbon or manganese steel.
  - (ii) A pair of wing rails bent in the shape of obtuse angle. One end of each wing rail is connected with a lead rail and the other end is flared to provide facility for the flanges to enter the gap.
  - (iii) A pair of check rails.
- In the case of acute angle crossing, the splice rail and point rail are placed in such a way that the angle formed by the two is acute angle.

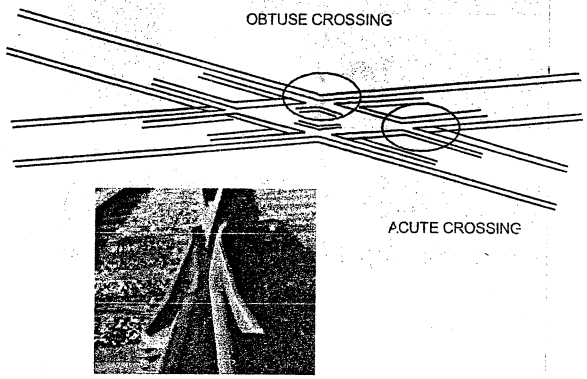


Fig. 6.4

(ii) Obtuse Angle Crossing: The crossing is obtained when left hand rail of one track crosses right hand rail of another track at an obtuse angle or vice verse.

(iii) Square Crossing:

- All the rail sections have been provided at an angle of 90° w.r.t. each other.
- There is heavy wear on such crossing due to dynamic loads.

6.3.1.2 Based on Assembly of Crossing

(i) Spring or movable wing crossing

(ii) Ramped crossing

(i) Spring or movable wing crossing

- The wing rails are provided with springs. (or there is a possibility of moving the wing rails in certain direction)

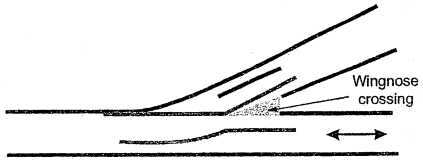


Fig. 6.5

(ii) Ramped crossing

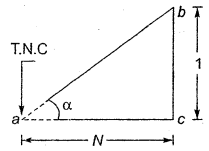
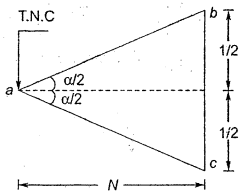
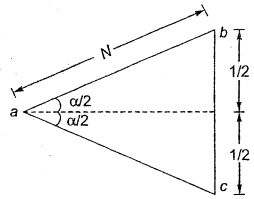
- No such above arrangement is being provided.
- They are provided with ramp for certain movement.

6.3.2 Number and Angle of Crossing

- The number of a crossing is defined as the ratio of the spread at the leg of the crossing to the length of the crossing measured from the theoretical nose.
- *V*-crossing are designated by either the angle which the gauge faces makes with each other or more commonly by their number, represented by symbol *N*.

Types of turnouts	Crossing numbers	Speed (in kmph)
Goods train turnout	1 in $8\frac{1}{2}$	16
Passenger turnouts	1 in 12	16

Methods to calculate number of crossing

1. Right angle or Cole's method	2. Center line method	3. Isosceles triangle method
$N = \cot\alpha$	$N = \frac{1}{2}\cot\left(\frac{\alpha}{2}\right)$	$N = \frac{1}{2}\text{cosec}\left(\frac{\alpha}{2}\right)$
		

Example 6.1 A crossover occurs between two parallel BG tracks of same crossing number of 1 in 8.5 with straight intermediate portion between the reverse curve. Distance between centres of tracks is 5 m. Find the overall length of cross-over.

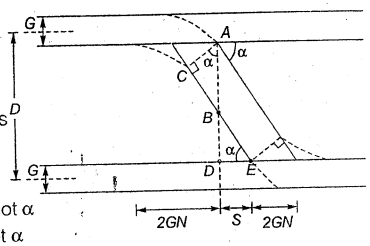
Solution:

Let, N = Crossing number

α = Angle of crossing

G = Gauge distance (1.676 m in case of BG)

D = Centre to centre distance between two tracks
= 5 m (given)
2 GN = Length of turnouts
S = Straight horizontal portion between the trunouts
$N = \cot\alpha = 8.5$ (given)



$$S = DE = BD\cot\alpha$$
$$= [(D-G) - AC\sec\alpha]\cot\alpha$$
$$= [(D-G) - G\sec\alpha]\cot\alpha$$
$$= \left[(D-G) - G\sqrt{1+\frac{1}{\cot^2\alpha}}\right]\cot\alpha$$
$$= \left[(D-G) - G\sqrt{1+\frac{1}{N^2}}\right]N$$
$$= (D-G)N - G\sqrt{N^2+1}$$

But, overall length of crossover $= 4\,GN + S$
$$= 4GN + (D-G)N - G\sqrt{N^2+1}$$
$$= 4\times1.676\times8.5 + (5-1.676)\times8.5 - 1.676\sqrt{8.5^2+1} = 70.894 \text{ m}$$

Example 6.2 A crossover between two MG parallel tracks of same crossing number 1 in 12 with straight intermediate portion between the reverse curves and the distance between the centres of tracks is 3.5 m. Find the intermediate straight distance and overall length of the crossover.

Solution:

Given: $N = 12$, $G = 1$ m (Meter gauge)
$D = 3.5$ m

1. The intermediate straight distance
$$S = (D-G)N - G\sqrt{1+N^2}$$
$$= (3.5-1)\times12 - 1\sqrt{1+12^2} = 17.96 \text{ m}$$
2. The overall length of the crossover i.e.,
$$l = 4\,GN + S$$
$$= 4 + 1\times12 + 17.96$$
$$= 65.96 \text{ m}$$

NOTE: The permitted speed on flattest turnout is 120 kmph.

6.3.3 Theoretical and Actual Nose of Crossing

- Nose of a crossing is a point, at which two rails i.e., point and splice rail meets.
- It is known as theoretical nose of crossing if the two rails meet at a point.
- If the toe of the nose is blunt (6 mm wide), then it is called actual nose of crossing.

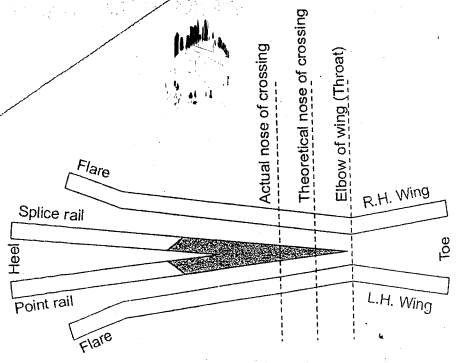


Fig. 6.6 Details of crossing

- Actually, a blunt nose used as point rail would break off under traffic.
- All calculations are made from theoretical nose of crossing.

6.4 Track Junctions (or Crossovers)

- It can be defined as a combination of points or crossing which enables the vehicles to crossover from one track to another.

6.4.1 Types of Track Junction

(i) Based on Flexure

(a) Similar Flexure
- Turnout takes turn in the same direction in which the main line turns.
- Similar flexure means similar curvature is being provided to main line as well as turnout.
- Degree of flexure of turnout is higher than that of main line.

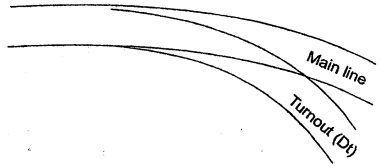


Fig. 6.7 Curve of similar flexure

(b) Contrary Flexure
- Turnout takes a turn in the opposite direction to that in which main line turns.

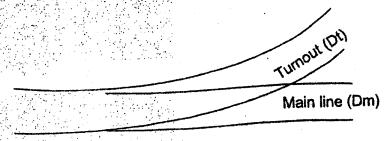


Fig. 6.8 Curve of contrary flexure

(ii) Based on Split

(a) Symmetrical Split
- It provides an opportunity to take a turn in the left or right or both directions
- When the radii of the curves in both the direction are equal, it is known as symmetrical split.
- It is suitable for localities where turnout from a straight line would take too much space.
- Also known as Y.
- It consists of a pair of points, four curved lead rails, two check rails, one acute angle crossing.

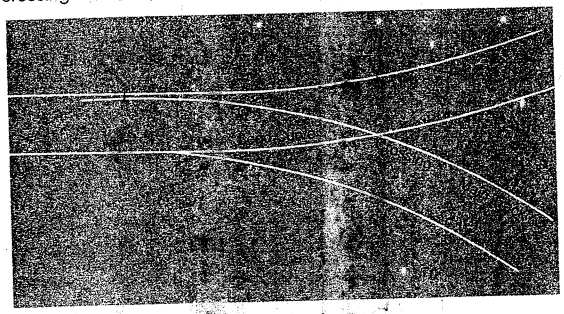


Fig. 6.9

(b) Three Throw Switch
- It may be of contrary or similar flexure.

- It consists of two switches, (each switch having two tongue rails side by side) Combined heel blocks, two stock rails, three crossings and check rails, four contrary and six for similar flexure condition.
- When two turnouts from the same tangent point of a straight track are taken out, the arrangement is known as three throw.
- This type of turnout has many objectionable features and is almost out of use.
- Two pair of tongue rails.

(iii) Double Turnout
- It is an improvement over a three throw switch.
- The turnout is staggered at two different places.
- In this case turnout is coming from different places (in the case of three throw switch, we saw that turnouts were coming from the same location)
- It is used in congested areas with heavy traffic.
- Also known as tandem or following point crossing.
- Heels of the two switches are at a certain distance from each other.

(iv) Crossover
- It consists of two pair of switches, two acute angles crossing with reverse curves with or without straight length in between and four check rail.
- Used generally for the low speed sidings or the crossing from one direction only.
- Two pair of check rails.

(v) Diamond Crossing
- It consists of two acute angle crossing, two obtuse angle crossings and four check rails.
- Indian Standard specifies the flattest diamond as 1 in 10 for broad gauge and 1 in $8\frac{1}{2}$ for other gauges.
- We have four crossings, so we have wing rails provided at this location.
- At diamond crossing, the train cannot change its direction.
- The biggest disadvantage with diamond crossing is that straight directional movement is allowed.

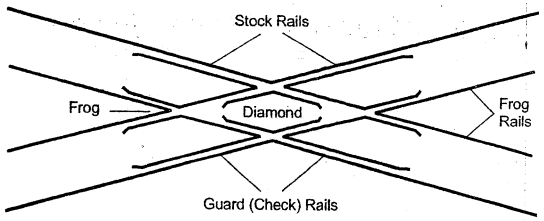


Fig. 6.10

(vi) Based on Slip

(a) Single Slip
- Allows vehicles to turn in only one direction.
- It consists of two acute angle crossings, two obtuse angle crossings, four check rails and special curved lead rails.

- It consists of two pair of switches.
- A modification of diamond crossing.
- Here, taking a turn is allowed (but not in diamond crossing).
- In this case of single slip, number of movements have increased.

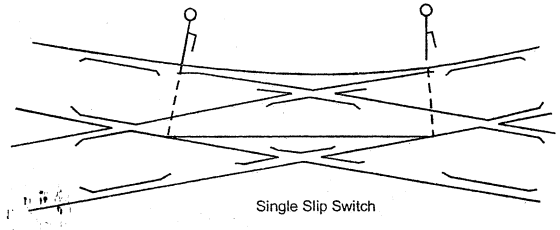


Fig. 6.11

(b) Double Slip
- Two pairs of curved lead rails are being provided in this form; so now there is a possibility of taking a movement in any of the direction.
- Restriction associated with diamond crossing movement have been completely eliminated by using a double slip.
- Four pair of switches.

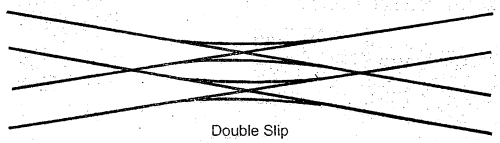


Fig. 6.12

(vii) Scissor Crossover
- A combination of two crossovers to enable the train to change the track, from either direction along the main track.
- It consists of four pair of switches, six acute angle crossing, two diamond crossings, check rails and straight lengths.
- It is used where there is space constraints.
- More expensive in initial cost and maintenance.

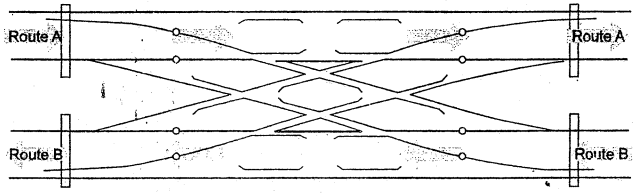


Fig. 6.13

(viii) Gauntlet Track

- It is provided under following conditions:
  - (a) where double track is to be narrowed for a short distance
  - (b) track is under repair
  - (c) on bridges

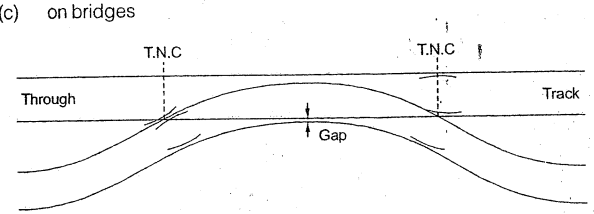


Fig. 6.14 Gauntletted Track

- If there is requirement of providing two tracks, which are of different specifications at the same location, then that type of condition is a gauntlet track.
- Two tracks are laid side by side having two sets of crossings without any switches.

(ix) Gathering Line

- It is a sloping line from which a number of parallel tracks are taken off.
- Provided in yard sidings to serve various requirements.
- The angle which the gathering line makes with the parallel sidings, is known as gathering line angle and is equal to angle of crossing adopted in yard.

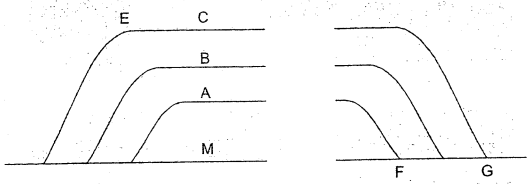


Fig. 6.15 702c

(x) Triangle

- Used to change direction of the engine on unimportant sections or where enough area is available.
- It is undesirable to provide a costly turn table.
- Consists of two simple turnouts and one symmetrical split. E.g, Roorkee, Saharanpur Belt.
- Turn tables are circular in section, on circular section rails have been provided and the locomotives comes and stands on the turntable.

  Then the turntable is rotated and it will reverse the direction of the locomotive and the locomotive goes out of the turn table.

  Turn table is very costly and requires a large amount of energy.
- Three crossings are being provided.

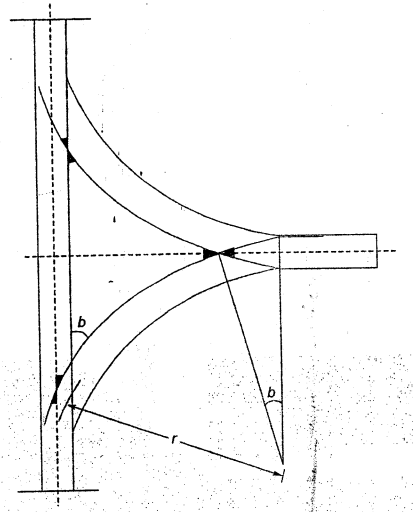


Fig. 6.16

(xi) Double Junction

- Provided with two or more main tracks having branches.
- It consists of turn outs and diamond crossing.

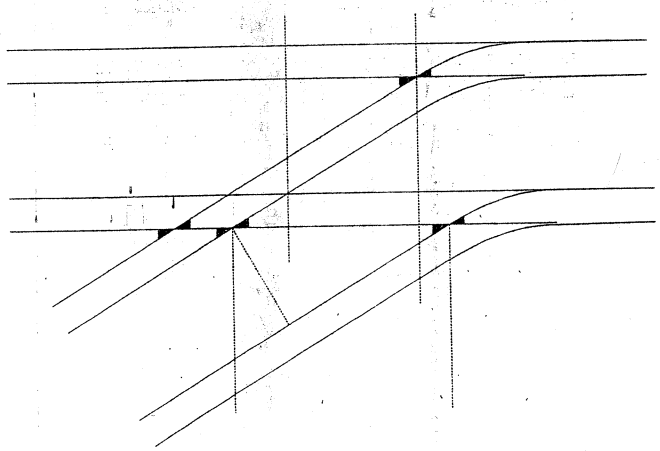


Fig. 6.17

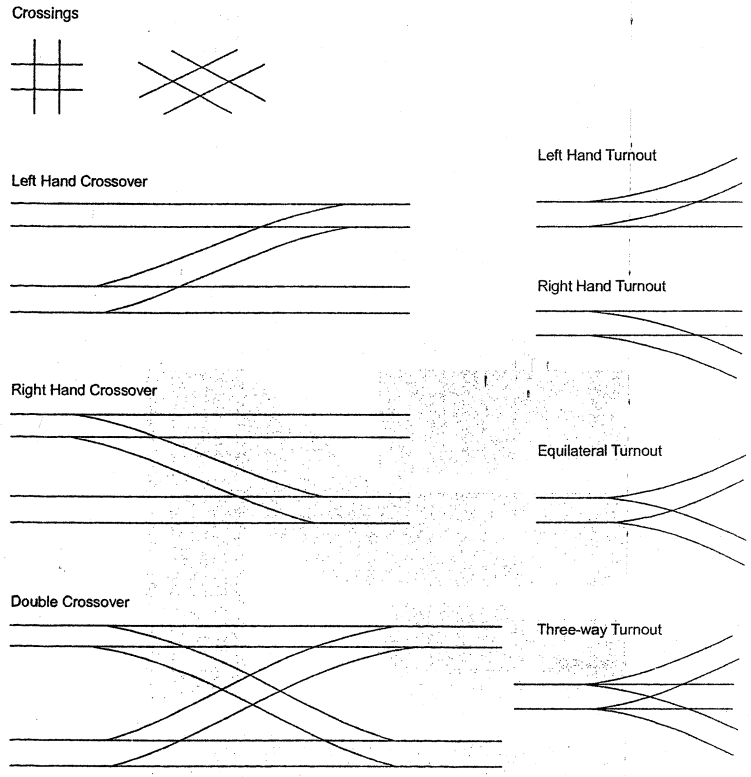


Fig. 6.18

Example 6.3 Design a diamond crossing between two BG tracks crossing each at an angle of 1 in 10.

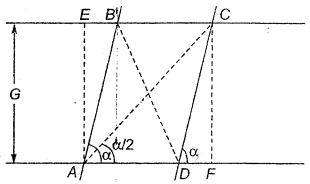
Solution:

Let, α = Angle of crossing

N = Number of crossing

G = 1.676 m

From the figure, we have



$$\sin\alpha = \frac{FC}{DC}$$

$$\Rightarrow \quad \sin\alpha = \frac{G}{DC}$$

Also, $AB = BC = CD = DA = G\,\text{cosec}\alpha = 1.676\,\text{cosec}\alpha$

Now we know that $N = \cot\alpha$

$\alpha = \cot^{-1}(10) = 5.71°$

(i) $AB = BC = CD = DA = 1.676\,\text{cosec}\alpha = 1.676 \times \text{cosec}\,5.71° = 16.85$ m

(ii) $EB = DF = G\cot\alpha = GN = 1.676 \times 10 = 16.76$ m

(iii) $$BD = G\sec\frac{\alpha}{2} = \frac{G}{\cos\left(\frac{\alpha}{2}\right)} = \frac{G}{\cos\left(\frac{5.71}{2}\right)} = 1.678 \text{ m}$$

(iv) $$AC = G\,\text{cosec}\frac{\alpha}{2} = \frac{G}{\sin\left(\frac{5.71}{2}\right)} = \frac{1.676}{0.05} = 33.65 \text{ m}$$

Summary

- A turnout is provided on a railway track to provide facilities for turning of vehicles from one track to another.
  It consists of a pair of points (switches), four lead rails, two check rails and a crossing.
- Tongue rail is connected to the stock rail at the heel of the tongue with the help of a heel block and ordinary fish plates.
  Tongue rail are supported on sliding plates and each pair of tongue rails is connected together at the toe with the stretcher bar.
- Points or the switches gives the facilities of diverting the vehicles and crossing provides gaps in the rails to be crossed by flanged wheels.
- Tapered end of the tongue rail is called toe while the thicker end is called heel.
- Switch angle is the angle between the gauge face of the stock rail and the tongue rail.
- Flangeway clearnace is the distance between the adjoining faces of the running rail and the check rail.
- Heel divergence is the distance between the adjoining faces of the running rail and check rail.
- Throw of the switch is the distance through which tongue rail moves laterally at the toe of the switch for movement of trains.
- A crossing is designated either by the angle the gauge faces make with each other on more commonly by crossing number 'N'.
- Methods adopted for measuring the crossing no. 'N' are centre line method, right angle method, Isoceles angle method.
- In India, right angle method is used.
- According to right angle method, 'N' is the cotangent of the angle formed by the two gauge faces.
- On Indian Railways, 1 in 8.5 turnouts are normally used for goods trains and 1 in 12 and 1 in 16 for passenger trains.
- Methods used for designing turnout from a straight track are coles method and IRS method.
- A cross-over is a means of transferring a train from one continuous track to another continuous track which may or may not be parallel to each other.
- Double junctions are necessary where a branch takes off a multiple track.
- Gauntletted track is a temporary diversion provided on a double line track so that one of the tracks is shifted and passes through the other.

Objective Brain Teasers

Q.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 : *Heal 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.

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

Q.2 To ensure exact gauge, the gauge tie plates are provided at
(a) toe of the switch
(b) nose of crossing
(c) both (a) and (b)
(d) none of the above

Q.3 A triangle is used for
(a) changing the direction of engine
(b) transferring wagons to and from parallel tracks without shunting
(c) separating all the siding and shunting lines from main lines
(d) preventing the vehicles from running off the track

Q.4 Which of the following devices is used to transfer the wagons or locomotives to and from parallel tracks without any necessity of shunting?
(a) triangle (b) turntable
(c) traverser (d) scotch block

Q.5 Heel divergence is
(a) always less than flangeway clearance
(b) equal to flangeway clearance
(c) always greater than flangeway clearance
(d) sometimes greater than flangeway clearance

Q.6 Flangeway clearance is the distance
(a) between the adjoining faces of the running rail and the check rail near the crossing
(b) between the gauge faces of the stock rail and the tongue rail
(c) through which the tongue rail moves laterally at the toe of the switch
(d) none of the above

Q.7 The distance through which the tongue rail moves laterally at the toe of the switch for movement of trains is called
(a) flangeway clearance
(b) heel divergence
(c) throw of the switch
(d) none of the above

Q.8 In a scissors crossover, the crossings provided are
(i) 2 obtuse angle crossings
(ii) 4 obtuse angle crossings
(iii) 4 acute angle crossings
(iv) 6 acute angle crossings

The correct answer is
(a) (i) and (iii) (b) (i) and (iv)
(c) (ii) and (iii) (d) (ii) and (iv)

Q.9 Number of switches provided on a Gauntletted track is
(a) 1 (b) 2
(c) 3 (d) none of the above

Q.10 Lead of crossing is the distance from the
(a) heel of the switch to the toe of the switch
(b) heel of the switch to the theoretical nose of the crossing
(c) toe of the switch to the theoretical nose of crossing
(d) toe of the switch to the actual nose of crossing

Q.11 Which of the following turnouts is most commonly used for goods train on Indian Railways?
(a) 1 in 8½ (b) 1 in 12
(c) 1 in 16 (d) 1 in 20

Q.12 If α is the angle of crossing, then the number of crossing '*N*' according to right angle method is given by
(a) $\frac{1}{2}\cot\left(\frac{\alpha}{2}\right)$ (b) $\cot\left(\frac{\alpha}{2}\right)$
(c) $\cot(\alpha)$ (d) $\frac{1}{2}\operatorname{cosec}\left(\frac{\alpha}{2}\right)$

Q.13 Which of the following methods of designation of crossing is mostly used in India?
(a) centre line method
(b) right angle method
(c) isosceles angle method
(d) none of the above

Q.14 Stretcher bar is provided
(a) to permit lateral movement of the tongue rail
(b) to maintain the two tongue rails at the exact distance
(c) to ensure exact gauge at the toe of the switch as well as the nose of crossing
(d) to prevent any vertical movement between the wing rail and nose of crossing

Q.15 Maximum value of 'throw of switch' for Broad Gauge track is
(a) 89 mm (b) 95 mm
(c) 100 mm (d) 115 mm

Q.16 Switch angle depends on
(i) heel divergence
(ii) length of tongue rail
(iii) flangeway clearance
(iv) throw of switch

The correct answer is
(a) (i) and (ii) (b) (ii) and (iii)
(c) (iii) and (iv) (d) (i) and (iv)

Q.17 Switch angle is the angle between
(a) the gauge face of the stock rail and tongue rail
(b) the outer face of the stock rail and tongue rail
(c) the gauge face of the stock rail and outer face of the tongue rail
(d) the outer face of the stock rail and the gauge face of the tongue rail

Q.18 Distance between the inner rail and check rail provided on sharp curve is
(a) 40 mm (b) 42 mm
(c) 44 mm (d) 46 mm

Q.19 Type of switch rails generally adopted for modern track, is
(a) straight switch (b) curved switch
(c) loose heel switch (d) bent switch.

Q.20 Stock rails are
(a) parts of crossing
(b) fitted against check rails
(c) fitted against tongue rails
(d) laid between heel of switch and nose of crossing

Q.21 Wing rails are provided
(a) near tongue rails (b) near check rails
(c) near stock rails (d) in crossing

Q.22 Heel divergency, the distance between the running faces of stock rail and gauge face of tongue rail, as recommended for Indian B.G. tracks, is
(a) 100 mm (b) 119 mm
(c) 125 mm (d) 135 mm

Q.23 The angle between the gauge faces of the stock rail and tongue rail, is called
(a) Switch angle (b) angle of crossing
(c) angle of turnout (d) None of these

Q.24 If L_1 and L_2 are actual and theoretical lengths of a tongue rail, *d* is heel divergence and *t* is thickness of tongue rail at toe, the switch angle α is
(a) $\sin^{-1}\frac{d-t}{L_1}$ (b) $\tan^{-1}\frac{d-t}{L_1}$
(c) $\cot^{-1}\frac{d-t}{L_2}$ (d) $\tan^{-1}\frac{d-t}{L_2}$

Q.25 To achieve best performance, the type of switch preferred to, is

(a) undercut switch (b) straight-cut switch
(c) overriding switch (d) both (a) and (b)

Q.26 In a diamond crossings, number of noses are
(a) 2 (b) 3
(c) 4 (d) 6

Q.27 On Indian Railways, angle of crossing between gauge faces of Vee, is generally calculated by
(a) Cole's method
(b) Centre line method
(c) Isosceles triangle method
(d) both (a) and (b)

Q.28 For calculating the length of curve lead (C.L.), the correct formula is
(a) C.L. = $G.\cot\alpha/2$ (b) C.L. = $\sqrt{2IG}$
(c) C.L. = $2GN$ (d) None of these

Q.29 To design a crossover between parallel tracks, the required components are:
(a) two switch points, two acute angle crossings and two check rails
(b) two switch points, two acute angle crossings and four check rails
(c) two switch points, two acute angle crossings and six check rails
(d) None of these

Q.30 A scissors crossover consists of
(a) two pairs of points, four acute angle crossing and two obtuse angle crossings.
(b) four pairs of points, four acute angle crossing and four obtuse angle crossings
(c) four pairs of points, six acute angle crossing and two obtuse angle crossings.
(d) two pairs of points, six acute angle crossing and four obtuse angle crossings.

Q.31 In railways a triangle is mainly provided for
(a) diverting trains from the main line to branch line
(b) crossing over between parallel tracks
(c) changing direction of engines through 180°
(d) shunting wagons in yards.

Q.32 If D is distance between centres of two parallel track of gauge G, then, total length of crossover (from the point of commencement to the point of terminations) with an intermediate straight portion and N crossing, is given by
(a) $DN + G(N + \sqrt{1+N^2})$
(b) $DN + G(2N + \sqrt{1+N^2})$
(c) $DN + G(3N - \sqrt{1+N^2})$
(d) $DN + G(4N + \sqrt{1+N^2})$

Q.33 The distance between the theoretical noses of crossing along the same rail, in a case of diamond crossing, is
(a) $\dfrac{G}{\sin\frac{1}{2}F}$ (b) $\dfrac{G}{\sin F}$
(c) $\dfrac{G}{\tan F}$ (d) $\dfrac{G}{\cos F}$

Q.34 The distance between theoretical nose of crossing and actual nose of crossing for practical purposes, is
(a) Nose thickness × tan α
(b) Nose thickness × cot α
(c) Nose thickness × sin α
(d) Nose thickness × cos α

Q.35 The arrangement of rails which permit trains to cross another track and also to divert to the other track, is called
(a) diamond crossing
(b) diamond crossing with single slip
(c) diamond crossing with double slip
(d) All of the above

Q.36 A scissors cross over consists of one diamond and
(a) one turn out (b) two turn out
(c) three turn outs (d) four turn outs

Q.37 To avoid the damage of nose of crossing, the wing rails are ramped so that nose of crossing remains at a lower level by
(a) 3 mm (b) 4 mm
(c) 5 mm (d) 6 mm

Q.38 The check rails are placed opposite the crossing so that

(a) it is symmetrically placed opposite nose of crossing
(b) Its one-third length is ahead of the nose of crossing
(c) Its two-third length is ahead of the nose of crossing
(d) Its three fourth length is ahead of the nose of crossing

Q.39 If the stock rails are B.H. rails, the type of switch generally provided is
(a) articulated (b) undercut
(c) over riding (d) straight cut

Q.40 Match List-I with List-II and select the correct answer by using codes given below the lists:

List-I
A. Chairs
B. Check rails
C. Guard rails
D. Bearing plates

List-II
1. Used on inner side of lower rail on sharp curves
2. Used for holding double headed and bull headed rails.
3. Used on long span bridges
4. Used in between sleeper and flat footed rails.

Codes:

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

Q.41 Match List I (Crossing) with List II (Turn out) and select the correct answer by using codes given below the lists:

List-I
A. 1 in 6
B. 1 in $8\frac{1}{6}$
C. 1 in 12
D. 1 in 16

List-II
1. Station yards and sharp curves
2. Turnout of main line in station yards
3. Symmetrical split
4. High speed turn outs

Codes:

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

Q.42 Match List-I with List-II and select the correct answer by using codes given below the lists:

List-I
A. Diamond crossing
B. Square crossing
C. Cross over
D. Double slip diamond

List-II
1. Two acute angle, two obtuse angles crossings, four special curved lead rails, four pairs of switches and four check rails
2. Two acute angle crossing, two obtuse angle crossings, two wing rails opposite obtuse angle crossing and four check rails.
3. Two pairs of tongue rails, two acute angle crossings, a reverse curve and four check rails.
4. Four right angle crossings and a square shaped check rail.

Codes:

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

Answers

1. (a)	2. (c)	3. (a)	4. (c)	5. (c)
6. (a)	7. (c)	8. (b)	9. (d)	10. (b)
11. (a)	12. (c)	13. (b)	14. (b)	15. (d)
16. (a)	17. (a)	18. (c)	19. (b)	20. (c)
21. (d)	22. (d)	23. (a)	24. (a)	25. (c)
26. (d)	27. (a)	28. (d)	29. (b)	30. (c)
31. (c)	32. (c)	33. (a)	34. (b)	35. (c)
36. (d)	37. (a)	38. (c)	39. (d)	40. (c)
41. (c)	42. (b)			

CHAPTER 07

Station Yard Layout and Equipment

7.1 Railway Station

It is a place where:

(a) Running train may be required to halt for traffic purposes i.e., to receive or drop passengers and goods.

(b) On a single line track, to enable train from opposite direction to cross each other and also to enable the following trains to follow with safety.

- Type of station to be provided depends upon the amount and type of traffic it is expected to handle.
- The simplest type is a flag station on passenger halt. It is a station where a train stops to receive or drop passengers.
- It is not telegraphically connected with its stations on either side, and has no apparatus or staff for controlling the movement of trains.
- Excluding the flag stations, the two types of stations we have are
  (i) Way side station
  (ii) Junction and terminals
- All these stations are telegraphically connected with the next adjacent stations and are fitted with block instruments and other facilities, depending upon the requirements.

7.2 Layout of Simple Wayside Station on Single Line, Double Line and Simple Junction

- Simple layout on a single line track would consist of the following:
  (i) a through track
  (ii) a loop to enable train to cross each other
  (iii) a passenger platform
  (iv) a goods loop with goods platform
- A loop to enable the trains to cross each other can be either of the following three types
  (i) Split turnout (ii) Trailing turnout (iii) Straight and loop
- Split turnout is unsuitable for fast through trains as they have to reduce their speed, while approaching the facing points.
- Trailing turnout is less objectionable, as slight reduction of speed would be necessary while leaving over a reverse curve.

- Straight and loop does not require any reduction in speed for fast through trains.
- For a double line, one or two passenger platforms may be provided depending upon the facilities required.
- Stations where a branch line joins a main line are known as junction stations.
  Junction station facilitate interchange of traffic between main and branch line.
- Stations where all lines come and terminate are known as terminal stations.
  Important terminal station in India are Howrah, Sealdah, Bombay, V-T etc.

NOTE

(i) A refuge line is provided to permit fast train to overtake slow train in the same direction.
(ii) Block section are sort of compartments in which a railway line is divided. They enable safety space between trains.
(iii) Stations at the ends of block section are known as block station.

7.3 Yards

- A yard may be defined as a system of tracks provided for receiving, storing, sorting making up and despatch of vehicles and other purposes over which movement is not authorized by a time table.
- They can be divided into two classes.
  (i) Marshalling yard (ii) Loco yard

7.3.1 Marshalling Yard

- They are provided at important junction stations which acts as distributing centre for various stations.
- loaded and empty wagons are received from different lines for booking in different directions.
- Wagons are separated and sorted and then made into full train for each line.
- While making a train, the wagons are arranged in the order of the stations i.e., wagon which are destined for first station are placed next to the engine and so on.
- Marshalling yards have three different functions.
  (i) Reception (ii) Sorting (iii) Departure
- Sidings for each or combination of two or even three functions is provided.
- Thus we have reception siding, sorting siding and departure siding.
- Separate sets of sidings may be provided for up and down directions.
- Marshalling yards can be any of the following three types depending upon the ground contours.
  (i) Flat yard (ii) Gravitational yard (iii) Hump yard

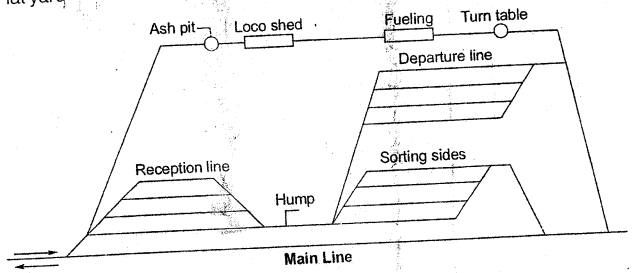


Fig. 7.1

7.3.1.1 Flat Yard

- Ground levels are almost the same.
- Hence, movements are to be carried out by means of locomotive.
- It is costly but justified at those places where there is limited space.

7.3.1.2 Gravitational Yard

- Wagons can be made to move under gravity.
- Ground is sloping.
- Movement of wagons is controlled by brakes.

7.3.1.3 Hump Yard

- A type of gravitational yard.
- The trains are pushed upon a hump which is located at the entrance to the sidings.
- The wagons are then let into the sidings, due to the action of gravity down the hump.

NOTE

(i) Hump and gravitational yard saves power.
(ii) For gravitational flow, the desirable gradients are 1 in 50 in the initial stage for a short length, followed by a grade of 1 in 150 and then by a level stretch.
(iii) For pushing the train up the hump, grade of 1 in 150 is usually adopted.

7.3.1.4 Sidings

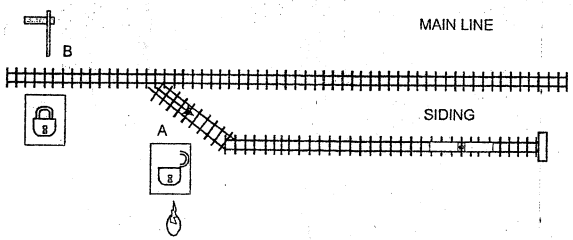


Fig. 7.2

- Provided for temporary storage of wagons.
- For medium and large stations separate sidings are provided for inward and outward wagons. They can be classified as follows:

(i) Trap Sidings
- Goods sidings are isolated from running lines by means of trap sidings.

(ii) Shunting Neck
- If these trap siding are of sufficient length, shunting can be performed on them without interfering with traffic on the running lines.
- The siding would then be formed as shunting necks.
- The trap siding and shunting necks are always dead end sidings with buffer on similar arrangement at its end.

(iii) Catch Siding
- Provided in hilly tracks (where gradient near station is so high (i.e., sleep) that there is a possibility of standing vehicles running down.)
- Should have a very flat or rising gradient.
- Sand hump should be provided at the end of the catch siding.

(iv) Private and Assisted Siding
- When siding is laid and maintained at the cost of the owner for whom siding is being laid then it is known as private siding.
- Associated siding is laid and maintained by railway.

7.3.2 Loco Yard

- Loco yard are required for servicing locomotives (i.e., cleaning, loading coal, filling water, oiling, turning roundetc.

NOTE: When a railway line and a road cross each other at the same level, it is called a level crossing.

7.4 Equipments

Equipments in station yards is provided for convenience of passengers and goods, for safety of traffic movements and locomotive. Important equipments in station yard is as follows:

(i) Station Building
- Facilities to be provided depends on the size and importance of station.
- They consist of
  - (a) properly located ticket window counter for different classes.
  - (b) arrangement for booking of goods
  - (c) waiting rooms
  - (d) eating shops
  - (e) bathrooms and toilets
  - (f) rooms fitted with proper working facilities for the railway staff
  - (g) clock room

(ii) Platforms
- The length of a platform depends on the largest train running on the section.
- For Broad Gauge, about 1000 feet is desirable.
- Minimum length specified for passenger platforms is 600 feet for all gauges.
- The ends of raised platforms are provided with ramps of 1 : 6 slope.
- Permissible width of passenger platform in front of station building for all gauges is 12′-0′.
- Platform is provided with a slope of about 1 in 30 across its width and may be paved with moorum, water bound macadam, stone, concrete or bitumen.

(iii) Cranes and Weighing Machines
- On large station, cranks are used for loading and unloading heavy articles.
- Most common types ⇒ mobile cranks mounted on a vehicle
- They can be used anywhere in the yards or on the line.

- Jib type located on the goods platform for loading and unloading heavy and bulky articles.
- Weigh bridges are provided for weighing loaded wagons.

(iv) Derailing Switches
- All siding and shunting lines are isolated from running lines.
- Running lines are tracks used for receiving on dispatching trains.
- Isolation is provided by means of trap joints, derailing switches or derail obstructions.
- Trap joint of derailing switches consists of half a set of switches which normally remains open.
- A derailing switch provides a break in the continuation of one rail.
- The derailing switch is closed when a vehicle is taken out of a trap siding.

(v) Fouling Marks
- Fixed between pair of tracks which converge.
- Indicate a point between two adjacent tracks beyond which a vehicle on one track may foul with passing vehicle on another track.
- Indian standards specify a minimum clear distance between two adjacent tracks for B.G. as 14 ft. and MG as 12 ft. Fouling marks should be provided at these two distances.

(vi) Buffer Stocks
- Provided at the end of dead end siding to prevent further movement of vehicles beyond the track end.
- Two buffers or wooden beam or rail pieces are fixed on a rail stand and at the level of buffers of the vehicles.

(vii) Turntable and Triangle
- For reversing or changing the direction of locomotive on the same track or to another track.
- Turntable is a circular platform rotating about its centre placed in a circular pit.
- The pivot is located on the centre line of the track.
- The diameter of the turntable is large than the diameter of engine using it.
- Platform is supported by wheels at its circumference running on a circular track.
- The track or the turn table is brought in line with the track from which the engine is to be brought.
- After the engine is received on the turntable, it can be made to rotate to the required degree.

(viii) Traverser
- Dwarf carriage mounted on small wheels which run on rails laid at right angles to the tracks, by means of which carriage are transferred, one at a time, to and from parallel roads without the necessity for shunting.

(ix) Water Column and other Water Supply Facilities
- For feeding water to steam locomotive.
- Provided at intermediate stations by the side of a running track, may be over an ashpit.
- Also provided in loco yards.
- Fixed in ground in the shape of an inverted "L" with spout being at 14′-6″ above the ground.
- Water is also required for passengers, staff, supply to passengers bogies etc.

(x) Ashpits, Examination Pits etc.
- Consists of rectangular masonry lines pits, about 2′-6″ to 4′-0″ deep.

- Located between two rails of a track.
- Meant for receiving oshes from a locomotive boiler and examination pits are for examining the engines from undereath.
- Examination pits are longer then ashpits.

(xi) Fuel Stages
- For feeding coal to the tender of a steam engines, sometimes fuel stages are provided to facilitate loading.
- The stage is built by the side of a track with its top level in line with the top of engine tender.

Summary

- The simplest type of station is a level ground where trains are stopped for passengers to enter or exit from trains. Such stations are called flag stations or passenger halts.
- Yard may be defined as a system of tracks provided for receiving, storing, sorting, making up and despatch of vehicles.
- Railway yards may be conveniently divided into four categories namely passenger, goods, marshalling and locomotive yards.
- Passenger yard provides facilities for the movement of passengers and vehicles for passengers.
- A goods yard has to cater for receiving, loading, unloading and delivery of goods and the movement of goods vehicles.
- Marshalling yards are required for sorting and marshalling so that they are placed in the order of the stations at which they are to be detached.
- Loco yards are required for servicing locomotives.
- Passenger and goods yards are required at most of the train halting places while marshalling and loco yards are situated considerable distances apart.
- Siding is provided for temporary storage of wagons.
- Examination pits are provided under the track in the shed so that engine mechanism may be inspected from below.
- Turn table is a device for changing the direction of an engine.
- Triangles are also used for turning an engine (at terminals of short branch lines).

Objective Brain Teasers

Q.1 Figure represents a

(a) goods yard (b) gravitational yard
(c) hump yard (d) loco yard

Q.2 The gradient on which an additional engine is required to negotiate the gradient, is called
(a) momentum gradient
(b) pusher gradient
(c) ruling gradient
(d) steep gradient

Q.3 Minimum gradient in station yards is generally limited to
(a) 1 in 1000 (b) 1 in 750
(c) 1 in 500 (d) Zero

Answers

1. (c) 2. (b) 3. (d)

CHAPTER 08

Train Resistance and Power of a Locomotive

8.1 Traction

Traction can be defined as the source through which the locomotive drives power.

There are different sources through which a locomotive drives power.

(a) Steam
(b) Diesel fuel
(c) Electrical supply (AC/DC)

NOTE: Electric traction gives greater tractive effort and very high speeds can be negotiated.

Traction depends upon the following factors:

(i) Load carrying capacity (different for passengers, different for goods)
(ii) Speed of the movement (how much time a locomotive takes between two points)
(iii) Economy (economy obtained during operation and maintenance, economy during procurement of locomotives)
(iv) Efficiency of service

Tractive effort is the effort applied by the locomotive in order to move the train after overcoming the train resistance.

8.2 Resistance to Traction

Resistances to traction can be divided into the four categories:

(i) Resistance due to rolling stock
(ii) Resistance due to track profile
(iii) Resistance due to tractive effort
(iv) Resistance due to certain climatic or atmospheric condition

8.2.1 Resistances Due to Rolling Stock (RT_1)

Also termed as train resistance

There are three types of train resistances.

(i) Resistances which are independent of speed.
(ii) Resistances which are dependent on speed.
(iii) Atmospheric resistances

(i) Resistances which are Independent of Speed (Rt_1)

- Cause behind this resistance is friction because of the locomotive parts of the wagons or the compartment and these frictions are known as journal friction.
- Journal friction depends on the type of bearing, lubricant used and the temperature of the atmosphere.

S.No.	Type of bearing	Friction value
1.	Roller bearing	0.5 to 1 kg per tonne
2.	Coupled boxes (hard grease)	1.3 to 1.5 kg per tonne

- Track resistance due to the wave action of the rails.
- Resistance due to internal parts i.e., the cylinder and the rim of the driving wheels and similar type of condition.
- Resistance independent of speed (Rt_1)

$$Rt_1 = 0.0016\ w$$

where, w = weight of train in tonnes

(ii) Resistance dependent on its speed (Rt_2)

- This type of resistance is caused due to track irregularities, vertical movement of wheels on rails (improper joints and maintenance), flange action (oscillations, sways etc.)
- When there is movement of the vehicles then these track irregularities causes resistance to the movement.
- Vertical movements of wheels is caused due to the track irregularities only.
- As per the coning of the wheels, there is some distance between the flange and the head of the rail and because of this distance, the flanges have flexibility in moving in the lateral direction. This is termed as the oscillation or the sway.
- Due to this oscillation or sway, the resistance being offered due to the section is inversely proportional to the length of the rigid base or it is proportional to the square of the speed of the train.
- If the speed of the train is very high then this type of action may cause derailments or overturning of the vehicles.
- Resistance dependent on speed (Rt_2)

$$Rt_2 = 0.00008\ wv$$

where, w is weight of the train in ton, v is speed of train in kmph.

(iii) Atmospheric Resistances

- In this level of categorization, we assume that wind is not blowing.
- So, total weight of the air will create effect on the sides of wagons or the locomotives or at the end of the wagons or the locomotives.
- Atmospheric resistance

$$Rt_3 = 0.0000006\ wv^2$$

where, w = weight of train in tonnes, v = speed of train in kmph

Train resistance

$$(RT_1) = Rt_1 + Rt_2 + Rt_3$$

$$RT_1 = 0.0016\,w + 0.00008\,wv + 0.0000006\,wv^2$$

8.2.2 Resistance Due to Track Profile (RT_2)

These resistance are due to physical features of the track.

Two main physical features of any track is

(i) Gradients

(ii) Curves

(i) Resistance due to Gradient (R_g)

$$R_g = w\tan\theta = \text{weight of train} \times \text{percent slope } (g)$$

where, θ = angle of inclination

(ii) Resistance due to Curves (R_C)

Factors controlling the movement on the curves are

(a) Rigidity of wheel base:

Wear on inner side of outer rail due to flange of leading axle and inner side of inner rail due to flange of trailing axle, causing mount on rail.

(b) Slippage of wheel (longitudinal and transverse)

(c) Insufficient superelevation (more pressure on inner rail)

(d) Extra superelevation (more pressure on outer rail)

(e) Poor maintenance of track and its components

- Resistances increases with increase in speed

Distance travelled by outer wheel = D_1

Distance travelled by inner wheel = D_2

Extra distance travelled = $D_1 - D_2$

Force of sliding friction = F

Here, work done = $(D_1 - D_2)F$

$$\text{Mean resistance} = \frac{(D_1 - D_2)F}{D} = \frac{G\alpha F}{R\alpha} = \frac{GF}{R}$$

Where, α = angle of the curve

R = radius of the curve

G = gauge of the curve

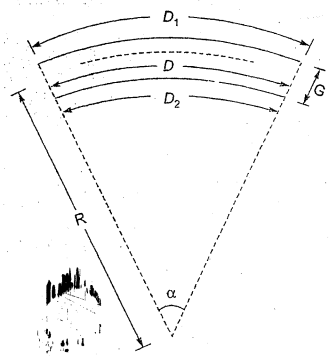


Fig. 8.1

Hence, resistance gets affected by the force of sliding friction (F), gauge of track and radius of curvature (R)

- Recommended values of curve resistances

For broad gauge, $R_C = 0.0004\,wD$

For metre gauge, $R_C = 0.0003\,wD$

For narrow gauge, $R_C = 0.0002\,wD$

where, D is the degree of the curve.

8.2.3 Resistance Due to Tractive Effort (R_{SA})

This gets induced due to the following two conditions

(i) Starting operation

(ii) Acceleration given to the locomotive

8.2.3.1 Resistance Due to Starting (R_S)

It varies according to the type of object

(i) For locomotives, $R_s = 0.15\,w_1$

(ii) For vehicles $R_s = 0.005\,w_2$

where, w_1 = weight of locomotive in tonnes

w_2 = weight of vehicles in tonnes.

8.2.3.2 Resistance Due to Acceleration (R_A)

This is caused due to change in speed with respect to time

$$R_A = \frac{0.028w(v_2 - v_1)}{t}$$

where, v_1 = velocity at the beginning (in kmph)

v_2 = velocity at the end (in kmph)

t = time taken in seconds for achieving the speed from v_2 to v_1

w = total weight of train in tonnes

8.2.4 Resistance Due to Wind (R_w)

Wind resistance depends on the following factors

(i) Wind velocity

(ii) Direction of wind w.r.t. direction of movement of train

(iii) Sectional area exposed to wind

Wind resistance, $R_w = 0.000017\,Av^2$

where, A = exposed area (in sqm.)

v = velocity of wind (in kmph)

So total resistance to traction (R_T)

$$R_T = RT_1 + RT_2 + R_{SA} + R_w$$

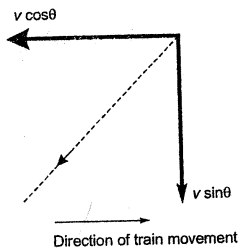


Fig. 8.2

8.3 Hauling Capacity of a Locomotive

- It can be defined as the total load that can be handled by the locomotive.
- It is an indicative of power available to a locomotive.
- It can be computed as the product of the coefficient of friction between driving wheels and rails and the weight on the driving wheels.
- It should be equal to or greater than the traction resistances.
- The coefficient of friction depends upon the condition of rail surface and speed of locomotive. At high speed it is taken as 0.1 and at low speed as 0.2

- It can be calculated by the following:
  Hauling capacity = $\mu wn = \mu W$
  Where,
  μ = coefficient of friction
  w = weight on driving axle
  n = number of pairs of driving wheels
  W = total load on driving wheels

Maximum axle load in India		
S.No.	Type of gauge	Maximum axle load (in tonnes)
1.	BG	28.56
2.	MG	17.34
3.	NG	13.26

8.4 Tractive Effort

- It is taken as equal to or little greater than the hauling capacity.
- Computed by equating work done by tractive effort to the total power developed by the locomotive.
- For steam locomotive,
  Tractive effort depends upon:
  (i) Difference in pressure on two sides of the cylinder (P)
  (ii) Length of stroke (L)
  (iii) Area of piston (A)
  (iv) Diameter of piston (d)
  (v) Diameter of wheel (D)
- If T_0 is the mean tractive effort then work done by a two cylinder engine

$$= 2\,pA(2L) = \pi pLd^2 \quad \text{...(i)}$$

Work done in one revolution of driving wheel

$$= \pi DT_e \quad \text{...(ii)}$$

Equating (i) and (ii), we get

$$T_e = \frac{pd^2L}{D}$$

where, T_e = tractive effort

Hence, a small diameter wheel will increase the tractive efforts but reduce the speed of movement.
For diesel locomotive

$$\text{Tractive effort} = \frac{308 \times HP_r}{v}$$

Where, HP_r = rated horse power of the engine
v = velocity (in kmph)

Example 8.1 A train having 20 wagons weighing 18 tonnes each is to run at a speed of 50 kmph. The tractive effort of a 2-8-2 locomotive with 22.5 tonnes load on each driving axle is 15 tonnes. The weight of locomotive is 120 tonnes.
Rolling resistance of wagons and locomotives are 2.5 kg/tonnes and 3.5 kg/tonne respectively.
The resistance which depend on the speed is computed as 2.65 tonnes.
Find out the steepest gradient for these conditions. Given, coefficient of friction is 1/6.

Solution:

No. of wagons in the train = 20
Weight of each wagon = 18 tonnes
Total weight of wagons = 20 × 18 = 360 tonnes
Weight of locomotive = 120 tonnes
∴ Weight of train = 360 + 120 = 480 tonnes
No. of driving axles in a 2-8-2 locomotive,

$$n = \frac{8}{2} = 4$$

Load on each driving axle = 22.5 tonnes
∴ Hauling capacity = μnW

$$= \frac{1}{6} \times 4 \times 22.5 = 15 \text{ tonnes} \quad \text{...(i)}$$

$$\text{Total resistance} = Rt_1 + Rt_2 + Rt_3 + w\tan\theta \quad \text{...(ii)}$$

Rt_1 = Rt_1 for locomotive + Rt_1 for wagons
= 3.5 × 120 + 2.5 × 360
= 1320 kg or 1.32 tonnes
Rt_2 = 2.65 tonnes
Rt_3 = $0.0000006\,w^2$
= $0.0000006 \times 480 \times 50^2$
= 0.72 tonnes
Now, hauling capacity = Total resistance
⇒ 15 = 1.32 + 2.65 + 0.72 + 480 tanθ
⇒ 10.31 = 480 tanθ

$$\Rightarrow \tan\theta = \frac{1}{46.56} \approx \frac{1}{47}$$

Thus, the steepest gradient will be approximately 1 in 47.

Summary

- Tractive effort of locomotive has to be adequate to overcome various resistances offered to the movement of trains and locomotives.
- Resistance to traction can be divided into four categories:
  (i) Resistance due to rolling stock
  (ii) Resistance due to track profile
  (iii) Resistance due to tractive effort
  (iv) Resistance due to climatic conditions
- Hauling capacity of locomotive is an indicative of power available to a locomotive.
- Hauling capacity should be equal to the train resistances.

Objective Brain Teasers

Q.1 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

Q.2 A train is hauled by 2-8-2 locomotive with 22.5 tonnes and 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

Q.3 A train is hauled by 4-8-2 locomotive. The number of driving wheels in this locomotive is
(a) 4 (b) 8
(c) 12 (d) 14

Answers

1. (c) 2. (b) 3. (b)

CHAPTER 09

Geometric Design

Geometric design is defined as the design of all the physical features of the track. (which has been provided so as to have smooth operation of the system). Elements involved in the geometric design are:

(i) Speed of the train
(ii) Horizontal curve and the superelevation
(iii) Vertical curve and the gradient
(iv) Widening of gauge on curves

9.1 Speed of the Train

9.1.1 Speed and its Effects

- Every train is allowed to move on a track with two types of speed, either average sped or maximum speed depending upon its category.
- Average speed is the speed that is helpful in finding out the total time period a train is going to take so as to cover a distance.
- Maximum speed is the value of speed which a driver is allowed to attain if there is requirement of attaining that value.
- Average speed depends on the length of the section and the number of stoppages.
- For every track, there is a maximum sanctioned speed. This has been defined by the track engineer who has designed that section.
- It is always better to be far below this maximum sanctioned speed in order to avoid any hazardous conditions.

NOTE: In the case of emergencies only, these maximum sanctioned speeds can be attained by the drivers of any train.

- Speed creates its effects in the augmentation of stresses as well as in the augmentation of the resistances.
- Dynamic effects of speed are as follows:
  (i) Pitching (ii) Rolling (iii) Bouncing
  (iv) Lateral oscillation (v) Resonance

- In the case of pitching, there is a throw in the forward direction or in the sideward direction.
  This sort of throw comes because of the irregularities of the surfaces or may be because of the poor maintenance of joints.
- In the case of rolling, there is movement w.r.t the x-axis. (i.e., anticlockwise or clockwise direction of that axis).
  where, x axis is actually along the track i.e., longitudinal direction of the track.
  In the case of trains, actually there is leaning effect towards the left or right side of the direction of movement.
- In the case of bouncing, there is a bumping in the vertical direction. So, the passengers feels a jerk in the upward direction or a sort of deflection in the downward direction.
- Lateral oscillation occurs if the train hits the one side of the rail. After one side of the rail is hit by the train, it rebounds back and moves towards the other side. Passenger observes that there is a relative motion of the compartments sideway w.r.t. the other wagons of the compartments.
- When metal surface of rail interacts with metal surface of wheels, there are chances that there are impacts or bouncing effects or pitching effects. (as discussed previously)
  If the frequency of the two matches, then a resonance condition is achieved at the bottom of the track level.
  People feels a pinching effect coming from the bottom.

9.1.2 Safe Speed (V_s)

- Safe speed in the case of straight track is limited by the maximum speed defined for each train.
- Safe speed means a speed which is safe from the danger of overturning and derailment with a certain margin of safety.
- Safe speed in the case of curves depends on certain factors like.
  (i) gauge of track (ii) radius of the curve
  (iii) superelevation (iv) transition curve length
  (v) resultant of weight and centrifugal force

9.1.2.1 Formula for Computation of Safe Speed

(i) Martin's Formula

- Depends on radius of curve (in meters) and the speed for transition curves.
- Speed for transitional curve (BG/MG)

$$V_s = 4.35\sqrt{R-67} \text{ km/hr}$$

$$V_s = 4.4\sqrt{R-70} \text{ km/hr}$$

- Speed for transitioned curve (NG)

$$V_s = 3.65\sqrt{R-6} \text{ km/hr}$$

Subject to maximum 50 kmph

- Speed for non-transitioned curve

$$V_s = \frac{4}{5} \text{ of the above in all cases}$$

subjected to maximum 40 kmph for NG

- For high speed $V_s = 4.58\sqrt{R}$
- Indian Railways no longer use above formulas for safe speed on curves.

(ii) Railways Board Formula

- Martin formula is replaced by Railway Board Formula.
- This formula considers the cant actually provided on the track and standard deficiency allowed in it along with the radius of the circular curve.
- Safe permissible speed is calculated by Railway Board Formula.
- Speed for fully transitioned curve.

$$\left.\begin{aligned} V &= 0.27\sqrt{R(C_a+C_d)} \text{ for B.G} \\ V &= 0.347\sqrt{R(C_a+C_d)} \text{ for M.G.} \\ V &= 3.65\sqrt{R-6} \text{ for N.G.} \end{aligned}\right\} \text{Maximum 50 kmph}$$

where C_a = actual SE or cant
C_d = cant deficiency (allowed on that track)

- Cant to be gained over virtual transition, which is 14.6 m on BG, 13.7 m on MG and 10.3 m on NG.

9.1.3 Equilibrium Speed

- It is defined as the speed at which effect of centrifugal force is exactly counter balanced by Cant provided.
- This is the basis of design of the superelevation.

9.1.3.1 Factors Controlling Equilibrium Speed

Equilibrium speed is decided on the following basis.

(i) Maximum permissible speed (V_m)
It is generally decided by the track engineer.

(ii) Permanent and Temporary speed restrictions
Imposed by traffic controller

(iii) No. of stoppages
Done w.r.t. the revenue requirements (done w.r.t the generation of revenue for the railways)

(iv) Gradients
(gradient should be such that there should be no reduction in the speed)

(v) Proportion of slow and fast trains
(computation of equilibrium speed is done on the basis of total no. of trains moving in any of the speed category)

9.1.3.2 Calculation of Equilibrium Speed

(i) For $V_m > 50$ kmph
Equilibrium speed (V_e)

$$V_e = \frac{3}{4}V_m \text{ or } V_s \text{ whichever is less.}$$

(ii) For $V_m < 50$ kmph

Take V_e as either V_m or V_s whichever is less.

where, V_m = maximum permissible speed

V_s = safe speed

(iii) On some railways, "weighted average" is calculated for finding out the equilibrium speed of trains. Weighted average of equilibrium speed

$$V_e = \frac{(n_1V_1 + n_2V_2 + ...n_mV_m)}{(n_1 + n_2 + ...n_m)}$$

where, $V_1, V_2, ..., V_m$ are speed of different number of trains $n_1, n_2, ... n_m$ moving on the same track.

NOTE: Limits of maximum SE or cant as laid down in the Indian Railways are as follows:

1. Broad Gauge
   Group A,B and C routes – 165 mm (a value of 185 mm may be adopted for planning of future works on all group 'A' routes)
   Group D and E routes – 140 mm
2. Metre Gauge – 90 mm
   (100 mm with special permission on high speed routes)
3. Narrow gauge (762 mm) – 65 mm
   (75 mm with special permission)

9.1.4 Maximum Permissible Speed (MPS)

MPS on a curve is the minimum of the values calculated as

(i) Maximum sactioned speed of the section (authorized by the commissioner of railway safety)

(ii) Speed based on the consideration of cant deficiency and actual cant.

(iii) Maximum speed taking into consideration speeds of goods train and cant excess.

(iv) Speed corresponding to the length of the Transition Curves (TC).

NOTE: If the length of the TC cannot be increased, then the speed based on the length of the TC is also considered along with the above three methods.

NOTE: Following values of maximum cant deficiency are permitted.

1. Broad gauge — 75 mm
   (For speeds in excess of 100 kmph on group A and B routes —100 mm with special permission)
2. Metre gauge — 50 mm
3. Narrow gauge (762 mm) — 40 mm

9.1.5 Important Technical Words

(i) Cant or Superelevation

- It is the difference between the height of the outer rail and inner rail on a curve.
- Inner rail is maintained at original level and called gradient rail.
- It is same as superelevation.

- The raised elevation of outer rail above the inner rail at a horizontal curve to counteract centrifugal force is known as cant as superelevation.
- Cant also provide equal distribution of wheel loads on two rails.

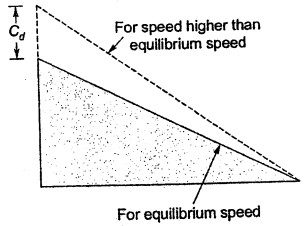


Fig. 9.1

(ii) Cant deficiency (C_d)

- There is deficiency in cant when train runs at a speed higher than the equilibrium speed.
- Tries to overturn on the outer side of the curve.
- So, higher speed is to be restricted or is to be fixed.

(iii) Cant excess (C_e)

- There is excess in cant when train runs at a speed lower than equilibrium speed.
- Derailment may occur.

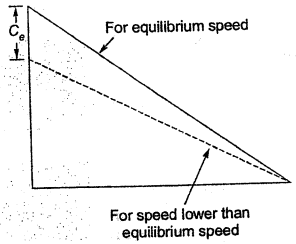


Fig. 9.2

NOTE

(i) Higher cant deficiency means higher discomfort, higher unbalanced centrifugal force and some extra lateral pressure on the outer rails.

(ii) A condition has to be achieved by providing superelevation in such a way that faster trains may travel safely without danger of overturning and slower train may run safely without fear of derailment.

9.1.4 Steps for Calculating C (Cant) and V_m

(i) Calculate cant for maximum sanctioned speed using

$$C_m = \frac{GV^2}{127R}$$

(ii) Calculate cant for slowest traffic (C_s)

(iii) Add cant excess to it ($C_s + C_e$)

(iv) Calculate cant for equilibrium speed (C)

(v) Check for cant deficiency (C_d) using C_m and C

(a) If less than standard value, OK

(b) If not, set it to standard value

(vi) Lowest value of (i) and (ii) is the permissible cant (C_a)

(vii) Add cant deficiency to it ($C_a + C_d$) and calculate V_m using standard formula

$$V_m = 0.27\sqrt{[(C_a + C_d)R]}$$

9.2 Curves

- A curve is a device required to change the direction of movement of an object either in vertical or horizontal plan.
- A horizontal curve is required to change the direction of movement of an object in the plan.

- A vertical curve is required to join the two gradients at the points where they meet so as to provide a smooth movement over those two gradients.

9.2.1 Limitation of Provision of Curve

- Prevents the use of heavy locomotive
- there is a possibility of derailment or overturning.
- unequal distribution of load
- running is not smooth on curvature
- various fittings are required

9.2.2 Degree of Curve

Angle subtended at the centre of curve C by a chord of 30.5 m or 100 ft. length

$$D = \frac{1750}{R} \qquad \left[\because \frac{30.5}{2\pi R} = \frac{D_1}{360}\right]$$

where, R = radius of circular curve (in metres)

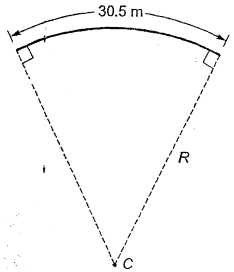


Fig. 9.3

9.2.3 Versine of Curve (V)

From principal of geometry

$$AB \times BC = DB \times BE$$

$$\Rightarrow \quad V \times (2R - V) = \frac{C}{2} \times \frac{C}{2}$$

$$\Rightarrow \quad 2RV - V^2 = \frac{C^2}{4}$$

$$\Rightarrow \quad 2RV = \frac{C^2}{4} \text{ [As V is very small]}$$

$$\Rightarrow \quad V = \frac{C^2}{8R}$$

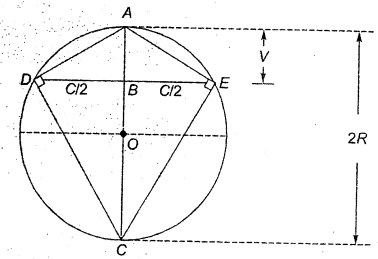


Fig. 9.4

where, C is chord in metres, R is radius in metres.

(i) V (in metres) $= \dfrac{C^2}{8R}$

(ii) V (in cm) $= \dfrac{12.5C^2}{R}$

9.2.4 Setting of Curve in the Field

Method of curve setting in the field are:

(i) Tangential offset method
(ii) Long chord offset method
(iii) Chord deflection method
(iv) Theodolite method

9.3 Superelevation

- It is difference between the height of outer rail and inner rail on a curve.
- Also known as cant.
- Inner rail is taken as the reference rail and w.r.t. inner rail, outer rail is raised.

9.3.1 Objective of Providing a Superelevation

- to neutralize the effect of centrifugal force.
- achieve equal distribution of wheel loads.
- to improve the comfort level of passengers.
- to avoid jerk when rolling stock moves from a straight section to a curved section.

9.3.2 Formula for Superelevation

$$e = \frac{GV^2}{127R} \text{ (in mm)}$$

where, G = gauge, V = speed (in m/s), R = radius (in metre), g = acceleration due to gravity (m/s^2)

G is 1750 mm for BG

G is 1058 mm for MG

9.3.3 Negative Superelevation

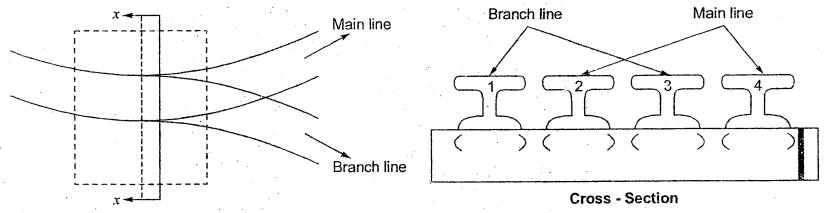


Fig. 9.5

1 is at higher elevation than 3.
2 is at higher elevation than 4

When main line is on a curve and a branch line takes off from a main line with a curve which is in contrary flexure to the main line, the outer rail of the branch line instead of being raised, has to remain lower than the inner rail upto a certain distance from take off point.

The amount by which outer rail of branch line is lower than the inner rail is called negative superelevation.

Example 9.1 For a broad gauge track in a transition zone in order to allow locomotives with a maximum permissible speed of 110 kmph, calculate the following

(i) Radius of curvature
(ii) Degree of curvature
(iii) Superelevation
(iv) Length of transition

Solution:

As per Martin's formula for a BG track in a transition zone

$$V = 4.35\sqrt{R - 67} \qquad \text{...(i)}$$

where, V is maximum permissible speed in kmph and R is radius of curvature in metres

Given, V = 110 kmph

From eq. (i) $110 = 4.35\sqrt{R - 67}$

$\Rightarrow$ $R = 706.45$ m

$\therefore$ Degree of curvature, $D = \frac{1719}{R} = \frac{1719}{706.45} = 2.43°$

Superelevation, $e = \frac{GV^2}{127R} = \frac{1.676 \times 110^2}{127 \times 706.45} = 0.226 \text{ m} = 22.6 \text{ cm}$

Length of transition is given by

$$L = \frac{V_{max} \times e}{198} \quad \text{(where, } e \text{ is in mm and } L \text{ is in m)}$$

$$= \frac{110 \times 226}{198} = 125.55 \text{ mm}$$

Example 9.2 For a 2° BG track, maximum sanctioned speed is 110 kmph, equilibrium superelevation speed 80 kmph and booked speed of goods train 50 kmph. Compute value of allowable maximum speed as well as the cant. (G = 1750 mm)

Solution:

Radius of curve, $R = \frac{1750}{D} = \frac{1750}{2} = 875$

where, D is in degree

Superelevation for equilibrium speed,

$$C = \frac{GV^2}{127R} = \frac{1750 \times 80^2}{127 \times 875} = 100.8 \text{ mm}$$

Superelevation for maximum permissible speed

$$C_m = \frac{1750 \times 110^2}{127 \times 875} = 190.6 \text{ mm}$$

Cant deficiency, $C_d = C_m - C = 190.6 - 100.8 = 89.8$ mm

Less than maximum cant deficiency. Hence, OK

Superelevation for booked speed of good trains

$$C' = \frac{1750 \times 50^2}{127 \times 875} = 39.37 \text{ mm}$$

Cant excess, $C_e = 100.8 - 39.37 = 61.43$ mm

Value of less than 75 mm, hence it is permitted

Maximum speed potential,

$$V_m = 0.27\sqrt{(C_a + C_d)R}$$

$$= 0.27\sqrt{(100.8 + 89.8) \times 875}$$

$$= 110.1 \text{ kmph} \quad [C_a \text{ is lowest value between } C \text{ and } C_m]$$

Therefore, maximum permissible speed is least of the following

(a) Maximum sanctioned speed = 110.1 kmph

(b) Speed computed = 10 kmph

$\therefore$ Allowable maximum permissible speed = 10 kmph

[Assuming that there is no restriction of transition curve length].

Example 9.3 From a BG main line curve of 2°, a 1 : 12 turnout takes off in contrary flexure for a branch line. Find out the permissible cant on main line and the speed that can be permitted on the main line.

Solution:

Degree of turnout curve = 4.76°

Degree of main line = 2°

Degree of branch line curve = 4.76 – 2 = 2.76°

Radius of branch line curve $= \frac{1750}{D} = \frac{1750}{2.76} = 633.22$ m

Speed on branch line = 30 kmph

Cant needed for branch line $= \frac{GV^2}{127R} = \frac{1750 \times 30^2}{127 \times 633.22} = 19.59 \simeq 20$ mm

To ensure that negative Cant for branch line does not increase the limit of cant deficiency of 75 mm, maximum Cant that can be permitted on main line

$$= 75 - 20 = 55 \text{ mm}$$

This will be negative Cant for branch line.

Allowing a Cant deficiency of 75 mm for main line, maximum speed that can be permitted on main line is

$$V = 0.27\sqrt{(55 + 75) \times 633.22}$$

$$= 77.47 \text{ kmph} \simeq 80 \text{ kmph}$$

NOTE: Speed on branch line assumed to be 30 kmph for all turnouts if it has not been specifically mentioned.

9.4 Transition Curve and Widening of Track

- Transition curve connects the straight section of track at one end and circular curve at the other end.
- Radius changes from infinity (for straight section of track) to finite radius (for circular section of track) at a uniform rate.
- Smooth traversing of vehicle occurs due to uniform rate of introduction of centrifugal force.
- Superelevation is introduced at uniform rate.

$$\left[e = \frac{GV^2}{127R}; \text{ superelevation depends on radius}\right]$$

9.4.1 Types of Transition Curve

(i) Euler's Spiral

It is given by the formula,

$$\phi = \frac{l^2}{2RL}$$

where, ϕ = angle between straight line track and tangent to the transition curve.
l = distance of any point on the transition curve from the takeoff point.
R = radius of the curve
L = overall length to be provided to the transition curve

- This is an ideal transition curve but is not preferred due to mathematical computations.
- Difficult to provide in the field.

(ii) Cubic Spiral

It is given by the formula

$$y = \frac{l^3}{6RL}$$

It is also difficult to set in the field.

(iii) Bernoulli's Lemniscate

- Radius decreases as the length increases and this causes radial acceleration to keep on falling.
- Within 30° deflection angle, this curve performs well. Beyond 30°, uniformity is lost.

(iv) Cubic Parabola

- Both the curvature and Cant increases at a linear rate.
- A straight line ramp is used to raise the outer rail while keeping the inner rail at the same level (level of outer rail is increased at a uniform rate while inner rail is at the same level)
- It is mostly used on Indian railways.
- It is given by the formula

$$y = \frac{x^3}{6RL}$$

where, y is vertical coordinate, x is horizontal coordinate
L is length of transition curve, R is radius of circular curve

9.4.2 Shift

- This is the amount by which a circular curve is shifted inwards so as to meet a transition curve.
- It is given by the formula

$$S = \frac{L^2}{24R}$$

where, S = shift (in metre), L = length of transition curve (in metre)
R = radius (in metre)

9.4.3 Length of Transition Curve

S.No.	Criterion	Desirable value	Minimum value
1.	Rate of change of Cant	$\frac{C_a V_m}{125}$	$\frac{C_a V_m}{198}$
2.	Rate of change of Cant deficiency	$\frac{C_d V_m}{125}$	$\frac{C_d V_m}{198}$
3.	Cant gradient	Cant gradient should not exceed 1 in 720.	Cant gradient should not be less than 1 in 360 for BG and 1 in 720 for MG and NG.

where, C_a and C_d are actual Cant and Cant deficiency respectively (in mm)
V_m is the maximum permissible speed (in kmph)

9.4.4 Widening of Gauge on Curves

Reasons for widening of gauge:

(i) Centrifugal force (tries to take vehicle in the outward direction)
(ii) Rigidity of wheel base (there are end throws or overthrows at the centre or the end of the base)
(iii) Relative distance travelled by the wheels (loss of contact between wheel and rail in trailing position)

Extra width required on curves is given by the following formula

$$w = \frac{13(B+L)^2}{R}$$

where, B = wheel base (6 m for broad gauge and 4.88 m for metre gauge)
L = lap of flange = $0.02\sqrt{h^2 + Dh}$ (in metre)
h = depth of flange below top of rail (in cm)
D = diameter of wheel (in cm)
R = radius of curve (in m)

NOTE

1. Overthrow is the extra clearance required at the centre of the vehicle, towards the inside of the curve

$$\text{Overthrow} = \frac{C^2}{8R}$$

where, C = total amount of the wheel base
R = radius of the curve

2. End throw is the extra clearance required at the ends where the vehicle projects towards outside of the curve

$$\text{End throw} = \frac{L^2 - C^2}{8R}$$

Example 9.4 Design the length of a transition curve for a BG railway curved track having 4° deflection and a 'cant' of 12 cm. The maximum design speed on the curve is 100 kmph. Also calculate offsets at every 15 m intervals and shift of the circular curve. Assume the cant deficiency as 7.6 cm.

Solution:

As per Indian Railways the length of the transition curve is the greater out of the following three values

(i) $L = 7.20 \times e = 7.20 \times 12 = 83.4$ m

(ii) $L = 0.073\, D \times V_{max} = 0.73\, D \times 7.6 \times 100 = 55.48$ m

(iii) $L = 0.073\, e \times V_{max} = 0.073 \times 12 \times 100 = 87.6$ m = 88 m

Hence length of curve is to be taken as 88 m.

Now, $L = 90$ m (say)

The equation of cubic parabola which is used as a transition curve is given by

$$y = \frac{x^3}{6RL}$$

But $$R = \frac{1720}{\text{Degree of curve}} = \frac{1720}{4°} = 430 \text{ m}$$

Taking offsets at 15 m intervals, we get

$$y_{15} = \frac{(15)^3 \times 100}{6 \times 430 \times 90} = 1.45 \text{ cm}$$

$$y_{30} = \frac{(30)^3 \times 100}{6 \times 430 \times 90} = 11.63 \text{ cm}$$

$$y_{45} = \frac{(45)^3 \times 100}{6 \times 430 \times 90} = 39.24 \text{ cm}$$

$$y_{60} = \frac{(60)^3 \times 100}{6 \times 430 \times 90} = 93.02 \text{ cm}$$

$$y_{75} = \frac{(75)^3 \times 100}{6 \times 430 \times 90} = 313.95 \text{ cm}$$

Chainage (m)	15	30	45	60	75	90
Offset (cm)	1.45	11.63	39.24	93.02	181.69	313.95

Shift of the curve, $$S = \frac{L^2}{24R} = \frac{(90)^2}{24 \times 430} = 0.785 \text{ m}$$

9.5 Vertical Curves and Gradients

- Vertical curves are basically provided in order to provide solution to the problems with meeting of two gradient.
- Problem with the meeting of two gradients
  (a) angular formation i.e., kinks
  (b) rough run of the vehicles on track
  (c) variation in the tension of couplings in the summit

- These problems results in train parting and an uncomfortable ride.
- Vertical curves are of two types
  (i) Summit curves
  (ii) Valley curves
- In summit curves, a rising gradient is followed by a falling gradient.
- In valley curves, a falling gradient is followed by a rising gradient.
- Vertical curves needs to be provided where the algebraic difference between the grades is greater than or equal to 0.4%.
- Rising gradient is normally considered positive and falling gradient is considered negative.

9.5.1 Parameters Related to Design of Vertical Curves

1. Length of vertical curve
   - depends upon the algebraic difference in grades and the type of curve.
2. Rate of change in gradient is restricted as
   - r should not exceed 0.1% per 30.5 metres length of chord for the summit curve.
   - r should not exceed 0.05% per 30.5 metres length of chord for the valley curve.
3. Required length of a vertical curve for achieving maximum permissible speed is given by

$$L = (g_i - g_j) \times \frac{30.5}{r}$$

where, g_i or g_j are successive % grades
r is rate of change of grade

4. Minimum radius of vertical curve

Route $A \rightarrow$ 4000 m Route $B \rightarrow$ 3000 m
Route $C, D, E \rightarrow$ 2500 m MG all routes $\rightarrow$ 2500 m

9.5.2 Gradients

- Gradients are provided to negotiate the rise or fall in the level of the railway track.
- It is represented by the distance travelled for a rise or fall of one unit. [1 in x where x is the horizontal distance]
- Objectives of providing gradient
  (i) to reach various stations at different elevations
  (ii) to follow the natural contours of the ground to the extent possible
  (iii) to reduce the cost of earthwork

9.5.3 Types of Gradients

1. Ruling Gradients
   - It is determined on the basis of the maximum load that a locomotive can haul with maximum permissible speed.
   - Extra pull required by locomotive on gradient with θ inclination

$$P = W \sin\theta \simeq W \times \text{Gradient}$$

   - Ruling gradient with one locomotive
     Plane area $\rightarrow$ 1 in 150 to 1 in 250
     Hilly area $\rightarrow$ 1 in 100 to 1 in 150

NOTE: Once a ruling gradient is specified for a section, then all other gradient provided in the section should be flatter than the ruling gradient.

- Ruling gradient is the design gradient.

9.5.3.1 Grade Compensation

- If there is any curvature along with the gradient then some compensation has to be made in terms of two types of resistances.
- One is resistance offered by the gradient and other is resistance offered by the curvature.
- BG → 0.04% per degree of curve or $70/R$
  MG → 0.03% per degree of curve or $52.5/R$
  NG → 0.02% per degree of curve or $35/R$
  } Minimum of the two volume.

2. Pusher Gradient
   - Gradient steeper than ruling gradient requiring extra locomotive
   - Reduces the length of railway section as well as the overall cost.
3. Momentum Gradient
   - Gradients are steeper the ruling gradient.
   - The resistance due to the gradient are overcome by the momentum which is gathered while having a run in plane or on falling gradient in valleys.
   - Uses additional kinetic energy received during run on a section.
4. Gradients in Station Yards
   - To prevent standing vehicle from rolling and moving away from the yard (due to combined effect of gravity and strong winds)
   - Desirable maximum value of gradient is 1 in 400.
   - Recommended minimum gradient from drainage considerations is 1 in 1000.

NOTE: Gradient should be provided in between the maximum value and minimum value.

Summary

- Elements involved in the geometric design are:
  (i) Speed of the train
  (ii) Horizontal curve and the superelevation
  (iii) Vertical curve and the gradient
- Average speed depends on the length of the section and no. of stoppages.
- Maximum sanctioned speed is defined by the track engineer who has designed that section.
- Equilibrium speed is the speed at which effect of centrifugal force is exactly counterbalanced by cant provided.
- Maximum cant deficiency permitted for BG, MG and NG (762 mm) are 75 mm, 50 mm, 40 mm respectively.
- There is deficiency in cant when train runs at a speed higher than equilibrium speed.
- There is cant excess when train runs at a speed lower than equilibrium speed.

- Degree of curve is the angle subtended at the centre of curve by a chord of 30.5 m length.
- Grade compensation has to be made if there is any curvature along with the gradient.
- Shift is the amount by which a circular curve is shifted in-wards to meet a transition curve.
- In a transition curve, radius changes from infinity to a finite value at a uniform rate.
- Euler's spiral is an ideal transition curve.
- Cubic parabola is mostly used on Indian Railways.

Objective Brain Teasers

Q.1 In a B.G. 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 gradient of
(a) 1 in 257 (b) 1 in 357
(c) 1 in 457 (d) 1 in 512

Q.2 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%

Q.3 For 8° curve track diverging from a main curve of 5° in an opposite direction in the layout of a broad gauge yard, the cant to be provided for the branch track for maximum speed of 45 km/h on the main line and 'G' = 1.676 m is (Permitted cant deficiency for the main line = 7.6 cm)
(a) 0.168 cm (b) –0.168 cm
(c) 7.432 cm (d) 7.768 cm

Q.4 The equilibrium superelevation to be provided on a curve of radius R metres and speed of vehicle V kmph is given by
(a) $\frac{GV^2}{127R}$ (b) $\frac{GV^2}{160R}$
(c) $\frac{GV^2}{147R}$ (d) $\frac{GV^2}{217R}$

Q.5 Normally maximum cant permissible in Metre Gauge is
(a) 75 mm (b) 90 mm
(c) 140 mm (d) 165 mm

Q.6 The steepest gradient permissible on a 2.5° curve for Broad Gauge line having ruling gradient of 1 in 200 is
(a) 1 in 250 (b) 1 in 222
(c) 1 in 235 (d) 1 in 275

Q.7 The limiting value of cant deficiency for Metre Gauge routes is
(a) 40 mm (b) 50 mm
(c) 75 mm (d) 100 mm

Q.8 Vertical curves are provided where algebraic difference between grades is equal to or
(a) less than 2 mm/m
(b) more than 2 mm/m
(c) less than 4 mm/m
(d) more than 4 mm/m

Q.9 The limiting value of cant excess for Broad Gauge is
(a) 55 mm (b) 65 mm
(c) 75 mm (d) 100 mm

Q.10 The desirable rate of change of cant deficiency in case of Metre Gauge is
(a) 20 mm/sec (b) 35 mm/sec
(c) 55 mm/sec (d) 65 mm/sec

Q.11 Staggered joints are generally provided
(a) on curves
(b) on straight track
(c) when two different rail sections are required to be joined
(d) None of the above

Q.12 Degree of a railway curve is defined as number of degrees subtended at the centre of a curve by an arc of
(a) 10 m (b) 15 m
(c) 20 m (d) 30.5 m

Q.13 Safe speed (V) on a curve of radius 970 metres provided with two transition curves on Broard Gauge track, is
(a) 112 km/hour (b) 122 km/hour
(c) 132 km/hour (d) 142 km/hour

Q.14 Cant deficiency occurs when a vehicle travels around a curve at
(a) equilibrium speed
(b) speeds higher than equilibrium speed
(c) speeds lower than equilibrium speed
(d) booked speed

Q.15 The compensation for curvature on gradient for Metre Gauge is given by
(a) $70/R$ (b) $52.5/R$
(c) $35/R$ (d) $105/R$
where R is radius of curve

Q.16 The shape of transition curve used by Indian Railways is
(a) cubic parabola
(b) spiral
(c) sine curve
(d) lemniscate of Bernoulli

Q.17 If R is the radius of a circular curve, then the versine on a chord of length C is given by
(a) $\frac{C^2}{4R}$ (b) $\frac{C}{8R}$
(c) $\frac{C^2}{8R}$ (d) $\frac{C}{4R}$

Q.18 A Broad Gauge branch line takes off as a contrary flexure from a main line. If the superelevation required for branch line is 10 mm and cant deficiency is 75 mm, the superelevation to be actually provided on the branch line will be
(a) –10 mm (b) 64 mm
(c) 85 mm (d) –65 mm

Q.19 One degree of curve is equivalent to
(a) $1600/R$ (b) $1700/R$
(c) $1750/R$ (d) $1850/R$
where R is the radius of curve in metres.

Answers

1. (b)	2. (b)	3. (b)	4. (a)	5. (b)
6. (a)	7. (b)	8. (d)	9. (c)	10. (b)
11. (a)	12. (d)	13. (c)	14. (b)	15. (b)
16. (a)	17. (c)	18. (d)	19. (c)	

CHAPTER 10

Signals and Interlocking

10.1 Signals

Signals constitute the controlling part of the movement of the rolling stock on a railway track which has been laid as per the design. Due to signals, trains are operated efficiently and tracks are used to the maximum extent maintaining the safety of the passengers, rolling stock and the staff. Main objectives of the signals are as follows:

(i) Efficient movement of trains
(ii) Ensuring safety of train moving on crossing tracks
(iii) Maximum utilization of the track
(iv) Safety during shunting operations
(v) Managing train movement during maintenance and repairs

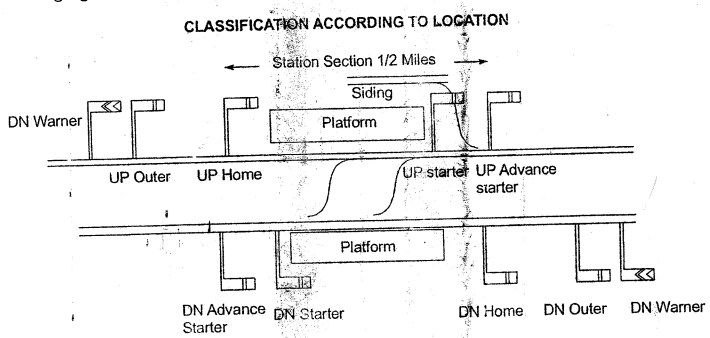


Fig. 10.1 Typical Signals Layout

10.2 Engineering Principles of Signalling

1. Any failure in signalling system should result in most restrictive aspect.
2. A given signal must convey the same indication to driver at all time and at all place.
3. It should be reliable, simple and economical.
4. Aspects of fixed signal should be distinctive and unambiguous.

10.3 Classification of Signals

Classification of signals can be done on the following basis:

(i) Classification based on operating characteristics:

- On this basis, there are audible signals as well as visual signals
- In case of audible signals, detonation is used so as to make a big noise
- Audible signals are used during low visibility condition (moist and fog)
- Detonators are fixed to the rails and are placed 400 to 500 m before the signals.
- Visual signals can further be divided as hand operated signals or the fixed signals.
- Fixed signals are most of the time placed at the top of the post.
- Fixed signals may be of movable arm type or colour light type or disc type.
- Either one or more number of fixed signals can be placed on the same post.

(ii) Classification based on the functional characteristics:

- On this basis, there are hand signals and fixed signals.
- Hand signals can be subdivided into flag, colour light and hand indication.
- Operating staffs are provided with two types of flag: Red Flag and Green Flag.
- Red defines the stopping condition, green defines the starting condition.
- Light indicators may be red and green or red, yellow and green.
- Yellow defines the caution i.e., the speeds needs to be reduced.
- Hand indications are used mainly when shunting operation is being carried out.
- Fixed signals can be classified as (a) stop signals (b) warner signals
- Stop signals defines that train has to be stopped.
- Warner signal defines that train has to move at a slower speed but there is no need to stop at those locations.
- Both stop signal and warner signal has a movable arm indicating whether movement is allowed on the track or not.
- Both stop signal and warner signal defines the movement condition based on the colour of the signal.
- Electric current is used in case of colour aspect condition whereas wires and keys are used for the movable arm condition.
- Movable arm signals are known as semaphore signals.
- Those signals which are provided with colour lights are termed as colour aspect signals.

(a) Semaphore Signals

- It consists of a movable arm pivoted on horizontal pin near the top of a post, spectacle holding two colour glasses, lamp for night indication, crank rod, cam, lever and counter weights, signal post, chain and pulley, wire to cabin.

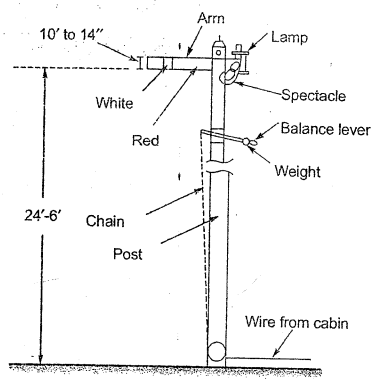


Fig. 10.2 Semaphore signal

- The arm is 4 to $5\frac{1}{2}$ ft. long ,9 to 12 inch wide at the inner edge and 10 to 14 inch wide at the outer edge.
- On the side facing the driver, it is painted red with a white vertical band.
- The other side is painted white with a black vertical band.
- When arm is in horizontal position or shows green light at night, it indicates stop.
- When arm is inclined at 45°, it indicates proceed.
- A semaphore signal at the entry to the station is combined with a warner signal.
- The arm of a warner signal is fish tailed and its white band is in the form of a V in unison with the outer edge.
- The warner is painted yellow and exhibits yellow or amber colour at night instead of red.
- It is placed on the same post of semaphore signal (about 6 to 7 ft. below the semaphore signal)
- When both the signals are horizontal, they indicate "Stop". This means neither approaching section is clear, nor next block section is clear.
- When semaphore is lowered and warner horizontal, they indicate "proceed with caution".

  This means section is clear upto the station but the next block section is not clear.
- When both the semaphore and warner are lowered, they indicate "proceed with confidence". This means the station section and also the next block section is clear.

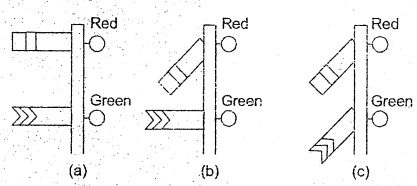


Fig. 10.3 Warner signaling

(b) Disc Signals (Shunting Signals)

- Used in station yards for shunting operation.
- Also known as shunting signals or miniature semaphore signals.
- They consists of circular discs painted white with a red band along its diagonal.
- The disc can revolve in a vertical plane by pulling of a lever by hand.
- When the red band is horizontal or shows red light at night, its indicates "STOP" and when inclined at 45° or show green light at night, it indicates "Proceed".
- The centre of the disc is about 2 feet above the ground level.

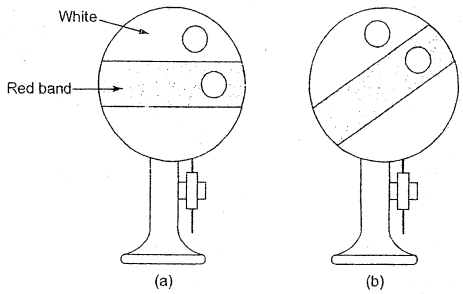


Fig. 10.4 Disc signal: (a) Indicates stop (b) Indicates proceed

(c) Colour Light Signals

- They are used on heavy traffic lines or where the no. of signals are too many.
- Usually adopted for automatic signalling.
- These signals gives indication by electric lights both during day and night.
- Light indications are the same as for semaphore.
- To make them visible during clear day they are provided with lenses.
- The signals may be having two lights i.e., red and green or three lights i.e., red, yellow or green.
- Discs with three lights are commonly adopted.

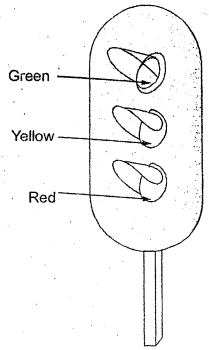


Fig. 10.5 Automatic colour light signal

(d) Point Indicators

- They are indicators placed in the yard near the points.
- They are not signals.
- They indicate whether the points are set for the main line or not.
- It consists of a box without a lid.
- Two opposite sides of the box are circular discs 15 inch in diameter and are painted white on the outside.
- The other two opposite sides consists of 5 inch wide bands painted green.
- Box can rotate about vertical axis.
- Inside the box there is a lamp with four sides.
- At night the two opposite sides parallel to the white disc emanate white light and the side parallel to the band emanate green light.
- When the points are set for the main track, the indicator shows white disc from either side of the track.
- When points are changed, the indicator rotates through 90° and indicator shows green disc or green light.
- Indicator is actuated by turning of the point.

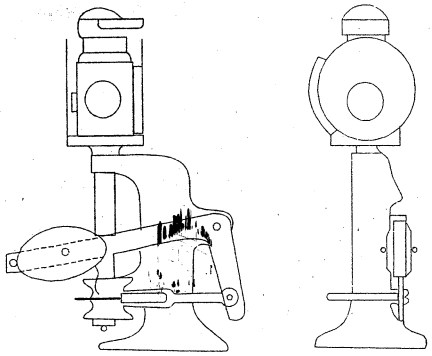


Fig. 10.6 Point indicator

(iii) Classification based on locational characteristics:

Locational characteristics can be subdivided into

(a) reception signals (b) departure signals

(c) routing signals (d) shunting signals

(a) Reception signals

- Signals which control the reception of trains into a station.
- The whole of railway track is divided into two sections, one is the station section, another one is block section.
- Station section is that section which comes under the direct control of that station and it is this particular section in which trains remain stationed at the platform.
- Block section is that section which is just after the station section (section between two station sections).
- These signals are related to the station section (not the block section).
- Here, also we have two types of signals (i) outer signal (ii) home signal.
- Outer signal is the first stop signal before the train enters from the block section to the station section.
- Outer signal is just at the outer periphery of the station section.
- In case of broad gauge, the distance of outer signal from station limit is 540 metres.
- In case of metre gauge, the distance of outer signal from station limit is 400 metres.
- Home signal is just provided at the door of the station (signal just before reaching the platform) i.e., it is the last point which can stop the train before coming to the platform.
- Home signals are not located at a distance more than 180 m from the start of points and switches.

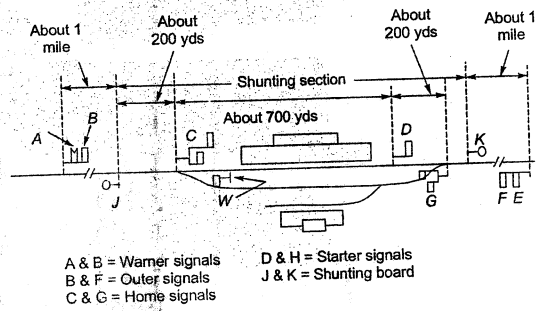


Fig. 10.7

(b) Departure signals

- When the train is standing on the platform and it has to depart, at that location the signal provided to dispatch the train from the station are known as departure signal.
- Departure signals can be subdivided into two types (i) starter signal (ii) advance starter signals.
- Starter signal is provided just ahead of the locomotive from where it is going to start and this marks the limit upto which a train stopping at the station should come to a stand.
- These are last stop signals which is provided within the station limits.
- This types of signal is provided beyond trailing points and switches at a distance 180 m or more.

NOTE

1. Station limits means the points after which there will be a block section.
2. Trailing points and switches are provided at the time when the train is departing or it is being dispersed from the station area.

(c) Routing signals

- It is a group of semaphore signals placed at facing point of a one or a number of turnouts.
- Lowering of any one of the signals indicates the track in which the points are set.
- Signal for a main track is at a higher level while signals for other turnouts are at a lower level.
- A plate is attached to it which defines the track to be taken up or being set for the train.

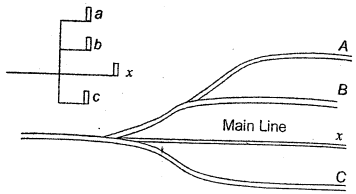


Fig. 10.8 Routing signal

(d) Shunting signals

- Used for shunting operations in station yards.
- Where semaphore signals are used, in those conditions the shunting signals are provided in the form of a circular disc shape (disc is provided with a red band on white background).

NOTE: Shunting operations are actually the slow operations which take place in station yards.

(iv) Classification based on special characteristics:

Different types of signals based on special characteristics are:

(a) Repeater signal
(b) Co-acting signal
(c) Calling on signal
(d) Indicators related to points, speed, shunt, caution, stop, level crossing, whistle, grade.

(a) Repeater signals

- It is provided when a signal is not visible to the driver from adequate distance, due to curvature or any other reason to the guard of the train at the rear end of the platform.
- It repeats the operation of a home signal.

(b) Co-acting signal

- They are provided when signal is not visible to the driver due to some obstruction such as overbridge, high structure etc.
- Sometimes this is being provided in such a way that it comes in the line of the sight of the driver or the guard and they are not in a position to see the main signal. So, in that case co-acting signal is provided and this co-acting signal is placed preferably on the same post above the main original signal.

(c) Calling on signal

- Placed on same post below the home signal.
- We mean by calling on signal that you are allowed or being called to take one track.
- It helps during main signal failure train movement.

(d) Indicators

- Point indicators indicates whether the train is taking main line or a turnout.
- Works as a precaution against bursting of points or runnings into an occupied line.

- It is provided with rotating discs which rotates with the change in setting of points.
- Caution indicator indicates what type of caution order is being given, whether it is a restricted condition or speed.
- Most of these have to be placed 700 m before the speed limit indicator board and 800 m before actual point of any permanent way work.
- Grade indicators defines the grades is terms of like 1 in *n* value it may be upgrade or downgrade.
- End of the grade is indicated by providing a sign with only letter L.
- We use arrows for indicating downgrade or upgrade.
- Stop indicator is used for temporary or permanent engineering restrictions which calls for train to come to a dead stop before proceeding further.
- Stop indicator is in the form of rectangular sheet where we have red background with white background on either side along the length.
- Sight board indicators warns the driver of signal ahead.
- Sight board indicators for goods trains are placed 1200 m ahead of the signal.
  For passenger train, they are placed 100 metres before the signal.
- Block section limit indicator defines the entry of the train into the station limit after the block section has completed.
- Block section limit indicator is generally placed at a distance of 180 m from the home signal.

10.4 Interlocking

- Interlocking is done to prevent the human error when points are set and signals are lowered or raised by means of levers.
- Any manipulation in human error can lead to an accident.
- Levers are interconnected or interlocked, such that only one point in a particular route can be opened at one time and would give signal for the same point.
- Signalling or interlocking can be done either mechanically or electrically.

10.4.1 Fundamentals of Interlocking

- Interlock between a point and its corresponding signal means that a signal cannot be lowered unless the line for which the signal is lowered is correctly set and locked. As long as the signal remains lowered, the points cannot be locked or reversed.
- No contradictory signal can be lowered at the same time. This means that admission of trains from opposite or converging direction to the same line and at the same time cannot take place.
- No loose wagons can enter the line after the points are set and signals lowered.
  This means that the points and signals should be so interlocked that when main or loop line routing signals at either end of yard are lowered, it is impossible to work the trap points.
- The track for which points are set and signal lowered should be clear of obstruction.

10.4.2 Mechanical Devices for Interlocking

Chief mechanical devices used are:

(i) Point lock

(ii) Treadle bars

(iii) Detectors

(iv) Connecting devices (e.g., rods, cranks and temperature compensators)

- To prevent accidents due to facing points, locks, detectors and treadle bars are used.
- A point lock is placed in the middle of the track a little in front of the toes of the tongue rails.
- The object of point lock is to ensure that each switch is correctly set.

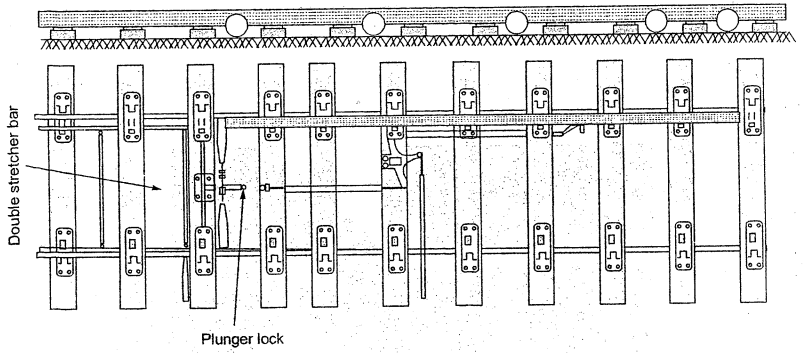


Fig. 10.9 Plunger lock and treadle bar

- Common type of point lock is the plunger type.
- The plunger is worked by a rod from a signal cabin.
- Two stretcher blades, each attached to one switch slide in the plunger casing at right angles to the plunger.
- The plunger can only be driven home when the slots in the stretcher blades register correctly and once the plunger gets into these slots, the switches cannot be moved.
- The length of a treadle bar is a little longer than the longest wheel base. When the point lock is worked, the treadle bar rises slightly above the rail level and then lowers.
- Detectors are special devices employed to prevent signals from being lowered when any part of the interlocking apparatus is out of order.
- The connecting devices between the lever in the signal cabin and switch or signal, consists of $1\frac{1}{4}$ inch diameter pipe or solid rods.
- Vertical or horizontal bends are provided by means of cranks.
- Temperature compensators are provided at about every 80 ft. distances or less in the line of rodding.
- They consists of pair of cranks (one acute and other obtuse angled) with a connecting link between them.

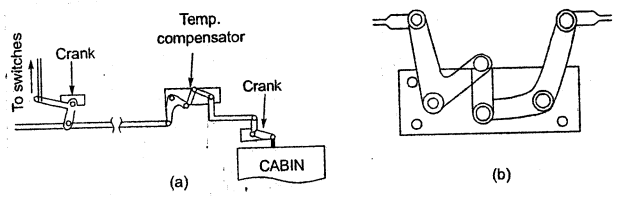


Fig. 10.10 (a) Connecting devices, (b) Temperature Compensator

NOTE: Double wire operation of points and signals has been adopted on Indian Railway for working of points and signals.

Summary

- Signals can be classified based on operating, functional, locational and special characteristics.
- Fixed signal are most of the time placed at the top of the post.
- Warner signal defines that train has to move at a slower speed at certain locations.
- Semaphore signals are movable arm signals.
- Disc signals are used in station yards for shunting operation.
- Semaphore signal is at the top of the post while warner signals are 6 to 7 feet below semaphore signal.
- When semaphore is lowered and warner horizontal, they indicate "process with caution".
- Interlocking prevents setting of conflicting switches or signals.
- Mechanical devices used for interlocking are:
  (i) Point lock (ii) Treadle bars
  (iii) Detectors (iv) Connecting devices
- In absolute block system, only one train at a time is permitted in a section. The track is divided into block section.

Objective Brain Teasers

Q.1 In a shunting signal if the red band is inclined at 45° it indicates
(a) stop
(b) proceed
(c) proceed cautiously
(d) None of the above

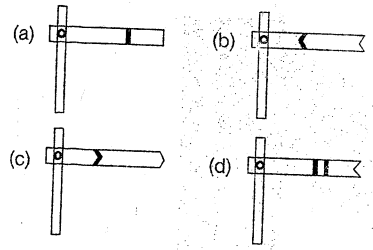
Q.2 When semaphore and warner are installed on the same post, then the stop indication is given when
(a) both arms are horizontal
(b) semaphore arm lowered but warner arm horizontal
(c) both semaphore and warner arms lowered
(d) None of the above

Q.3 Yellow light hand signal indicates
(a) stop
(b) proceed
(c) proceed cautiously
(d) None of the above

Q.4 The reception signal is
(i) outer signal (ii) home signal
(iii) starter (iv) advanced starter
The correct answer is
(a) (i) and (ii) (b) (ii) and (iii)
(c) (iii) and (iv) (d) (i) and (iv)

Q.5 The height of the centre of arm of a semaphore signal above the ground is
(a) 5.5 m (b) 6.5 m
(c) 7.5 m (d) 8.5 m

Q.6 Which one of the following figures represents a 'Warner signal' in railways?



Q.7 Consider the following statements:
Automatic signalling system results in
1. greater risk
2. higher efficiency
3. avoidance of block instruments
4. higher operating cost
Of these statements
(a) 1 and 2 are correct
(b) 3 and 4 are correct
(c) 1 and 4 are correct
(d) 2 and 3 are correct

Q.8 The object of providing a point lock is
(a) to ensure that each switch is correctly set
(b) to ensure that the point may not be operated while the train is no it
(c) to detect any obstruction between and tongue rail
(d) none of the above

Q.9 The treadle bar is provided
(a) in the middle of the track a little in front of the toes of the tongue rail
(b) near and parallel to inner side of one of the rails
(c) at right angle to the rail
(d) near and parallel to inner side of both the rails

Q.10 Which of the following mechanical devices is used to ensure that route cannot be change while the train is on the point even after putting back the signal?
(a) detectors (b) point lock
(c) lock bar (d) stretcher bar

Q.11 On B.G. track the distance of outer signal from station limit is kept
(a) 510 m (b) 520 m
(c) 530 m (d) 540 m

Answers

1. (b)	2. (a)	3. (c)	4. (a)	5. (c)
6. (b)	7. (d)	8. (a)	9. (b)	10. (c)
11. (d)				

Section - B

CHAPTER 1

Airport

1.1 Airport

- It is area regularly used for landing and take off of aircraft.
- It is also provided with facilities like shelter, repair of aircraft and for passengers and cargo.

Classification of Airport

A. According United State Federal Aviation Administration (FAA)

Primary Airport: These have more than 10,000 boardings each years.

Non-Primary Airports: Which handle less than 10,000 passengers each year.

B. According International Civil Aviation Organization (ICAO)

1. Based on runway length
   - The classification is done using code number 1 to 4.
   - Where code 1 has least basic runway length (< 800 m) and code 4 has longest runway length (≥ 1800 m)
2. Based on wing span and outer main gear wheel span
   - This classification is done using code letter A to E
   - Here A has least wing and outer main gear wheel spans while E has highest wing and outer main gear wheel spans.

1.2 Aircraft Components

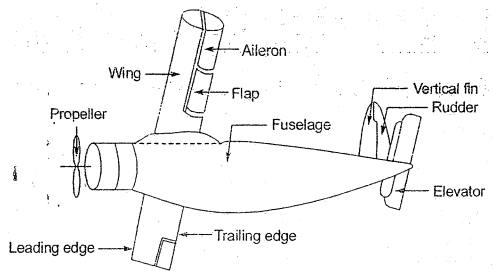


Fig. 1.1 Major Components of an Aeroplane

1. **Wings:** Wings support the aircraft in the flight when the engine has given it the necessary forward speed.

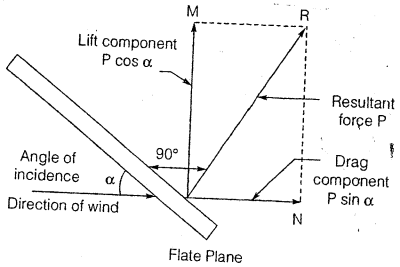


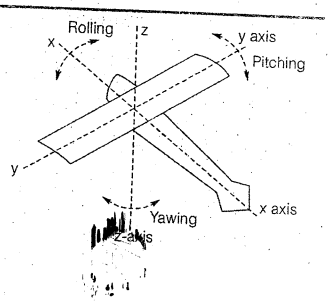
Fig. 1.2

Note: As the angle of incidence increase, the drag component also increases and the lift component reduces.

2. **Three principal controls:**
   There are three axes about which an aircraft may move to control these movements, the airplane is provided with three principal controls.
   (a) **Elevator:** Controls the pitching movement.
   (b) **Rudder:** Used for turning or yawing movement.
   (c) **Aileron:** Used to control the rolling moment.
3. **Fuselage:** It forms main body of aircraft and provides for power plant, fuel, cockpit, passengers, cargo etc.
4. **Flaps:** Used for increasing lift on aerofoils.

NOTE

- The movement of aircraft about the X-axis is called lateral or rolling movement.
- The movement about y and z axes are called pitching and yawing movements respectively.



1.3 Aircraft-Characteristics

The aircraft characteristics needed to be studies are:

1. Type of propulsion
2. Size of aircraft
3. Minimum turning radius
4. Minimum circling radius
5. Speed of aircraft
6. Capacity of aircraft
7. Aircraft weight and wheel configuration
8. Jet blast
9. Fuel spillage
10. Noise

1. **Type of Propulsion:** Propeller generally consists of two or more blades which are driven round in circular path reflecting air backwards with an acceleration and thus imparting forward thrust (lift) to the aeroplane, this is called propulsion.
   Size of aircraft, its circling radius, speed and weight carrying characteristics etc. depend upon the type of propulsion.

2. **Size of Aircraft:** Size of Aircraft Involves following dimensions
   1. Wing span
   2. Fuselage length
   3. Height
   4. Distance between main gears, i.e. gear tread
   5. Wheel base and
   6. Tail width
   - The wing span decides the width of taxiway, size of aprons, hangars etc.
   - The length of aircraft decides the widening of taxiways on curves, sizes of aprons and hangars etc.
   - The height of aircraft is known as empennage height decides the height of hanger gate.
   - The gear trade and the wheel base affect the minimum turning radius of the aircraft.
3. **Minimum Turning Radius:**
   - It is very essential to decide the radius of taxiways, to establish path of the movemnt of aircraft.
   - The distance of the farthest wing tip from the centre of rotation represents the minimum turning radius.
   - Theoretically, the maximum angle of rotation is 90° which corresponds absolute minimum turning radius which produces excessive tire wear.
4. **Minimum Circling Radius:** It is minimum radius with which the aircraft can take turn in space.
5. **Speed:** Cruishing speed/Ground Speed – Aircraft speed with respect to ground when aircraft is flying at its maximum speed. Air speed – Aircraft speed relative to wind.
6. **Aircraft Capacity:** Capacity of aircraft is described in terms of number of passengers, cargo and fuel that can be accommodated in the aircraft.
7. **Weight of Aircraft:** It influences the length of runway, thickness of runway, taxiway, apron and hanger.

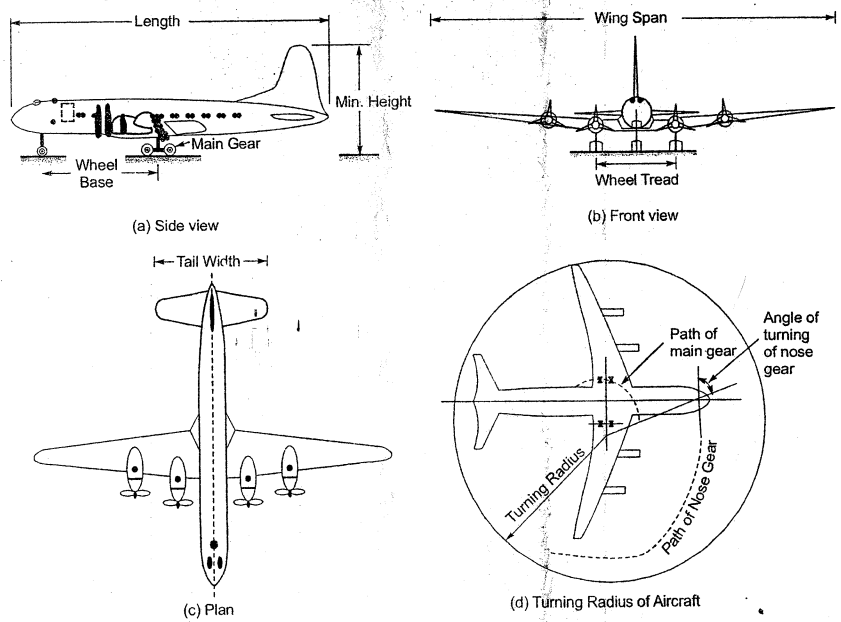


Fig. 1.3

Weight Components:

- Empty operating weight is a constant weight of aircraft.
- Zero fuel weight is the sum of empty operating weight and the maximum payload.
- Maximum take off weight is sum of empty operating weight and flexible combination of payloads and fuel.
- Maximum landing weight < Maximum take off weight (because fuel is burned during flight).
- Maximum ramp weight is slightly higher than the maximum take off weight (because some fuel is used in taxing etc).

8. **Jet Blast:** The flexible bituminous pavements are affected by the jet blast, therefore, it is desirable to provide cement concrete pavement at least at the touch down portion to resist the effect of blast in comparison to the bituminous pavements.
9. **Fuel Spillage:** The flexible bituminous pavements are affected by the fuel spillage and therefore constant supervision of the area by the airport authorities is essentrial.
10. **Noise:** The correct assessment of noise patterns is essential to the optimal layout of the runways.

Summary

- Classification of airport is done according to Federal Aviation Administration (FAA) and International Civil Aviation Organisation (ICAO).
- Fuselage is main body part of aircraft including passengers chamber, Pilot's cabin and tail of aircraft.
- The wing span decides the width of taxiway, size of hangers and aprons.

Objective Brain Teasers

Q.1 Cruishing speed of an aircraft is 650 kmph. If there is head wind of 50 kmph, than air speed and ground speed of aircraft respectively.
(a) 700 kmph and 700 kmph
(b) 650 kmph and 700 kmph
(c) 650 kmph and 650 kmph
(d) 700 kmph and 650 kmph

Q.2 Which of the following statement(s) is/are correct
(a) the speed of aircraft relative to the ground, is called cruising speed
(b) the speed of aircraft relative to wind, is called air speed
(c) when wind is blowing the direction of the flight, air speed is less than cruising speed
(d) all above

Q.3 Zero fuel weight of an aircraft is
(a) equal to empty operating weight
(b) equal to maximum operating weight
(c) equal to sum of empty operating weight and maximum pay load
(d) less than empty operating weight

Q.4 Maximum ramp weight of an aircraft is
(a) equal to maximum take off weight
(b) more than maximum take off weight
(c) less than maximum take off weight
(d) equal to maximum landing weight

Q.5 Maximum landing weight of an aircraft is
(a) equal to maximum take off weight
(b) more than maximum take off weight
(c) less than maximum take off weight
(d) equal to zero fuel weight

Q.6 **Statements (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 I and II are ture and Ii is correct explanation of A
(b) Both I and II are true but II is not a correct explanation of A
(c) I is true but II is false
(d) I is false but II is true

Q.7 Pick up the component not applicable to aeroplanes
(a) wings
(b) engines
(c) air screw
(d) None of these

Q.8 The fuselage includes
(a) passengers chamber
(b) pilot's cabin
(c) tail of aircraft
(d) All of the above

Q.9 Wing loading of an aircraft is
(a) load of the wings
(b) $\frac{\text{gross total weight of the aircraft}}{\text{load of wings}}$
(c) $\frac{\text{gross total weight of the aircraft}}{\text{wings area}}$
(d) $\frac{\text{gross total weight of the aircraft}}{\text{total available HP of engines}}$

Answers

1. (d)	2. (d)	3. (c)	4. (b)	5. (c)
6. (a)	7. (d)	8. (d)	9. (c)	

CHAPTER 2

Airport Planning

2.1 Airport Site Selection

1. **Regional Plan:** The site selected should fit well into the regional plan and forming an integral part of the national network of airports.
2. **Airport Use:** The selection of site depends on its usage i.e. whether for civilian or for military operations.
3. **Proximity to Other Airports:** The selected site should be at a reasonable distance from the existing airports so that it does not cause any interference with the movement of aircrafts.
4. **Ground Accessibility:** The site should be such that it is readily accessible to the users. Availability of public transportation facilities, e.g. bus, taxi etc. further qualifies the suitability of the site.
5. **Topography:** Ideal site for airports is hill top or plateau area so as to have less obstruction, natural drainage, uniform wind and better visibility due to lesser fog.
6. **Obstructions:** Long clearance areas are to be provided on either side of runway known as approach areas over which the aircraft can safety gain or loss altitude.
7. **Visibility:** Poor visibility lowers the traffic capacity of the airport. The selected site must be free from fog, smoke and haze.
8. **Wind:** Runway is so oriented that landing and take off is done by heading into the wind i.e. Runway orientation is opposite to wind direction. Data of direction, duration and intensity of wind is prepared for a minimum period of five years.
9. **Noise Nuisance:** There should not be any residential or industrial development in the vicinity of airport.
10. **Granding, Drainage and Soil Characteristics:** High water table sites requires costly sub-soil drainage system, thus should be avoided. Desirable soil for airport construction is of pervious material such as gravel, sand.
11. **Future Development:** Considering the anticipated future developments of the airport, large area should be acquired initially.

2.2 Surveys for Site Selection

1. **Traffic Survey:** To determine current and anticipate future air traffic.
2. **Meteorological Survey:** To determine direction, duration and intensity of wind, rainfall, fog, temperature and barometric pressure etc.

3. **Topographical Survey:** To prepare contour map showing natural features such as trees, streams etc and constructed objects as pole lines, building, roads etc.
4. **Soil Survey:** To determine soil type and ground water table.
5. **Drainage Survey:** To determine quantity of storm water, rainfall intensity and outlets for drain water.
6. **Material Survey:** To ascertain the availability of suitable construction materials at reasonable cost.

2.3 Airport Obstruction and Runway Orientation

2.3.1 Zoning Laws

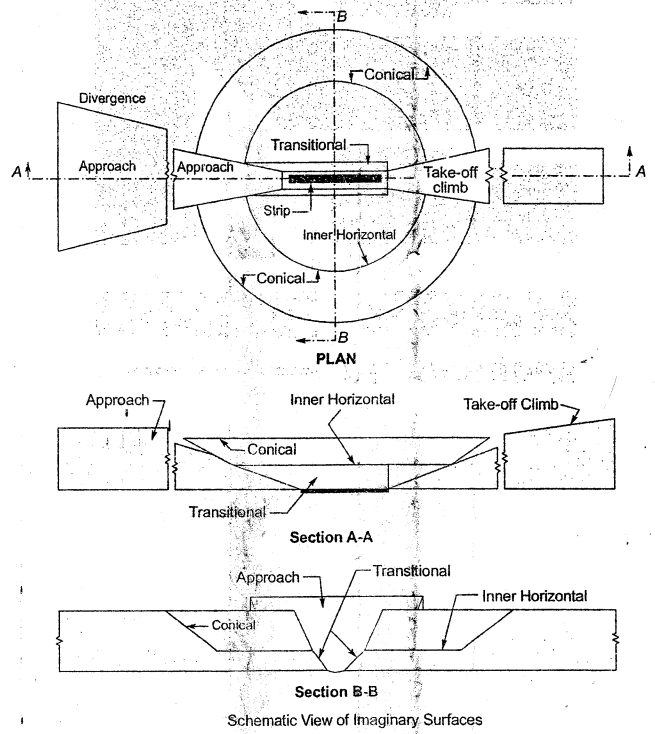
These are laws made by concerned authorities in order to prevent future development of obstructions. These laws check the construction of high rise buildings, which produce smokes in the vicinity of the airport.

2.3.2 Classification of Obstruction

Obstruction to safe air navigation are divided into two categories:

(i) Objects protruding above certain imaginary surfaces.

(ii) Objects exceeding their limiting heights above the ground surface in approach zones and turning zones.



Schematic View of Imaginary Surfaces

Fig. 2.1

Imaginary Surfaces

1. **Take-off Climb Surface:** It should be established beyond the end of runway or clearway for runway direction intended to be used for the aeroplanes take off.
2. **Approach Surface:** It should be established from smaller end of runway strip for runway direction intended to be used for landing of aeroplanes.

   It consists of the following:
   - An inner edge of specified length, horizontal and perpendicular to the extended centre line of the runway; located at a specified distance before the threshold. The elevation of the inner edge shall be equal to that of the midpoint of the threshold.
   - Two sides originating at the ends of the inner edge and diverging uniformly at a specified rate from the extended centre line of the runway. The surface extends upwards and outwards at a specified slope which is measured in the vertical plan containing the centre line of runway.
3. **Inner Horizontal Surface (IHS):** It is the surface located in a horizontal plane above aerodrome and its surrounding. The shape of IHS need not be circular always. The radius or outer limits of IHS shall be measured from airport reference point (ARP).
4. **Conical Surface:** It projects upwards and outwards from the periphery of inner horizontal surface (IHS).

   The limits of the conical surface shall comprise of the following:
   (a) A lower edge coincident with the periphery of the inner horizontal surface (IHS).
   (b) An upper edge located at a specified height above inner horizontal surface (IHS). The slope of the conical surface is measured in a vertical plane perpendicular to the periphery of the inner horizontal surface.
5. **Transitional Surface:** It is a complex surface from the edge of the approach surface that slopes upwards and outwards to the inner horizontal surface (IHS). It is intended to serve as the controlling obstacle limitation surface for buildings etc.

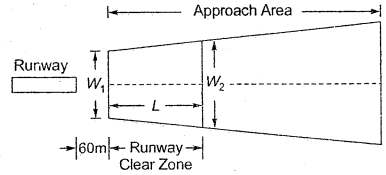
   The limits of a transitional surface consist of:
   (a) A lower edge beginning at the intersection of the side of approach surface with the inner horizontal surface and extending down the side of the approach surface to the inner edge of the approach surface and from there it extends along the length of the strip parallel to the runway centreline.
   (b) An upper edge located in the plane of the inner horizontal surface. The slope of the transitional surface is measured in a vertical plane at right angles to the centreline of the runway.
6. **Outer Horizontal Surface (OHS):** It is circular in plane with centre located at ARP (airport reference point).
   - The height of OHS is 150 m above the ARP elevation.
   - Constructions protruding above this surface will not be permitted.

Approach Zone

- The wide clearance areas are known as approach zone, required on either side of runway along the direction of landing and take off.
- Over this area, the aircraft can safely loose or gain altitude.
- The whole of this area has to be kept free from obstructions by applying zoning laws in this area.
- The plan of approach zone is the same as that of the approach surface, The only difference between two is that approach surface is an imaginary surface and the approach area indicates the actual ground area.

Clear Zone

- It is the inner most portion of approach zone and the most critical portion from obstruction view point.
- The dimention of clear zone depends upon type of runway and distance required to reach height of 15 m.
- Instrument runway is runway equipped with device permitting the landing under poor visibility conditions.



	W_1	W_2	L
Instrument runway	300 m	525 m	750 m
Non-instrument runway			
(a) Large airport	150 m	270 m	600 m
(b) Small airport	75 m	135 m	300 m

Runway Clear Zone

Turning Zone

- During the take off if the engine fails or pilot select to land in case of an emergency then aircraft will have to take a turn and come in line with runway before landing.
- The area of airport other than the approached area, which is used for turning operation is known as turning zone.

Summary

- Approach zones are wide clearance areas required on both sides of runway along the direction of landing and take-off.
- Clear zone is the inner most portion of approach zone and most critical portion from obstruction view point.
- Area used for turning operation, other than approach area is known as turning zone.

Objective Brain Teasers

Q.1 A surface longitudinally centered on the extended runway centre line and extending outwards and upwards is called
(a) Primary surface
(b) Conical surface
(c) Horizontal surface
(d) Approach surface

Q.2 Which one of the following imaginary surfaces 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

Q.3 What do we call the imaginary surface which extends upwards and outwards from periphery of inner horizontal surface at airports?
(a) Transitional surface
(b) Approach surface
(c) Trapezoidal surface
(d) Conical surface

Q.4 A surface longitudinally centered on the extended runway centre line and extending outward and upward from each end of the primary surface is known as
(a) conical surface (b) transition surface
(c) approach surface (d) horizontal surface

Q.5 Match List-I (Imaginary surface) with List-II (Characteristic) and select the correct answer

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

Q.6 Consider the following statements
Difference between airport and highway pavement thickness arises due to
1. Magnitude of wheel load
2. Tyre pressure
3. Number of repetitions
4. Size of the vehicle
Which of the statements given above are correct?
(a) 1, 2 and 4 only (b) 1, 2 and 3 only
(c) 1 and 4 only (d) 2, 3 and 4 only

Q.7 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.

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

Q.8 Minimum width of clearway for instrument runway
(a) 75 m (b) 150 m
(c) 300 m (d) 250 m

Q.9 Match the following:

List-I	List-II
A. PNB	1. Noise level
B. LCN	2. Visual range
C. STOL	3. Airport pavement classification
	4. Type of aircraft

Codes:

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

Q.10 Airport elevation is the reduced level about MSL of
(a) control tower
(b) highest point of the runways
(c) lowest point of the runways
(d) None of these

Q.11 For the proposed airport, the survey project provides
(a) master plan (b) topographic plan
(c) grading plan (d) All of these

Answers

1. (d) 2. (d) 3. (d) 4. (b) 5. (c)
6. (b) 7. (b) 8. (c) 9. (a) 10. (b)
11. (d)

Hints & Solution

9. (a)
PNB: Perceived noise level intensity
LCN: Load classification number (airport)
STOL: Short take off and landing

CHAPTER 3

Runway Design

3.1 Runway Orientation

- The orientation of runway depends upon the direction of wind and to some extent area available for development.
- Runway is oriented in the direction of prevailing wind such that the direction of wind is opposite to the direction of landing and take off.
- The head wind provides greater lift force on the wings of aircraft while taking off, thus aircraft rises above the ground earlier i.e. in a shorter length of runway.
- During landing, head wind provides greater drag force so that it comes to hault in a shorter length of runway.
- If landing and take off operation is done along the wind direction then it require longer runway.
- The wind blowing from opposite direction of head or nose of aircraft i.e., opposite to the movement of aircraft, while landing or take off is termed as head wind.
- The wind blowing in the same direction of landing or take off of aircraft is called as tail wind, it increase the stop distance or lift off distance.

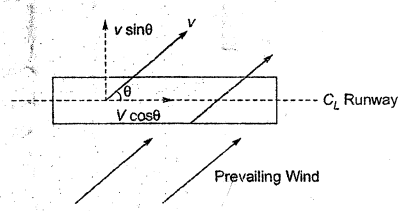


Fig. 3.1

3.2 Cross Wind Component and Wind Coverage

- It is not feasible to obtain the direction of wind along the direction of the center line of runway throughout the year.
- If the direction of wind is at an angle to runway centre line, then its components are shown in fig. 3.1.
- The normal component to movement of aircrafts is called cross wind component. It interrupts safe landing and take-off operations.

Type of Aircraft	Permissible limit of cross wind component
Small aircraft	15 kmph (10 mph)
Medium aircraft traffic	25 kmph (15 mph)
Big aircraft	35 kmph (23 mph)

- Centre line of the runway should not make an angle with the wind direction exceeding 30°.

3.2.1 Wind Coverage

- The percentage of time in a year during which cross wind component is within the permissible limit is called wind coverage or usability factor of airport.
- According to FAA, runway handling mixed air traffic is planned such that minimum wind coverage is 95%.
- For busy airport, wind coverage may be increased to 98-100%.

3.3 Wind Rose

- The graphical representation of wind datas i.e. direction, duration and intensity is called wind rose.
- The wind data of atleast 5 years and preferably of 10 years should be considered while designing an airport.
- The wind rose diagram is used for finding orientation.
- Wind rose diagrams can be plotted in two ways as follows:

Type-1: Showing direction and duration of wind:

- The radial lines indicate the wind direction and each circle represents the duration of wind.
- The best direction of runway is usually along the direction of the longest line on wind rose diagram.

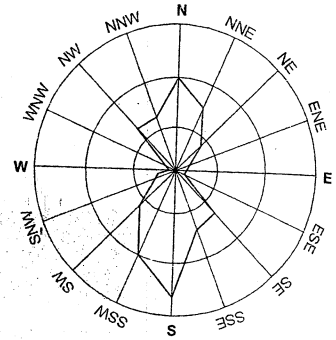


Fig. 3.2

Note: Calm period: Percentage of time during which wind intensity is less than 6.4 kmph.

Type-2: Showing direction, duration and intensity of wind

- Each circle represents the wind intensity to scale.

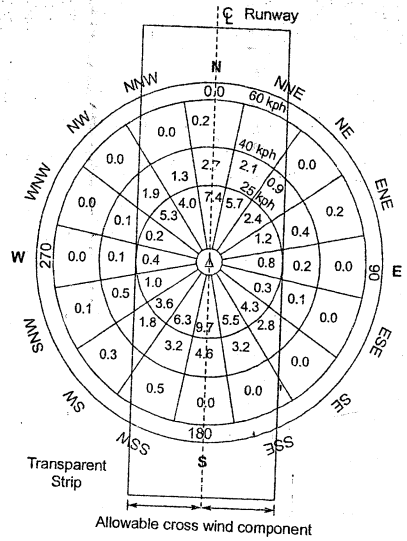


Fig. 3.3

- The value entered in each segment, represents the percentage of time in a year during which the wind, having a particular intensity, blows from respective direction.
- Summation of all the percentages (shown in segment) is wind coverage value.
- The best orientation of runway is along the direction of centre line rotated about centre of wind rose pivot such that wind coverage is maximum.

3.4 Basic Runway Length (BRL)

It is the length of runway calculated under the following assumed condition:

(i) Airport is at sea level.
(ii) Temperature at airport is standard (15°C).
(iii) Runway is levelled in longitudinal direction i.e., zero effective gradient.
(iv) No wind is blowing on runway.
(v) Aircraft is loaded at its full loading capacity.
(vi) There is no wind blowing enroute to destination.
(vii) Enroute temperature is standard.

Factors influencing basic runway length

(i) Aircraft performance characteristics.
(ii) Gross landing and takeoff weight of aircraft.
(iii) Safety requirements

Apart from these; humidity winds, condition of runway surface also influences the runway length.

The basic runway length is determined by three cases:

1. Normal Landing Case: In this case, aircraft should come to stop within 60% of landing distance/ runway length.
2. Normal Take Off Case: 115% of lift off disance required to reach height of 10.5 m.
3. Engine Failure Case: In this case, basic runway length considers either clearway or stopway or both.
   - Stopway is the area beyond the runway, centrally located in alignment with the centerline of runway.
   - Stopway is used for deceleration of aircraft and bringing it to halt during aborted take-off.
   - If the engine has failed at speed less than the designated engine failure speed then aircraft deaccelerates with use of stopway.
   - If engine fail at speed, higher than designated speed then pilot has to continue to take off, then turn in turning zone and land again for normal take-off.

Note: The case giving longest runway length is finalling recommended.

3.5 Correction for Elevation, Temperature and Gradient

- The basic runway length (discussed above) is for mean sea level elevation, having standard atmosphere conditions.
- Necessary corrections are applied for elevation, temperature and gradient for actual site conditions.

A. Correction for Elevation

- As the elevation increases, the air density reduces. Thus, lift on the wings of the aircraft reduces and the aircraft requires greater ground speed. To achieve greater speed, longer runway length is required.

- ICAO recommends that the basic runway length (BRL) should be increased at the rate of 7 percent per 300 m (1000 ft) rise in elevation above the mean sea level.

B. Correction for Temperature

- Airport reference temperature (ART) is calculated using

$$ART = T_a + \frac{T_m - T_a}{3}$$

where,

T_a = monthly mean of average daily temperature for the hottest month of the year.

T_m = monthly mean of maximum daily temperature for same month of the year.

- Rise in airport reference temperature has the same effect as the rise in elevation.
- According to ICAO, BRL (after have been corrected for elevation) should be further increased by 1% for 1°C rise in airport reference temperature above the standard atmosphere temperature at that elevation.
- Temperature gradient for standard atmosphere temperature at elevation from Mean Sea Level (MSL) to the altitude where temperature is –15.6°C is (–) 0.0065°C per meter.
- Temperature gradient become zero above the altitude where temperature is –15.6°C.
- Standard atmospheric temperature at mean sea level is taken as 15°C.

C. Check for total correction for Elevation plus Temperature

- ICAO recommends that if combine correction exceeds 35% of BRL, then these correction should be further checked by specific studies at the site by model testing.

D. Correction for Gradient

- In steeper gradient longer length of runway is required so that it can attain desired ground speed.
- ICAO recommends no correction for gradient.
- FAA recommends that after temperature and elevation corrections, BRL should be increased by rate of 20% for every 1% of effective gradient.
- Effective gradient is defined as maximum difference in elevation between highest and lowest points on runway divided by total runway length.

Example 3.1 The data for an hottest month of year gives mean of maximum daily temperature as 44.62°C and mean of average daily temperature as 28.12°C, then what is the airport reference temperature.

Solution:

Mean of maximum daily temperature (T_m) = 44.62°C

Mean of average daily temperature (T_a) = 28.12°C

$$\text{Airport reference temperature} = T_a + \frac{T_m - T_a}{3}$$

$$= 28.12 + \frac{44.62 - 28.12}{3} = 33.62°C$$

Example 3.2 Length of runway under standard conditions is 1650 m. The airport site has an elevation of 250 m. It has reference temperature of 32.90°C. If the runway is to be constructed with effective gradient of 0.2%. Then determine the corrected runway length

Solution:

(i) $$\text{Correction for elevation} = \frac{7}{100} \times 1650 \times \frac{250}{300} = 96.25 \text{ m}$$

$$\text{Corrected Runway length} = 1650 + 96.25 = 1746.25 \text{ m}$$

(ii) Standard atmospheric temperature of the given elevation

$$= 15° - 0.0065 \times 250 = 13.375°C$$

Difference in temperature,

$$\Delta T = 32.9° - 13.375°C$$

$$= 19.525°C$$

$$\text{Correction for temperature} = \frac{1746.25}{100} \times 19.525 = 340.96 \text{ m}$$

$$\therefore \quad \text{Corrected runway length} = 1746.25 + 340.96 = 2087.2 \text{ m}$$

(iii) Check for combine correction

$$\text{Total correction in \%} = \frac{2087.2 - 1650}{1650} \times 100 = 26.5\%$$

According to ICAO, this combine correction should not exceed 35%, hence OK

(iv) $$\text{Correction for Gradient} = \frac{20}{100} \times 2087.2 \times 0.2 = 83.49 \text{ m}$$

$$\text{Corrected length} = 2087.2 + 83.49 = 2170.7 \text{ m}$$

Finally after correction, corrected runway length ≃ 2171 m

Example 3.3 Determine the actual runway length after applying necessary corrections for elevation and temperature as per ICAO and gradient correction as per FAA specification for the data given below:

- Basic runway length = 2100 metres
- Elevation of airport site = 100 metres
- Monthly mean of average daily temperature for the hottest month of the year = 21°C
- Monthly mean of maximum daily temperature for the same month = 30°C
- Effective gradient = 0.6%

Solution:

Basic runway length, L = 2100 m

Elevation of airport site = 100 m

Monthly mean of average daily temperature for the hottest month of the year, T_a = 21°C

Monthly mean of maximum daily temperature for the same month, T_m = 30°C

Effective gradient, g = 0.6%

Correction for Elevation:

Correction for elevation as recommended by ICAO, is 7% per 300 m elevation.

Therefore, $$\text{Correction} = \frac{7}{100} \times \frac{\text{Elevation}}{300} \times L$$

$\Rightarrow$ Correction for elevation $= \frac{7}{100} \times \frac{100}{300} \times 2100 = 49$ m

$\therefore$ Corrected length, $L_1 = 2100 + 49$

$L_1 = 2149$ m

Correction for Temperature:

Standard atmospheric temperature at given elevation,

$$T_s = 15 - 0.0065 \times 100$$
$$= 14.35°C$$

Airport reference temperature, $T_R = T_a + \frac{T_m - T_a}{3}$

$\Rightarrow$ $T_R = 21 + \frac{30-21}{3} = 24°C$

Rise in temperature $= T_R - T_S$
$= 24 - 14.35$
$= 9.65°C$

As per ICAO, correction for temperature is 1% for every 1°C rise in temperature.

$$\text{Correction} = \left(\frac{1}{100}\right) \times \left(\frac{\text{Rise in temperature}}{1}\right) \times L_1$$

$\therefore$ Correction for temperature $= \frac{1}{100} \times 9.65°C \times 2149 = 207.38$ m

$\therefore$ Corrected length, $L_2 = 2149 + 207.38$
$= 2356.38$ m

Check:

As per ICAO, total correction for elevation plus temperature should not exceed 35% of basic runway length.

Total correction for elevation and temperature = 49 + 207.38 = 256.38 m

Total correction in percentage $= \frac{256.38}{2100} \times 100 = 12.2\% < 35\%$ Hence OK

Correction for gradient:

FAA recommends that runway length after having been corrected for elevation and temperature should be further increased at the rate of 20% for every 1% of effective gradient.

Corrected for gradient $= \frac{20}{100} \times g \times L_2$

$= \frac{20}{100} \times 0.6 \times 2356.38 = 282.77$ m

$\Rightarrow$ Final runway length $= 2356.38 + 282.77$
$= 2639.15$ m $\simeq 2640$ m

Example 3.4 Runway length required for landing at sea level in standard atmospheric condition is 2200 m. Runway length required for take off at a level site at sea level in standard atmospheric condition is 2400 m. Aerodrome elevation is 270 m and reference temperature is 25°C. Temperature in the standard atmosphere for 270 m elevation is 12°C and runway slope is 0.5%. Determine the length of the runway after applying correction to runway length.

Solution:

Basic runway take-off length, $L_T = 2400$ m
Basic runway landing length, $L_L = 2200$ m
Elevation $= 270$ m
Reference temperature, $T_R = 25°C$
Standard temperature, $T_S = 12°C$
Runway slope, $g = 0.5\%$

1. **Correction to runway take-off length**

Correction for elevation:

Correction for elevation as recommended by ICAO, is 7% per 300 m elevation

Correction for elevation $= \frac{7}{100} \times \frac{\text{Elevation}}{300} \times L_T$

$= \frac{7}{100} \times \frac{270}{300} \times 2400 = 151.2$ m

Corrected length, $L_T = 2400 + 151.2 = 2551.2$ m

Correction for temperature:

Rise in temperature $= T_R - T_S$
$= 25 - 12$
$= 13°C$

As per ICAO, correction for temperature is 1% for every 1°C rise in temperature

Correction for temperature $= \frac{1}{100} \times \frac{\text{Rise in temperature}}{1} \times L_1$

$\therefore$ Correction for temperature $= \frac{1}{100} \times \frac{13}{1} \times 2551.2 = 331.656$ m

$\therefore$ Corrected length $(L_2) = 2551.2 + 331.656$
$= 2882.856$ m

Check:

As per ICAO, total correction for elevation plus temperature should not exceed 35% of basic runway length.

Combined correction for elevation and temperature
$= 151.2 + 331.656$
$= 482.856$ m

Total correction (in percentage) $= \frac{482.856}{2400} \times 100 = 20.12\% < 35\%$ Hence OK

Correction for gradient:

FAA recommends that runway length after having been corrected for elevation and temperature should be further increased at the rate of 20% for every 1% of effective gradient.

$$\text{Correction for gradient} = \frac{20}{100} \times g \times L_2 = \frac{20}{100} \times 0.5 \times 2882.856 = 288.29 \text{ m}$$

$$\text{Final runway take-off length} = 2882.856 + 288.29 = 3171.14 \text{ m}$$

2. Correction to Runway landing length

Correction for elevation

$$\text{Correction} = \frac{7}{100} \times \frac{\text{Elevation}}{300} \times L_L = \frac{7}{100} \times \frac{270}{300} \times 2200 = 138.6 \text{ m}$$

$$\text{Corrected runway landing length} = 2200 + 138.6 = 2338.6 \text{ m}$$

Note: No corrections are needed to landing length for temperature and gradient.

Actual runway length to be provided would be greater of (1) and (2)

Therefore, Runway length = 3171.14 m ≃ 3172 m

Summary

- Runway is oriented opposite to wind direction for the ease in landing and take-off.
- Wind coverage is percentage of time in a year during which cross-wind component is within the permissible limit.
- Wind rose diagram is of two types, prepared to find the best possible orientation of runway.
- Basic runway level (BRL) is increased at the rate of 7% per 300 m rise in elevation above mean sea level (MSL).
- Temperature correction is done after elevation correction. And correction for gradient is done after elevation and temperature correction.
- Standard atmospheric temperature at mean sea level is 15°C.
- BRL is increased by 1% for 1°C rise in airport reference temperature above the standard atmosphere temperature at that elevation.
- BRL in increased by 20% for every 1% of effective gradient.

Objective Brain Teasers

Q.1 The runway orientation is kept so that landing and take off are
(a) against the wind direction
(b) along the wind direction
(c) perpendicular to wind direction
(d) none of these

Q.2 In wind-rose diagram data consist minimum period of
(a) 6 months (b) 1 year
(c) 5 years (d) 10 years

Q.3 For the design of runways, the standard atmospheric temperature at sea level is 15° C, then the standard temperature at an altitude of 1200 m will be:
(a) 7.2°C (b) 9.8°C
(c) 10.2°C (d) 11°C

Q.4 As per ICAO, for airport serving big aircraft the cross wind component should not exceed
(a) 15 kmph (b) 25 kmph
(c) 35 kmph (d) 45 kmph

Q.5 Calm period is the percentage of time duration during which wind intensity is less than
(a) 4.8 kmph (b) 6.4 kmph
(c) 8 kmph (d) 9.6 kmph

Q.6 The engine failure case to determine the basic runway length requires
(a) only clearway
(b) only stop way
(c) either clear way or stop way
(d) either clear way or stop-way or both

Q.7 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 code given below:
(a) 1 and 2 only (b) 1, 2 and 3
(c) 1, 3 and 4 (d) 2, 3 and 4

Q.8 The percentage of time in a year during which the cross wind component remains within the permissible limit, is:
(a) Wind coverage (b) Head wind
(c) Prevailing wind (d) Cross wind

Q.9 Wind-rose diagram is useful in deciding the orientation of:
(a) Taxiway (b) Hanger
(c) Apron (d) Runway

Q.10 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

Q.11 Consider the following statements:
Wind rose diagram is used for the purpose of
1. Runway orientation
2. Estimating the runway capacity
3. Geometric design of holding apron

Of these statements:
(a) 1 and 2 are correct
(b) 2 and 3 are correct
(c) 1 and 3 are correct
(d) 1 alone is correct

Q.12 Which of the following factors are taken into account for estimating the runway length required for aircraft ?
1. Normal maximum temperature
2. Airport elevation
3. Maximum landing weight
4. Effective runway gradient.

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

Q.13 Wind Rose diagram Type-II used for the orientation of runway shows
(a) direction and intensity of wind only
(b) direction of wind only
(c) direction and duration of wind only
(d) direction, duration and intensity of wind

Q.14 **Assertion (A):** Runway is usually oriented in the direction of the prevailing winds.
Reason (R): The direction of wind opposite to the direction of landing and take off provides greater lift on the wings of the aircraft, when it is taking off.
(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

Q.15 The best direction of a runway is
(a) along the longest line on the windrose diagram
(b) along the direction perpendicular to the longest line on the windrose diagram
(c) at 30° to the direction of the longest line on the windrose diagram
(d) along the NW – SE line

Q.16 Consider the corrections to be applied to the basic length of the runway
1. Elevation correction
2. Gradient correction
3. Temperature correction

The correct order of applying these corrections to obtain runway length is
(a) 1 – 2 – 3 (b) 1 – 3 – 2
(c) 2 – 3 – 1 (d) 3 – 1 – 2

Q.17 For determine the basic runway length, landing case requires that aircraft should come to a stop within %P of landing distance. The value of P is
(a) 40% (b) 50%
(c) 60% (d) 70%

Q.18 In the monthly mean of average daily temperature for the hottest month of the year is 26°C and monthly mean of maximum daily temperature of the same month of the year is 47°C then the airport reference temperature is
(a) 33°C (b) 35.5°C
(c) 40°C (d) 25°C

Q.19 The standard condition assumed for basic runway length
(a) airport altitude is at sea level
(b) temperature at airport is standard (15%)
(c) No wind blowing on runway
(d) All above

Q.20 As per ICAO, basic runway length will be increased a rate of *P*% per *Q* meter rise in elevation. The value of *P* and *Q* are respectively
(a) 7 and 300 (b) 7 and 250
(c) 5 and 300 (d) 5 and 250

Q.21 For basic runway length correction the temperature gradient for standard temperature is
(a) 0.0065°C (b) 0.0060°C
(c) 0.0055°C (d) 0.0045°C

Q.22 The length of runway under standard condition is 1700 m. The elevation of airport site is 300 m and its reference temperature is 33.05°C. If runway is to be constructed with an effective gradient of 0.25% then correct runway length is
(a) 2050 m (b) 2292 m
(c) 2712 m (d) 3919 m

Q.23 The runway length after correcting for elevation and temperature is 2565 m. If the effective gradient on runway is 0.6 percent, then the revised runway length will be
(a) 2873 m (b) 2910 m
(c) 3030 m (d) 3130 m

Q.24 For a runway at an elevation of 1000 m above MSL and airport reference temperature of 19°C, the rise in temperature to be taken into account as per ICAO is
(a) 24.5°C (b) 15°C
(c) 10.5°C (d) 6°C

Q.25 The monthly mean of maximum daily temperature and monthly mean of average daily temperature of the hottest month of year are 52°C and 40°C respectively. Then airport reference temperature is
(a) 44°C (b) 70°C
(c) 38°C (d) 56°C

Q.26 Which one of the following statements is correct? 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

Q.27 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

Q.28 As the elevation increases, the runway length has to be changed at what rate?
(a) Decreased @ 5% per 300 m rise in elevation above M.S.L.
(b) Increased @ 7% per 300 m rise in elevation above M.S.L.
(c) Decreased @ 9% per 300 m rise in elevation above M.S.L.
(d) Increased @ 15% per 300 m rise in elevation above M.S.L.

Q.29 The total correction percentage for elevation and temperature, in calculating the runway length from basic runway length, should not exceed as per ICAO
(a) 7 (b) 14
(c) 28 (d) 35

Q.30 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 lists:

List-I
A. Standard basic length
B. Elevation
C. Temperature
D. Effective gradient

List-II
1. 7% for every 300 meters
2. 1% for 1°C rise
3. 20% for each 1% gradient
4. Depends upon aircraft

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

Q.31 A runway is located at 450 m above the mean sea level. If the elevation of aeroplane reference field is 1900 m, what is the approximate corrected runway length for elevation?
(a) 1840 m (b) 2200 m
(c) 1980 m (d) 2100 m

Q.32 **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 air port, as per ICAO recommendations.
(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

Q.33 The best direction of a runway is along the direction of
(a) longest line of wind rose diagram
(b) shortest line on the wind rose diagram
(c) line clear of wind rose diagram
(d) None of these

Q.34 The landing and take off the aircraft is made against the direction of wind. In no case the centre line of the runway should make an angle with the wind direction exceeding
(a) 10° (b) 20°
(c) 30° (d) 40°

Answers

1. (a)	2. (c)	3. (a)	4. (c)	5. (b)
6. (d)	7. (c)	8. (a)	9. (d)	10. (b)
11. (d)	12. (a)	13. (d)	14. (a)	15. (a)
16. (b)	17. (c)	18. (a)	19. (d)	20. (a)
21. (a)	22. (b)	23. (a)	24. (c)	25. (a)
26. (a)	27. (a)	28. (b)	29. (d)	30. (a)
31. (d)	32. (c)	33. (a)	34. (c)	

Hints & Solution

3. (a)
$T_s = 15 - 0.0065 \times 1200 = 7.2°C$

7. (c)
Runway is usually oriented in direction of prevailing winds. It helps in landing and take off

operations. Also runway orientation should have adequate length for performing landing and takeoff operations. Obstruction free approaches are also essential for runway orientation. Future expansion plant for airport also come into effect in deciding the orientation of runway.

18. (a)

$$T_R = 26 + \frac{47-26}{3} = 33°C$$

22. (b)

$L = 1700 \times 1.07 \times 1.2 \times 1.05$
$= 2292$ m

23. (a)

Corrected length after applying elevation and temperature correction = 2565 m

Effective gradient = 0.6%

$$\text{Correction for gradient} = \frac{20}{100} \times 2565 \times 0.6$$
$$= 307.8 \text{ m}$$
$$\text{Corrected length} = 2565 + 307.8$$
$$= 2872.8 \text{ m} \simeq 2873 \text{ m}$$

24. (c)

Standard atmospheric temperature at given elevation (1000 m)

$$= 15° - 0.0065° \times 1000 = 8.5°C$$

Rise of temperature = 19° – 8.5° = 10.5°C

25. (a)

Mean of maximum daily temperature

$$T_m = 52°C$$

Mean of average daily temperature

$$T_a = 40°C$$

Airport reference temperature

$$= T_a + \frac{(T_m - T_a)}{3}$$
$$= 40 + \left(\frac{52-40}{3}\right)$$
$$= 40 + 4 = 44°C$$

31. (d)

Correction for elevation

$$= \frac{7}{100} \times 1900 \times \frac{450}{300} = 199.5 \text{ m}$$

Corrected length

$= 1900 + 199.5$
$= 2099.5 \simeq 2100$ m

32. (c)

- ICAO recommends no correction for gradient.
- FAA recommends that after temperature and elevation corrections, BRL should increased by rate of 20% for every 1% of effective gradient.

CHAPTER 4

Runway Geometric Design

4.1 Geometric Design of Runway

The following are to be considered in geometric design of runways

(i) **Runway Length:** Basic runway length depends upon category in which aircraft falls as per ICAO classification.

(ii) Runway Width

- ICAO recommends pavement width varying from 18 m to 45 m.
- it depends upon type of airport and largest aircraft in operation.

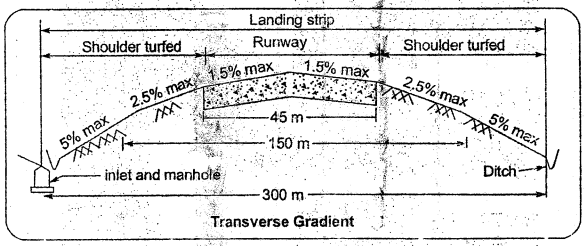


Fig. 4.1

(iii) Width and Length of Safety Area

- Width of safety area = runway width + shoulder on either side of runway + the area that is cleared, graded and drained.

Note: Length of safety area = length of runway + 120 m as length of safety area is 60 m beyond runway at both ends.

(iv) Effective Gradient

Maximum Limit for effective gradient should be for airport,

A, B, C type → 1%

D, E type → 2%

(v) Transverse Gradient

- It is provided for quick drainage of surface water
- According to ICAO
  Maximum transverse gradient for airport,
  A, B type → 2%
  C, D, E type → 1.5%
- However transverse gradient should not be less than 1% but for rigid pavement it may be kept as low as 0.5%.

(vi) Longitudinal Gradient

- Increase in longitudinal gradient results increase in runway length.
- ICAO recommends maximum longitudinal gradient for airports,
  A, B, C type → 1.5%
  D, E type → 2%

(vii) Rate of Change of effective Longitudinal Gradient

- Vertical curves should be provided to smoothen the change in gradient.
- ICAO Recommends rate of change of longitudinal gradient.
  Maximum limit for *A* and *B* type → 0.1% per 30 m length of vertical curves.
  Maximum limit *C* type → 0.2% per 30 m length of vertical curves
  Maximum limit *D, E* type → 0.4% per 30 m length of vertical curves.

Note: Vertical curves are generally not necessary if the change in slope is not more than 0.4%.

(vii) Sight Distance

- Generally there is no sight distance restrictions as the longitudinal gradients for the runway are quite gentle.
- If two runway or runway and taxiway intersect each other then sufficient sight distance is required.
- ICAO recommends for no collision.
  For *A, B* type of airport, any two points 1.5 m and 2.1 m respectively above surface of runway should be mutually visible from a distance equal to half of runway length.
- For *C, D* and *E* type, there should be unobstructed line of sight from any point 3 m above runway from a distance of atleast one half the length of runway.

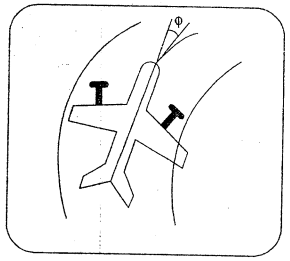


Fig. 4.2 ϕ = castor angle

4.2 Castor Angle

- Castor angle is the angle formed between the longitudinal axis of the aircraft and tangent to the centre line.

Objective Brain Teasers

Q.1 As per ICAO, rate of change of effective longitudinal gradient as per 30 m length of vertical curves for *A* and *B* type of airport is limited to a maximum of
(a) 0.1% (b) 0.2%
(c) 0.3% (d) 0.4%

Q.2 As per ICAO, for *C, D* and *E* type of airport 3 m high object should be visible from
(a) full runway length (b) half runway length
(c) 1/3 runway length (d) none of above

Q.3 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 velocity of the aircraft and the crosswind component
(d) Between the horizontal and the fuselage axis

Answers

1. (a) 2. (b) 3. (a)

CHAPTER 5

Airport Capacity

5.1 Airport Capacity

- It is the quantative measure for a supply of service over a specified period of time under given service conditions.
- Airport capacity during VFR (Visual Flight Rules) conditions is usually more than during IFR (Instrument Flight Rules) conditions.

5.2 Runway Configurations and the Connected Taxiways

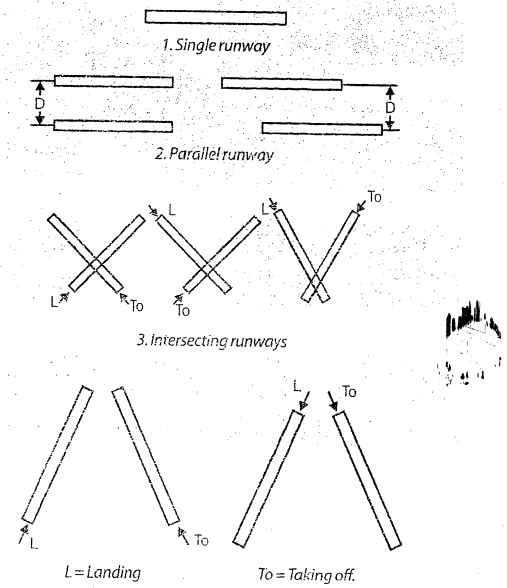


Fig. 5.1 Open V runway

- **Single Runway:** is usually adopted when the wind blows in one direction for most of the time in a year and air traffic requirement does not exceed the capacity of such pattern.
- **Parallel Runways:** The capacity of this pattern depends upon the lateral spacing between the two runways, the weather conditions and the navigational aids available at the airport.
- **Intersecting Runways:** is usually adopted when runway in a particular direction does not provide the required wind coverage. Whether both the runways can be used for simultaneous landing and take off, depends upon the cross wind component on each runway.
- **Open V runway:** When take-off and landing are made away from the two closer ends, operations per hour increases significantly.

5.3 Factors affecting Airport Operating Capacity

- Runway configuration and connected taxiway
- Arrival and departure ratio.
- Airport serving smaller and slower aircrafts generally have higher capacity than the one serving bigger and faster aircrafts.
- The ratio of arriving to departing aircrafts also influences the airport capacity because landing operations is generally given priority over taking off operations.
- Weather conditions
- Obstructions
- Loading apron space
- Navigational aids
- Aircrafts processing technique

5.3.1 Runway Capacity

- Ability of a runway system to accommodate aircraft landings and take-offs, during a specified time interval.
- It usually expressed in operations per hour or operations per year.

5.3.2 Saturation Capacity

- The ultimate or saturation capacity of a runway is the maximum number of aircraft that can be handled during a given period under condition of continuous demand.

5.3.3 Gate Capacity (GC)

Gate: It is an aircraft parking space (adjacent to a terminal building) used by a single aircraft for the loading, unloading of passengers, baggage and mail.

- **Gate Capacity:** Ability of a specified number of gates to accommodate aircraft loading and unloading operations under conditions of continuous demand. Gate capacity is inverse of weighted average gate occupancy time for all aircrafts served.
- Gate occupancy time depends upon:
  - Aircraft Types
  - Amount of baggage and mail per flight.
  - Whether the flight is originating, turning around or through flight.

- Gate capacity = $\frac{1}{\text{Weighted service time}}$ or Gate capacity = minimum all $\left[\frac{G_i}{T_i M_i}\right]$

For Gate System:

$G_i \rightarrow$ no. of gates that can accommodate aircraft of class i

$T_i \rightarrow$ Mean gate occupancy time of aircraft of class i

$F_i \rightarrow$ Fraction of aircraft class i demanding service

5.3.4 Taxiway Capacity

- Taxiway capacity is generally greater than capacities of either the runways or the gates.
- Cross runway taxiway capacity depends upon runway operation rate and location of exit taxiway etc.

Example 5.1 Determine the capacity of 25 gates which serve three classes of aircrafts.

Aircraft class	Mix percentage	Average Occupancy time (minutes)
1	20	10
2	20	30
3	60	60

Solution:

Assume each gate is available for aircraft:

The gate capacity for single gate is

$$GC = \frac{1}{\text{Weighted service time}}$$

$$= \frac{1}{(0.2\times10+0.2\times30+0.6\times60)}$$

$$= 0.0227 \text{ aircraft/min/gate}$$

Capacity for all gate C = GC × no. of gate

$$= 0.0227 \times 25$$

$$= 0.568 \text{ aircraft/min}$$

$$\Rightarrow \simeq 34 \text{ aircraft/hour}$$

Summary

- Runway capacity is capacity of runway to handle landing and take-off operations. Its unit is operations per hour or operations per year.
- Airport capacity during visual flight rules (VFR) conditions is usually more than during instrumental flight rules (IFR) conditions.

Objective Brain Teasers

Q.1 **Assertion (A):** The ratio of arriving and departing aircraft influences the airport capacity.

Reason (R): Landing operation is generally given priority over the taking off operation.

Select your answer based on the coding system given below

(a) Both A and R are true and R is correct explanation of A.

(b) Both A and R are 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

Q.2 The capacity of parallel runway pattern depends upon

(a) weather conditions and navigational aids available

(b) lateral spacing between two runway and weather conditions

(c) lateral spacing between two runway and navigational aids available

(d) lateral spacing between two runways, weather conditions and navigational aids available

Answers

1. (a) 2. (d)

CHAPTER 6

Taxiway Design

Main Functions of taxiway is to provide linkage to the aircraft from the runways to loading apron or service hanger etc.

6.1 Factors for Taxiway Layout

- Taxiway location should be such that landed aircraft, taxing toward apron should have minimum interference with aircraft taxing for take off.
- Separate entrance and exit taxiway should be provided at various locations along the runway to clear the runway as soon as possible.
- Route of taxiway should be shortest from terminal building to runway.
- The intersection of runway and taxiway should be avoided.
- Higher turn-off speeds should be facilitated, as it results in reduction of runway occupying time, hence airport capacity increases.

6.2 Geometric Design of Taxiway

Speed of an aircraft on runway is relatively faster than the speed on taxiway. Thus design standards, for a taxiway is not as rigid as they are for runway.

The geometric design standards of taxiway are:

(i) **Length of taxiway:** It should be short as it will save fuel consumption.

(ii) **Width of taxiway:** Width of taxiway is lesser than that of runway because speed at taxiway is lower and aircraft is not airborne.

(iii) **Width of Safety Area:** It includes partially paved shoulders on either side plus the area that is graded and drained.

(iv) **Longitudinal Gradient**

- Steeper gradient demands greater fuel consumption, so level taxiways are more desirable.
- ICAO recommends that maximum longitudinal gradient should be 3% for *A* and *B* types and 1.5% for other types of airports.

(v) **Transverse gradient:** Provided for quick drainage. Minimum transverse gradient is taken 0.5% for rigid pavement and 1% for other cases.

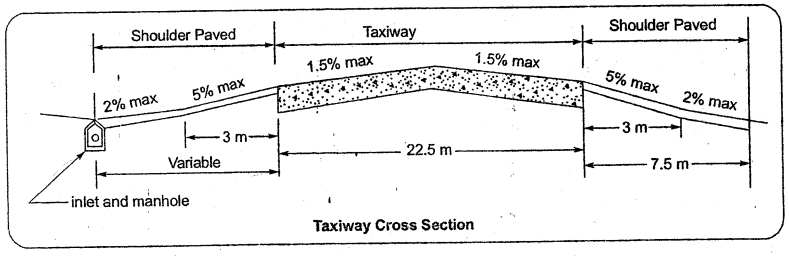


Fig. 6.1

(vi) **Rate of change of longitudinal gradient:** ICAO recommends that maximum rate of change of slope in longitudinal direction 1 per cent per 25 m length of vertical curve for *A*, *B* types and 3.33 per cent for *C*, *D* and *E* types of airports.

(vii) **Sight distance:** Since speed on taxiway is slower than runway so smaller sight distance is required comparatively. ICAO recommends that

- For *A*, *B*, *C* type of airport, surface of taxiway should be visible from 3 m height for 300 m distance.
- For *D*, *E* type of airport, surface of taxiway should visible from 2.1 m height for 250 m distance.

(viii) **Turning radius**

- To change the direction of aircraft path a horizontal curve is required.
- The curve is so designed that aircraft can negotiate it without reducing speed significantly.
- Circular curve of large radius is preferred.

$$\text{Radius of the curve } (R) = \frac{V^2}{125\,f}$$

$R \rightarrow$ Radius in meter

$V \rightarrow$ speed in kmph

$f \rightarrow$ Transverse coefficient of friction assumed equal to 0.13

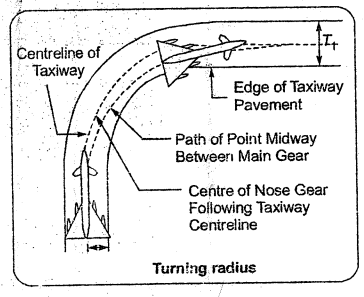


Fig. 6.2

Note:
- *For large subsonic jet R_{min} = 120 m (for any value of speed)*
- *For supersonic transport, R_{min} = 180 m (for any value of speed)*

- According to Horonjeff, the radius of taxiway should be decided such that the distant of the cleo strut of the nearby main gear is not less than 6 m from the pavement edge.
- According to Horonjeff, we have

$$R = \frac{0.388\,W^2}{\frac{T}{2} - S} \text{ (in meter)}$$

$W \rightarrow$ Wheel base of aircraft in meter

$T \rightarrow$ Width of taxiway pavement (meter)

$S \rightarrow$ Distance between midway point of the main gears and edge of taxiway pavement in meter.

$$S = 6 + \frac{\text{Wheel tread}}{2} \text{ in meter}$$

Example 6.1 A taxiway is to be designed for operating aircraft having following characteristics. Subsonic, aircraft, Wheel base = 17.80 m, Tread of main loading gear = 6.82, Turning speed = 45 kmph width of taxiway pavement = 22.5 m and Coefficient of friction between tyre and pavement = 0.13. Calculate turning radius.

Solution:

(i) Turning radius, $R = \frac{V^2}{125\,f} = \frac{45^2}{125 \times 0.13} = 124.62\text{m}$

(ii) From horonjeff's equation, $R = \frac{0.388\,W^2}{\frac{T}{2} - S}$

Here, $W = 17.80$ m

$T = 22.5$ m

$S = 6 + \frac{6.82}{2} = 9.41\text{m}$

So, $R = \frac{0.388 \times 17.8^2}{0.5 \times 22.5 - 9.41} = 66.81\text{m}$

(iii) Absolute min turning radius for subsonic aircraft regardless any speed = 120 m

Selecting maximum among three cases above so turning radius = 124.62 m ≃ 125 m

6.3 Exit Taxiway

Taxiway should be located such that landing aircraft leaves the runway as early as possible. Such taxiway is called exit taxiway.

6.4 Apron

- Paved area for aircraft parking, loading and unloading of passengers and cargos.
- This area is near to terminal building or hangers.
- Size of apron depends upon number of gate positions.
- Number of gate position itself depends upon the peak hourly aircraft movements and time (Ramp time) during which each aircraft remains in a gate position.
- Ramp time is few minutes for small aircraft and more than hour for big aircraft.

$$\text{Number of gate positions} = \frac{\text{Capacity of runway}}{60 \times 2} \times \text{Average gate occupancy time}$$

Here, unit of runway capacity is movements per hour.

Note: Gate position is an area embarked for loading and parking of each type of aircraft.

6.4.1 Holding Apron (Run-up and warm-up pads)

- Waiting area for aircrafts before take off is called holding apron.
- Its size depends upon peak hour aircraft movements, aircraft size and manoeuvring characteristics.

6.4.2 Apron Turn Table

- It is used to expedite the parking of aircraft and save parking space.

6.5 Hanger

- It is covered area for repair and servicing of the aircrafts.
- Number of hangers depends on peak hour volume of aircrafts.

Note: *Hanger size depends on the size of aircrafts and turning radius.*

Example 6.2 An exit taxiway is to be designed for Boeing 707 with turnoff speed of 70 km/hr. Calculate the turning radius of the exit taxiway using the following data:

Coefficient of lateral friction = 0.13, Wheel base = 18.0 m, Tread of main landing gear = 7.2 m, Width of taxiway = 22.5 m

Solution:

Given

Turning speed, $V = 70$ kmph

Wheel base, $W = 18.0$ m

Tread of main landing gear, $T' = 7.2$ m

Width of taxiway, $T = 22.5$ m

Coefficient of friction, $f = 0.13$

(i) Radius of taxiway, $R = \frac{V^2}{125f} = \frac{70^2}{125 \times 0.13} = 301.54\text{m}$

(ii) From Horonjeff's equation, $R = \frac{0.388\,W^2}{\frac{T}{2} - S}$

where, S = distance between midway point of main gears and edge of the taxiway pavement.

Assuming Oleo distance = 6 m

Then, $S = \text{Oleo distance} + \frac{T'}{2}$

$\Rightarrow$ $S = 6 + \frac{7.2}{2} = 9.6\text{m}$

Putting values in Horonjeff's equation, we get

$$R = \frac{0.388 \times 18^2}{\frac{22.5}{2} - 9.6} = 76.189 \text{ m}$$

(iii) Boeing-707 is sub-sonic aircraft, therefore, minimum radius of taxiway $R_{min} = 120$ m

From above maximum value of R is 301.54 m. Therefore, radius of taxiway will be 301.54 m.

Example 6.3 Determine the radius of a taxiway for a supersonic aircraft to negotiate the curve at a turning speed of 50 kmph. The wheel base is 32 m and the tread of main landing gear is 7.3 m. Width of taxiway is 22.5 m. Assume co-efficient of friction between tyre and pavement surface as 0.13.

Solution:

Turning speed, $V = 50$ kmph
Wheel base, $W = 32$ m
Tread of main landing gear, $T' = 7.3$ m
Coefficient of friction, $f = 0.13$
Taxiway width, $T = 22.5$ m

(i) Turning radius, $$R = \frac{V^2}{125\,f} = \frac{50^2}{125 \times 0.13} = 153.85 \text{ m}$$

(ii) From Horonjeff's equation, $$R = \frac{0.388\,W^2}{\frac{T}{2} - S}$$

where, S = distance between midway point of main gears and edge of the taxiway pavement in meters.

Assuming Oleo distance = 6 m

We know $$S = \text{Oleo distance} + \frac{T'}{2} = 6 + \frac{7.3}{2} = 9.65 \text{ m}$$

Putting values in Hornonjeff's equation, we get

$$R = \frac{0.388 \times 32^2}{\frac{22.5}{2} - 9.65 \text{ m}} = 248.32 \text{ m}$$

(iii) For supersonic aircraft, minimum radius of taxiway $R_{min} = 180$ m.
From above, maximum value of R is 248.32. Therefore radius of taxiway will be 248.32 m

Example 6.4 Determine the radius of a taxiway for a supersonic aircraft with a wheel base of 28 m and the tread of main landing gear is 6.2 m. For design turning speed of 52 kmph. Assume co-efficient of friction between tyre and pavement surface as 0.13 and width of taxiway pavement as 22.5 m.

Solution:

Given,
Turning speed, $V = 52$ kmph
Wheel base, $W = 28$ m
Tread of main landing gear, $T' = 6.2$ m
Coefficient of friction, $f = 0.13$
Width of taxiway, $T = 22.5$ m

Let radius of taxiway is 'R'.
Radius of taxiway will be maximum of

(i) $$R = \frac{V^2}{125\,f} = \frac{52^2}{125 \times 0.13} = 166.4 \text{ m}$$

(ii) From Horonjeff's equation, $$R = \frac{0.388\,W^2}{\frac{T}{2} - S}$$

where, S = distance between midway point of main gears and edge of the taxiway pavement in meters.

Assuming Oleo distance = 6 m

We know $$S = \text{Oleo distance} + \frac{T'}{2} = 6 + \frac{6.2}{2} = 9.1 \text{ m}$$

Putting values in Hornonjeff's equation, we get

$$R = \frac{0.388 \times 28^2}{\frac{22.5}{2} - 9.1 \text{ m}}$$

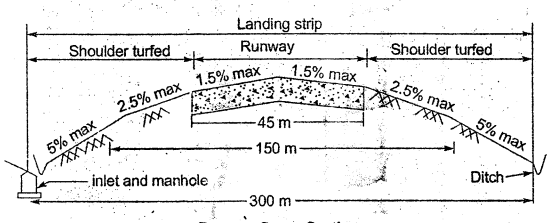
$$R = 141.5 \text{ m}$$

(iii) For supersonic aircraft, minimum radius of taxiway $R_{min} = 180$ m.
From above, maximum value of R is 180 m. Therefore radius of taxiway will be 180 m

Example 6.5 Sketch a typical cross-section of a runway and taxiway.

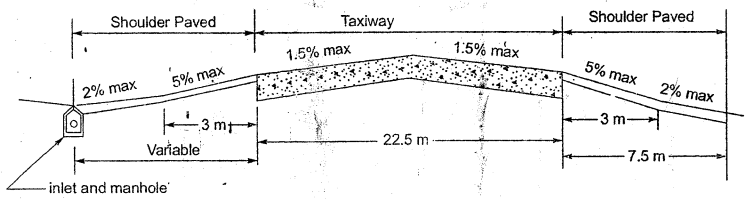
Solution:

Runway cross-section



Runway Cross Section

Taxiway cross-section



Taxiway Cross Section

Summary

- Taxiway provides access to the aircraft from the runways to loading apron or service hanger and back.
- Exit taxiways are taxiways located such that landing aircraft leaves the runway as early as possible.
- Aircraft speed on runway is significantly more than the speed on taxiway.
- Apron is area provided for parking, loading and unloading of pasengers and cargos.
- Hanger is closed area meant for repair and servicing of aircrafts.

Objective Brain Teasers

Q.1 **Assertion (A):** The width of taxiway is smaller than the runway width.
Reason (R): The speed of aircraft on a taxiway is greater than that on runway.

Q.2 **Assertion (A):** The paved area adjacent to the terminal building or the 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.

Q.3 For supersonic transport minimum turning radius of taxiway is
(a) 60 m (b) 120 m
(c) 180 m (d) 240 m

Q.4 Which of the following is covered area used for servicing and repair of aircraft.
(a) Apron (b) Hanger
(c) Terminal building (d) Holding apron

Q.5 The size of hangar in an airport is guided by
(a) Speed and direction of wind and visibility
(b) Weight of aircraft and turning needs
(c) The fueling capacity and storage space
(d) The length, wingspan and height of aircraft

Q.6 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 hangers
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

Q.7 Where the aircraft is standing (parking), the facility for loading and unloading operation in front of terminal building is known as
(a) holding apron (b) apron
(c) taxiway (d) hangar

Q.8 Match the following:

List-I	List-II
A. Taxiways	1. Large span structures
B. Control tower	2. Visibility all round and sound proof
C. Hangar	3. Turning radius
D. Apron	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

Q.9 Minimum turning radius of taxiway for subsonic aircraft is
(a) 100 m (b) 120 m
(c) 150 m (d) 180 m

Q.10 Friction coefficient between type and pavement of taxiway is assumed as
(a) 0.1 (b) 0.13
(c) 0.15 (d) 0.17

Q.11 Which one of the following gives the number of gate position in an airport?
(a) $\frac{\text{Capacity of runway}}{2} \times$ 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) $\frac{\text{Capacity of holding apron}}{2} \times$ average gate occupancy time

Q.12 Match the following:

List-I
A. Width and length of safety area of airport
B. Engine failure case
C. Location of exit taxiways
D. Grading of airport area

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

Answers

1. (c) 2. (b) 3. (c) 4. (b) 5. (d)
6. (d) 7. (b) 8. (b) 9. (b) 10. (b)
11. (c) 12. (c)

Hints & Solution

8. (b)
Control tower is located in airport such that to control the aircraft movement efficiently.

12. (c)
For runways design width and length of safety area is considered. For determination of basic runway length (BRL) engine failure case is considered. Runway capacity is affected by number, location and design of exit taxiways. Airport area is graded to enable the quick drainage of storm water.

CHAPTER 7

Visual Aids

7.1 Visual Aids

- The Pilot requires visual aids for performing landing and taking off operations during all type of weathers, safely.
- Runway threshold, runway edges, runway centerline and horizon are the important parameters which should be clearly visible to pilot.
- In day time visibility is enhanced by marking runways, taxiways and others with line and number.
- In night time adequate lightening at airport, runway and taxiway should be done, to improve visibility.

7.1.1 Airport Marking

Marking in the airport area is done so that pilots can easily recognise the various structures of the airport.

Types of airport marking are:

1. **Runway marking:** It includes the markings of centerline, edge strip and threshold runway landing zone. All markings are done with white paint.
2. **Taxiway marking:** All markings are done with yellow colour paint.
3. **Runway and Taxiway shoulder markings:** Shoulder marking are done with yellow colour paint.
4. **Apron Marking:** This marking is done with yellow colour paint. Paint should be fuel resistant as apron is prone to fuel spillage.
5. **Wind Direction Indicator:** It indicates the wind direction using wind c[illegible]
6. **Landing Direction Indicator:** It helps the pilot to know the direction of active runway of the airport. It is in the form of *T* or arrow shape and painted in orange or white colour.

7.1.2 Airport Lighting

- During night airport lighting is needed for better visibility
- Runway lighting is different than that of taxiway so as to avoid confusion.
- All runway lighting are usually white.
- All taxiway side lights are usually blue.
- The thresholds are lighted green for night landing.

7.2 Air Traffic Control (ATC)

- Air traffic control is essential for safety of operations, to increase capacity of airport and to expedite the traffic movements.

Need for Air Traffic Control

- To guide the aircraft for landing or take off.
- To guide the aircraft on the air-field between the apron and runway.
- To guide the aircraft along the air-routes for adequate lateral and vertical separation so as to avoid collision.
- To give airway and weather information to pilot during the flight.

Air Traffic Control Aids

- Visual flight rule (VFR) prevails when the weather condition is good enough so pilot can conduct the flight by visual inspection only without the need of air traffic control.
- Instrument flight rule (IFR) prevails when the visibility is inadequate during night or due to cloud or fog.
- During all visibility conditions, air traffic control aids that are always available to pilot during flight are:
  1. Enroute aids
  2. Landing Aids.
- The runway capacity is more under VFR (Visual /flight Rule) than capacity under IFR (Instrument flight Rule).

Various enroute aids are:

- Airway beacon
- Airground communication
- Marker beacon
- Air-route surveillance radar (ARSR)
- Low/medium frequency (LF/MF) ratio range.
- Distance measuring equipment (DME)
- Direction finder

Various possible landing aids for Aircraft are as follows:

- Instrument landing system (ILS)
- Airport surveillance radar (ASR)
- Approach lights
- Ground approach control (GAC)
- Airport surface detection equipment (ASDE)

The Instrumental Landing System (ILS)

- The instrumental landing system provides both vertical and lateral guidance to aircraft.
- Z markers, threshold lights, Glide slope antenna and localizer antenna are components of ILS installed in a sequence, in direction of landing.
- **Localiser Antenna:** emits ratio beam signal in vertical plane and indicates to the pilot whether he is to the left or to the right of the correct alignment for approach to the runway.

Summary

- All runway markings are done with white paint.
- All taxiway marking are done with yellow paint.
- All runway side lights are usually white.
- All taxiway side lights are usually blue.

Objective Brain Teasers

Q.1 **Assertion (A):** Airport capacity during IFR condition is usually less than that during VFR condition.

Reason (R): During clear weather condition (VFR), the aircraft on final approach to runway can be spaced closer than during poor visibility conditions.

(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

Q.2 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

Q.3 A VOR radio transmitter which emits beam in a vertical plane and gives an indication to the pilot whether he is to the left or right of the correct alignment for approach to the runway is known as
(a) Outer marker
(b) Localiser antenna
(c) Glide slope antenna
(d) Marker beacon

Q.4 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

Q.5 As per ICAO all marking of the runways are:
(a) yellow (b) white
(c) black (d) red

Q.6 As per ICAO, all marking of taxiway are
(a) yellow (b) white
(c) black (d) red

Q.7 As per ICAO, runway lighting colour is
(a) yellow (b) white
(c) blue (d) red

Q.8 As per ICAO, taxiway lighting colour is
(a) yellow (b) white
(c) blue (d) red

Q.9 For night landing, the thresholds are lighted
(a) green (b) red
(c) white (d) yellos

Answers

1. (a)	2. (c)	3. (b)	4. (d)	5. (b)
6. (a)	7. (b)	8. (c)	9. (a)	

CHAPTER 8

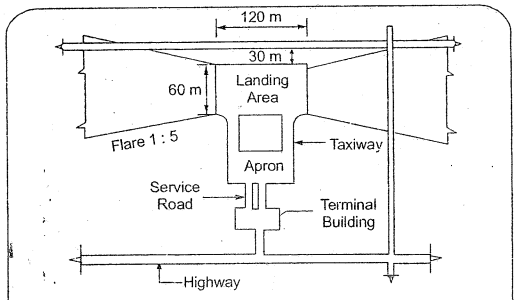
Heliport

8.1 Heliport

- Heliport/Helipad is the designated area provided for take-off and landing of the helicopters.
- Advantages of using helicopters:
  - Helicopter can lift off or land in a nearly vertical direction. This is referred to vertical take off and landing (VTOL).
  - During the winter aeroplane flights are risky because of snow fall.
  - These are preferred for distances less than 400 km
  - Helicopters have extensive use in military and relief operations.

8.1.1 Planning of Heliports

- Heliports are designated areas for landing and take-off operations. These also provide facilities for shelter, repair and servicing of helicopers also for loading and unloading of cargo, baggage and passengers.
- The area from where helicopter takes off and lands is called landing area.
- Remaining area is called terminal area.
- Heliports orientation is made so that landing and take off operations are done along the wind direction.



Typical layout of heliport for large size helicopters

Fig. 8.1

Note: Permissible cross wind component for helicopters are higher than that for fixed wind aircraft.

Sight Selection

- Location should be close to the traffic generating areas.
- Helipad should have convenient access by roadway or railway.
- Sites should be least objectionable for noise.
- Obstruction free path should be established for approach and departure.

Size of Landing Area (FAA with IATA recommendation)

Description of Helicopter	Size of Landing Area
A. Single engined	
(i) 2700 kg weight (VFR)	22.5 m × 22.5 m or circle of equivalent area
(ii) 6800 kg weight (VFR)	30 m × 30 m or circle of equivalent area
B. Multi-engined (IFR)	60 m × 120 m

8.1.2 Visual Aids and Marking

- ICAO recommends that landing and take-off area should be fully marked with capital letter 'H'
- This is done so that a clear vision is possible from all approach above the horizon.

Note: The recommended colour for painting is white.

Beaufort Scale

- It is an empirical scale for measuring wind speeds based on observed conditions.

Aerofoil

- It is a wing like structure which may be flat or curved and is designed to obtain reactions upon its surface from the air through which it moves.

Summary

- Heliport are the designated area provided for take-off and landing of the helicopters.
- Orientation of heliport is done along the wind direction.
- Landing and take-off area is fully marked with capital letter 'H'. The recommended colour of paint is white.

Objective Brain Teasers

Q.1 The heliport orientation is made so that landing and take off operations are done
(a) at a 45° angle to wind direction
(b) along the wind direction
(c) perpendicular ro wind direction
(d) none of these

Q.2 Size of landing area for multi-engined helicopters operating under IFR condition.
(a) 22.5 × 22.5 m (b) 30 × 30 m
(c) 22.5 × 30 m (d) 60 × 120 m

Q.3 Assertion (A): Helipads are usually located in close proximity to traffic-generating areas.

Reason (R): A helicopter cannot ascend or descent exactly vertically

Select your answer based on the coding system given below:
(a) Both A and R are true and R is correct explanation of A.
(b) Both A and R are 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

Q.4 Beaufort scale is used to determine
(a) velocity of wind
(b) direction of wind
(c) height of air-crafts
(d) None of these

Answers

1. (b) 2. (d) 3. (b) 4. (a)

Hints & Solution

3. (b)
From economic point of view, heliport site should be located in close proximity to the traffic generating areas. For helicopter the initial vertical rise to take off is helped by the ground cusion which built up the air pressure directed against the ground by revolving rotors. However exact vertical take off and landing is not practical.

CHAPTER 9

Port and Harbour

9.1 Basic Definitions for a Ship

- **Beam:** Beam of a vessel means the width of vessel, at its widest point.
- **Draft:** It is the depth of the keel of the ships below water level for the particular conditions of loading.
- **Ballast:** it is the weight added to ballast compartments of a ship to increase its draft , lowering its centre of gravity, thus improving the stability of the ship.

9.2 Port

- A port is a location on a shore having one or more harbours where ships can dock and transfer people or cargo to or from lands.
- It can be either natural or artificial.
- It can also be either river port or sea port.

9.3 Dredging

- It is the operation of removing material from the bed of a sea, river or lake and disposing it into stream or onto the shore.
- It is generally done for deepening bed under water, thus incresing the navigability of water ways.

9.4 Harbour

- A harbour is a protected water area to provide safe and suitable accommodation for vessels seeking refuge, supplies, refueling, repairs or transfer of passengers and cargo. In a harbour there are elements such as entrance, approach channel, breakwater, wharves, jetties, locks and dry docks.

9.4.1 Harbour Classification

A. On Basis of Genesis

1. **Natural Harbour:** This type of harbour is protected from the storms and waves by the natural land contours.
   Example: Mumbai
2. **Semi Natural Harbour:** Harbour protected from storms and waves on one side by natural land contours and other side by artificial man-made construction
   Example: Vishakhapatnam

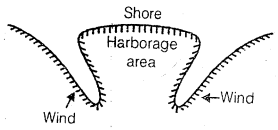


Fig. 9.1 *Natural harbour*

3. **Artificial Harbour:** Harbour which is protected from storms and waves from both sides by man-made structures called breakwaters or it may be created by dredging also.
   Example: Chennai

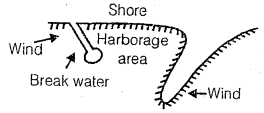


Fig. 9.2 *Semi-natural harbour*

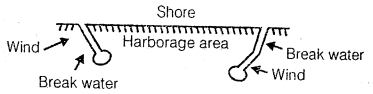


Fig. 9.3 Artificial harbour

B. On the Basis of Usage
1. Refuge Harbour
2. Commercial Harbour
3. Military Harbour
4. Fishery Harbour

C. On the Basis of Site Location
1. Canal Harbour
2. Lake harbour
3. River or Estuary Harbour
4. Sea or Ocean Harbour

9.4.2 Site Selection

- The site should have maximum natural protection from wind and waves.
- It should have adequate depth for different type of ships.
- Siltation and erosion should not pose a problem.
- The subsoil conditions for foundation should be favourable.
- It is preferably established on trade route.
- Availability of Industrial infrastructure, electrical energy and fresh water supply, cheap land, construction materials and labour are also important factors in site selection.

9.4.3 Harbour Layout Elements

1. **Harbour Depth**
   - Depth of harbour should be sufficient for navigation at low water level when ship is fully loaded.
   - The maximum harbour depth below lowest low water is given as:
     Maximum harbour depth = Loaded draft + 1.2 m (when bottom is soft)
     Maximum harbour depth = Loaded draft + 1.8 m (when bottom is rock).
     where, loaded draft means submerge depth of ship whenit is fully loaded.
2. **Harbour Entrance Channel**
   - Entrance without gates is known as tidal entrance and entrance with gate is known as impounded entrance.
   - The entrance to a harbour is more exposed to waves as compared to the harbour itself. Thus, depth and width required at the entrance are more than those required in the channel.

- The entrance should be wide enough for navigational requirements. But should not be too wide to increase wave height within harbour.

3. **Anchorage Area**
   - The place where ships are held for inspection and waits to enter port is called anchorage area.

4. **Turning Basin**
   - It is an enlargement of the channel used for turning of a ship.
   - The minimum diameter of turning basin for which the ship turns without tug assistance is 4 times the length of the ship.
   - When the ship has assistance, the turning diameter is 1.7 to 2 times the length of ship.

5. **Breakwaters**
   - Its function is to protect the enclosed area of water from storm waves.

6. **Fenders**
   - They are wooden members or rubbing strips fastened to the dock i.e. on the face of the dock to prevent a ship or dock from being damaged during mooring.
   - These absorbs the kinetic energy of impact of the ship and hence protect them from damage.

7. **Wharf and Quays**
   - These are constructed parallel to shore or breakwater within the harbour to permit berthing of vessel. They give necessary depth for navigation.
   - The have backfill of a suitable material and have wide platform at top.
   - When built along and parallel to the shore, then they are called as quays.
   - The space required alongside a wharf for berthing depends upon following factors
     1. Availability of materials.
     2. Wharf configuration
     3. Size and type of ship served

8. **Jetties**
   - These are structures in the form of piled projections. And they are built out from the shore to deep water and they may be constructed either for a navigable river or in the sea.
   - In the sea, the jetties are provided at places where harbour entrance is affected by littoral drift or the sea is shallow for a long distance. Thus, they extend from the shore to the deep sea to receive the ships.
   - In a limiting sense, a jetty is defined as a narrow structure projecting from the shore into water with berths on one or both sides and sometimes at the end also.

Differences Between Wharf and Jetty:

Following are the two differences between a wharf and a jetty:

1. The wharf is constructed parallel to the shore. A jetty is perpendicular to the shore or breakwater.
2. The wharf has berth on one side only as it has backfill of earth. A jetty may have berth on two faces.

9. **Piers**
   - The structures which are built perpendicular or oblique to the shore of a river or a sea are known as piers.

   - In the sea, the piers are constructed where the sea is not deep and the natural harbour is not convenient for allowing the ships to berth adjacent to the shore.

10. **Pierheads**
    - A pierhead is a structure constructed at the tip of a breakwater near the harbour entrance.
    - It helps in clearly demarcating the approach channel.

11. **Dolphins**
    - These are man-made marine structures for mooring vessels and to absorb impact force of vessels.
    - The construction in the form of a cluster of closely spaced piles is known as dolphins.
    - The piles are pulled together at the top and tied by a cable. They are marine structures for mooring vessels.

Note: They are usually used in combination with piles and wharves to shorten the length of these structures.

- Dolphins are used for tying up ships and also for transferring cargo from one ship to another when moored along both of their sides.
- Dolphins are mainly designed for resisting horizontal impact force, wind force and water current forces from a vessel when docking.

Types of Dolphins:

Dolphins are of the following two types:

1. **Breasting Dolphins**
   - They are provided with fenders to absorb the impact of ship and to protect the dolphins as well as the ship from the damage.
2. **Mooring Dolphins**
   - These are additional dolphins and they are provided to hold a ship against a broadside wind blowing in a direction away from the dock.
   - They are not designed for the impact of the ship.

12. **Slip**
    - The space of water area between two adjacent piers where ships are berthed is known as slip.
    - It should be sufficient for two vessels to be simultaneously located safely in the slip and grant enough space for barges to load or unload the ships.

13. **Moles**
    - The massive structures formed by rock filling and extending from shores are known as moles.
    - They are preferred to trestles when water depth is less than 3 m and in no case, the height of mole should exceed 8 m
    - The section of mole should be designed in such a way that it proves to be unyielding and stable from erosion.

14. **Lock and Locked Basin**
    - Locked basin is an enclosed basin where vessels can be berthed and its entrance is controlled by lock gates.
    - The water within locked area is independent of outside water level fluctuations.

15. **Dry Dock and Slipways**
    - It is provided for maintenance, repairs and construction of ships.

9.5 Breakwaters

It is manmade construction to form an artificial barrier for the safety of of artificial harbour. Breakwaters height is usually kept equal to 1.2 to 1.25 times of the height of the wave expected above the high water level so that waves do not penetrate inside the wall.

9.5.1 Types of Breakwaters

Breakwaters are of three types

1. Vertical mound breakwater (conventional type)
2. Rubble mound breakwater
3. Composite

Rubble Mound Breakwaters (Most Common):

These are constructed with stone rubble. The mount consists of three parts:

1. The armour (cover)
2. The first underlayer
3. The second underlayer (core)

The stability of the section depends upon the weight and shape of the armour block, the interlocking between individual blocks and the slopes at which they are laid.

9.5.2 Forces Acting on a Breakwater

A breakwater has to resist the forces imposed by waves impinging upon it. The forces include the following:

1. Hydrostatic pressure due to the rise in the level of wave on the sea sides of the wall up to the crest of the wall.
2. Hydrostatic pressure due to fall in the level on the seaside of the wall upto the trough of the wall.
3. Uplift pressure due to difference in level of water on two sides of wall.
4. Complex forces generated due to on-rush and down-rush of waves on a sloping surface.

Note: The level of wharf should be above the high water level.

9.6 Soundings

These are used to measure depth below the water surface. It is required for preparing nautical charts for navigation, estimating areas subjected to scouring or silting and to measure the quantities of dredged material and to secure information needed for the development and improvement of port facilities. Generally soundings measurements are taken from a small boat.

9.6.1 Sounding Instruments

Fathometer (Echo-sounding)

- It is an echo-sounding instrument in which deepwater depth are obtained by determining the time required for the sound waves to travel from a point near the surface of the water to the bottom and back to the point. These are usually employed for ocean depth measurement.

Saxtant

- It is a doubly reflecting navigational instrument which measures the angle between two visible objects.

Station Pointer

- It is a three arm protractor to fix a point from three or more trigonometric stations using resection.

Hi-Fix

- A high-precision electronic device known as hi-fix has been extensively used by ships and aircraft to determine their position by receiving radio signals.

Summary

- Draft is the depth of the keel of the ships below water level for the particular conditions of loading.
- Harbours is a protected water area to provide safe and suitable accommodation for vessels for refuge/ supplies, refueling , repairs or transfer of passengers and cargos.
- Breakwater protects the enclosed area of water from storm waves.
- Fenders are provided on the face of the dock to absorb impact of the ships. Thus protecting ships and dock from damage.

Objective Brain Teasers

Q.1 **Assertion (A):** Depth and width required at the entrance to a harbour are more than those required in the channel.

Reason (R): The entrance to a harbour is usually more exposed to waves as compared to the harbour itself.

Select your answer based on the coding system given below:

(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 the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true.

Q.2 The maximum harbour depth below lowest low water is generally equal to

(i) loaded draft + 1.2 m when bottom is rock
(ii) loaded draft + 1.8 m when bottom is soft
(iii) loaded draft + 1.2 m when bottom is soft
(iv) loaded draft + 1.8 m when bottom is rock

Of these statements

(a) (i) and (ii) are correct
(b) (i) and (iii) are correct
(c) (ii) and (iv) are correct
(d) (iii) and (iv) are correct

Q.3 The minimum diameter of turning basin, where ships turn by going ahead and without tug assistance should be

(a) L (b) 1.5 L
(c) 2.0 L (d) 4.0 L

where L is the length of the largest ship to use the port.

Q.4 **Assertion (A):** Breakwaters are common in natural harbours.

Reason (R): Breakwaters help in controlling wave action and sand movement into the harbour 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 the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true.

Q.5 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

Q.6 With a bit rate of 60 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) 1800 bits

Q.7 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

Q.8 When a ship floats at its designed water line, the vertical distance from water line to the bottom of the ship is known as
(a) beam (b) depth
(c) freeboard (d) draft

Q.9 A harbour is a place where
(a) ships get shelter and protection against destructive forces due to sea waves
(b) facilities are provided for receiving cargo and passengers
(c) port buildings are constructed for commercial purposes
(d) All of these

Q.10 As compared to wall type breakwater, mound type breakwater
(a) requires skilled labour
(b) requires low maintenance cost
(c) requires less material
(d) results in less damage due to gradual failure

Q.11 If H is the height of the wave expected, then the height of the breakwater is generally taken as
(a) 1.2 H to 1.25 H above the datum
(b) 1.2 H to 1.25 H above the low water level
(c) 1.2 H to 1.25 H above the high water level
(d) 1.2 H to 1.25 H above the mean sea level

Q.12 Which of the following structures are constructed parallel to shore line to develop a demarcating line between land area and water area?
(a) sea walls, bulk heads and groynes
(b) sea walls, bulk heads and revetments
(c) sea walls, revetments and groynes
(d) bulk heads, revetments and groynes

Q.13 Consider the following statements:
1. Fender is the cushion provided on the face of the jetty for ships to come in contact,
2. Slip is the space of water area between two adjacent piers where ships are berthed
3. Pier head is a structure constructed near the tip of a breakwater near the harbour entrance.

Of these statements:
(a) 1 and 2 are correct
(b) 2 and 3 are correct
(c) 1 and 3 are correct
(d) 1, 2 and 3 are correct

Q.14 Match the correct following:

List-I
A. Constructed approximately perpendicular to the shore to retard erosion of an existing beach
B. Structure 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 shore area

List-II
1. Jetties
2. Break waters
3. Seawalls
4. Groynes
5. Wharf

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

Q.15 Consider the following factors:
1. Size and type of ship served
2. Availability of materials.
3. Wharf configuration
4. Mooring procedures

The space required alongside a wharf for breathing would depend upon factors.
(a) 1, 2 and 4 (b) 2, 3 and 4
(c) 1, 2 and 3 (d) 1, 3 and 4

Q.16 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 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. Retard 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

Q.17 Consider the following factors:
1. Mass of ships to be breathed
2. Overall transit time
3. Speed of breathing
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

Q.18 The most popular method of construction of wall breakwaters is
(a) Barge method (b) Staging method
(c) Low level method (d) None of these

Answers

1. (a)	2. (d)	3. (d)	4. (d)	5. (d)
6. (d)	7. (b)	8. (d)	9. (d)	10. (d)
11. (c)	12. (b)	13. (d)	14. (a)	15. (c)
16. (c)	17. (c)	18. (b)		

Hints & Solution

4. (d)
Breakwater is protective barrier constructed to form an artificial harbour

6. (d)
With a bit rate of 60 bps and a cycle time of 30 seconds, the total information content of a navigation data set is 1800 bits.

7. (b)
A station pointer is used for plotting of soundings in harbour area.

CHAPTER 10

Tides

The Natural phenomena like tides, winds, waves, currents etc. affect the designing of protection works such as breakwater, offshore moorings etc.

Note: The mean sea level at Indian ports and harbours has been established based on analysis of tidal sea level fluctuation over 19 years.

10.1 Tides

- The Natural phenomena of periodic rise and fall in the level of ocean water is called tide.
- Tides are mainly caused by gravitatioal force exerted by the moon and the sun. The influence of moon is greater than sun.
- Generally, water level rises and falls approximately in a period of 12 hrs and 25 minutes.

Lunar Day

- It is the time taken by moon (24 hr 50 mins) to make a one full rotation on its axis. It is 50 minutes longer than solar day (24 hour earth day)

Spring Tides

- These are great rise in water levels and great fall in water levels occuring at about new and full moon times.

Neap Tides

- These are moderate rise and fall in water levels occuring about 7 days from new and full moons times.

NOTE

- In a year there is 12 full moon days and 12 new moon days in a year, so there is total 24 spring tides produced in a year.
- Similarly there is 24 neap tides (12 first quarter + 12 third quater of moon) in a year.
- Highest of high tide is produced when sun is nearest to earth at about new moon day or full moon day.

Wave

- Wave is generated by transfer of energy mostly from air moving over the water surface.
- As per Stevenson,

$H = 0.34\sqrt{F}$ where, H is height of wave (m) and F is fetch length (km).

- As per Bertin,

$V = 1.56\,t$ where, V is wave velocity in m/s

$L = 1.56\,t^2$, where L is wave length in meter and t is wave period in seconds.

- As waves are not uniform so significant wave height (H_s) is defined as the average wave height of 1/3rd highest wave.

$$\text{Average height } (H_{avg}) = 0.6\,H_S$$

$$\text{Highest wave height } (H_{max}) = 1.87\,H_S$$

- When a wave strikes a vertical breakwater in deep water. It is reflected back and on meeting another advancing wave of similar amplitude it merge and rise vertically in a wall of water. This phenomena is known as Clapotis.

Note: Fetch is the distance on which wind blows over water.

10.2 Shore Protection Work

1. **Off shore breakwater:** These provide protection to harbour against wave action, effective against littoral movement and serve as an aid to navigation.
2. **Sea-wall, bulkheads and revetments:** These are constructed parallel to shoreline to demarcate between land area and water area. The bulkheads are meant to prevent sliding of land. Seawalls and revetments are used to protect the land property against wave action.
3. **Groynes:** These are structures which are usually built perpendicular and little inclined to the shore to protect beach or to retard erosion of an existing or restored beach by trapping of littoral drift. Perpendicular gryone projects normal to the river-flow, repelling groyne projects upstream. Attracting gryone projects downstream into the river from the point of its origin from the bank.

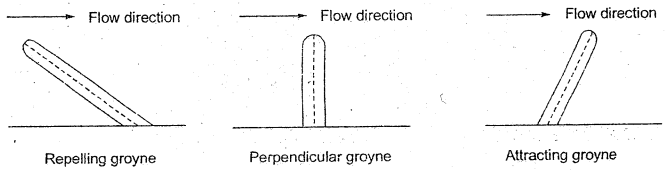


Fig. 10.1

10.3 Littoral Drift

- Wave usually carry the drifting sand in a zigzag manner. This process of movement and deposition of drifting sand in zigzag manner is known as littoral drift.
- Littoral drift can cause severe problems in harbour operations.

Example 10.1 From the following tidal data determine the wave height

Depth of water = 5 m

Fetch = 800 km

Solution:

Depth of water, $d = 5$ m

Fetch, $F = 800$ km

Let wave height be 'H'

From Stevenson formula $H = 0.34\sqrt{F}$ (Here H is in metres and F is in km)

$\Rightarrow$ $H = 0.34 \times \sqrt{800} = 9.62$ m

Summary

- The mean sea level at Indian ports and harbours is established on analysis of tidal sea level fluctuation over 19 years.
- Tide is natural phenomena of periodic rise and fall in the level of ocean water, caused by gravitational pull of moon and sun.
- Littoral drift is the phenomena of deposition of sand in a zig-zag manner by waves.

Objective Brain Teasers

Q.1 As per Stevenson's empirical formula, the approximate value of the height of the wave in metres is given by
(a) $0.34\sqrt{F}$ (b) $0.5\sqrt{F}$
(c) $1.5\sqrt{F}$ (d) $3.4\sqrt{F}$
where F is fetch in km.

Q.2 As per Bertin's formula, the length of wave in metres is given by
(a) $1.34\,t^2$ (b) $1.56\,t^2$
(c) $1.74\,t^2$ (d) $1.94\,t^2$
where 't' is the period in seconds for two successive waves to pass the same section.

Q.3 At a given port, the fetch is 500 nautical miles, the maximum height of storm wave will be
(a) 2.175 m (b) 8.272 m
(c) 9.346 m (d) 10.346 m

Q.4 If H_s is the significant wave height, then the average wave height and highest wave height respectively are given by
(a) 0.6 H_s and 1.67 H_s
(b) 0.6 H_s and 1.87 H_s
(c) 1.27 H_s and 1.87 H_s
(d) 1.27 H_s and 1.67 H_s

Q.5 The significant wave height is defined is the average height of the
(a) one-third highest waves
(b) one-fourth highest waves
(c) one-fifth highest waves
(d) one-tenth highest waves

Q.6 When a wave strikes a vertical breakwater in deep water, it is reflected back and on meeting another advancing wave of similar amplitude merges and rises vertically in a wall of water. This pehnomenon is called
(a) Surf (b) clapotis
(c) Fetch (d) Swell

Directions: The following items consist of two statements, one labelled the 'Assertion A' and the other labelled the 'Reason R'. You are to examine these two statements carefully and decide if the Assertion A and the Reason R are individually true and if so, whether the Reason is a correct explanation of the Assertion. Select your answer to these items ;using the codes given below and mark your answer sheet accordingly.

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 the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true.

Q.7 Assertion (A): Basin walls have to be of much greater height than dock walls.
Reason (R): Tidal basins are subject to fluctuations of levels due to tidal variations

Q.8 Assertion (A): The most common approach for control of beach erosion is to build groynes.
Reason (R): Groynes are constructed parallel to the shore.

Q.9 Assertion (A): Large size stones are required in stone revetment in shore protection.
Reason (R): Resistance of stone to wave force is proportional to its volume and wave force is proportional to the exposed area of the stone.

Q.10 The lowest tide which occurs in half lunar month is called
(a) spring tide (b) neap tide
(c) lunar tide (d) tidal bore

Q.11 Zigzag deposition and movement of sand on sea beach is called
(a) Littoral drift (b) Beach drift
(c) Trough action (d) Sedimentation

Q.12 What is the wave velocity for a uniform train of wave beyond the storm centre for a wave length of 30 m in 1.8 m deep water?
(a) 6.84 m/s (b) 11.2 m/s
(c) 4.5 m/s (d) 9 m/s

Q.13 Mean sea level at Indian ports and harbours has generally been established based on the analysis of tidal sea water level fluctuations over which period?
(a) 10 years (b) 16 years
(c) 19 years (d) 25 years

Q.14 On which of the following factors will be considered in selection of the type of groyne
1. Availability of material
2. Foundation condition
3. Presence of 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 only

Q.15 Which of the following structures protects the shore by trapping of littoral drift?
(a) groynes (b) sea walls
(c) revetments (d) moles

Q.16 Which of following statements is/are associated with groynes:
1. Hydraulic behaviour of a system of gryones is influenced by the characteristics of particles that constitute the littoral drift.
2. Groyne is constructed approximately parallel to shore.
(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

Answers

1. (a)	2. (b)	3. (d)	4. (b)	5. (a)
6. (b)	7. (a)	8. (c)	9. (a)	10. (a)
11. (a)	12. (a)	13 (c)	14. (a)	15. (a)
16. (a)				

Hints & Solution

3. (d)
1 n. mile = 1.852 km
$H = 0.34\sqrt{F} = 0.34\sqrt{1.852 \times 500} = 10.346$ m

12. (a)
Wave velocity $V = \frac{L}{T}$
L is wave length; T is wave period in sec.
As per Bertin's formula
$L = 1.56\,T^2$
Given $L = 30$
$T = \sqrt{\frac{30}{1.56}} = 4.385$ s
Thus; $V = \frac{30}{4.385} = 6.84$ m/s

CHAPTER 11

Dock

11.1 Dock

- It is an artificial enclosure for the reception of ships.
- Dock may be regulated by lock gates or kept open to the tides.
- Docks can be broadly classified as wet docks and dry docks.

Note: The size of a dock depends on the size of the largest ship it has to dock.

11.1.1 Wet Docks

- Wet docks or Harbour docks are used for berthing of vessels to facilitate loading and unloading of passengers and cargo. The water level inside the wet dock is almost constant. A wet dock consists of:
  1. Dock entrance
  2. An enclosed basin
  3. A dock-wall known as quay-wall
  4. Facilities for handling and storing of cargo and passengers.

11.1.2 Classification of Wet Docks

1. **Wet docks in tidal basin:** These are docks located on the open sea coast protected by an outlying breakwater.

   Advantages:
   - Vessel can come in and berth or leave any time.
   - Costly arrangement like lock gates for entrance closing are not required.

   Disadvantage:
   - If tidal range is more, then operations of loading and unloading are seriously effected.
   - The fluctuating water levels causes rubbing of sides of ships against the berths.
2. **Enclosed wet dock:**
   - In enclosed wet dock, water level remains constant by lock gates so that cargo handling and commercial activities are easy to perform.
   - Major disadvantages include that it is costly and because of lock gates ships will take more time for entry and exit.

Advantages:
- These helps in effective handling of cargo.
- These prevent the rubbing of the ship sides.
- Thes are effective when there is increase in draft of the vessel, or where considerable silting takes place.

11.1.3 Operations of Wet-dock Using Locks and Gates

A ship at the berth is expected to remain afloat but sometimes it becomes difficult at low water in a harbour with big tidal range. Also with big tidal range, there is difficulty in working cargo from the ships. Thus a steady water level is required. Therefore entrances of docks are provided by gates or caissons, so that entrance can be closed during periods when the tide falls below a particular level.

The figure given below is a horizontal section of a typical lock. Three pairs of gates are shown in figure. For the lock operation only two pairs are needed. But in order to conserve water while handling smaller vessels an additional intermediate pair of gates is provided sometimes.

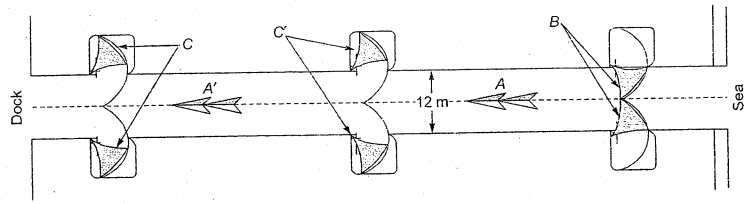


Fig. 11.1 A Typical Lock

Assume that the water level in the sea at a given time is +10 m, and the dock water level is +13 m. To take a vessel in the dock from the sea it is then necessary to lift it by 3 m. And, we assume the intermediate pair of gates to be open, as it will be the case for taking any big vessel.

First the water level in the chambers *A* and *A'* in figure are brought to level of +10 m (to the water level of the sea outside). The gates *B* are then opened and the awaiting vessel is taken in the lock chamber. The gates *B* are then closed and water level in the chambers *A* and *A'* is brought upto 10 m (to the water level in the dock) by allowing water from the dock to flow in or by pumping water from the sea. Lastly, the gates *C* are opened and the vessel is taken into the dock. If there is any vessel ready to return to sea, the same can be taken in, before the gates *C* are closed. The operations for the return passage are exactly the operations described above in the reverse order.

11.1.4 Shapes of Docks and Basin

- The shape of the dock should be straight instead of a curve so that ships can conveniently stand along them.
- The rectangular, diamond and inclined quay type shapes may be adopted.

11.1.5 Dry Dock (Repair Dock)

- These Docks are meant for repair of vessels.
- Maintenance at regular periods is very important for ships. Maintaining the internal part of vessel is easy but maintaining the outer parts which are below water-line is difficult.

Dry docks are classified as follows:

1. Graving docks.
2. Marine railway or slipway
3. Shiplift
4. Floating dock

Graving Dry Dock

- The principle involved in operation of a dry dock is that to admit a vessel into a chamber, close the gate and pump out the water.
- It stands still like a grave of dead body hence called graving dry dock.

Marine Railway or Slipway

- It is an inclined railway extending from the shore well into the water.
- It is useful for small vessels.

Shiplift

- In the shiplift the ships are lifted out of water. This can be done either by electric, hydraulic or pneumatic lifts.
- Among these systems, syncrolift is widely used.

Syncrolift

- It is a vertical marine elevator powered by a series of hoists driven by synchronous electric motors.

Floating Type of Dry Dock

- Floating dry dock is a hollow structure made of steel or RCC, consisting two walls and a floor with ends open.

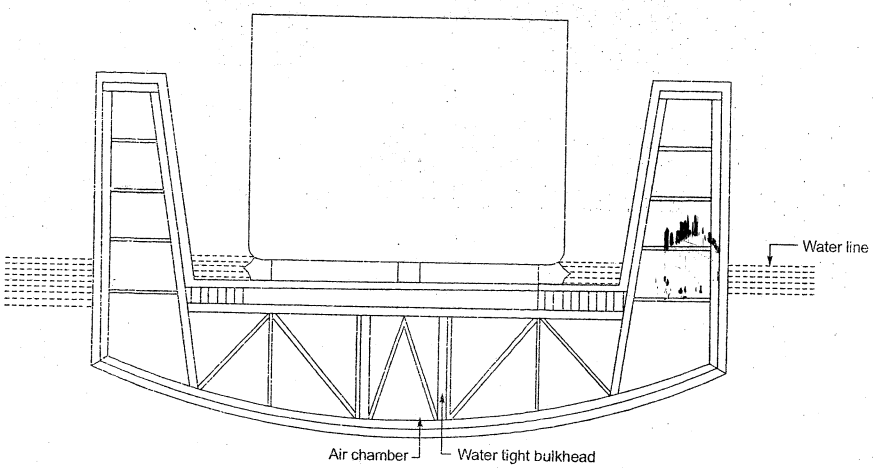


Fig. 11.2 Floating dock cross-section

- To receive a vessel for repairs, the floating dock is sunk to the required depth by allowing buoyancy chambers to be filled with water and when the vessel is berthed, it is raised bodily by pumping out water from buoyancy chamber and thus the vessel lifts above the water line.

Suitability:

- If land is available at suitable cost and soil conditions are moderately favorable then graving dock is always preferred.
- Floating dock has advantage of mobility but maintenance cost for both for ship repair and floating dock is high.

Summary

- Dock is an artifical enclosure for reception of ships.
- Wet docks are used for berthing of vessels to facilitate loading and unloading of passengers and cargos.
- Dry docks are meant for repair of vessels.

Objective Brain Teasers

Q.1 Which of the following conditions of loading imposes the greatest load on the foundation in case of dry docks?
(a) when the dock is empty
(b) when the dock is empty with the ship of maximum tonnage
(c) when the dock is full of water
(d) when the dock is dry and is under construction

Q.2 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

Q.3 Consider the following statements:
1. Dock is a marine structure for mooring up vessels, loading and unloading of passengers and 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 the statements given above are correct?
(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 2 (d) 1 and 3

Q.4 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

Q.5 **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.
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 the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true

Q.6 Which of the following are repair docks?
(a) marine railways, dry docks, floating docks, wet docks
(b) dry docks, wet docks, floating docks, lift docks

(c) floating docks, lift docks, marine railways
(d) wet docks, lift docks, marine railways

Q.7 In a wet dock system
(a) minimum required depth of water for the vessels in maintained
(b) entrance locks are provided with massive gates
(c) the locks of dock gate are operated by means of heavy bascule bridges and connected machinery
(d) All of these

Q.8 A dock
(a) is a marine structure for breathing of vessels for loading and unloading cargo and passengers
(b) is an artificial basin for vessels where the variation of water in the shore does not affect the level of water
(c) is provided with a arrangement to pump out water when required
(d) All of these

Q.9 The shape of docks and basins is generally kept
(a) rectangular
(b) diamond shape quays
(c) inclined qauys
(d) All of these

Answers

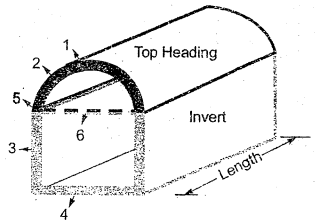
1. (c)	2. (c)	3. (a)	4. (a)	5. (a)
6. (c)	7. (d)	8. (d)	9. (d)	

CHAPTER 12

Tunnelling

12.1 Introduction

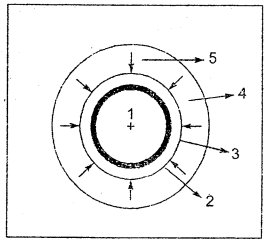
- A tunnel is an underground passageway completely enclosed except for openings for exit, commonly at each end.
- A tunnel may be for road traffic, rail traffic, canal, hydroelectric station, sewer etc.
- It is more efficient than bridges (as during wars it is much difficult to destroy the tunnel compared to bridge).



1. Key stone
2. Arch
3. Wall
4. Floor
5. Bench
6. Bench line or plane
7. Top heading
8. Invert

Fig. 12.1

Tunnel section for swelling ground



1. Digging section
2. Support
3. Swelling section
4. Pressurized area
5. Flow direction of water

Fig. 12.2

12.1.1 Why Necessity of Tunnelling Arises?

- Maintenance of cost of tunnel is much less than that of a bridge or a heavy cut.
- The main reason behind provision of a tunnel is to eliminate a circuitous route for reaching the other side of a hill (the length of railway line will be considerably reduced).
- In large cities, tunnelling would provide the most rapid and unobstructed transportation (leading to reduction in traffic congestion).
- Tunnels provide flat gradient in hilly areas.
- Tunnels under river bed is often economical and convenient than a bridge over the river.

NOTE: Shape of tunnel should be such that lining is able to withstand the pressure exerted by unsupported wall. Polycentric or horse-shoe type sections are used in railways.

12.2 Operations Involved in Bored Tunnelling

(i) Probe Drilling

- This type of drilling is done in order to find out suitable method for drilling.
- It is necessary part of all drilling operations.

(ii) Grouting

- It is the process to provide additional support to drilled mine.
- It is done by a thick emulsion (a suspension of non mixing small droplets of one liquid in a second liquid) called grout.
- Grout consists of of water, cement, colour tint and sometime fine gravel.
- Grouting leads to achievement of a good surface.

(iii) Excavation

- It is the digging and recording of artifacts at an archaeological site.
- It is necessary to know the anchaeological importance of a site before digging (this is performed by experts in scientific way)
- Many government grant permission for tunnelling after finding a go certificate in excavation.

(iv) Supporting

- After initial mining, tunnel needs supports for faster processing.
- Earlier, timber and masonry were usually applied, Now, support is provided by injecting final pipe or building completely before further tunnelling.

(v) Transportation of Muck

- Earlier, transportation was done by steam engine or manual transport. Today, it is done by arrangements made in TBMs (Tunnel boring machines) for transportation of muck.

(vi) Lining or Coating

- Lining is done by modern methods like polishing, painting, to prevent wear and tear and corrosion.

(vii) Draining

- It is the process to remove the water or other liquid from working site (having high ground water level) with the help of pumps and pipes.

(viii) Ventilation

- Ventilation is done by proper checking of oxygen and other parameters (in order to provide safety of workers) by proper installations for exit of hazardous gases coming out from tunnel.

12.3 Tunnel Construction Methods

12.3.1 Shield Tunnelling Method

1. TBM consists of a shield (a large metal cylinder) and trailing support mechanisms.
2. A tunnelling shield is a protective structure used in the excavation of tunnels through the soil that is too soft or unstable.
3. Shield serves as a temporary support structure.

4. At the front end of the shield, a rotating cutting wheel is located.

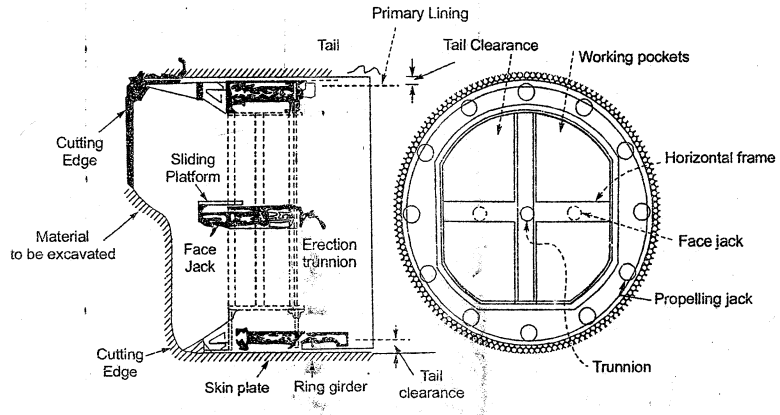


Fig. 12.3 Shield for Tunnelling

- Behind the cutting wheel, there is a chamber where, depending on the type of the TBM, the excavated soil is either mixed with slurry (so called slurry TBM) or left as it is (earth pressure balance).
- Modern TBM typically consist of the rotating cutting wheel, called a cutter head followed by a main bearing, a thrust system and trailing support mechanism.
- Behind the chamber there is a set of hydraulic jacks supported by the finished part of the tunnel which are used to push the TBM forward.
- Once a certain distance has been excavated (roughly 1.5-2 metres), a new tunnel ring is built using the erector.
- The erector is a rotating system which picks up precast concrete segments and places them in the desired positions.
- Behind the shield, inside part of the finished tunnel, several support mechanisms (part of TBM) can be found.
- These support mechanism are dirt removal, slurry pipe lines, control rooms, rail for transport of the precast segments.

12.3.1.1 Tunnel Lining

- Tunnel lining is the wall of the tunnel. It usually consists of precast concrete segments which form rings.
- Additives such as bentonite, polymers and foam are injected into the ground to further stabilize it.

12.3.1.2 Types of TBM

(i) Mechanical support TBM

- It has a full face cutterhead which provides face support by constantly pushing the excavated material ahead of the cutter head against the surrounding ground.

(ii) Compressed air TBM
- It can have either a full face cutterhead or excavating arms.
- Confinement is achieved by pressurizing the air in the cutter chamber.

(iii) Slurry shield TBM
- It has a full face cutterhead.
- Confinement is achieved by pressurizing boring fluid inside the cutterhead chamber.

(iv) Earth pressure balance machine
- It has a full face cutterhead.
- Confinement is achieved by pressurizing the excavated material in the cutterhead chamber.

(v) Mix face shield TBM
- It has full face cutterhead.
- It can work in closed and open mode and with various confinement techniques.

12.3.2 Cut and Cover Tunnelling Method
- In this construction method, whereby the site is fully excavated, the structure built and covered over, uses diaphragm retaining walls within the site area.
- First we construct diaphragm wall, decking and pin piles at both left area and right area.
- Then, excavation is done within the diaphragm walls, installing struts as work progresses.
- Then, construction of permanent floor slabs and walls takes place.
- Finally, the internal structures are fitted out, backfilling is done and the surface structures are reinstated.

12.3.3 Drill and Blast
- Before the advent of TBMs, drilling and blasting was the only economical way of excavating long tunnels through hard rock, where digging was not possible.

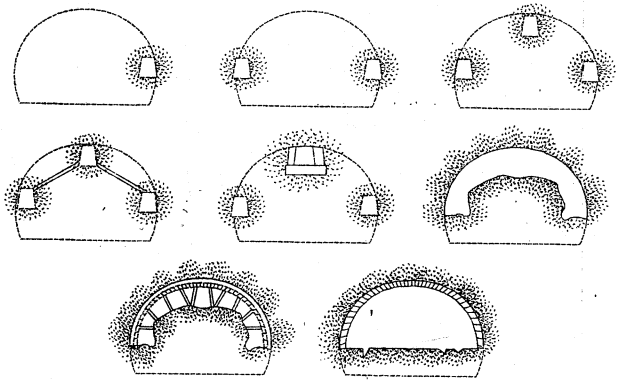


Fig. 12.4 How drill and blast is being done?

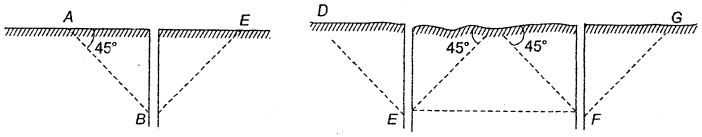


Fig. 12.5 Effect of blasting with (a) single hole, (b) double hole

- A drill hole normal to the quarry face when exploded with a proper charge will break out a crater whose sides are inclined at 45° as shown in figure.
- It is desirable to choose a depth such that the complete round of drilling, mucking, clean-up, setting up drills, firing and clearing smoke will be complete in one shift operation.

12.3.4 Immersed Tunnels
- These types of tunnels are partly or wholly underwater.
- In this type of method, there is no problem of congestion of traffic (as they do not block the route for ships), compared to bridges over riverse or seas.

12.3.5 Tunnel Jacking
- It is a process to make tunnels in already existing bodies such as roads and railway area.
- In this method, specially made pipes are pushed by hydraulic ram in ground.
- Maximum diameter of tunnel by this method is around 2.4 metre.

12.4 Tunnelling in Hard Rock

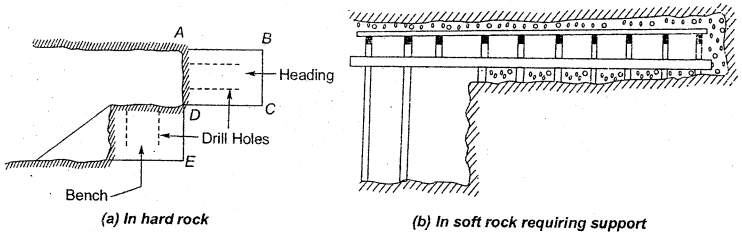


Fig. 12.6 Heading and bench method

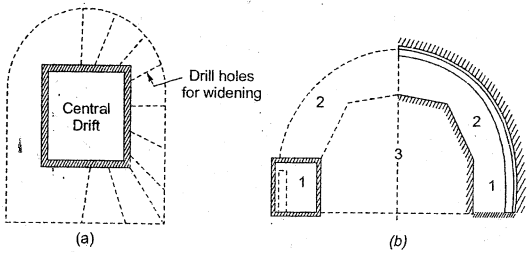


Fig. 12.7 (a) Central drift method, (b) Side drift method

The major methods of tunnelling in hard rock are:

(i) Full Face Method

- Whole section of the tunnel is attacked at the same time.
- It is suitable only for small tunnels.

(ii) Heading and Bench Method

- After the heading (8 to 10 ft. deep) has been formed as shown in Fig. 12.6 all the drill holes in the head and bench are loaded together for blasting.
- Bench is fired an instant before the top heading holes are fired.
- Most of the muck from the heading ABCD is thrown from the bench and the rest is cleared by labour.
- The advantage of this method is that while mucking operation is in progress, drilling can go on the heading, thus providing simultaneous drilling and mucking operation.
- When bad ground is encountered, longer headings (50-75 ft. deep) are provided and the roof arch is supported by shuttering. While excavating the bench posts are provided to support the roof arch shuttering.

(iii) Drift Method

This method is divided into central drift method and side drift method.

(a) Central drift method

- When the smaller section of the tunnel chosen for mining lies in the centre, it is known as central drift method.
- Central drift is carried out from portal to portal or between two exits.
- This method is economical in use of dynamite and provides good ventilation during widening.
- In bad ground, when central drift method is employed, the arch portion is excavated immediately after the centre drift.

(b) Side drift method

- The side drift represented as 1 in Fig. 12.7(b) is extended along the sides as shown by 2.
- Core no. 3 which is mined last, provides a working platform for mining core no. 2 close to the roof.

Summary

- Operations involved in a bored tunnelling are:
  (i) Prob drilling (ii) Grouting
  (iii) Excavation (iv) Supporting
  (v) Transportation of muck (vi) Lining
  (vii) Draining (viii) Ventilation
- Tunnel boring machine consists of a shield and trailing support mechanism.
- Cut and cover tunnelling method uses diaphragm retaining walls within the site area.
- Tunnel blasting is done by drilling holes in a set pattern.
- Major methods of tunnelling in hard rock are:
  (i) Full face method
  (ii) Heading and bench method
  (iii) Drift method

Objective Brain Teasers

Q.1 For highways, tunnelling is preferred to if the open cut exceeds.
(a) 10 metres depth
(b) 15 metres depth
(c) 20 metres depth
(d) 25 metres depth

Q.2 In case of railways,
(a) a detour round the hill is preferred
(b) a open cut is preferred
(c) tunnelling is preferred
(d) All the above

Q.3 Pick up the correct statement from the following:
(a) The topographical maps of the Survey of India are useful in the mountainous region for tunnelling.
(b) The height point on the ridge is fixed with the help of reciprocal ranging.
(c) The accuracy of 1 in 1000 is required for planimetric control
(d) All of the above

Q.4 Which of the following statements is not correct in respect of setting of an inclined tunnel:
(a) Reference points are constructed at every 300 m.
(b) The alignment is fixed from upper/lower apex point.
(c) The level of the invert at the heading is marked by a tape.
(d) None of above

Q.5 For transferring the tunnel alignment through shafts, we adopt the following steps:
1. Hanging two or more plumb lines in the shaft
2. Determining the bearing of the plumb lines i.e. plumb plane
3. Suspending a 35 kg weight by each plumb line
4. Immersing the weight of both the plumb lines in the buckets containing water.

The correct sequence of steps is:
(a) 1 2 3 4 (b) 4 3 2 1
(c) 1 3 2 4 (d) 2 1 4 3

Q.6 For B.G. single track, the section of the tunnel must have a width
(a) 4.2 m to 4.5 m (b) 4.5 m to 4.8 m
(c) 4.9 m to 5.5 m (d) 5.5 m to 5.8 m

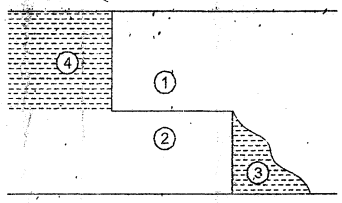
Q.7 For B.G. single track railway, the height of the tunnel above top of the rails should be
(a) 5.5 m to 5.8 m (b) 4.5 m to 4. 8 m
(c) 6.7 m to 7.3 m (d) 7.3 m to 7. 5 m

Q.8 For tunnels exceeding 300 m in length, the grade should be provided below
(a) 50% of the ruling gradient
(b) 60% of the ruling gradient
(c) 75% of the ruling gradient
(d) 80% of the ruling gradient

Q.9 Which one of the following methods is generally adopted for tunnelling in firm ground
(a) Full face method
(b) Top heading and benching method
(c) Drift method
(d) All the the above

Q.10 For full face method, the excavation to be done is generally divided into
(a) two sections (b) three sections
(c) four sections (d) five section

Q.11 In the below figure drill holes, heading, mucking and benching are numbered as 1, 2, 3, 4.



The correct sequence is:
(a) 4 1 2 3 (b) 1 2 3 4
(c) 4 1 3 2 (d) 3 4 1 3

Q.12 Railway tunnels, are generally
(a) polycentric (b) rectangular
(c) running ground (d) None of these

Q.13 In case of drift method of tunnelling, the drift may be excavated at
(a) the centre (b) the bottom
(c) the top (d) All of the above

Q.14 The following operations are generally employed for tunnelling in hard rock.
1. Removing ground water,
2. Loading holes and firing the explosive
3. Setting up and drilling
4. Grouting and lining
5. Removing muck
6. Ventilation and removing explosion
The correct sequence is:
(a) 3 2 6 5 1 4
(b) 3 4 6 1 5 2
(c) 4 1 2 3 6 5
(d) 5 4 2 1 3 6

Q.15 Which one of the following methods of tunnelling does not require the use of time bearing :
(a) Linear plate method
(b) Shield method
(c) Compressed air method
(d) Mechanical tunneler i.e. mole method

Q.16 The following operations are required for tunnelling in rocky terrain:
1. Removing the foul gases
2. Marking the tunnel profile
3. Setting up and drilling
4. Checking misfire
5. Mucking
The correct sequence is:
(a) 1 2 3 4 5 (b) 2 3 5 4 1
(c) 4 2 1 3 5 (d) 2 3 1 4 5

Q.17 Pick up the correct statement regarding drilling a tunnel from the following:
(a) Holes are drilled by pneumatically operated rock drills
(b) One drill is required for each 4 to 5 m^2 force area
(c) The diameter of the bore hole at the deepest point should be 6 mm more than the diameter of the cartridge
(d) All of the above

Q.18 Pick up the correct statements from the following during tunnel exacavation
(a) Oxygen should not be less than 19.5%
(b) Carbondioxide should not be more than 0.5%
(c) Hydrogen sulphide should not be more than 0.001%
(d) All of the above

Q.19 Which one of the following linings is suitable for shield driven tunnels particularly in the subaqueous regions:
(a) Brick lining (b) stone lining
(c) timber lining (d) cast iron lining

Q.20 Concrete lining is provided concurrently with the driving operation in case of
(a) rock terrain (b) soft rock
(c) running soil (d) None of these

Q.21 For hauling muck from the tunnel, the following type of muck-car is used.
(a) muck box (b) balle-ship
(c) side dump car (d) All of these

Answers

1. (b)	2. (c)	3. (d)	4. (d)	5. (a)
6. (c)	7. (c)	8. (c)	9. (d)	10. (b)
11. (c)	12. (a)	13. (d)	14. (b)	15. (b)
16. (a)	17. (d)	18. (d)	19. (d)	20. (a)
21. (d)				