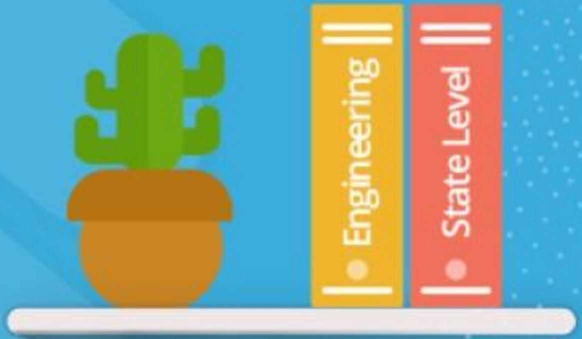

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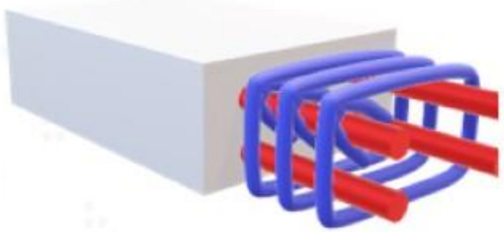
Design of Concrete Structures

By Sandeep Jyani Sir

02-08-2019



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Syllabus

Design of Concrete Structures

1. **Working Stress method**
2. **Limit State method**
3. **Analysis and design of singly reinforced and doubly reinforced sections**
4. **Shear, bond and development length**
5. **Analysis and design of T Beam, slab, axially loaded column and footings.**

Reinforced Cement Concrete

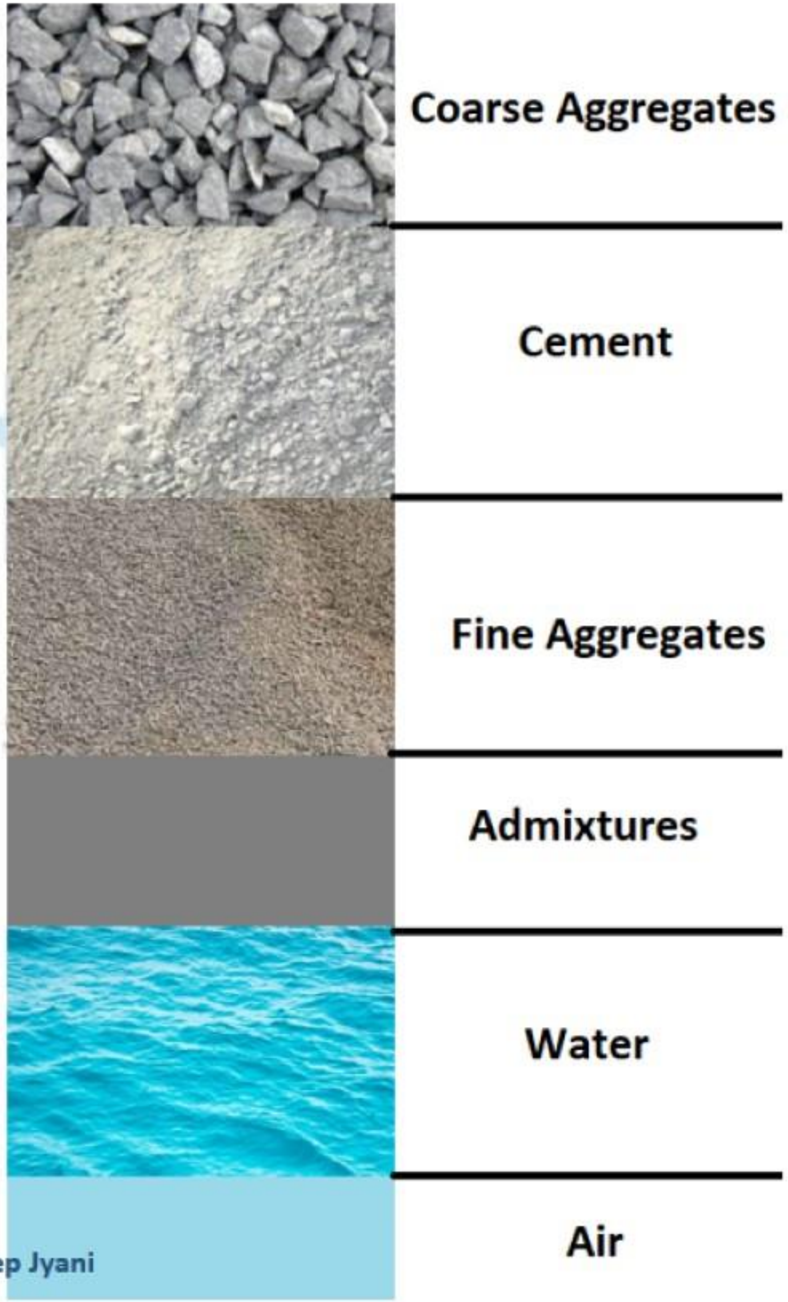
Reinforced Cement Concrete (RCC) is a composite mixture of Concrete and steel. Therefore, the structure formed is said to be Reinforced Cement Concrete Structure.

Some Important Codes

- IS 456: 2000 RCC
- IS 800: 2007 Steel (2007-LSM, 1984-WSM)
- IS 1343 Pre Stress Concrete
- IS 10262 Design Mix
- IS 383 Fine and Coarse Aggregate
- IS 875 Design Load for buildings and structures

Cement Concrete

It is a mixture of Cement, sand aggregate and water in a limited proportion .



Cement Concrete

It is a mixture of Cement, sand aggregate and water in a limited proportion .

The cement concrete is manufactured by two ways:

1. **Nominal Mix Concrete**
2. **Design Mix Concrete**

Cement Concrete

1. Nominal Mix Concrete

- Quality control is sacrificed
- Hard to determine the assurance of quality and strength of the concrete corresponding to the desired strength
- In a nominal mix, material for for the concrete like cement, sand and aggregate is not placed under ideal conditions before mixing
- Skilled workmanship is also sacrificed due to which required strength is not achieved

Grade of Concrete	Proportion (Cement: Fine aggregate: Coarse aggregate)
M5	1 : 5 : 10
M10	1 : 3 :6
M15	1 : 2: 4
M20	1 : 1.5 :3

Cement Concrete

2. Design Mix Concrete

- It is the ideal mix of the concrete for ideal strength
- Materials used like cement, sand, aggregate are always placed under ideal temperature and ideal humidity
- Skilled workmanship is used to achieve the ideal proportion of the mix
- In Design mix, Concrete is manufactured at the nodal place called Batching Plant and there after it is transported to the site through *transit mixture*
- During the process of transportation, the ideal temperature for the ideal proportion mix is maintained through admixtures like plasticizers and super plasticizers, which do not alter the strength of the mix proportion of concrete but delay the setting time of the concrete

Characteristic Compressive Strength

As per IS 456:2000, the value of strength below which not more than 5% of the test results are expected to fall

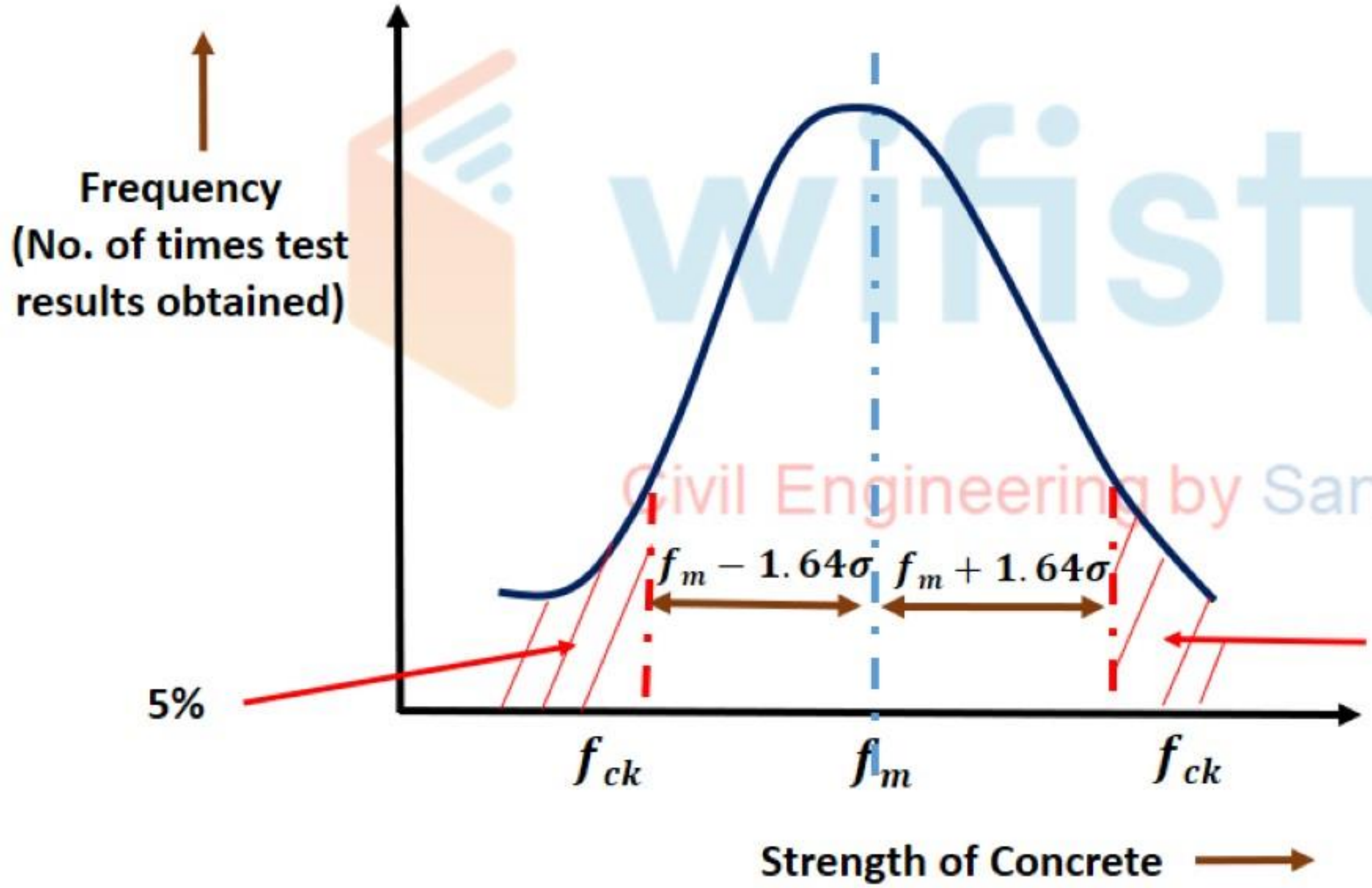
Mean Strength

It is the strength in which the 50 percent of test results are expected to fall and 50 percent are expected to pass. The strength is called Mean Strength

Confidence Limit

Confidence Limit is the maximum probability of a particular test result shall be within a range of $f_m - 1.64\sigma$ to $f_m + 1.64\sigma$

Probabilistic Curve



$\sigma = standard\ deviation$
$(depends\ on\ grade\ of\ concrete)$

$$f_m = fck + 1.64\sigma$$

$$=> f_{ck} = fm - 1.64\sigma$$

$$f_m = fck - 1.64\sigma$$

5% $$=> f_{ck} = fm + 1.64\sigma$$

$$\boxed{=> f_{ck} = fm \pm 1.64\sigma}$$

Young's modulus of Elasticity of Concrete

As per IS 456: 2000, young's modulus of elasticity of concrete is …

$$E_c = 5000\sqrt{f_{ck}}$$

$$f_{ck} = \text{Characteristic compressive strength}$$

Young's modulus of Elasticity of Concrete

As per IS 456: 2000, young's modulus of elasticity of concrete is …

$$E_c = 5000\sqrt{f_{ck}}$$

For example, for M25,

Mix

Characteristic compressive strength (N/mm²)

So, $E_c = 5000\sqrt{f_{ck}}$

$$E_c = 5000\sqrt{25}$$

$$E_c = 5000 \times 5 = 25000\ N/mm^2$$

Grades of Concrete

Group	Designation	Characteristic Compressive Strength OF 150mm cube at 28 days (N/mm^2)
Ordinary Concrete	M10	10
	M15	15
	M20	20
Standard Concrete	M25	25
	M30	30
	M35	35
	M40	40
	M45	45
	M50	50
	M55	55
	M60	60
High Strength Concrete	M65	65
	M70	70
	M75	75
	M80	80
	M85	85
	M90	90
	M95	95
	M100	100

Grades of Concrete

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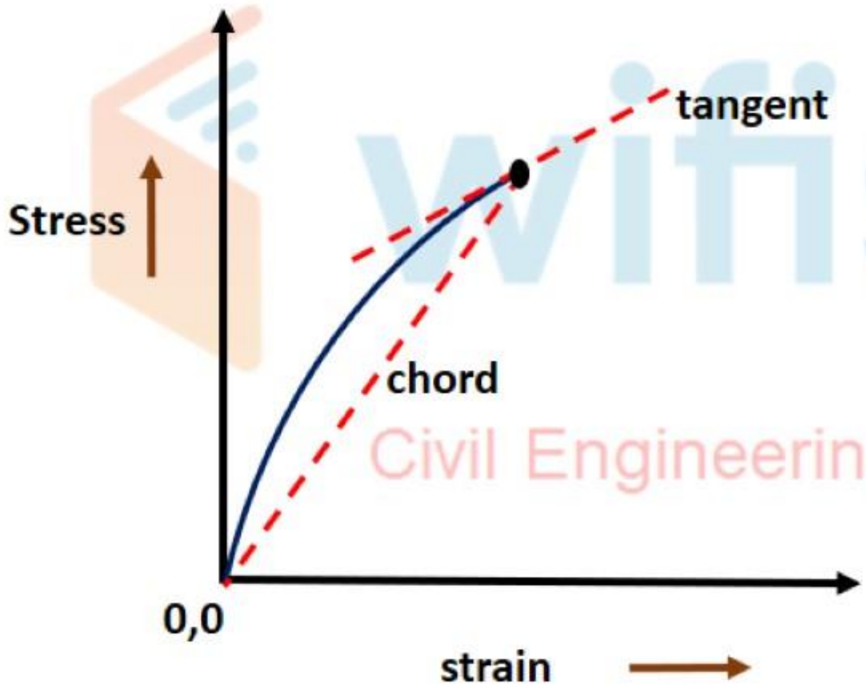
	M45	45
	M50	50
	M55	55
	M60	60
High Strength Concrete	M65	65
	M70	70
	M75	75
	M80	80
	M85	85
	M90	90
	M95	95
	M100	100

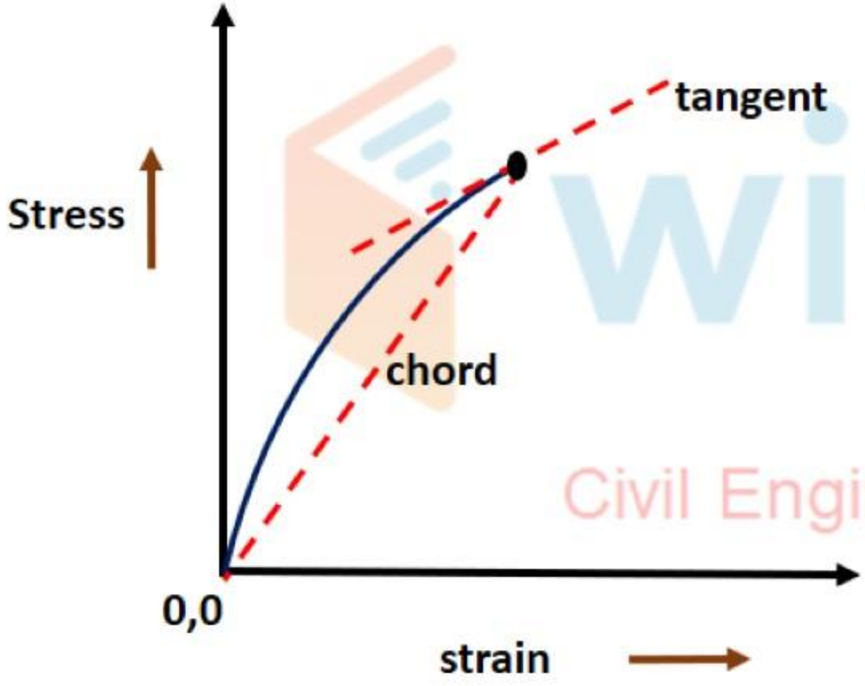
Important Notes

- The minimum grade of concrete for RCC work as per IS code recommendation is M20

Young's Modulus of Elasticity



Young's Modulus of Elasticity



Young's modulus of elasticity of concrete is also called as Young's modulus of Elasticity at origin

$$E_c = 5000\sqrt{f_{ck}}$$

Secant Young's modulus of elasticity of concrete slope of line joining any point with the origin.

Tangent Young's Modulus of Elasticity is the slope of tangent on any point on a curve

Effect of Creep on Young's Modulus of Elasticity

- Long term Young's Modulus of Elasticity of concrete

$$E_{CL} = \frac{5000\sqrt{f_{ck}}}{1+\theta}$$

Where θ is the creep coefficient

Effect of Creep on Young's Modulus of Elasticity

- **Long term Young's Modulus of Elasticity of concrete**

$$E_{CL} = \frac{5000\sqrt{f_{ck}}}{1+\theta}$$

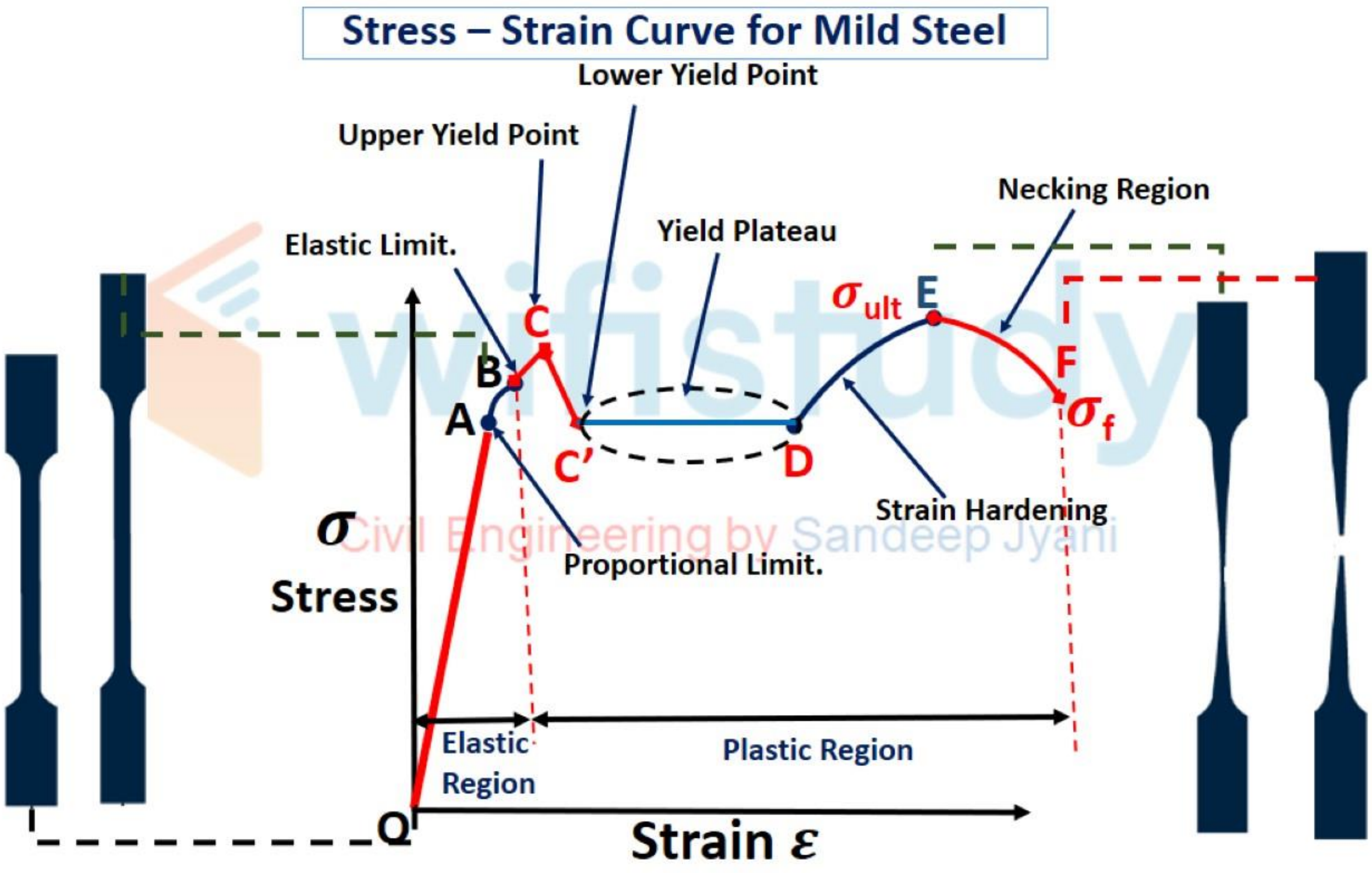
Where θ is the creep coefficient

Age of Loading	θ
7 days	2.2
28 days	1.6
1 year	1.1

Creep Strain is strain which occurs due to continuous loading and temperature effect for longer duration which may cause permanent deformation

Tensile Strength of Concrete in Flexure

$$f_{ct} = 0.7\sqrt{f_{ck}}$$



Stress – Strain Curve for Mild Steel
Lower Yield Point
Upper Yield Point
Necking Region
Yield Plateau
Elastic Limit.
σ_{ult} E
C
B
F
A
σ_f
C'
D
Strain Hardening
σ
Proportional Limit.
Stress
Elastic
Region
Plastic Region
Q
Strain ε

Types of Steel

Note: The Young's Modulus of Elasticity of steel for all types of grade is $2 \times 10^5\ N/mm^2$

1. Mild Steel:

- **The grade of Mild Steel is Fe-250**

$$\underset{\text{Iron}}{Fe} - \underset{\text{yield stress or tensile strength}}{250}$$

- **For Fe-250, Permissible tensile stress/strength**
  - $\sigma_{st} = 140\ N/mm^2$ up to and including 20 mm dia bar
  - $\sigma_{st} = 130\ N/mm^2$ for bars greater than 20 mm dia
- **For Fe-250, Permissible compressive stress/strength**
  - $\sigma_{sc} = 130\ N/mm^2$

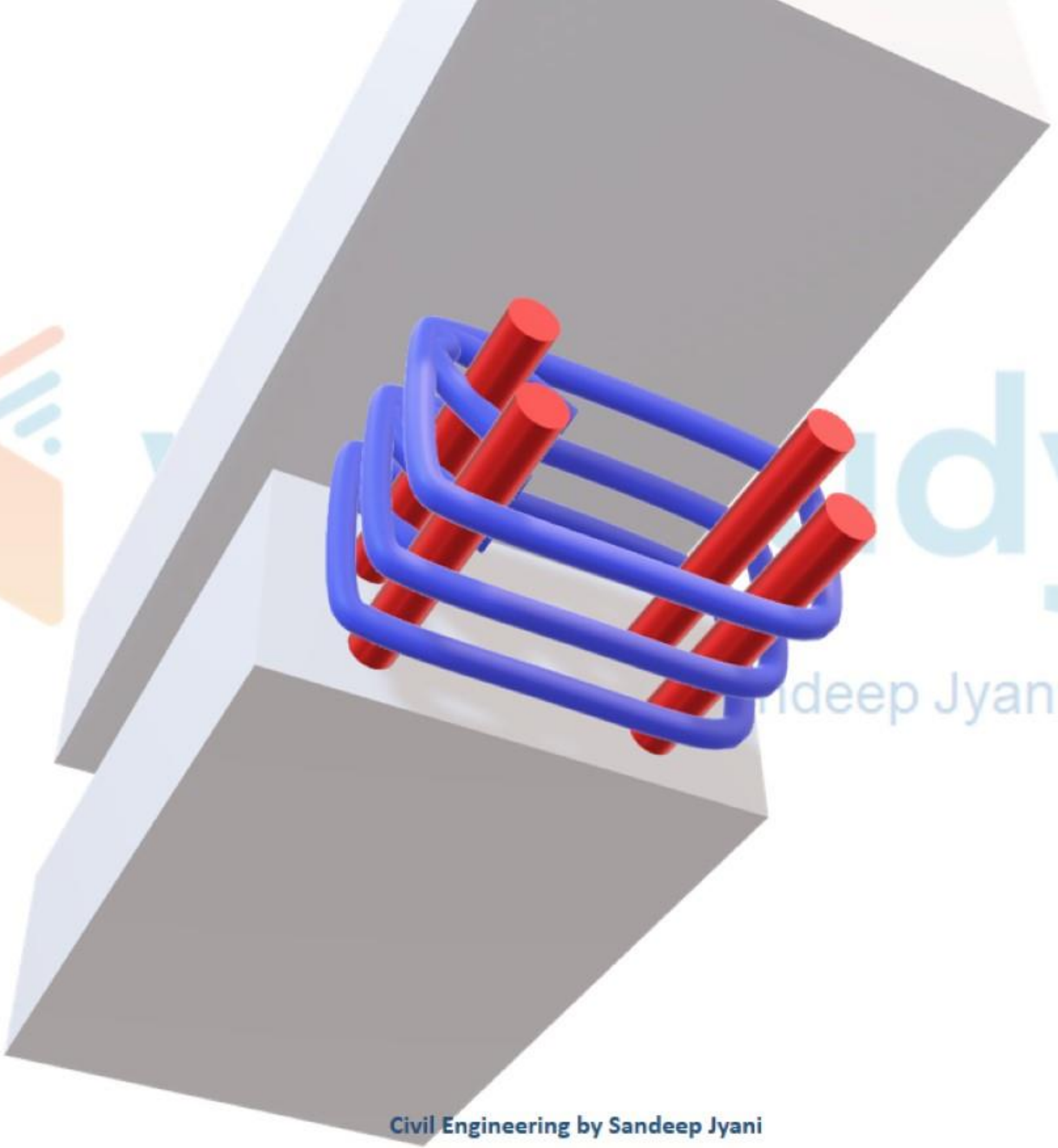
Types of Steel

2. Medium Tensile Strength Steel:

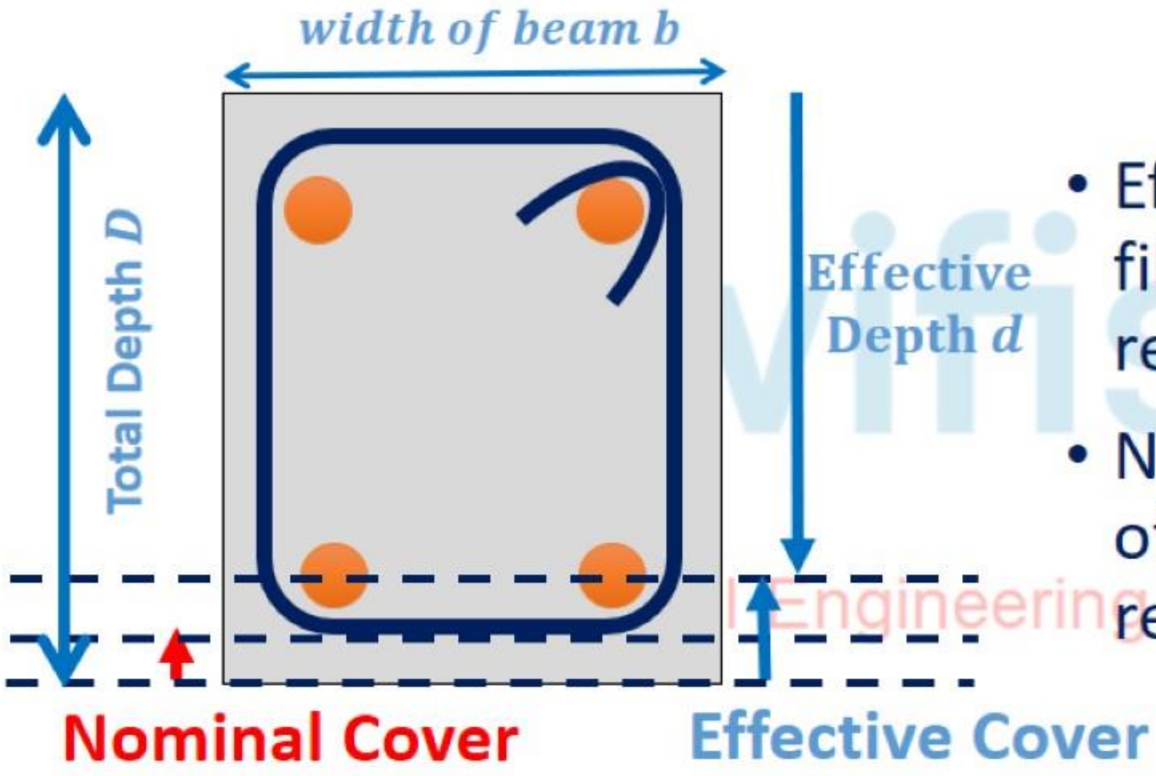
- $\sigma_{st} = \sigma_{sc} = 190\ N/mm^2$

3. HYSD (High Yield Strength Deformed Bar)

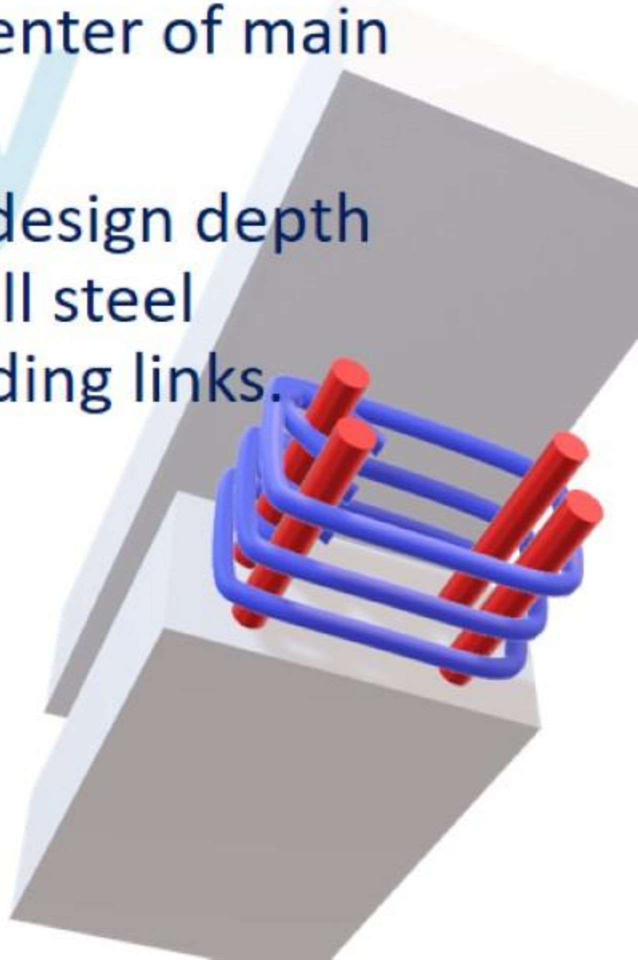
- Manufactured by hot rolled process
- It exists in two categories: Fe-415 and Fe-500
- For both Fe-415 and Fe-500,
  - $\sigma_{st} = 230\ N/mm^2$
  - $\sigma_{sc} = 190\ N/mm^2$



Nominal Cover and Effective Cover

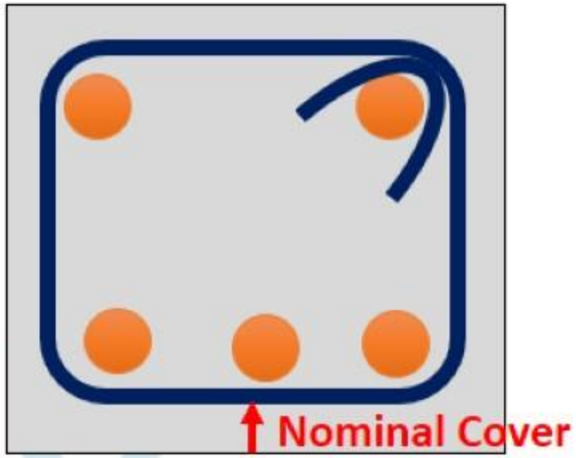


- Effective Cover: Cover from outer fiber of concrete to Center of main reinforcement
- Nominal cover is the design depth of concrete cover to all steel reinforcements, including links.



Nominal Cover

- Nominal cover is the design depth of concrete cover to all steel reinforcements, including links.
- It is the dimension used in design and indicated in the drawings. It shall be not less than the diameter of the bar.



IS 456 : 2000

Table 16 Nominal Cover to Meet Durability Requirements
(*Clause* 26.4.2)

Exposure	Nominal Concrete Cover in mm not Less Than	Minimum grade of concrete
Mild	20	M20
Moderate	30	M25
Severe	45	M30
Very severe	50	M35
Extreme	75	M40

NOTES

1 For main reinforcement up to 12 mm diameter bar for mild exposure the nominal cover may be reduced by 5 mm.

2 Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by $^{+10}_{\ 0}$ mm

3 For exposure condition 'severe' and 'very severe', reduction of 5 mm may be made, where concrete grade is M35 and above.

Exposure Conditions

Sr. No	Environment	Exposure Conditions
1	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
2	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet, Concrete exposed to condensation and rain, Concrete in contact or buried under non-aggressive soil / ground water.
3	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation.
4	Very severe	Concrete completely immersed in sea water, concrete exposed to coastal environment, concrete surfaces exposed to sea water spray, corrosive fumes or severe freeing conditions whilst wet.
5	Extreme	Concrete in contact with or buried under aggressive sub-soil / ground water, surface of members in tidal zone, members in direct contact with liquid / solid aggressive chemicals.

Nominal Value of Cover in “mild exposure”

1.	Slab	20mm
2.	Beam	25mm
3.	Column	40mm
4.	Foundation	50mm

Minimum grade of concrete used in construction

1. PCC	M15
2. RCC	M20
3. Water Tank	M20
4. PCC Subjected to sea water	M20
5. RCC Subjected to sea water	M30
6. Pre stress/pre tension concrete	M40
7. Post tension zone	M30

Table 3 Environmental Exposure Conditions

(*Clauses* 8.2.2.1 *and* 35.3.2)

Sl No. (1)	Environment (2)	Exposure Conditions (3)
i)	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
ii)	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet
		Concrete exposed to condensation and rain
		Concrete continuously under water
		Concrete in contact or buried under non-aggressive soil/ground water
		Concrete surfaces sheltered from saturated salt air in coastal area
iii)	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation.
		Concrete completely immersed in sea water
		Concrete exposed to coastal environment
iv)	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet
		Concrete in contact with or buried under aggressive sub-soil/ground water
v)	Extreme	Surface of members in tidal zone
		Members in direct contact with liquid/ solid aggressive chemicals

Table 5 Minimum Cement Content, Maximum Water-Cement Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum Size

(*Clauses* 6.1.2, 8.2.4.1 *and* 9.1.2)

Sl No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content kg/m³	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Mild	220	0.60	–	300	0.55	M 20
iii)	Moderate	240	0.60	M 15	300	0.50	M 25
iii)	Severe	250	0.50	M 20	320	0.45	M 30
iv)	Very severe	260	0.45	M 20	340	0.45	M 35
v)	Extreme	280	0.40	M 25	360	0.40	M 40

Design Philosophies

The object of Reinforced Concrete Design is to achieve a structure that will result in a safe and economical solution.

Design Problem Consists of:

1. **Idealization of structure for analysis**
2. **Estimation of loads**
3. **Analysis of idealized structure model to determine axial thrust, shear, bending moments and deflection**
4. **Material specifications and detailing of reinforcement**
5. **Detailed structural drawings and schedule of reinforcing bars**

Design Philosophies

There are four philosophies for the design of Reinforced Concrete, pre stressed as well as steel structures:

1. **Working Stress Design**
2. **Ultimate Load Design**
3. **Limit State Design**
4. **Performance Based Design**

Design Philosophies

1. **Working Stress Design**
   - Traditional method of design
   - It is assumed that concrete is elastic
   - Steel and Concrete together behaves elastically
   - The basis of this method is that the permissible stress for concrete and steel are not exceeded in any worst combination of working load
   - The sections are designed assuming the materials obey Hooke's law

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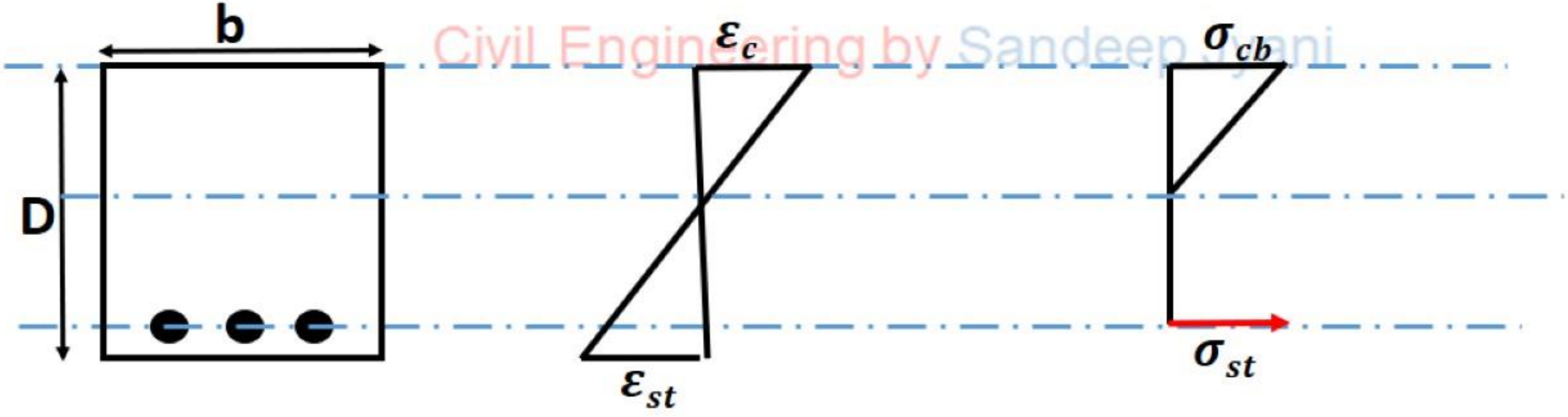

Design Philosophies

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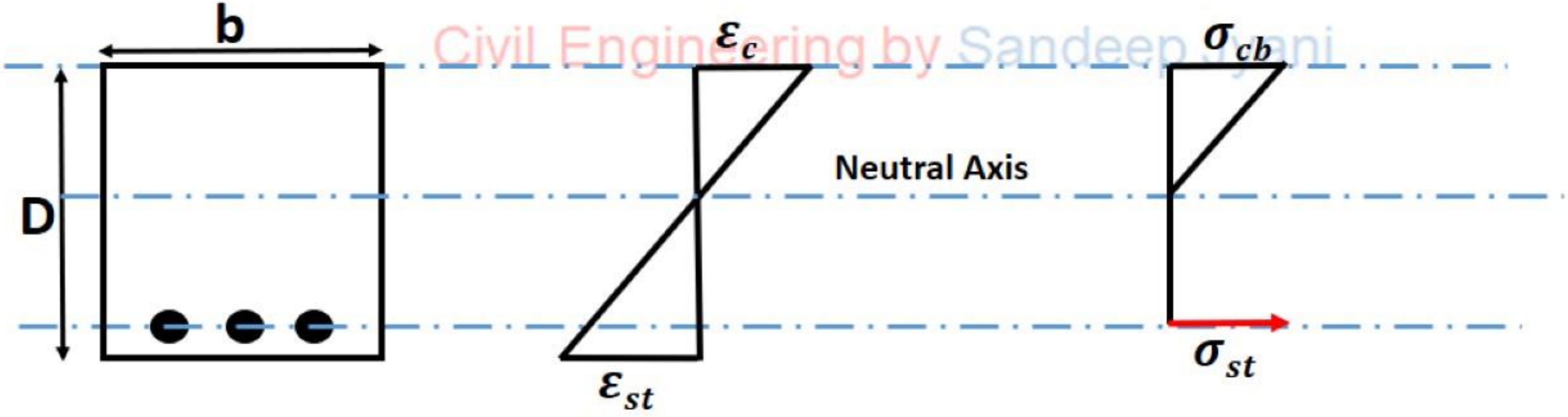
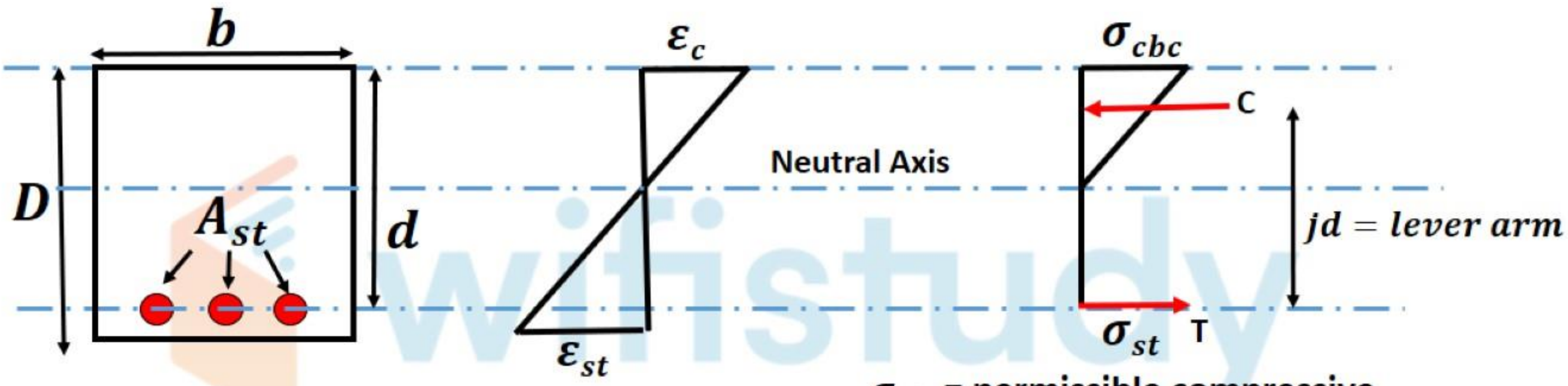


1. Working Stress Design



b = width of section

D= depth of section

d= effective depth of section

(depth from extreme compression fibre to centre of gravity of tensile steel)

A_{st} = area of steel in tension

σ_{cbc} = permissible compressive stress in concrete

σ_{st} = permissible tensile stress in steel

C= total force of compression

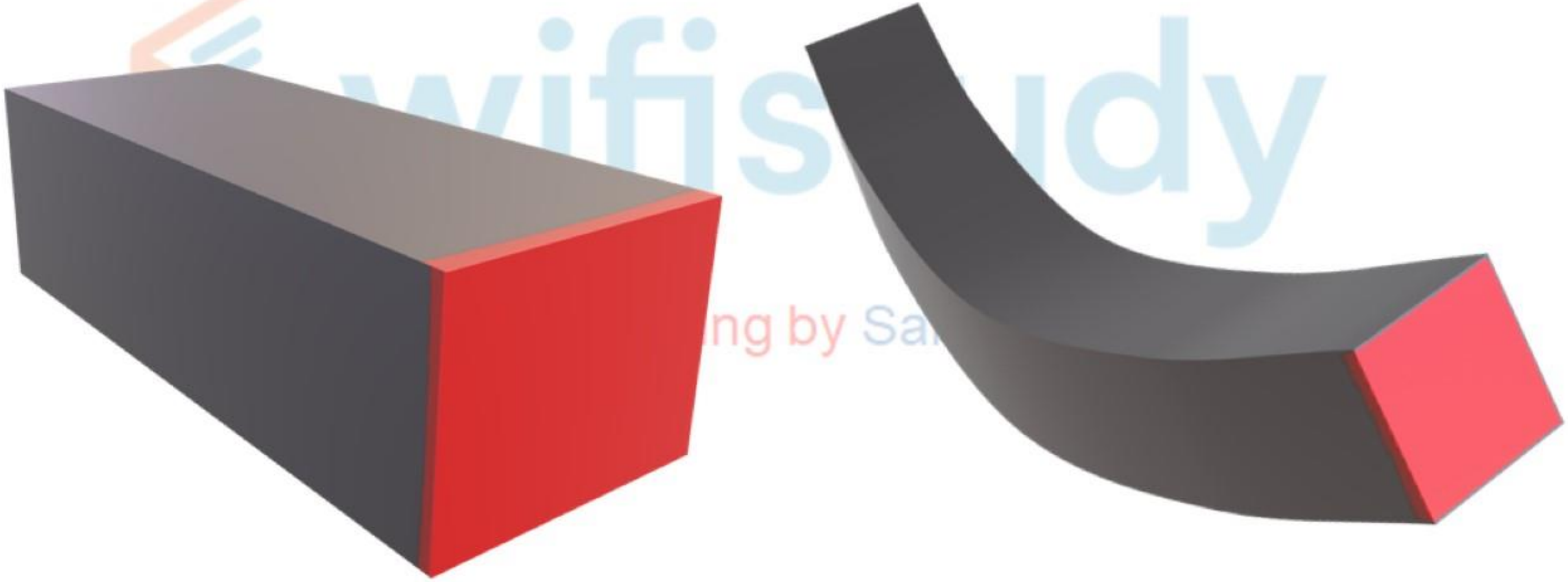
T = Total force of tension

$$jd = lever\ arm$$

(lever arm, defined as the distance between the point of application of force compression and force of tension)

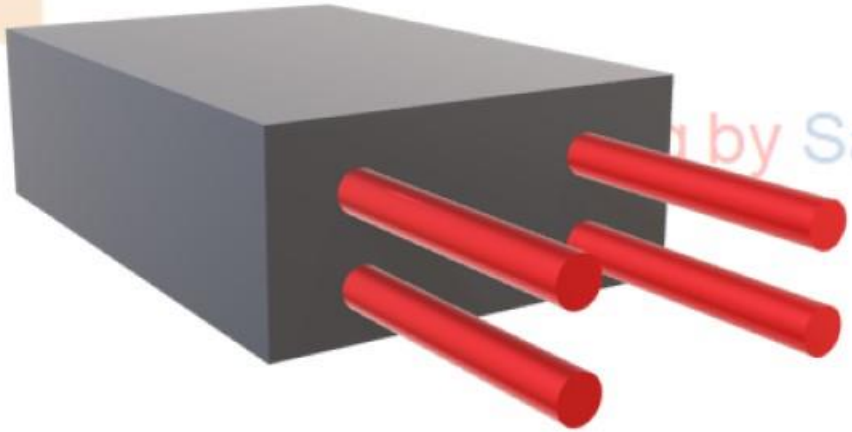
Assumptions in Working Stress Method:

- A section which is plane before bending remains plane after bending



Assumptions in Working Stress Method:

- A section which is plane before bending remains plane after bending
- Bond between steel and concrete is perfect within elastic limit of steel



Assumptions in Working Stress Method:

- A section which is plane before bending remains plane after bending
- Bond between steel and concrete is perfect within elastic limit of steel
- Tensile strength of concrete is ignored
- Concrete is elastic, i.e. stress in concrete varies linearly from zero at neutral axis to a maximum at the extreme fiber

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- A section which is plane before bending remains plane after bending
- Bond between steel and concrete is perfect within elastic limit of steel
- Tensile strength of concrete is ignored
- Concrete is elastic, i.e. stress in concrete varies linearly from zero at neutral axis to a maximum at the extreme fiber

Drawbacks of Working Stress Method:

- Concrete is not elastic
- Difficult to account for shrinkage and creep in WSM

Design Philosophies

2. Ultimate Load Design Method

- Working loads are increased by suitable load factors to obtain ultimate loads
- Structure is then designed to resist ultimate load
- Non linear stress strain behavior of concrete is observed

Design Philosophies

3. Limit State Method

- **Limit state is the state at which the structure becomes unfit for use**

Two types of Limit states :

1. **Limit state of Collapse**
    - Also known as Ultimate Limit State
    - Adequate margin of safety shall be available for normal overloading
    - This includes limit state of strength like overturning, sliding, buckling, fatigue, flexure, compression, etc
2. **Limit State of Serviceablity**
    - Satisfactory performance under service load (deflection, crack, vibration, leakage, loss of durability, etc)
    - If a structure has reached just before the limit state of serviceability and loads are removed, the structure regains its original shape, however a structure achieving Collapse load can not recover its original shape and dimension

PERMISSIBLE STRENGTH OF CONCRETE by WORKING STRESS METHOD

Grade of concrete	Bending stress in compression σ_{cbc} N/mm^2	Direct stress in compression N/mm^2	Average bond stress for plain tension bars N/mm^2
M 10	3.0	2.5	-
M 15	5.0	4.0	0.6
M 20	7.0	5.0	0.8
M 25	8.5	6.0	0.9
M 30	10.0	8.0	1.0
M 35	11.5	9.0	1.1
M 40	13.0	10.0	1.2
M 45	14.5	11.0	1.3
M 50	16.0	12.0	1.4

Singly Reinforced Section

- **Modular ratio:**

$$m = \frac{Young's\ modulus\ of\ elasticity\ of\ steel}{Young's\ modulus\ of\ elasticity\ of\ concrete}$$

  - **As per IS code modular ratio is modified by considering the creep factor partially and it is given by**

$$m = \frac{280}{3\,\sigma_{cbc}}$$

Que 1. Calculate Modular ratio for M20

Note: Total load = concrete + steel

=> $P = PC + PS$

$\Rightarrow P = \sigma_c A_c + \sigma_s A_s$ ……(1)

Any elongation $\Delta Lc = \Delta Ls$ ….(2)

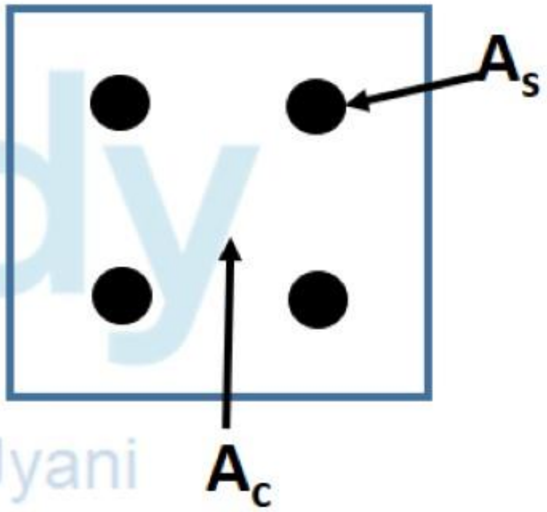
Hence,

$\Rightarrow \frac{P_C L_c}{A_c E_c} = \frac{P_s L_s}{A_s E_s}$

$\Rightarrow \frac{\sigma_c}{E_c} = \frac{\sigma_s}{E_s}$

$\Rightarrow \frac{\sigma_c}{\sigma_s} = \frac{E_c}{E_s}$

$\Rightarrow \sigma_c = \frac{\sigma_s}{m}$



Note: Total load = concrete + steel

=> $P = PC + PS$

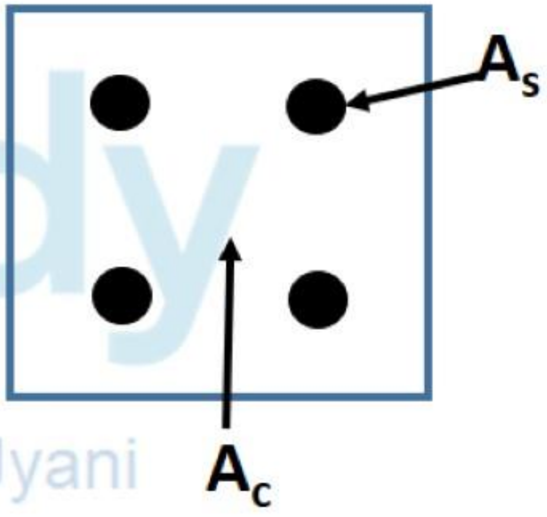
$\Rightarrow P = \sigma_c A_c + \sigma_s A_s$ ......(1)

$\Rightarrow \sigma_c = \frac{\sigma_s}{m}$

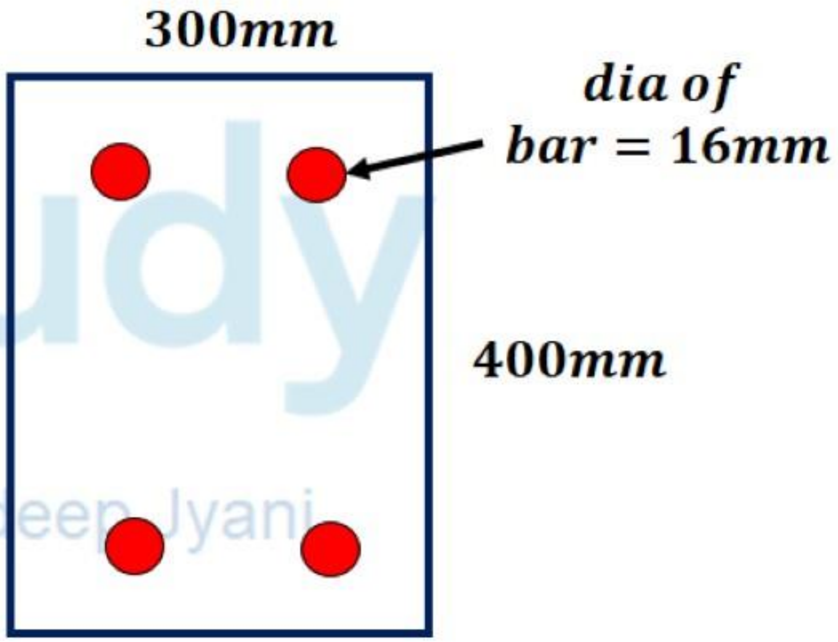
$\Rightarrow P = \sigma_c (A_c + mA_s)$

$\Rightarrow$The equivalent area of steel in terms of concrete is mA_s

$\Rightarrow$Equivalent total area in terms of concrete is $(A_c + mA_{st})$



Que 2. A beam has a section as shown. Find the total equivalent area in terms of concrete for M20.

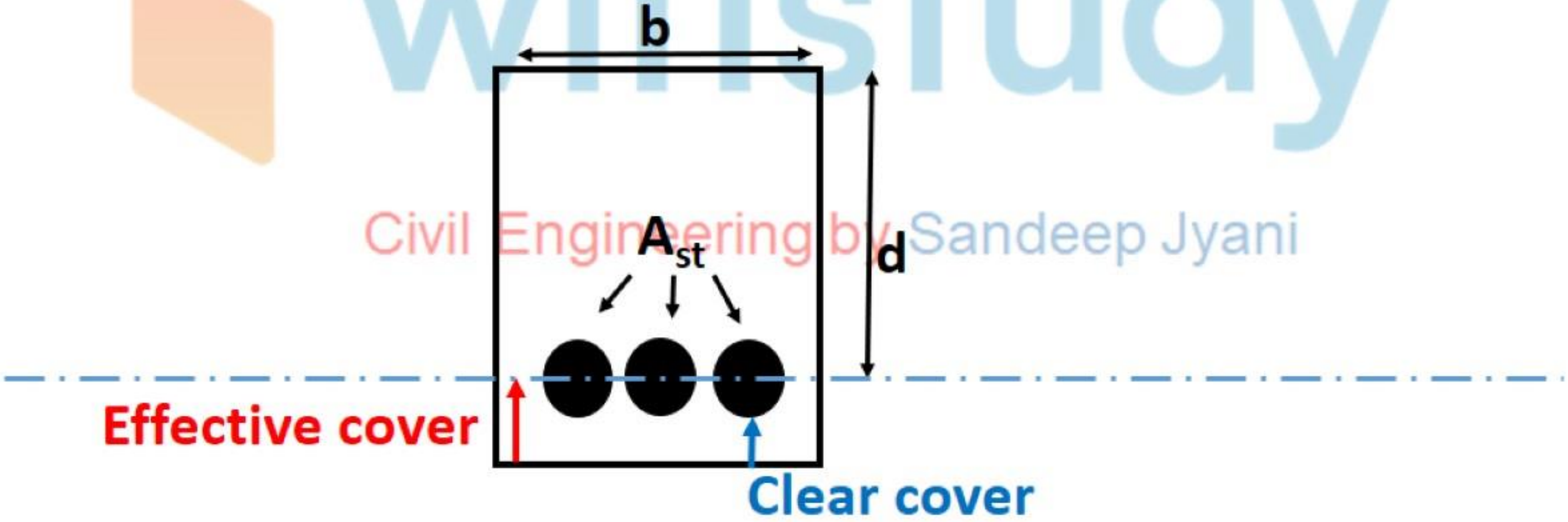


Assumptions in Singly Reinforced Structure

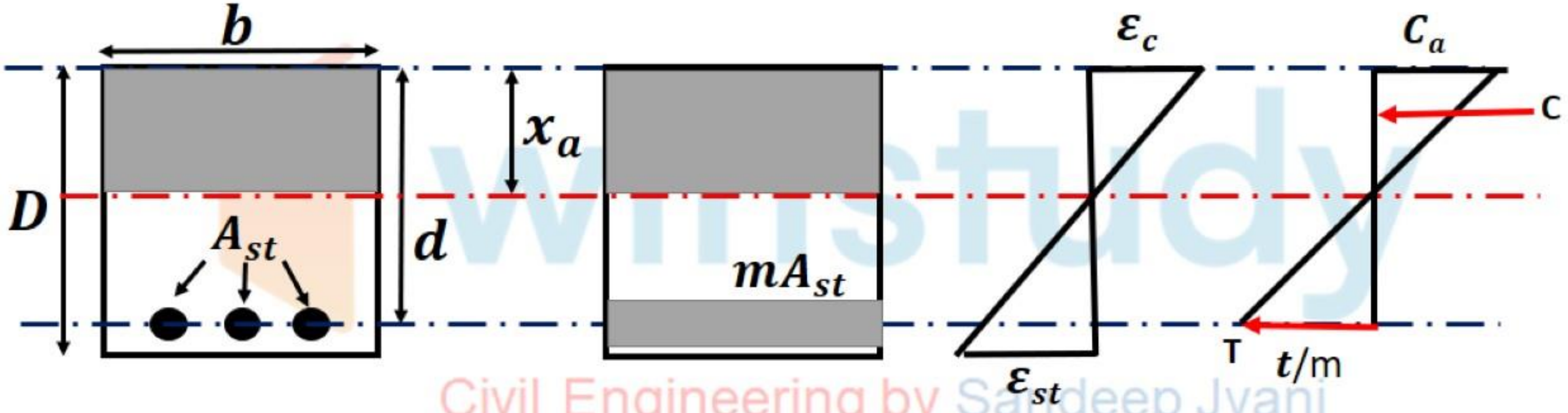
1. **Plane sections remains plane before and after bending (stress strain diagram is linear before and after bending)**
2. **All tensile stresses are taken up by steel reinforcement and none by concrete.**
3. **Young's modulus of elasticity for concrete is assumed constant**
4. **The modular ratio m has the value $280/3\sigma_{cbc}$**
5. **There is a perfect adhesion between steel and concrete and no slip takes place between steel and concrete.**

Analysis of Singly Reinforced Section

- Given data B, D, effective cover, A_{st} , f_{ck} , f_y

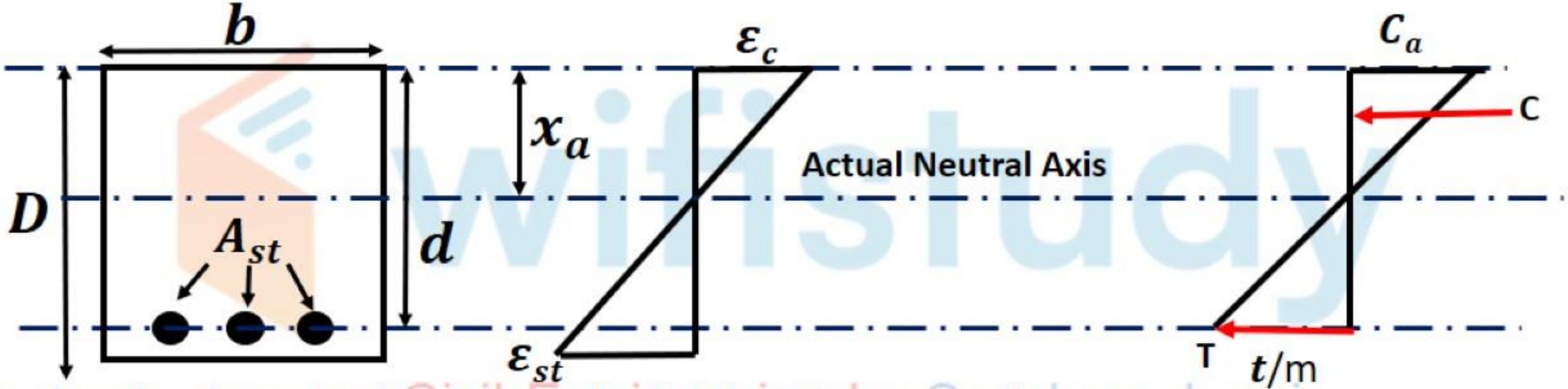


Analysis of Singly Reinforced Section



Analysis of Singly Reinforced Section

Step 1 Actual depth of Neutral axis (x_a)



- It is depth of Neutral axis which divides the overall section in compression and tension
- It is depth that tells overall failure is due to concrete or steel or both
- It is depth of Neutral axis which may be calculated by equating the moment of area of compression and tension

$$[b \times x_a] \times \frac{x_a}{2} = mA_{st} \times [d - x_a]$$

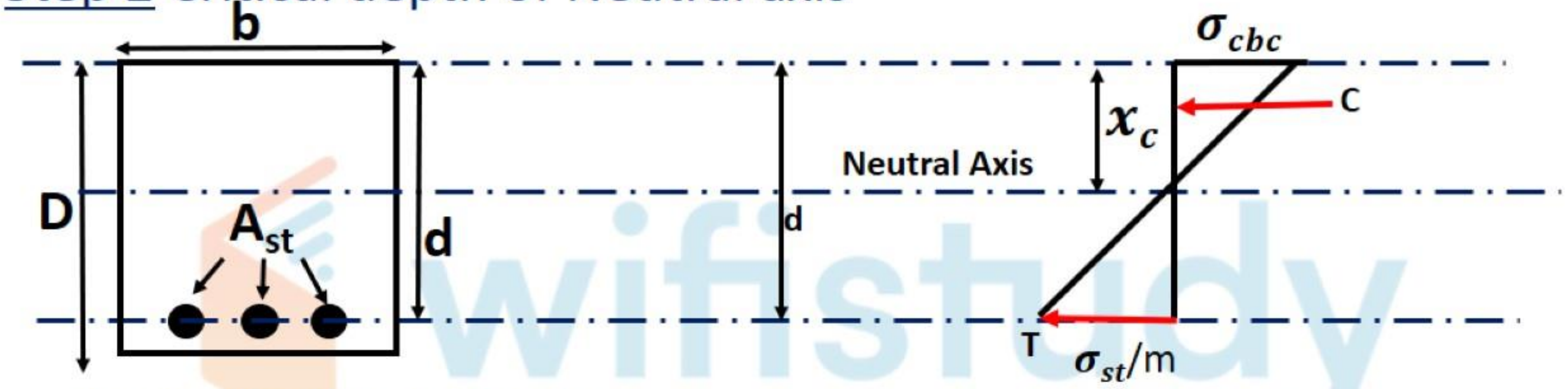
$$or \quad \frac{C_a}{x_a} = \frac{t/m}{d - x_a}$$

Analysis of Singly Reinforced Section

Step 2 Critical depth of Neutral axis

- Critical depth of neutral axis is the depth when steel and concrete fails simultaneously at that time overall structure fails
- This is the depth in which the variation can not exist, therefore it is also called as ideal depth of neutral axis

Step 2 Critical depth of Neutral axis



As per similar traingles,

$$\frac{\sigma_{cbc}}{x_c} = \frac{\sigma_{st}/\mathrm{m}}{d - x_c}$$

$$\Rightarrow \frac{x_c}{\mathrm{m}\sigma_{cbc}} = \frac{d - x_c}{\sigma_{st}}$$

$$\Rightarrow \frac{\sigma_{st}}{\mathrm{m}\sigma_{cbc}} = \frac{d - xc}{x_c}$$

$$\Rightarrow \frac{\sigma_{st}}{\mathrm{m}\sigma_{cbc}} = \frac{d}{x_c} - 1$$

$$\Rightarrow x_c = \frac{\mathrm{m}\sigma_{cbc}}{\mathrm{m}\sigma_{cbc} + \sigma_{st}} \times d$$

$$\Rightarrow x_c = k \times d$$

⇒Critical depth depends upon d and σ_{st} only

Step 2 Critical depth of Neutral axis

$$\Rightarrow x_c = \frac{m\sigma_{cbc}}{m\sigma_{cbc}+\sigma_{st}} \times d$$

$$\Rightarrow x_c = k \times d$$

Grade of Steel	Fe 250	Fe 415	Fe 500
K	0.40	0.289	0.253

Step 3 **Comparison between Actual Neutral axis and critical neutral axis**

- $x_a < x_c$; $\textit{Under Reinforced section}$
- $x_a = x_c$; $\textit{Balanced section}$
- $x_a > x_c$; $\textit{Over Reinforced section}$

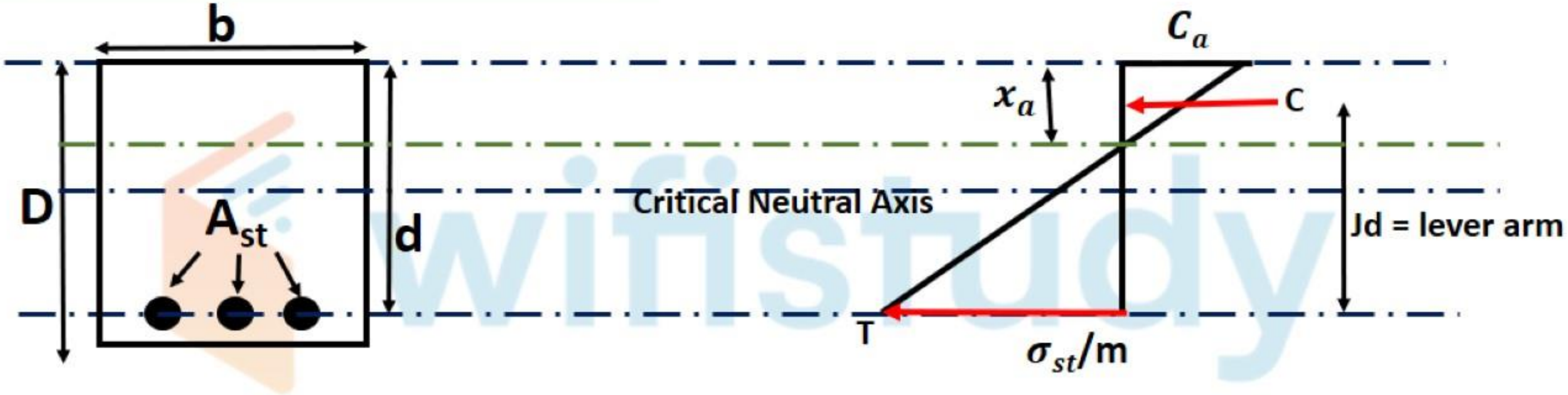
Step 4 Moment of Resistance

Bending moment: It depends upon the intensity of load which may be equal to moment of resistance or may not be equal

Moment of Resistance: It is the ***maximum capacity of the section*** to carry the maximum bending moment at which either the one material fails or both the materials fail

Step 4 Moment of Resistance

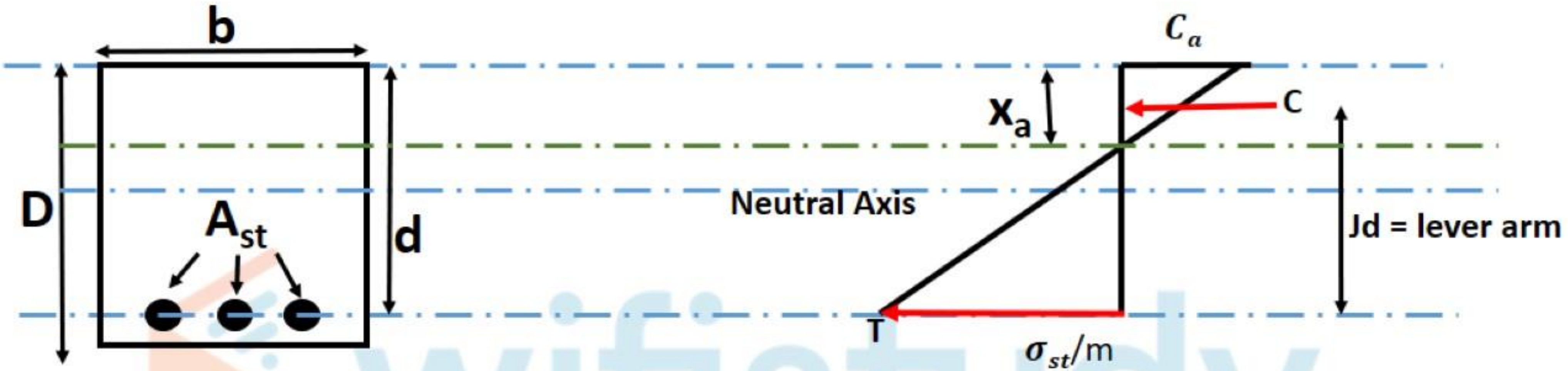
Case1: Under Reinforced section



MR for compression = Compressive force x Lever arm

= (average stress x area under stress) x lever arm

$$(MR)_{comp} = \left\{b \times x_a \times \left[\frac{C_a + 0}{2}\right]\right\} \times \left(d - \frac{x_a}{3}\right)$$



Step 4 Moment of Resistance

Case1: Under Reinforced section

MR for tension= tension force x Lever arm

= (average stress x area under stress) x lever arm

$$(MR)_{tension} = \left\{\frac{\sigma_{st}}{m} \times mA_{st}\right\} \times \left(d - \frac{x_a}{3}\right)$$

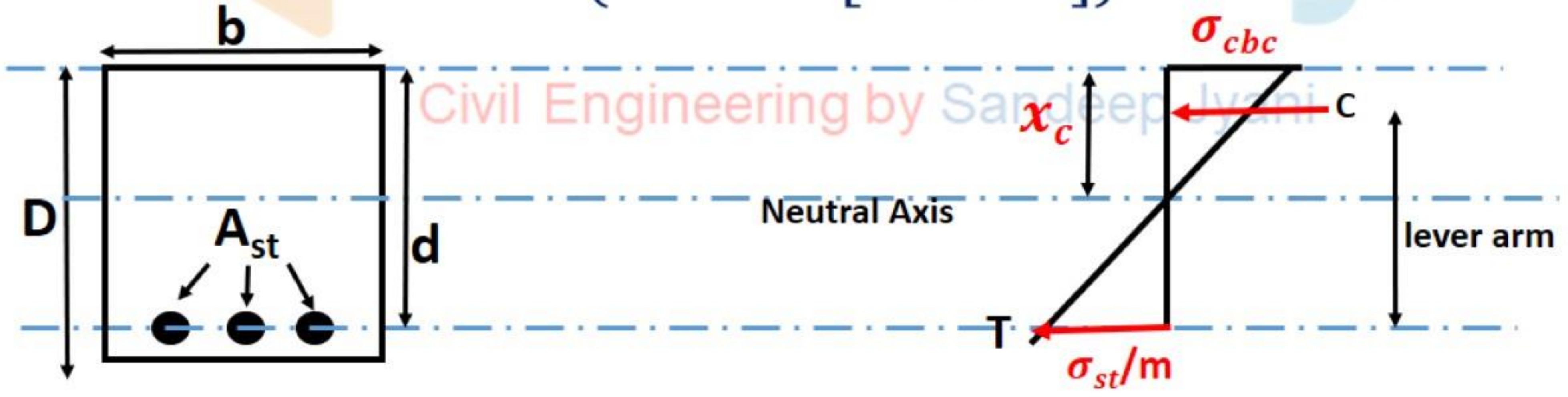
Step 4 Moment of Resistance

Case2: Balanced section

MR for compression = Compressive force x Lever arm

= (average stress x area under stress) x lever arm

$$(MR)_{comp} = \left\{ b \times x_c \times \left[\frac{\sigma_{cbc} + 0}{2} \right] \right\} \times \left(d - \frac{x_c}{3} \right)$$



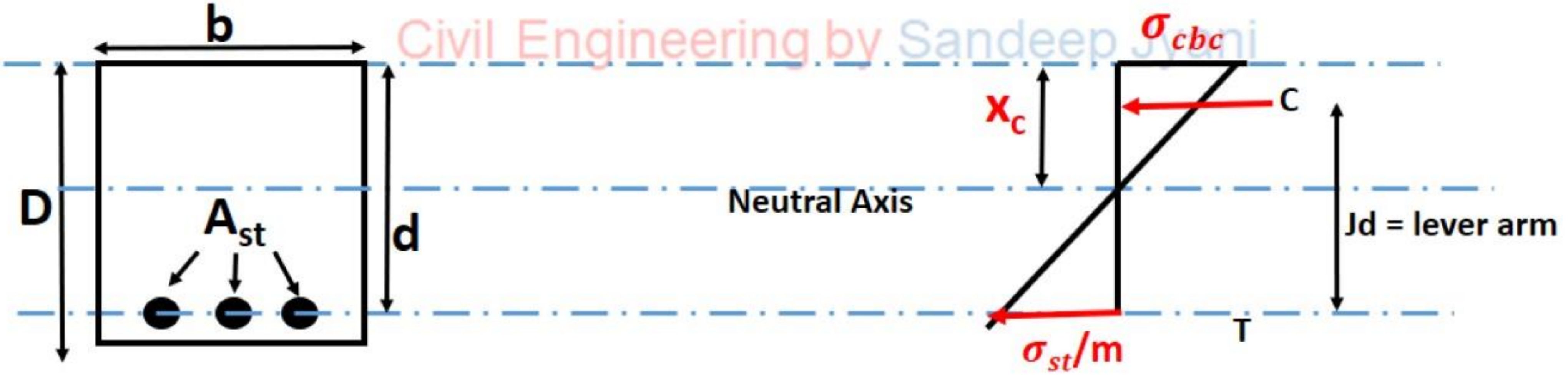
Step 4 Moment of Resistance

Case2: Balanced section

MR for tension= tension force x Lever arm

= (average stress x area under stress) x lever arm

$$(MR)_{tension} = \left\{\frac{\sigma_{st}}{m} \times mA_{st}\right\} \times \left(d - \frac{x_c}{3}\right)$$



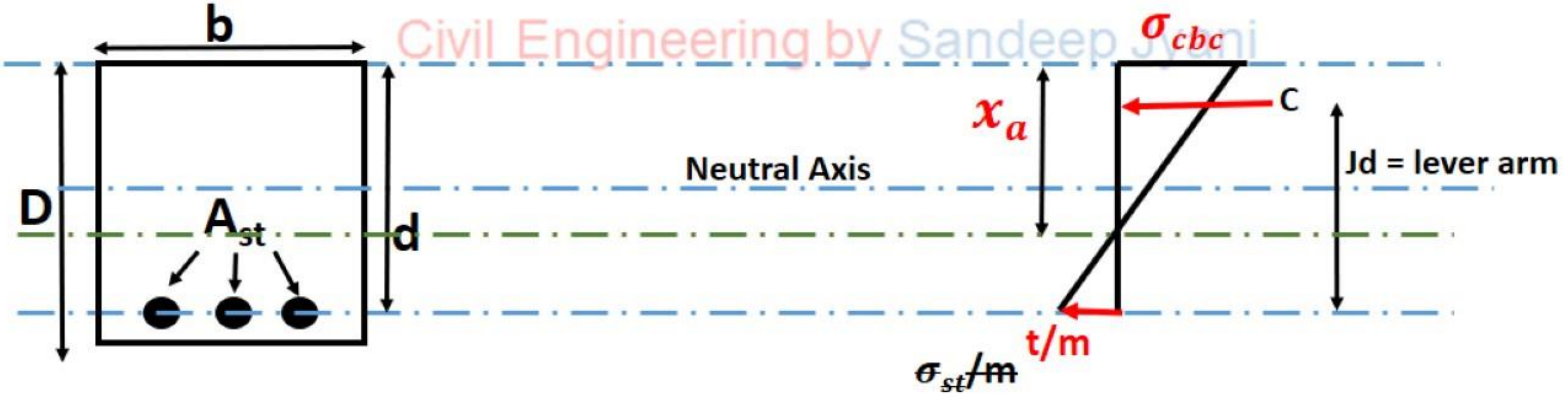
Step 4 Moment of Resistance

Case3: Over Reinforced section

MR for compression = Compressive force x Lever arm

= (average stress x area under stress) x lever arm

$$(MR)_{comp} = \left\{ b \times x_a \times \left[\frac{\sigma_{cbc} + 0}{2} \right] \right\} \times \left(d - \frac{x_a}{3} \right)$$



Step 4 Moment of Resistance

Case3: Over Reinforced Section

MR for tension= As per IS code recommendation, the moment of resistance never be calculated from tension side in a case of over reinforced section.

As in over reinforced section, the steel is under stress and the failure occurs due to concrete which makes it hard to determine the actual understressed condition of steel.

Properties of Under Reinforced Section

- **The under reinforced section failure occurs due to the failure of steel as the steel achieves its maximum permissible stress prior to concrete**
- **The concrete is understressed**
- **The failure shall be a ductile failure.**
- **It gives sufficient warning before failure. Therefore this kind of a section is always desirable**

Properties of Balanced Section

- Failure of section is due to failure of steel and concrete simultaneously
- These kind of a section is always preferable on safety and economy front
- In this, the actual depth of critical axis and neutral axis are equal
- It also gives ductile failure with warning

Properties of Over Reinforced Section

- **The failure of this section is due to failure of concrete**
- **As concrete achieves its maximum permissible strength prior to steel at the time of failure**
- **This kind of section is always avoided because it indicates or provides a brittle failure**
- **The brittle failure is always without warning, therefore such kind of a section which has brittle failure and high moment of resistance capacity is of no use.**

Summary

1. $[B \times x_a] \times \frac{x_a}{2} = mA_{st} \times [d - x_a]$ $\quad$ *Find* x_a

2. $x_c = \frac{m\sigma_{cbc}}{m\sigma_{cbc}+\sigma_{st}} \times d \qquad (x_c = kd)$

3. Different types of Sections
   - Balanced Section
     - $x_a = x_c$
     - $C_a = C = \sigma_{cbc}$
     - $t_a = t = \sigma_{st}$
   - Under Reinforced Section
     - $x_a < x_c$
     - $C_a < \sigma_{cbc}$
     - $t_a = \sigma_{st}$
   - Over Reinforced Section
     - $x_a > x_c$
     - $C_a = \sigma_{cbc}$
     - $t_a < \sigma_{st}$

Summary

4. Moment of resistance (Balanced Section)
   - $(MR)_{comp} = \left\{b \times \boldsymbol{x_a} \times \frac{\boldsymbol{\sigma_{cbc}}}{2}\right\} \times \left(d - \frac{x_a}{3}\right)$
   - $(MR)_{tension} = \{\boldsymbol{\sigma_{st}} \times A_{st}\} \times \left(d - \frac{x_a}{3}\right)$
5. Moment of resistance (Under reinforced Section)
   - $(MR)_{comp} = \left\{b \times \boldsymbol{x_a} \times \frac{\boldsymbol{C_a}}{2}\right\} \times \left(d - \frac{x_a}{3}\right)$
   - $(MR)_{tension} = \{\boldsymbol{\sigma_{st}} \times A_{st}\} \times \left(d - \frac{x_a}{3}\right)$ **Always find MR from tension side because (t_a= σ_{st})**
6. Moment of resistance (Over reinforced Section)
   - $(MR)_{comp} = \left\{b \times \boldsymbol{x_a} \times \frac{\boldsymbol{\sigma_{cbc}}}{2}\right\} \times \left(d - \frac{x_a}{3}\right)$ **Always find MR from compression side as (C_a= σ_{cbc})**
   - $(MR)_{tension} = \{\boldsymbol{t_a} \times A_{st}\} \times \left(d - \frac{x_a}{3}\right)$

Design Formula for balanced section

- Bending moment- given , Length – given
- Calculate (BxD, d, A_{st})
- Assume B=d/2

$$(MR)_{comp} = \left\{\overset{d/2}{B} \times xa \times \left[\frac{\overset{\sigma_{cbc}}{C_a}}{2}\right]\right\} \times \left(d - \frac{\overset{x_c}{x_a}}{3}\right)$$

$$\Rightarrow (MR)_{comp} = \left\{B \times \overset{kd}{x_c} \times \overset{C}{\left[\frac{\sigma_{cbc}}{2}\right]}\right\} \times \overset{kd}{\left(d - \frac{x_c}{3}\right)}$$

$$\Rightarrow (MR)_{comp} = \left\{B \times kd \times \frac{c}{2}\right\} \times d\,\underbrace{\left(1 - \frac{k}{3}\right)}_{\text{J=lever arm constant}}$$

$$\boxed{=> (MR)_{comp} = \left[\frac{1}{2}cjk\right] \times Bd^2}$$

Design Formula for balanced section

$$\boxed{\Rightarrow (MR)_{comp} = \underbrace{\left[\frac{1}{2} cjk\right]}_{Q} \times Bd^2}$$

$$\Rightarrow \frac{(MR)_{comp}}{Q\ B} = d^2$$

$$\Rightarrow d^2 = \sqrt{\frac{(MR)_{comp}}{Q\ B}}$$

$$Q = \frac{1}{2} cjk$$

$c = \sigma_{cbc}$

$j = \left(1 - \frac{k}{3}\right)$

$k = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}$

Design Formula for balanced section

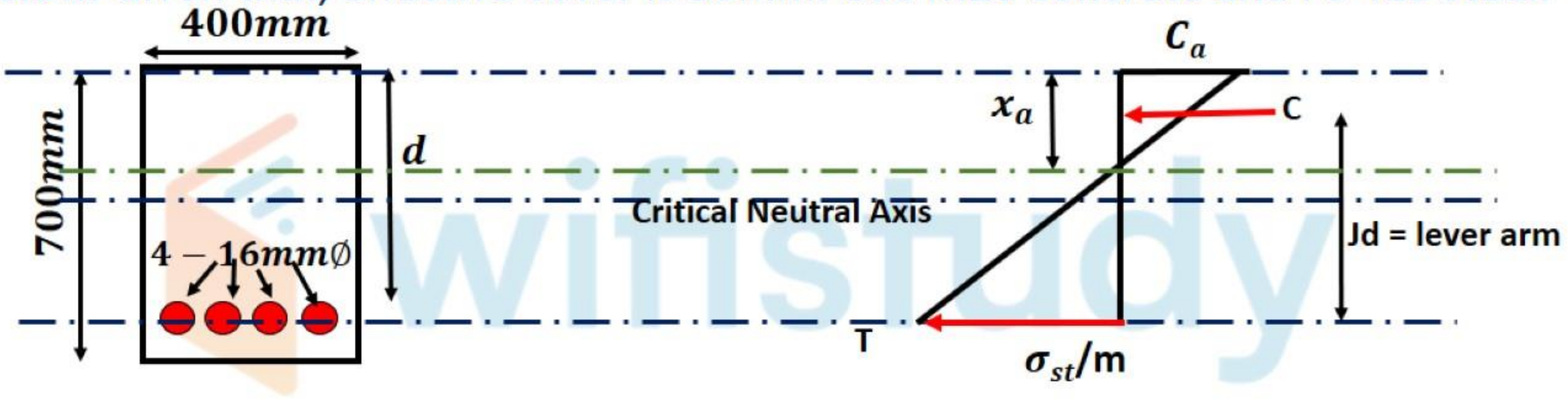
$$(MR)_{tension} = \left\{\frac{\sigma_{st}}{m} \times mA_{st}\right\} \times \left(d - \frac{x_c}{3}\right)$$

$$(MR)_{tension} = \{\sigma_{st} \times A_{st}\} \times \left(d - \frac{kd}{3}\right)$$

$$(MR)_{tension} = \{\sigma_{st} \times A_{st}\} \times d\underbrace{\left(1 - \frac{k}{3}\right)}_{j}$$

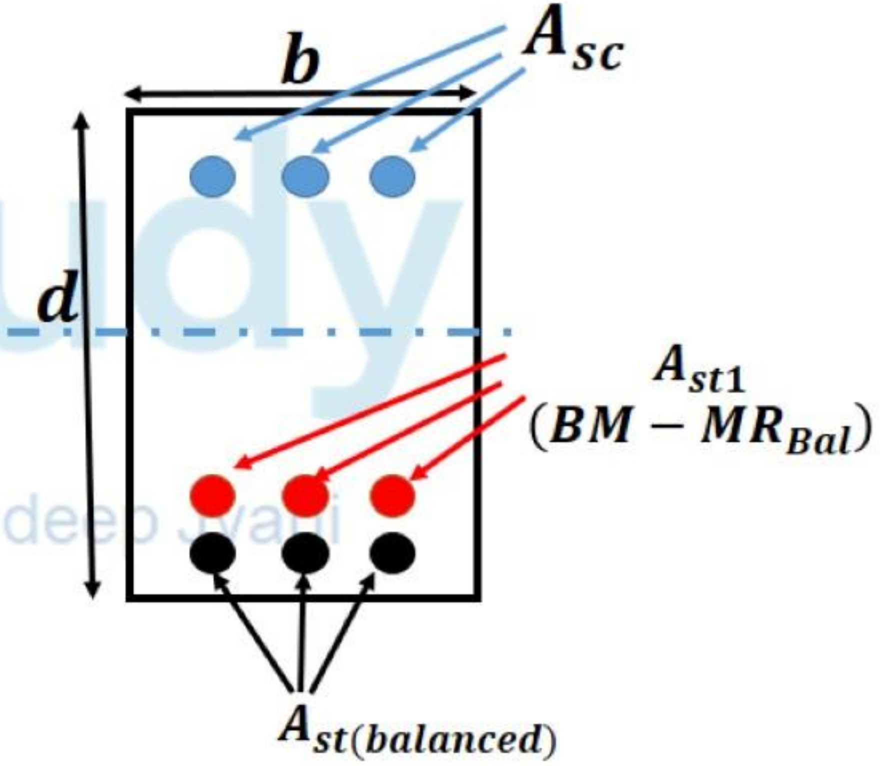
$$A_{st} = \frac{(MR)_{tension}}{\sigma_{st}\, j\ d}$$

Que 3. Calculate the moment of resistance of a rectangular RCC section shown as below. Given that, effective cover is 50mm. Use M20 concrete and Fe 415 steel.



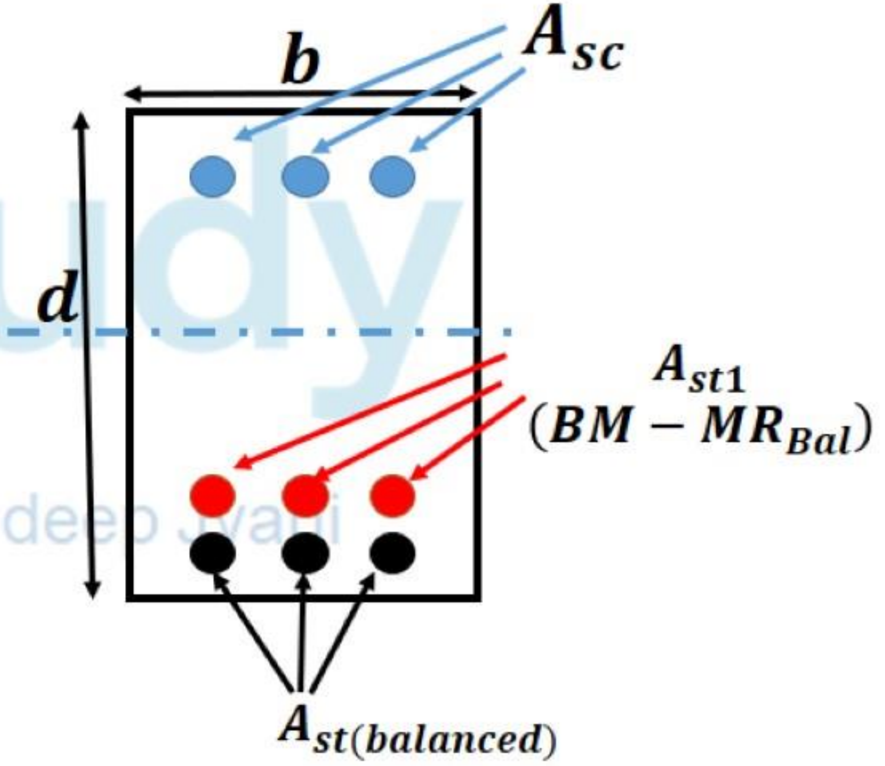
Doubly Reinforced Section

- **If the width and depth of both are restricted, and section of the beam has to resist a higher value of the bending moment than moment of resistance of the singly reinforced balanced section, then always we suppose to adopt a design of doubly reinforced balance section over over-reinforced section**



Doubly Reinforced Section

- **If BM > $(MR)_{bal}$**
  - **For Bending moment equal to $(MR)_{bal}$, A_{st} is used**
  - **$(MR)_{bal} \rightarrow A_{st}$(balanced)**
  - **For extra Bending moment, A_{st1} is used**
  - **$BM-MR_{bal} \rightarrow A_{st1}$**
  - **Now due to this A_{st1} , the section might become over reinforced, so to compensate it, we use steel in compression zone = A_{sc}**

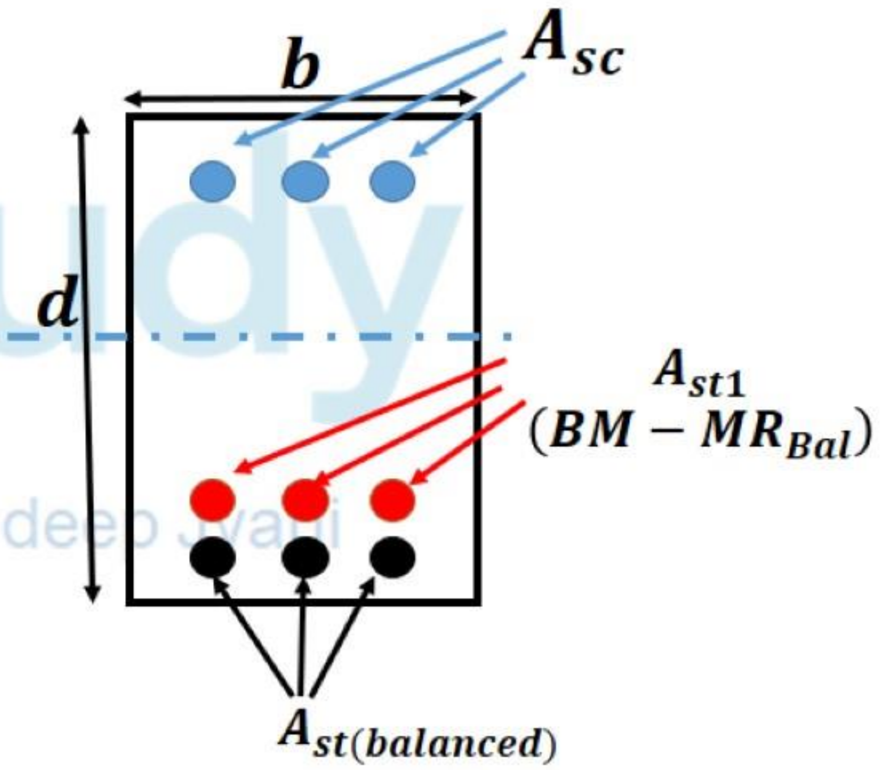


Doubly Reinforced Section

- **The maximum permissible Stress in steel in Compression is**

$$= 1.5\,m \times (\textit{permissible stress existing in surrounding concrete})$$

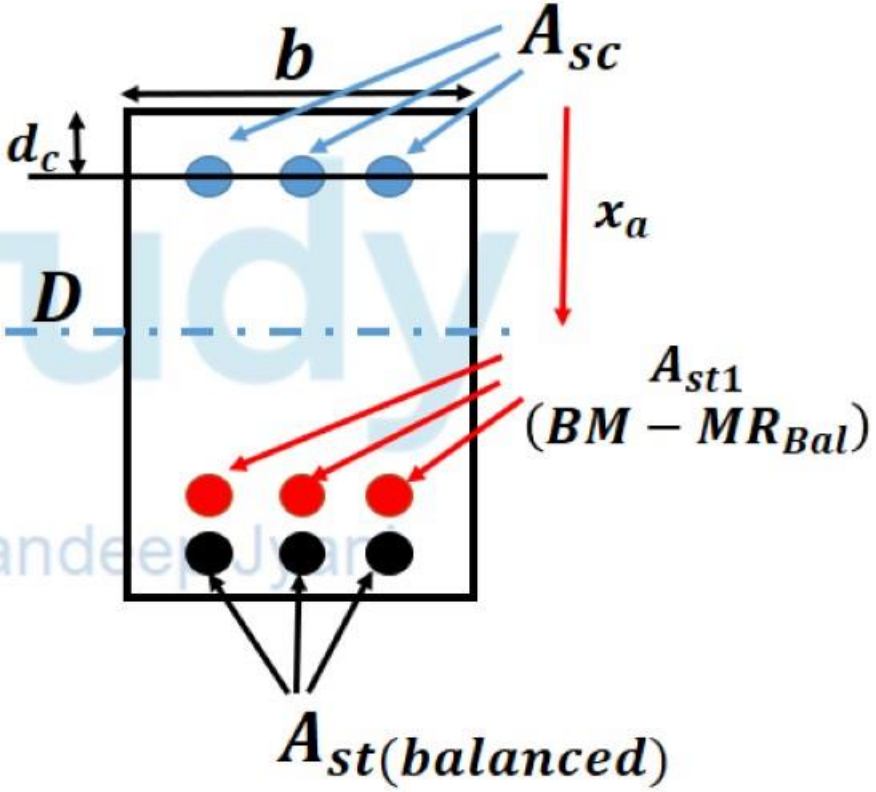
  - **Tension zone=>** $A_{st} \rightarrow mA_{st}$
  - **Compression zone=>** $A_{sc} \rightarrow 1.5\,mA_{sc}$
- **This 1.5 value for compression steel is due to the effect of creep due to continuous compressive stress in steel in compression and in surrounding concrete of compression steel.**
- **Considering the effect of creep, actual strain is much higher than elastic strain. Therefore, this continuous effect of creep, 1.5m value is used**



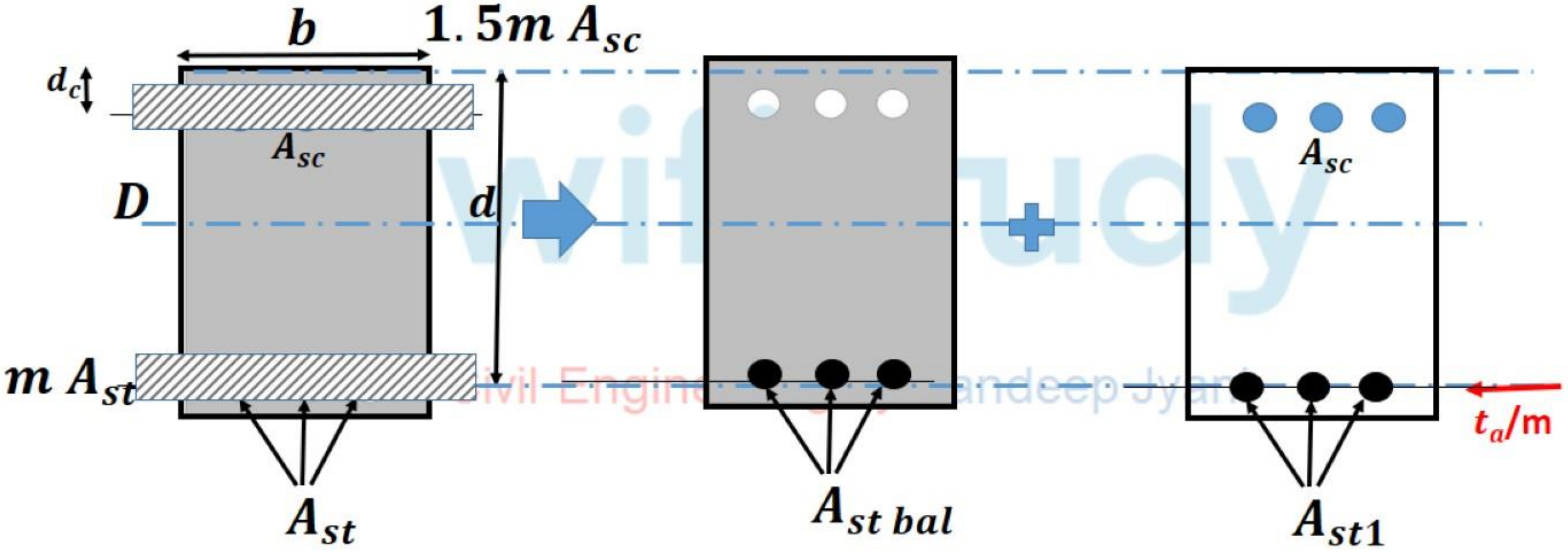
Analysis of Doubly Reinforced Section

1. Critical Neutral Axis

- $x_c = \dfrac{m\sigma_{cbc}}{m\sigma_{cbc}+\sigma_{st}} \times d \qquad (x_c = \mathrm{kd})$



Doubly Reinforced Section



Actual Neutral axis (x_a) $B \times x_a \times \frac{x_a}{2} - A_{sc}(x_a - d_c) + 1.5mA_{sc}(x_a - d_c) = mA_{st} \times [d - x_a]$

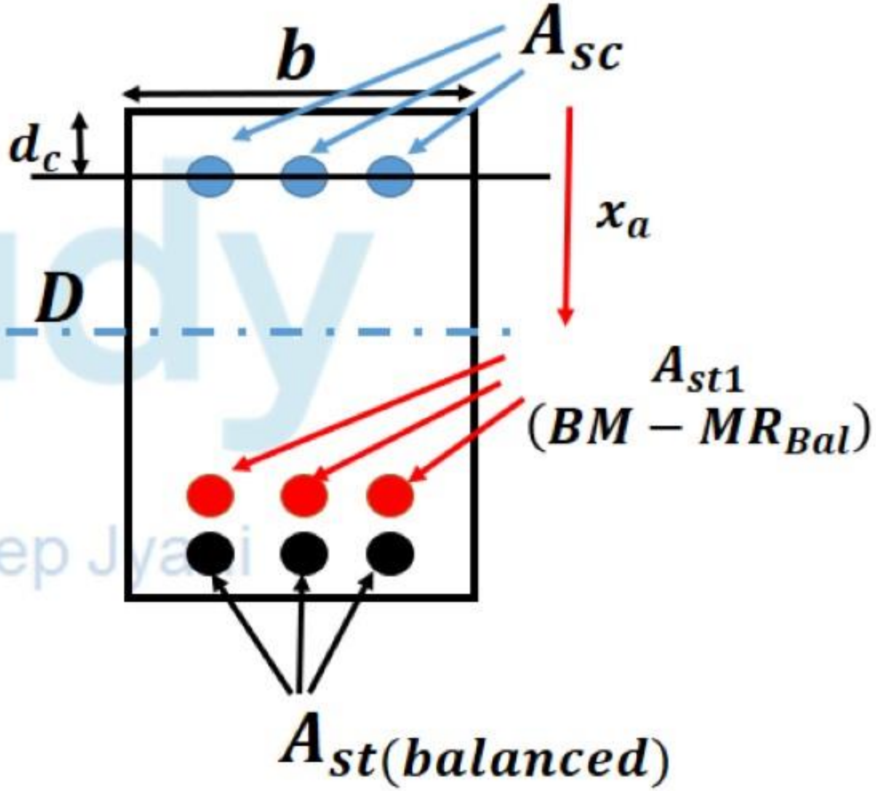
Analysis of Doubly Reinforced Section

1. Critical Neutral Axis
   - $x_c = \frac{m\sigma_{cbc}}{m\sigma_{cbc}+\sigma_{st}} \times d \qquad (x_c = \text{kd})$
2. Actual Neutral axis (x_a)

$$B \times x_a \times \frac{x_a}{2} - A_{sc}(x_a - dc) + 1.5mA_{sc}(x_a - d_c) = mA_{st} \times [d - x_a]$$

Concrete area moment **Compression steel area moment**

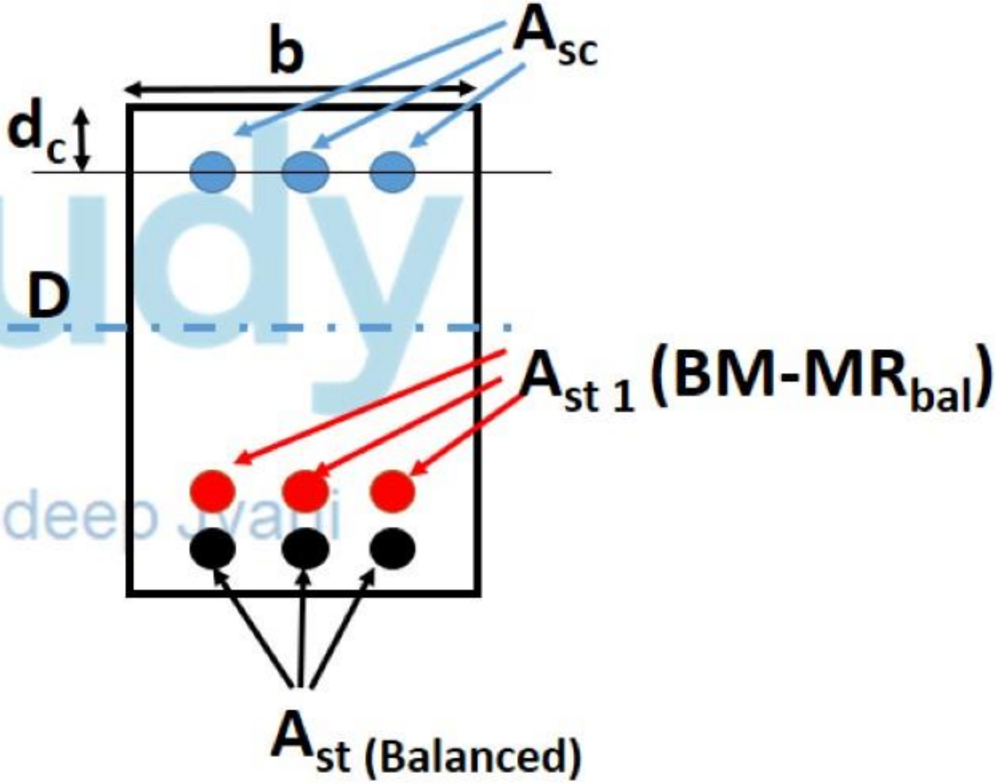
$$B \times \frac{{x_a}^2}{2} + (1.5m - 1)mA_{sc}(x_a - dc) = mA_{st} \times [d - x_a]$$

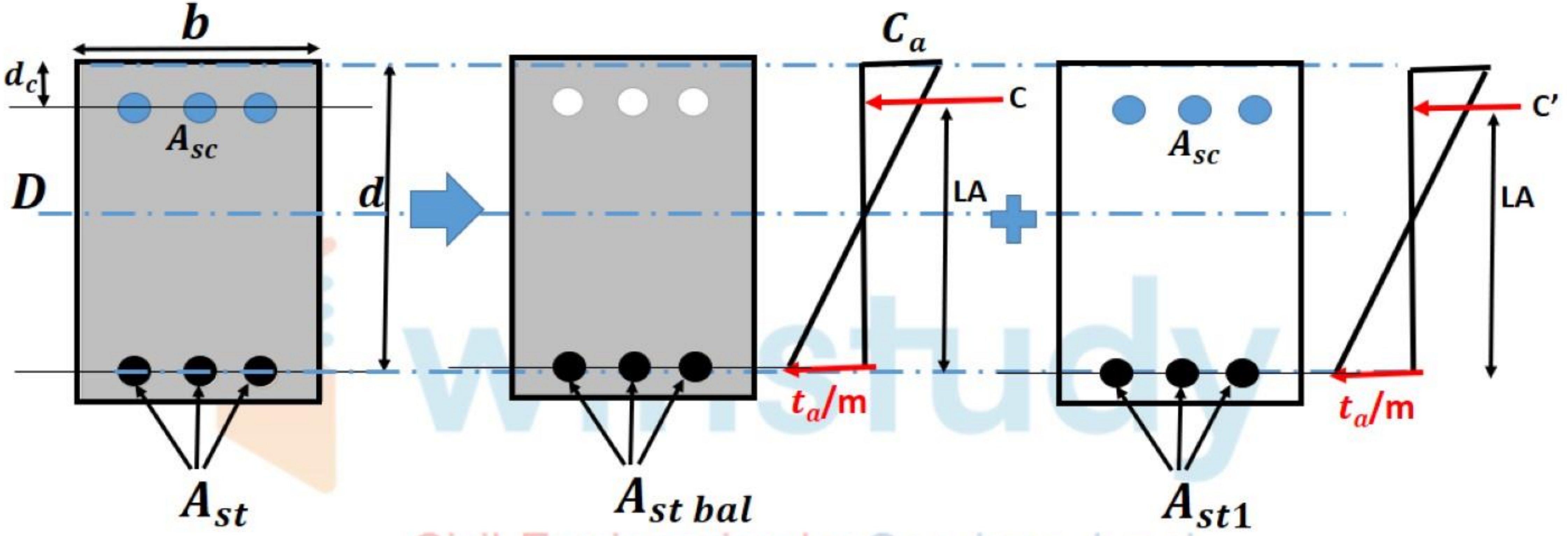


Analysis of Doubly Reinforced Section

3. Different types of Sections

- **Balanced Section**
  - $x_a = x_c$
  - $C_a = C = \sigma_{cbc}$
  - $t_a = t = \sigma_{st}$
- **Under Reinforced Section**
  - $x_a < x_c$
  - $C_a < \sigma_{cbc}$
  - $t_a = \sigma_{st}$
- **Over Reinforced Section**
  - $x_a > x_c$
  - $C_a = \sigma_{cbc}$
  - $t_a < \sigma_{st}$

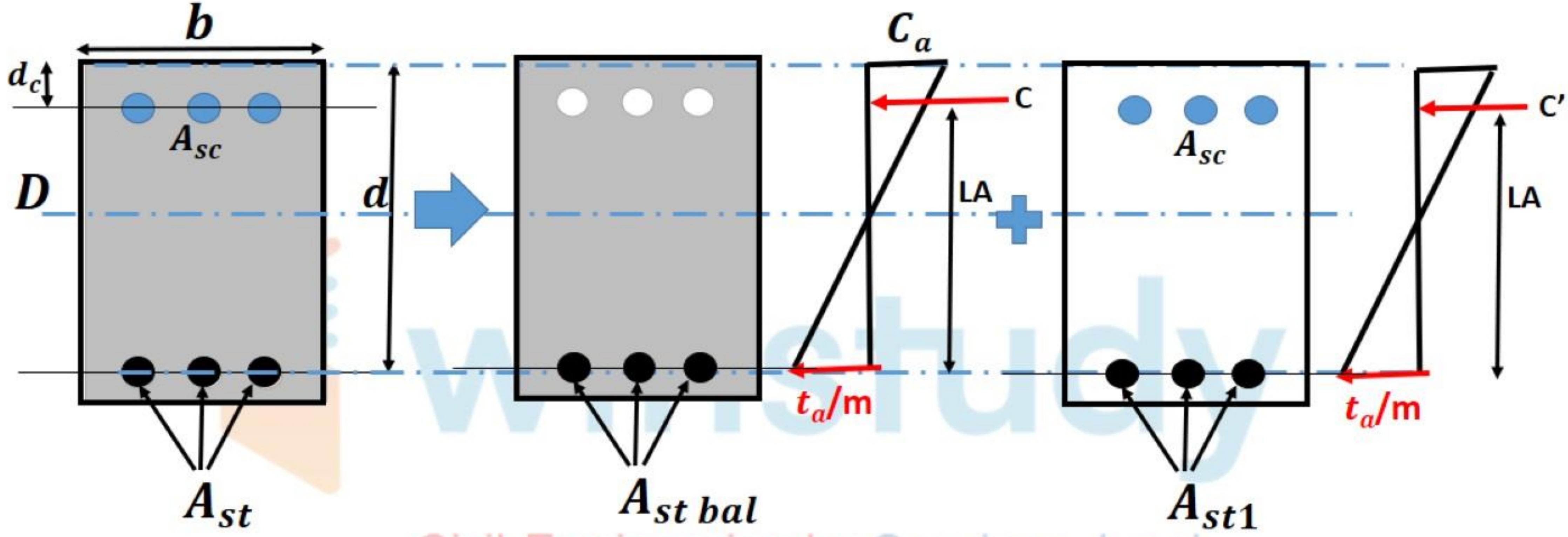




4. Moment of Resistance

$$(MR)_{comp} = \left\{b \times x_a \times \frac{C_a}{2}\right\} \times \left(d - \frac{x_a}{3}\right) - A_{sc}C' \times (d - dc) + (1.5mA_{sc}) \times C' \times (d - d_c)$$

$$(MR)_{comp} = \left\{b \times xa \times \frac{C_a}{2}\right\} \times \left(d - \frac{x_a}{3}\right) + (1.5m - 1)A_{sc}C' \times (d - dc)$$



4. Moment of Resistance

$$(MR)_{tension} = \left\{\frac{t_a}{m} \times mA_{st\ bal}\right\} \times \left(d - \frac{x_a}{3}\right) + mA_{st1} \times \frac{t_a}{m}(d - dc)$$

4. Moment of Resistance

$$(MR)_{tension} = \left\{\frac{t_a}{m} \times mA_{st\,bal}\right\} \times \left(d - \frac{x_a}{3}\right) + mA_{st1} \times \frac{t_a}{m}(d - d_c)$$

$MR_{\,balcanced}$ *or due to* $A_{st\,bal}$

$extra\,BM = BM - MR_{bal}$ or due to A_{s12}

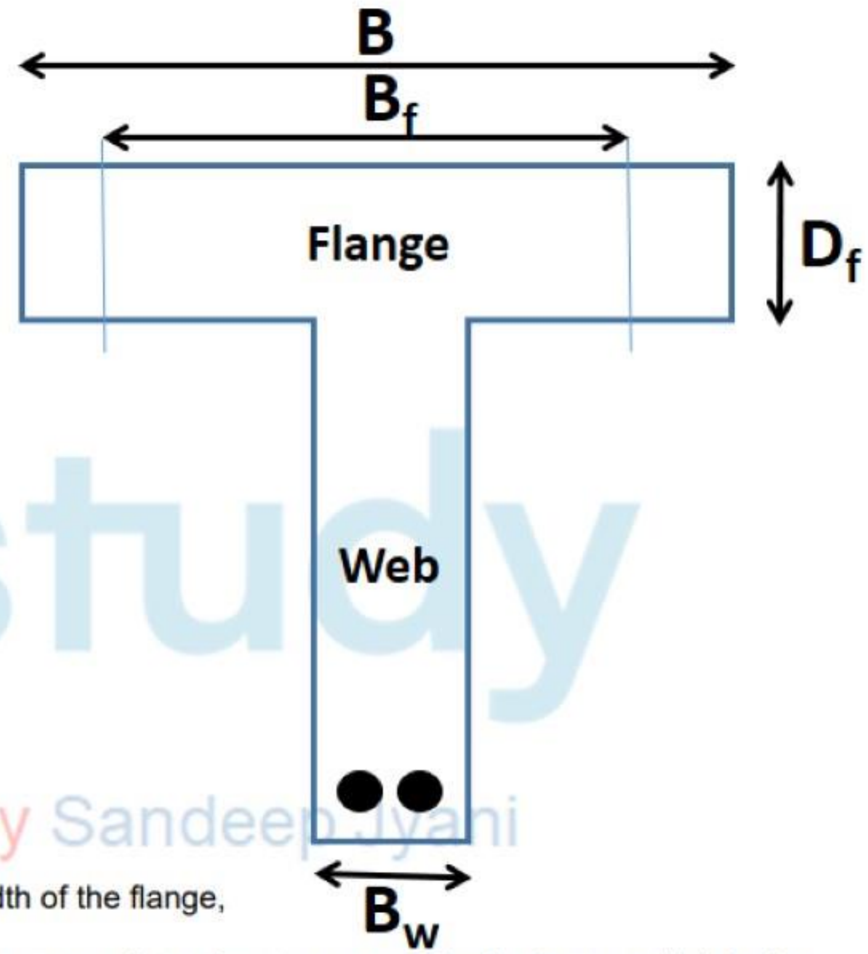
Design Formula

If beam is designed for some bending moment BM

- Calculate moment of resistance for singly reinforced balance section
- Compare bending moment to be designed with the moment of resistance of singly reinforced section
- If $BM>(MR)_{\text{for singly reinforced section}}$, then we never try to adopt over reinforced section. Therefore a doubly reinforced section is to be designed.

Effective Width

T - Beam



(a) For *T*-beams, the lesser of

(i) $b_f = l_o/6 + b_w + 6\,D_f$

(ii) b_f = Actual width of the flange

(b) For isolated *T*-beams, the lesser of

(i) $b_f = \dfrac{l_o}{(l_o/b) + 4} + b_w$

(ii) b_f = Actual width of the flange

(c) For *L*-beams, the lesser of

(i) $b_f = l_o/12 + b_w + 3\,D_f$

(ii) b_f = Actual width of the flange

(d) For isolated *L*-beams, the lesser of

(i) $b_f = \dfrac{0.5\,l_o}{(l_o/b) + 4} + b_w$

(ii) b_f = Actual width of the flange

b_f = effective width of the flange,

l_o = distance between points of zero moments in the beam, which is the effective span for simply supported beams and 0.7 times the effective span for continuous beams and frames,

b_w = beadth of the web,

D_f = thickness of the flange,

b = actual width of the flange.

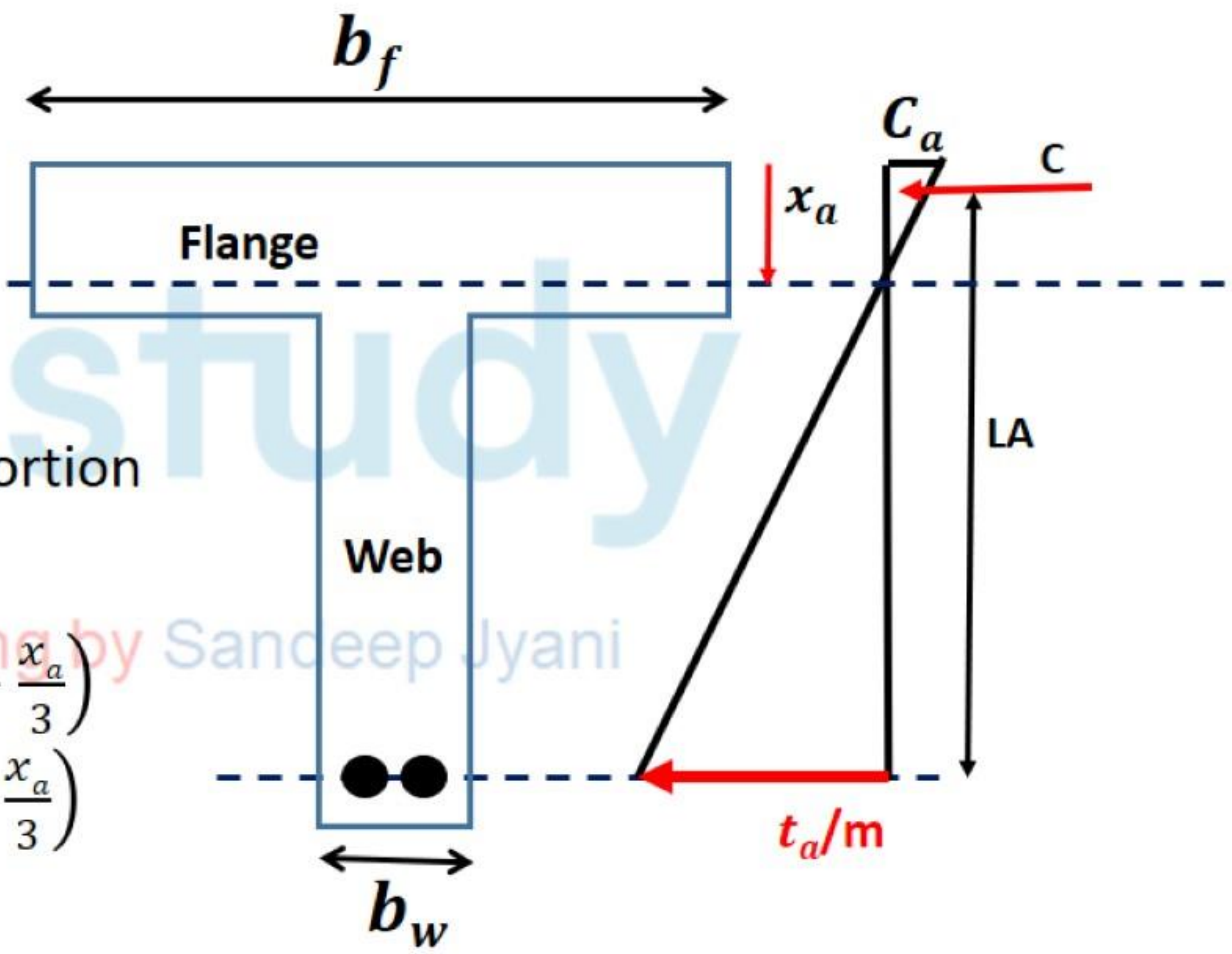
T - Beam

1. Critical Neutral Axis
   - $x_c = \frac{m\sigma_{cbc}}{m\sigma_{cbc}+\sigma_{st}} \times d \qquad (x_c = \text{kd})$
2. Actual Depth of Neutral Axis

A. CASE 1: When x_a lies in flange portion

$$[\boldsymbol{b_f} \times \boldsymbol{x_a}] \times \frac{\boldsymbol{x_a}}{\boldsymbol{2}} = \boldsymbol{mA_{st}} \times [\boldsymbol{d} - \boldsymbol{x_a}]$$

- $(MR)_{comp} = \left\{b \times \boldsymbol{x_a} \times \frac{\boldsymbol{c_a}}{2}\right\} \times \left(d - \frac{x_a}{3}\right)$
- $(MR)_{tension} = \left\{\frac{\boldsymbol{t_a}}{m} \times mA_{st}\right\} \times \left(d - \frac{x_a}{3}\right)$

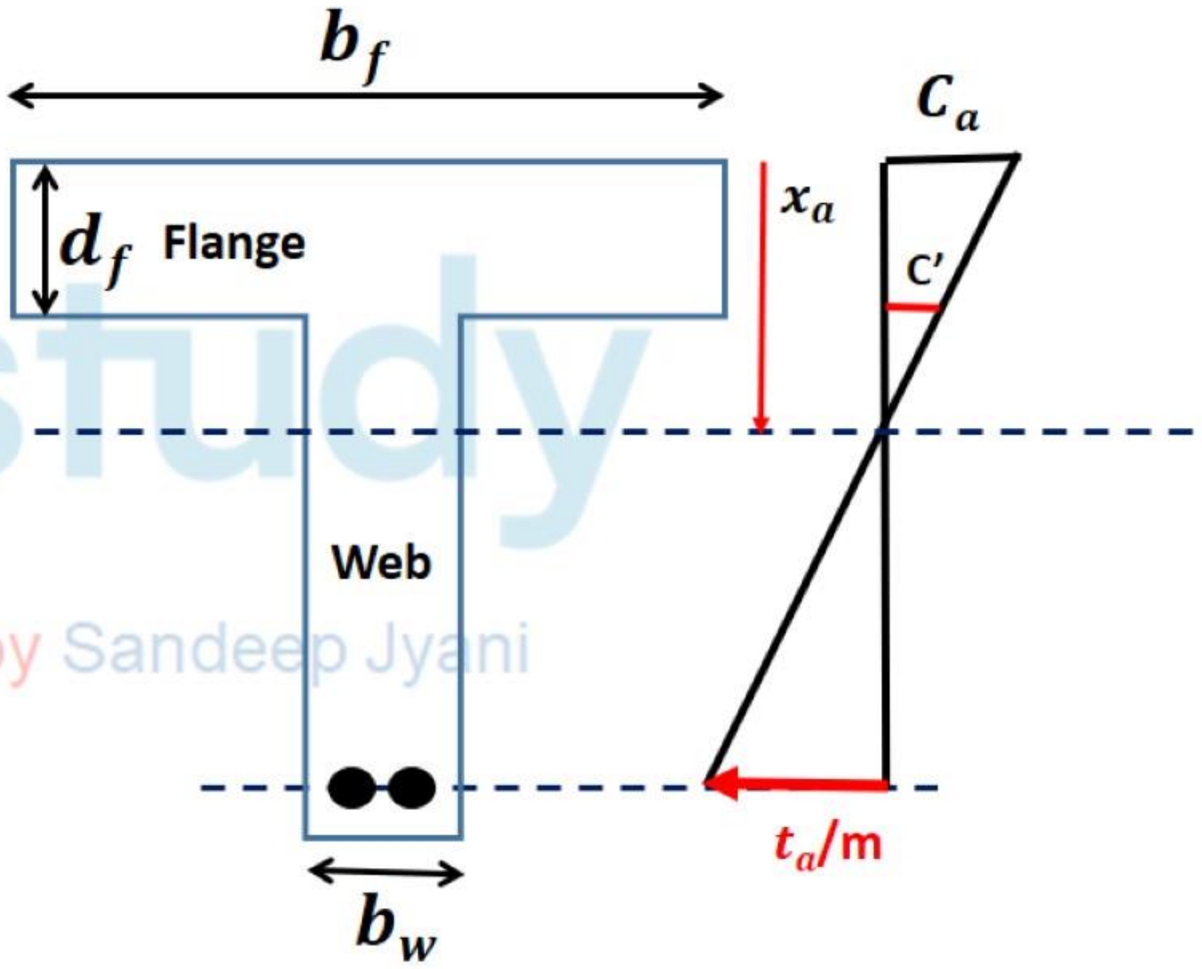


T - Beam

2. Actual Depth of Neutral Axis

B. CASE 2: When x_a lies in web portion

$$[b_f \times d_f] \times \left(x_a - \frac{d_f}{2}\right) + (x_a - df) \times bw \times \left(\frac{x_a - df}{2}\right) = mA_{st} \times [d - x_a]$$



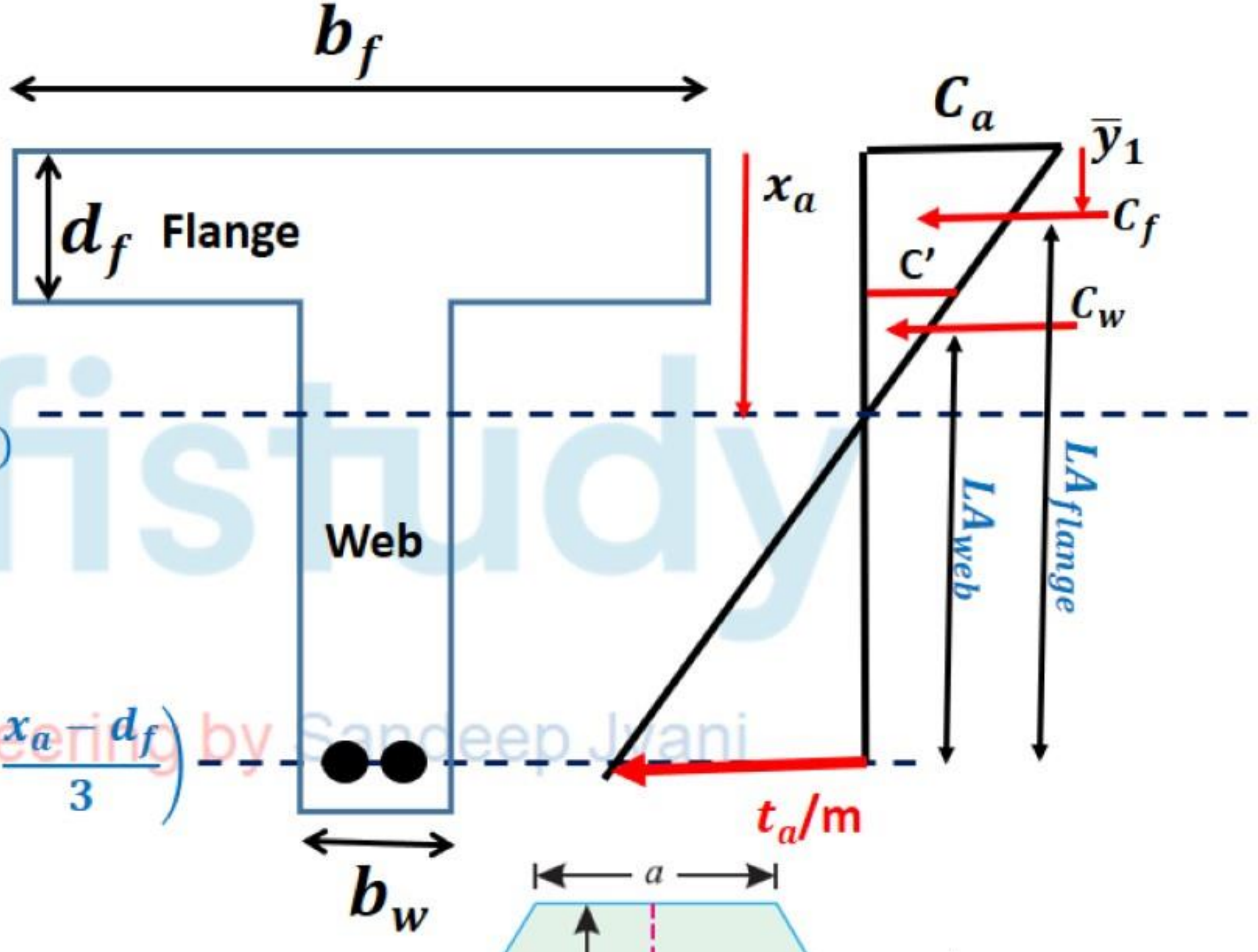
T - Beam

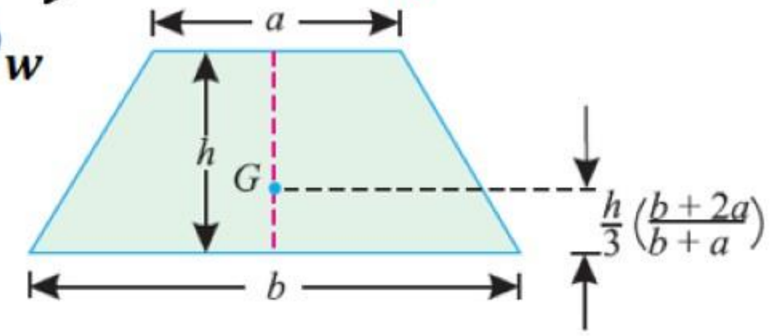
3. Moment of Resistance

$$MOR_{comp} = MOR_{flange} + MOR_{web}$$

$$MOR_{flange} = \underbrace{b_f \times d_f \times \frac{C_a + C'}{2}}_{C_f} \times \underbrace{(d - \overline{y_1})}_{LA_{flange}}$$

$$MOR_{web} = \underbrace{b_w \times (xa - d_f) \times \frac{C'}{2}}_{C_w} \times \underbrace{\left(d - d_f - \frac{x_a - d_f}{3}\right)}_{LA_{web}}$$





$$\bar{y}_1 = \frac{2C' + Ca}{C' + Ca} \times \frac{d_f}{3}$$

T - Beam

3. Moment of Resistance

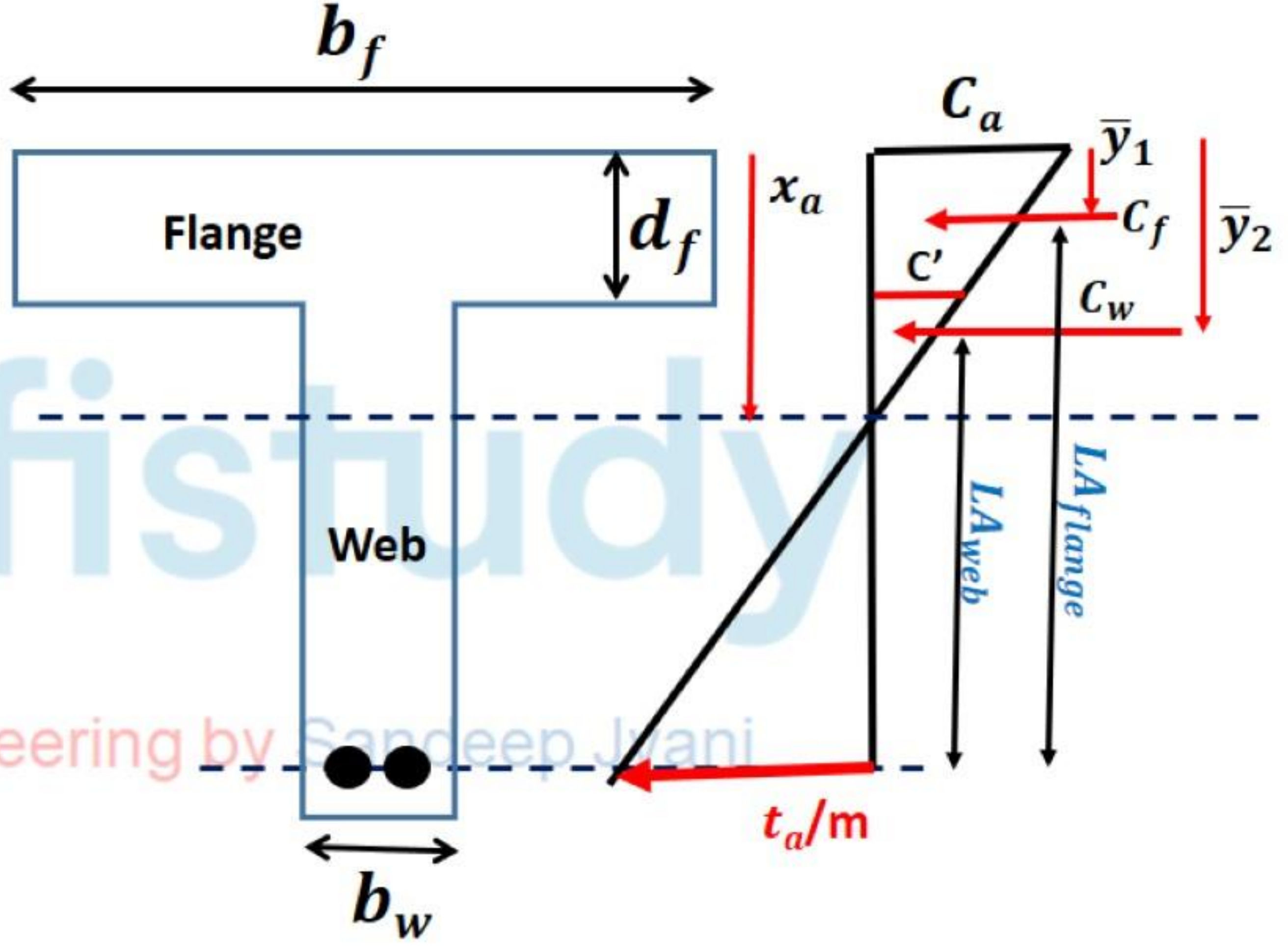
$MOR_{tension} = ?$

$$MOR = mA_{st} \times \frac{t_a}{m} \times (d - \bar{y})$$

$$\bar{y} = \frac{C_f \times \bar{y}_1 + C_w \times \bar{y}_2}{C_f + C_w}$$

$$\bar{y}_1 = \frac{2C' + Ca}{C' + C_a} \times \frac{d_f}{3}$$

$$\bar{y}_2 = d_f + \frac{x_a - d_f}{3}$$



Limit State Method

<u>What are limit states?</u>

- Limit states are the acceptable limits for the safety and serviceability requirements of the structure before failure occurs.
- The design of structures by this method will thus ensure that they will not reach limit states and will not become unfit for the use for which they are intended.
- It is worth mentioning that structures will not just fail or collapse by violating (exceeding) the limit states. Failure, therefore, implies that clearly defined limit states of structural usefulness has been exceeded.

How many Limit states are there?

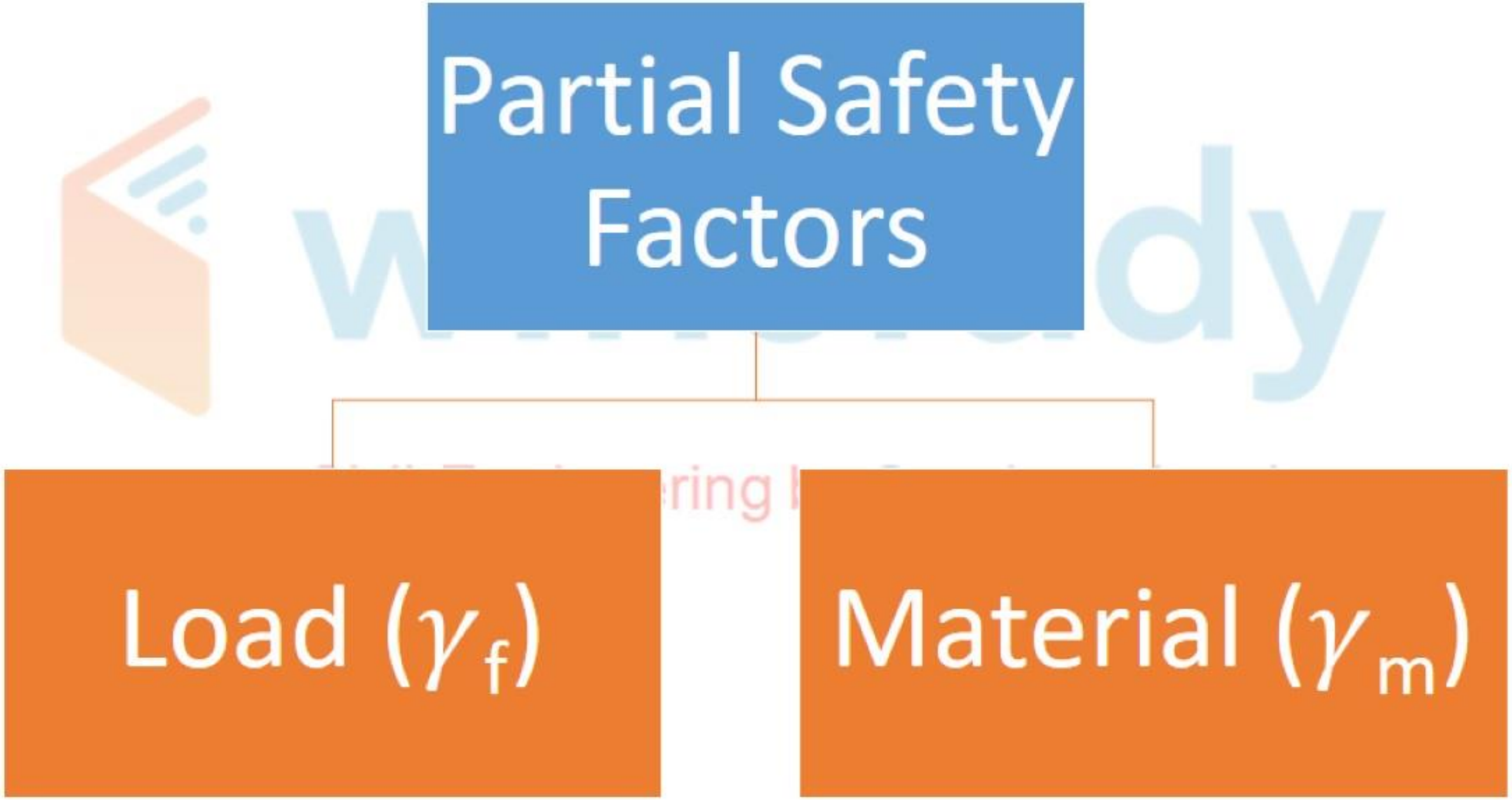
1. Limit state Of Collapse
   - Limit state of collapse deals with the strength and stability of structures subjected to the maximum design loads out of the possible combinations of several types of loads.
   - Therefore, this limit state ensures that neither any part nor the whole structure should collapse or become unstable under any combination of expected overloads.
   - Factors considered are Shear, Flexure, torsion, Compression

2. Limit state Of Serviceability
   - Limit state of serviceability deals with deflection and cracking of structures under service loads, durability under working environment during their anticipated exposure conditions during service, stability of structures as a whole, fire resistance , cracking, deflection, etc.

Partial safety factors

- Structures should be designed with loads obtained by multiplying the characteristic loads with suitable factors of safety depending on the nature of loads or their combinations, and the limit state being considered.
- These factors of safety for loads are termed as partial safety factors (γ_f) for loads. Thus, the design loads are calculated as

Partial safety factors



Values of partial safety factor γ_f for loads

Load combinations	Limit state of collapse			Limit state of serviceability (for short term effects only)		
	DL	*LL*	*WL*	*DL*	*LL*	*WL*
DL + IL	1.5		1.0	1.0	1.0	-
DL + WL	1.5 or 0.9	-	1.5	1.0	-	1.0
DL + IL + WL	1.2			1.0	0.8	0.8

- Wind load and Earthquake load should not be considered simultaneously
- 0.9 is considered when stability against overturning is critical

Design load=(Characteristic load) $\times$ (Partial safety factor for load)

Partial safety factors

1. Material Strength
   - The characteristic strength of a material as obtained from the statistical approach is the *strength of that material below which not more than five per cent of the test results are expected to fall*
   - $\boldsymbol{concrete = f_{ck}}$
   - $\boldsymbol{steel = f_y}$
   - However, such characteristic strengths may differ from sample to sample also. Accordingly, the design strength is calculated dividing the characteristic strength further by the ***partial safety factor*** for the material

Partial safety factors

2. Design Strength

- Design strength of material is the ratio of characteristic strength of material to partial factor of safety

$$\boldsymbol{Design\ strength\ f_d = \frac{characteristic\ strength\ of\ the\ material\ (f)}{partial\ factor\ of\ safety\ (\gamma_m)}}$$

- **Clause 36.4.2 of IS 456** states that γ_m for **concrete** and **steel** should be taken as **1.5** and **1.15**, respectively when assessing the strength of the structures or structural members employing limit state of collapse.
- Partial safety factor for steel (1.15) is comparatively lower than that of concrete (1.5) because the steel for reinforcement is produced in steel plants and commercially available in specific diameters with expected better quality control than that of concrete.

Partial safety factors

- ***For Steel*** $f_d = \frac{f_y}{1.15} = 0.87 f_y$
- ***For Concrete*** $f_d = \frac{f_{ck}}{1.5} = 0.67 fck$
- In case of concrete the characteristic strength is calculated on the basis of test results on 150 mm standard cubes. But the concrete in the structure has different sizes. To take the size effect into account, it is assumed that the concrete in the structure develops a strength of 0.67 or (1/1.50) times the characteristic strength of cubes.
- Accordingly, in the calculation of strength employing the limit state of collapse, the **characteristic strength (f_{ck}) is first multiplied with 0.67 (size effect)** and then divided by **1.5 (γ_m for concrete)** to have **0.446 f_{ck}** as the maximum strength of concrete in the stress block.
- ***For Concrete*** $f_d = \frac{f_{ck}}{1.5} \times 0.67 = 0.446 f_{ck}$

LSM VS WSM

WSM

- Stress analysis was done
- Working load is considered
- Total factor of safety is considered
- For concrete FOS=3
- For steel FOS=1.8

LSM

- Strain analysis will be done
- Ultimate load is considered
- Partial factor of safety is considered

Que 5. Which of the statements is true?

a) In LSM factor of safety is more in case of concrete

b) In WSM factor of safety is more in case of steel

c) Both a and b

d) None of these

Que 5. Which of the statements is true?

a) In LSM factor of safety is more in case of concrete

b) In WSM factor of safety is more in case of steel

c) Both a and b

d) None of these

LSM VS WSM

WSM

- Stress analysis was done
- Working load is considered
- Total factor of safety is considered
- For concrete FOS=3
- For steel FOS=1.8

LSM

- Strain analysis will be done
- Ultimate load is considered
- Partial factor of safety is considered

Que 4. The shape of stress strain curve for concrete as prescribed by IS 456 is

a) Rectangular

b) Parabolic

c) Rectangular Parabolic

d) None of these

Que 4. The shape of stress strain curve for concrete as prescribed by IS 456 is

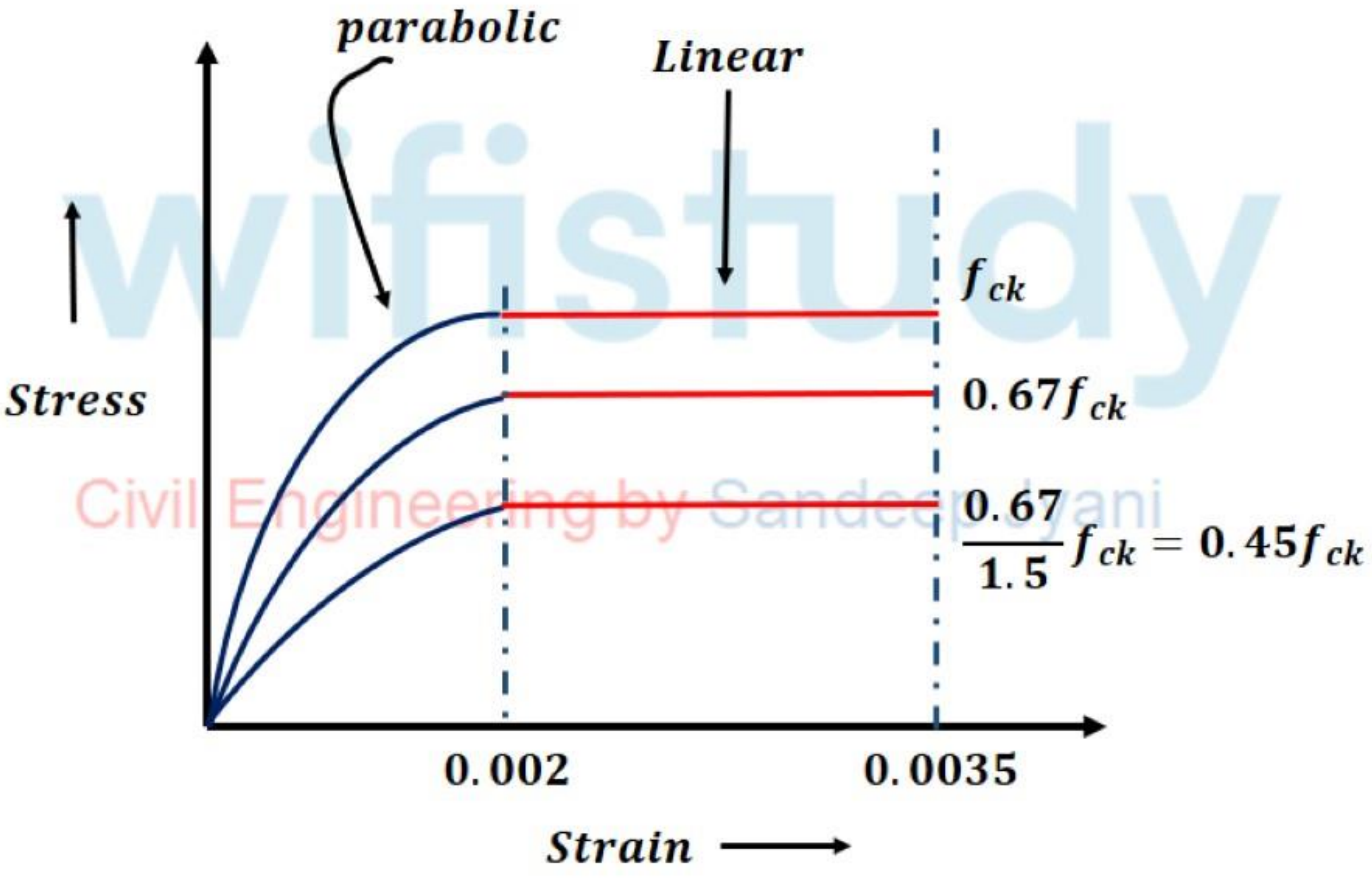
a) Rectangular

b) Parabolic

c) Rectangular Parabolic

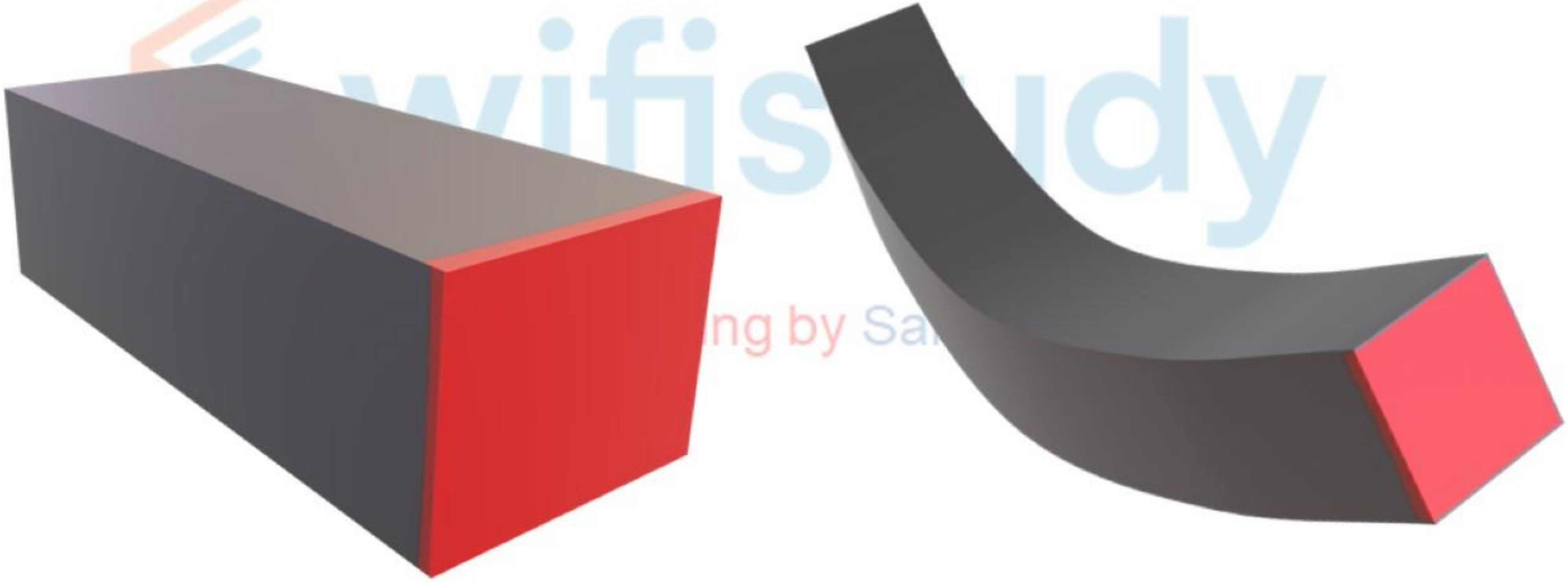
d) None of these

Stress Strain Relationship for Concrete



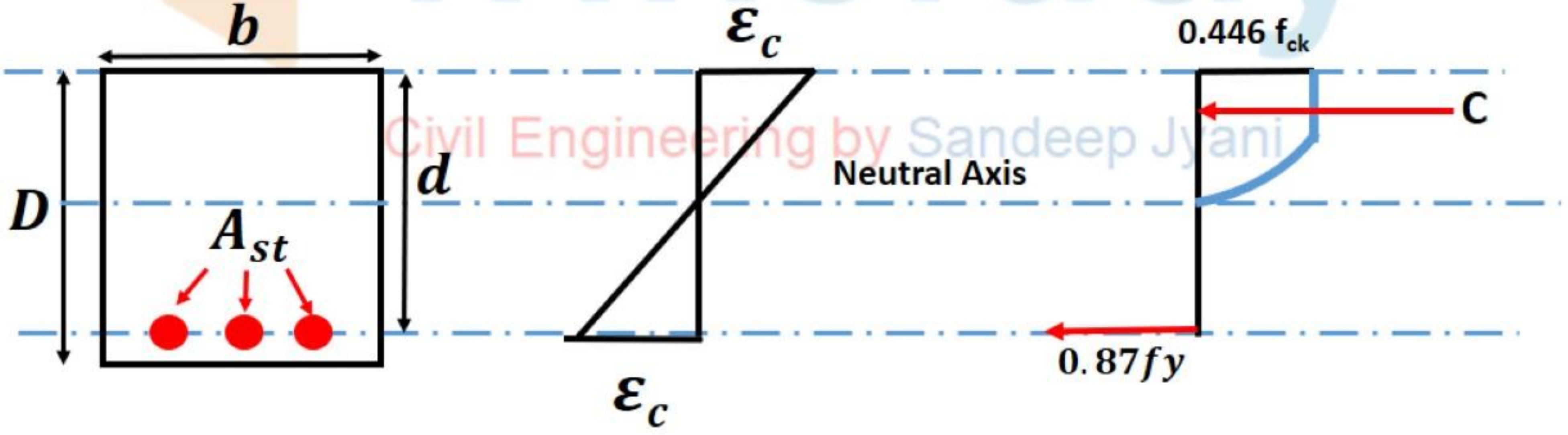
Assumptions of Limit State Method

1. Plane sections remain plane before and after bending



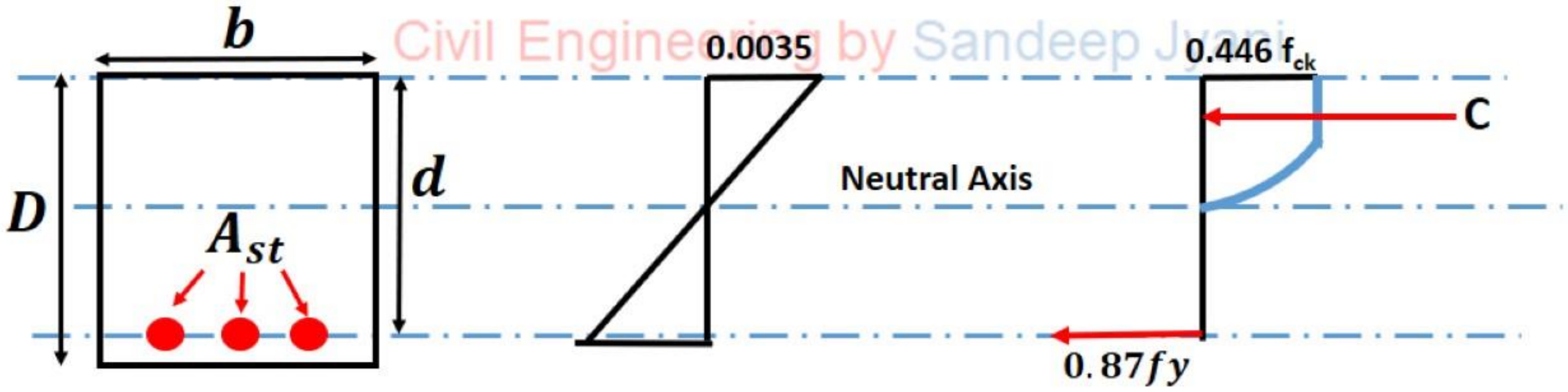
Assumptions of Limit State Method

1. Plane sections remain plane before and after bending
2. Strain diagram is linear and Stress diagram is partially parabolic and rectangular



Assumptions of Limit State Method

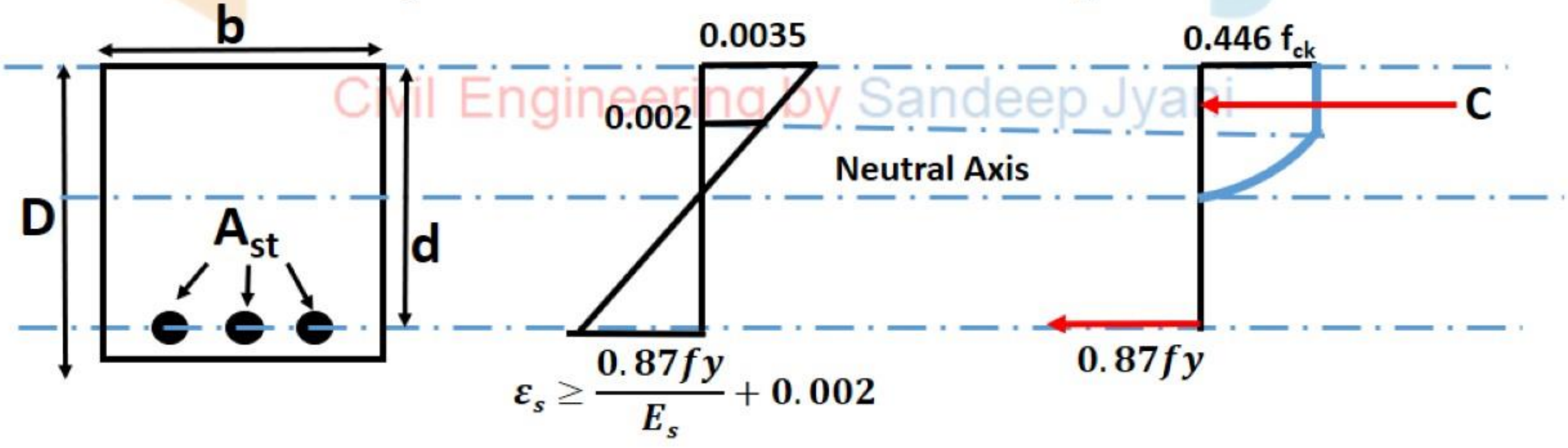
3. The maximum strain in concrete in outermost compression fiber is taken as 0.35% in bending regardless of the strength of concrete
4. The relationship between stress-strain distribution in concrete is assumed to be parabolic. The maximum compressive stress is equal to $0.67f_{ck}/1.5$ or $0.446\ f_{ck}$



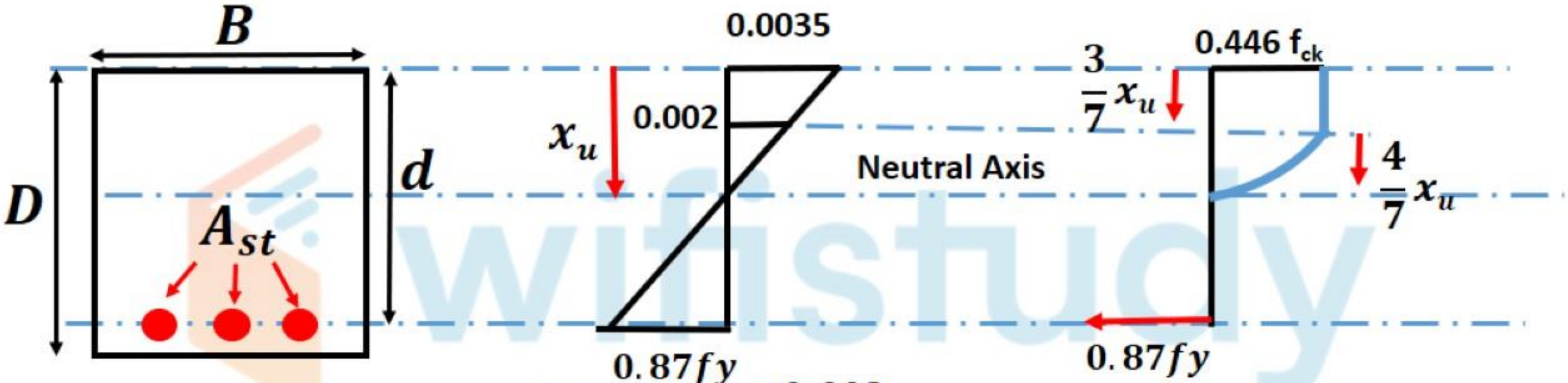
Assumptions of Limit State Method

5. Tensile strength of concrete is neglected
6. Maximum strain in tension reinforcement in the section at failure should not be less than

$$\varepsilon_s \geq \frac{0.87fy}{E_s} + 0.002 \quad or \quad \varepsilon_s \geq \frac{f_y}{1.15E_s} + 0.002$$

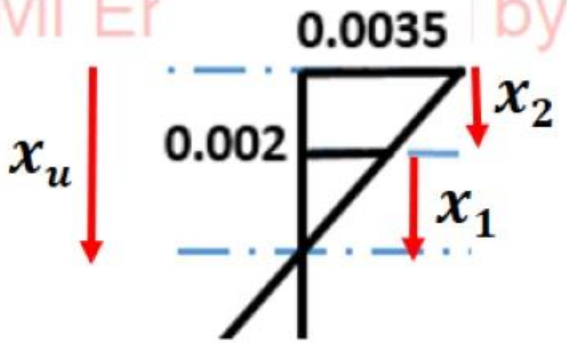


Limit State Method



$$\varepsilon_s \geq \frac{0.87fy}{E_s} + 0.002$$

$x_a \Rightarrow x_u$
$x_c \Rightarrow x_{u\,lim}$
$MR \Rightarrow M_u$
$\sigma \Rightarrow f$



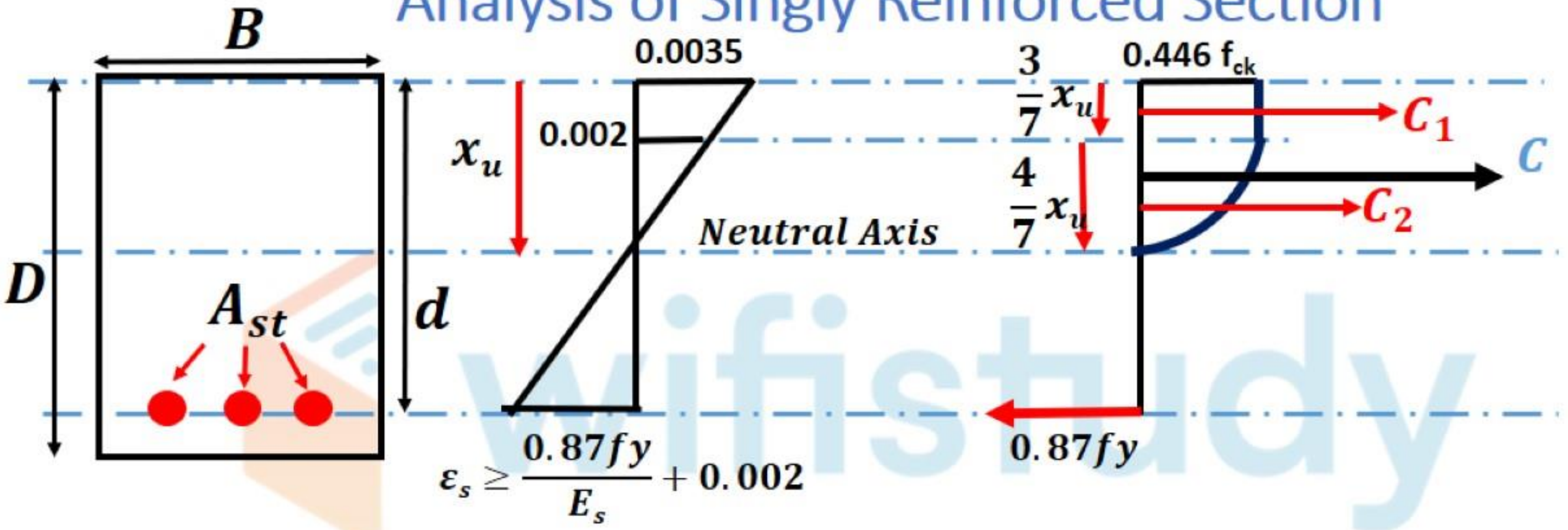
Using similar triangle property,

$$\frac{x_u}{0.0035} = \frac{x_1}{0.002}$$

$\Rightarrow x_1 = \frac{4}{7}x_u$, so

$\Rightarrow x_2 = \frac{3}{7}x_u$

Analysis of Singly Reinforced Section



Moment of resistance w.r.t concrete(compression)

$(M_u)_c = compressive\ force \times lever\ arm$

$(M_u)_c = C \times lever\ arm$

c_1 $\quad$ c_2

$C = c_1 + c_2$

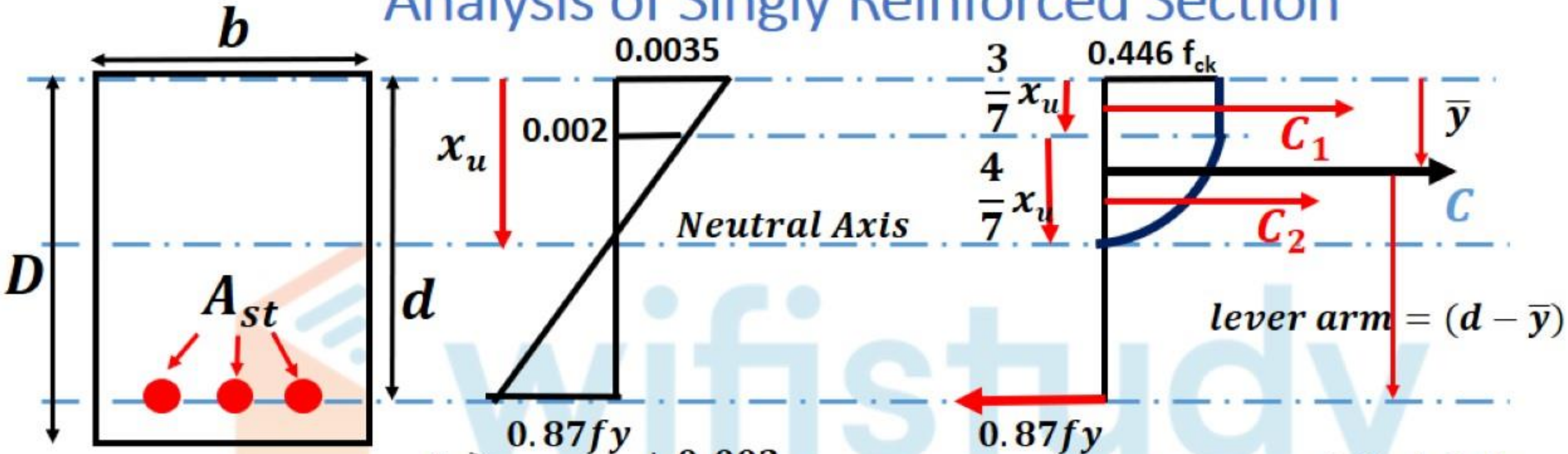
$$\boxed{\Rightarrow C = 0.36 f_{ck} x_u B}$$

area $\quad$ avg stress

$$c_1 = \left(\frac{3}{7}x_u \times B\right) \times 0.45 f_{ck} = 0.192 f_{ck} x_u B$$

$$c_2 = \left(\frac{2}{3} \times \frac{4}{7}x_u \times B\right) \times 0.45 f_{ck} = 0.171 f_{ck} x_u B$$

Analysis of Singly Reinforced Section



$$\varepsilon_s \geq \frac{0.87fy}{E_s} + 0.002$$

$$\Rightarrow \bar{y} = \frac{c_1y_1 + c_2y_2}{c_1 + c_2}$$

Moment of resistance w.r.t concrete(compression)

$$\boxed{\Rightarrow C = 0.36f_{ck}x_uB}$$

$$(M_u)_c = C \times \text{lever arm}$$

$$y_1 = \frac{1}{2}\left(\frac{3}{7}x_u\right) = \frac{3}{14}x_u$$

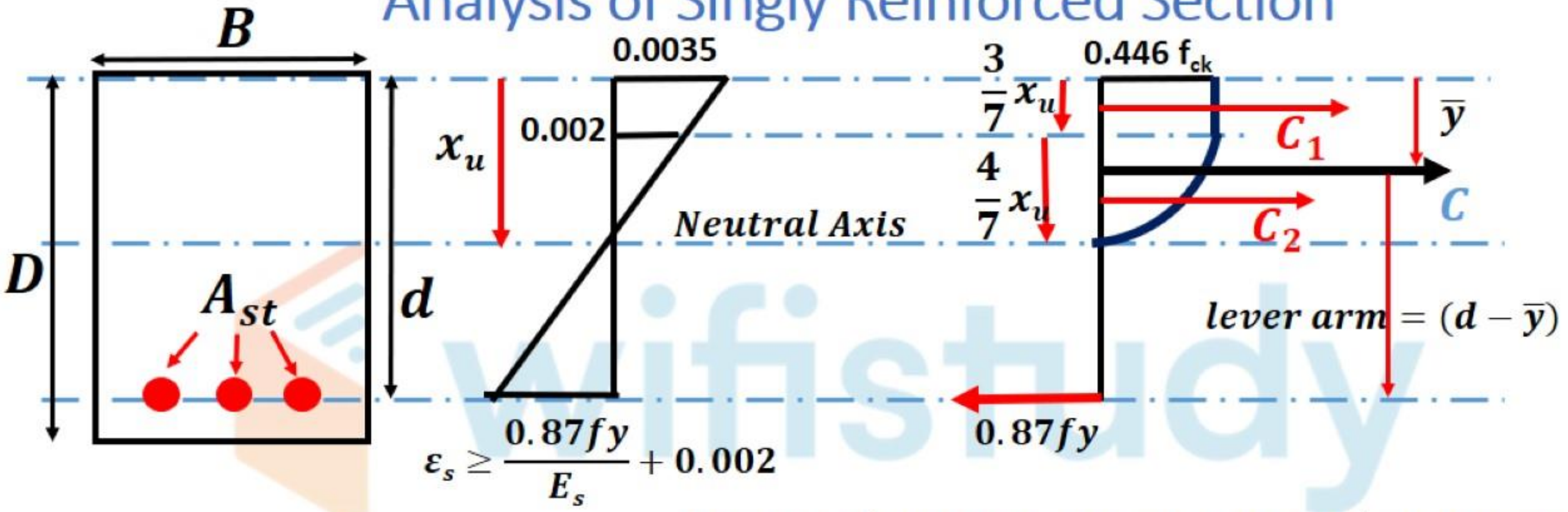
CG of parabola $\frac{3}{8}$ distance from top

$$y_2 = \frac{3}{7}x_u + \left(\frac{3}{8} \times \frac{4}{7}x_u\right) = \frac{9}{14}x_u$$

$$\bar{y} = \frac{(0.192f_{ck}x_uB)(\frac{3}{14}x_u) + (0.171f_{ck}x_uB)(\frac{9}{14}x_u)}{(0.192f_{ck}x_uB) + (0.171f_{ck}x_uB)}$$

$$\Rightarrow \bar{y} = \approx 0.42x_u$$

Analysis of Singly Reinforced Section



Moment of resistance w.r.t concrete(compression)

$$\boxed{\Rightarrow C = 0.36 f_{ck} x_u B}$$

$$\text{lever arm} = (d - 0.42x_u)$$

$$(M_u)_c = C \times \text{lever arm}$$

$$(M_u)_c = \boxed{0.36 f_{ck} x_u B} \times \boxed{(d - 0.42x_u)}$$

$$(M_u)_t = \text{tensile force} \times \text{lever arm}$$

$$(M_u)_t = \boxed{0.87 f_y A_{st}} \times \boxed{(d - 0.42x_u)}$$

Actual Depth of Neutral Axis

The actual depth of Neutral axis is calculated by equating the compression force to tensile force

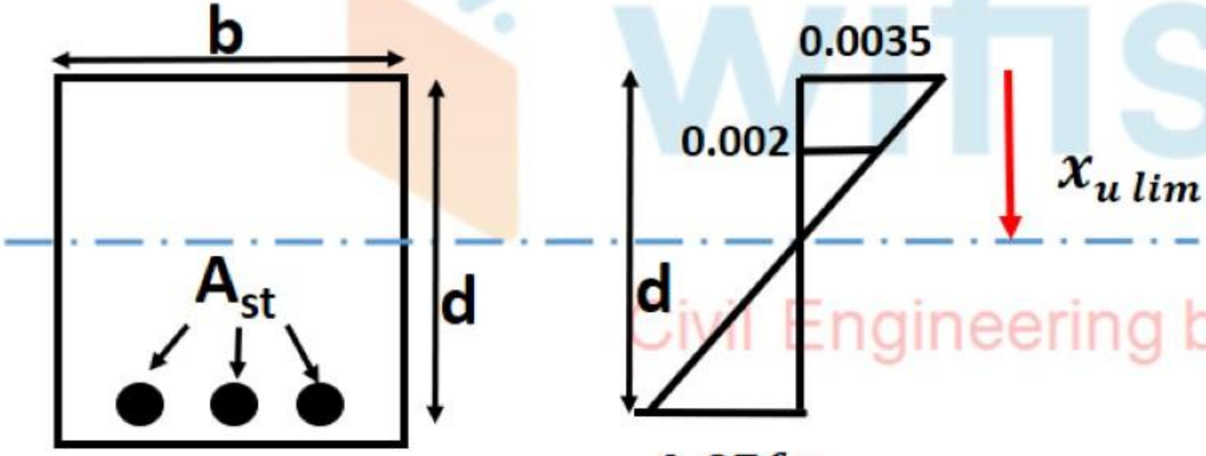
$$C = T$$

$$\Rightarrow 0.36 f_{ck}\, x_u\, B = 0.87 f_y\, A_{st}$$

$$\Rightarrow x_u = \frac{0.87\, f_y\, A_{st}}{0.36\, f_{ck}\, x_u\, B}$$

Limiting Depth of Neutral Axis

Since stress diagram is not linear, hence we use corresponding strain diagram



$$\varepsilon_s \geq \frac{0.87fy}{E_s} + 0.002$$

Using similar triangle property,

$$\frac{0.0035}{x_{u\,lim}} = \frac{\frac{0.87fy}{E_s} + 0.002}{d - x_{u\,lim}}$$

$$\Rightarrow \frac{d - x_{u\,lim}}{x_{u\,lim}} = \frac{\frac{0.87fy}{E_s} + 0.002}{0.0035}$$

$$\Rightarrow \frac{d}{x_{u\,lim}} = \frac{\frac{0.87fy}{E_s} + 0.002}{0.0035} + 1$$

$$\Rightarrow x_{u\,lim} = \frac{700}{1100 + 0.87fy} \times d$$

$$\Rightarrow x_{u\,lim} = k \times d$$

Maximum Depth of Neutral Axis

f_y N/mm²	x_{ulim}
Fe 250	0.53 d
Fe 415	0.48 d
Fe 500	0.46 d

Moment of Resistance

- *Moment of Resistance from compression side*
  - $\boldsymbol{MOR = 0.36\, f_{ck}\, B\, x_u(d - 0.42x_u)}$ **Valid for Balanced and over reinforced section**
- *Moment of Resistance from Tension side*
  - $\boldsymbol{MOR = 0.87 f_y\, A_{st}(d - 0.42x_u)}$ **Valid for Balanced and under reinforced section**

Design Formula

We always try to design the limiting section

Step 1: Depth of neutral axis

$$(M_u)_c = 0.36 f_{ck} B\, x_{u\,lim}(d - 0.42 x_{u\,lim})$$

$$= C\,B\,kd\,(d - 0.42kd)$$

$$= C\,B\,kd^2\,(1 - 0.42k)$$

$$= C\,B\,kd^2\,j$$

$$= Cjk\ Bd^2$$

$$= Q\ Bd^2$$

$$d = \sqrt{\frac{M_u}{QB}}$$

Design Formula

Step 2: Area of Steel A_{st}

$$(M_u)_T = 0.87\, f_y\, A_{st}\,(d - 0.42x_{u\,lim})$$

$$\Rightarrow A_{st} = \frac{(M_u)_T}{0.87 f_y (d - 0.42kd)}$$

$$\Rightarrow A_{st} = \frac{(M_u)_T}{0.87 f_y d(1 - 0.42k)}$$

$$\Rightarrow Ast = \frac{(M_u)_T}{0.87 f_y d\, j}$$

Limiting values of Tension steel

- Minimum area of tension reinforcement should not be less than

$$\frac{A_0}{bd} = \frac{0.85}{f_y}$$

A_0=minimum area of tension r/f

f_y = characteristic strength of steel in N/mm^2

- Maximum area of tension reinforcement should not be greater than **4 %** of the gross cross sectional area to avoid difficulty in placing and compacting concrete properly in framework

Effective Span of Beam

1) <u>Simply Supported beam or Slab</u>: **The effective span of a simply supported member is taken lesser of the following:**

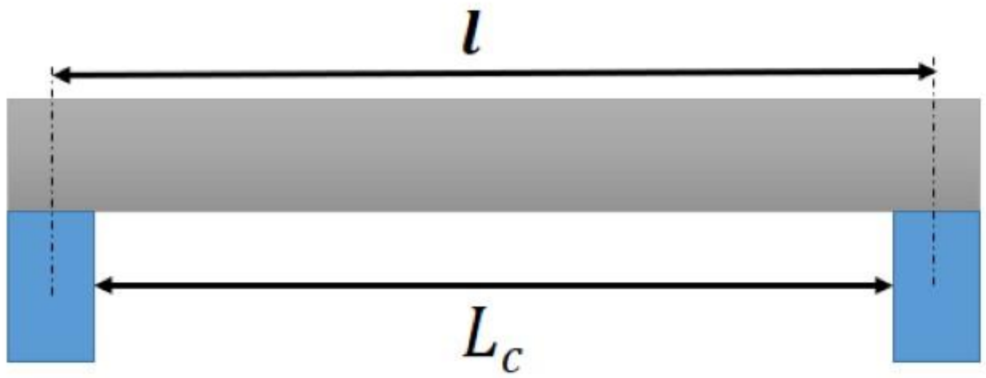
I. $l = Lc + d$

II. l (*centre to centre distance between supports*)

Where $l =$ *centre to centre distance between supports*

$L_c =$ *clear span*

$d = effective\ depth\ of\ beam\ or\ slab$



Effective Span of Beam

2) **Continuous Beam or Slab: The effective span of a continuous member is taken as:**

i. **If width of support $t_s \leq \frac{L_c}{12}$, then effective span is taken as lesser of …**

   a) $l = Lc + d$

   b) l (*centre to centre distance between supports*)

   Where $l =$ *centre to centre distance between supports*

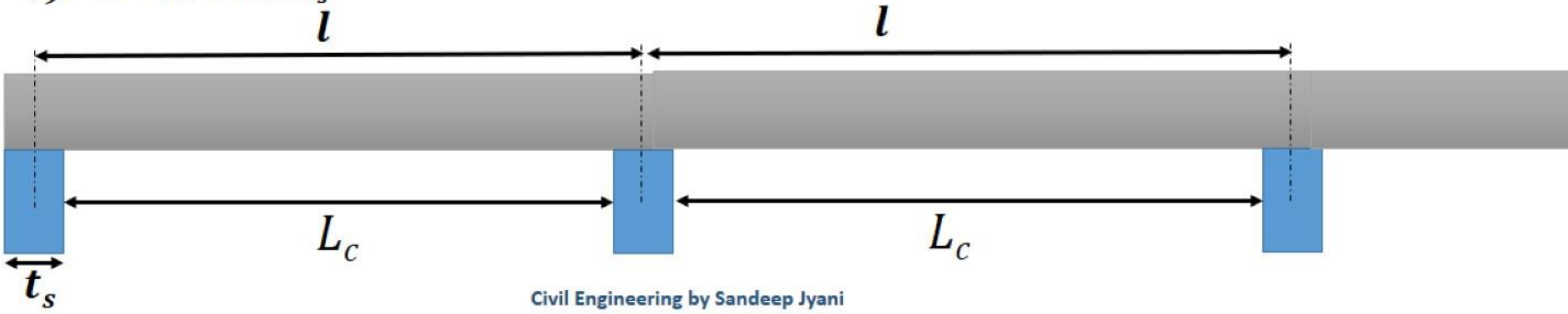
   $L_c =$ *clear span*

   $d = effective\ depth\ of\ beam\ or\ slab$

ii. **If width of support $t_s \geq \frac{L_c}{12}$, then effective span is taken as lesser of …**

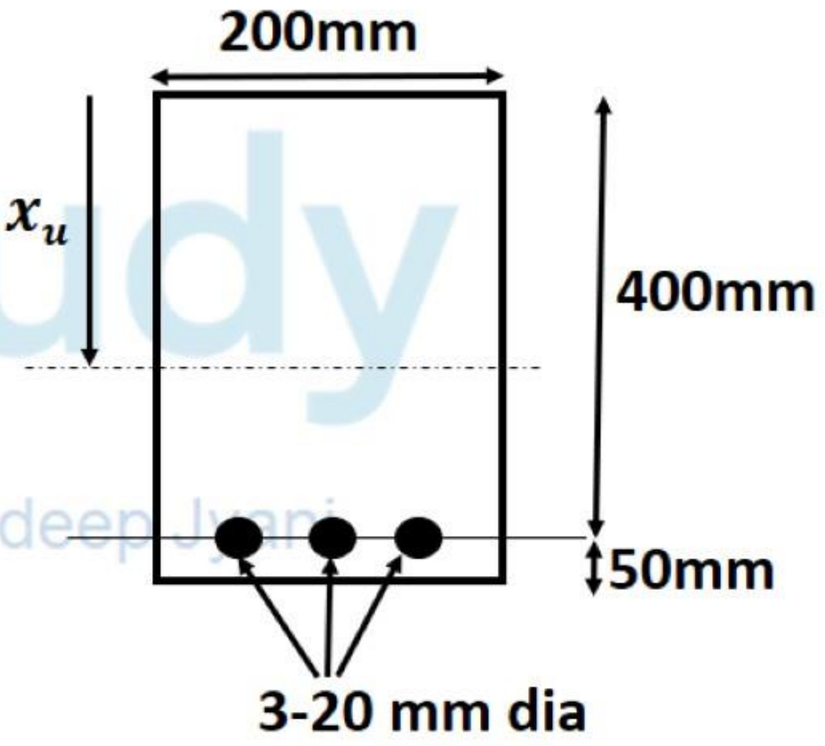
   a) $l = Lc + 0.5\,d$

   b) $l = Lc + 0.5\,t_s$

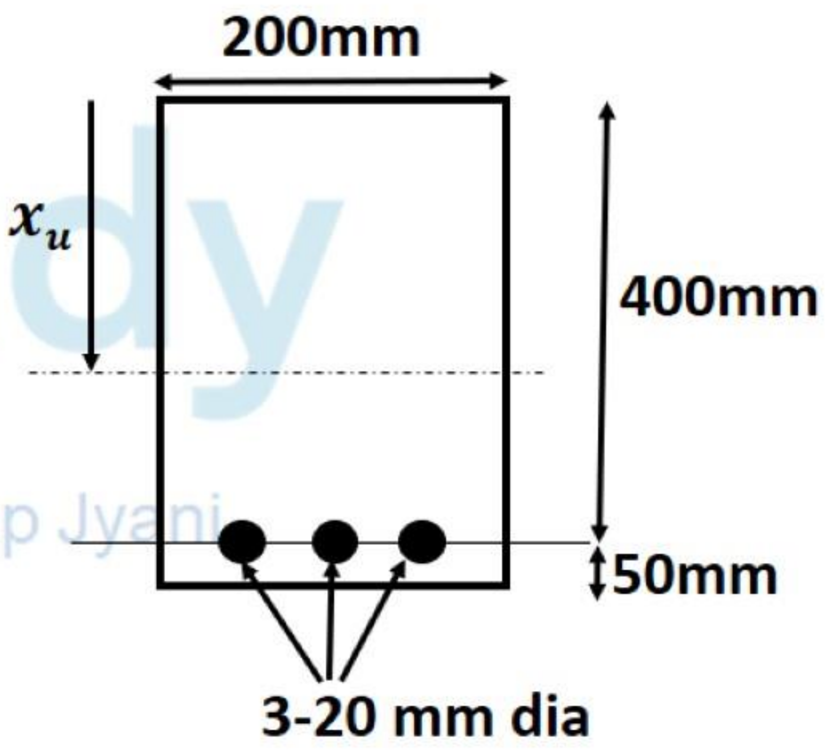


Que 5. Determine the depth of neutral axis for given section if $f_y = 250\ N/mm^2$ and f_{ck} is 15 N/mm^2:

Given data:



Que. Determine the depth of neutral axis for given section if $f_y = 250$ N/mm^2 and f_{ck} is 15 N/mm^2:



Given data:

Effective depth d= 400 mm

Area of steel = $A_{st} = 3 \times \frac{\pi}{4} \times 20^2 = 942mm^2$

Force of compression =force of tension

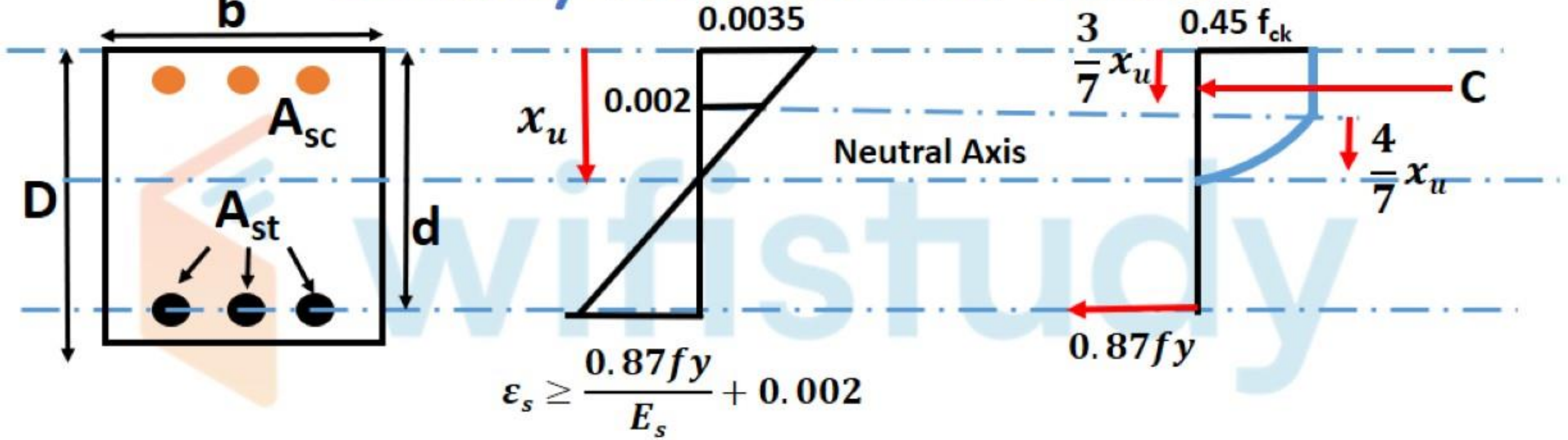
$$C = T$$
$$\Rightarrow 0.36\, f_{ck} x_u\, B = 0.87\, f_y A_{st}$$

$$x_u = \frac{0.87\, f_y A_{st}}{0.36\, f_{ck}\, B}$$

$$x_u = \frac{0.87 \times 250 \times 942}{0.36 \times 15 \times 200}$$

$$x_u = 190mm$$
$$x_{u\,lim} = 0.53 \times d = 400 \times 0.53 = 212mm$$

Doubly Reinforced Beam



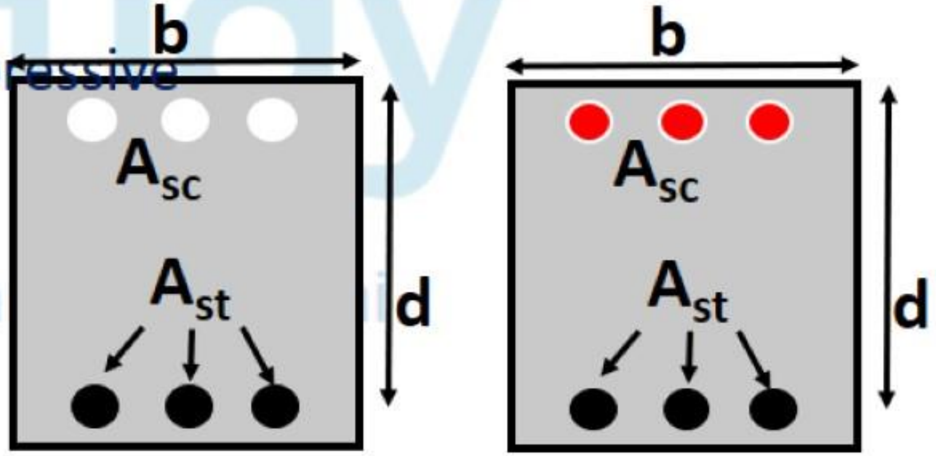
- When width and depth both are restricted, and the moment of resistance of a singly reinforced limiting section is smaller, then the bending moment is supposed to be carried by the section given
- Stress in concrete at top fiber **0.45 f_{ck}**
- Maximum stress in tension reinforcement 0.87 f_y
- The value of stress in compressive steel is read from stress or strain curve. Usually it is based on the value of strain at the level of compression steel

Analysis of Doubly reinforced section

- Step 1: Calculate $x_{u\,lim}$

f_y N/mm²	$x_{u\,lim}$
Fe 250	0.53 d
Fe 415	0.48 d
Fe 500	0.46 d

- Step 2: Total compressive force = concrete + compressive steel



$$C_{concrete} = 0.36\, f_{ck} x_u\, B\ - 0.45 f_{ck} \times A_{sc}$$

$$C_{steel} = f_{sc} A_{sc}$$

$$Total\ compressive\ force = 0.36\, f_{ck} x_u\, B\ - 0.45 f_{ck} \times A_{sc} + f_{sc} A_{sc}$$

Step 3: Tension force $T = 0.87 f_y A_{st}$

- Step 4: Actual Depth of neutral axis:
  - Tension force=compression force

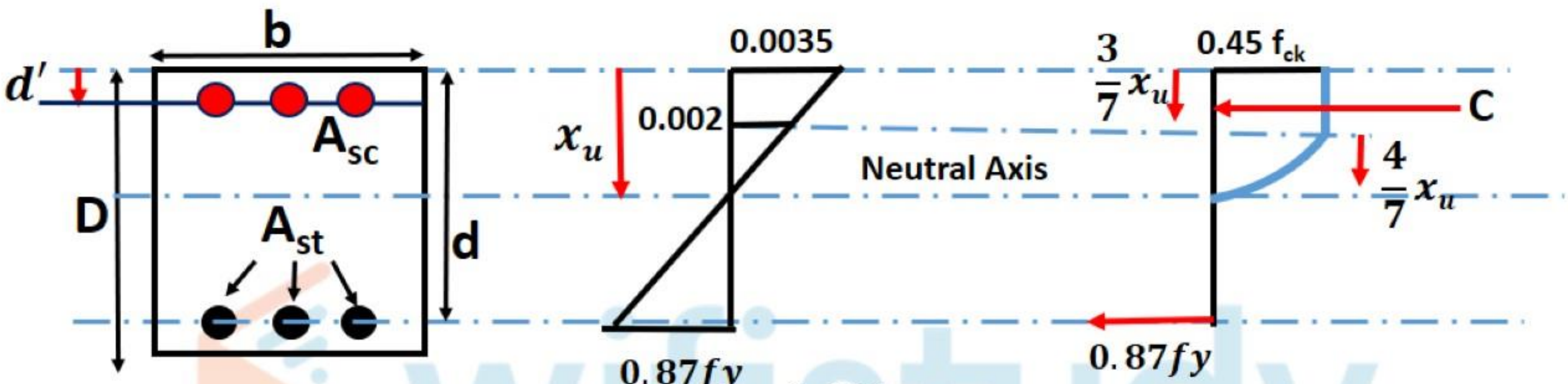
$$\Rightarrow 0.36\, f_{ck} x_u\, B - 0.45 f_{ck} \times A_{sc} + f_{sc} A_{sc} = 0.87 f_y A_{st}$$

$$\Rightarrow 0.36\, f_{ck} x_u\, B + (f_{sc} - 0.45 f_{ck}) A_{sc} = 0.87 f_y A_{st}$$

$$\Rightarrow 0.36\, f_{ck} x_u\, B = 0.87 f_y A_{st} - (f_{sc} - 0.45 f_{ck}) A_{sc}$$

$$\Rightarrow x_u = \frac{0.87 f_y A_{st} - (f_{sc} - 0.45 f_{ck}) A_{sc}}{0.36\, f_{ck}\, B}$$

- Step 5: Compare x_u with $x_{u\,lim}$:
  - **Balanced Section**
    - $\boldsymbol{x_u} = x_{u\,lim}$
  - **Under Reinforced Section**
    - $\boldsymbol{x_u} < x_{u\,lim}$
  - **Over Reinforced Section**
    - $\boldsymbol{x_u} > x_{u\,lim}$



$$\varepsilon_s \geq \frac{0.87fy}{E_s} + 0.002$$

- Step 6: Moment of Resistance:

From Compression side,

$M_u = (c)_{concrete} \times (\text{lever arm})_{concrete} + (c)_{steel} \times (\text{lever arm})_{steel}$

$$(M_u)_{steel} = fsc\ Asc \times (d - d')$$

$$(M_u)_{concrete} = 0.36\ fck\ xu\ B \times (d - 0.42x_u) - 0.45 f_{ck} A_{sc}(d - d')$$

$$(M_u)_{total\ compression} = 0.36 fck\ x_u\ B \times (d - 0.42x_u) - (0.45 f_{ck} A_{sc})(d - d') + f_{sc} A_{sc} \times (d - d')$$

$$(M_u)_{total\ compression} = 0.36 fck\ x_u\ B \times (d - 0.42x_u) + (f_{sc} - 0.45 f_{ck}) A_{sc}(d - d')$$

From Tension side,

$$(M_u)_{tension} = 0.87\ f_y A_{st} \times (d - \bar{y})$$

Que 6. An RCC beam can have maximum tension reinforcement as:

a) 6 % bD

b) 2 % bD

c) 3 % bD

d) 4 % bD

Que 6. An RCC beam can have maximum tension reinforcement as:

a) 6 % bD

b) 2 % bD

c) 3 % bD

d) 4 % bD

Que 7. The maximum depth of neutral axis for a beam with Fe 415 bars in limit state method of design

a) 0.46 d

b) 0.48 d

c) 0.50 d

d) 0.53 d

Que 7. The maximum depth of neutral axis for a beam with Fe 415 bars in limit state method of design

a) 0.46 d

b) 0.48 d

c) 0.50 d

d) 0.53 d

Que 8. The partial factor of safety for concrete is

a) 1.15
b) 1.5
c) 1.95
d) 2.0

Que 8. The partial factor of safety for concrete is

a) 1.15

b) 1.5

c) 1.95

d) 2.0

Que 9. Partial factor of safety for concrete and steel respectively may be taken as

a) 1.5 and 1.15
b) 1.5 and 1.78
c) 3 and 1.78
d) 3 and 1.2

Que 9. Partial factor of safety for concrete and steel respectively may be taken as

a) <u>1.5 and 1.15</u>

b) 1.5 and 1.78

c) 3 and 1.78

d) 3 and 1.2

Que 10. The characteristic strength of concrete in the actual structure is taken as

a) f_{ck}

b) $0.85\ f_{ck}$

c) $0.67\ f_{ck}$

d) $0.447\ f_{ck}$

Que 10. The characteristic strength of concrete in the actual structure is taken as

a) f_{ck}

b) 0.85 f_{ck}

c) 0.67 f_{ck}

d) 0.447 f_{ck}

Que 11. In limit state of collapse against flexure, the maximum strain in tension reinforcement at failure shall not be less than

(a) 0.002

(b) $0.002 + \frac{f_y}{E_s}$

(c) $0.002 + \frac{f_y}{0.87\, E_s}$

(d) $0.002 + \frac{f_y}{1.15 E_s}$

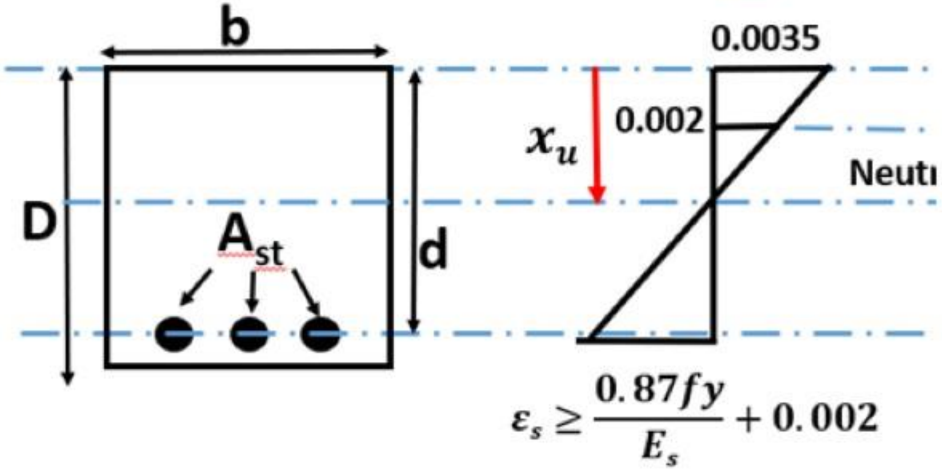
Que 11. In limit state of collapse against flexure, the maximum strain in tension reinforcement at failure shall not be less than

(a) 0.002

(b) $0.002 + \frac{f_y}{E_s}$

(c) $0.002 + \frac{f_y}{0.87\, E_s}$

(d) $0.002 + \frac{f_y}{1.15 E_s}$



Que 12. According to IS 456:2000, the maximum depth of stress block for balanced section of beam of effective depth d using steel with $f_y = 250$, is given by

(a)0.43 d

(b)0.53 d

(c)0.68 d

(d)0.73 d

Que 12. According to IS 456:2000, the maximum depth of stress block for balanced section of beam of effective depth d using steel with $f_y = 250$, is given by

(a)0.43 d

(b)<u>0.53 d</u>

(c)0.68 d

(d)0.73 d

Que 13. The characteristic strength of concrete is defined as that compressive strength below which NOT more than

(a)2% of results fall
(b)10% of results fall
(c)5% of results fall
(d)None of these

Que 13. The characteristic strength of concrete is defined as that compressive strength below which NOT more than

(a)2% of results fall

(b)10% of results fall

(c)5% of results fall

(d)None of these

Que 14. The modulus of elasticity of concerete (in N/mm^2) can be assumed as follows where f_{ck} is the characteristic cube compressive strength of concrete (in N/mm^2)

(a) $4000\sqrt{f_{ck}}$

(b) $5000\sqrt{f_{ck}}$

(c) $2000\sqrt{f_{ck}}$

(d) $3000\sqrt{f_{ck}}$

Que 14. The modulus of elasticity of concerete (in N/mm^2) can be assumed as follows where f_{ck} is the characteristic cube compressive strength of concrete (in N/mm^2)

(a) $4000\sqrt{f_{ck}}$

(b) $5000\sqrt{f_{ck}}$

(c) $2000\sqrt{f_{ck}}$

(d) $3000\sqrt{f_{ck}}$

Que 15. The horizontal distance between parallel main reinforcements in RC slab shall not be more than

(a)4 times effective depth of slab

(b)5 times effective depth of slab

(c)3 times effective depth of slab

(d)2 times effective depth of slab

Que 15. The horizontal distance between parallel main reinforcements in RC slab shall not be more than

(a)4 times effective depth of slab

(b)5 times effective depth of slab

(c)3 times effective depth of slab

(d)2 times effective depth of slab

Que 16. The factored loads at the limit state of collapse for DL + LL, DL + WL and DL + LL + WL combinations, according to IS : 456 – 2000 are respectively

(a)1.2 DL + 1.2 LL, 1.5 DL + 1.5 WL, 1.5 DL + 1.5 LL + 1.5 WL
(b)1.2 DL + 1.5 LL, (0.9 or 1.5) DL + 1.5 WL, 1.2 DL + 1.2 LL + 1.2 WL
(c)1.5 DL + 1.5 LL, 1.2 DL + 1.2 WL, 1.5 DL + 1.5 LL + 1.5 WL
(d)(0.9 or 1.5) DL + 1.5 LL, 1.5 DL + 1.5 WL, 1.2 DL + 1.2 LL + 1.2 WL

Que 16. The factored loads at the limit state of collapse for DL + LL, DL + WL and DL + LL + WL combinations, according to IS : 456 – 2000 are respectively

(a)1.2 DL + 1.2 LL, 1.5 DL + 1.5 WL, 1.5 DL + 1.5 LL + 1.5 WL
(b)1.2 DL + 1.5 LL, (0.9 or 1.5) DL + 1.5 WL, 1.2 DL + 1.2 LL + 1.2 WL
(c)1.5 DL + 1.5 LL, 1.2 DL + 1.2 WL, 1.5 DL + 1.5 LL + 1.5 WL
(d)(0.9 or 1.5) DL + 1.5 LL, 1.5 DL + 1.5 WL, 1.2 DL + 1.2 LL + 1.2 WL

Que 17. In limit state of collapse for direct compression, the maximum axial compressive strain in concrete is

(a)0.002
(b)0.003
(c)0.0035
(d)0.004

Que 17. In limit state of collapse for direct compression, the maximum axial compressive strain in concrete is

(a)0.002 compression
(b)0.003
(c)0.0035 (axial compression and bending)
(d)0.004

Que 18. As per IS 456–2000, in the absence of test data, the approximate value of the total shrinkage strain for design may be taken as:

(a)0.004

(b)0.001

(c)0.002

(d)0.0003

Que 18. As per IS 456–2000, in the absence of test data, the approximate value of the total shrinkage strain for design may be taken as:

(a)0.004

(b)0.001

(c)0.002

(d)0.0003

6.2.4.1 In the absence of test data, the approximate value of the total shrinkage strain for design may be taken as 0.000 3 (for more information, *see* IS 1343).

Que 19. Mid steel used in RRC structures conforms to

(a)IS : 432
(b)IS : 1566
(c)IS : 1786
(d)IS : 2062

Que 19. Mid steel used in RRC structures conforms to

(a)IS : 432

(b)IS : 1566

(c)IS : 1786

(d)IS : 2062

Que 20. percentage of steel for balanced design of a singly reinforced rectangular section by limit state method depends on

A. Characteristic strength of concrete

B. Yield strength of steel

C. Modulus of elasticity of steel

D. Geometry of the section

(a)Only (B)
(b)(A), (B) and (D)
(c)(B), (C) and (D)
(d)(A), (B) and (C)

Que 20. percentage of steel for balanced design of a singly reinforced rectangular section by limit state method depends on

A. Characteristic strength of concrete

B. Yield strength of steel

C. Modulus of elasticity of steel

D. Geometry of the section

$$x_u = \frac{0.87\, fy\, Ast}{0.36\, fck\, B}$$

(a)Only (B)

(b)(A), (B) and (D)

(c)(B), (C) and (D)

(d)(A), (B) and (C)

$$\frac{x_{u\,lim}}{d} = \frac{0.0035}{\frac{0.87fy}{E_s} + 0.002}$$

Que 21. From limiting deflection point of view, use of high strength steel in RC beam results in

(a)Reduction in depth
(b)No change in depth
(c)Increase in depth
(d)Increase in width

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(a)Reduction in depth

(b)No change in depth

(c)<u>Increase in depth</u>

(d)Increase in width

23.2.1 The vertical deflection limits may generally be assumed to be satisfied provided that the span to depth ratios are not greater than the values obtained as below:

a) Basic values of span to effective depth ratios for spans up to 10 m:

Cantilever	7
Simply supported	20
Continuous	26

b) For spans above 10 m, the values in (a) may be multiplied by 10/span in metres, except for cantilever in which case deflection calculations should be made.

c) Depending on the area and the stress of steel for tension reinforcement, the values in (a) or (b) shall be modified by multiplying with the modification factor obtained as per Fig. 4.

d) Depending on the area of compression reinforcement, the value of span to depth ratio be further modified by multiplying with the modification factor obtained as per Fig. 5.

Que 22. partial safety for concrete and steel are 1.5 and 1.15 respectively, because

(a)Concrete is heterogeneous while steel is homogeneous

(b)The control on the quality of concrete is not as good as that of steel

(c)Concrete is weak in tension

(d)Voids in concrete are 0.5% while those in steel are 0.15%

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Que 23. the tensile strength of concrete to be used in the design of reinforced concrete members is

(a) $0.2\ f_{ck}$

(b) $0.1\ f_{ck}$

(c) $0.7\sqrt{f_{ck}}$

(d) 0

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(a) $0.2\ f_{ck}$

(b) $0.1\ f_{ck}$

(c) $0.7\sqrt{f_{ck}}$

(d) <u>0</u>

Que 24. The allowable tensile stress in high yield strength deformed steel stirrups used in reinforced cement concrete is $(in\ N/mm^2)$

(a)140
(b)190
(c)230
(d)260

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(a)140

(b)190

(c)230

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IS 456 : 2000

Table 22 Permissible Stresses in Steel Reinforcement

(*Clauses* B-2.2, B-2.2.1, B-2.3 *and* B-4.2)

Sl No.	Type of Stress in Steel Reinforcement	Permissible Stresses in N/mm²		
		Mild Steel Bars Conforming to Grade I of IS 432 (Part 1)	Medium Tensile Steel Conforming to IS 432 (Part 1)	High Yield Strength Deformed Bars Conforming to IS 1786 (Grade Fe 415)
(1)	(2)	(3)	(4)	(5)
i)	Tension (σ_{st} or σ_{sv})			
	a) Up to and including 20 mm	140	Half the guaranteed yield stress subject to a maximum of 190	230
	b) Over 20 mm	130		230
ii)	Compression in column bars (σ_{sc})	130	130	190
iii)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1.5 times the modular ratio or σ_{sc} whichever is lower		

Que 25. Factor of safety is the ratio of ________.

(a)Yield stress to working stress.
(b)Tensile stress to working stress.
(c)Compressive stress to working stress.
(d)Bearing stress to working stress

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(a)Yield stress to working stress.
(b)Tensile stress to working stress.
(c)Compressive stress to working stress.
(d)Bearing stress to working stress

Que 26. The factor of safety for steel as compared to concrete is

(a)higher

(b)same

(c)lower

(d)None of these

Que 26. The factor of safety for steel as compared to concrete is

(a)higher

(b)same

(c)lower

(d)None of these

Que 27. pick up the correct statement from the following______.

(a)Dead load includes self-weight of the structure and super-imposed loads permanently attached to the structure

(b)Dead loads change their positions and vary in magnitude

(c)Dead loads are known in the beginning of the design

(d)None of these

Que 27. pick up the correct statement from the following______.

(a)Dead load includes self-weight of the structure and super-imposed loads permanently attached to the structure

(b)Dead loads change their positions and vary in magnitude

(c)Dead loads are known in the beginning of the design

(d)None of these

Que 28. In a single reinforced beam, if the permissible stress in concrete reaches earlier than that in steel, the beam section is called

(a)Underreinforced section
(b)Over reinforced section
(c)Economic section
(d)Critical section

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Que 29. Live load

(a)Varies in magnitude

(b)Varies in position

(c)Is expressed as uniformly distributed load

(d) both (a) and (b)

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(a) Varies in magnitude

(b) Varies in position

(c) Is expressed as uniformly distributed load

(d) both (a) and (b)

Que 30. Flexure strength of concrete is determined as:

(a)Modulus of rigidity
(b)Modulus of rupture
(c)Modulus of plasticity
(d)Modulus of elasticity

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(a)Modulus of rigidity

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Que 31. Live loads with time, can vary in:

(a)Magnitude

(b)Position

(c)Neither position nor magnitude

(d)Position as well as magnitude

Que 31. Live loads with time, can vary in:

(a)Magnitude

(b)Position

(c)Neither position nor magnitude

(d)<u>Position as well as magnitude</u>

WHERE THERE IS A CHANGE IN ***BENDING MOMENT***

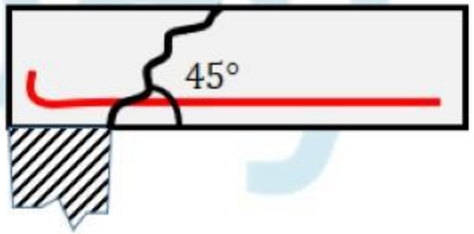
THERE IS ***SHEAR FORCE***

Rate of change of Bending moment is ***SHEAR FORCE***

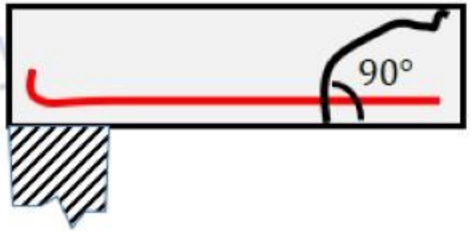
SHEAR

- Bending in reinforced concrete beams is usually accompanied by shear, the exact analysis of which is very complex.
- However, experimental studies confirmed the following three different modes of failure due to possible ***combinations of shear force and bending moment*** at a given section

1. *Diagonal Tension Failure*
   - **LARGE Shear Force and** Less bending moment
   - Web shear causes cracks which progress with 45° with horizontal

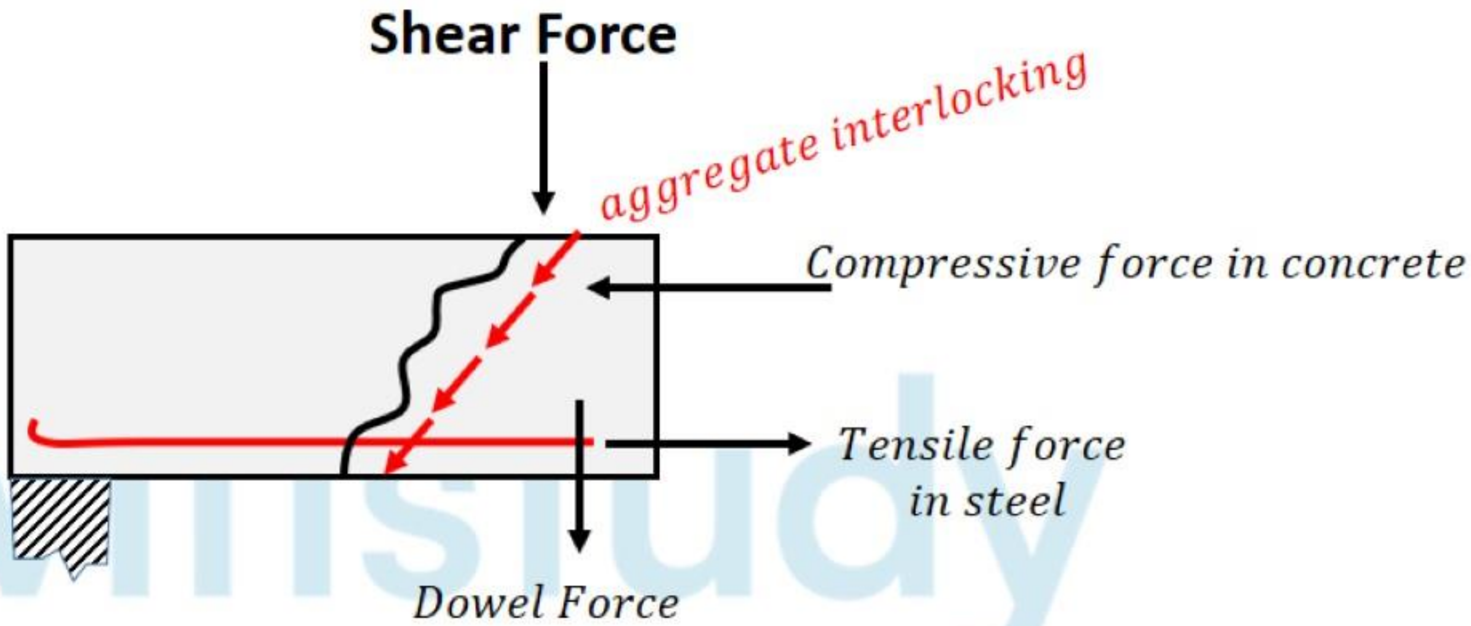


2. *Flexural shear Failure*
   - **LARGE BENDING MOMENT** and Less Shear Force
   - Such cracks are normally at 90°
   - Steel yields in flexural tension shear



3. *Diagonal compression Failure*
   - It occurs under **LARGE Shear Force**
   - Concrete crushes in compression due to flexural compression

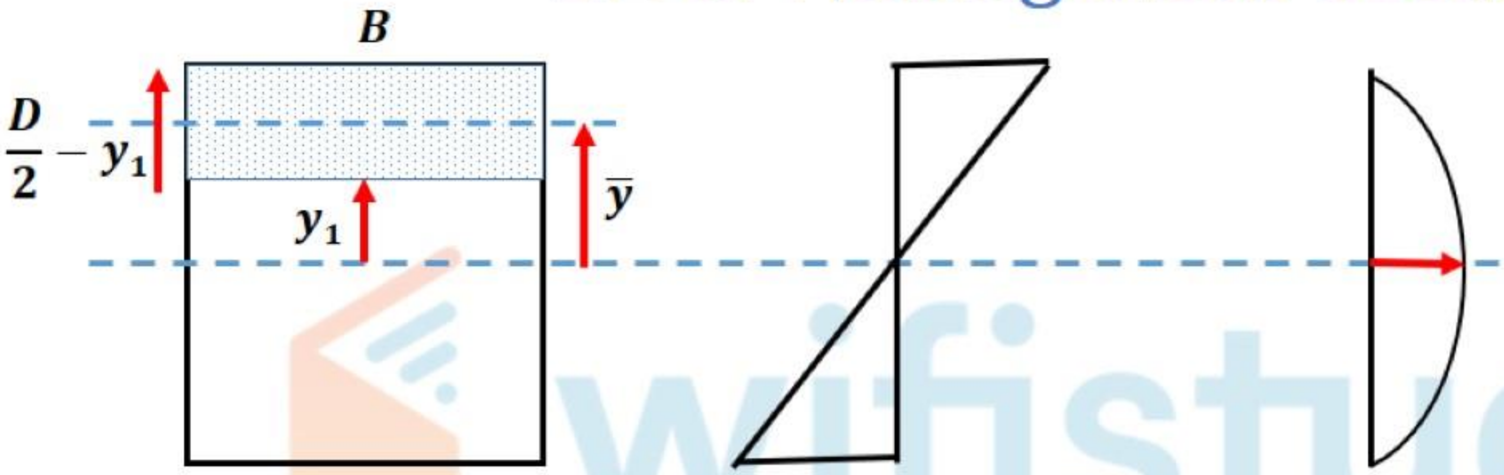
Shear



1. Shear force is resisted by the uncracked Concrete in compression region,
2. The aggregate interlocking and
3. The shear acting across longitudinal steel bars

The shear force across the steel bars is also known as *Dowel Force*

1. For Homogenous Section



- $I = \frac{BD^2}{12}$,
- $\bar{y} = \frac{\frac{D}{2} - y_1}{2} + y_1$
- $A = \left(\frac{D}{2} - y_1\right) \times B$

$$Shear\ Stress = \frac{VA\bar{y}}{IB}$$

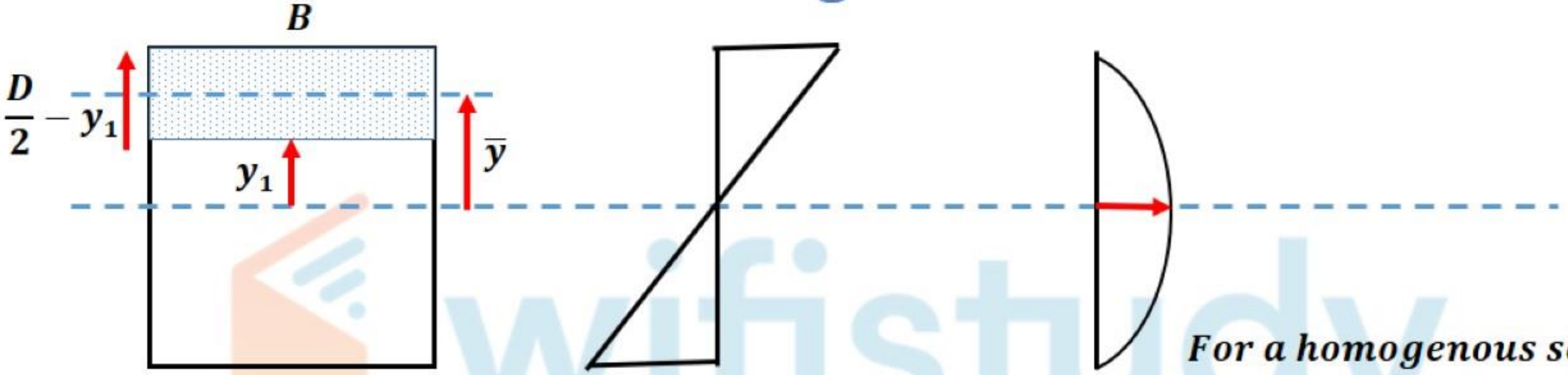
$$= \frac{V\left[\left(\frac{D}{2} - y_1\right) \times B\right]\left[\frac{\frac{D}{2} - y_1}{2} + y_1\right]}{IB}$$

$$= \frac{V\left[\left(\frac{D}{2} - y_1\right) \times B\right]\left[\frac{D}{4} + \frac{y_1}{2}\right]}{IB}$$

$$= \frac{V\left[\left(\frac{D}{2} - y_1\right) \times \frac{B}{2}\right]\left[\frac{D}{2} + y_1\right]}{IB}$$

$$= \frac{V}{2I}\left[\left(\frac{D}{2}\right)^2 - (y_1)^2\right]$$

1. For Homogenous Section



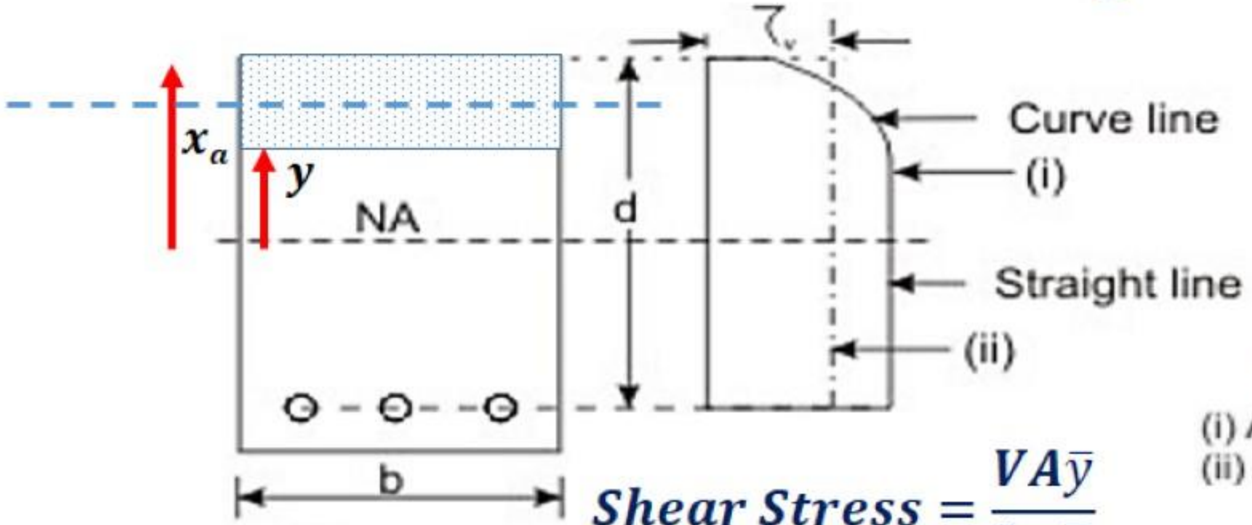
For a homogenous section, shape of shear stress diagram is parabolic

$$\textit{Shear Stress} = \frac{V}{2I}\left[\left(\frac{D}{2}\right)^2 - (y_1)^2\right]$$

$y_1 = \frac{D}{2}$, $\quad$ $\textit{Shear Stress} = 0$

$y_1 = 0$, $\quad$ $\textit{Shear Stress} = \textit{maximum}$

2. For Non Homogenous Section



(i) Actual distribution
(ii) Average distribution

For a RCC section, shape of shear stress diagram is parabolic above NA and rectangular below NA

$$Shear\ Stress = \frac{VA\bar{y}}{I_{eq}B}$$

$$= \frac{V[B(x_a - y)]\left[\frac{x_a - y}{2} + y\right]}{I_{eq}B}$$

$$= \frac{V}{2Ieq}[(x_a - y)(x_a + y)]$$

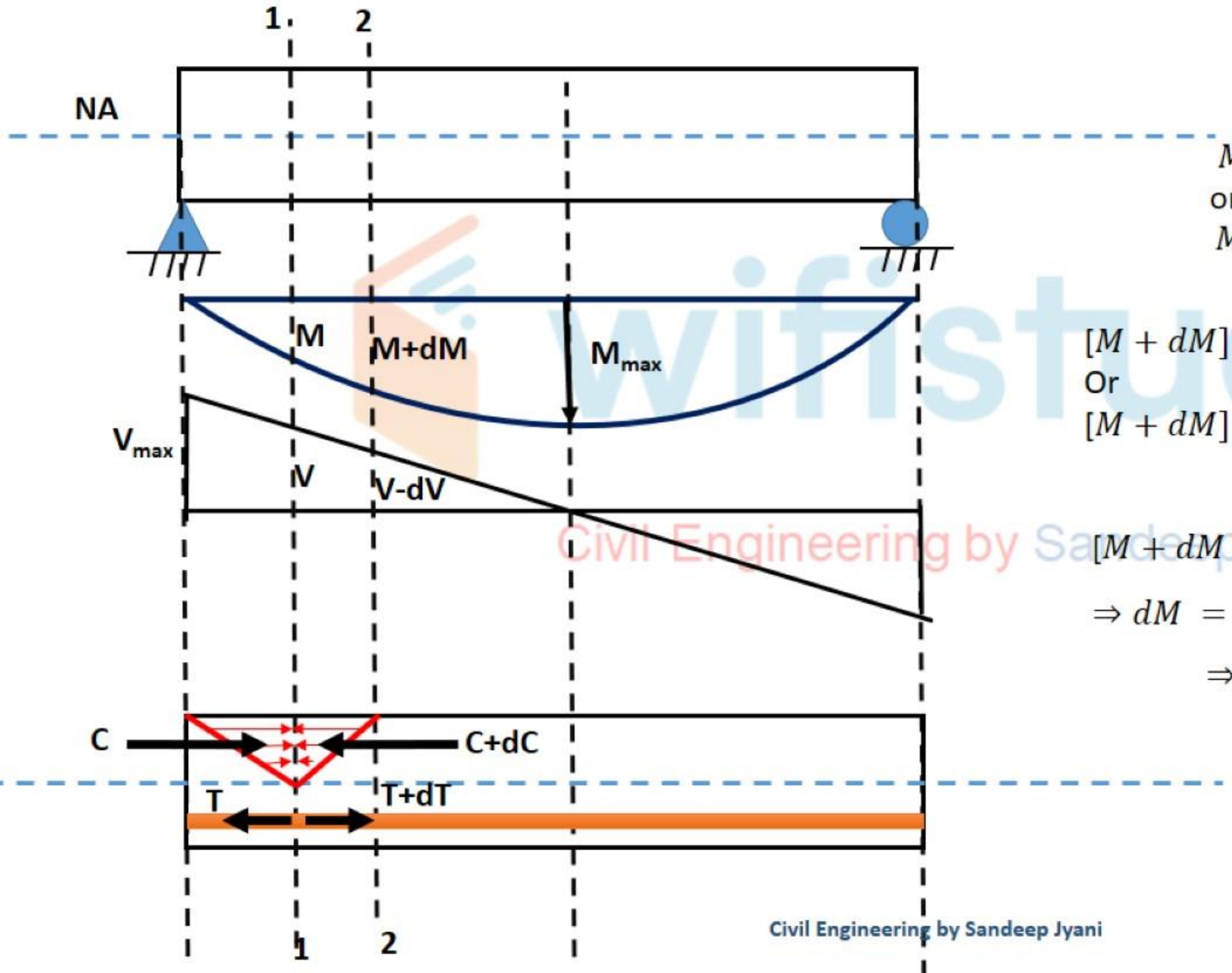
$$= \frac{V}{2Ieq}[(x_a{}^2 - y^2)]$$

$$Shear\ Stress = \frac{V}{2Ieq}[(x_a{}^2 - y^2)]$$

$y = x_a$ $Shear\ Stress = 0$

$y = 0$, $Shear\ Stress = maximum$

Shear Stress Below Neutral Axis



$$\textit{At section } 1-1$$

$$M = C \times Lever\ arm$$

or $\qquad\qquad \ldots\ldots(1)$

$$M = T \times Lever\ arm$$

$$\textit{At section } 2-2$$

$$[M + dM] = [C + dC] \times Lever\ arm$$

Or $\qquad\qquad \ldots\ldots(2)$

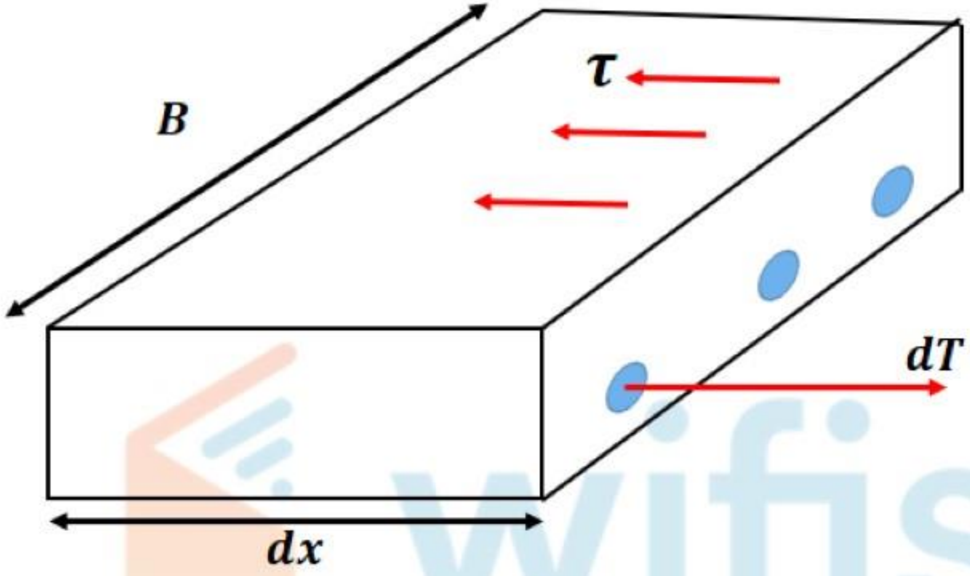
$$[M + dM] = [T + dT] \times Lever\ arm$$

$$[M + dM - M] = [T + dT - T] \times Lever\ arm$$

$$\Rightarrow dM = dT \times Lever\ arm$$

$$\Rightarrow dM = dT \times jd$$

$$\Rightarrow \boldsymbol{dT = \frac{dM}{j.d}}$$



$$\Rightarrow dT = \underbrace{\tau}_{\text{shear stress}} \times \underbrace{(B \times dx)}_{\text{area of cross section}}$$

$$\Rightarrow dT = \frac{dM}{j.d}$$

$$\Rightarrow \frac{dM}{j.d} = \tau \times (B \times dx)$$

$$\Rightarrow \tau = \frac{dM}{dx\, B.j.d}$$

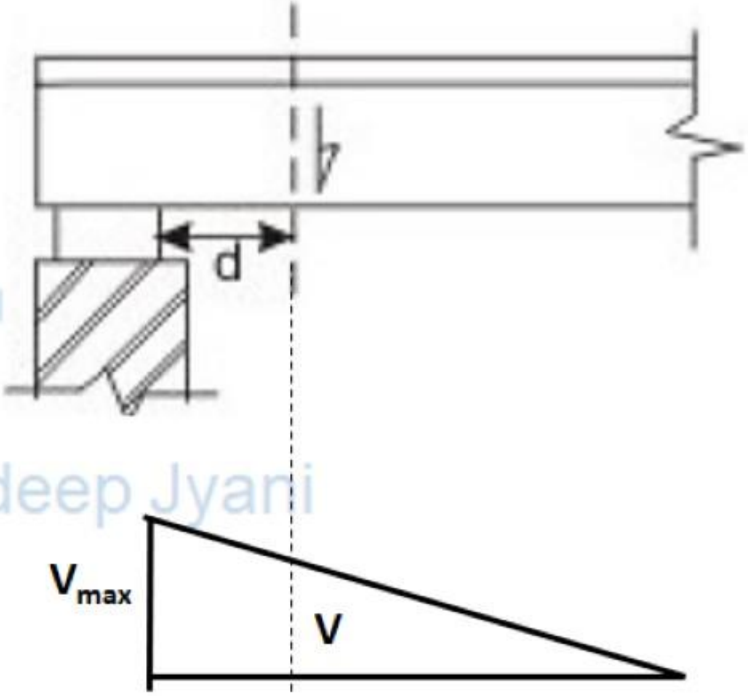
$$\boxed{\Rightarrow \tau = \frac{V}{B.j.d}}$$

IS Code Recommendation

1. As per IS code recommendation, the shear stress below the depth of neutral axis is assumed to be constant upto effective depth d due to ineffectiveness of the concrete in the tension zone
2. As per IS code recommendation, the I (moment of inertia) is taken as I_{eq} and that is equal to $\frac{\boldsymbol{B x_a}^3}{\mathbf{3}} + \boldsymbol{m A_{st}(d - x_a)^2}$
3. Circular section is best in carrying or resisting shear force and is assumed to be best section
4. As per IS code recommendation, the shear stress is assumed to be constant throughout the depth of the section, therefore it is considered as $\frac{V}{Bd}$

SHEAR

- As per IS recommendations, the beam can be designed either for maximum shear force or for maximum shear force at critical section.
- As per IS code 456, critical section is at a distance of ‘d’ from the face of the support.
- Concrete beams are expected to crack in flexure, with such cracks forming perpendicular to longitudinal tension reinforcement, i.e., perpendicular also to a free edge.



1. NOMINAL SHEAR STRESS

- It is the average shear stress developed in a cross section.
- It is generally denoted by

$$\tau_v = \frac{V}{Bd}$$

$$V = \tau_v \, B \, d$$

2. Design Shear Strength of Reinforced Concrete

- τ_c is the shear strength of reinforced concrete.
- It depends upon grade of concrete and % of main tension reinforcement.
- The shear force resisted by the concrete

$$V_c = \tau_c \, B \, d$$

Design Shear Strength of Reinforced Concrete

$(100\, A_s/b\, d)$	Grade of concrete				
	M 20	M 25	M 30	M 35	M40 and above
≤ 0.15	0.28	0.29	0.29	0.29	0.30
0.25	0.36	0.36	0.37	0.37	0.38
0.50	0.48	0.49	0.50	0.50	0.51
0.75	0.56	0.57	0.59	0.59	0.60
1.00	0.62	0.64	0.66	0.67	0.68
1.25	0.67	0.70	0.71	0.73	0.74
1.50	0.72	0.74	0.76	0.78	0.79
1.75	0.75	0.78	0.80	0.82	0.84
2.00	0.79	0.82	0.84	0.86	0.88
2.25	0.81	0.85	0.88	0.90	0.92
2.50	0.82	0.88	0.91	0.93	0.95
2.75	0.82	0.90	0.94	0.96	0.98
≥ 3.00	0.82	0.92	0.96	0.99	1.01

3. Stress in Shear Reinforcement

$$\textit{Nominal shear force}\ V = \tau_v\ B\ d$$
$$\textit{Shear force resisted by concrete}\ V_c = \tau_c\ B\ d$$

The remaining shear force is to be resisted by the Shear reinforcement (stirrups):

$$V_s = V - Vc$$
$$V_s = (\tau_v - \tau_c) B\ d$$

4. Maximum Shear Stress $\tau_{c\,max}$

- The shear stress developed in the beam should not be more than maximum shear stress of the beam
- $\tau_{c\,max}$ depends only on the grade of concrete
- If τ_v is greater than $\tau_{c\,max}$ then the size of beam has to be revised

4. Maximum Shear Stress $\tau_{c\,max}$

- The shear stress developed in the beam should not be more than maximum shear stress of the beam
- $\tau_{c\,max}$ depends only on the grade of concrete
- If τ_v is greater than $\tau_{c\,max}$ then the size of beam has to be revised
- $\tau_{c\,max} > \tau_v$ VALID
- $\tau_{c\,max} < \tau_v$ INVALID (SECTION TO BE REVISED, NO OTHER OPTION)

Maximum shear stress, $\tau_{c\,max}$ in N/mm2

Grade of concrete	M15	M 20	M 25	M 30	M 35	M 40 and above
$\tau_{c\,max}$ N/mm^2	2.5	2.8	3.1	3.5	3.7	4.0

Minimum Shear Reinforcement

- (Clause. 40.3, 26.5.1.5 and 26.5.1.6 of IS 456)
- Minimum shear reinforcement has to be provided even when τ_v is less than τ_c
- $\tau_v < \tau_c$ minimum shear reinforcement required
- $\tau_v < 0.5\ \tau_c$ No shear reinforcement is required
- The minimum shear reinforcement in the form of stirrups shall be provided such that

$$\frac{A_{sv}}{b\,s_v} \geq \frac{0.4}{0.87\,f_y}$$

  - A_{sv} = total cross-sectional area of stirrup legs effective in shear
  - s_v = stirrup spacing along the length of the member
  - b = breadth of the beam or breadth of the web of the web of flanged beam b_w, and
  - f_y = characteristic strength of the stirrup reinforcement in N/mm^2 which shall not be taken greater than 415 N/mm^2 .

Minimum Shear Reinforcement

- $\tau_v < \tau_c$ minimum shear reinforcement required
- $\tau_v < 0.5\ \tau_c$ No shear reinforcement is required
- $\tau_v > \tau_c$ Design shear reinforcement (vertical of inclined)
- $\tau_v > \tau_{c\,max}$ Redesign the section

Minimum Shear Reinforcement

- Clause 26.5.1.5 of IS 456 stipulates that the maximum spacing of shear reinforcement measured along the axis of the member shall not be more than **0.75 d for vertical stirrups** and **d for inclined stirrups** at 45° , where d is the effective depth of the section.

1. **S_v < 0.75 d Vertical shear Reinforcement**
2. **S_v < d Inclined shear Reinforcement**
3. **However, the spacing shall not exceed 300 mm in any case.**

Que: If depth of beam is 300mm, find spacing for shear reinforcement

Solution:

Que: If depth of beam is 300mm, find spacing for shear reinforcement

Solution:

i. For vertical stirrup
   - 0.75d = 0.75 x 300 =225mm
ii. For inclined stirrup
   - d=300mm
iii. For any case maximum r/f =300 mm

Answer: minimum of all these = (i)=225mm

The minimum shear reinforcement is provided for the following:

1. Any sudden failure of beams is prevented if concrete cover bursts and the bond to the tension steel is lost.
2. Brittle shear failure is arrested which would have occurred without shear reinforcement.
3. Tension failure is prevented which would have occurred due to shrinkage, thermal stresses and internal cracking in beams.
4. To hold the reinforcement in place when concrete is poured
5. Section becomes effective with the tie effect of the compression steel

Objective question

$\tau_{c\,max}$ → $grade\ of\ concrete$

τ_c → $percentage\ of\ tensile\ reinforcement$

τ_c → $grade\ of\ concrete$

Design of Shear Reinforcement

- Design of shear reinforcement is entirely based on the remaining shear force that is supposed to be resisted i.e.

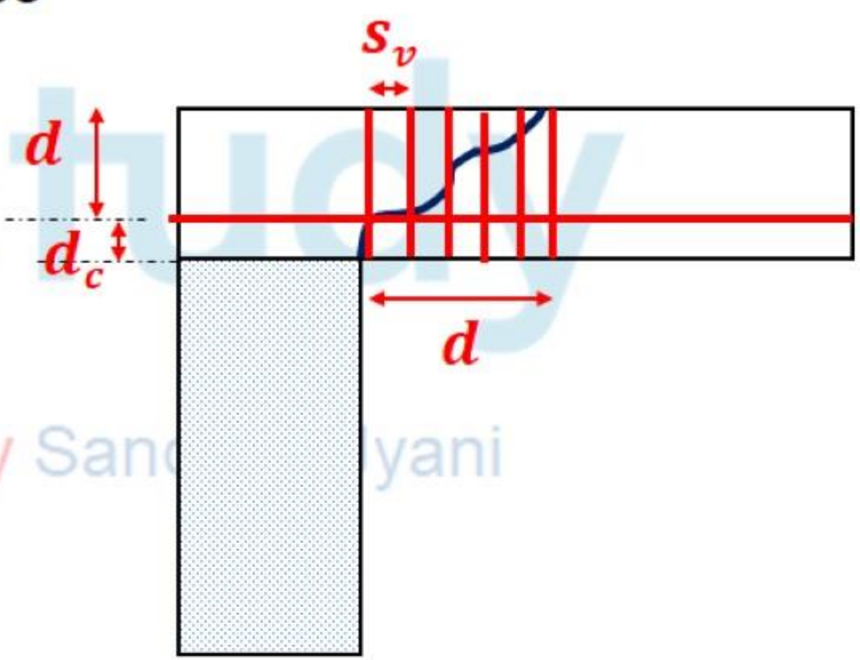
$$V_s = V - Vc$$
$$V_s = (\tau_v - \tau_c)B\, d$$

- When τ_v is more than τ_c , shear reinforcement shall be provided in any of the three following forms:
  (a) Vertical stirrups,
  (b) Bent-up bars along with stirrups, and
  (c) Inclined stirrups

Design of Shear Reinforcement

(a) Vertical Shear Reinforcement stirrups

- No. of shear reinforcements $= \frac{d}{s_v}$



WSM $$V_s = V - Vc = \sigma_{sv} \times \underbrace{A_{sv}}_{\text{Area of Shear reinforcement}} \times \overbrace{\frac{d}{s_v}}^{\text{No. of stirrups}}$$

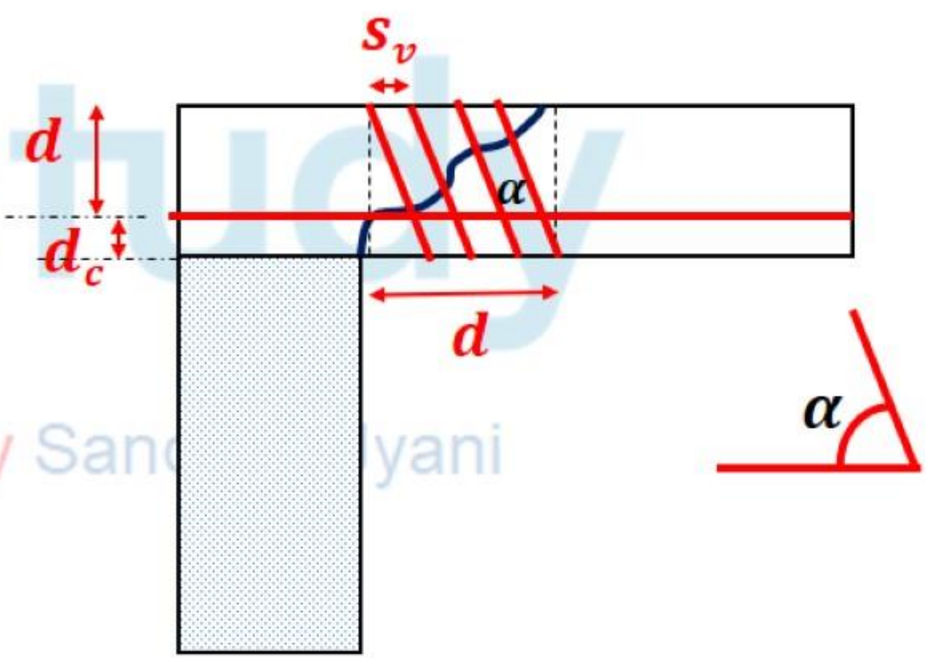
$$\boxed{\Rightarrow s_v = \frac{\sigma_{sv} \times A_{sv} \times d}{V_s}}$$

LSM $$\boxed{\Rightarrow s_v = \frac{0.87\, f_y \times A_{sv} \times d}{V_s}}$$

Design of Shear Reinforcement

b) Inclined Shear Reinforcement stirrups

- Spacing in inclined shear reinforcement is more as compared to vertical shear reinforcement in carrying the same shear force



WSM $$\Rightarrow sv = \frac{\sigma_{sv} \times Asv \times d}{V_s}(sin\alpha + cos\alpha)$$

LSM $$\Rightarrow sv = \frac{0.87\, f_y \times Asv \times d}{V_s}(sin\alpha + cos\alpha)$$

Design of Shear Reinforcement

c) Bent up bars

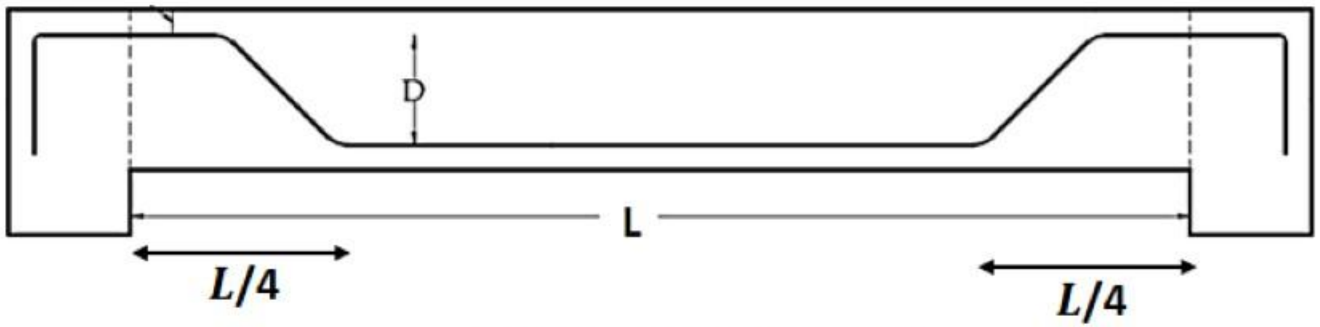
- Bentup bars are main r/f bent at any angle (generally 45°) to act as shear reinforcement
- Bent up bar can not be provided along with either vertical or inclined reinforcement
- Bent up bars should not be used beyond L/4 distance from each support

$$\Rightarrow Vsb = \sigma_{sb} \times Asb \times sin\alpha$$

WSM

$$\Rightarrow Vsb = 0.87\, f_y \times Asb \times sin\alpha$$

LSM



Steps for Design

1. **Find maximum shear force**
   - SSB = $\frac{WL}{2}$ or $\frac{W_u L}{2}$
2. **Nominal Shear Stress**
   - $\tau_v = \frac{V}{bd} or \frac{V_u}{bd}$ **and compare with $\tau_{c\,max}$**
3. **Shear Strength of Concrete (τ_c)**
4. **Net shear force resisted by Shear reinforcement**
   - $Vs = (\tau_v - \tau_c)Bd$
5. **Design of Shear reinforcement**

Steps for Design

6. **Minimum shear reinforcement**

$$\frac{A_{sv}}{b\, s_v} \geq \frac{0.4}{0.87\, f_y}$$

7. **Maximum spacing in shear reinforcement**

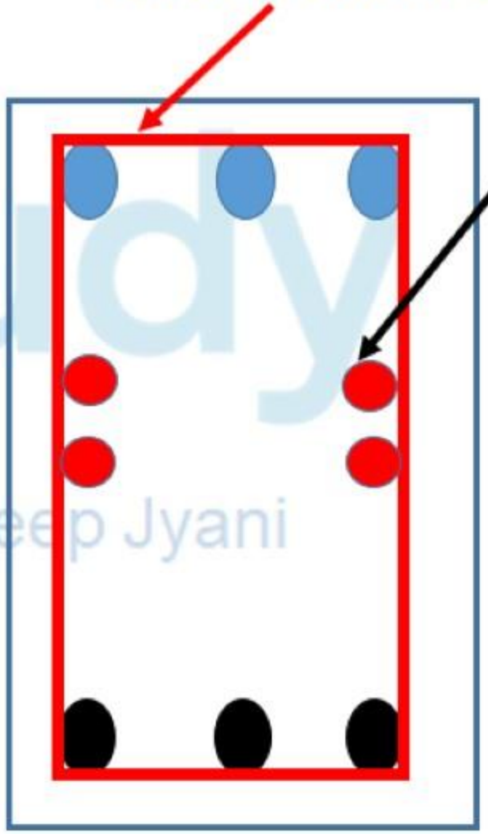
   1. $S_v < 0.75\, d$ Vertical shear Reinforcement
   2. $S_v < d$ Inclined shear Reinforcement
   3. However, the spacing shall not exceed 300 mm in any case.

   (whichever is minimum out of these)

Side Face Reinforcement

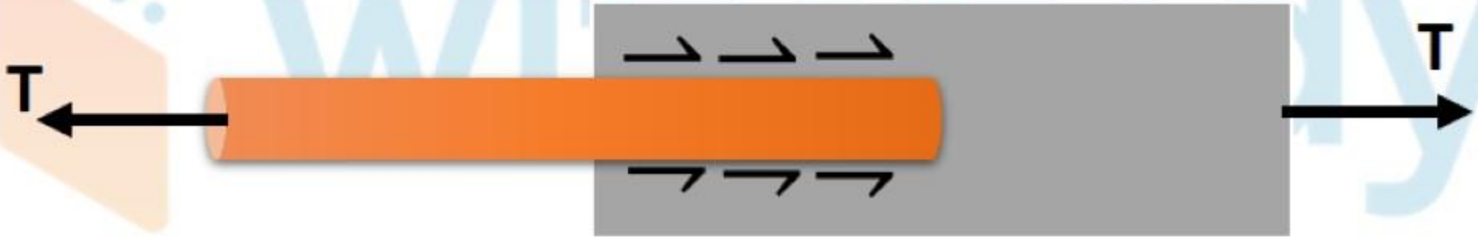
1. When depth of the beam is greater than 750mm (and beam is not subjected to torsion)
2. When beam is subjected to torsion, and depth of the beam is greater than 450mm, then side face reinforcement is also provided

- In above both cases, side face reinforcement at 0.1 % of the web area (B x d) is provided on both the faces respectively



Bond and Development Length

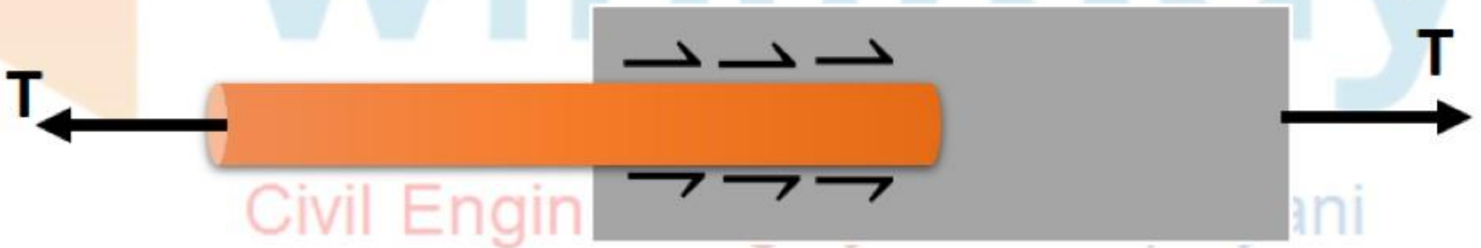
- Bond Stress is defined as the Shear Force per unit of Nominal Surface area of a reinforcement bar acting parallel to the bar on the interface between the bars and surrounding concrete



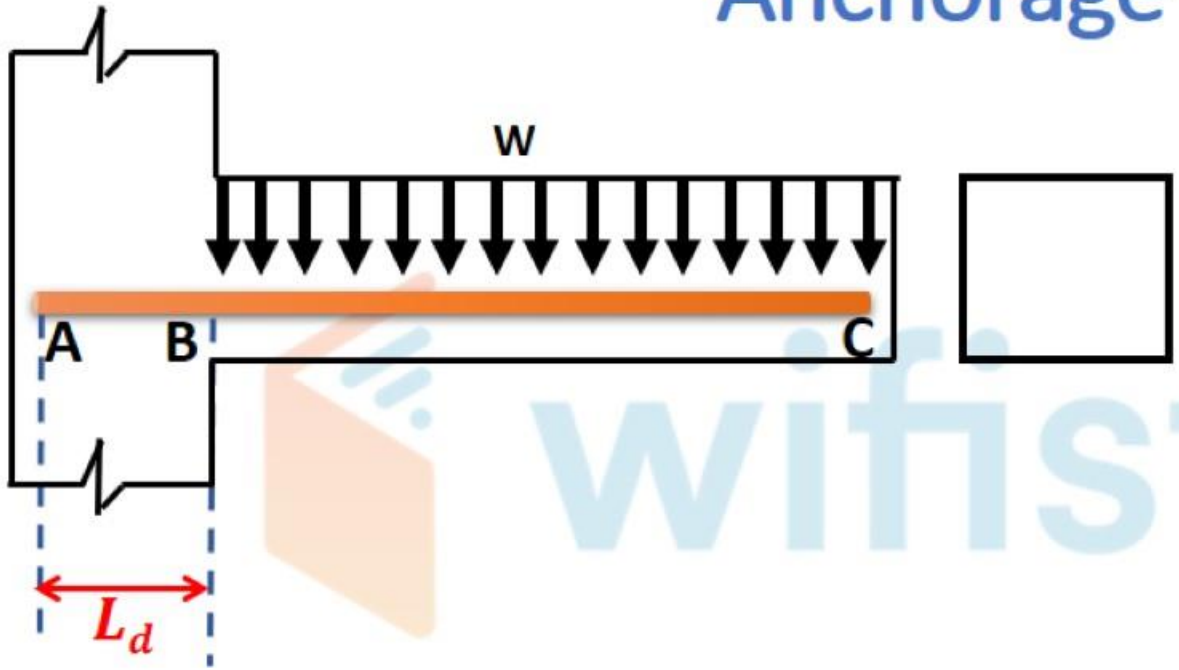
- Basic requirement in the reinforced concrete structures is that steel and surrounding concrete act together and there should be no slip of the bar relative to its surrounding concrete.
- Slippage of bar may result in overall failure of the beam
- A beam may continue to carry load as long as the bars are anchored at the ends.

Bond and Development Length

- Due to unbalanced tension force, shear stress is acting along longitudinal direction, that is called bond stress between steel and concrete



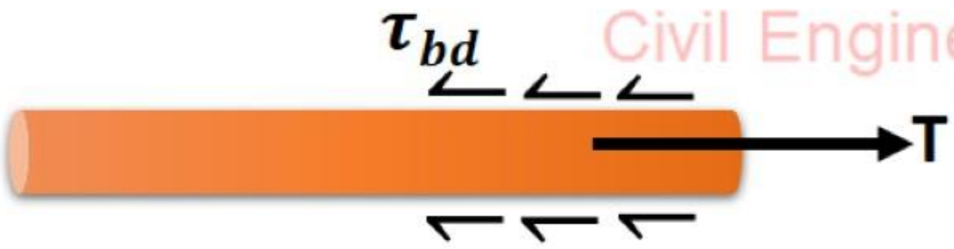
Anchorage Bond



- Let us consider a uniformly loaded cantilever beam which has to resist given BM and SF
- Let us assume that tension reinforcement consists of single bar of diameter Ø
- The tensile force at B is equal to

$$T = \frac{\pi}{4} \text{Ø}^2 \frac{f_y}{1.15}$$

- Which must be transmitted to concrete by bond stress in the embedded length $L_d = AB$
- If τ_{bd} is the average bond stress acting over the surface area $\pi \text{Ø} L_d$ then



$$\tau_{bd} \times \pi \text{Ø}\, L_d = \frac{\pi}{4} \text{Ø}^2 \frac{f_y}{1.15}$$

$$\boxed{WSM\ \ L_d = \frac{\sigma_{st} \text{Ø}}{4\tau_{bd}}}$$

$$\boxed{LSM\ \ L_d = \frac{0.87\, f_y \text{Ø}}{4\tau_{bd}}}$$

The length L_d is called as Development length

Design Bond Stresses for Mild steel bars as per IS 456:2000 and LSM

IS 456 : 2000

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress, τ_{bd}, N/mm²	1.2	1.4	1.5	1.7	1.9

- For deformed bars conforming to IS 1786 these values shall be increased by 60 percent
- For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

Deformed bars are rods of steels provided with lugs, ribs or **deformation** on the surface of **bar**, these **bars** minimize slippage in concrete and increases the bond between the two materials.
Deformed bars have more tensile stresses than that of mild steel **plain bars**.

Design Bond Stresses for Mild steel bars as per IS 456:2000 and LSM

IS 456 : 2000

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
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- For deformed bars conforming to IS 1786 these values shall be increased by 60 percent
- For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.
- **Que 44: Find bond stress for M30 concrete and Fe 415 bar in compression and tension using LSM**

Design Bond Stresses for Mild steel bars as per IS 456:2000 and LSM

IS 456 : 2000

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress, τ_{bd}, N/mm²	1.2	1.4	1.5	1.7	1.9

- For deformed bars conforming to IS 1786 these values shall be increased by 60 percent
- For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.
- **Que 44: Find bond stress for M30 concrete and Fe 415 bar in compression and tension using LSM**
  - **For Fe 415,** $\tau_{bd\ \ tension} = 1.5 \times 1.6 = 2.4$ $(Increase\ by\ 60\%\ for\ deformed\ bars\ (Fe\ 415)\ in\ case\ of\ tension)$
  - $\tau_{bd\ \ compression} = 1.5 \times 1.6 \times 1.25 = 3 \quad (Further\ Increase\ by\ 25\%\ in\ case\ of\ compression)$

Then calculate $L_d = \dfrac{0.87 f_y \text{Ø}}{4\tau_{bd}}$

Design Bond Stresses for Mild steel bars as per IS 456:2000 and LSM

IS 456 : 2000

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress, τ_{bd}, N/mm²	1.2	1.4	1.5	1.7	1.9

- For deformed bars conforming to IS 1786 these values shall be increased by 60 percent
- For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.
- **Que 45: Find bond stress for M30 concrete and Fe 250 bar in compression and tension using LSM**

Design Bond Stresses for Mild steel bars as per IS 456:2000 and LSM

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress, τ_{bd}, N/mm²	1.2	1.4	1.5	1.7	1.9

- For deformed bars conforming to IS 1786 these values shall be increased by 60 percent
- For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

- **Que 45: Find bond stress for M30 concrete and Fe 250 bar in compression and tension using LSM**
  - **For Fe 215,** $\tau_{bd\ \ tension} = 1.5$
  - $\tau_{bd\ \ compression} = 1.5 \times 1.25 = 1.87$

Then calculate $L_d = \dfrac{0.87\, f_y \varnothing}{4\tau_{bd}}$

- If one bar fails in bond then for safe section,

  i.e. if τ_{bd} (developed) > τ_{bd} (permissible)

  - Increase the number of bars, keeping area of steel as same
  - Reduce the dia of bar, reinforcement will become safe in bond

  - By practicing this,

    τ_{bd} (permissible) > τ_{bd} (developed)

Check for Development Length at simple support for positive moment reinforcement (IS 456:2000 Cl. 26.2.3.3)

As per IS 456, development length required is assumed to be satisfied if

$$L_d \leq \frac{M_i}{V} + L_0$$

- M_i = Moment of resistance if all steel is stressed upto $0.87fy$
- $V =$ Shear force value at the support
- L_0 = sum of anchorage beyond the centre of the support or $(12 \times \emptyset)$ whichever is greater
- $\emptyset$ = dia of bar

Anchoring Reinforcing Bar (26.2.2)

a) Deformed bars may be used without end anchorages provided development length requirement is satisfied. Hooks should normally he provided for plain bars in tension.

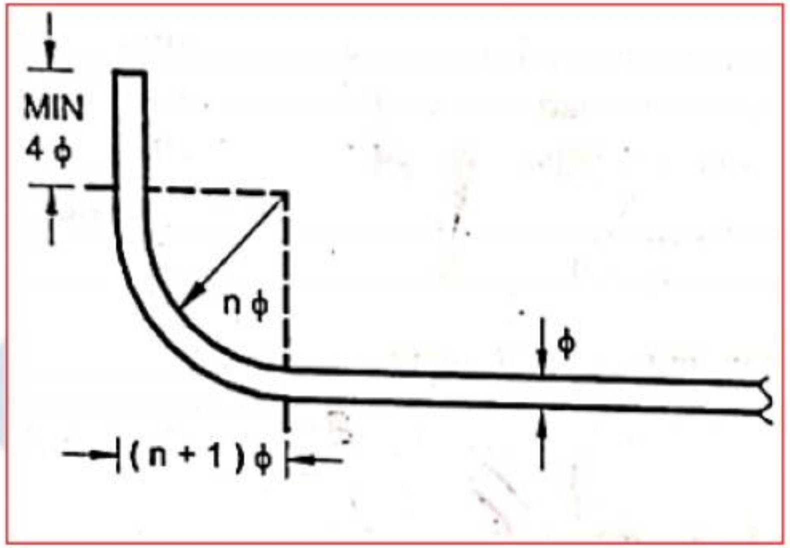
b) Bends and hooks - Bends and hooks shall conform to IS 2502

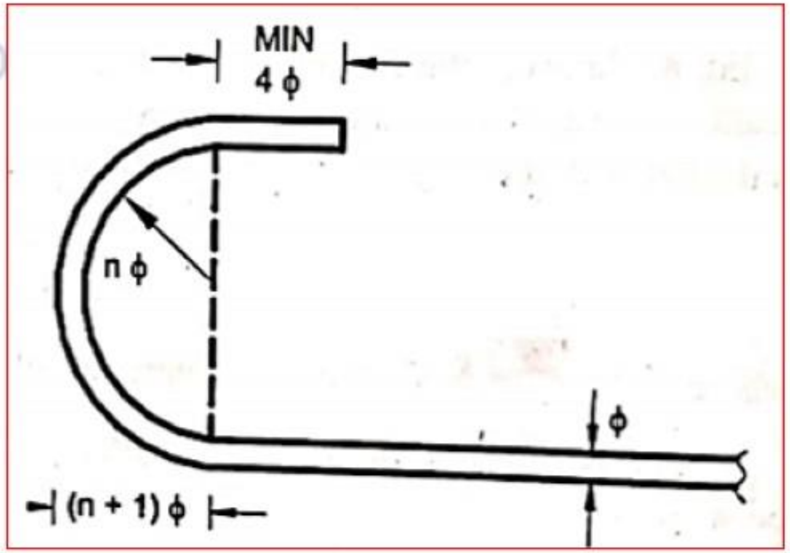
i. **Bends**-The anchorage value of bend shall be taken as 4 times the diameter of the bar for each 45° bend subject to a maximum of 16 times the diameter of the bar.

- **4Ø**
- **Maximum 16 Ø**

ii. **Hooks**-The anchorage value of a standard U-type hook shall be equal to 16 times the diameter of the bar

The minimum value of n for mild steel is 2 and for other steels is 4



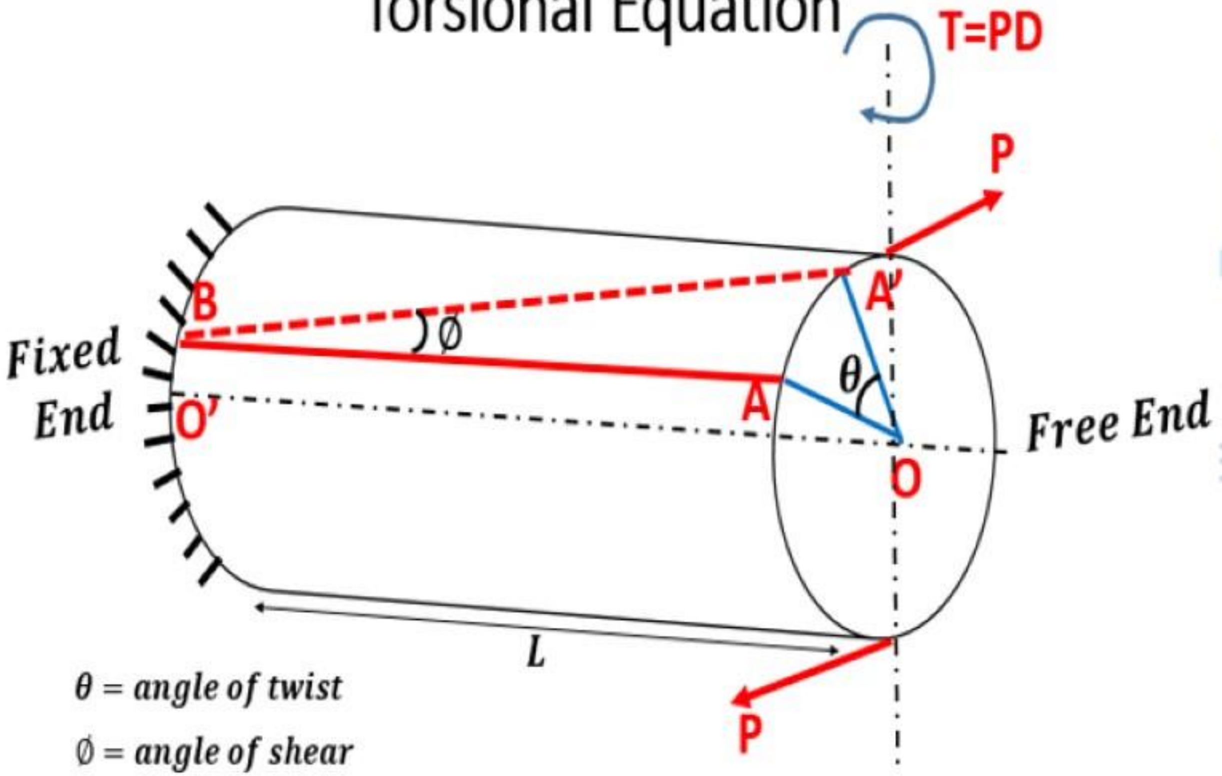


Torsion

- Monolithic construction of reinforced concrete structure tends to introduce torsional moments into the members which in general can not be ignored in the design
- Torsional strength of sections in case of homogenous sections can be estimated easily using theory of elasticity
- However it is very difficult to assess the torsional strength of heterogenous reinforced concrete sections
- More difficult is that the sections are subjected to bending, shear also rather than just pure torsion

PURE TORSION

Torsional Equation



$$\frac{\tau}{R} = \frac{G\theta}{L} = \frac{T_R}{J}$$

When Beam is subjected to Bending Moment and Torsional Moment

- Critical Section:
  - Sections located less than a distance d from the face of the support may be designed for the same torsion as computed at a distance d, where d is the effective depth

- Step 1: Equivalent shear force (41.3.1)
  - The equivalent shear force $V_e = Vu + 1.6\,\frac{T_u}{b}$
    - $V_e = Equivalent\ Nominal\ shear\ force$
    - $V_u = Factored\ shear\ force$
    - $T_u = Torsional\ moment$
    - $b = breadth\ of\ the\ beam$

- Step 2: Equivalent Nominal Shear Stress τ_{ve}
  - $\tau_{ve} = \frac{V_e}{Bd}$
  - This value of τ_{ve} should not exceed maximum shear stress $\tau_{c\,max}$
  - If $\tau_{ve} > \tau_{c\,max}$, then revise the section

Table 20 Maximum Shear Stress, $\tau_{c\,max}$, N/mm²

(*Clauses* 40.2.3, 40.2.3.1, 40.5.1 *and* 41.3.1)

Concrete Grade	M 15	M 20	M 25	M 30	M 35	M 40 and above
$\tau_{c\,max}$, N/mm²	2.5	2.8	3.1	3.5	3.7	4.0

When Beam is subjected to Bending Moment and Torsional Moment

- Step 2: Equivalent Nominal Shear Stress $\boldsymbol{\tau_{ve}}$
  - $\tau_{ve} = \frac{V_e}{Bd}$
  - This value of τ_{ve} should not exceed maximum shear stress $\tau_{c\,max}$
  - If $\tau_{ve} > \tau_{c\,max}$, then revise the section
  - If the equivalent nominal shear stress, τ_{ve} does not exceed τ_c (*Design shear strength of concrete, table* 19) given, minimum shear reinforcement shall he provided as per 26.5.1.6

26.5.1.6 ***Minimum shear reinforcement***

Minimum shear reinforcement in the form of stirrups shall be provided such that:

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{0.87 f_y}$$

eep Jyani

Table 20 Maximum Shear Stress, $\tau_{c\,max}$, N/mm²

(*Clauses* 40.2.3, 40.2.3.1, 40.5.1 *and* 41.3.1)

Concrete Grade	M 15	M 20	M 25	M 30	M 35	M 40 and above
$\tau_{c\,max}$, N/mm²	2.5	2.8	3.1	3.5	3.7	4.0

Table 19 Design Shear Strength of Concrete, τ_c, N/mm^2

(*Clauses* 40.2.1, 40.2.2, 40.3, 40.4, 40.5.3, 41.3.2, 41.3.3 *and* 41.4.3)

$100\frac{A_s}{bd}$	Concrete Grade					
	M 15	M 20	M 25	M 30	M 35	M 40 and above
(1)	(2)	(3)	(4)	(5)	(6)	(7)
≤ 0.15	0.28	0.28	0.29	0.29	0.29	0.30
0.25	0.35	0.36	0.36	0.37	0.37	0.38
0.50	0.46	0.48	0.49	0.50	0.50	0.51
0.75	0.54	0.56	0.57	0.59	0.59	0.60
1.00	0.60	0.62	0.64	0.66	0.67	0.68
1.25	0.64	0.67	0.70	0.71	0.73	0.74
1.50	0.68	0.72	0.74	0.76	0.78	0.79
1.75	0.71	0.75	0.78	0.80	0.82	0.84
2.00	0.71	0.79	0.82	0.84	0.86	0.88
2.25	0.71	0.81	0.85	0.88	0.90	0.92
2.50	0.71	0.82	0.88	0.91	0.93	0.95
2.75	0.71	0.82	0.90	0.94	0.96	0.98
3.00 and above	0.71	0.82	0.92	0.96	0.99	1.01

When Beam is subjected to Bending Moment and Torsional Moment

- Step 3: Equivalent Moment
  - $M_e = Mu + \frac{T_u}{1.7}(1 + \frac{D}{B})$
    - M_e = equivalent bending moment
    - M_u = bending moment at cross section
    - T_u = Torsional moment
    - D = overall depth
    - b = breadth of beam

- Step 4: Equivalent effective depth
  - $d = \sqrt{\frac{M_e}{\theta B}}$

$\left(1 - \frac{k}{3}\right)$

$$\boldsymbol{\theta} = \frac{1}{2} cjk$$

$\frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}$

σ_{cbc}

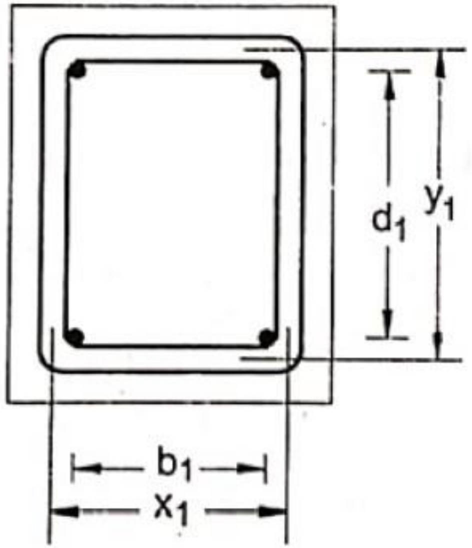
When Beam is subjected to Bending Moment and Torsional Moment

- Step 5: Steel Reinforcement Required

$$A_{st} = \frac{M_e}{\sigma_{st}\, jd}$$

  - If torsional moment is greater than BM then area of steel in compression is to be provided i.e. A_{sc} for extra bending moment
    - $M_{e2} = TM - BM$
    - Or $M_{e2} = M_{e1} - M_u$

- Step 6: Shear Reinforcement Spacing
  - $S_v = \dfrac{\sigma_{sv} \times Asv \times d_1}{V_{se}}$



  - Where $V_{se} = \dfrac{T_u}{b_1} + \dfrac{V_u}{2.5}$

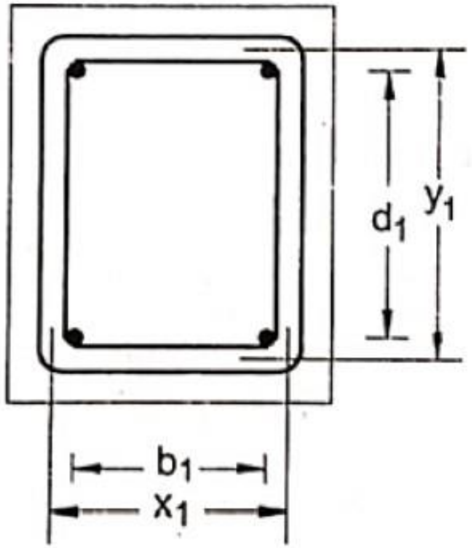
x = spacing of shear stirrups

b_1 = centre to centre distance between corner bars in the direction of the width

d_1 = centre to centre distance between corner bars in the direction of the depth

When Beam is subjected to Bending Moment and Torsional Moment

- Step 7: Maximum spacing of shear reinforcement
  - Maximum of
    - x_1 or
    - $\frac{x_1+y_1}{4}$ or
    - 300 mm



x = spacing of shear stirrups

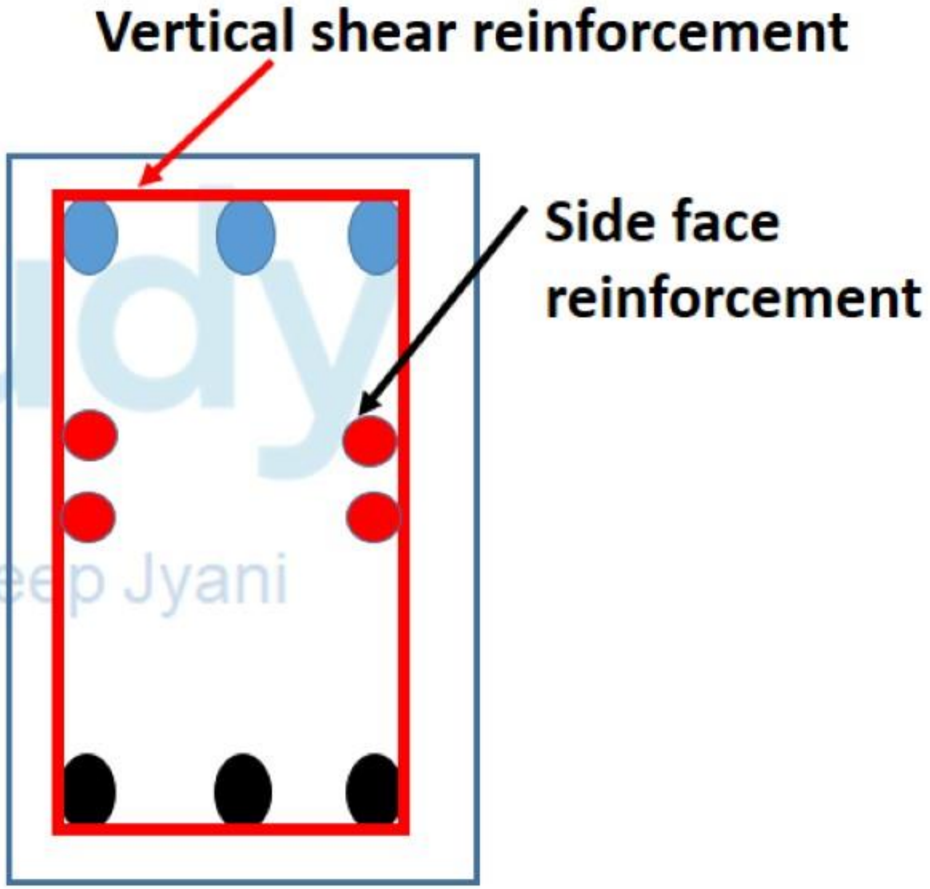
b_1 = centre to centre distance between corner bars in the direction of the width

d_1 = centre to centre distance between corner bars in the direction of the depth

Side Face Reinforcement

1. When depth of the beam is greater than 750mm (and beam is not subjected to torsion)
2. When beam is subjected to torsion, and depth of the beam is greater than 450mm, then side face reinforcement is also provided
3. Spacing of side face reinforcement should not be more than 140mm

- In above both cases, side face reinforcement at 0.1 % of the web area (B x d) is provided on both the faces respectively



Que 32. Which of the following is incorrect :

The intensity of horizontal shear stress at the elemental part of the beam section is directly proportional to

(a)Shear force

(b)Area of the section

(c)Distance of the CG of the area from its neutral axis

(d)Moment of the beam section about its neutral axis

Que 32. Which of the following is incorrect :

The intensity of horizontal shear stress at the elemental part of the beam section is directly proportional to

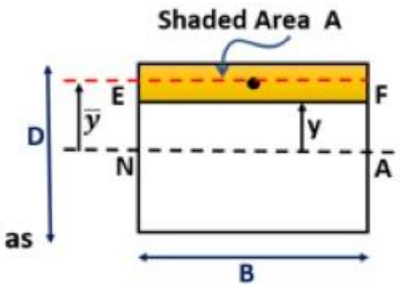
(a)Shear force

(b)Area of the section

(c)Distance of the CG of the area from its neutral axis

(d)Moment of the beam section about its neutral axis

$$\tau = \frac{FA\bar{y}}{IB}$$



Where

F = Shear Force at that section

A = Area of given cross section beyond the level EF as shaded in the figure

$\bar{y}$ = distance of CENTROID of shaded area A from the neutral axis

$A\bar{y}$ = Moment of shaded region A about the neutral axis

I = Moment of inertia of TOTAL CROSS SECTION AREA

B = width of the section at the level of EF

Que 33. The maximum shear stress (q) in concrete of a reinforced cement concrete beam is

(a)Shear force / (Lever arm × Width)
(b)Lever arm / (Shear force × Width)
(c)Width / (Lever arm × shear force)
(d)None of these

Que 33. The maximum shear stress (q) in concrete of a reinforced cement concrete beam is

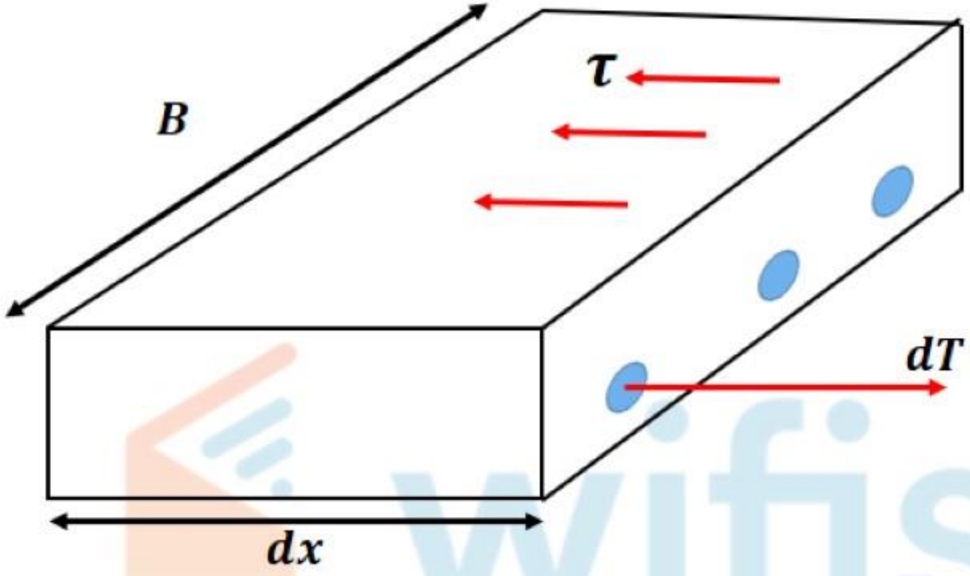
(a)Shear force / (Lever arm × Width)

(b)Lever arm / (Shear force × Width)

(c)Width / (Lever arm × shear force)

(d)None of these

$$\Rightarrow \tau = \frac{V}{B.j.d}$$



$$\Rightarrow dT = \underbrace{\tau}_{\text{shear stress}} \times \underbrace{(B \times dx)}_{\text{area of cross section}}$$

$$\Rightarrow dT = \frac{dM}{j.d}$$

$$\Rightarrow \frac{dM}{j.d} = \tau \times (B \times dx)$$

$$\Rightarrow \tau = \frac{dM}{dx\, B.j.d}$$

$$\Rightarrow \tau = \frac{V}{B.j.d}$$

Que 34. Which of the following structural loads are not applied commonly to a building?

(a)Dead load
(b)Rain load
(c)Live load
(d)Environmental load

Que 34. Which of the following structural loads are not applied commonly to a building?

(a)Dead load

(b)Rain load

(c)Live load

(d)Environmental load

Que 35. Modulus of elasticity of concrete, E is calculated using:

(a) $E = 5000\sqrt{f_{ck}}$

(b) $E = 500\sqrt{f_{ck}}$

(c) $E = 50\sqrt{f_{ck}}$

(d) $E = 5\sqrt{f_{ck}}$

Que 35. Modulus of elasticity of concrete, E is calculated using:

(a) $\underline{E = 5000\sqrt{f_{ck}}}$

(b) $E = 500\sqrt{f_{ck}}$

(c) $E = 50\sqrt{f_{ck}}$

(d) $E = 5\sqrt{f_{ck}}$

Que 36. Dead load comprises of:

(a)Permanently attached loads
(b)Temporarily attached loads
(c)Permanent as well as temporary loads
(d)Snow load

Que 36. Dead load comprises of:

(a)Permanently attached loads

(b)Temporarily attached loads

(c)Permanent as well as temporary loads

(d)Snow load

Que 37. Which of the following statements is true?

A. Impact loads are equal to the sum of the magnitude of the loads actually caused and the magnitude of the loads had they been dead loads.

B. Impact loads are equal to the difference between the above mentioned entities.

(a)Only A
(b)Only B
(c)Both A and D
(d)Neither A and B

Que 37. Which of the following statements is true?

A. Impact loads are equal to the sum of the magnitude of the loads actually caused and the magnitude of the loads had they been dead loads.

B. Impact loads are equal to the difference between the above mentioned entities.

(a)Only A

(b)Only B

(c)Both A and D

(d)Neither A and B

Que 38. the shear capacity of an RCC beam without shear reinforcement is

(a) τ_c bd

(b) τ_v bd

(c) $\tau_v bd^2$

(d) τ_v bd^2

Que 38. the shear capacity of an RCC beam without shear reinforcement is

(a) τ_c bd

(b) τ_v bd

(c) $\tau_v bd^2$

(d) τ_v bd^2

Que 39. Shear reinforcement is provided in the form of:

(a)Vertical bars
(b)Inclined bars
(c)Combination of vertical and inclined bars
(d)Any one of the above

Que 39. Shear reinforcement is provided in the form of:

(a)Vertical bars

(b)Inclined bars

(c)Combination of vertical and inclined bars

(d)Any one of the above

Que 40. The minimum percentage of shear reinforcement in R.C.C beams is

(a) $0.85/f_y$

(b) 0.4

(c) 4

(d) $\frac{40S_v}{0.87\ f_y d}$

Que 40. The minimum percentage of shear reinforcement in R.C.C beams is

(a) $0.85/f_y$

(b) 0.4

(c) 4

(d) $\frac{40S_v}{0.87\ f_y d}$

$$\frac{A_{sv}}{b\,s_v} \geq \frac{0.4}{0.87\,f_y}$$

Que 41. Pick up the correct statement from the following:

(a)The bent up bars at a support resist the negative bending moment.

(b)The bent up bars at a support resist the shearing force.

(c)The bending of bars near supports is generally at 45 degree.

(d)All options are correct

Que 41. Pick up the correct statement from the following:

(a)The bent up bars at a support resist the negative bending moment.

(b)The bent up bars at a support resist the shearing force.

(c)The bending of bars near supports is generally at 45 degree.

(d)All options are correct

Que 42. Spacing of stirrups in a rectangular beam, is

(a)Kept constant throughout the length

(b)Decreased towards the center of the beam

(c)Increased at the ends

(d)Increased at the center of the beam

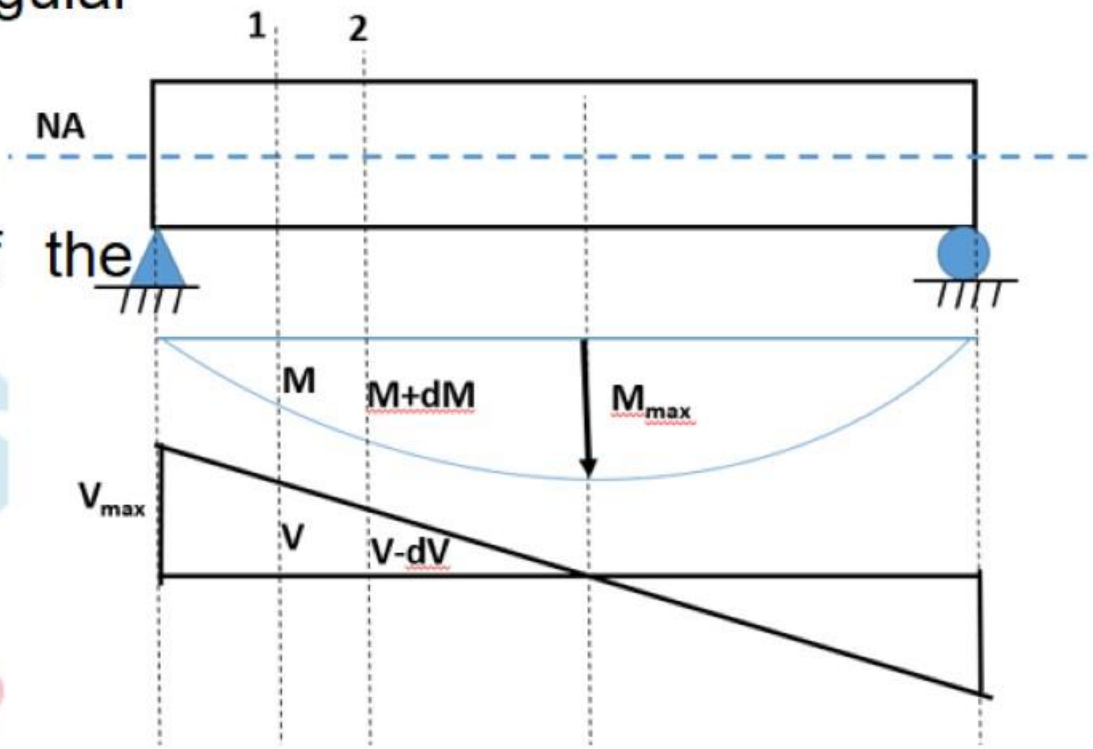
Que 42. Spacing of stirrups in a rectangular beam, is

(a)Kept constant throughout the length

(b)Decreased towards the center of the beam

(c)Increased at the ends

(d)Increased at the center of the beam



Que 43. The bond strength between steel and concrete is due to

(a)Friction

(b)Adhesion

(c) Both friction and adhesion

(d)None of these

Que 43. The bond strength between steel and concrete is due to

(a)Friction

(b)Adhesion

(c)Both friction and adhesion

(d)None of these

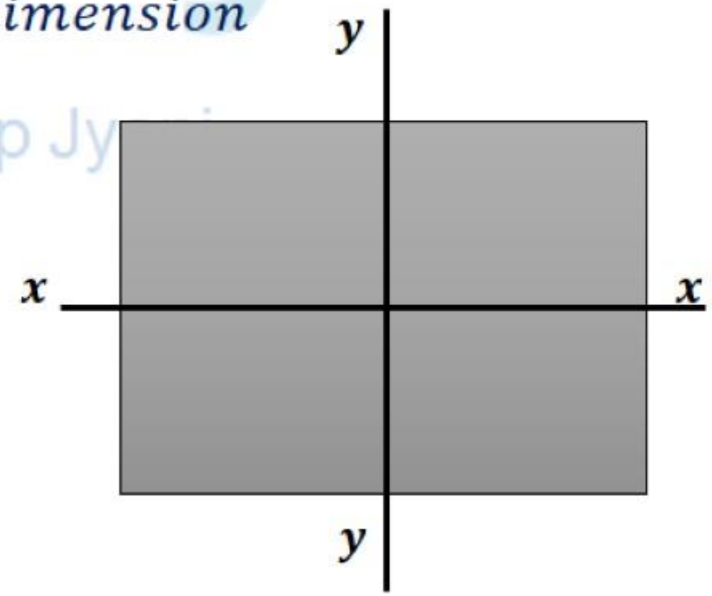
Columns

- A column may be defined as element used primarily to support axial compressive loads and with a height of at least three times its least lateral dimension
- A column is said to be long column when slenderness ratio is equal to or more than 12

$$Slenderness\ ratio = \frac{Effective\ length}{Least\ lateral\ dimension}$$

$$\Rightarrow \lambda = \frac{L_{effective}}{LLD}$$

$$Least\ lateral\ dimension = least\ of \begin{cases} lateral\ dimension\ about\ x-x \\ lateral\ dimension\ about\ y-y \end{cases}$$

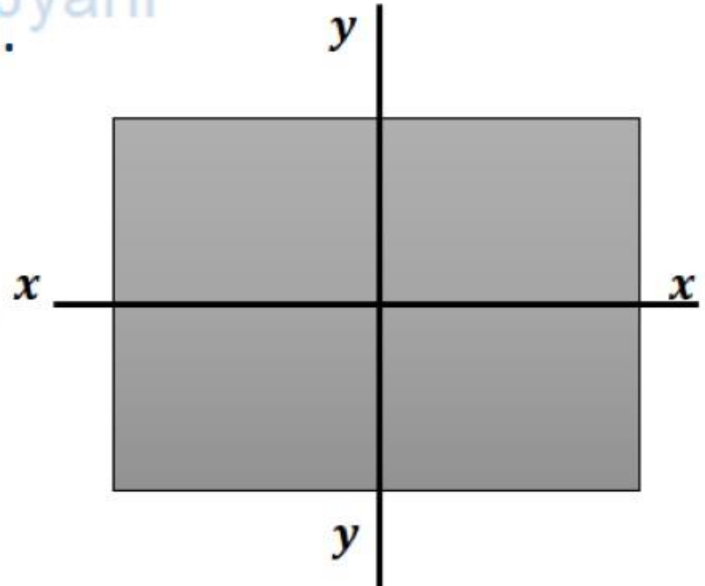


Columns

- A column may be defined as element used primarily to support axial compressive loads and with a height of at least three times its least lateral dimension
- Pedestal: It is a short column of effective length not greater than 3 times of least lateral dimension

$$\lambda = \frac{L_{effective}}{\gamma_{min}} < 3$$

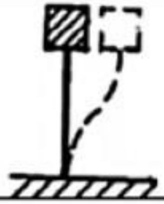
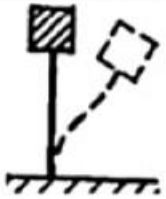
- In case of pedestal in which the Longitudinal reinforcement is not taken in account in strength calculations, nominal longitudinal reinforcement not less than 0.15 percent of the cross-sectional area shall be provided.



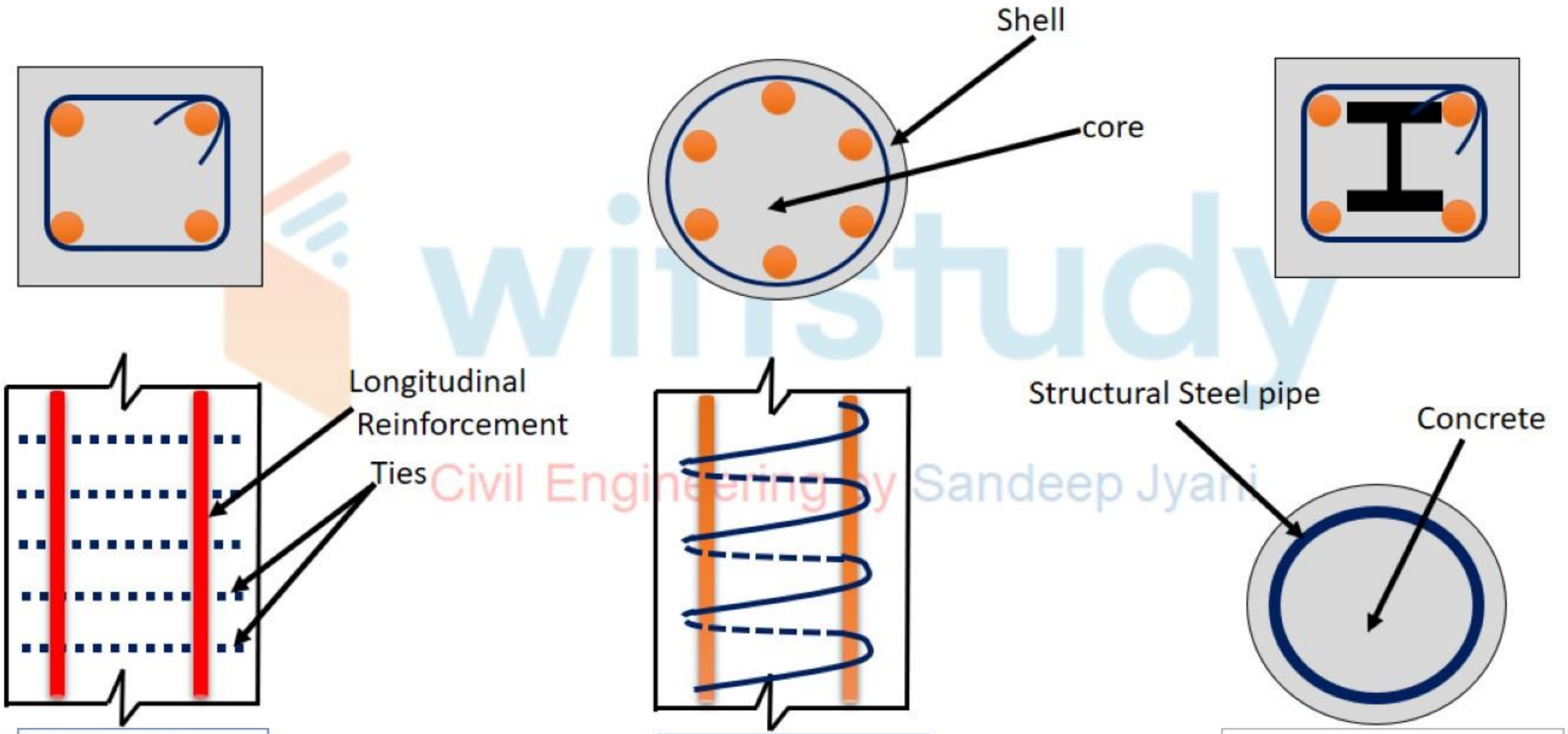
Effective Length of column

Sl. No.	Degree of End Restraint of Compression Members	Figure	Reco. Value of Effective Length
1	Effectively held in position and restrained against rotation in both ends		0.65l
2	Effectively held in position at both ends, restrained against rotation at one end		0.80l

Effective Length of column

Sl. No.	Degree of End Restraint of Compression Members	Figure	Reco. Value of Effective Length
3	Effectively held in position at both ends, but not restrained against rotation		1.00
4	Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.20
5	Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position		1.50
6	Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position		2.00
7	Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end		2.00

Typical Columns



1. Tied Column

2. Spiral Column

3. Composite Column

For columns, As per IS 456:2000, CL 26.5.3

1. Minimum percentage of steel= 0.8%
2. Maximum percentage of steel
   a) 4% if bar are lapped
   b) 6% if bars are not lapped
3. Minimum diameter of longitudinal bars = 12mm
4. Minimum number of bars
   a) For circular=6
   b) For Rectangular=4
5. Maximum spacing of longitudinal bars = 300mm

As per IS code

6. Load Carrying capacity of column is increased by 5% percent when helical reinforcement is provided as a transverse reinforcement
7. Maximum compressive strain in concrete in axial compression is taken to be **0.002**
8. Pitch and diameter of lateral ties
   A. The pitch of transverse reinforcement shall not more than the least of the following distances:
      a) The least lateral dimension of the compression members;
      b) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied, and
      c) 300 mm
   B. Diameter-
      A. The diameter of the polygonal links or lateral ties shall not be less than one fourth of the diameter of the largest longitudinal bar and in no case less than 16mm i.e.
         - Greater of $\begin{cases} \frac{dia\ of\ main\ bar}{4} \\ 6\ mm \end{cases}$

As per IS code

7. Pitch and diameter of lateral ties

A. The pitch of transverse reinforcement shall not more than the least of the following distances:

a) The least lateral dimension of the compression members;

b) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied, and

c) 300 mm

B. Diameter-

A. The diameter of the polygonal links or lateral ties shall not less than one fourth of the diameter of the largest longituc bar and in no case less than ~~16mm~~ i.e.

- Greater of $\begin{cases} \dfrac{dia\ of\ main\ bar}{4} \\ 6\ mm \end{cases}$

c) *Pitch and diameter of lateral ties*

1) *Pitch*—The pitch of transverse reinforcement shall be not more than the least of the following distances:

i) The least lateral dimension of the compression members;

ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and

iii) 300 mm.

2) *Diameter*—The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than ~~16 mm.~~

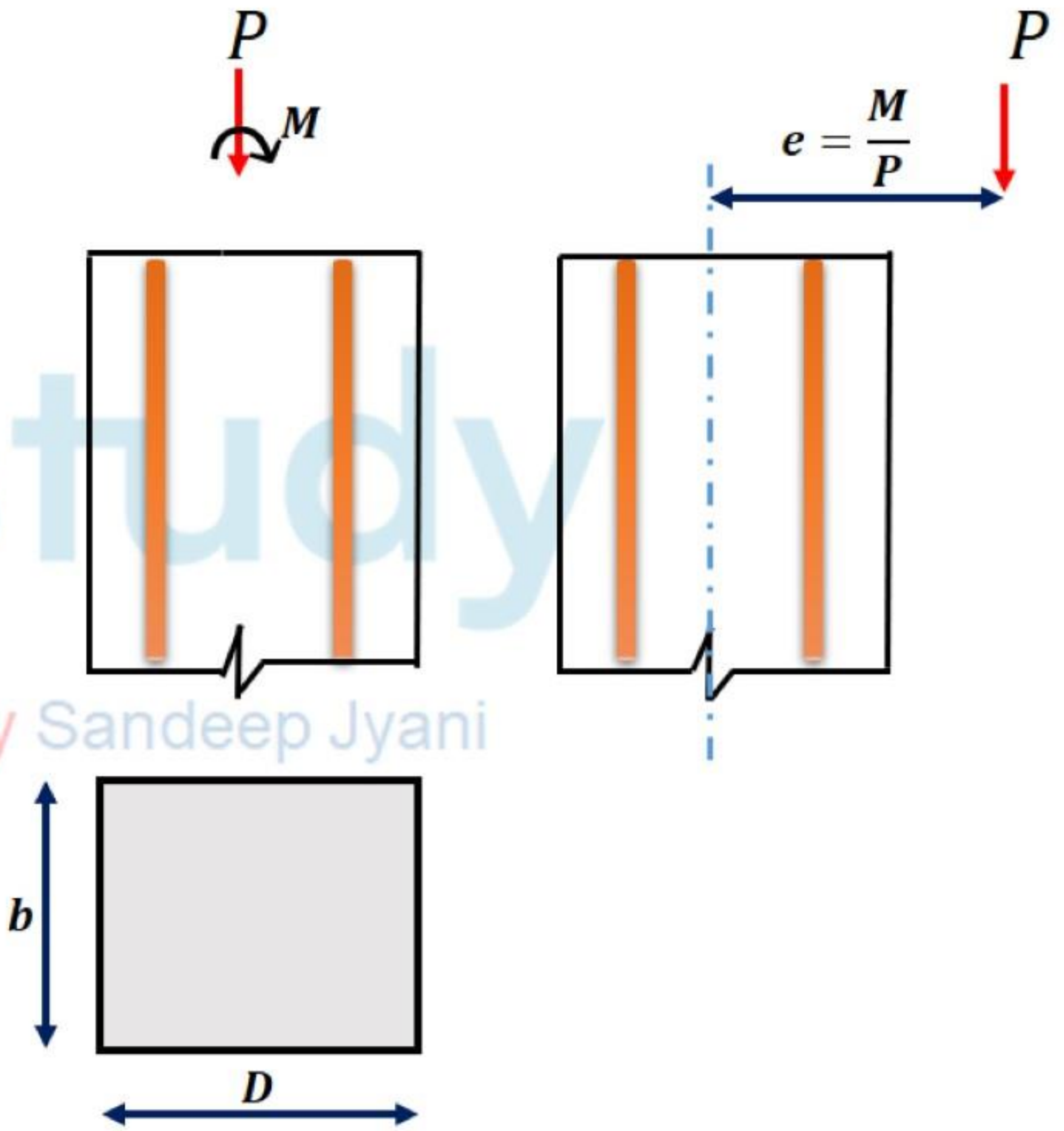
Minimum Eccentricity

$$e_{min} \geq \frac{l}{500} + \frac{D}{30}$$

$$> 20mm$$

Where $l = unsupported\ length\ of\ the\ column\ in\ mm$

$D = lateral\ dimesion\ of\ column\ in\ the\ direction\ under\ consideration\ in\ mm$



Design of Column

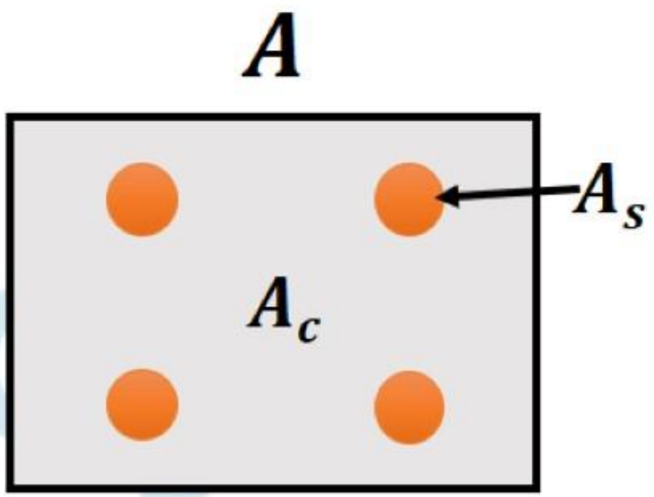
1. Short Column
    - Load carrying capacity:

$$P = Psteel + Pconcrete$$

$$= \sigma_s A_s + \sigma_c A_c$$

$$Since\ Total\ Area\ \ A = As + Ac$$

$$\Rightarrow \boldsymbol{P = \sigma_s (A - Ac) + \sigma_c A_c}$$



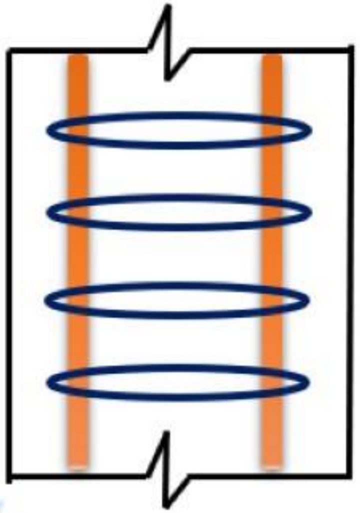
2. Long Column
    - Load carrying capacity:

$$\Rightarrow \boldsymbol{P = C_r \{\sigma_s (A - Ac) + \sigma_c A_c\}}$$

Where $\boldsymbol{C_r = 1.25 - \frac{L_{eff}}{48LLD}}$ $\boldsymbol{for\ Rectangular\ or\ square\ column}$

And $\boldsymbol{C_r = 1.25 - \frac{L_{eff}}{100LLD}}$ $\boldsymbol{for\ circular\ column\ \ (\gamma_{min} = D/4)}$

Design of Column



3. Circular Column
   a) With separate ring used as a stirrup:

$$P = Cr\{\sigma_s A_s + \sigma_c A_c\}$$

Design of Column

3. Circular Column

b) With helical reinforcement

$$P = 1.05 \times Cr \times \{\sigma_s A_s + \sigma_c A_c\}$$

For helical reinforcement, following criteria has to be satisfied

$$\frac{0.36fck}{f_y}\left[\frac{A_g}{A_c} - 1\right] \le \frac{V_h}{V_c}$$

- $A_g = gross\ area = \frac{\pi}{4} D_g^2$
- $A_c = core\ area$
- $V_h = volume\ of\ helical\ reinforcement$

$$= area\ of\ helical\ rf \times length\ in\ one\ loop \times no.\ of\ turns$$

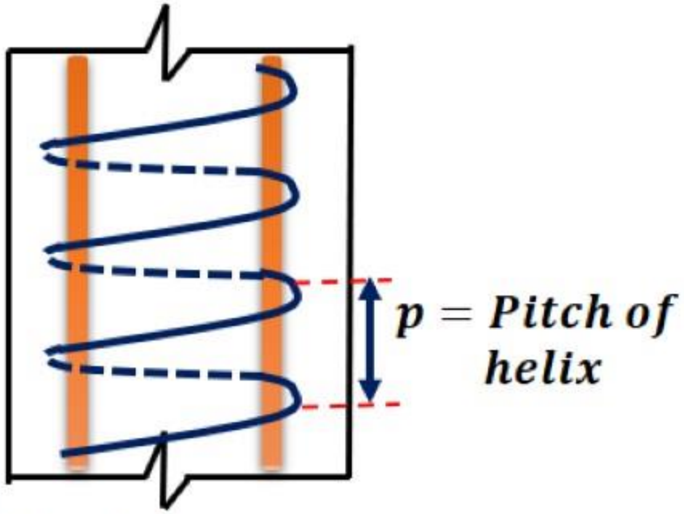
$$= \frac{\pi}{4} \emptyset_h^2 \times \pi Dh \times \frac{1000}{pitch}$$

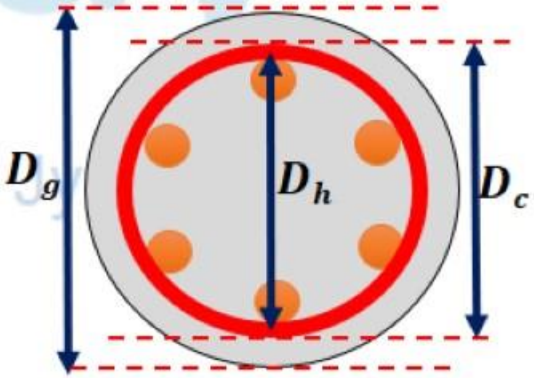
- $V_c = volume\ of\ core\ for\ 1m$

$$= 1000mm \times Acore$$

$$= 1000 \times \frac{\pi}{4} D_c^2$$

- $D_h = dia\ of\ centre\ to\ centre\ helical\ stirrup$





d) *Helical reinforcement*

1) *Pitch*—Helical reinforcement shall be of regular formation with the turns of the helix spaced evenly and its ends shall be anchored properly by providing one and a half extra turns of the spiral bar. Where an increased load on the column on the strength of the helical reinforcement is allowed for, the pitch of helical turns shall be not more than 75 mm, nor more than one-sixth of the core diameter of the column, nor less than 25 mm, nor less than three times the diameter of the steel bar forming the helix. In other cases, the requirements of **26.5.3.2** shall be complied with.

2) The diameter of the helical reinforcement shall be in accordance with **26.5.3.2** (c) (2).

Design of Slabs

- Slabs are plate elements forming floors and roofs of the buildings and carrying distributed loads primarily by flexure
- Inclined slabs may be used as ramps for multi-storey car parking
- Stair case may be considered as an inclined slab
- A slab may be supported by beams or walls or may be used as a flange of a T –Section beam
- Slab may be simply supported, continuous over one or more supports and is classified according to manner of support

IS code Recommendations

1. Minimum area of reinforcement
   - $For\ Fe\ 415 = 0.12\%\ of\ total\ area\ = 0.12\% \times B \times D$
   - $For\ Fe\ 250 = 0.15\%\ of\ total\ area\ = 0.15\% \times B \times D$
2. Maximum diameter of steel bar in slab
   - $\emptyset_{max} = \frac{Thickness\ of\ slab}{8}$
3. Maximum spacing of the reinforcement
   a) Main bar = lesser $of \begin{cases} 3d \\ 300\ mm \end{cases}$
   b) Distribution bar = lesser $of \begin{cases} 5d \\ 450\ mm \end{cases}$

‘d’ is the effective depth of slab.

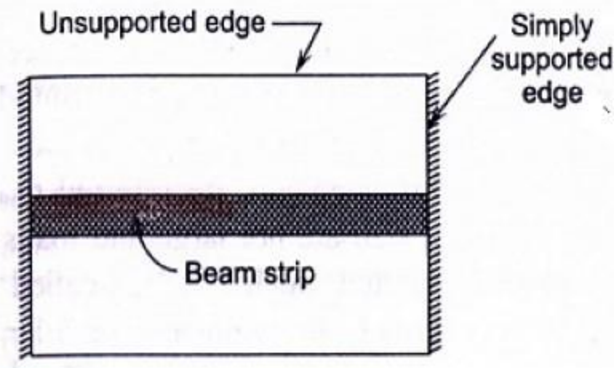
Design of One Way Slab

- One way slab is
  a) IF supported on two opposite sides, it is always one way slab
  b) If the lab is supported over two sides and $\frac{l_y}{l_x}$ ratio is greater than 2

$$\frac{l_y}{l_x} > 2$$

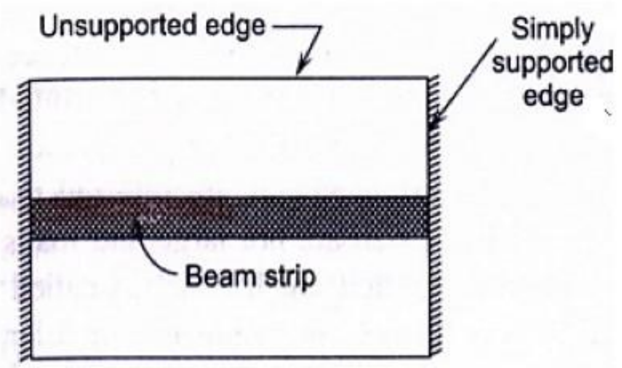
$$l_y = longer\ dimension\ (span) of\ slab$$
$$l_x = shorter\ dimension\ (span) of\ slab$$

Note: Slab is always designed for shorter span

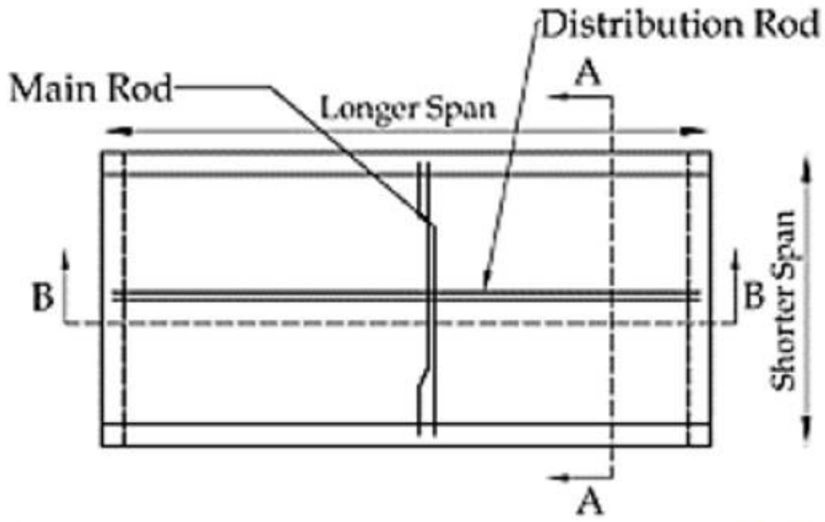


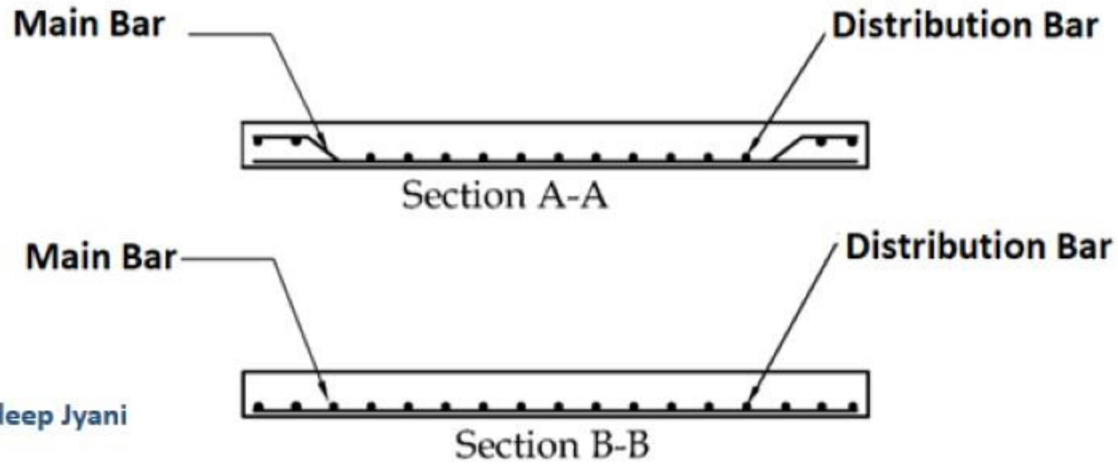
a) Also, if the slab is supported on all four edges and the ratio of longer span (l_y) to shorter span (l_x) i.e, $\frac{l_y}{l_x} > 2$, practically the slab spans across the shorter span. Such a slabs are also designed as one way slabs.
b) In this case, the main reinforcement is provided along the spanning direction to resist one way bending.

Design of One Way Slab



- Temperature and shrinkage reinforcement are invariably provided at right angles to the main longitudinal reinforcement because it occupies large area and so load and temperature has to be distributed evenly
- Distribution bars are always placed above main bar in case of one way slab to ensure higher effective depth
- In two way slab, both reinforcement are main reinforcement however higher load transfer will be on the shorter direction and hence we keep shorter direction reinforcement closer to tensile surface to get higher bending moment (higher effective depth)





- Minimum dia of main bar is 10mm for Fe 250 and 8mm for HYSD (practical recommendation, not as per IS code)
- Minimum dia of distribution steel is 6mm in both cases i.e. Mild steel and HYSD
- No maximum reinforcement recommendation is given in IS code so we consider the maximum reinforcement criteria same as in case of beam i.e. 4% of bD

Effective Span of Beam/Slab

1) **<u>Simply Supported beam or Slab</u>: The effective span of a simply supported member is taken lesser of the following:**

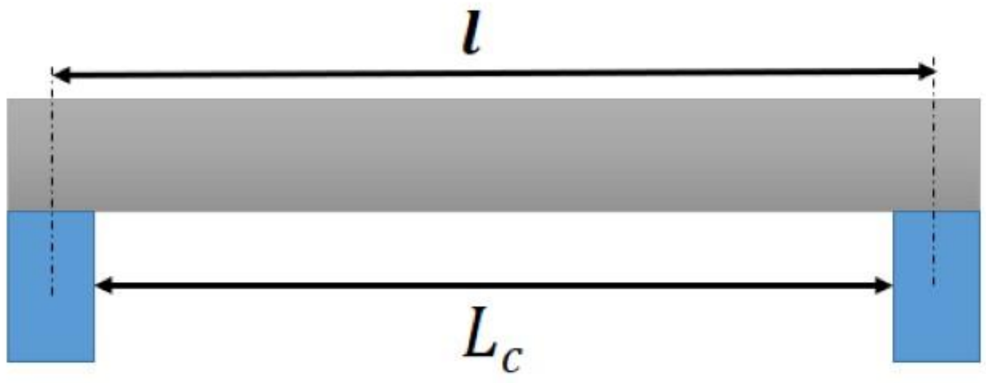
   I. $l = Lc + d$

   II. l (*centre to centre distance between supports*)

Where l = *centre to centre distance between supports*

L_c = *clear span*

d = *effective depth of beam or slab*



Effective Span of Beam/Slab

2) <u>Continuous Beam or Slab</u>: The effective span of a continuous member is taken as:

i. If width of support $t_s \leq \frac{L_c}{12}$, then effective span is taken as lesser of ...

a) $l = Lc + d$

b) l (*centre to centre distance between supports*)

Where $l =$ *centre to centre distance between supports*

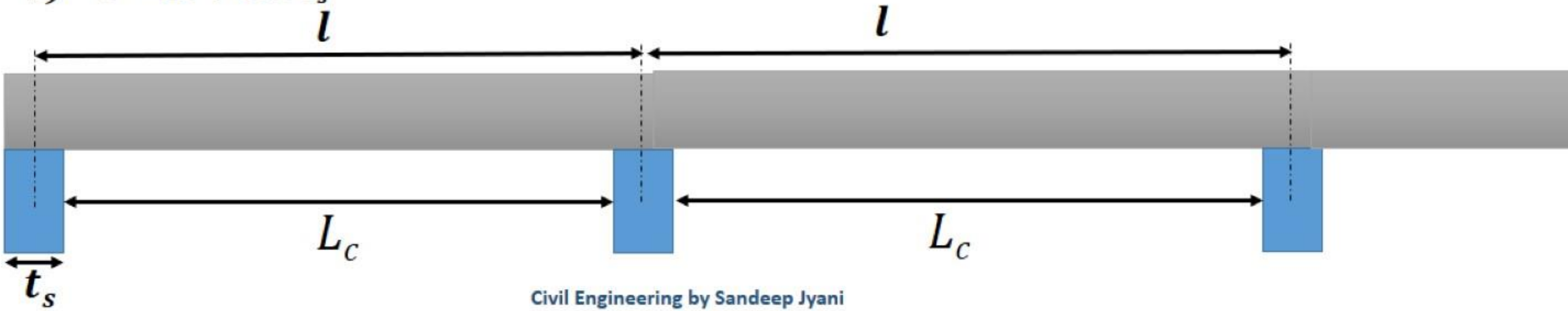
$L_c =$ *clear span*

$d = effective\ depth\ of\ beam\ or\ slab$

ii. If width of support $t_s \geq \frac{L_c}{12}$, then effective span is taken as lesser of ...

a) $l = Lc + 0.5\,d$

b) $l = Lc + 0.5\,t_s$



Depth of Slab

- **The depth of slab depends on bending moment and deflection criterion. the trail depth can be obtained using:**

23.2.1 The vertical deflection limits may generally be assumed to be satisfied provided that the span to depth ratios are not greater than the values obtained as below:

a) Basic values of span to effective depth ratios for spans up to 10 m:

Cantilever	7
Simply supported	20
Continuous	26

b) For spans above 10 m, the values in (a) may be multiplied by 10/span in metres, except for cantilever in which case deflection calculations should be made.

c) Depending on the area and the stress of steel for tension reinforcement, the values in (a) or (b) shall be modified by multiplying with the modification factor obtained as per Fig. 4.

d) Depending on the area of compression reinforcement, the value of span to depth ratio be further modified by multiplying with the modification factor obtained as per Fig. 5.

- The effective depth d of two way slabs can also be assumed using cl. 24.1,IS 456 provided short span is ≤ 3.5m and loading class is < $3.5 KN/m^2$

1 For slabs spanning in two directions, the shorter of the two spans should be used for calculating the span to effective *depth ratios.*

2 For two-way slabs of shorter spans (up to 3.5 m) with mild steel reinforcement, the span to overall depth ratios given below may generally be assumed to satisfy vertical deflection limits for loading class up to 3 kN/m^2.

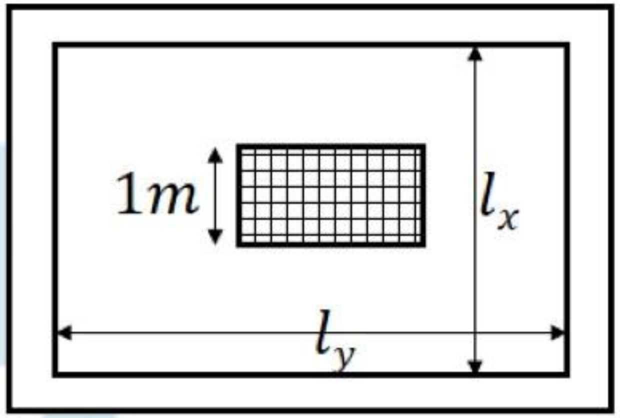
Simply supported slabs	35
Continuous slabs	40

For high strength deformed bars of grade Fe 415, the values given above should be multiplied by 0.8.

Type of support	Fe-250	Fe-415
Simply supported	l/35	l/28
continuous	l/40	l/32

Design of One Way Slab

- Step 1: Find load over 1m of span
  a) Live load
  b) $Self\ weight = Thickness \times 1m \times 25$
  c) $Floor\ finishing = Thickness\ of\ floor \times 1m \times 1m \times 24$

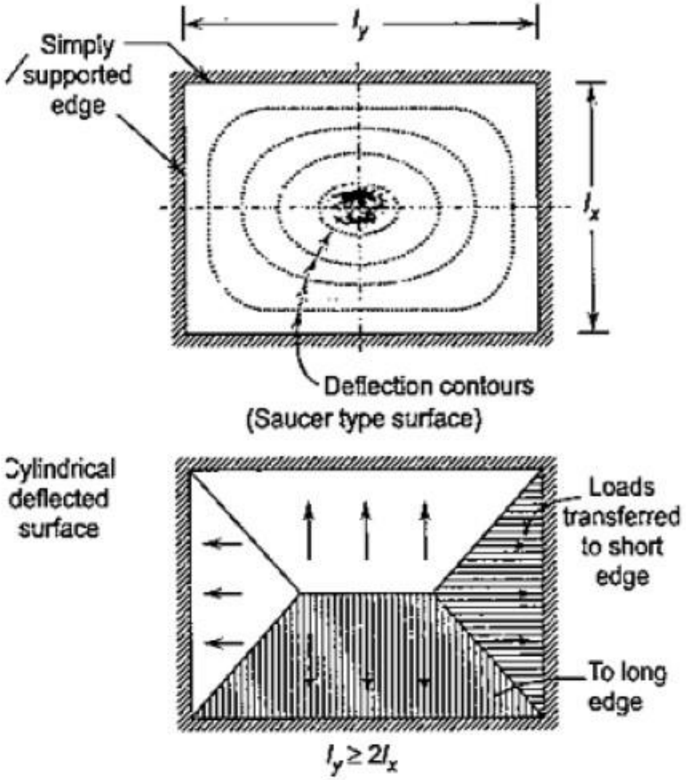


- Step 2: Bending Moment
  a) $BM_{max} = \frac{wL^2}{8}$ (for simply supported beam)
- Step 3: Area of Steel
  - $A_{st} = \frac{0.5fck}{f_y}\left[1 - \sqrt{1 - \frac{4.6\,BM}{f_{ck}Bd^2}}\right] \times B \times D$
- Step 4: Check for Shear
  - $\tau_v = \frac{V}{Bd} \ngtr \tau_{c\,max}$
  - $V = \frac{WL}{2}$

Note: Slab is not designed for shear, shear reinforcement shall not be provided as it is safe in shear

Two way Slab

- A rectangular slab supported on four edge supports, which bends in two orthogonal directions and deflects in the form of dish or a saucer is called two way slabs.
- If a slab is considered to be two way slab,
    a) if the slab is supported on 4 edges /sides
    b) The span ratio $\frac{l_y}{l_x} \leq 2$
- Since, the slab rest freely on all sides, due to transverse load the corners tend to curl up and lift up. The slab looses the contact over some region. This is known as lifting of corner. These slabs are called two way simply supported slabs
- If the slabs are cast monolithic with the beams, the corners of the slab are restrained from lifting. These slabs are called restrained slabs



Two-way slab action

Que The limit of percentage of longitudinal reinforcement in a column is given by

a) 0.15 - 2%

b) 0.8 - 4%

c) 0.8 - 6%

d) 0.8 – 8%

Que The limit of percentage of longitudinal reinforcement in a column is given by

a) 0.15 - 2%

b) 0.8 - 4%

c) <u>0.8 - 6%</u>

d) 0.8 – 8%

1. Minimum percentage of steel= 0.8%
2. Maximum percentage of steel
   a) 4% if bar are lapped
   b) 6% if bars are not lapped
3. Minimum diameter of longitudinal bars = 12mm
4. Minimum number of bars
   a) For circular=6
   b) For Rectangular=4
5. Maximum spacing of longitudinal bars = 300mm

Que. The minimum number of main reinforcement bars provided in RC circular column

a) 2

b) 3

c) 4

d) 6

Que. The minimum number of main reinforcement bars provided in RC circular column

a) 2

b) 3

c) 4

d) 6

-

Que The pitch of lateral ties should not exceed

a) The least lateral dimension

b) 16 times the diameter of longitudinal bars

c) 300mm

d) All of these

Que The pitch of lateral ties should not exceed

a) The least lateral dimension

b) 16 times the diameter of longitudinal bars

c) 300mm

d) <u>All of these</u>

Que. The minimum number of longitudinal bars provided in rectangular RCC column

a) 2

b) 4

c) 6

d) 8

Que. The minimum number of longitudinal bars provided in rectangular RCC column

a) 2

b) 4

c) 6

d) 8

Que The diameter of transverse reinforcement of columns should be equal to one fourth of the diameter of the main steel rods but not less than

a) 4mm

b) 5mm

c) 6mm

d) 7mm

Que The diameter of transverse reinforcement of columns should be equal to one fourth of the diameter of the main steel rods but not less than

a) 4mm

b) 5mm

c) <u>6mm</u>

d) 7mm

7. Pitch and diameter of lateral ties

A. The pitch of transverse reinforcement shall not more than the least of the following distances:
   a) The least lateral dimension of the compression members;
   b) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied, and
   c) 300 mm

B. Diameter-
   A. The diameter of the polygonal links or lateral ties shall not less than one fourth of the diameter of the largest longitu(bar and in no case less than ~~16mm~~ i.e.
      - Greater of $\begin{cases} \frac{dia\ of\ main\ bar}{4} \\ 6\ mm \end{cases}$

c) *Pitch and diameter of lateral ties*

1) *Pitch*—The pitch of transverse reinforcement shall be not more than the least of the following distances:
   i) The least lateral dimension of the compression members;
   ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and
   iii) 300 mm.
2) *Diameter*—The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than ~~16 mm.~~

Que Spacing between longitudinal bars measured along the periphery of RCC columns should not exceed

a) 150mm

b) 250mm

c) 300mm

d) 500mm

Que Spacing between longitudinal bars measured along the periphery of RCC columns should not exceed

a) 150mm

b) 250mm

c) <u>300mm</u>

d) 500mm

7. Pitch and diameter of lateral ties

A. The pitch of transverse reinforcement shall not more than the least of the following distances:

   a) The least lateral dimension of the compression members;

   b) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied, and

   c) 300 mm

B. Diameter-

   A. The diameter of the polygonal links or lateral ties shall not less than one fourth of the diameter of the largest longitu(bar and in no case less than ~~16mm~~ i.e.

   - Greater of $\begin{cases} \frac{dia\ of\ main\ bar}{4} \\ 6\ mm \end{cases}$

c) *Pitch and diameter of lateral ties*

1) *Pitch*—The pitch of transverse reinforcement shall be not more than the least of the following distances:

   i) The least lateral dimension of the compression members;

   ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and

   iii) 300 mm.

2) *Diameter*—The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than ~~16 mm.~~

Foundation

- Foundations are structural elements that transfer loads from the building or individual columns to the Earth below
- If these loads are to be properly transmitted, foundation must be designed to prevent excessive settlement and rotation, to minimize differential settlement and to provide adequate safety against sliding and overturning

Criteria for Design

1. Depth of footing:
    - All foundations should be located at a minimum depth of 0.5m below the ground surface
    - The depth is primarily governed by availability of bearing capacity, minimum seasonal variation like swelling and shrinkage of soil
    - Using rankine's formula, minimum depth of foundation is given by

$$D_f = \frac{q}{\gamma}\left[\frac{1 - sin\emptyset}{1 + sin\emptyset}\right]^2$$

q=gross safe bearing capacity

γ=unit weight of soil

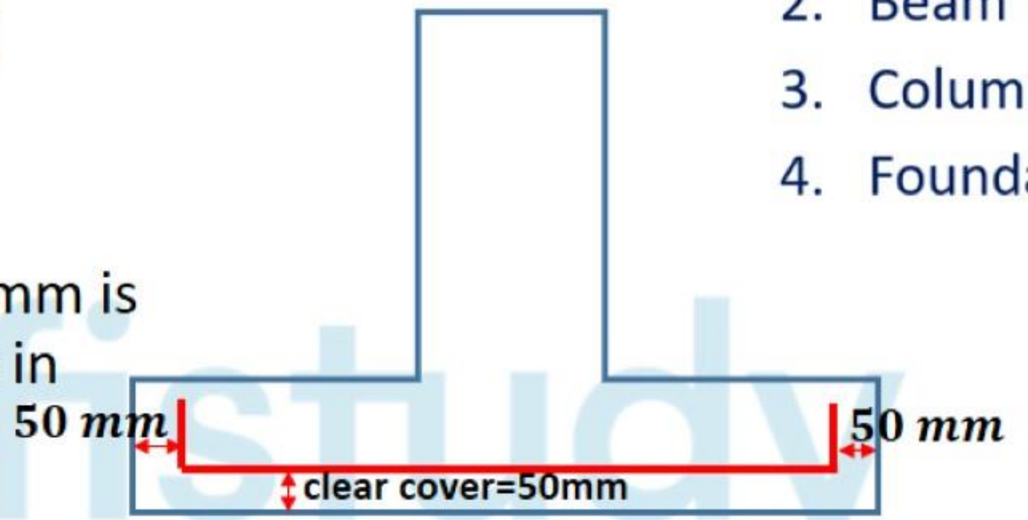
$\emptyset$=angle of friction

Criteria for Design

1. Slab 20mm
2. Beam 25mm
3. Column 40mm
4. Foundation 50mm

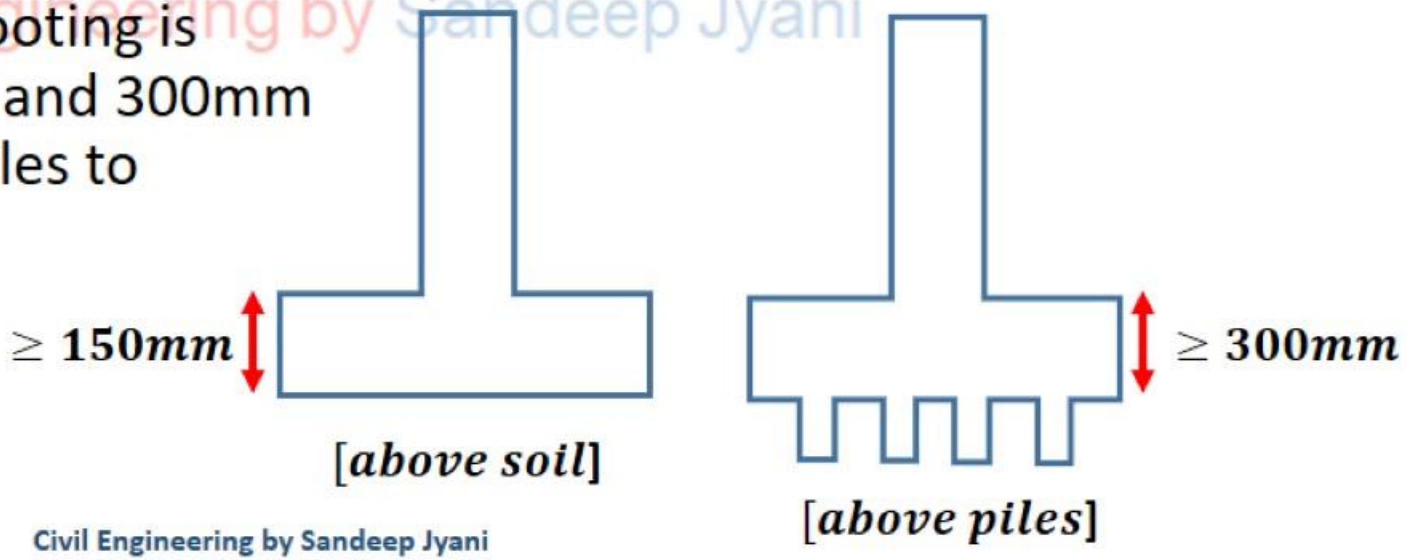
2. Minimum clear cover

- A minimum clear cover of 50mm is provided to all reinforcement in footing



3. Minimum thickness

- Thickness at the edge of footing is 150mm for footing on soil and 300mm minimum for footing on piles to ensure rigidity of footing



Criteria for Design

4. Extended longitudinal reinforcement or dowels of at least 0.5 % of the cross-sectional area of the supported column or pedestal and a minimum of four bars shall be provided.
5. Where dowels are used, their diameter shall no exceed the diameter of the column bars by more than 3 mm
6. Column bars of diameters larger than 36 mm, in compression only can be dowelled at the footings with bars of smaller size of the necessary area.

Critical Section

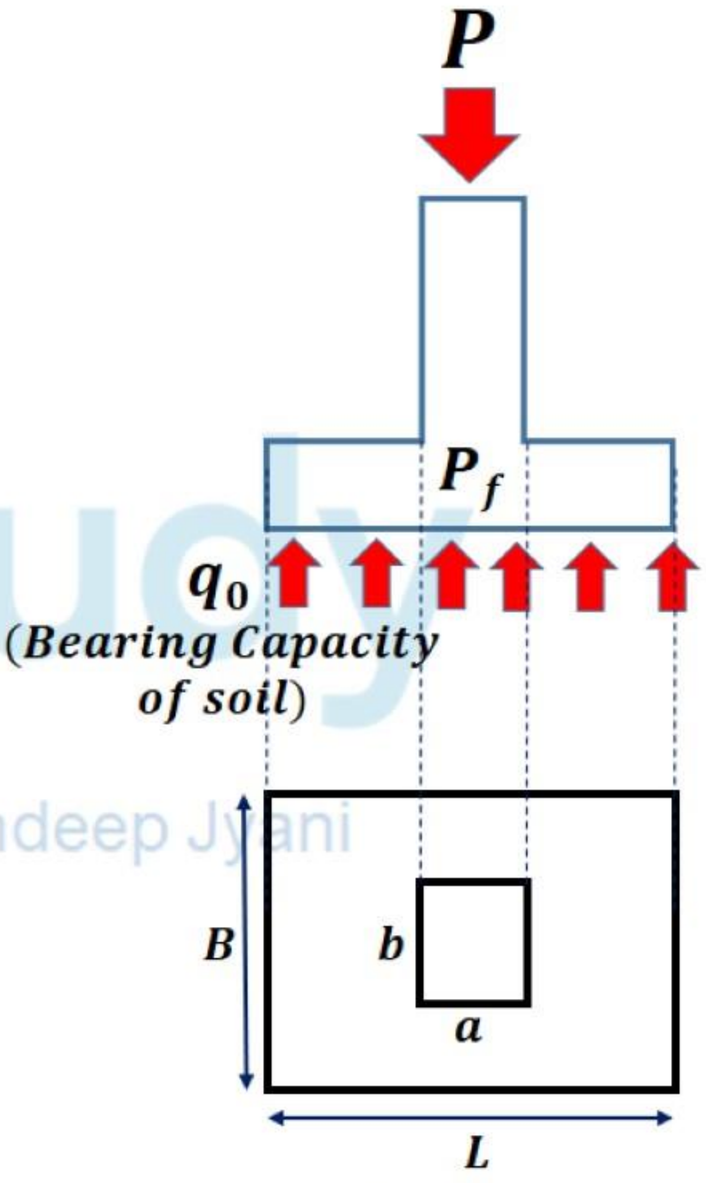
- Critical Section for Shear:
  - Shear governs the thickness of footing
  - In one way shear, critical section for shear is at
    - A distance 'd' from the face of wall/column when the footing is supported on soil
    - At a distance 'd/2' from face of wall when the footing is supported on piles
  - In two way shear, punching shear shall be checked around the column on a perimeter half the effective depth of footing away from the face of column
- Critical Section for Bending moment:
  - At the face of the column /pedestal/wall/ for footing supporting column, concrete pedestal or RCC wall, etc
  - Half way between the centre line and edge of wall for footing supporting masonry wall

Footing

1. **Size of Foundation:**
   a) Load from column = P
   b) Weight of foundation =$P_f = 10\%\ of\ P$
   c) Total load $P_t = P + Pf = 1.1\ P$
   d) Area of Foundation
      - $Area\ of\ foundation = \frac{P_t}{q_0}$
   e) Decide size of foundation
      - Square footing⇒ $Area = B \times B$
      - Rectangular Footing⇒ $Area = B \times L$
        $(assume\ B\ and\ find\ L)$
   f) Net design soil pressure on foundation

$$W = \frac{P}{A} \quad (WSM)$$

$$W_u = 1.5W \quad (LSM)$$



$Size\ of\ Column = a \times b$

$Size\ of\ Foundation = B \times L$

Footing

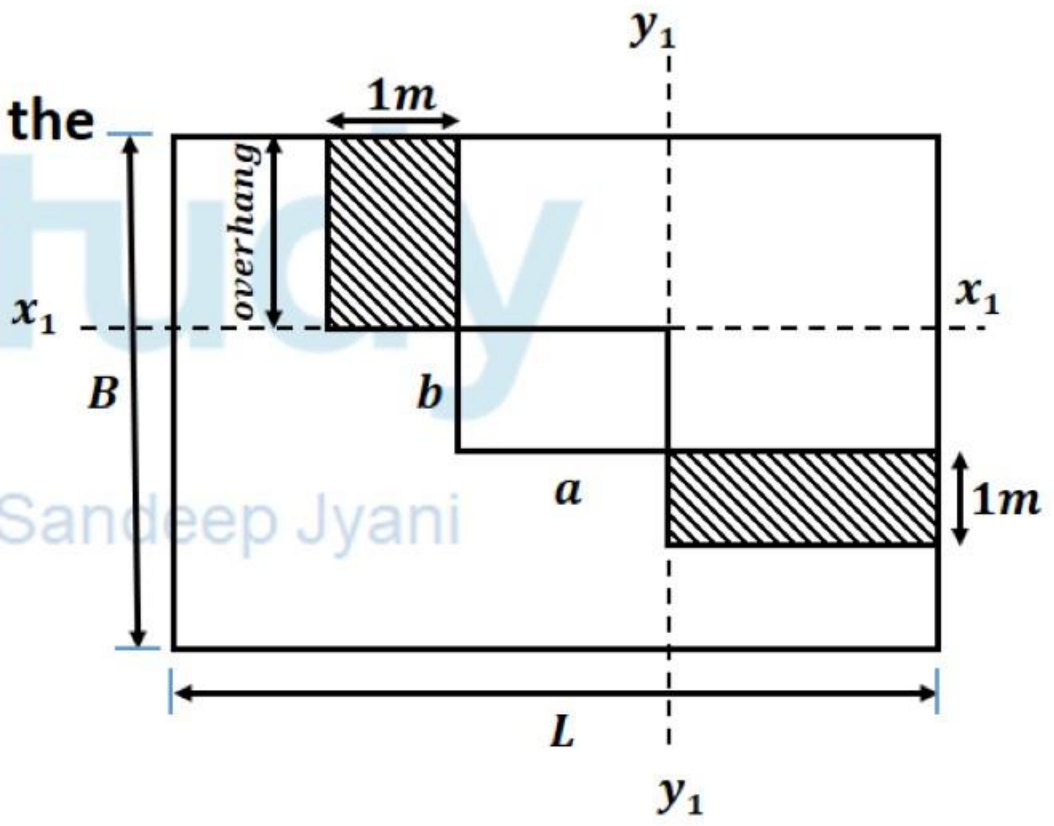
2. Check for Bending Moment

- Critical section for bending moment is at the face of the column.
  - ➢ Bending moment about x_1-x_1 axis
  - ➢ OX_1= overhang = $(\frac{B-b}{2})$
  - ➢ M_x= BM_{x1-x1}

$$=w_o \times 1m \times \frac{Ox_1^{\,2}}{2}$$

$$=w_o \times 1m \times \frac{\{\frac{B-b}{2}\}^2}{2}$$

$$= w_o \times 1m \times \frac{(B-b)^2}{8}$$



Footing

2. Check for Bending Moment

- **Critical section for bending moment is at the face of the column.**
  - $M_y = BM_{y1\text{-}y1}$

    $= w_o \times 1m \times \frac{Oy_1^2}{2}$

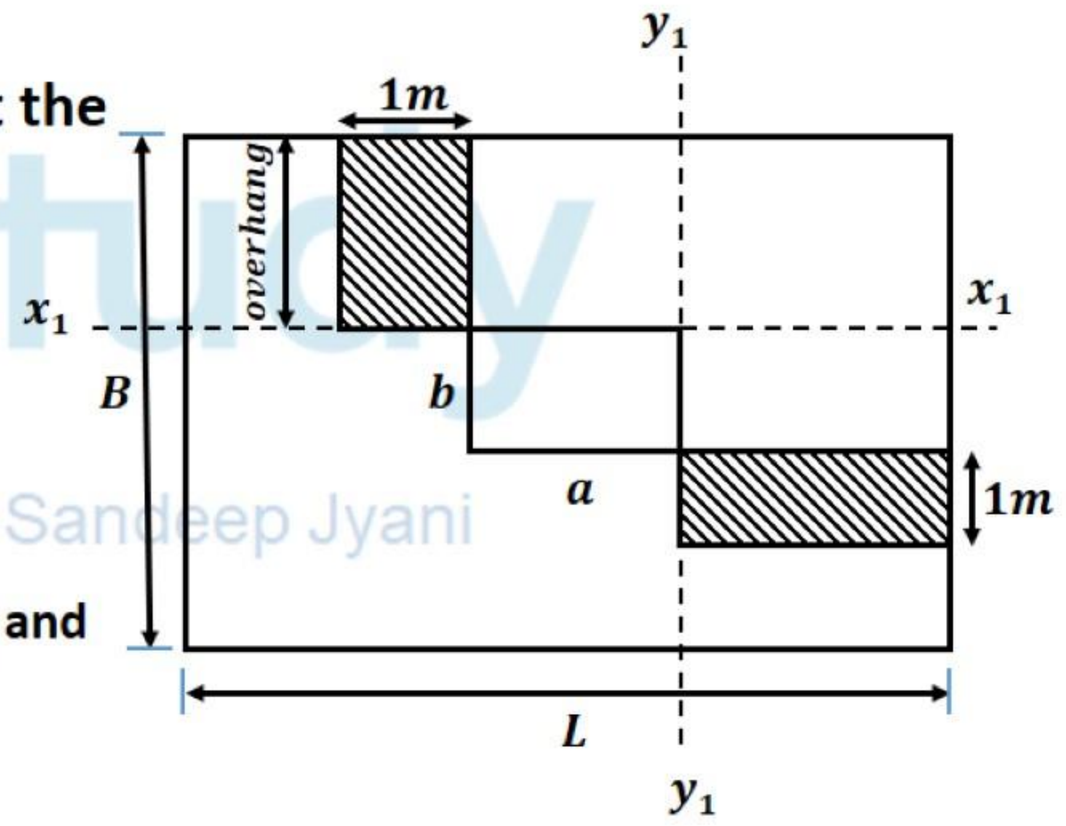
    $= w_o \times 1m \times \frac{\{\frac{L-a}{2}\}^2}{2}$

    $= w_o \times 1m \times \frac{(L-a)^2}{8}$

  - Maximum BM is maximum value among M_y and M_x
  - Depth required

    $$d = \sqrt{\frac{BM_{max}}{QB}}$$

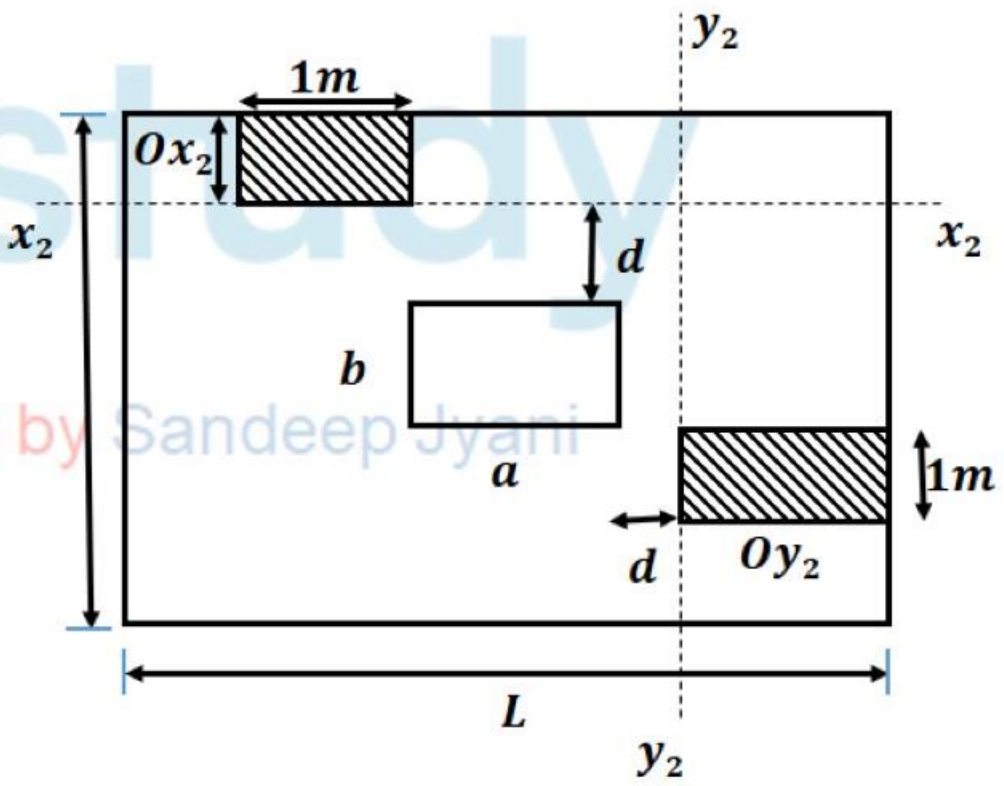
    where B = 1000mm



FOOTING

3. Check for Shear (one way shear)

- **Critical section for one way shear is at a distance 'd' from the face of column.**
  - $OX_2 = \left(\frac{B-b}{2} - \mathrm{d}\right)$
  - $OY_2 = \left(\frac{L-a}{2} - \mathrm{d}\right)$



- **Max shear about x_2-x_2**
  - $OX_2 = \left(\frac{B-b}{2} - \mathrm{d}\right)$
  - $V = w_o \times 1m \times OX_2$
  - $V = w_o \times 1m \times \left(\frac{B-b}{2} - \mathrm{d}\right)$

FOOTING

3. Check for Shear (one way shear)

- **Max shear about y_2-y_2**

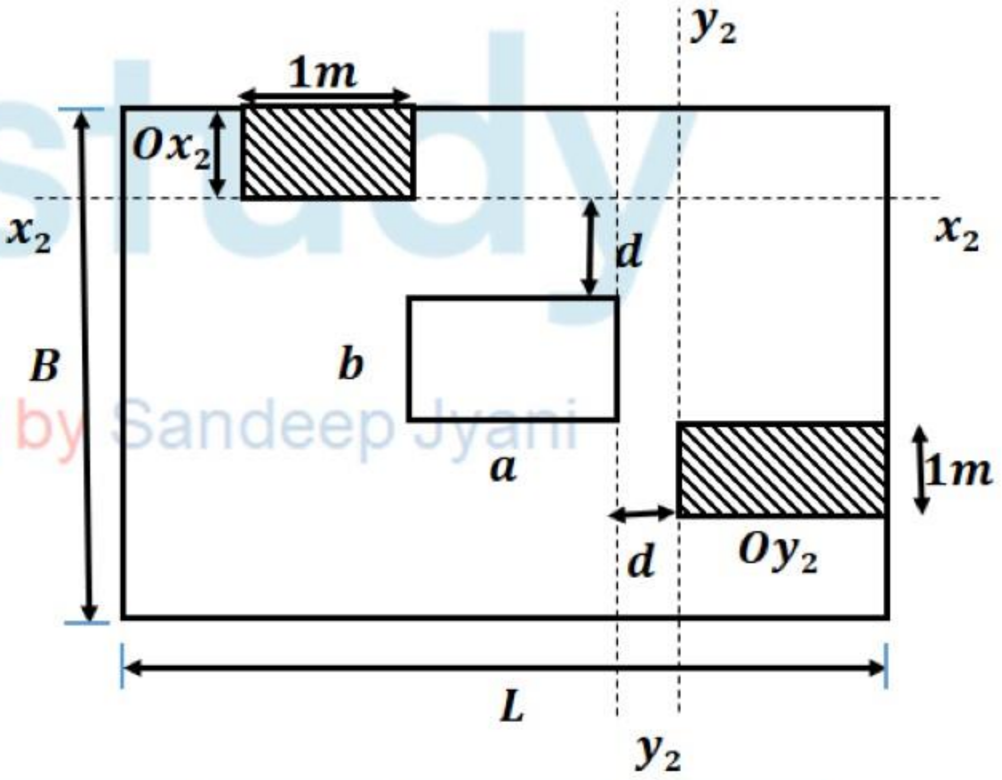
  - $OY_2 = \left(\frac{L-a}{2} - d\right)$
  - $V = w_o \times 1m \times OY_2$
  - $V = w_o \times 1m \times \left(\frac{L-a}{2} - d\right)$

- **Nominal shear stress**

  - $\tau_v = \frac{V}{B.d}$
  - $\tau_v = \frac{V}{1000 \times d}$
  - **τ_v should not be greater than $k.\tau_{cmin}$**

Where τ_{cmin} = 0.18N/mm² (WSM)

τ_{cmin} = 0.28N/mm² (LSM)



THICKNESS	>300	275	250	225	200	175	150
k	1	1.05	1.10	1.15	1.20	1.25	1.30

FOOTING

3. Check for Shear (two way shear)

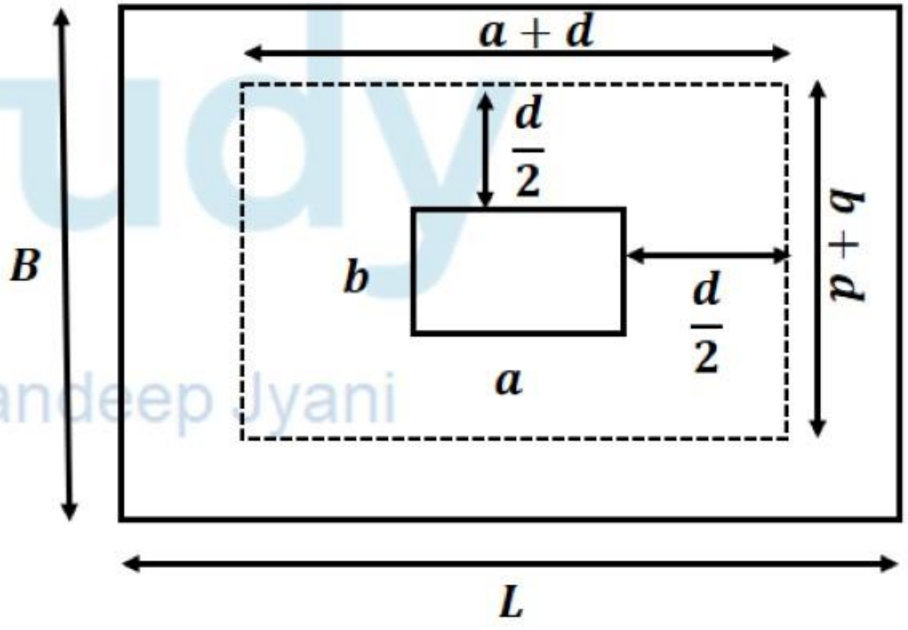
- **Net punching force**

$$P = w_0(L \times B) - w_0(a + d)(b + d)$$

- **Net punching shear stress developed**

$$\tau_{vp\,(developed)} = \frac{Net\ punching\ force}{Resisting\ area}$$

$$=> \tau_{vp\,(developed)} = \frac{w_0(L \times B) - w_0(a+d)(b+d)}{Resisting\ area}$$



- **Two way shear capacity = $k_s \tau'_c$**
  - **$K_s = 0.5 + \beta$**
  - $\tau'_c = 0.25\sqrt{f_{ck}}$
  - $\beta = \dfrac{shorter\ dimension}{larger\ dimension}$

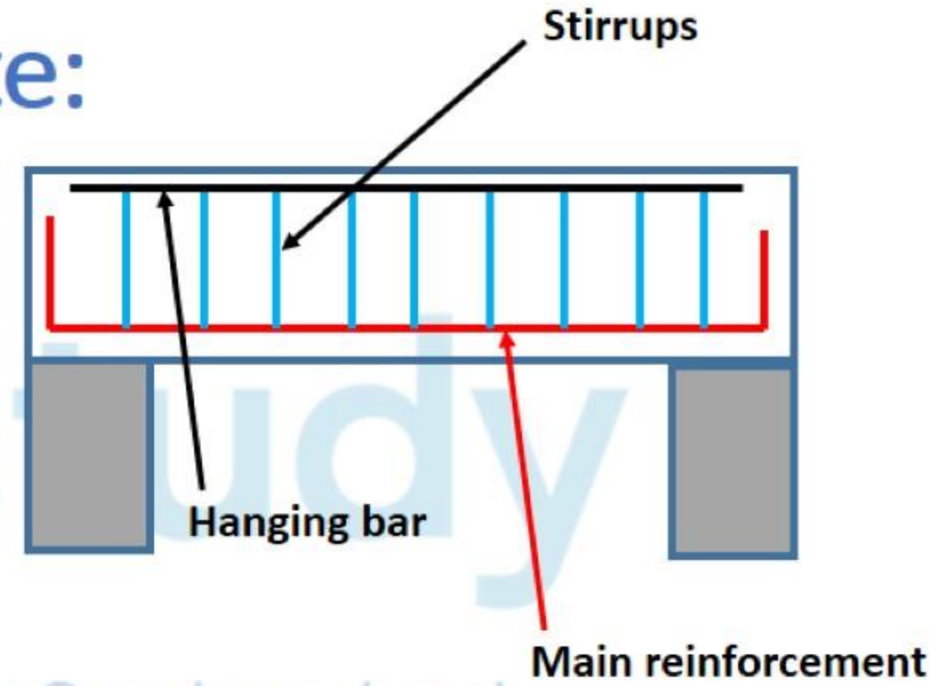
Please note:

1. **Lap Splices:**
   - A lap splice is the most common method of creating a single structural entity from two rebar segments. The lap splice is created by overlapping two lengths of rebar, then wiring them together
   - Lap splices shall not be used for bars larger than 36mm, for larger diameters, bars may be welded
   - In cases where welding is not practicable, lapping of bars larger than 36 mm may be permitted, in which case additional spirals should be provided around the lapped bars
   - Lap length for bars(including anchorage value of hooks) in flexural tension shall be
     - Greater of $\begin{cases} L_d \\ 30\ \emptyset \end{cases}$
   - Lap length for bars in direct tension shall be
     - Greater of $\begin{cases} 2Ld \\ 30\ \emptyset \end{cases}$
   - Splices ia tension members shall be enclosed in spirals made of bars not less than 6 mm diameter with pitch not more than 100mm
   - The lap length in compression shall be equal to
     - Greater of $\begin{cases} L_d \\ 24\ \emptyset \end{cases}$
   - When bars of two different diameters are to be spliced, the lap length shall be calculated on the basis of diameter of the smaller bar

Please note:

2. Hanging bar:

- **Hanging bar is used in compression side and supporting the stirrups in compression side**
- Hanger bars, are provided in a beam to keep the Main reinforcement (which takes care of tension at bottom fibers in simply supported beam, top fibers in cantilever beam) and stirrups (who take care of shear stresses and diagonal tension in beam) in position as the name indicated for them
- **The diameter of hanging bars should not be less than 10mm**



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Civil Engineering by Sandeep Jyani

THANK YOU