LECTURE NOTE

ON

# STRUCTURAL DESIGN-I **(TH.1)**

4TH SEMESTER IN CIVIL ENGG.


PREPARED BY

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## Limit State Method (LSM)

→ In this method of design based on limit state concept, the structure shall be designed to withstand safely all loads liable to act on it through out its life.

→ It shall also satisfy the serviceability requirements such as prevention of excessive deflection, excessive cracking and excessive vibrations.

→ The acceptable limit for the safety and serviceability requirements before failure occurs is called Limit state

→ The aim of the design is to achieve acceptable probabilities that the structure will not become unfit for the use for which it is intended i.e. It will not ~~become~~ reach a limit state.

## Concrete under special conditions

### 1- Concrete in Hot weather

Normally the concrete should be mixed at a normal temperature of 16 to 32°c. A few problems aries if the concreting is done in hot weather (temp more than 32°c) because of the increased rate of evaporation from the fresh mix.

→ This accelerates setting, lowers the workability and hence lower strength of hardened concrete is obtained.

### 2- Concrete in cold weather

If concreting is done in cold weather the water freezes before the concrete is set. No water is then available for chemical Reactions.

→ This delays the setting and hardening of concrete.

...crete Under water

When it is necessary to deposit concrete under water, it should be of at least M 15 grade in case of plain concrete and M 20 grade in case of reinforced concrete.

## Special concretes

1- Ready mixed concrete (pre-mixed concrete)
2- Light weight concrete
3- Fibre Reinforced concrete
4- Polymer concrete
5- Pumped concrete

## Stability of structures

In designing any structure, care should be taken to external stability of the structure or its component members individually in addition to its internal resistance.
For stability, generally two conditions are to be satisfied i.e. the structure should be safe against overturning and also against sliding.

## Working stress Method of design

→ Working stress Method is based on the behaviour of a section under the loads expected to be encountered by it during its service period.

→ The strength of concrete in tension zone of the member is neglected.

## Reinforced concrete beam

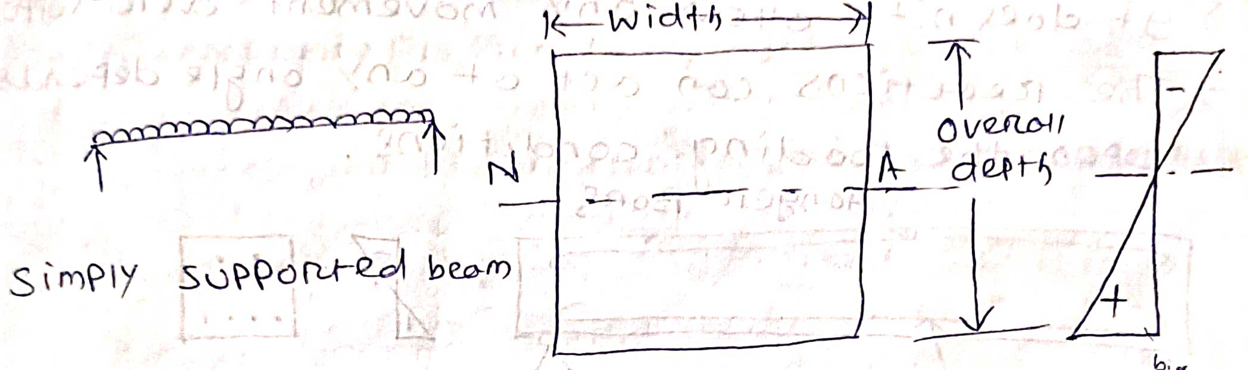
→ Beams are members that are subjected to bending.

→ In a simply supported beam, top half of cross section is under compression & the bottom half under tension.

→ In a cantilever beam, top half of the section will be under tension and bottom half under compression under the vertically downwards acting loads.

→ The variation of stresses in rectangular concrete section for a simply supported beam under vertically downward loads is shown in fig.

→ stresses shall be indicated negative if compressive and positive if ~~negative~~ tensile




Rectangular section    Variation of stresse

→ The stress at any point in a material can be calculated from the following formula

$$f = \frac{M}{I} y$$

where,

f = stress at distance y from neutral axis

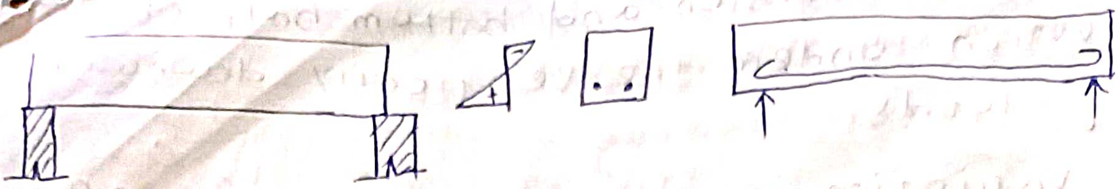
M = bending moment at the section

I = Moment of inertia of cross section about the neutral axis.

## End supports :

i- Beams simply supported at ends -: The beam rests on either wall or columns in a simple manner.

→ The ends of the beam can have rotation in either direction, clockwise or anticlock-wise in the vertical plane.

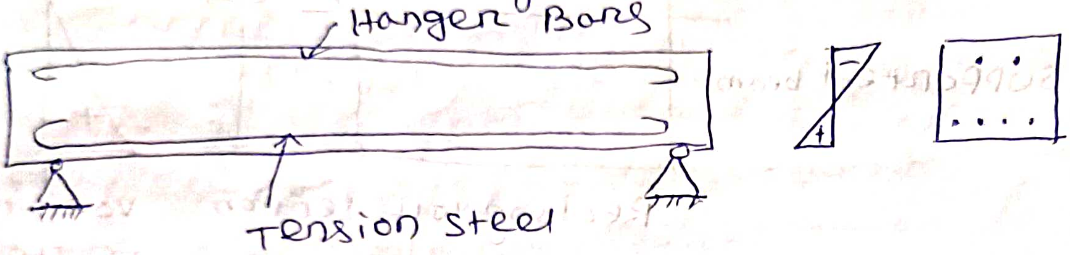


Simply supported Ends

ii - Beam with Hinged supports :- This type of support permits rotation in either direction, clockwise or anticlockwise.

→ It doesn't allow any movement over supports

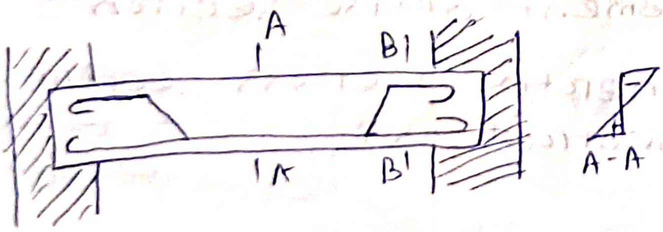
→ The reactions can act at any angle depends upon the loading conditions.




iii - Fixed support :- This type of support does not permit any translation or rotation in any direction

→ Loading produces reactions and movements over supports of this type.

The placement of reinforcement in a beam built in or fixed at ends is shown in fig




(P-80, B-1.3)

## Assumptions

The analysis and design of a reinforced concrete member are based on the following assumptions

1 - Concrete is assumed to be homogeneous.

2 - At any cross section, plane sections before bending remain plane after bending

3- The stress - strain relationship for concrete is a straight line under working loads

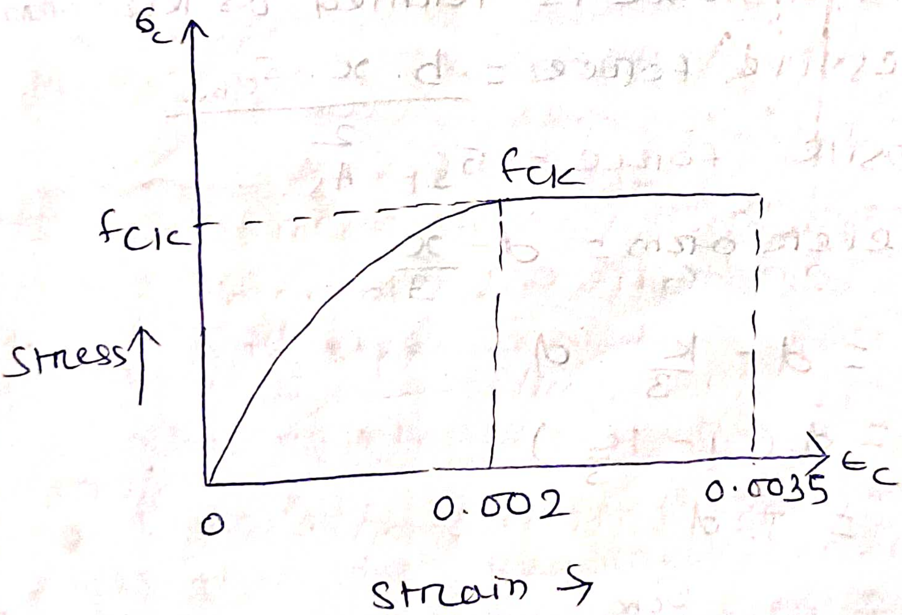
4- Concrete area on tension side is assumed to be ineffective.

5- All tensile stresses are taken up by reinforcement and none by concrete except when specially permitted

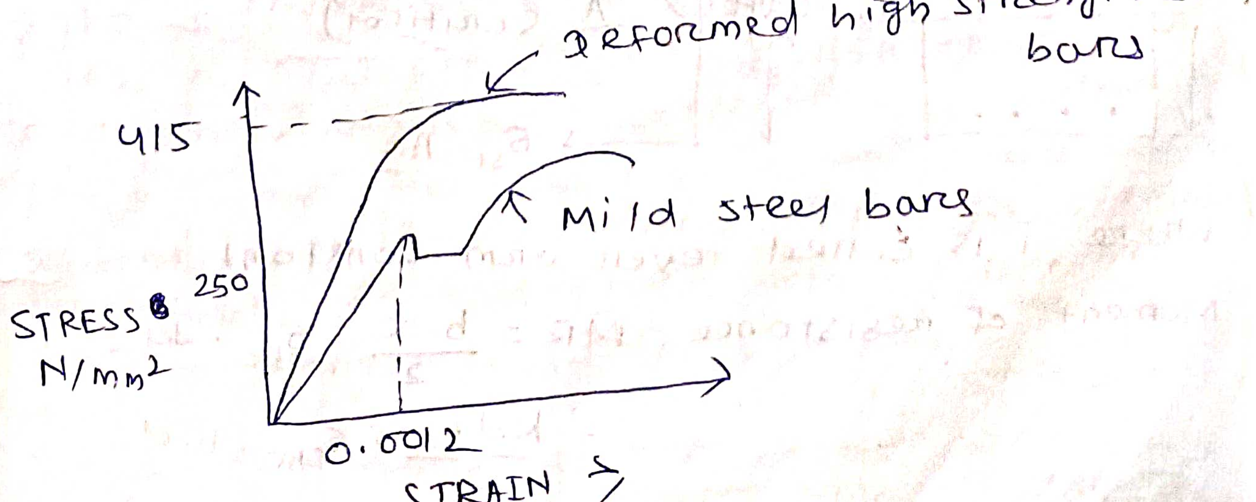
6- The steel area is assumed to be concentrated at the centroid of the steel.

7- The modular ratio has the value $\frac{280}{3\sigma_{cbc}}$

where, $\sigma_{cbc}$ = permissible stress in compression due to bending in concrete in N/mm 2.




stress strain curve for concrete




Stress strain curve for steel

The distance bet" the lines of action of resultant resistive forces is known as Lever arm

## Moment of resistance

a - For balanced section -: When the maximum stress in steel and concrete simultaneously reach the allowable values, the section is said to be a balanced section.

→ The moment of resistance shall be provided by the couple developed by compressive force acting at the centroid of stress diagram on the area of concrete in compression and tensile force acting at the centroid of reinforcement forces multiplied by the distance bet" these. This distance is termed as lever arm

Total compressive force $= \frac{b \cdot x \cdot \sigma_{cbc}}{2}$

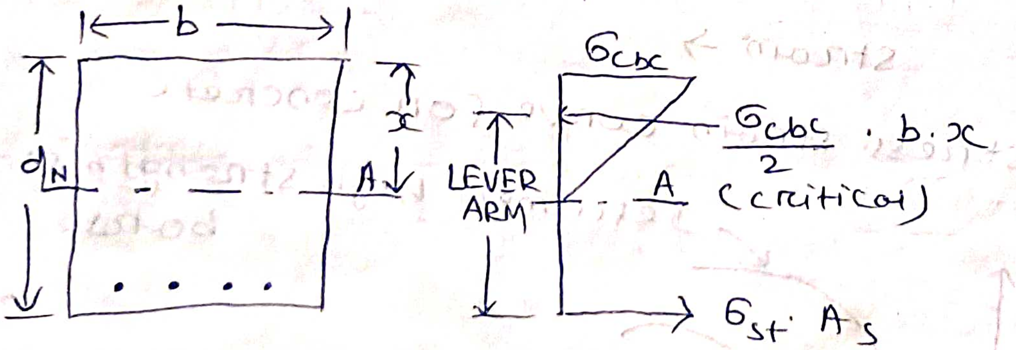
Total tensile force $= \sigma_{st} \cdot A_s$

$$Z = \text{lever arm} = d - \frac{x}{3}$$

$$= d - \frac{k}{3} \cdot d$$

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

$$= J \cdot d$$




Where j is called lever arm constant

Moment of resistance $= MR = \frac{b \cdot x}{2} \cdot \sigma_{cbc} \cdot Jd$

$$= \frac{kd \cdot j}{2} \cdot \sigma_{cbc} \cdot b \cdot d$$

$$= \frac{1}{2} \cdot k \cdot j \cdot \sigma_{cbc} \cdot b \cdot d^2$$

$$= Q b d^2$$

Where Q is called moment of resistance const. and is equal to $\frac{1}{2} \cdot k \cdot j \cdot \sigma_{cbc}$. The quantities k, j and Q are constant for a particular grade of concrete. For M15 concrete and mild steel (P-81, T-21)

$m = \frac{280}{3 \cdot \sigma_{cbc}}$ $\sigma_{cbc} = 5 N/mm^2$ $\sigma_{st} = 140 N/mm^2$

$= \frac{280}{3 \times 5} = \frac{280}{15} = 18.667$

$k = \frac{1}{1 + \sigma_{st}/m \cdot \sigma_{cbc}} = 0.4 = \frac{1}{1 + \frac{140}{18.667 \times 5}} = 0.4$

Lever arm constant $j = 1 - k/3 = 1 - \frac{0.4}{3}$
$= 0.87$

M.R. constant $Q = \frac{1}{2} \cdot k \cdot j \, \sigma_{cbc}$

$= \frac{1}{2} \times 0.4 \times 0.87 \times 5 = 0.87$.

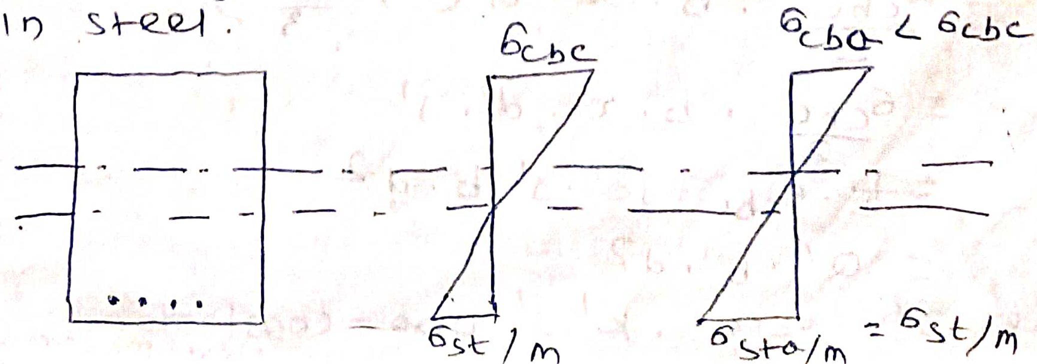
$M.R = Q \cdot b \cdot d^2 = 0.87 \times b \times d^2$ For $M_{15}$ concrete and mild steel.

b- Under reinforced section

When the percentage of steel in a section is less than that required for a balanced section, the section is called as under-reinforced section.

→ The position of N.A will shift upwards i.e. the N.A depth will be smaller than that in the balanced section as shown in fig.

The moment of resistance of such a section will be governed by allowable tensile stress in steel.



Moment of resistance $= \sigma_{st} \cdot A_s \cdot (d - \frac{x}{3})$

$= \sigma_{st} \cdot A_s \cdot j' \cdot d$ where $j' = 1 - \frac{k'}{3}$

since $P = \frac{A_s \times 100}{b \cdot d}$

Moment of resistance $= \sigma_{st} \cdot P \cdot \frac{b \cdot d}{100} \cdot j' \times d$

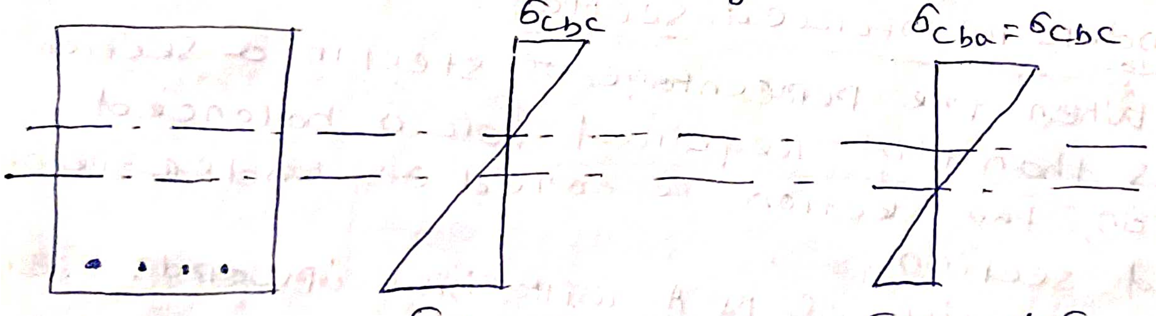
$= \frac{\sigma_{st} \cdot P \cdot j'}{100} \cdot b \cdot d^2$

$= Q' \cdot b \cdot d^2$

where $Q' = \frac{\sigma_{st} \cdot P \cdot j'}{100}$

## C- Over reinforced section

When the percentage of steel in a section is more than that required for a balanced section, the section is called over-reinforced section. In this case the stress in concrete reaches its maximum allowable value earlier than that in steel. The N.A depth will be greater than that in case of balanced section as shown in fig




$M \cdot R = b \cdot x \cdot \sigma_{cbc} \cdot \frac{1}{2} \cdot (d - x/3)$

$= \frac{\sigma_{cbc}}{2} \cdot b \cdot x \cdot d (1 - \frac{k'}{3})$

$= \frac{\sigma_{cbc}}{2} \cdot b \cdot x \cdot d \cdot j'$

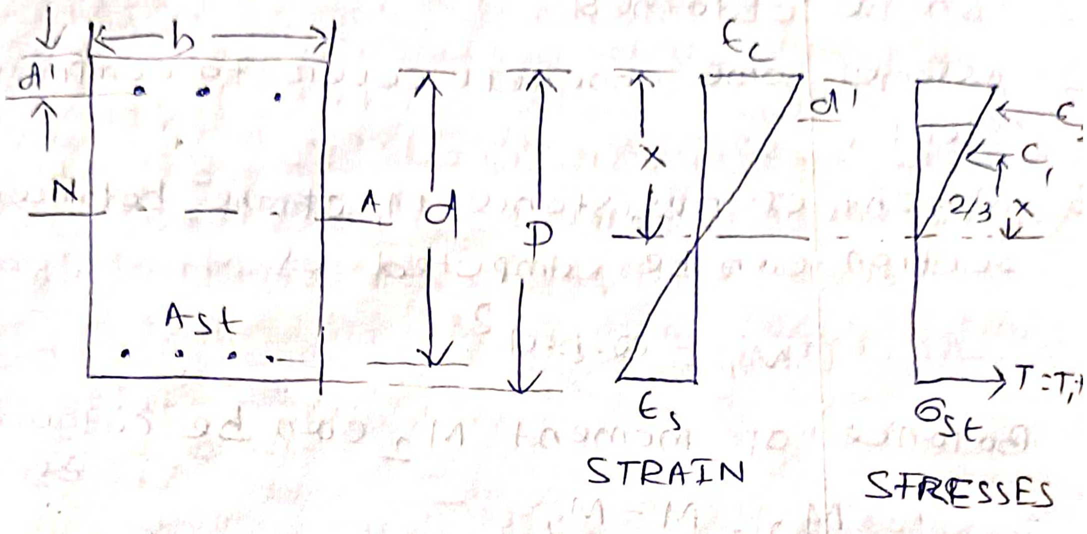
$= \frac{1}{2} \cdot \sigma_{cbc} \cdot k' \cdot j' \cdot b \cdot d^2$

$= Q' \cdot b \cdot d^2$

where $Q' = \frac{\sigma_{cbc}}{2} \cdot k' j'$ = constant

## Moment of resistance of doubly reinforced sections

Consider a rectangular section reinforced on tension as well as compression faces




Let

b = width of section

d = Effective depth of section

D = Overall depth of section

d' = cover to centre of compressive steel.

M = B.M or total moment of resistance

$M_{bal}$ = Moment of resistance of a balanced section with tension reinforcement

Ast = Total area of tensile steel

$Ast_1$ = Area of tensile steel required to develop $M_{bal}$

$Ast_2$ = Area of tensile steel required to develop $M_{ub}$.

Asc = Area of compressive steel

$\sigma_{st}$ = stress in tensile steel.

$\sigma_{sc}$ = stress in compressive steel

### Types of Problems

1 - Determination of Areas of Tension and compression reinforcement

For given allowable stresses in materials, depth of critical neutral axis, lever arm constant, coefficient of moment of resistance can be obtained

2 - Assume some concrete cover to compression steel

3 - Moment of resistance $M_1$ of the balanced section can be computed as

$$M_1 = Q.b.d^2$$

Balance of moment $M_2$ can be calculated as

$$M_2 = M - M_1$$
$$= M - Qbd^2$$

4 - Tension steel can be obtained from

$$A_{st_1} = \frac{M_1}{\sigma_{st} \cdot J \cdot d}$$

$$A_{st_2} = \frac{M - M_1}{\sigma_{st} (d - d')}$$

$$A_{st} = A_{st_1} + A_{st_2}$$

5 - Compression steel is determined from

$$A_{sc} = M - M_1 \; \frac{1}{1.5m - 1} \cdot \frac{x}{(x - d')} \cdot \frac{1}{\sigma_{cbc} (d - d')}$$

## To determine M.R of doubly reinforced beam section

The dimension of section, area both tensions compression steel, grade of concrete and type of steel are given

Step

1 - Determine actual position of the neutral axis $x_a$ by taking moments of concrete and equivalent steel areas about neutral axis

2 - For the given grade of concrete and the type of steel, permissible stresses can be

known. Then obtain the position of the critical N.A. '$x_c$'

3.- By comparing depth of actual N.A with critical N.A. determine whether concrete reaches maximum stress or steel reaches maximum stress.

If $x_a > x_c$, the concrete reaches allowable stress $\sigma_{cbc}$ first. M.R can be found out by taking moments about tensile steel.

$$M = b \cdot x \cdot \frac{\sigma_{cbc}}{2} \cdot \left(d - \frac{x}{3}\right) + (1.5m - 1) A_{sc} \cdot \sigma_{cbc} \cdot \frac{x - d'}{x} \cdot (d - d')$$

If $x_a < x_c$ then steel reaches max$^m$ stress earlier. Moment of resistance can be obtained by taking moment about tensile steel.

$$M = \frac{b \cdot x}{2} \cdot \frac{\sigma_{st}}{m} \cdot \frac{x}{d - x} \left(d - \frac{x}{3}\right) + (1.5m - 1) \cdot A_{sc} \cdot \frac{\sigma_{st}}{m} \cdot \frac{x}{d - x} \cdot \frac{x - d'}{x} (d - d')$$

## To check for stresses

Step

1- Determine position of neutral axis by equating areas of concrete and equivalent areas of steel about N.A

2- Taking moments of compressive forces about tensile steel and equating to external bending moment B.M.

$$M = (1.5m - 1) A_{sc} \cdot \frac{x - d'}{x} \cdot \sigma'_{cbc} \cdot (d - d') + b \cdot x \cdot \frac{\sigma'_{cbc}}{2} \cdot (d - x/3)$$

From this equation, value of $\sigma'_{cbc}$ stress in top fibre of concrete can be found

3- Stress in tensile steel

$$\sigma'_{st} = m \cdot \sigma'_{cbc} \cdot \frac{d - x}{x}$$

4- Stress in compression steel can be found f...

516 mm²

Provide 16 mm dia 3 Nos thus providing $A_{sc} = 603\ mm^2$

$\frac{\pi}{4} \times d^2$

$= \frac{\pi}{4} \times 16^2 = \frac{516}{Ans} = 2.56$ nos $\simeq$ 3 nos

$A_{st_1} = \frac{M_1}{\sigma_{st}\, j d} = \frac{55227.6 \times 1000}{140 \times 0.87 \times 460} = 985.7\ mm^2$

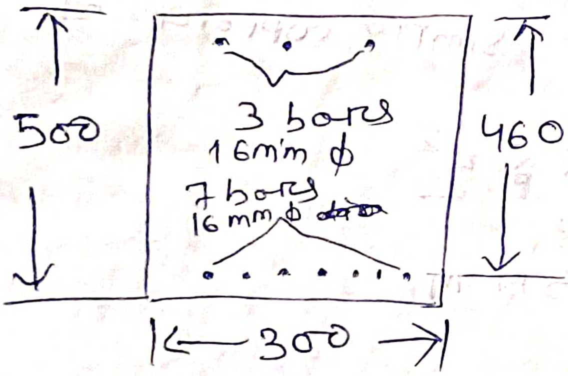
$A_{st_2} = \frac{M_2}{\sigma_{st}(d-d')} = \frac{22897.4 \times 1000}{140 \times 420}$

$= 389.41\ mm^2$

Total $A_{st} = A_{st_1} + A_{st_2} = 985.7 + 389.41$

$= 1375.11\ mm^2$

Provide 16 mm dia 7 Nos thus providing $A_{st} = 1407\ mm^2$




Pro

Determine the moment of resistance of the beam whose section is 300 × 600 mm and reinforced with 2 bars of 16 mm dia at top and 6 bars of 20 mm dia M.S bars at bottom. Take effective cover = 50 mm for tension and compression steel. Use M15 concrete as seen in fig. What superimposed load this beam can carry if its effective span is 8 m and it is simply supported at its ends.

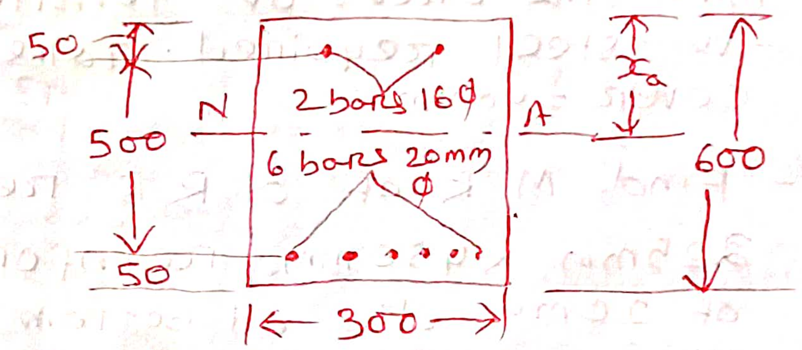
Sol$^n$

Let $x_a$ be the depth of actual N.A

Taking moments of compressive and tensile areas about the N.A

$$\frac{b x_a^2}{2} + (1.5m - 1) A_{sc} \cdot (x_a - d') = m \cdot A_{st} (d - x_a)$$

$$\frac{300}{2} x_a^2 + (1.5 \times 18.67 - 1) \times 402 (x_a - 50)$$




$$= 18.676 \times 314 \times (550 - x_a)$$

$$\Rightarrow x_a = 241.7 mm$$

Depth of critical N.A = $0.4 \times 550 = 220$ mm ($k \times d$)

less than $x_a$

The section is over reinforced

$$M = \frac{b \cdot x_a \cdot \sigma_{cbc}}{2} \left(d - \frac{x_a}{3}\right) + (1.5m - 1) A_{sc} \cdot \sigma_{cbc} \frac{x_a - d'}{x_a} (d - d')$$

$$= \frac{300 \times 241.7 \times 5.0}{2} \left(550 - \frac{241.7}{3}\right) + (1.5 \times 18.67 \times 402 \times 5.0 \times \left\{\frac{241.7 - 50}{241.7}\right\} (550 - 50)$$

$$\Rightarrow 106,622,149 \text{ N} \cdot \text{mm} = 106,622 \text{ N} \cdot \text{m}$$

Max$^m$ B.M for simply supported beam $= \frac{WL^2}{8}$

$$\Rightarrow \frac{W \times 8^2}{8} = 106622$$

$$\Rightarrow W = 13327.8 \text{ N/m}$$

weight of beam = 0.3×0.6×25000 = 4500 N/m
(code P-32, cl-19.2.1)

Superimposed load = 13327.8 − 4500 = 8827.8 N/m

ASS

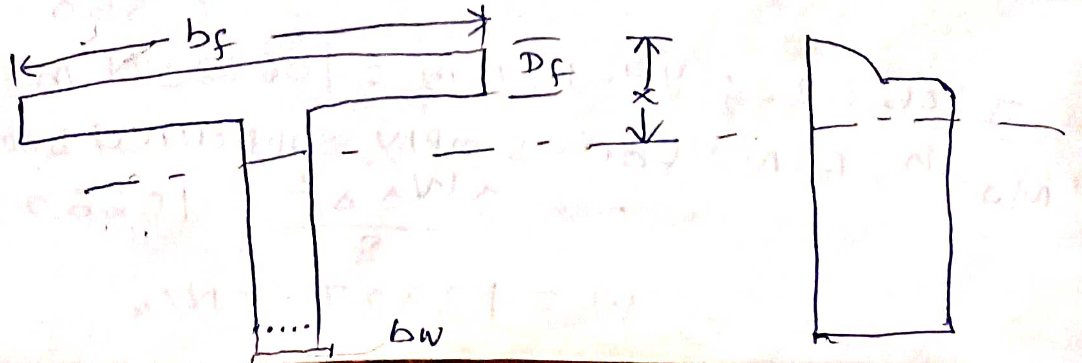
1 - A reinforced concrete beam 250 mm × 500 mm is simply supported over a span of 4 m and carries udl of 30 KN/m. concrete used is M15 and steel used is mild steel. Determine the areas of tensile and compressive steel required. Take effective cover = 40 mm

2 - Find M.R of a R.C. rectangular section 225 mm × 450 mm, reinforced with 4 bars of 20 mm dia at bottom and 3 bars of 16 mm dia at top. Take effective covers at top and bottom = 40 mm and m = 18

3 - A doubly reinforced concrete beam 250×550 mm size, is reinforced with 5 bars of 16 mm ϕ at top and 4 bars 20 mm ϕ at bottom. Determine the stresses in steel and concrete if the beam is simply supported over a span of 5 m & carries a load 22.4 KN/m inclusive of self weight. concrete used M15.

## T Beam

T beams are the beams constructed monolithically with the slabs. Shear stress distribution in T-sections with tension reinforcement is shown in fig.



Shear stress $= \frac{V}{z \cdot b_w}$

where $z$ = actual lever arm $= d - \frac{D_f}{3}\left[\frac{3 \cdot x - 2D_f}{2 \cdot x - D_f}\right]$

LSM

Characteristic strength of material – (code P-15 Cl-6.1.1)

$f_{ck}$ = Characteristic compressive strength of concrete

$f_y$ = Characteristic strength of steel

→ Limit state of collapse – (code P-67 Cl-35.2)

→ Limit state of serviceability – (P-67 Cl-35.3)

→ Limit state of durability – (P-17 - Cl-8)

partial safety factors & characteristic and design value – (P-67, Cl-36.1, 36.2, 36.4)

→ Define & explain different characteristic loads for structures – 36.2

→ Assumptions in LSM → (P-69 - Cl-38, 70)

LSM - of collapse of singly Reinforced members in bending

Pro

Calculate the area of mild steel required for section of width 250mm and overall depth 500mm (effective depth 460mm) if the Limit state moment is to be carried by the beam section is

i- 65KN.m  ii-117.7KN.m  ~~iii-140KN.m~~

Soln

For mild steel $F_y = 250\ N/mm^2$

$\frac{x_{umax}}{d} = 0.53$ – (code P-70, NOTE)

(code P-96, G-1)

$M_{ulim} = 0.36 \frac{x_{umax}}{d}\left(1 - 0.42 \frac{x_{umax}}{d}\right) b d^2 f_{ck}$

$= 0.36 \times 0.53 (1 - 0.42 \times 0.53) \times 250 \times 460^2 \times 15 = 117.7 \times 10^6\ N.mm$