CE-301: Design of Concrete Structures-I

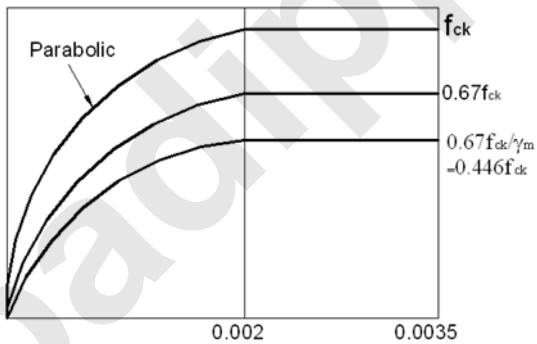
PART A

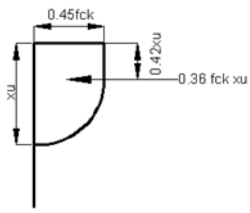
1. a) Explain the objectives of structural design

Ans: The objectives of structural design is to design the structure for stability, strength and serviceability. It must also be economical and aesthetic. To achieve an acceptable probability that structure being designed will perform satisfactorily during their intended life.With an appropriate degree of safety they should sustain all the loads and deformation of normal construction and use and have adequate durability and adequate resistance to the effect of misuse and life.

- Stability: to prevent
  - over turning
  - buckling
- Strength: to resist safely
  - stresses
  - moment
- Serviceability:
  - adequate stiffness – deflection, vibration, crackwidth
  - providing impermeability, durability
- Economy & Aesthetics

b) Derive the stress block parameters





Area :-

- Rectangle :

$$= \frac{3}{7} X_u \times 0.446 f_c k$$
$$A_1 = 0.191 f_c k X_u$$

- Parabola :

$$\frac{2}{3} \times \frac{4}{7} \times X_u \times 0.446 f_c k$$
$$A_2 = 0.169 f_c k X_u$$

- Y top

$$\frac{3}{7} X_u \times \frac{1}{2}$$
$$= \frac{3}{14} X_u$$
$$= \frac{3}{14} X_u + \frac{3}{7} X_u$$
$$= \frac{9}{14} X_u$$

$$A = 0.191 f_c k X_u + 0.169 f_c k x_u$$
$$A = 0.36 f_c k X_u$$

$$\bar{y}top = \frac{A_1 y_1 + A_2 y_2}{A_1 + A_2}$$

$$\bar{y}top = \frac{\left(0.1914 \times f_c k X_u \times \frac{3}{14} X_u\right) + \left(0.169 \times f_c k \times X_u \times \frac{9}{14} X_u\right)}{0.36 f_u k X_u}$$

$$\bar{y} = 0.42 X_u$$

2. Discuss the various properties of concrete and reinforcing steel in detail.

3. a)Explain the types of limit states

<u>Ans: Limit state of collapse</u> (P.69)

Resistance to bending, shear, torsion, and axial loads at any section. The structure or any part of structure could be assessed from rupture, from buckling due to elastic or plastic instability or overturning.

<u>Limit state of serviceability</u>

Limiting deflection and crack width. The surface width of cracks should not in general exceed

0.3mm in members where cracking is not harmful

0.2mm in exposed to moisture or contact with soil or ground water.

0.1mm for severe category.

Reinforcing steel characteristics strength is taken as yield stress or 0.2% proof stress

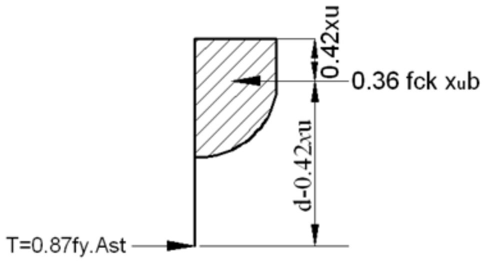
Characteristic loads that is 95% probable loads taken from IS 875 code.

γ_m for concrete 1.5 and

γ_m for steel 1.15

b) Derive the equation of moment of resistance of a rectangular over reinforced beam.

Ans:



If the value x_u/d is equal to the limiting value, the M.R is given by the equation

Mu limit = CxL.A

$= 0.36\ f_{ck} x_u\ b\ (d - 0.42\ x_u)$

$= 0.36\ f_{ck} x_{umax}\ b\ (d - 0.42\ x_{umax})$

$= 0.36\ f_{ck} x_{umax} bd\ (1 - 0.42\ x_{umax})$

$$\text{Mu limit} = 0.36\ \frac{x_{umax}}{d}\left(1 - 0.42\ \frac{x_{umax}}{d}\right) bd^2 f_{ck} \quad G.1.1[P96]$$

$$\text{Mu limit} = 0.36 \times\ 0.48\ (1 - 0.42\ \times 0.48) bd^2 f_{ck} \quad G.1.1[P96]$$

Mu limit = $0.138 f_{ck} bd^2$ for Fe 415

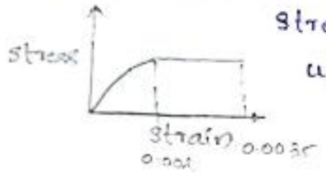
4 a)Discuss the assumptions in limit state of collapse in bending

1 a) Assumptions in limit state of collapse in bending. (Cl. 38.1)

a) Plane sections normal to the axis remain plane after bending

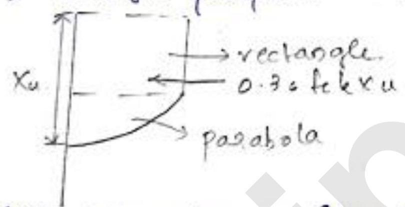
Normally plane sections after loading wont remain plane but we have to assume this for limit state. In limit state assumption this unbending is taken as figure of strain hence its taken.

b) Maximum strain in concrete at outermost compression fibre is taken as 0.0035



Stress - strain diagram of concrete is given upto 0.002 increase in stress is noted but after that it remains constant

c). The relationship b/w the compressive stress distribution in concrete & strain in concrete may be assumed to be rectangle. It's to make the calculations much more easier.
for design purpose. fck of concrete is 0.6 fck & $\gamma_m = 1.5$.

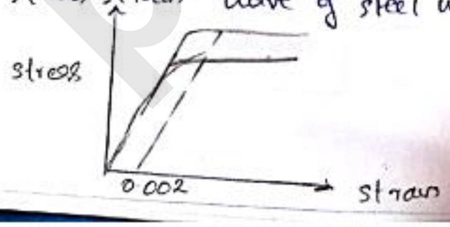


Stress block diagram

Actually gradual increase after that stress remain constant hence its used for easy way splitted it as parabola & rectangle

d). Here we only consider tensile strength of steel, where as tensile strength of concrete is neglected since tensile strength of concrete is $\frac{1}{10}$ th of its compressive strength its negligible.

e) stresses in reinforcement steel are calculated using stress strain curve of steel used, $\gamma_m = 1.15$



f) The maximum strain in tension is $\frac{0.87 f_y}{E_s} + 0.002$.

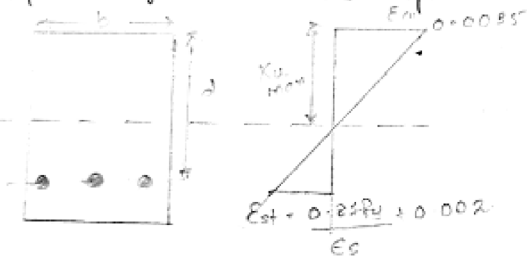
Since 0.2% of proof stress is provided as a residual strain, an extra addition of 0.002 acts here.

where f_y = characteristic strength of steel.

E_s = modulus of elasticity of steel.

X_{umax}/d	f_y
0.53	250
0.48	415
0.46.	500.

b) Expression for neutral axis depth in limit state method.



Consider a singly reinforced rectangular beam with width b & effective depth d. Let X_{umax} be the distance from neutral axis to the end. Considering similar triangles in figure d.

$$\frac{X_{umax}}{d - X_{umax}} = \frac{0.0035}{\frac{0.87 f_y}{E_s} + 0.002}$$

Let E_s be $2 \times 10^5 \, N/mm^2$.

$$\therefore X_{umax}\left[\frac{0.87 f_y}{2 \times 10^5} + 0.002\right] = 0.0035d - 0.0035 X_{umax}$$

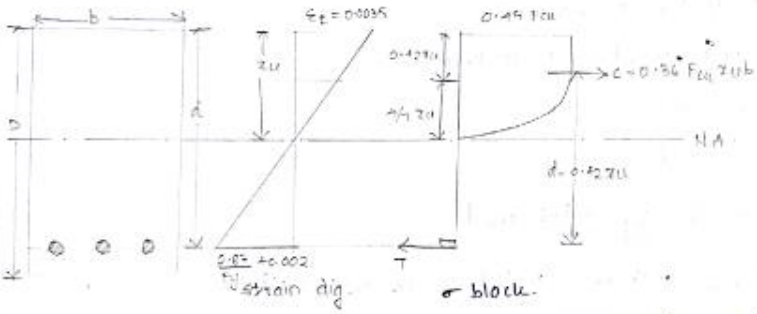
$$0.0035d = X_{umax}\left[\frac{0.87 f_y}{2 \times 10^5} + 0.002\right] + 0.0035 X_{umax}$$

$$\therefore \boxed{\frac{X_{umax}}{d} = \frac{0.0035}{\cancel{X_{umax}}\left[\frac{0.87 f_y}{2 \times 10^5} + 0.002 + 0.0035\right]}}$$

b) Derive expression for neutral axis depth in limit state method.

b) Neutral axis depth:-

The stress-strain curve for concrete and steel and the variation of stress along the depth of a rectangular beam is drawn.



From the given dig, the stress for concrete is $0.36 f_{cu} x_u$

$\therefore$ The compression force = stress x area

$= 0.36 f_{cu} \cdot x_u \cdot b$

The tension force = $0.87 f_y \cdot A_{st}$.

At equilibrium, or at the neutral axis the comp. force and the tensile force acting on a beam are in equilibrium. $\therefore$ on equating C and T we get

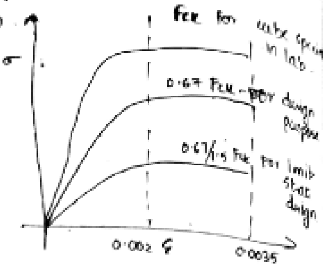
$$0.36 f_{cu} \cdot x_u \, b = 0.87 f_y \cdot A_{st}$$

$$x_u = \frac{0.87 \, f_y \cdot A_{st}}{0.36 \cdot f_{cu} \cdot b}$$

Here the neutral axis depth, x_u or $\frac{x_u}{d} = \frac{0.87 \cdot f_y \cdot A_{st}}{0.36 \, f_{cu} \cdot bd}$ Hence the proof (Annex G of IS:456-2000)

c) Explain, why IS 456 has assumed the compressive strength of concrete as 0.67 times the characteristic strength, for design purpose?

5) According to IS 456, the compressive strength of concrete is assumed as 0.67 times the characteristic strength. When we analysing the σ-ϵ curve of concrete, we have 3 curves. The σ-ϵ curves of concrete are obtained by testing a concrete cube of size 50x50x50 after 28 days curing in the testing machine. The 1st curve in the given σ-ϵ curve is obtained for that cube specimen tested in the lab. But in the actual structure, the concrete is loaded in a diff. way as that of the lab specimen. In the lab only axial loading is applied. But in the actual structure there may be changes in the



1. Duration of loading.
2. Size of the structure.
3. Shape of the structure
4. Type and variation of loading.
5. Nature of concrete
6. Curing errors
7. Nature of aggregates used.

Due to these problems listed above, we can't use the Fck value obtained by testing the lab specimen for design of structures. so to avoid problems of failure we are assuming a value less than Fck for concrete in designing ie 0.67 Fck. And in the limit state of design, as we know limit state is a ~~state of~~ acceptable limit for the safety and serviceability requirements before failure. In that philosophy we use partial factor of safety for all materials to avoid any strength failures and to ensure max. serviceability. so for limit state of design we use a strength of $\frac{0.67\,Fck}{\gamma m} = \frac{0.67}{1.5}\,Fck$, 0.45 Fck for design purpose.

5. a) Explain the advantages of limit state design concept.

Ans: A limit state is a state of impending failure, beyond which a structure ceases to perform its indented function satisfactorily, in terms of either collapses or become unserviceable.
They are two types of limit states

1. Ultimate limit state or limit state of collapse, which deal with strength, overturning, sliding, buckling, fatigue fracture etc.

2. Serviceability limit states, which deals with discomfort to occupancy and / or malfunction, caused by excessive deflection, crack width, vibration, leakage, etc and also loss of durability.

The ratio of ultimate load to the working load is called load factor.

The LSM philosophy uses a multiple safety factor format which attempts to provide adequate safety at ultimate loads as well as adequate serviceability at service loads, by considering all possible limit states. The selection of various multiple safety factors is supposed to have a sound probabilistic basis, involving the separate consideration of different kinds of failure, types of materials and types of loads in this sense, LSM is more than a mere extension of WSM and ULM. It represents a new paradigm – a modern philosophy.

•The philosophy of the limit states method of design (L.S.M) represents a definite advancement over the traditional design philosophies.

• Unlike working stress method which based on calculations of service load conditions alone,

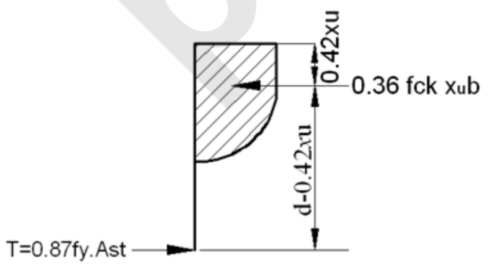
• unlike ULM which based on calculations of ultimate load conditions alone:

•LSM is for a comprehensive and rational solution to the design problem by considering safety at ultimate loads and serviceability at working loads.

b) Derive the equation for computing moment of resistance of a under reinforced, rectangular beam.

Ans: If the value of xu/d is less than the limiting value given in 38.1, it is under reinforced section and moment of resistance should be calculated as per the force in tension.

$$M_u = T \times lever\ arm$$
$$= 0.87 f_y A_{st} (d - 0.416 x_u)$$
$$= 0.87 f_y A_{st} \left(d - 0.416 \times \frac{0.87 fy.Ast}{0.36 f_{ck}.b}\right)$$
$$M_u = 0.87 f_y A_{st} d \left(1 - \frac{Ast.fy}{f_{ck}.bd}\right) \qquad G.1.1(b)$$



6. a) Discuss the various limit states of serviceability

calculatn may be done using formula given in Annex. F.

The surface width of the cracks should not, in gen. exceed 0.3mm in members where cracking is not harmful & doesn't have any serious adverse effects upon the preservation of reinforcing steel nor upon the durability of structure. In memb. where cracking in the tensile zone is harmful either because they are exposed to effects of weather or continuously exposed moisture or in contact soil or ground water, an upper limit of 0.2mm is suggested for max. width of cracks. For particularly agg. environment, such as severe in table 3, the assessed surface width of cracks should not in general, exceed 0.1mm.

2) Deflection:

Limiting values of deflectns are in 23.2.

For cantilever 7
simply supported 20
continuous 26

a) The final deflectn due to all loads including the eff. of temp, creep and shrinkage measured from the as-cast level of the supports of floors, roofs & all other horizontal memb should not normally exceed span/250

b) The deflectn including the effects of temp, creep & shrinkage occurring after erection of partitions and the application of finishes should not normally exceed span/350 or 20mm whichever is less.

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

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

b) Define partial safety factor? What are the partial safety factors for steel and concrete? Why do they differ?

The design strength (factored strength) of concrete or reinforcing steel is obtained by dividing characteristic strength by appropriate partial safety factor

b) Partial safety factor:- It is a factor of safety provided limit state of design to ensure serviceability at working & safety at ultimate load.

1) Materials:- $\gamma_m = \frac{f}{f_d} = \frac{\text{characteristic strength}}{\text{Design strength}}$

2) For loads: $F_d = F \gamma_F$

F = charact. load

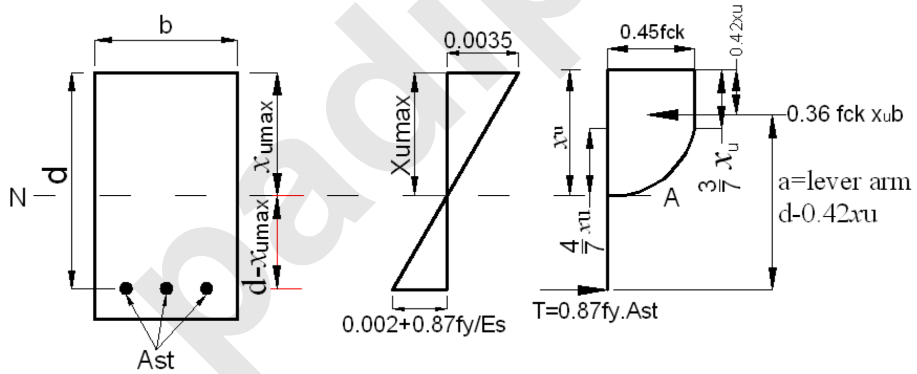
γ_F = partial safety factor

→ for concrete = 1.5

steel = 1.15

→ They diff. because the γ value is depend on the material nature. It will be diff. for diff. material. It also depend on the property such as modulus of elasticity and characteristic str of material. ∴ They are diff.

c) Draw a cross section of a singly reinforced rectangular beam, the strain and stress distribution along the depth of the section.



PART B

1. The rectangular beam of width, 300 mm is having overall depth of 450 mm. The concrete grade is M20 and the grade of reinforcing steel is Fe 415. The tensile reinforcement is provided by 4-20 mm diameter bars. The clear cover is 25 mm. Determine the shear capacity of the beam.

5. $b = 300$ mm

$D = 450$ mm

$f_{ck} = 20$ N/mm²

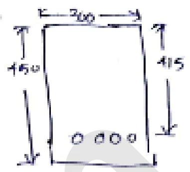
$f_y = 415$ N

$A_{st} = 4 \times \frac{\pi}{4}(20^2) = 1256.637$ mm²

clear cover = 25 mm

Eff. cover $= 25 + \frac{d}{2} = 25 + 10 = 35$ mm

$d = 450 - 35 = 415$ mm



$P_{st} = \frac{100 A_{st}}{bd} = \frac{100 \times 1256.637}{300 \times 415} = 1.0093 \approx 1.01$

For $P_{st} = 1.0093$ and M20 concrete the τ_v value (from table 19) is.

For $P_{st} = 1 \rightarrow 0.62$

$1.25 \rightarrow 0.67$

By interpolation, $\frac{x - x_1}{x_2 - x_1} = \frac{y - y_1}{y_2 - y_1}$

$\frac{1.01 - 1}{1.25 - 1} = \frac{y - 0.62}{0.67 - 0.62} \Rightarrow y = 0.622$

$\tau_c = 0.622$

~~For~~ ∴ shear capacity $= \tau_c \cdot b \cdot d$

$= 0.622 \times 300 \times 415$

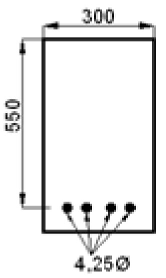
$= 77.439 \times 10^3$ N

$= 77.439$ kN

2. Determine the ultimate MR of the beam section.

Given b = 300 d = 550 Ast =1963; fy = 415; $f_{ck} = 20$

For f_y 415 $x_{umax} / d = 0.48$



$x_{umax} = 0.48 X 550 = 264$

$X_u > x_{umax}$ over reinforced section should be designed as balanced section

$Mu_{limit} = 0.138 f_{ck} bd^2 = 0.138X20X300X550^2$

= 250.47 kNm

3. a) Explain various types of shear reinforcement used in a beam with neat sketches.

4 a) various types of shear reinforcement used. (Cl 40.4 IS 456 2000)

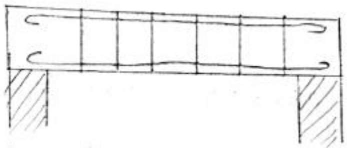
a) vertical stirrups.

b) Bent up bars along with stirrups.

c) Inclined stirrups.

Vertical stirrups

These are provided in such a manner that perpendicular to the beam.



There are different types of vertical stirrups.

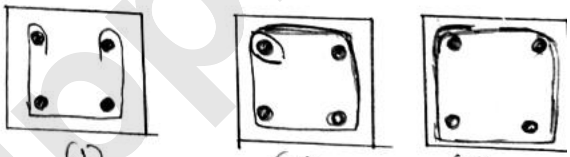
1) Single legged.

2) Double legged.

3) 4 legged.

4) 6 legged.

Single legged.

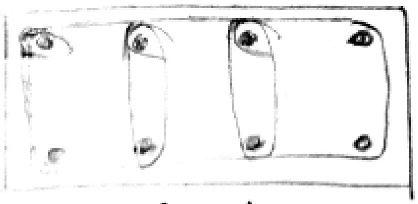


(1) (2) (3)

2 legged.

(3) is more preferable, loops wont split up.

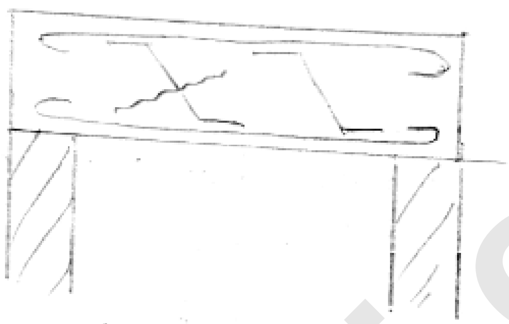
4 legged



6 legged

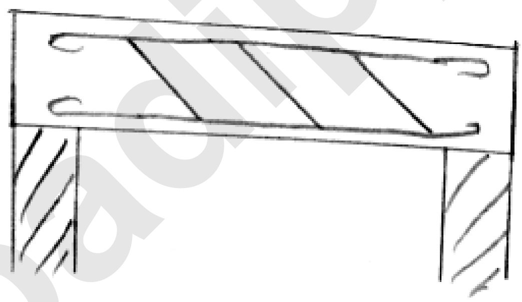
b) Inclined stirrups.

It's provided perpendicular to the crack mostly as 45°.



c). Bend up bars along with stirrups

They are provided along with longitudinal reinforcement in order to . get both flexure & shear action



b) Explain nominal shear stress and design shear strength of concrete

Nominal shear is taken as a magnitude of diagonal tension which causes cracking of concrete

Nominal shear stress,

$$\tau_v = \frac{V_u}{bd}$$

where, Vu: ultimate (design) shear force b:breadth

d:effective depth

Design shear strength

The resistance of RC beams to diagonal tension failure depends upon two factors

- Grade of concrete
- Percentage of tension steel in the beam

- Table 19, IS 456:2000 give the ultimate allowable shear stress, τ_c
- Which is function of percentage of tension steel and grade of concrete

The area of tension steel at a section to be taken into account is the area of steel which continues through the section

All beams where shear τ_v exceeds the allowable values given Table 19 τ_c ; shear reinforcement should be provided

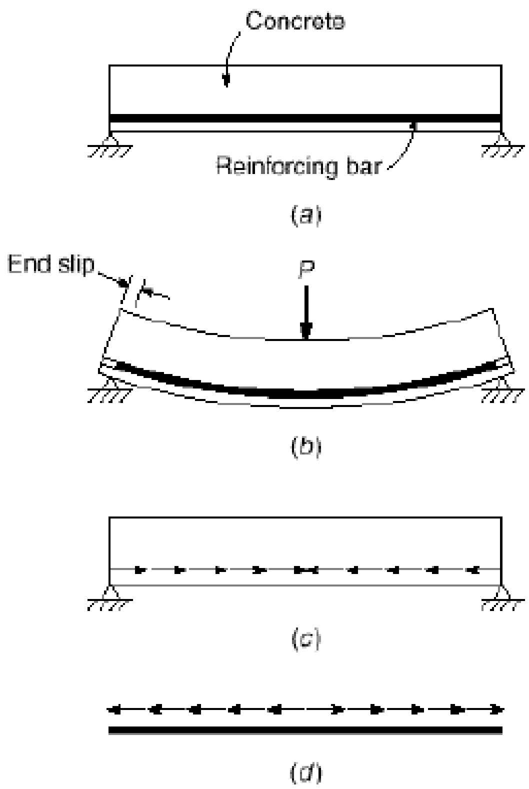
As shear failure are sudden and brittle, all important structures with shear stress even less than safe values should be provided with minimum shear reinforcement

- Cl. 26.5. 1.6

4. What is bond in reinforced concrete? Define development length and derive an expression for development length

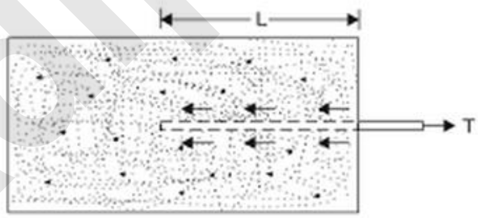
Ans:

Bond is the adhesion between the reinforcing steel and surrounding concrete. It is responsible for the transfer of axial force from steel to surrounding concrete. Inadequate bond causes *slipping* of reinforcing bar, destroying the composite action of RCC

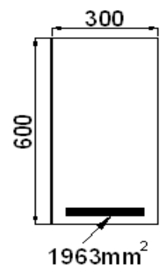


Development length:

The length or extension that should be provided on either side of the point of maximum tension in the steel so that the average bond stress is not exceeded is called development length in tension.



5. Determine the ultimate M.R for the beam sections M20 concrete Fe 250 steel(M.S) Given b = 300; d=550; Ast = 1963 mm^2; f_y = 250Mpa; f_{ck} = 20 MPa.



For Fe 250 Steel $X_{umax}/d = 0.53$

$X_{umax} = 0.53X550 = 291.5mm^2$

Assume $X_u \le X_{umax}$

$$Xu = \frac{0.87 \times 250 \times 1963}{0.36 \times 20 \times 300} = 197$$

$$< 292 \qquad under\ reinforced$$

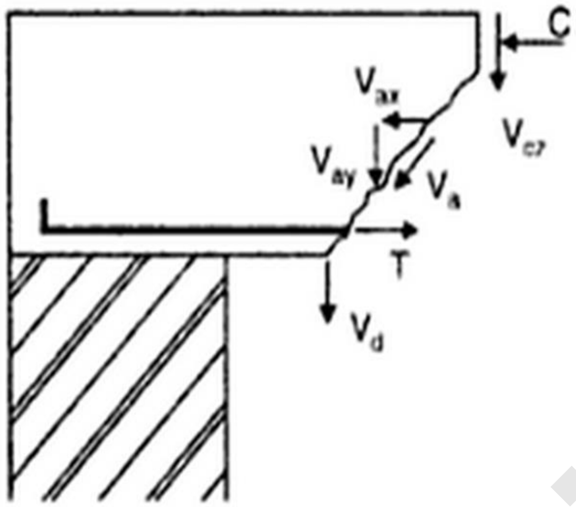
$$M_{uR} = 0.87 f_y A_{st}(d - 0.42 x_u)$$

$= 0.87 \times 250 \times 1963(550 - 0.42 \times 197)$

$= \mathbf{200kNm}$**[Ans]**

6. Describe the force components that participate in the shear transfer mechanism at a flexural shear crack location in a reinforced concrete beam.

Ans:



1. Shear resistance V_{cz} of the uncracked portion of concrete
2. Vertical component V_{ay} of the interface shear or aggregate interlocking force V_a
3. Dowel force V_d in the tension reinforcement due to dowel action
4. Shear resistance V_s carried by the shear reinforcement

PART C

1. A beam of effective span 8m carrying a load of 10kN/m inclusive of its own weight.Find the depth in BM criteria and A_{st}. M20 concrete and Fe 415 steel is used.

$$M = \frac{wl^2}{8} = \frac{10 \times 8^2}{8} = 80kN$$

$$M_u = 80 \times 1.5 = 120kNm$$

Assume 300mm width

$$d = \sqrt{\frac{M_u}{0.138 \times f_{ck} b}} = \sqrt{\frac{120 \times 10^6}{0.138 \times 20 \times 300}} = 380.69mm$$

Take effective cover = 40 mm

Assume D = 430

d=390

$$p' = \frac{A_{st}}{bd} = \frac{f_{ck}}{2f_y}\left[1 - \sqrt{1 - \frac{4.598R}{f_{ck}}}\right]; \qquad R = \frac{M_u}{bd^2} = \frac{120 \times 10^6}{300 \times 390^2} = 2.63$$

$$= \frac{20}{2 \times 415}\left[1 - \sqrt{1 - \frac{4.598 \times 2.63}{20}}\right] = 0.0089$$

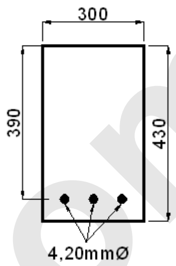
$$p'_{limit} = 0.414 \frac{f_{ck}}{f_y} . \frac{x_{umax}}{d}$$

$$= 0.419 \times \frac{20}{415} \times 0.48 = 0.0095$$

$$minimum\ reinforcement = \frac{0.85}{f_y} = \frac{0.85}{415} = 0.002$$

Provide A_{st} = 0.0089 x 300 x 390 = 1040 mm^2

Provide 4 nos 20mmΦbars; A_{st} provided = 1256mm^2



2. Determine the moment of resistance of a rectangular beam b=600mm , D=650mm A_{st}=804mm^2 , M20, Fe250

5. Given:-

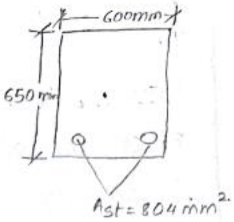
$b = 600\ mm$

$D = 650\ mm$

$A_{st} = 804\ mm^2$

M20 concrete $\Rightarrow F_{ck} = 20\ N/mm^2$

Fe 250 $\Rightarrow F_y = 250\ N/mm^2$



Assume effective cover = 50 mm

$\therefore d = D - 50 = 650 - 50 = \underline{\underline{600\ mm}}$

1) Determine neutral axis depth

$$\frac{x_u}{d} = \frac{0.87 F_y A_{st}}{0.36\, b d f_{ck}}$$

$$= \frac{0.87 \times 250 \times 804}{0.36 \times 600 \times 600 \times 20} = \underline{\underline{0.067}}$$

2) Determine Limiting neutral axis depth

For Fe 250, $\frac{x_{u\,max}}{d} = 0.53$ [Cl: 38.1, IS 456 : 2000]

$$\frac{x_u}{d} < \frac{x_{u\,max}}{d}$$

$\therefore$ It is under reinforced

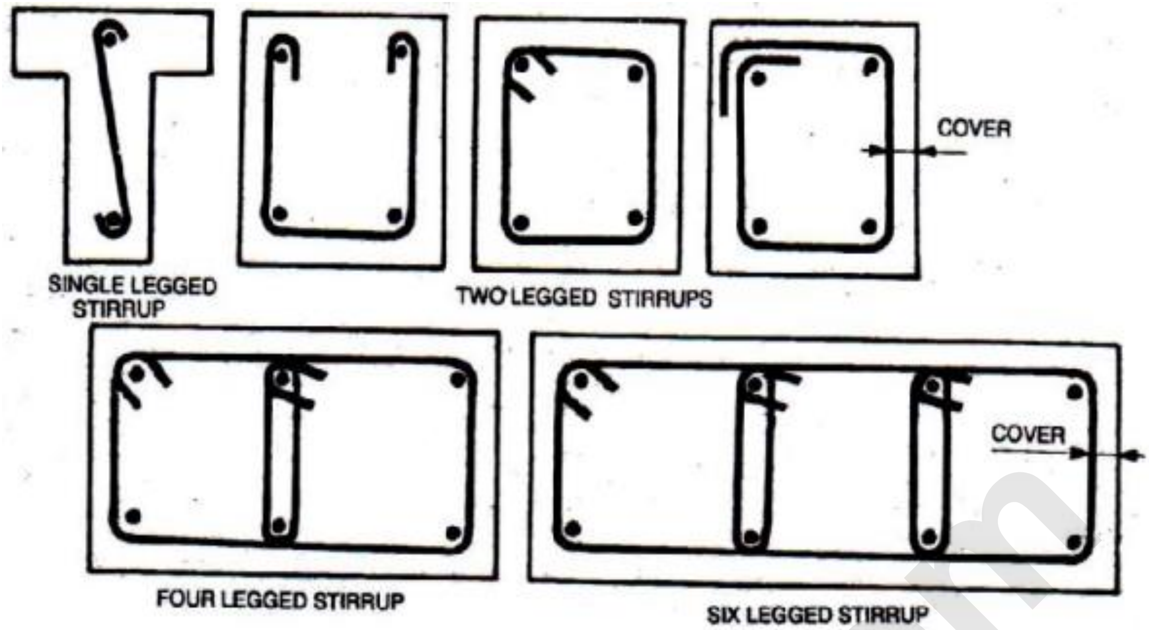
3) Determine Moment of Resistance.

$$MR = M_u = 0.87 F_y A_{st}\, d \left(1 - \frac{A_{st} F_y}{b d F_{ck}}\right)$$

$$= 0.87 \times 250 \times 804 \times 600 \times \left(1 - \frac{804 \times 250}{600 \times 600 \times 20}\right)$$

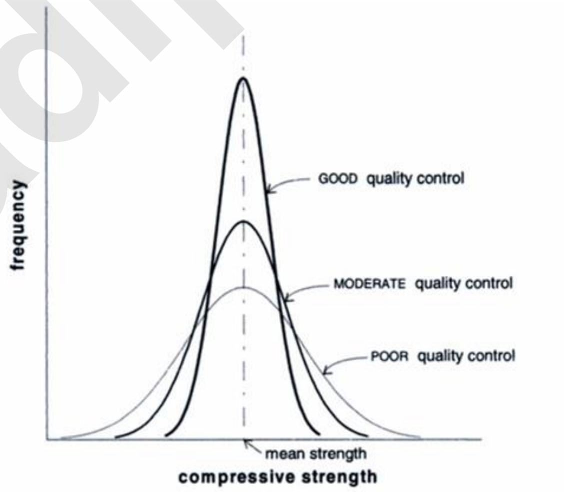
$$= 101.99 \times 10^6\ Nmm = \underline{\underline{101.99\ kNm}}$$

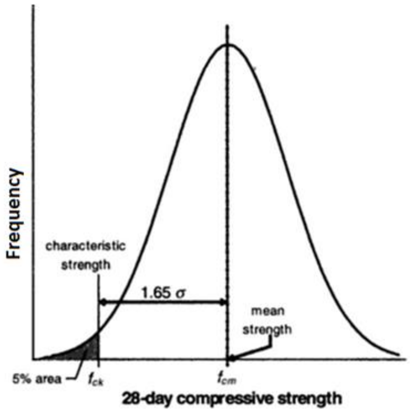
3. Explain the various types of shear reinforcement used with sketches.



5. Define characteristic strength and characteristic load

Characteristic Compressive Strength [cl 6.1.1.IS456] –'Defined as the compressive strength of concrete below which not more than 5% of test results are expected to fall'150mm cube specimen at 28 days. Cube specimen from same mix gives different values due to non homogeneous nature of concrete. Variability depends on the degree of quality control. Idealised Distribution of the values of compressive strength for no. of cubes





The Characteristic strength f_{ck} is the value in the x axis below which 5% of the total area under the curve falls

6. **Discuss the procedure for shear design**

Nominal shear is taken as a magnitude of diagonal tension which causes cracking of concrete

Nominal shear stress,

$$\tau_v = \frac{V_u}{bd}$$

where, Vu: ultimate (design) shear force

b:breadth

d:effective depth

Design shear strength

The resistance of RC beams to diagonal tension failure depends upon two factors

- Grade of concrete
- Percentage of tension steel in the beam

- Table 19, IS 456:2000 give the ultimate allowable shear stress, τ_c
- Which is function of percentage of tension steel and grade of concrete

The area of tension steel at a section to be taken into account is the area of steel which continues through the section

All beams where shear τ_v exceeds the allowable values given Table 19 τ_c ; shear reinforcement should be provided

As shear failure are sudden and brittle, all important structures with shear stress even less than safe values should be provided with minimum shear reinforcement

- Cl. 26.5. 1.6

- There is a limit to the maximum shear stress value for which the beam can be strengthened by shear reinforcement
- Beyond these values, diagonal compression can take over even if the diagonal tension is taken care of by steel reinforcement
- Under no circumstances should exceed
- Else, the section should be redesigned by changing the values of b and d

b) Procedure for shear design:-

According to the limit state of shear, a section is designed for it's serviceability at working load and safety at ultimate load. The procedure is as follows.

For a rectangular beam of width 'b' mm and eff. depth 'd' and area of steel 'Ast'.

1. Evaluate the nominal shear stress:-

The nominal shear stress is the stress introduced due to ext. loading on the beam. As per IS 456-2000, cl. 40.1, the nominal shear stress in beams of uni. depth shall be obtained by the following equation,

$$\tau_v = \frac{V_u}{bd}$$; V_u = shear force due to design loads

b = Breadth of the member

$$\tau_v = \frac{V_u \pm \frac{M_u}{d}\tan\beta}{bd}$$ (For vary depth) d = eff. depth.

2. Evaluate the τ_c value:-

From table 19, the value of design shear strength in N/mm² can be find out for a given percentage of steel and grade of concrete. The value of τ_c depends on $\frac{100\,Ast}{bd}$ and grade of concrete.

3. Determine the $\tau_{c\,max}$:-

The $\tau_{c\,max}$, max. shear stress can be found out from table 20. It depends only on grade of concrete.

4. Comparing the τ_c, τ_v & $\tau_{c\,max}$ value:-

If $\tau_v > \tau_{c\,max}$; The structure has to be redesigned. In no case the τ_v value should ~~greate~~ exceed the $\tau_{c\,max}$ value.

If. $\tau_v \geq \tau_c$ ⇒ The shear reinforcement has to be provided.

$\tau_v < \tau_c$ ⇒ No need of shear reinforcement. But a min. shear reinforcement is provided, ~~theoretically~~ to avoid the sudden brittle failure of concrete.

5. If $\tau_v > \tau_c$, the shear reinforcement can be provided as vertical stirrups, inclined stirrups or bent up stirrups.

→ Shear reinforcement shall be provided to carry a shear equal to $V_u - \tau_c \cdot bd$. The strength of shear reinforcement V_{us} shall be calculated as below [from cl (40.4)]

(i) For vertical stirrups: $V_{us} = \dfrac{0.87\, f_y \cdot A_{sv} \cdot d}{S_v}$

inclined stirrups: $V_{us} = \dfrac{0.87\, f_y \cdot A_{sv} \cdot d}{S_v} (\sin\alpha + \cos\alpha)$

Bent-up bars: $V_{us} = 0.87\, f_y\, A_{sv} \sin\alpha$

6. And the spacing should be provided according to cl [26.5.1.5 & 26.5.1.6]

→ The max. spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75d for vertical stirrups and d for inclined stirrups.

→ The min. shear reinforcement in the form of stirrups shall be provided such that,

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