Chapter 1

Concrete Technology

One-mark Questions

1. In shear design of an RC beam, other than the allowable shear strength of concrete ($c\ \tau$), there is also an additional check suggested in IS 456-2000 with respect to the maximum permissible shear stress (τ_{cmax}) . The check for τ_{cmax} is required to take care of **[2016]**

(a) additional shear resistance from reinforcing steel
(b) additional shear stress that comes from accidental loading
(c) possibility of failure of concrete by diagonal tension
(d) possibility of crushing of concrete by diagonal compression

Solution: (d)
Hence, the correct option is (d).

2. The compound which is largely responsible for initial setting and early strength gain of Ordinary Portland Cement is **[2016]**

(a) C_3A (b) C_3S
(c) C_2S (d) C_4AF

Solution: (b)
Hence, the correct option is (b).

3. Workability of concrete can be measured using slump, compaction factor and Vebe time. Consider the following statements for workability of concrete: **[2015]**

(i) As the slump increases, the Vebe time increases.
(ii) As the slump increases, the compaction factor increases.

Which of the following is TRUE?
(a) Both (i) and (ii) are True
(b) Both (i) and (ii) are False
(c) (i) is True and (ii) is False
(d) (i) is False and (ii) is True

Solution: (d)
Verbe time, the time to flow in vibration in verbee consistometer
So, as slump (flow) increases, time for flow decreases.
Hence, the correct option is (d).

4. Consider the following statements for air-entrained concrete: **[2015]**

(i) Air-entrainment reduces the water demand for a given level of workability.
(ii) Use of air-entrained concrete is required in environments where cyclic freezing and thawing is expected

Which of the following is TRUE?
(a) Both (i) and (ii) are True
(b) Both (i) and (ii) are False
(c) (i) is True and (ii) is False
(d) (i) is False and (ii) is True

Solution: (a)
Air entraining agents incorporate millions of air bubbles, which will act as flexible ball bearings and modify properties of concrete regarding workability, segregation, bleeding and finishing quality of concrete and even reduces water content.
It also modifies the properties of hardened concrete regarding resistance to feast action and permeability.
Hence, the correct option is (a).

5. The flexural strength of M 30 concrete as per IS : 456-2000 is **[2005]**
(a) 3.83 MPa (b) 5.47 MPa
(c) 21.23 MPa (d) 30.0 MPa

Solution: (a)
Flexural strength of concrete, $f_{cr} = 0.7\sqrt{f_{ck}}$

For M 30 grade concrete, f_{ck} = 30 N/mm^2

$$f_{cr} = 0.7\sqrt{30} = 3.83\,\text{N/mm}^2$$

Hence, the correct option is (a).

6. Group I contains some properties of concrete/cement and Group II contains list of some tests on concrete/cement. Match the property with the corresponding test. **[2003]**

Group I	Group II
P. Workability of concrete	1. Cylinder splitting test
Q. Direct tensile strength of concrete	2. Vee-Bee test
R. Bond between concrete and steel	3. Surface area test
S. Fineness of cement	4. Fineness modulus test
	5. Pull out test

(a) P: 2; Q: 1; R: 5; S: 3
(b) P: 4; Q: 5; R: 1; S: 3
(c) P: 2; Q: 1; R: 5; S: 4
(d) P: 2; Q: 5; R:1; S: 4

Solution: (a)

Property of concrete/cement	Test on concrete/cement
Workability of concrete	Slump cone test, Compaction factor test, Vee-Bee test
Direct tensile strength of concrete	Cylinder splitting test
Bond between concrete and steel	Pull out test
Fineness of cement	Surface area test

Hence, the correct option is (a).

7. As per the provisions of IS 456-2000, the (short term) modulus of elasticity of M 25 grade concrete (in N/mm^2) can be assumed to be **[2002]**
(a) 25000 (b) 28500
(c) 3000 (d) 36000

Solution: (a)
Modulus of elasticity of concrete,

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

For M 25 grade concrete, f_{ck} = 25 N/mm^2,
E_c =5000 × $\sqrt{25}$ = 25,000 N/mm^2
Hence, the correct option is (a).

8. The cylinder strength of the concrete is less than the cube strength because of **[1997]**
(a) the difference in the shape of the cross section of the specimens
(b) the difference in the slenderness ratio of the specimens
(c) the friction between the concrete specimens and the steel plate of the testing machine
(d) the cubes are tested without capping but the cylinders are tested with capping.

Solution: (b)
The cylinder strength of concrete is less than the cube strength because of the difference in the slenderness ratio of the specimens.
Hence, the correct option is (b).

9. The modulus of rupture of concrete gives **[1995]**
(a) the direct tensile strength of the concrete
(b) the direct compressive strength of the concrete
(c) the tensile strength of the concrete under bending
(d) the characteristic strength of the concrete

Solution: (c)
Modulus of rupture of concrete, $f_{cr} = 0.7\sqrt{f_{ck}}$
f_{ck}: Characteristic strength of concrete, N/mm^2
The modulus of rupture of concrete gives the tensile strength of concrete under bending
Hence, the correct option is (c).

Two-marks Questions

1. The composition of an air-entrained concrete is given below: **[2015]**

Water : 184 kg/m^3
Ordinary Portland Cement (OPC) : 368 kg/m^3
Sand : 606 kg/m^3
Coarse aggregate : 1155 kg/m^3

Assume the specific gravity of OPC, sand and coarse aggregate to be 3.14, 2.67 and 2.74, respectively. The air content is ______ liters/m^3.

Solution: 51

We know,

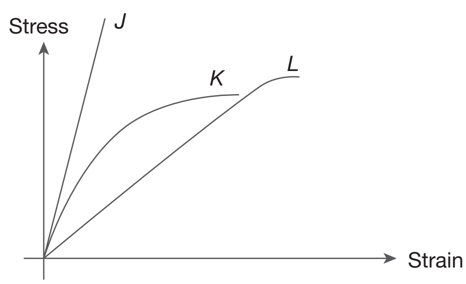
$$\frac{M_C}{e_C}+\frac{M_W}{e_W}+\frac{M_{FA}}{e_{FA}}+\frac{M_{CA}}{e_{CA}}+V_w+V_a=1$$

$$\frac{368}{3140}+\frac{184}{1000}+\frac{606}{2670}+\frac{1155}{2740}+\frac{V_v}{1000}=1$$

$$V_v = 51 \text{ litres/m}^3$$

Hence, the answer is 51.

2. Group I contains representative stress-strain curves as shown in the figure, while Group II gives the list of materials. Match the stress-strain curves with the corresponding materials. **[2014]**

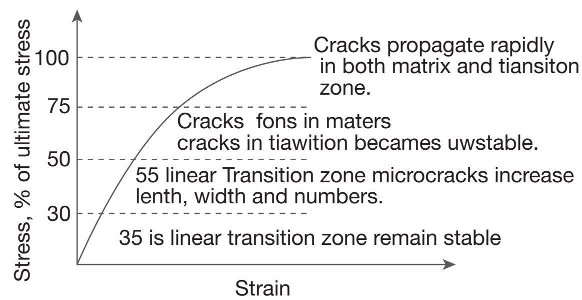


Group I	Group II
P. Curve J	1. Cement paste
Q. Curve K	2. Coarse aggregate
R. Curve L	3. Concrete

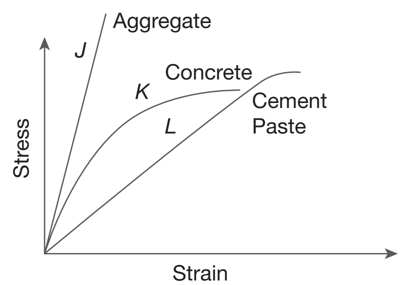
(a) P: 1; Q: 3; R: 2 (b) P: 2; Q: 3; R: 1
(c) P: 3; Q: 1; R: 2 (d) P: 3; Q: 2; R: 1

Solution: (b)

A typical relationship between stress and strain for normal strength concrete, which is a combination of aggregate and cement paste together shows a non linear relationship is shown in fig. After an initial linear portion lasting up to 30–40% of the ultimate load, the curve becomes non linear with large strains registered for small increments of stress. The non-linearity is primarily a function of the coalescence of micro-cracks at the paste-aggregate interface. The ultimate stress is reached when large crack network is formed within the concrete consisting of coalesced micro cracks and the cracks in the cement paste matrix. The strain corresponding to ultimate stress is 0.003 for normal strength concrete. The stress strain behavior in tension is similar to that in compression.



Stress strain curve for concete



The stress-strain relationship of aggregate alone and cement paste alone shows a fairly good straight line. The rate of increase of strain in aggregate is less than that in cement paste.

Hence, the correct option is (b).

3. Maximum possible value of compacting factor for fresh (green) concrete is **[2013]**

(a) 0.5 (b) 1.0
(c) 1.5 (d) 2.0

Solution: (b)

$$\text{Compaction factor} = \frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}} \le 1.0$$

Therefore, the maximum value of compacting factor for fresh concrete is 1.0.

Compaction factor is defined as the ratio of the density actually achieved in the test to the density of same concrete fully compacted. Its value is always less than 1.0.

Therefore, the maximum value of compacting factor of fresh concrete is 1.0.

Hence, the correct option is (b).

4. The creep strains are **[2013]**
   (a) caused due to dead loads only
   (b) caused due to live loads only
   (c) caused due to cyclic loads only
   (d) independent of loads.

   Solution: (a)
   Creep strains are caused due to dead loads only.
   The progressive inelastic strains due to creep in a concrete member are likely to occur under the sustained loads at ambient temperature.
   Hence, the correct option is (a).

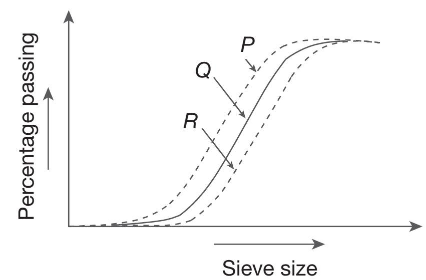
5. Consider a reinforcing bar embedded in concrete. In a marine environment this bar undergoes uniform corrosion which leads to the deposition of corrosion products on its surface and an increase in the apparent volume of the bar. This subjects the surrounding concrete to expansive pressure. As a result, corrosion induced cracks appear at the surface of concrete. Which of the following statements is TRUE? **[2011]**
   (a) Corrosion causes circumferential tensile stresses in concrete and the cracks will be parallel to the corroded reinforcing bar.
   (b) Corrosion causes radial tensile stresses in concrete and the cracks will be parallel to the corroded reinforcing bar.
   (c) Corrosion causes circumferential tensile stresses in concrete and the cracks will be perpendicular to the direction of the corroded reinforcing bar.
   (d) Corrosion causes radial tensile stresses in concrete and the cracks will be perpendicular to the direction of the corroded reinforcing bar. **[2011]**

   Solution: (c)
   The products of corrosion occupy a volume as much as six times the original volume of steel depending upon the oxidation rate. The increased volume of rust exerts thrust on concrete resulting in cracks, spalling or delamination of concrete.

   The concrete loses its integrity. It causes circumferential tensile stresses in concrete and the cracks will be perpendicular to the direction of the corroded reinforcing bar.

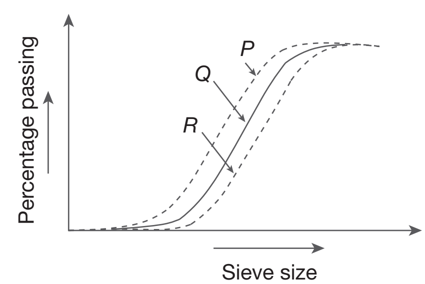
   Hence, the correct option is (c).

6. The results for sieve analysis carried out for three types of sand P, Q and R, are given in the adjoining figure. If the fineness modulus values of the three sands are given as FM_P, FM_Q and FM_R, it can be stated that **[2011]**



   (a) $FM_Q = \sqrt{FM_P \times FM_R}$
   (b) $FM_Q = 0.5\,(FM_P + FM_R)$
   (c) $FM_P > FM_Q > FM_R$
   (d) $FM_P < FM_Q < FM_R$

   Solution: (d)



   As per the fig, for the same percentage passing, the size of material is large in R than P.

   For a given sieve size, the percentage passing through is more for P than for R. Therefore the percentage retained is less in P than in R.

   Hence, the fineness modulus is less for P than for R.

$$FM_P < FM_Q < FM_R$$

   Hence, the correct option is (d).

7. The cross section of a thermo-mechanically treated (TMT) reinforcing bar has **[2011]**
   (a) soft ferrite-pearlite throughout
   (b) hard martensitic throughout
   (c) a soft ferrite-pearlite core with a hard martensitic rim
   (d) a hard martensitic core with a soft pearlite-bainitic rim.

Solution: (c)
The cross section of a thermo mechanically treated (TMT) reinforcing bar has a soft ferrite-pearlite core with a hard martensitic rim.
Hence, the correct option is (c).

8. The modulus of rupture of concrete in terms of its characteristic cube compressive strength (f_{ck}) in MPa according to IS 456:2000 is **[2009]**
(a) $5000 f_{ck}$ (b) $0.7 f_{ck}$
(c) $5000\sqrt{f_{ck}}$ (d) $0.7\sqrt{f_{ck}}$

Solution: (d)
f_{cr}: Modulus of rupture , MPa
f_{ck}: Characteristic strength of concrete, MPa

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

Hence, the correct option is (d).

9. Column I gives a list of test methods for evaluation properties of concrete and Column II gives the list of properties **[2009]**

Column I	Column II
P. Resonant frequency test	1. Tensile strength
Q. Rebound hammer test	2. Dynamic modulus of elasticity
R. Split cylinder test	3. Workability
S. Compacting factor test	4. Compressive strength

The correct match of the test with the property is
(a) P: 2; Q: 4; R: 1; S: 3
(b) P: 2; Q: 1; R: 4; S: 3
(c) P: 2; Q: 4; R: 3; S: 1
(d) P: 4; Q: 3; R: 1; S: 2

Solution: (a)

Methods for evaluation properties of concrete	Properties
Resonant frequency test	Dynamic modulus of elasticity
Rebound hammer test	Compressive strength
Split cylinder test	Tensile strength
Compacting factor test	Workability

Hence, the correct option is (a).

10. A reinforced concrete structure has to be constructed along a sea coast. The minimum grade of concrete to be used as per IS : 456-2000 is **[2008]**
(a) M 15 (b) M 20
(c) M 25 (d) M 30

Solution: (d)
As per the tables 3 and 5 of IS:456-2000, the minimum grade of concrete for reinforced concrete structures exposed to coastal environment is M 30. Concrete exposed to coastal environment comes under severe environmental condition.
Hence, the correct option is (d).

11. Consider the following statements:
I. The compressive strength of concrete decreases with increase in water-cement ratio of the concrete mix.
II. Water is added to the concrete mix for hydration of cement and workability.
III. Creep and shrinkage of concrete are independent of the water-cement ratio in the concrete mix.
The true statements are **[2007]**
(a) I and II (b) I, II and III
(c) II and III (d) Only II

Solution: (a)
The compressive strength of concrete decrease with increase in water cement ratio.
Water is added to the concrete mix for hydration of cement and workability.
Hence, the correct option is (a).

12. Consider the following statements :
I. Modulus of elasticity of concrete increases with increase in compressive strength of concrete.
II. Brittleness of concrete increases with decrease in compressive strength of concrete.
III. Shear strength of concrete increases with increase in compressive strength of concrete.
The **TRUE** statements are **[2007]**
(a) II and III (b) I, II and III
(c) I and II (d) I and III

Solution: (b)
Modulus of elasticity of concrete increases with increase in compressive strength of concrete.

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

f_{ck}: Characteristic cube compressive strength of concrete in N/mm^2

E_c: Short term static modulus of elasticity of concrete in N/mm^2

Brittleness of concrete increases with decrease in compressive strength of concrete due to less adhesion of the constituent materials.

Shear strength of concrete increases with increase in compressive strength of concrete.

Hence, the correct option is (b).

Chapter 2

Working Stress Method of Design

Two-marks Questions

1. A reinforced concrete (RC) beam with width of 250 mm and effective depth of 400 mm is reinforced with Fe415 steel. As per the provisions of IS 456-2000, the minimum and maximum amount of tensile reinforcement (expressed in mm^2) for the section are, respectively **[2016]**

(a) 250 and 3500 (b) 205 and 4000
(c) 270 and 2000 (d) 300 and 2500

Solution: (b)
Given:
Width of beam (b) = 250 mm
Effective depth (d) = 400 mm
As per IS-456:200
From clause 26.5.1.1 (a)
Minimum tension reinforcement

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

$$A_s = \frac{0.85bd}{f_y} = \frac{0.85 \times 250 \times 400}{4.15}$$

$$= 204.819 \cong 205 \text{ mm}^2$$

From clause 26.5.1.2(b)
Maximum tension reinforcement = 0.04bd = 0.04 $\times$ 250 $\times$ 400 = 4000 mm^2
Hence, the correct option is (b).

2. A reinforced concrete column contains longitudinal steel equal to 1 percent of net cross-sectional area of the column. Assume modular ratio as 10, the loads carried (using the elastic theory) by the longitudinal steel and the net area of concrete, are P_s and P_c respectively. The ratio P_s/P_c expressed as percent is **[2008]**

(a) 0.1 (b) 1
(c) 1.1 (d) 10

Solution: (d)
A: Cross sectional area of column
A_s: Area of steel reinforcement
A_c: Area of concrete
Modular ratio, $m = 10$
Stress in steel = $\sigma_s = m\sigma_c$
σ_c: Stress in concrete
P_s: Load carried by longitudinal steel
P_c: Load carried by the concrete

$$\frac{P_s}{P_c} = \frac{\sigma_s A_s}{\sigma_c A_c} = \frac{m\sigma_c}{\sigma_c}\frac{A_s}{A_c} = m\frac{A_s}{A_c}$$

A_s: 1% of net cross sectional area column = 0.01 A_c

$$\frac{P_s}{P_c} = 10 \times 0.01 = 0.1 = 10\%$$

Hence, the correct option is (d).

3. As per IS:456-2000, consider the following statements

I. The modular ratio considered in the working stress method depends on the type of steel used.

II. There is an upper limit on the nominal shear stress in beams (even with shear Reinforcement) due to the possibility of crushing of concrete in diagonal compression.

III. A rectangular slab whose length is equal to its width may not be a two-way slab for some support conditions.

The TRUE statements are **[2006]**

(a) only I and II (b) only II and III
(c) only I and III (d) II and III

Solution: (b)
Modular ratio,

$$m = \frac{280}{3\sigma_{abc}}$$

σ_{cbc}: Permissible compressive stress due to bending in concrete in N/mm^2.

$\tau_v \neq \tau_{c,max}$, Nominal shear stress in beams (even with shear reinforcement) should not be more than the maximum shear stress ($\tau_{c,max}$).

A slab supported on all its edges with ratio of longer side to shorter side is less than or equal to 2, it is termed as two way slab.
Hence, the correct option is (b).

4. The working stress method of design specifies the value of modular ratio, $m = 280/(3\sigma_{cbc})$, where σ_{cbc} is the allowable stress in bending compression in concrete. To what extent does the above value of m make any allowance for the creep of concrete? **[2003]**

(a) No compensation
(b) Full compensation
(c) Partial compression
(d) The two are unrelated

Solution: (c)
Modular ratio,

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

σ_{cbc}: Allowable stress in bending compression.

The expression given form partially takes into account long term effects such as creep. Therefore, m is not the same as the modular ratio obtained based on the value of $E_c = 5700\sqrt{f_{ck}}$

f_{ck}: Characteristic cube strength of concrete is N/mm^2
Hence, the correct option is (c).

5. Top ring beam of an Intze tank carries a hoop tension of 120 kN. The beam cross-section is 250 mm wide and 400 mm deep and it is reinforced with 4 bars of 20 mm diameter of Fe 415 grade. Modular ratio of the concrete is 10. The tensile stress in N/mm^2 in the concrete is **[2003]**

(a) 1.02 (b) 1.07
(c) 1.20 (d) 1.32

Solution: (b)
Hoop tension in ring beam, T = 120 kN
Cross section of ring beam = 250 × 400 mm
Area of tensile steel reinforcement,

$$A_{st} = 4 \times 314 = 1256\,\text{mm}^2$$

Modular ratio, m = 10
For Fe 415 grade steel, $f_y = 415\,\text{N/mm}^2$

Tensile stress in concrete,

$$\sigma_t = \frac{T}{bd + (m-1)A_{st}}$$

$$\sigma_t = \frac{120 \times 10^3}{250 \times 400 + (10-1)1256} = 1.07\ \text{N/mm}^2$$

Hence, the correct option is (b).

6. Permissible bending tensile stress in high yield strength deformed bars of grade 415 N/mm^2 in a beam is **[1997]**

(a) 190 N/mm^2 b. 230 N/mm^2
(c) 140 N/mm^2 d. None of the above

Solution: (b)
Permissible tensile stresses in steel reinforcement

HYSD bars	230 N/mm^2
Mild steel	230 N/mm^2 ($\phi \leq 20$ mm) 230 N/mm^2 ($\phi \geq 20$ mm)

Hence, the correct option is (b).

7. If ϕ = nominal diameter of reinforcing bar, f_s = compressive stress in the bar and f_{bd} design bond stress of concrete, the anchorage length L_a of straight bar in compression is equal to **[1996]**

(a) $L_a = \dfrac{\phi f_s}{f_{bd}}$ (b) $L_a = \dfrac{\phi f_s}{2 f_{bd}}$

(c) $L_a = \dfrac{\phi f_s}{\pi f_{bd}}$ (d) $L_a = \dfrac{\phi f_s}{4 f_{bd}}$

Solution: (d)

ϕ: Nominal diameter of reinforcing bar

f_s: Compressive stress in the bar

τ_{bd}: Design bond stress of concrete

L_d: Anchorage length

$$L_d = \frac{\phi f_s}{4\tau_{bd}}$$

Hence, the correct option is (d).

8. Axial load carrying capacity of a *RC* column of gross area of concrete A_c, area of steel A_s, and permissible stresses σ_c in concrete and σ_c in steel, m-modular ratio is given as **[1991]**

(a) $\sigma_c A_c + (m-1)\sigma_s A_s$ (b) $\sigma_s A_s + m\sigma_c A_c$

(c) $\sigma_s A_s + \sigma_c A_c$ (d) $\sigma_c (A_c - A_s) + \sigma_s A_s$

Solution: (d)

A_c: Gross area of concrete

A_s: Area of steel reinforcement

σ_c: Permissible stress in concrete

σ_s: Permissible stress in steel

m: Modular ratio

P: Axial load carrying capacity of column

$$= \sigma_{cc} A_c + \sigma_{sc} A_{sc}$$
$$= \sigma_c (A_c - A_s) + \sigma_s A_s$$

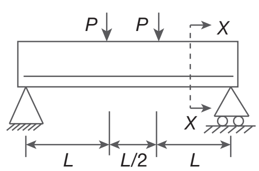
Hence, the correct option is (d).

Chapter 3

Limit State Method of Design

One-mark Questions

1. Consider the singly reinforced beam shown in the figure below: **[2015]**



At cross-section *XX*, which of the following statements is TRUE at the limit state?

(a) The variation of stress is linear and that of strain is non-linear

(b) The variation of strain is linear and that of stress is non-linear

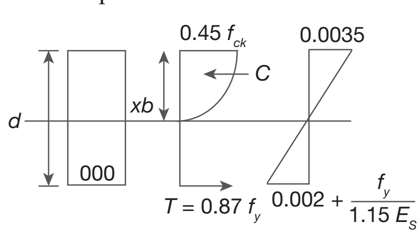
(c) The variation of both stress and strain is linear

(d) The variation of both stress and strain is non-linear

Solution: (b)

For limit state,

stress block parameters



Stress block

stress → non-linear

strain → liner

Hence, the correct option is (b).

2. A column of size 450 mm × 600 mm has unsupported length of 3.0 m and is braced against side sway in both directions. According to IS 456: 2000, the minimum eccentricities (in mm) with respect to major and minor principle axes are: **[2015]**

(a) 20.0 and 20.0 (b) 26.0 and 21.0

(c) 26.0 and 20.0 (d) 21.0 and 15.0

Solution: (a)

$$e_{min} = 20 \text{ mm}$$

$$= \frac{L}{500} + \frac{D}{30}\}\text{least value}$$

$$e_{yy} = \frac{3000}{500} + \frac{450}{30} = 21 \text{ mm}$$

$$e_{xx} = \frac{3000}{500} + \frac{600}{30} = 26 \text{ mm}$$

$\therefore \quad e_{min} = 20$ mm w.r.t

Both principal axes

Hence, the correct option is (b).

3. While designing for a steel column of Fe250 grade, a base plate resting on a concrete pedestal of M20 grade, the bearing strength of concrete (in N/mm^2) in limit state method of design as per IS 456: 2000 is ____________. **[2014]**

Solution: 9

As per IS: 456:2000, the permissible bearing stress

$$= 0.45 f_{ck}$$

$$= 0.45 \times 20 = 9 \text{ N/mm}^2$$

Hence, the answer is 9.

4. IS 456-1978 recommends to provide certain minimum steel in a RCC beam **[1997]**

(a) to ensure compression failure

(b) to avoid rupture of steel in case a flexural failure occurs

(c) to hold the stirrup steel in position

(d) to provide enough ductility to the beam

Solution: (d)

IS: 456 recommend certain minimum steel in a RCC beam to provide enough ductility to the beam.

Hence, the correct option is (d).

5. The span to depth ratio limit is specified in IS: 456-1978 for the reinforced concrete beams, in order to ensure that the **[1996]**

(a) tensile crack width is below a limit

(b) shear failure is avoided

(c) stress in the tension reinforcement is less than the allowable value

(d) deflection of the beam is below a limiting value

Solution: (d)

As per IS:456, the span to depth ratio is specified for reinforced concrete beams to ensure that the deflection of the beam is below a limiting value.

Hence, the correct option is (d).

6. The effective width of a reinforced concrete T-beam flange under compression, according to IS:456-1978, given l_0 is the distance between the adjacent zero moment points, b is the breadth of the rib and D is the thickness of the flange, is **[1995]**

(a) $\frac{l_0}{6} + B + 6D$ (b) $l_0 + 6D$

(c) $\frac{l}{6} + 6D$ (d) $\frac{l_0}{6} + b$

Solution: (a)

D: Thickness of floor slab

b: Width of the beam

l_0: Effective span

b_f: Effective width of slab

$$= \frac{L_0}{6} + b_w + 6t$$

Hence, the correct option is (a).

7. Which one of the following set of values give the minimum clear cover (in mm) for the main reinforcements in the slab, beam, column and footing respectively, according to IS:456-1978? **[1995]**

(a) 20, 25, 30, 75 (b) 5, 15, 25, 50

(c) 15, 25, 40, 75 (d) None of these

Solution: (c)

Structural element	Minimum clear cover
Slab	15 mm
Beam	25 mm
Column	40 mm
Footing	75 mm

Hence, the correct option is (c).

8. In a reinforced concrete beam column, the increase in the flexural strength along with the increase in the axial strength occurs **[1995]**

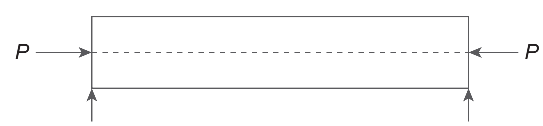
(a) beyond the elastic limit of the material

(b) when the yielding of the tension reinforcement governs the strength

(c) when the crushing of the concrete in the compression zone governs the strength

(d) never

Solution: (b)



σ_t: Stress induced at top of the beam $= \frac{P}{A} + \frac{M}{Z_t}$ (compressive)

σ_b: Stress induced at bottom of the beam $= \frac{P}{A} - \frac{M}{Z_t}$ (tensile)

The concrete is strong in compression and extremely weak in tension. As the axial compressive strength increases, the resultant compressive stress increases across the cross section. With further increase of flexural strength, compressive stress increases at top fibre and increases the tensile stress (decreases the compressive stress) at bottom fibre till the yielding of the tension reinforcement.

Hence, the correct option is (b).

9. The factored loads at the limit state of collapse for $DL+LL, DL+WL$ and $DL+LL+WL$ combinations, according to IS:456-1978 are respectively **[1993]**

(a) $1.5DL+1.5LL, 1.2DL+1.2WL, 1.5DL+1.5LL+1.5WL$

(b) $(0.9\,\text{or}\,1.5)DL+1.5LL, 1.5DL+1.5WL, 1.2DL+1.2LL+1.2WL$

(c) $1.2DL+1.2LL, 1.2DL+1.5WL, 1.5DL+1.5LL+1.5WL$

(d) $1.5DL+1.5LL, (0.9\,\text{or}\,1.5)DL+1.5WL, 1.2DL+1.2LL+1.2WL$

Solution: (d)

According to IS: 456, the partial safety factors for loads is shown in table.

S.No.	Load combination	Partial factor of safety			
		DL	**LL**	**WL**	**EL**
1	$DL+LL$	1.5	1.5	–	–
2	$DL+WL$	1.5 or 0.9	–	1.5	–
3	$DL+LL+WL$	1.2	1.2	1.2	–
4	$DL+LL+EL$	1.2	1.2	–	1.2

Hence, the correct option is (d).

10. A floor slab of thickness t is cast monolithically transverse to a rectangular continuous beam of span L and width B. If the distance between two consecutive points of contraflexure is L_0, the effective width of compression flange at a continuous support is **[1992]**

(a) B (b) $L/3$
(c) $B + 12t$ (d) $B + 6t + L_0/6$

Solution: (d)

t: Thickness of floor slab
L: Span of the beam
B: Width of the beam
L_0: Effective span
b_f: Effective width of slab

$$= \frac{L_0}{6} + b_w + 6t$$

Hence, the correct option is (d).

11. A reinforced concrete member is subjected to combined action of compressive axial force and bending moment. If ε_c is the least compressive strain in the member, f_y, the yield stress of steel and, E_s, the modulus of elasticity of steel, the maximum permissible compressive strain in concrete member will be **[1992]**

(a) 0.002 (b) $0.002 + \dfrac{f_y}{1.15E_s}$
(c) $0.0035 - 0.75\,\varepsilon_c$ (d) 0.0035

Solution: (c)

ε_c: Least compressive strain in the member
f_y: Yield stress of steel
E_s: Modulus of elasticity of steel
$\varepsilon_{c,max}$: Maximum compressive strain in concrete member

As per IS: 456-2000, the maximum compressive strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending and when there is no tension on the section shall be 0.0035 minus 0.75 times the strain at the least compressed extreme fibre.

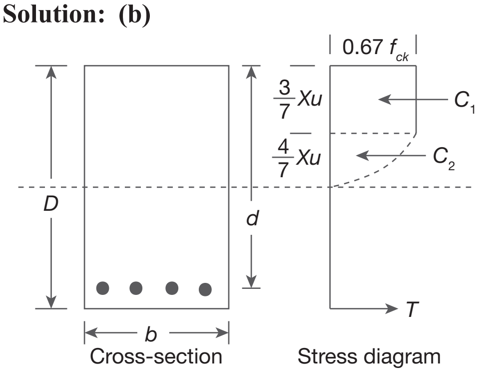
Hence, the correct option is (c).

12. The total compressive force at the time of failure of a concrete beam section of width b without considering the partial safety factor of the material is **[1991]**

Where, x_u is depth of neutral axis, f_{ck} is cube strength of concrete.

(a) $0.36 f_{ck}bx_u$ (b) $0.54 f_{ck}bx_u$
(c) $0.66 f_{ck}bx_u$ (d) $0.80 f_{ck}bx_u$

Solution: (b)



Total compressive force, $C = C_1 + C_2$
= Area of stress block × width of beam

$$= 0.67 f_{ck}\frac{3}{7}x_u b + \frac{2}{3}\times 0.67 f_{ck}\frac{4}{7}x_u b$$

$$= 0.2871 f_{ck}bx_u + 0.255 f_{ck}bx_u$$

$$C = 0.542 f_{ck}bx_u$$

Hence, the correct option is (b).

TWO-MARKS QUESTIONS

1. For M 25 concrete with creep coefficient of 1.5, the long-term static modulus of elasticity (expressed in MPa) as per the provisions of IS:456-2000 is ________. **[2016]**

Solution: 10000

Long term elasticity $= \dfrac{E_c}{1+\theta}$

1 + 6

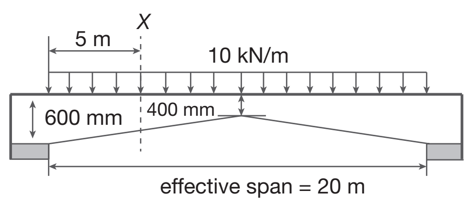
$$E_c = 5000\sqrt{f_{ck}}$$
$$= 5000\sqrt{25}$$
$$= 500 \times 5$$
$$= 25000$$

Creep coefficient (θ) = 1.5

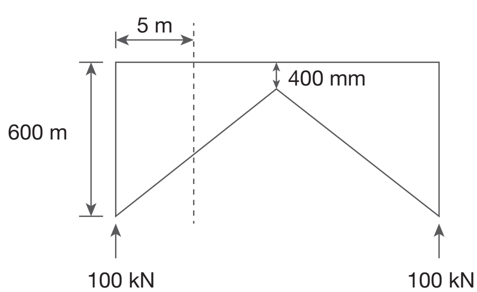
Long-term elasticity $= \dfrac{25000}{1+1.5} = 10,000$

Hence, the answer is 10000.

2. A haunched (varying depth) reinforced concrete beam is simply supported at both ends, as shown in the figure. The beam is subjected to a uniformly distributed factored load of intensity 10 kN/m. The design shear force (expressed in kN) at the section *X-X* of the beam is ________. **[2016]**



Solution: 65



$$\tau_v = \frac{V_x \pm \dfrac{M}{d}\tan\beta}{bd}$$

$$\Rightarrow \quad V_d = \tau_v bd = V_x \pm \frac{M_x}{dx}\tan\beta$$

$$V_x = 100 - 10 \times 5 = 50 \text{ kN};\ dx = 500 \text{ mm}$$

$$M_x = 100 \times 5 - 10 \times \frac{5 \times 5}{2} = 375 \text{ kN-m}$$

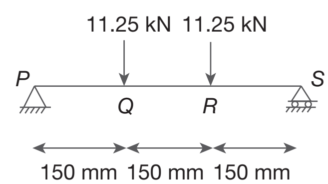
$$V_d = 50 + \frac{375}{0.5} \times \tan\beta$$

$$\tan\beta = \frac{600-400}{10 \times 1000} = \frac{200}{10,000}$$

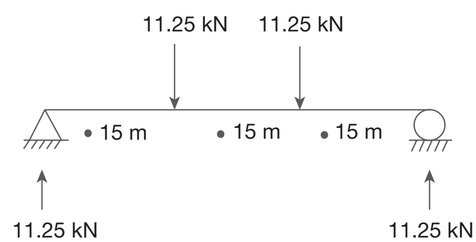
$$V_d = 50 + \frac{375}{0.5} \times \frac{200}{10,000} = 50 + 15 = 65 \text{ kN}$$

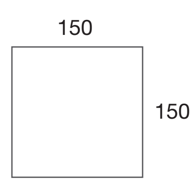
Hence, the answer is 65.

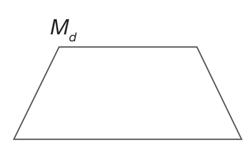
3. A 450 mm long plain concrete prism is subjected to the concentrated vertical loads as shown in the figure. Cross section of the prism is given as 150 mm × 150 mm. Considering linear stress distribution across the cross-section, the modulus of rupture (expressed in MPa) is ________. **[2016]**



Solution: 3







$$M_d = 11.25 \times 0.15 = 1.6875 \text{ kN-m}$$

Section Modulus,

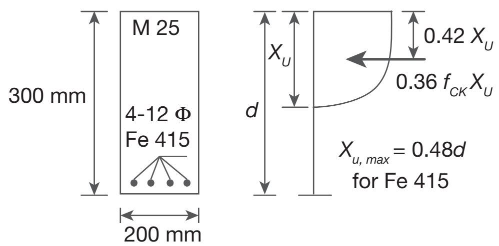
$$Z = \frac{bd^2}{6} = \frac{0.15 \times (0.15)^2}{6} = 0.000563 \text{ m}^3$$

Modulus of rupture,

$$f = \frac{M}{Z} = \frac{1.6875}{0.000563} \times 10^{-3} \text{MPa} = 3 \text{ MPa}$$

Hence, the answer is 3.

4. Consider the singly reinforced beam section given below (left figure). The stress block parameters for the cross-section from IS:456-2000 are also given below (right figure). The moment of resistance for the given section by the limit state method is ______ kN-m. **[2015]**



Solution: 42.78

$$x = \frac{0.87 f_y A_s t}{0.36 f_{ck} b}$$

$$= \frac{0.87 \times 415 \times 4 \times \frac{\pi}{4} \times 12^2}{0.36 \times 25 \times 200}$$

$$= 90.74$$

$$x_u = 0.48d = 0.48 \times 300 = 144$$

$$x < x_u \Rightarrow \text{UR}$$

Under reinforced

$\therefore$ $\quad M_R = 0.87fy \text{ Ast } (d - 0.42x)$

$$= 0.87 \times 415 \times 4 \times \frac{\pi}{4} \times 12^2$$

$$(300 - 0.42 \times 90.7)$$

$$= 42.78 \text{ kNm}$$

Hence, the answer is 42.78.

5. According to the concept of limit state design as per IS 456: 2000, the probability of failure of a structure is ________. **[2015]**

Solutions: (0.0975)

Probability of not failing under load = 95% = 0.95

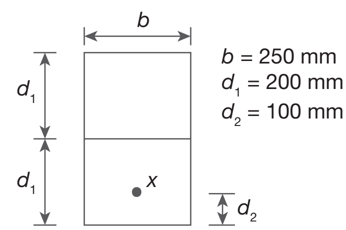
Probability of not failing under material strength criteria = 95% = 0.95

Overall probability of not failing is = 0.95 × 0.95 = 0.9025

Therefore the overall probability of failure of a structure as per IS: 456-2000 = 1 – 0.9025 = 0.0975

Hence, the answer is 0.0975.

6. In a pre-stressed concrete beam section shown in the figure, the net loss is 10% and the final pre-stressing force applied at X is 751 kN. The initial fiber stresses (in N/mm²) at the top and bottom of the beam were: **[2015]**



(a) 4.166 and 20.833
(b) –4.166 and –20.833
(c) 4.166 and –20.833
(d) –4.166 and 20.833

Solution: (d)

Pre-stressing force accounting for losses

$$P_i = 1.1 \times 750 \text{ kN}$$

$$\text{Stress} = \frac{P_i}{A} \pm \frac{P_e}{Z}$$

$$= \frac{1.1 \times 750 \times 10^3}{250 \times 400} \pm \frac{1.1 \times 750 \times 10^3 \times 100}{\frac{250 \times 400^3}{12}}$$

$$\sigma_{top} = -4.125 \times \text{N/mm}^2$$

$$\sigma_{bottom} = 20.625 \text{ N/mm}^2$$

Hence, the correct option is (d).

7. For a beam cross section, width = 230 mm and effective depth = 500 mm, the number of rebars of 12 mm diameter required to satisfy minimum tension reinforcement requirement specified by IS:456-2000 (assume grade of steel reinforcement as Fe500) is _________. **[2014]**

Solution: 2

Width of beam, b = 230 mm
Effective depth, d = 500 mm
Diameter of the bar, ϕ = 12 mm
Number of bars = n
Grade of steel: Fe500, f_y = 500 N/mm²

Minimum tension reinforcement as per IS:456-2000 is $\frac{A_{st}}{bd} \geq \frac{0.85}{f_y}$

$$\frac{A_{st}}{230 \times 500} \geq \frac{0.85}{500} \Rightarrow A_{st} \geq 195.5 \text{ mm}^2$$

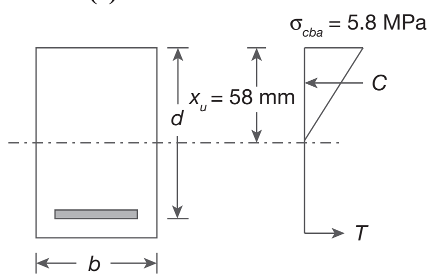
$$\text{Number of 12 mm } \phi \text{ bars} = \frac{195.5}{113} = 1.732 \approx \text{nos}$$

Hence, the answer is 2.

8. In a reinforced concrete section, the stress at the extreme fibre in compression is 5.80 MPa. The depth of neutral axis in the section is 58 mm and the grade of concrete is M 25. Assuming linear elastic behavior of the concrete, the effective curvature of the section (in per mm) is **[2014]**

(a) 2.0×10^{-6} (b) 3.0×10^{-6}
(c) 4.0×10^{-6} (d) 5.0×10^{-6}

Solution: (c)



Stress at extreme compression fibre, $\sigma = 5.8$ MPa
Depth of neutral axis from compression fibre, $y = 58$ mm
Grade of concrete: M 25, $f_{ck} = 25$ N/mm^2

Curvature of the section, $\frac{1}{R} = ?$

Modulus of elasticity of section, $E = 5000\sqrt{f_{ck}}$

$$E = 5000\sqrt{25} = 25000 \text{ N/mm}^2$$

Bending equation is $\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$

Curvature, $\frac{1}{R} = \frac{\sigma}{yE}$

$$= \frac{5.8}{58 \times 25000} = 4 \times 10^{-6} \text{ per mm}$$

Hence, the correct option is (c).

9 The target means strength f_{cm} for concrete mix design obtained from the characteristic strength f_{ck} and standard deviation σ, as defined in IS:456-2000, is **[2014]**

(a) $f_{ck} + 1.35\sigma$ (b) $f_{ck} + 1.45\sigma$
(c) $f_{ck} + 1.55\sigma$ (d) $f_{ck} + 1.65\sigma$

Solution: (d)
As per IS: 456-2000, in design of concrete target mean strength is given by

$$f_m = f_{ck} + 1.65\sigma$$

f_{ck}: Characteristic strength of concrete, N/mm^2
σ: Standard deviation, N/mm^2
Hence, the correct option is (d).

10. The flexural tensile strength of M 25 grade of concrete, in N/mm^2, as per IS:456-2000 is _______. **[2014]**

Solution: 3.5
Flexural strength of concrete, $f_{cr} = 0.7\sqrt{f_{ck}}$ N/mm^2
f_{ck}: Characteristic strength of concrete in N/mm^2
For M25 grade of concrete, $f_{ck} = 25$ N/mm^2

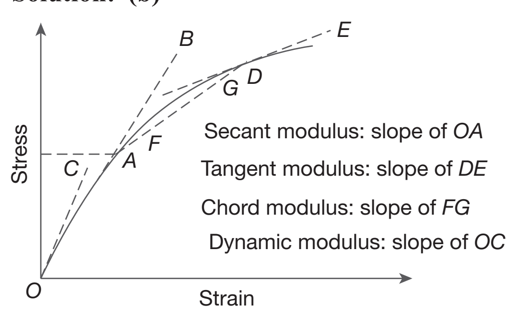
$$f_{cr} = 0.7\sqrt{25} = 3.5 \text{ N/mm}^2$$

Hence, the answer is 3.5.

11. The modulus of elasticity, $E = 5000\sqrt{f_{ck}}$ where f_{ck} is the characteristic compressive strength of concrete, specified in IS 456-2000 is based on **[2014]**

(a) tangent modulus
(b) initial tangent modulus
(c) secant modulus
(d) chord modulus

Solution: (b)



Stress strain diagram for concrete

Secant Modulus: The slope of a line drawn from the origin to the point on the stress-strain curve corresponding to 40% of the failure stress. The modulus of elasticity most commonly used in practice is secant modulus.

Tangent Modulus: The slope of a line drawn tangent to the stress strain curve at any point on the curve.

Chord Modulus: The slope of a line drawn between two points on the stress-strain curve.

Dynamic Modulus or Initial tangent Modulus: The modulus of elasticity corresponding to a small instantaneous strain. It is equal to the tangent modulus drawn at the origin.

As per IS: 456-2000, $E_c = 5000\sqrt{f_{ck}}$

E_c: Short term static modulus of elasticity in N/mm^2

f_{ck}: Characteristic cube compressive strength of concrete in N/mm^2

Hence, the correct option is (b).

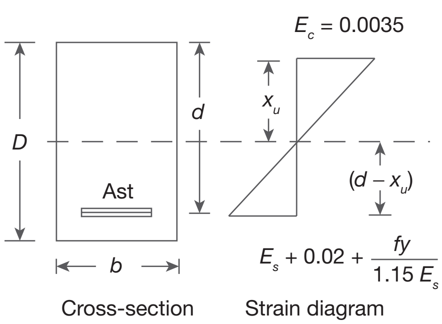
12. As per IS 456:2000, in the limit state design of a flexural member, the strain in reinforcing bars under tension at ultimate state should not be less than **[2012]**

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

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

Solution: (d)

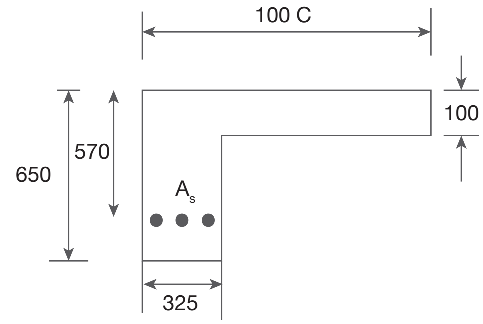
$$\varepsilon_s \geq \frac{f_y}{1.15E_s} + 0.002$$



Hence, the correct option is (d).

Statement for Linked Questions 13 and 14:

The cross-section at mid-span of a beam at the edge of a slab is shown in the sketch. A portion of the slab is considered as the effective flange width for the beam. The grades of concrete and reinforcing steel are M25 and Fe 415, respectively. The total area of reinforcing bars (A_s) is 4000 mm². At the ultimate limit state x_u denotes the top fibre. Treat the section as under-reinforced and flanged (X_u > 100 mm). **[2012]**



13. The value of x_u(in mm) computed as per the Limit State Method of IS 456:2000 is

(a) 200.0 (b) 223.3

(c) 236.3 (d) 273.6

Solution: (c)

The depth of NA lies outside the flange.

$$f_{ck} = 25\,\text{N/mm}^2,\ f_y = 415\,\text{N/mm}^2$$

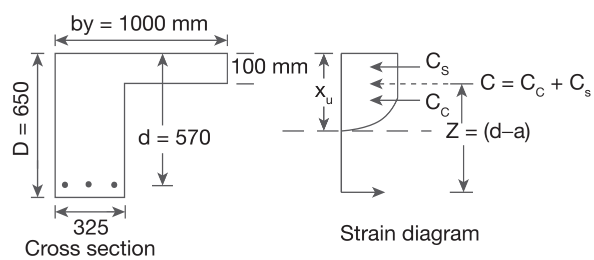
Overall depth of beam, $D = 650\,\text{mm}$

Effective depth of beam, $d = 570\,\text{mm}$

Effective width of flange, $b_f = 1000\,\text{mm}$

Width of rib, $b = 325\,\text{mm}$

Depth of flange, $D_f = 100\,\text{mm}$



Area of steel reinforcement, $A_{st} = 4000\,\text{mm}^2$

$$\frac{D_f}{d} = \frac{100}{570} = 0.175 < 0.2$$

The depth of rectangular stress block is more than the depth of flange.

$$C = T$$

$$C_c + C_f = T$$

$$0.36 f_{ck} b x_u + 0.446 f_{ck}(b_f - b_w)D_f = 0.87 f_y A_{st}$$

$$0.36 \times 25 \times 325 x_u + 0.446 \times 25(1000 - 325) \times 100$$

$$= 0.87 \times 415 \times 4000$$

$$x_u = 236.4 \text{ mm}$$

Hence, the correct option is (c).

14. The ultimate moment capacity (in kNm) of the section, as per the Limit State Method of IS 456:2000 is

(a) 475.2 (b) 717.0

(c) 756.4 (d) 762.5

Solution: (b)

$$x_{u,\max} = 0.48\text{d} = 0.48 \times 570 = 273.6 \text{ mm}$$

$x_u < x_{u,\max}$, the section is under reinforced section

Moment of resistance, $M_u = Tz = 0.87 f_y A_{st}(d - a)$

a = distance of CG of compressive forces from top

$$= \frac{C_c \times 0.42 x_u + C_f \times \frac{D_f}{2}}{C_c + C_f}$$

Compressive resistance of web, $C_c = 0.36 f_{ck} b x_u$

$$C_c : 0.36 \times 25 \times 325 \times 236.4 = 691470 \text{ N}$$

Compressive resistance of flange, $C_y = 0.446 f_{ck}(b_f - b_w)D_f$

$$C_f : 0.446 \times 25(1000 - 325)100 = 752625 \text{ N}$$

$$a = \frac{691470 \times 0.42 \times 236.4 + 752625 \times 50}{691470 + 752625} = 73.6 \text{ mm}$$

$$M_u = 0.87 \times 415 \times 4000(570 - 73.6) = 716.9 \text{ kNm}$$

Hence, the correct option is (b).

Statement for Linked Questions 15 and 16:

A doubly reinforced rectangular concrete beam has a width of 300 mm and an effective depth of 500 mm. The beam is reinforced with 2200 mm^2 of steel in tension and 628 mm^2 of steel in compression. The effective cover for compression steel is 50 mm. Assume that both tension and compression steel yield. The grades of concrete and steel used are M20 and Fe250 respectively. The stress block parameters (rounded off to first two decimal places) for concrete shall be as per IS 456:2000. **[2010]**

15. The depth of neutral axis is

(a) 205.30 mm (b) 184.56 mm

(c) 160.91 mm (d) 145.30 mm

Solution: (c)

Width of beam, b = 300 mm

Effective depth, d = 500 mm

Area of tension steel, A_{st} = 2200 mm^2

Area of compression steel, A_{sc} = 628 mm^2

Effective cover to the compression steel, d' = 50 mm

Grade of steel: *Fe* = 250, f_y = 250 N/mm^2

Both tension and compression steel yield.

$$C = T$$

$$C_c + C_s = T$$

$$0.36 f_{ck} b x_u + (f_{sc} - f_{cc})A_{sc} = 0.87 f_y A_{st}$$

$$f_{sc} = 0.87 f_y = 0.87 \times 250 = 217.5 \text{ N/mm}^2$$

$$f_{cc} = 0.45 f_{ck} = 0.45 \times 20 = 9 \text{ N/mm}^2$$

$$0.36 \times 20 \times 300 x_u + (217.5 - 9)628$$

$$= 0.87 \times 250 \times 2200$$

$$x_u = 160.91 \text{ mm}$$

$$x_{u,\max} = 0.53d = 0.53 \times 500 = 265 \text{ mm}$$

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

Therefore, assumed value of $f_{sc} = 0.87 f_y$ is alight.

Hence, the correct option is (c).

16. The moment of resistance of the section is

(a) 206.00 kN-m (b) 209.20 kN-m

(c) 236.80 kN-m (d) 251.90 kN-m

Solution: (b)

Moment of resistance of the section is given by

$$M_u = C_c(d - 0.42 x_u) + C_s(d - d')$$

$$= 0.36 f_{ck} b x_u (d - 0.42 x_u) + (f_{sc} - f_{cc})A_{sc}(d - d')$$

$$= 0.36 \times 20 \times 300 \times 160.91(500 - 0.42 \times 160.91)$$

$$+ (217.5 - 9)628(500 - 50)$$

$$= 150.29 + 58.92$$

$$M_u = 209.21 \text{ kNm}$$

Hence, the correct option is (b).

17. For limit state of collapse, the partial safety factors recommended by IS 456:2000 for estimating the design strength of concrete and reinforcing steel are respectively **[2009]**

(a) 1.15 and 1.5 (b) 1.0 and 1.0
(c) 1.5 and 1.15 (d) 1.5 and 1.0

Solution: (c)
Partial factor of safety
For concrete, $\gamma_f = 1.5$

For steel, $\gamma_f = 1.15$

Hence, the correct option is (c).

18. Un-factored maximum bending moments at a section of a reinforced concrete beam resulting from a frame analysis are 50, 80,120 and 180 kNm under dead, live, wind and earthquake loads respectively. The design moment (kNm) as per IS: 456-2000 for the limit state of collapse (flexure) is **[2008]**

(a) 195 (b) 250
(c) 345 (d) 372

Solution: (d)
Moment due to DL = 50 kNm
Moment due to $LL = 80\,\text{kNm}$

Moment due to $WL = 120\,\text{kNm}$

Moment due to $EL = 150\,\text{kNm}$

As per IS: 456-2000, the various load combinations are

i. Ultimate Load $= 1.5(DL + LL)$

$$= 1.5(50 + 80) = 195 \text{ kNm}$$

ii. Ultimate Load $= 1.2(DL + LL + WL \text{ or } EL)$

$$= 1.2(50 + 80 + 180) = 372 \text{ kNm}$$

iii. Ultimate Load = 1.5(DL + EL) or 0.9 DL + 15 EL

$$= 1.5(50 + 180) = 345\,\text{kNm}$$

The design moment is the maximum of the above cases, *i.e.,* $372\,\text{kNm}$

Hence, the correct option is (d).

Common Data for Questions 19 and 20:
A reinforced concrete beam of rectangular cross section of breadth 230 mm and effective depth 400 mm is subjected to a maximum factored shear force of 120 kN. The grade of concrete, main steel and stirrup steel are M20, F415 and Fe 250 respectively. For the area of main steel provided, the design shear strength τ_c as per IS: 456-2000 is 0.48 N/mm^2. The beam is designed for collapse limit state. **[2008]**

19. The spacing (mm) of 2-legged 8 mm stirrups to be provided is

(a) 40 (b) 115
(c) 250 (d) 400

Solution: (b)
Width of rectangular beam, b = 230 m
Effective depth, d = 400 mm
Factored shear force, V_u = 120 kN
Design shear strength, τ_c = 0.48 N/mm^2
Shear resistance of concrete, $V_c = \tau_c bd$

$$= 0.48 \times 230 \times 400 = 44.16\,\text{kN}$$

Shear to be resisted by stirrups, $V_{us} = V_u - V_c$

$$= 120 - 44.16 = 75.84 \text{ kN}$$

Spacing of 8 mm dia. 2 legged stirrups is given by

$$s_v = \frac{0.87 f_y A_{sv} d}{V_{us}}$$

$$= \frac{0.87 \times 250 \times 2 \times 50 \times 400}{75.84 \times 10^3} = 114.7\,\text{mm} \approx 115\,\text{mm}$$

Hence, the correct option is (b).

20. In addition, the beam is subjected to a torque whose factored value is 10.90 kNm. The stirrups have to be provided to carry a shear (kN) equal to

(a) 50.42 (b) 130.56
(c) 151.67 (d) 200.23

Solution: (c)
Factored torque, T_u = 10.9 kNm

Equivalent shear force, $V_e = V + 1.6\dfrac{T}{b}$

$$= 120 + 1.6 \times \frac{10.9}{0.23} = 195.83 \text{ kN}$$

Shear to be resisted by stirrups, $V_{us} = V_u - V_c$

$$= 195.83 - 44.16 = 151.67\,\text{kN}$$

Hence, the correct option is (c).

Statement for Linked Questions 21 and 22:
A singly reinforced rectangular concrete beam has a width of 150 mm and an effective depth of 330 mm. The characteristics compressive strength of concrete is 20 MPa and the characteristics

tensile strength of steel is 415 MPa. Adopt the stress block for concrete as given in IS 456-2000 and take limiting value of depth of neutral axis as 0.48 times the effective depth of the beam. **[2007]**

21. The limiting value of the moment of resistance of the beam is kNm is
(a) 0.14 (b) 0.45
(c) 45.08 (d) 156.82

Solution: (c)
Width of beam, $b = 150$ mm
Effective depth beam, $d = 330$ mm
Characteristic compressive strength of concrete,

$$f_{ck} = 20\ \text{N/mm}^2$$

Characteristic tensile strength of steel,

$$f_y = 415\ \text{N/mm}^2$$

Limiting depth of neutral axis,

$$x_{u,\max} = 0.48d$$
$$= 0.48 \times 330 = 158.4\ \text{mm}$$

Limiting value of moment of resistance of the beam,

$$M_{u,\lim} = 0.36 f_{ck} b x_{u,\max}(d - 0.42x_{u,\max})$$
$$= 0.36 \times 20 \times 150 \times 158.4(330 - 0.42 \times 158.4)$$
$$M_{u,\lim} = 45.07\ \text{kNm}$$

(or)

$$M_{u,\lim} = 0.138 f_{ck} bd^2$$
$$= 0.138 \times 20 \times 150 \times 330^2 = 45.07\ \text{kNm}$$

Hence, the correct option is (c).

22. The limiting area of tension steel in mm^2 is
(a) 473.9 (b) 412.3
(c) 373.9 (d) 312.3

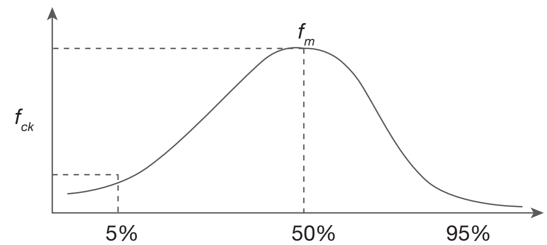
Solution: (a)
The limiting area of tension steel is given by

$$M_u = 0.87 f_y A_{st}(d - 0.42x_{u,\max})$$
$$45.07 \times 10^6 = 0.87 \times 415 \times A_{st}(330 - 0.42 \times 158.4)$$
$$A_{st} = 473.9\ \text{mm}^2$$

Hence, the correct option is (a).

23. If the characteristic strength of concrete f_{ck} is defined as the strength below which not more than 50% of the test results are expected to fall, the expression for f_{ck} in terms of mean strength f_m and standard deviation S would be **[2006]**
(a) $f_m - 0.1645S$ (b) $f_m - 1.645S$
(c) f_m (d) $f_m + 1.645S$

Solution: (c)



By definition, f_{ck} is the strength below which not more than 5% of the test results are expected to fall.

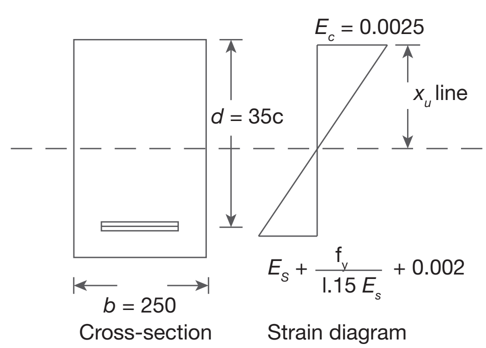
In this question, f_{ck} is defined as the strength below which not more than 50% of the results are expected to fall.

Therefore, $f_{ck} = f_m$
Hence, the correct option is (c).

Statement for Linked Questions 24 and 25:
In the design of beams for the limit state of collapse in flexure as per IS:456-2000, let the maximum strain in concrete be limited to 0.0025 (in place of 0.0035). For this situation, consider a rectangular beam section with breadth as 250 mm, effective depth as 350 mm, area of tension steel as 1500 mm^2, and characteristics strengths of concrete and steel as 30 MPa and 250 MPa respectively. **[2006]**

24. The depth of neutral axis for the balanced failure is
(a) 140 mm (b) 156 mm
(c) 168 mm (d) 185 mm

Solution: (b)



Area of tensile steel reinforcement, $A_{st} = 1500 \text{ mm}^2$

Characteristic strength of concrete, $f_{ck} = 30 \text{ N/mm}^2$

Characteristic strength of steel, $f_y = 250 \text{ N/mm}^2$

From the strain diagram,

$$\frac{x_{u,\lim}}{0.0025} = \frac{d - x_{u,\lim}}{\frac{0.87 f_y}{E_s} + 0.002}$$

$$\frac{x_{u,\lim}}{d - x_{u,\lim}} = \frac{0.0025}{\frac{0.87 f_y}{E_s} + 0.002};$$

$$\frac{x_{u,\lim}}{d} = \frac{0.0025}{\frac{0.87 f_y}{E_s} + 0.0045}$$

Modulus of elasticity of steel, $E_s = 2 \times 10^5 \text{ N/mm}^2$

$$\frac{x_{u,\lim}}{d} = \frac{0.0025}{\frac{0.87 \times 250}{2 \times 10^5} + 0.0045} = 0.448$$

$$x_{u,\lim} = 0.448 \times 350 = 156.8 \approx 156 \text{ mm}$$

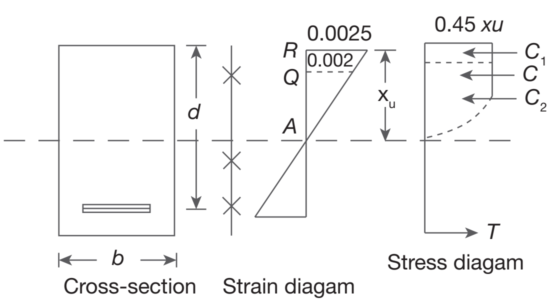
Hence, the correct option is (b).

25. At the limiting state of collapse in flexure, the force acting on the compression zone of the section is

(a) 326 kN (b) 389 kN

(c) 424 kN (d) 542 kN

Solution: (b)



From the strain diagram,

$$\frac{x_u}{0.0025} = \frac{PQ}{0.002}; \; PQ = \frac{4}{5} x_u = 0.8 x_u; \; QR = 0.2 x_u$$

C_1: Compressive force due to rectangular portion of stress block $= 0.45 f_{ck} \times 0.2 x_u \times b = 0.09 f_{ck} b x_u$

C_2: Compressive force due to parabolic portion of stress block

$$= \frac{2}{3} \times 0.45 f_{ck} \times 0.8 x_u \times b = 0.24 f_{ck} b x_u$$

C: Total compressive resistance $= C_1 + C_2$

$$= 0.09 f_{ck} b x_u + 0.24 f_{ck} b x_u = 0.33 f_{ck} b x_u$$

For limiting case of collapse in flexure,

$$x_u = x_{u,\lim} = 156 \text{ mm}$$

Therefore,

$$C = 0.33 \times 30 \times 250 \times 156 = 386.1 \text{ kN}$$

Hence, the correct option is (b).

26. The partial factor of safety for concrete as per IS:456-2000 is **[2005]**

(a) 1.50 (b) 1.15

(c) 0.87 (d) 0.446

Solution: (a)

Partial factor of safety for concrete, $\gamma_c = 1.50$ and for steel, $\gamma_m = 1.15$

Hence, the correct option is (a).

27. In a random sampling procedure for cube strength of concrete, one sample consists of X number of specimens. These specimens are tested at 28 days and average strength of these X specimens is considered as test result of the sample, provided the individual variation in the strength of specimens is not more than $\pm Y$ percent of the average strength. The values of X and Y as per IS : 456-2000 are **[2005]**

(a) 4 and 10 respectively

(b) 3 and 10 respectively

(c) 4 and 15 respectively

(d) 3 and 15 respectively

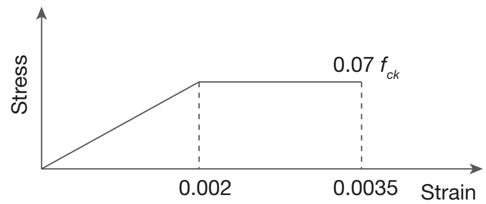
Solution: (d)

As per IS: 456-2000, three test specimens shall be made for each sample for testing at 28 days. The individual strength variation should not be more than ±15% of the average strength of cubes.

Hence, the correct option is (d).

Statement for Linked Questions 28 and 29:

Assume straight line instead of parabola for stress-strain curve of concrete as follows and partial factor of safety as 1.0.



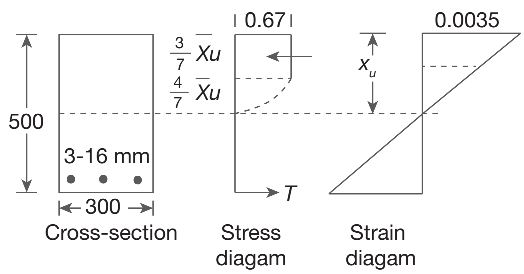
A rectangular under-reinforced concrete section of 300 mm width and 500 mm effective depth is reinforced with 3 bars of grade Fe415, each of 16 mm diameter. Concrete mix is M20. **[2005]**

28. The depth of the neutral axis from the compression fibre is

(a) 76 mm (b) 81 mm

(c) 87 mm (d) 100 mm

Solution: (a)



Compressive force due to rectangular portion of stress block,

$$C_1 = 0.67 f_{ck} \frac{3}{7} x_u b = 0.2871 f_{ck} b x_u$$

Compressive force due to triangular portion of stress

$$C_2 = \frac{1}{2} \times 0.67 f_{ck} \frac{4}{7} x_u b = 0.1914 f_{ck} b x_u$$

Total compressive force,

$$C = C_1 + C_2$$
$$= (0.2871 + 0.1914) f_{ck} b x_u = 0.4785 f_{ck} b x_u$$

Tensile force, $T = 0.87 f_y A_{st}$

$$C = T$$
$$0.4785 f_{ck} b x_u = 0.87 f_y A_{st}$$
$$0.4785 \times 20 \times 300 x_u = 0.87 \times 415 \times 3 \times 201$$
$$x_u = 75.83 \text{ mm} = 76 \text{ mm}$$

Hence, the correct option is (a).

29. The depth of the neutral axis obtained as per IS : 456-2000 differs from the depth of neutral axis obtained in Q.83a. by

(a) 15 mm (b) 20 mm

(c) 25 mm (d) 32 mm

Solution: (c)

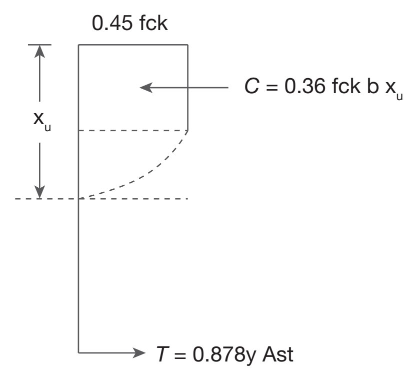
As per IS: 456-2000,

C: Compressive force $= 0.36 f_{ck} b x_u$

T: Tensile force $= 0.87 f_y A_{st}$

$$C = T$$
$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b}$$
$$= \frac{0.87 \times 415 \times 3 \times 201}{0.36 \times 20 \times 300} = 100.8 \text{ mm.} \approx 101 \text{ mm}$$

Difference of depth of neutral axis = 101 − 76 = 25 mm



Hence, the correct option is (c).

30. In the limit state design method of concrete structures, the recommended partial material safety factor (γ_m) for steel according to IS:456-2000 is **[2004]**

(a) 1.5 (b) 1.15

(c) 1.00 (d) 0.87

Solution: (b)

As per IS: 456-2000, the partial factor of safety for steel, $\gamma_m = 1.15$

For concrete, $\gamma_m = 1.50$

Hence, the correct option is (b).

31. For avoiding the limit state of collapse, the safety of RC structures is checked for appropriate combinations of dead load (DL), imposed load or live load (IL), wind load (WL) and earthquake load

(EL). Which of the following load combinations is NOT considered? **[2004]**

(a) 0.9 DL + 1.5 WL

(b) 1.5 DL + 1.5 WL

(c) 1.5 DL + 1.5 WL + 1.5 EL

(d) 1.2 DL + 1.2 IL + 1.2 WL

Solution: (c)

Partial safety factors for load under limit state of collapse.

Load combination	DL	LL	WL
DL + LL	1.5	1.5	–
DL + WL	1.5	–	1.5
DL + WL*	0.9	–	1.5
DL + LL + WL	1.2	1.2	1.2

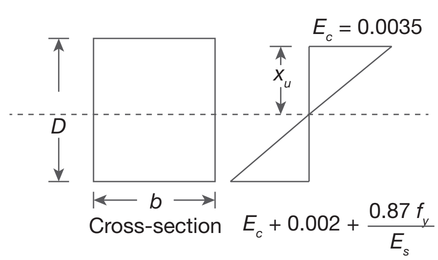
*This value should be considered when stability against overturning or stress reversal is critical.

Hence, the correct option is (c).

32. Maximum strains in an extreme fibre in concrete and in the tension reinforcement (Fe 415 grade and E_s = 200 kN/mm^2) in a balanced section at limit state of flexure are respectively **[2003]**

(a) 0.0035 and 0.0038
(b) 0.002 and 0.0018
(c) 0.0035 and 0.0041
(d) 0.002 and 0.0031

Solution: (a)



Maximum strain in concrete, $\varepsilon_c = 0.0035$

Maximum strain in steel,

$$\varepsilon_s = 0.002 + \frac{0.87 f_y}{E_s}$$

$$= 0.002 + \frac{0.87 \times 415}{200 \times 10^3} = 0.002 + 0.0018 = 0.00380$$

Hence, the correct option is (a).

Common Data for Questions 33 and 34.

A reinforced concrete beam, size 200 mm wide and 300 mm deep overall is simply supported over a span of 3 m. It is subjected to two point loads P of equal magnitude placed at middle third points. The two loads are gradually increased simultaneously. Beam is reinforced with 2 HYSD bars of 16 mm diameter placed at an effective cover of 40 mm on bottom face and nominal shear reinforcement. The characteristic compressive strength and the bending tensile strength of the concrete are 20.0 N/mm^2 and 2.2 N/mm^2, respectively. **[2003]**

33. Ignoring the presence of tension reinforcement, find the value of load P in kN when the first flexure crack will develop in the beam.

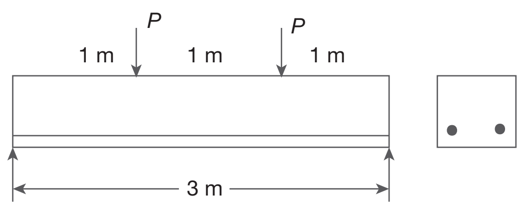
(a) 4.5 (b) 5.0
(c) 6.6 (d) 7.5

Solution: (c)

Width of beam, $b = 200\,\text{mm}$

Overall depth of beam, $D = 300\,\text{mm}$

Span of beam, $l = 3\,\text{m}$



Effective cover, $d' = 40\,\text{mm}$

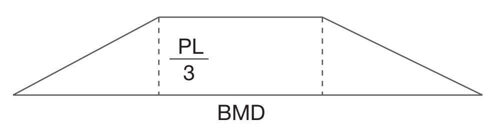
Effective depth, $d = 300 - 40 = 260\,\text{mm}$

Characteristic compression strength, $f_{ck} = 20$ N/mm^2

Bending tensile strength, $\sigma_{bt} = 2.2\,\text{N/mm}^2$

Maximum stress in concrete, $\sigma_{cc} = 0.45 f_{ck}$

$$= 0.45 \times 20 = 9\,\text{N/mm}^2$$



Maximum BM $= \dfrac{PL}{3}$

z: Section modulus

$$= \frac{bD^2}{6} = \frac{200 \times 300^2}{6} = 3 \times 10^6\,\text{mm}^3$$

Moment of resistance of concrete, $MR = \sigma_{bt} z$

$$= 2.2 \times 3 \times 10^6 = 6.6 \times 10^6 \text{ N-mm} = 6.6 \text{ kNm}$$

Maximum BM = Moment of resistance

$$\frac{PL}{3} = 6.6; \quad \frac{P \times 3}{3} = 6.6; \quad P = 6.6 \text{ kN}$$

Hence, the correct option is (c).

34. The theoretical failure load of the beam for attainment of limit state of collapse in flexure is

(a) 23.7 kN (b) 25.6 kN
(c) 28.7 kN (d) 31.6 kN

Solution: (d)

A_{st}: Area of tensile steel reinforcement

$$= 2 \times 201 = 402 \text{ mm}^2$$

x_u: Depth of neutral axis

$$= \frac{0.87 f_y A_{st}}{0.36 f_{ck} b} = \frac{0.87 \times 415 \times 402}{0.36 \times 20 \times 200} = 100.8 \text{ mm}$$

$$x_{u,\lim} = 0.48\text{d} = 0.48 \times 260 = 124.8 \text{ mm}$$

$x_u < x_{u,\lim}$, the section in URS

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

$$= 0.87 \times 415 \times 402(260 - 0.42 \times 100.8)$$

$$= 31.6 \text{ kNm}$$

$$M_u = \frac{PL}{3}$$

$$31.6 = \frac{P \times 3}{3}; \quad P = 31.6 \text{ kN}$$

Hence, the correct option is (d).

35. Read the following statements. **[2002]**

I. Maximum strain in concrete at the outermost compression fibre is taken to be 0.0035 in bending

II. The maximum compressive strain in concrete in axial compression is taken as 0.002.

Keeping the provisions of IS 456-2000 on limit state design in mind, which of the following is true?

(a) Statement I is true and but II is false
(b) Statement I is false but II is true
(c) Both statements I and II are true
(d) Both statement I and II are false

Solution: (c)

As per IS: 456, maximum strain in concrete at the outermost compression fibre is taken as 0.0035 (or 0.35%) in bending. The maximum compression strain in concrete in axial compression is taken as 0.002.

Hence, the correct option is (c).

36. As per the provisions of IS:456-2000, in the limit state method for design of beams, the limiting value of the depth of neutral axis in a reinforced concrete beam of effective depth '*d*' is given as **[2002]**

(a) $0.53d$
(b) $0.48d$
(c) $0.46d$
(d) any of the above depending on the different grades of steel.

Solution: (d)

$x_{u\max}$: Limiting depth of neutral axis

$x_{u\max} = 0.53d$ for Fe 250 grade steel

$= 0.48d$ for Fe 415 grade steel

$= 0.46d$ for Fe 500 grade steel

The limiting depth of neutral axis depends on the grades of steel.

Hence, the correct option is (d).

37. Identify the FALSE statement from the following, pertaining to the design of concrete structures. **[2001]**

(a) The assumption of a linear strain profile in flexure is made use of in working stress design, but not in ultimate limit state design.
(b) Torsional reinforcement is not required to be provided at the corners of simply supported rectangular slabs, if the corners are free to lift up.
(c) A rectangular slab, whose length exceeds twice its width, always behaves as a two way slab, regardless of the support conditions.
(d) The 'load balancing' concept can be applied to select the appropriate tendon profile in a prestressed concrete beam subject to a given pattern of loads.

Solution: (a & c)
The assumption 'plane sections normal to the axis remain plane after bending' means the strain is proportional to the distance from the neutral axis. This assumption is used in both working stress method and limit state method of design. Option 'a' is false.

For simply supported rectangular slabs, if corners are

I. held down, torsional reinforcement is to be provided as per code.

II. not held down (*i.e.,* free to lift), No torsional reinforcement is required.

Option 'b' is true.

If the slab is supported on all four sides and length to width ratio is greater than 2, then the slab will be considered as one way slab. Option 'c' is false.

The shape of the cable in prestressed concrete beam is same as the shape of bending moment diagram due to loads. Therefore, load balancing concept is used to select the appropriate tendon profile in prestressed concrete beam. Option 'd' is true.

Hence, the correct option is (a & c).

38. The following two statements are made with reference to a simply supported under reinforced RCC beam: **[2000]**

I. Failure takes place by crushing of concrete before the steel has yielded.

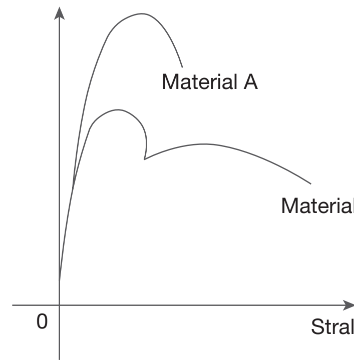
II. The neutral axis moves up as the load is increased.

With reference to the above statements, which of the following applies?
(a) Both the statements are false.
(b) I is true but II is false.
(c) Both the statements are true.
(d) I is false but II is true.

Solution: (a)
For simply supported under reinforced RCC beam i. failure takes place by yielding of the steel reinforcement and ii. The position of neutral axis is independent of the load.
Position of neutral axis is given by $0.36 f_{ck} b x_u = 0.87 f_y A_{st}$

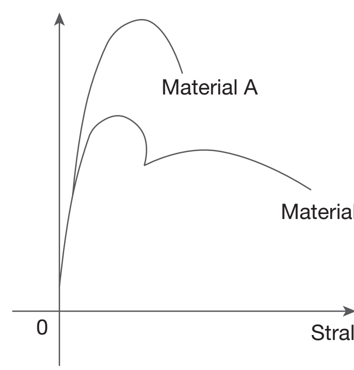
Both the statements are false.
Hence, the correct option is (a).

39. The stress-strain diagram for two materials A and B is shown below: **[2000]**



The following statements are made based on this diagram:
I. Material A is more brittle than material B.
II. The ultimate strength of material B is more than that of A.
With reference to the above statements, which of the following applies?
(a) Both the statements are false.
(b) Both the statements are true.
(c) I is true but II is false.
(d) I is false but II is true.

Solution: (c)



As the yield strength of material increases, the property of brittleness increases. Material A is more brittle than material B. Statement I is true.
The ultimate strength of material A is more than that of B. Statement II is false.
Hence, the correct option is (c).

40. The minimum area of tension reinforcement in a beam shall be greater than **[1999]**

(a) $\frac{0.85bd}{f_y}$ (b) $\frac{0.87 f_y}{bd}$
(c) $0.04\,bd$ (d) $\frac{0.4bd}{y}$

Solution: (a)

Minimum area of tension reinforcement is given by

$$\frac{A_s}{bd} = \frac{0.85}{f_y}; \qquad A_s = \frac{0.85bd}{f_y}$$

A_s: Minimum area of tension reinforcement
b: Breadth of beam or breadth of the web of T section.
d: Effective depth
f_y: Characteristic strength of reinforcement in N/mm^2
Hence, the correct option is (a).

41. The characteristic strength of concrete is defined as that compressive strength below which not more than **[1999]**

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

Solution: (b)

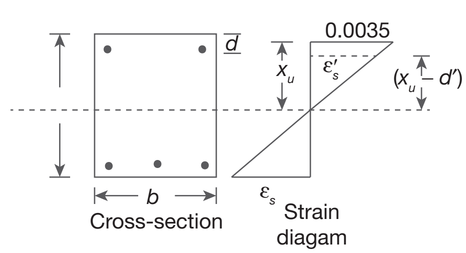
Characteristic strength is the value of the strength of the material below which not more than 5 percent of the test results are expected to fall.
Hence, the correct option is (b).

42. Maximum strain at the level of compression steel for a rectangular section having effective cover to compression steel as d' and neutral axis depth from compression face x_u is **[1999]**

(a) $0.0035\left(1-\frac{d'}{x_u}\right)$ (b) $0.002\left(1-\frac{d'}{x_u}\right)$

(c) $0.0035\left(1-\frac{x_u}{d'}\right)$ (d) $0.002\left(1-\frac{x_u}{d'}\right)$

Solution: (a)



x_u: Depth of neutral axis
d': Effective cover to compression steel reinforcement.
d: Effective depth of the section.
ε_c': Strain at the level of compression steel.

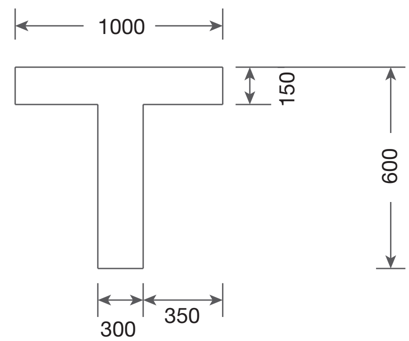
From the strain diagram

$$\frac{\varepsilon_c'}{(x_u - d')} = \frac{0.0035}{x_u}$$

$$\varepsilon_c' = 0.0035\left(\frac{x_u - d'}{x_u}\right) = 0.0035\left(1 - \frac{d'}{x_u}\right)$$

Hence, the correct option is (a).

43. An isolated T beam is used as a walkway. The beam is simply supported with an effective span of 6 m. The effective width of flange, for the cross-section shown in figure, is **[1998]**



(a) 900 mm (b) 1000 mm
(c) 1259 mm (d) 2200 mm

Solution: (a)

Effective span of simply supported T beam, $l_e = 6$ m
Width of flange, $b = 1000$ mm

Width of web, $b_w = 300$ mm

Thickness of flange, $D_f = 150$ mm

For an isolated T beam, the effective width of flange is given by

$$b_f = \frac{l_0}{\frac{l_0}{b} + 4} + b_w$$

$$= \frac{6000}{\frac{6000}{1000} + 4} + 300 = 900 \text{ mm}$$

Hence, the correct option is (a).

Five-marks Questions

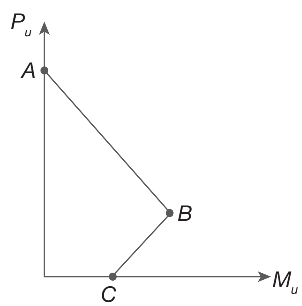
1. A schematic representation of a $P_u - M_u$ interaction diagram for the design of reinforced concrete column is given in the following figure. Based on the given diagram, answer the following questions. **[2002]**

(a) What do the points A and C physically signify?

(b) What is the basic difference between the points AB and BC?

(c) In the region BC, why does the moment capacity of the column increase even as the axial load is also being increased?

(d) Design codes often required the designer to ensure adequate strength for a minimum eccentricity. How is such a provision incorporated into the interaction diagram?



Solution:

(a) Failure occurs due to axial compression because at point A, $M_u = 0$ and P_u is maximum. Failure occur due to bending only At point C, because $P_u = 0$, and M_u is non zero, so.

(b) Portion BC is known ascension zone and Portion AB is known as compression zone

(c) In region BC, region of tension failure at C, the ultimate moment is M_u while the ultimate axial load is zero. As load is of tension in nature, it produce negative moment and then net moment will be less than Mu, so the moment carrying capacity will increase.

(d) load is maximum at point A because minimum eccentricity is at the point A.

2. Given reasons for the following in not more than 20 words: **[2002]**

(a) A concrete mix is targeted to give higher compressive strength than the required characteristic strength.

(b) In the case of slabs running over supports, reinforcement needs to be provided on the top in the neighborhood of the supports.

(c) The load carrying capacity of an RC column with appropriate helical reinforcement can be taken to be slightly higher than that having lateral ties.

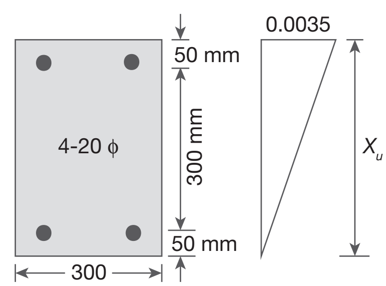
Solution:

(a) A concrete mix is targeted to give the high compressive stress due to compaction and compressive characters of mixture and binding material.

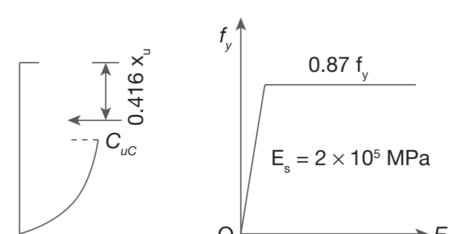
(b) Because the compressive force exerted on the slab is distributed on support through the reinforcement.

(c) Because in the helical reinforcement number of bars is generally greater than lateral tie and spaced slightly close together.

3. The plan of a reinforced concrete column section, and the distribution of strains at the ultimate limit stage are shown below. The concrete is of M 20 grade and the steel of Fe 250 grade. Sketched below, for convenience, are the concrete compression stress block and the design stress-strain curves for Fe 250, with all notations as per IS 456. Ignore the reduction in concrete area due to the embedded steel. **[2001]**



Section Strain profile



$C_{uC} = 0.362\ f_{ck}\ b_o\ x_u$

Stresses in concrete

Design stress-strain Curve for Fe 250

(a) Determine the ultimate axial compression capacity P_u (in kN units)

(b) Determine the corresponding eccentricity e in mm units) of loading, with respect to the centroidal axis at the ultimate limit state. **[2001]**

Solution:

(a)
$$T_u = 0.87 f_y A_{st}$$
$$= 0.87 \times 250 \times \frac{\pi}{4}(20)^2 \times 4$$
$$= 273318.56 \text{ mm}^2$$
$$P_u = 0.362 f_{ck} X_{ub} + f_{SC} A_{SC}$$

Where, f_{SC} = stress in the compression reinforcement to be read of from stress-strain curve

$$\in_{SC} = \frac{0.0035(x_u - d')}{x_u}$$

Assume

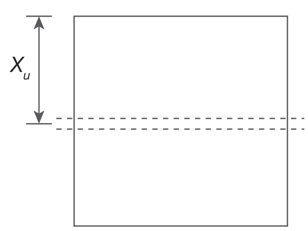
$$\frac{x_u}{d} = 0.4 \quad \text{or, } x_u = 0.4 \times 350 = 140$$

$$\therefore \quad \in_{SC} = \frac{0.0035(140-50)}{140} = 0.00225$$

For strain greater than 0.2%

$$F_{sc} = 0.87 f_y = 0.87 \times 250 = 217.5 \text{ N/m}^2$$
$$P_u = 0.362 \times 20 \times 140 \times 300$$
$$+ 217.5 \times \frac{\pi}{4}(20)^2 \times 4$$
$$= 577398.56 \text{ N} = T_u \text{(adopt)}$$

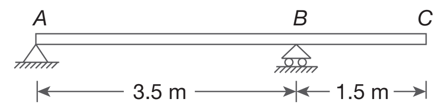
(b) Centroid $= \frac{400}{2} = 200$ mm



We know that x_u = 140 mm

$$e = \text{Centroid} - x_u$$
$$= 200 - 140 = 60 \text{ mm}$$

4. The effective spans for a simple one way slab system, with an overhang, are indicated in the figure below. The specified ultimate design loads on the slab are 6.0 kN/m² and 4.5 kN/m² for dead load and live loads respectively. Considering the possibility of live loads not occurring simultaneously on both spans, determine the maximum spacing (in mm units) of 8 mm diameter bars required as bottom reinforcement in the span *AB*, assuming an effective depth of 125 mm. Assume M 20 concrete and Fe 415 steel. **[2001]**



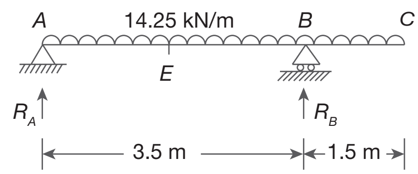
Solution:

we know that d = 150 mm

Unit weight of *RCC* = 25 kN/m³

Safe weight = 25 × 0.150 kN/m = 3.75 kN/m

Consider the figure given below



We know that

$$d_{total} = d_{eff} + \text{clear cover} + \frac{1}{2}\text{dia. of bar} = 125 + 15 + 4$$
$$= 144 \text{ mm}$$

Total load = DL + LL + Self weight

= 6 + 4 . 5 + 3.7 5 = 14.25 kN/m

Now, $R_B \times 3.5 = 14.25 \times 5 \times 2.5$

$$\text{or} \quad R_B = \frac{14.25 \times 5 \times 2.5}{3.5} = 50.89 \text{ kN}$$

$$\therefore \quad R_A = 20.36 \text{ kN}$$

Critical moment either at *B* or mid span of *AB* (say *E*)

$$\text{At} \quad B \; M_B = 14.25 \times \frac{1.5^2}{2} = 16.03 \text{ kNm}$$

$$M_E = 20.36 \times 1.75 - 14.25 \times \frac{1.75^2}{2}$$
$$= 13.80 \text{ kNm}$$

Again, we know that

$$M_{max} = 16.03 \text{ kNm} = Rbd^2$$

Also we know that, $R = 0.898$

$$\therefore \quad d = \sqrt{\frac{16.03 \times 10^6}{0.898 \times 1000}}$$
$$= 133.30 \text{(safe)}$$

$$M = A_{st} jd$$

or $16.03 \times 10^6 = A_{st} \times 230 \times 90 \times 125$

or $A_{st} = 619\ \text{mm}^2$

Area,

$$A_\phi = \frac{\pi}{4}(8)^2 = 50.3\ \text{mm}^2$$

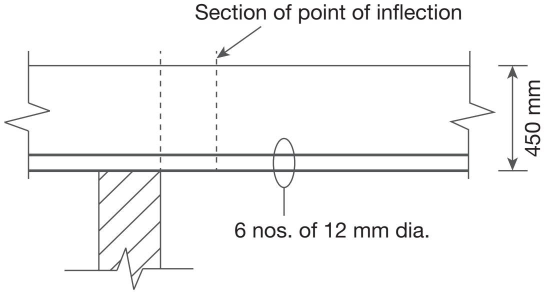
∴ Spacing of 8 mm bar

$$= \frac{1000 A_\phi}{A_{st}} = \frac{1000 \times 50.3}{619}$$

$$= 81.26\ \text{mm}$$

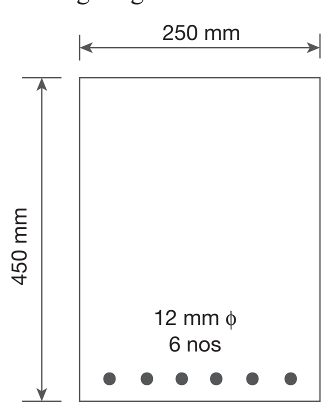
2. Shear, Torsion, Bond, Anchorage & Development Length

5. A continuous beam 250 mm × 450 mm carries 6 numbers of 12 mm diameter longitudinal bars as shown. The factored shear force at the point of inflection is 200 kN. Check, if the beam is safe in bond. Assume M 15 mix with f_{ck} = 15 N/mm2 and mild steel with f_y = 250 N/mm^2. A clear cover of 25 mm can be assumed. The design bond stress for mild steel bars for M 15 concrete is specified to be 1.0 N/mm^2. **[2000]**



Solution:

Consider the figure given below



(a) At point A, Mu = 0 and Pu is maximum, so failure occurs due to axial compression.
At point C, Pu = 0, and Mu is non-zero, so failure occur due to bending only.

(b) Portion AB is known as compression zone and torfion BC Is known ascension zone.

(c) In region BC, region of tension failure at C, the ultimate moment is Mu while the ultimate axial load is zero. As load is of tension in nature, it produce negative moment and then

Bending moment can be expressed as

$$M = 0.87 f_y A_{st}\left(d - \frac{f_y}{f_{ck}}\frac{A_{st}}{b}\right)$$

Area of steel can be calculated using

$$A = 6 \times \frac{\pi}{4} \times (12)^2 = 678.6\ \text{mm}^2$$

We know that effective depth

$$d = 450 - 25 - \frac{12}{2} = 419\ \text{mm}$$

$$\therefore \quad M = 0.87 \times 250 \times 678.6 \left(419 - \frac{250}{15} \times \frac{678.6}{250}\right)$$

$$= 55.16\ \text{kNm}$$

Development length can be calculated using

$$L_d = \frac{\phi\sigma_s}{4\tau_{bd}}$$

$$= \frac{\phi \times 0.87 \times 250}{4 \times 1} = 54.375\phi$$

Also development length can be expressed as

$$L_d = \frac{M_1}{V} + L_0,\ L_0 = 0$$

or $$L_d < \frac{55.16}{200}$$

or $$\phi < \frac{55.16}{200} \times \frac{1}{54.375}$$

Since $$\phi < 5$$

Hence, beam is not safe in bond.

6. The diameter of a ring beam in water tank is 7.8 m. It is subjected to an outward radial force of 15 kN/m. Design the section using M 25 grade of concrete and Fe 415 reinforcement. **[1998]**

Solution:

The outward radial force cause a hoop tension in the ring beam

∴ Hoop tension in ring beam σ_h = 15 kN/m

Tensile force can be calculated using

$$P = \sigma_h \frac{D}{2} = 15 \times \frac{7.8}{2} = 58.5 \text{ kN}$$

For Fe 415 grade of steel

$$\sigma_{st} = 230 \text{ N/mm}^2$$

Provide ring of size

Area of steel required can be calculated using

$$A_{st} = \frac{P}{\sigma_{st}} = \frac{58.5 \times 10^3}{230} = 254.347 \text{ mm}^2$$

Provide 16 mm ϕ bars

$$\therefore \text{ Number of bars} = \frac{254.347}{\frac{\pi}{4}(16)^2} = 1.27 = 2$$

∴ Provide - 2 No. of bars of 16 mm diameter.

Actual area of steel provided

$$= \frac{\pi}{4}(16)^2 \times 2 = 402.12 \text{ mm}^2$$

$$\approx 403 \text{ mm}^2$$

Let A = Area of ring beam

Equivalent area of composite section

$$A_{eq} = A + (m-1)A_{st}$$

$$\therefore \quad m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 8.5} = 10.98 = 11$$

$$\therefore \quad A_{eq} = A + (11-1) \times 402.12$$

$$= A + 4021.2$$

Allowing a stress of 1.2 N/mm² in the composite section

$$\therefore \quad 1.2 = \frac{58.5 \times 10^3}{A + 4021.2}$$

$$\Rightarrow \quad A = 4021.2 \text{ mm}^2$$

Provide ring of size = 250 mm × 200 mm

Provide 8 mm ϕ stirrups @ 200 mm c/c to tie the ring.

7. A hall is covered by a beam and slab system with beams placed at 3.0 m centres. The effective span of the beam is 8.35 m. The thickness of the slab is 120 mm. The size of the beam below the slab is 230 mm width and 380 mm depth. The beam is reinforced with two numbers of 32 mm diameter steel rods of grade 415 N/mm². Compute the maximum total load/m run, the beam can carry, including its own weight at service stage. Grade of concrete is M 25. **[1997]**

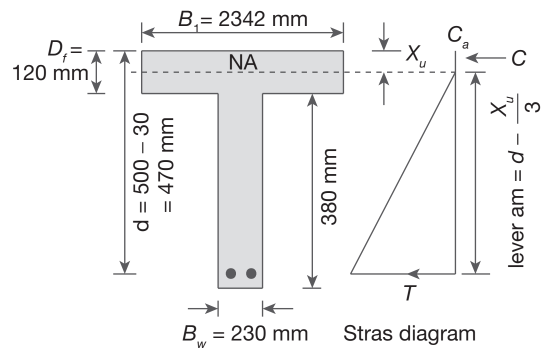
Solution:

Thickness of slab, D_f = 120 mm

Spacing of beam = 3 m

Effective span, l_{eff} = 8.35 m = 230 mm

Consider the figure given below



Area of steel,

$$A_{st} = 2 \times \frac{\pi}{4}(32)^2 = 1608.50 \text{ mm}^2$$

Effective width of flange

$$B_{eff} = \frac{l_0}{6} + 6D_1 + B_w$$

$$= \frac{8.35 \times 1000}{6} + 6 \times 120 + 230$$

$$= 2341.6 = 2342 \text{ mm} = B_1$$

Take an effective cover of 30 mm

∴ Effective depth,

$$d = 500 - 30 = 470 \text{ mm}$$

For M 25 Concrete

Modular ratio,

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 8.5} = 10.98 = 11$$

Now for actual depth of neutral axis,

Moment of area of tension side should be equal to moment of area of compression side.

Assume neutral axis lies in the flange portion.

$$\therefore \quad B_f X_a \frac{X_a}{2} = mA_{st}(d - X_a)$$

$$\Rightarrow \quad 2342\frac{X_a^2}{2} = 11 \times 1608.50 \times (470 - X_a)$$

$$1171X_a^2 = 17693.5(470 - X_a)$$

$$1171X_a^2 + 17693.5X_a - 8315945 = 0$$

$$X_a = 77.05 < D_f \text{ (hence ok)}$$

$\therefore$ Moment of residence,

$$M = \frac{1}{2}C_a B_f X_a\left(d - \frac{X_a}{3}\right)$$

$$= \frac{1}{2} \times 8.5 \times 2342 \times 77.05\left(470 - \frac{77.05}{3}\right)$$

$$= 340.75 \times 10^6 \text{ N/mm}$$

$$= 340.75 \text{ kNm}$$

Critical depth of neutral axis can be calculated using

$$X_c = \frac{m\sigma_{cbc}}{\sigma_y + m\sigma_{cbc}} \times d$$

$$= \frac{11 \times 8.5}{230 + (11 \times 8.5)} \times 470$$

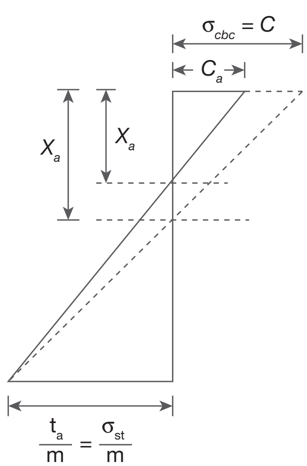
$$= 135.84 \text{ mm}$$

$$\therefore \quad X_a < X_c$$

Beam is under reinforced

$$\therefore \quad C_a < \sigma_{cbc} \text{ or } C$$

and $\quad \frac{t_a}{m} = \frac{\sigma_{at}}{m}$



Moment of resistance can be calculated as

$$M = \sigma_{st} A_{st}\left(d - \frac{X_a}{3}\right)$$

$$= 230 \times 1608.50\left(470 - \frac{77.05}{3}\right)$$

$$= 164.38 \times 10^6 \text{ Nmm}$$

$$= 164.38 \text{ kNm}$$

$$\text{Maximum bending moment} = \frac{Wl^2}{8}$$

$$\Rightarrow \quad 164.38 = \frac{W(8.35)^2}{8}$$

$$\Rightarrow \quad W = 18.86 \text{ kN/m}$$

8. A simply supported beam of a beam and slab system, rests on a support of width 450 mm. The clear span of the beam is 10.0 m. The thickness of the slab is 120 mm. The depth of the beam below the slab is 480 mm and the width of the beam is 250 mm. The beam is reinforced with one row of 32 mm diameter steel rods. The total load including the super imposed dead load, live load an d its own weight is 25.0 kN/m at service stage. Compute the maximum nominal design shear stress in the concrete. **[1997]**

Solution:

Effective span, l_{eff} = Minimum

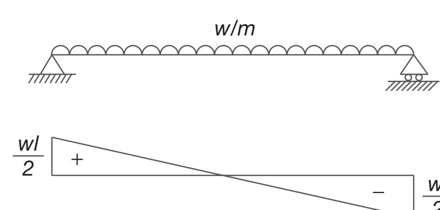
$$l_0 + W = 10 + 0.45 = 10.45$$

$$l_0 + d = 10 + 0.48 = 10.48$$

$$l_{eff} = = 10.45 \text{ m}$$

Maximum shear force,

$$V_{max} = \frac{wL}{2} = \frac{25 \times 10.45}{2} = 130.625 \text{ kN}$$



Shear force diagram

Assume effective cover = 25 mm

Now, effective depth = $(D_1 + D_2 - 25)$

$$= (120 + 480 - 25) = 575 \text{ mm}$$

Nominal shear stress in the beam can be calculated using

$$\tau_v = \frac{V}{bd} = \frac{130.625 \times 1000}{250 \times 575}$$

$$= 0.9 \text{ k/mm}^2$$

Design shear stress for concrete

$$= 0.90 \text{ N/mm}^2$$

9. Design a square RCC column to resist an axial load of 400 kN due to dead load and 240 kN due to live load at service stage. Design the section as a short axially loaded column. Use M 25 concrete and steel of grade 415 N/mm². Give a neat sketch of the cross-section. **[1997]**

Solution:

Axial load for a short axially loaded column is

$$P = \sigma_{SC} A_{SC} + \sigma_{CC} A_C$$

Assume A_{SC} = 1 % of Ag

$$\Rightarrow \quad P = \sigma_{SC} 0.04\, A_g + \sigma_{CC}(A_g - A_{SC})$$

$$= 0.016\, \sigma_{SC} A_g + \sigma_{CC}(0.99 A_g)$$

For M 25 concrete Fe 415 grade of steel

$$\sigma_{CC} = 6 \text{ N/mm}^2 \text{ and } \sigma_{SC} = 190 \text{ N/mm}^2$$

$$\Rightarrow \quad P = 0.01 \times 190 \times A_g + 6 \times 160 \text{ N/mm}^2$$

$$= 640 \times 10^3 = 7.84\, A_g$$

$$A_g = 81632.65 \text{ mm}^2$$

Let us design a square column of size $b \times b$

$$\Rightarrow \quad b = \sqrt{81632.65} = 285.71 \text{ mm}$$

Now provide 16 mm diameter bar

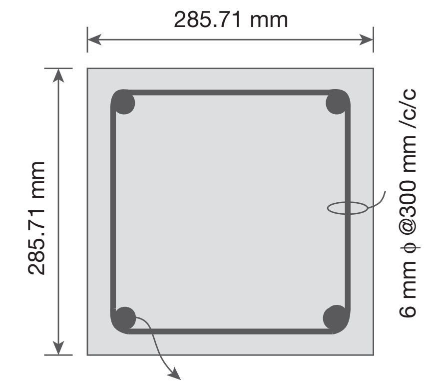
$$\therefore \text{ Number of bars } = \frac{0.01 \times 81632.65}{\frac{\pi}{4}(16)^2} = 4.06 = 4$$

Spring of bar

$$= \frac{1000}{816.32} \times \frac{\pi}{4}(16)^2$$

$$= 246.30 \text{ mm} = 247 \text{ mm}$$

$\therefore$ Provide 16 mmϕ bar @ 247 mm c/c



Transverse reinforcement (Ties)

Diameter of tie bar,

$$\phi = \text{maximum} \begin{cases} \frac{1}{4}\phi_{\text{main}} \\ 6 \text{ mm} \end{cases}$$

$$= \text{maximum} \begin{cases} \frac{1}{4} \times 16 = 4 \text{ mm} \\ 6 \text{ mm} \end{cases}$$

$$\therefore \quad \phi = 6 \text{ mm}$$

Spacing

$$= \text{maximum} \begin{cases} \text{least lateral dimension} = 287.71 \text{ mm} \\ 16\phi_{\text{min}} = 16 \times 6 = 256 \text{mm} \\ 300 \text{mm} \end{cases}$$

$\therefore$ Provide 6 mm ϕ @ 256 mm c/c

3. Footing, Columns, Beams and Slabs

10. Derive the following relations for the limit state design of a balanced rectangular RCC beam **[1996]**

(a) Depth of the neutral axis, $x_u = 0.479$ d

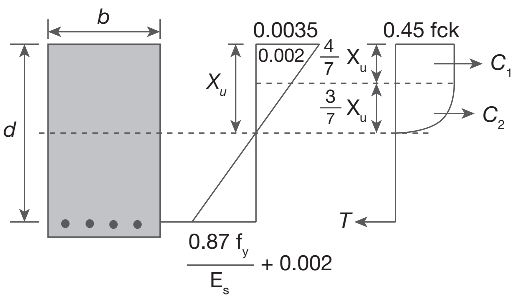
(b) Limiting BM, $M_c = 0.138\, f_{ck} bd^2$

(c) Steel area, $A_s = 4.78 \times 10^{-4} f_{ck} bd$ Where, Width of beam = b Depth of beam = d

Characteristic strength of concrete = f_{ck} MPa Characteristic strength of steel = 415 MPa and modulus of elasticity of steel = 2×10^5 MPa

Solution:

Consider the figure given below



From above given strain diagram we conclude that

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

$$\Rightarrow \quad \frac{d - X_u}{X_u} = \frac{\frac{0.87 f_y}{E_s} + 0.002}{0.035}$$

We know that $f_y = 415$ MPa and $E_s = 2 \times 10^5$ MPa, substituting these values in above equation we get

$$\Rightarrow \quad \frac{d}{X_u} - 1 = \frac{\frac{0.87 f_y}{2\times10^5} + 0.002}{0.0035}$$

$$\Rightarrow \quad \frac{d}{X_u} = 2.0872$$

$$\Rightarrow \quad X_u = 0.479d$$

(b) Limiting BM, $M_{u(llm)} = C$(lever arm)

$$C = C_1 + C_2$$

$$= \left(0.45 f_{ck} \frac{3}{7} \times X_u b\right) + \left(\frac{2}{3} \times 0.45 f_{ck} \frac{4}{7} X_u b\right)$$

$$= 0.19 f_{ck} bX_u + 0.17 f_{ck} bX_u$$

$$= 0.36 f_{ck} bX_u$$

$$C\bar{X} = C_1\bar{X}_1 + C_2\bar{X}_2$$

$$0.19 f_{ck} bX_u \left(\frac{3}{14}\right) + 0.17$$

$$\Rightarrow \quad \bar{X} = \frac{f_{ck} bX_u \left(\frac{3}{8} \times \frac{4}{7} + \frac{3}{7}\right) X_u}{0.36 f_{ck} bX_u}$$

∴ Lever arm = d - 0.42 X_u

So from eq. (i)

$$M_{u|lm} = 0.36 f_{ck} bX_u (d - 0.42 X_u)$$

$$= 0.36 f_{ck} b \times 0.479d(d - 0.92 \times 0.479d)$$

$$= 0.138 f_{ck} bd^2$$

(c) $C = T$

$$\Rightarrow \quad 0.36 f_{ck} bX_u = 0.87 f_y A_S$$

$$\Rightarrow \quad 0.36 f_{ck} b(0.479d) = 0.87 \times 415 \text{ As}$$

$$\Rightarrow \quad A_S = 4.78 \times 10^{-4} f_{ck} bd$$

Chapter 4

Design for Shear, Bond and Torsion

One-mark Questions

1. As per IS 456 – 2000 for the design of reinforced concrete beam, the maximum allowable shear stress (τ_{cmax}) depends on the **[2016]**

(a) grade of concrete and grade of steel
(b) grade of concrete only
(c) grade of steel only
(d) grade of concrete and percentage of reinforcement

Solution: (b)
By IS 456:2000

$$\tau_{c_{\max}} = 0.62\sqrt{f_{ck}}$$

$\tau_{a_{\max}}$ depends on grade of concrete only.

Hence, the correct option is (b).

2. The development length of a deformed reinforcement bar can be expressed as $(1/k)$ $(\Phi\ \sigma_s/\tau_{bd})$. From the IS:456-2000, the value of k can be calculated as _______. **[2015]**

Solution: 6.4
As per is = 456 – 2000
Development length

$$Ld = \frac{\phi T_s}{4T_{bd}}$$

For deformed bars, T_{bd} is increased by 60% as per code.

$$\therefore \quad Ld = \frac{\phi\sigma_s}{4\times 1.6T_{bd}}$$

$$\therefore \quad K = 4 \times 1.6$$

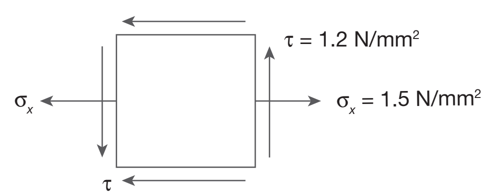
$$K = 6.4$$

Hence, the answer is 6.4.

3. The state of two dimensional stress acting on a concrete lamina consists of a direct tensile stress, σ_x = 1.5 N/mm², and shear stress τ = 1.20 N/mm², which cause cracking of concrete. Then the tensile strength of the concrete in N/mm² is **[2003]**

(a) 1.5 (b) 2.08
(c) 2.17 (d) 2.29

Solution: (c)



Direct tensile stress, $\sigma_x = 1.5\ \text{N/mm}^2$

Shear stress, $\tau = 1.20\ \text{N/mm}^2$

The major and minor principle stresses are given by

$$\sigma_{1,3} = \frac{\sigma_x + \sigma_y}{2} \pm \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}$$

$$= \frac{1.5}{2} \pm \frac{1}{2}\sqrt{(1.5)^2 + 4(1.2)^2}$$

$$= 0.75 \pm \frac{1}{2}\sqrt{2.25 + 5.76} = 0.75 \pm 1.42$$

$$\sigma_1 = 0.75 + 1.42 = 2.17 \text{ N/mm}^2$$

Hence, the correct option is (c).

4. Consider the following two statements related to reinforced concrete design, and identify whether they are TRUE or FALSE: **[2001]**

I. Curtailment of bars in the flexural tension zone in beams reduces the shear strength at the cut-off locations.

II. When a rectangular column section is subject to biaxially eccentric compression, the neutral axis will be parallel to the resultant axis of bending.

(a) Both statements I and II are TRUE.
(b) Statement I is TRUE, and Statement II is FALSE.
(c) Statement I is FALSE, and statement II is TRUE.
(d) Both Statements I and II are FALSE.

Solution: (b)

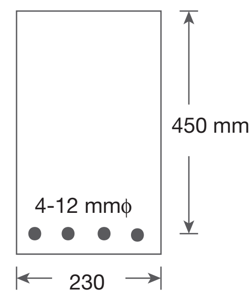
Shear strength of concrete (τ_c) depends on the percentage of tensile steel reinforcement. Therefore, curtailment of bars in the flexural tension zone reduces shear strength at the cutoff locations.
Statement I is true.
When a rectangular column section is subjected to biaxially eccentric compression, the neutral axis is not parallel to the resultant axis of the bending. *i.e.,* Biaxial bending about diagonal axis.
Statement II is false.
Hence, the correct option is (b).

Two-marks Questions

1. A rectangular beam of width (b) 230 mm and effective depth (d) 450 mm is reinforced with four bars of 12 mm diameter. The grade of concrete is M 20 and grade of steel is Fe 500. Given that for M 20 grade of concrete the ultimate shear strength, $\tau_{uc} = 0.36 \text{ N/mm}^2$ for steel percentage, p = 0.25, and $\tau_{uc} = 0.48 \text{ N/mm}^2$ for steel p = 0.5. For a factored shear force of 45 kN, the diameter (in mm) of Fe 500 steel two legged stirrups to be used at spacing of 325 mm, should be **[2014]**

(a) 8 (b) 10
(c) 12 (d) 16

Solution: (a)



Width of beam, $b = 230 \text{ mm}$

Effective depth, $d = 450 \text{ mm}$

Steel reinforcement = 4 bars of 12 mm ϕ

$$f_{ck} = 20 \text{ N/mm}^2$$

$$f_y = 500 \text{ N/mm}^2$$

Shear strength of concrete $\tau_c = 0.36 \text{ N/mm}^2$ for $p = 0.25\%$

$$= 0.48 \text{ N/mm}^2 \text{ for } p = 0.5\%$$

Factored shear force, $V_u = 45 \text{ kN}$

Diameter of stirrups $= 8 \text{ mm}$

Spacing of 2 legged stirrups, $s_v = 325 \text{ mm}$

Nominal shear stress,

$$\tau_v = \frac{V_u}{bd} \frac{45 \times 10^3}{230 \times 450} = 0.44 \text{ N/mm}^2$$

Percentage of tensile steel reinforcement,

$$p = \frac{100 A_{st}}{bd} = \frac{100 \times 4 \times 113}{230 \times 450} = 0.433\%$$

Shear strength of concrete,

$$\tau_c = 0.36 + \frac{0.48 - 0.36}{0.50 - 0.25}(0.433 - 0.25)$$

$$= 0.45 \text{ N/mm}^2$$

Since $\tau_v < \tau_c$, minimum shear reinforcement is to be provided.
Minimum area of shear reinforcement is given by

$$\frac{A_{sv}}{bS_v} \ge \frac{0.4}{0.87 f_y}$$

$$A_{sv} \geq \frac{0.4 \times 230 \times 325}{2 \times 0.87 \times 500} \geq 34.35 \text{ mm}^2$$

$$\frac{\pi\phi^2}{4} \geq 34.35 \Rightarrow \quad \phi \geq 6.61 \text{ mm}$$

Therefore, provide 8 mm diameter steel bars as stirrups.
Hence, the correct option is (a).

2. As per IS:456-2000 for M 20 grade concrete and plain bars in tension the design bond stress τ_{bd} = 1.2 MPa. Further, IS 456:2000 permits this design bond stress value to be increased by 60% for HSD bas. The stress in the HSD reinforcing steel bars in tension, σ_s = 360 MPa. Find the required development length, L_d, for HSD bars in terms of the bar diameter, ϕ. **[2013]**

Solution: 46.875ϕ
Grade of concrete: M 20
Bond stress, $\tau_{bd} = 1.2 \text{ N/mm}^2$

Bond stress τ_{bd} increased by 60% for HSD bars.

Stress in HSD reinforcing steel bar in tension,

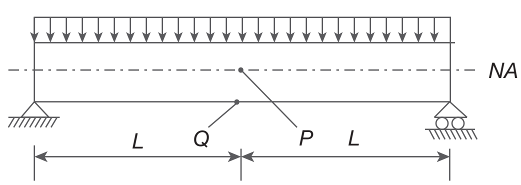
$$\sigma_s = 360 \text{ MPa}$$

Development length, $L_d = \dfrac{\phi\sigma_s}{4\tau_{bd}}$

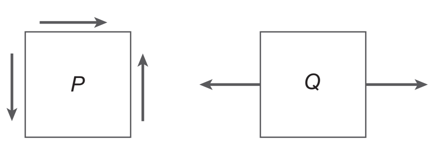
$$= \frac{\phi.360}{4 \times 1.2 \times 1.6} = 46.875\phi$$

Hence, the answer is 46.875ϕ.

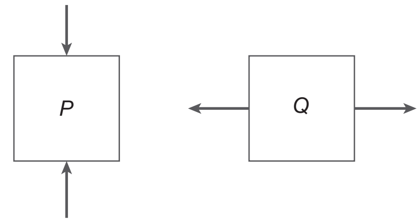
3. Consider a simply supported beam with a uniformly distributed load having a neutral axis (NA) as shown. For points P (on the neutral axis) and Q (at the bottom of the beam) the state of stress is best represented by which of the following pairs? **[2011]**



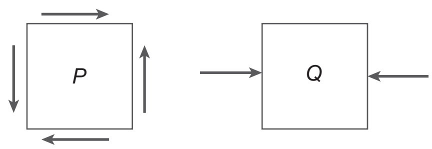
(a)



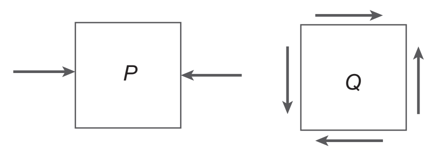
(b)



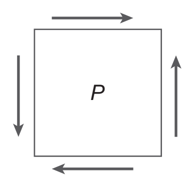
(c)



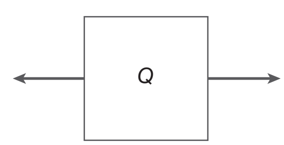
(d)



Solution: (a)

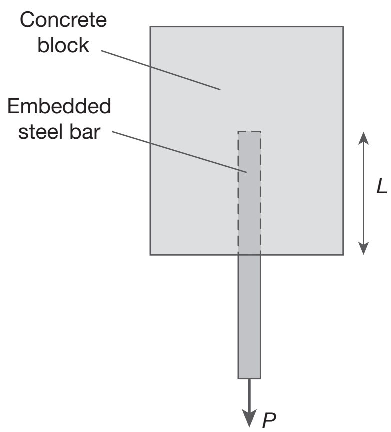


Point P at midspan at NA:
At neutral axis, the bending stress is equal to zero in x direction. At neutral axis, the point is subjected to shear stress.
Point Q at bottom of midspan:
The bending stress is maximum and is tensile in nature. The shear stress at the extreme fibre is equal to zero



Hence, the correct option is (a).

4. Consider a bar of diameter 'D' embedded in a large concrete block as shown in the adjoining figure, with a pull out force P being applied. Let σ_b and σ_{st} be the bond strength (between the bar and concrete) and the tensile strength of the bar, respectively. If the block is held in position and it is assumed that the material of the block does not fail, which of the following options represents the maximum value of P? **[2011]**



(a) Maximum of $\left(\frac{\pi}{4}D^2\sigma_b\right)$ and $(\pi DL\sigma_{st})$

(b) Maximum of $\left(\frac{\pi}{4}D^2\sigma_{st}\right)$ and $(\pi DL\sigma_b)$

(c) Minimum of $\left(\frac{\pi}{4}D^2\sigma_{st}\right)$ and $(\pi DL\sigma_b)$

(d) Minimum of $\left(\frac{\pi}{4}D^2\sigma_b\right)$ and $(\pi DL\sigma_{st})$

Solution: (c)
Maximum pull out force is obtained from
i. Tensile failure of the reinforced bar,

$$P = \frac{\pi D^2}{4}\sigma_{st}$$

ii. Bond failure between concrete and steel,

$$P = \pi DL\sigma_b$$

The maximum value of P is the minimum of (i) and (ii).
Hence, the correct option is (c).

5. Consider two RCC beams, P and Q, each having the section 400 mm × 750 mm (effective depth, d = 750 mm) made with concrete having a τ_{cmax} = 2.1 N/mm^2. For the reinforcement provided and the grade of concrete used, it may be assumed that the τ_c = 0.75 N/mm^2. The design shear in beam P is 400 kN and in beam Q is 750 kN. Considering the provisions of IS 456-2000, which of the following statements is TRUE? **[2011]**

(a) Shear reinforcement should be designed for 175 kN for beam P and the section for beam Q should be revised.

b. Nominal shear reinforcement is required for beam P and the shear reinforcement should be designed for 120 kN for beam Q.

c. Shear reinforcement should be designed for 175 kN for beam P and the shear reinforcement should be designed for 525 kN for beam Q.

d. The sections for both beams P and Q need to be revised.

Solution: (a)
For beams P and Q
Width of beam, b = 400 mm
Effective depth of beam, d = 750 mm
Permissible maximum shear stress,

$$\tau_{c,\max} = 2.1 \text{ N/mm}^2$$

Shear strength of concrete, $\tau_c = 0.75$ N/mm^2

For beam P, design shear = 400 kN

τ_v: Nominal shear stress

$$= \frac{V}{bd} = \frac{400\times10^3}{400\times750} = 1.33 \text{ N/mm}^2 < \tau_{c,\max}$$

V_c: Shear strength of concrete

$$= \tau_c bd = 0.75\times400\times700 = 225 \text{ kN}$$

V_s: Shear to be resisted by steel reinforcement

$$= V - V_c = 400 - 225 = 175 \text{ kN}.$$

Therefore, the beam should be designed for shear reinforcement for 175 kN.
For beam Q, design shear = 750 kN
τ_v: Nominal shear stress

$$= \frac{V}{bd} = \frac{750\times10^3}{400\times750} = 2.5 \text{ N/mm}^2 > \tau_{c,\max}$$

Therefore, the section of the beam Q should be revised.
Hence, the correct option is (a).

6. In the design of a reinforced concrete beam the requirement for bond is not getting satisfied. The economical option to satisfy the requirement for bond is by **[2008]**

(a) bundling of bars
(b) providing smaller diameter bars more in number
(c) providing larger diameter bars less in number
(d) providing same diameter bars more in number

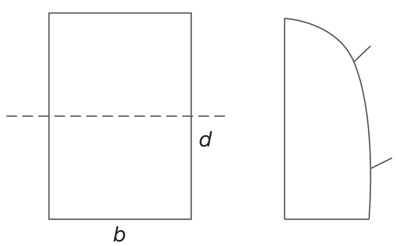
Solution: (b)
The economical option to satisfy the requirement for bond in RCC beams is by providing more number of smaller diameter bars so that the surface area of steel reinforcement in contact with concrete increases and thereby bond stress decreases.

$$\tau_{bd} = \frac{V}{(\sum O)z}$$

Hence, the correct option is (b).

7. Assuming concrete below the neutral axis to be cracked, the shear stress across the depth of a singly-reinforced rectangular beam section, **[2006]**
(a) increases parabolically to the neutral axis and then drops suddenly to zero value.
(b) increases parabolically to the neutral axis and then remains constant over the remaining depth
(c) increases linearly to the neutral axis and then remains constant up to the tension steel
(d) increases parabolically to the neutral axis and then remains constant up to the tension steel.

Solution: (d)



Singly-reinforced tectangular beam   Shear Stress distribution

Shear stress across the depth of a singly reinforced rectangular beam section increases parabolically to the neutral axis and then remains constant up to the tension steel.
Hence, the correct option is (d).

Data for Questions 8–9 given below. Solve the problems and choose the correct answers.
At the limit state of collapse, an R.C. beam is subjected to flexural moment 200 kN-m, shear force 20 kN and torque 9 kN-m. The beam is 300 mm, wide and has a gross depth of 425 mm, with an effective cover of 25 mm. The equivalent nominal shear stress (τ_{ve}) as calculated by using the design code turns out to be lesser than the design shear strength (τ_c) of the concrete. **[2004]**

8. The equivalent shear force (V_c) is
(a) 20 kN (b) 54 kN
(c) 56 kN (d) 68 kN

Solution: (d)
Factored moment, $M_u = 200$ kNm

Factored shear force, $V_u = 20$ kN

Factored torque, $T_u = 9$ kNm

Width of beam, $b = 300$ mm

Overall depth of beam, $D = 425$ mm

Effective cover, $d_c = 25$ mm

Equivalent shear force,

$$V_e = V + 1.6\frac{T}{b}$$

$$= 20 + 1.6 \times \frac{9}{0.3} = 20 + 48 = 68 \text{ kN}$$

Hence, the correct option is (d).

9. The equivalent flexural moment (M_{eq}) for designing the longitudinal tension steel is
(a) 187 kN-m (b) 200 kN-m
(c) 209 kN-m (d) 213 kN-m

Solution: (d)
Equivalent flexural moment,

$$M_{eq} = M + \frac{T}{1.7}\left(1 + \frac{D}{B}\right)$$

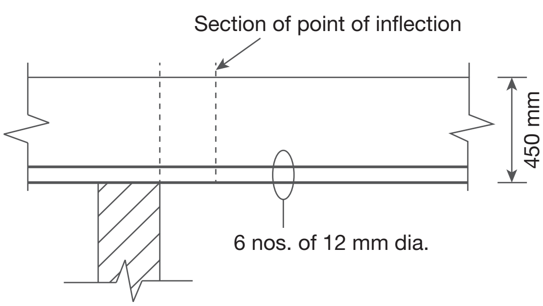
$$M_{eq} = 200 + \frac{9}{1.7}\left(1 + \frac{425}{300}\right) = 200 + 12.8$$

$$= 212.8 \text{ kNm} \approx 213 \text{ kNm}$$

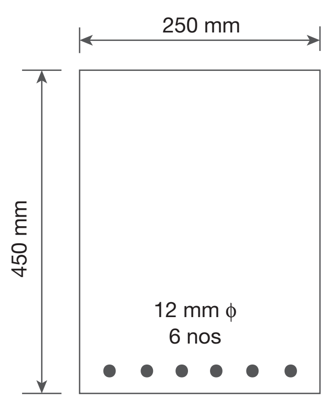
Hence, the correct option is (d).

FIVE-MARKS QUESTIONS

1. A continuous beam 250 mm × 450 mm carries 6 numbers of 12 mm diameter longitudinal bars as shown. The factored shear force at the point of inflection is 200 kN. Check, if the beam is safe in bond. Assume M 15 mix with f_{ck} = 15 N/mm2 and mild steel with f_y = 250 N/mm². A clear cover of 25 mm can be assumed. The design bond stress for mild steel bars for M 15 concrete is specified to be 1.0 N/mm². **[2000]**



Solution:
Consider the figure given below



(a) At point A, Mu = 0 and Pu is maximum, so failure occurs due to axial compression.

At point C, Pu = 0, and Mu is non zero, so failure occur due to bending only.

(b) Portion AB is known as compression zone and Torfion BC Is known ascension zone.

(c) In region BC, region of tension failure at C, the ultimate moment is Mu while the ultimate axial load is zero. As load is of tension in nature, it produce negative moment and then

Bending moment can be expressed as

$$M = 0.87 f_y A_{st}\left(d - \frac{f_y}{f_{ck}}\frac{A_{st}}{b}\right)$$

Area of steel can be calculated using

$$A = 6\times\frac{\pi}{4}\times(12)^2 = 678.6 \text{ mm}^2$$

We know that effective depth

$$d = 450 - 25 - \frac{12}{2} = 419 \text{ mm}$$

$$\therefore \quad M = 0.87\times 250\times 678.6 \left(419 - \frac{250}{15}\times\frac{678.6}{250}\right)$$

$$= 55.16 \text{ kNm}$$

Development length can be calculated using

$$L_d = \frac{\phi\sigma_s}{4\tau_{bd}}$$

$$= \frac{\phi\times 0.87\times 250}{4\times 1} = 54.375\phi$$

Also development length can be expressed as

$$L_d = \frac{M_1}{V} + L_0, L_0 = 0$$

or $$L_d < \frac{55.16}{200}$$

or $$\phi < \frac{55.16}{200}\times\frac{1}{54.375}$$

Since $$\phi < 5$$

Hence, beam is not safe in bond.

Chapter 5

Design of Columns

One-mark Questions

1. Net ultimate bearing capacity of a footing embedded in a clay stratum **[2015]**

(a) increases with depth of footing only
(b) increases with size of footing only
(c) increases with depth and size of footing
(d) is independent of depth and size of footing

Solution:

2. In reinforced concrete, pedestal is defined as compression member, whose effective length does not exceed its dimension by **[1999]**

(a) 12 times (b) 3 times
(c) 16 times (d) 8 times

Solution: (b)
Pedestal is defined as compression member whose effective length does not exceed its least lateral dimension by 3 times.
Hence, the correct option is (b).

3. A reinforced concrete wall carrying vertical loads is generally designed as per recommendations given for columns. The ratio of minimum reinforcements in the vertical and horizontal directions is **[1998]**

(a) 2:1 (b) 5:3
(c) 1:1 (d) 3:5

Solution: (d)
For deformed bars upto 16 mm diameter, minimum reinforcement in vertical and horizontal directions is 0.12 and 0.2% of cross sectional area respectively.
For mild steel, minimum reinforcement in vertical and horizontal directions is 0.15% and 0.25% of cross sectional area respectively.
Minimum reinforcement in vertical to horizontal directions

$$= \frac{0.12\%}{0.20\%} = \frac{12}{20} = \frac{3}{5}$$

Hence, the correct option is (d).

4. The lateral ties in a reinforced concrete rectangular column under axial compression are used to **[1995]**

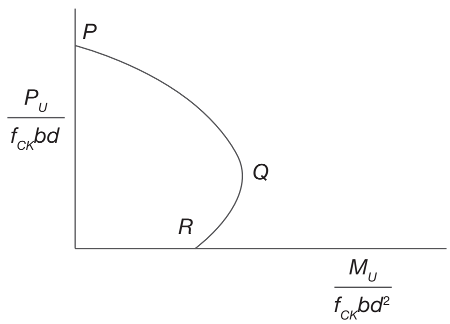
(a) avoid the buckling of the longitudinal steel under compression
(b) provide adequate shear capacity
(c) provide adequate confinement to concrete
(d) reduce the axial deformation of the column

Solution: (a)
Lateral ties in a reinforced concrete rectangular column under axial compression are used

i. to avoid the buckling of the longitudinal steel under compression.
ii. to keep the longitudinal bears in proper position.
iii. to provide adequate confinement to concrete.

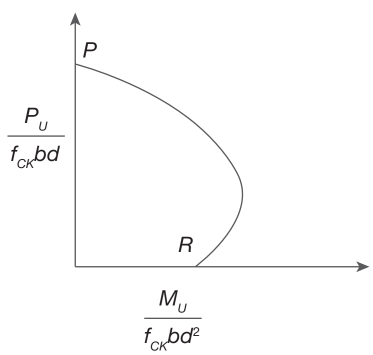
Hence, the correct option is (a).

Common statement for Questions 5 and 6:
Interaction diagram of a rectangular reinforced concrete beam column is shown in figure. With reference to this figure, which of the following statements in 1 and in 2 below are correct? **[1993]**



5. (a) Point Q represents balanced failure
(b) Point R represents balanced failure
(c) Point P represents balanced failure
(d) Point Q represents balanced failure under maximum eccentric compression.

Solution: (a)



R: Column subjected to only moment
Q: Balanced failure
P: Column subjected to only axial load
Hence, the correct option is (a).

6. (a) PQ corresponds to the primary tension failure range
(b) QR corresponds to the primary tension failure range
(c) QR corresponds to the primary compression failure range
(d) PQ corresponds to the range of increase in axial force capacity with increase in bending moment capacity

Solution: (b)
PQ: Primary compression failure
QR: Primary tension failure
When the axial compressive load is zero, the column section behaves as a doubly reinforced beam. It is represented by point 'R' and the moment carrying capacity is M_0. As the axial compressive load increases, the moment carrying capacity increases until the balanced section is reached at the point 'Q'.
Hence, the correct option is (b).

Two-marks Questions

1. A 16 mm thick plate 650 mm × 420 mm is used as a base plate for an ISHB 300 column subjected to a factored axial compressive load of 2000 kN. As per IS 456-2000, the minimum grade of concrete that should be used below the base plate for safely carrying the load is **[2011]**
(a) M 15 (b) M 20
(c) M 30 (d) M 40

Solution: (a)
Permissible stress,

$$\sigma_{cbc} = \frac{\text{Load on column}}{\text{plan area of base plate}}$$

Factored load, $P_u = 2000 \text{ kN}$

Size of base plate: $650 \times 420 \text{ mm}$

$$\text{Working load} = \frac{\text{Factored load}}{\text{Factor of safety}}$$

$$= \frac{2000}{1.5} = 1333.33 \text{ kN}$$

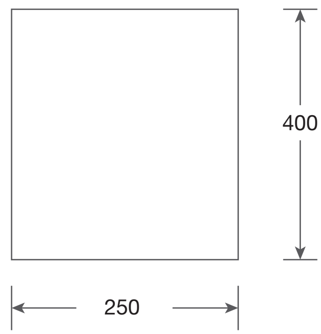
$$\sigma_{cbc} = \frac{1333.33 \times 10^3}{650 \times 420} = 4.88 \text{ N/mm}^2 \approx 5 \text{ N/mm}^2$$

Therefore, minimum grade of concrete : M 15
Hence, the correct option is (a).

2. A rectangular column section of 250 mm × 400 mm is reinforced with five steel bars of grade Fe 500, each of 20 mm diameter. Concrete mix is M 30. Axial load on the column section with minimum eccentricity as per IS : 456-2000 using limit state method can be applied upto **[2005]**
(a) 1707.37 (b) 1805.30
(c) 1806.40 (d) 1903.7

Solution: (a)
Axial load carrying capacity of the column is given by

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$



Characteristic strength of concrete, f_{ck} = 30 N/mm^2
Characteristic strength of steel, f_y = 500 N/mm^2
Area of compression steel reinforcement, A_{sc} = 5 × 314 = 1570 mm^2
Area of concrete, $A_c = A_g - A_{sc}$

$$= 250 \times 400 - 1570 = 98430 \text{ mm}^2$$

$$P_u = 0.4 \times 30 \times 98430 + 0.67 \times 500 \times 1570 = 1707.37 \text{ kN}$$

Hence, the correct option is (a).

3. An R.C. short column with 300 mm × 300 mm square cross-section is made of M20 grade concrete and has 4 numbers, 20 mm diameter longitudinal bars of Fe 415 steel. It is under the action of a concentric axial compressive load. Ignoring the reduction in the area of concrete due to steel bars, the ultimate axial load carrying capacity of the column is **[2004]**

(a) 1659 kN (b) 1548 kN
(c) 1198 kN (d) 1069 kN

Solution: (d)
Size of column = 300 mm × 300 mm
f_{ck} = 20 N/mm^2, f_y = 415 N/mm^2

A_{sc}: Area of steel reinforcement

$$= 4 \times 314 = 1256 \text{ mm}^2$$

P_u: Ultimate load carrying capacity of the column under the action of concentric axial compressive load.

When the minimum eccentricity does not exceed 0.05 D,

$$P_u = 0.4\, f_{ck} A_c + 0.67\, f_y A_{sc}$$
$$= 0.4 \times 20 \times 300 \times 300 + 0.67 \times 415 \times 1256$$
$$= 1069 \text{ kN}$$

Hence, the correct option is (d).

4. The effective length of a column in a reinforced concrete building frame, as per IS : 456-2000, is independent of the **[2003]**

(a) frame type *i.e.,* braced (no sway) or un-braced (with sway)
(b) span of the beam
(c) height of the column
(d) loads acting on the frame

Solution: (d)
The effective length of columns in framed structure may be obtained from the ratio of effective length to unsupported length (l_{eff}/l). Effective length of column depends upon

i. The end conditions
ii. Flexural stiffness ($K_c = EI/L$) of columns joining a point
iii. Flexural stiffness ($K_b = EI/L$) of beams joining a point.
iv. Type of frame (sway or non-sway)

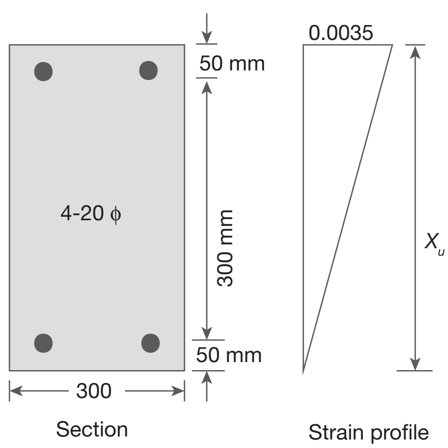
Hence, the correct option is (d).

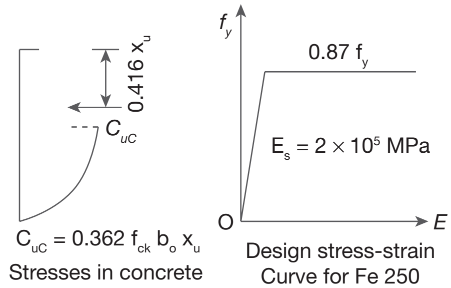
FIVE-MARKS QUESTIONS

1. Give reasons for the following in not more than 20 words: **[2002]**
   (a) A concrete mix is targeted to give higher compressive strength than the required characteristic strength.
   (b) In the case of slabs running over supports, reinforcement needs to be provided on the top in the neighborhood of the supports.
   (c) The load carrying capacity of an RC column with appropriate helical reinforcement can be taken to be slightly higher than that having lateral ties.

   Solution:
   (a) A concrete mix is targeted to give the high compressive stress due to compaction and compressive characters of
   (b) Because the compressive force exerted on the slab is distributed on support through the reinforcement.
   (c) Because in the helical reinforcement number of bars is generally greater than lateral tie and spaced slightly close together.

2. The plan of a reinforced concrete column section, and the distribution of strains at the ultimate limit stage are shown below. The concrete is of M 20 grade and the steel of Fe 250 grade. Sketched below, for convenience, are the concrete compression stress block and the design stress-strain curves for Fe 250, with all notations as per IS 456. Ignore the reduction in concrete area due to the embedded steel. **[2001]**





(a) Determine the ultimate axial compression capacity P_u (in kN units)
(b) Determine the corresponding eccentricity e in mm units) of loading, with respect to the centroidal axis at the ultimate limit state.

Solution:

(a) $T_u = 0.87 f_y A_{st}$

$$= 0.87 \times 250 \times \frac{\pi}{4}(20)^2 \times 4$$

$$= 273318.56 \text{ mm}^2$$

$$P_u = 0.362 f_{ck} X_{ub} + f_{SC} A_{SC}$$

Where, f_{SC} = stress in the compression reinforcement to be read of from stress-strain curve

$$\in_{SC} = \frac{0.0035(x_u - d')}{x_u}$$

Assume

$$\frac{x_u}{d} = 0.4 \text{ or, } x_u = 0.4 \times 350 = 140$$

$$\therefore \quad \in_{SC} = \frac{0.0035(140-50)}{140} = 0.00225$$

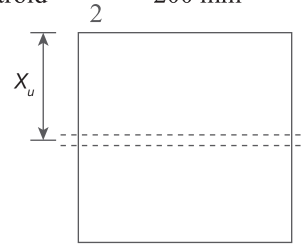
For strain greater than 0.2%

$$F_{sc} = 0.87 f_y = 0.87 \times 250 = 217.5 \text{ N/m}^2$$

$$P_u = 0.362 \times 20 \times 140 \times 300 + 217.5 \times \frac{\pi}{4}(20)^2 \times 4$$

$$= 577398.56 \text{ N} = T_u \text{ (adopt)}$$

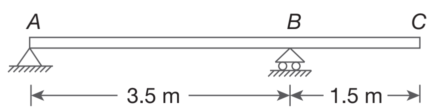
(b) Centroid $= \dfrac{400}{2} = 200$ mm



We know that $x_u = 140$ mm

$$e = \text{Centroid} - x_u$$
$$= 200 - 140 = 60 \text{ mm}$$

3. The effective spans for a simple one way slab system, with an overhang, are indicated in the figure below. The specified ultimate design loads on the slab are 6.0 kN/m^2 and 4.5 kN/m^2 for dead load and live loads respectively. Considering the possibility of live loads not occurring simultaneously on both spans, determine the maximum spacing (in mm units) of 8 mm diameter bars required as bottom reinforcement in the span AB, assuming an effective depth of 125 mm. Assume M 20 concrete and Fe 415 steel. **[2001]**



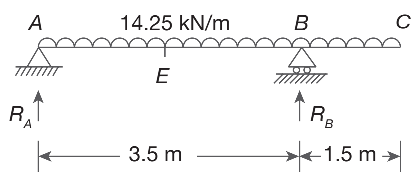
Solution:

we know that $d = 150$ mm

Unit weight of RCC = 25 kN/m^3

Safe weight = 25 × 0.150 kN/m = 3.75 kN/m

Consider the figure given below



We know that

$d_{total} = d_{eff} + \text{clear cover} + \frac{1}{2}$ dia. of bar = 125 + 15 + 4 = 144 mm

Total load = $DL + LL$ + Self weight

$$= 6 + 4.5 + 3.75 = 14.25 \text{ kN/m}$$

Now, $R_B \times 3.5 = 14.25 \times 5 \times 2.5$

or $$R_B = \frac{14.25 \times 5 \times 2.5}{3.5} = 50.89 \text{ kN}$$

∴ $$R_A = 20.36 \text{ kN}$$

Critical moment either at B or mid span of AB (say E)

At $$B\ M_B = 14.25 \times \frac{1.5^2}{2} = 16.03 \text{ kNm}$$

$$M_E = 20.36 \times 1.75 - 14.25 \times \frac{1.75^2}{2}$$

$$= 13.80 \text{ kNm}$$

Again, we know that

$$M_{max} = 16.03 \text{ kNm} = Rbd^2$$

Also we know that, $R = 0.898$

∴ $$d = \sqrt{\frac{16.03 \times 10^6}{0.898 \times 1000}}$$

$$= 133.30 \text{(safe)}$$

$$M = A_{st} jd$$

or $$16.03 \times 10^6 = A_{st} \times 230 \times 90 \times 125$$

or $$A_{st} = 619 \text{ mm}^2$$

Area,

$$A_\phi = \frac{\pi}{4}(8)^2 = 50.3 \text{ mm}^2$$

∴ Spacing of 8 mm bar

$$= \frac{1000 A_\phi}{A_{st}} = \frac{1000 \times 50.3}{619}$$

$$= 81.26 \text{ mm}$$

4. The diameter of a ring beam in water tank is 7.8 m. It is subjected to an outward radial force of 15 kN/m. Design the section using M 25 grade of concrete and Fe 415 reinforcement. **[1998]**

Solution:

The outward radial force cause a hoop tension in the ring beam

∴ Hoop tension in ring beam $\sigma_h = 15$ kN/m

Tensile force can be calculated using

$$P = \sigma_h \frac{D}{2} = 15 \times \frac{7.8}{2} = 58.5 \text{ kN}$$

For Fe 415 grade of steel

$$\sigma_{st} = 230 \text{ N/mm}^2$$

Provide ring of size

Area of steel required can be calculated using

$$A_{st} = \frac{P}{\sigma_{st}} = \frac{58.5 \times 10^3}{230} = 254.347 \text{ mm}^2$$

Provide 16 mm ϕ bars

∴ Number of bars $= \dfrac{254.347}{\frac{\pi}{4}(16)^2} = 1.27 = 2$

∴ Provide - 2 No. of bars of 16 mm diameter.

Actual area of steel provided

$$= \frac{\pi}{4}(16)^2 \times 2 = 402.12 \text{ mm}^2$$
$$\approx 403 \text{ mm}^2$$

Let A = Area of ring beam
Equivalent area of composite section

$$A_{eq} = A + (m-1)A_{st}$$

$$\therefore \quad m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3\times 8.5} = 10.98 = 11$$

$$\therefore \quad A_{eq} = A + (11-1)\times 402.12$$
$$= A + 4021.2$$

Allowing a stress of 1.2 N/mm² in the composite section

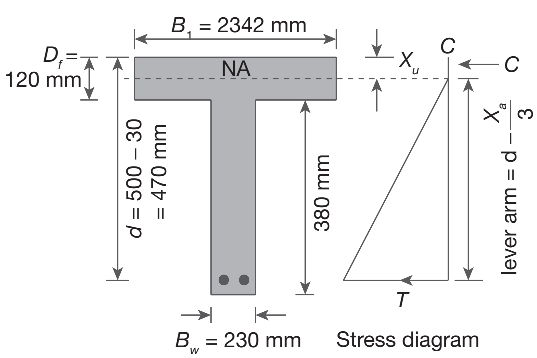
$$\therefore \quad 1.2 = \frac{58.5\times 10^3}{A + 4021.2}$$

$$\Rightarrow \quad A = 4021.2 \text{ mm}^2$$

Provide ring of size = 250 mm × 200 mm
Provide 8 mm ϕ stirrups @ 200 mm c/c to tie the ring.

5. A hall is covered by a beam and slab system with beams placed at 3.0 m centres. The effective span of the beam is 8.35 m. The thickness of the slab is 120 mm. The size of the beam below the slab is 230 mm width and 380 mm depth. The beam is reinforced with two numbers of 32 mm diameter steel rods of grade 415 N/mm². Compute the maximum total load/m run, the beam can carry, including its own weight at service stage. Grade of concrete is M 25. **[1997]**

Solution:
Thickness of slab D_f = 120 mm
Spacing of beam = 3 m
Effective span, l_{eff} = 8.35 m = 230 mm
Consider the figure given below



Area of steel,

$$A_{st} = 2\times \frac{\pi}{4}(32)^2 = 1608.50 \text{ mm}^2$$

Effective width of flange

$$B_{eff} = \frac{l_0}{6} + 6D_1 + B_w$$
$$= \frac{8.35\times 1000}{6} + 6\times 120 + 230$$
$$= 2341.6 = 2342 \text{ mm} = B_1$$

Take an effective cover of 30 mm
∴ Effective depth,

$$d = 500 - 30 = 470 \text{ mm}$$

For M 25 Concrete
Modular ratio,

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3\times 8.5} = 10.98 = 11$$

Concrete Modular ratio,

280 280

m =

Now for actual depth of neutral axis,
Moment of area of tension side should be equal to moment of area of compression side.
Assume neutral axis lies in the flange portion.

$$\therefore \quad B_f X_a \frac{X_a}{2} = mA_{st}(d - X_a)$$

$$\Rightarrow \quad 2342\frac{X_a^2}{2} = 11\times 1608.50\times(470 - X_a)$$
$$1171X_a^2 = 17693.5(470 - X_a)$$
$$1171X_a^2 + 17693.5X_a - 8315945 = 0$$
$$X_a = 77.05 < D_f \text{ (hence ok)}$$

∴ Moment of residence,

$$M = \frac{1}{2}C_a B_f X_a\left(d - \frac{X_a}{3}\right)$$
$$= \frac{1}{2}\times 8.5\times 2342\times 77.05\left(470 - \frac{77.05}{3}\right)$$
$$= 340.75\times 10^6 \text{ Nmm}$$
$$= 340.75 \text{ kNm}$$

Critical depth of neutral axis can be calculated using

$$X_c = \frac{m\sigma_{cbc}}{\sigma_y + m\sigma_{cbc}} \times d$$

$$= \frac{11 \times 8.5}{230 + (11 \times 8.5)} \times 470$$

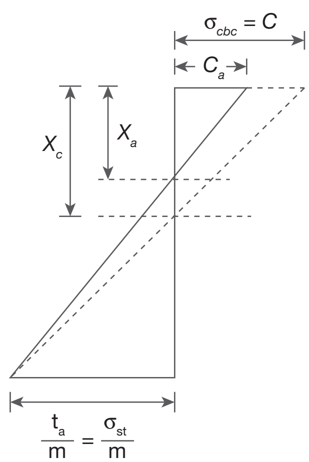
$$= 135.84 \text{ mm}$$

$\therefore$ $X_a < X_c$

Beam is under reinforced

$\therefore$ $C_a < \sigma_{cbc}$ or C

and $\frac{t_a}{m} = \frac{\sigma_{at}}{m}$



Moment of resistance can be calculated as

$$M = \sigma_{st} A_{st}\left(d - \frac{X_a}{3}\right)$$

$$= 230 \times 1608.50\left(470 - \frac{77.05}{3}\right)$$

$$= 164.38 \times 10^6 \text{ Nmm}$$

$$= 164.38 \text{ kNm}$$

Maximum bending moment $= \frac{Wl^2}{8}$

$\Rightarrow$ $164.38 = \frac{W(8.35)^2}{8}$

$\Rightarrow$ $W = 18.86$ kN/m

6. A simply supported beam of a beam and slab system, rests on a support of width 450 mm. The clear span of the beam is 10.0 m. The thickness of the slab is 120 mm. The depth of the beam below the slab is 480 mm and the width of the beam is 250 mm. The beam is reinforced with one row of 32 mm diameter steel rods. The total load including the super imposed dead load, live load an d its own weight is 25.0 kN/m at service stage. Compute the maximum nominal design shear stress in the concrete. **[1997]**

Solution:

Effective span, l_{eff} = Minimum

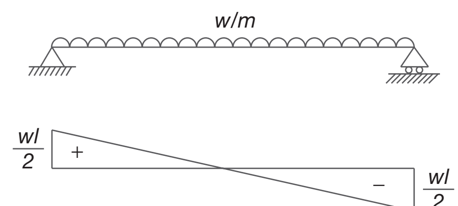
$$l_0 + \text{W} = 10 + 0.45 = 10.45$$

$$l_0 + \text{d} = 10 + 0.48 = 10.48$$

$$l_{eff} = = 10.45 \text{ m}$$

Maximum shear force,

$$V_{\max} = \frac{\text{wL}}{2} = \frac{25 \times 10.45}{2} = 130.625 \text{ kN}$$



Shear force diagram

Assume effective cover = 25 mm

Now, effective depth = $(D_1 + D_2 - 25)$

= (120 + 480 – 25) = 575 mm

Nominal shear stress in the beam can be calculates using

$$\tau_v = \frac{V}{bd} = \frac{130.625 \times 1000}{250 \times 575}$$

$$= 0.9 \text{ k/mm}^2$$

Design shear stress for concrete

$$= 0.90 \text{ N/mm}^2$$

7. Design a square RCC column to resist an axial load of 400 kN due to dead load and 240 kN due to live load at service stage. Design the section as a short axially loaded column. Use M 25 concrete and steel of grade 415 N/mm^2. Give a neat sketch of the cross-section. **[1997]**

Solution:

Axial load for a short axially loaded column is

$$P = \sigma_{SC} A_{SC} + \sigma_{CC} A_C$$

Assume $A_{SC} = 1$ % of Ag

$$\Rightarrow \quad P = \sigma_{SC} 0.04\, A_g + \sigma_{CC}(A_g - A_{SC})$$

$$= 0.016\, \sigma_{SC} A_g + \sigma_{CC}(0.99 A_g)$$

For M 25 concrete Fe 415 grade of steel

$$\sigma_{CC} = 6 \text{ N/mm}^2 \text{ and } \sigma_{SC} = 190 \text{ N/mm}^2$$

$$\Rightarrow \quad P = 0.01 \times 190 \times A_g + 6 \times 160 \text{ N/mm}^2$$

$$= 640 \times 10^3 = 7.84\, A_g$$

$$A_g = 81632.65 \text{ mm}^2$$

Let us design a square column of size $b \times b$

$$\Rightarrow \quad b = \sqrt{81632.65} = 285.71 \text{ mm}$$

Now provide 16 mm diameter bar

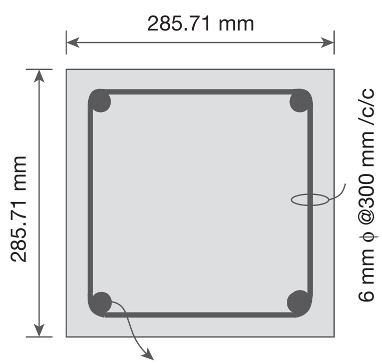
$$\therefore \text{ Number of bars } = \frac{0.01 \times 81632.65}{\frac{\pi}{4}(16)^2} = 4.06 = 4$$

Spring of bar

$$= \frac{1000}{816.32} \times \frac{\pi}{4}(16)^2$$

$$= 246.30 \text{ mm} = 247 \text{ mm}$$

$\therefore$ Provide 16 mmϕ bar @ 247 mm c/c



Transverse reinforcement (Ties)
Diameter of tie bar,

$$\phi = \text{maximum} \begin{cases} \frac{1}{4}\phi_{\text{main}} \\ 6\text{mm} \end{cases}$$

$$= \text{maximum} \begin{cases} \frac{1}{4} \times 16 = 4\text{mm} \\ 6\text{mm} \end{cases}$$

$$\therefore \quad \phi = 6\text{mm}$$

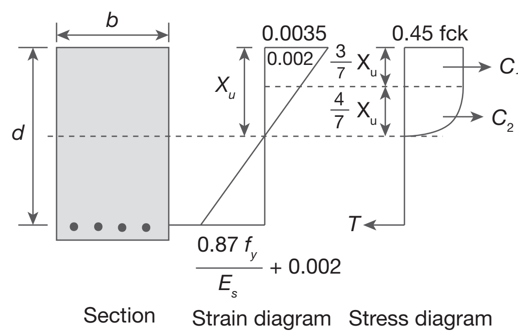
Spacing

$$= \text{maximum} \begin{cases} \text{least lateral dimension} = 287.71 \text{ mm} \\ 16\phi_{\min} = 16 \times 6 = 256 \text{ mm} \\ 300 \text{ mm} \end{cases}$$

$\therefore$ Provide 6 mm ϕ @ 256 mm c/c

8. Derive the following relations for the limit state design of a balanced rectangular RCC beam
(a) Depth of the neutral axis, $x_u = 0.479$ d
(b) Limiting BM, $M_c = 0.138\, f_{ck} bd^2$
(c) Steel area, $A_s = 4.78 \times 10^{-4} f_{ck}$ bd
Where, Width of beam = b Depth of beam = d
Characteristic strength of concrete = f_{ck} MPa Characteristic strength of steel = 415 MPa and modulus of elasticity of steel = 2 × 10⁵ MPa **[1996]**

Solution:
Consider the figure given below



From above given strain diagram we conclude that

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

$$\Rightarrow \quad \frac{d - X_u}{X_u} = \frac{\frac{0.87 f_y}{E_s} + 0.002}{0.035}$$

We know that $f_y = 415$ MPa and $E_s = 2 \times 10^5$ MPa, substituting these values in above equation we get

$$\Rightarrow \quad \frac{d}{X_u} - 1 = \frac{\frac{0.87 f_y}{2 \times 10^5} + 0.002}{0.0035}$$

$$\Rightarrow \quad \frac{d}{X_u} = 2.0872$$

$$\Rightarrow \quad X_u = 0.479d$$

(b) Limiting BM, $M_{u(llm)} = C$(lever arm)

$$C = C_1 + C_2$$

$$= \left(0.45 f_{ck} \frac{3}{7} \times X_u b\right) + \left(\frac{2}{3} \times 0.45 f_{ck} \frac{4}{7} X_u b\right)$$

$$= 0.19 f_{ck} bX_u + 0.17 f_{ck} bX_u$$

$$= 0.36 f_{ck} bX_u$$

$$C\bar{X} = C_1\bar{X}_1 + C_2\bar{X}_2$$

$$0.19 f_{ck} bX_u \left(\frac{3}{14}\right) + 0.17$$

$$\Rightarrow \quad \bar{X} = \frac{f_{ck} bX_u \left(\frac{3}{8} \times \frac{4}{7} + \frac{3}{7}\right) X_u}{0.36 f_{ck} bX_u}$$

$\therefore$ Lever arm = d – 0.42 X_u

So from eq. (1)

$$M_{u|lm} = 0.36 f_{ck}\, bX_u\, (d - 0.42X_u)$$

$$= 0.36 f_{ck} b \times 0.479d\, (d - 0.92 \times 0.479d)$$

$$= 0.138\ f_{ck} bd^2$$

(c) $$C = T$$

$$\Rightarrow \quad 0.36 f_{ck}\, bX_u = 0.87 f_y A_S$$

$$\Rightarrow \quad 0.36 f_{ck} b(0.479d) = 0.87 \times 415\ As$$

$$\Rightarrow \quad A_S = 4.78 \times 10^{-4} f_{ck} bd$$

Chapter 6

Prestressed Concrete

Two-marks Questions

1. A rectangular concrete beam 250 mm wide and 600 mm deep is pre-stressed by means of 16 high tensile wires, each of 7 mm diameter, located at 200 mm from the bottom face of the beam at a given section. If the effective pre-stress in the wires is 700 MPa, what is the maximum sagging bending moment (in kNm) (correct to 1-decimal place) due to live load that this section of the beam can withstand without causing tensile stress at the bottom face of the beam? Neglect the effect of dead load of beam. **[2013]**

Solution: 86.24

Width of beam, $b = 250$ mm

Depth of beam, $D = 600$ m

Cross sectional area, $A = 250 \times 600 = 15 \times 10^4$ mm^2

Area of prestressing steel $= 16 \times 38.5 = 616$ mm^2

Eccentricity, $e = 300 - 200 = 100$ m

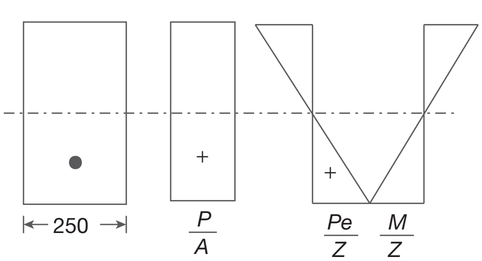
Effective prestress, $f_p = 700$ MPa

Maximum sagging bending moment, $M = ?$

Prestressing force, $P = 616 \times 700 = 431.2$ kN

Section modulus,

$$Z = \frac{250 \times 600^2}{6} = 15 \times 10^6 \text{ mm}^4$$



Stress at the bottom fibre, $\sigma_b = \frac{P}{A} + \frac{pe}{Z} - \frac{M}{Z} = 0$

$$\frac{431.2 \times 10^3}{15 \times 10^4} + \frac{431.2 \times 10^3 \times 100}{15 \times 10^6} - \frac{M}{15 \times 10^6} = 0$$

$$M = 86.24 \times 10^6 \text{ Nmm} = 86.24 \text{ kNm}$$

Hence, the answer is 86.24.

2. Which one of the following is categorized as a long-term loss of prestress in a prestressed concrete member? **[2012]**

(a) Loss due to elastic shortening

(b) Loss due to friction

(c) Loss due to relaxation of strands

(d) Loss due to anchorage slip

Solution: (c)

Long term loss of prestress in prestressed concrete member are:

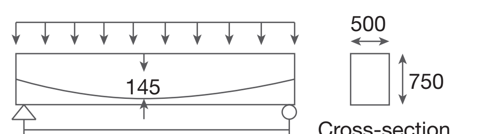
Loss due to relaxation of stress in steel

Loss due to shrinkage

Loss due to creep

Hence, the correct option is (c).

3. A concrete beam prestressed with a parabolic tendon is shown in the sketch. The eccentricity of the tendon is measured form the centroid of the cross-section. The applied prestressing force at service is 1620 kN. The uniformly distributed load of 45 kN/m includes the self-weight. **[2012]**



Sectional elevation

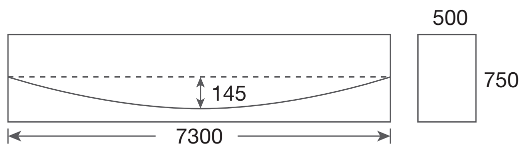
Cross-section (tendon not shown)

All dimension are in mm

The stress (in N/mm^2) in the bottom fibre at mid-span is

(a) Tensile 2.90 (b) Compressive 2.90
(c) Tensile 4.32 (d) Compressive 4.32

Solution: (b)



Stress at bottom fibre at mid span,

$$f_b = \frac{P}{A} + \frac{Pe}{Z} - \frac{M_g}{Z}$$

Cross sectional area, $A = 500 \times 750 = 375 \times 10^3$ mm^2
Section modulus,

$$Z = \frac{1}{6}bD^2 = \frac{1}{6} \times 500 \times 750^2 = 46875 \times 10^3 \text{ mm}^3$$

Prestressing force, P = 1620 kN
Eccentricity at mid span, e = 145 mm
Moment due to udl,

$$M_g = \frac{wl^2}{8} = \frac{45 \times 7.3^2}{8} = 299.75 \text{ kNm}$$

$$f_b = \frac{1620 \times 10^3}{375 \times 10^3} + \frac{1620 \times 10^3 \times 145}{46875 \times 10^3} - \frac{299.75 \times 10^6}{46875 \times 10^3}$$

$$= 4.32 + 5.01 - 6.40 = 2.93 \text{ N/mm}^2 \text{ (compressive)}$$

Hence, the correct option is (b).

4. As per Indian standard code of practice for pre-stressed concrete (IS:1343-1980) the minimum grades of concrete to be used for post-tensioned and pre-tensioned structural elements are respectively **[2010]**

(a) M 20 for both (b) M 40 and M 30
(c) M 15 and M 20 (d) M 30 and M 40

Solution: (d)

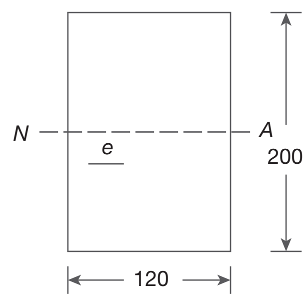
Type of concrete	Minimum grade of concrete
Pre-tensioned prestressed concrete	M 40
Post-tensioned prestressed concrete	M 30

Hence, the correct option is (d).

5. A rectangular concrete beam of width 120 mm and depth 200 mm is prestressed by pre tensioning to a force of 150 kN at an eccentricity of 20 mm. The cross sectional area of the prestressing steel is 187.5 mm^2. Take modulus of elasticity of steel and concrete as 2.1×10^5 MPa and 3.0×10^4 MPa respectively. The percentage loss of stress in the prestressing steel due to elastic deformation of concrete is **[2009]**

(a) 8.75 (b) 6.125
(c) 4.81 (d) 2.19

Solution: (b)



Width of beam, b = 120 mm
Depth of beam, D = 200 mm
Prestressing force, P = 150 kN
Eccentricity, e = 20 mm
Cross sectional area of beam, $A = 120 \times 200 = 24 \times 10^3$ mm^3
Cross sectional area of Prestressing steel, A_s = 187.5 mm^2
Modulus of elasticity of steel, $E_s = 2.1 \times 10^5$ MPa
Modulus of elasticity of concrete, $E_c = 3 \times 10^4$ MPa
Moment of inertia of the section about NA,

$$I = \frac{120 \times 200^3}{12} = 80 \times 10^6 \text{ mm}^4$$

Modular ratio,

$$\alpha = \frac{E_s}{E_c} = \frac{2.1 \times 10^5}{3 \times 10^4} = 7$$

$$\text{Initial stress in steel} = \frac{150 \times 10^3}{187.5} = 800 \text{ N/mm}^2$$

Prestress in concrete at the level of steel,

$$f_c = \frac{P}{A} + \frac{Pe}{I}y$$

$$f_c : \frac{150\times10^3}{120\times200} + \frac{150\times10^3\times20\times20}{80\times10^6} = 6.25 + 0.75$$

$$= 7 \text{ N/mm}^2$$

Loss of stress in prestressing steel = αf_c = 7 × 7 = 49 N/mm^2

% loss of prestress = $\frac{\text{loss of prestress}}{\text{intial stress in steel}} \times 100$

$$= \frac{49}{800} \times 100 = 6.125\%$$

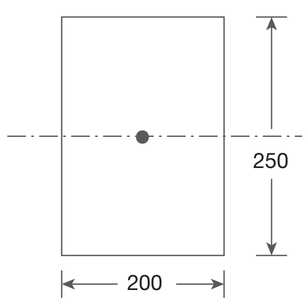
Hence, the correct option is (b).

6. A pre-tensioned concrete member of section 200 mm × 250 mm contains tendons of area 500 mm^2 at the centre of gravity of the section. The pre-stress in tendons is 1000 N/mm^2. Assuming modular ratio as 10, the stress (N/mm^2) in concrete is **[2008]**

(a) 11 (b) 9
(c) 7 (d) 5

Solution: (b)
Width of the beam, b = 200 mm
Depth of the beam, D = 250 mm
Cross sectional area of tendons, A_s = 500 mm^2
Eccentricity, e = 0
Modular ratio, α = 10
Initial prestress in steel, σ = 1000 N/mm^2
Prestressing force, $P = \sigma_c A_s$

= 1000 × 500 = 500 kN



Equivalent area of concrete, $A_c = A + (\alpha - 1)A_s$

= 200 × 250 + (10 – 1) × 500 = 54500 mm^2

Stress in concrete,

$$\sigma_c = \frac{P}{A_c} = \frac{500\times10^3}{54500} = 9.17 \text{ N/mm}^2$$

Hence, the correct option is (b).

7. The percentage loss of prestress due to anchorage slip of 3 mm in a concrete beam of length 30 m which is post-tensioned by a tendon with an initial stress of 1200 N/mm^2 and modulus of elasticity equal to 2.1 × 10^5 N/mm^2 is **[2007]**

(a) 0.0175 (b) 0.175
(c) 1.75 (d) 17.5

Solution: (c)
Anchorage slip, ΔL = 3 mm
Length of concrete beam, L = 30 m
Initial prestress in tendon = 1200 N/mm^2
Modulus of elasticity of steel, E_s = 2.1 × 10^5 N/mm^2

Loss of prestress due to anchorage slip $= \frac{\Delta L}{L} E_s$

$$= \frac{3\times10^{-3}}{30\times10^3} \times 2.1\times10^5 = 21 \text{ N/mm}^2$$

% loss of prestress $= \frac{\text{Loss of prestress}}{\text{Initial prestress}} \times 100$

$$= \frac{21}{1200} \times 100 = 1.75\%$$

Hence, the correct option is (c).

8. A concrete beam of rectangular cross-section of size 120 mm (width) and 200 mm (depth) is pre-stressed by a straight tendon to an effective force of 150 kN at an eccentricity of 20 mm (below the censorial axis in the depth direction). The stresses at the top and bottom fibres of the section are **[2007]**

(a) 2.5 N/mm^2 (compression), 10 N/mm^2 (compression)
(b) 10 N/mm^2 (tension), 2.5 N/mm^2 (compression)
(c) 3.75 N/mm^2 (tension), 3.75 N/mm^2 (compression)
(d) 2.75 N/mm^2 (compression), 3.75 N/mm^2 (compression)

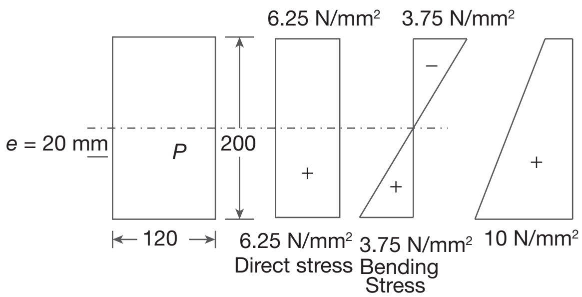
Solution: (a)
Width of beam, b = 120 mm
Depth of beam, d = 200 mm
Effective prestressing force, P = 150 kN
Eccentricity, e = 20 mm
Stress at top, σ_{top} = ?
Stress at bottom, σ_{bot} = ?

Moment of Inertia, $I = \frac{120\times200^3}{12} = 8\times10^8 \text{ mm}^4$

Direct stress due to prestress,

$$\sigma_d = \frac{P}{A}$$

$$= \frac{150 \times 10^3}{120 \times 200} = 6.25 \text{ N/mm}^2$$



Bending stress due to prestress,

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

$$= \frac{150 \times 10^3 \times 20}{8 \times 10^8} \times 100 = 3.75 \text{ N/mm}^2$$

$$\sigma_{top} = \sigma_d - \sigma_b = 6.25 - 3.75 = 2.5 \text{ N/mm}^2 \text{(c)}$$

$$\sigma_{bot} = \sigma_d + \sigma_b = 6.25 + 3.75 = 10.0 \text{ N/mm}^2 \text{(c)}$$

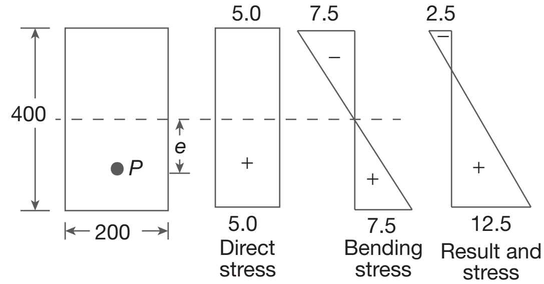
Hence, the correct option is (a).

9. IS:1343-1980 limits the minimum characteristic strength of prestressed concrete for post tensioned works and pretension work as **[2005]**
(a) 25 MPa, 30 MPa respectively
(b) 25 MPa, 35 MPa respectively
(c) 30 MPa, 35 MPa respectively
(d) 30 MPa, 40 MPa respectively

Solution: (d)
The minimum characteristic strength of prestressed concrete as per IS:1343-1980 40 N/mm² for pre-tensioned members and 35 N/mm² for post-tensioned members.
Hence, the correct option is (d).

10. A concrete beam of rectangular cross section of 200 mm × 400 mm is prestressed with a force 400 kN at eccentricity 100 mm. The maximum compressive stress in the concrete is **[2005]**
(a) 12.5 N/mm² (b) 7.5 N/mm²
(c) 5.0 N/mm² (d) 2.5 N/mm²

Solution: (a)



Prestressing force, $P = 400$ kN.
Cross sectional area of beam, $A = 200 \times 400 = 8 \times 10^4$ mm²
Eccentricity, $e = 100$ mm
Section modulus,

$$Z = \frac{200 \times (400)^2}{6} = 5.33 \times 10^6 \text{ mm}^3$$

Maximum compressive stress,

$$\sigma_{\max} = \sigma_d + \sigma_b = \frac{P}{A} + \frac{Pe}{Z}$$

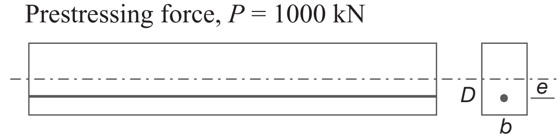
$$= \frac{400 \times 10^3}{8 \times 10^4} + \frac{400 \times 10^3 \times 100}{5.33 \times 10^6}$$

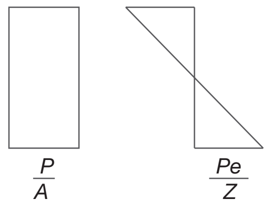
$$= 5 + 7.5 = 12.5 \text{ N/mm}^2$$

Hence, the correct option is (a).

11. A simply supported prestressed concrete beam is 6 m long and 300 mm wide. Its gross depth is 600 mm. It is prestressed by horizontal cable tendons at a uniform eccentricity of 100 mm. The prestressing tensile force in the cable tendons is 1000 kN. Neglect the self weight of beam. The maximum normal compressive stress in the beam at transfer is **[2004]**
(a) Zero (b) 5.55 N/mm²
(c) 11.11 N/mm² (d) 15.68 N/mm²

Solution: (c)
Width of beam, $b = 300$ mm
Overall depth of beam, $D = 600$ mm.
Length of beam, $L = 6$ m.
Eccentricity, $e = 100$ mm
Prestressing force, $P = 1000$ kN





Maximum normal compressive stress,

$$\sigma_{\max} = \frac{P}{A} + \frac{Pe}{Z}$$

Section modulus,

$$Z = \frac{bD^2}{6} = \frac{300 \times 600^2}{6} = 18 \times 10^6 \text{ mm}^3$$

Cross sectional area of the beam, $A = 300 \times 600 = 18 \times 10^4$ mm^2

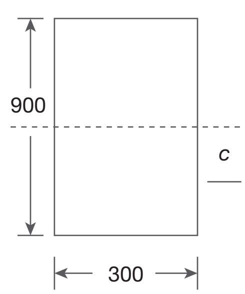
$$\sigma_{\max} = \frac{1000 \times 10^3}{18 \times 10^4} + \frac{1000 \times 10^3 \times 100}{18 \times 10^6} = 11.11 \text{ N/mm}^2$$

Hence, the correct option is (c).

12. A prestressed concrete rectangular beam of size 300 mm × 900 mm is prestressed with an initial prestressing force of 700 kN at an eccentricity of 350 mm at midspan. Stress at top of the beam due to prestress alone, in N/mm^2, is **[1997]**

(a) –3.469(tension)
(b) 2.59(compression)
(c) zero
(d) 8.64(compression)

Solution: (a)



Breadth of beam, b = 30 mm
Overall depth of beam, D = 900 mm
Initial prestressing force, P = 700 kN
Eccentricity, e = 350 mm

Stress at top due to prestress, $f_{\text{top}} = \frac{P}{A} - \frac{Pe}{Z_t}$

$$f_{\text{top}} = \frac{700 \times 10^3}{300 \times 900} - \frac{700 \times 10^3 \times 350}{\frac{1}{6} \times 300 \times 900^2}$$

$= 2.59 - 6.05 = -3.46$ N/mm^2

$= 3.46$ N/mm^2 (tensile)

Hence, the correct option is (a).

13. The loss of prestress due to elastic shortening of concrete is least in **[1992]**

(a) one wire pre-tensioned beam
(b) one wire post-tensioned beam
(c) multiple wire pre-tensioned beam with sequential cutting of wires
(d) multiple wire post-tensioned beam subjected to sequential prestressing

Solution: (b)

In pre-tensioning, Loss of prestress due to elastic shortening of concrete = αf_c

α: Modular ratio

f_c: Stress in concrete at the level of prestressing steel

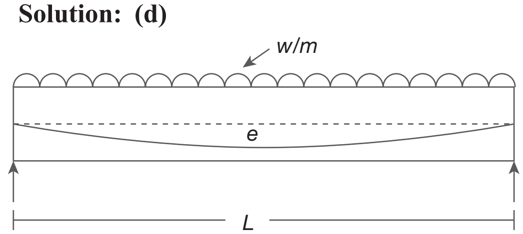
In post-tensioning, there is no loss of prestress due to elastic shortening of concrete if all the wires are tensioned simultaneously. When the wires are tensioned successively, the stretched wire is shortened by the subsequent stretching of all the other tendons, and the last tendon is not shortened by any subsequent stretching. No loss of stress due to elastic shortening in the last wire stretched. When there is only one wire in post tensioned prestressed concrete, no loss of stress due to elastic shortening of concrete.

Hence, the correct option is (b).

14. A uniformly distributed load intensity w acting on a simply supported prestressed concrete beam of span L producing a bending moment M at mid-span is to be balanced by a parabolic tendon with zero eccentricity e at mid-span. The prestressing force required depends on **1992]**

(a) w and e
(b) w and l
(c) L and e
(d) M and e

Solution: (d)



L: Span of the beam
M: Bending moment at mid span
Cable profile: Parabolic tendon
Using the load balancing concept,
Moment induced by the cable at mid span = Bending moment at mid span

$$Pe = \frac{wL^2}{8}$$

Pre-stressing force P depends on w,L and e. *ie., e* and M
Hence, the correct option is (d).

15. A prestressed concrete beam has a cross-section with the following properties:
Area $A = 46{,}400\ \text{mm}^2$, $I = 75.8 \times 10^7\ \text{mm}^4$, $y_{\text{bottom}} = 244$ mm, $y_{\text{top}} = 156$ mm. It is the subjected to a prestressing force at an eccentricity 'e' so as to have a zero stress at the top fibre. The value of 'e' is given by **[1991]**

(a) 66.66 mm (b) 66.95 mm
(c) 104.72 mm (d) 133.33 mm

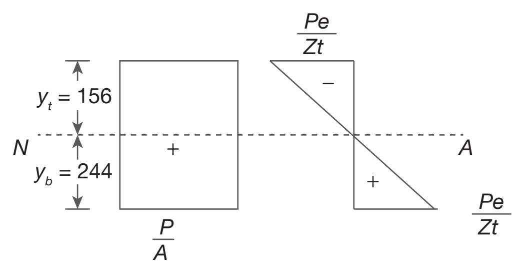
Solution: (c)
Cross sectional area of beam, $A = 46{,}400\ \text{mm}^2$
Moment of inertia of the section about NA, $I = 75.8 \times 10^7\ \text{mm}^4$
Distance of extreme bottom fibre from NA, $y_b = 244$ mm
Distance of extreme top fibre from NA, $y_t = 156$ mm

Section modulus about top $= \frac{I}{y_t} = \frac{75.8\times10^7}{156}$
$= 48.59\times10^5\ \text{mm}^3$

Eccentricity = e
Stress at top fibre, $\sigma_t = 0$

$$\sigma_t = \frac{P}{A} - \frac{Pe}{Z_t}$$

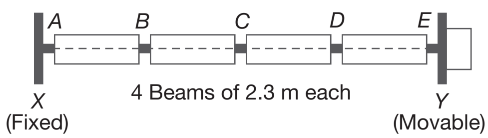
$$e = \frac{Z_t}{A} = \frac{48.59\times10^5}{46,400} = 104.72\ \text{mm}$$



Hence, the correct option is (c).

Five-marks Questions

1. A 10 m long prestressing bed is used to cast 4 (pretensioned) prestressed concrete beams of 2.3 m each. A schematic representation of the bed is given in the following figure. The continuous prestressing reinforcement is pulled at the end V of the bed through a distance of 20 mm to introduce the required 'prestress' before the concrete is cast. After the concrete has hardened, the prestressing reinforcement is cut at points, A, B, C, D and E. Assuming that the prestress is introduced without eccentricity, what is the loss in prestress on account of elastic deformation of concrete. Assume E_s = 200,000 N/mm². E_c = 20,000 N/mm², Area of prestressing reinforcement 500 mm², size of beams = 200 mm (b) × 400 mm (h) **[2002]**



Solution:
Given
E_s = 200,000 N/mm².
E_c = 20,000 N/mm²
Area of prestressing reinforcement 500 mm²
size of beams = 200 mm (b) × 400 mm (h)
Now using the relation

$$\sigma_e = \frac{E_s}{E_c} = \frac{200000}{20000} = 10$$

Strain in steel $= \dfrac{\Delta l}{l} = \dfrac{20}{10 \times 1000}$

Stress in steel,

$$= \frac{200000 \times 20}{1000} = 400 \text{ N/mm}^2$$

Tensile force in steel,

P = Stress × Area
= 400 × 500 = 200 kN

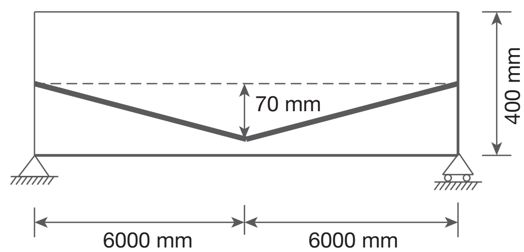
Stress in concrete at the level of steel

$$f_c = \frac{P}{A}$$
$$f_c = \frac{200 \times 1000}{200 \times 400} = 2.5 \text{ N/mm}^2$$

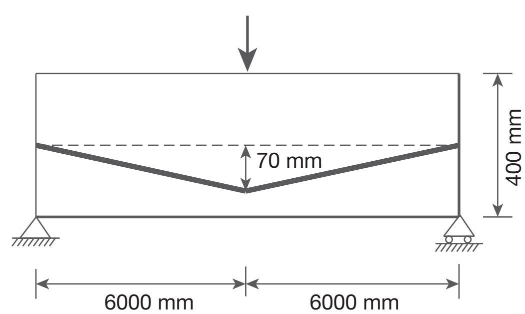
Loss due to elastic deformation

$= f_c \alpha$
= 2.5 × 10 = 25 N/mm²

2. A simply supported rectangular prestressed concrete beam 200 mm wide and 400 mm deep has an effective span of 12 m. The prestressing cable has a triangular profile with zero eccentricity at ends and 70 mm at the midspan as shown in the figure below. The effective prestressing force is 800 kN after all losses. Determine the value of a point load, the beam can support at the midspan if the pressure line passes through the upper kern of the section. The weight density of the material of the beam can be taken to be 25 kN/m³.



Solution:
Width of beam b = 200 mm
Depth of beam d = 400 mm,
Length of beam L = 12 m
eccentricity e = 70 mm at mid span
eccentricity = 0 at ends
Effective prestress, P = 800 kN
weight density of the material of the beam Y_c= 25 kN/m³
W = ? (At mid span)
Consider the figure given below



Area of cross-section,

$A- = bd$ = 200 × 400 = 80 × 103 mm²

And

$$I = \frac{1}{12}bd^3 = \frac{1}{12} \times 200 \times (400)^3$$
$$= 1.067 \times 10^9 \text{ mm}^4$$

At mid span

$$e = 70 \text{ mm}$$

$\Rightarrow$ $y_t = 200$ mm

and $y_b = 200$ mm

$$\Rightarrow \quad Z_t = \frac{I}{y_t} = \frac{1.067 \times 10^9}{200}$$
$$= 5.335 \times 10^6 \text{ mm}^3$$
$$Z_b = \frac{1.067 \times 10^9}{200} = 5.335 \times 10^6 \text{ mm}^3$$

Hence at service load,

$$\sigma_{\text{bot}} = \frac{P}{A} + \frac{Pe}{Z_b} - \frac{M_d}{Z_b} - \frac{M_l}{Z_b} \qquad (1)$$

Now self weight of beam,

$$w = A \times 1 \; x \; y_c$$
$$= 0.2 \times 0.4 \times 25 \text{ kN/m}^3$$
$$= 2 \text{ kN/m}$$

So dead load moment,

$$M_d = \frac{Wl^2}{8} = \frac{2 \times 12^2}{8} = 36 \text{ kNm}$$

Live load moment,

$$M_l = \frac{Wl}{4} = \frac{W \times 12}{4} = 3 \text{ WkNm}$$

Substituting values in eq. (1), we get

$$\Rightarrow \quad \sigma_{\text{bot}} = \frac{800}{A} + \frac{800 \times 0.07}{Z_b} - \frac{36}{Z_b} - \frac{3W}{Z_b}$$

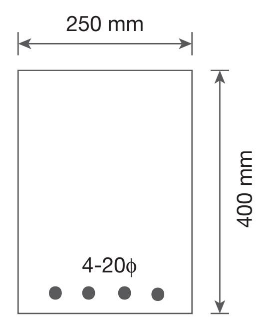
We know that For no tension in beam,

$$\sigma_{\text{bot}} = 0$$
$$\Rightarrow \quad 0 = 800 \times \frac{Z_b}{A} + 800 \times 0.07 - 36 - 3W$$
$$\Rightarrow \quad 3W = 53.35 + 56 - 36$$
$$W = 24.45 \text{ kN}$$

3. The width and depth of a reinforced concrete beam is 250 mm and 400 mm respectively. The beam is provided with 4 Nos. of 20 mm bars in the tension zone. The beam is subjected to a shear force of 150 kN (Factored). Check the requirement of shear reinforcement and provide if required. Grade of concrete is M 20 and that of steel is Fe 415. The shear strength of concrete for different percentages of tensile steel are as below: **[1999]**

% of steel	**Shear strength of concrete (τ_c) in N/mm²**
1.0	0.62
1.25	0.67
1.50	0.72

Solution:



$$A_{st} = 4 \times \frac{\pi}{4} \times 20^2 = 1256.64 \text{ mm}^2$$
$$V_u = 150 \text{ kN}$$

We know that

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

Let effective cover = 40 mm from the underside of the beam,

Thus the Effective depth = 400 – 40 = 360 mm

$$\therefore \quad \tau_v = \frac{150 \times 10^3}{250 \times 360} = 1.67 \text{ N/mm}^2$$

Percentage of steel will be

$$\frac{100A_{st}}{bd} = \frac{1256.64 \times 100}{250 \times 360} = 1.396\%$$

τ_c can be calculated by interpolation from the table given

$$\therefore \quad \tau_c = 0.67 + \left(\frac{0.72 - 0.67}{1.5 - 1.25}\right) \times (1.396 - 1.25)$$
$$= 0.67 + 0.0292$$
$$= 0.6992 \text{ N/mm}^2$$
$$\Rightarrow \quad \tau_v > \tau_c$$

∴ Provide shear reinforcement

$$V_{us} = \frac{0.87 f_y A_{sv} d}{s_v}$$

Also we know that

$$V_{us} = V_u - \tau_c bd$$
$$= 150 \times 10^3 - 0.6992 \times 250 \times 360$$
$$= 87072 \text{ N}$$

Design of vertical stirrups:
Providing 2-legged 8 mm ϕ shear stirrups Area of shear stirrups,

$$A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 32\pi \text{ mm}^2$$

$$\therefore \quad s_v = \frac{0.87 \times f_y \times A_{sv} \times d}{V_{us}}$$

$$\Rightarrow \quad s_v = \frac{0.87 \times 415 \times 32\pi \times 360}{87072}$$
$$= 150.07 \text{ mm}$$

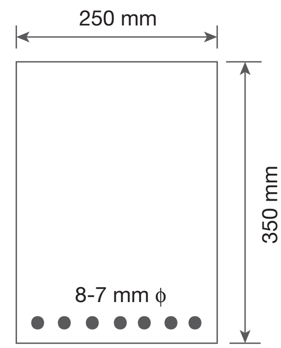
Spacing as per minimum shear reinforcement

$$\frac{A_{sv}}{s_v} \geq \frac{0.4b}{0.87 f_y}$$
$$s_v \leq \frac{0.87 f_y A_{sv}}{0.4b}$$
$$s_v \leq \frac{0.87 \times 415 \times 32 \times \pi}{0.4 \times 250}$$
$$= 362.96 \text{ mm(OK)}$$

∴ Provide 2-legged 8 mm diameter shear stirrups @ 150 mm c/c.

4. A beam with a rectangular cross-section of size 250 mm wide and 350 mm deep is prestressed by a force of 400 kN using 8 nos. 7 mm ϕ steel cables located at an eccentricity of 75 mm. Determine the loss of prestress due to creep of concrete. Grade of concrete is M 40; Coefficient of creep is 2; Stress at transfer is 80%, Modulus of elasticity of steel (E_s) is 2.0×10^5 MPa. **[1999]**

Solution:
Length of beam $D = 350$ mm
Prestressed force, $P = 400$ kN
Area of cross-section, $A = 250 \times 350 = 87500$ mm^2
Width of beam $b = 250$ mm,
8 Nos.– 7ϕ mm bars
Grade of concrete = M 40
Coefficient of creep = 2
Modulus of elasticity of steel, $E_s = 2 \times 10^5$ MPa
Consider the figure given below



Now, Modulus of elasticity of concrete

$$E_c = 5000 \times \sqrt{f_{ck}}$$
$$= 5000 \times \sqrt{40}$$
$$= 3.1622 \times 10^4 \text{ N/mm}^2$$
$$E_s = 2 \times 10^5 \text{ MPa}$$

Modular ratio can be calculated using

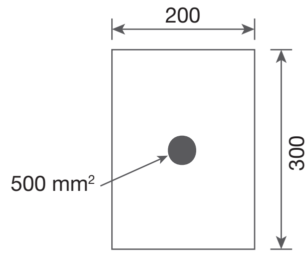
$$m = \frac{E_s}{E_c} = \frac{2 \times 10^5}{3.1622 \times 10^4} = 6.325$$

Prestressing force $P = 400$ kN
Stress at transfer = 80%
Prestressing force a Mransfer- = −0.8 × 400 = 320 kN
Loss of prestress due to creep of concrete = $\phi m f_c$
ϕ = coefficient of creep = 2
m = modular ratio = 6.325
stress in concrete at level of steel, f_c

$$= \frac{P}{A} + \frac{Pe^2}{l}$$
$$= \frac{320 \times 10^3}{87500} + \frac{320 \times 10^3 \times 75^2 \times 12}{250 \times 350^3}$$
$$= 3.6571 + 2.015$$
$$= 5.67 \text{ N/mm}^2$$

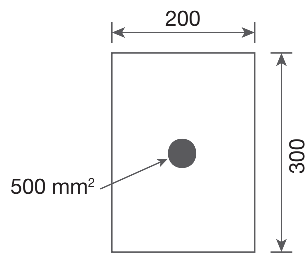
Loss of stress = $\phi m f_c$
$= 2 \times 6.325 \times 5.67$
$= 71.75$ N/mm^2

5. The cross-section of a pretensioned prestressed concrete beam is shown in figure. The reinforcement is placed concentrically. If the stress in steel at transfer is 1000 MPa, compute the stress in steel immediately after transfer. The modular ratio is 6 **[1998]**



Dimensions in mm

Solution:
Consider the figure given below



Dimensions in mm

∴ Area,

$$A = b \times d$$
$$= 200 \times 300$$
$$= 60000 \text{ mm}^2$$

Initial stress in steel

$$= 1000 \text{ MPa}$$
$$= 1000 \text{ N/mm}^2$$

Area of steel placed concentrically

$$= 500 \text{ mm}^2$$

Initial prestressing force,

$$P = 500 \times 1000 = 500{,}000 \text{ N}$$

Modular ratio = 6.0
∴ Direct stress in concrete,

$$f_c = \frac{500{,}000}{60{,}000} = 8.33 \text{ N/mm}^2$$

Loss of stress due to elastic deformation of concrete

$$= mf_c$$
$$= 6 \times 8.33 = 49.98 \text{ N/mm}^2$$

Chapter 7

Miscellaneous Topics

One-mark Questions

1. Bull's trench kiln is used in the manufacturing of **[2016]**

(a) lime (b) cement
(c) bricks (d) none of these

Solution: (c)

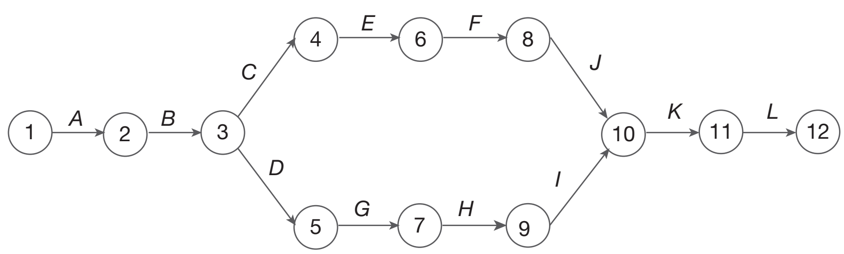
2. As per Indian standards for bricks, minimum acceptable compressive strength of any class of burnt clay bricks in dry state is **[2016]**

(a) 10.0 MPa (b) 7.5 MPa
(c) 5.0 MPa (d) 3.5 MPa

Solution: (d)

3. A construction project consists of twelve activities. The estimated duration (in days) required to complete each of the activities along with the corresponding network diagram is shown below. **[2016]**

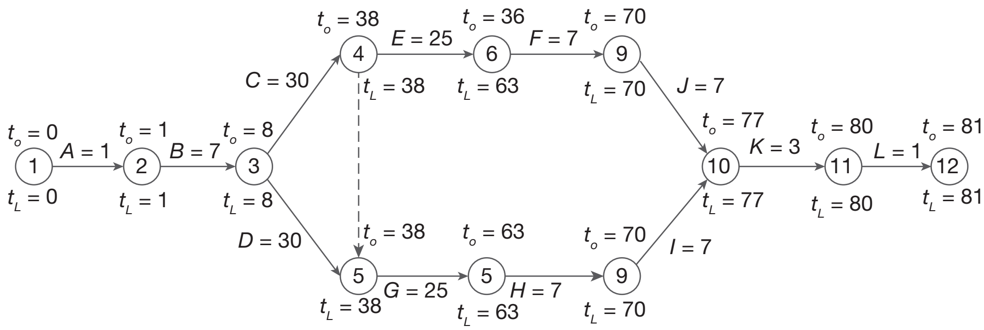
Activity	Duration (days)	Activity	Duration (days)	
A. Inauguration	1	G	Flooring	25
B. Foundation work	7	H	Electrification	7
C. Structural construction – 1	30	I	Plumbing	7
D. Structural construction – 2	30	J	Wood work	7
E. Brick masonry work	25	K	Coloring	3
F. Plastering	7	L	Handing over function	1



Total floats (in days) for the activities 5-7 and 11-12 for the project are, respectively,

(a) 25 and 1 (b) 1 and 1
(c) 0 and 0 (d) 81 and 0

Solution: (c)



(5) – (7) = Total float = $t_e - t_L = 0$

(11) – (12) = Total float = $t_e - t_L = 0$

Hence, the correct option is (c).

4. The permissible bending tensile stress in concrete for the vertical wall of an RC. water tank made of M 25 concrete is **[1997]**

(a) 8.5 N/mm^2 (b) 6.0 N/mm^2

(c) 2.5 N/mm^2 (d) 1.8 N/mm^2

Solution: (d)

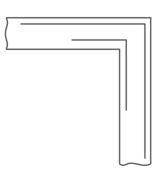
Permissible bending tensile stress in concrete used for water tank

Grade of concrete	Permissible bending tensile stress, N/mm^2
M 20	1.7
M 25	1.8
M 30	2.0

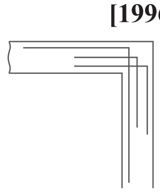
Hence, the correct option is (d).

5. The correct reinforcement details at the corner of a rectangular water tank, in horizontal plane is given by **[1996]**

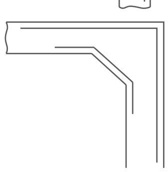
(a)



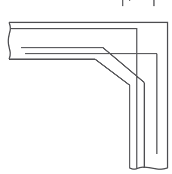
(b)



(c)

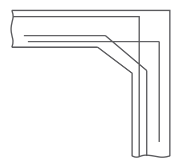


(d)



Solution: (d)

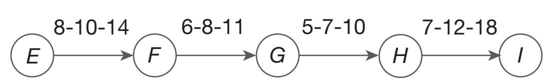
Reinforcement details at the corner of a rectangular water thank in a horizontal plane is shown in figure.



Hence, the correct option is (d).

Two-marks Questions

1. The Optimistic Time (*O*), Most likely Time (*M*) and Pessimistic Time (*P*) (in days) of the activities in the critical path are given below in the format *O*-*M*-*P*. **[2016]**



The expected completion time (in days) of the project is ________

Solution: 37.83

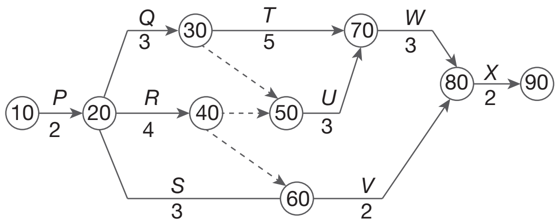
$$t_e = \frac{8+4\times10+14}{6} + \frac{6+8\times4+11}{6} + \frac{5+7\times4+10}{6} + \frac{7+4\times12+18}{6}$$

$$= 10.333 + 8.1666 + 7.1666 + 12.166$$

$$= 37.8328$$

Hence, the answer is 37.83.

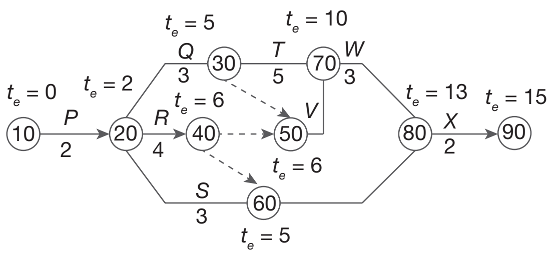
2. The activity-on-arrow network of activities for a construction project is shown in the figure. The durations (expressed in days) of the activities are mentioned below the arrows. **[2016]**



The critical duration for this construction project is

(a) 13 days (b) 14 days
(c) 15 days (d) 16 days

Solution: (c)

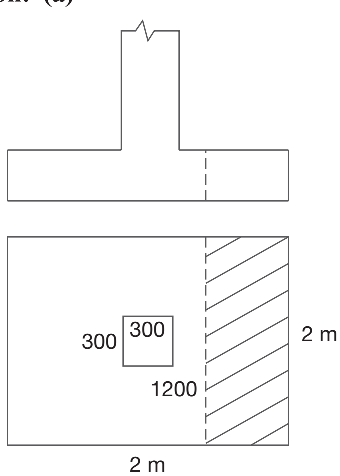


Hence, the correct option is (c).

3. An R.C. square footing of side length 2 m and uniform effective depth 200 mm is provided for a 300 mm × 300 mm column. The line of action of the vertical compressive load passes through the centroid of the footing as well as of the column. If the magnitude of the load is 320 kN, the nominal transverse one way shear stress in the footing is **[2004]**

(a) 0.26 N/mm^2 (b) 0.30 N/mm^2
(c) 0.34 N/mm^2 (d) 0.75 N/mm^2

Solution: (a)



Size of footing: 2 m × 2 m
Effective depth, d = 200 mm
Size of column: 300 × 300 mm
Compressive load, P = 320 kN
Upward intensity of pressure,

$$q_0 = \frac{P}{A} = \frac{320}{2\times 2} = 80 \text{ kN/m}^2$$

The critical section for shear is at a distance of d = 200 mm from the face of column.
Vu: Shear force at critical section

$$= q_0 \times \text{plan area of the hatched portion}$$

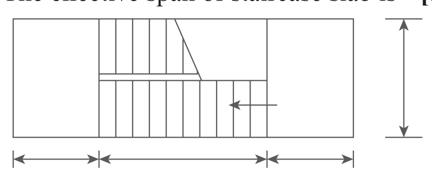
$$= 80\times 2\times\left(\frac{2-0.3}{2}-0.2\right) = 104 \text{ kN}$$

Nominal shear stress,

$$\tau_v = \frac{V_u}{bd} = \frac{104\times 10^3}{2\times 10^3\times 200} = 0.26 \text{ N/mm}^2$$

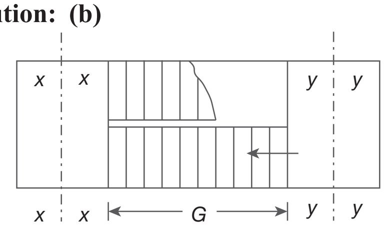
Hence, the correct option is (a).

4. The plane of stairs supported at each end by landings spanning parallel with risers is shown in figure. The effective span of staircase slab is **[1998]**



(a) 3000 mm (b) 4600 mm
(c) 4750 mm (d) 6400 mm

Solution: (b)



When spanning on to the edge of a landing slab, which spans parallel with the risers, a distance equal to the going of the stairs plus at each end either half the width of the landing or one metre, whichever is smaller.

Effective span of staircase slab, $l_{ef} = G + x + y$
Going, G = 3000 mm,

$$x = \frac{1200}{2} = 600 \text{ mm}$$

$$y = \frac{2200}{2} = 1100 \text{ mm} \leq 1000 \text{ mm}$$

$$l_{ef} = 3000 + 600 + 1000 = 4600 \text{ mm}$$

Hence, the correct option is (b).