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UPSC ESE 2020

Main Exam Detailed Solutions

Civil Engineering

PAPER-I

EXAM DATE : 18-10-2020 | 09:00 AM to 12:00 AM

MADE EASY has taken due care in making solutions. If you find any discrepency/ error/typo or want to contest the solution given by us, kindly send your suggested answer with detailed explanations at info@madeeasy.in

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Civil Engineering Paper Analysis
ESE 2020 Main Examination

ESE Mains Paper-I

Sl.	Subjects	Marks	Percentage Weightage
1.	Building Materials and Construction	52	10.83
2.	Strength of Materials	84	17.5
3.	Structural Analysis	104	21.67
4.	Steel Structures	84	17.5
5.	RCC	104	21.67
6.	CTPM and Equipments	52	10.83
Total		**480**	**100.00**

Scroll down for detailed solutions

SECTION 'A'

1. (a) (i) How are aggregates classified based on particle size? What is bulking of sand?

[6 Marks]

(ii) How is workability of concrete defined as per Indian Standard Specification IS 1199 - 1959? Briefly explain the method of measurement of workability through compacting factor test.

[6 Marks]

Solution:

(i) (a) **Coarse aggregate**

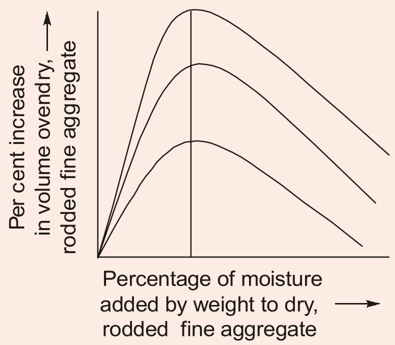
- Size = 4.75 mm - 80 mm
- This composes the main matrix of concrete.
- These are generally obtained from natural disintegration or artificial crushing of rocks.

(b) **Fine aggregate**

- Size = 45 micron - 4.75 mm
- This composes the filler matrix in between the coarse aggregate
- These are generally obtained from natural sand deposited by river or crushed stones.

Bulking of sand:

The presence of free moisture in sand increases the volume of sand which is known as bulking of sand. Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighbouring particles away from it. Similarly, the force exerted by surface tension keeps every particle away from each other. Therefore, no contact point is possible between the particles. This causes bulking of the volume.



The extent of surface tension and consequently how far the adjacent particles are kept away will depend upon the percentage of moisture content and the particle size of the fine aggregate. It is interesting to note that the bulking increases with the increase in moisture content upto a certain limit and beyond that with further increase in the moisture content, it results in the decrease in volume and at a moisture content representing saturation point, the fine aggregate shows no bulking. It can be seen from the figure below that fine sand bulks more and coarse sand bulks less. From this it follows that the coarse aggregate also bulks but the bulking is so little that it is always neglected.

Due to the bulking, fine aggregates show completely unrealistic volume. Thus, the extent of bulking can be estimated by a simple field test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner. The level is noted down say h_1. Pour water in the measuring cylinder and completely inundate the sand and shake it. Since the volume of the saturated sand is same as that of dry sand, the inundated sand completely offsets the bulking effects. The level of the sand is again noted down say h_2. Then $h_1 - h_2$ shows the bulking of the sample of sand under test.

$$\% \text{ of bulking} = \left(\frac{h_1 - h_2}{h_2}\right) \times 100$$

(ii) As per IS 1199-1959 workability defined as the property of concrete which determines the amount of useful internal work necessary to produce complete compaction.

Compaction factor test:

- In the compaction factor test, the degree of workability of concrete is measured in terms of internal energy required to compact the concrete thoroughly.
- A compaction factor of 0.95 represents flowing concrete having high workability; 0.92 plastic concrete having medium workability; 0.85 stiff plastic concrete having low workability and a compaction factor of 0.75 represents stiff concrete having very low workability.
- The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field.
- It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability and is normally used when concrete is to be compacted by vibration like, dry concrete which is insensitive to slump test.
- The sample of concrete to be tested is placed in the upper hopper up to the brim.
- The trap-door is opened so that the concrete falls into the lower hopper.
- Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder.
- In the case of a dry mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion.
- The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades supplied with the apparatus.
- The outside of the cylinder is wiped clean.

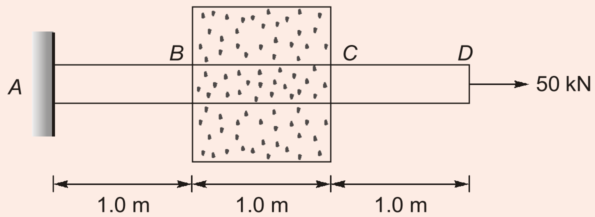
- The concrete is filled up exactly up to the top level of the cylinder.
- It is weighed to the nearest 10 gm.
- This weight is known weight of partially compacted concrete.
- The cylinder is emptied and then **refilled with the concrete from the same sample** in layers approximately 5 cm deep.
- The layers are heavily rammed or preferably vibrated so as to obtain full compaction.
- This weight is known as weight of fully compacted concrete

$$\text{C.F.} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

Sources: (i) MADE EASY Theory Book (Ch. 2)
Conventional Practice Question (Pg. 33, Q.44)
(ii) MADE EASY Theory Book (Ch.3) Click here for reference

End of Solution

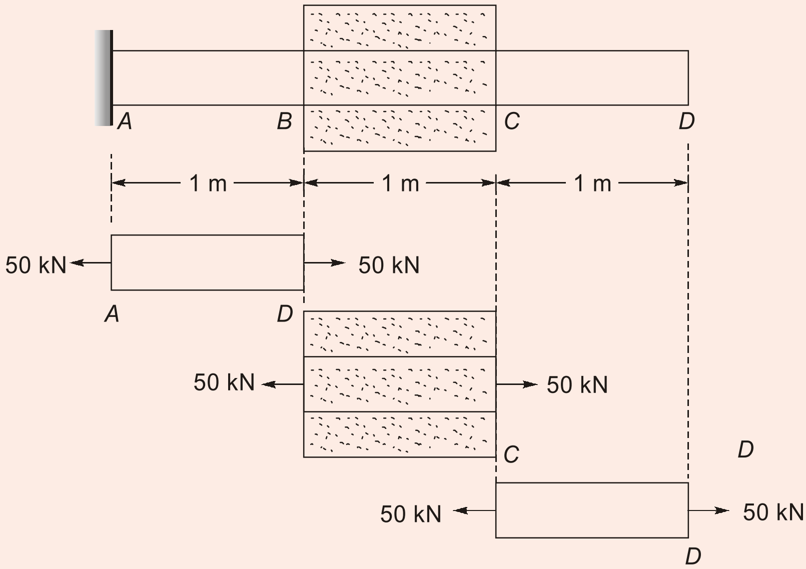
1. (b) A semi-composite steel bar as shown in figure is loaded at free end with an axial load of 50 kN. Determine the axial stiffness of the system and extension of the free end. Diameter of steel bar is 40 mm. Outer diameter of the concrete portion is 200 mm. Modulus of elasticity of steel = 200 GPa, modulus of elasticity of concrete = 20 GPa. Central portion of the bar is embedded with concrete.



[12 Marks]

Solution:

The bar could be divided into three parts *AB*, *BC* and *CD* and each part will have axial loads as shown below:



Now deformation due to axial load in CD,

$$\Delta_{CD} = \left(\frac{PL}{AE}\right)_{CD} = \frac{50 \times 10^3 \times 1000}{\frac{\pi}{4} \times 40^2 \times 200 \times 10^3} = 0.1989 \text{ mm}$$

Similarly,

$$\Delta_{AB} = \left(\frac{PL}{AE}\right)_{AB} = \frac{50 \times 10^3 \times 1000}{\frac{\pi}{4} \times 40^2 \times 200 \times 10^3} = 0.1989 \text{ mm}$$

Now, for BC, compatibility condition,

$$\Delta_{BC} = \Delta_{conc.} = \Delta_{bar}$$

$$\Rightarrow \quad \left(\frac{PL}{AE}\right)_{conc} = \left(\frac{PL}{AE}\right)_{bar}$$

$$\Rightarrow \quad \frac{P_{conc} \times 1000}{\frac{\pi}{4}\left(200^2 - 40^2\right) \times 20 \times 10^3} = \frac{P_{bar} \times 1000}{\frac{\pi}{4} \times 40^2 \times 200 \times 10^3}$$

$$P_{conc} = 2.4\, P_{bar}$$

As we know,

$$P_{conc} + P_{bar} = 50 \text{ kN}$$

$$(2.4 + 1)P_{bar} = 50 \text{ kN}$$

$$P_{bar} = 14.706 \text{ kN}$$

Thus,

$$\Delta_{BC} = \frac{14.706 \times 10^3 \times 1000}{\frac{\pi}{4} \times 40^2 \times 200 \times 10^3} = 0.0585 \text{ mm}$$

Total elongation of system,

$$\Delta_{total} = \Delta_{AB} + \Delta_{BC} + \Delta_{CD}$$

$$= 0.1989 + 0.0585 + 0.1989$$

$$\Delta_{total} = 0.4563 \text{ mm}$$

As we know, stiffness of system

$$k_{system} = \frac{\text{Force}}{\text{Deformation}} = \frac{50 \times 10^3}{0.4563 \times 10^{-3}}$$

$$k_{system} = 109.577 \times 10^6 \text{ N/m}$$

Sources: MADE EASY Theory Book (Pg. 36, Ex. 2.17) Click here for reference

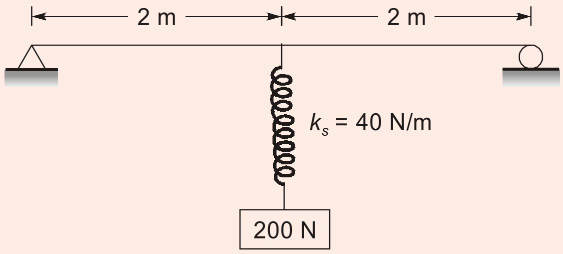
End of Solution

1. (c) A machine is mounted at the centre of a simple supported beam that can exert a harmonic load $F(t) = 20 \sin(0.12t)$ kN in vertical direction. The length of beam is 4 m and its cross-section is uniform throughout. Cross-section of beam width 20 mm and depth 40 mm. A weight W = 200 N is suspended from the centre of the beam by a spring of spring constant K_S = 40 N/m. Determine the natural frequency of the weight W. Neglect mass of the beam and weight of machine. $E = 2 \times 10^5$ MPa.

[12 Marks]

Solution:

The arrangement of machine and spring system could be simplified as shown below:



$$\text{Cross-section of beam} = 20 \text{ mm} \times 40 \text{ mm}$$

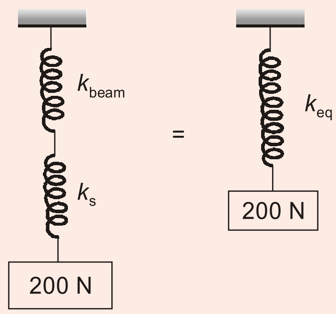
So, MOI of beam, $I = \frac{bd^3}{12} = \frac{20 \times 40^3}{12}$

Stiffness of beam loaded at midpoint

$$= \frac{48EI}{l^3} = \frac{48 \times 2 \times 10^5 \times 20 \times 40^3}{12 \times (4000)^3}$$

$$k_{beam} = 16 \text{ N/m m} = 16000 \text{ N/m}$$

Now, spring and beam are in series as shown below:



$$k_{eq} = \frac{k_s \times k_{beam}}{k_s + k_{beam}} = \frac{16000 \times 40}{16000 + 40} = 39.90 \text{ N/m}$$

Natural circular frequency of system,

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{39.90}{\frac{200}{9.81}}} = 1.399 \text{ rad/s}$$

$$\text{Natural frequency} = \frac{1}{T} = \frac{\omega}{2\pi} = \frac{1.399}{2\pi} = 0.22 \text{ Hz}$$

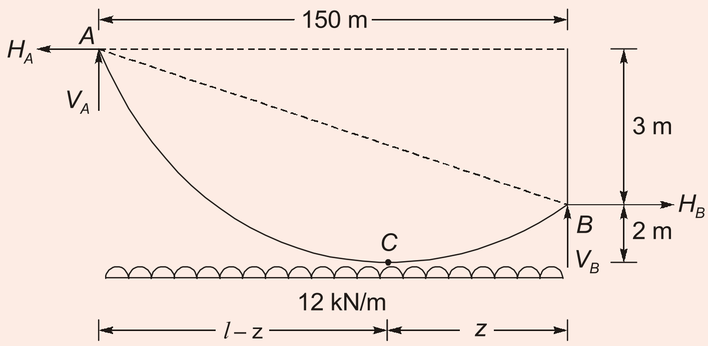
Sources: MADE EASY Theory Book (Pg. 454, Ex. 11.1) Click here for reference

End of Solution

1. (d) A cable of uniform cross-section hangs between two points A and B, which are 150 m apart. The end 'A' of the cable is 3 m above the other end of the cable. The sag of the cable measured from 'B' = 2 m. If the cable carries a UDL of 12 kN/m, determine the maximum tension in the cable. Also find the horizontal pull.

[12 Marks]

Solution:



w = UDL = 12 kN/m, l = 150 m, d = 3 m, h = 3 + 2 = 5 m

Lowest point, $y_c = 2$ m

Location of lowest point:

$$\frac{l - z}{z} = \sqrt{\frac{y_C + d}{y_C}} = \sqrt{\frac{5}{2}} = 1.581$$

$$l - z = 1.581\, z$$

So $z = 58.117$ m

$$\Sigma F_x = 0$$

$\Rightarrow$ $-H_A + H_B = 0$ ...(i)

$$\Sigma F_y = 0$$

$\Rightarrow$ $V_A + V_B - 12 \times 150 = 0$ ...(ii)

$$\Sigma M_A = 0$$

$$\Rightarrow \quad -V_B \times 150 - H_B \times 3 + 12 \times 150 \times 75 = 0$$

$$\Rightarrow \quad 150\,V_B + 3H_B = 1800 \times 75 \qquad \text{...(iii)}$$

$$M_C = 0 \text{ (RHS)}$$

$$\Rightarrow \quad -V_B \times z + H_B \times 2 + \frac{12z^2}{2} = 0$$

$$\Rightarrow \quad -58.117V_B + 2H_B = -6(58.117)^2 \qquad \text{...(iv)}$$

From eq. (iii) and (iv)

$$V_B = 697.366 \text{ kN}$$

$$H_B = 10131.670 \text{ kN} = H_A$$

$$V_A = 1102.634 \text{ kN} \qquad \text{From eq. (ii)}$$

Max tension in the cable:

$$T_{max} = \sqrt{H^2 + V_A^2}$$

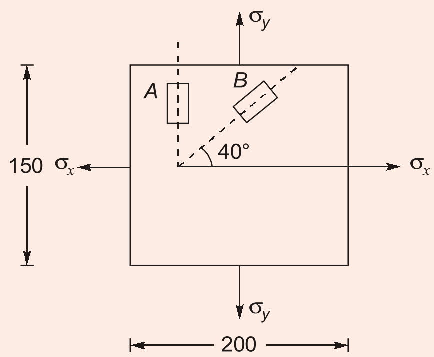
$$= \sqrt{1102.634^2 + 10131.670^2}$$

$$= 10191.493 \text{ kN}$$

Sources: MADE EASY Theory Book (Pg. 498, Ex. 12.4) Click here for reference

End of Solution

1. (e) A 200 mm × 150 mm × 10 mm aluminium plate is subjected to uniform bi-axial stresses σ_x and σ_y. Two strain gauges A and B are attached to the surface of the plate as shown in the figure. If readings in strain gauges are $\varepsilon_A = 200 \times 10^{-6}$ and $\varepsilon_B = 285 \times 10^{-6}$, what are the value of σ_x and σ_y? What is the reduction in thickness of the plate as a result of stresses?
Take Young's modulus E = 75 GPa and Poisson's ratio ν = 0.33.



[12 Marks]

Solution:

$$\varepsilon_A = 200 \times 10^{-6}$$

$$\varepsilon_B = 285 \times 10^{-6}$$

$$E = 75 \text{ GPa} = 75 \times 10^3 \text{ MPa}$$

$$\nu = 0.33$$

$$t = 10 \text{ mm}$$

Strain gauge A is along y

Thus $\varepsilon_A = \varepsilon_y = 200 \times 10^{-6}$

From strain transformation,

$$\varepsilon_B = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{\varepsilon_x - \varepsilon_y}{2}\cos 2\theta + \frac{\gamma_{xy}}{2}\sin 2\theta$$

$$\varepsilon_B = \frac{\varepsilon_x + \varepsilon_y}{2} + \frac{\varepsilon_x - \varepsilon_y}{2}\cos(2\times 40) + \frac{\gamma_{xy}}{2}\sin(2\times 40)$$

Since no shear is acting on plane normal to x and y thus $\gamma_{xy} = 0$

So, $$285 \times 10^{-6} = \frac{\varepsilon_x + 200\times 10^{-6}}{2} + \frac{\varepsilon_x - 200\times 10^{-6}}{2}\cos 80°$$

$$570 \times 10^{-6} = \varepsilon_x(1+\cos 80°) + 200\times 10^{-6}\times(1-\cos 80°)$$

Thus, $\varepsilon_x = 344.847 \times 10^{-6}$

Now, $$\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_x + \nu\varepsilon_y)$$

$$= \frac{75\times 10^3}{1-0.33^2}(344.847 + 0.33\times 200)\times 10^{-6}$$

$$\sigma_x = 34.579 \text{ MPa}$$

Similarly, $$\sigma_y = \frac{E}{1-\nu^2}(\varepsilon_y + \nu\varepsilon_x)$$

$$\sigma_y = 26.411 \text{ MPa}$$

For change in thickness,

$$\varepsilon_z = \frac{\sigma_z}{E} - \nu\frac{\sigma_y}{E} - \nu\frac{\sigma_x}{E}$$

Since $\sigma_z = 0$, $$\varepsilon_z = \frac{-0.33(26.411+34.579)}{75\times 10^3}$$

$$\varepsilon_z = \frac{\Delta t}{t} = -2.684\times 10^{-4}$$

$$\Delta t = -10 \times 2.674 \times 10^{-4} \text{ mm}$$

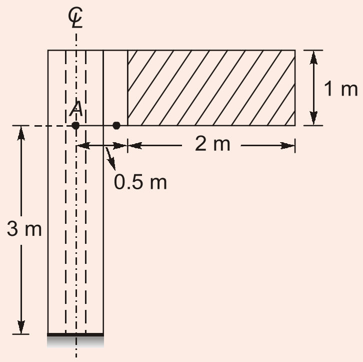
Thus, reduction in thickness, $\Delta t = 2.684 \times 10^{-3}$ mm

Sources: MADE EASY ESE Mains Workbook (Pg. 11, Q. 33)

ESE Mains Test Series (Test No. 4) Q.8(a) Click here for reference

End of Solution

2. (a) A steel tube is to be used as a post for a road sign board as shown in figure. The maximum wind pressure on the sign board is 1960 N/m². The angle of rotation of the tube at the bottom of the sign board marked as A must not exceed 4° and the maximum shear stress (due to torsion only) must not be greater than 38 MPa. Determine the mean diameter of the tube if the wall thickness is 4.2 mm. Take G = 70 GPa. Assume wind is transmitting only over the sign board portion.



[20 Marks]

Solution:

Wind pressure, $p = 1960 \text{ N/m}^2$

Force on sign board, $pA = 1960 \times 1 \times 2 = 3920 \text{ N}$

Torsion on tube, $T = Fr = 3920 \times \left(0.5 + \frac{2}{2}\right)$

$= 3920 \times 1.5$

$= 5880 \text{ Nm}$

At a point A, rotation due to torsion,

$$\phi_A = \frac{Tl_A}{GJ}$$

Assuming the tube to be thin cylinder with mean diameter d_m.

Polar MOI, $J = \pi d_m \times t \times \left(\frac{d_m}{2}\right)^2 = \frac{\pi d_m^3 t}{4}$

For $\phi_A \leq 4°$

$$\frac{Tl_A}{GJ} \leq \frac{4\pi}{180}$$

$$\frac{5880 \times 10^3 \times 3000}{70 \times 10^3 \times J} \leq \frac{4\pi}{180}$$

$$J \geq 3.609 \times 10^6 \text{ mm}^4$$

$$\frac{\pi d_m^3 \times t}{4} \geq 3.609 \times 10^6$$

So, $d_m \geq 103.048 \text{ mm}$ ...(i)

Also, $\tau_{max} \leq 38 \text{ MPa}$

$$\frac{T}{2A_m t} \leq 38 \text{ MPa}$$

$$\Rightarrow \quad \frac{5880 \times 10^3}{2A_m \times 4.2} \leq 38 \text{ MPa}$$

$$A_m \geq 18421.053 \text{ mm}^2$$

$$\frac{\pi d_m^2}{4} \geq 18421.053 \text{ mm}^2$$

So, $d_m \geq 153.148 \text{ mm}$ ...(ii)

From eq. (i) and (ii), $d_m \geq 153.1448 \text{ mm}$

For calculated mean dia., $\dfrac{d_m}{t} = \dfrac{153.148}{4.2} = 36.46 > 20$

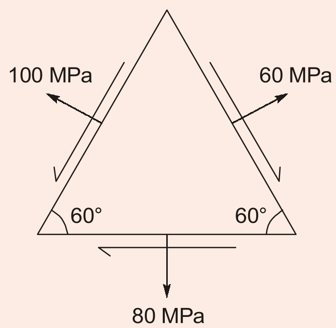
So, our assumption of thin cylinder is correct.

Sources: MADE EASY Theory Book (Similar Question) (Pg. 346, Ex. 8.4)

Click here for reference

End of Solution

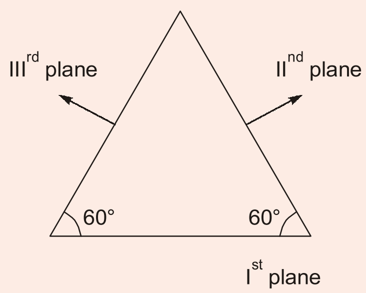
2. (b) In a strained body the normal stresses on three planes inclined as shown in figure are 60 MPa (Tensile), 80 MPa (Tension) and 100 MPa. Determine the shear stresses acting on these planes. Also find the principal stresses.



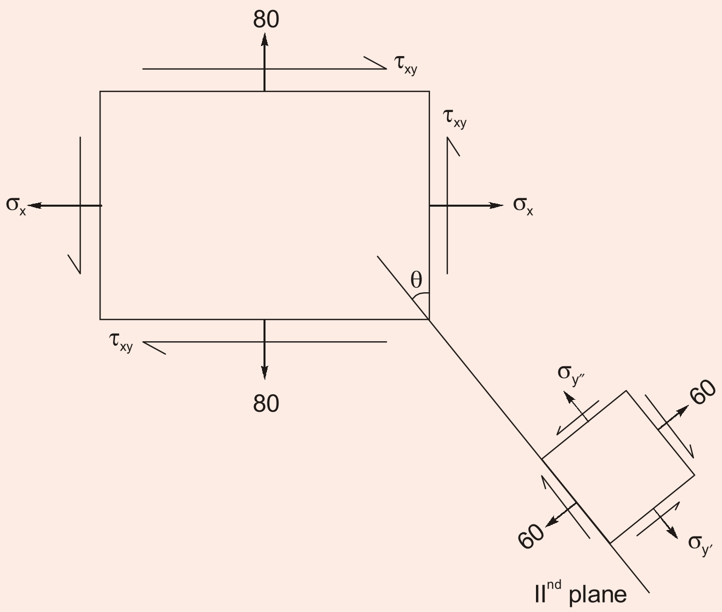
[20 Marks]

Solution:

Let us assume the plane arrangements as shown in figure.



For II[nd] plane



$$\sigma_y = 80 \text{ MPa}$$
$$\theta = 90° - 60° = 30°$$
$$\sigma_x' = 60 \text{ MPa}$$

As we know,

$$\sigma_x' = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2}\cos 2\theta + \tau_{xy}\sin 2\theta$$

$$\sigma_x' = \sigma_x \cos^2\theta + \sigma_y \sin^2\theta + 2\tau_{xy}\sin\theta\cos\theta$$

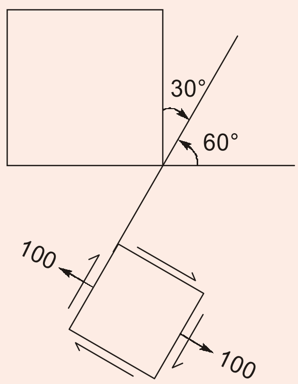
So,

$$60 = \sigma_x \cos^2 30° + 80\sin^2 30° + 2\tau_{xy}\cos 30° \sin 30°$$

$$60 = \frac{3}{4}\sigma_x + \frac{80}{4} + \frac{2\sqrt{3}\,\tau_{xy}}{4}$$

$$160 = 3\sigma_x + 2\sqrt{3}\,\tau_{xy} \quad \text{...(i)}$$

For III[rd] plane



$$\sigma_x'' = 100 \text{ MPa}$$
$$\theta'' = -30° \qquad \text{[Since clockwise]}$$
$$\sigma_x'' = \sigma_x \cos^2\theta'' + \sigma_y \sin^2\theta'' + 2\tau_{xy}\sin\theta''\cos\theta''$$
$$100 = \frac{3\sigma_x}{4} - \frac{2\sqrt{3}}{4}\tau_{xy} + 20$$
$$320 = 3\sigma_x - 2\sqrt{3}\,\tau_{xy} \qquad \text{...(ii)}$$

From eq. (i) and (ii)

$$\sigma_x = 80 \text{ MPa}$$
$$\tau_{xy} = -23.09 \text{ MPa}$$

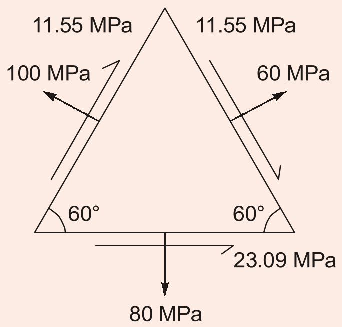
Similarly for plane II,

$$\tau_{x'y'} = (\sigma_y - \sigma_x)\cos\theta\sin\theta + \tau_{xy}(\cos^2\theta - \sin^2\theta)$$
$$= 0 - 23.09 \times (\cos^2 30° - \sin^2 30°)$$
$$= -11.55 \text{ MPa}$$

Similarly for plane III,

$$\tau_{x''y''} = -11.55 \text{ MPa}$$

So final arrangement is



Since,

$$\sigma_x = 80 \text{ MPa}$$
$$\sigma_y = 80 \text{ MPa}$$
$$\tau_{xy} = -23.09 \text{ MPa}$$
$$\sigma_{major}/\sigma_{minor} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$
$$= \frac{80+80}{2} \pm \sqrt{\left(\frac{80-80}{2}\right) + (-23.09)^2}$$
$$= 80 \pm 23.09$$
$$\sigma_{major} = 80 + 23.09 = 103.09 \text{ MPa}$$
$$\sigma_{minor} = 80 - 23.09 = 56.91 \text{ MPa}$$

Sources: MADE EASY Class Notes Click here for reference

End of Solution

2. (c) (i) Describe how the compounds of clinker affect the properties of cement. [12 Marks]

(ii) What do you mean by normal consistency of cement? What is its significance? How is it tested? [8 Marks]

Solution:

(i) The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide.

These oxides when subjected to high clinkering temperature combine with each other to form complex compounds.

The identification of major complex compounds is based on R.H. Bogue's work and hence these are called Bogue's compound.

There are 4 Bogue's compounds:

1. **Tricalcium Silicate (C_3S)**

Chemical formula : 3 $CaOSiO_2$

Percentage : 30 - 50%

- It undergoes hydration within a week and is responsible for development of early strength in cement.
- It is the best cementing material and is well burnt.
- Increases resistance to freezing and thawing.
- Renders the clinker easier to grind.
- Its proportion can be increased where early gain of strength is required.

Example : Emergency repair work, cold weather concreting, prefabricated construction, etc.

2. **Dicalcium silicate (C_2S)**

Chemical formula : $2CaOSiO_2$

Percentage : 20-45%

- It hydrates and hardens slowly and takes long time to add to strength (1 year or more).
- Imparts resistance to chemical attack.
- Proportion is increased when early strength is not required and higher heat of hydration should not be there.

Example : dam or bridge construction.

3. **Tricalcium Aluminate (C_3A)**

Chemical formula : $3CaOAl_2O_3$

Percentage : 8-12%

- Responsible for flash set of cement as it undergoes hydration within 24 hours after water addition.
- Highest heat of hydration and tendency to volume changes causing cracking.
- If present in higher amount, resistance to sulphate attack decreases.

4. **Tetracalcium Alumino Ferrite (C_4AF)**

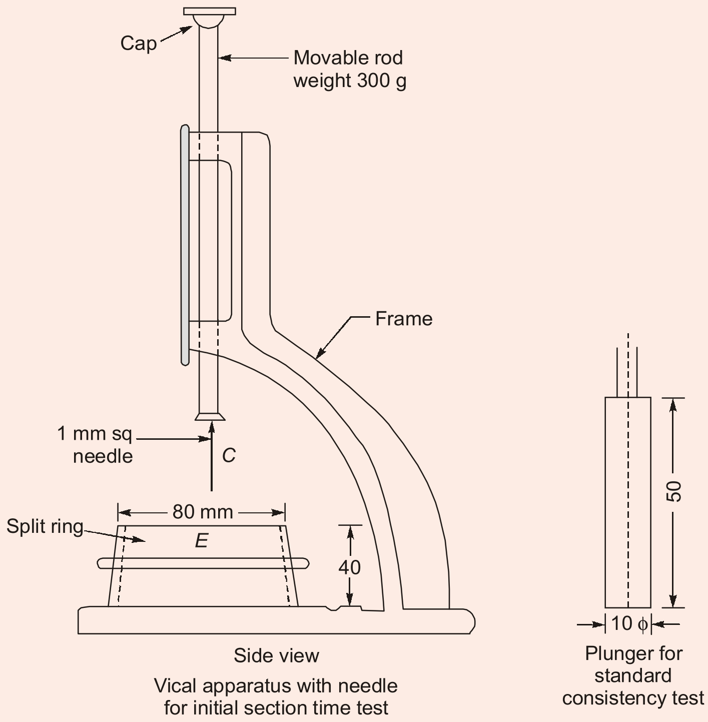
Chemical formula : $4CaOAl_2O_3Fe_2O_3$

Percentage : 6-10%

- Responsible for flash set but generates less heat.
- Poorest cementing value.
- Raising its content reduces the strength slightly.

(ii) **Normal consistency of cement:**

- The normal (standard) consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom) of the mould.



Significance:

It is necessary to determine consistency because the amount of water affects the setting time of the cement. It is resistance to shear deformation. Thus, it plays vital role in the determination of compressive strength or workability of concrete.

Vicat Apparatus:

- Vicat apparatus assembly consists of a plunger 300 gm in weight with a length of 50 mm and diameter of 10 mm and a mould which is 40 mm deep and 80 mm in diameter.

Test Procedure:

- To prepare the paste, take weighed quantity (300 g) of cement and place it in a crucible.
- Mix a weighed quantity of water (approximately 24% by weight of cement) for the first trial.

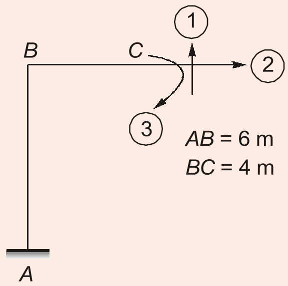
- The time of mixing or gauging should not be less than 3 minutes nor more than 5 minutes and gauging time should be counted from the time of adding water to the dry cement until commencing to fill the mould.
- The Vicat mould is filled with the paste, which is levelled off at its top.
- The mould is placed under the Vicat plunger.
- The vicat plunger is brought down to touch the surface of paste in the mould and quickly released allowing it to sink into the paste by its own weight.
- Take the reading by noting the depth of penetration of the plunger.
- Similarly conduct the trials with increasingly water/cement ratios till such time the plunger penetrates for a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom).
- That particular percentage of water which allows the plunger to penetrate only to a depth of 33 to 35 from the top (or 5 to 7 mm from the bottom) is known as the percentage of water required to produce a cement paste of normal (standard) consistency.
- This percentage is generally denoted by *P*.
- This test should be conducted at a constant temperature of 27° ± 2°C and a constant humidity of 90%.

Sources: (i) MADE EASY Conventional Practice Question Book (Pg. 1, Q.2)
ESE Mains Workbook-2 (Pg. 150. Q.2)

(ii) MADE EASY Theory Book (Pg 17, Q.18) Click here for reference

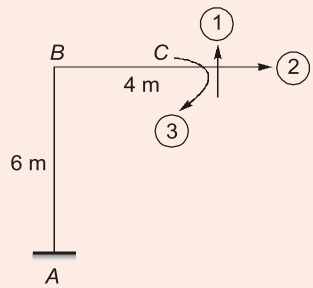
End of Solution

3. (a) Develop the flexibility matrix for the beam shown in figure, with respect to the generalized coordinates mentioned. EI is constant for all members.



[20 Marks]

Solution:



Order of flexibility matrix is 3.
The required deflection may be calculated from unit load method.

Portion	CB	BA
Origin	C	B
Limit	0-4	0-6
m_1	x	4
m_2	0	$-x$
m_3	-1	-1

m_1 = Bending moment at any section when unit load is in the direction of coordinate 1.
m_2 = Bending moment at any section when unit load is in the direction of coordinate 2.
m_3 = Bending moment at any section when unit load is in the direction of coordinate 3.

First column of flexibility matrix

$$f_{11} = \int \frac{m_1 m_1 dx}{EI} = \int_0^4 \frac{x^2 dx}{EI} + \int_0^6 \frac{(4)^2 dx}{EI} = \frac{117.33}{EI}$$

$$f_{21} = \int \frac{m_1 m_2 dx}{EI} = \int_0^4 \frac{x(0) dx}{EI} + \int_0^6 \frac{-4x dx}{EI} = -\frac{72}{EI}$$

$$f_{31} = \int \frac{m_1 m_3 dx}{EI} = \int_0^4 \frac{-x dx}{EI} + \int_0^6 \frac{-4 dx}{EI} = -\frac{32}{EI}$$

Second column of flexibility matrix

$$f_{12} = \int \frac{m_1 m_2 dx}{EI}$$

Also, $$f_{21} = f_{12} = -\frac{72}{EI}$$

(Property of flexibility matrix by reciprocal theorem)

$$f_{22} = \int \frac{m_2 m_2 dx}{EI} = \int_0^4 \frac{0 dx}{EI} + \int_0^6 \frac{x^2 dx}{EI} = \frac{72}{EI}$$

$$f_{32} = \int \frac{m_2 m_3 dx}{EI} = \int_0^4 \frac{0(-1) dx}{EI} + \int_0^6 \frac{x dx}{EI} = \frac{18}{EI}$$

Third column of flexibility matrix

$$f_{13} = \int \frac{m_1 m_3 dx}{EI}$$

$$f_{13} = f_{31} = -\frac{32}{EI}$$

$$f_{23} = \int \frac{m_2 m_3 dx}{EI}$$

$$f_{23} = f_{32} = \frac{18}{EI}$$

$$f_{33} = \int \frac{m_3\, m_3\, dx}{EI} = \int_0^4 \frac{(-1)^2\, dx}{EI} + \int_0^6 \frac{(-1)^2\, dx}{EI} = \frac{10}{EI}$$

$$[f] = \frac{1}{EI}\begin{bmatrix} 117.33 & -72 & -32 \\ -72 & 72 & 18 \\ -32 & 18 & 10 \end{bmatrix}$$

Sources: MADE EASY ESE Mains Workbook-1 (Similar Qustion)(Pg.242, Q.8)

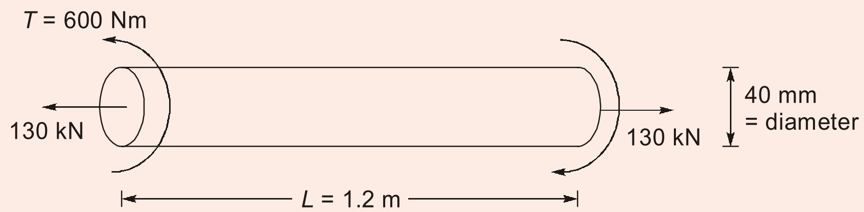
Click here for reference

End of Solution

3. (b) A bar of length 1.2 m, diameter 40 mm is subjected to an axial tensile load of 130 kN and a twisting moment of 600 N-m. If the same material yielded at an axial stress of 200 N/mm^2, determine the safety factor associated with the bar, considering.
(i) Principal stress failure theory
(ii) Maximum shear stress theory
(iii) Distortional strain energy theory
Take E = 200 GPa and μ = 0.25.

[20 Marks]

Solution:



$$\sigma_y = 200 \text{ MPa}$$

$$E = 200 \text{ GPa}$$

$$\mu = 0.25$$

$$E = 2G(1+\mu)$$

$$G = \frac{200}{2(1.25)} = 80 \text{ GPa}$$

$$\sigma = \frac{P}{A} = \frac{130 \times 10^3}{\frac{\pi}{4} \times 40^2} = 103.451 \text{ MPa}$$

By torsion formula,

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}, \qquad \tau = \frac{Tr}{J} = \frac{600 \times 10^3 \times \left(\frac{40}{2}\right)}{\frac{\pi}{32}(40)^4}$$

$$= \frac{16 \times 600 \times 10^3}{\pi \times (40)^3} = 47.746 \text{ MPa}$$

Principal stresses,

$$\sigma_1/\sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= \frac{103.451}{2} \pm \sqrt{\left(\frac{103.451}{2}\right)^2 + (47.746)^2}$$

$$\sigma_1 = 122.12 \text{ MPa (Tensile)}$$

$$\sigma_2 = -18.667 \text{ MPa (Compressive)}$$

Calculating FOS considering,

(i) Principal stress theory,

$$\sigma_1 \le \sigma_y \text{ (Tensile)}$$

$$122.12 \times \text{FOS} = 200$$

$$\text{FOS} = 1.637$$

(ii) Maximum shear stress theory

$$\tau_{max} \le \left(\frac{\sigma_y}{2}\right)$$

$$\tau_{max} = \frac{\sigma_{major} - \sigma_{minor}}{2}$$

$$= 70.393 \text{ MPa}$$

$$70.393 \times \text{FOS} = 100$$

$$\text{FOS} = 1.420$$

(iii) Distortional strain energy theory,

$$\frac{1}{12G}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] \le \frac{1}{6G}\left(\frac{\sigma_y}{\text{FOS}}\right)^2$$

$$\frac{1}{2}\left[(122.12)^2 + (18.667)^2 + (122.12 + 18.667)^2\right] \le \left(\frac{\sigma_y}{\text{FOS}}\right)^2$$

$$17541.365 = \left(\frac{\sigma_y}{\text{FOS}}\right)^2$$

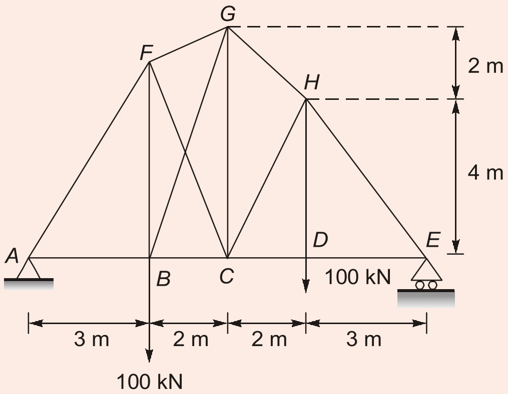
$$\text{FOS} = 1.51$$

Sources: MADE EASY ESE Mains Test Series (Similar Question) Test-5, Q.6(c)

Click here for reference

End of Solution

3. (c) Determine the forces in the members of the truss shown in figure. All members have same axial rigidity.

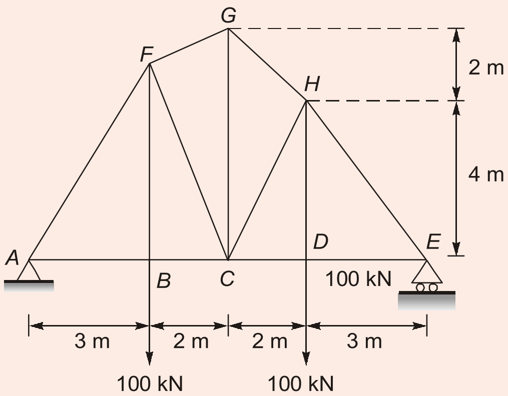


[20 Marks]

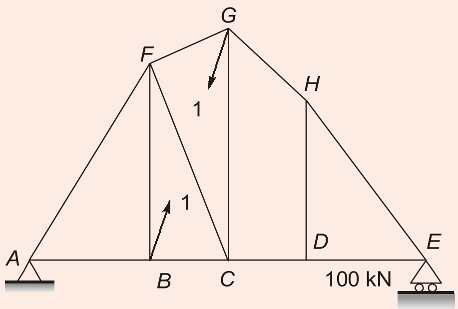
Solution:

Note: Since data of BF is not given so as per diagram assuming BF = 5 m.

Truss is indeterminate with 1-degree, so considering member force BG as redundant "R".



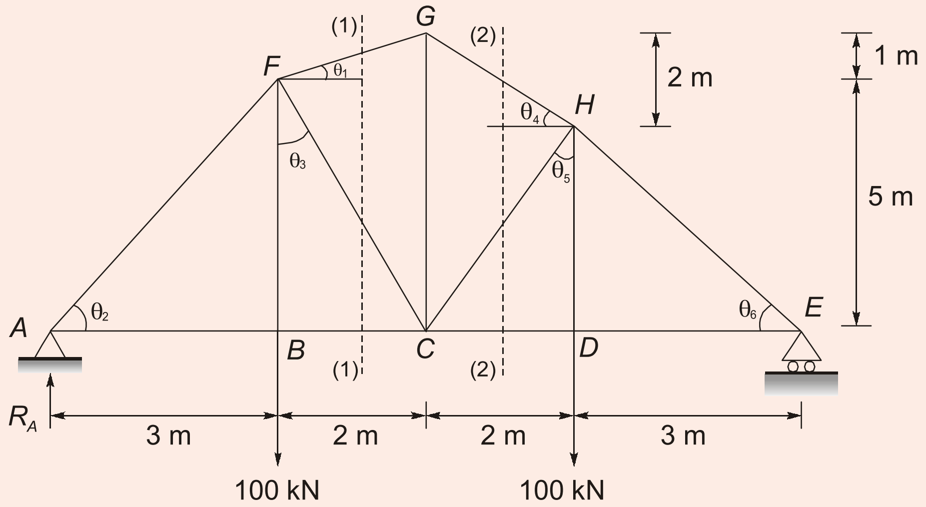
P-Force



K-forces

$$R = -\frac{\frac{\Sigma P_i K_i l_i}{AE}}{\frac{\Sigma K_i^2 l}{AE}}$$

P-force calculation



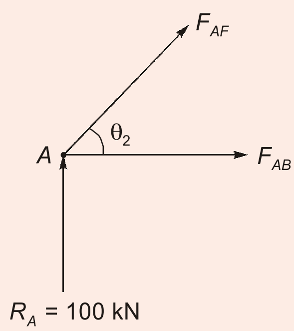
$\Sigma M_E(\circlearrowright) = 0$

$$R_A \times 10 - 100 \times 7 - 100 \times 3 = 0$$

$\Sigma F_y (\uparrow) = 0$

$$R_A + R_E = 200 \text{ kN}$$
$$R_E = 100 \text{ kN}$$

Take joint A,



$$\tan\theta_2 = \frac{5}{3}$$
$$\theta_2 = 59.036°$$
$$F_{AF} = -\frac{100}{\sin\theta_2} = -\frac{100}{\sin 59.036}$$
$$= -116.619 \text{ kN}$$
$$F_{AB} = 100 \cot\theta_2$$
$$= 100 \cot 59.036 = 60 \text{ kN}$$

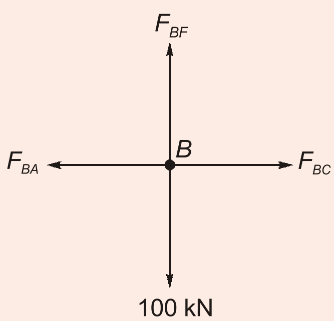
Take joint B,

$\Sigma F_x = 0$

$\Rightarrow$ $F_{BC} = F_{BA} = 60$ kN

$\Sigma F_y = 0$

$\Rightarrow$ $F_{BF} = 100$ kN



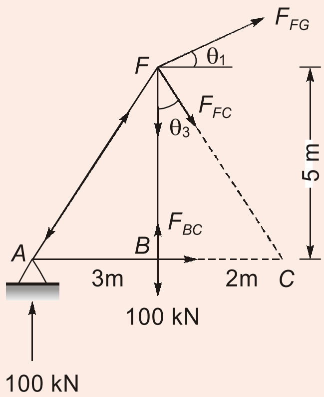
Take section (1)-(1)

$$\tan\theta_1 = \frac{1}{2}$$

$$\theta_1 = 26.565°$$

$$\tan\theta_3 = \frac{2}{5}$$

$$\theta_3 = 21.801°$$



$\Sigma M_C(\circlearrowright) = 0$

$100 \times 5 - 100 \times 2 + F_{FG}\sin\theta_1 \times 2 + F_{FG}\cos\theta_1 \times 5 = 0$

$$-\frac{300}{[2\sin 26.565° + 5\cos 26.565°]} = F_{FG}$$

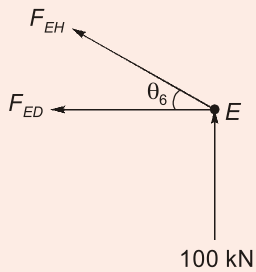
$$F_{FG} = -55.9 \text{ kN}$$

$\Sigma F_y (\uparrow) = 0$

$$-F_{FC}\cos\theta_3 + F_{FG}\sin\theta_1 = 0$$

$$F_{FC} = -55.901 \times \frac{\sin 26.565°}{\cos 21.801°} = -26.925 \text{ kN}$$

Take joint E,



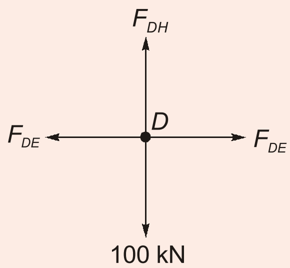
$$\tan\theta_6 = \frac{4}{3}$$

$$\theta_6 = 53.13°$$

$$F_{EH} = -\frac{100}{\sin 53.13°} = -125 \text{ kN}$$

$$F_{ED} = 125\cos 53.13° = 75 \text{ kN}$$

Take joint D,



$\Sigma F_y (\uparrow) = 0$

$$F_{DH} = 100 \text{ kN}$$

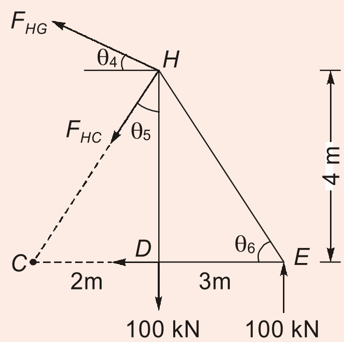
$\Sigma F_x = 0$

$$F_{DC} = F_{DE} = 75 \text{ kN}$$

Take section (2)-(2)

$$\tan\theta_4 = \frac{2}{2}$$

$$\theta_4 = 45°$$



$$\tan\theta_5 = \frac{2}{4}$$

$$\theta_5 = 26.565°$$

$\Sigma M_C(\circlearrowright) = 0$

$-100 \times 5 + 100 \times 2 - F_{HG}\cos\theta_4 \times 4 - F_{HG}\sin\theta_4 \times 2 = 0$

$300 + F_{HG} \times \cos 45° + 4 + F_{HG}\sin 45° \times 2 = 0$

$$F_{HG} = -\frac{300}{[4\cos 45° + 2\sin 45°]} = -70.7106 \text{ kN}$$

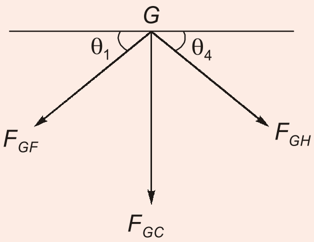
$\Sigma F_y (\uparrow) = 0$

$$F_{HG}\sin\theta_4 - F_{HC}\cos\theta_5 = 0$$

$$-70.7106 \times \frac{\sin 45°}{\cos 26.565°} = F_{HC}$$

$$F_{HC} = -55.901 \text{ kN}$$

Take joint G,



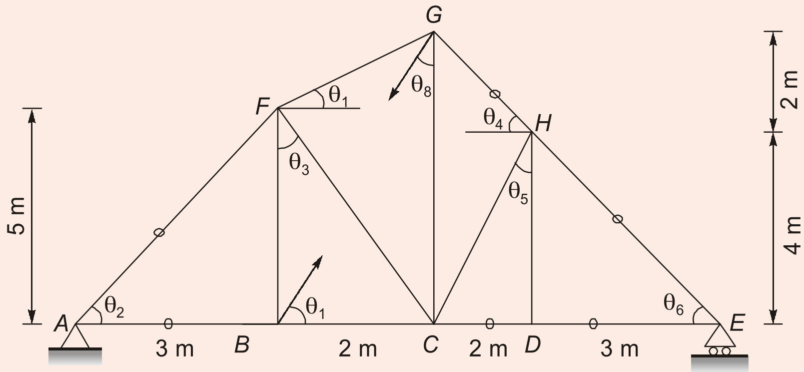
$\Sigma F_y = 0$

$$F_{GF}\sin\theta_1 + F_{GH}\sin\theta_4 + F_{GC} = 0$$

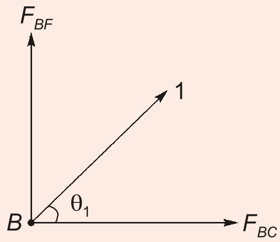
$$F_{GC} - 55.901 \times \sin 26.565° - 70.7106 \times \sin 45° = 0$$

$$F_{GC} = 75 \text{ kN}$$

K-force calculation



Take joint B,



$$\tan\theta_7 = \frac{6}{2}$$

$$\theta_7 = 71.565°$$

$\Sigma F_y = 0,$

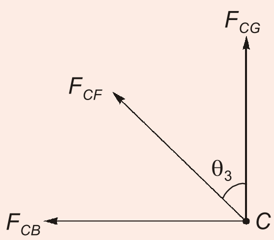
$$F_{BF} = 1\sin\theta_7 = 0$$

$$F_{BF} = -\sin 71.565 = -0.949$$

$\Sigma F_x = 0$

$$F_{BC} = -\cos\theta_7 = -\cos 71.565 = -0.3162$$

Take joint C,



$$\tan\theta_3 = \frac{2}{5}$$

$$\theta_3 = 21.801°$$

$\Sigma F_x = 0$

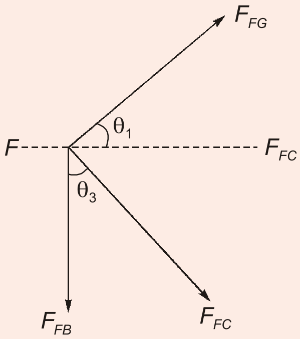
$$F_{CF}\sin 21.801° + F_{CB} = 0$$

$$F_{CF} = -\frac{F_{CB}}{\sin 21.801°} = -\left(\frac{-0.3162}{\sin 21.801}\right) = 0.8514$$

$\Sigma F_y = 0,$

$$F_{CF} = \cos\theta_3 + F_{CG} = 0$$
$$F_{CF} = -0.8514\cos 21.801°$$
$$F_{CG} = -0.791$$

Take joint F,



$$\tan\theta_1 = \frac{1}{2}$$
$$\theta_1 = 26.565°$$

$\Sigma F_x = 0$

$$F_{FG}\cos\theta_1 + F_{FC}\sin\theta_3 = 0$$
$$F_{FG} = -\frac{0.8514\times\sin 21.801°}{\cos 26.565°} = -0.354$$

Member	P	K	L	KPL	K^2L	P + RK
AB	60	0	3	0	0	60.0
BC	60	–0.316	2	–37.920	0.200	44.2
CD	75	0	2	0.000	0	75.0
DE	75	0	3	0	0	75.0
AF	–116.6	0	5.83	0	0	–116.6
FG	–55.9	–0.354	2.236	44.247	0.280	–73.6
GH	–70.71	0	283	0.000	0	–70.7
HE	–125	0	5	0	0	–125.0
FB	100	–0.949	5	–474.500	4.503	52.6
FC	–26.926	0.851	5.385	–123.392	3.900	15.6
GB	0	1	6.24	0	6.324	50.0
GC	75	–0.791	6	–355.950	3.754	35.5
HC	–55.9	0	4.472	0	0	–55.9
HD	100	0	4	0	0	100.0
				Σ = –947.515	18.961	

$$\Sigma PKL = -947.45$$
$$\Sigma K^2L = 18.96$$

So,
$$R = -\left(\frac{\Sigma PKL}{\Sigma K^2L}\right) = -\left(-\frac{947.45}{18.96}\right) = 49.97 \text{ kN}$$

Sources: MADE EASY Theory Book (Pg. 102, Q.13)

ESE Mains Workbook (Pg.213) (Q. 4, 5, 6, 8) **Click here for reference**

End of Solution

4. (a) (i) Differentiate in brief between Thermoplastic and Thermosetting plastic.

[8 Marks]

(ii) Discuss in brief the methods of preserving timbers by water soluble preservatives.

[12 Marks]

Solution:

(i) **Thermo-plastics**

- Thermo-plastics variety softens by heat and hardens when cooled down. It can be used by remolding as many times as required.
- The thermo-plastic or heat non-convertible group is the general term applied to the plastics which becomes soft when heated and hard when cooled.
- Thermoplastic materials can be cooled and heated several times.
- When thermoplastics are heated, they melt to a liquid. They also freeze to a glassy state when cooled enough.
- Thermoplastic can be moulded into any shape.

Thermo-setting plastics

- **Thermo-setting plastics** cannot be reused. This variety requires a great pressure and momentary heat during moulding which hardens on cooling.
- The thermo-setting or heat convertible group is the general term applied to the plastics which become rigid when moulded at suitable pressure and temperature.
- This type of plastic passes originally through thermo-plastic stage. When they are heated in temperature range of 127°C to 177°C, they set permanently and further application of heat does not alter their form or soften them.
- But at the temperature of about 343°C, the charring occurs. This charring is a peculiar characteristic of the organic substances.

(ii) **Preservative treatment**

Preservatives: Timber in exposed application should be treated to minimize fungal decay and attack by insects. Preservative fall into three main groups:

1. Creosote oil preservative
2. Water borne preservative
3. Organic solvent preservative

Water soluble perspectives are odourless organic or inorganic salts and are adopted for inside locations only. If applied over outside surfaces, the salts can be leached by rainwater . Examples of leachable type of preservatives are zinc chloride, boric acid (borex), etc. Zinc chloride, sodium fluoride and sodium-penta-chloro-phenate are toxic to fungi. These are expensive and odourless (except for sodium-penta-chloro-phenate). Benzene-hexa-chloride is used as spray against borers. Boric acid is used against Lyctus borers and to protect plywood in tea chests.

Some of the other water soluble preservatives are fixed type and are as follows:

Copper-chromate-arsenic composition is made of three chemicals:

Arsenic-pentraoxide	$As_2O_5 2H_2O$	1 part
Copper sulphate	$CuSO_4 5H_2O$	3 parts
Sodium or potassium dichromate	$(Na\ or\ K)_2 Cr_2CO_7$	4 part

The preservatives is in the form of a powder and is used with water. Six parts of this powder is mixed with 100 parts by weight of water. The solution is applied in two coats. The timber is then allowed to dry for six weeks. This treatment renders the timber immune to the attacks of white ants and is known as AsCu treatment.

Acid-cupric-chromate composition:

Chromic acid	1.7 parts
Copper sulphate	50 parts
Sodium dichromate	48.3 parts

Chromate-zinc chloride composition:

Zinc chloride	1 part
Sodium or potassium dichromate	1 part

Copper-chrome-boric composition:

Boric acid	1.5 parts
Copper sulphate	3 parts
Sodium or potassium dichromate	4 parts

Zinc-meta-arsenic composition:

Arsenious trioxide	3 parts
Zinc oxide	2 parts
Acetic acid	Just to keep the above in solution under operating conditions

Zinc-chrome-boric compassion:

Boric acid	1 part
Zinc chloride	3 parts
Sodium dichromate	4 parts
Water	100 parts

Sources: (i) MADE EASY Theory Book (Pg.130-131)

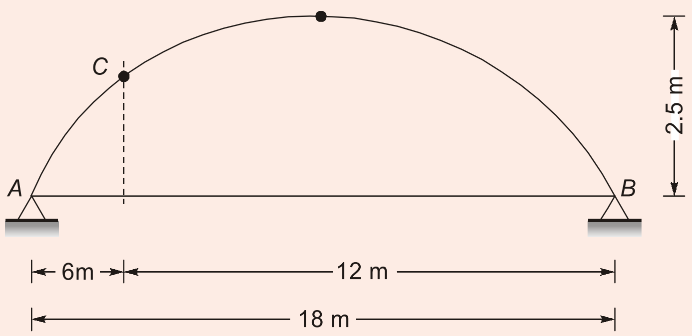
(ii) ESE Mains Test Series (Test-10) Q.3(b) Click here for reference

End of Solution

4. (b) Sketch influence line diagram for the bending moment at a point 'C' located 6 m from one of the supports of a three hinged symmetrical parabolic arch having span of 18 m and central rise 2.5 m. Locate the point from where the moving load changes the sign of bending moment at C.

[20 Marks]

Solution:



ILD for bending moment at C (M_c)

Bending moment at any section= BM in simply supported beam – Hy

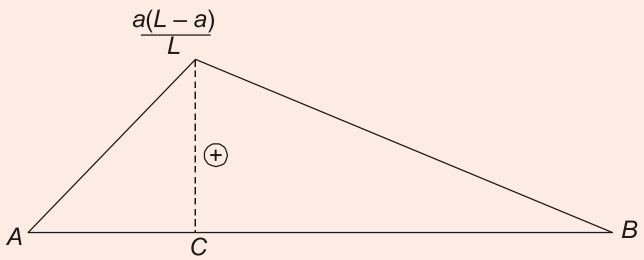
$\therefore$ ILD can be drawn by superimposing beam ILD and (Hy) ILD

We know, for parabolic arch

$$y = \frac{4h}{l^2}x(l-x)$$

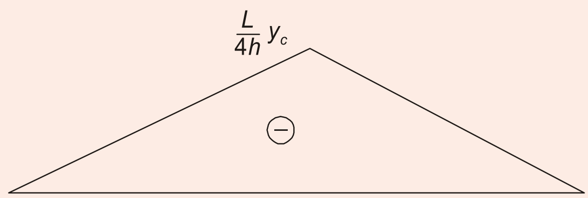
$$y \text{ at C } (x = 6 \text{ m}) = \frac{4\times 2.5}{(18)^2}\times 6\times(18-6) = \frac{20}{9}$$

ILD for bending moment,



Beam ILD for M_c

$$\frac{a(L-a)}{L} = \frac{6\times 12}{18} = 4$$

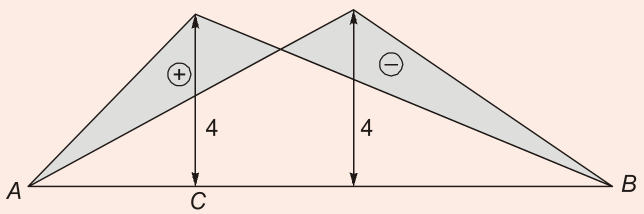


ILD for Hy_c

$$\frac{Ly_c}{4h} = \frac{18}{4\times 2.5}y_c$$

$$\frac{18}{4\times 2.5}\times\frac{20}{9} = 4$$

Superimposing both ILD



ILD for bending moment at C

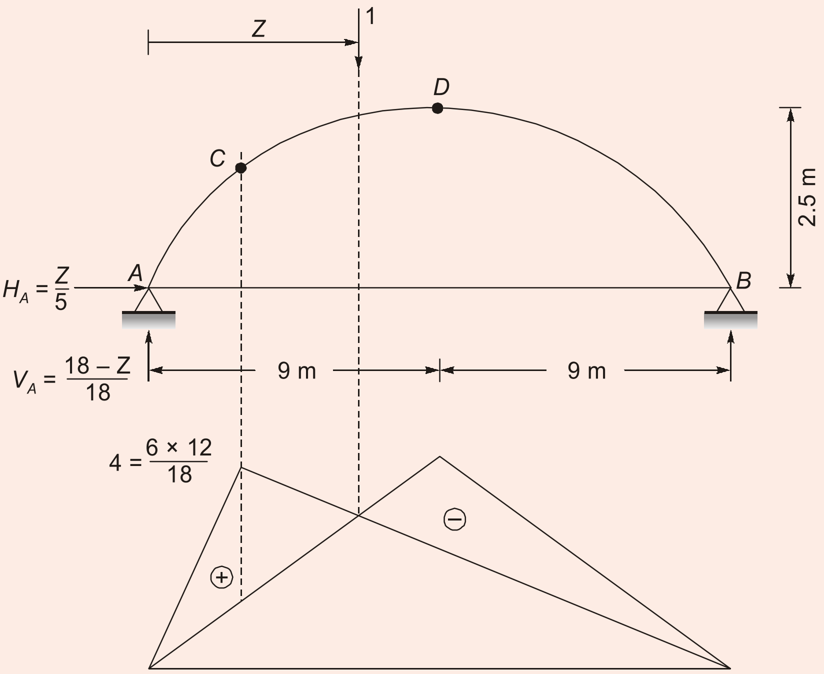
Assuming load is placed at Z than BM at C would be zero because at Z distance from A. ILD changes its sign.

$$\Sigma M_B = 0$$

$$\Rightarrow \quad V_A = \frac{18-Z}{18}$$

$$M_D = 0 \text{ (LHS)}$$

$$\Rightarrow \quad H_A = \frac{Z}{5}$$



Now, $\quad BM_C = 0$

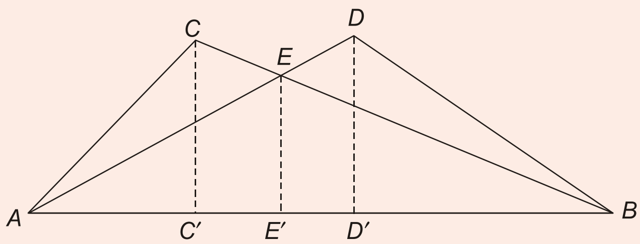
$$\Rightarrow \quad \frac{18-Z}{18} \times 6 - \frac{Z}{5} \times y_C = 0$$

$$\Rightarrow \quad \frac{18-Z}{18} \times 6 - \frac{Z}{5}\left\{\frac{4 \times 2.5}{18^2} \times 6(18-6)\right\} = 0$$

$$\Rightarrow \quad Z = 7.714 \text{ m}$$

Alternative Solution:

Location where bending moment changes its sign is the intersection point of both triangles i.e., *E*



$\Delta ADD'$ and $\Delta AEE'$

$$\frac{EE'}{AE'} = \frac{DD'}{AD'}$$

$$EE' = \frac{4}{9} \times AE' \qquad \text{...(i)}$$

$\Delta BEE'$ and $\Delta BC'C$

$$\frac{EE'}{BE'} = \frac{CC'}{BC'}$$

$$EE' = \frac{4}{12} \times BE' \qquad \text{...(ii)}$$

Equating eq. (i) and (ii)

$$\frac{4}{9}AE' = \frac{4}{12}BE'$$

$$\Rightarrow \quad AE' = \frac{3}{4}BE'$$

$$AE' + BE' = 18$$

$$\frac{7}{4}BE' = 18$$

$$BE' = 10.285 \text{ m}$$

$$AE' = 7.714 \text{ m}$$

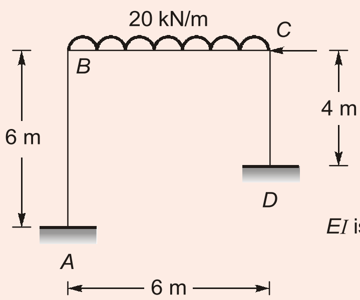
Bending moment changes, its sign at point 7.714 m from A.

Sources: MADE EASY Theory Book (Pg.167)

ESE Mains Workbook (Pg. 134, Q.3) Click here for reference

End of Solution

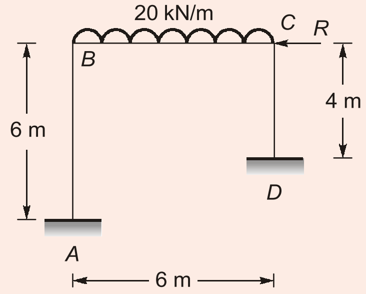
4. (c) Frame ABCD shown in figure, is acted upon by a UDL of intensity 20 kN/m on the horizontal span. What should be value of horizontal force '*P*' applied at C, that will prevent sway of the frame? Draw BMD.



EI is same for all members

[20 Marks]

Solution:



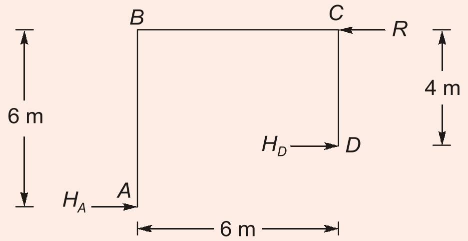
Joint	Member	Relative stiffness	Total stiffness	Distribution factor
B	BA	$\frac{I}{6}$	$\frac{I}{3}$	$\frac{1}{2}$
	BC	$\frac{I}{6}$		$\frac{1}{2}$
C	CB	$\frac{I}{6}$	$\frac{5I}{12}$	$\frac{2}{5}$
	CD	$\frac{I}{4}$		$\frac{3}{5}$

$$(M_F)_{BA} = (M_F)_{AB} = (M_F)_{CD} = (M_F)_{DC} = 0$$

$$(M_F)_{BC} = -60 \text{ kNm}$$

$$(M_F)_{CB} = +60 \text{ kNm}$$

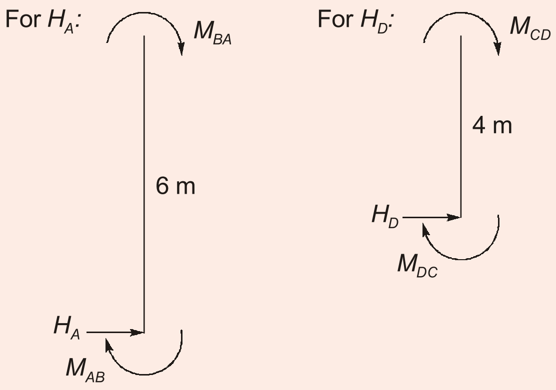
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{2}{5}$	$\frac{3}{5}$	
0	0	–60	60	0	0
	30	30	–24	–36	
15		–12	+15		–18
	+6	+6	–6	–9	
+3		–3	+3		–4.5
	+1.5	+1.5	–1.2	–1.8	
0.75		–0.6	+0.75		–0.9
	+0.3	+0.3	–0.3	–0.45	
18.75	37.8	–37.8	47.25	–47.25	–23.4



$$\Sigma F_x = 0$$

$$\Rightarrow \quad H_A + H_D - R = 0$$

$$\Rightarrow \quad R = H_A + H_D$$

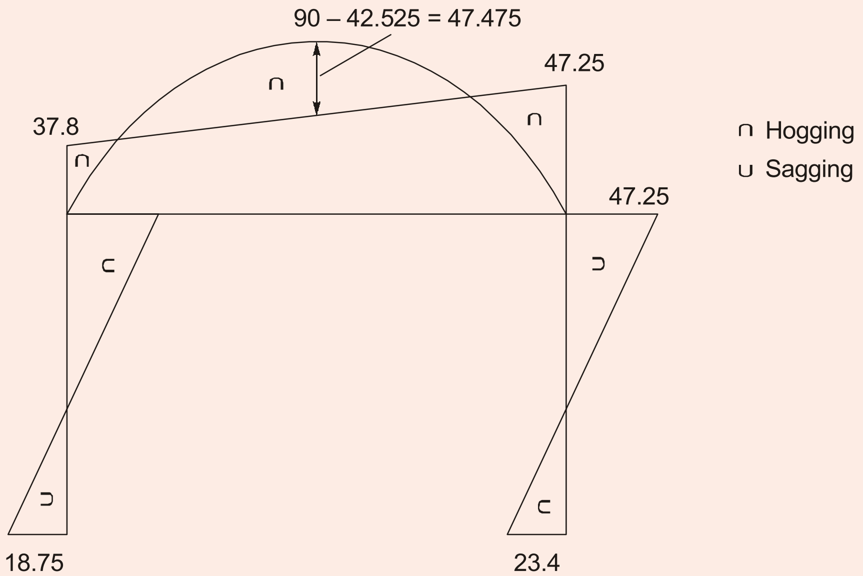


$$\text{Horizontal reaction at } A = \frac{M_{AB} + M_{BC}}{6} = \frac{56.55}{6} = 9.425 \text{ kN}$$

$$(H)_D = \frac{M_{DC} + M_{CD}}{4} = -17.6625 \text{ kN}$$

Sway force (unbalanced horizontal force) = –8.2375 kN

–ve sign represents R is towards right.



Sources: MADE EASY ESE Mains Workbook-1 (Similar Question)
(Pg. 106, Q.24), (Pg.148, Q.3), Pg.(184, Q.24)

Click here for reference

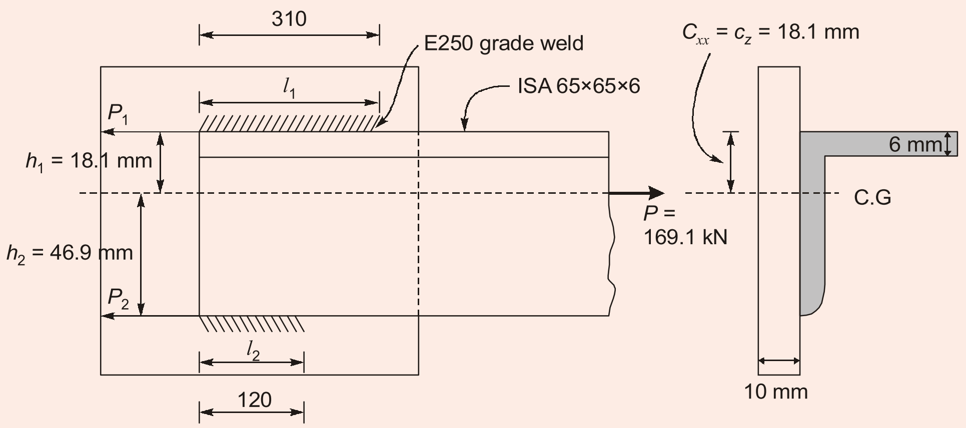
End of Solution

SECTION 'B'

5. (a) A tie member of a truss consisting of an angle section ISA 65 × 65 × 6 is welded to a gusset plate. Design a fillet weld to transmit a load equal to full tensile strength of the plate. Assume shop weld. Take grade of steel E 250 (Fe410). Also sketch the weld length.
Properties of ISA 65 × 65 × 6
A = 744 mm^2, C_z = 18.1 mm
Thickness of gusset plate is 10 mm.

[12 Marks]

Solution:



ISA 65 × 65 × 6
A = 744 mm^2
C_z = 181 mm

$$\text{Max.size of weld} = \frac{3}{4}\times 6 = 4.5 \text{ mm}$$

Min. size of weld = for a thicker plate of 10 mm
Min. size of weld = 3 mm

So, provide. s = size of weld = 3 mm

{always provide minimum size of weld}

P_T = Factored tensile strength of angle section

$$= A_g \times \frac{f_y}{1.1} = 744\times\frac{250}{1.1}$$

= 169.1 kN

P_T = 169.1 kN

[Since there are no holes in the angle, no net area cracking]

Analysis : Finding P_1 and P_2

$\Sigma X = 0$

$\Rightarrow$ $-P_1 - P_2 + P = 0$

$\Rightarrow$ $P_1 + P_2 = 169.1$ kN ...(i)

$\Sigma M_{\text{C.G. line}} = 0$

$\Rightarrow \quad -P_1 \times h_1 + P_2 \times h_2 = 0$ {A characteristic of any moment free connection}

$\Rightarrow \quad -P_1 \times 18.1 = -P_2 \times 46.9$

$P_1 = 2.59\, P_2$ ...(ii)

Eq. (ii) in (i)

$\Rightarrow \quad 2.59\, P_2 + P_2 = 169.1$

$\Rightarrow \quad P_1 = 2.59 \times 47.1 = 122 \text{ kN}$

Design : Finding l_1 and l_2

$$P_1 = f_s \times l_1 \times t_t$$

$$\Rightarrow \quad 122 \times 10^3 \text{ N} = \frac{410}{\sqrt{3} \times 1.25} \times l_1 \times 0.7 \times 3$$

$$f_s = \frac{f_u}{\sqrt{3} \times 1.25} \text{ for E 250 grades, } f_u = 410 \text{ MPa}$$

$t_t = 0.7s = 0.7 \times 3 = 2.1$ mm = throat the thickness

$l_1 = 306.7$ mm

Provide effective length

$l_1 = 310$ mm

$$P_2 = f_s \times l_2 \times t_t$$

$$47.1 \times 10^3 \text{ N} = \frac{410}{\sqrt{3} \times 1.25} \times l_2 \times 0.7 \times 3$$

$l_2 = 118.4$ mm

Provide effective length,

$l_2 = 120$ mm as shown in figure

Note : Always welds must begin from the end of angle section as shown in figure. (Gaylord and gaylord, design of steel structures)

Sources: MADE EASY Conventional Practice Question Book (Pg.302, Q.22)

ESE Mains Test Series (Test-2) Q.5(d) Click here for reference

End of Solution

5. (b) Find the web buckling and web crippling strength of a beam (ISLB 350) simply supported at both ends. Assume the stiff bearing length 100 mm and grade of steel *E* 250.

Section properties of ISLB 350 : t_w = 7.4 mm, t_f = 11.4 mm, R = 16 mm

R = radius of root.

Given: Design compressive stress f_{cd}, N/m^2

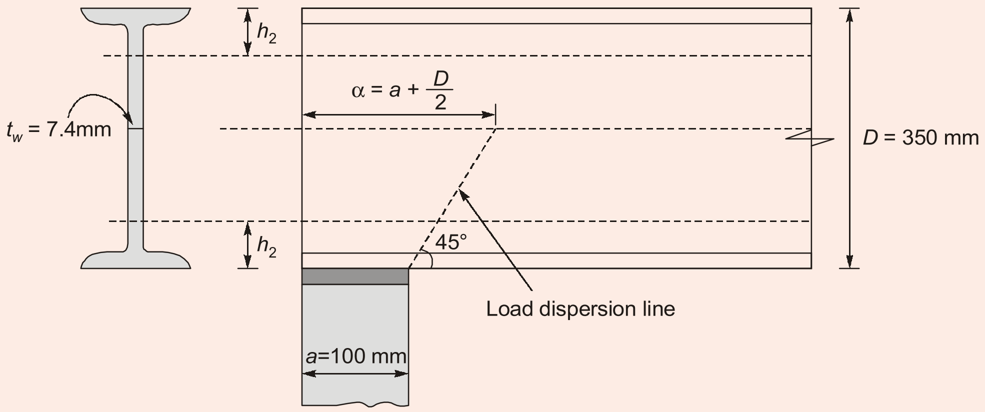
KL/r	f_{cd}
90	121
100	107
110	94.6

[12 Marks]

Solution:

ISLB 350 t_f = 11.4 mm, R = 16 mm

(i) Web buckling strength:



h_2 = Depth of fillet

$= t_f + R = 11.4 + 16 = 27.4$ mm

a = Stiff bearing length = 100 mm

Width of web at N.A. $= \alpha = a + \frac{D}{2} = 100 + \frac{350}{2} = 275$ mm

Section area of imaginary column $= A_g = \alpha \times t_w = 275 \times 7.4 = 2035$ mm^2

Slenderness ratio of imaginary column

$$= \frac{kL}{r_{min}} = \frac{2.425d}{t_w}$$

d = depth of web between toes of fillets $= D - 2h_2 = 350 - 2 \times 27.4$

$d = D - 2h_2 = 350 - 2 \times 27.4 = 295.2$ mm

So, for $$\frac{kL}{r_{min}} = \frac{2.425d}{t_w} = \frac{2.425 \times 295.2}{7.4} = 96.73$$

$$f_{cd} = 121 - \frac{6.73}{10} \times (121 - 107) \quad \text{(from the given table)}$$

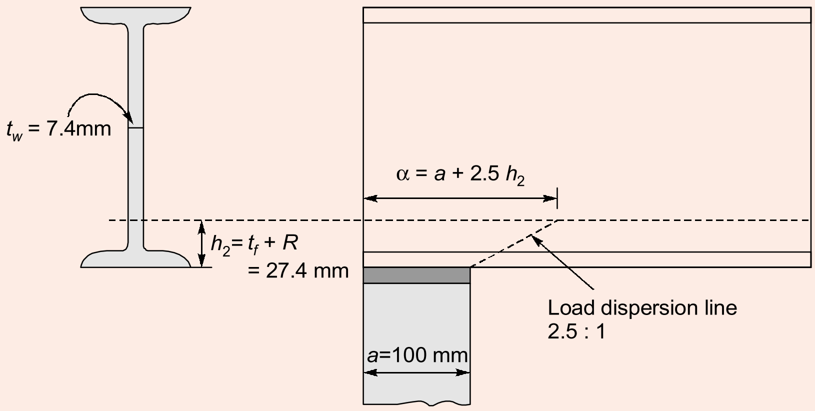
$$= 111.58 \text{ N/mm}^2$$

So, imaginary column strength = web buckling strength

$$= f_{cd} \times A_g = 111.58 \times 2035$$

$$= 227.06 \text{ kN}$$

(ii) **Web crippling strength:**



$$\alpha = a + 2.5\,h_2 = 100 + 2.5 \times 27.4 = 168.5 \text{ mm}$$

Web bearing strength $= P_b = (\alpha \times t_w) \times \sigma_P$

at toe of fillet σ_P = Design bearing strength $= \dfrac{f_y}{1.1}$

$$P_b = (168.5 \times 7.4) \times \frac{250}{1.1} = 283.386 \text{ kN}$$

Sources: MADE EASY Conventional Practice Question Book (Pg.367, Q.54)

Click here for reference

End of Solution

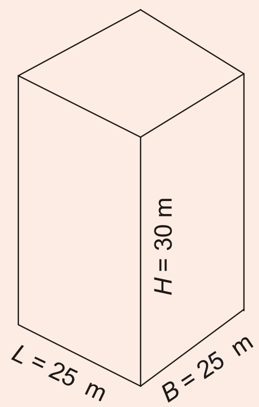
5. (c) A symmetrical reinforced concrete frame building 25 m × 25 m in plan is located in seismic zone IV on hard soil. The height of the building is 30 m. Determine the base shear due to earthquake.
Given:
Z = 0.24, I = 1.5
Total dead load = 150000 kN
Total live load (effective) = 50000 kN

$$T = 0.09\frac{h}{\sqrt{d}}$$

$$\frac{S_a}{g} = \begin{cases} 1+15T & 0 \le T \le 0.10 \\ 2.5 & 0.10 \le T \le 0.40 \\ \frac{1}{T} & 0.40 \le T \le 4.0 \end{cases}$$

[12 Marks]

Solution:



$I = 1.5$m, $Z = 0.24$, $R = 5$ (Assuming special RC frame)

Height of building, $h = 30$ m

Base dimension, $D = 25$ m

So, time period, $T = 0.09\frac{h}{\sqrt{D}}$

$$= 0.09 \times \frac{30}{\sqrt{25}} = 0.54 \text{ s}$$

For $T = 0.54$ s

$$\frac{S_a}{g} = \frac{1}{T} = \frac{1}{0.54} = 1.852$$

Thus horizontal seismic coefficient,

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)$$

$$= \left(\frac{0.24}{2}\right)\left(\frac{1.5}{5}\right)(1.852)$$

$$= 0.0667$$

Response reduction factor

$$R = 5.0$$

(For framed RCC building with ductile detailing)

Note: *In zone IV ductile detailing is must for all buildings as per IS 13920.*

Total seismic weight of building = DL + 50% LL

= 150000 + 50% of 50000

= 175000 kN

Total base shear

$$V_B = W \times A_h$$

$$= 0.0667 \times 175000$$

$$= 11667.6 \text{ kN}$$

Sources: MADE EASY ESE Mains Workbook-2 (Similar Question) (Pg.148, Q.7)

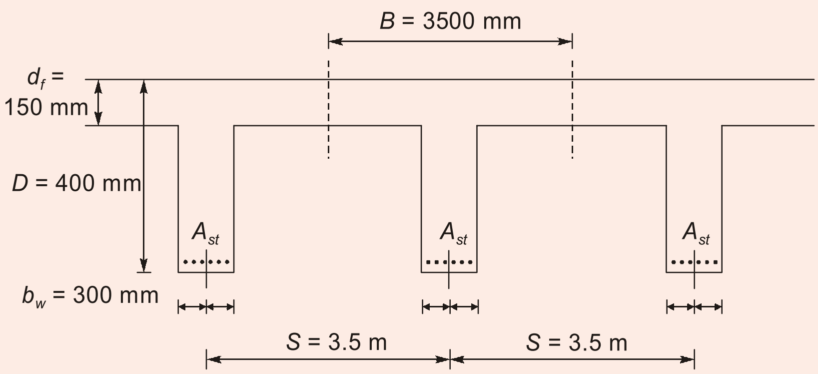
Click here for reference

End of Solution

5. (d) A floor of an old building consists of 150 mm thick RC slab monolithic with the beam of width 300 mm and total depth 400 mm. The beams are spaced 3.5 m c/c and their effective span (simply supported) is 7 m. The beams are reinforced with 5 Nos. 28 ϕ bars as tension reinforcement. Determine the moment carrying capacity of the beams. Use M25 and Fe500. Adopt limit state method of design. Nominal cover = 30 mm. Diameter of the stirrups = 8 mm.

[12 Marks]

Solution:



Given:

Grade of concrete = M25

Grade of steel = Fe500

$\phi_s = 8$ mm

So, effective depth, $d = 400 - 30 - 8 - \frac{28}{2} = 348$ mm

Effective flange width, $b_f = b_w + 6D_f + \frac{l_o}{6} \ngtr \frac{l_1 + l_2}{2}$

$= 300 + 6 \times 150 + \frac{7000}{6} \ngtr \frac{3500 + 3500}{2}$

$= 2366.67 \ngtr 3500$ mm

So, $b_f = 2366.67$ mm

Assuming neutral axis depth $x < D_f$

From $C = T$

$0.36\, f_{ck}\, b_f\, x = 0.87\, f_y\, A_{st}$

$\Rightarrow \quad 0.36 \times 25 \times 2366.67 \times x = 0.87 \times 500 \times 5 \times \frac{\pi}{4} \times 28^2$

$x = 62.88 \text{ mm} < 150 \text{ mm}$ (OK)

Thus moment capacity, $\text{MOR} = 0.36\, f_{ck}\, b_f\, x\,(d - 0.42x)$

$$= 0.36 \times 25 \times 2366.67 \times 62.88 \times (348 - 0.42 \times 62.88)$$

$$M_u = 430.72 \text{ kNm}$$

$$\text{Working MOR} = \frac{M_u}{1.5} = \frac{430.72}{1.5} = 287.15 \text{ kNm}$$

Sources: MADE EASY Conventional Practice Question Book (Pg.217, Q.7)
ESE Mains Workbook-2 (Pg. 41, Q.1)
ESE Mains Test Series (Test-1) Q.5(b) Click here for reference

End of Solution

5. (e) What is Work Breakdown Structure (WBS) with respect to construction planning and management? How is WBS classified into different levels?

[12 Marks]

Solution:

The first major step in the planning process after project requirements definition is the development of the Work Breakdown Structure (WBS). A WBS is a product-oriented family tree subdivisions of the hard ware, services and data required to produce the end product. The WBS is structure in accordance with the way the work will be performed and reflects the way in which project costs and data will be summarized and eventually reported. Preparation of the WSB also considers other that required structured data, such as scheduling, configuration management, contract funding, the technical performance parameters.

The work breakdown structure acts as a vehicle for breaking the work down into smaller elements thus providing a greater probability that every major and minor activity will be accounted for Although a variety of work breakdown structure exist, the most common is the six-level indented structure shown below :

	Level	Description
Managerial levels	1	Total program
	2	Project
	3	Task
	Level	
Technical levels	1	Subtask
	2	Work package
	3	Level of effort

Level 1 is the total program and is composed of a set of projects. The summation of the activities and costs associated with each project must equal the total program. Each project, however can be broken down into task where the summation of all tasks equal the summation of all projects, which in turn, comprises the total program. The reason for this subdivision of effort is simply case of control. Program management therefore becomes synonymous with the integration of activities, and project manager acts as the integrator, using the work breakdown structure as the common framework.

The upper three levels of the WBS are normally specified by the customer (if part of an RPF/RFQ) as the summary level for reporting purposes. The lower levels are generated by the contractor for in house control. Each level serves a vital purpose. Level 1 is generally used for the authorization and release of all work budgets are prepared at level 2 and schedules are prepared at level 3.

Sources: MADE EASY ESE Mains Test Series (Test-7) Q.1(e) Click here for reference

End of Solution

6. (a) A simply supported reinforced concrete beam of size 300 mm × 500 mm is reinforced with 5 Nos. 16 ϕ bars as tension reinforcement. Two bars are curtailed at quarter span from both ends. Find out the load carrying capacity (UDL) of the beam having effective span of 6 m. Also design the beam against shear force. Use M25 and Fe415. Nominal cover = 30 mm. Use limit state method of design. Show the reinforcement detail (cross-section) also. Use 2 Nos. 12 ϕ bars as hanger bars.

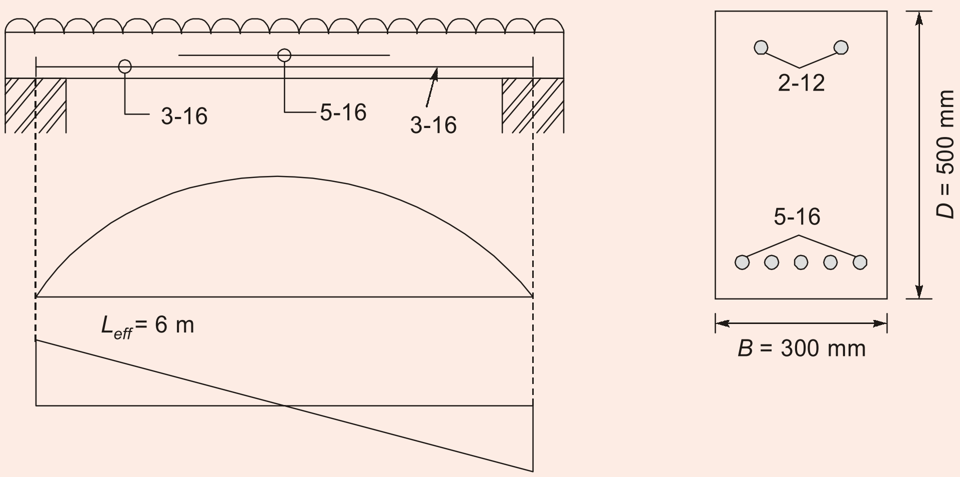
$\frac{M_u}{bd^2}$	2	2.5	2.75	3	3.25	3.5
P_t	0.51	0.61	0.74	0.83	0.91	–

P_t	0.25	0.5	0.75	1.0	1.25
τ_c, MPa	0.36	0.49	0.57	0.64	0.7

[20 Marks]

Solution:

A.



$\left[\frac{M25}{Fe415}\right]$ $A_{st} = 5\times\frac{\pi}{4}(16)^2 = 1005.31\text{ mm}^2$

1. Load carrying capacity of beam.
   (neglecting huger bars)
   (a) Assuming 8 mm ϕ stirrups

$$\text{Effective cover} = \text{Nominal cover} + \text{Dia. of stress} + \frac{1}{2}\text{ dia. of main}$$

$$= 30 + 8 + \frac{16}{2} = 46 \text{ mm}$$

$$d = 500 - 46 = 454 \text{ mm}$$

(b) $x_{u,\,lim} = 0.48 \times d = 0.48 \times 454$

$$= 217.92 \text{ mm}$$

(c) $$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} B} = \frac{0.87 \times 415 \times 5 \times \frac{\pi}{4}(16)^2}{0.36 \times 25 \times 300}$$

$$= 134.43 \text{ mm}$$

$x_u < x_{u,\,lim}$ (Under reinforcement section)

(d) Moment of resistance

$$M_u = 0.36 f_{ck} B x_u (d - 0.42 x_u)$$

$$= 0.36 \times 25 \times 300 \times 134.43 \times \frac{(454 - 0.42 \times 134.43)}{10^6}$$

$$= 144.30 \text{ kN-m}$$

(e) Working MR, $\text{MR} = \frac{M_u}{1.50} = \frac{144.30}{1.50} = 96.20 \text{ kNm}$

(g) From table given in equation

$$P_t\% = \frac{A_{st}}{Bd} \times 100 = \frac{1005.31}{300 \times 454} \times 100 = 0.738$$

$$\frac{M_u}{Bd^2} = 250 + \frac{2.75 - 2.50}{(0.74 - 0.61)} \times (0.738 - 0.61) = 2.746$$

$$M_u = \frac{2.746 \times 300 \times 454^2}{10^6} = 169.80 \text{ kNm}$$

$$MR_w = \frac{169.80}{1.50} = 113.20 \text{ kNm}$$

(h) Considering minimum of above two (as per limit state method)

$$\text{MR} = 96.20 \text{ kNm}$$

(i) So total load on beam

$$\text{MR} = \text{BM} = \frac{wL^2}{8} = 96.20$$

$$w = \frac{96.20 \times 8}{L_{eff}^2} = \frac{96.20 \times 8}{6^2} = 21.38 \text{ kN/m}$$

Deducting self weight = 0.30 × 0.50 × 1 × 25 = –3.75 kN/m

Net S.I. load capacity of the beam

= 21.38 – 3.75 = 17.63 kN/m

B. Design of shear reinforcement

Total load on beam = 21.35 kN/m

(width of support is not given)

So considering , $L_d = L_{eff} = 6.0$ m

(i) Maximum shear force

$$V_u = 1.50 \times \frac{21.38 \times 6}{2} = 96.21 \text{ kN}$$

(ii)
$$\tau_v = \frac{V_u}{Bd} = \frac{96.21 \times 1000}{300 \times 454} = 0.706 \text{ N/mm}^2$$

(iii)
$$P_t\% = \frac{A_{st}}{Bd} = \frac{3 \times \frac{\pi}{4} \times (16)^2}{300 \times 454} \times 100 = 0.44\%$$

(2 bars are curtailed)

(iv)
$$\tau_c = 0.36 + \frac{(0.49 - 0.36)}{(0.50 - 0.25)} \times (0.44 - 0.25) = 0.46 \text{ N/mm}^2$$

(v)
$$V_c = \tau_c Bd$$

$$= 0.46 \times 300 \times \frac{454}{1000} = 62.65 \text{ kN}$$

(vi)
$$V_s = V_u \; V_c$$

$$= 96.21 - 62.65$$

$$= 33.56 \text{ kN}$$

(vii) Spacing of 2L – 8 mm ϕ

$$S_v = \frac{A_{sv} \times 0.87 f_y \times d}{V_s} = \frac{2 \times \frac{\pi}{4}(8)^2 \times 0.87 \times 415 \times 454}{33.56 \times 1000}$$

$$= 491 \text{ mm}$$

(viii) Minimum shear reinforcement

$$\frac{A_{SV}}{BS_v} \geq \frac{0.40}{0.87 f_y}$$

$$S_v \leq \frac{0.87 \times f_y \times A_{sv}}{0.40 \times B} \leq \frac{0.87 \times 415 \times 2 \times \frac{\pi}{4}(8)^2}{0.40 \times 300}$$

$$\leq 302 \text{ mm}$$

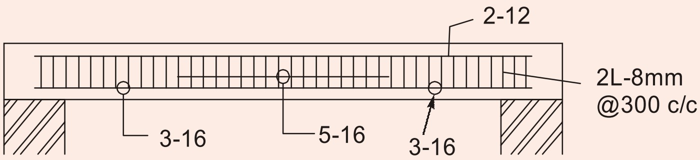
(ix) Maximum spacing

(i) = 0.75 d = 0.75 × 454 = 340

(ii) 300 mm

So provide 8ϕ - 2L - @ 300 mm c/c

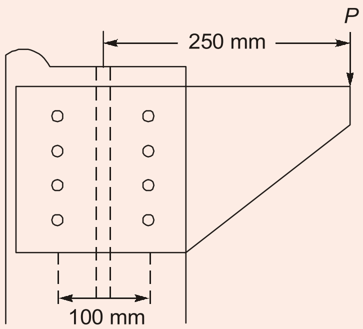
Throughout the span of the beam



Sources: MADE EASY Conventional Practice Question Book (Similar) (Pg.224, Q.22)
ESE Mains Workbook-2 (Pg.4 Q.8) Click here for reference

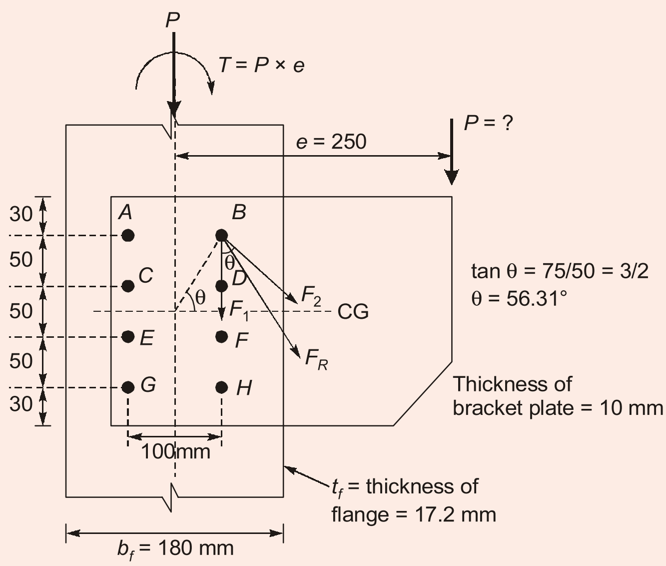
End of Solution

6. (b) A bracket plate is connected to a flange of ISMB 500 as shown in figure. Find the safe load P carried by the joint. M16 bolts of grade 4.6 are provided at a pitch of 50 mm and end distance 30 mm.
Given:
Thickness of bracket plate = 10 mm
Width of flange b_f = 180 mm
Thickness of flange t_f = 17.2 mm
Steel grade of bracket plate Fe410



[20 Marks]

Solution:



Diameter of bolt, $\phi = 16$ mm

Diameter of bolt hole in the plate,

$d = \phi + 2 = 18$ mm

Note : The most critically stressed bolt is the are for which 'r' is maximum and θ is minimum. In this case, bolts B and H are most critically stressed be cause, r is maximum and θ is minimum.

Analysis :

1. $$F_1 = \frac{P}{n} = \frac{P}{8} = 1.125\,P$$

2. $$F_2 = \frac{P.e}{\Sigma r^2} \times r_B$$

$e = 250$ mm

$$r_A = r_B = r_G = r_H = \sqrt{75^2 + 50^2} = 90.14 \text{ mm}$$

$$r_C = r_D = r_E = r_F = \sqrt{25^2 + 50^2} = 55.9 \text{ mm}$$

$$F_2 = \frac{P \times 250}{4\left[90.14^2 + 55.9^2\right]} \times 90.14 = 0.5\,P$$

3. $$F_R = \sqrt{F_1^2 + F_2^2 + 2F_1 F_2 \cos\theta}$$

$$= \sqrt{(0.125P)^2 + (0.5P)^2 + 2 \times 0.125P \times 0.5P \times \cos 56.3°}$$

$$= 0.579\,P$$

4. $F_R \le R_V$

Bolt value (R_V)

Bolt is in single shear

$$P_s = \text{shear strength of bolt} = \left(0.78 \times \frac{\pi}{4} \times d^2\right) \times f_s$$

$$= 0.78 \times \frac{\pi}{4} \times 16^2 \times \frac{400}{\sqrt{3} \times 1.25} = 28.975 \text{ kN}$$

t = t of bracket = 10 mm

$$P_b = (d \times t)\, f_b$$

$$k_b = \min\begin{cases} = \dfrac{p}{3d_0} - 0.25 = \dfrac{50}{3 \times 18} - 0.25 = 0.675 \\ = \dfrac{e}{3d_0} = \dfrac{30}{3 \times 18} = 0.555 \\ = \dfrac{f_{ub}}{f_{up}} = \dfrac{400}{410} \\ = 1.0 \end{cases}$$

$$f_b = 2.5 \times k_b \times \frac{f_{u,p}}{1.25} = 2.5 \times 0.555 \times \frac{410}{1.25}$$

$$P_b = (16 \times 10) \times 2.5 \times 0.555 \times \frac{410}{1.25}$$

$$= 72.816 \text{ kN}$$

So, Bolt value $R_V = 28.975$ kN

$$0.579\,P \leq 28.975 \text{ kN}$$

$\Rightarrow$ $P \leq 50.043$ kN

So, P = Max factored load that can be applied

$$= 50.04 \text{ kN}$$

$$P_{safe} = \text{safe load} = \frac{P}{1.5} = \frac{50.04}{1.5} = 33.36 \text{ kN}$$

Sources: MADE EASY Conventional Practice Question Book (Pg.287, Q.13)

Click here for reference

End of Solution

6. (c) What is a crane? How is it used in the construction industry? Briefly explain three different types of cranes that are being used in construction works.

[20 Marks]

Solution:

A crane is a tower or derrick that is equipped with cables and pulleys that are used to lift and lower material. They are commonly used in the construction industry and in the manufacturing of heavy equipment. Cranes for construction are normally temporary structures, either fixed to the ground or mounted on a built vehicle.

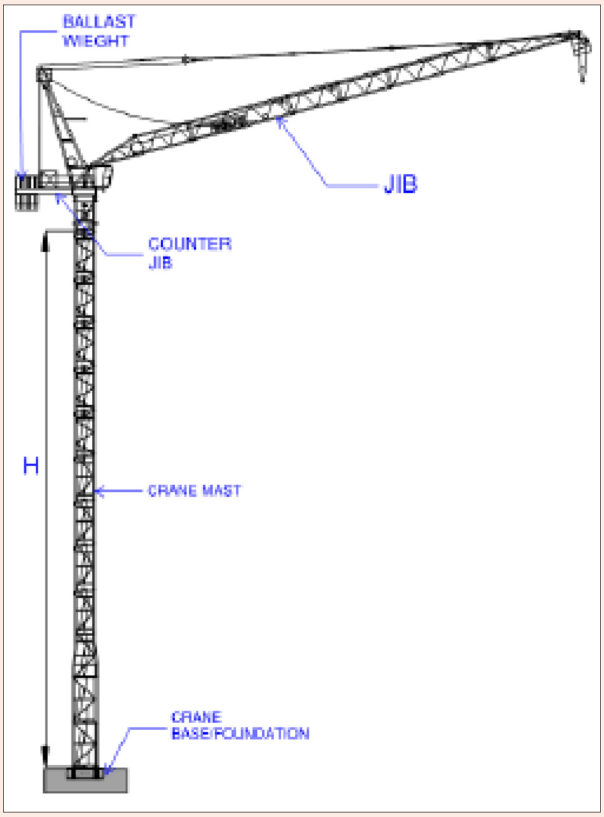
The crane is an essential piece of equipment for heavy construction work and lifting tasks of all kinds. Equipped with cables and pulleys, and based upon the application of fundamental mechanical principles, a crane can lift and lower loads well beyond the capabilities of human construction workers.

Crane design has evolved to meet the demands of a variety of industrial needs, and modern cranes often coordinate simple systems to achieve complex lifting tasks – sometimes in environments which would be dangerous for human workers.

Types of Cranes:

1. Tower Crane:

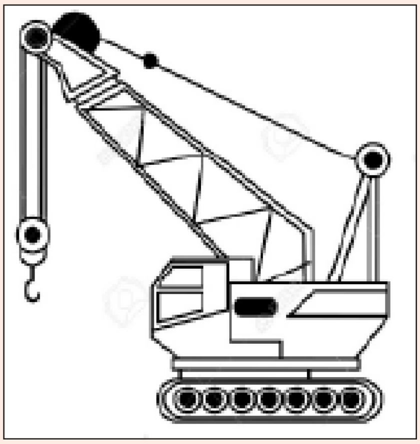
The tower crane is a form of balance crane which is commonly used on urban construction sites. This machine is anchored to the ground and provides an optimum blend of height and lifting capability which is often deployed to erect multi-storey city buildings.



Two horizontal arms jut from a central tower, with one used to suspend the heavy loads to be lifted, and the other fitted with heavy concrete blocks as a counter-weight. A tower crane is controlled by a driver who either sits high above in a small cabin located at the top of the tower, or else uses a remote-control system to operate his machine from the ground.

2. **Mobile Cranes:**

Mobile cranes are commonly mounted on wheeled vehicles, but cranes used for railway work are adapted to travel on rail tracks, and various floating cranes can be attached to barges when used for construction work on bridges and waterways.



Many types of crane are mobile, including Mobile Tower Cranes. Different types of crane serve a temporary purpose, and a mobile crane may be little more than a robust steel boom fitted to a transportable platform.

The lifting arm is typically hinged to allow it to be hoisted and lowered as required. This is usually achieved by cable systems or hydraulic mechanisms, and the whole mobile structure can be fitted with outriggers to provide further stability during on-site operations.

3. **Gantry Cranes:**

Using a hoist installed in a fixed machinery housing, or otherwise able to slide along a rail framework, this crane employs a strong overhead gantry to lift and maneuver extremely heavy industrial loads.

Gantry cranes and other so-called 'overhead' cranes – which also carry suspended loads in a similar fashion – are widely used in factories and shipyards and similar commercial locations where their robust qualities make them essential equipment.

Sources: MADE EASY Theory Book, CTPM (Pg.118-119) Click here for reference

End of Solution

7. (a) Design a square column of height 3 m subjected to an axial load of 1500 kN under dead and live load condition. Use limit state method of design. Assume effective length factor = 1.2. Size of the column is fixed at 400 mm × 400 mm. Show the reinforcement detail (cross-section). Use M25 and Fe500.

[20 Marks]

Solution:

Step-1: Checking the column as short or long

Unsupported length of column

$$L_0 = 3.0 \text{ m} = 3000 \text{ mm}$$

$$(l_e)_x = (l_e)_y = 3000 \times 1.2 = 3600 \text{ mm}$$

$$D_x = D_y = 400 \text{ mm}$$

Slenderness ratio,
$$\lambda = \frac{l_e}{D} = \frac{3600}{400} = 9 < 12$$

Slenderness ratio is less than 12 so the column is short.

Step-2: Calculation of minimum eccentricity

$$(e_x)_{min} = (e_y)_{min} = \max\begin{cases}\frac{l_x}{500} + \frac{D}{30} = \frac{3000}{500} + \frac{400}{30} = 19.33 \text{ mm}\\ 20 \text{ mm}\end{cases}$$

$$0.05B = 0.05 \times 400 = 20 \text{ mm}$$

So,
$$e_{min} \ngtr 0.05B$$

Since, the minimum eccentricities are less than 0.05 times the least lateral dimensions, the following formula given by IS 456 : 2000 can be used of the design of axially loaded short columns.

Step-3: Use of column design formula

$$P_u = 0.4 f_{ck} A_g + (0.67 f_y - 0.4 f_{ck}) A_{sc}$$

Factored axial load, $P_u = 1.5 \times 1500 = 2250$ kN

$$2250 \times 10^3 = (0.4 \times 25 \times 400^2) + (0.67 \times 500 - 0.4 \times 25)\, A_{sc}$$

$$A_{sc} = 2000 \text{ mm}^2$$

Step-4: Reinforcement design

Provide (4-16 mm) + (4 + 20 mm) bars with 20 mm diameter bars at the corner and 16 mm diameter bars at the face.

$$(A_{sc})_{provided} = 2060.9 \text{ mm}^2 > 2000 \text{ mm}^2$$

$$\text{Percentage of R/F provided} = 2060.9 \times \frac{100}{400^2} = 1.288\%$$

> Minimum R/F required (= 0.8%)
< Maximum reinforced (= 6%)

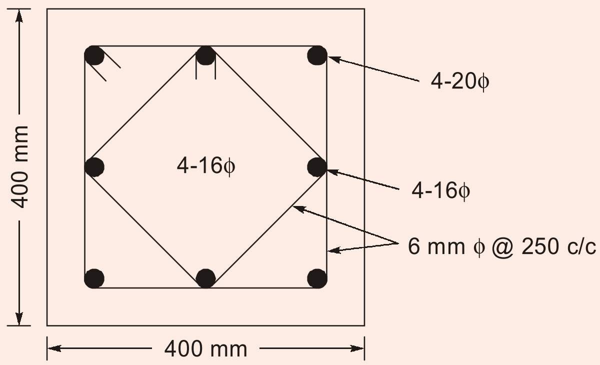
Step-5: Lateral ties

Diameter of tie, $\phi_t \geq \begin{cases} \frac{\phi_{max}}{4} = \frac{20}{4} = 5 \text{ mm} \\ 6 \text{ mm} \end{cases}$

Adopt tie members as 6 mm

Spacing of ties, $S_t \leq \begin{cases} \text{Least lateral dimension of column} = 400 \text{ mm} \\ 16 \times \phi_m = 16 \times 16 = 256 \text{ mm} \\ 300 \text{ mm} \end{cases}$

Provide 6 mm ϕ @ 250 mm c/c



Sources: MADE EASY Theory Book (Pg.248, Q.1)

ESE Mains Workbook-2 (Pg. 74) Q.1, 2 **Click here for reference**

End of Solution

7. (b) In an industrial shed, it is proposed to provide a hot rolled section ISMB 500 to carry a two-wheeled system crab on it. The crab can move over the flange of the beam from one end to another end and each wheel of the crab is capable to carry a maximum vertical load of 60 kN (including self weight of wheel).

The centre to centre distance between two supporting ends of the beam is 6 m and the end of the beams are restrained against torsion.

The space between two wheels = 2.4 m. Take impact factor for vertical load as 25%.

Verify the capability of the beam to carry the bending moment developed due to vertical load only. Assume the section is plastic. Grade of steel *E* 250.

Properties of ISMB 500:

b_f = 180 mm, t_f = 17.2 mm, t_w = 10.2 mm

r_z = 202.1 mm, r_y = 35.2 mm

Z_{ex} = 1808.7 cm^3, Z_{pz} = 2074.67 cm^3

Critical stress,

$f_{cr,b}$ (MPa)

$\frac{KL}{r}$	$\frac{h}{t_f}$	
	25	30
170	136.7	121.3
180	127.1	112.2

Design bending compressive stress to lateral buckling f_{bd}, for f_y = 250 MPa.

$f_{cr,b}$	f_{bd} (MPa)
150	106.8
100	77.3

[20 Marks]

Solution:

Part - 1 : Factored applied BM ($M_{u,\,cal}$)

Each wheel load reaction = 60 kN

Impact factor = 1.25

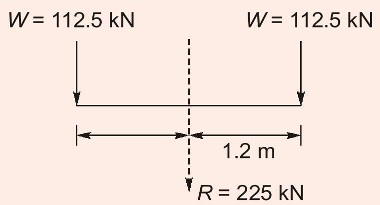
Partial safety factor for loads = 1.5

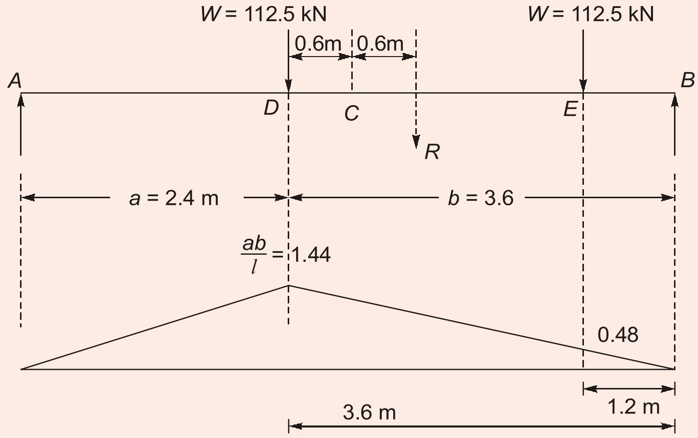
Factored wheel load = $W = 1.5 \times 1.25 \times 60 = 112.5$ kN

Since ends of beam are restrained against torsion, effective length of compression flange of beam

l = length of beam = 6 m

To get maximum B.M, keep 2 loads as shown in figure.





ILD for BM at *D*

$$\frac{ab}{l} = \frac{2.4 \times 3.6}{6} = 1.44 \text{ m}$$

So, maximum applied factored B.M.,

$$M_{u,cal} = 112.5\,(1.44 + 0.48)$$

$$M_{u,cal} = 216 \text{ kN-m}$$

Part - 2 : Factored moment carrying capacity of beam (M_u)

For $\quad \dfrac{kL}{r_{min}} = \dfrac{6000 \text{ mm}}{35.2 \text{ mm}} = 170.45$

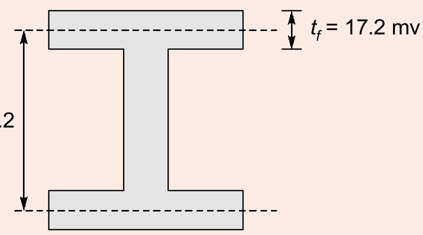
$$\frac{h}{t_f} = \frac{465.6 \text{ mm}}{17.2 \text{ mm}} = 27.07$$

$\frac{kL}{r_{min}}$	h/t_f		
	25	27.07′	30
170	136.7	↓	121.3
170.45→	136.27	129.9	120.89
180	127.1		112.2

$f_{cr,\,b} = 129.9 \text{ N/mm}^2 \qquad F_{bd} = ?$

$f_{cr,b}$	f_{bd}
150	106.8
129.9→	?
100	77.3

$h = D - 2t$
$= 550 - 2 \times 17.2$
$= 465.6$ mm



h = Centre of centre distance between flanges

$$f_{bd} = 106.8 - \frac{20.1}{50}(106.8 - 77.3) = 94.94 \text{ N/mm}^2$$

M_u = Factored moment carrying capacity

$$= f_{bd} \times z_P \quad \text{(for plastic section)}$$
$$= 94.94 \times 2074.67 \times 10^3 = 196.9 \text{ kNm}$$

Since $M_{u,cal} > M_u$, the beam is unsafe against bending.

Sources: MADE EASY Previous Conventional Solved Questions (Pg.458, Q.5.9)

Click here for reference

End of Solution

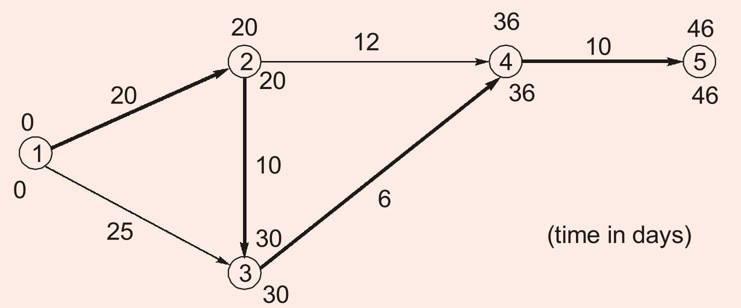
7. (c) The following table gives the activities in a construction project and other relevant information.

Activity	Duration (Days)
1 – 2	20
1 – 3	25
2 – 3	10
2 – 4	12
3 – 4	6
4 – 5	10

(i) Draw the network for the project.
(ii) Find the critical path.
(iii) Find free, total and independent floats for each activity.

[20 Marks]

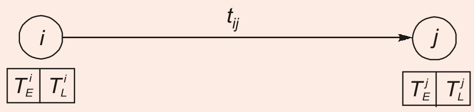
Solution:



Critical path (1-2-3-4-5) (Duration = 46 days)

Activity	Time	EST	EFT	LST	LFT	F_T	F_F	F_N	Remarks
1-2	20	0	20	0	20	0	0	0	Critical
1-3	25	0	25	5	30	5	5	5	
2-3	10	20	30	20	30	0	0	0	Critical
2-4	12	20	32	24	36	4	4	4	
3-4	6	30	36	30	36	0	0	0	Critical
4-5	10	36	46	36	46	0	0	0	Critical

Note:



$$EST = T_E^i$$
$$LST = T_L^j - t_{ij}$$
$$EFT = T_E^i + t_{ij}$$
$$LFT = T_L^j$$

Total float, $TF = LST - EST = LFT - EFT$

Free float $FF = T_F - S_j$

Independent float, $IF = FF - S_i$

Sources: MADE EASY Mains Test Series (Mock Test-3) Q.7(b) **Click here for reference**

End of Solution

8. (a) A combined footing is to be provided for two columns (size 300 × 300) spaced at 3 m c/c. Axial load on each of the columns is 350 kN. The width of the footing is fixed at 1.4 m. A foundation beam of 400 mm × 800 mm is provided along the length. Design the foundation slab using M25 and Fe500. Assume the thickness of the slab varies from 250 mm to 150 mm. Also show the reinforcement detail (in cross-section) of the footing slab. Use limit state method of design. Bearing capacity of the soil is 100 kN/m^2.

$\frac{M_u}{bd^2}$	0.3	0.35	0.4	0.45	0.5
P_t	0.070	0.082	0.094	0.106	0.118

P_t	< 0.15	0.25	0.5	0.75	1.0
τ_c, MPa	0.29	0.36	0.49	0.57	0.64

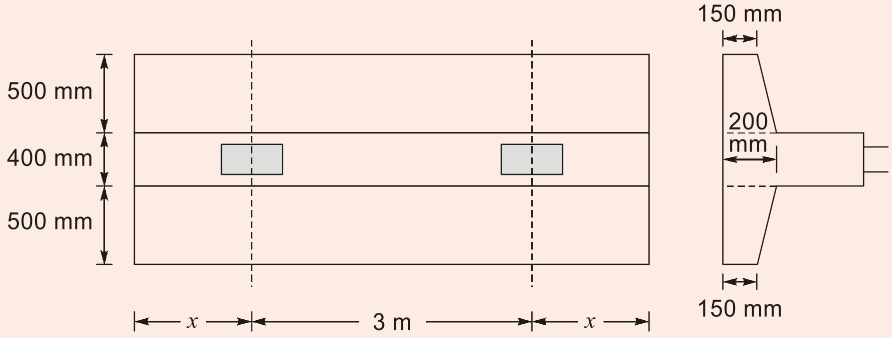
[20 Marks]

Solution:

Load on each column, $P = 350$ kN

Size of column $= 300 \times 300$ mm

Width of footing, $B = 1.40$ m



A. Size of footing

Total load from column $= (2 \times 350) = 700$ kN

Load of beam and foundation slab (20% P)

$= 140$ kN

Total $P_T = 840$ kN

Area of footing required,

$$\frac{P_T}{q_0} = \frac{840}{100} = 8.40 \text{ m}^2$$

Length of footing, $\frac{A}{B} = \frac{8.40}{1.40} = 6$ m

Load on both column is same. So projection on two side of column will be same

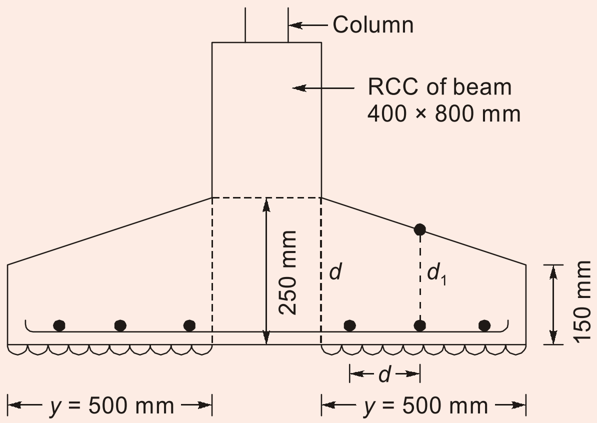
$L = 3\text{ m} + 2x = 6\text{m}$

So, $x = 1.50$ m

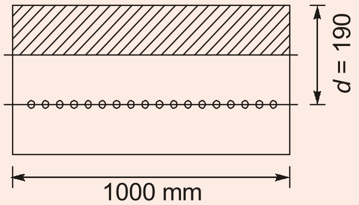
Design soil pressure

$$w_u = \frac{P_T}{A} = \frac{700}{6 \times 1.40} = 83.33 \text{ kN/m}^2$$

B. Design of slab



- Thickness of slab is already given in question, the slab on two sides of beam shall be designed as cantilever projection.
- Depth at face of beam = 250 mm
- Consider 1 m width of cantilever slab for design.
- Effective cover = $50 + \frac{16}{2} = 58 \text{ mm} \simeq 60 \text{ mm (say)}$
- Effective depth, $d = 250 - 60 = 190$ mm at face of beam



(i) Maximum bending moment (factored)

$$M_u = 1.50 \times w_0 \times \frac{y^2}{2}$$

$$= 1.50 \times 83.33 \times \frac{0.50^2}{2}$$

$$= 15.62 \text{ kNm}$$

(ii)
$$\frac{M_u}{Bd^2} = \frac{15.62 \times 10^6}{1000 \times 190^2} = 0.433$$

From table given in question

$$P_t\% = 0.094 + \frac{(0.106 - 0.094)}{(0.45 - 0.40)} \times (0.433 - 0.40)$$

$$= 0.102\%$$

$$A_{st} = \frac{0.102}{100} \times 1000 \times 190 = 194 \text{ mm}^2$$

(iii) As per IS code

Minimum area of steel

$$A_{st\,min} = \frac{0.12}{100} \times BD$$

$$= \frac{0.12}{100} \times 1000 \times 250$$

$$= 300 \text{ mm}^2 \qquad \text{(Provide)}$$

Spacing of 10 mm ϕ bars

$$= \frac{1000}{300} \times \frac{\pi}{4}(10)^2 = 261 \text{ mm}$$

Provide 10 mm ϕ @ 260 mm c/c

(iv) Same minimum reinforcement may be provided as distribution bars. 10 mm ϕ @ 260 mm c/c

(v) Check for shear

Maximum shear force at 'd' distance from face of beam c/s of shear

Projection $y_2 = y - d$

$= 0.50 - 0.19$

$= 0.31$ m

Maximum shear force,

$V_u = 1.50 \times w_0 \times y_2 \times 1$

$= 1.50 \times 83.33 \times 0.31 \times 1$

$= 38.75$ kN

Total depth of slab at 'd' distance

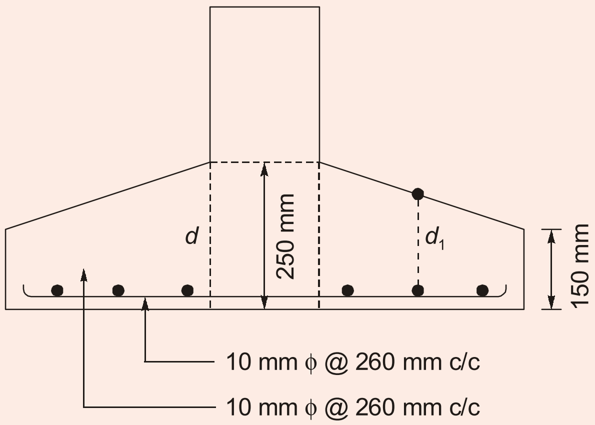
$$= 250 - \frac{(250-150)}{500} \times 190 = 212 \text{ mm}$$

Effective depth, $d_1 = 212 - 60 = 152$ mm

Shear stress, $\frac{V_u}{BD_1} = \frac{38.75 \times 1000}{1000 \times 152} = 0.255 \text{ N/mm}^2$

$P_t\% = 0.12\%$ provided.

$\tau_c = 0.29$ $\tau_V < \tau_C$ = safe in shear.



(Beam reinforcement no asked to design in question)

Sources: MADE EASY Theory Book (Pg.315, Q.8) Click here for reference

End of Solution

8. (b) A rafter member of a roof truss caries 40 kN compressive load (DL + LL) and 67 kN tensile load (DL + WL). The effective nodal length of the member is 2.1 m. A circular tube section of nominal bore diameter of 50 mm is used. Check the adequacy of the section. Grade of steel = E 250, Young's modulus E = 200 GPa.

Given:
Sectional properties of the section A = 523 mm^2, r = 20.3 mm
Outside diameter = 60.3 mm

Stress reduction factor $\chi = \dfrac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$

$\phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2]$

$\lambda = \sqrt{\dfrac{f_y}{f_{cc}}}$, $f_{cc} = \dfrac{\pi^2 E}{\left(\dfrac{KL}{r}\right)^2}$

Buckling class	*a*	*b*	*c*	*d*
α	0.21	0.34	0.49	0.76

[20 Marks]

Solution:

Compressive load = 40 kN (Dl + LL)

Tensile load = 67 kN (DL + WL)

kL = 2.1 m

Cross-section of column ⇒ Hollow circular section

Most efficient cross-section so, buckling class is '*a*'

A_g = 523 mm^2

r = 20.3 mm

Outside diameter = 60.3 mm

So, the thickness of hollow circular section is $\dfrac{10.3}{2}$ = 5.15 mm

P_c = Factored comp. of load carrying capacity of member

$= f_{cd} \times A_g$

$$f_{cc} = \frac{\pi^2 E}{\left(\frac{kL}{r}\right)^2} = \frac{\pi^2 \times 2 \times 10^5}{\left(\frac{2100}{20.3}\right)^2} = 184.45 \text{ N/mm}^2$$

$$\lambda = \sqrt{\frac{f_y}{f_{cc}}} = \sqrt{\frac{250}{184.45}} = 1.164$$

Note: *There is a printing mistake in question in formula for stress reduction factor.*

$$\phi = 0.5[1 + 0.21(1.164 - 0.2) + 1.164^2] = 1.279$$

(For hollows circular section buckling class is a so, α = 0.21)

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$$

$$= \frac{1}{1.279 + \sqrt{(1.279)^2 - (1.164)^2}} = \frac{1}{1.81}$$

$$= 0.552$$

$$f_{cd} = \chi\left(\frac{f_y}{1.1}\right) = 0.552 \times \left(\frac{250}{1.1}\right) = 125.56 \text{ N/mm}^2$$

$$P_c = f_{cd} \times A_g = 125.56 \times 523 = 65.67 \text{ kN}$$

$$P_u = \text{Factored comp. load} = 1.5 \times 40$$

$$= 60 \text{ kN}$$

Since $P_u < P_c$, member is safe in comp.

Tensile load carrying capacity = $P_T = A_g \times \frac{f_y}{1.1}$

$$P_T = 523 \times \frac{250}{1.1} = 118.86 \text{ kN}$$

Factored tensile force, $P_{T\,'cal} = 1.5 \times 67 = 100.5$ kN

Partial safety factor for DL + WL = 1.5

Since $P_{T\,'cal} < P_T$, member is safe in tension also.

Sources: MADE EASY Conventional Practice Question Book (Pg.34, Q.45)

ESE Mains Test Series (Test-14) Q.8(b) Click here for reference

End of Solution

8\. (c) A simply supported prestressed concrete beam of width 100 mm, depth 200 mm and span 10 m, carries a UDL of intensity '*w*'. If the member is prestressed with a parabolic cable having zero eccentricity at the ends and 60 mm eccentricity at mid, determine the value '*w*' for the following conditions, for effective prestressing force of 125 kN.

(i) Load balancing case.

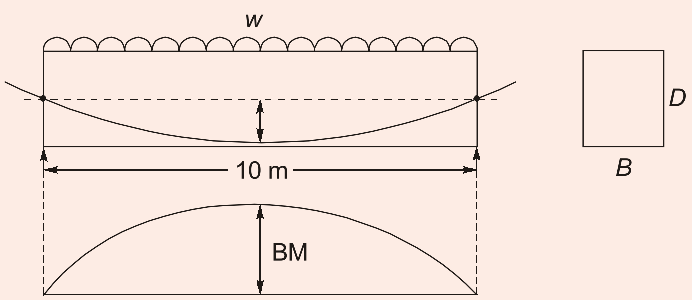
(ii) For no tensile stress condition at mid span.

(iii) For cracking condition taking the tensile strength of concrete as 1.5 N/mm^2.

For all cases neglect the weight of concrete.

[20 Marks]

Solution:



B = 100 mm

$$D = 200 \text{ mm}$$
$$\text{Span} = 10 \text{ m}$$
$$\text{UDL} = w$$

Parabolic cable, $e_1 = 0$ at ends

$e_2 = 60$ mm at midspan

P-force = 125 kN (Neglect weight of concrete)

For all cases we have to neglect weight of concrete.

1. For load balancing, $Pe = \dfrac{wL^2}{8}$

So, $$w = \frac{8Pe}{L^2} = \frac{8 \times 125 \times 0.06}{10^2} = 0.6 \text{ kN/m}$$

2. For no tensile stress condition at mid span (at bottom)

$$\frac{P}{A} + \frac{Pe}{Z} - \frac{M}{Z} = 0$$

$$\frac{125000}{100 \times 200} + \frac{125000 \times 60}{100 \times \frac{200^2}{6}} = \frac{M}{100 \times \frac{200^2}{6}}$$

$$(6.25 + 11.25) \times \frac{100 \times 200^2}{6 \times 10^6} = \text{BM}$$

So $$\text{BM} = 11.67 \text{ kNm} = \frac{wL^2}{8}$$

$$w = \frac{8 \times 11.67}{10^2} = 0.933 \text{ kN/m}$$

3. For cracking condition

Stress at bottom fibre = –1.5 N/mm^2

$$\frac{P}{A} + \frac{Pe}{Z} - \frac{M}{Z} = -1.50$$

$$6.25 + 11.25 + 1.50 = \frac{M}{Z}$$

$$M = 19 \times Z = \frac{19 \times 100 \times 200^2}{6 \times 10^6}$$

$$\text{BM} = 12.67 \text{ kNm} = \frac{wL^2}{8}$$

$$w = \frac{8 \times 12.67}{10^2} = 1.0133 \text{ kN/m}$$

Sources: MADE EASY ESE Mains Workbook (Pg.107, Q.3) Click here for reference

End of Solution

■■■■