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ESE 2023

Main Exam Detailed Solutions

Civil Engineering

PAPER-I

EXAM DATE : 25-06-2023 | 09:00 AM to 12:00 PM

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ANALYSIS

Civil Engineering Paper-I
ESE 2023 Main Examination

Sl.	Subjects	Marks
1	Building Materials and Construction	96
2	Strength of Materials	44
3	Structural Analysis	112
4	Steel Structures	84
5	RCC	84
6	Construction Planning and Management	60
		Total 480

Scroll down for detailed solutions

SECTION : A

Q.1 (a) (i) Explain the types of glazing used for the clay products.

(ii) What are the causes and remedies of efflorescence in bricks?

[6 + 6 = 12 marks : 2023]

Solution:

(i)

- Glazing the clay products seals porosity of product, make the product water proof, protect surface from external attacks and also decorate the product.
- Types of glazing can be as follows :
  1. **Transparent glazing,** is also known as salt glazing in which NaCl is thrown in kiln when burning is in its peak. Salts at that high temperature reacts with silica of clay and makes sodium silicate which makes product impermeable.
  2. **Lead glazing,** is related with dipping clay product in solution of lead oxide and tin oxide. After this product is again returned to potter's kiln where these adhered particle of lead and tin melts and form a thin transparent layer on outer surface. This metal of glazing suits for product which can't withstand against high temperature as in transparent glazing.
  3. **Opaque glazing,** also known of enamelling in which borax, chalk and other colouring matter fired with feldspar fint and lead oxide. The resulting molten glass is poured into water and grounded with remaining material in order to make product of consistency like cream known as slip.
     Now fully burn earthen wave is dipped into slip and a thin layer glaze is formed over the surface which can be burnt after drying to fuse the glaze over surface.

(ii) **Efflorescence:** This defect is caused because of alkalis present in bricks. When bricks come in contact with moisture, water is absorbed by them. This absorbed water dries out by evaporation from the exposed faces, and as it does so, the soluble salts it contains crystallize out on the surface. On drying grey or white powder patches appear on the brick surface. The process depends on the quantity of salts present in the bricks and their solubility.

Efflorescence can be minimized by selecting proper clay materials for brick manufacturing, preventing moisture to come in contact with the masonry. This can be achieved by providing waterproof coping and by using water repellent materials in mortars and by providing damp proof course.

Surface affected	Efflorescence degree
0%	nil
0 - 10%	Slight
10 - 50%	Moderate
> 50%	Heavy

Efflorescence will be serious when deposits are heavy and powder or flake gets detatched the brick surface.

End of Solution

Q.1 (b) Explain the specific reasons for the following:

(i) For prestressed concrete, the code recommends to use high tensile steel and high strength of concrete.

(ii) Helically reinforced circular columns have better compressive strength than that of similar columns withlateral ties.

[6 + 6 = 12 marks : 2023]

Solution:

(i)

1. Reasons for using high strength steel:

(a) In steel large amount of loss of stresses are observed after prestressing of cable. Loss of stress due to various reasons are around 200 – 300 N/mm^2.

(b) High strength steel is used of initial strength of about 1000 – 2000 N/mm^2, so that even after losses, about 80 to 90% of initial prestress are left in steel for effective working of prestressed concrete member.

$$\text{Loss of stress} \ngtr 10 \text{ to } 20\% \text{ of } p_0 (200 \text{ N/mm}^2)$$

So, $$p_0 \text{ required} \nless 1000 \text{ to } 2000 \text{ N/mm}^2$$

2. Reasons for using high strength concrete:

(a) To bear large stresses developed due to high value of force.

(b) To bear high bond stressed developed in pre tensioned members.

(c) To bear high bearing stresses developed in post tensioned members.

(d) To get high value of E_C

$$\Rightarrow \quad E_C = 5000\sqrt{f_{ck}}$$

(e) To keep the loss of stress less in steel due to various reasons.

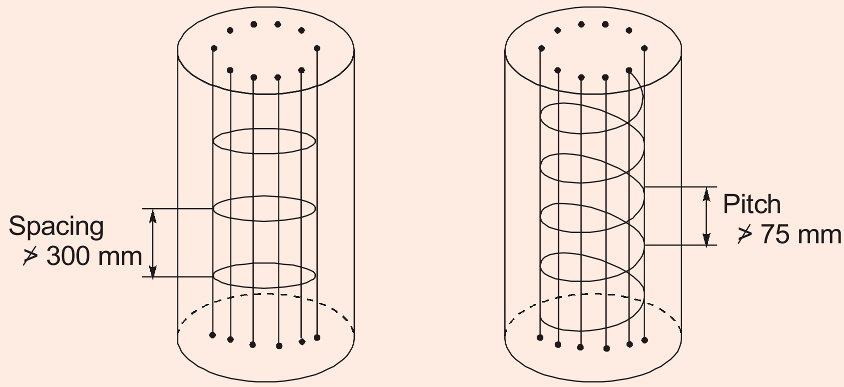
(ii)

Load carrying capacity of helically reinforced column are generally found more than column with normal lateral ties.

IS 456 - recommend to consider compressive strength of helically reinforced column 5% more than normal column with lateral ties.

Reasons:

1. Helical reinforcement are provided like a spring at very close pitch (value $\ngtr$ 75 mm) and the reinforcement is provided continuously providing better lateral strength of concrete.
2. In case of helically reinforced column concrete, inside core is subjected to triaxial compression so chance of failure of such column are reduced.
3. Column with helical reinforcement are generally used in circular column-and such columns are found more ductile than column with normal lateral ties, due to less pitch and continuity of steel around main bars.
4. Such columns are considered more effective for earthquake resistant structure.



Column with seperate lateral ties
(Less strength)
(Less ductile)

Column with helical reinforcement
(More strength)
(More ductile)

End of Solution

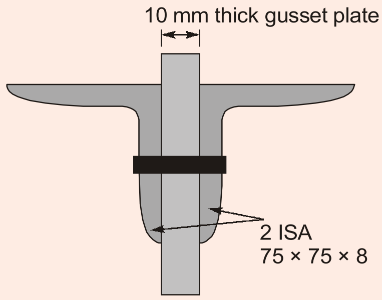
Q.1 (c) The rafter member of a truss consists of two angles ISA 75 × 75 × 8 placed (back-to-back) both sides of the gusset of thickness 10 mm. It carries factored axial compressive force of 200 kN. Determine the number of 16 mm diameter, 4.6 grade ordinary bolts for the joint. Assume E250 grade of steel and the cross-sectional area in the threaded part for 16 mm diameter bolt is 157 mm^2. Use K_b = 0.49, γ_{mb} = 1.25. Use limit state method of design.

[12 marks : 2023]

Solution:

Given:

$$Pu = 200 \text{ kN}$$
$$d = 16 \text{ mm}$$
$$k_b = 0.49$$
$$f_{ub} = 400 \text{ N/mm}^2$$
$$f_{up} = 410 \text{ N/mm}^2$$
$$A_{nb} = 157 \text{ mm}^2$$



Strength of bolt in shearing (double shear):

$$V_{dsb} = 2 \times A_{nb} \times \frac{f_{ub}}{\sqrt{3} \times \gamma_{mb}}$$

$$= 2 \times 157 \times \frac{400}{\sqrt{3} \times 1.25} = 58012.155 \text{ N}$$

Strength of bolt in bearing:

$$t_{min} = \begin{Bmatrix} 10 \text{ mm} \\ 8+8=16 \text{ mm} \end{Bmatrix} \text{minimum}$$

$$= 10 \text{ mm}$$

$$\therefore \quad V_{dpb} = 2.5 k_b d t_{min} \times \frac{f_{up}}{\gamma_{mb}}$$

$$= 2.5 \times 0.49 \times 16 \times 10 \times \frac{410}{1.25} = 64288 \text{ N}$$

So, strength of each bolt $= \text{minimum}\{58012.155, 64288\}$

$$= 58012.155 \text{ N}$$

$$\therefore \quad \text{No. of bolts required} = \frac{200 \times 10^3}{58012.155} = 3.44 \approx 4 \text{ bolts}$$

End of Solution

Q.1 (d) A bar specimen of 38 mm diameter was subjected to a pull of 98 kN during a tensile test. The extension on a gauge length of 200 mm was measured to be 0.092 mm and the change in diameter of 0.0048 mm. Determine the Poisson's ratio, modulus of elasticity, modulus of rigidity and bulk modulus of the material of bar specimen.

[12 marks : 2023]

Solution:

Given:

Length of bar, $L = 200$ mm
Diameter of bar, $d = 38$ mm
Axial force, $P = 98$ kN
Axial deflection, $\Delta L = 0.092$ mm

Now, As we know,

$$\Delta L = \frac{PL}{AE}$$

Putting values, we get

$$0.092 = \frac{98 \times 10^3 \times 200}{\frac{\pi}{4} \times 38^2 \times E} \qquad \left[\because A = \frac{\pi}{4} d^2\right]$$

where E is young's modulus of elasticity.

$$\Rightarrow \quad E = 1.88 \times 10^5 \text{ N/mm}^2$$

Also, change in diameter, $\Delta d = -0.0048$ mm

$$\text{Now,} \quad \text{Poisson's ratio, } \mu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$= \frac{-\left(\frac{-\Delta d}{d}\right)}{\frac{\Delta L}{L}}$$

$$\Rightarrow \qquad \mu = \frac{-\left(\frac{-0.0048}{38}\right)}{\frac{0.092}{200}} = 0.275$$

Now, $E = 2G(1 + \mu)$ where G is shear modulus

So, $$G = \frac{E}{2(1+\mu)} = \frac{1.88\times10^5}{2\times(1+0.275)}$$

$$= 0.74 \times 10^5 \text{ N/mm}^2$$

Also, $E = 3K(1 - 2\mu)$ where K is bulk modulus of elasticity

$$\Rightarrow \qquad K = \frac{E}{3(1-2\mu)} = \frac{1.88\times10^5}{3\times(1-2\times0.275)}$$

$$= 1.39 \times 105 \text{ N/mm}^2$$

So, Young's modulus of elasticity,

$E = 1.88 \times 10^5$ N/mm^2

Shear modulus, $G = 0.74 \times 10^5$ N/mm^2

Bulk modulus of elasticity, $k = 1.39 \times 10^5$ N/mm^2

Poisson's ratio, $\mu = 0.275$

End of Solution

Q.1 (e) (i) Withe the help of neat sketch of a typical grading curve, describe the term 'gap-graded aggregate' and the adverse effects of using such types of aggregates in concrete.

(ii) How is PPC different from OPC on the basis of their ingredients? Describe the advantages of using PPC in comparison to OPC.

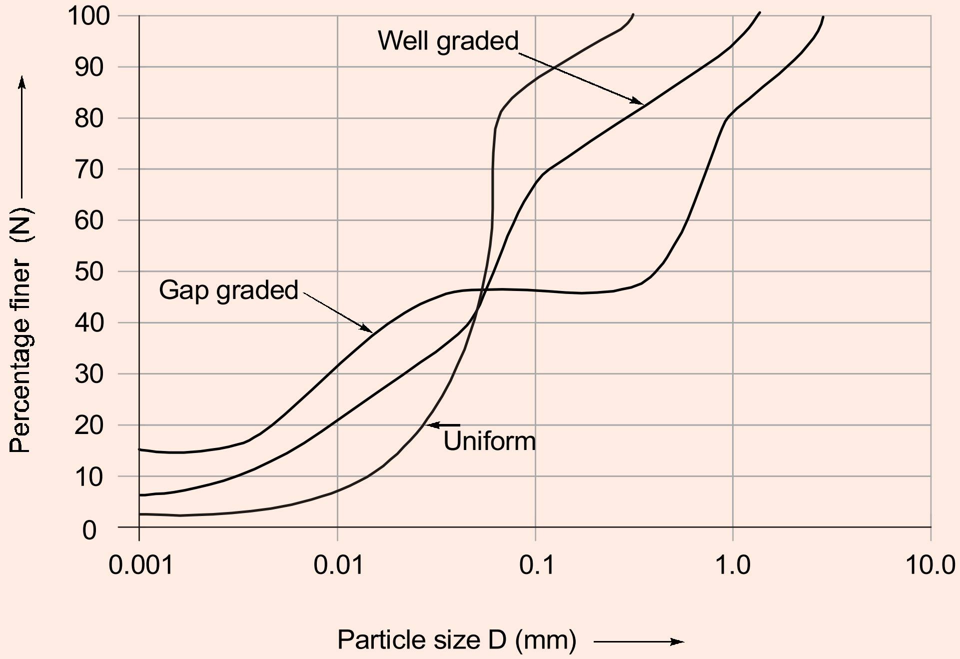
[6 + 6 = 12 marks : 2023]

Solution:

(i)

- A mix of aggregate which doesn't carry a particular range of grain size or in a aggregate mix if a particular range of grain size is absent is known as gap graded aggregate.
- It contains higher proportion of coarse aggregate and low percentage of fine aggregate which results in lesser surface area hence require lesser cement and lower w/c ratio.

  As it contains higher proportion of coarse aggregate hence chances of segregation will be more and may create problem of blockage if is transported through reinforcements. Hence it is recommended to make low workable mix with gap graded aggregate and then compact it by vibration.



(ii)

- Portland Pozzolma cement is prepared by inter grinding of opc clinker with 15-35% pozzolonic additive like fly ash, granulated blast furnance slag, surkhi, silica fume and rice husk etc.
- Pozzolonic materials are artificial mineral admixture obtained as different industrial waste and used as replacement of certain amount of clinker. Hence, production of clincker can be reached which makes ppc becomes environmental friendly cement.
- As clinker is replaced by pozzolanic materials, hence PPC is found to be more economical.
- Pozzolonic material doesn't have binding property but when it reacts with portlandite $Ca(OH)_2$ which was supposed to be during hydration of OPC, it forms C-S-H gel. Hence PPC results into more durability and impermeability.
- As PPC is finer than OPC. So mix becomes more cohesive hence resistance against segregation is more.
- PPC reduces requirement of water hence reduces chances of bleeding.
- PPC results in more volume of mortar than OPC due to its lower density.
- PPC results in improvement over strength.
- PPC results in resistance against external attack like chloride attack, carbonation and also provide electrolyte resistance.
- PPC also reduces chances of alkali-aggregate reaction due to replacement of clinker.

End of Solution

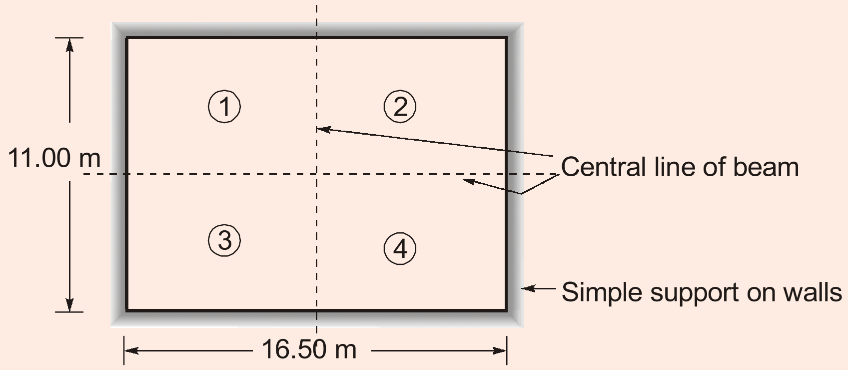
Q.2 (a) A room of effective span 16.50 m × 11.00 m is surrounded by brick walls. In order to lay the RCC slab over it, the room is divided in four equal panels by providing two central beams. The slab is simply supported on all the four walls as shown in the figure below. Using limit state design, determine and provide main reinforcement in a single panel, using 12 mm diameter steel bars of Fe-415 grade. Consider the grade of concrete as M-20. Draw the reinforcement detail of a panel. Use the following additional data:

Total factored load on slab (dead load + live load) = 16 kN/m².

Thickness of slab - 175 mm

Effective depth of slab = 150 mm

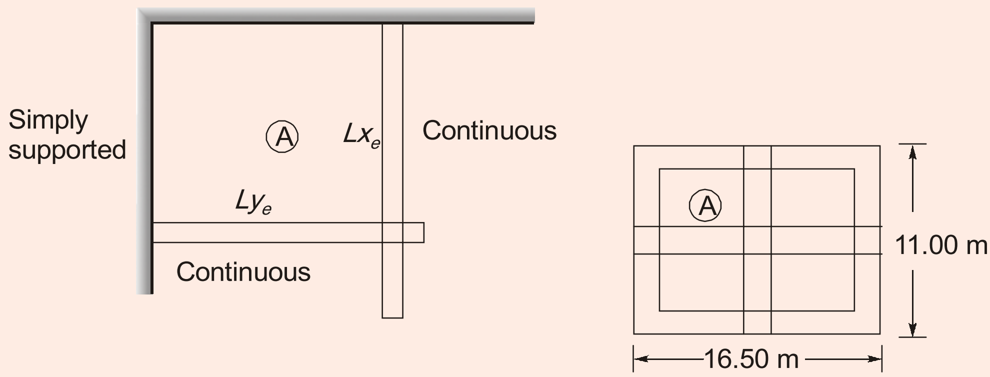
Note: Refer Annex D of IS 456: 2000 for finding the moments at different locations. The Annex is reproduced at Page Nos. 11 and 12.



[20 marks : 2023]

Solution:

One slab of the structure



1. Considering effective span

$$L_{xe} = \frac{11.0}{2} = 5.50\text{m}$$

$$L_{ye} = \frac{16.50}{2} = 8.25\text{m}$$

$$r = \frac{L_{ye}}{L_{xe}} = \frac{8.25}{5.50} = 1.50 < 2.0$$

$\Rightarrow$ So, it is a two way slab.

2. Depth of slab

$D = 175\text{ mm}$ Given

$d = 150$ mm

3. Loads

Total factored load, $w_u = 16$ kN/m^2

4. The slab is panel number 4.

Moment coefficients for r = 1.50

$\alpha_{x(-)} = 0.075 \qquad \alpha_{y(-)} = 0.047$

$\alpha_{x(+)} = 0.056 \qquad \alpha_{y(+)} = 0.035$

5. Moments = $\alpha.\ w_u.\ L_{xe}$

$M_{x(-)} = 0.075 \times 16 \times 5.50^2 = 36.3$ kNm

$M_{x(+)} = 0.056 \times 16 \times 5.50^2 = 27.10$ kNm

$M_{y(-)} = 0.047 \times 16 \times 5.50^2 = 22.75$ kNm

$M_{y(+)} = 0.035 \times 16 \times 5.50^2 = 16.94$ kNm

6. Area of steel required.

$$\text{Ast}_{x(-)} = \frac{0.5\times20}{415}\times\left[1-\sqrt{1-\frac{4.6\times36.3\times10^6}{20\times1000\times150^2}}\right]\times1000\times150$$

$= 748$ mm^2

$$\text{Ast}_{x(+)} = \frac{0.5\times20}{415}\times\left[1-\sqrt{1-\frac{4.6\times27.10\times10^6}{20\times1000\times150^2}}\right]\times1000\times150$$

$= 543.33$ mm^2

Considering 12 mm diameter bars –

For y-direction, $d_y = d_x - 12 = 150 - 12 = 138$ m

$$Ast_{y(-)} = \frac{0.5\times20}{415}\times\left[1-\sqrt{1-\frac{4.6\times22.75\times10^6}{20\times1000\times138^2}}\right]\times1000\times138$$

$= 493.4$ mm^2

$$Ast_{y(+)} = \frac{0.5\times20}{415}\times\left[1-\sqrt{1-\frac{4.6\times16.94\times10^6}{20\times1000\times138^2}}\right]\times1000\times138$$

$= 360$ mm^2

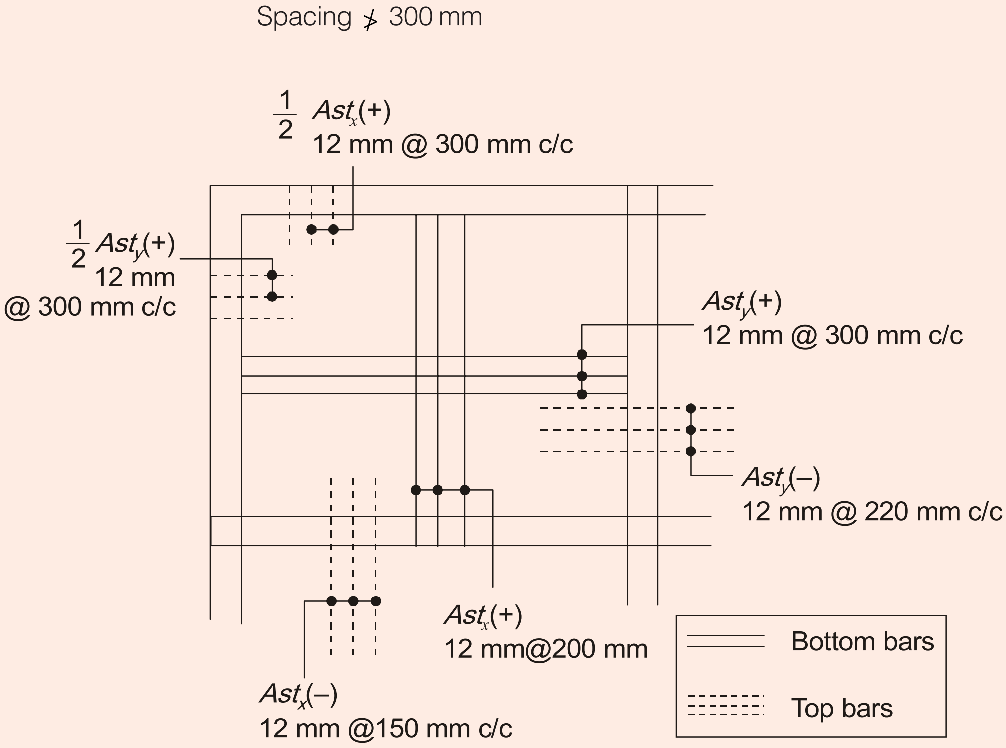
7. Spacing of 12 mm dia. bars.

(a) For $Ast_{x(-)}, S = \frac{1000}{748}\times\frac{\pi}{4}(12)^2 = 151$ mm, provide 12mm@ 150mm c/c

(b) For $Ast_{x(+)}, S = \frac{1000}{543.33}\times\frac{\pi}{4}(12)^2 = 208$ mm, provide 12mm@ 200mm c/c

(c) For $Ast_{y(-)}, S = \frac{1000}{493.4}\times\frac{\pi}{4}(12)^2 = 229$ mm, provide 12 mm@ 220 mm c/c

(c) For $Ast_{y(+)}, S = \frac{1000}{360}\times\frac{\pi}{4}(12)^2 = 314$ mm, provide 12mm@ 300mm c/c



End of Solution

Q.2 (b) Explain the mechanism of alkali-aggregate reaction in concrete. How can it be controlled?

[20 marks : 2023]

Solution:

- Alkali aggregate reaction is reaction between Silica in aggregate and alkali in cement that results into extensive expansion and may lead to complete disruption and disintegration of concrete, also known as cancer of concrete.
- A reactive aggregate in finely grounded state will inhibit the reaction which exits in range of 150 μm to 300 μm especially.
- This reaction takes place only in presence of water or water vapour. The water forms strong caustic solute with alkali of cement and attack over reactive silica which results in swelling type alkali silica gel. As due to this, cracking will occur.
- These crack reduces elasticity and strength of concrete.
- Reaction between cement and aggregate can be of two type i.e. reaction between alkali of cement and either silica or carbonates in the aggregate.
- Carbonate rocks having excess of Mg are prone to alkali aggregate reaction.
- Reactivity of aggregates, alkali content of cement, availability of moisture and temperature condition can affect the alkali aggregate reaction.

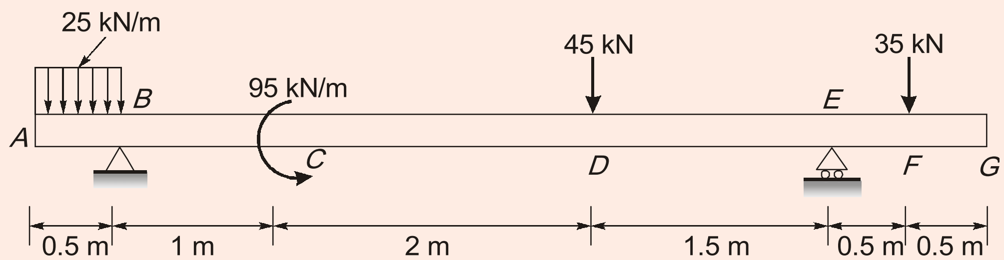
Control of Alkali-aggregate Reaction

- By Selecting Non-reactive Aggregate:
- **By Using Low Alkali Cement:** Cements with alkali less than 0.6 per cent should be used.

- **By Controlling Moisture:** Concrete should not be allowed to come in contact with water. The best way is to apply mortar with water proofing agents on concrete surface.
- **By Puzzolanas:** The aggregates are found to be reactive when they contain silica in a particular proportion and fineness. When fly-ash or surkhi or crushed stone dust is added, this optimum condition of silica being in particular proportion and fineness is disturbed.
- **By Air Entraining Agents:** The alkali-silica-gel imparts osmotic pressure over the set cement gel and this is mainly responsible for formation of cracks. When air entraining agents are added they absorb the osmotic pressure and control the expansion.

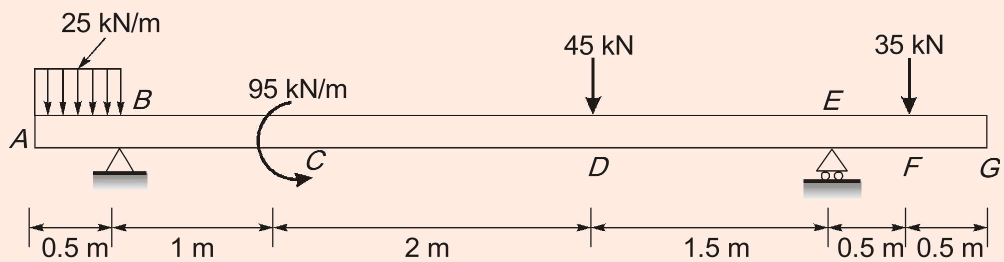
End of Solution

Q.2 (c) Draw the bending moment and shearing force diagrams for the overhanging beam loaded as shown in the figure below. Determine the positions of maximum bending moment, maximum shearing force and locate the locations of zero bending moment:



[20 marks : 2023]

Solution:



Let, V_B and V_E be the vertical reactions developed at B and E respectively.

Now, $\Sigma F_y = 0$

$\Rightarrow -25 \times 0.5 + V_B - 45 + V_E - 35 = 0$

$\Rightarrow V_B + V_E = 92.5$ ..(i)

Also, $\Sigma M_E = 0$

$$\Rightarrow -25\times0.5\times\left(4.5+\frac{0.5}{2}\right)+V_B\times4.5-95-45\times1.5+35\times0.5 = 0$$

$\Rightarrow -59.375 + V_B \times 4.5 - 95 - 67.5 + 17.5 = 0$

$\Rightarrow \quad V_B = 45.42$ kN

Putting V_B in (i), we get

$$V_E = 92.5 - V_B$$
$$= 92.5 - 45.42 = 47.08 \text{ kN}$$

For shear force diagram

Take a section x-x at 'x' distance from A

Portion *AB*

$$S_x(x \text{ from A}) = -25x \qquad [0 \le x < 0.5]$$
$$\Rightarrow \quad S_A = -25 \times 0 = 0$$
$$S_B(\text{just left of } B) = -25 \times 0.5$$
$$= -12.5 \text{ kN}$$

Portion *BD*

$$S_x = -25 \times 0.5 + V_B \qquad [0.5 \le x < 3.5]$$
So, $$S_B(\text{just right of } B) = -12.5 + 45.42$$
$$= 32.92 \text{ kN}$$
$$S_D(\text{just left of } D) = 32.92 \text{ kN}$$

NOTE: In portion *BD*, shear force will be constant.

Portion *DE*

$$S_x = -25 \times 0.5 + V_B - 45 \qquad [3.5 \le x < 5]$$
So, $$S_D(\text{just right of } D) = -12.5 + 45.42 - 45$$
$$= -12.08 \text{ kN}$$
$$S_E(\text{just left of } E) = -12.08 \text{ kN}$$

NOTE: In portion *DE*, shear force will be constant.

Portion *EF*

$$S_x = -25 \times 0.5 + V_B - 45 + V_E \qquad [5 \le x < 5.5]$$
$$\Rightarrow \quad S_E(\text{just right of } E) = -12.5 + 45.42 - 45 + 47.08$$
$$= 35 \text{ kN}$$
$$\Rightarrow \quad S_F(\text{just left of } F) = 35 \text{ kN}$$

NOTE: In portion *EF*, shear force will be constant.

Portion *FG*

$$S_x = -25 \times 0.5 + V_B - 45 + V_E - 35 \qquad [5.5 \le x < 6]$$
$$\Rightarrow \quad S_F(\text{just right of } F) = -12.5 + 45.42 - 45 + 47.08 - 35$$
$$= 0$$

NOTE: In portion *FG*, shear force will be constant.

For bending moment diagram:

Take a section *x-x* at 'x' distance from A

Portion *AB*

$$M_x(x \text{ from } A) = -\frac{25x^2}{2} \qquad [0 \le x < 0.5]$$

So, At $x = 0$, $M_A = -25 \times 0 = 0$

At $x = 0.5$, M_B (just left of B) $= -25 \times \dfrac{0.5^2}{2} = -3.125$ kN-m

Portion BC

$$M_x = -25 \times 0.5 \times \left(x - \frac{0.5}{2}\right) + V_B \times (x - 0.5) \qquad [0.5 \le x < 1.5]$$

At $x = 0.5, M_B$ (just right of B) $= -25 \times 0.5 \times \left(0.5 - \dfrac{0.5}{2}\right) + 45.4 \times (0.5 - 0.5)$

$= -3.125$ kN-m

$x = 1.5$, M_C(just left of C) $= -25 \times 0.5 \times \left(1.5 - \dfrac{0.5}{2}\right) + 45.42 \times (1.5 - 0.5)$

$= 29.795$ kN-m

Portion CD

$$M_x = -25 \times 0.5 \times \left(x - \frac{0.5}{2}\right) + V_B \times (x - 0.5) - 95 \qquad [1.5 \le x < 3.5]$$

At $x = 1.5, M_C$ (just right of C) $= -25 \times 0.5 \times \left(1.5 - \dfrac{0.5}{2}\right) + 45.42 \times (1.5 - 0.5) - 95$

$= -25 \times 0.5 \times \left(3.5 - \dfrac{0.5}{2}\right) + 45.42 \times (3.5 - 0.5) - 95$

$= -65.205$ kN-m

At $x = 3.5$, M_{CD}(just left of D) $= -25 \times 0.5 \times \left(3.5 - \dfrac{0.5}{2}\right) + 45.42 \times (3.5 - 0.5) - 95$

$= 0.63$ kN-m

Portion DE

$$M_x = -25 \times 0.5 \times \left(x - \frac{0.5}{2}\right) + V_B \times (x - 0.5) - 95 - 45(x - 3.5)$$

$[3.5 \le x < 5]$

So, at $x = 3.5$,

M_D (just right of D) $= -25 \times 0.5 \times \left(3.5 - \dfrac{0.5}{2}\right) + 45.42 \times (3.5 - 0.5) - 95 - 45(3.5 - 3.5)$

$= 0.63$ kN-m

So, at $x = 5$,

M_E (just left of E) $= -25 \times 0.5 \times \left(5 - \dfrac{0.5}{2}\right) + 45.42 \times (5 - 0.5) - 95 - 45(5 - 3.5)$

$= -17.5$ kN-m

Portion *EF*

$$M_x = -25\times0.5\times\left(x-\frac{0.5}{2}\right)+V_B\times(x-0.5)-95-45\times(x-3.5)+V_E\,(x-5)$$

[$5 \le x < 5.5$]

So, at x = 5,

$$M_E\text{(just right of } E) = -25\times0.5\times\left(5-\frac{0.5}{2}\right)+45.42\times(5-0.5)-95-45\times(5-3.5)+47.08(5-5)$$

$= -17.5$ kN-m

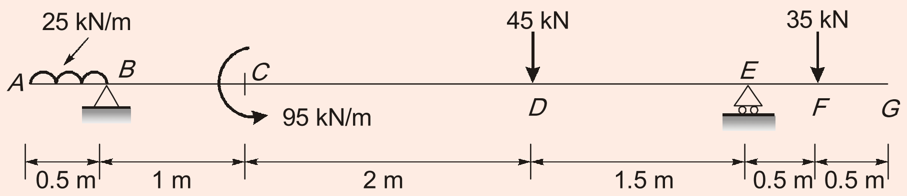
So, at x = 5.5,

$$M_F\text{(just left of } F) = -25\times0.5\times\left(5.5-\frac{0.5}{2}\right)+45.42\times(5.5-0.5)$$

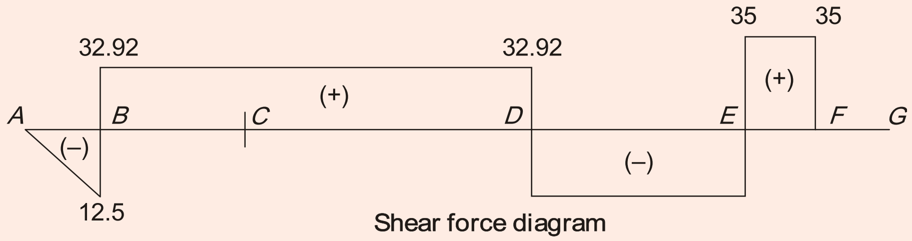
$$-95-45(5.5-3.5)+47.08\times(5.5-5)$$

$= 0$

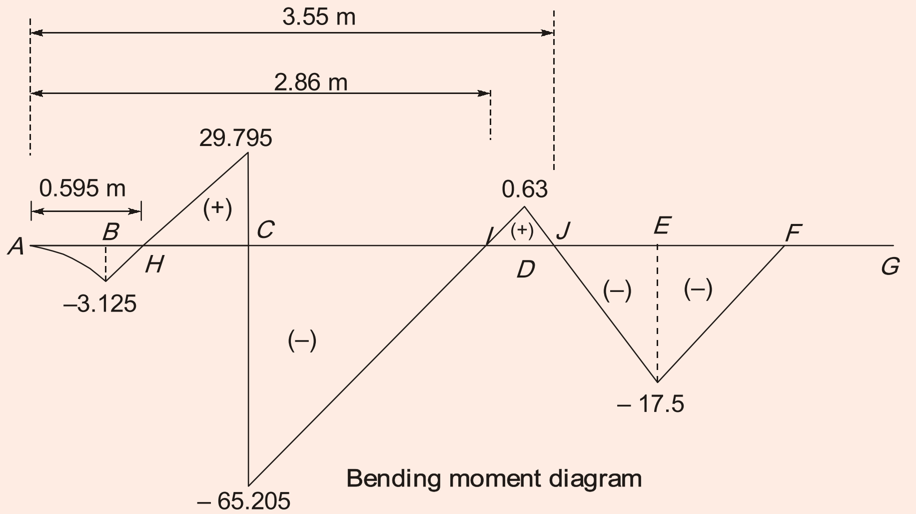
NOTE: In portion *FG*, there will be no bending moment.



Loading diagram



Shear force diagram



Bending moment diagram

Maximum shear force,

Shear force will be maximum in portion EF and its value will be 35 kN.

Maximum bending moment.

Maximum bending moment will be at just right of C i.e. at 1.5 m from A and its value will be 65.205 kN-m (hogging)

Locations of zero bending moment.

(i) Bending moment is zero in portion BC i.e., at H.

Now, In portion *BC*, $M_x = -25\times0.5\times\left(x-\frac{0.5}{2}\right)+45.42\times(x-0.5)$

$\Rightarrow$ $0 = -12.5\times(x-0.25)+45.42\times(x-0.5)$

$\Rightarrow$ $x = 0.595$ m

(ii) Bending moment is zero in portion *CD* i.e. at *I*.

Now, In portion *CD*, $M_x = -25\times0.5\times\left(x-\frac{0.5}{2}\right)+45.42\times(x-0.5)-95$

$\Rightarrow$ $0 = -12.5\times(x-0.25)+45.42\times(x-0.5)-95$

$\Rightarrow$ $x = 2.86$ m

(iii) Bending moment is zero in portion *DE* i.e. at *I*.

Now, In portion *DE*, $M_x = -25\times0.5\times\left(x-\frac{0.5}{2}\right)+45.42\times(x-0.5)-95-45(x-3.5)$

$\Rightarrow$ $0 = -12.5\times(x-0.25)+45.42\times(x-0.5)-95-45(x-3.5)$

$\Rightarrow$ $x = 3.55$ m

End of Solution

Q.3 (a) (i) What is gel-space ratio? How is it estimated? Discuss its effect on strength of concrete.

(ii) What are the factors affecting durability of concrete?

[10 + 10 = 20 marks : 2023]

Solution:

(i)

- As per gel space ratio concept development of strength in concrete depends on formation of C-SH gel.
- Formation of C-S-H gel depends on hydration rate which will be controlled by fineness of cement and temperature at which hydration is taking place.
- Other than formation of gel, strength at any w/c ratio depends on air content and formation of crack due to bleeding and shrinkage.
- Strength calculated on basis of gel space ratio is independent of age and found to be much more than actual as concrete assumed to be flawless and homogenous in this theory.

$$\Rightarrow \quad \text{Gel space ratio } (x) = \left[\frac{\text{Volume of gel formed } (ml)}{\text{Volume of cement hydrated + Volume of water } (ml)}\right]$$

Specific volume of 1g cement = 0.319 m*l*

1 m*l* of cement forms 2.06 ml of Gel

0.319 m*l* of cement = (1 g cement) = (0.319 × 2.06) = 6.6571 m*l* of gel

$$\Rightarrow \quad x = \left(\frac{0.6571\,C\alpha}{0.319\,C\alpha + w_0}\right)$$

where, C = weight of cement (g)

α = % hydrated

w_0 = volume of water (m*l*)

$\Rightarrow$ Theoritical strength, $S = 240\,x^3$ (Intrinsic strength of gel)

(ii)

Major factors affecting durability are as follows:

(a) **Permeable surface:** Due to deficiency of compaction of concrete the entrapped voids are left over finished concrete surface, which are non-uniformly distributed and interconnected. Permeable surface can also be caused due to leaching out Portlandite during hydration.

- Permeable surface allows all form of deterioration in concrete like all external chemical can penetrate into concrete in liquid form.
- Through permeable surface, effect of frost action can accelerate.

(b) **Excess water-cement Ratio:** Excess water-cement Ratio results into high porosity of mix which results in high volume changes which causes heavy shrinkage cracks.

(c) **Carbonation:** CO_2 from nature enters in concrete through pores and reacts with water present in concrete, as the result CO_2 changes into Carbonic acid and makes the medium acidic.

CO_2 also reacts with $Ca(OH)_2$ present in concrete is converted into $CaCO_3$ causing reduction in pH of concrete. Once pH goes below 10 the corrosion of steel reinforcement begins due to reduction in alkaline environment.

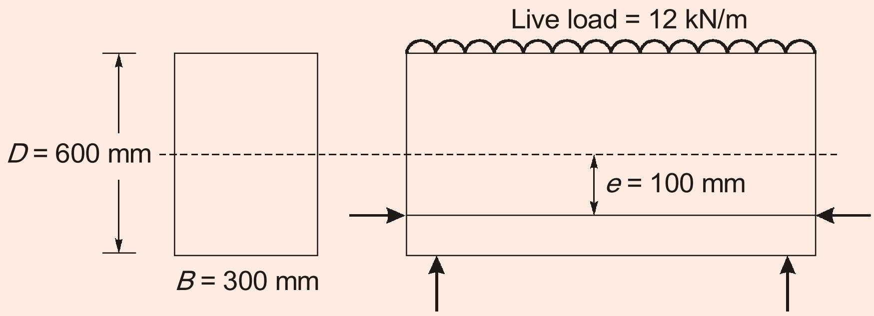
Other than above, frost action, sulphur attack, attack of mineral oil, attack of organic acid, attack of sugar, mineral oil, and temperature changes will harm durability of concrete. If coefficient of thermal expansion differ by more than 5.4×10^{-6}/°C between two material of concrete, durability will be affected by freezing and thawing.

End of Solution

Q.3 (b) A rectangular beam of size 300 mm × 600 mm is used over a simply supported effective span of 7 m. The beam supports a live load of 12 kN/m. A straight tendon is provided at an eccentricity of 100 mm below the centroid of the beam section. Find the minimum prestressing force required for no tension condition at mid-span under live load. Also, show the stress distribution under self- weight only at mid-span and at the ends of the member.

[20 marks : 2023]

Solution:



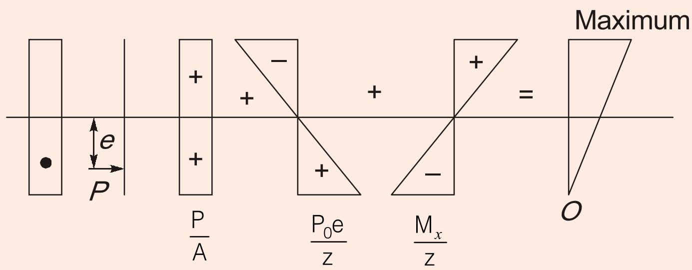
1. $$\text{Dead load} = 0.30 \times 0.60 \times 1.0 \times 25 = 4.50 \text{ kN/m}$$

$$\text{Live load} = 12.00 \text{ kN/m}$$

$$\text{Total load} = 16.50 \text{ kN/m}$$

$$\text{Maximum bending moment} = \frac{wL^2}{8} = \frac{16.50 \times 7^2}{8} = 101.0625 \text{ kN-m}$$

2. For no tension condition at mid span under live load (DL will always act with LL).



$$\text{Stress at bottom fibre} = 0$$

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

$$\frac{P}{A} + \frac{Pe}{Z} = \frac{M_x}{Z} \qquad \left\{ \begin{aligned} z &= \frac{BD^2}{6} \\ A &= BD \\ \frac{z}{A} &= \frac{D}{6} \end{aligned} \right\}$$

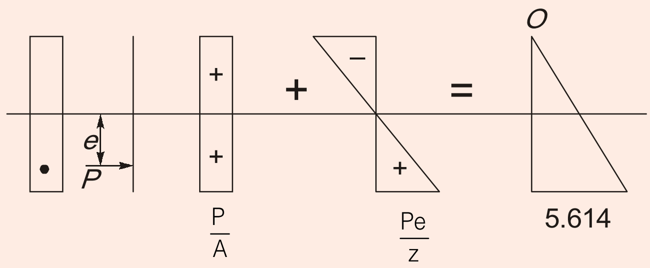
$$P\left(\frac{Z}{A} + e\right) = M_x$$

$$P = \frac{M_x}{\left(\frac{D}{6} + e\right)}$$

$$= \frac{101.0625 \times 10^6}{\left(\frac{600}{6} + 100\right) \times 1000} \text{kN} = 505.3125 \text{ kN}$$

3. Stresses developed only due to DL.

(a) At end, moment = 0:



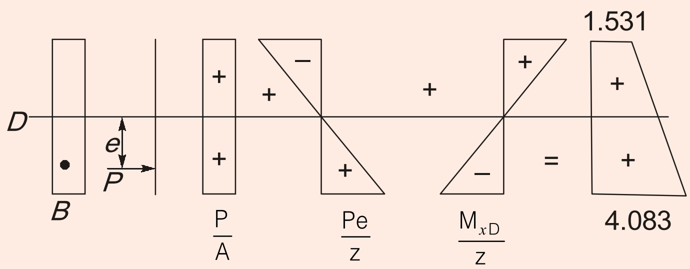
$$\frac{P}{A} = \frac{505.3125 \times 1000}{300 \times 600} = 2.807 \text{ N/mm}^2$$

$$\frac{Pe}{Z} = \frac{505.3125 \times 1000 \times 100}{\left(\frac{300 \times 600^2}{6}\right)} = 2.807 \text{ N/mm}^2$$

$$\text{At top} = \frac{P}{A} - \frac{Pe}{Z} = 2.807 - 2.807 = 0 \text{ N/mm}^2$$

$$\text{At bottom} = \frac{P}{A} + \frac{Pe}{Z} = 2.807 + 2.807 = 5.614 \text{ N/mm}^2$$

(b) At mid span:



Due to DL $\quad M_{xD} = \dfrac{w_d \cdot L^2}{8} = \dfrac{4.50 \times 7^2}{8} = 27.5625$ kN-m

$$\frac{M_{xD}}{Z} = \frac{27.5625 \times 10^6}{\left(300 \times \frac{600^2}{6}\right)} = 1.531$$

$$\text{Stress at Top} = \frac{P}{A} - \frac{Pe}{Z} + \frac{M_{xD}}{Z}$$

$$= 2.807 - 2.807 + 1.531 = 1.531 \text{ N/mm}^2$$

$$\text{Stress at bottom} = \frac{P}{A} + \frac{Pe}{z} - \frac{M_{xD}}{z}$$

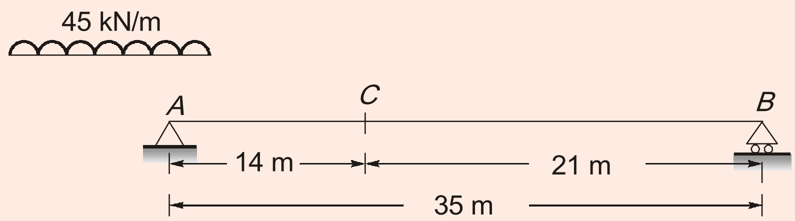
$$= 2.807 + 2.807 - 1.531 = 4.083 \text{ N/mm}^2$$

End of Solution

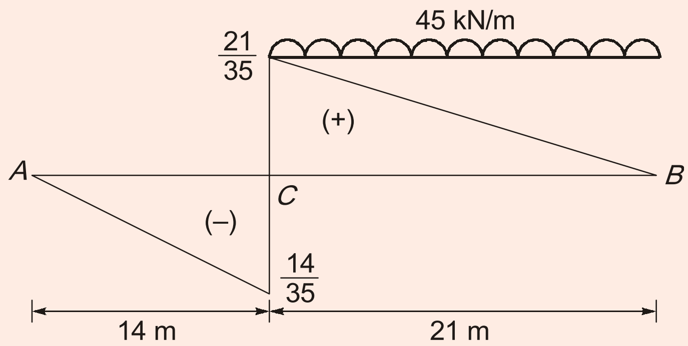
Q.3 (c) A uniformly distributed load of 45 kN/m longer than the span rolls over a simply supported girder of 35 m span. Using influence line diagram for shear force and bending moment, determine the maximum shear force and maximum bending moment at a section 14 m from left-hand support.

[20 marks : 2023]

Solution:



Influence line diagram of shear force at C using Muller breaslau's principle is shown below.

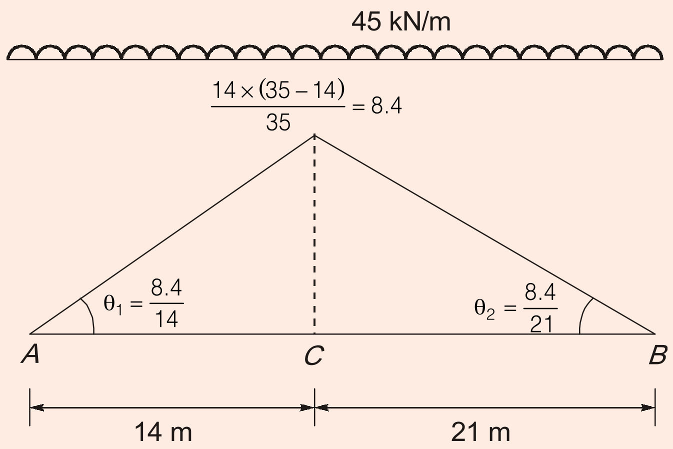


Now, when load moves from *A* to *C*, then shear force at C will be maximum when load covers the whole portion *BC*.

(Now), $(\text{S.F.})_C = \frac{1}{2} \times 21 \times \frac{21}{35} \times 45 = 283.5 \text{ kN}$

Influence line diagram for bending moment at *C*.

Influence line diagram of bending moment at C using Muller breaslau's principle is shown below.



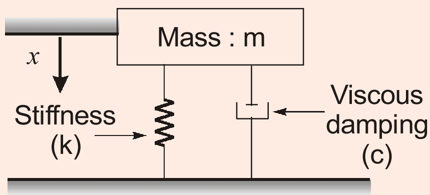
When load moves from A to C, bending moment will be maximum at C when load covers the entire span.

So, $$(B.M.)_C = \frac{1}{2} \times 35 \times 8.4 \times 45$$
$$= 6615 \text{ kN-m}$$

End of Solution

Q.4 (a) (i) For the vibrating system shown in the figure below, determine the following parameters

(1) Natural frequency of the vibrating system
(2) Critical damping of the vibrating system
(3) Damping ratio
(4) Damped natural frequency of the vibrating system



$m = 10$ kg
$k = 2400$ N/m
$c = 77$ N-s/m

[10 marks : 2023]

(ii) A short braced reinforced concrete column has unsupported length of 3.5 m and size of 300 mm × 360 mm. Verify the applicability of simplified formula of P_u (i.e., ultimate load-carrying capacity of a short axially loaded column) as given in the Code. Also, determine the design moments due to minimum eccentricity to be considered for this case if the column is subjected to an ultimate axial load of 1600 kN."

[10 marks : 2023]

Solution:

(i)

1. Natural frequency of system,

$$\omega_n = \sqrt{\frac{k}{m}} \qquad \text{...(i)}$$

where k is stiffness and m is mass.

So, $$\omega_n = \sqrt{\frac{2400}{10}} = 15.49 \text{ rad/s}$$

2. Critical damping coefficient,

$$C_{cr} = \frac{2k}{\omega_n}$$

$$= \frac{2 \times 2400}{15.49} = 309.88 \text{ N-s/m}$$

3. Damping ratio, $$\xi = \frac{C}{C_{cr}}$$

$$= \frac{77}{309.88} = 0.25$$

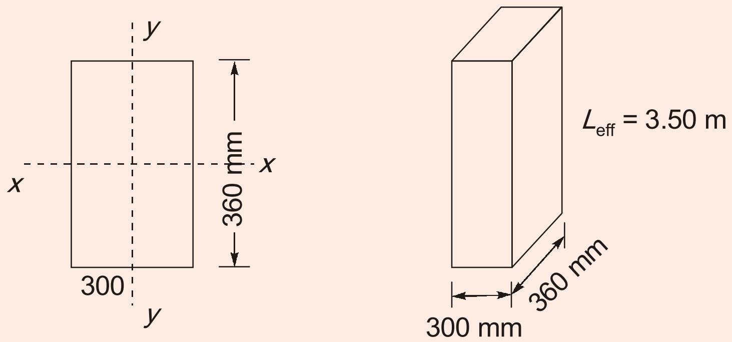
As the ratio is less than 1, system is underdamped.

4. Damped natural frequency of system,

$$\omega_D = w_n\sqrt{1-\xi^2}$$

$$= 15.49\sqrt{1-0.25^2} \simeq 15 \text{ rad/s}$$

(ii)



Before using I.S. code formula, as per provision number 39.3.

$$P_u = 0.40\, f_{ck} \cdot A_C + 0.67\, f_y \cdot A_{sc}$$

Following conditions need to be checked:

(a) The column is axially loaded.

$$P_u = 1600 \text{ kN} \qquad \text{(OK)}$$

(b) The column is short column.

$$\frac{L_e}{D} = \frac{3500}{360} = 9.72 < 12$$

$$\frac{L_e}{B} = \frac{3500}{300} = 11.67 < 12$$

$\therefore$ It is a short column (OK)

(c) Minimum eccentricity as per

$$25.4 \leq 0.05 \times \text{lateral dimension}$$

1. About x-x

$$e_{\min;\,x} = \frac{L_{x0}}{500} + \frac{D}{30} = \frac{3500}{500} + \frac{360}{30}$$

$$= 19 \text{ mm or } 20 \text{ mm (Maximum of two)}$$

$$\therefore \quad e_{\min;\,x} = 20 \text{ mm}$$

$$0.05\text{ D} = 0.05 \times 360 = 18 \text{ mm}$$

$$e_{\min,\,x} > 0.05\text{D} - \text{Condition not satisfied.}$$

2. About y-y axis

$$e_{\min;\,y} = \frac{L_{y0}}{500} + \frac{B}{30} = \left(\frac{3500}{500} + \frac{300}{30}\right)$$

$$= 17 \text{ mm} \quad \text{or } 20 \text{ mm}$$

$$\therefore \quad e_{\min,\,y} = 20 \text{ mm} \quad \text{(Maximum of two)}$$

$$0.05B = 0.05 \times 300 = 15 \text{ mm}$$

$$e_{\min,\,y} > 0.05\text{B} - \text{Condition not satisfied.}$$

So, the formula $P_u = 0.40\, f_{ck} \cdot A_c + 0.67 f_y \cdot A_{SC}$ should not be used.

(d) Due to minimum eccentricity, minimum design moments:

$$e_{\min,\,xx} = 20 \text{ mm} \quad \text{(as calculated above)}$$

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

$$M_{u,\,min,\,xx} = P_u \cdot e_{\min,\,x}$$

$$= 1600 \times \frac{20}{1000} = 32 \text{ kN-m}$$

$$M_{u,\,min,\,yy} = P_u \cdot e_{\min,\,y}$$

$$= 1600 \times \frac{20}{1000} = 32 \text{ kN-m}$$

End of Solution

Q.4 (b) (i) What are the factors affecting rheological properties of concrete?

[10 marks : 2023]

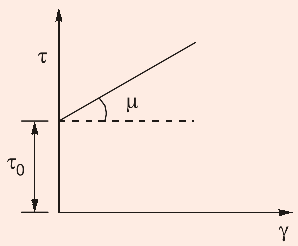
(ii) How are the properties of concrete affected by seawater and industrial wastewater, if they are used for making the concrete?“

[10 marks : 2023]

Solution:

(i)

- Consistency and homogeneity of concrete mixture signifies Rheological behaviour of concrete.
- Fluid behaviours of concrete is similar to Bingham plastic fluid.



$\tau = \tau_0 + \mu\gamma$

τ = shear stress

γ = rate of shear strain

- Consistency of mix controls over viscosity of mix and homogeneity signify internal resistance against segregation, bleeding, honey combing etc. means homogeneity gives significance of shear stress development.

Rheology of concrete deals with flow and deformation of material which is concerned with relationship between stress (shear), shear stain, rate of shear strain and time. Rheology indirectly signify the stability of concert mix, flow ability (viscosity, cohesion, internal friction).

Factors affecting Rheological Properties

1. **Mix Proportions:** Excess amount of coarse aggregate in a mix lacks in sufficient mortar required to fill the voids; there will be a loss of cohesion and mobility of the whole mix. If amount of fine aggregate is in excess or air is entrained, the cohesion increases and will affect the mobility of the mix. Moreover, more the fine aggregate more will be the cement requirement (because of the greater surface area of the mix) to obtain the desired mobility; the drying shrinkage may increase resulting in cracks.
2. **Consistency:** More than required water content (slump) to produce a workable mix results in greater fluidity. Water content more than that needed will not improve the rheological properties of concrete. Segregation and bleeding in concrete have higher chance to occur with increase in fluidity. A very low water content reduces the compactability, resulting in difficulties in placement and compaction.
3. **Hardening and Stiffening:** Use of rapid hardening cement, cement deficient in gypsum and use of accelerating admixtures, increase the rate of hardening, and consequently the mobility of concrete reduces.
4. **Aggregate Shape and Texture:** The rough aggregate particles have higher percentage of voids. Consequently, more mortar, higher fine aggregate content and correspondingly higher water content is required to fill the voids. Similarly angular fine aggregate increases internal fraction in the concrete mix and require higher water contents than well rounded aggregates.
5. **Aggregate Grading:** Well graded aggregates results in good workability; this helps in filling the voids systematically. Gap graded aggregate affects void system and workability. The increase in the fine aggregate requires more water and result in sticky concrete mix.

6. **Maximum Size of Aggregate:** For same workability, an increase in the maximum size of aggregate reduces the fine aggregate requirement so as to maintain a given workability and thereby reduces the surface area to be wetted.
7. **Admixtures:** A variety of admixtures are added in concrete mixes for specific purposes. Rheology of concrete is significantly influenced by the use of plasticizers and super-plasticizers, air-entraining agents, and accelerators and retarders.

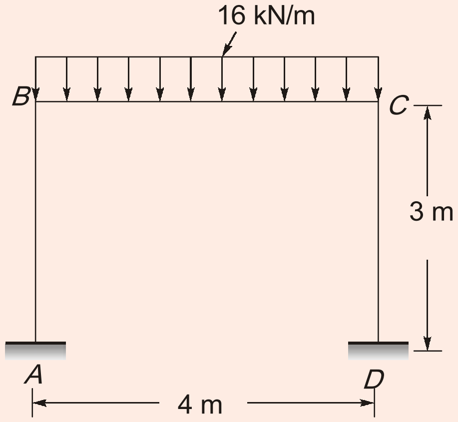
(ii)

Sea Water : Sea water should be avoided due to following reasons:
- Salt in sea water cause efflorescence and unsoundness (due to Alkali-aggregate reaction).
- The salt of chloride increase the chances of corrosion.
- Due to presence of salt of chloride and sulpahte both, ultimate strength reduces however 3 day strength may be more due to accelerator salts.
- Sea water can be suitable for PCC.

Industrial Waste Water
- Most waters carrying industrial waste have less than 3,000 ppm of total solids. When such water is used as mixing water in concrete, the reduction in compressive strength is generally less than about 10 per cent. Waste waters from paint factories, coke plants, chemical and galvanizing plants may contain harmful impurities. It is advisable to test any waste water that contains even few hundred parts per million-of unusual solids before using it for mining concrete.
- One way of using sewage containing large organic matters (say 400 ppm) is to dilute it in a good disposal system to reduce the concentration to about 30 ppm or less, an amount too low to have any significant effect on concrete strength.

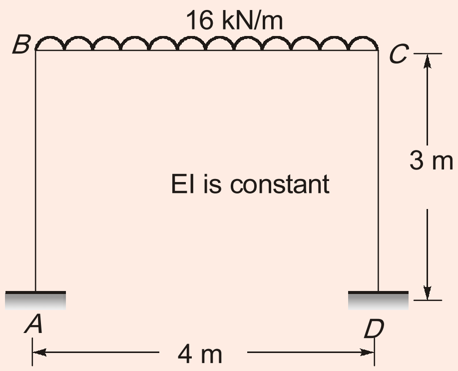
End of Solution

Q.4 (c) Analyze the portal frame shown in the figure below by moment distribution method. The frame is fixed at A and D, and has rigid joints at B and C. Draw the bending moment diagram and sketch the deflected shape of the structure. Take EI as constant:



[20 marks : 2023]

Solution:



Fixed end moment,

$$M_{FAB} = M_{FBA} = 0$$

$$M_{FBC} = \frac{-wL^2}{12}$$

$$= \frac{-16 \times 4^2}{12} = -21.33 \text{ kN-m}$$

$$M_{FCB} = \frac{wL^2}{12} = \frac{16 \times 4^2}{12} = 21.33 \text{ kN-m}$$

$$M_{FCD} = M_{FDC} = 0$$

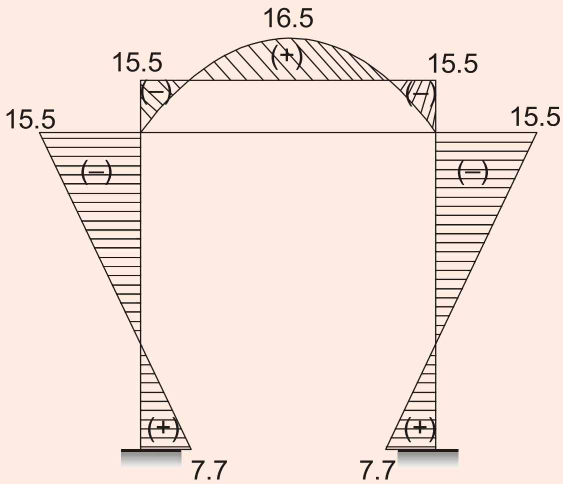
Distribution factor:

Joint	Member	Stiffness	Total stiffness	Distribution factor
B	*BA*	$\frac{4EI}{3}$	$\frac{7EI}{3}$	$\frac{4}{7}$
	BC	$\frac{4EI}{4}$		$\frac{3}{7}$
C	*CB*	$\frac{4EI}{4}$	$\frac{7EI}{3}$	$\frac{3}{7}$
	CD	$\frac{4EI}{3}$		$\frac{4}{7}$

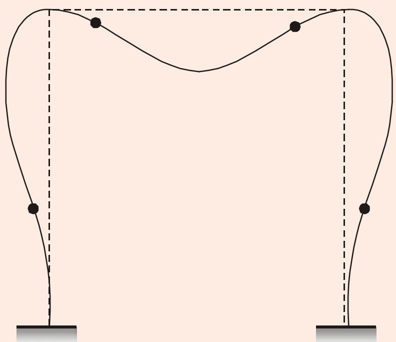
Moment distribution table

Joint	A	B		C		D
Distribution factor		$\frac{4}{7}$	$\frac{3}{7}$	$\frac{3}{7}$	$\frac{4}{7}$	
Fixed end moment	0	0	−21.33	21.33	0	0
Balancing moment		12.19	9.14	−9.14	−12.19	
Carry over moment	6.095		−4.57	4.57		−6.095
Balancing moment		2.61	1.96	−1.96	−2.61	
Carry over moment	1.305		−0.98	0.98		−1.305
Balancing moment		0.56	0.42	−0.42	−0.56	
Carry over moment	0.28		−0.21	0.21		−0.28
Final end moment	7.7	15.5	−15.5	−15.5	−15.5	−7.7

Now, B.M.D. can be drawn as shown.



Deflected shape is shown below.



End of Solution

SECTION : B

Q.5 (a) (i) Describe the mechanical properties of ceramics.

[6 marks : 2023]

(ii) Explain roller-compacted concrete. What are the advantages of roller compacted concrete?

[6 marks : 2023]

Solution:

(i)

Mechanical Properties of Ceramic

- Tensile Strength: Theoretically, the tensile strength of ceramics is very high but in practice it is quite low. Tensile failures of ceramics are attributed to the stress concentrations at the pores and micro-cracks at grain corners. Even minute cracks and scratches may reduce drastically the tensile stresses. The modulus of elasticity ranges from 7×10^4 to 42×10^4 N/mm^2. Glass fibres have tensile strength of the order of 700 N/mm^2.
- Compressive Strength: The compressive strength is high and it is usual to use ceramics like clay, cement and glass products in compression.
- Shear Strength: Ceramics have very high shear strength with resistance to failing in a brittle manner.
- Transverse Strength is difficult to ascertain and ceramics are not used in places where such strength is the criteria. However, slight flexure may not be a problem.

(ii)

Roller-compacted concrete is a no-slump concrete mix that can be transported, placed, and compacted with the same construction equipment that is used for earth and rockfill dams, and can meet the design specifications for conventional mass concrete. It is a mixture of aggregates, cement (with or without puzzolanas), water and sometimes water reducing admixtures. The stiff (dry or lean), zero slump concrete mixture has consistency of damp gravel. The air entraining, water reducing and set controlling admixtures are effective in reducing the vibration time required for full consolidation. This lowers the entrapped air-void content, increases strength and lowers the permeability of concrete.

RCC is dry to prevent sinking of the vibratory roller equipment but wet enough to permit adequate distribution of the binder mortar throughout the material during the mixing and vibratory compaction operations. From the point of workability, fly ash is commonly included in RCC mixtures.

RCC mixes contain less cement and cementitious material paste (250-350 kg/m^3) and significantly high fly-ash proportion (25-70%) by weight of cementitious material. The 28 day strength is comparable with OPC.

Since consistency of RCC is low, the bonding of fresh concrete to hardened concrete is not adequate. The creep and thermal properties of RCC are within the range of those of conventional normal concrete.

Advantages

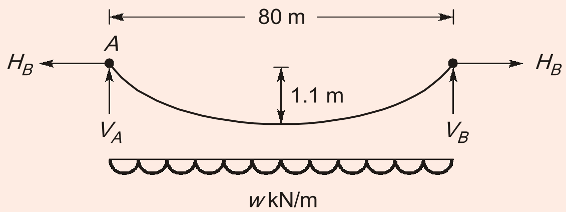
1. Cement consumption is lower because much leaner concrete can be used.
2. Form work costs are lower because of the layer placement method.
3. Cost of transporting concrete is lower because concrete can be hauled by end dump trucks.
4. The construction period can be shortened considerably.

End of Solution

Q.5 (b) A steel cable of 12 mm diameter is stretched across two poles 80 m apart. If the central dip is 1.10 m at normal temperature, determine the stress intensity in the cable. Also, determine the change in temperature necessary to raise the stress to 80 MPa. Take unit weight of steel γ = 78 kN/m³ and α = 12 × 10⁻⁶/°C.

[12 marks : 2023]

Solution:



Let, V_A and V_B be the vertical reactions developed at A and B and H_A and H_B be the horizontal reactions developed at A and B respectively.

Self weight of cable will act as uniformly distributed load of intensity w kN/m.

Now, $w = \gamma \times A$ where γ is unit weight of cable and A is cross-section area of cable

$$= 78 \times 10^3 \frac{N}{m^3} \times \frac{\pi}{4} \times (12 \times 10^{-3}\ m)^2 = 8.82\ N/m$$

Now,
$$V_A = V_B = \frac{wl}{2} = \frac{8.82 \times 80}{2} = 352.8\ N$$

$$H = \frac{wl^2}{8h} = \frac{8.82 \times 80^2}{8 \times 1.1} = 6414.55\ N$$

So, maximum tension in cable,
$$T_{max} = \sqrt{V_A^2 + H^2}$$

$$= \sqrt{352.8^2 + 6414.55^2} = 6424.24\ N$$

Therefore, stress in cable,
$$f = \frac{T_{max}}{A} = \frac{6424.24\ N}{\frac{\pi}{4} \times (12\ mm)^2} = 56.80\ N/mm^2$$

Now,
$$\frac{\delta f}{f} = \frac{-\delta h}{h}$$

where δf and δh are change in stress and dip respectively due to temperature change.

$$\frac{\delta h}{h} = \frac{3}{16} \alpha t \frac{l^2}{h^2}$$

where α is coefficient of thermal expression and t is temperature change

So, $$\frac{\delta f}{f} = \frac{-3}{16}\alpha t \frac{l^2}{h^2}$$

$$\Rightarrow \quad \frac{(80-56.80)}{56.80} = \frac{-3}{16} \times 12 \times 10^{-6} \times t \times \frac{80^2}{1.1^2}$$

$$\Rightarrow \quad t = -34.32°$$

(–ve) indicates that temperature should be decreased than normal temperature.

End of Solution

Q.5 (c) A T beam is continuous over a span of 10 m. The sectional parameters of the beam are as below:

Width of web = 250 mm

Width of flange = 1100 mm

Effective depth of beam = 460 mm

Area of steel in tension = 1800 mm^2

Area of steel in compression = 1000 mm^2

Use M 20 grade of concrete and Fe-415 grade of steel. Estimate the safety of the beam for deflection control using the empirical method given in the Code IS 456 : 2000. The corresponding graphs are reproduced at Page Nos. 13-15.

[12 marks : 2023]

Solution:

Effective depth of T-beam required :

$$d = \frac{\text{Effective span}}{A\text{-Value} \times MF_t \times MF_C \times RF_T}$$

(i) Beam is continuous so, A - value = 26

(ii) $$P_t\,\% = \frac{A_{st}}{b_w d} \times 100 = \frac{1800}{250 \times 460} \times 100 = 1.565\%$$

$$f_s = 0.58 f_y \times \frac{A_{st\ (\text{required})}}{A_{st\ (\text{provided})}}$$

$$= 0.58 \times 415 \times \frac{1800}{1800} = 240.7$$

Modification factor based on tension steel

(Using figure 4)

$$MF_t = 0.90 \text{ (approx.)}$$

(iii) $$P_c\,\% = \frac{A_{sc}}{b_w \cdot d} \times 100 = \frac{1000}{250 \times 460} \times 100 = 0.87\%$$

Modification factor based on compression steel (using figure 5)

$$MF_C = 1.22$$

(iv) Reduction factor for flange section

$$\text{Ratio of } \frac{b_w}{B_f} = \frac{250}{1100} = 0.227$$

$$RF_{flanged} = 0.80 \quad \text{(Using figure 6)}$$

(iv) Effective depth of T-beam required

$$d = \frac{\text{Effective span}}{A \times MF_t \times MF_C \times RF_{flanged}}$$

$$= \frac{10000}{26 \times 0.9 \times 1.22 \times 0.80} = 438 \text{ mm}$$

Since, Effective depth provided = 460 mm > 438 mm

So, Beam is safe for deflection.

End of Solution

Q.5 (d) A single angle ISA 100 × 100 × 10 is connected to a gusset plate of thickness 10 mm by weld along two parallel edges. The size of weld (fillet) is 6 mm. The member is subjected to an axial compressive load of 150 kN (factored). Find the weld length along two parallel edges. Assume E250 grade of steel and shop welded. For ISA 100 × 100 × 10, $c_y = c_z = 27.6$ mm. Use limit state method.

[12 marks : 2023]

Solution:

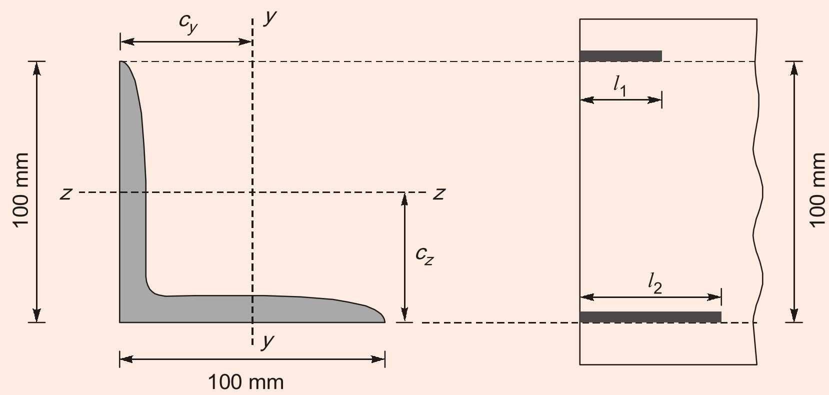
Given $f_y = 250$ MPa

$f_u = 410$ MPa

Factored load, $P_u = 150$ kN

Size of weld, $S = 6$ mm

For ISA 100 × 100 × 10, $C_y = C_z = 27.6$ mm



Let, force resisted by upper portion $l_1 = P_1$

$$\therefore \quad P_1 = \frac{150 \times C_z}{100} = \frac{150 \times 27.6}{100}$$

$$= 41.4 \text{ kN}$$

Force resisted by lower portion, $l_2 = P_2$

$$\therefore \quad P_2 = \frac{150(100 - C_z)}{100} = \frac{150(100 - 27.6)}{100}$$

$$= 108.6 \text{ kN}$$

$\therefore$ Throat thickness, $t = 0.7\,s = 0.7 \times 6 = 4.2$ mm

Length of weld l_1 had to resist a force of P_1

$$\therefore \quad P_1 = l_1 t \frac{f_u}{\sqrt{3}\,\gamma_{mw}}$$

$$\Rightarrow \quad 41.4 \times 10^3 = \frac{l_1 \times 4.2 \times 410}{\sqrt{3} \times 1.25} \qquad (\text{shop weld } r_{mw} = 1.25)$$

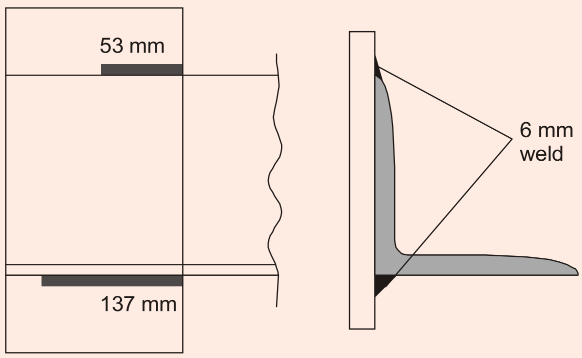
$$\therefore \quad l_1 = 52.05 \text{ mm} \simeq 53 \text{ mm}$$

Similarly, length of weld l_2 has to resist a force of P_2

$$\therefore \quad P_2 = \frac{l_2\, t\, f_u}{\sqrt{3}\,\gamma_{mw}}$$

$$108.6 \times 10^3 = \frac{l_2 \times 4.2 \times 410}{\sqrt{3} \times 1.25}$$

$$\therefore \quad l_2 = 136.54 \text{ mm} \simeq 137 \text{ mm}$$



End of Solution

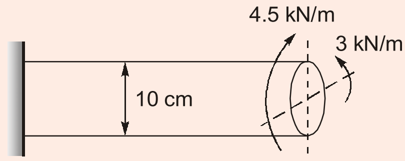
Q.5 (e) Determine the maximum principal stress developed in a cylindrical shaft 10 cm in diameter, subjected to a BM of 3.0 kN-m and twisting moment of 4.50 kN m. If the yield stress of the shaft material is 230 MN /m^2, determine the factor of safety according to the maximum shearing stress theory of failure.

[12 marks : 2023]

Solution:

Bending moment, $M = 3$ kN-m

Twisting moment, $T = 4.5$ kN-m



Now, maximum principal stress, $\sigma_{P_1} = \dfrac{16}{\pi D^3}\left[M + \sqrt{M^2 + T^2}\right]$

where D is diameter of shaft

So, $\sigma_{P_1} = \dfrac{16}{\pi \times (100)^3}\left[3 + \sqrt{3^2 + 4.5^2}\right] \times 10^6 = 42.82 \text{ N/mm}^2$

Minor principal stress, $\sigma_{P_2} = \dfrac{16}{\pi D^3}\left[M - \sqrt{M^2 + T^2}\right]$

$$= \frac{16}{\pi \times (100)^3}\left[3 - \sqrt{3^2 + 4.5^2}\right] \times 10^6 = -12.26 \text{ N/mm}^2$$

Therefore, maximum shear stress,

$$\tau_{max} = \frac{\sigma_{P_1} - \sigma_{P_2}}{2} = \frac{42.82 - (-12.26)}{2} = 27.54 \text{ N/mm}^2$$

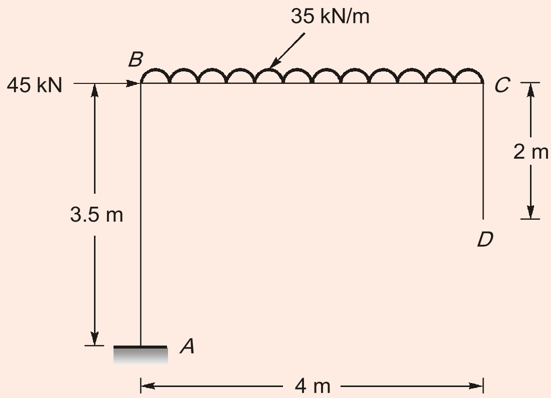
Now, as per maximum shear stress theory,

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

$\Rightarrow$ $$FOS = \frac{\sigma_y}{2\tau_{max}} = \frac{230}{2 \times 27.54} = 4.17$$

End of Solution

Q.6 (a) Determine the vertical and horizontal deflections at the free end of the frame shown in the figure below. Take $EI = 12 \times 10^4$ kN-m^2:

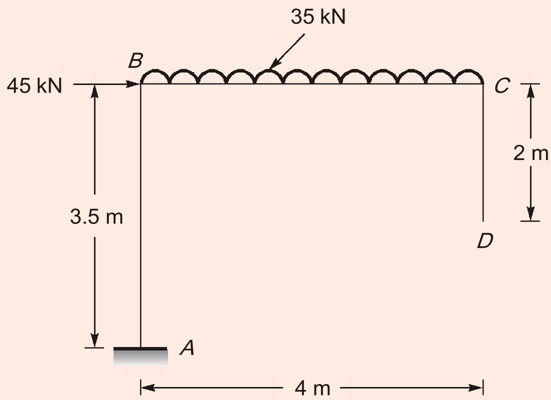


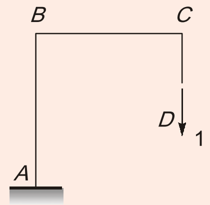
[20 marks : 2023]

Solution:

Vertical deflection of D :

For vertical deflection at D (in downward direction)
Apply a unit load at D
Using unit load method calculations are done below:





Portion	DC	CB	BA
Origin	D	C	B
Limit	0 - 2	0 - 4	0 - 3.5
M	0	$\frac{-35x^2}{2}$	$-45x-280$
m_1	0	$-x$	-4

Therefore vertical deflection of C, $\Delta_{VC} = \sum \frac{Mm, dx}{EI}$

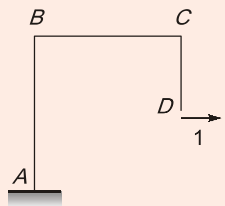
So, $$\Delta_{VC} = 0 + \int_0^4 \frac{\frac{-35x^2}{2} \times -x\ dx}{EI} + \int_0^{3.5} \frac{(-4)\times(-45x-280)}{EI}$$

$$= \frac{1120}{EI} + \frac{10045}{2EI} = \frac{6142.5}{EI} = \frac{6142.5}{12\times 10^4} = 51\times 10^{-3}\ \text{m} = 51\ \text{mm}$$

Horizontal deflection at D :

Apply a unit load at horizontal direction using unit load method, calculations are done below:

Portion	DC	CB	BA
Origin	D	C	B
Limit	0 - 2	0 - 4	0 - 3.5
M	0	$\frac{-35x^2}{2}$	$-45x-280$
m_2	x	2	$2-x$



So, $$\Delta_{HC} = \int \frac{Mm_2 dx}{EI}$$

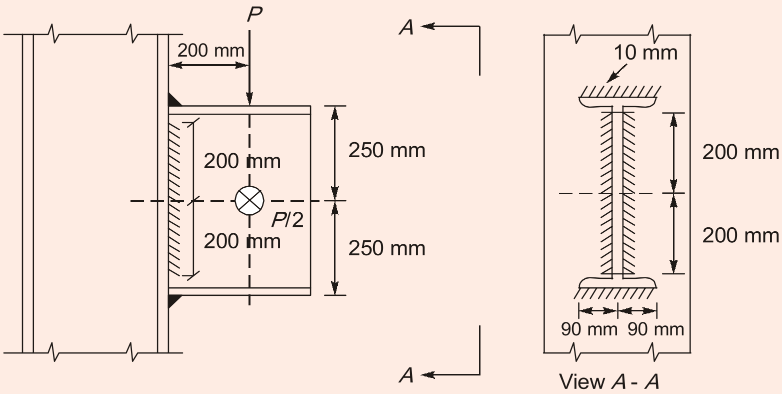
$$= 0 + \int_0^4 \frac{\frac{-35x^2}{2} \times 2dx}{EI} + \int_0^{3.5} \frac{(-45x-280)(2-x)}{EI}$$

$$= \frac{-2240}{3EI} + \frac{-1225}{8EI} = \frac{-899.79}{EI} = \frac{-899.79}{12 \times 10^4} = -7.5 \text{ mm}$$

(–ve) sign indicates that deflection will be in opposite direction to that of load applied.

End of Solution

Q.6 (b) A cantilever beam (ISMB 500) in connected to the flange of the column (ISHB 450) by fillet weld of size 5 mm. The beam is subjected to a vertical load P and a horizontal load $\frac{P}{2}$ at a distance of 200 mm from the flange of the column as shown in the figure below. Find the factored P that can be applied for the joint. Assume E250 grade of steel, site weld. Given, $f_e = \sqrt{f_a^2 + 3q^2}$. Use limit state method. Assume that the beam section is safe :

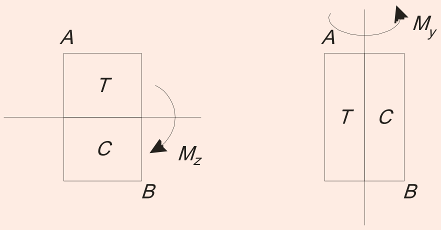


[20 marks : 2023]

Solution:

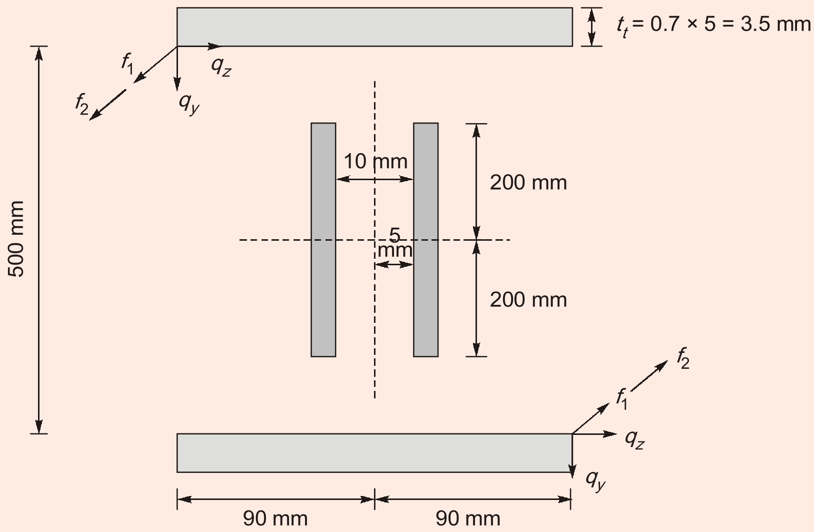
Concept :

Welding will be subjected to direct shear force in y and z direction and bending moment about both z and y axis.



Critical points will be A and B as the effect of stress will be added

Welded Area



Assuming welding as thin line element so we will neglect term like t_t^2 and t_t^3.

Calculation of stress:

1. Direct shear stress in y-direction

$$q_y = \frac{P}{A_w} = \frac{P \times 10^3 \text{ N}}{L_w \times t_t}$$

$$= \frac{P \times 10^3}{4060} = 0.246 \text{ P}$$

2. Direct shear stress in z-direction

$$q_z = \frac{P/2}{A_w}$$

$\Rightarrow$
$$= \frac{P}{2} \times \frac{10^3}{L_w t_t} = 0.123 \text{ P}$$

3. Maximum flexural stress at point A or B due to M_{zz}

$$f_1 = \frac{M_{zz}}{I_{zz}} \times y_{max}$$

where
$$I_{zz} = \frac{3.5 \times 400^3}{12} \times 2 + \left(180 \times 3.5 \times 250^2\right) \times 2$$

$$= -116.083 \times 10^6 \text{ mm}^4$$

$$f_1 = \frac{P \times 10^3 \times 200 \times 250}{116.083 \times 10^6} = 0.4307\ P$$

4. Maximum flexural stress of point A or B due to M_{yy}

$$f_2 = \frac{M_{yy}}{I_{yy}} \times z_{max}$$

where
$$I_{yy} = \left(\frac{3.5 \times 180^3}{12} \times 2\right) + \left[400 \times 3.5 \times 5^2\right] \times 2$$

$$= 3.472 \times 10^6\ \text{mm}^4$$

$$f_2 = \frac{\frac{P}{2} \times 200 \times 10^3 \times 90}{3.472 \times 10^6} = 2.592\ P$$

Resultant direct shear stress at point A or B

$$q = \sqrt{q_y^2 + q_z^2} = \sqrt{(0.246P)^2 + (0.123P)^2}$$

$$= 0.275\ P$$

Resultant flexural stress at point A or B

$$f = f_1 + f_2 = 0.4307\ P + 2.592\ P$$

$$= 3.0227\ P$$

Equivalent stress, $$f_e = \sqrt{3q^2 + f^2}$$

$$f_e = \sqrt{3(0.275P)^2 + (3.0227P)^2} = 3.06\ P$$

For safety $f_e \le \frac{f_u}{\sqrt{3}\,\gamma_{M_u}}$, $\quad 3.06P \le \frac{410}{\sqrt{3} \times 1.50}$, $\quad P \le 51.57$ kN

So, required P value = 51.57 kN

End of Solution

Q.6 (c) The following table gives the details of various activities of a construction project:

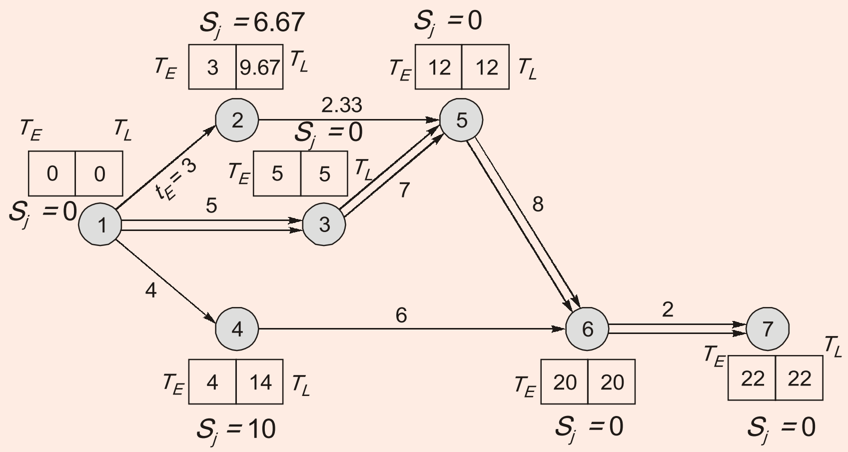
Activity	Optimistic time (months)	Most likely time (months)	Pessimistic time (months)
1 - 2	2	2	8
1 - 3	2	5	8
1 - 4	3	3	9
2 - 5	2	2	4
3 - 5	3	6	15
4 - 6	3	6	9
5 - 6	4	7	16
6 - 7	2	2	2

(i) Draw the network for the project.
(ii) Find the expected duration and variance of each activity.
(iii) What is the expected project length?
(iv) What is the probability that the project will be completed at least 3 months earlier than expected?
(v) What will be the time required for 95% probability of its completion?

[20 marks : 2023]

Solution:

(i) Network diagram for the project is as shown below:



(ii)

Activity	Optimistic time (t_o) months	Most likely time (t_m) months	Pessimistic time (t_p) months	Expected time (t_E) months $t_E = \left(\frac{t_o + 4t_m + t_p}{6}\right)$	Variance $\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$ (months)^2
1 - 2	2	2	8	3	1
1 - 3	2	5	8	5	1
1 - 4	3	3	9	4	1
2 - 5	2	2	4	2.33	0.11
3 - 5	3	6	15	7	4
4 - 6	3	6	9	6	1
5 - 6	4	7	16	8	4
6 - 7	2	2	2	2	0

(iii) In the figure shown above, S_j denotes the slack of event and critical path is the path joining events of zero slack. So, critical path is along 1 - 3 - 5 - 6 - 7 and expected projected length is 22 months.

(iv) Probability that the project will be completed at least 3 months earlier than expected i.e. probability that the project will be completed in 19 months.

$$Z = \frac{T_S - T_E}{\sigma}$$

where, Z = Probability factor

T_S = 19 months, T_E = 22 months

σ = Standard deviation of project

$$\sigma = \sqrt{1+4+4+0} = 3$$

Now, $$Z = \frac{19-22}{3} = -1$$

Now, probability of completion is given as

Z	P
0	50%
–1	15.87%

P = 15.87%

(v) Time required for 95% probability completion of its completion is given as below:

$$Z = \frac{T_S - T_E}{\sigma}$$

Probability factor (Z) for 95% probability is given as

Z	P
1	84.13%
?	95%
2	99.87%

Now from interpolation,

$$\frac{99.87-84.13}{2-1} = \frac{95-84.13}{Z-1}$$

Z = 1.691

Now, $$Z = \frac{T_S - 22}{3}$$

$$1.691 = \frac{T_S - 22}{3}$$

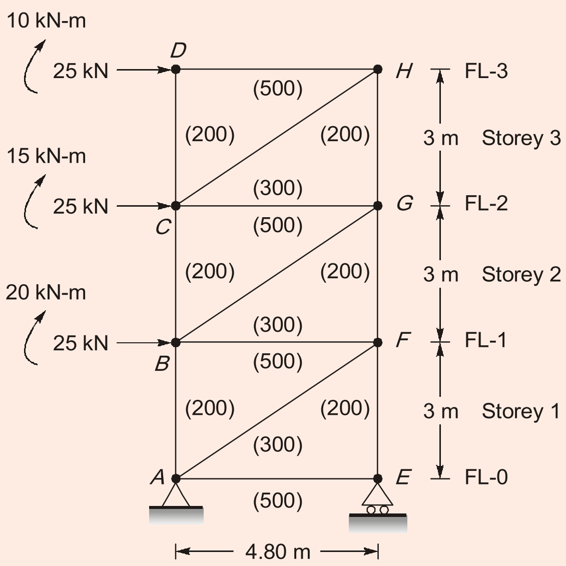
T_S = 27.073 months

Hence, time required for 95% probability of its completion is 27.073 months.

End of Solution

Q.7 (a) Determine the forces in the member of the braced frame as shown in the figure below. Also, determine the drift due to shear in each storey. Areas of diagonals and horizontal girders are shown in brackets and they are in mm^2.

Take E = 205 kN/mm^2 :



[20 marks : 2023]

Solution:

Let, V_A and V_E be the vertical reactions developed at A and E respectively. H_A be the horizontal reaction developed at A.

Now, $\Sigma F_y = 0$

$\Rightarrow \quad V_A + V_E = 0 \quad$ ...(i)

$\Sigma F_x = 0$

$\Rightarrow \quad 25 + 25 + 25 - H_A = 0$

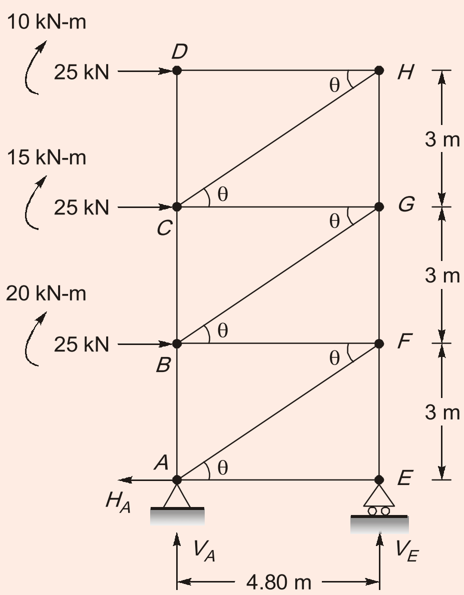
$\Rightarrow \quad H_A = 75 \text{ kN } (\leftarrow)$

$\Sigma M_E = 0$

$\Rightarrow \quad 25 \times 9 + 25 \times 6 + 25 \times 3 + V_A \times 4.8 = 0$

$\Rightarrow \quad V_A = 93.75 \text{ kN } (\downarrow)$

So using (i) $\quad V_E = 93.75 \text{ kN } (\uparrow)$



Note: Moments applied will not be considered in analysis of truss.

Now, number of numbers, $m = 13$

Number of external reactions, $r_e = 3$

Number of joints, $j = 8$

So, degree of static indeterminacy,

$$D_s = m + r_e - 2j$$
$$= 13 + 3 - 2 \times 8 = 0$$

Force in member DC and AE will be zero because

(i) At D, two forces are collinear and one is non-collinear.

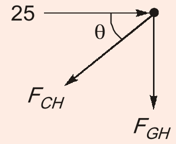
(ii) At E, two forces are collinear and one is non-collinear.

In figure,

$$\tan\theta = \frac{3}{4.8} \Rightarrow \theta = 32°$$

Now, $F_{DH} = 25$ kN (compressive)

Consider joint H



$$\Sigma F_x = 0$$

$$\Rightarrow \quad F_{CH}\cos\theta - 25 = 0$$

$$\Rightarrow \quad F_{CH} = \frac{25}{\cos\theta} = 29.5 \text{ kN (Tension)}$$

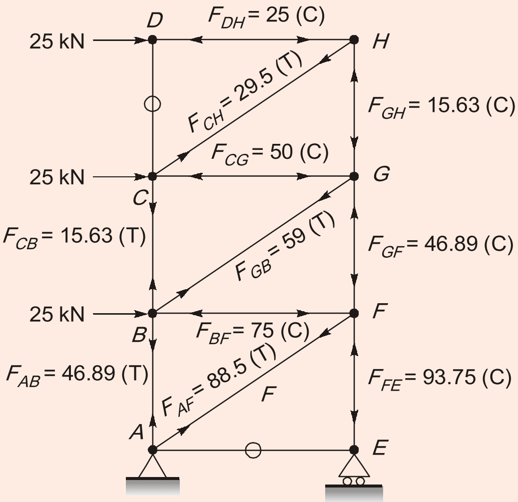
$$\Sigma F_y = 0$$

$$\Rightarrow \quad F_{CH}\sin\theta + F_{GH} = 0$$

$$\Rightarrow \quad 29.5 \times \sin 32° + F_{GH} = 0$$

$$\Rightarrow \quad F_{GH} = -15.63 \text{ kN} = 15.63 \text{ kN (compressive)}$$

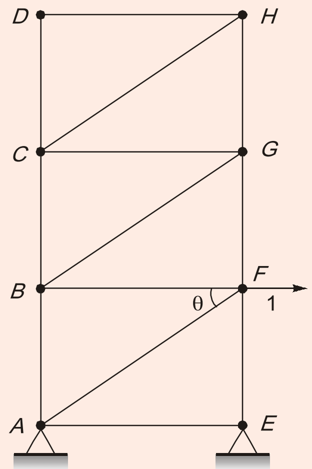
Forces in other members are shown below in figure.



Drift due to shear:

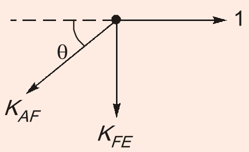
Let, a unit load is applied at joint F as shown in figure. Due to this unit load, there will be force in only AF and EF. In all other members, force will be zero.

So, consider joint F



Now, $\Sigma F_x = 0$

$$\Rightarrow \quad K_{AF}\cos\theta - 1 = 0$$



$$\Rightarrow \quad K_{AF} = \frac{1}{\cos\theta} = \frac{1}{\cos 32°} = 1.18$$

$$\Sigma F_y = 0$$

$$\Rightarrow \quad K_{AF}\sin\theta + K_{FE} = 0$$

$\Rightarrow \quad 1.18 \times \sin 32° + K_{FE} = 0$

$\Rightarrow \quad K_{FE} = -0.625$

Also, $\quad L_{AF} = \sqrt{AE^2 + EF^2}$

$= \sqrt{4.8^2 + 3^2} = 5.66$ m

Now, Deflection of F, $\Delta_F = \dfrac{P_{AF} \times k_{AF} \times L_{AF}}{A_{AF} \times E} + \dfrac{P_{EF} \times k_{EF} \times L_{EF}}{A_{EF} \times E}$

$= \dfrac{88.5 \times 1.18 \times 5660}{300 \times 205} + \dfrac{(-93.75) \times (-0.625) \times 3000}{200 \times 205} = 13.9$ mm

By linear interpolation,

Deflection of G, $\quad \Delta_H = 2 \times 13.9 = 27.8$ mm

Deflection of H, $\quad \Delta_H = 3 \times 13.9 = 41.7$ mm

End of Solution

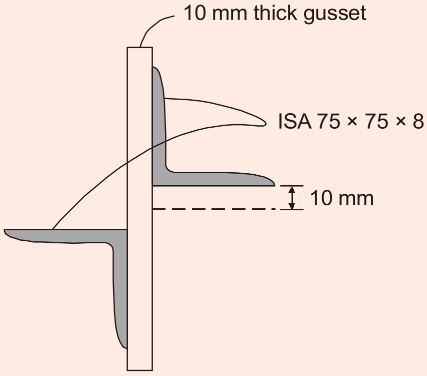
Q.7 (b) A member of a transmission tower is composed of two angles ISA 75 × 75 × 8 in star configuration as shown in the figure below. The angles are tack welded by a gusset plate of thickness 10 mm suitably. Find the axial compressive load carrying capacity of the member under dead and live load condition. The nodal length of the member is 3 m. Assume K = 0.85 and E250 grade of steel. The properties of ISA 75 × 75 × 8 are as follows :

$A = 1140$ mm^2, $I_{yy} = I_{zz} = 59$ cm^4, $C_y = C_z = 21.4$ mm,

$r_{uu} = 28.8$ mm, $r_{vv} = 14.5$ mm

Given:

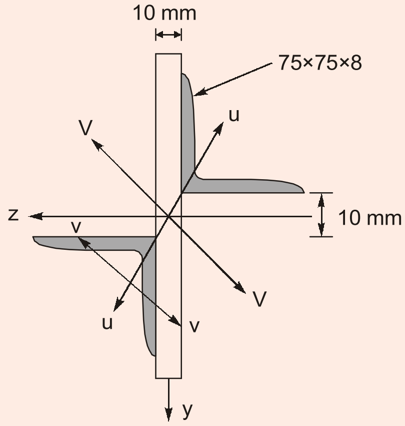
$\frac{KL}{r}$	60	70	80	90	100	110	120	130
f_{cr}(MPa)	168	152	136	121	107	94.6	83.7	74.3



Use limit state method.

[20 marks : 2023]

Solution:



$$A = 1140 \text{ mm}^2$$
$$I_{yy} = I_{zz} = 59 \text{ cm}^4$$
$$c_y = c_z = 21.4 \text{ mm}$$
$$r_{uu} = 28.8 \text{ mm}$$
$$r_{vv} = 14.5 \text{ mm}$$

$$I_{zz} = I_{yy} = \left[I_{yy} + A\left(c_y + \frac{10}{z}\right)^2\right] \times 2$$

$$= \left[59 + 11.4\left(2.14 + \frac{1}{2}\right)^2\right] \times 2 = 276.907 \text{ cm}^4$$

$$r_{zz} = r_{yy} = \sqrt{\frac{I_{yy}}{A}} = \sqrt{\frac{276.907}{2 \times 11.4}}$$
$$= 3.485 \text{ cm or } 34.85 \text{ mm}$$

$$r_{VV} = \sqrt{r_{vv}^2 + 2\left(c_y + \frac{10}{2}\right)^2}$$

$$= \sqrt{14.5^2 + 2\left(21.4 + \frac{10}{2}\right)^2} = 40.05 \text{ mm}$$

$r_{uu} = r_{UU} = 28.8$ mm (As there is not shift in *uu* axis)

$\therefore$ Least radius of gyration : $r_{uu} = 28.8$ mm

Slenderness ratio, $\lambda = \dfrac{KL}{r_{min}} = \dfrac{0.85 \times 3000}{28.8} = 88.541$

From table

λ	f_{cr}
80	136
88.541	x
90	121

$$\frac{88.541-80}{90-80} = \frac{x-136}{121-136}$$

$\therefore$ $x = 123.188 \text{ N/mm}^2$

So, Compressive strength $= f_{cr} \times A$

$= 123.19 \times 140 \times 2 = 280.87 \text{ kN}$

End of Solution

Q.7 (c) (i) What are the precautions to be taken for labour safety during formwork construction?

[10 marks : 2023]

(i) Discuss the parameters influencing the degree of compaction achieved by a vibratory roller.

[10 marks : 2023]

Solution:

(i) Safety measurers for scaffolding, ladders formwork and other equipments are as follows:

(a) All scaffolds and working platforms should be securely fastened to the building or structure. If independent of a building, they should be braced or guyed properly.

(b) In case, scaffolds are to be kept for a long period, a regular plank stair-way, wide enough to allow two persons to pass, should be erected with handrails on both sides.

(c) When work is being carried out over a scaffold platform, a protective overhead covering should be provided for the men working on the scaffold.

(d) All wooden ladders or bamboo ladders, must be strong enough.

(e) Ladders in heavy duty work should not exceed 6 m in length, for light work it should not exceed 8 m in length.

(f) Dismantling of scaffold should be in a proper sequence.

(g) No un-insulated electric wires should exist within 3 m of working platform.

(h) The supporting ballas should be individually strong and properly braced and fastened.

(i) All persons handling construction equipment should be fully acquainted with the safety aspects of the machines and their operation.

(ii) The various parameters influencing the degree of compaction achieved by a vibratory roller are as follows:

(a) **Operating frequency:** Frequency controls the number of impacts per meter between the drum and mat. Each material has natural frequency under which it vibrates or show maximum displacement of particles. Maximum compaction occurs when it vibrates near resonant frequency. Typically, vibratory rollers operate in the range of 1500 to 3000 vibrations per minute.

(b) **Amplitude of vibration:** It is the vertical displacement of the roller drum. Amplitude of vibration is directly linked to the impact force. Higher amplitude results in achieving higher thickness of compacted material at minimum number of passes, thereby improving productivity.

(c) **Speed of travel:** Slow speed results in closeness of impacts, whereas high speed results in increase in the spacing between blows. Working speed from 2.0 to 6.0 kmph will provide the best results. The machine should be able to move forward and reverse with vibrations to achieve higher productivity.

(d) **Roller weight:** Heavier rollers exert greater force on the surface, which helps in compressing the material more efficiently. Higher rollers may be suitable for finishing or surface compaction, while heavier rollers are often used for base or sub base compaction.

(e) **Number of roller passes:** Density of soil increases with the number of passes of roller but after optimum number of passes, further increase in density is insignificant.

End of Solution

Q.8 (a) (i) A mass of 1000 kg is placed at the free end of a cantilever beam of span 3 m. Assume that the beam is massless compared to applied mass. The flexural rigidity of the beam is 10^3 kN-m^2. Determine the natural time period of the system. (Assume g = 10 m/s^2)

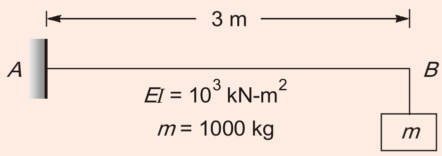
[10 marks : 2023]

(ii) A trapezoidal combined footing supports two columns of sizes 450 mm × 450 mm and 550 mm × 550 mm carrying service load of 750 kN and 1250 kN respectively. The CG of smaller column lies at 0.45 m from the property line. The centre-to-centre distance of two columns is 4.4 m. The total length of footing is to be restricted to 5.6 m. Determine and show the layout plan of the above footing. Consider safe bearing capacity of soil = 155 kN/m^2.

[10 marks : 2023]

Solution:

(i)



Stiffness of beam,

$$k_b = \frac{3EI}{L^3} = \frac{3 \times 10^3 \text{ kN-m}^2}{(3 \text{ m})^3}$$

$$= 111.11 \text{ kN-m} = 111.11 \times 10^3 \text{ N-m}$$

Now, natural time period, $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1000}{111.11 \times 10^3}} = 0.596$ seconds

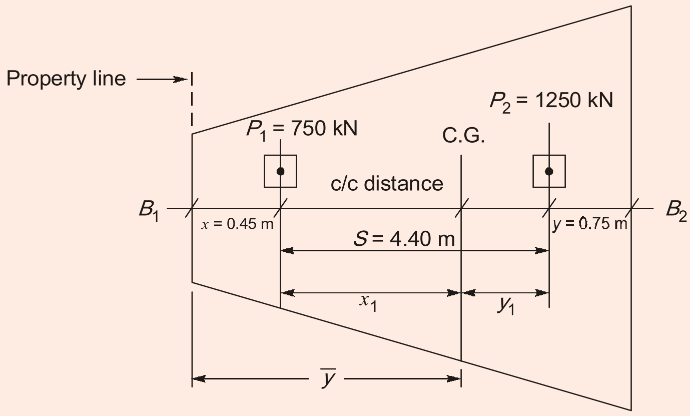
(ii)

Column 1 = 450 × 450 mm

P_1 = 750 kN

Column 2 = 550 × 550 mm

P_2 = 1250 kN



(1) Distance of short column centre to property line

$$x = 0.45 \text{ m}$$

c/c distance, $S = 4.40$ m

Total length, $L = 5.60$ m

$$y = L - x - S$$
$$= 5.60 - 0.45 - 4.40 = 0.75 \text{ m}$$

(2) Size of footing required

$$\text{Total load} = P_1 + P_2$$
$$= 750 + 1250 = 2000 \text{ kN}$$

wt of footing [assuming 20% of $(P_1 + P_2)$] = 400 kN

Assuming wt of soil [10% of $(P_1 + P_2)$] = 200 kN

$$\text{Total load} = 2600 \text{ kN}$$

Area of footing required

$$A = \frac{P_{total}}{q_0} = \frac{2600}{155} = 16.775 \text{ say } 16.80 \text{ m}^2$$

$$\therefore \quad \left(\frac{B_1 + B_2}{2}\right) \times L = 16.80$$

$$B_1 + B_2 = \frac{16.80 \times 2}{5.60} = 6.0 \text{ m}$$

(3) C.G of footing:

$$\bar{y}_{CG} = \left(\frac{B_1 + 2B_2}{B_1 + B_2}\right) \times \frac{L}{3}$$

$$= \frac{B_1 + 2B_2}{6.0} \times \frac{5.60}{3.0} = (B_1 + 2B_2) \times \left(\frac{5.60}{18.0}\right)$$

C.G of load from P_1:

$$x_1 = \frac{P_2 \cdot S}{P_1 + P_2} = \frac{1250 \times 4.4}{2000} = 2.8125 \text{ m}$$

$$\bar{y}_{CG} = x_1 + x$$
$$= 2.8125 + 0.45 = 3.2625 \text{ m}$$

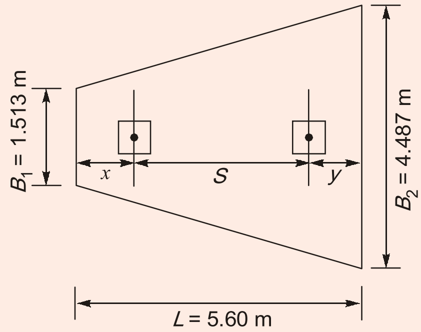
So, $$(B_1 + 2B_2) \times \frac{5.60}{18.0} = 3.2625$$

$$\Rightarrow \quad (B_1 + B_2 + B_2) = \frac{3.2625 \times 18}{5.60}$$

$$\Rightarrow \quad 6.0 + B_2 = 10.4866 \text{ m} = 10.487 \text{ m say}$$

$$\Rightarrow \quad B_2 = 10.487 - 6.0 = 4.487 \text{ m}$$

$$\therefore \quad B_1 = (B_1 + B_2) - B_2$$
$$= 6.0 - 4.487 = 1.513 \text{ m}$$

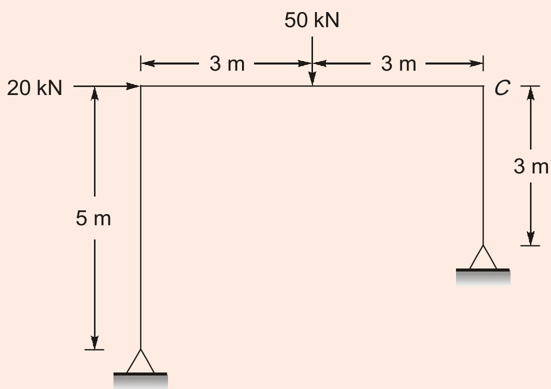


End of Solution

Q.8 (b) Find the designed plastic moment for the portal frame as shown in the figure below under collapse condition for the factored (applied) loads. Assume that the frame has uniform cross-section. Also, find the minimum section required for the frame for E250 grade of steel:

Given:

Section	ISMB 125	ISMB 150	ISMB 175	ISMB 200	ISMB 225	ISMB 250	ISMB 300	ISMB 350
Plastic section modulus (cm^3)	81	110	184	255	348	466	651	889



[20 marks : 2023]

Solution:

The possible location of plastic hinges are B, C and D.

Number of possible plastic hinge, $N = 3$

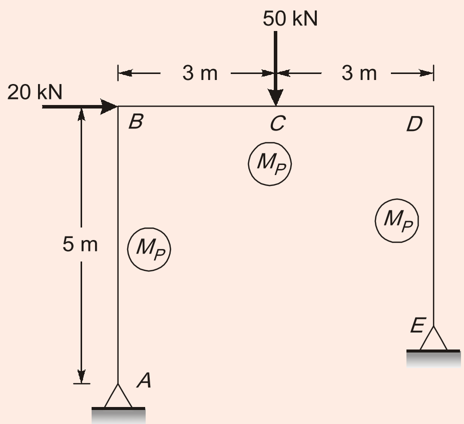
Degree of redundancy, $r = 4 - 3 = 1$

$\therefore$ No. of possible independent mechanism,

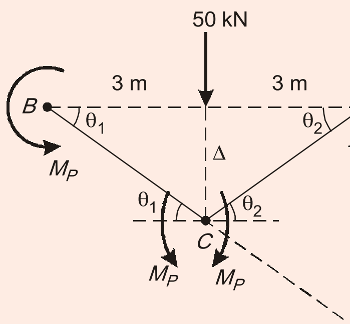
$$n = N - r = 3 - 1 = 2$$

The two independent mechanisms are

1. Beam mechanism
2. Sway mechanism



Mechanism-1:



$\therefore \quad \Delta = 3 \times \theta_1 = 3\theta_2$

$\Rightarrow \quad \theta_1 = \theta_2$

By principle of virtual work

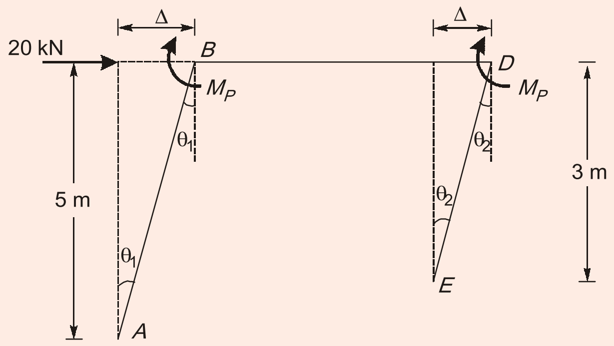
External work done = Internal work done

$\Rightarrow \quad M_P\theta_1 + M_P\theta_1 + M_P\theta_2 + M_P\theta_2 = 50 \times \Delta$

$\therefore \quad 4M\theta_1 = 50 \times 3\theta_1$

$$\therefore \quad M_P = \frac{150}{4} = 37.5 \text{ kNm}$$

Mechanism-2:



$$\Delta = 5 \times \theta_1 = 3\theta_2$$

$$\therefore \quad \theta_1 = \frac{3\theta_2}{5}$$

By principal of virtual work,

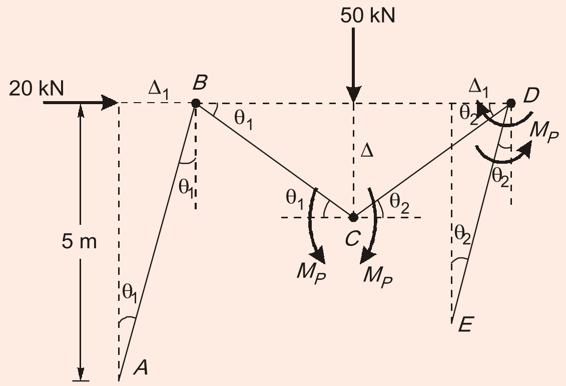
External work done = Internal work done

$$\Rightarrow \quad M_P\theta_1 + M_P\theta_2 = 20 \times \Delta$$

$$\Rightarrow \quad M_P\left(\frac{3\theta_2}{5}\right) + M_P\theta_2 = 20 \times 3\theta_2$$

$$\therefore \quad M_P = \frac{60 \times 5}{8} = 37.5 \text{ kNm}$$

Mechanism-3:



$$\Delta_1 = 5\theta_1 = 3\theta_2$$

$$\Rightarrow \quad \theta_2 = \frac{5\theta_1}{3}$$

$$\Delta = 3\theta_1$$

By principal of virtual work,

External work done = internal work done

$$\Rightarrow \quad M_P\theta_1 + M_P\theta_1 + M_P\theta_1 + M_P\theta_2 = 20 \times \Delta_1 + 50 \times \Delta$$

$$\Rightarrow \quad 3M_P\theta_1 + M_P\left(\frac{5\theta_1}{3}\right) = 20 \times 5\theta_1 + 50 \times 3\theta_1$$

$$\therefore \quad M_P = \frac{(100+150)}{(14/3)} = 53.571 \text{ kNm}$$

Therefore, the design plastic moment for the frame = 53.571 kN

Let us assume, the plastic section modulus of section is z_p.

$$\therefore \quad M_P = z_p \times f_y$$

$$\Rightarrow \quad 53.571 \times 10^6 = z_p \times 250$$

$$\therefore \quad z_p = 214284 \text{ mm}^3$$

$$z_p = 214.284 \text{ cm}^3$$

So, from the given table, minimum section required for the frame is ISMB 200 (z_p = 255 cm^3)

End of Solution

Q.8 (c) (i) Explain different types of contract. Discuss the importance of each type of contract.

[10 marks : 2023]

(ii) On a homogenous embankment, compacting rollers are used to compact silty clay soil. Determine the quantity of earth compacted if the sheeps-foot roller travels at 4 km/hr, time of rolling is 50 min, length of drum is 2.4 m, number of drums is one, fraction of overlap is $\frac{1}{8}$, layer thickness is 0.45 m and number of passes given is 5.

[10 marks : 2023]

Solution:

(i) Item rate contract is also known as Unit Price contract or Schedule contract. A contractor undertakes the execution of work on an item rate basis. He is required to quote rate for individual item of work on the basis of schedule of quantities (i.e., Bill of Quantities) furnished by the department. The amount to be received by the contractor, depends upon the quantities of work actually performed. The payment to the contractor is made on the basis of the detailed measurements of different items of work actually executed by him.

Merits:

(a) This method ensures a very detailed analysis of cost and payment to the contractor and also is based upon detailed measurements of each item actually done, so this method is more scientific.

(b) Changes in drawings and quantities of individual item can be made as per requirements within agreed limits.

(c) There is no urgency of providing detailed drawings at the time of awarding the contract. It can be prepared later on.

(d) A contractor is asked to write down the rate of individual in figures and words both so it is not easy to form a cartel during item submission of tender.

(e) An engineer can compare the rates quoted by the contractor with the of schedule of rates prepared by the department to find out whether tender is unbalanced.

PERCENTAGE RATE CONTRACT:

In this form of contract, the department draws up 'item rate tender' i.e., Bill of quantities with-rate, amount and total amount. The contract are required to offer to carry out the work as per with the rates shown inspecific price schedule or some percentage above or some percentage be the rates indicated in the schedule of work attached with the tender. The percentage above or below or at par is applicable on the over all cost of work also.

Merits:

(i) The ranking amongst the contractors is easily known just on the opening of the tenders.

(ii) As there is no provision to quote contractor's own rate for an individual item, benefit due to increased quantity with a beneficial rate can not be availed by the contractor. The chance of unbalanced tender gets eliminated.

LUMP-SUM CONTRACT:

In this type of contract, a contractor is required to quote a fixed sum for execution of work complete in all respect in the stipulated time according to the drawing, design and specifications supplied to him with the tender.

The departmental schedule of rates for various items of work are also provided which regulates the payment of the contractor in respect of any additions and alterations which are made over the original work. On the completion of the work, no detailed measurement of different items of work is needed but the whole work done must be compared and checked with the drawings and specifications.

Merits:

(i) As the total cost of the work known before hand, the owner can arrange the fund in time.

(ii) Detailed measurements of the work done are not required except in respect of additions and alterations.

(iii) The contractor's profit mainly lies in the completion time. Hence for getting more profit the contractor tries to complete the work as early as possible. This concept on the part of contractor coincides with the objective of the owner also.

(iv) As it is difficult to get intermediate payment, the contractor tries to finish earliest to get the full payment earliest and go to another venture. The owner also benefits from the project being completed early or in time.

(v) Due to competition among the contractors, the contractor tries to take the work up even at the less profit, resulting in low cost of the work.

COST PLUS PERCENTAGE RATE CONTRACT:

In this type of contract, a contractor agrees to take the work of construction on the actual cost of work plus on agreed percentage in addition, for his services. It is generally adopted when the labour and material cost are liable to fluctuate heavily in the market. The contractor arranges materials and labour at his cost and keeps proper account which is paid by the department or owner with certain percentage (say 10%) of the cost of construction as his profit. An agreement is made accordingly in advance.

Merits:

(i) The contract can be quickly drawn up and agreed and work can be completed in the shortest possible time. It is well suited during war period or calamity-period when the shortest possible project time is the main criteria in place of the cost involved.

(ii) It is particularly suitable when work can not be executed by other types of contracts due to uncertainty and fluctuations in the market rates of labour and materials.

COST PLUS FIXED FEE CONTRACT:

In this type of contract, the contractor is paid by the owner an agreed fixed lump-sum amount over and above actual cost of the work. This fixed fee will include overhead and profit to the contractor. The fee does not vary with the actual cost of the work as in the case of cost plus percentage rate contract.

Merits:

(i) Since the fixed fee covers the contractor's overhead charges and *p* the contractor will try to finish the work as early as possible, so the owner gets the advantage of early completion.

(ii) For any intermediate payment, the value of work done should *n* less than the payment being made.

(iii) It is suitable form of contract where considerable amount of addition and alterations are expected.

LABOUR CONTRACT:

In labour contract, the contractor undertakes contract for the labour portion only excluding the materials which are arranged and supplied at the work site by the department/ owner. The contractor engages the required labour and gets the work done as per drawings and specifications. It is a item rate basis for labour portion only and the contractor is paid for the quantities of work done on measurement of different items of work at the stipulated rate in the contract agreement.

Merits:

(i) The materials stored by the department are thus utilized.

(ii) The work done through labour contract is of superior quality as better quality materials are arranged by the owner.

(iii) The overall cost of construction may be less, as no profit is paid on the cost of materials.

(iv) This system is very convenient for private building construction.

(ii) Given: Speed $= 4 \text{ km/hr} = \dfrac{4 \times 1000}{60}$ m/min

Time of rolling, $t = 50$ min

Length of drum, $l = 2.4$ m

Number of drums, $n = 1$

Fraction of overlap, $p = \frac{1}{8}$

Thickness of layer, $h = 0.45$

Number of passes, $N = 5$

$$\therefore \quad \text{Output of roller } (Q) = \frac{S \cdot h \cdot l \cdot n(1-p) \cdot t}{N}$$

$$= \frac{\left(\frac{4000}{60}\right) \times 0.45 \times 2.4 \left(1 - \frac{1}{8}\right) \times 50}{5} = 630 \text{ m}^3$$

So, Quantity of earth compacted $= 630 \text{ m}^3$ End of Solution

End of Solution

■■■■