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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-3

Section A : Design of Concrete and Masonry Structure [All topics]

Section B : Design of Steel Structures [All topics]

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	40
Q.2	60
Q.3	55
Q.4	
Section-B	
Q.5	30
Q.6	
Q.7	45
Q.8	
Total Marks Obtained	230

Signature of Evaluator: Shreyab

Cross Checked by ....

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Keep it up

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1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Design of Concrete and Masonry Structure

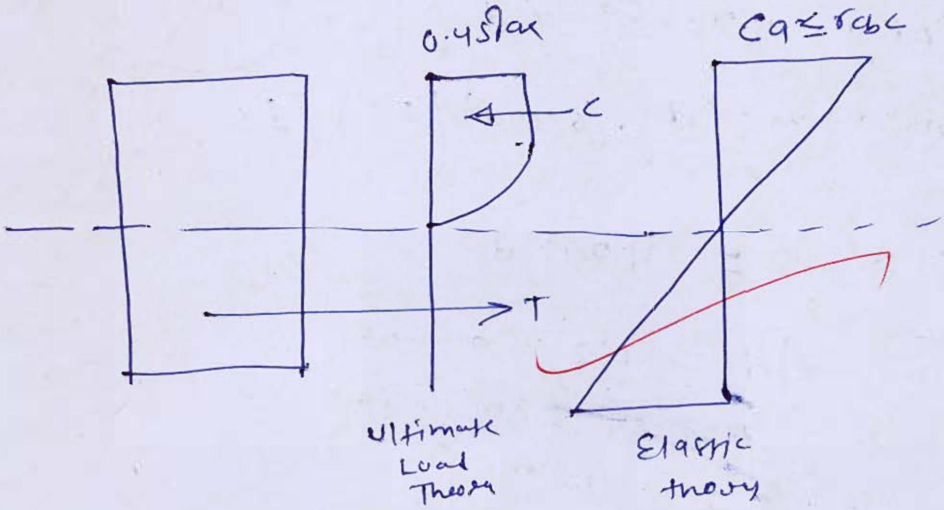
1 (a) (i) Write the comparison of ultimate load method and elastic theory method.

(ii) A singly reinforced concrete beam of rectangular section is of breadth equal to half of its effective depth. Determine the area of tension steel required to resist a bending moment of 6 tm.
(Take: σ_{cbc} = 50 kg/cm^2, σ_{st} = 1400 kg/cm^2, m = 18).

[6 + 6 = 12 marks]

Comparison of ultimate Load method and Elastic theory method

① In ultimate Load method As per IS456 Stree strain Curve is half parabolic and half Rectangular but in case of Elastic theory stress - Strain Curve is Linear



②

Given :→ $d = 2B$

$BM = 6tm = 6 \times 10^6$ kg cm

$\sigma_{cbc} = 50$ kg/cm²

$\sigma_{st} = 1400$ kg/cm²

$m = 18$

(I) critical depth of Neutral Axis

$$x_c = \left(\frac{mc}{mc + \sigma_{st}}\right) d = \left(\frac{18 \times 50}{18 \times 50 + 1400}\right) d$$

$$\boxed{x_c = 0.39d}$$

(II) ~~Actual depth of Neutral Axis~~

~~As~~ design as limiting (balanced) section :→

$$BM = B \cdot x_c \cdot \frac{c_a}{2}\left(d - \frac{x_c}{3}\right)$$

$$6 \times 10^6 \text{ kg cm} = \left(\frac{d}{2}\right) \cdot (0.39d)\left(\frac{50}{2}\right)\left(d - \frac{0.39}{3}\right)$$

$$6 \times 10^6 = 4.241 d^3$$

$$\boxed{d = 112.26 \text{ cm}}$$

$B = 56.13$ cm, $x_a = 43.78$ cm

(III) $$A_{st} = \frac{B \cdot x_a \cdot \frac{c_a}{2}}{\sigma_{st}}$$

$$= \frac{56.13 \times 43.78 \times \frac{50}{2}}{1400}$$

$$\boxed{A_{st} = 43.883 \text{ cm}^2}$$

the do work on Concept of WSM

2+4

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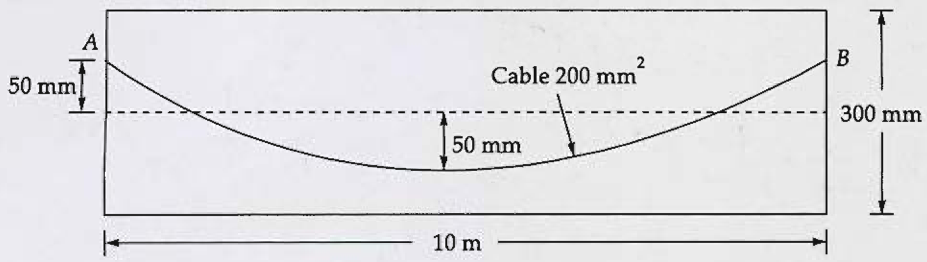
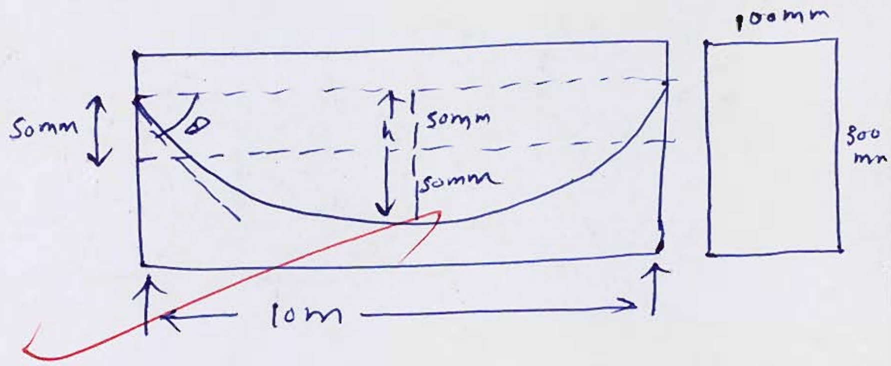
1 (b) A concrete beam of 10 m span, 100 mm wide and 300 mm deep is prestressed by a cable with cross-sectional area of 200 mm^2. The cable profile is parabolic with an eccentricity of 50 mm above the centroid of the section at the supports and 50 mm below at mid-span. If the cable is tensioned from one end only, estimate the percentage loss of prestress in the cable due to effect of friction. Assume $\mu = 0.35$ and $k = 0.0015$ per metre.



[12 marks]

Soln:→



Friction loss

$= P_0(Kx + \mu\alpha)$

$h = 100 mm = 0.1 m$

$L = 10 m = 10000 mm$

$\mu = 0.35$

$K = 0.0015$

cable is tensione from one End only

hence $x = L = 10 m$

$\alpha = 2\theta$

$\theta = \tan^{-1}\left(\frac{4h}{L}\right)$

$= \tan^{-1}\left(\frac{4 \times 0.1}{10}\right) = 2.2906^\circ$

$= \frac{2.2906 \times \pi}{180}$

$= 0.03998$ radian

$\alpha = 2\theta = 0.07996$ radian

hence friction loss

$$= p_0 (k x + \mu \alpha)$$

$$= p_0 (0.0015 \times 10 + 0.35 \times 0.07996)$$

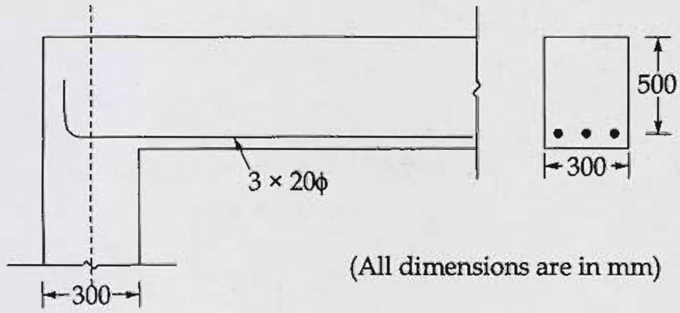
$$= 0.042986\, p_0$$

% loss due to friction $= \dfrac{0.042986\, p_0}{p_0} \times 100$

$$= \boxed{4.2986\%}$$ Ans.

12

1 (c) Determine the anchorage length of bars at the simply supported end of reinforced concrete beam as shown below, if it is subjected to an ultimate shear force of 300 kN at the centre of support. Assume M20 grade concrete and steel of grade Fe415.
[Take τ_{bd} = 1.92 N/mm^2]



(All dimensions are in mm)

[12 marks]

Soln:

$V_u = 300\ kN$ $\quad$ $B = 300\ mm$

$\tau_{bd} = 1.92\ N/mm^2$ $\quad$ $d = 500\ mm$

M20 | Fe415

development length

$$L_d = \frac{0.87 f_y \times \phi}{4 \tau_{bd}} = \frac{0.87 \times 415 \times 20}{4 \times 1.92}$$

$$= 940.24\ mm$$

at support

As per IS456 $\boxed{1.3\frac{M_{u1}}{V_u} + L_0 \geq L_d}$

M_{u1} = moment of Resistance of secn.

For that $\quad A_{st} = 3 \times \frac{\pi}{4}(20)^2 = 942.48\ mm^2$

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} B} = \frac{0.87 \times 415 \times 942.48}{0.36 \times 20 \times 300}$$

$$= 157.54\ mm$$

$x_{u,lim} = 0.48d = 0.48 \times 500 = 240\ mm$

— URS

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

$= 0.36 \times 20 \times 300 \times 157.54 (500 - 0.42 \times 157.54)$

$M_R = \underline{147.63 \text{ kNm}}$

<u>Now</u> $1.3 \times \frac{M_{u1}}{V_u} + L_0 \geq L_d$

10

$1.3 \times \frac{147.63 \times 10^6}{300 \times 10^3} + L_0 \geq 942.29$

300.8

<u>Ancorage length :-</u>

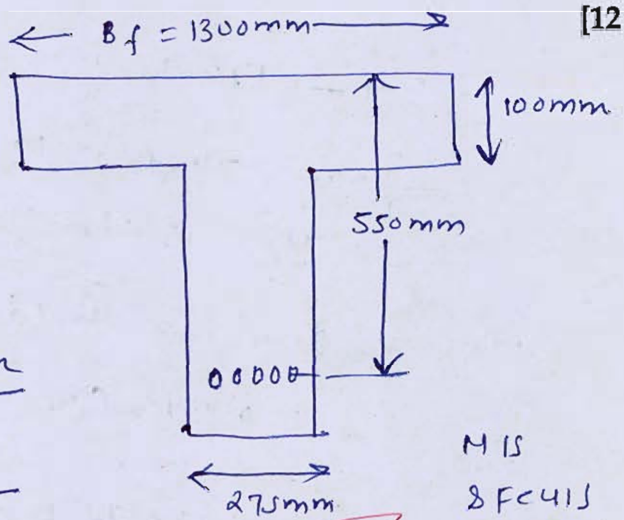
$\boxed{L_0 = 450.14 \text{ mm}}$

<u>Ans.</u>

Q.1 (d) A T-beam of effective flange width 1300 mm, flange thickness 100 mm, rib width 275 mm has an effective depth of 550 mm. The beam is reinforced with 5 bars of 25 mm diameter. Find the ultimate moment of resistance by the limit-state method. Use M15 grade of concrete and Fe415 steel.

[12 marks]

Soln:→



Given $B_f = 1300mm$

$D_f = 100mm$

$b_w = 275mm$

$d = 550mm$

M15

& Fe415

$A_{st} = 5 \times \frac{\pi}{4}(25)^2$

$= 2454.37 mm^2$

$x_{u,lim} = 0.48 d = 0.48 \times 550$

$= 264mm$

Step-1 Actual depth of N.A Assuming $x_u < d_f$

$x_u < x_{u,lim}$

$x_u \Rightarrow 0.36 f_{ck} B_f x_u = 0.87 f_y A_{st}$

$x_u = \frac{0.87 \times 415 \times 2454.37}{0.36 \times 15 \times 1300}$

$x_u = \cancel{}$ $126.21mm \nless d_f = 100mm$

$< x_{u,lim} = 264mm$

Not (OK)

Step-2 Assuming $x_u > d_f$

$\frac{3}{7} x_u < d_f$

$x_u < x_{u,lim}$

$\cancel{y_f = 0.15 d_f \; 0.15 d_f}$

$y_f = 0.65 d_f + 0.15 x_u$

$0.36 f_{ck} b_w \cdot x_u + 0.45 f_{ck} (b_f - b_w) \cdot y_f = 0.87 f_y \cdot A_{st}$

$\Rightarrow 0.36 \times 15 \times 275 \times x_u + 0.45 \times 15 (1300 - 275) \times (0.65 \times 100 + 0.15 x_u)$

$= 0.87 \times 415 \times 2454.37$

$x_u = 172.99 \text{ mm} < x_{u,lim} = 264 \text{ mm}$ (OK)

$\frac{3}{7} x_u = 74.14 < 100 = D_f$ OK

$y_f = 0.15 \times 172.99 + 0.65 \times 100 = 90.95 \text{ mm}$

Hence $M_R = 0.36 f_{ck} b_w \cdot x_u (d - 0.42 x_u) + 0.45 f_{ck} (B_f - b_w)(y_f)(d - \frac{y_f}{2})$

$M_R = 0.36 \times 15 \times 275 \times 172.99 \times (550 - 0.42 \times 172.99) + 0.45 \times 15 \times (1300 - 275) \times 90.95 \times (550 - \frac{90.95}{2})$

$= \boxed{M_R = 408.64 \text{ KNM}}$ Ans.

$(M_R)_{working} = \frac{408.64}{1.5} = 272.42 \text{ KNM}$ Ans.

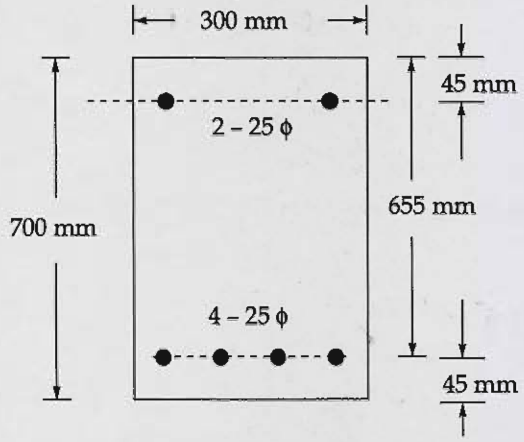
12

.1 (e) (i) Describe light weight concrete or foam concrete.

(ii) Briefly explain how underwater concreting is done?

[7 + 5 = 12 marks]

.2 (a) Determine the ultimate moment of resistance of the doubly reinforced section as shown in figure below. Assume M20 concrete and Fe415 steel.



Strain, ϵ_{sc}	0.00000	0.00144	0.00163	0.00192	0.00241	0.00276	≥ 0.00380
Stress, f_{sc} (MPa)	0.0	288.7	306.7	324.8	342.8	351.8	360.9

[20 marks]

Soln:→

Step-1 $A_{st} = 4\times\frac{\pi}{4}(25)^2 = 1963.5\ mm^2$

$A_{sc} = 2\times\frac{\pi}{4}(25)^2 = 981.75\ mm^2$

D = 700 mm M20

d = 655 mm Fe415

B = 300mm

Step-2 Actual depth of N.A.

$0.36 f_{ck} B\cdot x_u + (f_{sc}-0.45 f_{ck})A_{sc} = 0.87 f_y\cdot A_{st}$

$0.36\times 20\times 300\, x_u + (f_{sc}-0.45\times 20)\times 981.75$

$= 0.87\times 415\times 1963.5$

$x_u = \frac{717757.425 - 981.75 f_{sc}}{2160}$

Let's Assuming $f_{sc} = 350\ N/mm^2$

$x_u = \frac{717737.425 - 981.75\times 350}{2160}$

$x_u = 173.2$ mm

$\varepsilon_{sc} = \frac{173.2-45}{173.2}\times 0.0035 = 0.00259$

$$f_{sc} = 342.8 + \frac{(351.8 - 342.8)}{0.00276 - 0.00241} \times (0.00259 - 0.00241)$$

$$f_{sc} = \underline{347.43\ N/mm^2}$$

Taking $f_{sc} = 347.43\ N/mm^2$

$$x_u = \frac{717757.425 - 981.75 \times 347.43}{2160}$$

$$x_u = 174.4\ mm$$

$$\varepsilon_{sc} = \frac{174.4 - 45}{174.4} \times 0.0035$$

$$= 0.002597$$

$$f_{sc} = 342.8 + \frac{(351.8 - 342.8)}{0.00276 - 0.00241}(0.002597 - 0.00241)$$

$$= \underline{347.6\ N/mm^2}$$

hence taking $f_{sc} = 347.6\ N/mm^2$

and $x_u = \underline{174.4\ mm}$

$x_{u\,lim} = 0.48d = 0.48 \times 655 = 314.4\,m$

$x_u < x_{u\,lim}$ $\underline{\underline{URS.}}$

~~Mr = 0.36~~

OK

<u>Step-3</u> <u>Moment of Resistance (M_R)</u>

$$M_R = 0.36 f_{ck}\, B \cdot x_u (d - 0.42 x_u) + (f_{sc} - 0.45 f_{ck}) A_{sc} (d - d_c)$$

$$= 0.36 \times 20 \times 800 \times 174.4 (655 - 0.42 \times 174.4) + (347.6 - 0.45 \times 20) \times 981.75 \times (655 - 45)$$

$$= 421.925 \times 10^6\ Nmm$$

$$\boxed{M_{RU} = 421.925\ KNM}$$ Ans.

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$$(M_R)_{safe} = \left(\frac{421.925}{1.5}\right) = 281.28 \text{ kNm}$$

20

Q.2 (b) (i) State the assumptions made while analyzing the reinforced concrete beam using Limit State Method as per **IS 456:2000 Code**.

(ii) A short RCC column 400 mm × 400 mm is provided with 8 bars of 16 mm diameter. If the effective length of the column is 2.25 m, find the ultimate load for the column. Use M20 concrete and Fe415 steel.

[10 + 10 = 20 marks]

Soln (1)

Assumption use in bending (flexure) as per

IS 456 : 2000

(1) plain section before bending remains plain after bending. It means that strain diagram is linear

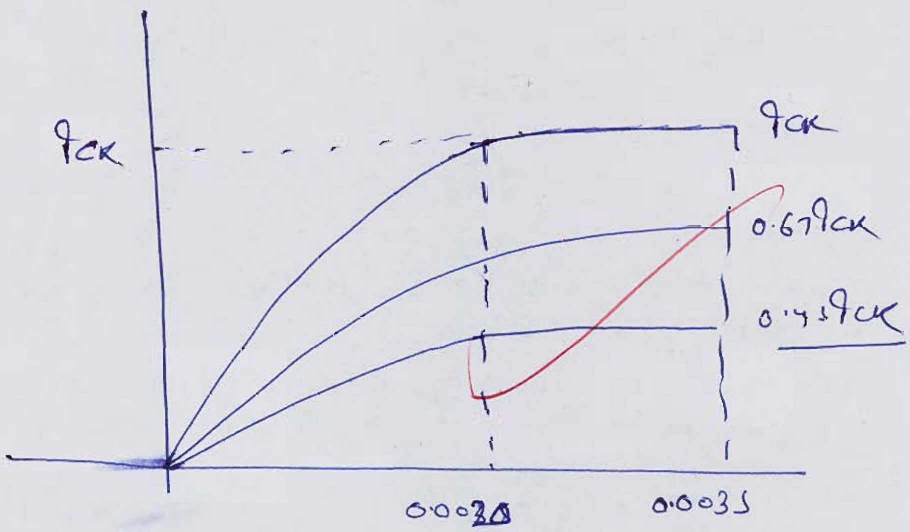
(2.) maximum strain in outmost compression fibre in flexure is 0.0035.

(3.) strain in steel at time of failure

$$\varepsilon_{st} \nless \left[0.002 + \frac{f_y}{1.15 E_s}\right]$$

(4.) Tensile strength of concrete is ignored That means all Tension are Taken by steel only.

(5.) Stress - strain curve of concrete is Taken as any shape i.e. Trapezoidal, Rectangular or Parabolic or any other shape an Acceptable stress strain curve is shown below



(ii) RCC column 400 mm x 400 mm

$$A_{sc} = 8 \times \frac{\pi}{4} (16)^2 = 1608.5\, mm^2$$

$$L_{eff} = 2.5\, m = 2500\, mm$$

M20 | Fe415

$$(SR) = \frac{L_{eff}}{D} = \frac{2500}{400} = 6.25 < 12$$

OK Short column

$$e_{min} = \frac{L}{500} + \frac{D}{30} = \frac{2500}{500} + \frac{400}{30}$$

or 20mm

$$= 18.33 < 0.05D$$

$$= 20\, mm \text{ (OK)}$$

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Ultimate load capacity with minimum moment

$P_u = 0.40 f_{ck} A_c + 0.67 f_y A_{sc}$

$= 0.40 \times 20 \times (400^2 - 1608.5)$

$+ 0.67 \times 415 \times (1608.5)$

$= 1714.375 \times 10^3 N$

$\boxed{P_u = 1714.375 KN}$ Ans.

Load capacity without minimum moment

$P_{uz} = 0.45 f_{ck} A_c + 0.75 f_y \cdot A_{sc}$

$= 0.45 \times 20 \times (400^2 - 1608.5)$

$+ 0.75 \times 415 \times 1608.5$

$\boxed{P_{uz} = 1926.17 KN}$ Ans.

20

Q.2 (c) Design the reinforcement in a column of size 450 mm × 600 mm, subjected to an axial load of 2000 kN under service dead and live loads. The column has an unsupported length of 3.0 m and is braced against side sway in both directions. Use M20 and Fe415.

[20 marks]

Step-1

Soln: → Size $B = 450$ mm M20

$D = 600$ mm Fe415

$L_o = 3$ m

$P = 2000$ kN

$P_u = 1.5 \times 2000 = 3000$ kN

$L_{eff} = 1 \times 3 = 3$ m.

Step-2 $(SR)_{xx} = \frac{3000}{600} = 5 < 12$

$(SR)_{yy} = \frac{3000}{450} = 6.67 < 12$

hence short column

$e_{x\,min} = \frac{L_o}{500} + \frac{D}{30}$ or 20mm

$= \frac{3000}{500} + \frac{600}{30}$

$= 25\text{ mm} < 0.05D = 0.05 \times 600$

$= 30$ mm

OK

$e_{y\,min} = \frac{L_o}{500} + \frac{B}{30}$ or 20mm

$= \frac{3000}{500} + \frac{450}{30} = 20$ mm

$< 0.05B = 22.5$ mm (OK)

hence we can apply formula for

short column.

Step-3 $P_u = 0.40 f_{ck} \cdot A_c + 0.67 f_y \cdot A_{sc}$

$3000 \times 10^3 = 0.40 \times 20 \times (600 \times 450 - A_{sc}) + 0.67 \times 415 \times A_{sc}$

$$\boxed{A_{sc} = 3110.53\ mm^2}$$

No of 28 mm dia bar $= \dfrac{3110.53}{\frac{\pi}{4}(28)^2}$

$= 5.05$

hence provide Asc as 6-28 mm dia bar

Asc provided $= 6 \times \frac{\pi}{4} 28^2 = 3694.5\ mm^2$

$P(\%) = \dfrac{A_{sc}}{B \cdot D} \times 100 = \dfrac{3694.5 \times 100}{450 \times 600}$

$= 1.368\%$

$\not> 6\%$ Asc(%) max

$\not< 0.8\%$ OK

Step-4 Design of ties

diameter $= \phi$, $\Rightarrow$ i) $\dfrac{\phi_{main}}{4} = 7\ mm$

ii) 6 mm as IS 456 : 2000

iii) 8 mm as per IS 13920

hence provide 8 mm ties

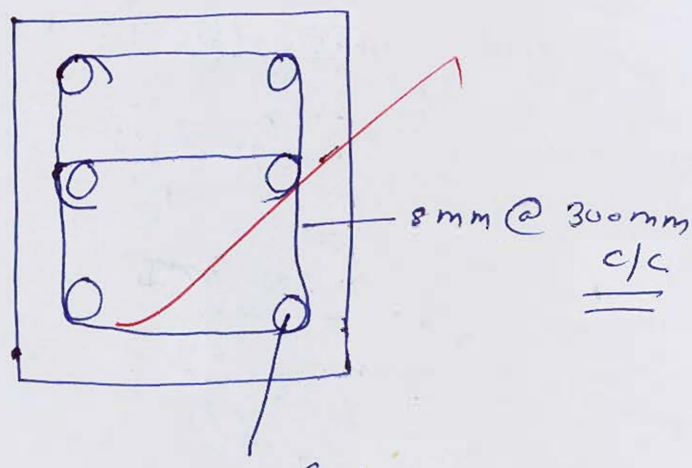
ii) Spacing i) Least later dimension = 450 mm

ii) $16 \times \phi_{main} = 16 \times 28 = 448\ mm$

iii) 300 mm

provide 8mm @ 300 mm c/c

Steps
Reinforcement Details



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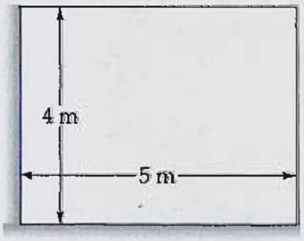
Q.3 (a) Design a two way slab of 4 m × 5 m size. Slab is subjected to a superimposed load of 8 kN/m^2. Self weight should be included as per depth and weight of finishes. Depth should satisfy the deflection criteria as mentioned in **IS 456:2000**. For the given end condition as shown in figure, values of α_x and α_y for positive and negative moments as per **IS 456:2000** are as follows:

	α_x	α_y
+ve moment at mid span	0.047	0.035
–ve moment at ends	0.062	0.047

Calculate the reinforcement required at mid span for positive B.M. in both the directions. Use M20 concrete and Fe415 steel. [Assume modification factor (k_t) for tension reinforcement = 1.6, as per IS 456:2000].



[20 marks]

Soln: → Step-1 $l_{xc} = 4m$ $K_t = 1.6$

$l_{yc} = 5m$ M20, fe 415.

Live Load = $8 KN/m^2$

$$r = \frac{l_y}{l_x} = \frac{5}{4} = 1.25 < 2$$

(Two way slab)

Step-2 $$d = \frac{l_{eff}}{A \times M_{ff}} = \frac{4000}{20 \times 1.6}$$

$= 125 \; mm$

Let's provide $d = 160 \; mm$

Eff cover = 40mm

$D = 200 \; mm$

dead Load:–

Step-3 $w_d = (0.2 \times 1 \times 1) \times 25 = 5 KN/M$

$w_L = (8 \times 1 \times 1) = 8 KN/M$

Total UDL $w_u = 13 KN/M$

factored UDL = $13 \times 1.5 = 19.5 KN/M$

Step-4 $\boxed{M = \alpha \, w_u \, L_{xc}^2}$

$M_x(+)$	$0.047 \times 19.5 \times 4^2 = 14.664$ KNM
$M_x(-)$	$0.062 \times 19.5 \times 4^2 = 19.344$ KNM
$M_y(+)$	$0.035 \times 19.5 \times 4^2 = 10.92$ KNM
$M_y(-)$	$0.047 \times 19.5 \times 4^2 = 14.664$ KNM

Step-5 $BM_{max} = 19.344 KNM$

$$d_{req} = \sqrt{\frac{BM}{QB}} = \sqrt{\frac{19.344 \times 10^6}{0.138 \times 20 \times 1000}}$$

$$= 83.72 \, mm$$
$$< 160 \, mm$$

OK

Step-6 +ve Reinforcement for mid span in Both direction

$Ast_{(x+)} \Rightarrow$ $M_{x+} = 14.664$

$$Ast_{+x} = \frac{0.5 f_{ck}}{f_y} \left[1 - \sqrt{1 - \frac{4.6 BM}{f_{ck} B d^2}}\right] B \cdot d$$

$$= \frac{0.5 \times 20}{415} \left[1 - \sqrt{1 - \frac{4.6 \times 14.664 \times 10^6}{20 \times 1000 \times 160^2}}\right] \times 1000 \times 160$$

$$\boxed{Ast_{x+} = 262.94 \, mm^2}$$

$Ast_{(y+)} =$ $M_{y+} = 10.92 \, KNM$

$$Ast_{y(+)} = \frac{0.5 \times 20}{415} \left[1 - \sqrt{1 - \frac{4.6 \times 10.92 \times 10^6}{20 \times 1000 \times 160^2}}\right] 1000 \times 160$$

$$= 194 \, mm^2$$

$$Ast_{min} = \frac{0.12 BD}{100} = \frac{0.12 \times 1000 \times 200}{100}$$

$$= 240 \, mm^2$$

here provide Ast_{min}

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Check for deflection :- (As per IS 456)

$$L_{eff} = 4000 mm$$

$$\alpha_{value} = 20$$

$$K_t = 1.6$$

$$d_{req} = \frac{4000}{20 \times 1.6} = \frac{L_{eff}}{\alpha \times K_t}$$

$$= 125 mm < d_{provide} = 160 mm$$

(OK)

15

2 Show detailing top and side view.

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Q.3 (b) The size of a *RC* column is 400 mm × 600 mm. The column has to support a dervice load of 1500 kN. Find out the effective depth of foundation for this column if safe bearing capacity of the soil is 160 kN/m^2. Use M25 grade concrete and Fe500 steel. The width of the footing in one of the direction can not exceed 2.5 m and the value of design shear strength of concrete corresponding to minimum tensile reinforcement for M25 is 0.29 N/mm^2. Use Limit State Method. For an effective cover of 60 mm, what is the total depth of foundation?

[20 marks]

Soln: →

Step-1

Given = $P = 1500$ KN

$P_u = 1.5P = 2250$ KN

Safe bearing capacity $q_0 = 160$ kN/m^2

$B = 2.5$ m

$\tau_c = 0.29$ N/mm^2

Eff cover = 60 mm

M25 | Fe500

Step-2 Area of footing

$$A = \frac{P + W_f + W_s}{q_0}$$

Assuming $W_f + W_s = 20\%$ of P

$= 0.2 \times 1500 = 300$ kN

$$A = \left(\frac{1500 + 300}{160}\right)$$

$= 11.25$ m^2

$$L = \frac{11.25}{2.5} = 4.5\text{ m}$$

here provide 4.5×2.5 mm footing

Step-3

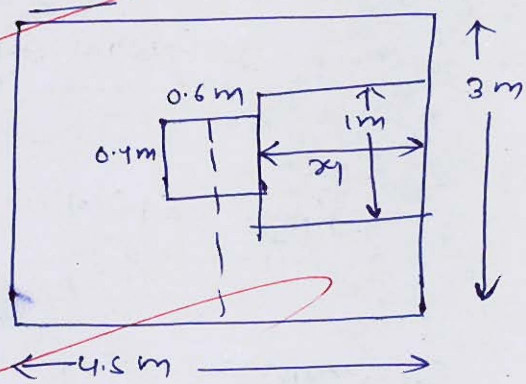
net ultimy design soil pressure

$$w_u = \frac{1.5P}{A} = \left(\frac{2250}{4.5 \times 1.5}\right)$$

$$= 200\ kN/m^2$$

Design for bending (per unit m)

Step-3



$$x_1 = \frac{4.5 - 0.6}{2} = 1.95\ m$$

$$BM_u = \frac{w_u \cdot x_1^2}{2}$$

$$= \frac{200 \times 1.95^2}{2}$$

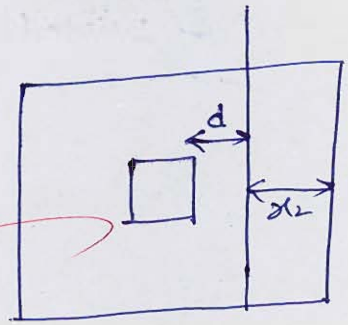
$$= 380.25\ kNm$$

$$d_{req} = \sqrt{\frac{BM_u}{QB}} = \sqrt{\frac{380.25 \times 10^6}{0.133 \times 25 \times 1000}}$$

$$= 338.17\ mm$$

Let's provide $d = 350\ mm$

Step-4 Check for oneway shear



$$x_2 = x_1 - d = 1.95 - 0.35$$

$$= 1.6\ m$$

$$V_u = w_u \cdot x_2 = 200 \times 1.6$$

$$= 320\ kN$$

$$\tau_v = \frac{V_u}{B \cdot d} = \frac{320 \times 10^3}{1000 \times 350} = 0.914\ N/mm^2$$

$\rightarrow \tau_c = 0.29$

Not ok

hence increase $d = 800\ mm$

$$x_2 = 1.95 - 0.8 = 1.15$$

$$V_u = w_u x_2 = 200 \times 1.15 = 230$$

$$\tau_v = \frac{V_u}{B \cdot d} = \frac{230 \times 10^3}{1000 \times 800} = 0.2875 \, N/mm^2$$

$< \tau_c = 0.29 \, N/mm^2$

OK

hence provid $d = 800$ mm

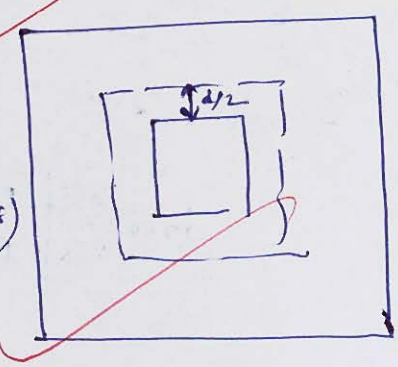
Eff cover $= 60$ mm

Total Depth $D = 860$ mm

finaly Effective $d = 800$ mm

$D = 860$ mm

Check for punching shear



$$P_{unef} = P_u - w_u (a+d)(b+d)$$

$$= 2250 - 200 (0.6+0.8)(0.4+0.8)$$

$$= 1914 \text{ KN}$$

$$\tau_{vp} = \frac{P_{une}}{2((a+d)+(b+d))\, d} = \frac{1914 \times 1000}{2(800+600+400+800) \times 800}$$

20

$$= 0.46 \, N/mm^2$$

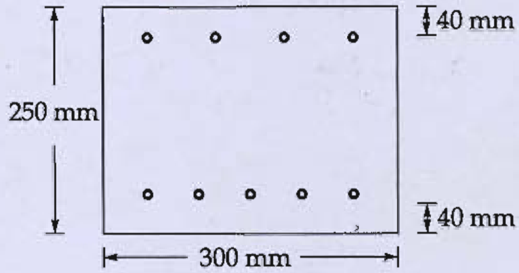
$$\tau_{upperm} = 0.25 \sqrt{f_{ck}} = 0.25 \times \sqrt{25}$$

$$= 1.25 \, N/mm^2$$

OK

Q.3 (c) (i) Enumerate the situations in which doubly reinforced concrete beams become necessary. What is the role of compression steel?

(ii) A prestressed concrete sleeper produced by pretensioning method has a rectangular cross-section of 300 mm × 250 mm depth. It is prestressed with 9 numbers of straight 7 mm diameter wires at 0.8 times the ultimate strength of 1570 N/mm^2. Cut of 9 wires, four are placed at top at a distance of 40 mm from top and balance five wires are located at bottom at a distance of 40 mm from bottom of beam. Estimate the percentage loss of stress due to elastic shortening of concrete. [Take m = 6].



[8 + 12 =20 marks]

Soln: →

situation where doubly Reinforced beam is provided

(1) when section width and depth is limited and Bending moment exceed ultimate limiting moment of Resistance then we provide doubly Reinforced beam.

(2.) Doubly Reinforced beam is provided In case of Reversal of stress due to any type of Load.

(3.) when beam is designed for Twisting moment

Role of compression steel :→

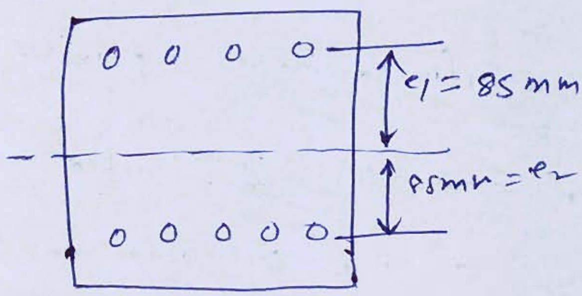
(1) compression steel Ensures that beam should not fail due to over Reinforcement or primary compression failure. It allow beam to fail under ductile failure

(2.) In case of Reversal of stress compression steel is Act as tension Reinforcement.

(3.) In case of beam is designed for Twisting moment ~~then~~ sagging BM is Ensured by Tension Reinforcement and hogging is Ensured by Compression Reinforcement.

Soln:

(11) →



$$\text{Steel at TOP} = 4 \times \frac{\pi}{4}(7)^2 = 153.94\,mm^2$$

$$\text{at bottom} = 5 \times \frac{\pi}{4}(7)^2 = 192.42\,mm^2$$

$$\underset{(P1)}{\text{P force at TOP}} = \frac{153.94 \times 1570}{1000} = 241.7\,KN$$

$$\underset{(P2)}{\text{at bottom}} = \frac{192.42 \times 1570}{1000} = 302.1\,KN$$

$$\text{Total P-force} = 543.8\,KN$$

Stress at location of steel

$$\frac{P}{A} = \frac{543.8 \times 1000}{300 \times 250} = 7.25\,N/mm^2$$

at TOP steel $= \left(\frac{P_1 e_1 - P_2 e_2}{I}\right) e_1 = \frac{243.7\times10^3 \times 85 - 302.1\times10^3 \times 85}{\frac{300\times250^3}{12}} \times 85$

$= -1.098 N/mm^2$

at bottom steel $= \left(\frac{P_2 e_2 - P_1 e_1}{I}\right) e_1 = \frac{302.1\times10^3\times85 - 243.7\times10^3\times85}{\frac{300\times250^3}{12}} \times 85$

$= \cancel{+\ldots}$

$= +1.098 N/m^2$

Stress at TOP $= 7.25 - 1.098 = 6.152 N/mm^2$

at bottom $= 7.25 + 1.098 = 8.348 N/mm^2$

loss in top wire $= m \cdot f_c$

$= 6 \times 6.152 = 36.912 N/mm^2$

in bottom wire $= 6 \times 8.348 = 50.388 mm^2$

Total loss $= 36.912 \times 153.94 + 50.388 \times 192.42$

$= 15.377 kN$

20

% loss $= \frac{15.377}{543.8} \times 100$

$= 2.828\%$

Ans

Q.4 (a) Determine suitable dimensions of a cantilever retaining wall, which is required to support a 4.0 m high bank of earth above the ground level on the toe side of the wall. Consider the backfill surface to be inclined at an angle of 15° with the horizontal. Assume good soil for foundation at a depth of 1.25 m below the ground level with a safe bearing capacity of 160 kN/m^2. Further assume the backfill to comprise granular soil with a unit weight of 16 kN/m^3 and an angle of shearing resistance of 30°. Assume the coefficient of friction between soil and concrete to be 0.5.

[20 marks]

Do not write in this margin

Q.4 (b) A rectangular beam section of 300 mm width and 500 mm effective depth is reinforced with 5 bars of 20 mm ϕ, out of which 2 bars have been bent at 45°. Determine the shear resistance of the bent up bars and additional shear reinforcement required if it is subjected to ultimate shear force of 300 kN. Also show the reinforcement details. (Use M20 grade of concrete and Fe415 steel)

Design shear strength for M20 grade concrete:

$\frac{100A_{st}}{bd}$	0.50	0.75	1.00	1.25
$\tau_c\left(N/mm^2\right)$	0.48	0.56	0.62	0.67

[20 marks]

Q.4 (c) A post-tensioned prestressed concrete beam spans 20 m and carries a uniformly distributed live load of 12 kN/m covering the entire span besides its own weight. The cross-section of beam at mid span is as follows:

Top flange : 500 mm × 150 mm

Web : 150 mm × 650 mm

Bottom flange : 300 mm × 200 mm

The prestressing force is applied by cables of total area 1385.44 mm^2 stretched initially to 1100 N/mm^2 and located at 100 mm from the bottom edge of the beam. Determine the stresses in the beam at transfer and at final stage of loading at mid span. Assume 15% loss of prestress in final stage. (Take density of concrete as 24 kN/m^3)

[20 marks]

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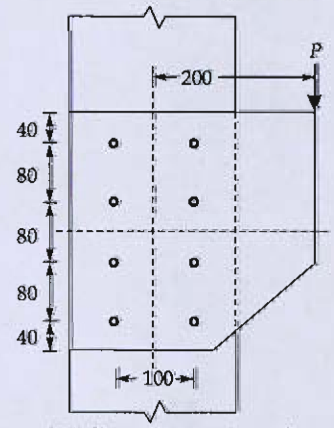
Section B : Design of Steel Structures

Q.5 (a) In the bracket connection as shown in the figure, the bracket plate of 10 mm thickness is connected to column whose flange thickness is 9.1 mm. The bolts used are 20 mm diameter of grade 4.6. Calculate the safe load P that can be carried by the bracket connection. (Use grade of steel Fe410)

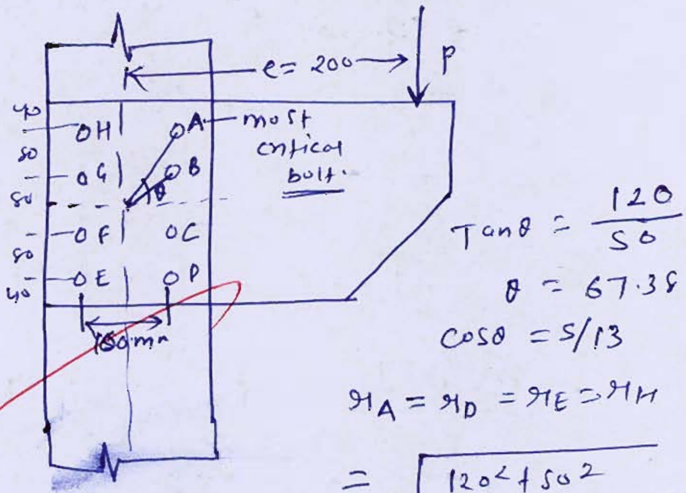
[Assume k_b = 0.606 in calculation of bearing strength of bolt]



(All dimensions are in mm)

[12 marks]

Soln.



1) direct shear force on bolt A

$F_1 = \frac{P}{8} = 0.125P$

2) Torsional shear force on bolt

$F_2 = \frac{P \cdot e}{\Sigma r^2} \times r_A$

$\tan\theta = \frac{120}{50}$

$\theta = 67.38$

$\cos\theta = 5/13$

$r_A = r_D = r_E = r_H$

$= \sqrt{120^2 + 50^2}$

$= 130\ mm$

$r_B = r_C = r_F = r_G = \sqrt{40^2 + 50^2}$

$= 64.03\ mm^2$

$\Sigma r^2 = 64.03^2 \times 4 + 130^2 \times 4$

$= 84000\ mm^2$

$F_2 = \frac{P \times 200 \times 130}{84000} = 0.3095P.$

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

$= \sqrt{(0.125P)^2 + (0.3095P)^2 + 2 \times 0.125P \times 0.3095P \times 5/13}$

$\boxed{F_R = 0.37573P}$

$f_u = 400 \quad f_y = 240, \quad d = 20\ mm$

Strength of bolt

1) Shear strength of bolt $= \left(0.78 \times \frac{\pi}{4} d^2\right) \times \frac{f_u}{\sqrt{3} \times 1.25}$

$= \left(0.78 \times \frac{\pi}{4} 20^2\right) \times \frac{400}{\sqrt{3} \times 1.25}$

$= 45.272\ KN$

2) bearing strength of bolt $= \frac{2.5 K_b d t f_{up}}{\gamma_{m1}}$

$$= \left(\frac{2.5 \times 0.606 \times 20 \times 9.1 \times 410}{1.25}\right)$$

$$= 90.439 \text{ KN}$$

hence bolt strength $= 45.272 \text{ KN}$

for safety $\quad F_R \leq$ bolt strength

$$0.37573 P \leq 45.272$$

$$\boxed{P \leq 120.49 \text{ KN}}$$

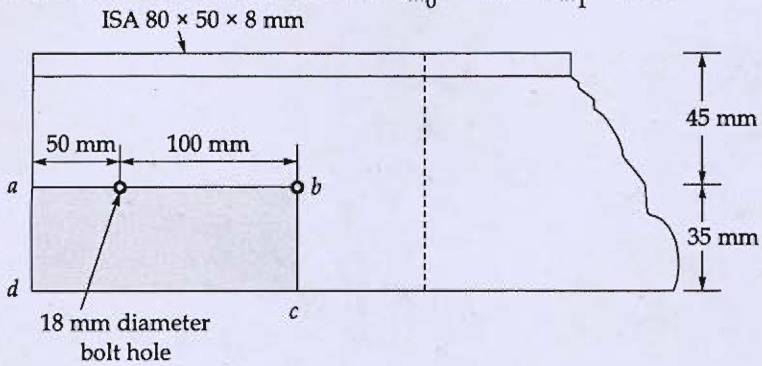
$$P_{safe} = \left(\frac{120.49}{1.5}\right) = \boxed{80.32 \text{ KN}}$$

Ans.

12

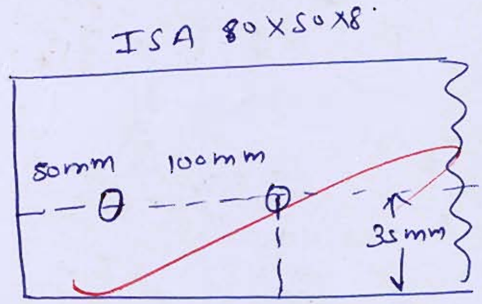
Q.5 (b) Determine the block shear strength of the tension member as shown below. The steel is of grade Fe 410.

Take partial safety factors for materials : $\gamma_{m_0} = 1.1$; $\gamma_{m_1} = 1.25$



[12 marks]

Soln:



$\gamma_{mo} = 1.1$, $\gamma_{m1} = 1.25$

$d_o = 18\ mm$

$f_u = 410$

$f_y = 250$

$A_{vg} = 150 \times 8 = 1200\ mm^2$

$A_{vn} = (150 - 1.5 \times 18) \times 8 = 984\ mm^2$

$A_{tg} = 35 \times 8 = 280\ mm^2$

$A_{tn} = (35 - 0.5 \times 18) \times 8 = 208\ mm^2$

block shear strength :→

① $P_{T1} = A_{vg} \times \dfrac{f_y}{\sqrt{3} \times \gamma_{mo}} + A_{tn} \times \dfrac{0.9 f_u}{\gamma_{m1}}$

$= 1200 \times \dfrac{250}{1.1 \times \sqrt{3}} + 208 \times \dfrac{0.9 \times 410}{1.25}$

$= \boxed{218.86\ kN}$

② $P_{T2} = \dfrac{A_{vn} \times 0.9 f_u}{\sqrt{3} \times \gamma_{m1}} + \dfrac{A_{tg} \times f_y}{\gamma_{mo}}$

$$= 984 \times \frac{0.9 \times 410}{\sqrt{3} \times 1.25} + 280 \times \frac{250}{1.1}$$

$$= \underline{230.661 \text{ KN}}$$

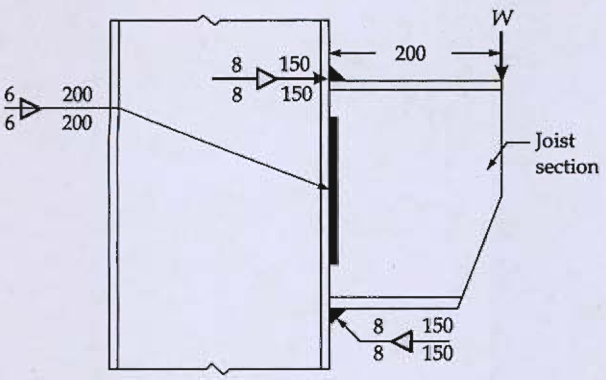
hence block shear strength is minimum of two :—

$$= \boxed{218.86 \text{ KN}}$$

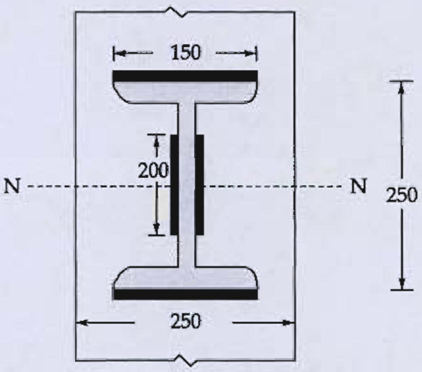
Ans.

12

Q.5 (c) The bracket connection as shown in below figures (a) and (b) consists of a joist cutting welded to the flange of a column by shop fillet welds 8 mm in size on the flanges and 6 mm on the web. Determine the safe service load W, the bracket can support at a distance of 200 mm from the face of the column if structural steel used is of grade Fe410.



(a) Side view



(b) Front view (weldlines)

γ_{mw} = 1.25 for shop weld *(All dimensions are in mm)*

[12 marks]

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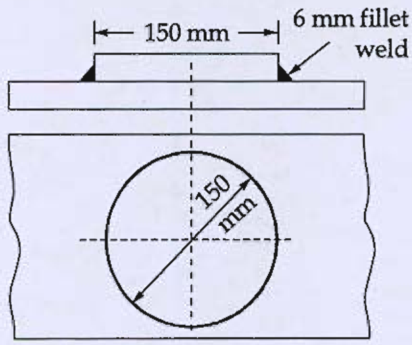
Q.5 (d) **(i)** What are the various limit states of design for a steel structure as per **IS : 800-2007**?

(ii) A circular plate, 150 mm in diameter is welded to another plate by means of 6 mm fillet weld as shown in figure. Calculate the ultimate twisting moment that can be resisted by the weld use steel of grade Fe410 and shop welding.



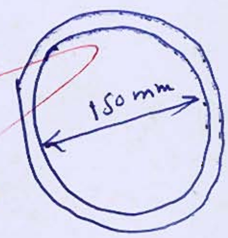
[6 + 6 = 12 marks]

Soln: ~~Various limit state of design~~

~~(I) Limit state of~~

(II) size of weld

$s = 6mm$



$t = KS = 0.7 \times 6 = 4.2mm$

6

$f_u = 410, \quad \gamma_{mw} = 1.25.$

$\frac{J_{\text{Twin weld}}}{r_{max}} = \frac{\pi d^2 t}{2} = \frac{\pi \times 150^2 \times 4.2}{2}$

$= 148440 \, mm^3$

Twisting moment capacity

$T = \frac{J}{r_{max}} \times \frac{f_u}{\sqrt{3} \times 1.25}$

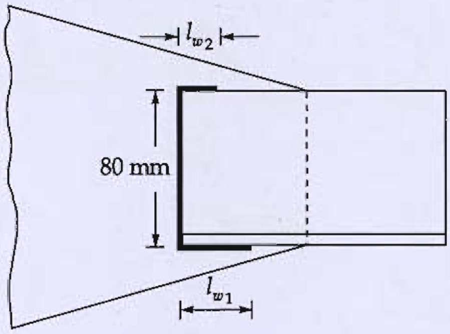
$= 148440 \times \frac{410}{\sqrt{3} \times 1.25}$

$\boxed{T = 28.11 \, KNM}$

Ans

Do not write in this margin

Q.5 (e) Design the fillet weld for the angle secion, if the welding is to be done on its three sides as shown in figure. Take design strength of tie member is 222.27 kN and size of weld is 6 mm. Use grade of steel Fe410.



[12 marks]

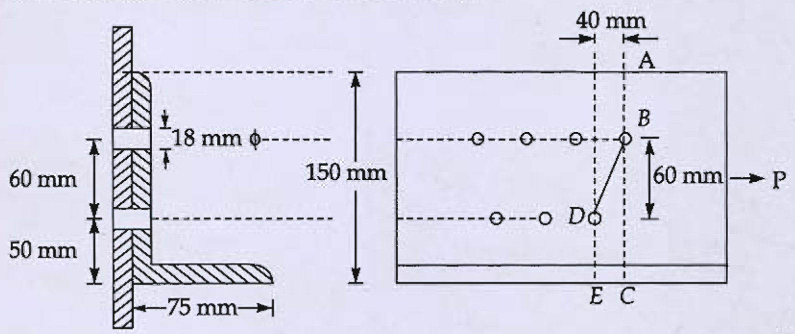
Soln: →

design strength of member P

00

Q.6 (a) **(i)** Explain the upper bound and lower bound theorems as applied to plastic analysis taking an example of a fixed beam under UDL.

(ii) An ISA 150 × 75 × 12 angle riveted on one side of gusset plate by two rows of 18 mm rivets through the 150 mm leg as shown in the figure. Calculate the allowable load in tension if allowable stress is 150 MPa.



[10 + 10 = 20 marks]

Q.6 (b) A welded plate girder of span 25 m is laterally restrained throughout its length. It has to carry a load of 80 kN/m over the whole span besides its weight. The girder is without intermediate transverse stiffeners. The steel used is of grade E250 (Fe 410). Design the cross-section and the welded connections. Draw a neat sketch of the designed section. (Plate girder is fabricated in the workshop).

Take, $E = 2 \times 10^5$ N/mm², $\mu = 0.3$

Partially safety factor, $\gamma_{mw} = 1.25$

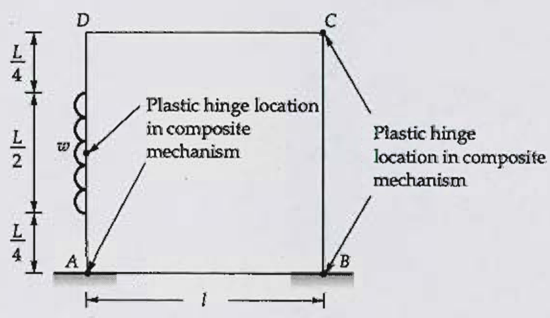
Self weight of the plate girder = $\dfrac{WL}{400}$

Where, W is superimposed load acting on the girder.

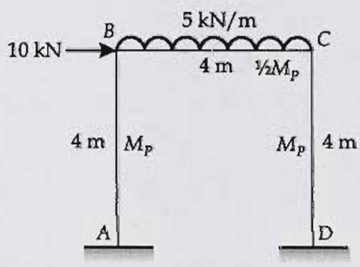
Use limit state method of design.

[20 marks]

Q.6 (c) (i) Given is a rectangular frame of uniform section whose plastic moment capacity is M_p. What is the ultimate load in composite mechanism as shown. Sketch BM distribution at collapse.

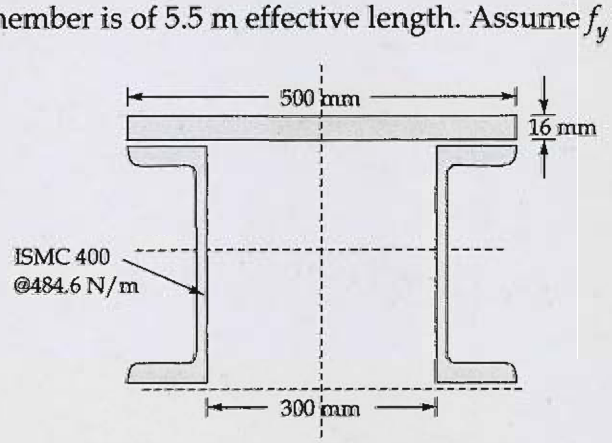


(ii) For the service load system shown, final minimum M_p required to prevent failure, if $(M_P)_{\text{beam}} = \frac{1}{2}(M_P)_{\text{column}}$. Assume load factor = 2.



[10 + 10 = 20 marks]

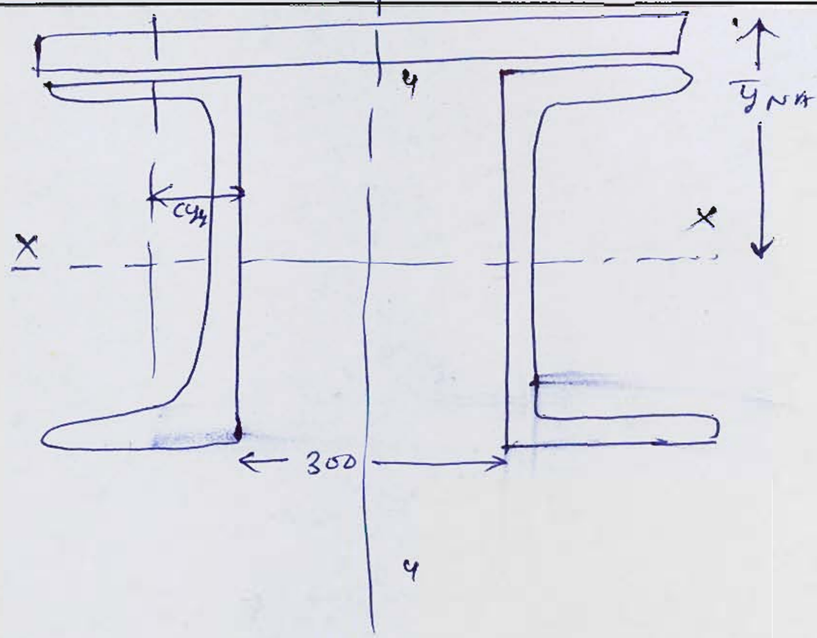
Q.7 (a) Determine the allowable compressive load which the built-up member can carry as shown in figure, if the member is of 5.5 m effective length. Assume $f_y = 250\ \text{N/mm}^2$.



[For ISMC 400@484.6 N/m, A = 6293 mm^2, b_f = 100 mm, t_f = 15.3 mm, t_w = 8.6 mm, r_{xx} = 154.8 mm, I_{xx} = 15082.8 × 10^4 mm^4, I_{yy} = 504.8 × 10^4 mm^4, C_{yy} = 24.2 mm] [Use WSM]

For $f_y = 250\ \text{N/mm}^2$	
$\lambda = l / r$	$\sigma_{ac}\ (\text{N/mm}^2)$
30	145
40	139
50	132

[20 marks]



calculating moI of built up section :—

About x-x : →

from top $y_{NA} = \dfrac{500 \times 16 \times 8 + 6293 \times \left(16 + \frac{400}{2}\right) \times 2}{500 \times 16 + 6293 \times 2}$

$= 135.17\ mm$

$$I_{xx} = \frac{500 \times 16^3}{12} + 500 \times 16 \times (135.17 - 8)^2$$
$$+ 2 \times \left[15082.8 \times 10^4 + 6293 \times (216 - 135.17)^2\right.$$

$I_{xx} = 51341.88 \times 10^4\ mm^4$

About yy

$$I_{yy} = \frac{16 \times 500^3}{12} + 2 \times \left[504.8 \times 10^4 + 6293 \left(\begin{matrix}242\\+150\end{matrix}\right)^2\right]$$

$I_{yy} = 55869.29\ mm^4$

here $I_{min} = I_{xx} = 51341.88 \times 10^4\ mm^4$

$A = (500 \times 16 + 6293 \times 2)$

$= \underline{20586 \text{ mm}^2}$

$r_{min} = \sqrt{\dfrac{I_{min}}{A}} = \sqrt{\dfrac{51341.88 \times 10^4}{20586}}$

$= \underline{157.92 \text{ mm}}$

$l = 5.5 \text{ m}$

$\lambda = \dfrac{l}{r} = \dfrac{5.5 \times 1000}{157.92} = 34.82$

<u>from table</u>

$\sigma_{ac} = 145 - \dfrac{(145 - 139)}{(40 - 10)} \times (34.82 - 30)$

$\sigma_{AC} = 142.1 \text{ N/mm}^2$

20

<u>Allowable compressive Load</u>

$P = \sigma_{AC} \times \text{Area}$

$= \left(\dfrac{142.1 \times 20586}{1000}\right)$

$\boxed{P = 2925.4 \text{ KN}}$

Ans

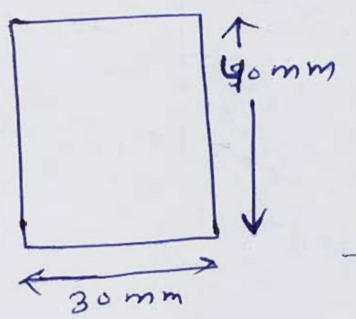
Q.7 (b) A simply supported rectangular beam 3 cm × 4 cm carries a concentrated load W, at mid point of span 3 m. Take yield stres, σ_y = 250 MPa.

(i) Determine load W and draw the shape of the plastic zone when strain at the extreme fiber is $4\in_y$ (4 times yield strain)

(ii) Determine the plastic hinge length at mid span of beam.

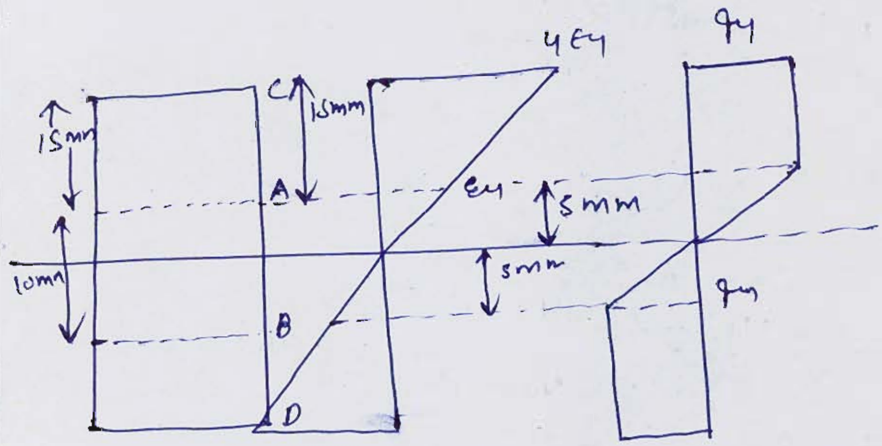
[20 marks]

Soln:→



$\sigma_y = 250$ mpa

Extreme fibre strain $= 4\epsilon_y$



moment capacity of Elastic section

$$M_1 = \sigma_y . Z = 250 \times \left(\frac{30 \times 10^2}{6}\right)$$

$$= 125 \times 10^3 \text{ N mm}$$

moment capacity of Remaining plastic section

$$M_2 = \sigma_y . Z_p -$$

$$Z_p = \frac{A}{2} (\bar{y}_1 + \bar{y}_2)$$

$$\frac{A}{2} = 15 \times 30 = 450 \text{ mm}$$

$$\bar{y}_1 = \bar{y}_2 = 5 + \frac{15}{2} = 12.5 \text{ mm}$$

$Z_p = 450 \times (12.5 + 12.5) = 11250\ mm^3$

$M_2 = \underline{11250 \times 250} = 2.8125 \times 10^6\ Nmm$

Total moment capacity $= (2.8125 + 0.125)$

$= \underline{2.9375\ KNm}$

Now for plastic hinge length

$Z_{TOTAL} = 11250 + \frac{30 \times 10^2}{6}$

$= 11750$

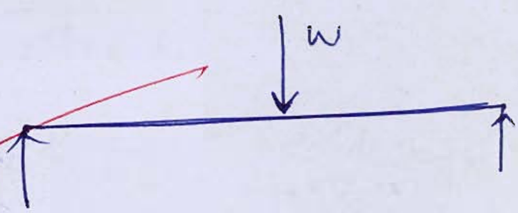
$Z_E = \frac{bd^2}{6} = \frac{30 \times 40^2}{6}$

$= 8000$

Shape factor

$SF = \frac{11750}{8000}$

$= \underline{1.46875}$



Collapse Load $= \frac{4M_p}{L}$

$W = \frac{4 \times 2.9375}{3}$

$\boxed{W = 3.916\ KN}$

Length of plastic hinge for concentrated load at mid span

17

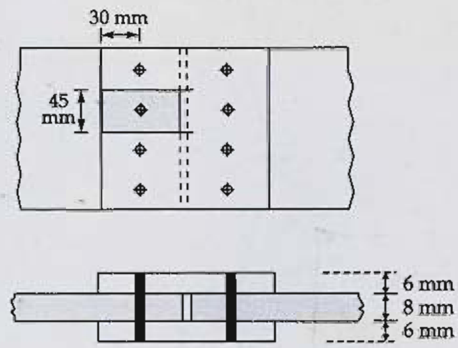
$L_p = l\left(1 - \frac{1}{SF}\right)$

$= 3\left(1 - \frac{1}{1.46875}\right)$

$\boxed{L_p = 0.9574\ m}$

Ans.

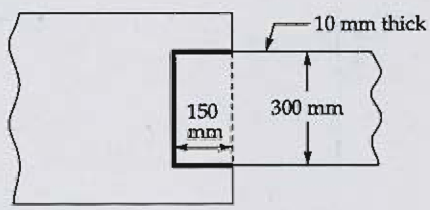
Q.7 (c) **(i)** A double cover butt joint is used to connect two plates which are 8 mm thick. Assume 16 mm diameter bolts of grade 4.6 and cover plates to be 6 mm thick. Arrangement of bolts is as shown in figure. Steel used is of grade Fe410.



Calculate:

1. Strength of joint per pitch length
2. Efficiency of the joint per pitch length

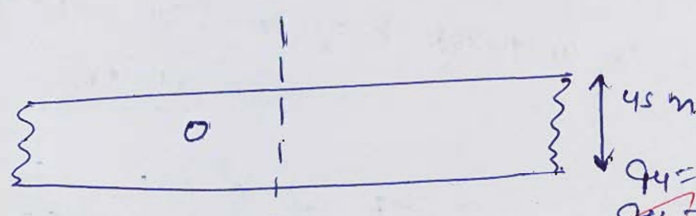
(ii) Determine the block shear strength of the welded tension member as shown in figure. Steel is of grade Fe410.



Given: $T_{db_1} = \dfrac{A_{vg} f_y}{\sqrt{3}\gamma_{m_0}} + \dfrac{0.9 A_{tn} f_y}{\gamma_{m_1}}$ and $T_{db_2} = \dfrac{0.9 A_{vn} f_u}{\sqrt{3}\gamma_{m_1}} + \dfrac{A_{tg} f_y}{\gamma_{m_0}}$

[10 + 10 = 20 marks]

Soln: →



(1) strength of solid plate per pitch

$$T_{dg} = \frac{A_g \times f_y}{\gamma_{m0}} = \frac{(45 \times 8) \times 250}{1.1}$$

$$= 81.818 \text{ KN}$$

(2) strength as per net area cracking

$$T_{dn} = \frac{0.9 f_u}{1.25} \times A_n$$

$A_n = (B - d_0)\,t = (45-18)\times 8 = 216\,mm^2$

$T_{dn} = \dfrac{0.9\times 410}{1.25}\times 216\times 10^{-3}$

$= 63.763\,kN$

(iii) strength of bolt joint per pitch –

i) shear strength of bolt joint $= \left(0.78\times\frac{\pi}{4}d^2\right)\times\dfrac{f_{u,b}}{\sqrt{3}\times\gamma_{m1}}$

$P_s = \left(0.78\times\frac{\pi}{4}16^2\right)\times\dfrac{400}{\sqrt{3}\times 1.25}$ ×2

$P_s = 28.979\,kN$ ×2

ii) bearing strength of bolt joint

$P_b = \dfrac{2.5\,K_b\,d\,t\,f_{up}}{\gamma_{m1}}$

$K_b = \dfrac{e}{3d_0} = \dfrac{30}{3\times 18} = 0.555$

$= \dfrac{P}{3d_0} - 0.25 = \dfrac{45}{3\times 18} - 0.25 = 0.585$

$= \dfrac{f_{u,b}}{f_{up}} = \dfrac{400}{410} = 0.975$

$= 1$

min^m of All

8

$K_b = 0.555$

$P_b = \dfrac{2.5\times 0.555\times 16\times 8\times 410}{1.25\times 1000} = 58.25\,kN$

hence Strength of joint per pitch length

minimum of All $= 28.974\,kN$

Efficiency $(\eta) = \dfrac{St\ of\ joint}{St\ of\ solid\ plate}\times 100 = \dfrac{28.974 \times 2}{81.818}\times 100$

$\boxed{\eta = 35.41\,\%}$ Ans

Do not write in this margin

Q.8 (a) Design a built up column with four angles. The column is 12 m long and supports a factored axial compressive load of 700 kN. The ends of the column are held in position and restrained against rotation. Design a suitable connecting system. Use steel of grade of Fe410. (Assume f_{cd} = 168 MPa)

[For ISA 90 × 90 × 6, A = 1047 mm^2, $C_{xx} = C_{yy}$ = 24.2 mm, $r_z = r_y$ = 27.7 mm, $I_z = I_y$ = 80.1 × 10^4 mm^4. For design compressive stress of 168 MPa, f_y = 250 MPa and buckling curve c, the effective slenderness ratio is 60. For (l_1/r) = 85.70, f_y = 250 MPa and buckling curve c, the design compressive stress, f_{cd} = 127.45 N/mm^2]

[25 marks]

Q.8 (b) A steel column consisting of ISMB 350 is effectively restrained at mid-height by a bracing member in y-y direction, but it is free to move in z-z direction and both the ends of the column are pinned. Its unsupported length is 6 m. Determine its axial load carrying capacity at service loads, using the limit state design as per IS 800-2007.

$$f_{cd} = \frac{f_y / \gamma_{m0}}{\phi + [\phi^2 - \lambda^2]^{0.5}}$$

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

$\lambda = \sqrt{\frac{f_y}{f'_{cc}}}$ $\alpha = 0.34$ for buckling class *b*

$= 0.21$ for buckling class *a*

$f_y = 250\ \text{N/mm}^2$, $\gamma_{m0} = 1.1$, $\gamma_f = 1.5$, $E = 2 \times 10^5\ \text{N/mm}^2$.

Minimum radius of gyration for ISMB 350 is given below:

$$r_{yy} = 28.4\ \text{mm},\ r_{zz} = 142.9\ \text{mm}$$

Area of cross-section of the ISMB 350 is 6671 mm^2.

[20 Marks]

Q.8 (c) Check the suitability of ISMB 300 to be used as a simply supported beam with an effective span of 8 m carrying a factored uniformly distributed load of 10 kN/m. The compression flange is restrained laterally along its entire length and the yield stress of steel is 250 MPa. (Use LSM).

The properties of ISMB 300 section are given below:

Area = 5870 mm^2; D = 300 mm; b_f = 140 mm;

t_f = 13.1 mm; t_w = 7.7 mm; I_{xx} = 8985.7 cm^4;

r_{xx} = 124 mm; r_{yy} = 28.6 mm; Unit weight, w = 0.461 kN/m;

Z_e = 599 × 10^3 mm^3

Assume section to be plastic.

[20 marks]

■■■■

Space for Rough Work

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