292

MADE EASY

Leading Institute for ESE, GATE & PSUs

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 ☐	
Pune ☐	Kolkata ☐	Hyderabad ☐	

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	53
Q.2	58
Q.3	46
Q.4	
Section-B	
Q.5	52+2
Q.6	
Q.7	
Q.8	40
Total Marks Obtained	249+2=251

Signature of Evaluator: Sheryab

Cross Checked by ....

Keep it up - Very good. Performance.

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

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.

do work on the handwritting for better representation

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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/cm², σ_{st} = 1400 kg/cm², m = 18).

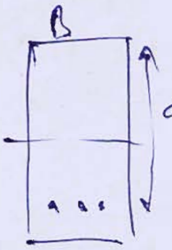
[6 + 6 = 12 marks]

(ii) $d = 2B$

$A_{st} = ?$

$BM = 6$ tm

$M_u = 6 \times 10^6$ kg mm $= 60 \times 10^6$ N mm



① $M = QBd^2 = M$

$6 \times 10^6 = \left(\frac{1}{2} c j k\right) B d^2$

$j = \left(1 - \frac{k}{3}\right) = 0.87$

$k = \left(\frac{mc}{t + mc}\right) = 0.4$

~~$6 \times 10^5 = \frac{1}{2} \times 50 \times 0.87 \times 0.4 \times B(2B)^2$~~

~~$B = 45.26$ cm ≈ 46 cm~~

~~$d = 92$ cm~~

~~$\frac{B x^2}{2} = m A_{st} (d - x)$~~

$x_a = x_c = kd$

$\sigma_{cbc} = \frac{50 \times 10}{100} = 5$ MPa

$\sigma_{st} = \frac{1400 \times 10}{100} = 140$ MPa

$M_{u,lim} = Q B d^2$

$60\times10^6 = \frac{1}{2}\times 5 \times 0.87\times0.4\times B\,(2B)^2$

$B = 258.34 \simeq 260\,mm$

$d = 520\,mm$

$x_a = x_c = kd = 208\,mm$

$\frac{Bx^2}{2} = mA_{st}(d - x_c)$

$\frac{260\times208^2}{2} = 18\,A_{st}(520-208)$

$A_{st} = 1001.48\,mm^2$

6+4

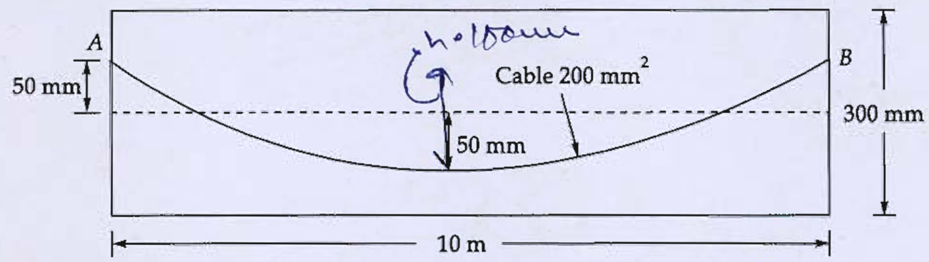
(i) Elastic theory mtd

- it is also called working stress method
- permissible stresses are defined using factor of safety on yield stresses
- only marginal strength is considered
- section designed are big in size.

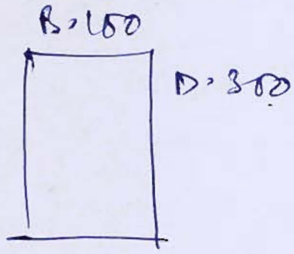
Ultimate load mtd

- Ultimate loads are defined multiplying FOS to working load
- generally fails in serviceability
- section designed are big in size.

.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]



A = 200

Loss due to friction = $P_0(kx + \mu\alpha)$

$k = 0.0015$ /m

$x = L = 10$ m

$\mu = 0.35$

$\alpha = \frac{8h}{L} = \frac{8 \times 150}{10000}$

Loss = $P_0 \times 0.043$

% Loss = $\frac{P_0 \times 0.043}{P_0} \times 100$

% Loss = 4.3 %

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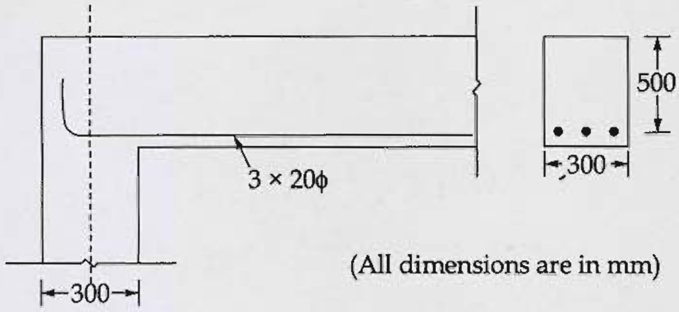
.1 (c) Determine the anchorage length of bars at the simply supported end of reinforced concrete beam as shown below, if it is subjected to an ultimate shear force of 300 kN at the centre of support. Assume M20 grade concrete and steel of grade Fe415.
[Take $\tau_{bd} = 1.92\ N/mm^2$]



(All dimensions are in mm)

[12 marks]

(c) $V_U = 300\,kN$ M20/Fe415

$$\frac{M_U}{V_U} + L_0 \geq L_d$$

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} B} = \frac{0.87 \times 415 \times 3 \times \frac{\pi}{4} \times 20^2}{0.36 \times 20 \times 300}$$

$x_u = 157.54\ mm$

$$M_U = 0.87 f_y A_{st}(d - 0.42 x_u)$$
500

$M_U = 147.63\ kNm$

$$L_d = \frac{0.87 f_y \phi}{4 \tau_{bd}\ per} = \frac{0.87 \times 415 \times 20}{4 \times 1.92 \times 1.6}$$

$L_d = 587.64\ mm$

$$\Rightarrow L_0 = 587.64 - \frac{147.63 \times 10^3}{300}$$

$L_0 = 95.54\ mm$

9

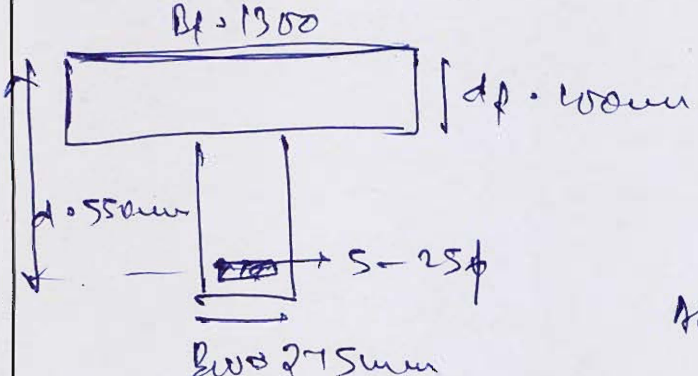
For M20
$\tau_{bd} = 1.2\ MPa$.
$\tau_{bd} = 1.2 \times 1.6 = 1.92$
given in quest

Anchorage length from face of support $= 95.54 + \frac{300}{2}$

$= 245.54$ mm

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]



M15/Fe415

Ast = 5 × π/4 × 25² = 2454.37 mm²

(1) Assume xu < df

C = T

0.36 fck Bf xu = 0.87 × fy × Ast

xu = 126.23 mm > df

wrong assumption

(2) Assume xu > df & 3/7 xu < df

yf = 0.15 xu + 0.65 df = (0.15xu + 65)

C1 + C2 = T

0.36 fck Bw xu + 0.45 fck (Bf − Bw) yf = 0.87 × fy × Ast

xu = 178 mm > df

3/7 xu = 72 mm < df

(ok)

(12)

(3) Mu = C1 LA1 + C2 LA2   yf = 91.7 mm

= 0.36 fck Bw xu (d − 0.42 xu)
+ 0.45 fck (Bf − Bw) yf (d − yf/2)

Mu = 445.78 kNm Ans

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

(ii) Briefly explain how underwater concreting is done?

[7 + 5 = 12 marks]

(i) Light weight concrete / foam concrete

→ these type of concrete are manufactured either using light weight aggregate or foam inducing agent like Zn powder.

→ low strength

→ used in places where ~~partial is~~ partition is required to be given.

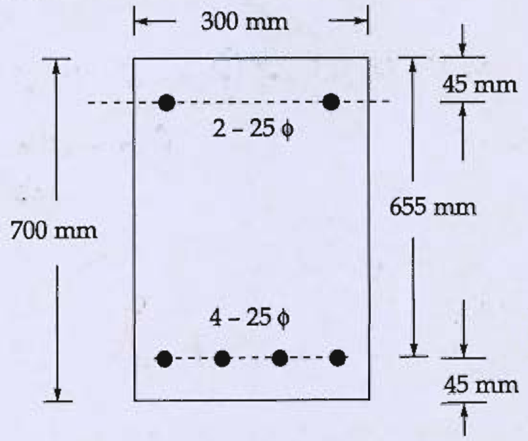
→ foam induces million of non-interconnecting bubbles in concrete matrix.

(ii) → underwater concreting is done using Quick setting cement

→ method used are Bottom - Dump Bucket or tremie pipe.

4+2

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



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

$A_{st} = 4 \times \frac{\pi}{4} \times 25^2$
$= 1963.5 \text{ mm}^2$

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]

M20 / Fe415

① x_u :

$C_u + C_s = T$

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

$0.36 \times 20 \times 300 x_u + (f_{sc} - 0.45 \times 20) \times 981.75$
$= 0.87 \times 415 \times 1963.5$

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

Assume, $x_u = 175 \text{ mm}$

$\epsilon_{sc} = \frac{0.0035}{x_u}(x_u - d_c) = 0.0026$

$f_{sc} = 342.8 + \frac{351.8 - 342.8}{276 - 241}(260 - 241)$

$f_{sc} = 347.68 \text{ MPa}$

$\Rightarrow x_u = 174.26 \simeq 175 \text{ mm}$ (ok)

BMu = C1 LA1 + C2 LA2

= 0.36 fck B xu (d - 0.42 xu) + (fsc - 0.45 fck) Asc (d - dc)

BMu = 422.63 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]

(ii) B = 400mm

Asc = $8 \times \frac{\pi}{4} \times 16^2 = 1608.5 mm^2$

$L_{eff} = 2.25m$

SR = $\frac{L_{eff}}{B} = 5.625 < 12$

$e = \frac{L_o}{500} + \frac{B}{30} = 17.833$

$0.05 \times 400 = 20$

$\Rightarrow e < 0.05 B$

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

$= 0.4 \times 20 \times (400^2 - 1608.5)$
$+ 0.67 \times 415 \times 1608.5$

$P_u = 1714.375 kN$

(10+8)

(i) Assumption

(1). plane section remains plane before & after bending. It means strain diagram is linear.

(2) Strain in concrete in highly compressed fibre is 0.0035

(3) Tensile strength of concrete is ignored. All tensile stress are taken by steel only

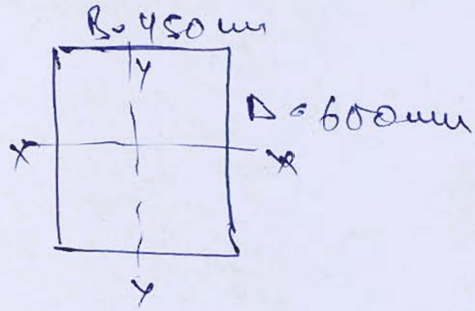
(4). Strength of concrete is '0.67 fck' & a partial factor of safety of 1.5 is applied.

(5) Strength of steel is 'fy' & partial FOS is 1.15.

(6) Strain in steel should not be less than $\left(0.002 + \frac{0.87 f_y}{E_s}\right)$

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]



$P_u = 1.5 \times 2000$

$P_u = 3000\,kN.$

$l_0 = 3m$

$l_{eff} = k\,l_0 = 1 \times 3m$

$l_{eff} = 3m.$

M20/Fe415

① $SR_x = \frac{l_e}{D} = \frac{3000}{600} = 5 < 12$ {short column}

$SR_y = \frac{l_e}{B} = 6.67 < 12$

② $e_{min_x} = \frac{l_0}{500} + \frac{D}{30} = 26mm$

$e_{min_y} = \frac{l_0}{500} + \frac{B}{30} = 21mm$

$0.05D = 30\,mm > 26mm$ {short column}

$0.05B = 22.5mm > 21mm$

③ $P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$

$3000 \times 10^3 = 0.4 \times 20 \times (450 \times 600 - A_{sc}) + 0.67 \times 415\,A_{sc}$

$A_{sc} = 3110.53 mm$

provide 10-20 mm φ A_{sc} prov. $= 3141.6 mm^2$

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(4) Design of lateral ties

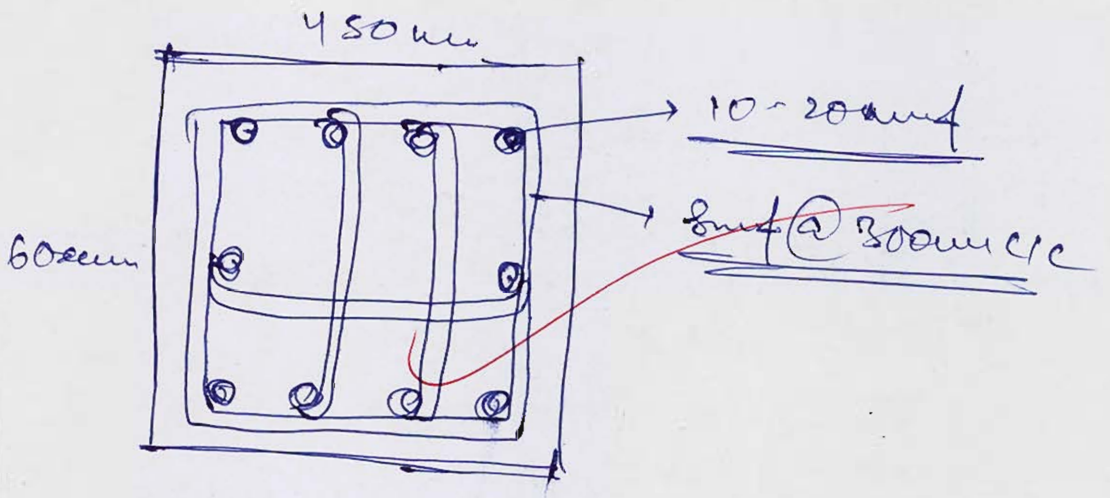
dia = max of { $\frac{\phi_{main}}{4}$ → 5mm ; 6mm }

provide 8mm φ.

Spacing = min of { 16 φ main → 16×20 = 320mm ; LLD → 450mm ; 300mm }

provide 300mm c/c

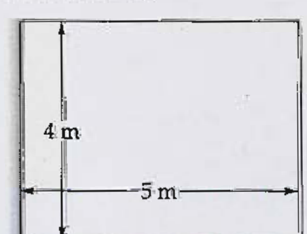
20



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]

Assume L_x = 4m, L_y = 5m (clear spans)

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(a) $r = \frac{L_y}{L_x} = \frac{5}{4} = 1.25 < 2$ (two way)

(2). $d = \frac{span}{20 \times MF}$ let $w > d$

$d = \frac{4000+d}{20 \times 1.6}$

$d \simeq 129$ mm

provide $d = 140$ mm

$c_c = 40$ m (Assumed)

$D = 180$ mm

(3) Load, : DL = $.18 \times 1 \times 1 \times 25 = 4.5$ kN/m

LL = 8 kN/m

$w_f = 12.5$ kN/m

$w_u = 1.5 w_f = 18.75$ kN/m

$l_{ex} = 4 + .14 = 4.14$ m

$l_{ey} = 5 + .14 = 5.14$ m

(8) $M_{ux}(+) = \alpha_x(+) w_u l_{ex}^2 = 15.10$ kNm

$M_{ux}(-) = \alpha_x(-) w_u l_{ex}^2 = 19.92$ kNm

$M_{uy}(+) = \alpha_y(+) w_u l_{ex}^2 = 11.24$ kNm

$M_{uy}(-) = \alpha_y(-) w_u l_{ex}^2 = 15.10$ kNm

(4) $M_{ulim} = Q\,bd^2 = 0.138 \times 20 \times 1000 \times 140^2$

$= 54$ kNm > all moment

(5) $A_{st} = \frac{0.5 f_{ck}}{f_y}\left[1 - \sqrt{1 - \frac{4.6 M_u}{f_{ck} B d^2}}\right] Bd$

$A_{st}x(+) = 313.44 \text{ mm}^2$

$A_{st}x(-) = 420.5 \text{ mm}^2$

$A_{st}y(+) = 230.34 \text{ mm}^2$

$A_{st}y(-) = 313.44 \text{ mm}^2$

$A_{st,min} = \frac{0.12}{100} \times 1000 \times 180 = 216 \text{ mm}^2$

Sp. of Rmf $= \frac{1000}{A_{st}} \times \frac{\pi}{4} \times \phi^2$

$S_x(+) = 160.36 \simeq 160 \text{ mm}$

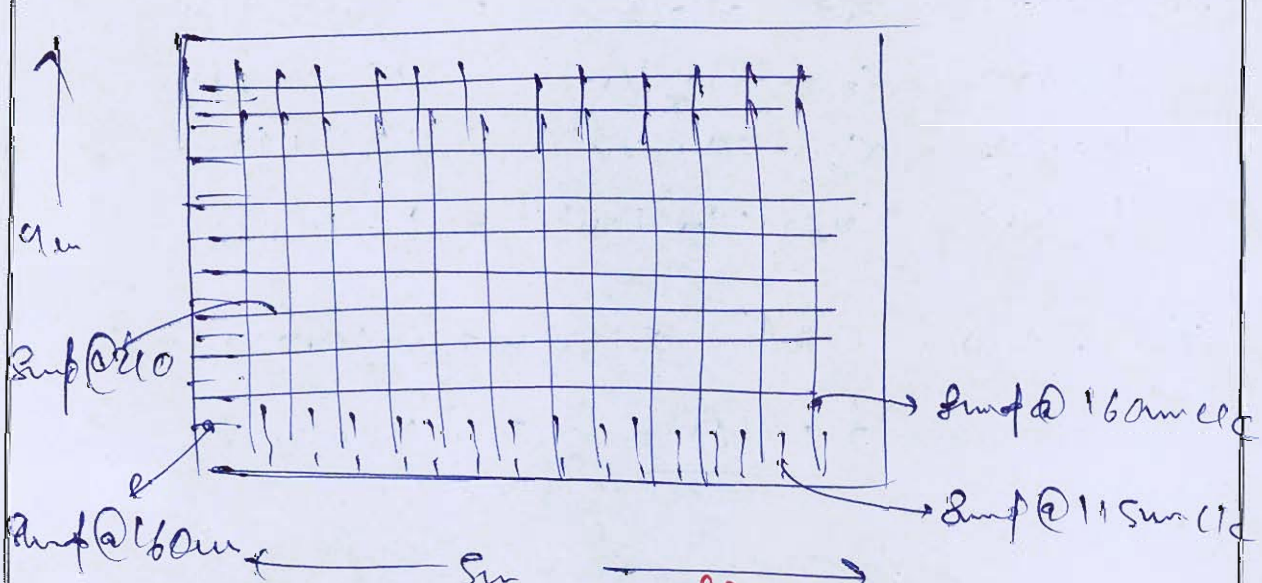
$S_x(-) = 119.53 \simeq 115 \text{ mm}$

$S_y(+) = 218.22 = 210 \text{ mm}$

$S_y(-) = 160.36 \simeq 160 \text{ mm}$

(12)

apply check for deflection



Show side view also

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]

M25/Fe 500

(1) Size of footing

Column load = P = 1500 kN
Soil load = 0.1P = 150 kN [Assume]
footing load = 0.2P = 300 kN
P_T = 1950 kN

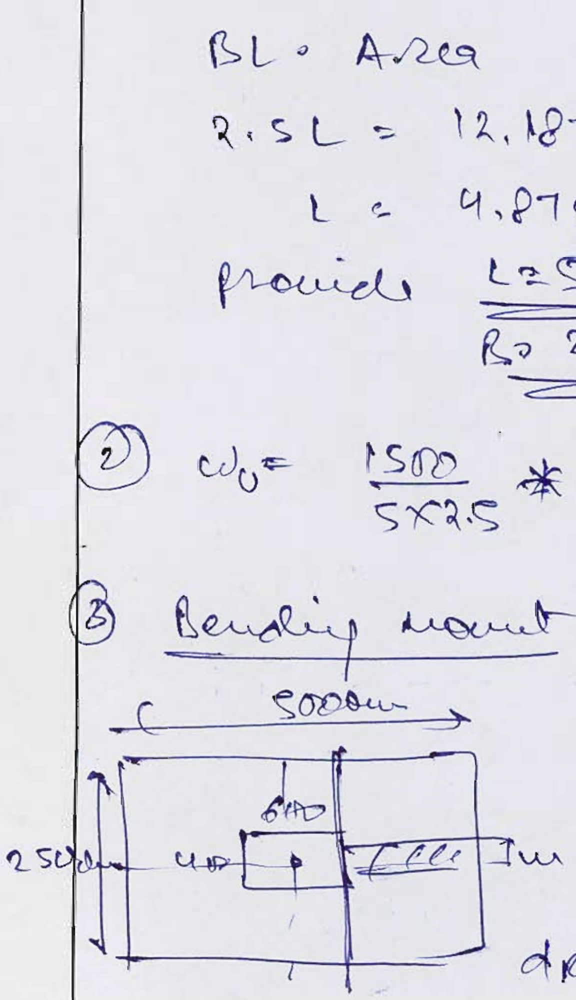
Area = $\frac{P_T}{q_0}$ = $\frac{1950}{160}$ = 12.1875 m^2

BL = Area
2.5L = 12.1875 m^2
L = 4.875 ≈ 5 m

provide L = 5 m
B = 2.5 m

(2) w_u = $\frac{1500}{5\times2.5}$ * 1.5 = 180 kN/m^2

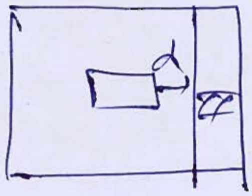
(3) Bending moment



BM_{max} = $w_{u0}\times2.2\times1\times2.2/2$
= 435.6 kN m

d_{req} = $\sqrt{\frac{BM_{max}}{0.133 \times 25 \times 1000}}$ = 362 mm provide d = 330mm

(4) check for one way shear



$v_u = 180(2.5 - .3 - .33) \times 1$

$v_u = 336.6 kN$

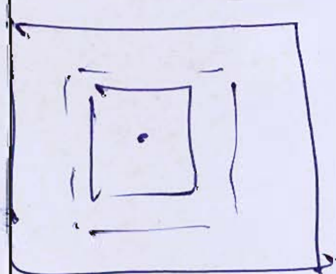
$\tau_v = \frac{V_u}{Bd} = \frac{336.6 \times 10^3}{1000 \times 330} = 1.02 > 0.28$

provide d = 850mm

$\tau_v = \frac{180(2.5 - .3 - .85)}{10^3 \times .85 \times 10^3} = 0.28 < 0.28$ (ok)

D = 850 + 60 = 910mm (total Depth)

(5) check for two way shear



$\tau_{vp\,dev} = \frac{P_u - 180 \times (a+d)(b+d)}{(a+d) \times d \times 2 + (b+d)d \times 2}$

$= \frac{1.5 \times 1500 - 180 \times 1.45 \times 1.25}{1.45 \times .85 \times 2 + 1.25 \times .85 \times 2}$

$= 0.42$ MPa

$\tau_{vp(per)} = 0.25\sqrt{f_{ck}} = 1.25$ MPa

$\tau_{vp\,dev} < \tau_{vp\,per}$ (safe)

Do not write in this margin

(6) check for Bearing

$q_B = \frac{P_u}{ab} = 9.375$ MPa

$\tau_{B(per)} = 0.45 f_{ck} = 11.25$ MPa

$\tau_B < \tau_{B(per)}$ (Safe)

(7)

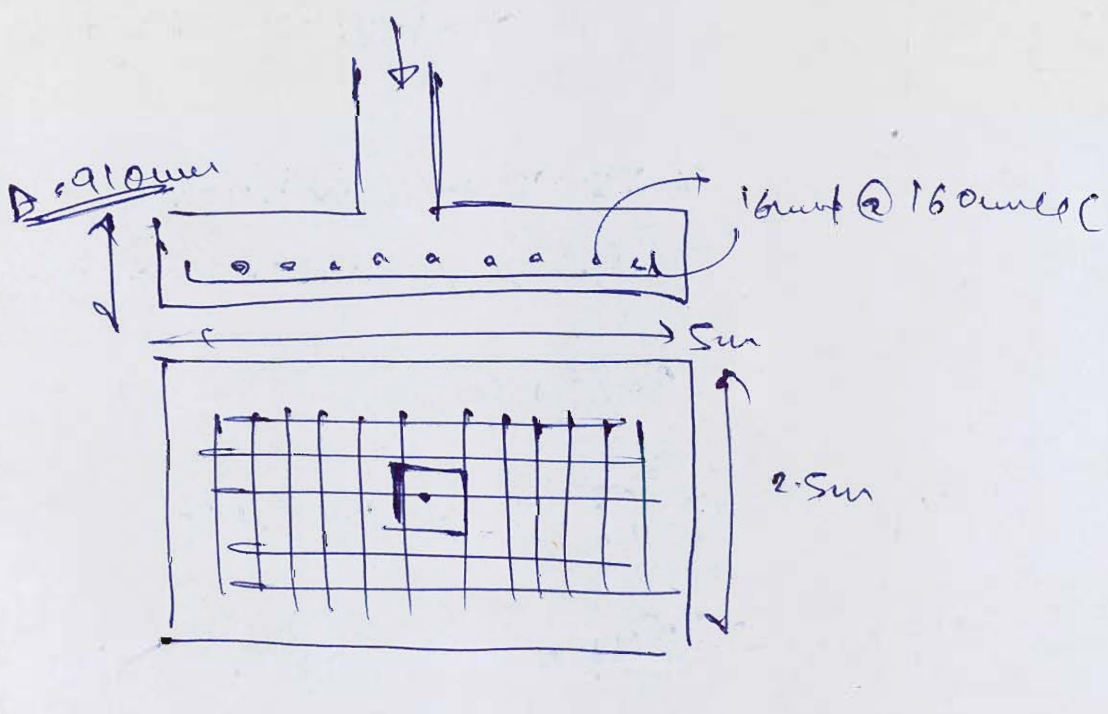
$A_{st} = 0.5 \frac{f_{ck}}{f_y} \left(1 - \sqrt{1 - \frac{4.6 B M_0}{f_{ck} B d^2}}\right) B d$

18

$= 1213.52$

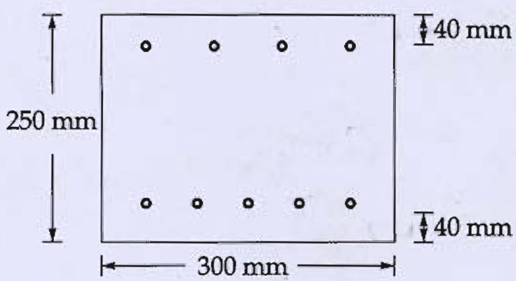
S_v of 16 mm $= \frac{1000}{A_{st}} \times \frac{\pi}{4} \phi^2 = 165$ mm

provide 16 mm @ 160 mm c/c in Both dir^n



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

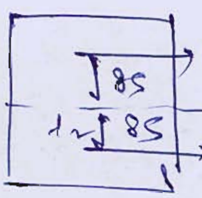
(ii) A prestressed concrete sleeper produced by pretensioning method has a rectangular cross-section of 300 mm × 250 mm depth. It is prestressed with 9 numbers of straight 7 mm diameter wires at 0.8 times the ultimate strength of 1570 N/mm^2. Cut of 9 wires, four are placed at top at a distance of 40 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]

$\phi = 7mm$

$P_0 = 0.8 \times 1570 = 1256$ MPa



$P_1 = 4 \times \frac{\pi}{4} \times 7^2 \times 1256 = 193.35$ kN

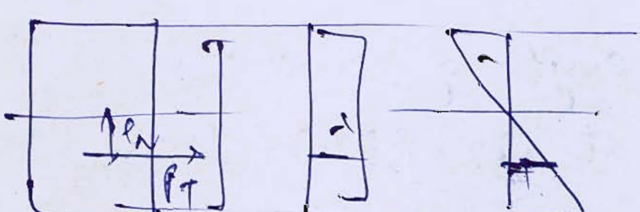
$P_2 = 5 \times \frac{\pi}{4} \times 7^2 \times 1256 = 241.68$ kN

$e_{eff} = \frac{P_2 e_2 - P_1 e_1}{P_2 + P_1} = 9.45$ mm

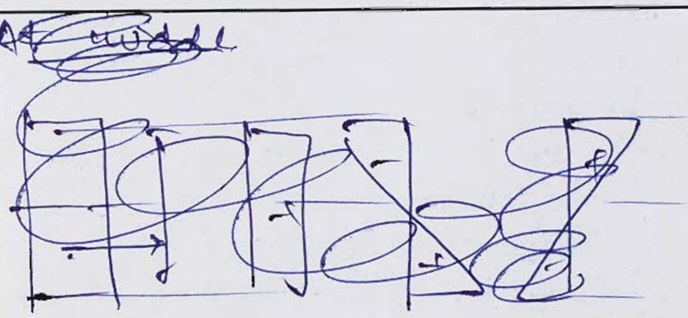
$P_{total} = 435$ kN.

Loss = $m f_{c,avg}$.

At ends



$f_{c1} = \frac{P_T}{A} + \frac{P e_N}{I} e_N = 5.9$ MPa



$f_a = f_{cag} = 5.9$ MPa

loss $= m f_{cag} = 6 \times 5.9$

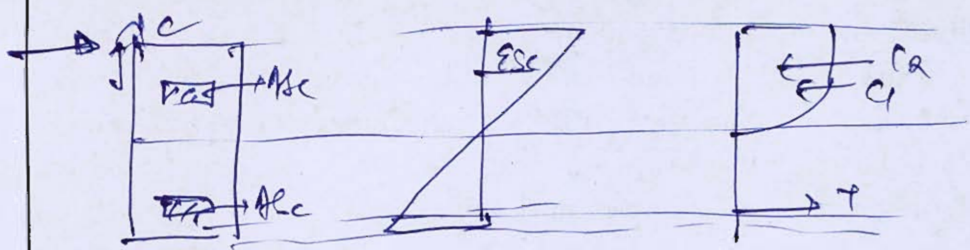
loss = 35.4 MPa

Consider loss of stress in top and bottom wire.

(i) → Doubly reinforced section are provided when the bending moment onto the section exceeds limiting moment of resistance of the section.

→ It is observed that the moment of resistance of the section doesn't increase as tension reinforcement because the comp^n concrete attains its max^m limit.

→ to increase strength of concrete comp^n reinforcement is provided.



initial : BMu = C1 LA1
BMu = 0.36 fck B xu (d - 0.42 xu)

final (after providing comp^n steel) :

BMu = C1 LA1 + C2 LA2
= 0.36 fck B xu (d - 0.42 xu)
+ (fsc - 0.42 fck) Asc (d - dc)

MoR increases because of comp^n steel.

8+8

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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]

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
$\tau_c\,(\text{N/mm}^2)$	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

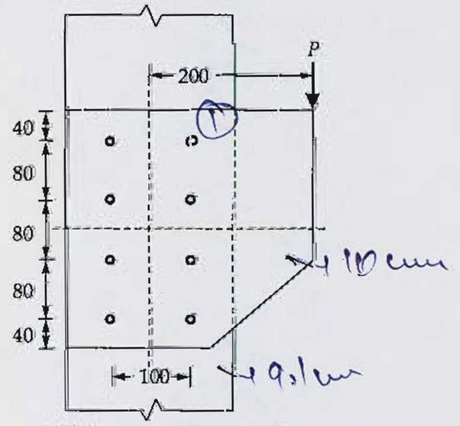
The prestressing force is applied by cables of total area 1385.44 mm^2 stretched initially to 1100 N/mm^2 and located at 100 mm from the bottom edge of the beam. Determine the stresses in the beam at transfer and at final stage of loading at mid span. Assume 15% loss of prestress in final stage. (Take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

[20 marks]

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]

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d = 20 mm

f_u = 450 MPa
f_y = 250 MPa
f_{up} = 410 MPa

① Bolt strength

(i) shear strength

$V_{dsb} = \left(\frac{f_u}{\sqrt{3} \times 1.25}\right) \times 0.78 \times \frac{\pi}{4} d^2$

$V_{dsb} = 45.27 \text{ kN}$

(ii) Bearing strength

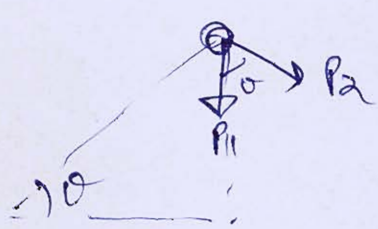
$k_b = 0.606$

$V_{dpb} = \frac{2.5 k_b (d \times t) f_{up}}{1.25}$ (t = 9.1)

$= 90.44 \text{ kN}$

$V_{dL} = 45.27 \text{ kN}$

② Most critical bolt is ①



$P_1 = \frac{P}{8}$

$P_1 = 0.125P$

$P_2 = \frac{Pe}{\Sigma r_i^2} \times r_1$

$\Sigma r_i^2 = 4(40^2 + 50^2) + (50^2 + 120^2) \times 4$

$\Sigma r_i^2 = 84000 \text{ mm}^2$

$r_1 = \sqrt{50^2 + 120^2} = 130 \text{ mm}$

$P_2 = \frac{P \times 200}{84000} \times 130 = 0.31P$

$\theta = \tan^{-1}\left(\frac{120}{50}\right) = 67.38°$

$P_{net} = \sqrt{P_1^2 + P_2^2 + 2P_1P_2\cos\theta}$

$P_{net} = 0.376P$

$P_{net} \leq V_{dL}$

$0.376P \leq 45.27\ kN$

$P \leq 120.4\ kN$

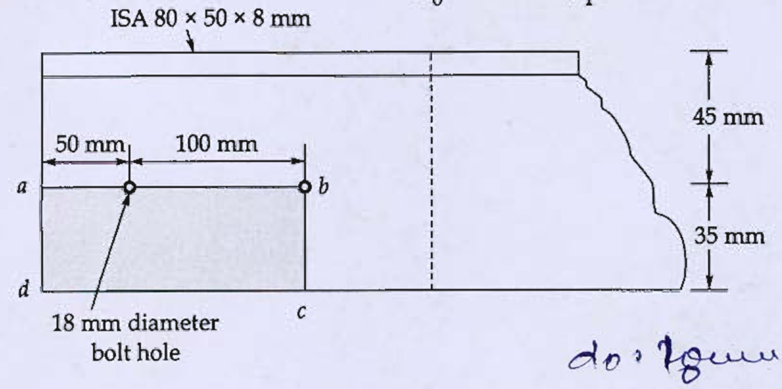
$\boxed{P_{safe} = 120.4\ kN}$

12

Service load $= \frac{120.4}{1.5} = 80.27\ KN$

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 : $\gamma_{m_0} = 1.1$; $\gamma_{m_1} = 1.25$



$d_0 = 18$ mm.

[12 marks]

$T_{db1} = A_{vn} \frac{0.9 f_u}{1.25\sqrt{3}} + A_{tg} \frac{f_y}{1.1}$

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

$= \underline{231.34 \text{ kN}}$

$T_{db2} = A_{vg} \frac{f_y}{1.1\sqrt{3}} + A_{tn} \frac{f_u (0.9)}{1.25}$

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

$= \underline{218.86 \text{ kN}}$

12

$A_{vg} = 150 \times 8 = 1200 \text{ mm}^2$ $\quad A_{tg} = 35 \times 8 = 280 \text{ mm}^2$

$A_{vn} = (150 - 1.5 \times 18) \times 8$ $\quad A_{tn} = (35 - 0.5 \times 18) \times 8$

$= 984 \text{ mm}^2$ $\quad = 208 \text{ mm}^2$

Block shear ~~st~~ = $\underline{218.86 \text{ kN}}$

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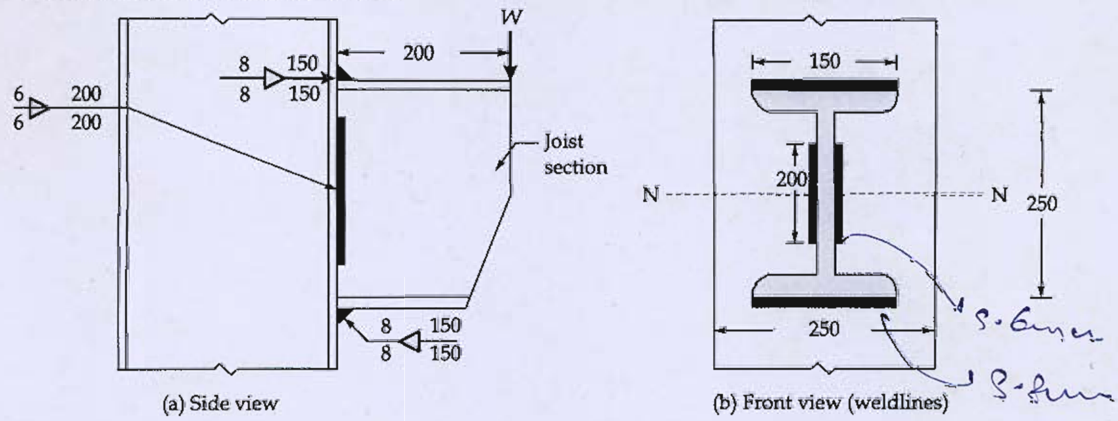
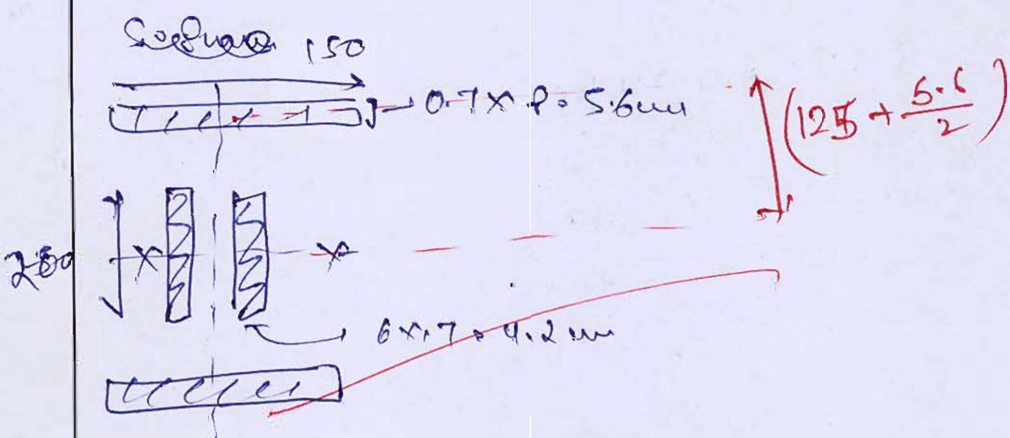
Q.5 (c) The bracket connection as shown in below figures (a) and (b) consists of a joist cutting welded to the flange of a column by shop fillet welds 8 mm in size on the flanges and 6 mm on the web. Determine the safe service load W, the bracket can support at a distance of 200 mm from the face of the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



① Shear stress, $q = \frac{W}{(\text{Area total})}$

$= \frac{W \times 10^3}{150 \times 5.6 \times 2 + 200 \times 4.2 \times 2}$

$= 0.298\ W$

② Bending stress, $f = \frac{We}{I_{xx}} \cdot y$

$I_{xx} = 2 \times \frac{4.2 \times 200^3}{12} + 2\left[\frac{150 \times 5.6^3}{12} + 150 \times 5.6 \times 125^2\right]$

$= 31.85 \times 10^6\ mm^4$

$y = 125\ mm$

$\left(125 + \frac{5.6}{2}\right)^2$

$$f = \frac{w \times 10^3 \times 200 \times 125}{31.85 \times 10^6}$$

$f = 0.784\, w.$

$$\sqrt{q^2 + f^2} \leq \frac{f_y}{\sqrt{3} \times 1.25}$$

10

$$\sqrt{0.784^2 + 0.298^2}\,.\, w \leq \frac{410}{\sqrt{3} \times 1.25}$$

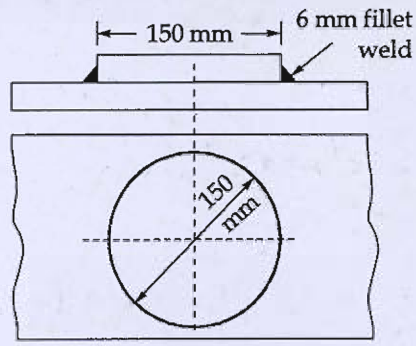
$w \leq 225.784\,kN$

$w_{safe} = 225.784\,kN$

1.5

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]

(ii)

$$\frac{T}{J} = \frac{\tau}{r}$$

$$J = Ar^2 = (\pi d t_t) r^2 = \pi d t_t \left(\frac{d}{2}\right)^2 = \frac{\pi d^3 t_t}{4}$$

$$\tau = \frac{f_u}{\sqrt{3} \times 1.25}$$

$$\Rightarrow \frac{T}{\left(\frac{\pi d^3 t_t}{4}\right)} = \frac{f_u / \sqrt{3} \times 1.25}{d/2}$$

$$\boxed{T = 28.11 \text{ kNm}}$$

(12)

(i) ① limit state of collapse

→ failure due to tension, compression, Bending or torsion is considered

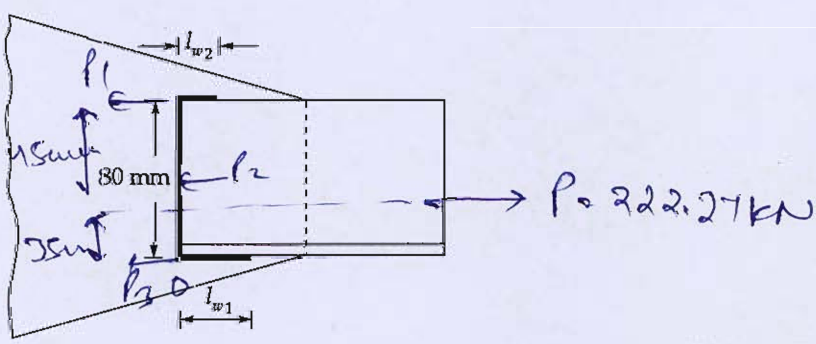
→ effect of shrinkage & creep not taken in consideration.

② limit state of serviceability

→ failure due to excessive deflection, cracks, slopes or vibration is considered

→ Effect of shrinkage & creep is taken in consideration

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]

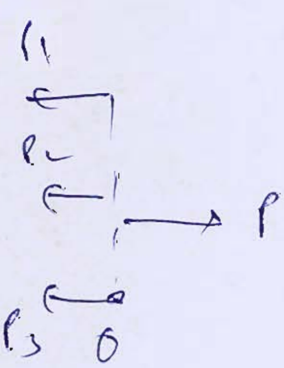
$C_{yy} = ??$

Assuming $C_{yy} = 35\,mm$

$P_2 = \frac{f_u\ 410}{\sqrt{3} \times 1.25} \times (80 \times 6 \times 0.7)$

$P_2 = 63.63\,kN.$

avoid Calculation Error.



$\Sigma M_O = 0$

$P \times 35 = P_2 \times 40 + P_1 \times 80$

$P_1 = 65.425\,kN$

$\Rightarrow P_3 = 93.21\,kN$

$P_1 = \frac{f_u}{\sqrt{3}\times 1.25}(w_1 \times 0.7 \times 6)$

$w_1 = 82.26$

$w_1 \simeq 83mm$

6+2

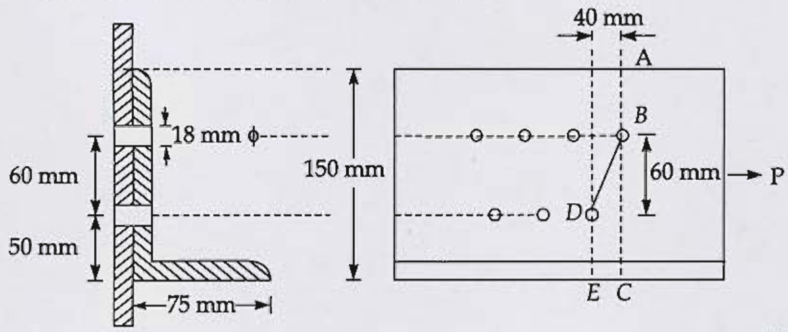
$P_3 = \frac{f_y}{\sqrt{3}\times 1.25}(w_2 \times 0.7 \times 6)$

$w_2 = 117.19m$

$w_2 \simeq 118mm$

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, $\gamma_{mw} = 1.25$

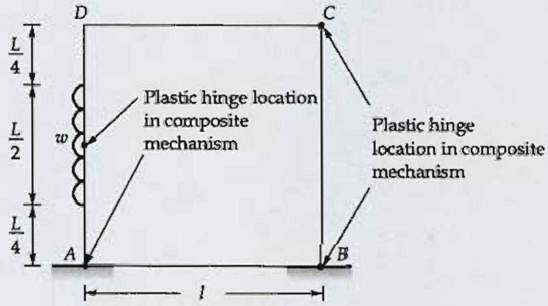
Self weight of the plate girder = $\frac{WL}{400}$

Where, W is superimposed load acting on the girder.

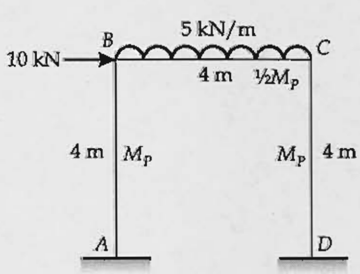
Use limit state method of design.

[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.

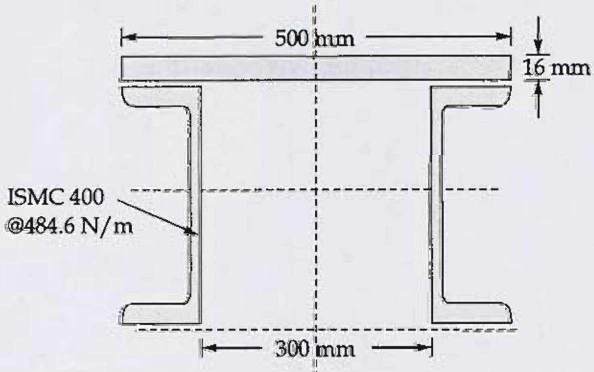


(ii) For the service load system shown, final minimum M_p required to prevent failure, if $(M_p)_{beam} = \frac{1}{2}(M_P)_{column}$. Assume load factor = 2.



[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 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 N/mm^2	
$\lambda = l / r$	σ_{ac} (N/mm^2)
30	145
40	139
50	132

[20 marks]

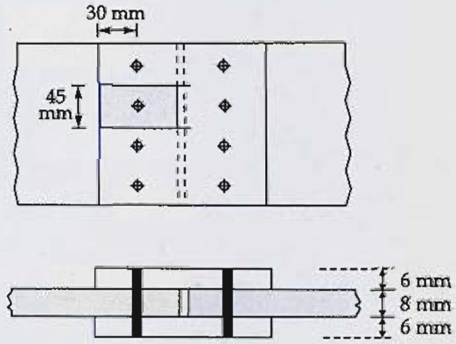
Q.7 (b) A simply supported rectangular beam 3 cm × 4 cm carries a concentrated load *W*, at mid point of span 3 m. Take yield stres, σ_y = 250 MPa.

(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]

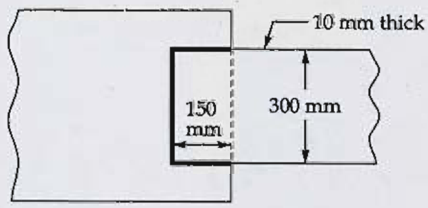
Q.7 (c) **(i)** A double cover butt joint is used to connect two plates which are 8 mm thick. Assume 16 mm diameter bolts of grade 4.6 and cover plates to be 6 mm thick. Arrangement of bolts is as shown in figure. Steel used is of grade Fe410.



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]

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] → 20

L = 12m

Pu = 700kN

Leff = 0.65×12 = 7.8m

(1) $A_{g\,req} = \frac{P_u}{f_{cd}} = \frac{700\times10^3}{168} = 4166.67\ mm^2$

provide 4 - ISA 90×90×6

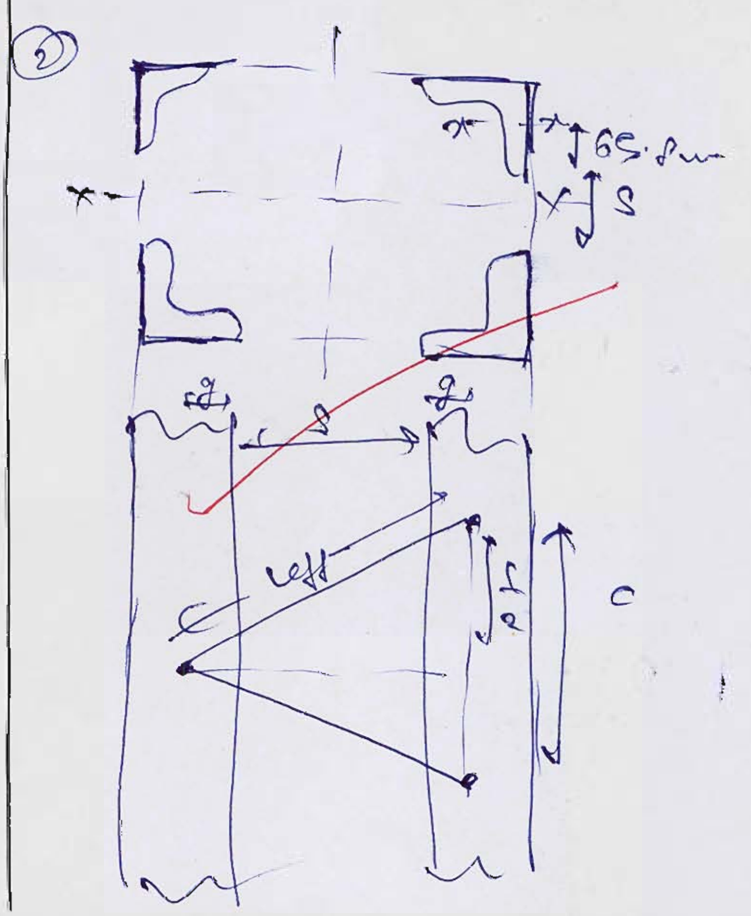
A_g prov = 4×1047 = 4188 mm^2

⇒ $f_{cd} = \frac{700\times10^3}{4188} = 167.14$ MPa ≤ 168 MPa

⇒ λ = 60

(10)

(2)



$I_{xx} = 4\left(I_{x_1x_1} + A_g\left(\frac{S}{2} + 65.8\right)^2 \right)$

$\lambda = \frac{KL}{r} = \frac{KL}{\sqrt{\frac{I_{xx}}{A_g}}}$

increase 5% for lacing.

$\lambda_e = 1.05 \times \frac{KL}{\sqrt{\frac{I_{xx}}{A_g}}} = 60$

$1.05 \times \frac{0.65 \times 12000}{\sqrt{I_{xx}/4 \cdot 88}} = 60$

$I_{xx} = 78.03 \times 10^6\ mm^4$

$\Rightarrow S = 135\ mm$

(3) Design of lacing

provide $\theta = 45°$, $g = 35mm$
$d = 20mm$, $d_0 = 22mm$

$\Rightarrow \frac{c}{2} = (S + 2g)$

$C = 410mm$

$\frac{C}{r_{min}} = \lambda_{comp} = \frac{410}{27.7} = 14.8 < 50$
$< 0.7\lambda_{colm} = 60$

(OK).

$l_{eff} = \sqrt{\left(\frac{c}{2}\right)^2 + (S + 2g)^2} = 290mm$

$B = 3d = 3\times 20 = 60mm$

$t = \frac{l_{eff}}{40} = \frac{290}{40} = 7.25 \simeq 10mm$

provided $\Rightarrow$ (290×60×10) plate

$V = \frac{2.5}{100} \times 700 = 17.5kN.$

forces in lacing = $\frac{V}{N\sin\theta}$ = 12.37kN.

$\lambda_{lacing} = \frac{l_{eff}}{r} = \frac{290}{10/\sqrt{12}} = 100 < 145$ (OK)

$f_{cd} = 127.45MPa$

$P_d = f_{cd} A_g = 127.47 \times (70 \times 60)$

$= 76.48kN > 12.37 kN$ (OK)

section of lacing flat.
Connection design.

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

$f_y = 250$ N/mm², $\gamma_{m0} = 1.1$, $\gamma_f = 1.5$, $E = 2 \times 10^5$ N/mm².

Minimum radius of gyration for ISMB 350 is given below:

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

Area of cross-section of the ISMB 350 is 6671 mm².

[20 Marks]

(1) $P_d = A_g f_{cd}$

$f_{cc} = \frac{\pi^2 E}{\lambda_{max}^2}$

$\lambda = \max \begin{cases} \frac{L_{ez}}{r_{zz}} = \frac{6000}{142.9} = 41.99 \approx 42 \\ \frac{L_{ey}}{r_{yy}} = \frac{3000}{28.4} = 105.63 \end{cases}$

$f_{cc} = \frac{\pi^2 \times 2 \times 10^5}{105.63^2} = 187.40$ MPa

$\lambda = \sqrt{\frac{f_y}{f_{cc}}} = 1.154$ → $\lambda_y = \sqrt{\frac{f_y \left(\frac{L_y}{r_y}\right)^2}{\pi^2 E}}$ → 0.951

$\alpha = 0.34$ (class B)

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

$\phi = 0.5(1 + 0.34(1.154 - 0.2) + 1.154^2)$

$\phi = 1.328$

$$f_{cd} = \frac{250/1.1}{1.328 + \sqrt{1.328^2 - 1.154^2}}$$

$f_{cd} = 114.49$ MPa

$P_d = f_{cd} A_f$

$= 114.49 \times 6671 / 10^3$

$P_d = 763.73$ kN

10

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]

① Design moments & forces

Net udl = 10 + 1.5 × 0.461 = 10.7 kN/m

Mu = 10.7 × 8 = 85.6 kNm

Vu = 42.8 kN

② Req. section modulus

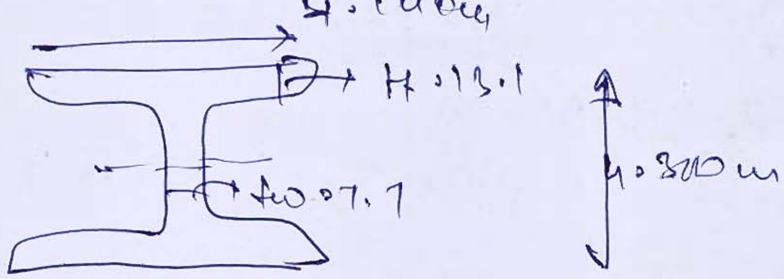
$Z_{req} = \frac{M_u}{F_y/1.1} = \frac{85.6 \times 10^6}{250/1.1}$

$Z_{p\,req}$ = 376.64 × 10^3 mm^3

$Z_{p\,prov}$ = 1.12 × 599 × 10^3 = 670.88 × 10^3 mm^3 (OK)

(SF)

③



Secⁿ is plastic (given)

(4) Shear strength of sec^n

$V_d = \frac{f_y}{1.1\sqrt{3}} \times (h \times t_w)$

$V_d = 303.11$ kN $> V_u$ (Safe)

$\frac{d}{t_w} = \frac{h - 2(R_1 + t_f)}{t_w} = \frac{500 - 2(18 + 13.1)}{7.7}$

$= 30.88 < 67\epsilon_1$ {Safe in shear Buckling}

Assume $R_1 = 18$ mm

(5) flexural strength

$0.6 V_d = 181.866$ kN $> V_u$

⇒ Low shear case

$M_d = \beta_b Z_p \frac{f_y}{1.1}$

$= 670.88 \times 10^3 \times \frac{250}{1.1}$

$= 152.47$ kN $> M_u$ (Safe)