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ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-7 : Section A : Design of Steel Structure + Hydrology (All Topics)
Section B : Structural Analysis-1+CPM PERT-1, Flow of fluids, hydraulic machines and hydro power-2 [Part syllabus]

Name : ....

Roll No :

Test Centres	Student's Signature
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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	34
Q.2	—
Q.3	52
Q.4	50
Section-B	
Q.5	32
Q.6	52
Q.7	
Q.8	
Total Marks Obtained	220

Signature of Evaluator: SB

Cross Checked by: ....

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Good! (Keep it up) Accuracy is good.

IMPORTANT INSTRUCTIONS

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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.

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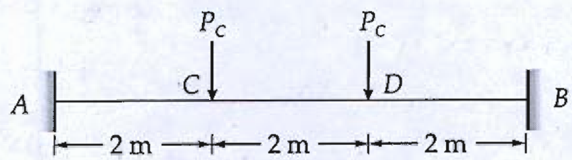
Section A : Design of Steel Structure + Hydrology

Q.1 (a) **(i)** Write the basic assumptions made in plastic analysis.

(ii) A fixed beam *AB* of span 6 m carries two-point loads *P* at distances of 2 m and 4 m from support *A*. Assuming the beam has a constant plastic moment capacity M_P, calculate the collapse load P_c.



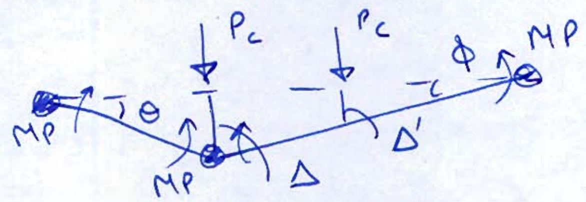
[6 + 6 = 12 marks]

(ii)

$D_s = r_e - 2$
$= 4 - 2 = 2$

No. of hinges required to collapse = 2+1
= 3

Case I Hinge at C



$\Delta' = 2\phi = \theta$

$\Delta = 2\theta = 4\phi$

External work done = $P_c\Delta + P_c\Delta'$

Internal work done = $2M_p\theta + 2M_p\phi$

By principle of virtual work

$P_c\Delta + P_c\Delta' = 2M_p\theta + 2M_p\phi$

$P_c\,2\theta + P_c\theta = 2M_p\theta + 2M_p\frac{\theta}{2}$

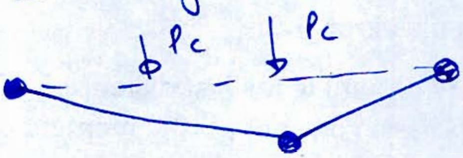
$3P_c = 3M_p$

$\boxed{P_c = M_p}$

(6)

Due to symmetry of the beam and loading, PH will get develop at both the ends and under the both loads simultaneously

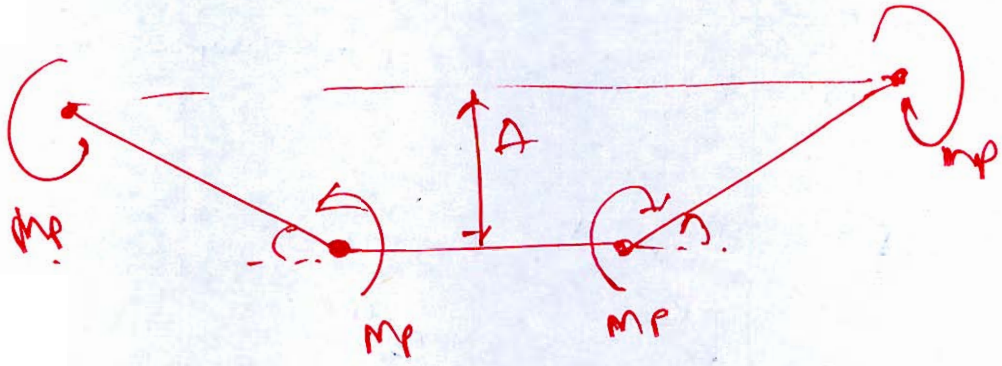
Case II hinge at D



By symmetry from the previous case, here also $P_c = M_p$

collapse load is max^m ~~of~~ ~~P~~. value of P_c

$\therefore$ $\boxed{P_c = M_p}$



Q.1 (b) A steel column section ISHB 350 @ 710.2 N/m is subjected to a factored axial compressive load of 1850 kN. The column is supported by a rectangular slab base resting on a concrete pedestal of grade M25. The column end and the base plate are both machined for perfect bearing. The load is transferred to the base plate through a welded connection, and the overhangs of the base plate beyond the column flanges are to be kept equal in both the direction. Design the base slab thickness using Fe 410 grade steel. Do not design the connection.

Section properties for ISHB 350 @ 710.2 N/m:

Depth of section, $D = 350$ mm

Width of flange, $b_f = 250$ mm

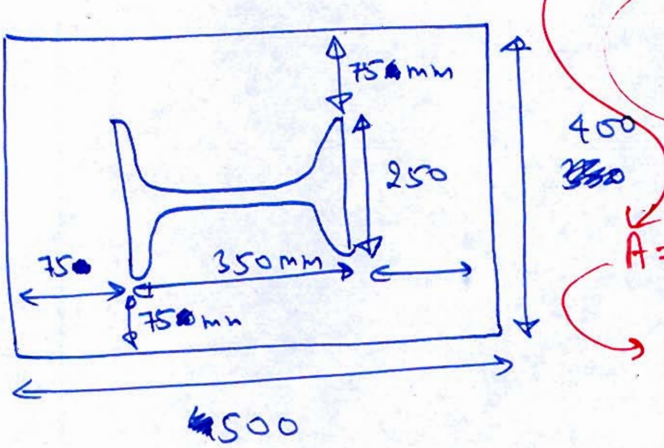
Thickness of flange, $t_f = 11.6$ mm

Thickness of web, $t_w = 10.1$ mm **[12 marks]**

→ Factored load = 1850 kN

Area required for the base slab

$$= \frac{1850 \times 10^3}{0.45 \times 25} = 164444.49 \text{ mm}^2$$



a = b = 75 mm

$A = (350 + 2a)(250 + 2b)$

$\because a = b$

$a = 54.294 \text{ mm} \simeq 60 \text{ mm}$ (Provide)

Providing overhang both direction as 75 mm

Area of base plate = 500×400

$= 200000 \text{ mm}^2 > 164444.4 \text{ mm}^2$

$$w_o = \frac{1850 \times 1000}{200000} = 9.25 \text{ N/mm}^2$$

(4)

$$t = \sqrt{\frac{2.5\, w_o (a^2 - 0.3 b^2)}{f_y/\gamma_{m0}}}$$

✓

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$$t = \sqrt{\frac{2.5\times 9.5\,(75^2 - 0.3\times 75^2)}{250/1.1}}$$

$= 64.145\ mm$

uneconomical design

Providing thickness of base plate as 65mm

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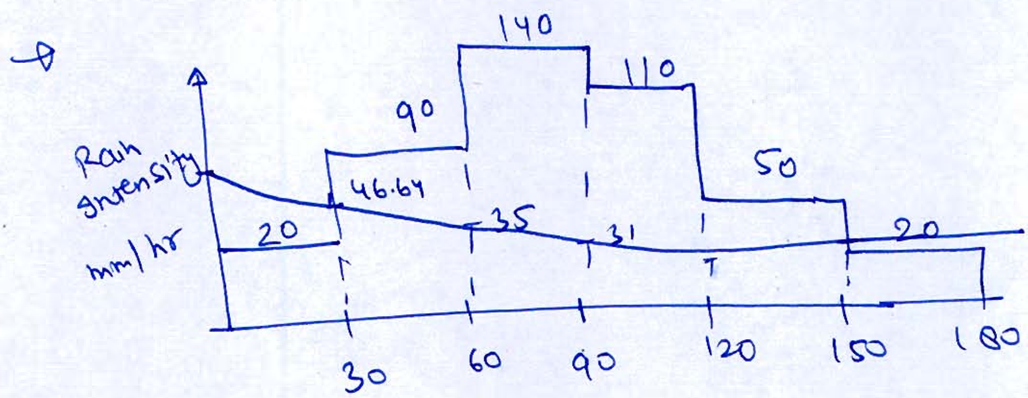
Q.1 (c) The following rainfall mass curve data was recorded during a storm of 180 minutes at 30 minute intervals. The infiltration capacity of the soil is governed by the Horton's equation: $f(t) = 30 + 50e^{-2.2t}$, where f is in mm/hr and t is in hours. Compute the effective rainfall for the storm.

Time (min)	Accumulated Rainfall (cm)	Incremental rain	Intensity cm/hr
0	0	0	0
30	1.0	1	2
60	5.5	4.5	9
90	12.5	7	14
120	18.0	5.5	11
150	20.5	2.5	5
180	21.5	1	2

[12 marks]



$f(t)$ at t=30 minutes = 46.64 mm/hr

$f(t)$ at t = 150 minutes = 30.204 mm/hr

t = 180 minutes = 30.0680 mm/hr

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As from graph effective rainfall is only produced from t = 30 min to t = 150 minutes

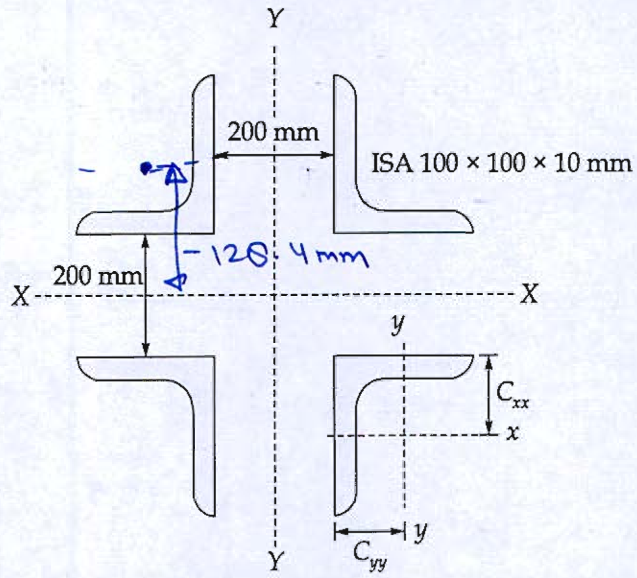
Total Rainfall = $\frac{1}{2}(90+140+110+50) = 195$ mm

Infiltration $= \int_{0.5}^{2.5} 30 + 50e^{-2.2t}\, dt = 67.472$ mm

Effective Rainfall = 195 − 67.472

= 127.527 mm

Q.1 (d) A laced built-up column of effective length 6 m to carry a factored axial load. The column consists of four equal angle sections of size ISA 100 × 100 × 10 mm arranged in the shown pattern with a clear distance of 200 mm between the adjoining faces of the angles.



The properties of a single ISA 100 × 100 × 10 mm are as follows:

Cross-sectional Area (A) = 1903 mm^2

Moment of Inertia ($I_{xx} = I_{yy}$) = 177 × 10^4 mm^4

Distance of Centroid ($C_{xx} = C_{yy}$) = 28.4 mm

Assume yield stress f_y = 250 MPa, and use IS 800:2007 specifications to determine the safe factored axial compressive load for the column.

Slenderness Ratio (λ)	Design Compressive Stress (f_{cd})
20	224 MPa
30	211 MPa
40	198 MPa
50	183 MPa
60	168 MPa

[12 marks]

→ $I_{xx} = [177\times10^4 + 1903\times(128.4)^2]\times 4$

$I_{xx} = 132575694.7 \text{ mm}^4$

$I_{yy} = I_{xx}$

$r = \sqrt{\frac{I_{xx}}{A}} = \sqrt{\frac{132575694.7}{4\times1903}} = 131.972 \text{ mm}$

$L_e = 6 \text{ m} = 6000 \text{ mm}$

$\lambda = K\frac{L_e}{r}$

Assuming K = 1.0

$\lambda = \frac{6000}{131.972} = 45.464$

Since it is laced

$\lambda_e = 1.05\lambda = 47.737$

for $\lambda_e = 47.737$

$f_{cd} = 198 - \frac{198-183}{10} \times 7.737$

$= 186.394$ MPa

$P_d = 186.394 \times 4 \times 1903$

$= 1418034.934$ N

$P_d = 1418.0349$ kN

12

Q.1 (e) Explain briefly the factors affecting the evaporation and suggest methods to reduce evaporation losses in detail.

[12 marks]

~~Factors affecting evaporation~~

Q.2 (a) (i) Write short note on -

(a) Standard Project Flood (SPF)

(b) Probable Maximum Flood (PMF)

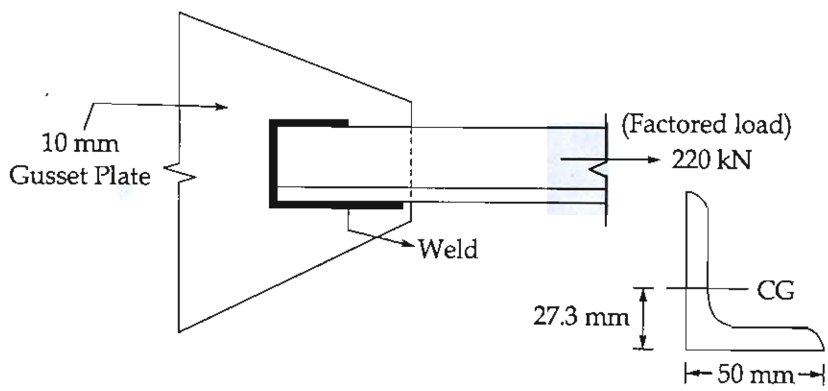
(c) Design flood

(ii) The annual peak flood discharges recorded over a period of 16 years at a gauging station are given. Estimate the flood discharge corresponding to a return period of 20 years using the Weibull method. Also, determine the probability that a flood discharge of 6000 cubic meters per second will be exceeded in any given year.

Year	Discharge (m^3/s)	Year	Discharge (m^3/s)
2010	3500	2018	5400
2011	6200	2019	2500
2012	3200	2020	2800
2013	3100	2021	8000
2014	7900	2022	4700
2015	6800	2023	2200
2016	4000	2024	5100
2017	3800	2025	9500

[6 + 14 = 20 marks]

Q.2 (b) Design a welded joint to connect an unequal angle section ISA 80 × 50 × 8 to a 10 mm thick gusset plate to carry a factored tensile load of 220 kN. The longer leg is connected to the gusset plate. Welding is provided on three sides, two longitudinal and one transverse. Welding is shop welding. Yield stress of steel is 250 MPa and ultimate stress is 410 MPa. Also check the safety against Block shear.

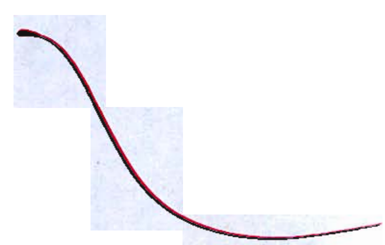


[20 marks]

Q.2 (c) Design a simply supported steel beam with an effective span of 6.0 m that carries a factored uniformly distributed load of 25 kN/m over its entire span including self-weight. The beam is laterally supported throughout its length. Use steel of grade E250 with yield stress 250 N/mm^2 and perform necessary design checks including bending capacity, shear capacity, deflection, web buckling, and web crippling. Assume the bearing length at the support is 100 mm. Sectional properties of ISMB 250 and 300 are as below. Take f_{cd} = 132 N/mm^2.

Sectional Property	ISMB 250 @ 37.3 kg/m	ISMB 300 @ 44.2 kg/m
h (mm)	250	300
b_f (mm)	125	140
t_f (mm)	12.5	12.4
t_w (mm)	6.9	7.5
I_{zz} (mm^4)	5131.6×10^4	8604×10^4
Z_e (mm^3)	410.5×10^3	574×10^3
Z_p (mm^3)	465.7×10^3	652×10^3
r_1 (mm)	13	14

[20 marks]



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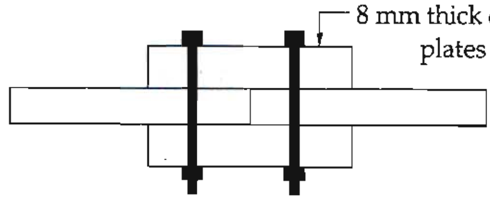
Q.3 (a) A double-cover butt joint is utilized to connect two main plates, each having a thickness of 12 mm. The connection is made using M24 grade 4.6 bolts with a gauge distance of 80 mm. The cover plates provided on both sides are 8 mm thick. Determine the efficiency of this joint considering a plate grade of Fe 410. Assume that the bolt experience shear such that one shear plane passes through the threaded portion (root) and the other through the unthreaded shank.



(Side view)

[20 marks]

→ Strength of bolt in shear

$V_{dsb} = \frac{f_{ub}}{\sqrt{3} \times \gamma_{mb}} (A_{nb} + A_{sb})$

$= \frac{400}{\sqrt{3} \times 1.25} \left(\frac{\pi}{4} \times 24^2 \times 0.78 + \frac{\pi}{4} \times 24^2\right)$

$\boxed{V_{dsb} = 148.772 \text{ KN}}$

Strength of bolt in bearing

Assuming $e_0 = 40$ mm

40 mm > $1.5 \times 26 = 39$ mm

$p = 70$ mm

$V_{dpb} = \frac{2.5 \, k_b \, d \, t \, f_u}{\gamma_{mb}}$

$\boxed{d_0 = 26 \text{ mm}}$

$k_b \begin{cases} \frac{e}{3d_0} = \frac{40}{3 \times 26} = 0.512 \\ \frac{p}{3d_0} - 0.25 = 0.647 \\ \frac{f_{ub}}{f_u} = \frac{400}{410} = 0.97 \\ 1.0 \end{cases}$

minimum $k_b = 0.512$

$$V_{dpb} = \frac{2.5 \times 0.512 \times 24 \times 12 \times 410}{1.25}$$

$= 120913.92 \text{ N} = 120.913 \text{ KN}$

$$\boxed{V_{dpb} = 120.913 \text{ KN}}$$

Strength of plate (per gauge length)

(i) Gross section yielding

$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{12 \times 80 \times 250}{1.1 \times 10^3} = \boxed{218.181 \text{ KN}}$$

(ii) Net section rupture

$$T_{dn} = [B - d_o] \times 12 \times \frac{f_u}{\gamma_{m1}} = \frac{(80-26) \times 12 \times 410}{1.25 \times 10^3}$$

$$\boxed{T_{dn} = 212.54 \text{ KN}}$$

Strength of cover plate

Net section rupture

$$= \frac{(80-26) \times 8 \times 2 \times 410}{1.25 \times 10^3} = 283.392 \text{ KN}$$

20

Maximum load plates can carry = 212.54 KN

Maximum load bolts can carry = 120.913 KN

$$\text{Efficiency} = \frac{120.913}{212.54} \times 100 = \boxed{56.88 \%}$$

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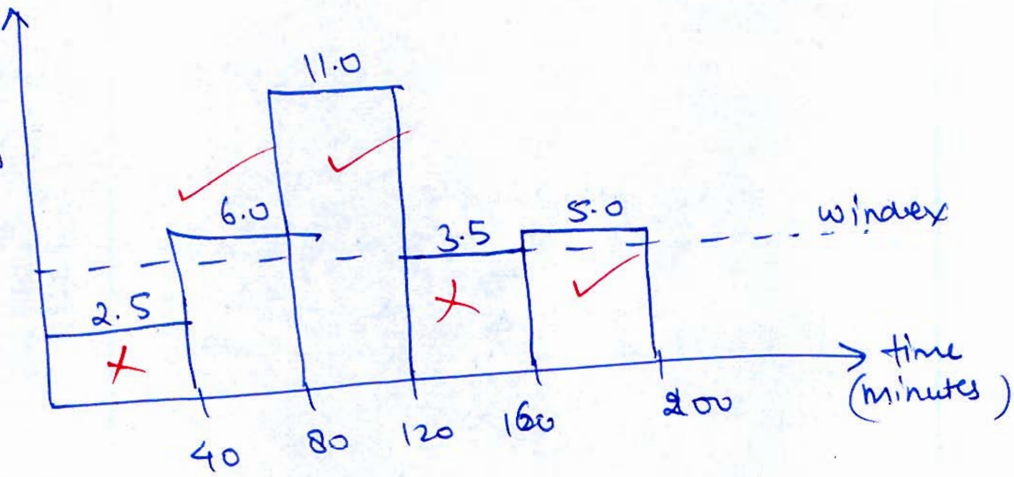
Q.3 (b) **(i)** Write the advantages and disadvantages of weld connections over bolted connections.

(ii) During a storm of 200 minutes, the following rainfall rates were observed for successive 40 minute intervals. If the total runoff resulting from this storm is measured as 7 cm, determine the ϕ_{index} and the W_{index} for the catchment area.

Time Period (min)	0 – 40	40 – 80	80 – 120	120 – 160	160 – 200
Rainfall Rate (cm/hr)	2.5	6.0	11.0	3.5	5.0

[8 + 12 = 20 marks]

(ii)



$$\text{Total rainfall} = 2.5 \times \frac{40}{60} + 6 \times \frac{40}{60} + [11 + 3.5 + 5] \times \frac{4}{6}$$

$$= 18.6667 \text{ cm}$$

(6)

Runoff = 7 cm

Infiltration = 18.667 − 7 = 11.666 cm

$$W_{index} = \frac{11.666}{200/60} = 3.4999 \approx \boxed{3.5 \text{ cm/hr}}$$

$\phi_{index} \geq W_{index}$

Trial 1.

$$\phi_{index} = \frac{11.66 - 2.5 \times 4/6}{160} \times 60 = 3.7475 \text{ cm/hr}$$

Do not write in this margin

Check:

$$\left[(11-3.7475)+(6-3.7475)+(5-3.7475)\right]\times\frac{4}{6}$$

$= 7.171$ cm

Hence not correct.

Trial 2:

$$\left[(11-x)+(6-x)+(5-x)\right]\times\frac{4}{6}=7$$

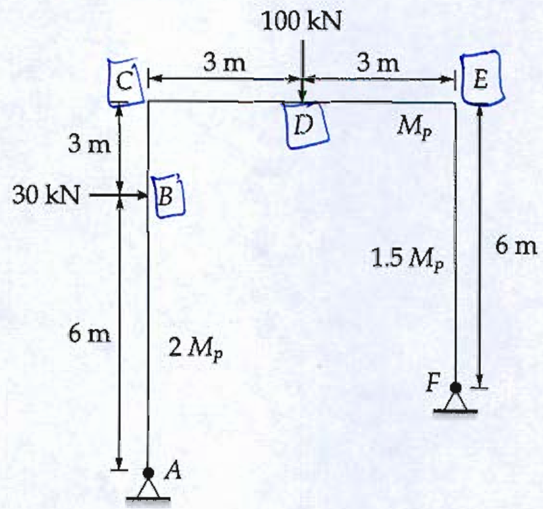
$x = 3.833$ cm/hr

Since all other intensities are below 3.833 cm/hr

$\therefore$ ϕ index $= 3.833$ cm/hr

6

Q.3 (c) A portal frame *ABCDEF* is uniform in cross-section for the beam but varies in the columns. The frame is pin-jointed at supports *A* and *F*. It is subjected to collapse loads: a horizontal force of 30 kN at point *B* and a vertical concentrated load of 100 kN at the midpoint *D* of the beam *CE*. Determine the value of plastic section modulus (M_p). The plastic moment capacities are: Left Column (*ABC*) = $2M_p$, Right Column (*FE*) = $1.5M_p$, Beam (*CE*) = M_p.



[20 marks]

→ $D_s = 3 \times 1 - 2 = 1$

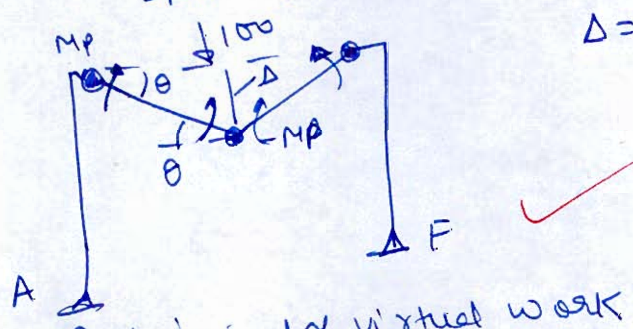
Possible Hinge locations = 4

Independent Mechanism = 4 − 1 = 3

① Beam mechanism

Span CE

$\Delta = 3\theta$



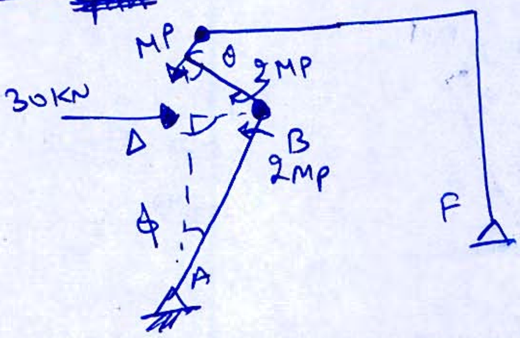
By principal of virtual work

$100 \times \Delta = 4M_p\theta$

$100 \times 3\theta = 4M_p\theta$

$M_p = 75\,\text{kNm}$

② Mechanism 2.



$\Delta = 3\theta = 6\phi$

By principal of virtual work

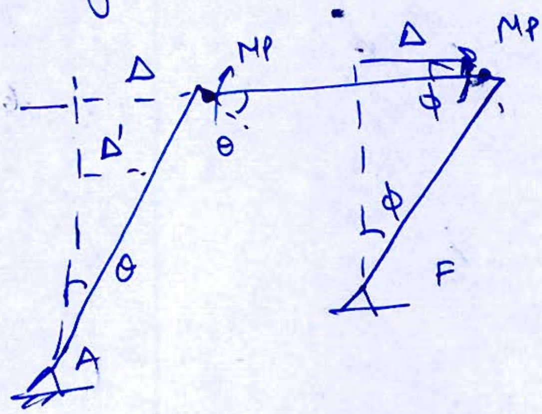
$30 \times \Delta = M_p\,\theta + 2M_p\,\theta + 2M_p\,\phi$

$30 \times 3\theta = 3M_p\theta + 2M_p\frac{\theta}{2}$

$90 = 4M_p$

$M_p = 22.5\,KNm$

③ Sway Mechanism



$\Delta = 9\theta = 6\phi$

$\Delta' = 6\theta$

By principal of virtual work.

$30\,\Delta' = M_p\,\theta + M_p\,\phi$

$30 \times 6\theta = M_p\theta + M_p\frac{9}{6}\theta$

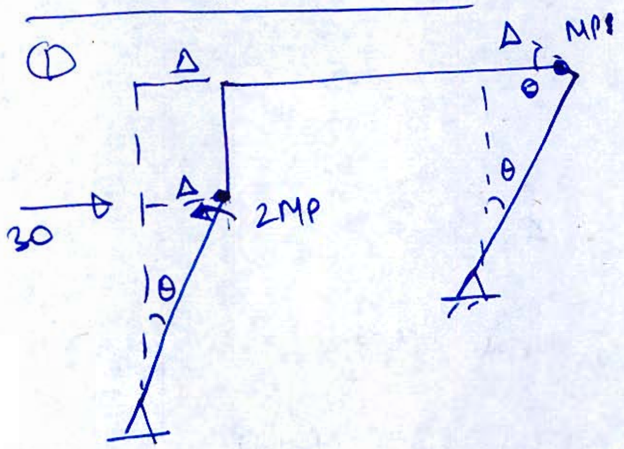
$180 = 2.5M_p$

$M_p = 72\,KNm$

20

Combined Mechanism

(1)



$\Delta = 6\theta = 6\phi$

$\theta = \phi$

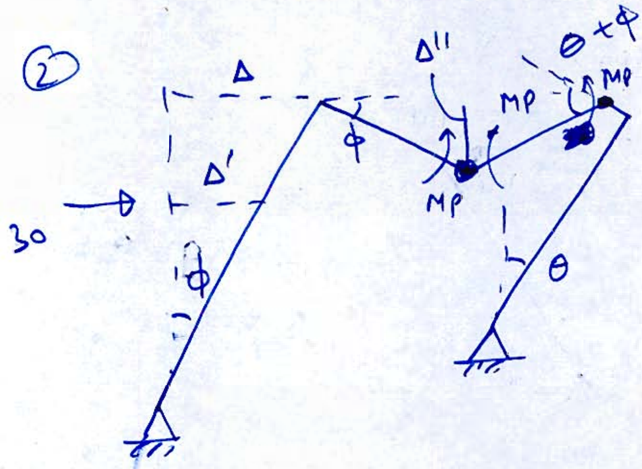
Equation of virtual work

$30 \times \Delta = 2M_p\,\theta + M_p\,\theta$

$30 \times 6\theta = 3M_p\,\theta$

$\boxed{M_p = 60 \text{ KNm}}$

(2)



$\Delta = 9\phi = 6\theta$

$30\,\Delta' + 100 \times \Delta'' = M_p\phi + M_p\phi + M_p(\theta + \phi)$

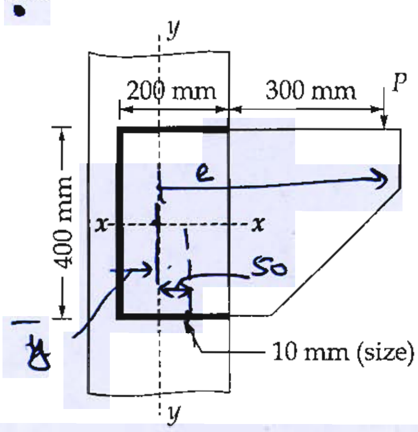
$30 \times 6\phi + 100 \times 3\phi = 3M_p\phi + M_p\frac{9}{6}\phi$

$\boxed{M_p = 106.667 \text{ KNm}}$

Mp is maxm of all values

$\therefore \boxed{106.67 \text{ KNm}}$

Q.4 (a) Determine the maximum safe load P that can be resisted by a bracket connection welded to a column flange using a 10 mm fillet weld. The weld is provided on three sides consisting of one vertical weld of length 400 mm and two horizontal welds each of length 200 mm. The load acts at an eccentricity of 300 mm from the face of the column. Assume shop welding and Fe 410 grade for the weld.



[20 marks]

→ Centroid of weld

$$\bar{y} = \frac{[200 \times t \times 100] \times 2}{200 \times t \times 2 + 400 \times t} = 50\,mm$$

$s = 10\,mm$

$t_t = 0.707 \times 10 = 7.07\,mm$

$e = 300 + 200 - 50 = 450\,mm$

$I_{xx} = \left[200 \times 7.07 \times 200^2\right] \times 2 + \frac{7.07 \times 400^3}{12}$

$= 150826666.7 \, mm^4$

$I_{yy} = 400 \times 7.07 \times 50^2 + 2\left[\frac{7.07 \times 200^3}{12} + 7.07 \times 200 \times 50^2\right]$

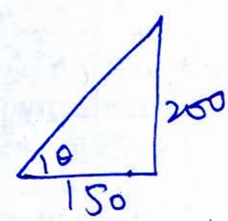
$= 23566666.67 \, mm^4$

$I_{zz} = I_{xx} + I_{yy}$

$= 174393333.4 \, mm^4$

$r = 250 \, mm$

$\theta = 53.130°$



Shear stress due to direct load

$q_1 = \frac{P}{A_w}$

$A_w = 800 \times 7.07 = 5656 \, mm^2$

$q_1 = \frac{P}{5656}$

Shear stress due to Torsional moment

$q_2 = \frac{(P \cdot e) \times r}{I_{zz}} = \frac{P \times 450 \times 250}{174393333.4}$

$q_2 = \frac{P}{1550.1629}$

Resultant shear

$$q_R = \sqrt{q_1^2 + q_2^2 + 2 q_1 q_2 \cos\theta}$$

For safety

$$q_R < \frac{f_u}{\sqrt{3} \times 1.25}$$

$$\sqrt{\left(\frac{P}{5656}\right)^2 + \left(\frac{P}{1550.1629}\right)^2 + 2\left(\frac{P}{5656}\right)\left(\frac{P}{1550.1629}\right)\cos 53.130}$$

$$\leq \frac{410}{\sqrt{3} \times 1.25}$$

$P = 247745.6481 \text{ N}$

20

$\boxed{P = 247.745 \text{ kN}}$

$$\text{Safe load} = \frac{247.745}{1.5} = \boxed{165.163 \text{ kN}}$$

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Q.4 (b) (i) Define routing and its types in context of hydrology. Discuss the applications of flood routing.

(ii) A stream reach has the Muskingum coefficients $K = 12$ hand $x = 0.2$. The inflow hydrograph for this reach is provided in the table. Assuming the initial outflow at $t = 0$ is $10\ m^3/s$, determine the outflow hydrograph for the reach using a routing time interval of $\Delta t = 6\ h$. Report the attenuation in the peak and leg time.

Time (h)	0	6	12	18	24	30	36	42	48
Inflow (m^3/s)	10	20	50	60	55	45	35	25	15

[10 + 10 = 20 marks]

(ii)

$$C_0 = \frac{-Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t}$$

$$= \frac{-12\times0.2 + 0.5\times6}{12 - 12\times0.2 + 0.5\times6} = 0.04761$$

$$C_1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t} = 0.4285$$

$$C_2 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t} = 0.5238$$

$$Q_2 = C_0 I_2 + C_1 I_1 + C_3 Q_1$$

Time	Inflow (m^3/s)	Outflow (m^3/s)
0	10	10
6	20	10.475
12	50	16.437
18	60	32.891
24	55	45.557
30	45	49.572
36	35	46.915
42	28	40.761
48	15	32.777

$Q_2 = 0.04761 \times 20 + 0.4285 \times 10 + 0.5238 \times 10$

$= 10.475\ m^3/s$

$Q_3 = 0.04761 \times 50 + 0.4285 \times 20 + 0.5238 \times 10.47$

$= 16.437\ m^3/s$

(10)

and so on.

Peak in Inflow hydrograph ⇒ $60\ m^3/s$

time of peak → 18 hrs

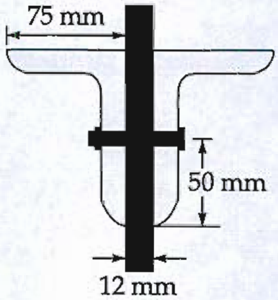
Peak in outflow hydrograph = $49.572\ m^3/s$

time of peak = 30hrs

Attenuation = $60 - 49.572 = 10.428\ m^3/s$

lag time = $30 - 18 = 12$ hrs

Q.4 (c) Design a double angle tension member connected on both sides of a 12 mm thick gusset plate to carry an axial factored load of 450 kN. Use 20 mm diameter bolts of Grade 4.6 for the connection. The angle section selected for the design is 2 Nos. of ISA 100 × 75 × 8 mm of Grade Fe410. Assume a pitch of 60 mm and an end distance of 40 mm. One shear plane of the bolts passes through the threaded portion and the other through the shank.



[20 marks]

→ $A_g = [100+75-8] \times 8 = 1336\ mm^2$

Strength of Angle in gross section yielding

$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{1336 \times 250}{1.1 \times 10^3} = 303.636\ KN$

load on one angle $= \frac{450}{2} = 225\ KN$

Strength of angle in net section rupture

$A_{go} = (75-4) \times 8 = 568\ mm^2$

$A_{nc} = (100-4-22) \times 8 = 592\ mm^2$

$\beta = 1.4 - 0.076 \frac{w}{t} \frac{b_s}{L_c} \frac{f_y}{f_u}$

$= 1.4 - 0.076 \times \frac{75}{8} \times \frac{(75+50-8)}{240} \times \frac{250}{410}$

$\beta = 1.1882$ > 0.7, < 1.44

$T_{dn} = \frac{0.9 f_u A_{nc}}{\gamma_{m1}} + \beta \frac{A_{go} f_y}{\gamma_{mo}}$

$= \frac{0.9 \times 410 \times 592}{1.25} + \frac{1.1882 \times 568 \times 250}{1.1}$

$T_{dn} = 328.144\,kN > 225\,kN$

Hence o.k.

Strength of bolt in shear

$$V_{dsb} = \frac{400}{\sqrt{3} \times 1.25} \times \frac{\pi}{4} \times 20^2 \times \frac{1.78}{10^3} = 103.314\,0\,kN$$

strength of bolt in bearing

$$k_b = \begin{cases} \frac{e_o}{3d_o} = \frac{40}{3 \times 22} = 0.60 \\ \frac{p}{3d_o} - 0.25 = \frac{60}{3 \times 22} - 0.25 = 0.65 \\ \frac{f_{ub}}{f_u} = 0.975 \\ 1.0 \end{cases}$$

minm

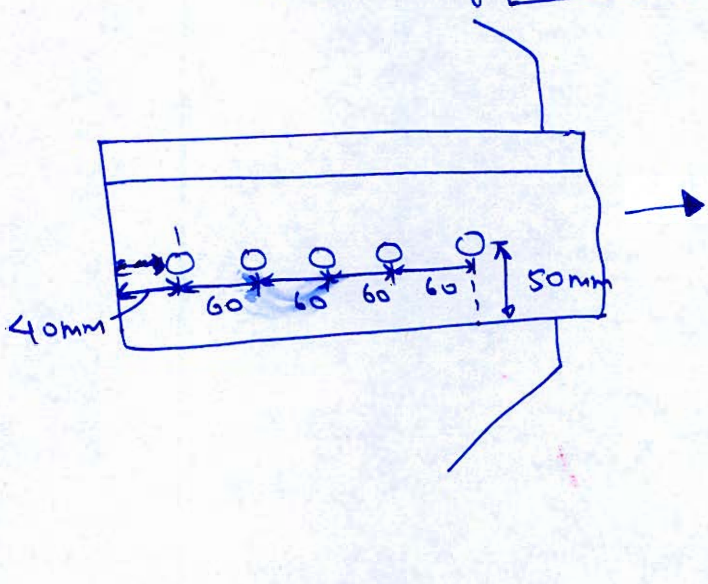
$K_b = 0.60$

$$V_{dpb} = \frac{2.5 \times 0.6 \times 20 \times 12 \times 410}{1.25 \times 10^3} = 119.260\,kN$$

strength of bolt = 103.314 kN

No. of bolts required $= \frac{450}{103.314} = 4.35$

Providing **5 bolts** for the connection



20

Strength of angle check in block shear failure

$A_{vg} = 280 \times 8 = 2240\ mm^2$

$A_{vn} = (280 - 4.5 \times 22) \times 8 = 1448\ mm^2$

$A_{tg} = 50 \times 8 = 400\ mm^2$

$A_{tn} = (50 - 0.5 \times 22) \times 8 = 312\ mm^2$

$$T_{db1} = \frac{0.9 f_u A_{vn}}{\sqrt{3}\gamma_{m1}} + \frac{A_{tg} \times 250}{\gamma_{m0}}$$

$$T_{db2} = \frac{A_{vg} \times 250}{\sqrt{3} \times \gamma_{m0}} + \frac{A_{tn} \times 0.9 \times 410}{\gamma_{m1}}$$

$T_{db1} = 337.697\ KN$

$T_{db2} = 386.026\ KN$

Block shear strength = **337.697 KN** > 225 KN

Hence Angle is safe

Do not write in this margin

Section B : Structural Analysis-1+CPM PERT-1, Flow of fluids, hydraulic machines and hydro power-2

Q.5 (a) Differentiate between

(i) Flexibility method and Stiffness method.

(ii) Framed Structures and Truss Structures **[6 + 6 = 12 marks]**

(i)

Flexibility Method	Stiffness method
(i) Unknown: Forces	(i) Unknown: Displacements
(ii) Compatibility Equations are used to solve forces	(ii) Equations of Equilibrium are used to solve.
(iii) This method is best to use when static Determinacy is less	(iii) This method is best to use when Kinematic Indeterminacy is less
(iv) Example: Strain energy method.	Example - Moment distribution method, Slope deflection method

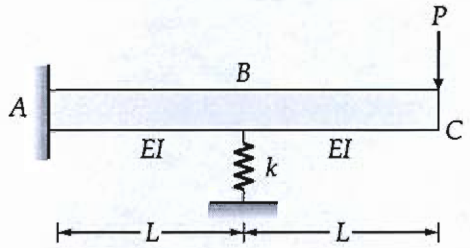
4

(ii)

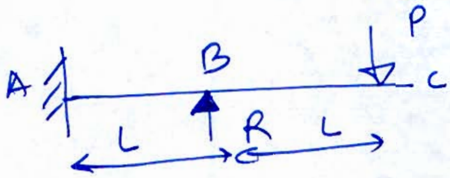
Framed structure	Truss structure
(i) They have rigid joints	(i) They have pin jointed connections
(ii) Load can be anywhere on the frame	(ii) Load is applied at the joints

3

Q.5 (b) A beam is subjected to a concentrated load *P* and is supported at its midpoint by a vertical spring of stiffness *k*. The reaction in the spring is taken as the redundant force *R*. Using compatibility of deflections, determine the expression for the spring reaction *R* in terms of *P*, *L*, *EI* and *k*.



[12 marks]



Deflection at B due to P

$$\Delta_P = \frac{P \times L^3}{3EI} + \frac{PL \times L^2}{2EI}$$

Deflection at B due to R

$$\Delta_R = \frac{RL^3}{3EI}$$

Total deflection

$$\Delta = \Delta_P - \Delta_R = \frac{PL^3}{3EI} + \frac{PL^3}{2EI} - \frac{RL^3}{3EI} = \frac{5}{6}\frac{PL^3}{EI} - \frac{RL^3}{3EI} \quad (I)$$

Also this deflection ~~$k\Delta$~~ $R = K\Delta$ (II)

From (I) and (II)

$$\frac{5PL^3}{6EI} - \frac{RL^3}{3EI} = \frac{R}{K}$$

12

$$\frac{5PL^3}{6EI} = \frac{RL^3}{3EI} + \frac{R}{K} = R\left[\frac{L^3}{3EI} + \frac{1}{K}\right]$$

$$\boxed{R = \frac{5PL^3/6EI}{\left[\frac{1}{K} + \frac{L^3}{3EI}\right]}}$$

Q.5 (c) Explain the concepts of Net Positive Suction Head (NPSH) and Thoma's cavitation factor in the context of hydraulic machines, including their mathematical expressions.

[12 marks]

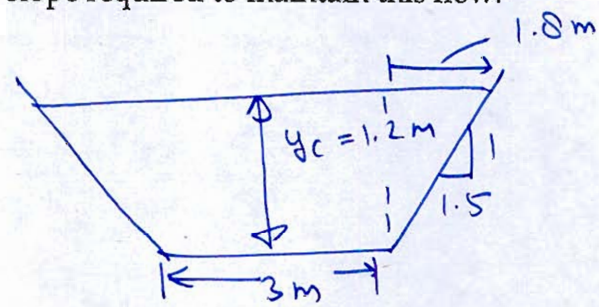
Q.5 (d) A trapezoidal channel has a bottom width of 3 m and side slopes of 1:1.5 (1 vertical to 1.5 horizontal). The channel is lined with concrete having Manning's coefficient of 0.015. If the critical depth of flow is 1.2 m, calculate the following:

(i) The critical flow rate through the channel.

(ii) The critical slope required to maintain this flow.

[12 marks]

→ (i)



At critical flow

$$\frac{Q^2 T}{gA^3} = 1$$

$$T = 3 + (1.2 \times 1.5) \times 2 = 6.6 \text{ m}$$

$$A = \frac{1}{2}(T + B) \times y_c = \frac{1}{2}(6.6 + 3) \times 1.2$$

$$= 5.76 \text{ m}^2$$

$$Q_c = \sqrt{\frac{gA^3}{T}} = \sqrt{\frac{9.81 \times 5.76^3}{6.6}}$$

$$\boxed{Q_c = 16.853 \text{ m}^3/\text{s}}$$

12

(ii) By mannings equation

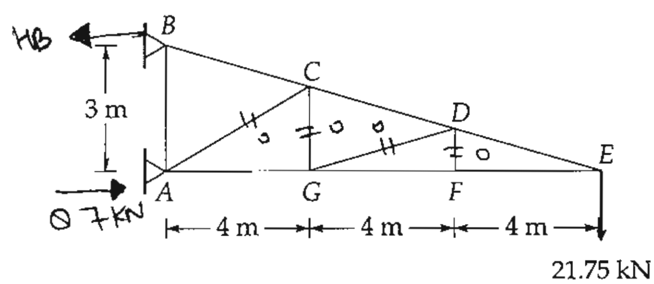
$$Q = \frac{1}{n} A R^{2/3} \sqrt{S_0}$$

$$R = \frac{A}{P} = \frac{5.76}{3 + 2 \times (\sqrt{1.2^2 + 1.8^2})} = 0.786$$

$$16.853 = \frac{1}{0.015} \times 5.76 \times 0.786^{2/3} \sqrt{S_c}$$

$$\boxed{S_c = \frac{1}{376.592}}$$

Q.5 (e) A pin-jointed truss is supported and loaded as shown in the figure. Considering the applied load at *E* to be 21.75 kN, determine the vertical deflection under the load at joint *E*. Assume the axial rigidity *AE* = 1890000 kN for all members of the truss.



[12 marks]

Members DF, DG, GC, CA
zero force members

(1)

$\Sigma M_A = 0$

$21.75 \times 12 - H_B \times 3 = 0$

$H_B = 87$ KN ←

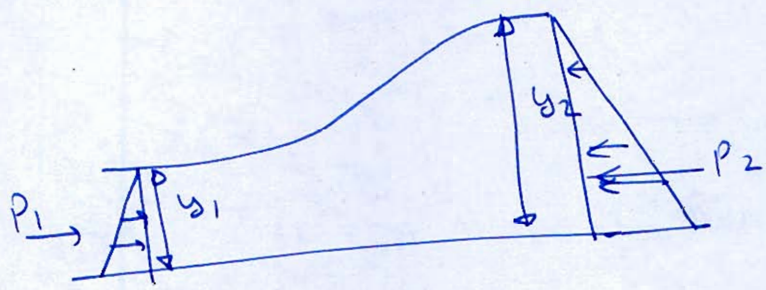
$\Sigma H = 0$

$H_A = 87$ KN →

Q.6 (a) A hydraulic jump forms in a horizontal rectangular channel having a constant width of 1.5 m. The depth of flow before the jump is observed to be 10 cm, while the depth after the jump is 45 cm. Initially, assume the channel is frictionless and estimate the discharge of water passing through the section. Subsequently, consider a scenario where the channel is not frictionless, and a resistance force of 45 N is exerted on the water over the jump length. Determine the revised estimated discharge for this second case.

[20 marks]

→ $y_1 = 10\,cm = 0.1\,m$. $y_2 = 45\,cm = 0.45\,m$



using momentum Equation

$$P_1 - P_2 = M_2 - M_1$$

$$\gamma A_1 \frac{y_1}{2} - \gamma A_2 \frac{y_2}{2} = \frac{\gamma}{g} Q (V_2 - V_1)$$

$$\gamma A_1 \frac{y_1}{2} - \gamma A_2 \frac{y_2}{2} = \frac{\gamma Q^2}{g}\left(\frac{1}{A_2} - \frac{1}{A_1}\right)$$

$$A_1 = 0.1 \times 1.5 = 0.15\,m^2$$

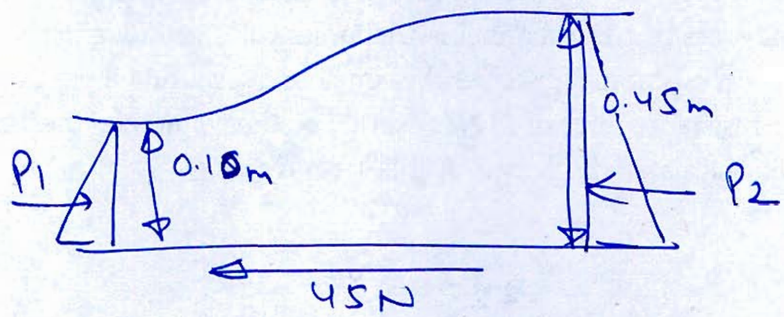
$$A_2 = 1.5 \times 0.45 = 0.675\,m^2$$

$$0.15 \times \frac{0.1}{2} - 0.675 \times \frac{0.45}{2} = \frac{Q^2}{9.81}\left(\frac{1}{0.675} - \frac{1}{0.15}\right)$$

$$\boxed{Q = 0.5226\,m^3/s}$$

20

when channel bed has friction



using momentum equation

$$P_1 - P_2 - 45 = M_2 - M_1$$

$$\gamma \times 0.15 \times \frac{0.1}{2} - \gamma \times 0.675 \times \frac{0.45}{2} - \frac{45}{9810}$$

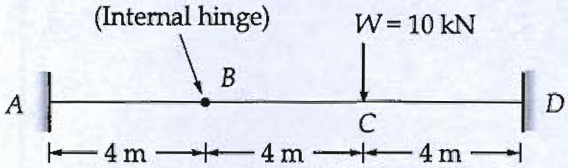
$$= \frac{\gamma}{g} Q^2 \left(\frac{1}{0.675} - \frac{1}{0.15}\right)$$

$$Q = 0.53087 \ m^3/s$$

Do not write in this margin

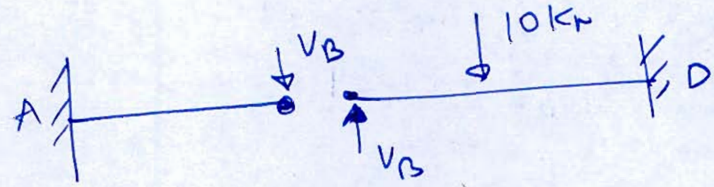
Q.6 (b) **(i)** Discuss the primary advantages of Surge tanks. Specify their location in plant by making a sketch.

(ii) Two prismatic beams with the same cross-sectional area *AB* and *BD* have fixed ends at *D* and form an internal hinge at *B*. Beam *BD* carries a single vertical load *W* = 10 kN at its mid-point C. Analyze the beam and determine the reactions and bending moments draw the shear force and bending moment diagrams.



[8 + 12 = 20 marks]

(ii)



Deflection at B.
considering span DB

$$-\frac{V_B(8^3)}{3EI} + \frac{10\times 4^3}{3EI} + \frac{10\times 4^2}{2EI}\times 4 = \frac{640}{EI}\left[\frac{5}{6}\right] - \frac{V_B\times 512}{3EI}$$

$$\text{(II)} - \Delta = \frac{533.33}{EI} - \frac{170.667 V_B}{EI}$$

Deflection at B considering AB

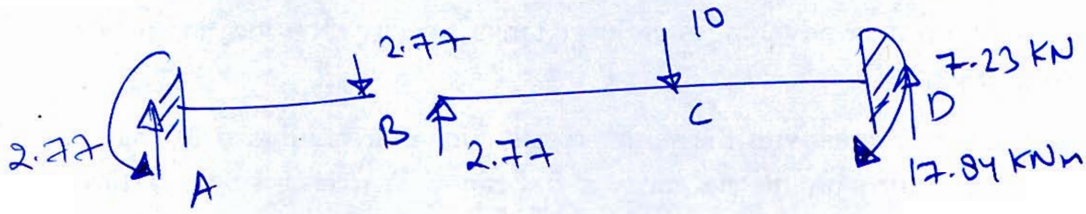
$$\frac{V_B\times 4^3}{3EI} = \Delta \quad \text{— (I)}$$

~~Equation~~ equating both (I) and (II)

$$\frac{533.33}{EI} - \frac{170.667 V_B}{EI} = \frac{21.333 V_B}{EI}$$

$$\frac{533.33}{EI} = \frac{192 V_B}{EI}$$

$$\boxed{V_B = 2.77 \text{ kN}}$$



$\Sigma M_A = 0$

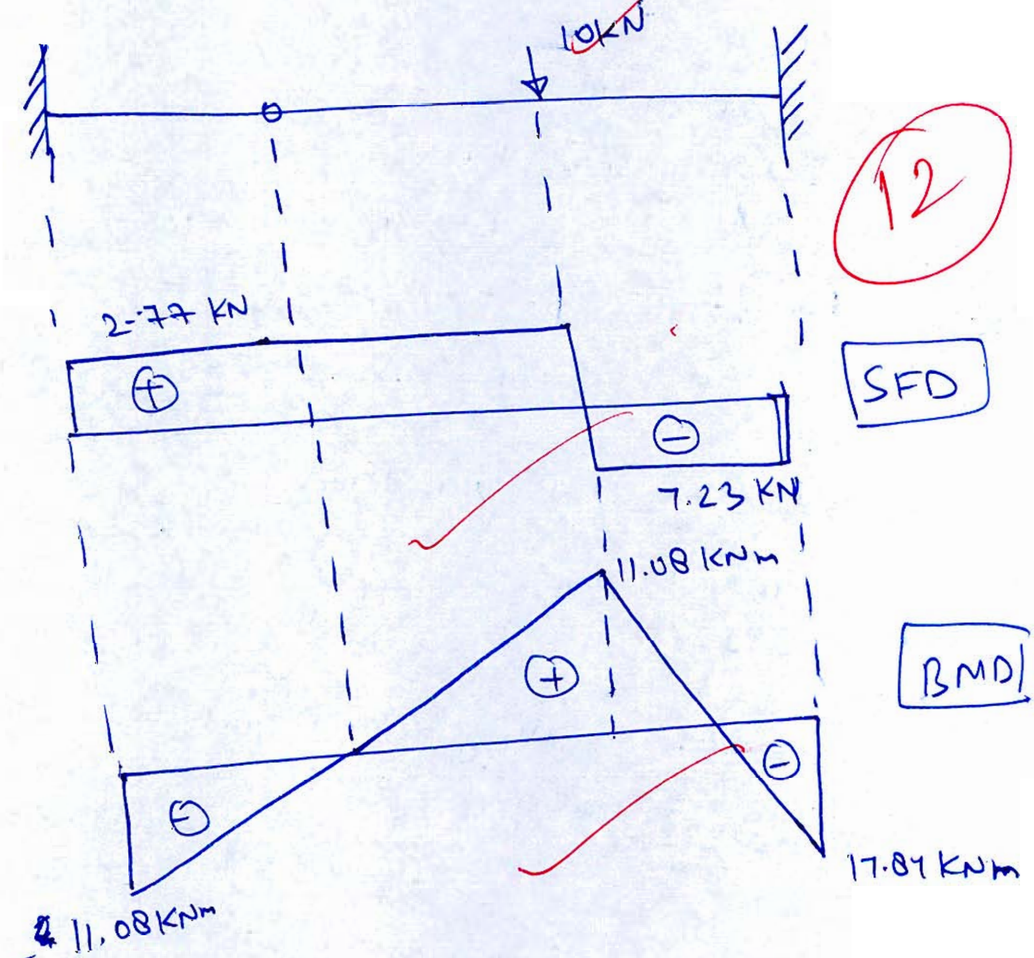
$M_A + 2.77 \times 4 = 0$

$M_A = 11.08$ KNm

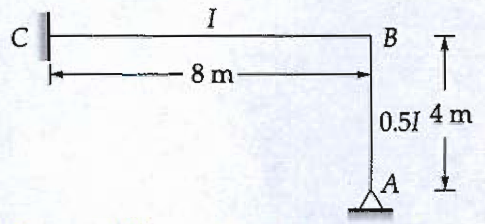
$\Sigma M_D = 0$

$2.77 \times 8 - 40 - M_D = 0$

$M_D = -17.84$



Q.6 (c) If the member *AB* in the rigid jointed frame shown below is fabricated 10 mm too long, determine the moments and reactions created in the frame when it is erected. Take EI = 100,000 kNm^2. Also draw *BMD*.



[20 marks]

$\delta = \frac{10}{1000} = 0.01\,m$ for span CB

Fixed End moments

$m_{fCB} = 0$ $\quad m_{fBA} = m_{fAB} = 0$

$m_{fBC} = 0$

$M_{CB} = m_{fCB} + \frac{2EI}{L}\left(2\theta_C + \theta_B - \frac{3\delta}{L}\right)$

$M_{BC} = m_{fBC} + \frac{2EI}{L}\left(2\theta_B + \theta_C - \frac{3\delta}{L}\right)$

$M_{CB} = \frac{2EI}{8}\left[\theta_B + 3 \times \frac{10}{1000 \times 8}\right]$

$M_{CB} = \frac{EI}{4}\left[\theta_B + 0.00375\right]$

$M_{BC} = \frac{2EI}{8}\left[2\theta_B + 0.00375\right]$

$M_{BA} = \frac{2EI}{2 \times 4}\left[2\theta_B + \theta_A\right]$

$M_{AB} = \frac{2EI}{2 \times 4}\left[2\theta_A + \theta_B\right]$

Equation of Equilibrium at Jt. B

$M_{BC} + M_{BA} = 0$

$$2\frac{EI}{4}\left[2\theta_B + 0.00375\right] + \frac{EI}{4}\left[2\theta_B + \theta_A\right] = 0$$

$$4\theta_B + 0.00375 + \theta_A = 0 \quad \text{— (I)}$$

At A $M_{AB} = 0$

$$2\theta_A = -\theta_B \quad \text{— (II)}$$

From (I) and (II)

$$4(-2\theta_A) + \theta_A + 0.00375 = 0$$

$$-7\theta_A = -0.00375$$

$$\boxed{\theta_A = 0.0005357 \text{ rad}}$$

$$\boxed{\theta_B = -0.00107 \text{ rad}}$$

$$M_{CB} = \frac{100000}{4}\left[-0.00107 + 0.00375\right]$$

$$M_{CB} = 67 \text{ KNm}$$

$$M_{BC} = \frac{EI}{4}\left[2(-0.00107) + 0.00375\right]$$

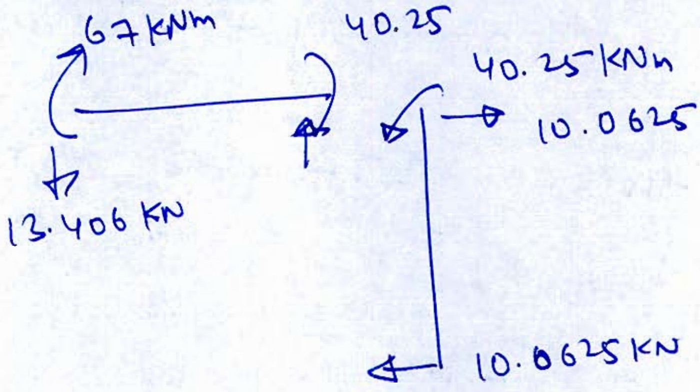
M_{BC} = ~~4025 KNm~~ 40.25 KNm

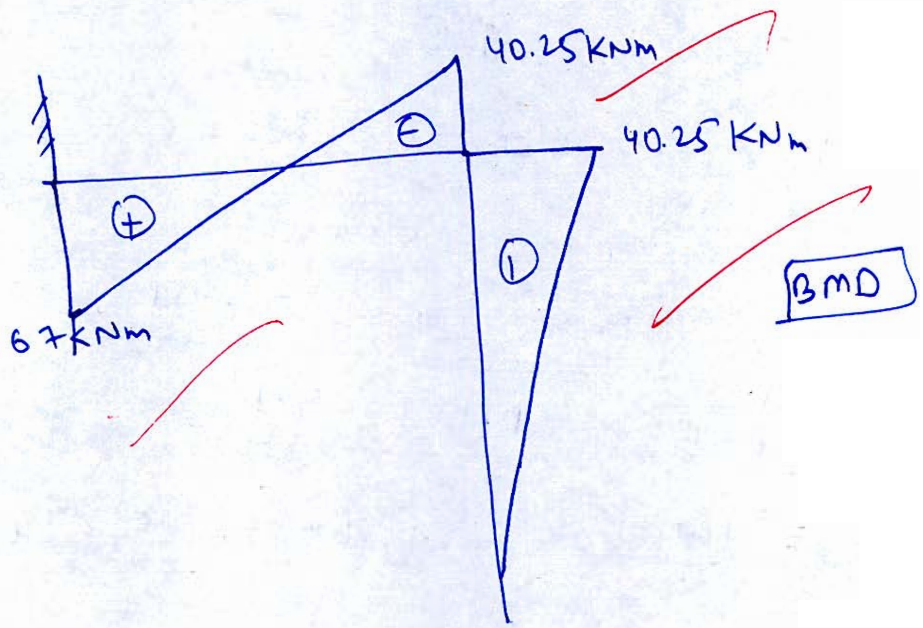
$$M_{BA} = \frac{EI}{4}\left[2(-0.00107) + 0.0005357\right]$$

$$M_{BA} = -40.25 \text{ KNm}$$

$$M_{AB} = 0$$

20


67 KNm
40.25
40.25 KNm
10.0625
13.406 KN
10.0625 KN


40.25 KNm
40.25 KNm
67 KNm
BMD

Q.7 (a) A three-hinged circular arch of span 40 m and rise 8 m carries a concentrated load of 120 kN at a horizontal distance of 10 m from the left end. Find the maximum positive and negative bending moments and draw the bending moment diagram.

[20 marks]

Q.7 (b) (i) Explain the work breakdown structure? What are its merits and demerits?

(ii) The objective is to plan a Civil Engineering project using CPM-Network analysis based on the provided activity data. This involves drawing the network, establishing the critical path, preparing a complete *CPM* schedule with total, free, and independent floats, and computing the total project duration.

Activity	Duration (Weeks)	Preceding Activity	Following Activity
A	3	–	E
B	4	–	D, F, G
C	14	–	H
D	3	B	H
E	5	A	–
F	6	B	–
G	4	B	I
H	1	C, D	I
I	1	G, H	–

[10 + 10 = 20 marks]

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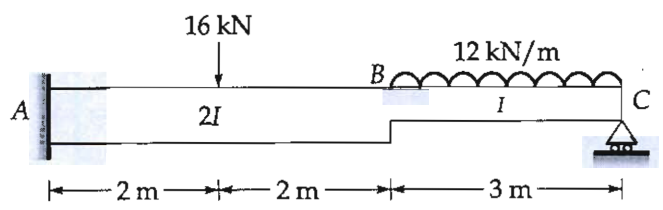
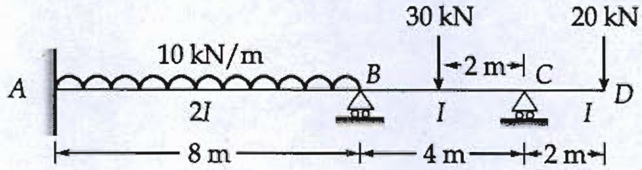
Q.7 (c) Analyse the beam shown in the figure using moment distribution method.



[20 marks]

Q.8 (a) Determine the bending moments at all ends of the spans of the given continuous beam using the slope-deflection method. Draw *BMD* and *SFD*.



[20 marks]

Q.8 (b) **(i)** Show that for a wide rectangular channel, the bed slope S_0 is classified as mild or steep according to whether S_0 is less than or greater than the critical slope S_c, given by

$$S_c = \frac{n^2 g^{10/9}}{q^{2/9}}$$

where, n = Manning's coefficient

g = Acceleration due to gravity

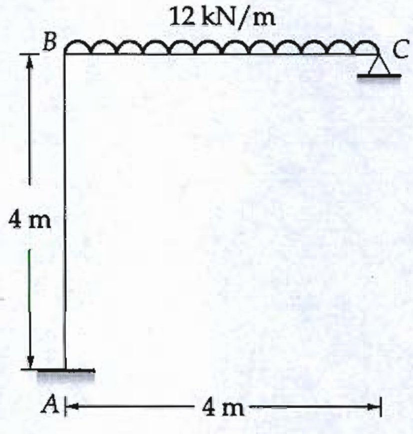
q = Discharge per unit width

(ii) Write short notes on the following types of contracts used in construction projects:

1. Lump Sum Contract
2. Item Rate Contract
3. Percentage Rate Contract
4. Cost Plus Contract
5. Turnkey Contract
6. EPC (Engineering, Procurement and Construction) Contract

[8 + 12 = 20 marks]

Q.8 (c) Analyse the portal frame shown below by strain energy method and draw the BMD. Take, EI = Constant



[20 marks]

OOOO

Space for Rough Work

Space for Rough Work