MADE EASY

Leading Institute for ESE, GATE & PSUs

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
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ 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	33
Q.2	—
Q.3	50
Q.4	—
Section-B	
Q.5	39
Q.6	53
Q.7	
Q.8	52
Total Marks Obtained	227

Signature of Evaluator .... Cross Checked by ....

Corp. office : 44 - A/1, Kalu Sarai, New Delhi-110016 | **Ph:** 9021300500 | **Web:** www.madeeasy.in

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

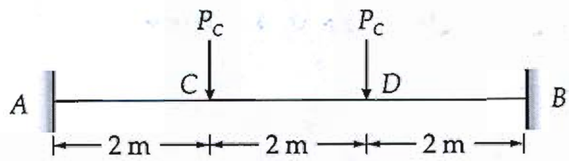
1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough 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 not write in this margin

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.

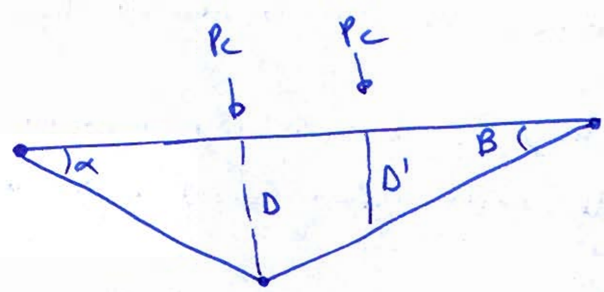


[6 + 6 = 12 marks]

(ii) $D_s = r - s = 4 - 2 = 2$

$N = D_s + 1 = 3$

Let PH at A, C, B



$\Delta = 2\alpha = 4\beta$

$\Rightarrow (\beta = 0.5\alpha)$

$[\Delta' = 2\beta = \alpha]$

Now

$P_c \cdot \Delta + P_c \cdot \Delta' = M_p(\alpha) + M_p(\alpha + \beta) + M_p(\beta)$

$P_c(2\alpha + \alpha) = 2M_p(\alpha + 0.5\alpha)$

$M_p = P_c$

$\boxed{P_c = M_p \text{ kN}}$

4

Assumptions in Plastic Analysis

① Balance Mechanism is developed in which the No. of plastic Hinges developed are equal to 1 greater than the Static Indeterminacy of the Structure

$$N = D_s + 1$$

② for Section at Mp, all the fibres at that section are experiencing Yield stress

③ Equilibrium is Maintained at Plastic State.

4

④ External work done by forces is equal to the Internal work done due to Moment developed

⑤ at plastic Hinge, there is Very High Rotation in Very Small length Making Curvature Near Infinite.

⑥ Out of all the Possible Cases of Mechanism, plastic Moment is given by that Case which gives Maximum Value of the Moment.

Do not write in this margin

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]

Let overhang be a

$P_u = 1850$ kN

$f_{ck} = 25$ Mpa.

$D = 350$mm

$b_f = 250$mm

$L = (350 + 2a)$

$B = (b_f + 2a)$

(2)

Now $f_b = \dfrac{P_u}{L \cdot B} \leq 0.45 f_{ck}$

$$\frac{1850 \times 10^3}{(350+2a)(250+2a)} \leq 0.45 \times 25$$

$a \geq 54.29$mm

take $[a = 55\text{mm}]$

Now $w = \dfrac{P_u}{L \cdot B} = \dfrac{1850 \times 10^3}{(350 + 2\times55) \times (250 + 2\times55)}$

$(w = 11.17 \text{N/mm}^2)$

$$t = \sqrt{\frac{w(a^2 - 0.3a^2)}{(f_y/\sqrt{3} \times 1.1)}} = \sqrt{\frac{11.17 \times (55^2 - 0.3\times55^2)}{(410/\sqrt{3}\times1.25)}}$$

$t = 11.17$ mm Take $\boxed{t = 12\text{mm}}$

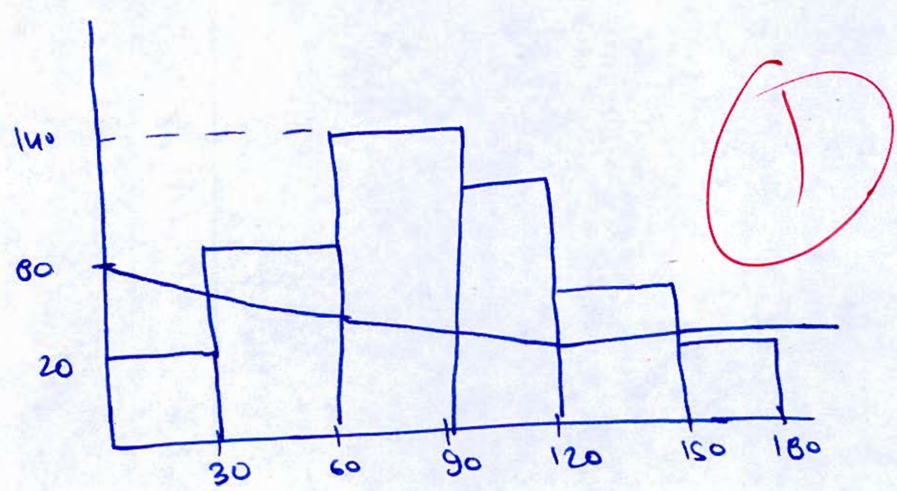
Q.1 (c) The following rainfall mass curve data was recorded during a storm of 180 minutes at 30 minute intervals. The infiltration capacity of the soil is governed by the Horton's equation: $f(t) = 30 + 50e^{-2.2t}$, where f is in mm/hr and t is in hours. Compute the effective rainfall for the storm.

Time (min)	Accumulated Rainfall (cm)
0	0
30	1.0
60	5.5
90	12.5
120	18.0
150	20.5
180	21.5

[12 marks]

Time	Rainfall (mm)	Intensity (mm/h)
30	10	20
60	45	90
90	70	140
120	55	110
150	25	50
180	10	20

$$f_t = 30 + 50e^{-2.2t}$$



Total Infiltration $= (20+20)\times 1 + \int_{0.5}^{2.5} (30+50\,e^{-2.2t})\,dt$

$= 40 + 67.47$

$= 107.47\text{mm}$

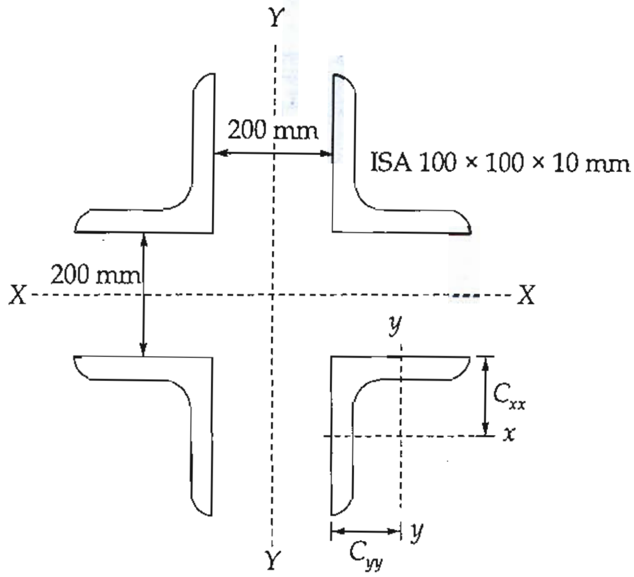
Total Rainfall $= (20+90+140+110+50+20) \times \frac{30}{60}$

$= 215\text{mm}$

Effective Rainfall $R_e = 215 - 107.47$

$R_e = 107.53\text{mm}$

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]

$I_{xx} = I_{yy} = I = 4\times\left(177\times10^4 + 1903\times\left(\frac{200}{2}+28.4\right)^2\right)$

$[I = 132.57\times10^6\ mm^4]$

$L_e = 6\ m$

$f_y = 250\ MPa.$

$r = \sqrt{\frac{I}{4A}} = \sqrt{\frac{132.57\times10^6}{4\times1903}}$

$[r = 131.97\ mm]$

$\lambda = \frac{l_e}{r} = \frac{6000}{131.97} = 45.46$

from table $f_{cd} = 198 + \left(\frac{45.46 - 40}{50 - 40}\right) \times (183 - 198)$

$[f_{cd} = 189.81 \text{ MPa}]$

$P_u = f_{cd} \times (A) = 189.81 \times \frac{(4 \times 1903)}{10^3}$

$P_u = 1444.83 \text{ kN}$

$\left[P_s = \frac{P_u}{1.5} = 963.22 \text{ kN} \right]$

12

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

[12 marks]

Factor affecting Evaporation

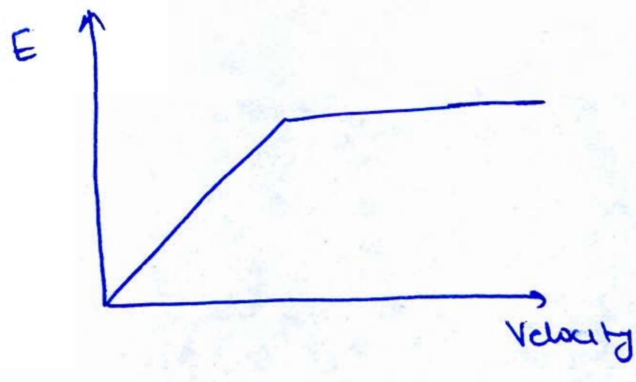
① Evaporation is Directly proportional to the Difference of Saturation vapor pressure of water (e_s) and actual vapor pressure of air above water Surface (e_a)

$$E \propto (e_s - e_a)$$ $e_s, e_a \rightarrow$ mm of Hg.

② Evaporation is Directly proportional to the Surface Area of water Surface. Evaporation Increases with Surface Area.

③ Salinity :- As water Becomes Saline Its Saturation vapor pressure Decreases Resulting in Decreasing the evaporation.

④ Velocity :- Evaporation Increases with Increase in velocity above the surface upto some extent after which evaporation Becomes constant.



⑤ Temperature : As temperature Increases actual vapor pressure of Air Decreases which Results In Increase of Evaporation.

⑥ Coating :- Providing Coating with Certain Chemicals Reduces the Evaporation Potential.

Methods To Reduce evaporation losses

10

① Decreasing the Surface area of evaporation results in Decrease in evaporation

② Increasing Relative Humidity Results in ~~Increase~~ of Ea which Decreases evaporation

③ Increasing Salinity of water.

④ Provide chemical film over the Surface of water To Reduce evaporation

⑤ Decreasing temperature of the Surrounding.

Do not write in this margin

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

(a) Standard Project Flood (SPF)

(b) Probable Maximum Flood (PMF)

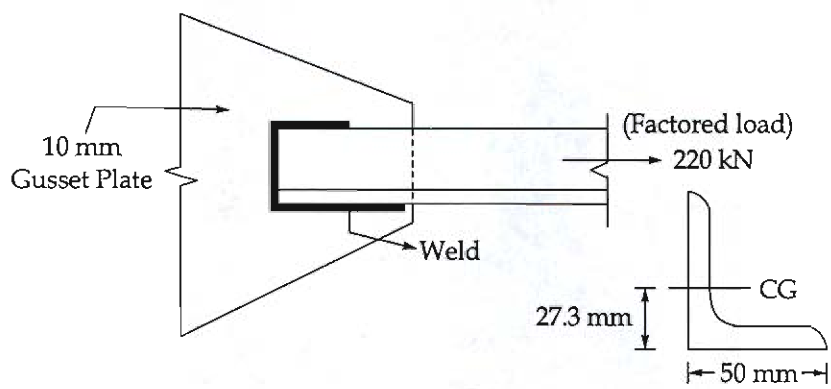
(c) Design flood

(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]

Do not write in this margin

Do not write in this margin

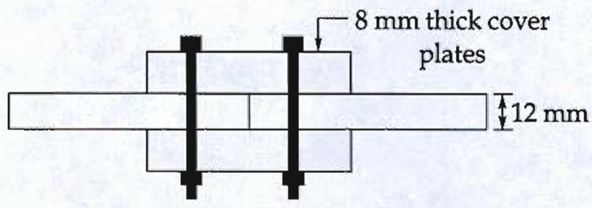
Q.2 (c) Design a simply supported steel beam with an effective span of 6.0 m that carries a factored uniformly distributed load of 25 kN/m over its entire span including self-weight. The beam is laterally supported throughout its length. Use steel of grade E250 with yield stress 250 N/mm^2 and perform 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]

Do not write in this margin

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]

$t_c = 12mm$

$d = 24mm$

$d_o = 26mm$

$f_{ub} = 400 Mpa.$

$f_{yb} = 240 Mpa$

$g = 80mm$

$t_p = 8mm$

$t = min^m \begin{Bmatrix} t_c = 12mm \\ 2t_p = 16mm \end{Bmatrix}$

$[t = 12mm]$

$V_{ds} = \frac{(0.78 \times \pi/4\, d^2 + \pi/4\, d^2) \times f_{ub}}{\sqrt{3} \times 1.25}$

$= \frac{(1.78 \times \pi/4 \times 24^2) \times 400}{\sqrt{3} \times 1.25 \times 10^3}$

$[V_{ds} = 148.77\, kN]$

$e_{min} = 1.5\, d_o = 1.5 \times 26 = 39mm \quad (e = 40mm)$

$p_{min} = 3d = 3 \times 24 = 72mm \quad (p = 80mm)$

$k_b = min \begin{Bmatrix} e/3d_o = 40/3\times26 = 0.51 \\ p/3d_o - 0.25 = 80/3\times26 - 0.25 = 0.76 \\ f_{ub}/f_{up} = 400/410 = 0.98 \end{Bmatrix}$

$[k_b = 0.51]$

$$V_{db} = \frac{2.5 k_b d t f_u}{1.25}$$

$$= \frac{2.5 \times 0.51 \times 24 \times 12 \times 410}{1.25 \times 10^3}$$

$$\boxed{V_{db} = 120.44 \text{ kN}}$$

$[B = g = 80 mm]$

$$V_b = min^m \begin{Bmatrix} V_{ds} = 148.77 \\ V_{db} = 120.44 \end{Bmatrix}$$

$$[V_b = 120.44 \text{ kN}]$$

Now $$T_{dg} = \frac{A_g f_y}{1.1} = \frac{(12 \times 80) \times 250}{1.1 \times 10^3}$$

$$T_{dg} = 218.18 \text{ kN}$$

$$T_{dn} = \frac{0.9 A_n f_u}{1.25} = \frac{0.9 \times (80-26) \times 12 \times 410}{1.25 \times 10^3}$$

$$[T_{dn} = 191.28 \text{ kN}]$$

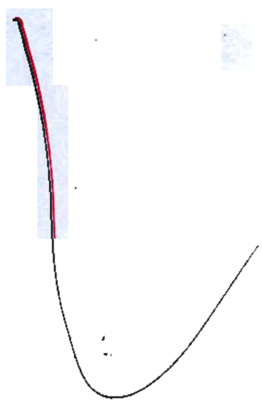
20

Strength of Butt Joint $= S_B = min \begin{Bmatrix} V_B = 120.44 \\ T_{dg} = 218.18 \\ T_{dn} = 191.28 \end{Bmatrix}$

$$[S_B = 120.44 \text{ kN}]$$

Now efficiency of Joint $$\eta = \frac{S_B}{T_{dg}} \times 100 = \frac{120.44}{218.18} \times 100$$

$$\boxed{\eta = 55.2\%}$$



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) $P = (2.5+6+11+3.5+5) \times \frac{40}{60}$

$(P = 18.67\text{cm})$

$(R = 7\text{cm})$

Total time

$T = 200\text{mm}$
$= 10/3\text{ h}$

$W_{Index} = \frac{P-R}{T} = \frac{18.67 - 7}{10/3}$

$W_{Index} = 3.5 \text{ cm/h}$

2.5 cm/h & 3.5 cm/h will not contribute in ϕ - Index

$P' = 18.67 - (2.5+3.5) \times \frac{40}{60} = 14.67 \text{ cm}$

$t = 200 - 2\times40 = 120 \text{ min} = 2h$

12

$\phi_{Index} = \frac{P'-R}{t} = \frac{14.67 - 7}{2}$

$\phi_{Index} = 3.835 \text{ cm/h}$

(i) Advantages

→ Materials are Not Wasted as Holes in the Member is Not Required.

→ More Resistant To fatigue, Vibration and Sudden loading.

→ Deflection of the Joint Decreases Because weld Connection is More Rigid.

→ Decreasing the Time of Construction

→ Members Having Different angle b/w them Can be easily Joined.

6

(ii) Disadvantages

→ High Power Consumption and Noise pollution

→ Residual Stresses due to Uneven Heating and Cooling During welding.

→ Sudden Collapse is possible as weld Connection is Brittle in nature.

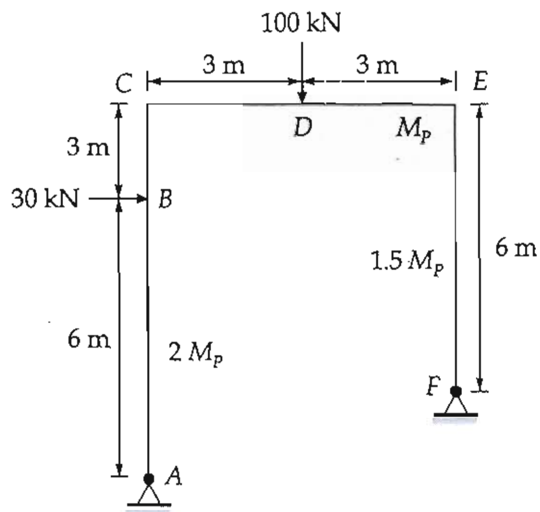
→ Determination of failure and Cracks are Hard to find and Regular Inspection is Required.

→ Skilled Professional is Required for the Work

→ Chance of Net Area Rupture Increases in the weld

→ Efficiency Decreases due to Eccentric loading.

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.

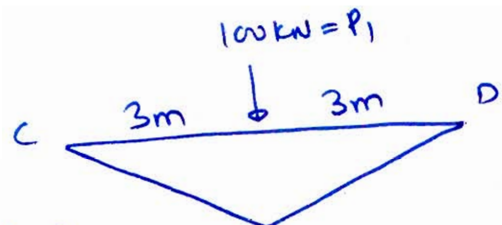


[20 marks]

$D_s = r - s = 4 - 3 = 1$

No. of plastic Hinges $= D_s + 1 = 2$

① Beam Mechanism



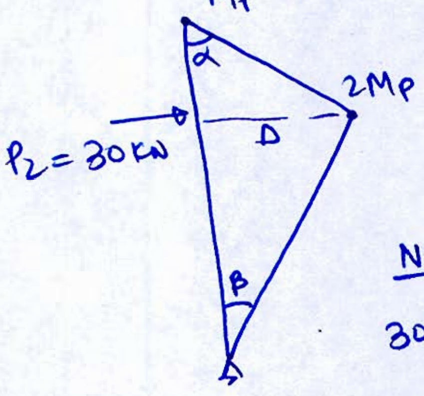
(L=6m)

$P_1 = \frac{8M_P}{L}$

$100 = \frac{8M_P}{6}$

$[M_P = 75 \text{ kN-m}]$

② Column Mechanism



$\Delta = \alpha \times 3 = \beta \times 6$

$[\beta = 0.5\alpha]$

Now

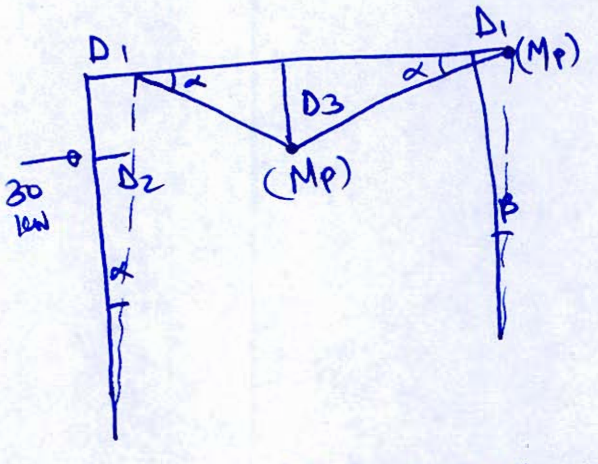
$30(\Delta) = M_p(\alpha) + 2M_p(\alpha+\beta)$

$30(3\alpha) = M_p(3\alpha + 2\beta) = 4M_p\alpha$

$[M_p = 22.5 \text{ kN-m}]$

12

③ Combined Mechanism (PH at D & E)



$D_1 = 9\alpha = 6\beta$

$(\beta = 1.5\alpha)$

$D_2 = 6\alpha$

$D_3 = 3\alpha$

Now $30(D_2) + 100(D_3) = M_p(\alpha+\alpha) + M_p(\alpha+\beta)$

$30(6\alpha) + 100(3\alpha) = M_p(3\alpha + 1.5\alpha)$

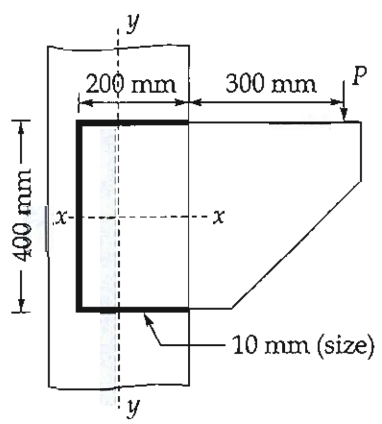
$M_p = 106.67 \text{ kN-m}$

$M_p = \max\left\{ \begin{array}{c} 75 \\ 22.5 \\ 106.67 \end{array} \right\}$

$M_p = 106.67 \text{ kN-m}$

Do not write in this margin

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]

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

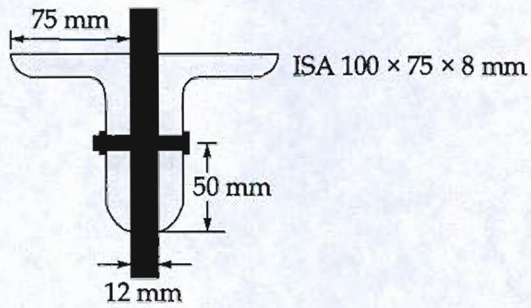
(ii) A stream reach has the Muskingum coefficients $K = 12$ hand $x = 0.2$. The inflow hydrograph for this reach is provided in the table. Assuming the initial outflow at $t = 0$ is $10\ m^3/s$, determine the outflow hydrograph for the reach using a routing time interval of $\Delta t = 6\ h$. Report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

Do not write in this margin

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]

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
→ Forces are unknown quantity	→ Displacement is unknown
→ Extra equation is found by compatibility condition	→ Extra equation is found by Equilibrium equations.
→ Also called force Method	→ Called Displacement Method.
→ flexibility of members occur in the equations	→ Stiffness of Members occur in the equations.
→ Used when $D_s < D_k$	→ used when $D_s > D_k$
→ Ex: flexibility Matrix Method, Strain energy Method, 3 Moment method, etc.	→ Ex: MDM, SDM, Stiffness Matrix Method, Kani's Method, etc.

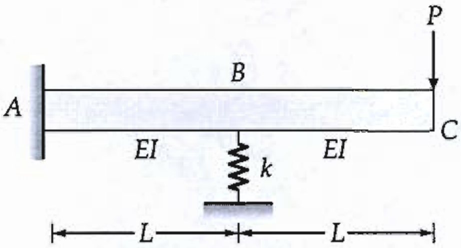
4

(ii)

Framed Structures	Truss Structures
→ Joints are fixed, Pinned or free end.	→ All Joints are pinned Joints.
→ Members Carry Axial force, Shear force and Bending Moment.	→ Members do not carry Bending Moment only carry Axial forces.
→ At each Joint 3 Deflections are possible ($\Delta x, \Delta y, \theta$)	→ only 2 Deflections are possible ($\Delta x, \Delta y$)

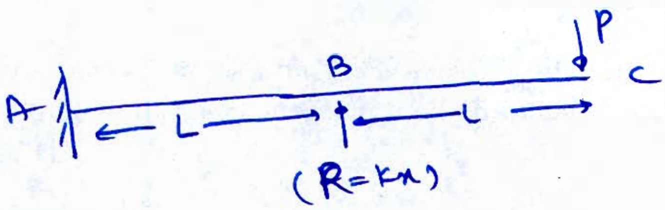
3

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]

Let Deflection at B be x Downwards



$$D_B = x = \frac{PL^3}{3EI} + \frac{(PL)\cdot L^2}{2EI} - \frac{R\cdot L^3}{3EI}$$

$$x = \frac{5}{6}\frac{PL^3}{EI} - \frac{(k\cdot x)\cdot L^3}{3EI}$$

12

$$x\left(1+\frac{kL^3}{3EI}\right) = \frac{5}{6}\frac{PL^3}{EI}$$

$$x\left(\frac{3EI+kL^3}{3EI}\right) = \frac{5}{6_2}\times\frac{PL^3}{EI}$$

$$x = \frac{2.5PL^3}{3EI+kL^3}$$

$$R = kx = \frac{2.5PL^3\cdot k}{3EI+kL^3}$$

$$\boxed{R = \frac{2.5PL^3}{\frac{3EI}{k}+L^3}}$$

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]

Net Positive Suction Head (NPSH) :- It is the Min^m Head that the Pump Needs on the Suction Side of the pump so that there is little to No possibility of Cavitation in the ~~pump~~. pump.
~~Failure~~

$$NPSH = H_{atm} - h_v - h_{fs} - h_s$$

H_{atm} → atmospheric pressure Head.
h_v → vapor pressure Head
h_s → Suction Head.
h_{fs} → friction loss on Suction side of pipe.

Thoma's Cavitation factor (σ) :- It is Defined as the Ratio of Net positive Suction Head and Manometric Head of pump.

$$\sigma = \frac{NPSH}{H_m}$$

$H_m \rightarrow$ Manometric Head.

for each pump σ_c is defined by expermetal Results and called as Critical Thomas's Cavitation factor.

7

Now $\sigma \geq \sigma_c \Rightarrow$ No Cavitation occurs

$\sigma < \sigma_c \rightarrow$ Cavitation occurs.

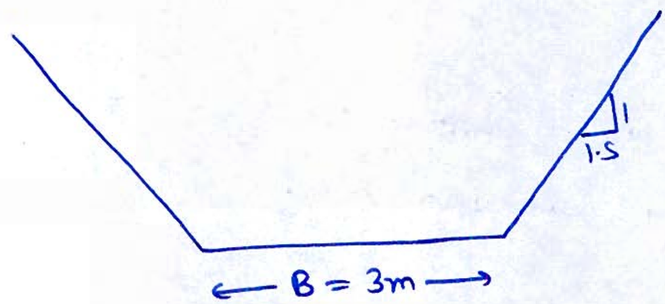
Do not write in this margin

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]



$m = 1.5$

$n = 0.015$

$y_c = 1.2m$

$T = B + 2my = 3 + 2\times1.5\times1.2$

$[T = 6.6m]$

$A = By + my^2 = 3\times1.2 + 1.5\times(1.2)^2$

$[A = 5.76 m^2]$

$P = B + 2y\sqrt{1+m^2} = 3 + 2\times1.2\times\sqrt{1+(1.5)^2} = 7.33m$

$R = A/P = \frac{5.76}{7.33} = 0.786m$

for Critical flow $\quad Fr^2 = 1 = \frac{Q_c^2 T}{gA^3} = \frac{(Q_c^2)\times6.6}{9.81\times(5.76)^3}$

$\boxed{Q_c = 16.85 \ m^3/s}$

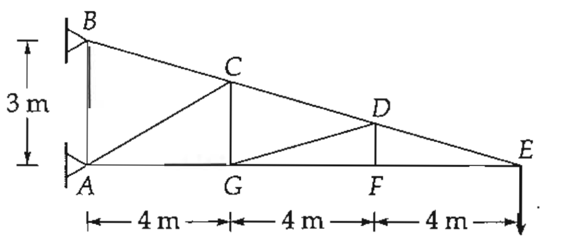
12

Now $\quad Q = \frac{A}{n}(R)^{2/3}(S)^{1/2}$

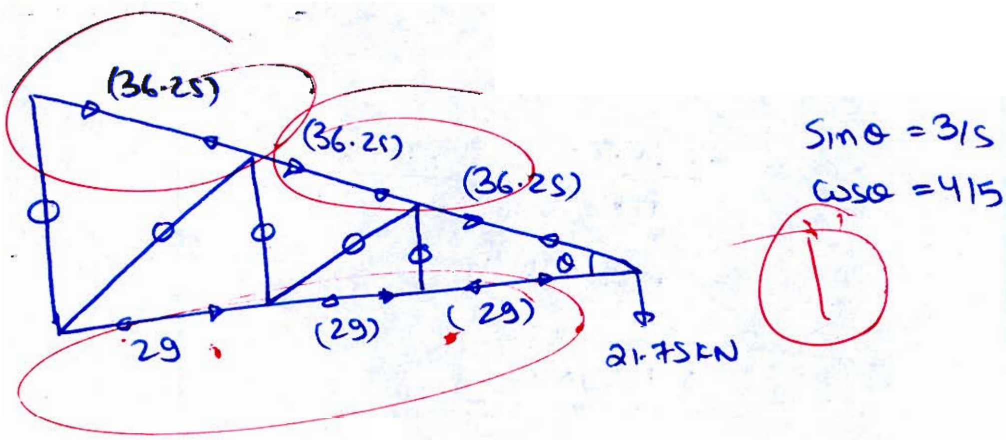
$16.85 = \frac{5.76}{0.015}\times(0.786)^{2/3}(S)^{1/2}$

$\boxed{S = 2.65\times10^{-3} = \frac{1}{376.73}}$

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.



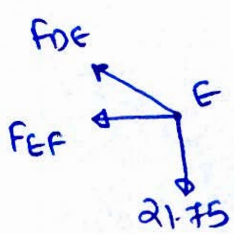
[12 marks]



$\sin\theta = 3/5$

$\cos\theta = 4/5$

at E



$\Sigma F_y = 0 \Rightarrow F_{DE} \times \frac{3}{5} - 21.75 = 0$

$[F_{DE} = 36.25 \text{ kN}]$

$\Sigma F_x = 0 \Rightarrow F_{DE}\cos\theta + F_{EF} = 0$

$36.25 \times \frac{4}{5} + F_{EF} = 0$

$[F_{EF} = -29\ kN]$

Similarly all forces are shown in figure

for BC, CD, DE

$L = 5m$

$P = 36.25\ kN$

$K = \frac{36.25}{21.75} = 5/3$

for EF, FG, GA

$L = 4m$

$P = -29\ kN$

$K = \frac{-29}{21.75} = -4/3$

for all other Members $(P = K = 0)$

Now $\Delta v_c = \frac{\Sigma PKL}{AE}$

$= \frac{1}{AE}\left[3 \times 36.25 \times \frac{5}{3} \times 5 + 3 \times (29)(-4/3) \times 4\right]$

$= \frac{1370.25}{AE} = \frac{1370.25}{189 \times 10^4}$

$= 7.25 \times 10^{-4} m$

$\boxed{\Delta v_c = 0.725\ mm}$

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]

frictionless channel

$B = 1.5\,m$

$y_1 = 0.1\,m$

$y_2 = 0.45\,m$

for HJ $\quad F_1 + M_1 = F_2 + M_2$

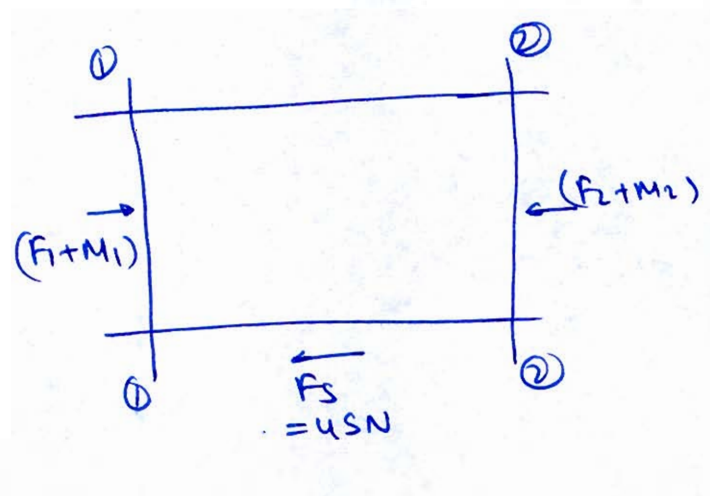
$$\frac{\gamma g y_1^2 B}{2} + \gamma Q \cdot V_1 = \frac{\gamma g y_2^2 B}{2} + \gamma Q V_2 \qquad \left(V_1 = \frac{Q}{A_1}, \; V_2 = \frac{Q}{A_2} \right)$$

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

$$Q^2\left(\frac{1}{1.5 \times 0.1} - \frac{1}{1.5 \times 0.45}\right) = \frac{9.81 \times 1.5}{2}(0.45^2 - 0.1^2)$$

$$\boxed{Q = 0.523\ m^3/s}$$

for friction Channel



By NSL

$$F_1 - F_2 - F_s = \rho Q (v_2 - v_1)$$

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

$$= \frac{10^3 \times 9.81 \times 1.5}{2}(0.1^2 - 0.45^2) - 45 = 10^3 \times Q^2 \left(\frac{1}{0.45 \times 1.5} - \frac{1}{0.1 \times 1.5}\right)$$

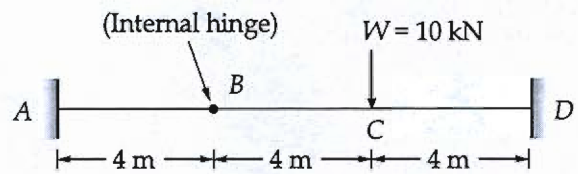
$$\Rightarrow \quad -1461.32 = -5185.18\, Q^2$$

$$Q = 0.531\ m^3/s$$

8

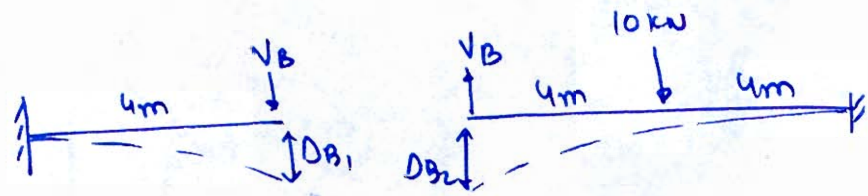
Q.6 (b) **(i)** Discuss the primary advantages of Surge tanks. Specify their location in plant by making a sketch.

(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)



$DB_1 = DB_2$

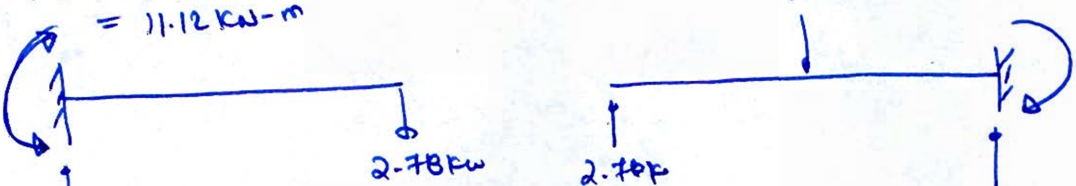
$$\frac{V_B(4)^3}{3EI} = \frac{10(4)^3}{3EI} + \frac{10(4)^2}{2EI}\cdot 4 - \frac{V_B(8)^3}{3EI}$$

$$192 V_B = \frac{1600}{3}$$

$$\boxed{V_B = 2.78 \text{ kN}}$$

$M_A = 2.78 \times 4$

$= 11.12$ kN-m



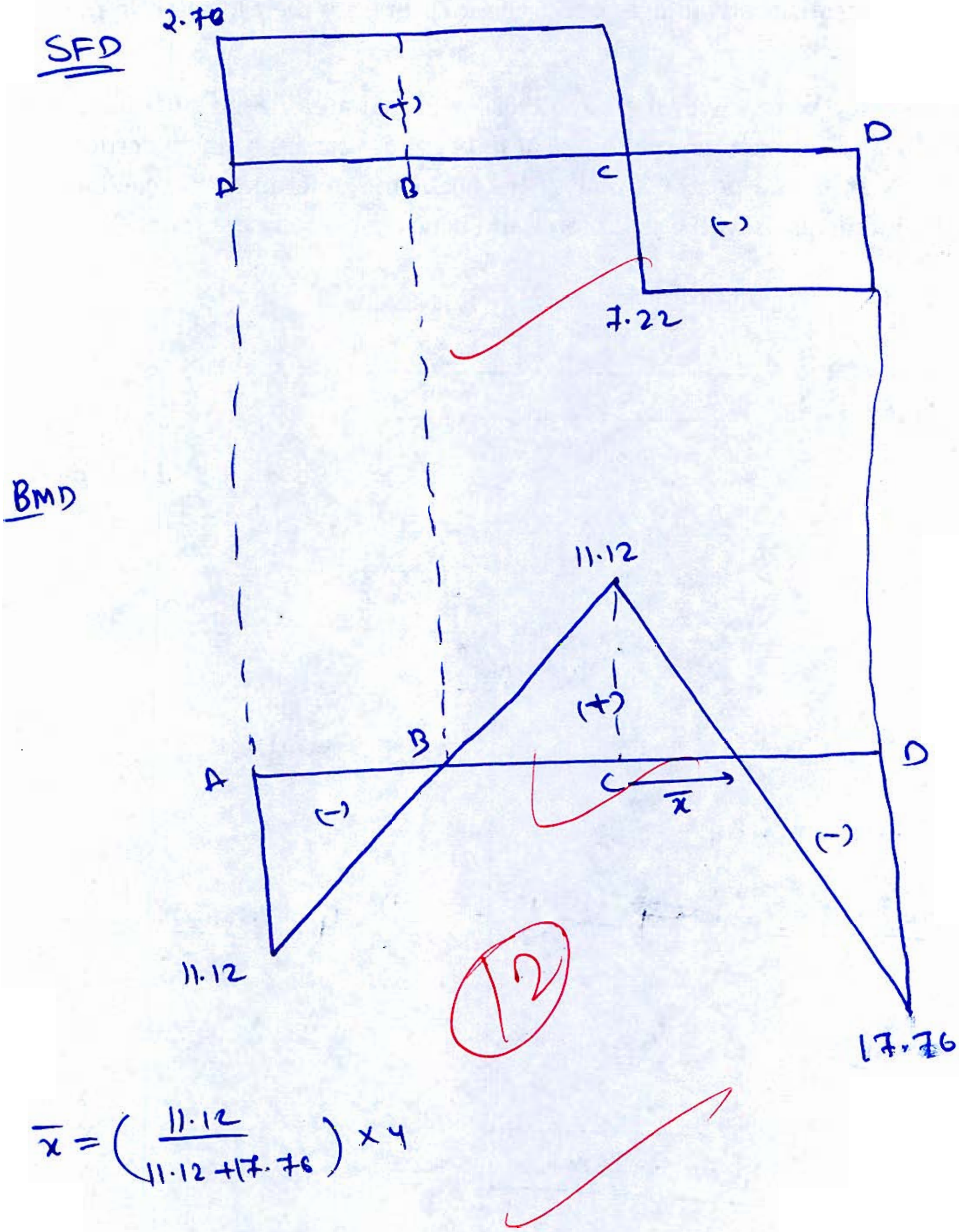
$V_A = 2.78$ kN

$V_B = 10 - 2.78$

$= 7.22$ kN

$M_D = 10 \times 4 - 2.78 \times 8$

$= 17.76$ kN-m



$$\bar{x} = \left(\frac{11.12}{11.12 + 17.76}\right) \times 4$$

$$\left[\bar{x} = 1.54\,m\right]$$

Advantages of Surge Tank

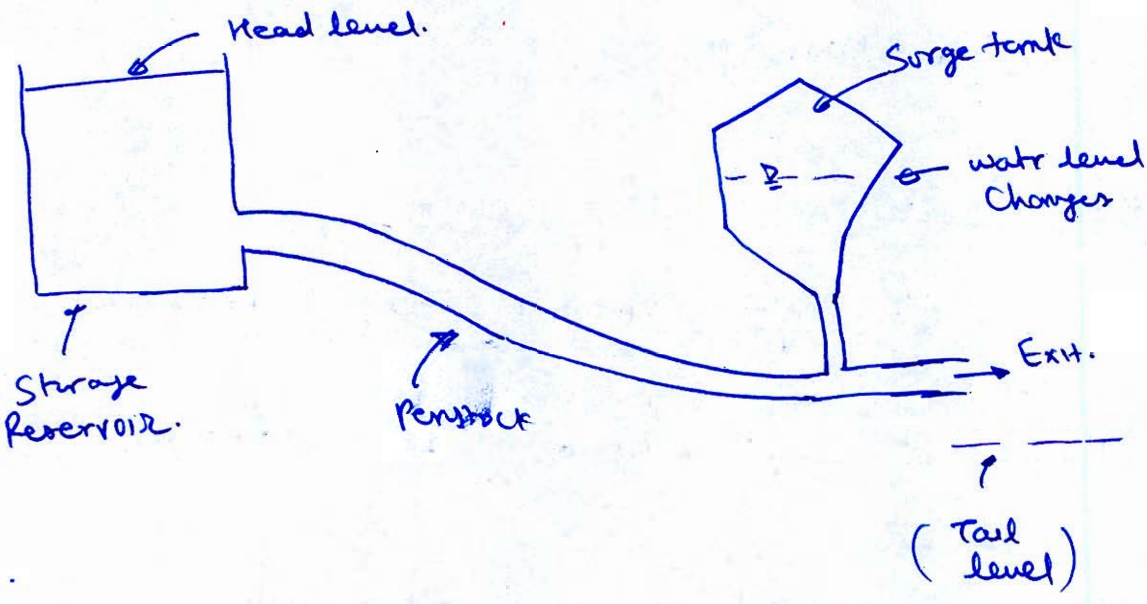
→ It Helps in Constant velocity of water at exit by Storing the water when flow is Higher and Releasing the stored water in case of low flow.

→ Head loss due to Accelartion Decreases which Increases efficiency of the System.

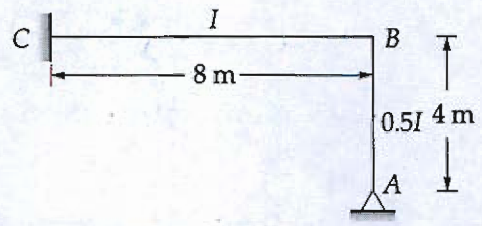
→ It Decreases the Impact of water Hammer on the Pipe due to Sudden closure of valve by Storing the water in it.

6

→ Location of Surge tank Should be Near the downstream as much as Possible as it only protect Upstream pipe of it from the water Hammer effect.



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]

$$M_{fCB} = M_{fBC} = \frac{6EI\Delta}{L^2} = \frac{6\times10^5\times(10\times10^{-3})}{8^2}$$

$$M_{fCB} = M_{fBC} = 93.75 \text{ kN-m}$$

$$[M_{fBA} = M_{fAB} = 0]$$

Now by SDM

$$M_{AB} = 0 + \frac{2E(0.5I)}{4}(2\theta_A + \theta_B) = EI(0.5\theta_A + 0.25\theta_B)$$

$$M_{BA} = 0 + \frac{2E(0.5I)}{4}(2\theta_B + \theta_A) = EI(0.25\theta_A + 0.5\theta_B)$$

$$M_{BC} = 93.75 + \frac{2EI}{8}(2\theta_B) = 93.75 + 0.5EI\theta_B$$

$$M_{CB} = 93.75 + 0.25EI\theta_B$$

Do not write in this margin

Now $M_{AB} = 0 \Rightarrow 0.5\theta_A + 0.25\theta_B = 0$

$[\theta_B = -2\theta_A]$

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

$93.75 + 0.5EI\theta_B + EI(0.25\theta_A + 0.5\theta_B) = 0$

$93.75 - 1.75 EI\theta_A = 0$

$$\left[\begin{array}{l} \theta_A = \frac{53.57}{EI} \\ \theta_B = -\frac{107.14}{EI} \end{array}\right]$$

17

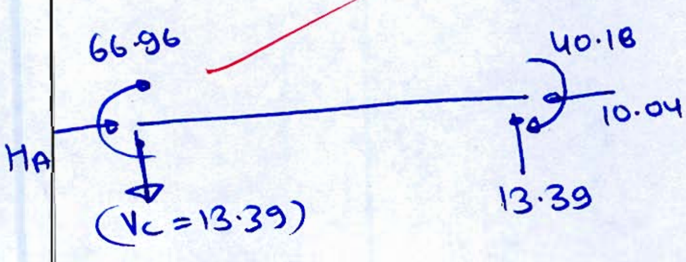
Putting values

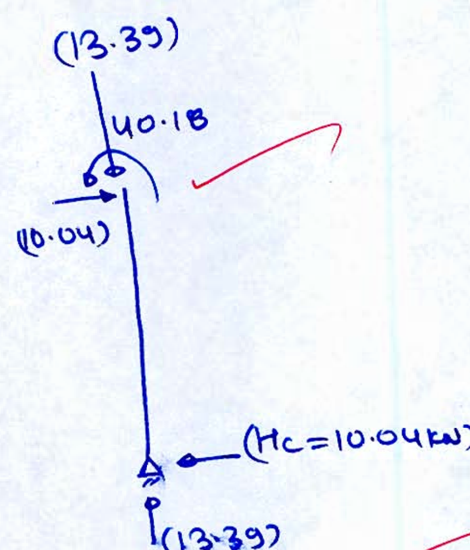
$M_{AB} = 0$

$M_{BA} = -40.18\ kN\text{-}m$

$M_{BC} = 40.18\ kN\text{-}m$

$M_{CB} = 66.96\ kN\text{-}m$





$V_c = \frac{66.96 + 40.18}{8}$

$[V_c = 13.39\ kN\ (\downarrow)]$

$[H_A = 10.04\ kN\ (\rightarrow)]$

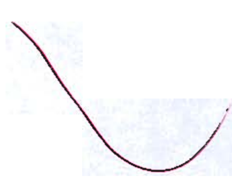
$H_c = \frac{40.18}{4}$

$[H_c = (10.04\ kN) \leftarrow]$

Draw 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]



Do not write in this margin

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

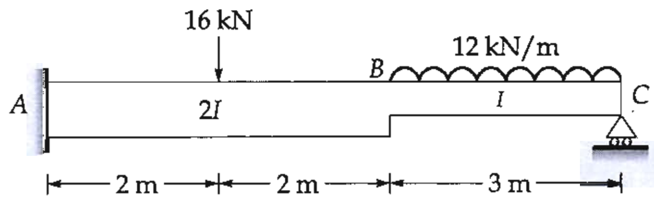
(ii) The objective is to plan a Civil Engineering project using CPM-Network analysis based on the provided activity data. This involves drawing the network, establishing the critical path, preparing a complete *CPM* schedule with total, free, and independent floats, and computing the total project duration.

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]

Do not write in this margin

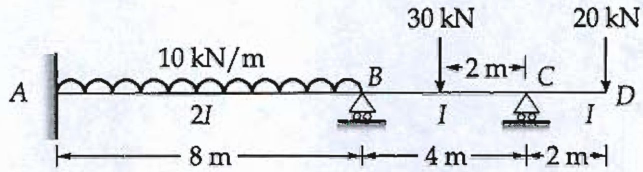
Q.7 (c) Analyse the beam shown in the figure using moment distribution method.



[20 marks]

Do not write in this margin

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]

$M_{CD} = -20\times2 = -40$ kN-m

$Mf_{AB} = -\frac{10\times8^2}{12} = -53.33$ kN-m

$Mf_{BA} = 53.33$ kN-m

$Mf_{BC} = -\frac{30\times4}{8} = -15$ kN-m

$Mf_{CB} = 15$ kN-m

Now By SDM

$M_{AB} = -53.33 + \frac{2E(2I)}{8}(\theta_B) = -53.33 + 0.5EI\theta_B$

$M_{BA} = 53.33 + EI\theta_B$

$M_{BC} = -15 + \frac{2EI}{4}(2\theta_B + \theta_C) = -15 + EI\theta_B + 0.5EI\theta_C$

$M_{CB} = 15 + 0.5EI\theta_B + EI\theta_C$

By Compatibility

$\Rightarrow M_{CB} + M_{CD} = 0$

$15 + 0.5EI\theta_B + EI\theta_C - 40 = 0$

$[0.5EI\theta_B + EI\theta_C = 25]$ —(1)

$\Rightarrow M_{BA} + M_{BC} = 0 \Rightarrow 38.33 + 2EI\theta_B + 0.5EI\theta_C = 0$

$[2EI\theta_B + 0.5EI\theta_C = -38.33]$ —(2)

from ① & ②

$$\left[\begin{array}{l}\theta_B = -29.05/EI \\ \theta_C = 39.52/EI\end{array}\right]$$

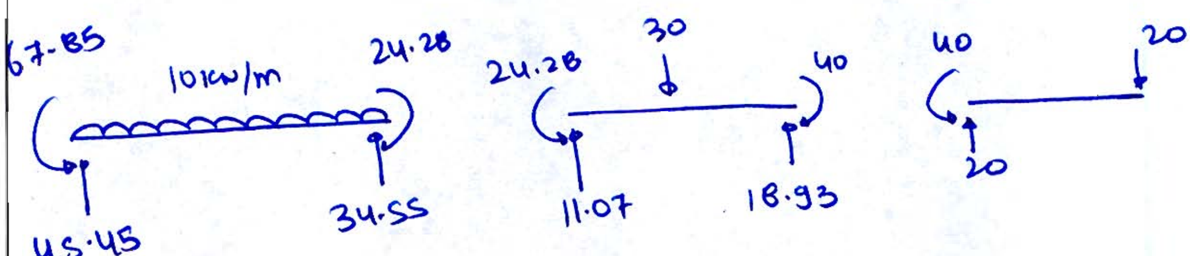
$M_{AB} = -67.85$ kN-m

$M_{BA} = 24.28$ kN-m

$M_{BC} = -24.28$ kN-m

$M_{CB} = 40$ kN-m

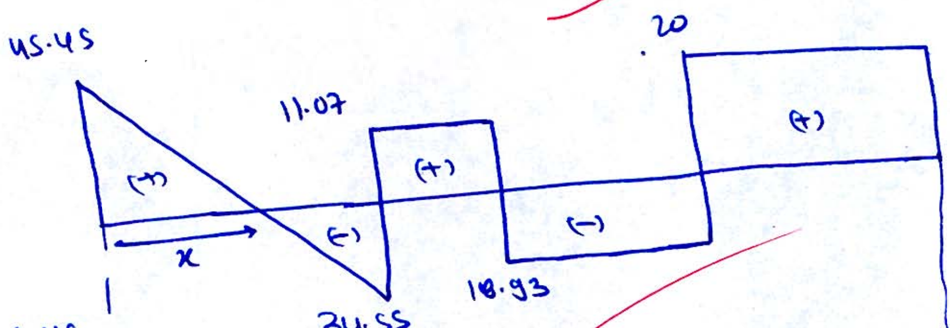
18



$V_B = 34.55 + 11.07 = 45.62$ kN (↑)

$V_C = 18.93 + 20 = 38.93$ kN (↑)

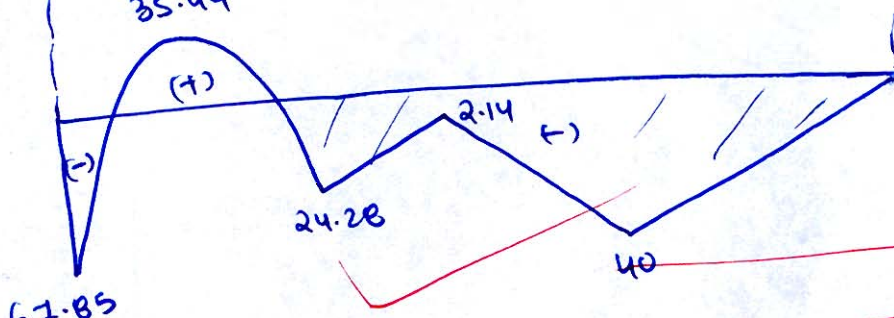
SFD



$x = \frac{45.45}{10}$

$= 4.54$ m

BMD



Do not write in this margin

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]

(i) for wide Rectangular channel

$(R = y)$

$$Fr^2 = 1 = \frac{Q^2 T}{g A_c^3} = \frac{Q^2 \cdot B}{g(B \cdot y_c)^3} = \frac{q^2}{g y_c^3}$$

$$\left[y_c = \left(\frac{q^2}{g}\right)^{1/3} \right]$$

Now

$$Q_c = \frac{A_c}{n} \cdot (R)^{2/3} (S_c)^{1/2}$$

$$Q_c = \frac{B \cdot y_c}{n} \cdot (y_c)^{2/3} (S_c)^{1/2} \qquad (Q_c/B = q)$$

$$q = \frac{(y_c)^{5/3}}{n} (S_c)^{1/2} \qquad y_c = \left(\frac{q^2}{g}\right)^{1/3}$$

$$(y_c)^{5/3} = \left(\frac{q^2}{g}\right)^{5/9}$$

$$q = \frac{(q^2/g)^{5/9}}{n} (S_c)^{1/2}$$

$$(Sc)^{1/2} = \frac{n(g)^{5/9}}{\cancel{g^{5/9}}} \cdot 9^{(1-10/9)}$$

$$(Sc)^{1/2} = \frac{n(g)^{5/9}}{\cancel{g^{5/9}}} \cdot 9^{(-1/9)}$$

$$(Sc)^{1/2} = \frac{n(g)^{5/9}}{(9)^{1/9}}$$

$$\boxed{Sc = \frac{n^2 \cdot g^{10/9}}{9^{2/9}}}$$

(8)

(ii)

① **Lump sum Contract :-** In this contract a lump sum amount is provided to Contractor on the Basis of Quantities and rate of Item Including Certain profit for the contractor.

→ Contractor Has Huge Risk in this Contract and no Risk to the owner.

② **Item rate Contract :** It is the Most famous Contract in which the Rate of Contract is Decided on the Basis of rate of each Item used and Payment is made in Parts as the work is Being Completed.

→ Certain clauses for penalty and Escalation are Included in the contract.

(3) Percentage Rate Contract :- In this contract the cost of contract is found by adding the Calculated cost of project and plus some fixed percentage profit to the contractor.

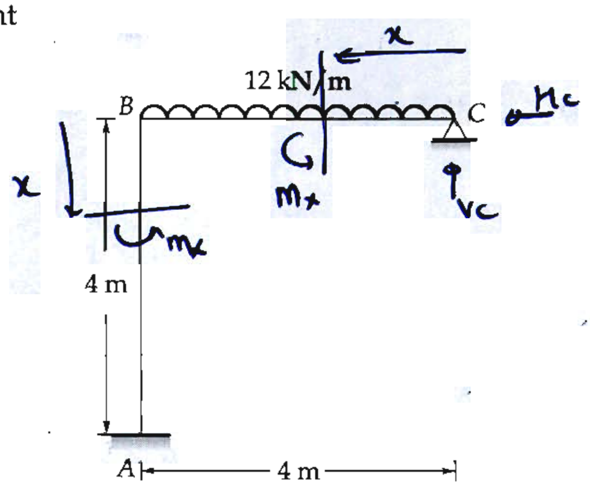
(4) Cost Plus contract :- In this type of contract a fixed profit is Decided for the contractor whatever be the percentage in Respect of the project. Contractor has to complete the JOB in the Decided rates.

8

(5) Turn Key Contract :- It is the type of contract in which All the Responsibility from Design to execution lies with the contractor and Owner Just needs To Turn the Key and start the project after completion.

(7) EPC Contract :- EPC contract is that type of contract in which Engineering, procurement and construction are Contractors Responsibility and Owner Responsibility is only Inspection and Quality check. Often Used for very Big projects.

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



[20 marks]

Let V_c be the Redundant
H_c

for BC: $-M_x - V_c\cdot x + 12\cdot\frac{x^2}{2} = 0$

$[M_x = -V_c\cdot x + 6x^2]$

$\left(m_1 = \frac{\partial M_x}{\partial V_c} = -x\right)$ $\left(m_2 = \frac{\partial M_x}{\partial H_c} = 0\right)$

for AB: $-M_x - V_c\times 4 + 12\times\frac{4^2}{2} - H_c\cdot x = 0$

$(M_x = 96 - 4V_c - H_c\cdot x)$

$m_1 = \frac{\partial M_x}{\partial V_c} = -4$

$\left(m_2 = \frac{\partial M_x}{\partial H_c} = -x\right)$

Now By strain energy theorem

$$\Delta_{V_C} = 0 = \sum \frac{M_x m\, dx}{EI}$$

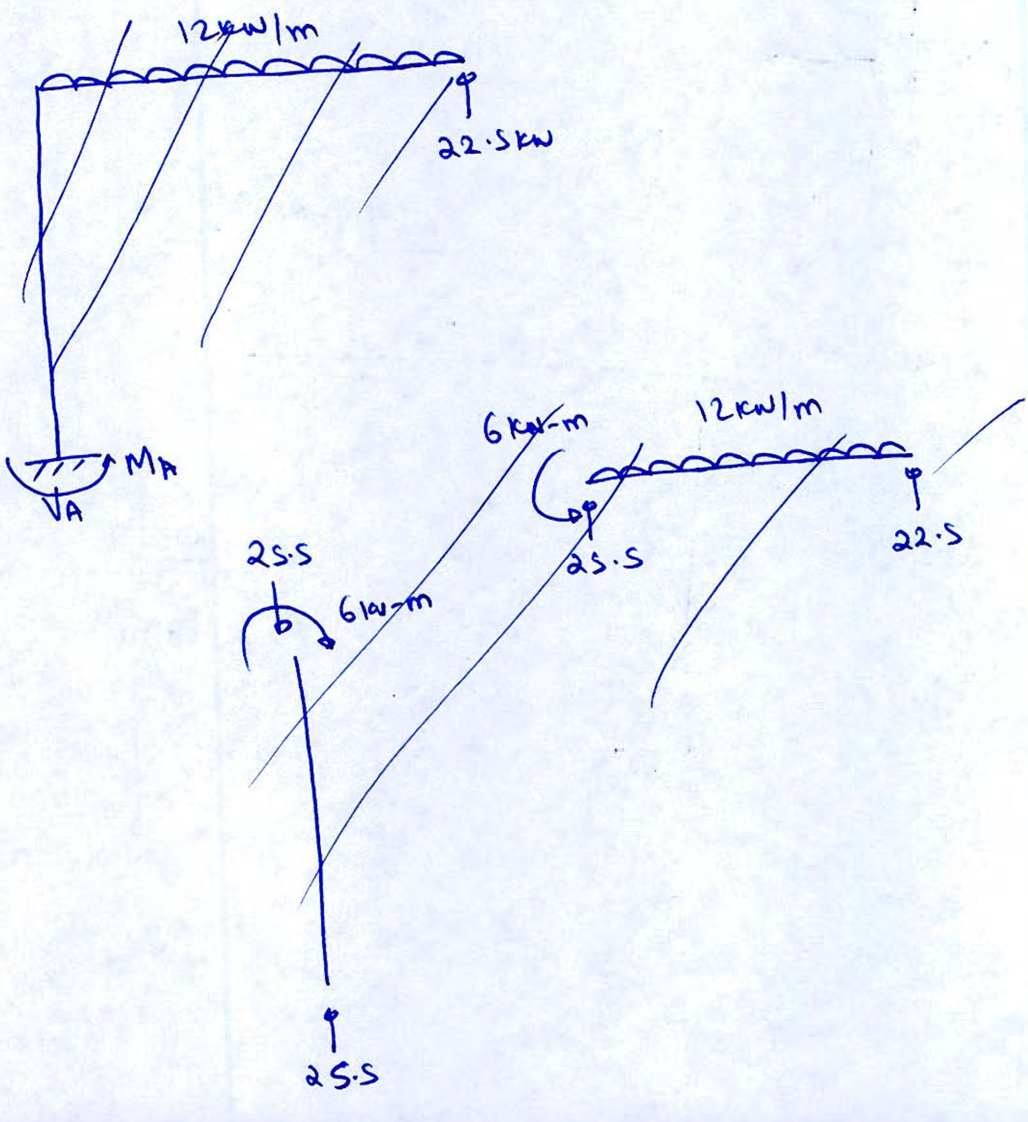
$$\Rightarrow 0 = \int_0^4 [(6x^2 - V_C x)(-x)]dx + \int_0^4 (96 - 4V_C - H_C x)(-4)\,dx$$

$$0 = -\frac{6\times 4^4}{4} + \frac{V_C(4)^3}{3} - 96\times4\times4 + 16V_C\times4 + 4H_C\cdot\frac{4^2}{2} = 0$$

18

~~$\Rightarrow 0 = -1920 + \frac{256}{3}V_C = 0$~~

~~$V_C = 22.5\,kN$~~ $\left[\frac{256}{3}V_C + 32H_C = 1920\right]$ —(1)



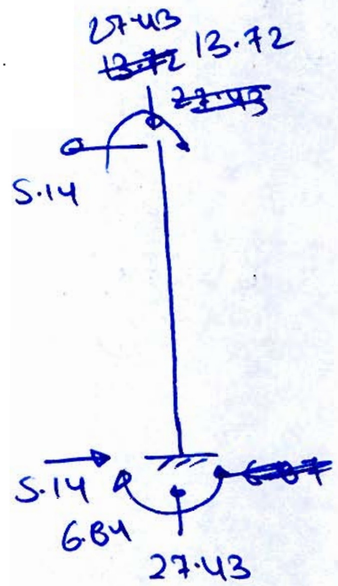
$$\Delta H_c = 0 = \int \frac{M_x m_2 \, dx}{EI}$$

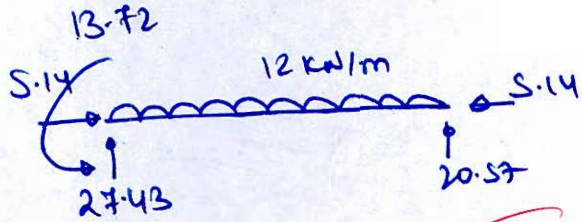
$$0 = \int_0^4 (96 - 4V_c - H_c x)(-x)\, dx = 0$$

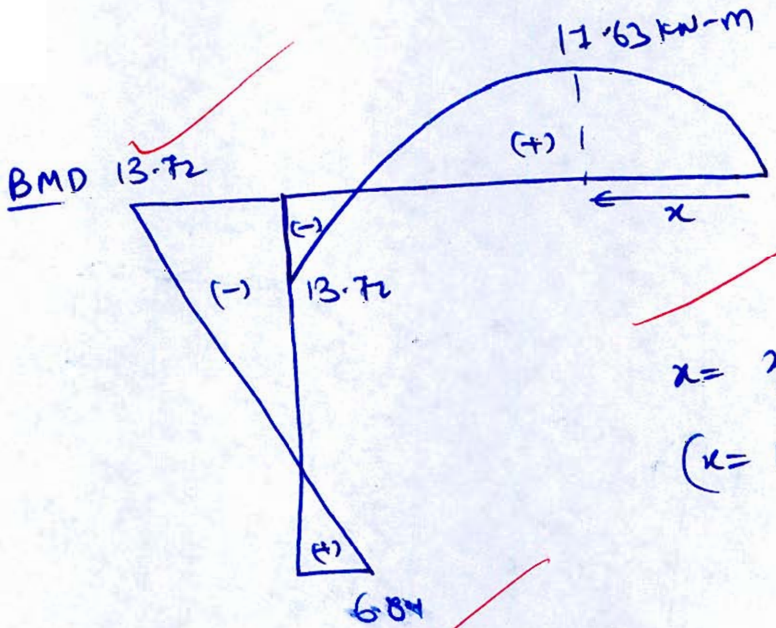
$$\left[-768 + 32V_c + \frac{64}{3} H_c = 0\right] \quad -②$$

from ① & ②

$$\begin{cases} V_c = 20.57 \text{ kN} \\ H_c = 5.14 \text{ kN} \end{cases}$$







$$x = \frac{20.57}{12}$$

$$(x = 1.71 \text{ m})$$

oooo

Space for Rough Work

Space for Rough Work