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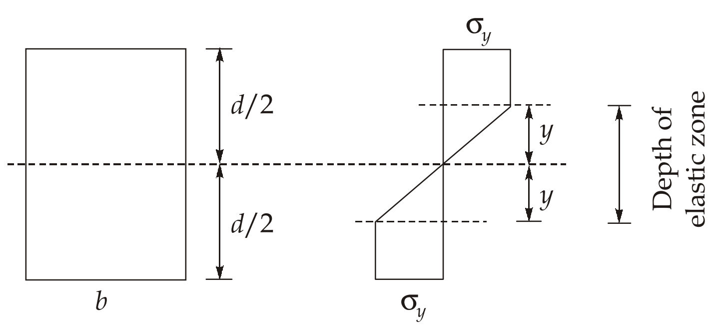
Detailed Solutions

ESE-2022 Mains Test Series

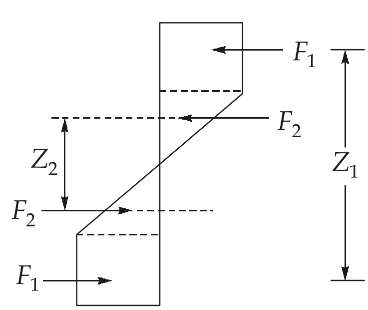
Civil Engineering Test No : 7

Q.1 (a) Solution:



$$\text{Depth of elastic zone} = y + y = 2y$$

$$\text{Depth of plastic zone} = d - 2y$$



$\therefore$ Moment of resistance of section, $M = F_1Z_1 + F_2Z_2$

$$F_1 = \sigma_y \times b \times \left(\frac{d}{2} - y\right)$$

$$Z_1 = \left[y + \left(\frac{d}{2} - y\right) \times \frac{1}{2}\right] \times 2 = 2y + \frac{d}{2} - y = y + \frac{d}{2}$$

Now,
$$F_2 = \frac{1}{2} \times \sigma_y \times y \times b = \frac{\sigma_y yb}{2}$$

$$Z_2 = \left[\frac{2y}{3}\right] \times 2 = \frac{4y}{3}$$

$\therefore$
$$M = \sigma_y b\left(\frac{d}{2} - y\right) \times \left[\frac{d}{2} + y\right] + \frac{\sigma_y yb}{2} \times \frac{4y}{3}$$

$\Rightarrow$
$$M = \sigma_y b\left[\frac{d^2}{4} - y^2\right] + \frac{4}{6}\sigma_y by^2$$

$\Rightarrow$
$$M = \sigma_y \times \frac{bd^2}{4} - \sigma_y by^2 + \frac{2}{3}\sigma_y by^2$$

$\Rightarrow$
$$M = \frac{\sigma_y bd^2}{4} - \frac{\sigma_y by^2}{3}$$

$\Rightarrow$
$$M = \frac{3\sigma_y bd^2 - 4\sigma_y by^2}{12} \quad \text{...(i)}$$

Given applied bending moment = $0.8M_p$ ...(ii)

We know that shape factor for a rectangular section is 1.5.

$\therefore$
$$\text{SF} = \frac{Z_p}{Z_e} = 1.5$$

$\Rightarrow$
$$Z_p = 1.5Z_e$$

$\Rightarrow$
$$Z_p = 1.5 \times \frac{bd^2}{6} = \frac{bd^2}{4}$$

Using eq. (i) and (ii),

$$\frac{3\sigma_y bd^2 - 4\sigma_y by^2}{12} = 0.8 \times \sigma_y \times \frac{bd^2}{4}$$

$\Rightarrow$
$$\frac{\sigma_y b\left[3d^2 - 4y^2\right]}{12} = 0.2\sigma_y bd^2$$

$\Rightarrow$
$$3d^2 - 4y^2 = 2.4d^2$$

$\Rightarrow$
$$0.6d^2 = 4y^2$$

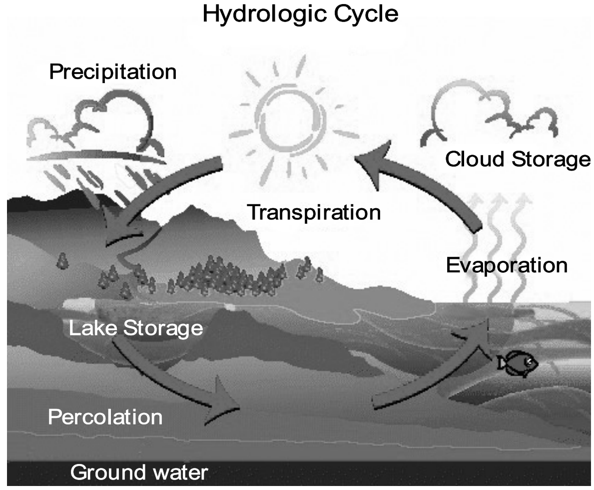
$\Rightarrow$
$$y = \sqrt{\frac{0.6}{4}d^2} = 0.387d$$

$\therefore$ Total depth of elastic core = $2y = 0.774\,d$

Q.1 (b) Solution:

(i) Hydrologic cycle: On planet Earth, water is stored in following reservoirs viz. oceans, rivers, soils, glaciers and as groundwater. Hydrologic cycle is a sort of conceptual model that describes the movement of water within the Earth traversing through the hydrosphere (oceans), lithosphere (ground), atmosphere and biosphere. Thus water moves from one reservoir to another by various processes like evaporation, condensation, transpiration, precipitation, runoff, infiltration, melting of ice, ground water flow etc. All this is described by the Hydrologic cycle.

Hydrologic Cycle



The various processes involved in the hydrologic cycle are as follows:

Evaporation: Evaporation from the oceans and other water bodies like lakes, ponds, streams etc. goes on throughout the day and night but its rate varies from time of the day. Evaporation rate is highest somewhere around mid-noon and least at night. Thus liquid water gets converted to gaseous state which leads to formation of clouds. Evaporation is measured by Pan evaporation method as

$$\text{Evaporation (in mm)} = \text{Pan coefficient} \times \text{Pan evaporation (in mm)}$$

Transpiration: It is the loss of water from the plant leaves. It also leads to formation of clouds. Transpiration rate varies from plant to plant and from time to time in a day and in the year too.

Evaporation and transpiration (i.e. evapotranspiration) are quantified by the use of *Blaney Criddle* equation as

$$ET_o = kp$$

where $$k = 0.46T_{avg} + 8$$

Condensation: This gaseous form of water when rises up gets cooler and becomes denser where gaseous water gets converted into tiny water droplets. This commences the formation of clouds. These clouds get carried away due to wind.

Precipitation: When clouds become sufficiently heavy due to condensation of water, they cannot retain the weight of water and thus it comes back to earth in the form of precipitation. Precipitation can occur in various forms like rain, hail, sleet, mist etc. depending of characteristics of the location and weather conditions. Precipitation is measured by rain gauges.

Infiltration: Once precipitation has started, some part of it flows on the surface called as *overland flow* which joins the streams. A part of this precipitation infiltrates through the ground and flows below ground called as base flow. It is quantified by Horton's infiltration equation as:

$$f_t = f_c + (f_o - f_c)e^{-kt}$$

where f_t = Infiltration rate at any time 't'

f_c = Final or equilibrium infiltration capacity of the soil

f_o = Infiltration capacity at time t = 0.

k = A constant (Horton's constant) that represents a decrease in infiltration capacity.

(ii) Using Mayer's formula,

Evaporation losses, $E = k_m(e_s - e_a)\left[1 + \frac{V_9}{16}\right]$

Given, $k_m = 0.36$

e_s = 32 mm of Hg and Relative humidity = 45%

So, $e_a = 0.45 \times 32 = 14.4$ mm of Hg

And, $V_9 = V_n\left(\frac{9}{4}\right)^{1/7} = 18.6\left(\frac{9}{4}\right)^{1/7} = 20.88 \text{ km/h}$

$\therefore$ $E = 0.36(32 - 14.4)\left[1 + \frac{20.88}{16}\right] = 14.604 \text{ mm/day}$

Q.1 (c) Solution:

$$D_{se} = 3 + 3 - 3 = 3$$

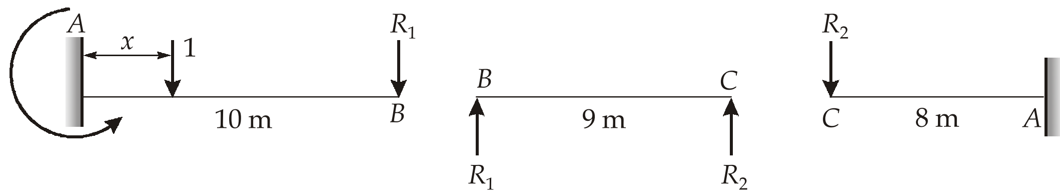
$$D_{si} = 0$$

$$F_r = 1 + 2 = 3$$

$\therefore$ $D_s = 3 - 3 = 0$

Hence, ILDs will be linear function for moment and shear force at A.

Unit load in the region *AB*,



Consider span *BC*

$\Sigma F_y = 0 \Rightarrow$ $\Sigma F_y = 0 \Rightarrow R_2 \times 9 = 0$

$\Rightarrow R_2 = 0$

$\therefore R_1 + R_2 = 0$

$R_1 = R_2 = 0$

Consider span *AB*,

$SF_A = 1 + R_1$ $[R_1 = 0 \text{ for } x \in (0, 10\text{ m})]$

$\Rightarrow SF_A = 1 \text{ unit}$

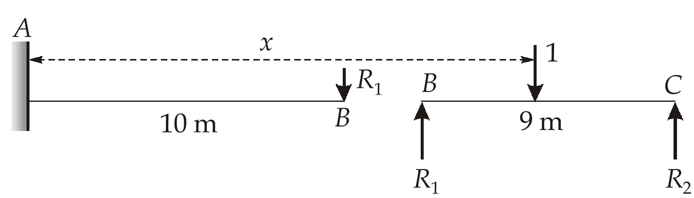
$M_A = 1 \times x + R_1 \times 10$ $x \in (0, 10)$

But since in *AB* $R_1 = 0,\ M_A = 1 \times x$

$\therefore$ At $x = 0\text{ m},\ M_A = 0$

At $x = 10\text{ m},\ M_A = 10$

Unit load in the region *BC*



For span *BC*,

$\Sigma F_y = 0 \Rightarrow R_1 + R_2 = 1$

$\Sigma M_C = 0$

$\Rightarrow R_1 \times 9 = 19 - x$

$\Rightarrow R_1 = \dfrac{19 - x}{9}$

$\therefore SF_A = R_1 = \dfrac{19 - x}{9}$

At $x = 10\text{ m},\ R_1 = 1$

At $x = 19\text{ m},\ R_1 = 0$

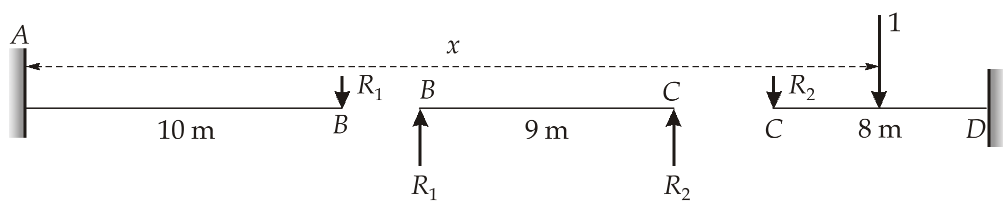
In span AB, $M_A = R_1 \times 10$ $\left[R_1 = \frac{19-x}{9} \text{ for } x \in (10\text{ m}, 19\text{ m})\right]$

$\Rightarrow$ $M_A = \frac{19-x}{9} \times 10$

At $x = 10$ m, $M_A = 10$

At $x = 19$ m, $M_A = 0$

Unit load in region *CD*,

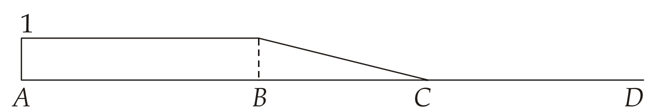


From span BC $R_1 = R_2 = 0$

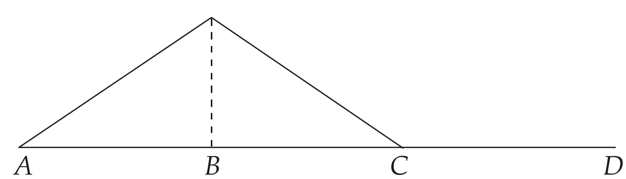
$\Rightarrow$ $SF_A = R_1 = 0$ for $x \in (19\text{ m}, 27\text{ m})$

$M_A = R_1 \times x = 0$ $x \in (19\text{ m}, 27\text{ m})$

ILD for shear force at A.



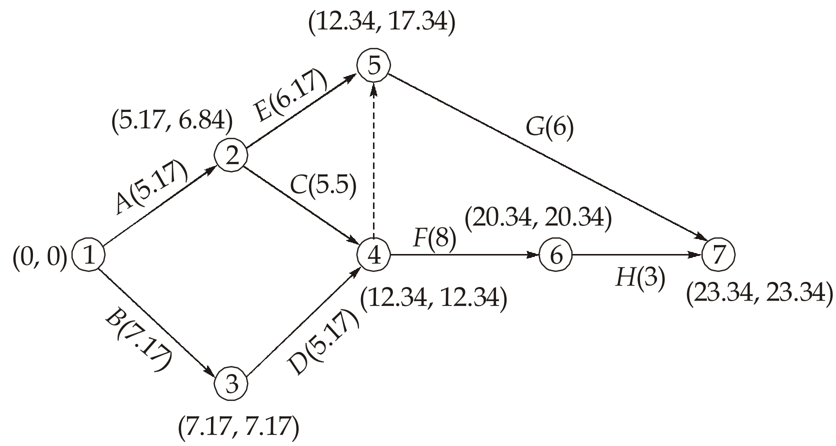
ILD for bending moment at A.



Q.1 (d) Solution:

(i)

Activity	Expected time $\left(t_e = \frac{a+4m+b}{6}\right)$
A	5.17
B	7.17
C	5.5
D	5.17
E	6.17
F	8
G	6
H	3



(ii) Critical path is: $1 \rightarrow 3 \rightarrow 4 \rightarrow 6 \rightarrow 7$

i.e., *B*, *D*, *F* and *H* are critical activities.

$\therefore$ Expected project completion time = 23.34 weeks.

Q.1 (e) Solution:

Given: $y_1 = 25 \text{ cm} = 0.25 \text{ m}$

$V_1 = 15 \text{ m/s}$

Froude number, $$Fr_1 = \frac{V_1}{\sqrt{gy_1}} = \frac{15}{\sqrt{9.81 \times 0.25}} = 9.58 > 1$$

$\therefore$ Super-critical flow

Applying Belenger's momentum equation,

$$\frac{y_2}{y_1} = \frac{-1+\sqrt{1+8Fr_1^2}}{2}$$

$$\Rightarrow \quad \frac{y_2}{0.25} = \frac{-1+\sqrt{1+8(9.58)^2}}{2}$$

$$y_2 = 3.26 \text{ m}$$

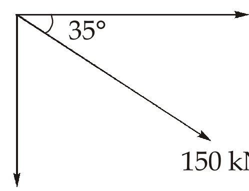
For downstream velocity, $V_2 y_2 = V_1 y_1$

$$\Rightarrow \quad V_2 = \frac{15 \times 0.25}{3.26} = 1.15 \text{ m/s}$$

$\therefore$ Head loss due to jump, $$E_l = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(3.26-0.25)^3}{4 \times 0.25 \times 3.26} = 8.365 \text{ m}$$

Q.2 (a) Solution:

$$\text{Factored load} = 1.5 \times 100 = 150 \text{ kN}$$



Grade of steel used, Fe410

$$\therefore \quad f_u = 410 \text{ MPa}, f_y = 250 \text{ MPa}$$

Grade of bolt used, 4.6

$$\therefore \quad f_{ub} = 400 \text{ MPa}$$

$$f_{yb} = 0.6 \times 400 = 240 \text{ MPa}$$

Tension in each bolt, $T_b = \dfrac{122.873}{8} = 15.359 \text{ kN}$

Shear in each bolt, $V_b = \dfrac{86.036}{8} = 10.755 \text{ kN}$

Strength of single bolt in shear,

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}\left[n_n A_n + n_s A_s\right]$$

$$\Rightarrow \quad V_{\text{dsb}} = \frac{400}{\sqrt{3} \times 1.25} \times 0.78 \times \frac{\pi}{4} \times 16^2 \text{ N}$$

$$V_{\text{dsb}} = 28.97 \text{ kN}$$

Strength of bolt in tension

(a) Gross section yielding, $T_{ng} = \dfrac{\left(\dfrac{\pi}{4} d^2 \times f_{yb}\right)}{\gamma_{mo}}$

$$\Rightarrow \quad T_{ng} = \frac{\frac{\pi}{4} \times 16^2 \times 240}{1.1} \text{ N} = 43868.06 \text{ N}$$

$$\Rightarrow \quad T_{ng} \simeq 43.87 \text{ kN}$$

(b) Net section rupture, $T_{nb} = \dfrac{0.9 \times f_{ub} \times A_{nb}}{\gamma_{mb}}$

$$\Rightarrow \quad T_{nb} = \frac{0.9 \times 400 \times 0.78 \times \frac{\pi}{4} \times 16^2}{1.25} \text{ N} = 45166.55 \text{ N}$$

$$\Rightarrow \quad T_{nb} \simeq 45.167 \text{ kN}$$

$\therefore$ Strength of bolt in tension, $T_{db} \simeq 43.87$ kN

Checking with interaction equation

$$\left(\frac{V_b}{V_{dsb}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \leq 1$$

$$\Rightarrow \quad \left(\frac{10.755}{28.97}\right)^2 + \left(\frac{15.359}{43.87}\right)^2 \leq 1$$

$$\Rightarrow \quad 0.1378 + 0.1226 \leq 1$$

$$\Rightarrow \quad 0.2604 \leq 1$$

Hence, the connection is safe and section *P-P* also.

Connection of double angle section to the web of Tee-bracket.

The angles are placed on the opposite sides of the web of tee-bracket.

Here the bolts (18 mm) will be in double shear and bearing.

Strength of bolt in double shear,

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

$$\Rightarrow \quad V_{\text{dsb}} = 2 \times 0.78 \times \frac{\pi}{4} \times 18^2 \times \frac{400}{\sqrt{3} \times 1.25}$$

$$= 73341.34 \text{ N} \simeq 73.341 \text{ kN}$$

Strength of bolt in bearing,

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

$$k_b = \text{minimum}\left[\frac{e}{3d_0}, \frac{p}{3d_0} - 0.25, \frac{f_{ub}}{f_u}, 1\right]$$

$$= \text{minimum}\left[\frac{50}{3 \times (20)}, \left(\frac{60}{3 \times 20} - 0.25\right), \frac{400}{410}, 1\right]$$

$$= \text{minimum}[0.833, 0.75, 0.976, 1] = 0.75$$

$$t = \text{minimum}(8 + 8,\ 10) = 10 \text{ mm}$$

$$\therefore \quad V_{dpb} = \frac{2.5 \times 0.75 \times 18 \times 10 \times 410}{1.25} = 110700 \text{ N} = 110.7 \text{ kN}$$

Strength of bolt, V_{db} = minimum [73.341, 110.7] = 73.341 kN

$$\therefore \quad \text{No. of bolts required} = \frac{150}{73.341} = 2.045 \simeq 3 \text{ bolts}$$

Thus, provide 3 bolts of 18 mm diameter of grade 4.6 for making the connections.

Q.2 (b) Solution:

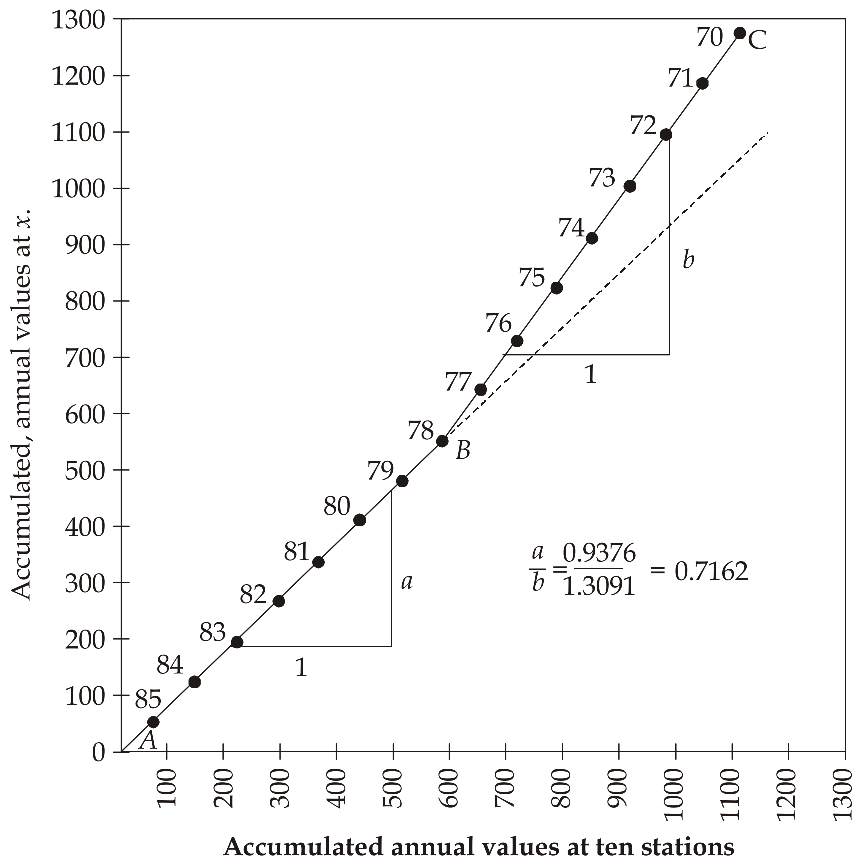
(i) Double Mass Curve of Rainfall:

Double mass curve is a technique used for checking the consistency of rainfall record. The trend in the rainfall records at a station may slightly change after some years due to change in the environment of a station, or tampering of the instrument or shift in the observation practices. The change due to meteorological factors will equally affect all stations in the test and thus will cause a lack of consistency created by the external effects.

A double mass curve is a graph plotted between the accumulated annual rainfall at a given station X(test station) versus accumulated annual values of the average of group of base stations, for various consecutive time periods.

(ii) Computations for cumulative rainfalls at station X and at average of 10 surrounding stations are arranged in tabular form as under, starting from data of most recent year.

Year	Annual rainfall at X (cm)	Cumulative rainfall at X (cm)	Average of annual rainfall at 10 base stations (cm)	Cumulative rainfall of base station (cm)
1985	69	69	77	77
1984	55	124	62	139
1983	62	186	67	206
1982	67	253	68	274
1981	87	340	86	360
1980	70	410	90	450
1979	65	475	65	515
1978	75	550	75	590
1977	90	640	70	660
1976	100	740	70	730
1975	90	830	70	800
1974	95	925	75	875
1973	85	1010	65	940
1972	90	1100	70	1010
1971	75	1175	55	1065
1970	95	1270	75	1140

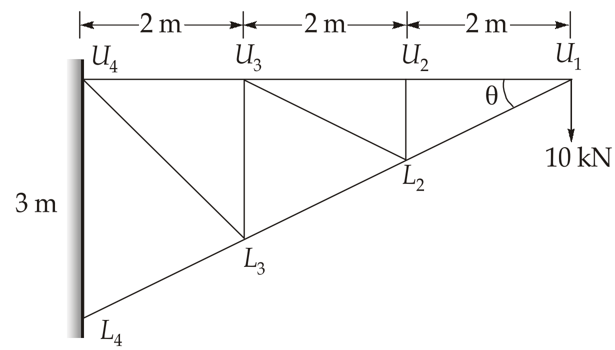


$$P_{xe} = P_x \times \frac{a}{b} = 0.7162 P_x$$

The corrected rainfall data at station X are tabulated as under:

Year	Observed rainfall at X (= P_x) (cm)	Adjusted rainfall at X, P_{xe} = 0.7162P_x (cm)
1970	95	68.04
1971	75	53.72
1972	90	64.46
1973	85	60.88
1974	95	68.04
1975	90	64.46
1976	100	71.62
1977	90	64.46

Q.2 (c) Solution:



$$\tan\theta = \frac{3}{6} = \frac{1}{2}$$

$$\sin\theta = \frac{1}{\sqrt{5}}, \cos\theta = \frac{2}{\sqrt{5}}$$

$$\delta_V = \Sigma\frac{Pk_v l}{AE} \qquad \text{(Unit load applied in vertical direction at } U_1\text{)}$$

$$\delta_H = \Sigma\frac{Pk_H l}{AE} \qquad \text{(Unit load applied in horizontal direction at } U_1\text{)}$$

P = Force in a member due to applied external load

l = Length of member

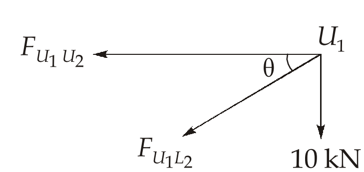
A = Cross-sectional area of member

E = Young's modulus

k = Force in a member due to unit load

Members carrying zero force : U_2L_2, U_3L_2, U_3L_3, U_4L_3

Consider joint U_1



$\Sigma F_V = 0$

$$\Rightarrow \quad F_{U_1L_2}\sin\theta + 10 = 0$$

$$\Rightarrow \quad F_{U_1L_2} = -10\sqrt{5}\,\text{kN} = 10\sqrt{5}\,\text{kN (C)}$$

$\Sigma F_H = 0$

$$\Rightarrow \quad F_{U_1L_2}\cos\theta + F_{U_1U_2} = 0$$

$$\Rightarrow \quad F_{U_1U_2} = 10\sqrt{5} \times \frac{2}{\sqrt{5}} = 20\,\text{kN (T)}$$

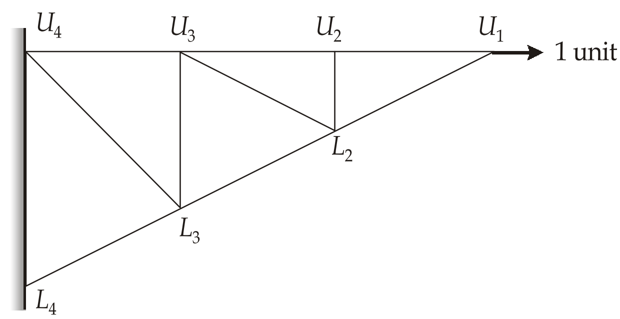
$$F_{U_2U_3} = 20 \text{ kN (T)}$$

$$F_{U_3U_4} = 20 \text{ kN (T)}$$

$$F_{L_2L_3} = -10\sqrt{5}\,\text{kN} = 10\sqrt{5}\,\text{kN (C)}$$

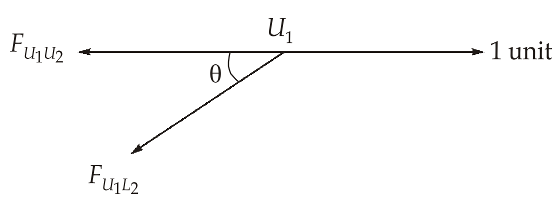
$$F_{L_3L_4} = -10\sqrt{5}\,\text{kN} = 10\sqrt{5}\,\text{kN (C)}$$

For horizontal deflection, apply unit load at U_1 in horizontal direction.



Zero force members : U_2L_2, U_3L_2, U_3L_3, U_4L_3, U_1L_1, L_2L_3, L_3L_4

Consider joint U_1



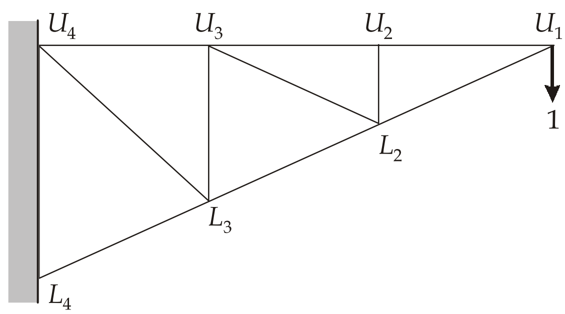
$$\Sigma F_H = 0 \quad \Rightarrow F_{U_1L_2} = 1 \text{ unit}$$

$$\therefore \quad F_{U_1U_2} = F_{U_2U_3} = F_{U_3U_4} = 1 \text{ unit}$$

Member	P(kN)	Length (mm) (L)	Area (mm^2)(A)	k_H (k)	$\frac{PkL}{AE}$(mm)
U_1U_2	20	2000	800	1	0.25
U_2U_3	20	2000	800	1	0.25
U_3U_4	20	2000	800	1	0.25
U_1L_2	$-10\sqrt{5}$	$\sqrt{5}\times 10^3$	1200	0	0
L_2L_3	$-10\sqrt{5}$	$\sqrt{5}\times 10^3$	1200	0	0
L_3L_4	$-10\sqrt{5}$	$\sqrt{5}\times 10^3$	1200	0	0
U_2L_2	0	1000	400	0	0
U_3L_3	0	2000	400	0	0
U_3L_2	0	$\sqrt{5}\times 10^3$	400	0	0
U_4L_3	0	$2\sqrt{2}\times 10^3$	400	0	0

$$\therefore \qquad \delta_H = \Sigma\frac{PkL}{AE} = 0.25 + 0.25 + 0.25 = 0.75 \text{ mm}$$

For vertical deflection, apply unit load at U_1 in vertical direction.



Zero force members : U_2L_2, U_3L_2, U_3L_3, U_4L_3

Member	$P(kN)$	Length (mm)	Area (mm^2)	$k_V = \left(\frac{P(\text{kN})}{1000\times10}\right)(k)$	$\frac{PkL}{AE}$
U_1U_2	20	2000	800	2	0.5
U_2U_3	20	2000	800	2	0.5
U_3U_4	20	2000	800	2	0.5
U_1L_2	$-10\sqrt{5}$	$\sqrt{5}\times10^3$	1200	$-\sqrt{5}$	0.466
L_2L_3	$-10\sqrt{5}$	$\sqrt{5}\times10^3$	1200	$-\sqrt{5}$	0.466
L_3L_4	$-10\sqrt{5}$	$\sqrt{5}\times10^3$	1200	$-\sqrt{5}$	0.466
U_2L_2	0	1000	400	0	0
U_3L_3	0	2000	400	0	0
U_3L_2	0	$\sqrt{5}\times10^3$	400	0	0
U_4L_3	0	$2\sqrt{2}\times10^3$	400	0	0

$$\delta_v = \Sigma\frac{Pk_VL}{AE} = 0.5 \times 3 + 0.466 \times 3 = 2.898 \text{ mm}$$

Q.3 (a) Solution:

Size of weld = 8 mm

Throat thickness = 0.7 × 8 = 5.6 mm

Total area of weld = 2 × 150 × 5.6 + 300 × 5.6

= 3360 mm^2

Due to symmetry, I_{xx} centroidal axis is at the mid height of vertical weld. Let centroidal y-y axis be at a distance $\bar{x}$ from the vertical weld.

$\bar{x}$ = the distance of the centroid of the weld group from the left edge of the bracket plate.

$$\bar{x} = \frac{2 \times 150 \times 5.6 \times 75}{3360} = 37.5 \text{ mm}$$

$$I_{xx} = \frac{5.6 \times 300^3}{12} + 2\left[\frac{150 \times 5.6^3}{12} + 150 \times 5.6 \times 150^2\right]$$

$$= 12.6 \times 10^6 + 37.804 \times 10^6$$

$$= 50.404 \times 10^6 \text{ mm}^4$$

$$I_{yy} = 2\left[\frac{5.6 \times 150^3}{12} + 5.6 \times 150 \times (75 - 37.5)^2\right]$$

$$+ \frac{300 \times 5.6^3}{12} + 300 \times 5.6 \times 37.5^2$$

$$= 7.879 \times 10^6 \text{ mm}^4$$

$\therefore$ $$I_p = I_{xx} + I_{yy}$$

$$= 50.404 \times 10^6 + 7.879 \times 10^6$$

$$= 58.283 \times 10^6 \text{ mm}^4$$

Point of maximum radial distance,

$$r_{max} = \sqrt{150^2 + (150 - 37.5)^2} = 187.5 \text{ mm}$$

$$\tan\theta = \frac{150}{(150 - 37.5)} = 1.333$$

$\Rightarrow$ $$\theta = 53.13°$$

Eccentricity of load from CG of the system of weld

$$e = (150 - 37.5) + 250 = 362.5 \text{ mm}$$

Direct shear stress, $$q_1 = \frac{P}{3360} = 2.976 \times 10^{-4} P$$

Shear stress due to torsion, $$q_2 = \frac{P \times e \times r_{max}}{I_{zz}}$$

$\Rightarrow$ $$q_2 = \frac{P \times 362.5 \times 187.5}{58.283 \times 10^6} = 11.662 \times 10^{-4} P$$

We know that, $$q_{resultant} = \sqrt{q_1^2 + q_2^2 + 2q_1q_2\cos\theta}$$

$$\Rightarrow \quad q_{\text{resultant}} = \sqrt{\left(2.976\times10^{-4}P\right)^2+\left(11.662\times10^{-4}P\right)^2+2\times2.976\times11.662\times10^{-8}\times\cos 53.13^\circ}$$

$$\Rightarrow \quad q_{resultant} = 13.657 \times 10^{-4}\,P$$

Weld can resist a stress of $\dfrac{f_{uw}}{\sqrt{3}\gamma_{mw}} = \dfrac{410}{\sqrt{3}\times1.25} = 189.371$ MPa

$$13.657 \times 10^{-4}\,P = 189.371$$

$$\Rightarrow \quad P = 138662.22 \text{ kN}$$

$$\Rightarrow \quad P \simeq 138.66 \text{ kN}$$

Q.3 (b) Solution:

(i) **Assumptions of unit hydrograph theory:** The various assumptions of unit hydrograph theory are as follows:

1. The effective rainfall is uniformly distributed within its duration of specified period of time.
2. The effective rainfall is uniformly distributed throughout the whole area of the drainage basin.
3. The base or time duration of the hydrograph of direct run-off due to an effective rainfall of unit duration is constant.
4. The ordinates of direct run-off of common base-time are directly proportional to the total amount of direct run-off represented by each hydrograph.
5. For a given drainage basin, the hydrograph of run-off due to a given period of rainfall reflects all the combined physical characteristics of the basin.

(ii)

Time in hr	4 hr unit hydrograph ordinates (cumecs)	Imaginary offsetted S-curve (shifted by t_1 = 4 hr) cumecs	S-curve ordinates cumecs	S-curve lagged by 4 hours	Difference (4) – (5)	Required ordinates of 5 hr U.H = (6) × t_1/t_2 = 4/5 col(6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	0	–	0		0	0
1	6	–	6		6	4.8
2	36	–	36		36	28.8
3	66	–	66		66	52.8
4	91	0	91		91	72.8
5	106	6	112	0	112	89.6
6	93	36	129	6	123	98.4
7	79	66	145	36	109	87.2
8	68	91	159	66	93	74.4
9	58	112	170	91	79	63.2
10	49	129	178	112	66	52.8
11	41	145	186	129	57	45.6
12	34	159	193	145	48	38.4
13	27	170	197	159	38	30.4
14	23	178	201	170	31	24.8
15	17	186	203	178	25	20
16	13	193	206	186	20	16
17	9	197	206	193	13	10.4
18	6	201	207	197	10	8
19	3	203	206	201	5	4
20	1	206	207	203	4	3.2
21	0	207	207	206	1	0.8
22	0	207	207	207	0	0

Q.3 (c) Solution:

Given, $d_1 = 2$ m, $N = 400$ rpm, $V_{f_1} = 10$ m/s

$$P = 15 \text{ MW} = 15000 \text{ kW}$$

$$Q = 10 \text{ m}^3/\text{s}$$

$$\left(\frac{p_1}{\rho g}+Z_1\right)-\left(\frac{p_2}{\rho g}+Z_2\right) = 100 \text{ m}$$

(a) At entrance, peripheral velocity,

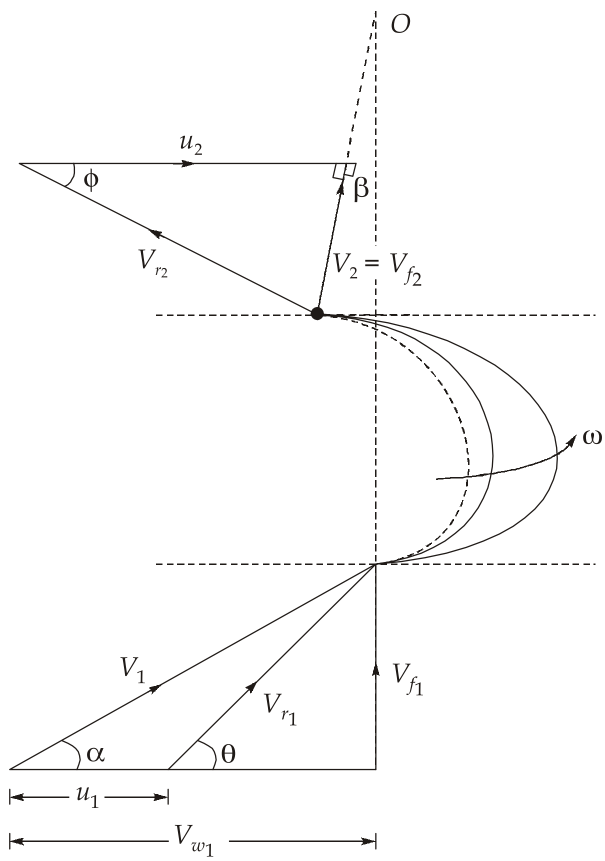
$$u_1 = \frac{\pi d_1 N}{60} = \frac{\pi \times 2 \times 400}{60} = 41.89 \text{ m/s}$$

Now, power produced,

$$P = \rho Q u_1 V_{w_1}$$

Swirl velocity at entry,

$$V_{w_1} = \frac{P}{\rho Q u_1} = \frac{15000 \times 10^3}{1000 \times 10 \times 41.89} = 35.81 \text{ m/s}$$



Absolute velocity, $V_1 = \sqrt{V_{w_1}^2 + V_{f_1}^2} = \sqrt{35.81^2 + 10^2} = 37.18 \text{ m/s}$

From velocity triangle at inlet,

$$\tan \alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{10}{35.81} = 0.279$$

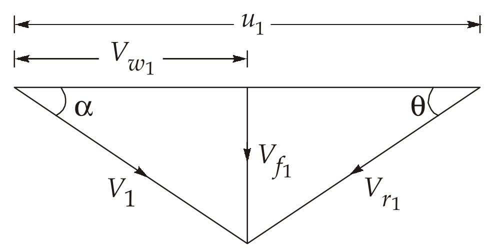
$\Rightarrow$ $\alpha = 15.6°$

(b) Blade angle at inlet, θ

$$\tan\theta = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{10}{35.81 - 41.89} = -1.645$$

$$\Rightarrow \quad \theta = -58.7°$$

Correct velocity triangle at inlet is as shown below.



(c) Loss of head in runner,

Power developed by water,

$$P = \rho g Q H_e$$

$$\Rightarrow \quad H_e = \frac{P}{\rho g Q} = \frac{15\times10^6}{1000\times9.81\times10} = 152.905 \text{ m}$$

Applying energy equation (in terms of head) at the entrance of the runner (1) and at exit from runner (2)

$$H_1 = H_2 + H_e + H_L$$

where, $$H_1 = \left(\frac{p_1}{\rho g} + Z_1\right) + \frac{V_1^2}{2g}$$

and $$H_2 = \left(\frac{p_2}{\rho g} + Z_2\right) + \frac{V_2^2}{2g}$$

$$\therefore \quad \left(\frac{p_1}{\rho g} + Z_1\right) + \frac{V_1^2}{2g} = \left(\frac{p_2}{\rho g} + Z_2\right) + \frac{V_2^2}{2g} + H_e + H_L$$

$$\Rightarrow \left(\frac{p_1}{\rho g} + Z_1\right) - \left(\frac{p_2}{\rho g} + Z_2\right) + \frac{V_1^2}{2g} - \frac{V_2^2}{2g} - H_e = H_L$$

$$\Rightarrow H_L = 100 + \frac{37.18^2 - 10^2}{2\times9.81} - 152.905 = 12.45 \text{ m}$$

(d) For Francis turbine, degree of reaction, R is given by

$$R = 1-\frac{V_{w_1}}{2u_1} = 1-\frac{35.81}{2\times 41.89} = 0.573$$

(e) Given, $N = 200$ (SI)

Specific speed of turbine is given by,

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

where N is in rpm and P is in kW.

$$\Rightarrow \quad 200 = \frac{400\sqrt{15000}}{H^{5/4}}$$

$\Rightarrow$ Net head, $\quad \text{H} = 81.52\text{m}$

Let gross head be H_G.

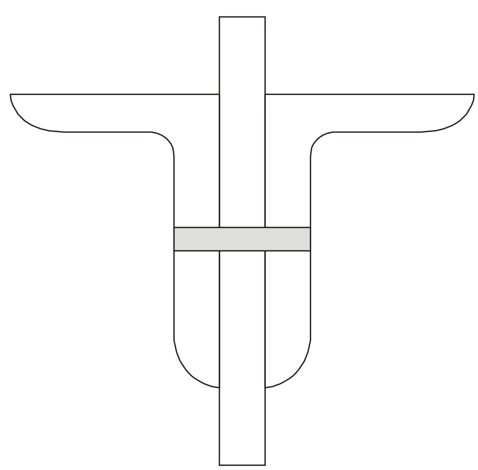
$$\therefore \quad H = H_G - H_F = H_G - 0.3H_G$$

$$\Rightarrow \quad 81.52 = 0.7H_G$$

$$\Rightarrow \quad H_G = 116.46 \text{ m}$$

Q.4 (a) Solution:

Calculation of number of bolts required:



Bolts are in double shear

$$\therefore \quad V_{dsb} = \frac{f_{ub}}{\sqrt{3}\gamma_{mb}}\left[1\times 0.78\times\frac{\pi}{4}\times 20^2 + 1\times\frac{\pi}{4}\times 20^2\right]$$

$$= \frac{400}{\sqrt{3}\times 1.25}\left[0.78\times\frac{\pi}{4}\times 20^2 + \frac{\pi}{4}\times 20^2\right] \text{ N}$$

$$= 103.31 \text{ kN}$$

Given, $e = 40$ mm, $p = 60$ mm

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

$$k_b = \text{minimum}\left[\frac{e}{3d_0}, \left(\frac{p}{3d_0} - 0.25\right), \frac{f_{ub}}{f_u}, 1\right]$$

$$= \text{minimum}\left[\frac{40}{3 \times 22}, \left(\frac{60}{3 \times 22} - 0.25\right), \frac{400}{410}, 1\right]$$

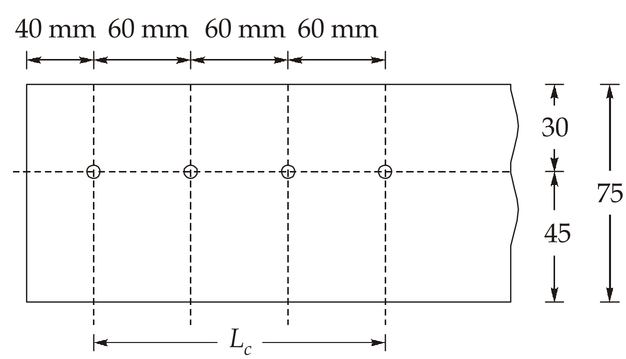
$$= \text{minimum}\left[0.606,\ 0.659, 0.976,\ 1\right] = 0.606$$

$\therefore$
$$V_{dpb} = \frac{2.5 \times 0.606 \times 20 \times (10) \times 400}{1.25}\text{N} = 96.96 \text{ kN}$$

$\therefore$
$$V_{db} = \text{minimum}[103.31,\ \ 96.96] = 96.96 \text{ kN}$$

$\therefore$ No. of bolts required,
$$n = \frac{380}{96.96} = 3.919 \simeq 4 \ (\text{say})$$

$\therefore$ Provide 4 bolts in a row as shown.



Check for design strength check as tension member:

1. Strength against yielding,

$$T_{dg} = \frac{A_g f_y}{\gamma_{m0}}$$

$$A_g = \left[\left(75 - \frac{8}{2}\right) \times 8 + \left(50 - \frac{8}{2}\right) \times 8\right] \times 2 = 1872 \text{ mm}^2$$

$\therefore$
$$T_{dg} = \frac{1872 \times 250}{1.1}\text{N} = 425454.54\,\text{N} \simeq 425.455 \text{ kN}$$

2. Strength against rupture,

$$T_{dn} = \frac{0.9 f_u A_{nc}}{\gamma_{m1}} + \frac{\beta A_{go} f_y}{\gamma_{m0}}$$

Area of connected leg,

$$A_{nc} = 2 \times \left[75 - 22 - \frac{8}{2}\right] \times 8 = 784 \text{ mm}^2$$

Area of outstanding leg,

$$A_{go} = 2\left(50 - \frac{8}{2}\right) \times 8 = 736 \text{ mm}^2$$

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

w =50 mm, t = 8 mm, f_y = 250 MPa, f_u = 410 MPa

$$b_s = w + w_1 - t$$
$$= 50 + 30 - 8 = 72 \text{ mm}$$
$$L_c = 3 \times 60 = 180 \text{ mm}$$

∴ $$\beta = 1.40 - 0.076 \times \frac{50}{8} \times \frac{250}{410} \times \frac{72}{180} = 1.284$$

Now, $$0.7 \le \beta \le \frac{f_u}{f_y} \times \frac{\gamma_{m0}}{\gamma_{m1}}$$

⇒ $$0.7 \le 1.284 \le \frac{410}{250} \times \frac{1.1}{1.25} = 1.4432 \qquad \text{(OK)}$$

∴ $$T_{dn} = \left(\frac{0.9 \times 410 \times 784}{1.25} + \frac{1.284 \times 736 \times 250}{1.1}\right) \times 10^{-3} \text{kN}$$

⇒ $$T_{dn} = 231.437 + 214.778 = 446.215 \text{ kN}$$

3. Strength against block shear

Required areas of section,

$$A_{vg} = (40 + 60 + 60 + 60) \times 8 \times 2 = 3520 \text{ mm}^2$$
$$A_{vn} = (40 + 3 \times 60 - 3.5 \times 22) \times 8 \times 2 = 2288 \text{ mm}^2$$
$$A_{tg} = (75 - 30) \times 8 \times 2 = 720 \text{ mm}^2$$
$$A_{tn} = \left(75 - 30 - \frac{22}{2}\right) \times 8 \times 2 = 544 \text{ mm}^2$$

(i) Shear yielding and tension rupture

$$T_{db_1} = \frac{A_{vg} \times f_y}{\gamma_{m0}\sqrt{3}} + \frac{0.9 A_{tn} f_u}{\gamma_{m1}}$$

$$= \left(\frac{3520 \times 250}{1.1 \times \sqrt{3}} + \frac{0.9 \times 544 \times 410}{1.25}\right) \times 10^{-3} \text{kN}$$

$$= 461.88 + 160.589 = 622.47 \text{ kN}$$

(ii) Shear rupture and tension yielding,

$$T_{db_2} = \frac{0.9 A_{vn} f_u}{\gamma_{m1} \times \sqrt{3}} + \frac{A_{tg} f_y}{\gamma_{m0}}$$

$$= \left(\frac{0.9 \times 2288 \times 410}{1.25 \times \sqrt{3}} + \frac{720 \times 250}{1.1}\right) \times 10^{-3} \text{kN}$$

$$= 389.95 + 163.636 = 553.586 \text{ kN}$$

$\therefore$ Block shear strength $= \text{minimum}\left[T_{db1}, T_{db2}\right] = 553.586 \text{ kN}$

Since in all the three cases considered, strength is found to be greater than the applied load.

Hence, use of 2ISA 75 × 50 × 8 with 4 bolts of 20 mm (grade 4.6) is safe.

Q.4 (b) Solution:

(i) The weight per unit length lumped at the deck level = Ar

$$= 10 \times 25 = 250 \text{ kN/m}$$

The total lumped weight at the deck level

$$W = 100 \times 250 = 25000 \text{ kN}$$

Mass, $$m = \frac{W}{g} = 2548.42 \times 10^3 \text{kg}$$

The longitudinal stiffness provided by each pier is

$$k_p = \frac{12EI}{l^3} \times 4 \qquad \{1 \text{ pier} \rightarrow 4 \text{ column}\}$$

$$\Rightarrow \quad k_p = \frac{12 \times 28000 \times 10^6 \times 0.12 \times 4}{8^3} \text{ N/m}$$

$$\Rightarrow \quad k_p = 315000 \text{ kN/m}$$

Two piers provide total stiffness $k = 2 \times 315000 = 6.3 \times 10^5$ kN/m $= 6.3 \times 10^8$ N/m

The equation of motion in x-direction is given by

$$m\ddot{x} + kx = 0$$

$$\Rightarrow 2548.42 \times 10^3 \ddot{x} + 6.3 \times 10^8 x = 0$$

Natural circular frequency,

$$w = \sqrt{\frac{k}{m}} = \sqrt{\frac{6.3 \times 10^8}{2548.42 \times 10^3}} = 15.723 \text{ rad/sec}$$

Natural period, $$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{2548.42 \times 10^3}{6.3 \times 10^8}} = 0.399 \text{ second}$$

$$\text{Natural frequency} = \frac{\omega}{2\pi} = \frac{15.723}{2\pi} = 2.5/\text{seconds}$$

(ii)

$$\Delta z = 0.15 \text{ m}$$

$$y_1 = 0.8 \text{ m}$$

$$V_1 = 1.2 \text{ m/s}$$

Upstream Froude number,

$$F_{r_1} = \frac{V_1}{\sqrt{gy}} = \frac{1.2}{\sqrt{9.81 \times 0.8}} = 0.428 < 1$$

∴ Subcritical flow.

$$E_1 = E_2 + \Delta z$$

$$\Rightarrow \quad y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g} + \Delta z$$

$$\Rightarrow \quad 0.8 + \frac{1.2^2}{2 \times 9.81} = y_2 + \frac{\left(\frac{y_1 V_1}{y_2}\right)^2}{2 \times 9.81} + 0.15$$

$$\Rightarrow \quad 0.873 = y_2 + \frac{0.047}{y_2^2} + 0.15$$

$$\Rightarrow \quad 0.723 y_2^2 = y_2^3 + 0.047$$

$$\Rightarrow \quad y_2 = -0.22 \text{ m}, 0.586 \text{ m}, 0.36 \text{ m}$$

Neglect the –ve value,

$$\therefore \quad y_2 = 0.586 \text{ m}, 0.36 \text{ m}$$

Critical depth, $y_c = \left(\frac{q^2}{g}\right)^{1/3} = \left(\frac{Q^2}{gb^2}\right)^{1/3}$

$\Rightarrow$ $y_c = \left[\frac{(y_1V_1b)^2}{gb^2}\right]^{1/3} = \left(\frac{y_1^2V_1^2}{g}\right)^{1/3}$

$\Rightarrow$ $y_c = \left(\frac{0.8^2 \times 1.2^2}{9.81}\right)^{1/3} = 0.455 \text{ m}$

$\therefore$ Neglect y_2 = 0.36 m also, as flow is subcritical.

Hence, y_2 = 0.586 m

$\therefore$ Depression in water surface = $y_1 - (y_2 + \Delta z) = 0.8 - (0.586 + 0.15) = 0.064$ m

Q.4 (c) Solution:

(i) **Standard Project Flood (SPF):** It is the flood that would result from the most severe combination of metereorological and hydrological factors that are reasonably applicable to the basin. However, extreme rare combinations are excluded.

Maximum Probable Flood (MPF): This includes the extreme rare combinations also which are excluded in SPF. Thus, it is defined as extreme flood that is physically possible in a region as a result of severmost combination including extreme rare combination of meteorological and hydrological factors. It is observed that SPF is about 80% of MPF.

Design Flood: A design flood is the flood discharge adopted for design of a hydraulic structure after careful considerations of hydrologic and economic factors. A design flood in most of the cases may be less than MPF. There may be several design flood values adopted for various components of a project. For example, design flood used for spillway will be more than the design flood used for cofferdam of the same project.

(ii) Risk = 10%, n = 10 years

$R = 1 - (1 - p)^n$

$\Rightarrow$ $p = 0.01048$

where p is exceedence probability

Return period, $T = \frac{1}{p} = \frac{1}{0.01048} = 95.42$ years

Probability of occurrence twice in 10 years,

$$P(r, n) = {}^{n}C_r p^r q^{n-r}$$

$\because \quad q = 1 - p$

$\Rightarrow \quad q = 1 - 0.01048 = 0.98952$

$\therefore \quad P(2, 10) = {}^{10}C_2 (0.01)^2 (0.98952)^8 = 0.004136$

Probability of occurrence once in 10 years

$$P(1, 10) = {}^{10}C_1 (0.01)(0.98952)^9 = 0.09095$$

(iii) Slope of catchment, $S = \dfrac{1}{250}$

Length of travel, $L = 2000$ m

Time of concentration using Kirpich formula

$$t_c = 0.01947 \, (L^{0.77}) \, (S)^{-0.385}$$

$$= 0.01947(2000)^{0.77}\left(\frac{1}{250}\right)^{-0.385} = 56.80 \text{ min.}$$

Using given table, maximum depth of rainfall can be calculated by interpolation.

$$\text{Maximum depth of flow} = 8.7 + \frac{9.2 - 8.7}{60 - 50}(56.80 - 50) = 9.04 \text{ cm}$$

Average rainfall intensity,

$$i_{avg} = \frac{9.04}{\left(\dfrac{56.80}{60}\right)} = 9.55 \text{ cm/hr}$$

Using rational formula,

$$Q_p = 2.778\, CiA$$

Runoff coefficient, $C = 0.25$

Area, $A = 3 \text{ km}^2$

$\therefore \quad Q_p = 2.778 \times 0.25 \times 9.55 \times 3$

$\Rightarrow \quad Q_p = 19.897 \text{ m}^3/\text{s}$

Q.5 (a) Solution:

Required area of slab base, $A = \dfrac{1600 \times 10^3}{0.45 f_{ck}} = \dfrac{1600 \times 10^3}{0.45 \times 20} = 177777.78 \text{ mm}^2$

Area of base plate, $A = (L + 2a)(B + 2b)$

Given, $a = b$

$\therefore \quad 177777.778 = (350 + 2a)(250 + 2a)$

$$\Rightarrow \quad 4a^2 + 1200a + 87500 = 177777.778$$

$$\Rightarrow \quad a = 62.295 \text{ mm} \simeq 65 \text{ mm}$$

$$\therefore \quad L = 350 + 2 \times 65 = 480 \text{ mm}$$

$$B = 250 + 2 \times 65 = 380 \text{ mm}$$

$\therefore$ Bearing pressure of concrete, $w = \dfrac{P}{A_1} = \dfrac{1600 \times 10^3}{480 \times 380}$

$$\Rightarrow \quad w = 8.772 \text{ MPa} \leq 9 \text{ MPa} \quad \text{(OK)}$$

Thickness of base plate, $t_s = \sqrt{\dfrac{2.5 \times w\left(a^2 - 0.3b^2\right)\gamma_{m0}}{f_y}}$

$$\Rightarrow \quad t_s = \sqrt{\frac{2.5 \times 8.772\left(65^2 - 0.3 \times 65^2\right)1.1}{250}}$$

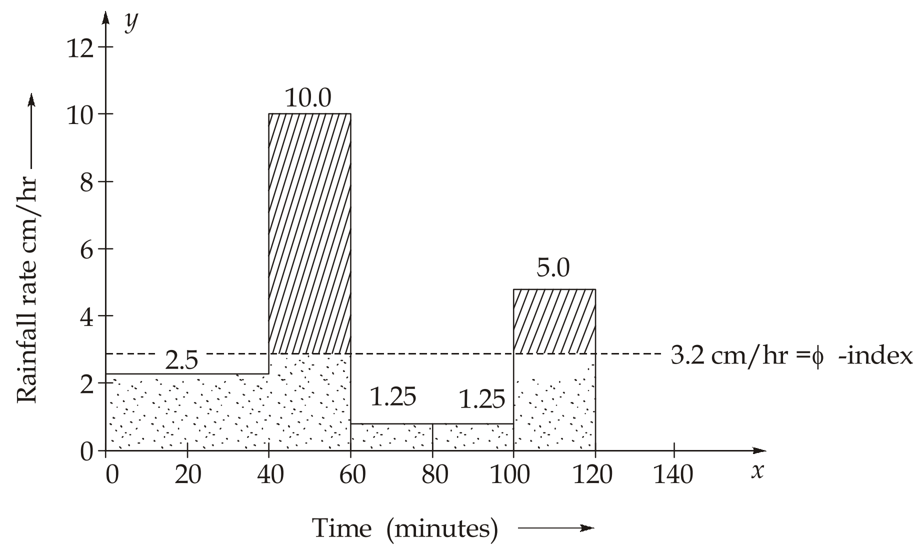
$$\Rightarrow \quad t_s = 16.893 \text{ mm} \simeq 17 \text{ mm} \geq t_f \quad \text{(OK)}$$

Q.5 (b) Solution:

(i) Principal factors affecting the flow from a catchment area are:

1. **Precipitation characteristics:** This is the most important factor on which runoff depends. Important precipitation characteristics are intensity, duration, aerial distribution, form of precipitation, and evapotranspiration. Runoff increases with increase in intensity and extent of rainfall over catchment.
2. **Shape and size of catchment:** More intense rainfalls are generally distributed over a relatively smaller areas, i.e., a stream collecting water from a small catchment area is likely to give greater runoff intensity per unit area. Runoff discharge will be greater or smaller depending upon the shape of catchment weather it is fan shaped or fern shaped respectively.
3. **Topography of catchment:** The runoff depends upon weather the surface of the catchment is smooth or rugged. If the surface is steep, water will flow quickly hence absorption and evaporation will be less, resulting in greater runoff.
4. **Geological characteristics of basin:** Geological characteristics are such as type of surface soil and subsoil, type of rock and their permeability characteristics. If the soil and subsoil is pervious, seepage will be more and this is turn reduces the peak discharge. If the surface is rocky, the absorption will be practically nil and runoff will be more.

(ii) The rain intensity pattern (rainfall hyetograph) from the given rainfall rates, is shown in figure.



ϕ_{index} line at a height of 3.2 cm/hr is superimposed. The hatched area is calculated, so as to obtain the value of runoff:

Total runoff, $R = (10-3.2)\times\frac{20}{60}+(5-3.2)\times\frac{20}{60}$

Total runoff, $R = 2.267 + 0.6 = 2.867$ cm

Total precipitation, $P = 2.5\times\frac{40}{60}+10\times\frac{20}{60}+1.25\times\frac{40}{60}+5\times\frac{20}{60}$

$= 7.5$ cm

$$W_{index} = \frac{P-R}{t_r\ (\text{hr})} = \frac{7.5-2.867}{\left(\frac{120}{60}\right)} = 2.3165 \text{ cm/hr}$$

Q.5 (c) Solution:

Using moment distribution method.

Calculation of fixed-end moment.

$$M_{FAB} = \frac{-10\times 8^2}{12} = -53.33 \text{ kNm}$$

$$M_{FBA} = \frac{10\times 8^2}{12} = 53.33 \text{ kNm}$$

$$M_{FBC} = \frac{-30 \times 4}{8} = -15 \text{ kNm}$$

$$M_{FCB} = \frac{30 \times 4}{8} = 15 \text{ kNm}$$

$$M_{FCD} = -20 \times 2 = -40 \text{ kNm}$$

Number of joints = 2 (B, C)

Distribution factors:

$$(DF)_{BA} = \frac{\frac{4E(2I)}{8}}{\frac{4E(2I)}{8} + \frac{3EI}{4}} = 0.571$$

$$(DF)_{BC} = \frac{\frac{3EI}{4}}{\frac{3}{4}EI + \frac{4E(2I)}{4}} = 0.429$$

Alternatively, $(DF)_{BC} = 1 - (DF)_{BA} = 1 - 0.571 = 0.429$

$$(DF)_{CB} = \frac{\frac{3EI}{4}}{\frac{3EI}{4} + 0} = 1$$

Moment distribution table:

	A		*B*	*C*	
Distribution factor		0.571	0.429	1	0
FEM	–53.33	53.33	–51	25	–40
Balance				25	
Carry over			12.5		
New FE moments	–53.33	53.33	–25	40	–40
Balance		–29.02	–21.81		
Carry over	–14.51				
Final moments	–67.84	24.31	–24.31	40	–40

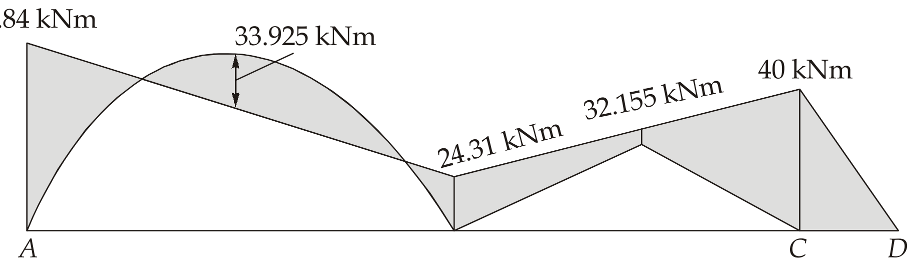
∴ $M_{AB} = -67.84$ kNm

$M_{BA} = 24.31$ kNm

$M_{BC} = -24.31$ kNm

$M_{CB} = -40$ kNm

$M_{CD} = -40$ kNm



BMD

Q.5 (d) Solution:

(i) Maximum possible rimpull prior to slippage of driving tyres is given by,

$$P = 0.5 \times 16480 \text{ kg} = 8240 \text{ kg}$$

$$\text{Total weight of unit} = 27650 \text{ kg} = 27.65 \text{ tonnes}$$

Rolling resistance of haul road

$$= 27.65 \times 48 = 1327.2 \text{ kg}$$

$\therefore$ Available rimpull to negotiate the slope = $P - R$

$$= 8240 - 1327.2 = 6912.8 \text{ kg}$$

The pull required per 1 tonne of the gross weight per 1% slope = 10 kg

$\therefore$ The pull required for 27.65 tonnes per 1% slope = 276.50 kg

Since 276.50 kg pull is required per 1% slope.

$\therefore$ 6912.8 kg pull is required for $\dfrac{6912.8}{276.5} = 25\%$ slope

(ii) Resource Smoothing:

- In resource smoothing the total project duration is not changed but some of the activity start times are shifted by their available float so that more or less uniform demand is generated.
- Resource in this case is considered unlimited and critical activities remain unchanged.
- The total project completion time also remains unchanged.

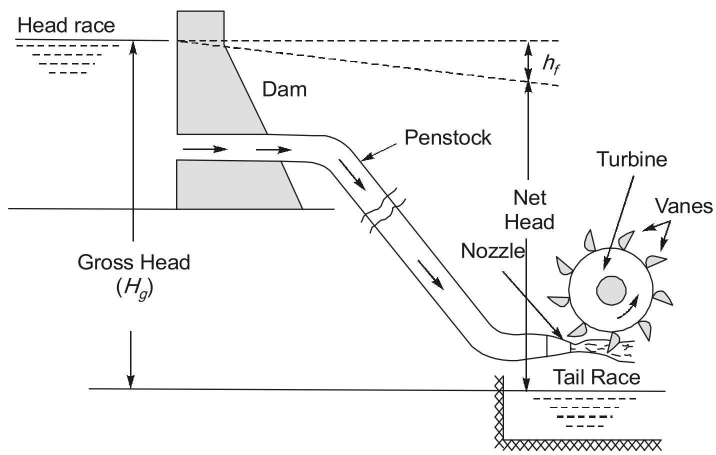
Resource Levelling:

- In resource levelling, the activity start times are so rescheduled that the peak demand does not exceed the available limit of resource. If it does not give the desirable result by consideration of floats, the total project duration to minimum extent may be extended.

- Resource in this case is considered limited
- Critical path as well as the project completion time may be altered.

Q.5 (e) Solution:

(i) A general layout of a hydroelectric power plant consists of:



1. A **dam** constructed across a river to store water.
2. Pipes of large diameters called **penstocks, which carry water under pressure from the storage reservoir to the turbines**. These pipes are made of steel or reinforced concrete.
3. Turbines having different types of vanes fitted to the wheels.
4. **Tail race**, which is a channel which carries water away from the turbines after the water has worked on the turbines. The surface of water in the tail race channel is also known as a tail race.

(ii) **(a)** **Surge tank:** It is a reservoir of water placed near to turbine and used to avoid water hammer in penstock.

(b) **Gross head:** It is defined as the head under which hydropower plant is working or it is the difference between head race level and tail race level.

(c) **Net head:** It is defined as the head available with water at entry to turbine or it is the head under which turbine is working.

$$H = H_G - H_F$$

where H = Net head

H_G = Gross head

H_F = Head loss in penstock

where, $H_F = \left.\frac{fLV^2}{2gD}\right|_P$

and $f = 4f'$

Q.6 (a) Solution:

Total factored load = 1.5 × 40 = 60 kN

Maximum bending moment,

$$M_{max} = \frac{(wl)l}{8} = \frac{60 \times 4}{8} = 30 \text{ kN.m}$$

Maximum shear force, $V_{max} = \frac{wl}{2} = \frac{60}{2} = 30$ kN

Plastic section modulus required,

$$Z_{p,required} = \frac{M_{max} \times \gamma_{m0}}{f_y} = 30 \times 10^6 \times \frac{1.1}{250}$$

$$= 132 \times 10^3 \text{ mm}^3$$

$< Z_{pz}$ of ISLB 200 (= 184.34×10^3 mm^3) (OK)

Check for shear capacity

Maximum shear force, V = 30 kN

Design shear strength of the section,

$$V_d = \frac{f_y}{\sqrt{3}\gamma_{mo}}(ht_w)$$

$$= \frac{250 \times 200 \times 5.4}{\sqrt{3} \times 1.1 \times 1000} \text{ kN} = 141.713 \text{ kN} > 30 \text{ kN}$$ (OK)

Check for high/low shear

$0.6\ V_d$ = 0.6 × 141.713 = 85.02 kN

∴ $V < 0.6\ V_d$

⇒ Low shear case

Check for design bending strength

$$M_d = \beta_b Z_p \frac{f_y}{\gamma_{m0}}$$

$$= 1 \times 184.34 \times 10^3 \times \frac{250}{1.1} \times 10^{-6} = 41.895 \text{ kNm}$$

Also,
$$M_d \le 1.2 Z_e \frac{f_y}{\gamma_{mo}}$$
$$= 1.2 \times 169.7 \times 10^3 \times \frac{250}{1.1} \times 10^{-6} = 46.28 \text{ kNm}$$

$\therefore$ M_d (=41.895 kNm) <46.28 kNm and also M = 30 kNm < M_d

$\therefore$ Hence safe in bending

Check for deflection

$$\delta_{\text{limit}} = \frac{l}{300} = \frac{4 \times 10^3}{300} = 13.33 \text{ mm}$$
$$\delta = \frac{5}{384}\frac{wl^4}{EI}$$
$$= \frac{5}{384} \times \frac{40 \times 10^3 \times (4 \times 10^3)^3}{2 \times 10^5 \times 1696.6 \times 10^4}$$
$$= 9.82 \text{ mm} < 13.33 \text{ mm}$$

$\therefore$ $\delta_{\text{limit}} > \delta$

$\Rightarrow$ Safe in deflection

Check for web buckling and web crippling

Since ISLB 200 is a rolled section, thus dimensions are so adjusted that check for secondary criteria i.e. for web crippling and web buckling are not required.

Thus section ISLB 200 is safe for the given loading and support conditions.

Q.6 (b) Solution:

(i) **Factors affecting evaporation losses:** The evaporation losses from a water surface depend upon the following factors.

1. **Area of the water surface:** The amount of evaporation is directly proportional to the area of evaporation. If the exposed area is large, the evaporation will be more and vice-versa.
2. **Depth of water in the water body:** The depth of water influences the evaporation considerably. More depth reduces the summer evaporation and increases the winter evaporation.
3. **Humidity:** If the humidity of the atmosphere is more, the evaporation will be less. Because during the process of evaporation, water vapour move from the zone of higher moisture content to the zone of lower moisture content and the rate of this movement is governed by the difference of their moisture contents or the moisture gradient existing in the air. So, if the humidity, as measured by a hygrometer, is more, the evaporation will be less.

4. **Wind velocity:** The process of evaporation also depends upon the prevailing turbulence in the air. If the turbulence is more or in other words if the velocity of the air in contact with water surface is more, the saturated film of air containing the water vapour will move easily, and the diffusion and dispersion of vapour will become easier, causing more evaporation and hence more evaporation losses.
5. **Temperature:** The process of evaporation also depends upon the temperature. If the temperature is more, the saturation vapour pressure increases, and thus the evaporation increases. Thus, in summer season or in hot countries, the evaporation will be more as compared to that in the winter season or in cold countries.
6. **Atmospheric pressure:** If the atmospheric pressure (e_a) is more, naturally there will be lesser evaporation (Dalton's law). At higher altitudes, the atmospheric pressure is less and hence the evaporation should normally be higher. However, this is not exactly so, because of the decrease of temperature at higher altitude, which reduces the evaporation.
7. **Quality of water:** The quality of water in the water body also affects the rate of evaporation, since the presence of any dissolved salts in water reduces the saturated vapour pressure of water (e_s) which consequently reduces the rate of evaporation. For this reason, usually, the evaporation decreases by 1% for every 1% increase in the salinity of a water body. Turbidity may also affect the rate of evaporation by affecting the heat transfer within the depth of the water body.

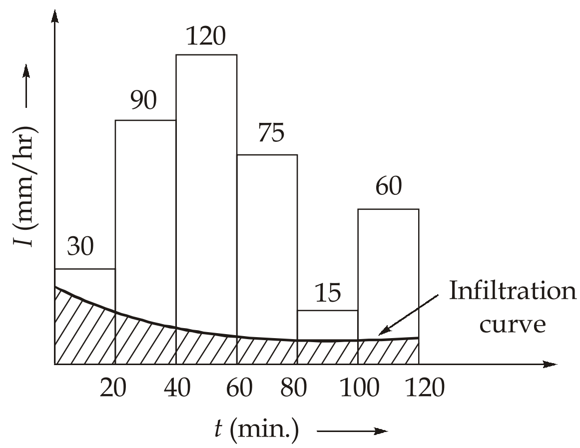
(ii)

Time (min.)	0-20	20-40	40-60	60-80	80-100	100-120
Rainfall (cm/hr) intensity	3	9	12	7.5	1.5	6
Rainfall (mm)	10	30	40	25	5	20

For infiltration, from Horton's curve,

$$f = 9.6 + 10.2\, e^{-3t}$$

Time (min.)	0	20	40	60	80	100	120
f (mm/hr)	19.8	13.35	10.98	10.11	9.79	9.67	9.63

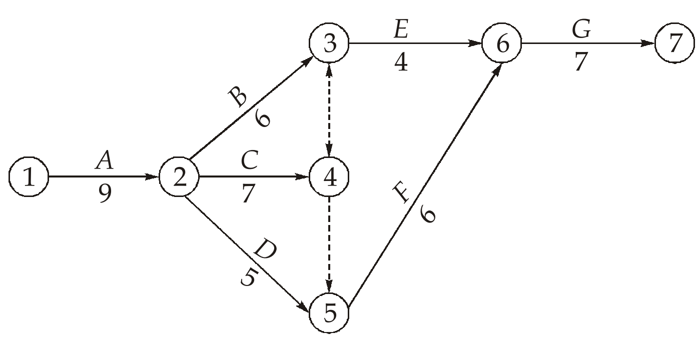


$$P_e = (10+30+40+25+5+20)-\left[\int_0^2 (9.6+10.2e^{-3t})\,dt\right]$$

$$\Rightarrow \quad P_e = 130 - 22.59$$

$$\Rightarrow \quad P_e = 107.41 \text{ mm}$$

Q.6 (c) Solution:



Activity	Normal time (days)	Normal Cost (Rs.)	Crash time (days)	Crash cost (Rs.)	Cost slope (Rs/dsy)	Possible no. of days crashing (days)
A	9	700	6	1000	100	3
B	6	600	4	800	100	2
C	7	800	4	890	30	3
D	5	300	4	320	20	1
E	4	700	3	850	150	1
F	6	350	5	430	80	1
G	7	400	4	850	150	3

$\Sigma_{\text{Normal cost}}$ = Rs. 3850

Possible paths: $A\text{-}B\text{-}E\text{-}G \rightarrow$ 26 days

$A\text{-}C\text{-}E\text{-}G \rightarrow$ 27 days

A-C-F-G $\rightarrow$ 29 days (critical path)

A-D-F-G $\rightarrow$ 27 days

In path *A-C-F-G*, least cost slope activity is activity *C* and it can be crashed by 2 days.

New cost for the 27 days will be given by,

$$(\text{Total cost})_1 = \Sigma\text{Normal cost + Crash cost – Savings}$$
$$= \text{Rs. } 3850 + (30 \times 2) - (50 + 20) \times 2$$
$$= \text{Rs. } 3770$$

New possible paths, *A-B-E-G* $\rightarrow$ 26 days

A-C-E-G $\rightarrow$ 25 days

A-C-F-G $\rightarrow$ 27 days (critical path)

A-D-F-G $\rightarrow$ 27 days (critical path)

In two critical paths *A-C-F-G* and *A-D-F-G* the least cost slope activities are *C* and *D*, and it can be crashed by one-day each.

New cost for duration of 26 days will be given by,

$$(\text{Total cost})_2 = 3770 + 1 \times (30 + 20) - 1 \times (50 + 20)$$
$$= \text{Rs. } 3750$$

New possible paths, *A-B-E-G* $\rightarrow$ 26 days (critical path)

A-C-F-G $\rightarrow$ 24 days

A-C-F-G $\rightarrow$ 26 days (critical path)

A-D-F-G $\rightarrow$ 26 days (critical path)

Now there are three critical paths viz. *A-B-E-G*, *A-C-F-G* and *A-D-F-G* and least cost activity is A, and it can be crashed by 1 day.

Now cost for duration of 25 days,

$$(\text{Total cost})_3 = 3750 + 1 \times 100 - 1 \times (50 + 20)$$
$$= \text{Rs. } 3780$$

$\therefore$ Further crashing results in increase in total project cost so further crashing is not feasible.

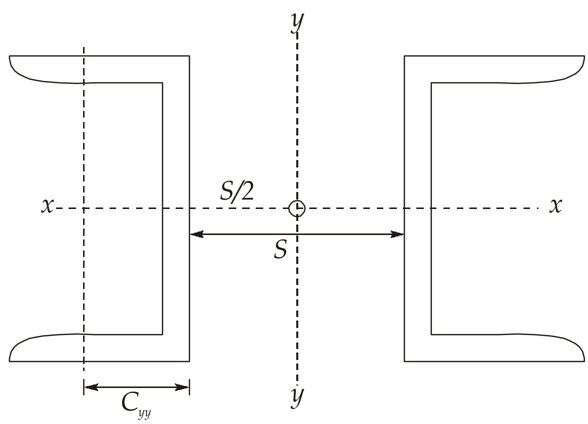
$\therefore$ Most economical project cost is Rs. 3750 and most economical completion time is 26 days.

Q.7 (a) Solution:

(i) Channel section properties

$$\text{Area} = 38.67 \text{ cm}^2$$
$$I_{xx} = 3816.8 \text{ cm}^4$$
$$I_{yy} = 219.1 \text{ cm}^4$$
$$C_{yy} = 2.30 \text{ cm}$$

1. Built-up section properties



$$I_{yy,B} = I_{yy} + A\left(C_{yy} + \frac{S}{2}\right)^2 \times 2$$
$$I_{xx,B} = 2 \times I_{xx}$$

2. Spacing between two sections to carry maximum load.

Condition $I_{yy,B} \leq I_{xx,B}$

$$\Rightarrow \left[I_{yy} + A\left(C_{yy} + \frac{S}{2}\right)^2\right] \times 2 \leq 2 \times I_{xx}$$

$$\Rightarrow 219.1 + 38.67\left(2.3 + \frac{S}{2}\right)^2 \leq 3816.8$$

$$\Rightarrow S \leq 14.69 \text{ cm} \simeq 16 \text{ cm (say)}$$

Hence provide spacing = 16 cm

3. Slenderness ratio of column

$$\lambda_0 = \frac{L_e}{r_{min}}$$

where $r_{min} = r_{xx} = \sqrt{\frac{I_{xx}}{A}}$

$$r_{xx} = \sqrt{\frac{3816.8}{38.67}} = 9.935 \text{ cm}$$

As per IS 800, the effective slenderness ratio of battened column should be increased by 10%

$$\therefore \quad \lambda_e = 1.1 \times \frac{L_e}{r_{min}} = 1.1 \times \frac{8.5 \times 10^2}{9.935}$$

$$= 1.1 \times 85.556 = 94.11$$

4. Working stress (σ_{ac})

Using table, $$\frac{94.11 - 80}{100 - 80} = \frac{\sigma_{ac} - 101}{84 - 101}$$

$$\therefore \quad \sigma_{ac} = 89 \text{ N/mm}^2$$

5. Maximum safe load, $P_d = \sigma_{ac} \times A$

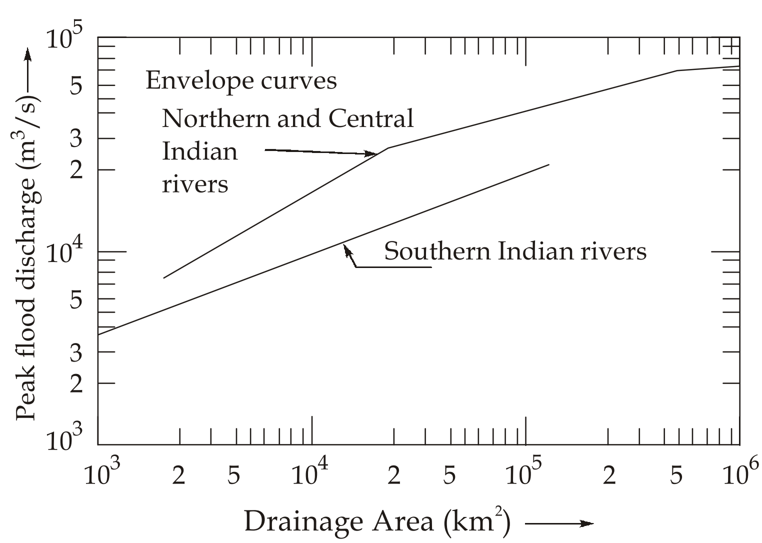
$$= 89 \times 2 \times 38.67 \times 10^2 \times 10^{-3} \text{ kN} = 688.33 \text{ kN}$$

(ii) Refer IS 800 : 2007, Clause 7.6

Q.7 (b) Solution:

(i) Envelope Curve

- In regions having same climatological characteristics, if the available flood data are not sufficient, then the envelope curve technique can be used. In this we develop a relationship between the *peak flood* and *drainage area* and all other factors are ignored.
- The flood peak obtained from such a curve will tell us the maximum flood which occurred in the available area and cannot tell us anything about the future possibilities. The peak value obtained from this curve cannot be relied upon and used only for preliminary survey.



- If equations are fitted in those enveloping curves, then they provide empirical formula of the type

$$Q_p = f(A)$$

Based on maximum recorded floods throughout the world and plotting envelope curve we get

$$Q_{mp} = \frac{3025\,A}{(278 + A)^{0.78}}$$

where Q_{mp} = Maximum flood discharge (m^3/s)
A = Catchment Area (km^2)

(ii) Arranging data in descending order and assigning rank number m here $N = 16$.

Rank (m)	Discharge (descending order)	Recurrence Interval		Probability (P) as per Hazen's
		California method $T = \frac{N}{m}$	Hazen's method $T_1 = \frac{2N}{2m-1}$	$P = \frac{1}{T_1}$
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
1	9200	16	32	0.031
2	7800	5.33	6.4	0.156
3	7800	5.33	6.4	0.156
4	6600	4	4.57	0.219
5	5800	3.2	3.55	0.282
6	5260	2.67	2.91	0.344
7	4980	2.28	2.46	0.407
8	4525	2	2.13	0.469
9	3630	1.6	1.68	0.595
10	3630	1.6	1.68	0.595
11	3110	1.45	1.52	0.658
12	3090	1.23	1.28	0.781
13	3090	1.23	1.28	0.781
14	2380	1.14	1.18	0.847
15	2290	1.07	1.10	0.909
16	2100	1	1.03	0.971

For return period of 10 years, discharge can be calculated by interpolation using data in Col. 2 and Col. 3

For T = 10 years

$$Q = 7800 + \frac{(9200 - 7800)}{16 - 5.33}(10 - 5.33) = 8412.75 \text{ m}^3/\text{s}$$

Exceedence probability of discharge of 2500 m^3/s as per Hazen's method can be calculated using data in Col. 2 and Col. 5

$$P = 0.847 - \frac{(0.847 - 0.781)}{(3090 - 2380)}(2500 - 2380) = 0.836$$

Q.7 (c) Solution:

(i) Chezy's equation, $Q = CA\sqrt{RS}$

where C = Chezy's constant

R = Hydraulic radius

S = Channel slope

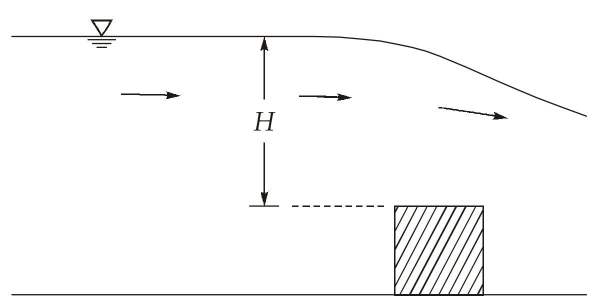
Manning's formula: $C = \dfrac{R^{1/6}}{N}$ where N is Manning's constant.

Bazin's formula: $C = \dfrac{157.6}{1.81 \dfrac{m}{\sqrt{R}}}$ where m is Bazin's constant.

Kutter's formula: $C = \dfrac{23 + \dfrac{0.00155}{S} + \dfrac{1}{n}}{1 + \left(23 + \dfrac{0.00155}{S}\right)\dfrac{n}{\sqrt{R}}}$ where n is Kutter's constant

Dimension of Chezy's constant C is $L^{1/2}T^{-1}$.

(ii)



Length of weir, L = 50 m

Head of water, H = 50 cm = 0.5 m

C_d = 0.60

1. Neglecting the velocity of approach

   Maximum discharge over a broad crested weir is given as

$$Q_{max} = 1.705 \times C_d \times L \times H^{3/2}$$

$$\Rightarrow \quad Q_{max} = 1.705 \times 0.6 \times 50 \times (0.5)^{3/2}$$

$$\Rightarrow \quad Q_{max} = 18.084 \text{ m}^3/\text{s}$$

2. Taking velocity of approach into consideration.

Area of channel, $A = 50 \text{ m}^2$

Velocity of approach,

$$V_a = \frac{Q}{A} = \frac{18.084}{50} = 0.36 \text{ m/s}$$

Now,
$$h_a = \frac{V_a^2}{2g} = \frac{0.36 \times 0.36}{2 \times 9.81} = 0.00661 \text{ m}$$

$$\therefore \quad Q_{max} = 1.705 \times C_d \times L \times \left[(H + h_a)^{3/2} - h_a^{3/2}\right]$$

$$\Rightarrow \quad Q_{max} = 1.705 \times 0.6 \times 50 \times \left[(0.5 + 0.00661)^{3/2} - 0.00661^{3/2}\right]$$

$$\Rightarrow \quad Q_{max} = 18.417 \text{ m}^3/\text{s}$$

Q.8 (a) Solution:

(i) **(a)** **Plastic hinge**: It is an yielded zone due to flexure in a structural member in which infinite rotation can take place at a constant restraining moment (M_p) of the section.

(b) **Shape factor** : It is defined as the ratio of the plastic moment and the yield moment of the section.

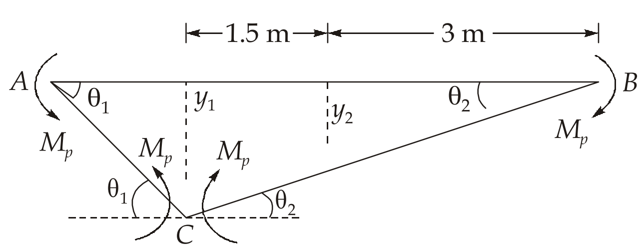
(c) **Plastic Moment**: Plastic moment is the maximum moment of resistance of a fully yielded cross section.

(d) **Mechanism**: When the segments of the beam between the plastic hinges are able to move without any increase of load, the condition of the member is called as mechanism.

(ii) **1st mechanism:**

Let P_c be the collapse load.

$$\therefore \quad M_p\theta_1 + M_p\theta_2 + M_p(\theta_2 + \theta_2) = P_0 y_1 + P_0 y_2$$



$$\theta_1 = \frac{y_1}{1.5}, \quad \theta_2 = \frac{y_1}{4.5}$$

Also, $$\frac{y_2}{3} = \frac{y_1}{4.5}$$

$\Rightarrow$ $$y_2 = \frac{2y_1}{3}$$

$\therefore$ $$M_p\frac{y_1}{1.5} + M_p\frac{y_1}{4.5} + M_p\left(\frac{y_1}{1.5} + \frac{y_1}{4.5}\right) = P_c y_1 + P_c y_2$$

$$= P_c y_1 + P_c \times \frac{2y_1}{3}$$

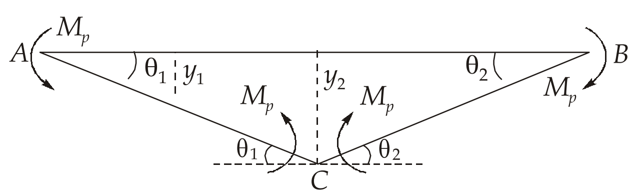
Multiplying each term by $\frac{4.5}{y_1}$,

$$3M_p + M_p + 4M_p = P_c[4.5 + 3] = 7.5\, P_c$$

$\Rightarrow$ $$P_c = \frac{8}{7.5}M_p$$

2nd mechanism

Let P_c be the collapse load



$$\theta_1 = \theta_2 = \frac{y_2}{3}$$

$$y_1 = \frac{y_2}{2}$$

$\therefore$ $$M_p\theta_1 + M_p\theta_2 + M_p(\theta_1 + \theta_2) = P_c y_1 + P_c y_2$$

$\Rightarrow$ $$M_p\frac{y_2}{3} + M_p\frac{y_2}{3} + M_p\left(\frac{2y_2}{3}\right) = \frac{P_c y_2}{2} + P_c y_2$$

Multiplying each term by $\frac{6}{y_2}$

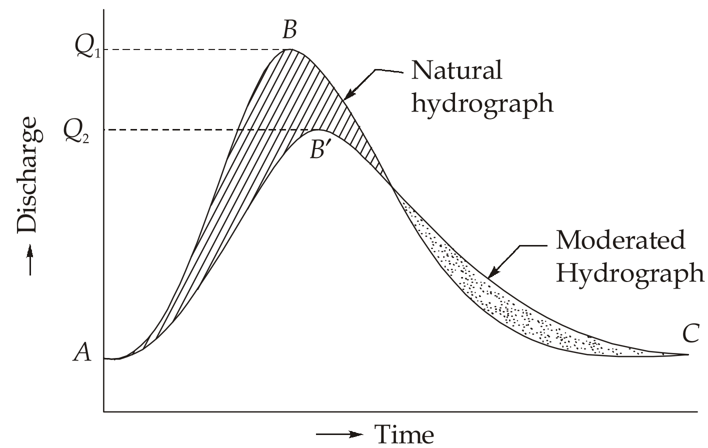
$$2M_p + 2M_p + 4M_p = 3P_c + 6P_c$$

$\Rightarrow$ $$P_c = \frac{8M_p}{9}$$

Therefore, collapse will take place by second mechanism and collapse load will be $\frac{8M_p}{9}$.

Q.8 (b) Solution:

(i) **Flood control reservoir:** Flood control or flood protection reservoirs are those which store water during flood and release it gradually at a safe rate when the flood reduces. By the provision of artificial storage during the floods, flood damage in the downstream is reduced. There are two pillars in flood prevention planning viz. river bed stabilizing planning for stabilizing the river channel from the upper stream and flood disposition planning for causing the flood water to flow down without causing any damage. Flood control by means of dam is a part of the flood disposition planning covering the whole river system and sometimes it shares part of river-bed stabilization planning also.



Thus, in the figure *ABC* is the natural hydrograph at the dam site, having a maximum flood discharge Q_1. By the construction of the dam, the natural hydrograph is moderated by the reservoir, as shown by the dotted lines (*AB′C*). Thus, the flood discharge is reduced from Q_1 to Q_2. The area shown hatched represents the storage to be provided in the reservoir. The portion marked by dots represents the excess volume released later.

(ii) Given the reach storage equation as under:

$$S = K[xI + (1 - x)O] \quad \text{...(i)}$$

Also, the basic routing equation is,

$$\frac{I_1 + I_2}{2}t - \frac{O_1 + O_2}{2}t = S_2 - S_1 \quad \text{...(ii)}$$

Substituting the following values of S_1 and S_2 from eq. (i) and (ii), we get

$$S_1 = K[xI_1 + (1 - x)O_1]$$

and $S_2 = K[xI_2 + (1 - x)O_2]$

$$\therefore \quad \frac{I_1+I_2}{2}t-\frac{O_1+O_2}{2}t = K[xI_2+(1-x)O_2]-K[xI_1+(1-x)O_1]$$

$$\Rightarrow \quad \frac{I_1+I_2}{2}t+K[xI_1+(1-x)O_1] = \frac{O_1+O_2}{2}t+K[xI_2+(1-x)O_2]$$

$$\Rightarrow \quad (I_1+I_2)+\frac{2K}{t}[xI_1+(1-x)O_1] = O_1+O_2+\frac{2K}{t}[xI_2+(1-x)O_2]$$

$$\Rightarrow \quad I_1+I_2+\frac{KxI_1}{0.5t}+\frac{K}{0.5t}(1-x)O_1 = O_1+O_2+\frac{xKI_2}{0.5t}+\frac{KO_2(1-x)}{0.5t}$$

$$\Rightarrow \quad \left[I_1+\frac{KxI_1}{0.5t}\right]+\left[I_2-\frac{xKI_2}{0.5t}\right]+\left[\frac{K(1-x)}{0.5t}O_1-O_1\right] = \left[O_2+\frac{K(1-x)}{0.5t}O_2\right]$$

$$\Rightarrow \quad O_2\left[\frac{0.5t+K(1-x)}{0.5t}\right] = I_1\left[\frac{0.5t+Kx}{0.5t}\right]+I_2\left[\frac{0.5t-Kx}{0.5t}\right]+O_1\left[\frac{K(1-x)-0.5t}{0.5t}\right]$$

$$\Rightarrow \quad O_2(K-Kx+0.5t) = I_1(Kx+0.5t)+I_2(-Kx+0.5t)+O_1(K-Kx-0.5t)$$

$$\Rightarrow \quad O_2 = I_1\left[\frac{Kx+0.5t}{K-Kx+0.5t}\right]+I_2\left[\frac{-Kx+0.5t}{K-Kx+0.5t}\right]+O_1\left[\frac{K-Kx-0.5t}{K-Kx+0.5t}\right]$$

$$\Rightarrow \quad O_2 = C_0I_2+C_1I_1+C_2O_1$$

The above is the required Muskingnum equation, where

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

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

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

Sum of the coefficients i.e., $C_0 + C_1 + C_2$

$$= \frac{1}{K-Kx+0.5t}[Kx+0.5t-Kx+0.5t+K-Kx-0.5t]=1$$

Q.8 (c) Solution:

(i) Area of cross-section, $A = 1.5 \times 4 = 6 \text{ m}^2$

Discharge in channel with existing dimensions,

$$Q_1 = AC\sqrt{RS}$$

$$= 6 \times 55 \times \sqrt{\left(\frac{6}{4 + 2 \times 1.5}\right) \times \frac{1}{1000}}$$

$$= 9.661 \text{ m}^3/\text{s}$$

As we all know, for most efficient rectangular section,

$$\text{Bed width} = \text{Depth} \times 2$$

$$\Rightarrow \quad B = 2y$$

Since, area of the cross-section is same,

$$\therefore \quad B \times y = 6 \text{ m}^2$$

$$\Rightarrow \quad 2y^2 = 6$$

$$\Rightarrow \quad y = \sqrt{3} = 1.732 \text{ m}$$

$$\therefore \text{ Bed width,} \quad B = 2y = 3.464 \text{ m}$$

Discharge in channel with new dimensions,

$$Q_2 = 6 \times 55 \times \sqrt{\frac{y}{2} \times S}$$

$$\Rightarrow \quad Q_2 = 6 \times 55 \times \sqrt{\frac{1.732}{2} \times \frac{1}{1000}}$$

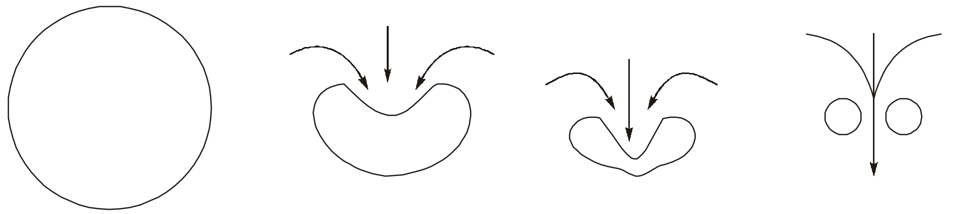
$$Q_2 = 9.711 \text{ m}^3/\text{s}$$

$\therefore$ Increase in discharge,

$$\Delta Q = Q_2 - Q_1 = (9.711 - 9.661) \text{ m}^3/\text{s}$$

$$= 0.05 \text{ m}^3/\text{s}$$

(ii) In hydraulic machinery, due to high velocities that exist at the runner and impellers, due to opportunities for occurrence of high local vapour pressure of water, water vapour is released in the form of vapour bubbles. This phase is similar to boiling of water. When these bubbles move to regions of higher pressure in the flow, they get compressed, diminish is size and eventually may collapse. The collapse of a vapour bubble is an implosion (internal bursting) phenomenon and the surrounding water rushes into the void created by the collapsed bubble. Microjets are formed in the process of filling up of the void by the surrounding water. These microjets may impinge on the neighbouring boundary. When the bubbles collapse near a wall, the microjets, in turn, cause local high-pressure pulse on the boundary. This process of formation, travel and collapse of vapour bubbles in negative pressure zones of a liquid flow is known as cavitation.



The main effects of cavitation in a flow device, such as a hydraulic machine, are:

1. Alternation of the performance of the system, for instance reduction of lift, increase in the drag, fall in the turbo-machine efficiency, etc.
2. Occurrence of noise and vibration of the component.
3. Pitting damage in the wall region of the component undergoing cavitation.
4. Significant shortened life of the machinery/equipment.

In reaction turbines, the blade suction side and exit location of the runner are regions highly susceptible to cavitation. In addition, cavitation may occur at the runner's leading edge at off-design operation. The top portion of the draft tube is another region where cavitation has a high possibility of occurrence. In pumps, the suction pipe and inlet region of impellers are regions with cavitation possibility.

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