DETAILED SOLUTIONS

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ESE 2025 : Prelims Exam
CLASSROOM TEST SERIES

CIVIL ENGINEERING

Test 14

Section A : Flow of Fluids, Hydraulic Machines and Hydro Power [All Topics]
Section B : Design of Concrete and Masonry Structures - I [Part Syllabus]
Section C : Structural Analysis - II [Part Syllabus]

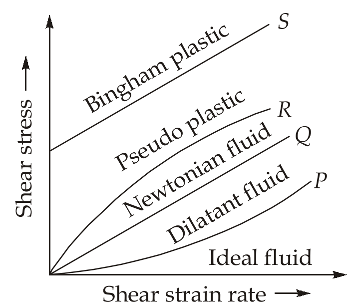
1.	(b)	16.	(a)	31.	(c)	46.	(b)	61.	(d)
2.	(b)	17.	(d)	32.	(d)	47.	(b)	62.	(c)
3.	(b)	18.	(b)	33.	(a)	48.	(c)	63.	(c)
4.	(d)	19.	(a)	34.	(b)	49.	(d)	64.	(c)
5.	(d)	20.	(d)	35.	(b)	50.	(a)	65.	(c)
6.	(c)	21.	(c)	36.	(a)	51.	(b)	66.	(c)
7.	(d)	22.	(b)	37.	(b)	52.	(d)	67.	(c)
8.	(d)	23.	(c)	38.	(d)	53.	(a)	68.	(a)
9.	(c)	24.	(b)	39.	(b)	54.	(c)	69.	(d)
10.	(b)	25.	(d)	40.	(a)	55.	(d)	70.	(d)
11.	(d)	26.	(b)	41.	(c)	56.	(d)	71.	(c)
12.	(c)	27.	(c)	42.	(c)	57.	(b)	72.	(b)
13.	(d)	28.	(b)	43.	(c)	58.	(c)	73.	(a)
14.	(d)	29.	(d)	44.	(b)	59.	(c)	74.	(a)
15.	(b)	30.	(d)	45.	(c)	60.	(b)	75.	(a)

DETAILED EXPLANATIONS

Section A : Flow of Fluids, Hydraulic Machines and Hydro Power

1. (b)

The relationship between τ and $\left(\frac{du}{dy}\right)$ is known as rheological behavior and is a schematic representation of rheological classification of fluids.



2. (b)

Velocity at radius r, $v = r\omega$

Now, Shear stress, $\tau = \mu\frac{v}{h} = \frac{\mu}{h}\omega r$

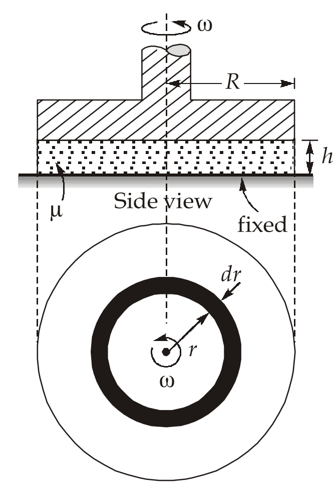
Consider an element of width dr at distance r from centre,

Force on the element, $dF = \tau.dA$

$$\Rightarrow \quad dF = \frac{\mu}{h}\omega r\,(2\pi r dr)$$

Viscous torque on the element, $dT = dF \times r$

$$dT = \frac{\mu}{h}\omega r\,(2\pi r dr)\,r = \frac{\mu\omega}{h}2\pi r^3 dr$$



Now, Total torque, $T = \int_0^R dT = \int_0^R \frac{\mu\omega}{h}2\pi r^3 dr$

$$= \frac{2\pi\mu\omega}{h}\left[\frac{r^4}{4}\right]_0^R$$

$$\Rightarrow \quad T = \left(\frac{\pi\mu\omega}{2h}\right)R^4$$

3. (b)

Given: $$P_{Base} = \left(\frac{1000}{13.6}\right) \text{ cm of Hg} = 13600 \times 10 \times \frac{1000}{13.6} \times 10^{-2} \frac{N}{m^2} = 100 \text{ kN/m}^2$$

$$P_{Summit} = \left(\frac{750}{13.6}\right) \text{ cm of Hg} = 13600 \times 10 \times \frac{750}{13.6} \times 10^{-2} \frac{N}{m^2} = 75 \text{ kN/m}^2$$

Now, $P_{Base} - P_{Summit} = \rho_{air}\, g\, H_{mountain}$

⇒ $(100 - 75) \times 10^3 = 1 \times 10\, H$

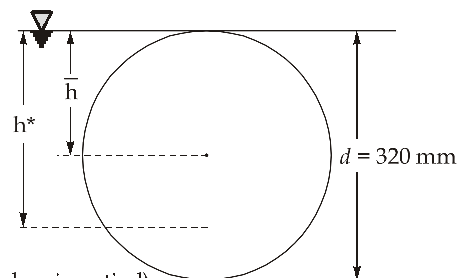
⇒ $H_{mountain} = 2500$ m

4. (d)

Given:

Diameter, $d = 320$ mm

Let centre of pressure be h^* distance below water surface,



(Since plane is vertical)

Now, $$h^* = \bar{h} + \frac{I_G}{A\bar{h}}$$

⇒ $$h^* = \frac{d}{2} + \frac{\left(\frac{\pi}{64} d^4\right)}{\frac{\pi}{4} d^2 \times \frac{d}{2}}$$

⇒ $$h^* = \frac{d}{2} + \frac{d}{8} = \frac{5}{8} d$$

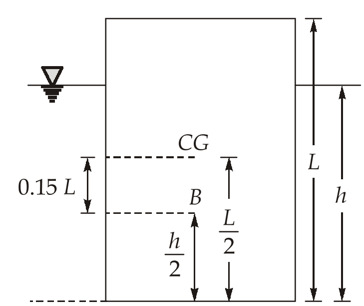
⇒ $$h^* = \frac{5}{8} \times 320 \text{ mm} = 200 \text{ mm}$$

5. (d)

Let specific gravity of the wooden block be G

At equilibrium,

Weight of body = Weight of water displaced by body



⇒ $G \rho_{water} g(AL) = \rho_{water}\, g(Ah)$

⇒ $GL = h$ ...(i)

From figure; $$\frac{L}{2} - \frac{h}{2} = 0.15 \text{ L}$$

$h = 0.70$ L

From equation (i), $GL = 0.70$ L

$G = 0.70$

6. (c)

At the stagnation point,

$u = 0$ and $v = 0$

⇒ $x + y = -1$ ...(i)

and $x - 2y = 4$ ...(ii)

On solving equation (i) and (ii) we get,

$x = 0.67$ unit

$y = -1.67$ unit

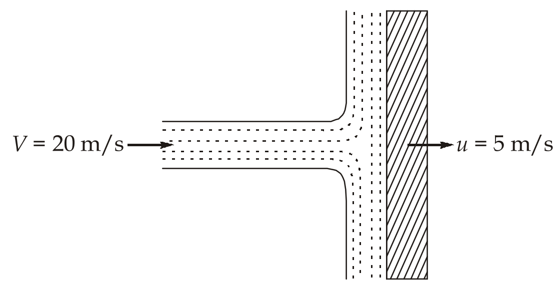
7. **(d)**

8. **(d)**

In one-dimensional method of analysis, the average velocity V is used to represent the velocity at a cross section. The actual velocity distribution in the cross-section may be non-uniform. Hence, the kinetic energy calculated by using V must be multiplied by a correction factor (α).

$$\alpha = \frac{1}{AV^3}\int u^3 dA$$

9. **(c)**



Given, $V = 20$ m/s, $u = 5$ m/s

Dia. of jet, $d = 75$ mm

Force on flat vertical plate moving in the direction of jet

$$F_x = \rho a (V - u)^2$$

$$= 1000 \times \frac{\pi}{4} \times (0.075)^2 \times (20-5)^2$$

$$= 994 \text{ N}$$

$\therefore$ Work done per second by the jet on the plate

$$= F_x \times u = 994 \times 5 = 4970 \text{ Nm/s (Output)}$$

Kinetic energy of the jet per sec (input)

$$= \frac{1}{2}\rho a V^3 = \frac{1}{2} \times 1000 \times \frac{\pi}{4} \times (0.075)^2 \times (20)^3$$

$$= 17671.46 \text{ Nm/s}$$

$\therefore$ Efficiency of jet, $\eta = \dfrac{4970 \times 100}{17671.46} = 28.12\% \simeq 28\%$

10. **(b)**

Euler's equation of motion is

$$\frac{dp}{\rho} + Vdv + gdz = 0$$

Assumptions:

- Flow is steady, ideal and along the stream line.
- Flow is homogeneous and incompressible.
- Fluid is inviscid.

11. (d)

In series, the discharge of one pump feeds into the suction of the next, increasing the total head while in parallel, the discharges combine thereby increasing the total flow.

12. (c)

Given;

$$\text{Linear scale ratio, } L_r = \frac{L_m}{L_p} = \frac{1}{16}$$

$$\text{Scale factor for power, } P_r = \frac{P_m}{P_p} = L_r^{3.5}$$

$$\Rightarrow \quad P_p = P_m\left(\frac{1}{L_r}\right)^{3.5} = 0.1 \times (16)^{3.5} = 0.1(4)^7 = 1638.4 \text{ kW}$$

13. (d)

Types of GVF profiles:

Slope of channel bed	Region	Condition	Profile
1. Mild slope	1, 2, 3	$y > y_n > y_c$	M_1
		$y_n > y > y_c$	M_2
		$y_n > y_c > y$	M_3
2. Sleep slope	1, 2, 3	$y > y_c > y_n$	S_1
		$y_c > y > y_n$	S_2
		$y_c > y_n > y$	S_3
3. Critical slope	1, 3	$y > y_n = y_c$	C_1
		$y < y_n > y_c$	C_3
4. Horizontal slope	2, 3	$y > y_c$	H_2
		$y < y_c$	H_3
5. Adverse slope	2, 3	$y > y_c$	A_2
		$y < y_c$	A_3

where; y_n = Normal depth of flow

y_c = Critical depth of flow

It is clear that, flow profiles C_2, H_1 and A_1 are not possible.

14. (d)

Given: $Q = 1 \text{ m}^3/\text{sec}, y = 0.2 \text{ m}, B = 2.5 \text{ m}$

$$\text{Velocity, } v = \frac{Q}{A} = \frac{1}{2.5 \times 0.2} = 2 \text{ m/sec}$$

$$\text{Froude's number, } F_r = \frac{v}{\sqrt{gy}}$$

$$\Rightarrow \quad F_r = \frac{2}{\sqrt{10 \times 0.2}}$$

$$\Rightarrow \quad F_r = \sqrt{2} = 1.41 < 1.7$$

For $F_r < 1.7$, jump can be classified as undular jump.

S.No.	Classification of jump	Initial Froude number range (F_r)
1.	Undular jump	$1 < F_r \le 1.7$
2.	Weak jump	$1.7 < F_r \le 2.5$
3.	Oscillating jump	$2.5 < F_r \le 4.5$
4.	Steady jump	$4.5 < F_r \le 9.0$

15. (b)

$$Q = A_1V_1 = A_2V_2$$

$$\Rightarrow \quad Q = By_1V_1 = By_2V_2$$

$$\Rightarrow \quad q = y_1V_1 = y_2V_2$$

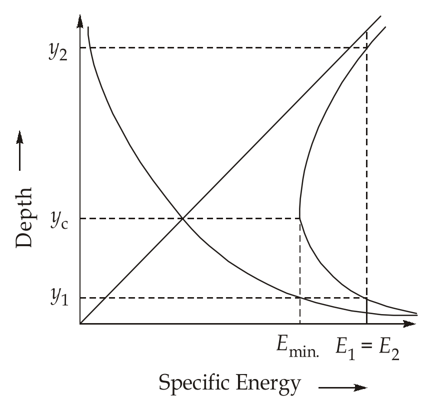
For alternate depths, $E_1 = E_2$

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

$$\Rightarrow \quad y_1 - y_2 = \frac{q^2}{2g}\left(\frac{1}{y_2^2} - \frac{1}{y_1^2}\right)$$

$$\Rightarrow \quad y_1 - y_2 = \frac{y_c^3}{2}\cdot\frac{(y_1-y_2)(y_1+y_2)}{y_1^2\cdot y_2^2} \qquad \left[\because y_c = \left(\frac{q^2}{g}\right)^{1/3}\right]$$

$$y_c = \left(\frac{2y_1^2y_2^2}{y_1+y_2}\right)^{1/3}$$

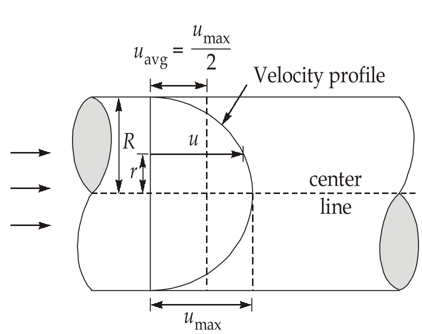


For minimum specific energy

$$E_{min} = y_1 + \frac{q^2}{2gy_1^2} = y_1 + \frac{y_c^3}{2y_1^2} = y_1 + \frac{y_2^2}{y_1+y_2}$$

$$\Rightarrow \quad E_{min} = \left(\frac{y_1^2 + y_1y_2 + y_2^2}{y_1+y_2}\right)$$

16. (a)



Velocity expression in pipe flow, $u = u_{max}\left(1 - \frac{r^2}{R^2}\right)$

If $u = u_{avg} = \frac{u_{max}}{2}$

then $\frac{u_{max}}{2} = u_{max}\left(1 - \frac{r^2}{R^2}\right)$

$\Rightarrow \quad \frac{r^2}{R^2} = \frac{1}{2}$

From center line, $r = \frac{R}{\sqrt{2}} = 0.707\ R$

Distance from wall of pipe $y = R - r = R - 0.707\ R = 0.293\ R.$

17. (d)

Head loss in pipe flow,

$$h_f = \frac{P_1 - P_2}{\rho g} = \frac{32\mu\ \bar{u}L}{\rho g D^2}$$

where; D = diameter of pipe

Friction factor for laminar flow is given by

$$f = \frac{64}{R_e}$$

$$\therefore \quad f \propto \frac{1}{R_e}$$

18. (b)

Given; $\vec{V} = -y\hat{i} + x\hat{j}$

$\therefore \quad u = -y, v = x$

Equation of stream line is

$$\frac{dx}{u} = \frac{dy}{v}$$

$$\Rightarrow \quad -\frac{dx}{y} = \frac{dy}{x}$$

$$\Rightarrow \quad -xdx = ydy$$

Integrating both sides,

$$-\frac{x^2}{2} = \frac{y^2}{2} + c \quad \text{...(i)}$$

Since streamline is passing through (1, 1)

$$\therefore \quad -\frac{1}{2} = \frac{1}{2} + c$$

$$\Rightarrow \quad c = -1$$

$\therefore$ Equation of stream line from equation (i) is,

$$x^2 + y^2 = 2$$

This is the equation of circle of radius $\sqrt{2}$ units and center at (0, 0).

$\therefore$ Area enclosed by stream line will be $\pi R^2 = 2\pi$ unit.

19. (a)

Flow out side the boundary layer is irrotational and shear stresses are not present.

20. (d)

Given: Velocity profile, $\frac{u}{u_\infty} = \left(\frac{y}{\delta}\right)^{1/7}$

Displacement thickness :

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{u_\infty}\right) dy = \int_0^\delta \left\{1 - \left(\frac{y}{\delta}\right)^{1/7}\right\} dy = \left[y - \frac{7y^{8/7}}{8\delta^{1/7}}\right]_0^\delta = \frac{\delta}{8}$$

Momentum thickness:

$$\theta = \int_0^\delta \frac{u}{u_\infty}\left(1 - \frac{u}{u_\infty}\right) dy = \int_0^\delta \left(\frac{y}{\delta}\right)^{1/7} \left\{1 - \left(\frac{y}{\delta}\right)^{1/7}\right\} dy$$

$$\Rightarrow \quad \theta = \int_0^\delta \left\{\left(\frac{y}{\delta}\right)^{1/7} - \left(\frac{y}{\delta}\right)^{2/7}\right\} dy = \left[\frac{7y^{8/7}}{8\delta^{1/7}} - \frac{7y^{9/7}}{9\delta^{2/7}}\right]_0^\delta = \frac{7}{72}\delta$$

$$\therefore \quad \text{Shape factor } (H) = \frac{\delta^*}{\theta} = \frac{\left(\frac{\delta}{8}\right)}{\frac{7\delta}{72}} = \frac{9}{7}$$

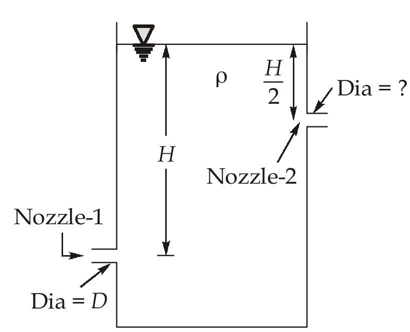
Alternate Solution

Shape factor for velocity profile $\frac{u}{u_\infty} = \left(\frac{y}{\delta}\right)^{1/m}$ is given by

$$H = \frac{\delta^*}{\theta} = \frac{(m+2)}{m}$$

$$H = \frac{7+2}{7} = \frac{9}{7}$$

21. (c)



For net horizontal force on the tank is zero

$$\rho A_1 v_1^2 - \rho A_2 v_2^2 = 0 \quad \text{...(i)}$$

where,
A_1 = Area of nozzle-1
A_2 = Area of nozzle-2
v_1 = Velocity at nozzle-1 = $\sqrt{2gH}$
v_2 = Velocity at nozzle-2 = $\sqrt{2g(H/2)} = \sqrt{gH}$

From equation (i)

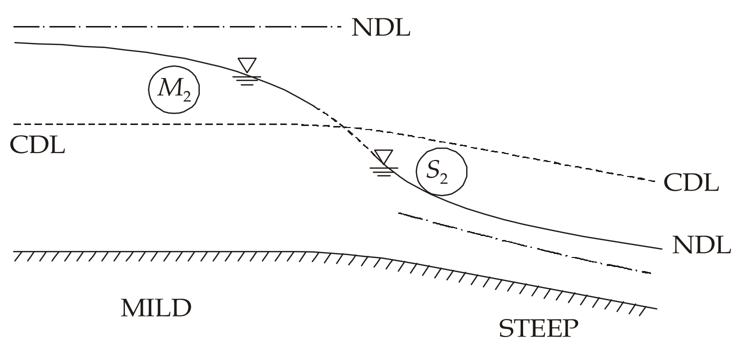
$$\frac{\pi}{4}D^2 \times 2gH = \frac{\pi}{4}D_2^2 \times gH$$

$$D_2 = \sqrt{2}D$$

22. (b)

- If the curvature in a varied flow is large and the depth changes appreciably over short lengths such a phenomenon is called as rapidly varied flow (RVF). The frictional resistance is relatively insignificant in such cases and it is usual to regard RVF as a local phenomenon.
- A hydraulic jump occurring below a spillway or a sluice gate is an example of steady RVF.

23. (c)



24. (b)

Given: $B = 2$ m, $y = 1$ m, $S_0 = 1 \times 10^{-3}$

Average boundary shear stress; $\tau_0 = \gamma R S_0$

$$\text{Hydraulic radius, } R = \frac{A}{P} = \frac{By}{B+2y} = \frac{2\times 1}{2+2\times 1} = 0.5 \text{ m}$$

$$\gamma_w = \rho_w g = 10^3 \times 10 \text{ N/m}^3 = 10^4 \text{ N/m}^3$$

$$\Rightarrow \quad \tau_0 = 10^4 \times 0.5 \times 10^{-3} = 5 \text{ N/m}^2$$

25. (d)

Let y_1 and y_2 be the alternate depth

$$\text{Specific energy, } E = y_1 + \frac{v_1^2}{2g} = y_2 + \frac{v_2^2}{2g}$$

$$y_1\left(1+\frac{v_1^2}{2gy_1}\right) = y_2\left(1+\frac{v_2^2}{2gy_2}\right)$$

$$\frac{y_1}{y_2} = \frac{\left(1+F_2^2/2\right)}{\left(1+F_1^2/2\right)} \qquad \left(\because\ F=\frac{v}{\sqrt{gy}}\right)$$

$$\frac{y_1}{y_2} = \frac{2+F_2^2}{2+F_1^2} \qquad \text{...(i)}$$

Now,

$$F_1^2 = \frac{v_1^2}{gy_1} = \frac{Q^2}{B^2gy_1^3} \text{ and } F_2^2 = \frac{Q^2}{B^2gy_2^3}$$

$$\frac{y_1^3}{y_2^3} = \left(\frac{F_2}{F_1}\right)^2 \Rightarrow \frac{y_1}{y_2} = \left(\frac{F_2}{F_1}\right)^{2/3} \qquad \text{...(ii)}$$

From equations (i) and (ii)

$$\frac{y_1}{y_2} = \left(\frac{F_2}{F_1}\right)^{2/3} = \left(\frac{2+F_2^2}{2+F_1^2}\right)$$

26. (b)

Pressure variation with depth when the fluid mass is subjected to vertical acceleration is given by

$$P = \gamma\left(1+\frac{a_Z}{g}\right)h$$

In order to create a vacuum pressure of 10 cm of mercury on the tank bottom,

$$\Rightarrow \quad -13.6 \times 1000 \times 10 \times 0.1 = 1000\times10\left(1+\frac{a_Z}{10}\right)\times1.5$$

$$\Rightarrow \quad -13.6 \times 0.1 = \left(1+\frac{a_Z}{10}\right)\frac{3}{2}$$

$$\Rightarrow \quad -0.9067 = 1+\frac{a_Z}{10}$$

$$\Rightarrow \quad a_z = -1.9067 \times 10$$

$$\Rightarrow \quad a_z = -19.067 \text{ m/s}^2 \simeq -19.1 \text{ m/s}^2$$

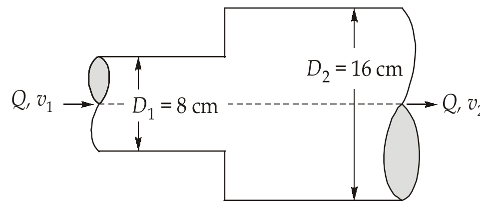
–ve sign indicates that acceleration in downwards.

27. (c)

Characteristics	Pelton	Francis	Kaplan and Propeller
Head H(m)	100-1760	30-450	1.5 - 75
Speed N (rpm)	75-1000	70-1000	70-600
Specific speed N_s	8-30	40-420	380-950

28. (b)

29. (d)



Here $D_2 = 2D_1$

From continuity equation

$$Q = A_1 v_1 = A_2 v_2$$

$$\frac{\pi}{4} D_1^2 v_1 = \frac{\pi}{4} D_2^2 v_2$$

$$v_1 = 4v_2 \quad \text{...(i)}$$

Head loss due to sudden expansion is given by

$$h = \frac{(v_1 - v_2)^2}{2g}$$

From equation (i)

$$h = \frac{\left(v_1 - \frac{v_1}{4}\right)^2}{2g} = \frac{9v_1^2}{32g}$$

30. (d)

In pipe flow, the Prandtl mixing length l is assumed to be proportional to the distance from the wall

$\Rightarrow$ $$l = Ky$$

31. (c)

Drag force, $$F_D = C_D \frac{\rho A V^2}{2}$$

The total weight of parachute is balanced by the drag

$\therefore$ $$W = F_D = 1.2 \times \left(\frac{1 \times \frac{\pi}{4}(8)^2 \times 4^2}{2}\right)$$

$$= 153.6\,\pi\,\text{N}$$

32. (d)

33. (a)

Given: $$\Psi = y^2 - x^2$$

We know, $$u = \frac{\partial \psi}{\partial y} = \frac{\partial \phi}{\partial x}$$

and $$v = \frac{-\partial\psi}{\partial x} = \frac{\partial\phi}{\partial y}$$

$\therefore$ $$\frac{\partial\phi}{\partial x} = 2y$$

$\therefore$ $$\phi = 2xy + f(y) \quad \text{...(i)}$$

$$\frac{\partial\phi}{\partial y} = 2x + f'(y) \quad \text{...(ii)}$$

$\because$ $$v = \frac{-\partial\psi}{\partial x} = \frac{\partial\phi}{\partial y}$$

$\Rightarrow$ $$\frac{\partial\phi}{\partial y} = -(-2x) = 2x$$

From equation (ii) $$2x = 2x + f'(y)$$

$$f'(y) = 0$$

$\therefore$ $$f(y) = \text{constant}$$

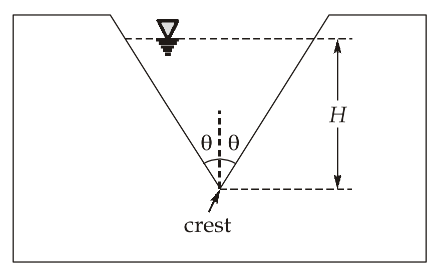
$\Rightarrow$ $$\phi = 2xy + \text{constant}$$

34. **(b)**

The discharge over a triangular or V-notch is,

$$Q = \frac{8}{15}C_d \tan\theta\sqrt{2g}(H)^{5/2}$$

$$Q \propto H^{5/2}$$



(Triangular weir)

$\therefore$ $$\frac{Q_2}{Q_1} = \left(\frac{H_2}{H_1}\right)^{5/2}$$

$\Rightarrow$ $$\frac{Q_2}{Q_1} = \left(\frac{0.4}{0.2}\right)^{5/2} = 2^{5/2} = (\sqrt{2})^5$$

35. **(b)**

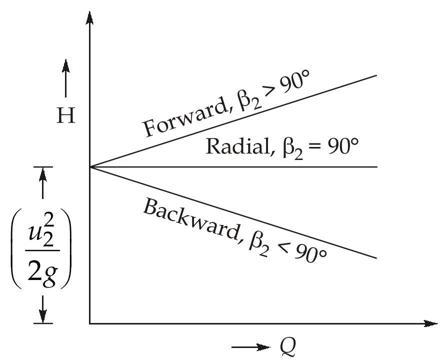
Piezometric head difference Δh depends upon the gauge reading y and is independent of the orientation of the venturimeter

$$\Delta h = y\left(\frac{G_m}{G_p} - 1\right) \text{ when } G_m > G_p$$

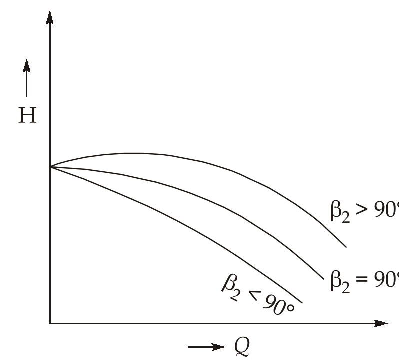
$$\Delta h = y\left(1 - \frac{G_m}{G_p}\right) \text{ when } G_m < G_p$$

36. (a)

37. (b)



(H-Q Relationship for ideal pump)



(H-Q Relationship for actual pump)

38. (d)

39. (b)

Net head loss

$H_{net} = H_{gross} - H_{PL} - H_{Sn}$

Where;

H_{gross} = Gross head = Difference in water surface elevation of upstream reservoir and tail water levels

H_{PL} = Head loss in the penstock

H_{Sn} = Height of the lowest nozzle above the tail water level.

40. (a)

Given; $D_2 = 0.30$ m, $N = 1400$ rpm, $\eta_0 = 0.80$

From velocity triangle, $V_2 \cos\alpha_2 = V_{u2} = u_2$

where, $$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.3 \times 1400}{60} = 21.99 \text{ m/sec}$$

Manometric efficiency, $$\eta_0 = \frac{gH_m}{u_2 V_{u2}} = \frac{gH_m}{u_2^2} \qquad (\because V_{u2} = u_2)$$

$$0.8 = \frac{10 \times H_m}{(21.99)^2} \Rightarrow H_m = 38.68 \text{ m}$$

41. (c)

$$\Delta y = y_2 - y_1$$

$\Rightarrow$ $$0.8 = y_2 - 2.0$$

$\Rightarrow$ $$y_2 = 2.8 \text{ m}$$

Celerity, $$C = \pm\sqrt{\frac{1}{2} \times g \times \frac{y_2}{y_1} \times (y_1 + y_2)}$$

$$= \pm\sqrt{\frac{1}{2} \times 9.81 \times \frac{2.8}{2} \times (2.8 + 2)} = \pm 5.74 \text{ m/s}$$

42. (c)

$$\text{Reynold's number, } (R_e) = \frac{\text{Inertia force}}{\text{Viscous force}}$$

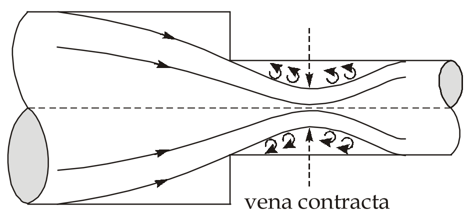
$$\text{Froude's number } (F_r) = \left(\frac{\text{Inertia force}}{\text{Gravity force}}\right)^{1/2}$$

$$\text{Mach number } (M_a) = \left(\frac{\text{Inertia force}}{\text{Elastic force}}\right)^{1/2}$$

$$\text{Weber's number } (W_e) = \left(\frac{\text{Inertia force}}{\text{Surface tension force}}\right)^{1/2}$$

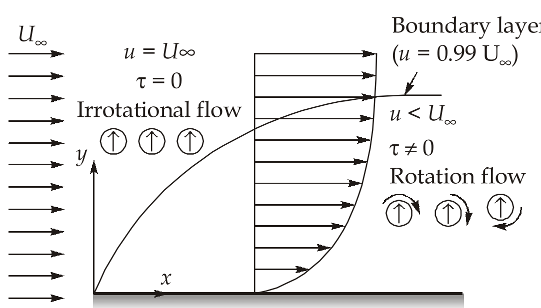
$$\text{Euler's number } (E_u) = \left(\frac{\text{Inertia force}}{\text{Pressure force}}\right)^{1/2}$$

43. (c)



- At vena-contracta, the effective flow area becomes considerably less than the cross-sectional area of the small-diameter pipe. Boundary layer has no chance to separate and consequently there is little loss of head between the entrance and the vena-contracta.

44. (b)



For a laminar boundary layer, the boundary condition are :

1. At the wall $y = 0$, $u = 0$
2. At the outer edge $y = \delta$, $u = U_\infty$
3. Shear stress at wall, $\tau_0 = u\left(\frac{du}{dy}\right)_{y=0} \neq 0$

   Shear stress at outer edge $y = \delta$, $\tau = u\left(\frac{du}{dy}\right)_{y=\delta} = 0$

45. (c)

When, frictional head = $\dfrac{\text{Head at inlet}}{3}$, maximum power transmission is achieved

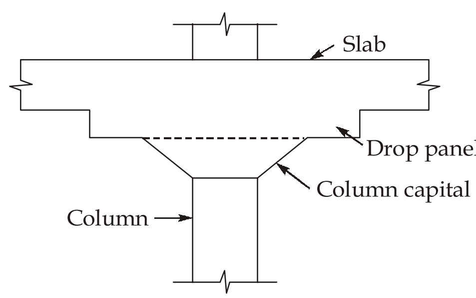
$$P_{act} = \gamma Q(H-h) \qquad \left\{h = \frac{H}{3}\right\}$$

$$= \gamma Q\left(H - \frac{H}{3}\right) = \frac{2}{3}\gamma QH$$

Section B : Design of Concrete and Masonry Structures - I

46. (b)

The column capital (or column head) is provided at the top of a column to increase the capacity of the slab to resist punching shear.



47. (b)

Span = 20 m

As per Cl. 23.2 of IS 456 : 2000, for continuous beam, (span > 10 m)

Basic value of span to effective depth ratio

$$= 26 \times \frac{10}{\text{Span}} = 26 \times \frac{10}{20} = 13$$

48. (c)

Refer IS 456 : 2000 (Table 28)

49. (d)

- Bond in reinforced concrete refers to the pure adhesion between the reinforcing steel and the surrounding concrete.
- Decrease in depth of beam does not affect bond strength.

50. (a)

Given, $H = 4$ m, $D = 10$ m, $T = 160$ mm

$$\frac{H^2}{DT} = \frac{(4)^2}{10 \times 0.16} = 10$$

From table given,

For $\dfrac{H^2}{DT} = 10$, maximum tension coefficient = 0.608 (at 0.6H)

$\therefore$ Hoop tension = Coefficient × $\gamma_w H \frac{D}{2}$ per meter

$$= 0.608 \times 9.81 \times 4 \times \frac{10}{2} \text{kN/m}$$

$$= 119.3 \text{ kN/m}$$

51. (b)

Positive moment tension reinforcement:

Atleast $\frac{1}{3}$rd of the tensile reinforcement in simply supported member and $\frac{1}{4}$th of tensile reinforcement in continuous member shall extend along the same face into the support to a length of $\frac{L_d}{3}$.

52. (d)

Given: $d = 600$ mm, $f_{ck} = 25$ MPa, $f_y = 500$ MPa

$$p_t = \frac{A_{st}}{bd} \times 100 = 1\% \quad \Rightarrow \quad A_{st} = \frac{bd}{100}$$

$$C = T$$

$$\Rightarrow \quad 0.36 f_{ck} bx_u = 0.87 \times 500 \times \frac{b \times 600}{100}$$

$$\Rightarrow \quad x_u = 290 \text{ mm}$$

Now, limiting depth of neutral axis

$$x_{u,\text{lim}} = 0.46\, d = 0.46 \times 600 = 276 \text{ mm} \quad \text{(For Fe500)}$$

As $x_u > x_{u,\text{lim}}$ section is over reinforced and steel would not have yielded and thus the strain compatibility method will be adopted to obtain the correct value of x_u.

53. (a)

For a singly under reinforced beam

$$0.36 f_{ck} bx_u = 0.87 f_y A_{st}$$

$$\Rightarrow \quad x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b} \quad \text{...(i)}$$

For a doubly under reinforced beam

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

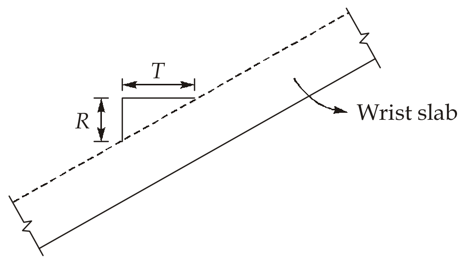
$$\Rightarrow \quad x_u = \frac{0.87 f_y A_{st} - \left(f_{sc} - 0.45 f_{ck}\right) A_{sc}}{0.36 f_{ck} b} \quad \text{...(ii)}$$

From equation (i) and (ii)

$$(x_u)_{\text{Singly}} > (x_u)_{\text{Doubly}}$$

$\therefore$ Neutral axis moves upwards that is towards compression steel.

54. (c)



Weight of each step, $W = \left[\frac{1}{2}RT\right]\gamma_c = \left[\frac{1}{2}\times 0.14\times 0.26\right]\times 25$

$= 0.455$ kN/m width of staircase

55. (d)

The minimum reinforcement in edge strip, parallel to that edge shall be 0.15% for mild steel and 0.12% for HYSD bars, of the cross-section area of concrete.

56. (d)

Amount of strain in concrete at the time of failure is 0.0035

Amount of plastic strain, concrete experiences before failure = 0.0035 – 0.002 = 0.0015

57. (b)

58. (c)

Minimum shear reinforcement is provided in the beams to arrest the longitudinal cracks on the side surface due to shrinkage of concrete and temperature changes.

When $\tau_v < \tau_c$, minimum shear reinforcement shall be provided as

$$\frac{A_{sv}}{b\,S_v} \geq \frac{0.4}{0.87\,f_y}$$

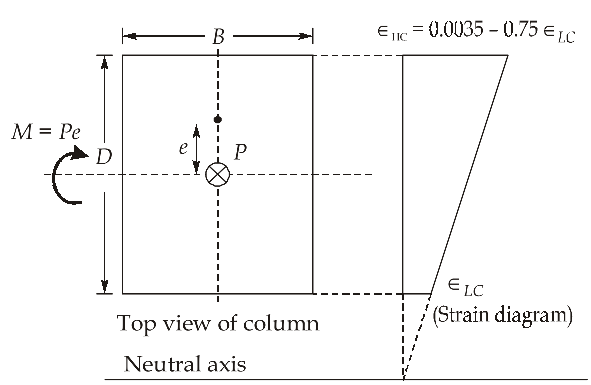
59. (c)

As per IS 456 : 2000 (Cl. 26.5.3.1)

$$\text{Maximum area of steel} = \begin{cases} 6\% \text{ of } A_g & \text{(when bars are not overlapped)} \\ 4\% \text{ of } A_g & \text{(when bars are overlapped)} \end{cases}$$

$$\text{Minimum area of steel} = 0.8\% \text{ of } A_g$$

Neutral axis of compression member may exist beyond the cross-section.



60. **(b)**

Refer IS 456 : 2000 (Cl. 31.2.1)

Section C : Structural Analysis - II

61. **(d)**

Product of flexibility and stiffness matrix is an identity matrix i.e. flexibility matrix and stiffness matrix are inverse of each other.

$$[K] = [F]^{-1}$$

$$[K] = \frac{12EI}{L^3}\begin{bmatrix} 3 & 3 \\ 3 & 15 \end{bmatrix}^{-1}$$

$$[K] = \frac{12EI}{L^3} \times \frac{1}{(3\times 15 - 3\times 3)}\begin{bmatrix} 15 & -3 \\ -3 & 3 \end{bmatrix} \qquad \left[\because A^{-1} = \frac{\text{adj}(A)}{|A|}\right]$$

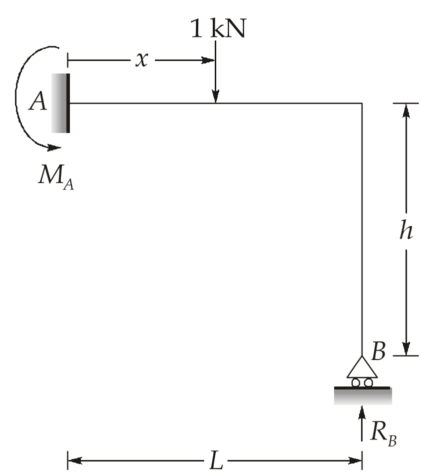
$$[K] = \frac{EI}{3L^3}\begin{bmatrix} 15 & -3 \\ -3 & 3 \end{bmatrix}$$

$$[K] = \frac{EI}{L^3}\begin{bmatrix} 5 & -1 \\ -1 & 1 \end{bmatrix}$$

62. **(c)**

$$\text{Logarithmic decrement} = \frac{2\pi\xi}{\sqrt{1-\xi^2}} = \frac{2\pi\times 0.6}{\sqrt{1-0.6^2}} = 4.712$$

63. **(c)**



$$\Sigma M_A = 0$$

$$\Rightarrow \quad -M_A - R_B \times L + 1 \times x = 0$$

$$\Rightarrow \quad R_B \times L = x - M_A$$

$$= x - y_1$$

$$= x - f(x)$$

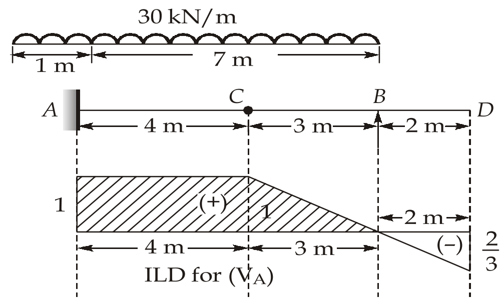
$$\therefore \quad R_B = y_2 = \frac{x}{L} - \frac{f(x)}{L}$$

64. **(c)**

Stresses are induced due to effect of lack of fit and temperature change in statically indeterminate truss only. In determinate truss, no axial force gets induced in any of its members due to lack of fit and temperature change. The given truss is both externally and internally determinate. Therefore, stress in member QS is zero.

65. (c)

ILD for vertical reaction at A can be drawn as shown below.



For maximum positive vertical reaction at *A*, udl (uniformly distributed load) should be placed between *A* and *B*,

$$\therefore \quad (V_A)_{max} = 30\times\left(\frac{1}{2}\times3\times1+4\times1\right) = \frac{30\times11}{2}\text{ kN}$$

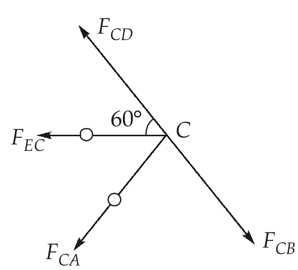
$$\Rightarrow \quad (V_A)_{max} = 165\text{ kN}$$

66. (c)

For absolute maximum bending moment under one of the concentrated loads, this load is so positioned on the beam that this load and the resultant load of the system of loads are equidistant from the beam's centreline.

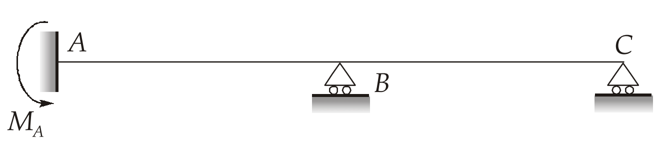
67. (c)

FBD of joint *C*

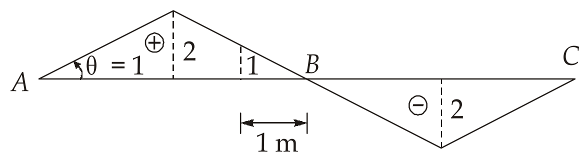


Since members *DE* and *EA* are collinear and no force is acting at joint *E*, member *EC* will not carry any force. Now at joint *C* two members *DC* and *CB* are collinear and no external force is acting on joint *C*. Therefore member *CA* also carries no force.

68. (a)



ILD for M_A



$$M_A = 2\times\left(\frac{1}{2}\times2\times2\right)+10\times1-3\times\left(\frac{1}{2}\times2\times2\right)$$

$$= 4 + 10 - 6 = 8 \text{ kNm}$$

69. (d)

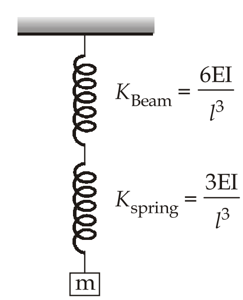
In MDM, when multiple joints are involved, the moments at the ends of members connected to a joint are not initially balanced. The process involves distributing the unbalanced moment to the adjacent members. This distribution generates new unbalanced moment at the neighboring joints, requiring further iterations.

- Iteration is necessary to gradually balance the moment at all the joints.
- The process is continued until the unbalanced moment becomes negligible, resulting in the final moment value.

NOTE: If only one joint rotation is involved, no further distribution occurs, and the moments are directly obtained without iteration.

70. (d)

Here beam and spring are in series combination.



Stiffness of beam :

$$K_{\text{Beam}} = \frac{48EI}{(2l)^3}=\frac{6EI}{l^3}$$

Stiffness of spring:

$$K_{\text{spring}} = \frac{3EI}{l^3}$$

For equivalent stiffness,

$$\frac{1}{K_{eq}} = \frac{1}{K_{\text{Beam}}}+\frac{1}{K_{\text{spring}}}$$

$$\Rightarrow \quad \frac{1}{K_{eq}} = \frac{l^3}{6EI}+\frac{l^3}{3EI}=\frac{l^3}{2EI}$$

$$\Rightarrow \quad K_{eq} = \frac{2EI}{l^3}$$

∴ Natural frequency of block,

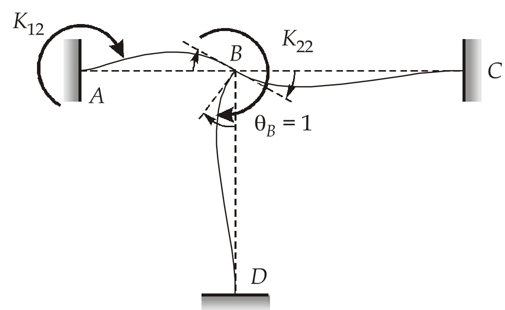
$$\omega_n = \sqrt{\frac{K_{eq}}{m}}=\sqrt{\frac{2EI}{ml^3}}$$

71. **(c)**

72. **(b)**

K_{12} = Load in the direction of coordinate ① due to unit displacement in the direction of coordinate 2.

Apply unit rotation at ② only,



$$K_{12} = \frac{1}{2}\left(\frac{4EI}{4}\right) = \frac{EI}{2}$$

73. **(a)**

The elements of flexibility matrix are dependent on the choice of coordinates.

74. **(a)**

75. **(a)**

Diagonal elements of both flexibility as well as stiffness matrices are always positive.

This is because displacement along any coordinate due to unit load at that coordinate is always in the same direction of unit load.

■■■■