DETAILED SOLUTIONS

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ESE 2026 : 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.	(a)	16.	(d)	31.	(d)	46.	(d)	61.	(d)
2.	(d)	17.	(b)	32.	(a)	47.	(d)	62.	(b)
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7.	(b)	22.	(d)	37.	(b)	52.	(b)	67.	(c)
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11.	(b)	26.	(a)	41.	(a)	56.	(d)	71.	(b)
12.	(c)	27.	(b)	42.	(d)	57.	(d)	72.	(c)
13.	(c)	28.	(d)	43.	(a)	58.	(c)	73.	(c)
14.	(a)	29.	(c)	44.	(a)	59.	(b)	74.	(a)
15.	(a)	30.	(b)	45.	(d)	60.	(c)	75.	(d)

DETAILED EXPLANATIONS

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

1. (a)

The most efficient hydraulic sections are the ones that carry the maximum flow rate for any given slope, roughness coefficient and area of flow.

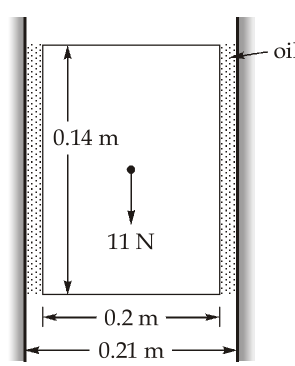
- For a rectangular section, efficiency is achieved when the width becomes twice the flow depth, making the hydraulic radius equal to half the depth of flow.
- For a trapezoidal section, the most economical shape occurs when the side slopes make 60° angle with the horizontal, which also leads to the **hydraulic radius** becoming half the depth of flow.

These geometric conditions ensure maximum discharge with minimum excavation and lining cost, making them preferred in practical channel design.

2. (d)

- The drag on a thin disc with surface kept normal to the flow is almost entirely due to pressure difference created by the large separated wake behind it, and the contribution of friction drag is practically negligible.
- A sphere, on the other hand, produces a much smaller wake, which greatly reduces its pressure drag and makes its total drag considerably lower than that of a disc of the same size.
- For a streamlined body, separation is delayed and the wake becomes very small, leading to a major reduction in pressure drag; however, the increased wetted surface makes the friction drag relatively more significant.
- Streamlining therefore reduces the wake size and pressure drag while increasing the share of friction drag in the total resistance.

3. (a)



Viscosity of oil = 5 poise

$\Rightarrow$ $\mu = 5 \times 10^{-1}\ \text{N/m}^2$

Shear stress developed by vertical descent of the piston

$$= \frac{\text{Weight of piston and load}}{\text{Piston area in contact with oil}}$$

$$= \frac{11}{\frac{22}{7} \times (0.2) \times 0.14} = 125 \text{ N/m}^2$$

Velocity gradient when piston attains a constant velocity of v in the annular gap of 0.005 m,

$$\frac{du}{dy} = \frac{v}{5 \times 10^{-3}}$$

By Newton's law,

$$\tau = \mu \frac{du}{dy}$$

$$\Rightarrow \quad 125 = 5 \times 10^{-1} \times \frac{v}{5 \times 10^{-3}}$$

$$\Rightarrow \quad v = 1.25 \text{ m/s}$$

4. (b)

When a floating body is given a small angular displacement, the centre of buoyancy shifts due to change in the shape of the submerged volume, causing the line of action of buoyant force to change. The point at which the new and original lines of buoyant force intersect is called the metacenter

5. (c)

Let the vorticity components be Ω_x, Ω_y and Ω_z

Now,
$$\Omega_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} = -18yz - 3y$$

$$\Omega_y = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = -2z$$

$$\Omega_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = -2y - 3$$

At (1, 2, 1), $\Omega_x = -42$ units; $\Omega_y = -2$ units; $\Omega_z = -7$ units

6. (b)

Series connection

$$\frac{L_1}{D^2} = \frac{l}{d^5} + \frac{l}{d^5} = \frac{2l}{d^5}$$

$$\therefore \quad L_1 = 2l$$

Parallel connection

$$h_{f2} = h_{f1}$$

$$\frac{fL_2 Q^2}{12.1 D^5} = \frac{fl(Q/2)^2}{12.1\, D^5}$$

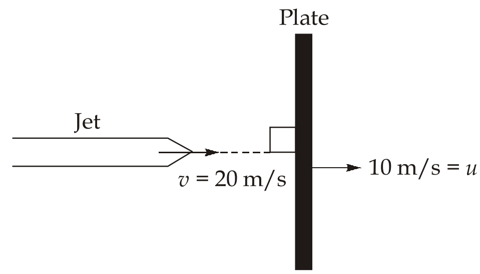
$$L_2 = \frac{l}{4}$$

$$\therefore \quad \frac{L_1}{L_2} = \mathbf{8:1}$$

7. **(b)**

Among all open-channel cross-sections for a given area of flow, the semi-circular section has the smallest wetted perimeter and therefore is the most efficient section.

8. **(c)**



$$\text{Kinetic energy of jet} = \frac{1}{2}mv^2$$

$$= \frac{1}{2}\rho Avv^2 = \frac{1}{2}\rho Av^3$$

$$\text{Work done on plate by jet} = (\text{Force exerted on plate}) \times (\text{Distance moved by plate})$$

$$= \rho A(v-u)^2 \times u$$

$$\therefore \quad \text{Efficiency of jet, } \eta = \frac{\text{Work done}}{\text{K.E. of jet}} \times 100$$

$$\Rightarrow \quad \eta = \frac{\rho A(v-u)^2 u}{\frac{1}{2}\rho Av^3} \times 100$$

$$\Rightarrow \quad \eta = \frac{2 \times (20-10)^2 \times 10 \times 100}{20^3}$$

$$\Rightarrow \quad \eta = 25\%$$

9. **(b)**

For double acting reciprocating pump, $Q_{\text{theoritical}} = \dfrac{2ALN}{60}$

$$= \frac{2 \times 0.1 \times 0.3 \times 60}{60}$$

$$Q_{\text{theoritical}} = 0.06 \text{ m}^3/\text{s}$$

Actual discharge, $Q_{\text{actual}} = \dfrac{3.0}{60} \text{m}^3/\text{sec} = 0.05 \text{ m}^3/\text{s}$

$$\text{Volumetric slip} = Q_{\text{theoritical}} - Q_{\text{actual}}$$

$$= 0.06 - 0.05 = 0.01 \text{ m}^3/\text{s}$$

Power $P = \rho g Q_{act} H$

$$= 10^3 \times 9.81 \times 0.05 \times 10$$

$$P = 4.91 \text{ kW}$$

10. (a)

Path lines represent the actual trajectories traced by individual fluid particles as they move, and therefore inherently depend on time because a particle takes a finite duration to travel from one point to another. Since different particles released at different times may follow different trajectories, two path lines may intersect under unsteady flow conditions, and even a single path line can form a loop if the motion of the particle brings it back close to its earlier position. These characteristics arise from the Lagrangian description of motion, where the focus is on following each particle and observing how its location changes with time.

11. (b)

When the load on the turbine varies suddenly, the discharge is accordingly adjusted by increasing or decreasing the water flow to the turbines. This sudden variation in the flow gives rise to the condition of water hammer. Surge tanks are thereby provided to eliminate water hammer formation. It stabilizes transient pressures by allowing free rise and fall of water level.

12. (c)

Same specific speed does not guarantee same efficiency as efficiency depends on losses and operating conditions.

13. (c)

As submarine is to resist viscous forces, the similarity of Reynold's number is essential.

$$\therefore \quad \left(\frac{vl}{\nu}\right)_p = \left(\frac{vl}{\nu}\right)_m$$

$$\Rightarrow \quad v_m = v_p \frac{l_p}{l_m}\frac{\nu_m}{\nu_p} = 10 \times 25 \times \frac{1.44 \times 10^{-1}}{1.20 \times 10^{-2}}$$

$$\Rightarrow \quad v_m = 3000 \text{ m/s}$$

Drag force,

$$F = \text{Mass} \times \text{Acceleration}$$

$$\Rightarrow \quad F = \rho l^3 \frac{v}{t} = \rho l^2 v^2$$

Ratio of drag force,

$$F_r = \frac{\rho_p}{\rho_m}\left(\frac{l_p}{l_m}\right)^2\left(\frac{v_p}{v_m}\right)^2$$

$$\Rightarrow \quad F_r = \frac{1053}{1.3}(25)^2\left(\frac{10}{3000}\right)^2$$

$$\Rightarrow \quad F_r = 810 \times 625 \times \frac{100}{9 \times 10^6} = 5.625$$

14. (a)

Friction factor of laminar flow and turbulent flow is given as,

For Laminar flow, $f = 64/R_e$

The friction factor is inversely proportional to Reynold's Number

For Turbulent flow, $f = 0.316/R_e^{1/4}$

The pressure drop in a fully developed laminar flow through pipe is given as,

$$\Delta P = \frac{32\mu V_{\text{mean}} L}{D^2}$$

∴ ΔP is proportional to mean velocity or average velocity in pipe.

15. (a)

In a mercury barometer, the space above the mercury column can never be a perfect vacuum because a small amount of mercury vapour always occupies this region. The pressure inside this space equals the vapour pressure of mercury at the prevailing temperature, and since this vapour pressure is extremely low, it is normally neglected in practical calculations. This near-vacuum condition created at the top of the barometer column is known as the Torricellian vacuum.

16. (d)

A surge in an open channel is a moving wave formed due to a sudden change in flow conditions such as rapid opening or lowering of a gate.

- A positive surge occurs when the flow depth increases, and this wave travels upstream with a definite celerity relative to the channel bottom.
- A negative surge results when the flow depth decreases, typically due to the sudden partial lowering of a gate, and it propagates downstream.
- Since a surge represents a travelling disturbance that alters velocity and depth over a short region, its passage produces conditions of unsteady flow in the channel.

17. (b)

Net positive suction head,

$$NPSH = \frac{(P_{atm})_{avs}}{\gamma} - z_s - h_L - \frac{Pv}{\gamma}$$

$$= 10.3 - 4 - 1 - 0.3$$

$$NPSH = 5 \text{ m}$$

18. (c)

Role of Air Vessel in Suction Pipe:

For a given speed, there will be reduction in cavitation susceptibility due to increase in NPSH. For a given minimum pressure head, discharge can be increased. Suction pipe length can be increased. Power expended in pumping will reduce due to reduction in frictional losses.

Role of Air Vessel in Delivery Pipe:

Steady discharge in the delivery pipe is assured. Reduction in frictional losses, considerable saving in power expended (can be as high as 84%). For a given minimum pressure head, running speed of the pump can be increased.

19. (d)

The flow is said to be gradually varied when the depth changes gradually over a long distance as a result of one or more of the following factors:

i. Change in the shape and size of the channel cross-section

ii. Change in the channel slope

iii. Presence of obstructions, such as a weir, etc.

iv. Change in the frictional forces at the boundaries.

20. (a)

From Bernoulli's equation,

$$z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = z_z + \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + \frac{(v_1 - v_2)^2}{2g}$$

Here, $$(z_2 - z_1) + \left(\frac{P_2}{\gamma} - \frac{P_1}{\gamma}\right) = 1 \text{ cm} = \frac{1}{100} \text{ m}$$

By continuity,

$$A_1 v_1 = A_2 v_2$$

$$\Rightarrow \quad v_2 = \frac{d_1^2}{d_2^2} v_1 = \left(\frac{14^2}{28^2}\right) v_1$$

$$\Rightarrow \quad v_2 = 0.25\, v_1$$

$\therefore$ From Bernoulli's equation,

$$\frac{v_1^2}{2g} = \frac{1}{100} + \frac{(0.25\, v_1)^2}{2g} + \frac{(v_1 - 0.25 v_1)^2}{2g}$$

$$\Rightarrow \quad \frac{v_1^2}{20} = \frac{1}{100} + \frac{0.0625 v_1^2}{20} + \frac{0.5625 v_1^2}{20}$$

$$\Rightarrow \quad v_1^2 = 1.875$$

$$\Rightarrow \quad v_1 = 1.37 \text{ m/s}$$

$$\therefore \quad \text{Flow rate } Q = A_1 v_1 = \frac{\pi}{4} d_1^2 \cdot v_1$$

$$\Rightarrow \quad Q = \frac{22}{7 \times 4} \times 0.14^2 \times 1.37$$

$$\Rightarrow \quad Q = 2.11 \times 10^{-2} \text{ m}^3/\text{s}$$

21. (d)

For laminar layer, $$\frac{\delta}{x} = \frac{5}{\sqrt{R_e}} = \frac{5}{\sqrt{\frac{\rho v d}{\mu}}}$$

For turbulent layer $$\frac{\delta}{x} = \frac{0.37}{R_e^{0.2}} = \frac{0.37}{\left(\frac{\rho v d}{\mu}\right)^{0.2}}$$

In the light of the dependence of δ upon *Re*, it may be concluded that the boundary layer thickness is likely to be greater

- at a point downstream the flow than at a point upstream of it.
- for a lower free-stream velocity than for a higher free-stream velocity.
- for a more viscous fluid than for a less viscous fluid.
- for a lower density fluid.

22. (d)

- The horizontal component of the hydrostatic force on a curved surface is equal to the force that would act on the vertical projection of that surface because pressure acts normal to the surface and the horizontal components of these normal pressures add up to give the pressure distribution on the vertical projection.
- The vertical component equals the weight of the prism of liquid vertically above the curved surface, this is because the vertical pressure forces support the column of fluid above the surface.
- The line of action of this vertical component passes through the centre of gravity of that liquid prism, since the vertical resultant is equivalent to the weight of the prism acting through its centroid.
- The overall resultant on the curved surface is found by vectorial addition the horizontal and vertical components

23. (d)

Bulk modulus of elasticity is given by,

$$E_V = -\frac{dP}{dV/V}$$

$$\Rightarrow \quad E_V = -\frac{(12.40-0.40)}{\left(-\frac{1.5V}{100}\right)\Big/V}$$

$$\Rightarrow \quad E_V = 800 \text{ MPa}$$

24. (b)

A Cipolletti weir is a type of trapezoidal weir in which the sides have a slope of 1 horizontal to 4 vertical. It is said to have an advantage over a rectangular weir i.e. the decrease in discharge due to end contraction is balanced by the discharge through the triangular portion and that a rectangular weir formula can then be used to compute the discharge.

25. (d)

Only three types of jet pumps are:

1. Shallow-well jet pumps
2. Deep-well jet pumps
3. Convertible jet pumps

26. (a)

The small lateral holes in the outer tube are specifically positioned so the flow over them is nearly parallel, letting them sense the local static pressure of the undisturbed stream; they do not create or correct turbulence or measure stagnation pressure.

27. (b)

Given that, $\phi = 4xy$

We know, $u = \dfrac{-\partial\phi}{\partial x}$ and $v = \dfrac{-\partial\phi}{\partial y}$

$\therefore$ $u = -4y$ and $v = -4x$

Also, $u = \dfrac{\partial\Psi}{\partial y}$ and $v = \dfrac{-\partial\Psi}{\partial x}$

Total derivative of stream function may be written as,

$$d\Psi = \frac{\partial\psi}{\partial x}dx + \frac{\partial\psi}{\partial y}dy$$

$\Rightarrow$ $d\Psi = -vdx + udy$

$\Rightarrow$ $d\Psi = 4xdx - 4ydy$

On integrating,

$$\Psi = \frac{4x^2}{2} - \frac{4y^2}{2} + C$$

$\Rightarrow$ $\Psi = 2x^2 - 2y^2 + C$

Discharge passing between streamlines passing through the points (1, 2) and (2, 3) is,

$Q = \Psi_{(1,2)}$ and $\Psi_{(2,3)}$

$\Rightarrow$ $Q = 2 - 8 + C - 8 + 18 - C = 4$ units

28. (d)

Given: $L_1 = 200$ m, $d_2 = 400$ mm, $d_1 = 200$ mm,

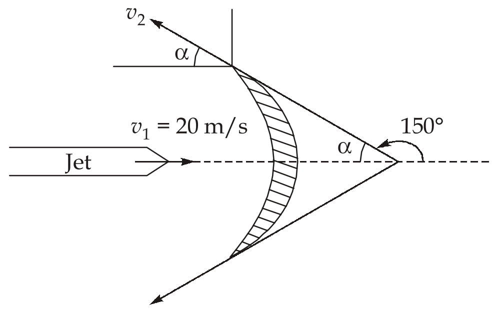
$f_2 = 0.012$, $f_1 = 0.015$

$$\because \quad \frac{8f_1L_1Q^2}{\pi^2 d_1^5 g} = \frac{8f_2 \times L_2 \times Q^2}{\pi^2 d_2^5 g}$$

$$\Rightarrow \quad \frac{0.015 \times 200}{(0.2)^5} = \frac{0.012 \times L_2}{(0.4)^5}$$

$\Rightarrow$ $L_2 = 8000$ m

29. (c)



Angle of deflection, $\alpha = 180° - 150°$

$\Rightarrow$ $\alpha = 30°$

From impulse-momentum principle, the force exerted by the jet in direction normal to vane i.e. thrust is,

$$F = m\,[v_1 - v_2]$$

$$\Rightarrow \quad F = \rho A v_1\,[v_1 - (-v_1 \cos\alpha)]$$

$$\Rightarrow \quad F = \rho A v_1^2\,[1 + \cos\alpha]$$

$$\Rightarrow \quad F = 10^3 \times \frac{\pi}{4} \times 0.05^2 \times 20^2\,[1 + \cos 30°]$$

$$\Rightarrow \quad F = 1.4656 \times 10^3 \text{ N}$$

$$\Rightarrow \quad F \simeq 1.47 \text{ kN}$$

30. (b)

The lift on a rotating cylinder arises due to the Magnus effect. Rotation increases the velocity of flow on one side of the cylinder and decreases it on the other, creating an asymmetry in the pressure distribution around the surface. According to Bernoulli's principle, the side with higher velocity has lower pressure, while the opposite side has higher pressure. This pressure difference acts normal to the flow direction and produces a net lift force on the cylinder. The lift is generated primarily because rotation creates a pressure difference across the cylinder.

31. (d)

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - F_r^2} \qquad \text{...(A)}$$

We know,

$$F_r^2 = \frac{Q^2 T}{gA^3} = \frac{Q^2 B}{gB^3 y^3}$$

$$\Rightarrow \quad F_r^2 = \frac{Q^2}{gB^2 y^3} = \frac{q^2}{gy^3} \qquad \text{...(i)}$$

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

$$\Rightarrow \quad y_c^3 = \frac{q^2}{g} \quad ...(ii)$$

Using (i) and (ii),

$$F_r^2 = \frac{y_c^3}{y^3} \quad ...(iii)$$

Now, $$Q = \frac{1}{n}AR^{2/3}S_o^{1/2} = \frac{1}{n}AR^{2/3}S_f^{1/2}$$

$$\Rightarrow \quad \frac{1}{n}By_oy_o^{2/3}S_o^{1/2} = \frac{1}{n}By\,y^{2/3}S_f^{1/2}$$

$$\Rightarrow \quad y_o^{5/3}\,S_o^{1/2} = y^{5/3}\,S_f^{1/2}$$

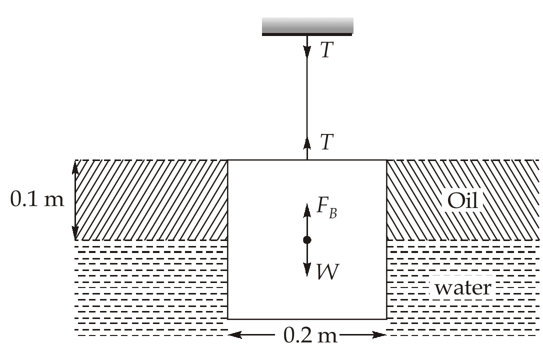
$$\Rightarrow \quad S_f = \left(\frac{y_o}{y}\right)^{10/3} S_o \quad ...(iv)$$

Substitute the value of S_f and F_r^2 from (iv) and (iii) in (A)

$$\frac{dy}{dx} = S_0\left[\frac{1-(y_0/y)^{10/3}}{1-(y_c/y)^3}\right]$$

32. (a)

Tension in the string,



$$T = W - F_B$$

$$\Rightarrow \quad T = 20 \times 10^3 \times 0.2^3 - 10\times10^3\left[\frac{0.2^3}{2}(0.8+1)\right]$$

$$\Rightarrow \quad T = 88\ N$$

33. (d)

- The coefficients α and β account for non-uniformity in velocity distribution across an open-channel section. As the velocity distribution becomes more uneven, the values of α and β increase and generally satisfy α > β > 1.
- Larger and deeper channels with more regular sections tend to show lower values of these coefficients, whereas small or irregular channels may exhibit comparatively higher values. In natural and compound channels, α and β can reach significantly large values depending on flow irregularities.
- Under ideal conditions of uniform velocity distribution, both coefficients become unity, i.e., α = β = 1. For engineering analysis, this unity assumption is often acceptable in straight prismatic channels or when the flow is nearly uniform. However, in practical natural channels, approximate ranges of α and β are recommended to account for nonuniform flow behaviour.

34. (b)

Elbow-type draft tube is mainly used with axial-flow turbines such as Kaplan, propeller, bulb and tubular turbines.

35. (b)

Scale ratio, $D_r = \frac{1}{10}$

$\because$ Power; $\frac{P}{H^{3/2}D^2} = \text{constant}$

$$\therefore \quad \frac{P_m}{P_p} = \left(\frac{H_m}{H_p}\right)^{3/2}\left(\frac{D_m}{D_p}\right)^2$$

$$\Rightarrow \quad P_m = 25\times\left(\frac{36}{81}\right)^{3/2}\left(\frac{1}{10}\right)^2$$

$$\Rightarrow \quad P_m = 0.07407 \text{ MW}$$

$$\Rightarrow \quad P_m = 74.07 \text{ kW}$$

36. (c)

For pure water and clean glass, the value of contact angle, θ, is 0°. For any other value of θ, the magnitude of capillary rise will decrease.

37. (b)

Although the flow path changes, the major cause of bend losses is the formation of secondary flow and the pressure differences between the inner and outer walls of the bend.

38. (d)

Total minor head losses in the pipe,

$$= \frac{0.5v^2}{2g}(\text{Entrance loss}) + \frac{v^2}{2g}(\text{Exit loss})$$

$$= \frac{0.5\times 4^2}{2\times 10} + \frac{4^2}{2\times 10} = 1.2 \text{ m}$$

39. **(a)**

40. **(a)**

In flows where the viscosity is very low and the Reynolds number is high, the influence of viscous forces is restricted to a narrow region next to the solid boundary. This thin layer is where the velocity increases from zero at the wall to the free-stream value, and where the viscous shear stresses remain significant. Outside this boundary-layer zone, the flow is governed predominantly by inertial effects, and the velocity is essentially unaffected by viscosity.

41. **(a)**

The centre of pressure always lies below the centre of gravity of the plane surface because pressure intensity increases linearly with depth.

42. **(d)**

The total energy line continues to drop along the flow whereas the hydraulic gradient line, though always below the energy gradient line, may show an upward or downward trend.

43. **(a)**

When disturbances in the boundary layer grow, they promote transition from laminar to turbulent flow; the pressure gradient along the flow controls how fast those disturbances amplify. If the pressure increases in the flow direction ($\partial p/\partial x > 0$, an adverse pressure gradient) the boundary-layer becomes less stable and transition is hastened, whereas a decreasing pressure ($\partial p/\partial x < 0$, a favourable pressure gradient) stabilizes the layer and delays transition. Consequently, boundary-layer growth and earlier transition are more likely over surfaces or passages that produce an adverse pressure gradient than over a flat plate with zero pressure gradient.

44. **(a)**

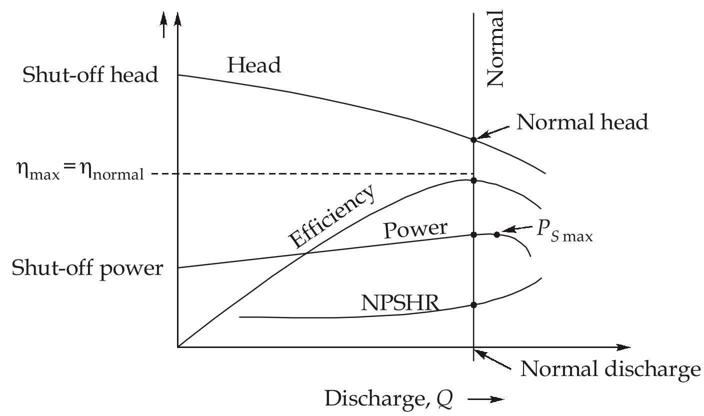
A hydraulic ram pump is capable of delivering water to elevations significantly higher than the available supply head. The rapid closure of the waste valve generates a water-hammer pressure surge, which forces part of the incoming water into the air vessel and up the delivery pipe. The water-hammer pressure created by the sudden valve closure provides the additional energy required to lift water to a higher elevation than the supply head.

Thus, without the pressure surge as described in statement-II, the phenomenon stated in statement-I would not occur.

Therefore, statement-II is the correct explanation of statement-I.

45. (d)

Head vs Discharge (H-Q) characteristic curve exhibits a monotonic decrease in head as the discharge increases.



Section B : Design of Concrete and Masonry Structures - I

46. (d)

Creep of concrete increases when:

- Cement content is high.
- Water-cement ratio is high.
- Aggregate content is low.
- Air entrainment is high.
- Relative humidity is low.
- Temperature is high.
- Loading occurs at an early age.

47. (d)

Let the prestressing force be P kN

Now, intensity of equivalent load due to prestress,

$$w_p = \frac{8Ph}{l^2} = \frac{8P \times 0.2}{10^2} = 0.016\text{ P kN/m}$$

At balanced stage,

$$w_p = 18\text{ kN/m}$$

$$\therefore \quad 0.016\,P = 18$$

$$\Rightarrow \quad P = 1125\text{ kN}$$

48. (b)

Given: $b = 250$ mm, $d = 500$ mm

As per IS 456 : 2000 (C*l* 23.3) for a simply supported or continuous beam, clear distance between lateral restraints is

$$l \not> \min \begin{cases} \dfrac{250b^2}{d} \\ 60\,b \end{cases}$$

$$\Rightarrow \quad l_{max} = \min \begin{cases} \dfrac{250 \times 250^2}{500} = 31.25 \text{ m} \\ 60 \times 250 \quad = 15 \text{ m} \end{cases}$$

$$\Rightarrow \quad l_{max} = 15 \text{ m}$$

49. (b)

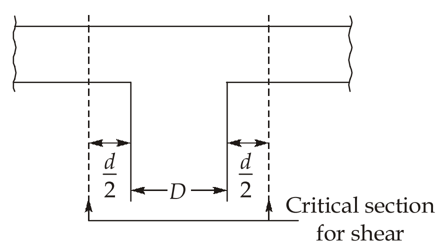
Refer IS 456:2000 (C*l* 26.2.5.1)

- When bars of two different diameters are to be spliced, the lap length shall be calculated on the basis of diameter of the smaller bar.

50. (c)

Given: $D = 400$ mm, $d = 150$ mm

As per IS 456: 2000 C*l*.31.6.1.



The critical section for punching shear in a flat slab is located at a distance of $d/2$ (half the effective depth) from the face of the column.

$$\frac{d}{2} = \frac{150}{2} = 75 \text{ mm}$$

Length of the critical perimeter,

$$L_p = 4\,[400 + 2 \times 75]$$

$$\Rightarrow \quad L_p = 2200 \text{ mm}$$

51. (c)

A beam is called deep beam if, $\dfrac{L}{D} < 2.5$ for continuous beam and $\dfrac{L}{D} < 2.0$ for simply supported beam.

So, here $L < 2\,D$

So, maximum effective span $= 2 \times (600 + 50)$

$$\Rightarrow \quad (l_{eff})_{max} = 1300 \text{ mm} = 1.3 \text{ m}$$

52. (b)

Given: $G = 3 \text{ m}, \quad x = 1.2 \text{ m}, y = 0.8 \text{ m}$

Effective span, $l_{eff} = G + x + y$

where, $x = \min \begin{cases} x = 1.2\, m \\ 1\, m \end{cases} = 1\, m$

$y = \min \begin{cases} y = 0.8\, m \\ 1\, m \end{cases} = 0.8\, m$

$\therefore \quad l_{eff} = 3 + 1 + 0.8 = 4.8 \text{ m}$

53. (a)

As per IS 1893: 2025, (*Cl* 8.2.4.5)

The design lateral force at i^{th} floor is given by

$$Q_i = \frac{W_i H_i^2}{\Sigma\left(W_i H_i^2\right)} V_{B.S}$$

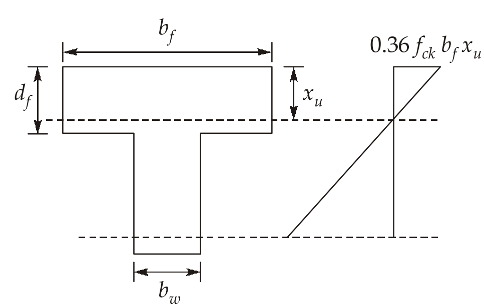
For 2^{nd} floor, $i = 2$

$$Q_2 = \frac{W(6)^2 \times 1980}{W(3)^2 + W(6)^2 + W(9)^2 + \frac{W}{2}(12)^2}$$

$$\Rightarrow \quad Q_2 = \frac{36 \times 1980}{198}$$

$$\Rightarrow \quad Q_2 = 360 \text{ kN}$$

54. (c)

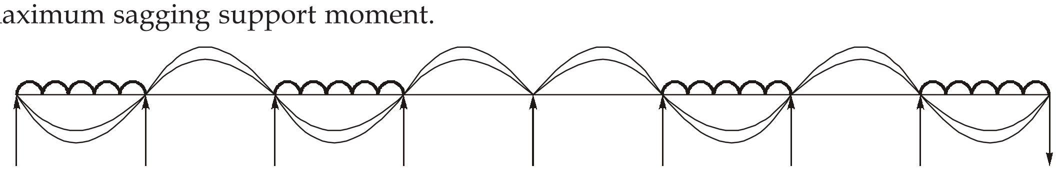


If the neutral axis (NA) falls within the flange:

The compression zone is limited entirely to the top rectangular area defined by the flange width (b_f) and the distance to the neutral axis (x_u). The web below the *NA* is in tension and is ignored. Therefore, the beam is analyzed exactly like a simple rectangular beam of width b_f.

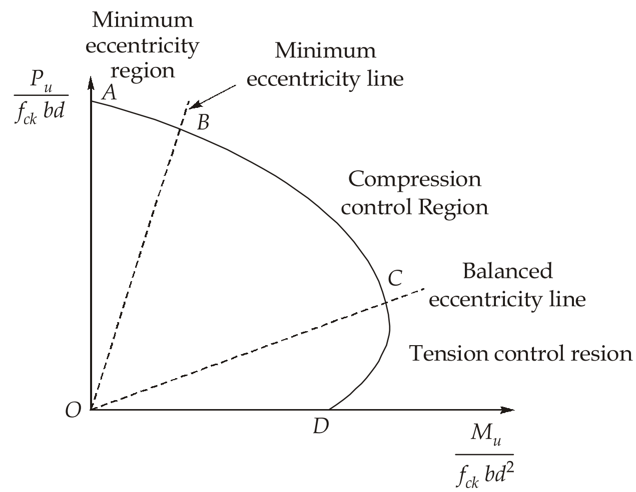
55. (c)

For maximum sagging support moment.



Loading should be applied on next to adjacent span plus alternate spans.

56. (d)



57. (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.

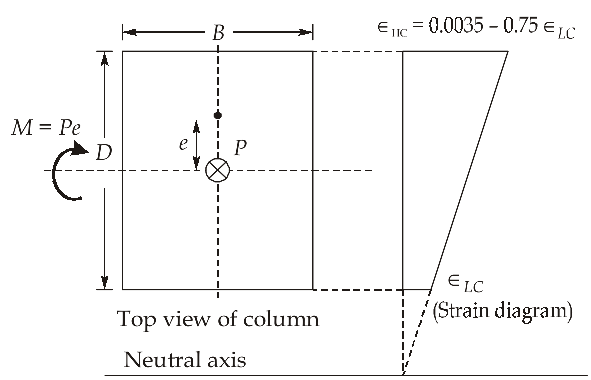
58. (c)

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.



59. (b)

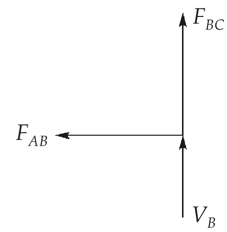
60. (c)

For concrete mix design, apart from meeting the criteria for characteristic strength, concrete must be workable in fresh state and impermeable and durable in hardened state Nominal mix concrete is permitted only for ordinary concrete (i.e. upto M20 grade concrete).

Section C : Structural Analysis - II

61. (d)

FBD of joint *B*:

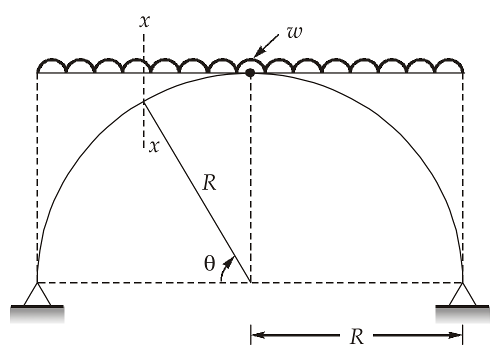


Now, $\Sigma F_x = 0 \Rightarrow F_{AB} = 0$

62. (b)

Bending moment at *x-x* section is given by,

$$M_x = \frac{-wR^2}{2}\left(\sin\theta - \sin^2\theta\right)$$



For maximum bending moment,

$$\frac{dM_x}{d\theta} = 0$$

$$\Rightarrow \quad \frac{wR^2}{2}\left(\cos\theta - 2\sin\theta\cos\theta\right) = 0$$

$$\Rightarrow \quad \cos\theta\,(1 - 2\sin\theta) = 0$$

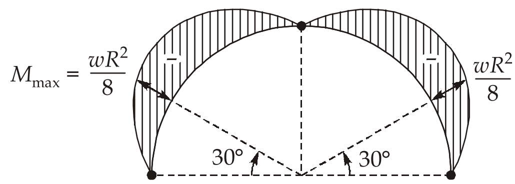
$$\Rightarrow \quad \cos\theta = 0 \Rightarrow \theta = 90° \text{ and } \sin\theta = \frac{1}{2} \Rightarrow \theta = 30°$$

$$\theta = 90° \text{ (Rejected as } BM = 0)$$

$$\therefore \quad \theta = 30°$$

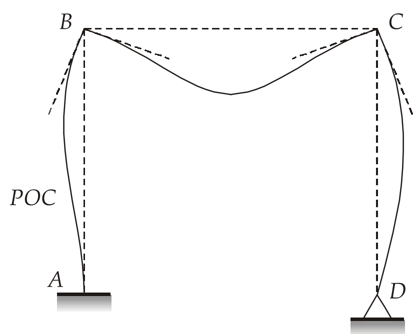
$$\therefore \quad M_{max} = -\frac{wR^2}{2}(\sin 30° - \sin^2 30°)$$

$$\Rightarrow \quad M_{max} = -\frac{wR^2}{8} \text{ or } \frac{wR^2}{8} \text{ (Hogging)}$$

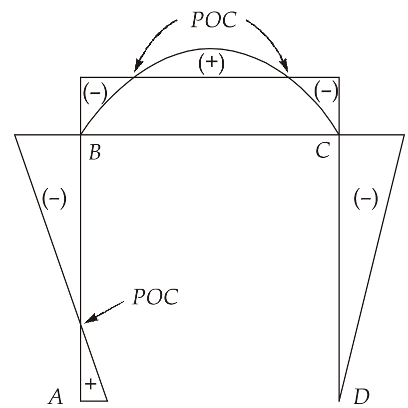


Bending moment diagram

63. (c)



Deflected shape



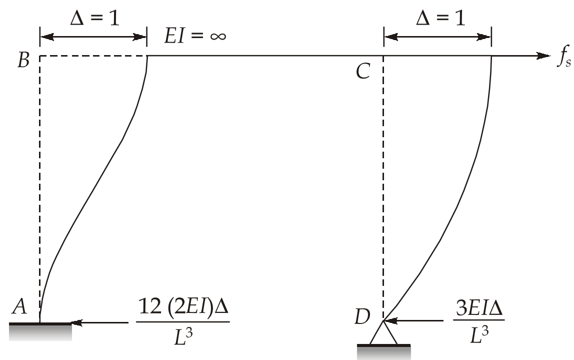
BMD

64. (a)

- Moment distribution method is a relaxation technique for structural analysis that was developed by Hardy Cross.
- Slope deflection method is a displacement method where the unknowns are joint rotations and displacements (slopes and deflections), hence it is associated with displacements.
- Kani's method is a displacement method of structural analysis that uses a series of approximations involving the calculation of rotation factor.
- Force method (also known as the flexibility method) uses forces as primary unknowns and is therefore associated with flexibility of members.

65. (c)

66. (d)



Lateral stiffness of frame

$$f = \frac{12(2EI)\Delta}{L^3} + \frac{3EI\Delta}{L^3}$$

$$\Rightarrow \quad f = \frac{27EI\Delta}{L^3}$$

$$\Rightarrow \quad f = \frac{27EI}{L^3} \qquad (\because \quad \Delta = 1)$$

67. (c)

Stiffness matrix = Inverse of flexibility matrix

$$\Rightarrow \quad [S] = [F]^{-1}$$

$$\Rightarrow \quad [S] = \frac{EI}{|F|}\begin{bmatrix} 3 & -8 \\ -8 & 25 \end{bmatrix}$$

$$\Rightarrow \quad [S] = \frac{EI}{(25 \times 3 - 64)}\begin{bmatrix} 3 & -8 \\ -8 & 25 \end{bmatrix}$$

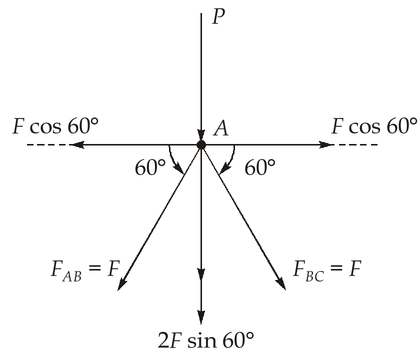
$$\Rightarrow \quad [S] = \frac{EI}{11}\begin{bmatrix} 3 & -8 \\ -8 & 25 \end{bmatrix}$$

68. (b)

FBD of joint *A*:

$$\Sigma F_y = 0$$

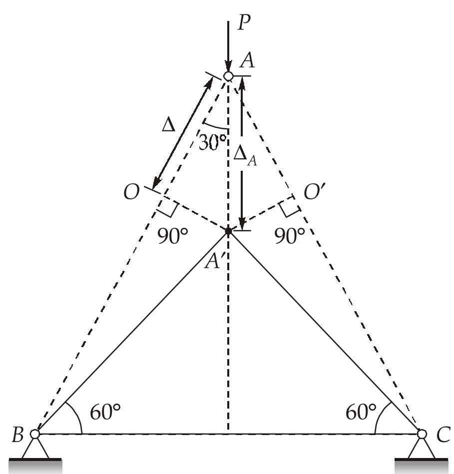
$$\Rightarrow \quad P + 2F \sin 60° = 0$$



$$\Rightarrow \quad F = -\frac{P}{\sqrt{3}}$$

$$\therefore \quad F = \frac{P}{\sqrt{3}} \text{ (compressive)}$$

$$\because \quad \Delta = \frac{F_{AB}l}{AE} = \frac{Pl}{\sqrt{3}AE}$$



In $\Delta AOA'$

$$\Delta_A \cos 30° = \Delta$$

$$\Rightarrow \quad \Delta_A \frac{\sqrt{3}}{2} = \frac{Pl}{\sqrt{3}AE}$$

$$\Rightarrow \quad \Delta_A = \frac{2Pl}{3AE} (\downarrow)$$

69. (c)

External support reactions, $R_e = 4$

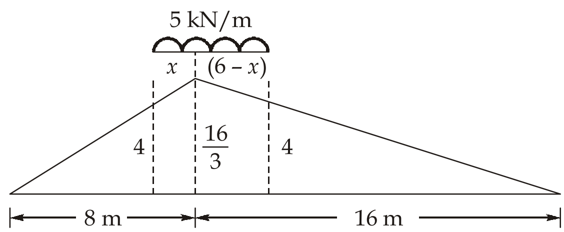
Number of joints, $j = 8$

Kinematic indeterminacy

$$D_k = 2j - R_e$$

$$\Rightarrow \quad D_k = 2 \times 8 - 4 = 12$$

70. (c)



Let 'x' be the length of UDL, on 8 m length of beam.

$$\therefore \quad \frac{x}{8} = \frac{6-x}{24-8}$$

$$\Rightarrow \quad x = 2 \text{ m}$$

$$\therefore \quad M_{max} = \frac{1}{2} \times \left(4 + \frac{16}{3}\right) \times 2 \times 5 + \frac{1}{2} \times \left(\frac{16}{3} + 4\right) \times 4 \times 5$$

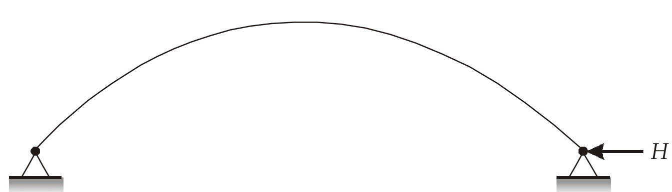
$$\Rightarrow \quad M_{max} = 140 \text{ kNm}$$

71. (b)

72. (c)

- The flexibility matrix will always be a square matrix in which diagonal elements will be non-negative and non zero,
- Order of flexibility matrix will be equal to degree of static indeterminacy.

73. (c)



$$U = \int_0^l \frac{(M_s - Hy)^2 \, dS}{2EI}$$

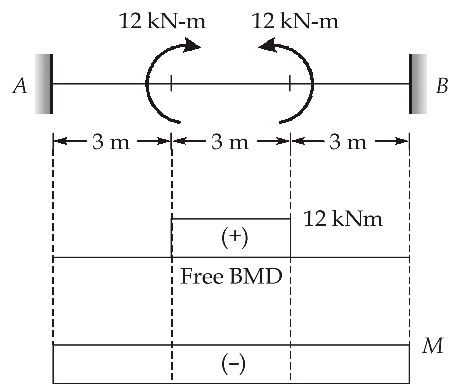
Given $$\frac{\partial U}{\partial H} = -\delta$$

$$\therefore \quad \frac{\partial U}{\partial H} = \int_0^l \frac{(M_s - Hy)(-y)}{EI} dS = -\delta$$

$$\Rightarrow \quad \int_0^l -\frac{M_s y dS}{EI} + \int_0^l \frac{Hy^2}{EI} dS = -\delta$$

$$\Rightarrow \quad H = \frac{\int_0^l \frac{M_s y dS}{EI} - \delta}{\int_0^l \frac{y^2}{EI} dS}$$

74. (a)



Fixed end moment diagram

∵ Slope at A is zero

$$\therefore \quad \frac{\text{Area of free BMD}}{EI} = \frac{\text{Area of fixed end moment diagram}}{EI}$$

$$\Rightarrow \quad 12 \times 3 = 9\text{ M}$$

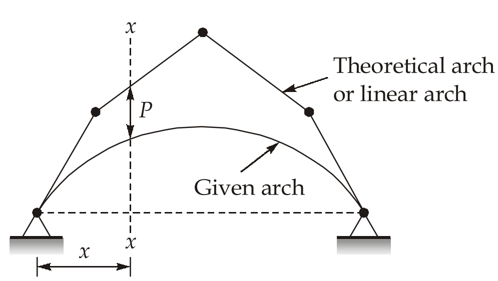
$$\Rightarrow \quad M = 4\text{ kN-m}$$

75. (d)

Eddy's theorem states that, if a linear arch is superimposed on a given arch, then the bending moment at any section on given arch is proportional to the difference of ordinates between given arch and theoretical arch.

$$M_x \propto P$$

Where P is difference of ordinates between given arch and theoretical arch.



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