CLASS TEST

SL. : 01SP_ME_ABCDEFG_270924

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FLUID MECHANICS

MECHANICAL ENGINEERING

Date of Test : 27/09/2024

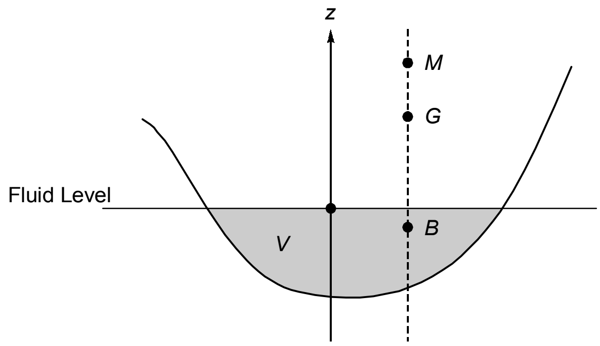
ANSWER KEY

1.	(d)	7.	(b)	13.	(c)	19.	(b)	25.	(b)
2.	(b)	8.	(b)	14.	(d)	20.	(d)	26.	(c)
3.	(a)	9.	(b)	15.	(c)	21.	(b)	27.	(b)
4.	(c)	10.	(d)	16.	(b)	22.	(a)	28.	(c)
5.	(c)	11.	(a)	17.	(d)	23.	(a)	29.	(a)
6.	(c)	12.	(d)	18.	(a)	24.	(b)	30.	(a)

DETAILED EXPLANATIONS

1. (d)

Stable equilibrium condition



2. (b)

For geometrically similar model and prototype

$$\left(\frac{P}{N^3D^5}\right)_{model} = \left(\frac{P}{N^3D^5}\right)_{prototype}$$

Given, $N_m = N_p$

$$\Rightarrow \quad \frac{P_m}{N_m^3 D_m^5} = \frac{P_p}{N_p^3 D_p^5}$$

$$\frac{P_m}{P_p} = \frac{N_m^3 D_m^5}{N_p^3 D_p^5}$$

$$\frac{P_m}{P_p} = \frac{2^3 N_p^3}{N_p^3} \times \frac{D_m^5}{16^5 D_m^5}$$

$$P_m = \frac{10 \times 10^6 \times 2^3}{16^5} W = 76.29 \text{ W}$$

3. (a)

$$P_A - H \times 9.81 \times 1 - 0.18 \times 9.81 \times 0.827 = P_B - 13.6 \times 9.81 \times (H + 0.53)$$

$$-H \times 9.81 - 1.4603 = 97 - 13.6 \times 9.81 \times H - 13.6 \times 9.81 \times 0.53$$

$$\Rightarrow \quad H = 0.2245 \text{ m}$$

$$\therefore \quad H = 22.45 \text{ cm}$$

4. (c)

$$\therefore \quad \bar{V} = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}d^2} \Rightarrow \frac{4Q}{\pi d^2} = \frac{4 \times 880 \times 10^{-9}}{\pi \times 0.50^2 \times 10^{-6}} = 4.48 \text{ m/s}$$

We know, $$Q = \frac{\pi \Delta p D^4}{128 \mu L}$$

$$\Rightarrow \quad \mu = \frac{\pi \Delta p D^4}{128 Q L} = \frac{\pi \times 10^6 \times (0.5)^4 \times 10^{-12}}{128 \times 880 \times 10^{-9} \times 1}$$

$$\mu = 1.74 \times 10^{-3} \text{ Ns/m}^2$$

5. (c)

$$Re_{critical} = 2000 = \frac{VD}{\nu} = \frac{\rho VD}{\mu}$$

$$2000 = \frac{950 \times V \times 0.15}{8 \times 10^{-2}}$$

$$V = 1.123 \text{ m/s}$$

$$\text{Head loss} = \frac{32\mu VL}{\rho g D^2} = \frac{32 \times 8 \times 10^{-2} \times 1.123 \times 300}{950 \times 9.81 \times 0.15^2}$$

$$= 4.113 \text{ m} \Rightarrow \text{Maximum difference in oil elevations.}$$

6. (c)

During cavitation, the vapour bubbles starts forming where the pressure of the liquid falls below the vapour pressure and sudden collapsing of these vapour bubbles in a region of higher pressure. When they collapse, a very high pressure is created. This causes pitting action on the surfaces over which they collapse. Hence during, cavitation and subsequent, pitting, pre-dominant forces are compressive forces.

7. (b)

$$\text{Force on piston} = \text{Shear force due to oil viscosity}$$

$$18 = \tau \,.\, A$$

$$18 = \frac{\mu V}{h} \times \pi \times d \times L$$

$$\Rightarrow \quad 18 = \frac{3 \times 0.1 \times V \times \pi \times 0.0795 \times 0.3}{0.025 \times 10^{-2}}$$

$$\Rightarrow \quad V = 0.2001 \text{ m/s}$$

$$\Rightarrow \quad V = 20 \text{ cm/s}$$

8. (b)

$$\text{Sensitivity} = \frac{1}{\sin\theta} = \frac{1}{\sin 30°} = 2$$

9. (b)

Surface tension is due to cohesion between liquid particles at the surface.

10. (d)

$$P = \rho_{Hg} \times g \times H$$

$$6.8 \times 10^4 = 13.6 \times 10^3 \times 9.81 \times H$$

$$H_{Hg} = 0.5096 \text{ m}$$

$$H_{water} = \frac{13.6}{1} \times 0.5096$$

$$H_{water} = 6.931 \text{ m}$$

11. (a)

For the condition of verge of tipping, the centre of pressure must be at C.

$$\therefore \quad \text{Height of C above B} = \frac{9.5}{3} = 3.16 \text{ m}$$

[$\because$ for a rectangular plane surface of height H, just completely inside fluid, the centre of pressure is at $\frac{H}{3}$ from base.]

12. (d)

$$\text{Volume of cube} = a^3$$

$$a^3 = 125 \times 10^{-3} \times 10^{-3} \text{ m}^3$$

$$\Rightarrow \quad a = 5 \times 10^{-2}$$

$$\Rightarrow \quad a = 0.05 \text{ m}$$

$$F = p \times A$$

$$P_{bottom} = p_{atm} + h_1 g \rho_{oil} + h_2 \rho_{water}\, g$$

$$= 101325 + 0.5 \times 0.8 \times 1000 \times 9.81 + 0.3 \times 1000 \times 9.81$$

$$P_{bottom} = 108192 \text{ Pa}$$

$$F = P_{bottom} \times A = 108192 \times 0.05^2 = 270.48 \text{ N}$$

$$T = \text{Upthrust} - W$$

$$= 125 \times 10^{-6} \times 1000 \times 9.81 - 125 \times 10^{-6} \times 0.77 \times 1000 \times 9.81$$

$$= 0.282 \text{ N}$$

13. (c)

$$u = \frac{\partial \psi}{\partial y}$$

$$u = 2x^2 + (x + t)\, 2y$$

$\therefore$ for face OB, $\quad x \Rightarrow 0$

$$u_{OB} = 2ty$$

Discharge through AB

$$\therefore \quad Q_{AB} = \int_0^2 u_{OB} \cdot 5dy = \int_0^2 2ty \cdot 5dy$$

At $\quad t = 1$

$$Q_{OB} = 20 \text{ units}$$

$$\therefore \quad V = -\frac{\partial \psi}{\partial x} = -\left[4xy + y^2\right]$$

At $\quad y = 0$

$$V = 0$$

$$\therefore \quad Q_{AO} = 0$$

$$\therefore \quad Q_{AB} = Q_{OB} + Q_{OA}$$

$$= 20 + 0$$

$$= 20 \text{ units}$$

14. (d)

$$V_2 = \frac{Q}{A_2} = \frac{1.13 \times 10^{-6}}{\frac{\pi}{4} \times (0.0012)^2} \simeq 1 \text{ m/s}$$

$$\frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_f$$

$$h_f = z_1 - z_2 - \frac{\alpha_2 V_2^2}{2g}$$

$$\Rightarrow \quad h_f = 0.6 - 0 - \frac{(2)(1)^2}{2 \times 9.81} = 0.5 \text{ m}$$

$$h_f = \frac{32 \mu V L}{\rho g D^2}$$

$$\Rightarrow \quad 0.5 = \frac{32 \times \mu \times 0.3 \times 1}{9000 \times 0.0012^2}$$

$$\Rightarrow \quad \mu = 6.75 \times 10^{-4} \text{ Pa-s}$$

15. (c)

$$\mu = 0.97 \text{ poise} = 0.097 \text{ Ns/m}^2$$

$$\rho = 0.9 \times 998 = 898.2 \text{ kg/m}^3$$

$$\dot{m} = \text{mass rate of flow} = \frac{100}{30} = 3.333 \text{ kg/s}$$

$$Q = \text{Volume rate of flow}$$

$$= \frac{3.333}{898.2}$$

$$\Rightarrow \quad 3.711 \times 10^{-3} \text{ m}^3\text{/s} = 3.711 \text{ L/s}$$

$$\text{Area of flow} = A = \frac{\pi}{4}(0.1)^2 = 0.007854 \text{ m}^2.$$

$$\bar{U} = \frac{3.711 \times 10^{-3}}{0.007854} = 0.4725 \text{ m/s}$$

$$-\Delta P = \frac{32 \mu \bar{U} L}{D^2} = \frac{32 \times 0.097 \times 0.4725 \times 10.0}{(0.1)^2}$$

$$-\Delta P = 1467 \text{ Pa}$$

16. (b)

$$Re_L = \frac{UL}{\nu} = \frac{1.75 \times 5}{1.475 \times 10^{-5}}$$

$$Re_L = 5.932 \times 10^5$$

$$C_f = \frac{0.074}{Re_L^{1/5}} = \frac{0.074}{(5.932 \times 10^5)^{1/5}} = 5.183 \times 10^{-3}$$

Drag force on one side of the plate,

$$F_d = C_f \times \text{area} \times \frac{1}{2}\rho U^2$$

$$= 5.183\times10^{-3}\times(1.8\times5)\times1.22\times\frac{(1.75)^2}{2}$$

$$F_d = 0.0871\text{ N}$$

17. (d)

$\because$ Continuity equation holds,

$$\therefore \quad \frac{\pi}{4}\times(5)^2\times2 = \frac{\pi}{4}\times3^2\times x$$

$$x = 5.55\text{ m/s}$$

Mars flow rate

$$\Rightarrow \quad \dot{m} = \rho A_1V_1 = 1000\times\frac{\pi}{4}\times0.05^2\times2 = 3.9269\text{ kg/s}$$

Let f_x and f_y be the force in Right and vertically upward diversion respectively to hold the box in position.

$\therefore$ Now, $\Sigma f_x = 0$ [Box is stationary after applying force]

$$-\dot{m}\times V_1\cos65°+f_x = -\dot{m}\times V_2\cos0°$$

$$-3.9269\times2\times\cos65°+f_x = -3.9269\times5.55\times1$$

$$f_x = -18.475\text{ N.}$$

f_x must be in left as f_x comes out to be negative.

Similarly for vertical direction $\Sigma f_y = 0$

$$f_y - 3.9269\times2\times\sin65° = 0$$

$$f_y = 7.11\text{ N}$$

$\therefore$ It is towards vertically upward direction.

18. (a)

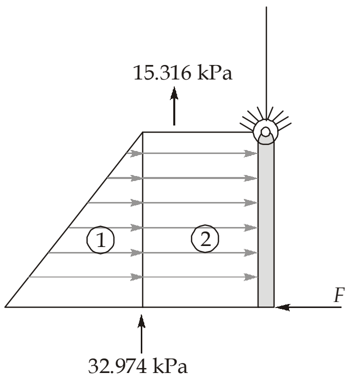
Gauge pressure at the upper end of the gate

$$= 80 + 0.9\times9.81\times4 - 100$$

$$= 15.316\text{ kPa}$$

Gauge pressure at the lower end of the gate

$$= 80 + 0.9\times9.81\times6 - 100 = 32.974\text{ kPa}$$



Using pressure diagram

For equilibrium,

Net moment about the hinge = 0

$$M_1 + M_2 = F \times 2$$

$$\frac{1}{2}\times(32.974-15.316)\times 2\times 4\times\left(\frac{2}{3}\times 2\right)+15.316\times 2\times 4\times\frac{2}{2} = F\times 2$$

On solving $F = 108.352$ kN

19. (b)

$$H_m = H+\frac{fLV_d^2}{2gd}+1.3\times\frac{V_d^2}{2g}+\frac{V_d^2}{2g}$$

H_m = Net head required

$$H_m = 30+\frac{4f'LV_d^2}{2gd}+1.3\times\frac{V_d^2}{2g}+\frac{V_d^2}{2g}$$

$f' = 0.02$ $\quad A_dV_d = 50\times 10^{-3}$ m^3/s

$d = 200$ mm

$$\frac{\pi}{4}\times 0.2^2\times V_d = 50\times 10^{-3}$$

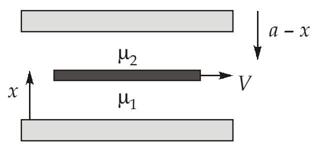
$$V_d = 1.59 \text{ m/s}$$

$$\Rightarrow \quad H_m = 30+\frac{4\times 0.02\times 100\times 1.59^2}{2\times 9.81\times 0.2}+\frac{1.3\times 1.59^2}{2\times 9.81}+\frac{1.59^2}{2\times 9.81}$$

$$= 35.45 \text{ m}$$

$$\Rightarrow \quad \text{Power} = \rho Qg\,H_m = 17388.225 \text{ W} = 17.388 \text{ kW}$$

20. (d)



τ_1 = shear stress at bottom

$$= \mu_1\times\frac{V}{x}$$

$$\tau_2 = \text{shear stress at top} = \mu_2\frac{V}{a-x}$$

$$\text{drag force} = (\tau_1+\tau_2)\times A = F_D$$

$$= F_D = A\times\left[\frac{\mu_1 V}{x}+\frac{\mu_2 V}{a-x}\right]$$

$$\frac{dF_D}{dx} = 0 = \frac{-\mu_1 V}{x^2}+\frac{\mu_2 V}{(a-x)^2} \Rightarrow \frac{\mu_1}{x^2}=\frac{\mu_2}{(a-x)^2}$$

$$a-x = \sqrt{\frac{\mu_2}{\mu_1}}x$$

$$\Rightarrow \quad \frac{a\sqrt{\mu_1}}{\sqrt{\mu_1}+\sqrt{\mu_2}} = x$$

21. (b)

Momentum thickness, $$\theta = \int_0^\delta \frac{u}{U}\left(1-\frac{u}{U}\right)dy$$

Let, $$z = \frac{y}{\delta}$$ (For $y \to 0$, $z \to 0$ and $y \to \delta$, $z \to 1$)

$$\frac{u}{U} = 2z - z^2$$

$$= \int_0^1 (2z-z^2)(1-2z+z^2)\delta dz$$

$$= \delta\int_0^1 \left[(2z-z^2)-2z(2z-z^2)+z^2(2z-z^2)\right]dz$$

$$= \delta\int_0^1 (2z-z^2-4z^2+2z^3+2z^3-z^4)dz$$

$$= \delta\int_0^1 (2z-5z^2+4z^3-z^4)dz$$

$$\theta = \delta\left[z^2-\frac{5z^3}{3}+z^4-\frac{z^5}{5}\right]_0^1$$

$$= \delta\left(1-\frac{5}{3}+1-\frac{1}{5}\right) = \delta\left(2-\left(\frac{5}{3}+\frac{1}{5}\right)\right)$$

$$= \delta\left(2-\frac{28}{15}\right) = \frac{2\delta}{15}$$

22. (a)

(1) $$u = x^2\cos y$$
$$v = -2x\sin y$$

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial y}{\partial y} = 0$$

$$= \frac{\partial u}{\partial x}(x^2\cos y)+\frac{\partial}{\partial y}(-2x\sin y)$$

$$(2x)\cos y-(2x)\cos y = 0$$

hence it satisfy the continuity equation.

(2) $$u = x + 2$$
$$v = 1 - y$$

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial y}{\partial y} = 0$$

$$= \frac{\partial}{\partial x}(x+2)+\frac{\partial}{\partial y}(1-y) = 1 - 1 = 0$$

hence, it satisfy the continuity equation.

(3)
$$u = xyt$$
$$v = x^3 - y^2\frac{t}{2}$$

Continuity equation
$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$
$$= \frac{\partial}{\partial x}(xyt) + \frac{\partial}{\partial y}\left(x^3 - \frac{y^2 t}{2}\right) = yt - yt = 0$$

hence, it satisfy continuity equation

(4)
$$u = ln(x + y)$$
$$v = xy - \frac{y}{x}$$

Continuity equation
$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$
$$= \frac{\partial}{\partial x} ln(x+y) + \frac{\partial}{\partial y}\left(xy - \frac{y}{x}\right) = \frac{1}{x+y} + x - \frac{1}{x} \neq 0$$

Hence, it does not satisfy continuity equation.

23. (a)

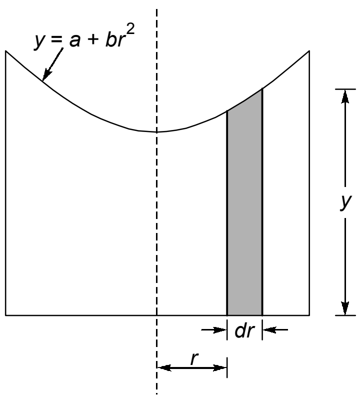
$$\text{Pressure head} = \frac{p}{\rho g} = \frac{19.62 \times 10^3}{1000 \times 9.81 \times 0.8} = 2.5 \text{m of oil}$$

$$\text{Velocity head} = \frac{V^2}{2g} = \frac{Q^2}{2A^2 g} = \frac{(0.12)^2}{2 \times \left(\frac{\pi}{4} \times 0.25^2\right)^2 \times 9.81} = 0.3 \text{ m of oil}$$

$$\text{Datum head} = 2.7 \text{ m}$$

$$\text{Total head} = \text{Pressure head + Velocity head + Datum head}$$
$$= 2.5 + 0.3 + 2.7 = 5.5 \text{ m}$$

24. (b)



Elemental mass, $dm = (2\pi r)\, y\, (dr)\rho$

total mass, $m = \int dm = \rho\int_0^R (2\pi r)\, dr.y$

$$= \rho\int_0^R (2\pi r)(a+br^2)dr = 2\pi\rho\left[\frac{ar^2}{2}+\frac{br^4}{4}\right]_0^R$$

$$m = 2\pi\rho\left[\frac{aR^2}{2}+\frac{bR^4}{4}\right]$$

$$m = \rho\pi R^2\left[a+\frac{bR^2}{2}\right]$$

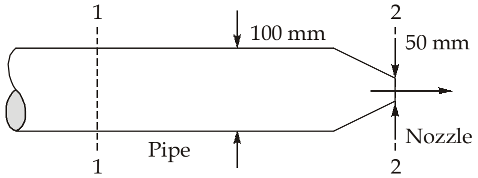
25. (b)

By using continuity equation,

$$V_1A_1 = V_2A_2$$

$$5\times\frac{\pi}{4}(0.1)^2 = V_2\times\frac{\pi}{4}(0.05)^2$$

$\Rightarrow$ $$V_2 = 20 \text{ m/s}$$



From force balance in x-diagram

$$P_1A_1 + R_x - P_2A_2 = \rho Q(V_2 - V_1)$$

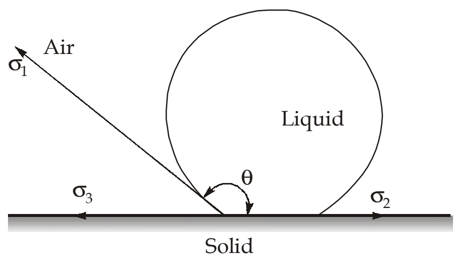
$\Rightarrow$ $$R_x = \rho Q(V_2 - V_1) + P_2A_2 - P_1A_1$$

$$= 1000\times\frac{\pi}{4}(0.1)^2\times 5(20-5)+100\times 10^3\times\frac{\pi}{4}(0.05)^2 - 500\times 10^3\times\frac{\pi}{4}(0.1)^2$$

Force required to hold the nozzle, $R_x = -3141.6$ N

26. (c)

From force balance at point of contact,



$$\sigma_1\cos(180° - \theta) + \sigma_3 = \sigma_2$$

or $$\cos(180° - \theta) = \frac{\sigma_2 - \sigma_3}{\sigma_1} = -\cos\theta$$

$\therefore$ $\sigma_1 = 0.0720$ N/m (liquid and air)

$\sigma_2 = 0.0418$ N/m (liquid and solid)

$\sigma_3 = 0.0008$ N/m (air and solid)

$$\cos\theta = \frac{0.0008 - 0.0418}{0.072} = -0.56944$$

$$\theta = 124.7°$$

27. (b)

$$\therefore \quad Re = \frac{16}{f} = \frac{16}{0.04} = 400$$

∴ The flow is viscous.

The shear stress in case of viscous flow through a pipe is given by

$$\tau = \frac{-\partial p}{\partial x}\left(\frac{r}{2}\right)$$

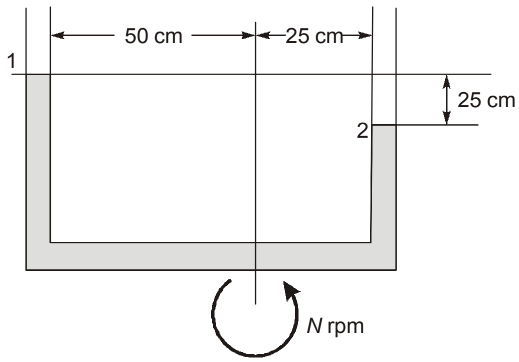
∴ $\frac{\partial p}{\partial x}$ is constant across a section.

$$\therefore \quad \tau \propto r$$

$$\therefore \quad \frac{\tau}{r} = \frac{\tau_0}{R} = \frac{0.00981}{40} = \frac{\tau_0}{100}$$

$$\therefore \quad \tau_0 = \frac{100 \times 0.00981}{40} = 0.0245\ \text{N/cm}^2$$

28. (c)



$$\frac{\overset{0}{\cancel{P_1}}}{\cancel{\rho g}} - \frac{V_1^2}{2g} + Z_1 = \frac{\overset{0}{\cancel{P_2}}}{\cancel{\rho g}} - \frac{V_2^2}{2g} + Z_2$$

$$Z_1 - Z_2 = \frac{V_1^2}{2g} - \frac{V_2^2}{2g}$$

$$0.25 = \frac{1}{2g}\left\{r_1^2\omega^2 - r_2^2\omega^2\right\}$$

$$0.25 \times 2 \times 9.81 = \omega^2\left\{\left(\frac{50}{100}\right)^2 - \left(\frac{25}{100}\right)^2\right\}$$

$$\omega = 5.115\ \text{rad/s}$$

$$N = \frac{60\omega}{2\pi} = \frac{60 \times 5.515}{2 \times \pi}$$

$$= 48.8\ \text{rpm}$$

29. (a)

$$Re_L \leq 2000$$

$$\Rightarrow \quad \frac{\rho VD}{\mu} \leq 2000$$

$$\Rightarrow \frac{(0.92\times1000)\times\frac{Q}{A}\times(10\times10^{-2})}{0.9\times10^{-1}} \leq 2000$$

$$\Rightarrow \quad Q \leq \frac{2000\times0.9\times10^{-1}\times A}{(0.92\times1000)\times(10\times10^{-2})}$$

$$\Rightarrow \quad Q \leq 1.95652\times\frac{\pi}{4}\times\left\{\frac{10}{100}\right\}^2$$

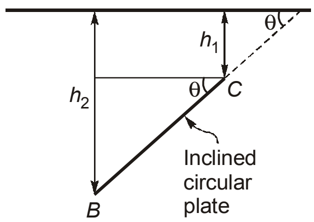
$$\Rightarrow \quad Q \leq 0.015366 \text{ m}^3/\text{s}$$

$$\Rightarrow \quad Q \leq 15.36 \simeq 15.4 \text{ L/s}$$

30. (a)

Given; $d = 3$ m; $h_1 = 1.5$ m; $h_2 = 4$ m

So, $$\sin\theta = \frac{h_2 - h_1}{BC} = \frac{4-1.5}{3} = 0.833$$



$$\theta = 56.44°$$

Now, $$h_{cp} = \bar{h} + \frac{I_G \sin^2\theta}{A\bar{h}}$$

$$\bar{h} = \frac{d}{2}\sin\theta + h_1 = 2.75 \text{ m}$$

$$A = \frac{\pi d^2}{4},\ I_G = \frac{\pi d^4}{64}$$

$$h_{cp} = 2.75 + \frac{\frac{\pi d^4}{64}\times(0.833)^2}{\frac{\pi d^2}{4}\times 2.75} = 2.75 + 0.1420 = 2.892 \text{ m}$$

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