

# MECHANICAL ENGINEERING

## ESE SUBJECTWISE CONVENTIONAL SOLVED PAPER-I



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# MECHANICAL ENGINEERING

ESE SUBJECTWISE  
CONVENTIONAL SOLVED PAPER-I

1995-2017



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## PREFACE

It is an immense pleasure to present topic wise previous years solved paper of Engineering Services Exam. This booklet has come out after long observation and detailed interaction with the students preparing for Engineering Services Exam and includes detailed explanation to all questions. The approach has been to provide explanation in such a way that just by going through the solutions, students will be able to understand the basic concepts and will apply these concepts in solving other questions that might be asked in future exams.

Engineering Services Exam is a gateway to a immensely satisfying and high exposure job in engineering sector. The exposure to challenges and opportunities of leading the diverse field of engineering has been the main reason for students opting for this service as compared to others. To facilitate selection into these services, availability of arithmetic solution to previous year paper is the need of the day. Towards this end this book becomes indispensable.

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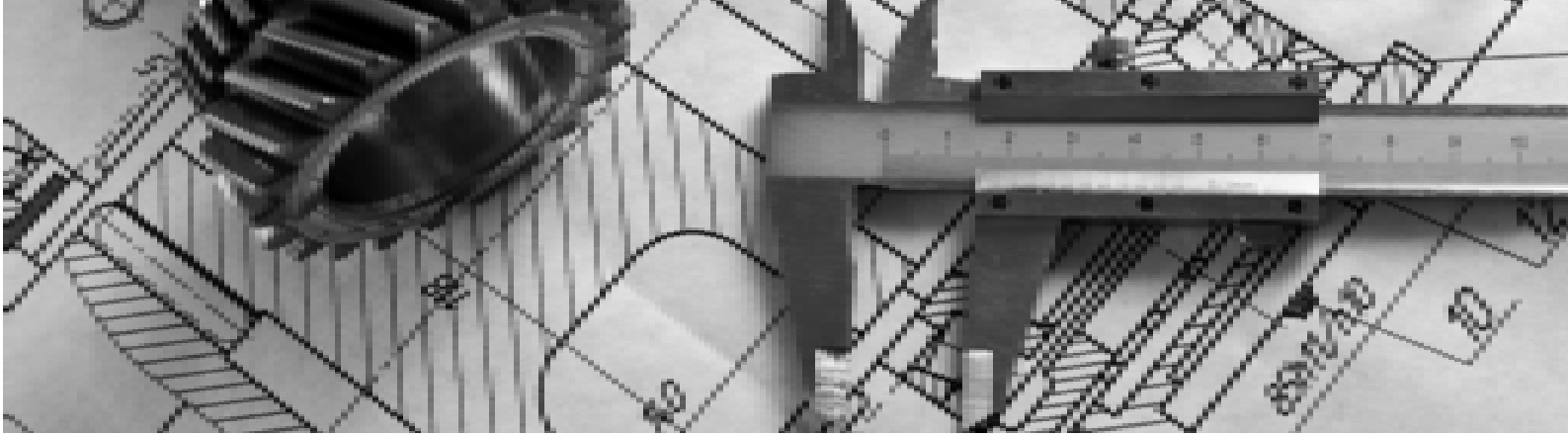
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# UNIT 1

# FLUID MECHANICS

## SYLLABUS

*Basic Concepts and Properties of Fluids, Manometry, Fluid Statics, Buoyancy, Equations of Motion, Bernoulli's equation and applications, Viscous flow of incompressible fluids, Laminar and Turbulent flows, Flow through pipes and head losses in pipes. Reciprocating and Rotary pumps, Pelton wheel, Kaplan and Francis Turbines and velocity triangles.*

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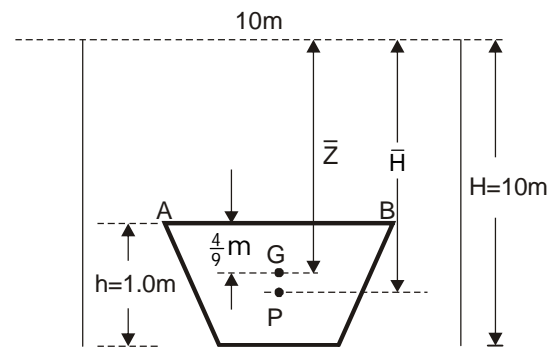
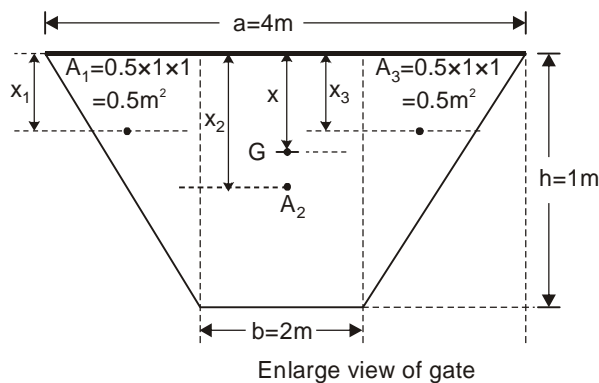


# CHAPTER 1

# Fluid Statics and Buoyancy

**Q-1:** A water storage tank 10 m × 10 m × 10 m has a drainage opening on one of the vertical sides at the bottom which is trapezoidal in shape with a width 2 m at the bottom 4 m at the top and 1 m height. A gate of same dimension hinged along the top edge is used to close it. What is the minimum horizontal force required to be applied at the bottom to keep the gate closed if the tank has full of water in it? Will there be any change in the force required if the tank is only half full? If yes how much? [10 Marks ESE-2014]

**Sol-1:** The gate is trapezoidal shape of the following dimensions.  $A_1$ ,  $A_2$  and  $A_3$  represent the area of respective portion of gate as shown in figure.



The centroid of trapezoidal gate

$$\bar{x} = \frac{x_1 A_1 + x_2 A_2 + x_3 A_3}{A_1 + A_2 + A_3} = \frac{\frac{1}{3} \times 0.5 \times \frac{1}{2} \times 2 + \frac{1}{3} \times 0.5}{0.5 + 2 + 0.5} = \frac{1 + \frac{1}{3}}{3} = \frac{4}{3 \times 3} = \frac{4}{9} \text{ m}$$

This gate is fitted to a wall of size 10m × 10m as shown in figure.

The depth of centroid of gate from top

$$\bar{Z} = 9 + \frac{4}{9} = \frac{85}{9} \text{ m}$$

The area moment of gate about its centre of gravity,

$$I_G = \frac{(a^2 + 4ab + b^2)}{36(a+b)} \times h^3 = \frac{(4^2 + 4 \times 4 \times 2 + 2^2)}{36 \times (4+2)} \times 1^3 = 0.2407 \text{ m}^4$$

The depth of centre of pressure

$$\bar{H} = \bar{Z} + \frac{I_G}{A \bar{Z}} = \frac{85}{9} + \frac{0.2407 \times 9}{3 \times 85} = \frac{85}{9} + 0.0085 = 9.453 \text{ m}$$



Total pressure force on gate

$$F = \rho g \bar{Z} A = 1000 \times 9.81 \times \frac{85}{9} \times 3 \text{ N} = 278 \text{ kN}$$

Let the applied force at bottom of gate is  $F_0$ , so

$$F_0 = \frac{F \times (\bar{H} - 9)}{(\bar{H} - 9)} = 125.93 \text{ kN}$$

Now the tank is half full,

The centroid, 
$$\bar{Z}' = 4 + \frac{4}{9} = \frac{40}{9} \text{ m}$$

Centre of pressure, 
$$\bar{H}' = \frac{40}{9} + \frac{0.2407 \times 9}{3 \times 40} = \frac{40}{9} + 0.01805 = 4.4625 \text{ m}$$

Total pressure force, 
$$F' = \rho g \bar{Z}' \cdot A = 1000 \times 9.81 \times \frac{40}{9} \times 3 \text{ N} = 130.8 \text{ kN}$$

Now the force to hold the gate, 
$$F'_0 = \frac{F' \times (\bar{H}' - 4)}{(\bar{H}' - 4)} = 60.5 \text{ kN}$$

Hence the holding force reduces from 125.93 kN to 60.5 kN.

**Q-2:** A tank with the vertical sides measuring 3m × 3m contains water to a depth of 1.2 m. An oil of density 900 kg/m<sup>3</sup> was poured in the tank up to a depth of 0.8 m. The vertical wall can withstand the trust of 58 kN. Calculate the actual thrust on the wall and centre of pressure. If the oil level is increased up to 0.9 m, what will be stability of the wall? [10 Marks ESE-2012]

**Sol-2:** The size of wall is 3m × 3m. Density of oil,  $\rho_0 = 900 \text{ kg/m}^3$ . Since the oil is lighter than water so it will float on water as shown in figure.

The pressure force due to oil,

$$P_1 = \frac{1}{2} \rho_0 g h.A = \frac{1}{2} \times 900 \times 9.81 \times 0.8 \times 0.8 \times 3 = 8475.84 \text{ N}$$

The increase in pressure force on lower zone i.e. water due to pouring of oil,

$$P_2 = \rho_0 g h.A = 900 \times 9.81 \times 0.8 \times 1.2 \times 3 = 25427.52 \text{ N}$$

The pressure force due to water,

$$P_3 = \frac{1}{2} \rho g h.A = \frac{1}{2} \times 1000 \times 9.81 \times 1.2 \times 1.2 \times 3 = 21189.6 \text{ N}$$

Total pressure force on wall

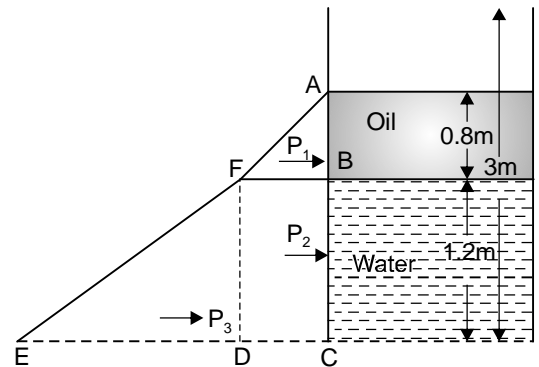
$$P = P_1 + P_2 + P_3 = 8475.84 + 25427.52 + 21189.6 = 55092.46$$

$$N = 55.093 \text{ kN}$$

Since the total force is less than critical thrust of 58 kN so the wall is safe.

The centre of pressure from bottom,

$$\begin{aligned} \bar{x} &= \frac{P_3 \times \frac{FD}{3} + P_2 \times \frac{BC}{2} + P_1 \left( BC + \frac{AB}{3} \right)}{P} \\ &= \frac{21189.6 \times 0.4 + 25427.52 \times 0.6 + 8475.84 \times \left( 1.2 + \frac{0.8}{3} \right)}{55092.96} \\ &= \frac{36163.6}{55092.86} = 0.6564 \text{ m} \end{aligned}$$





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From top of wall =  $3 - 0.6564 = 2.3436$  m

Now the depth of oil is increased to 0.9m from 0.8m

$$\begin{aligned} \therefore P_{\text{total}} &= P'_1 + P'_2 + P_3 \\ &= \frac{900 \times 9.81 \times 0.9 \times 0.9 \times 3}{2} + \frac{900 \times 9.81 \times 0.9 \times 1.2 \times 3}{2} + 21189.6 \\ &= 10727.235 + 28605.96 + 21189.6 = 60522.795 \text{ N} = 60.523 \text{ kN} \end{aligned}$$

This total force is more than critical thrust (58 kN) and the wall will fail.

**Q-3:** A hydraulic lift of the type commonly used for greasing automobiles consists of a 280 mm diameter ram that slides in a 280.18 mm cylinder. The annular space between the ram and cylinder is filled with oil having a kinematic viscosity of  $0.00042 \text{ m}^2/\text{s}$  and specific gravity of 0.86. If the rate of travel of the ram is  $0.22 \text{ m/s}$ , find the frictional resistance when 2m of the ram is engaged in the cylinder. [5 Marks ESE-2011]

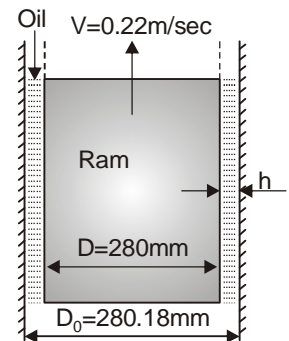
**Sol-3:** The schematic of ram in cylinder,  
Kinematic viscosity of oil,  $\nu = 0.00042 \text{ m}^2/\text{sec}$ .  
Specific gravity,  $\rho = 0.86$

The shear stress,

$$\tau = \mu \cdot \frac{du}{dy} = \mu \frac{(V-0)}{h} = \frac{\mu V}{h} = \frac{0.00042 \times 860 \times 0.22}{0.09 \times 10^{-3}} \text{ N/m}^2 = 882.93 \text{ N/m}^2$$

The force on piston/ram i.e. friction resistance,

$$F = \tau \cdot A = \tau_0 \cdot \pi DL = 882.93 \times \pi \times 0.28 \times 2 = 1553.3 \text{ N}$$



**Q-4:** A solid, half-cylinder-shaped log of 0.48 m radius and 2.5 m long, floats in water with the flat face up.

- If the immersion depth of the lowest point is 0.3, what is the uniform specific weight of the log?
- The log tilts about its axis (zero and net applied force), by less than  $22^\circ$ . Is it in stable equilibrium? Justify your answer with a sketch and logic.
- If the log tilts by  $18^\circ$  (left side down; zero net applied force), what is the magnitude and sense of any moment that results? [15 Marks ESE-2011]

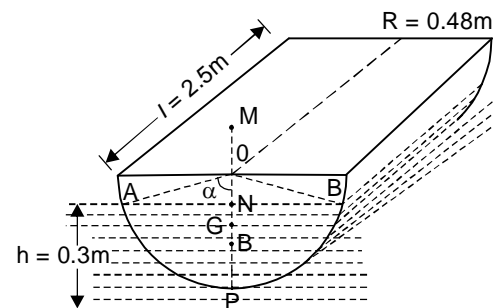
**Sol-4:** The half cylinder in water,

Let the specific density of wood is  $\rho$ , then in floating condition, Buoyancy force,

$$\begin{aligned} F_B &= W \\ \text{Area ABP} \times \text{Length} \rho_0 g &= \frac{\pi R^2}{2} \cdot L \cdot \rho \cdot g \\ \text{Area ABP} \times \rho_0 &= \frac{\pi R^2}{2} \rho \quad \dots(i) \end{aligned}$$

The area ABP is required to be calculated separately as

$$\begin{aligned} \text{Area ABP} &= \text{Area OAPBO} - \text{Area OAB} \\ &= \frac{2\alpha}{2\pi} (\pi R^2) - 2 \times \text{Area of triangle OAN} \\ &= \alpha R^2 - 2 \times \frac{1}{2} \text{AN} \cdot \text{ON} \end{aligned}$$



where,

$$\cos \alpha = \frac{ON}{AO} = \frac{R-h}{R} = 1 - \frac{h}{R} = 1 - \frac{0.3}{0.48}$$

$$\alpha = 68^\circ$$

∴

$$\begin{aligned} \text{Area ABP} &= 68 \times \frac{\pi}{180} \times 0.48^2 - 2 \times \frac{1}{2} \times OA \sin \theta \cdot ON \\ &= 1.187 \times 0.482 - 0.48 \times \sin 68 \times (0.48 - 0.3) \\ &= 0.27344 - 0.080107 = 0.1933 \text{m}^2 \end{aligned}$$

From equation (i),

$$0.1933 \times 1000 = \frac{\pi}{2} 0.48^2 \rho$$

$$\rho = \frac{193.3 \times 2}{\pi \times 0.48^2} = 534.12 \text{ kg/m}^3$$

Density of wood,

$$\rho = 534.1 \text{ kg/m}^3$$

Specific density = 0.5341

Distance of centre of Gravity of log cross-sections

$$OG = \frac{4R}{3\pi} = \frac{4 \times 0.48}{3 \times \pi} = 0.204 \text{m}$$

The location of centre of Buoyancy (B) is centre of gravity of log cross-section inside water (B).

So, location of centre of gravity of cross-section OABP ( $OG_2$ ) as,

∴

$$x = \frac{2}{3} R \frac{\sin \alpha}{\alpha} = \frac{2}{3} \times \frac{0.48 \times \sin 68}{1.187} = 0.25 \text{ m}$$

∴

$$NG_2 = OG_2 - ON = x - ON = 0.25 - 0.18 = 0.07 \text{m}$$

Now to get location of centre of Buoyancy 'B' inside cross section. Take the moment of areas OAB and ABG about  $G_2$ .

∴

$$\begin{aligned} BG_2 &= \frac{\text{Area of OAB} \times G_1 G_2}{\text{Area ABP}} = \frac{\text{Area OAB} \times (NG_1 + NG_2)}{\text{Area ABP}} \\ &= \frac{0.18 \times 0.48 \sin 68 \times (0.06 + 0.07)}{0.1933} = 0.054 \text{m} \end{aligned}$$

∴ Distance of centre of Buoyancy from plane surface of log,

$$\begin{aligned} OB &= ON + NG_2 + G_2 B \\ &= 0.18 + 0.07 + 0.054 = 0.304 \text{ m} \end{aligned}$$

∴ Distance between centre of gravity 'G' and centre of Buoyancy, B

$$GB = OB - OG = 0.304 - 0.204 = 0.1 \text{ m}$$

Moment of area of surface of log in the plane of water.

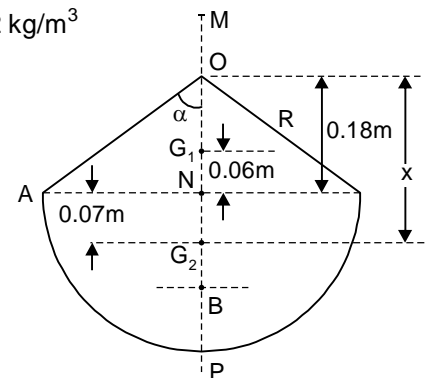
$$I = \frac{1}{12} \cdot L \times AB^3 = \frac{1}{12} \times 2.5 \times (2 \times R \sin 68)^3 = 0.147 \text{ m}^4$$

Volume of displaced liquid,

$$\begin{aligned} V &= \text{Area ABP} \times \text{length} \\ &= 0.1933 \times 2.5 = 0.48325 \text{ m}^3 \end{aligned}$$

∴ Metacentric height

$$\begin{aligned} GM &= BM - GB = \frac{I}{V} - GB = \frac{0.147}{0.48325} - 0.1 \\ &= 0.3042 - 0.1 = 0.2042 \text{ m} \end{aligned}$$





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