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- COMPLETE SOLUTIONS WITH EXPLANATIONS
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MECHANICAL ENGINEERING

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1995-2018

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Office: F-126, (Lower Basement), Katwaria Sarai, New Delhi-110 016

Phone: 011-2652 2064 ▪ **Mobile:** 81309 09220, 97118 53908

Email: info@iesmasterpublications.com, info@iesmaster.org

Web: iesmasterpublications.com, iesmaster.org

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F-126, (Lower Basement), Katwaria Sarai, New Delhi-110016

Phone : 011-26522064, **Mobile :** 8130909220, 9711853908

E-mail : info@iesmasterpublications.com, info@iesmaster.org

Web : iesmasterpublications.com, iesmaster.org

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PREFACE

Engineering Services Exam (ESE) is one of most coveted exams written by engineering students aspiring for reputed posts in the various departments of the Government of India. ESE is conducted by the Union Public Services Commission (UPSC), and therefore the standards to clear this exam too are very high. To clear the ESE, a candidate needs to clear three stages – ESE Prelims, ESE Mains and Personality Test.

It is not mere hard work that helps a student succeed in an examination like ESE that witnesses lakhs of aspirants competing neck to neck to move one step closer to their dream job. It is hard work along with smart work that allows an ESE aspirant to fulfil his dream.

After detailed interaction with students preparing for ESE, IES Master has come up with this book which is a one-stop solution for engineering students aspiring to crack this most prestigious engineering exam. The book includes previous years' solved conventional questions segregated Topicwise along with detailed explanation. This book will also help ESE aspirants get an idea about the pattern and weightage of questions asked in ESE.

IES Master feels immense pride in bringing out this book with utmost care to build upon the exam preparedness of a student up to the UPSC standards. The credit for flawless preparation of this book goes to the entire team of IES Master Publication. Teachers, students, and professional engineers are welcome to share their suggestions to make this book more valuable.

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CONTENTS

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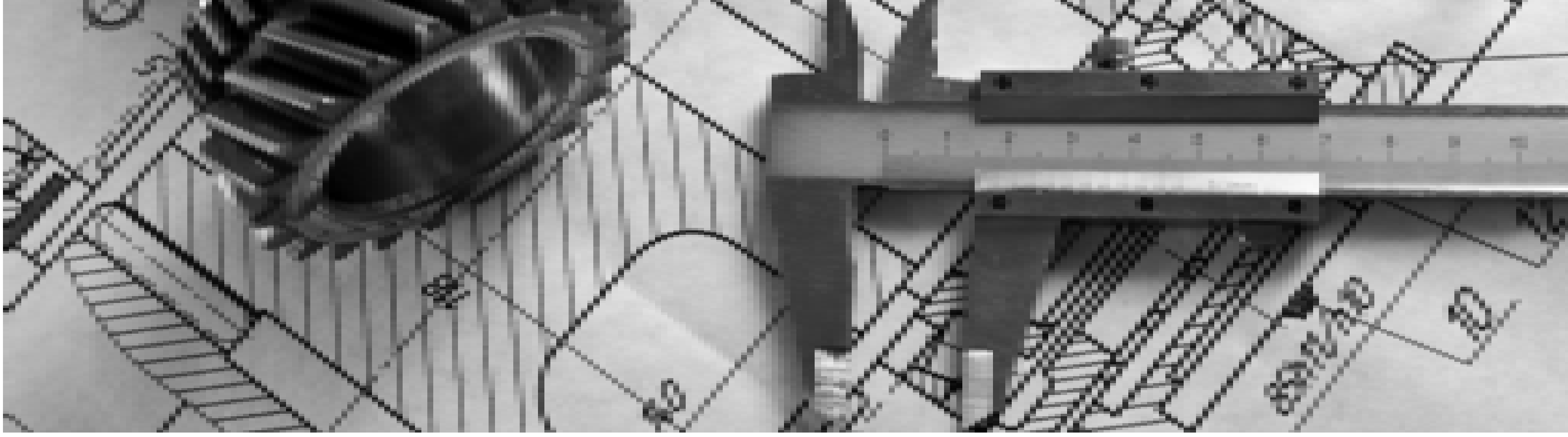


UNIT-1 FLUID MECHANICS

SYLLABUS

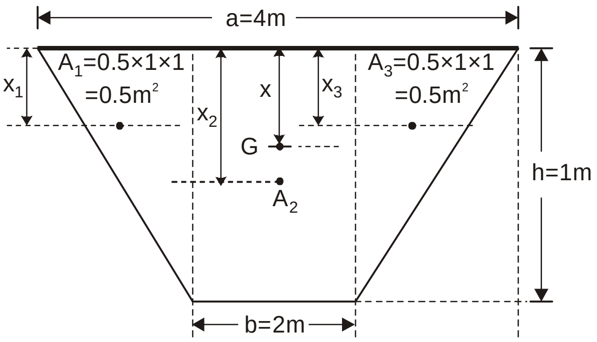
Basic Concepts and Properties of Fluids, Manometry, Fluid Statics, Buoyancy, Equations of Motion, Bernoulli's equation and applications, Viscous flow of incompressible fluids, Laminar and Turbulent flows, Flow through pipes and head losses in pipes. Reciprocating and Rotary pumps, Pelton wheel, Kaplan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

CONTENTS

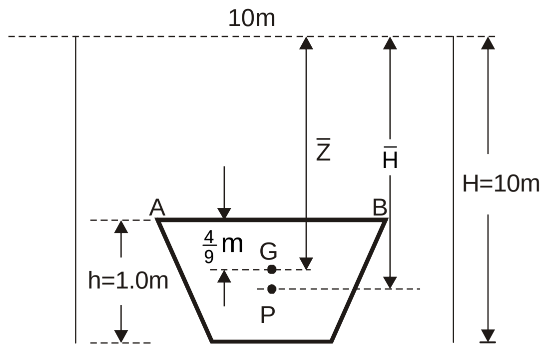
CHAPTER 1 FLUID STATICS AND BUOYANCY

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 by any change in the force required if the tank is only half full? If yes how much?*** ***[10 Marks ESE–2014]***

Sol: 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.



Enlarge view of gate



The centroid of trapezoidal gate

$$\bar{x} = \frac{x_1A_1 + x_2A_2 + x_3A_3}{A_1 + A_2 + A_3} = \frac{\frac{1}{3}\times 0.5\times\frac{1}{2}\times 2+\frac{1}{3}\times 0.5}{0.5+2+0.5} = \frac{1+\frac{1}{3}}{3} = \frac{4}{3\times 3} = \frac{4}{9}\text{m}$$

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

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

Now the tank is half full,

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

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

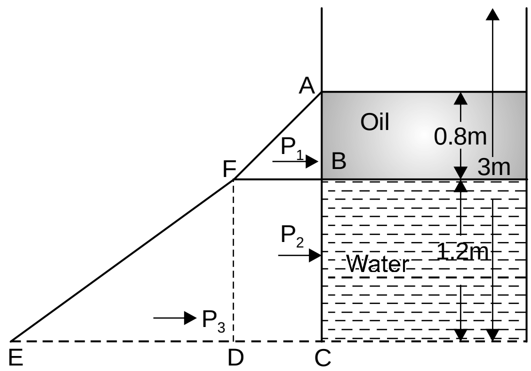
Total pressure force, $F' = \rho g \bar{Z}' \cdot A = 1000 \times 9.81 \times \frac{40}{9} \times 3 \text{ N} = 130.8 \text{ kN}$

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

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 detph of 1.2 m. An oil of density 900 kg/m^3 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 Makrs ESE–2012]***

Sol: 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,

$$P_1 = \frac{1}{2}\rho_o gh.A = \frac{1}{2} \times 900 \times 9.81 \times 0.8 \times 0.8 \times 3 = 8475.84\text{N}$$

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

$$P_2 = \rho_o gh.A = 900 \times 9.81 \times 0.8 \times 1.2 \times 3 = 25427.52 \text{ N}$$

The pressure force due to water,

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

Total pressure force on wall

$P = P_1 + P_2 + P_3 = 8475.84 + 25427.52 + 21189.6 = 55092.46$ N = 55.093 kN

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

The centre of pressure from bottom,

$$\bar{x} = \frac{P_3 \times \frac{FD}{3} + P_2 \times \frac{BC}{2} + P_1\left(BC + \frac{AB}{3}\right)}{P}$$

$$= \frac{21189.6 \times 0.4 + 25427.52 \times 0.6 + 8475.84\text{x}\left(1.2 + \frac{0.8}{3}\right)}{55092.96}$$

$$= \frac{36163.6}{55092.86} = 0.6564 \text{ m}$$

From top of wall = 3 – 0.6564 = 2.3436 m

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

$$\therefore \qquad P_{total} = P_1' + P_2' + P_3$$

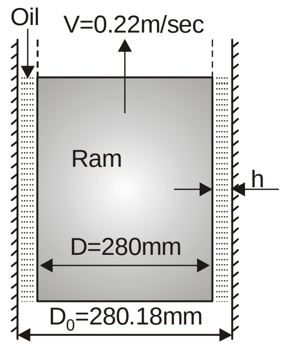
$$= \frac{900\times 9.81\times 0.9\times 0.9\times 3}{2} + \frac{900\times 9.81\times 0.9\times 1.2\times 3}{} + 21189.6$$

$$= 10727.235 + 28605.96 + 21189.6 = 60522.795 \text{ N} = 60.523 \text{ kN}$$

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 m²/s and specific gravity of 0.86. If the rate of travel of the ram is 0.22 m/s, find the frictional resistance when 2m of the ram is engaged in the cylinder.*** ***[5 Marks ESE–2011]***

Sol: The schematic of ram in cylinder,



Kinematic viscosity of oil, V = 0.00042 m²/sec.

Specific gravity, ρ = 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,

$F = \tau.A = \tau_0\cdot\pi DL$ = 882.93 × π × 0.28×2 = 1553.3 N

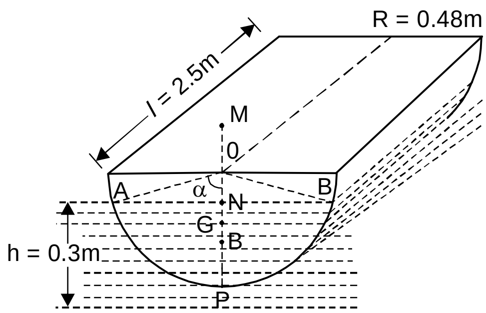
Q–4: ***A solid, half-cylinder-shaped log of 0.48 m radius and 2.5 m long, floats in water with the flat face up.***

(i) If the immersion depth of the lowest point is 0.3, what is the uniform specific weight of the log?

(ii) The log tilts about its axis (zero and net applied force), by less than 22°. Is it in stable equilibrium? Justify your answer with a sketch and logic.

(iii) If the log tilts by 18° (left side down; zero net applied force), what is the magnitude and sense of any moment that results? ***[15 Marks ESE-2011]***

Sol: The half cylinder in water,



Let the specific density of wood is ρ, then in floating condition, Buoyancy force,

$$F_B = W$$

$$\text{Area ABP} \times \text{Length } \rho_0 g = \frac{\pi}{2}R^2\cdot L\cdot\rho\cdot g$$

$$\text{Area ABP}\times\rho_0 = \frac{\pi}{2}R^2\rho \qquad \text{...(i)}$$

The area ABP is required to be calculated separately as

$$\text{Area ABP} = \text{Area OAPBO} - \text{Area OAB}$$

$$= \frac{2\alpha}{2\pi}(\pi R^2) - 2\times \text{Area of triangle OAN}$$

$$= \alpha R^2 - 2\times\frac{1}{2}AN\cdot ON$$

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