MECHANICAL ENGINEERING
ESE TOPICWISE
CONVENTIONAL SOLVED PAPER-I

1995-2018

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### CONTENTS

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>FLUID MECHANICS</td>
<td>01</td>
</tr>
<tr>
<td>2.</td>
<td>THERMODYNAMICS</td>
<td>169</td>
</tr>
<tr>
<td>3.</td>
<td>HEAT TRANSFER</td>
<td>247</td>
</tr>
<tr>
<td>4.</td>
<td>REFRIGERATION AND AIR Conditioning</td>
<td>343</td>
</tr>
<tr>
<td>5.</td>
<td>POWER PLANT ENGINEERING</td>
<td>434</td>
</tr>
<tr>
<td>6.</td>
<td>IC ENGINE</td>
<td>600</td>
</tr>
<tr>
<td>7.</td>
<td>RENEWABLE SOURCES OF ENERGY</td>
<td>670</td>
</tr>
</tbody>
</table>

---

01 – 168
169 – 246
247 – 342
343 – 433
434 – 599
600 – 669
670 – 680
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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

<table>
<thead>
<tr>
<th>Chapter No.</th>
<th>Topic</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fluid Statics and Buoyancy</td>
<td>01–14</td>
</tr>
<tr>
<td>2.</td>
<td>Fluid Kinematics</td>
<td>15–18</td>
</tr>
<tr>
<td>4.</td>
<td>Laminar and Turbulent Flow</td>
<td>37–52</td>
</tr>
<tr>
<td>5.</td>
<td>Boundary Layer Theory, Drag and Lift</td>
<td>53–70</td>
</tr>
<tr>
<td>6.</td>
<td>Pipe and Open Channel Flow</td>
<td>71–86</td>
</tr>
<tr>
<td>7.</td>
<td>Dimensional and Model Analysis</td>
<td>87–115</td>
</tr>
<tr>
<td>8.</td>
<td>Fluid Jet and Hydraulic Turbines</td>
<td>116–141</td>
</tr>
<tr>
<td>9.</td>
<td>Pumps and other Hydraulic Machines</td>
<td>142–168</td>
</tr>
</tbody>
</table>
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.

The centroid of trapezoidal gate

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

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

The depth of centroid of gate from top

\[
Z = 9 + \frac{4}{9} = \frac{85}{9} \text{ m}
\]

The area moment of gate about its centre of gravity,

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

The depth of centre of pressure

\[
R = Z + \frac{l_G}{AZ} = \frac{85}{9} + \frac{0.2407 \times 9}{3 \times 85} = \frac{85}{9} + 0.0085 = 9.453 \text{ m}
\]

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

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

Now the tank is half full,

The centroid,

$$Z' = 4 + \frac{4}{9} = \frac{40}{9} \text{ m}$$

Centre of pressure,

$$H' = \frac{40 + 0.2407 \times 9}{3 \times 40} + \frac{0.01805}{4.4625} = 4.4625 \text{ m}$$

Total pressure force,

$$F' = \rho g Z' A = 1000 \times 9.81 \times \frac{40}{9} \times 3 = 130.8 \text{ kN}$$

Now the force to hold the gate,

$$F'_0 = \frac{F' \times (H' - 4)}{(H' - 4)} = 60.5 \text{ kN}$$

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

**Q-2:** A tank with the vertical sides measuring $3m \times 3m$ contains water to a depth of 1.2 m. An oil of density $900 \text{ kg/m}^3$ 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?

**Sol:** The size of wall is $3m \times 3m$. 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,

$$P_1 = \frac{1}{2} \rho_0 ghA = \frac{1}{2} \times 900 \times 9.81 \times 0.8 \times 0.8 \times 3 = 8475.84 \text{ N}$$

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

$$P_2 = \rho_0 ghA = 900 \times 9.81 \times 0.8 \times 1.2 \times 3 = 25427.52 \text{ N}$$

The pressure force due to water,

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

Total pressure force on wall

$$P = P_1 + P_2 + P_3 = 8475.84 + 25427.52 + 21189.6 = 55092.46 \text{ N}$$

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

The centre of pressure from bottom,

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

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

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

From top of wall = 3 – 0.6564 = 2.3436 m
Now the depth of oil is increased to 0.9m from 0.8m.

\[
P_{\text{total}} = P_1 + P_2 + P_3 = \frac{900 \times 9.81 \times 0.9 \times 0.9 \times 3}{2} + \frac{900 \times 9.81 \times 0.9 \times 1.2 \times 3}{2} + 21189.6
\]

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

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, \( V = 0.00042 \text{ m}^2/\text{sec} \)

Specific gravity, \( \rho = 0.86 \)

The shear stress,

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

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

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

**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.

(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 \( \rho \), then in floating condition, Buoyancy force,

\[
F_B = W
\]

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

\[
\text{Area ABP} \cdot \rho = \frac{\pi}{2} R^2 \rho \quad \text{...(i)}
\]

The area ABP is required to be calculated separately as

\[
\text{Area ABP} = \text{Area OAPBO} - \text{Area OAB}
\]

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

\[
= \alpha R^2 - 2 \times \frac{1}{2} \text{AN} \cdot \text{ON}
\]
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