



Center of Pressure and Hydrostatic Force
On Submerged Bodies

ME 309
Fluid Mechanics

SAFETY INSTRUCTIONS



All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times.**

Hot Surfaces and Liquids

The unit incorporates a pumped electric water heater, and is capable of producing temperatures that could cause skin burns.

Before disconnecting any of the pipes or tubing:

- Stop all the pumps.
- Leave time for the water to cool
- Check that the temperature is at a safe level
- Do not touch any surfaces close to 'Hot Surfaces' warning labels, or any of the interconnecting tubing, whilst the equipment is in use.



General Instructions

- If a spill occurs, turn off the pumps (if possible without injury) and immediately get in touch with the Laboratory Instructor or Technician.
- Ensure that protective clothing (LAB coat) and gloves are worn when handling any of the substances used in the reactor.
- Shorts or skirts should not be worn to the lab.
- Sandals, high heels, or open-toe shoes are not acceptable.
- Safety glasses are a required item to be worn in all areas of the laboratories.
- Electrical - Burn / Shock: Care with electrical connections, particularly with grounding, and not using frayed electrical cords, can reduce hazard.



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Objective

The purpose of this experiment is to:

- Understand the hydrostatic pressure distribution.
- Calculate the magnitude of the hydrostatic force on a submerged body.
- Calculate and verify the location of center of pressure.

The experimentally determined values will be compared to theoretical calculations.

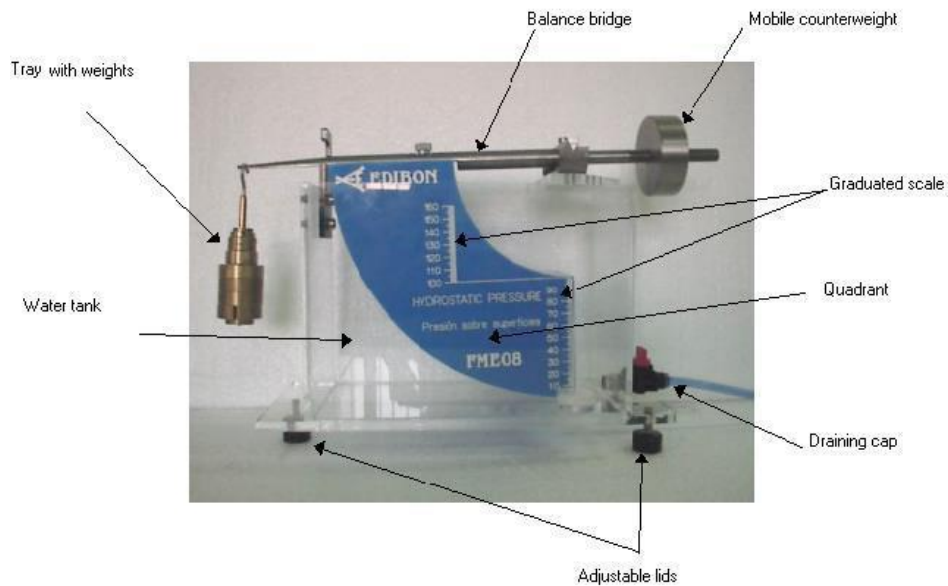


Figure 1: Experimental apparatus with parts labeled.

Learning Outcomes & relationship to ABET Student Outcomes (SO)

Experiment Name	Learning Outcomes	ABET Student Outcomes
Center of Pressure and Hydrostatic Force On Submerged Bodies	- To calculate the hydrostatic force a fluid exerts on a submerged plane surface. - To compare the experimental hydrostatic force to the theoretical one.	<i>b, g</i>

* *b*: An ability to design and conduct experiments, as well as to analyze and interpret data.

* *g*: An ability to communicate effectively.

Performance indicators for SO; Students are expected to be able to

SO (b) 1. Design an experiment plan

2. Identify variables and acquire data related to the experiment

3. Compare obtained data and results to appropriate theoretical models

4. Explain observed differences between model and experiment

SO (g) 1. Deliver an organized written document

Theory

Consider a completely submerged rectangular plate of height b and width a tilted at an angle from the horizontal and whose top edge is horizontal and is at a distance s from the free surface along the plane of the plate, as shown in Fig. 2. The resultant hydrostatic force on the upper surface is equal to the average pressure, which is the pressure at the midpoint of the surface, times the surface area A . That is,

$$F_R = P_c A = \left[P_o + \rho g \left(s + \frac{b}{2} \right) \sin \theta \right] ab \quad (1)$$

$$y_p = y_c + \frac{I_{xx,c}}{\left[y_c + \frac{P_o}{\rho g \sin \theta} \right] A} \quad (2)$$

The force acts at a vertical distance of $h_p = y_p \sin \theta$ from the free surface directly beneath the centroid of the plate where, from Eq. 2

$$y_p = s + \frac{b}{2} + \frac{ab^3/12}{\left[s + \frac{b}{2} + \frac{P_o}{\rho g \sin \theta} \right] ab} = s + \frac{b}{2} + \frac{b^2}{12 \left[s + \frac{b}{2} + \frac{P_o}{\rho g \sin \theta} \right]} \quad (3)$$

For a completely submerged vertical plate ($\theta = 90^\circ$) whose top edge is horizontal, the hydrostatic force can be obtained by setting $\sin 90^\circ = 1$ (Fig. 3)

$$F_R = \left[P_o + \rho g \left(s + \frac{b}{2} \right) \right] ab \quad (4)$$

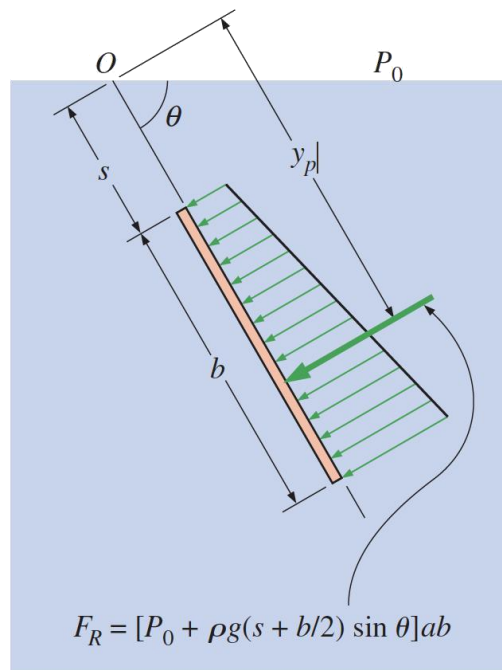


Figure 2: Tilted Plate

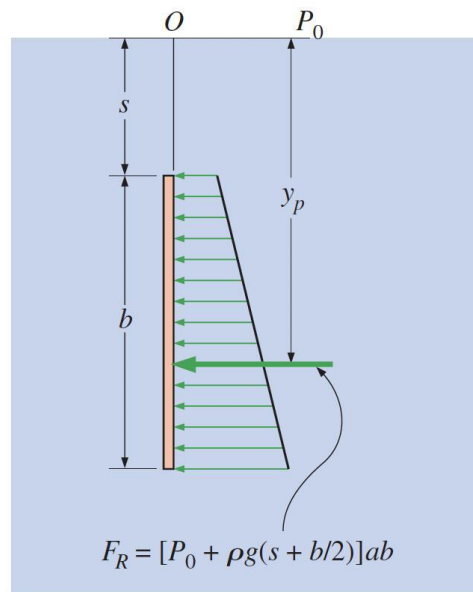


Figure 3: Vertical plate

P.S. Please refer to Fluid Mechanics textbook by Fox and McDonald (Chapter 3-Section 3.4)

Rig Specifications

The equipment shown in figure 1 resembles the complete setup for this experiment. The dimensions and specifications of the setup are as follows:

- Tank capacity 5.5 L
- Distance between the masses in suspension and the supporting point is 285 mm (Length of the revolving arm)
- Cross sectional area is 0.007 m^2
- Maximum depth of the submerged quadrant is 160 mm
- Height of the supporting point over the quadrant is 100 mm
- A set of masses of different weights is also supplied:
 - 4 weights of 100 gm
 - 1 weight of 50 gm
 - 5 weights of 10 gm
 - 1 weight of 5 gm

Dimensions and weight:

- Estimated dimensions: 500 x 200 x 300 mm
- Estimated volume: 0.04 m^3
- Estimated weight: 5 kg

Procedure

N.B. Make sure to carry out the necessary calibration before performing the experiment.

The steps of this experiment go as follows:

1. Place the setup on a flat horizontal surface. Use the built-in spirit level to make sure the setup is leveled. You may need to do slight adjustments using the adjustable lids.
2. With an empty hook attached, use the counter weight to level off the balance bridge.
3. Make sure the drain valve is closed, then start filling up the tank until you have the rectangular surface on the quadrant fully submerged. The water level should be higher than the height of the rectangular surface. You can add weights to the hook as you slowly fill the tank so that the balance bridge won't tip over.
4. Your aim now is to balance out the balance bridge with the amount of water in the tank. You can do this by adding weights to the hook, or removing weights as needed. The balance bridge should be restored back to its balanced position.
5. Note down the depth of water and use this to find the magnitude of the hydrostatic force acting on the vertical plate.
6. Perform a moment balance on the pivot of the moving arm (Balance Bridge) to determine the point of action of the hydrostatic force.
7. Theoretically calculate the point of action of the hydrostatic force using equation 3. Compare between the theoretical value and that obtained experimentally from the previous step.
8. Repeat the steps from 4 to 7 for four different water levels. Open the drain valve briefly to lower the water to the desired level in the tank.

Observations and Calculations

Analyze your findings and compare the values obtained from the experiment to those calculated theoretically. Check for discrepancies between the two, if any, and justify them. Also investigate the effect of the omission of the atmospheric pressure in equations 3 and 4 how that affect the fidelity of the results at the different water levels. A good description of the test rig must be included in your report.

b(m)	Mass (kg)	$F_R(N)$	$Y_{p,th}(m)$	L(m)	α (m)	$Y_{p,Exp}(m)$	Error %
0.1							
0.09							
0.08							
0.07							
0.06							

Relative Error = (Measured Value – Actual Value) / Actual Value

Percent Error = $|\text{Relative Error}| \times 100$

Conclusion and Recommendations:

- Comment on the error percentage.
- General comments about the experiment
- Your recommendations.

References

1. Çengel, Y. A., & Cimbala, J. M. (2014). *Fluid mechanics: Fundamentals and applications*. New York: McGraw Hill.
2. *Edibon FME-08 User's Manual*.

Appendix

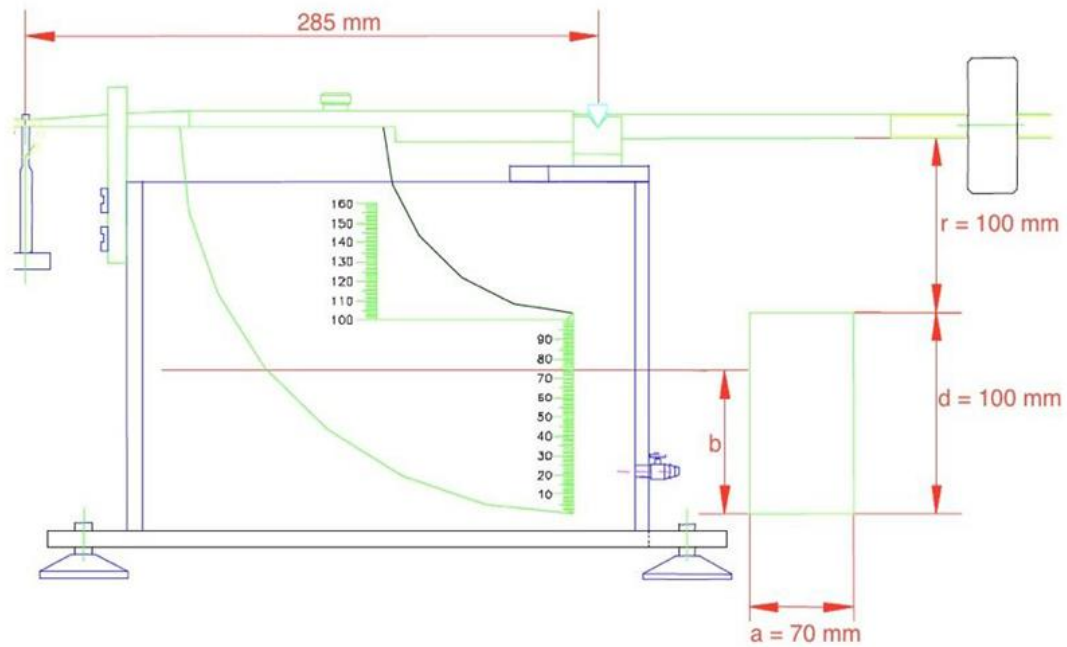


Figure 4: Schematic sketch of the apparatus.