Experiment- 6

ARKA PRAMANICK, AE21B007
Department of Aerospace Engineering
IIT Madras
Basic Aerospace Engineering lab
HYDROSTATIC PRESSURE

Instructor:
Professor Dr. Manikandan Mathur

28 October,2022

1. Aim:

- To determine the hydrostatic pressure force exerted by water on a partially or fully submerged surface.
- To determine the center of pressure theoretically and experimentally, and thus verify the linear relation between hydrostatic pressure and depth.

2. Apparatus:

- Arm-field F1-12 Hydro-static Pressure Apparatus.
- A jug and water.
- Calipers or rulers for measuring the actual dimensions of the quadrant.
- Different weights

2.1 Arm-field F1-12 Hydro-static Pressure Apparatus:

The equipment is comprised of a rectangular transparent water tank, a fabricated quadrant, a balance arm, an adjustable counter-balance weight, and a water-level measuring device.
The water tank has a drain valve at one end and three adjustable screwed-in feet on its base for leveling the apparatus. The quadrant is mounted on a balance arm that pivots on knife edges. The knife edges coincide with the center of the arc of the quadrant; therefore, the only hydrostatic force acting on the vertical surface of the quadrant creates moment about the pivot point. This moment can be counterbalanced by adding weight to the weight hanger, which is located at the left end of the balance arm, at a fixed distance from the pivot. Since the line of actions of hydrostatic forces applied on the curved surfaces passes through the pivot point, the forces have no effect on the moment. The hydrostatic force and its line of action (center of pressure) can be determined for different water depths, with the quadrant's vertical face either

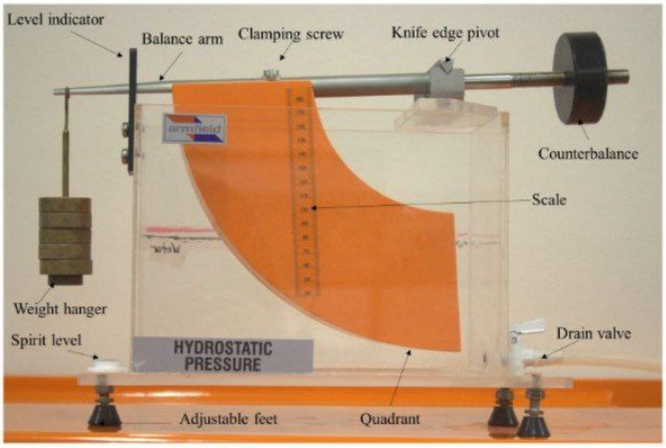

Figure 1: Arm-field F1-12 Hydro-static Pressure Apparatus

partially or fully submerged.
A level indicator attached to the side of the tank shows when the balance arm is horizontal. Water is admitted to the top of the tank by a flexible tube and may be drained through a cock in the side of the tank. The water level is indicated on a scale on the side of the quadrant.

3. Theory:

In this experiment, when the quadrant is immersed by adding water to the tank, the hydrostatic force applied to the vertical surface of the quadrant can be determined by considering the following:

- The hydrostatic force at any point on the curved surfaces is normal to the surface and resolves through the pivot point because it is located at the origin of the radii. Hydrostatic forces on the upper and lower curved surfaces, therefore, have no net effect – no torque to affect the equilibrium of the assembly because the forces pass through the pivot.
- The forces on the sides of the quadrant are horizontal and cancel each other out (equal and opposite).
- The hydrostatic force on the vertical submerged face is counteracted by the balance weight. The resultant hydrostatic force on the face can, therefore, be calculated from the value of the balance weight and the depth of the water.
- The system is in equilibrium if the moments generated about the pivot points by the hydrostatic force and added weight (=mg) are equal,i.e.:

$$mg \times L = F \times y$$

where,
m : mass on the weight hanger,
L : length of the balance arm F : Hydrostatic force
y : distance between the pivot and the center of pressure.

3.1 Hydrostatic Force:

The magnitude of the resultant hydrostatic force (F) applied to an immersed surface is given by:

F=$P_c A = \rho g y_c A$

where:

P_c : pressure at centroid of the immersed surface,

A: area of the immersed surface,

y_c : centroid of the immersed surface measured from the water surface,

ρ : density of fluid, and

g : acceleration due to gravity.

The hydrostatic force acting on the vertical face of the quadrant can be calculated as:

- Partially immersed vertical plane $F = \frac{\rho g B d^2}{2}$
- Fully immersed vertical plane $F = \rho g B d(d - \frac{D}{2})$

where,

B : width of the quadrant face, d : depth of water from the base of the quadrant, and D : height of the quadrant face.

3.2 Theoretical Determination of Center Of Pressure:

The center of pressure is calculated as:

$y_p = \frac{I_x}{A y_c}$

$I_x = The 2nd moment of area of immersed body about an axis in the free surface.$

- For fully immersed vertical plane: $I_x = BD[\frac{D^2}{12} + (d - \frac{D}{2})^2]$
- For partially immersed vertical plane: $I_x = \frac{Bd^3}{12} + Bd(\frac{d}{2})^2 = \frac{Bd^3}{3}$

The depth of the center of pressure below the pivot point is given by:

- Partially immersed vertical plane $y = H - \frac{d}{3}$
- Fully immersed vertical plane $y = \frac{\frac{D^2}{12} + (d - \frac{D}{2})^2}{d - \frac{D}{2}} + H - d$

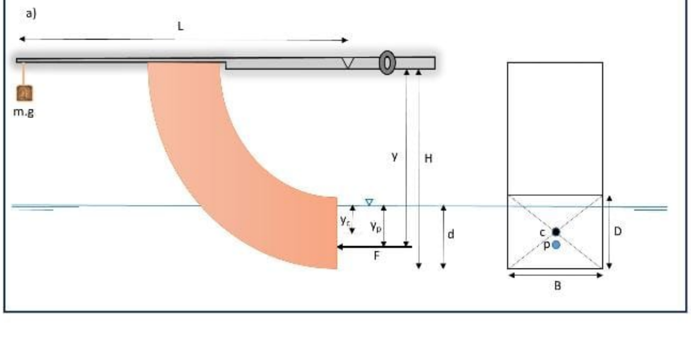

Figure 2: Partially submerged quadrant (c: centroid, p: center of pressure)

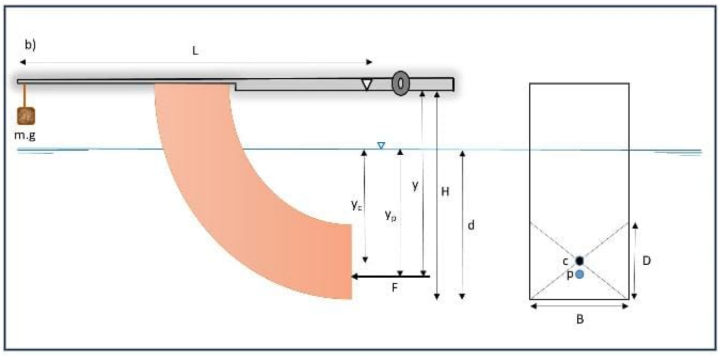

Figure 3: Fully submerged quadrant (c: centroid, p: center of pressure)

4. Procedure:

Before starting the experiment, measure the dimensions of the quadrant vertical surface and the distances (H and L) carefully. and perform the following steps:

1. Place the apparatus on level surface and check if the arm can swing freely and is horizontal without any weights placed on the hanger.
2. Add a weight block to the hanger.
3. Add water in the tank and wait till it is settled.
4. Slowly add water to the tank until the hydrostatic force on the vertical surface of the quadrant is balanced. This will be indicated when the arm is horizontal and the base of the arm aligns with the central marking on the balance rest.
5. Record the water height displayed on the scale on one side of the quadrant.
6. Add some weights and repeat the process.
7. Release the water valve, remove the weights and cleanup any spilled water after the experiment done.

5. Result:

The following dimensions are:

- Height of quadrant endface, (D) = 0.075m
- Width of submerged, B =0.075m
- Length of balance arm, L =0.275m
- Distance from base of quadrant to pivot, H =0.200m
- Density of water, $\rho = 1000 kg/m^3$
- Accleration due to gravity = 9.81 m/s^2

5.1 Percentage error:

Following formula is used to calculate percentage error between theoretical and experimental value of y:

$$Percentageerror = \frac{|Theoreticalvalue - Experimentalvalue|}{Theoreticalvalue}$$

5.2 Observation:

S.No.	Immersion type	Mass(Kg)	Water level(d)(m)	Theoretical y(in m)	Experimental y(in m)	Hydrostatic force,F(in N)	percentage error
1	Partially	0.05	0.045	0.185	0.181	0.745	2.16
2	Partially	0.07	0.054	0.182	0.176	1.073	3.30
3	Partially	0.12	0.072	0.176	0.170	1.907	3.41
4	Fully	0.24	0.105	0.0169	0.174	3.725	2.96
5	Fully	0.29	0.117	0.0168	0.178	4.387	5.95
6	Fully	0.34	0.130	0.167	0.180	5.104	7.78

6. Graphs:

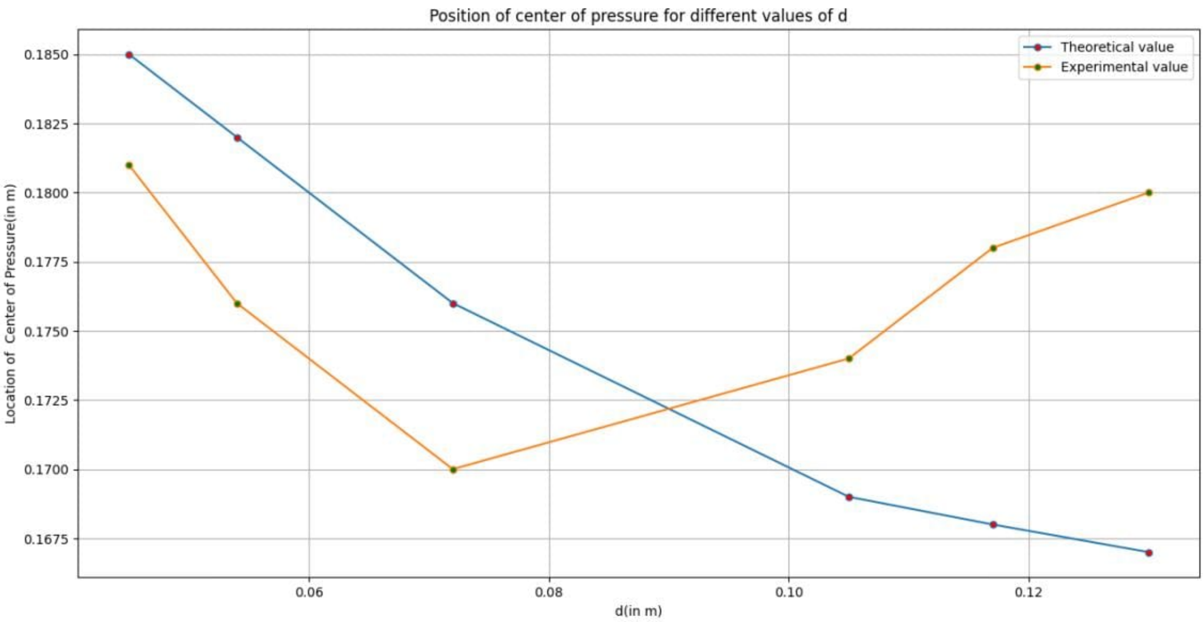

Figure 4: Position of crentre of pressure(y)(in m)(Theoretical and experimental) vs different values of d(in m)

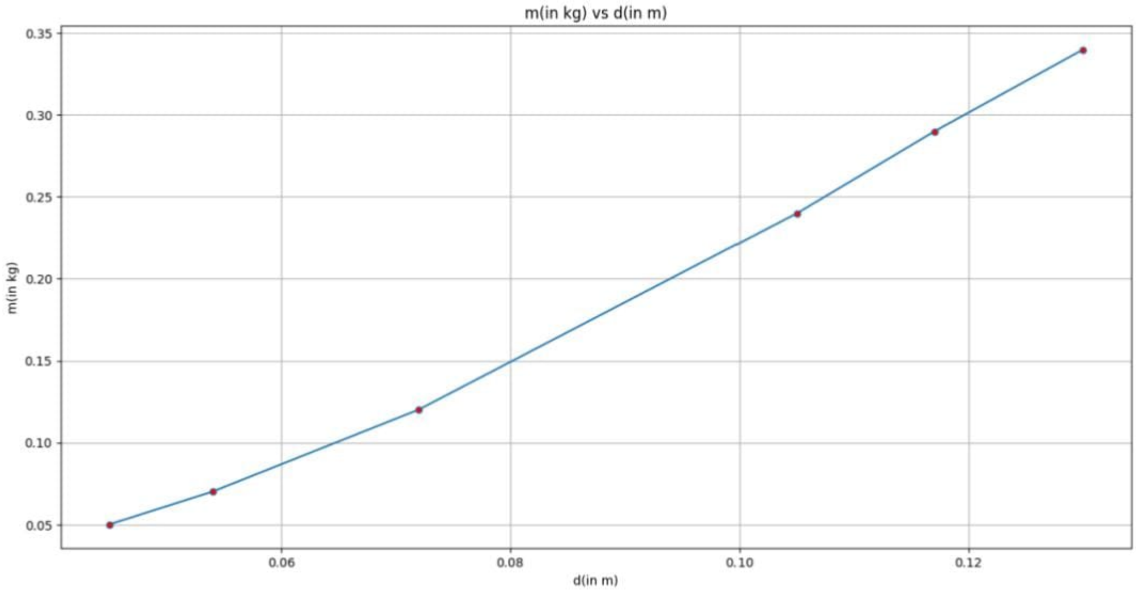

Figure 5: mass(m)(in Kg) vs depth of water from the base of the quadrant(d)(in m)

7. Interpretation:

From first we can interpret that as depth of water from the base of the quadrant(d) increases theoretical value of location of center of pressure decreases but experimental value of location of center of pressure shows an irregular trend.
From second as graph we can see as depth of water from the base of the quadrant(d) increases,the mass m loaded on the weight hanger also increases.
Therefore there is a difference between theoretical and experimental values of center of pressure.

8. Sources of error:

- Inaccurate reading due to parallax error
- Instrumental errors.
- Error due to viscous effect and surface tension of water.
- Air disturbances and other disturbances may effect the experiment.

9. Conclusion:

- The location of center of pressure is a function of depth of water filled and it decreases as depth of water increases.
- Hydrostatic force is directly proportional to mass loaded.
- There is a little deflection of Experimental value from Theoretical value due to different sources of error.