

HYDROSTATIC PRESSURE

Objective

The two objectives of this experiment are:

- To determine the hydrostatic thrust acting on a plane surface immersed in water when the surface is partially submerged or fully submerged.
- To determine the position of the line of action of the thrust and to compare the position determined by experiment with the theoretical position.

In this exercise, F1-10 Hydraulics Bench and F1-12 Hydrostatic Pressure Apparatus are used. The F1-10 and F1-12 are test devices created for use in physics and engineering laboratories by Armfield Limited, Ringwald, Hampshire England.

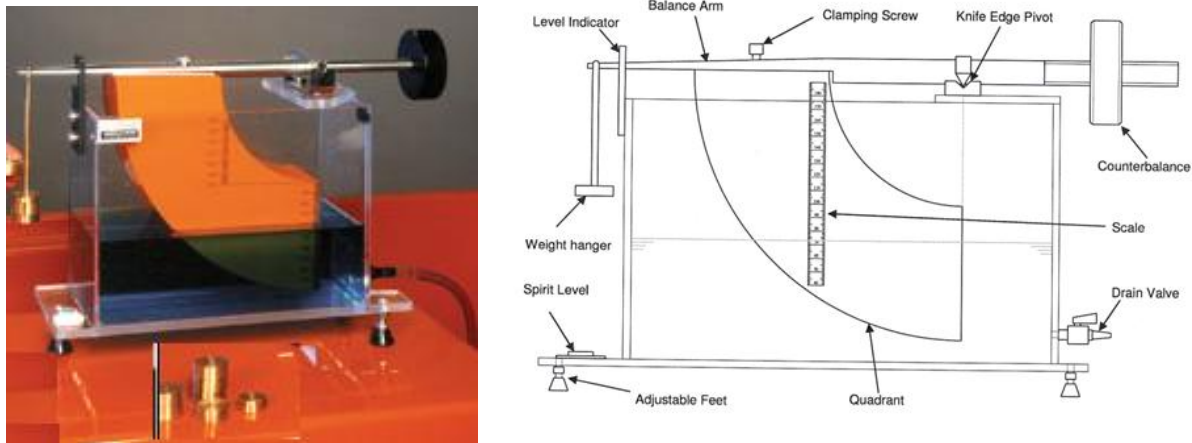


Figure 1: F1-12 Hydrostatic Pressure Apparatus.

Theory

Fluid force is constant at any particular depth, but varies vertically. This force is calculated as liquid weight per unit volume times the depth. The total force exerted by the liquid on the ring section is non-uniformly applied vertically. When the quadrant is immersed in water it is possible to analyze the forces acting on the surfaces of the quadrant as follows:

The hydrostatic force at any point on the curved surface is normal to the surface and therefore resolves through the pivot point because this 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 all of these forces pass through the pivot. The forces on the sides of the quadrant are horizontal and cancel out (equal and opposite). The hydrostatic force on the vertical submerged face is counteracted by the balanced weight W . The resultant hydrostatic force on the face can therefore be calculated from the value of the balance weight and the depth of the water as follows:

When the system is in equilibrium, the moments about the pivot point are equal:

$$mgL = Fh''$$

Where,

m is the mass on the weight hang,
 g is the acceleration due to gravity,
 L is the length of the balance arm,
 F is the hydrostatic thrust, and
 h'' is the distance between the pivot and the center of pressure.

Hence by calculating the hydrostatic thrust and center of pressure on the end face of the quadrant, we can compare theoretical and experimental results.

Partially Submerged Vertical Plane

This involves the case where the vertical face of the quadrant is partially submerged.

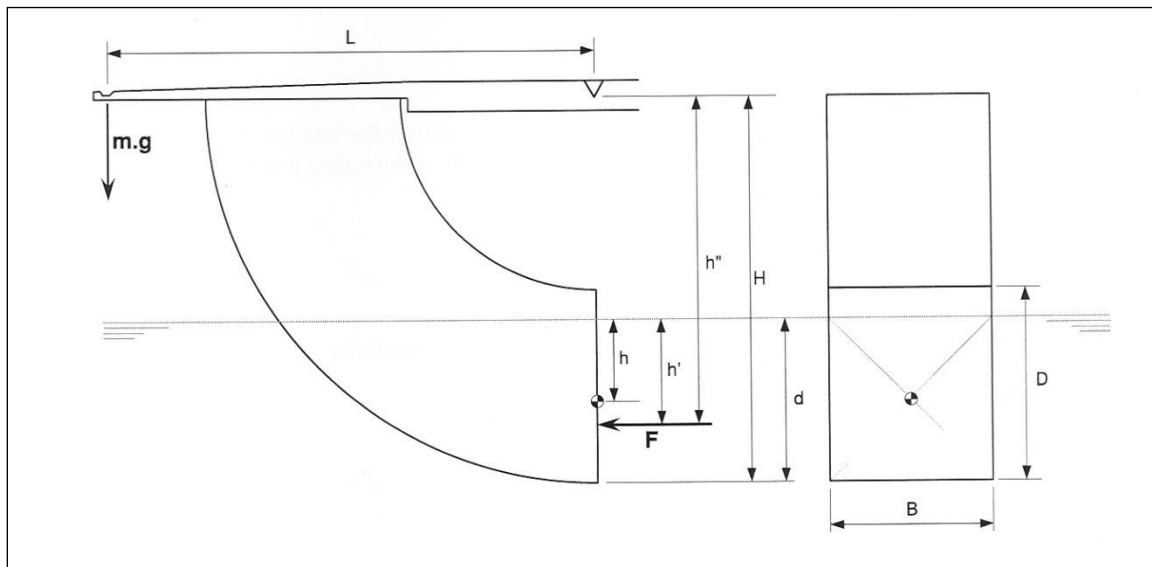


Figure 2. Diagram of Partially submerged case.

Where:-

L is the horizontal distance between the pivot point and the weight hanger,
 H is the vertical distance between the pivot and the base of the quadrant,
 D is the height of the quadrant face, B is the width of the quadrant face,
 d is the depth of water from the base of the quadrant, and
 h' is the vertical distance between the surface and the center of pressure.

The forces shown are F , the hydrostatic thrust, and $m.g$, the weight.

Hydrostatic Thrust

The hydrostatic thrust can be defined as:

$$F = \rho g A h \quad (\text{Newtons})$$

Where,

A is the area = $A = Bd$

h is the mean depth of immersion = $h = d/2$

Therefore:

$$F = (1/2) \rho g B d^2 \quad (1)$$

Experimental Depth of Pressure

The moment, M, can be defined as

$$M = F h'' \quad (\text{Newton-Meter})$$

A balancing moment is produced by the weight, W, applied to the hanger at the end of the balance arm. The moment is proportional to the length of the balance arm, L.

For static equilibrium the two moments are equal, i.e.

$$F h'' = W L = m g L$$

By substitution of the derived hydrostatic thrust, F from (1), we have

$$h'' = (m g L / F) = (2 m L / \rho B d^2) \quad (\text{meters})$$

Theoretical Depth of Pressure

The theoretical result for depth of pressure P below the free surface is

$$h' = (I_x / A h) \quad (2)$$

Where I_x is the 2nd moment of area of immersed section about an axis in the free surface. By use of the parallel axes theorem:

$$\begin{aligned} I_x &= I_c + A h^2 \\ &= (B d^3 / 12) + B d (d/2)^2 = (B d^3 / 3) \end{aligned} \quad (3)$$

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

$$h'' = h' + H - d \quad (\text{m}) \quad (4)$$

Hence:

$h'' = H - (d/3)$ for partially submerged vertical plane.

The turning moment can be calculated.

Fully Submerged Vertical Plane

For the case where the vertical face of the quadrant is fully submerged.

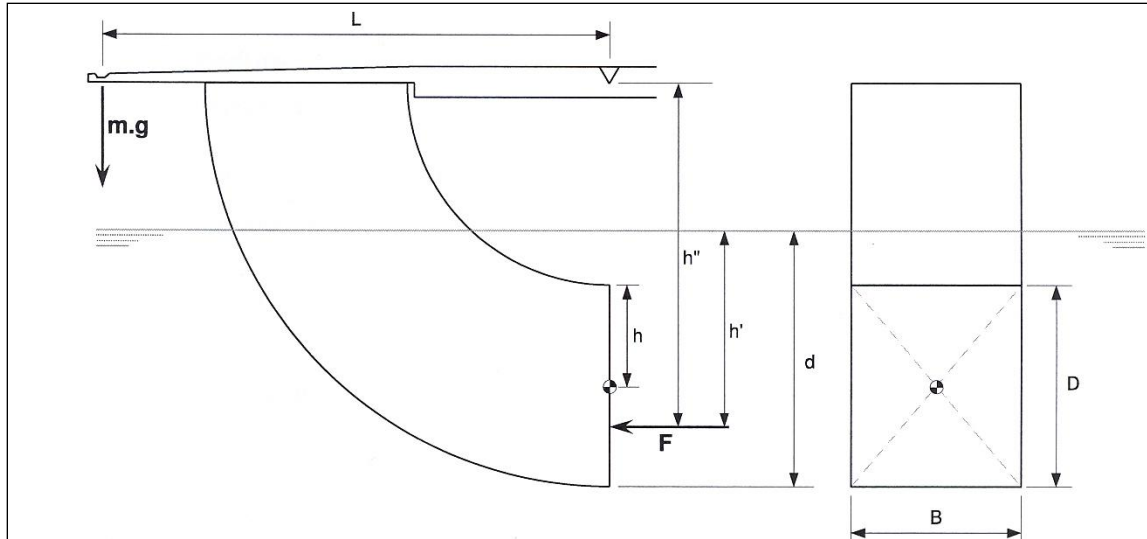


Figure 3. Diagram of Fully submerged case.

Where :

d is the depth of submersion,

F is the hydrostatic thrust exerted on the quadrant,

h' is the depth of the center of pressure,

h'' is the distance of center of pressure below the pivot,

B is the width of the surface, and

D is the depth of the surface,

W is the weight on the hanger ($=mg$)

Hydrostatic Thrust

The hydrostatic thrust F can be defined as

$$F = \rho g B D (d - (D/2)) \quad (5)$$

Experimental Depth of Pressure

The moment M can be defined as

$$M = F h'' \quad (\text{N-m})$$

The balancing moment is produced by the weight, W , applied to the hanger at the end of the balance arm. The moment is proportional to the length of the balance arm L .

For static equilibrium the two moments are equal, i.e.

$$F h'' = W L = m g L$$

By substitution of the derived hydrostatic thrust, F , from (5), we have

$$h'' = (m L) / (\rho B D (d - (D/2))) \quad (\text{m})$$

Theoretical Depth of Pressure

The theoretical results for the depth of center of pressure below the free surface is

$$h' = I_x / Ah$$

where I_x is the 2nd moment of area of immersed section about an axis in the free surface.

By use of the parallel axes theorem:

$$I_x = I_c + Ah^2$$

$$= BD \left[\frac{D^2}{12} + \left(d - \frac{D}{2} \right)^2 \right] \quad (m)$$

The depth of the center of pressure below the surface is

$$h'' = h' + H - d \quad (m)$$

Substitution as before then gives the theoretical result of:

$$h'' = \frac{\frac{D^2}{12} + \left(d - \frac{D}{2} \right)^2}{d - \frac{D}{2}} + H - d \quad (6)$$

for fully submerged vertical plane.

The turning moment can hence be calculated.

Equipment Set-up

1. Measure the dimensions B, D of the quadrant end-face and the distance H and L and record the values for future reference.
2. Position the empty F1-12 flotation tank on the F1-10 Hydraulics Bench or other suitable level surface, then adjust the screwed feet until the built in circular spirit level indicates that the tank is leveled in both planes.
3. Position the balance arm on the knife edges and check that the arm is free to swing.
4. Locate the empty weight hanger in the groove at the end of the balance arm.
5. Move the counter balance weight until the balance arm is horizontal, indicated by the central index mark on the beam level indicator.

Procedure

1. Check the bench is leveled properly with the use of spirit level.
2. Add a small mass (typically 50g) to the weight hanger.
3. Get tap water using steel vessel and fill up the flotation tank.
4. Fill the floatation tank with water initially until the balance arm rises. Avoid wetting the balance arm or the quadrant above the water level in the tank.
5. Continue to add water until the balance arm is horizontal, checking this by aligning the flat of the balance arm with the central mark on the level indicator.
6. When the arm is horizontal read the depth of immersion from the scale on the face of the quadrant.
7. Repeat the above procedure for different load increments by adding further weights to the weight hanger.
8. Continue until the water level reaches the top of the upper scale on the quadrant face.
9. Repeat the procedure in reverse, by progressively removing the weights.

Calculations and Results

All readings must be recorded as follows:

Constants

Height of End Face:	D =	(m)
Width of the End Face	B =	(m)
Length of Arm	L =	(m)
Height of Pivot	H =	(m)

Variables

Mass Added m (kg)	Measured Turning Moment (Nm)	Depth d (m)	Hydrostatic Thrust F (N)	Distance to Center of Pressure h (m)	Turning Moment (Nm)