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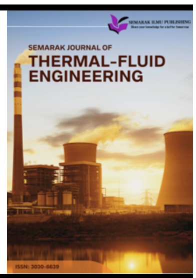

Investigate the Effect of Pressure Depends on Submerged Plane with Artificial Dam Model

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ABSTRACT

Relationship of submerged structures and fluid pressure can be determined by experimenting the science behind gravity dam. Since pressure behaviours are crucial in understanding how to design the hydrostatic pressure. Therefore, the gravity dam is utilized to investigate the pressure distribution on a submerged plane. We've constructed a simple model using modelling clay as our base or core of the dam, cardboard for the straight-line shape sealed with adhesive tape intended as water resistance and 3-second glue as sealant ensuring no water pass through the gaps. Then, pressure measurement was taken at three specific depths, 3 cm, 5 cm, and 7 cm. Principle of hydrostatic pressure are used in this experiment as a basis for finding the theoretical pressure on the submerged plane. Analytical methods applied based on the fluid mechanic and fluid statics in explaining what have been observed. The results shows that depth of water does influence pressure inside water at rest. A linear increase between depth and pressure are demonstrated proving the theoretical relationship between pressure-depth. It is verified where the base of the gravity dam does not affect pressure at any given depth as long there's no additional effect such as current or turbulence changing the velocity of water which are out of hydrostatic analysis scope. By any means, there's no doubt that pressure is determined solely by the depth and fluid density of the submerged point. This small project highlights that by using an affordable and accessible experimental setup others can practice the application of fundamental of fluid mechanics concept regarding to real-world applications. Thus, the findings valuable for understanding pressure behaviour on submerged plane based on the geometry of experimental setup and influences from such density and depth of the fluid.

1. Introduction

Experimental modeling has been extensively used to study the relationship between water pressure and submerged surfaces under a variety of conditions, focusing particularly on hydrostatic forces [1-3]. Gaining insights into pressure behavior acting on submerged structures is crucial for assessing the stability and longevity of hydraulic systems like dams and sluice gates [4,5]. The impact

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of water pressure on submerged surfaces has been explored through controlled experiments, offering valuable understanding of the forces applied by water at varying depths [6]. This knowledge serves as a fundamental basis for enhancing the design and construction of water-related infrastructure to ensure lasting structural integrity and efficiency in practical applications [7,8]. It is widely recognized that hydrostatic pressure rises in direct relation to depth, owing to the weight of the fluid above. This relationship can be expressed mathematically by the equation $P = \rho gh$, where the pressure (P) at a certain depth is calculated using the fluid density (ρ), the acceleration due to gravity (g), and the height of the fluid column above the point of measurement (h) [9]. This concept has been applied extensively in hydraulic engineering, especially in designing submerged structures, as variations in pressure need to be carefully addressed to avoid structural failures that might lead to considerable economic and environmental repercussions [10,11]. Incorporating hydrostatic principles into engineering designs is crucial to guarantee the safety and effectiveness of such structures under different water conditions [12].

The importance of hydrostatic pressure is further demonstrated through experimental tests in which a plastic container is used to mimic a dam structure, featuring small openings at various heights along its side to observe changes in pressure with depth [13]. It has been noted that water escaping from the lowest opening travels the farthest distance, whereas water from the middle and top openings reaches shorter distances [14,15]. This serves as direct evidence that increased pressure is applied by water at greater depths due to the additional weight of the fluid above, resulting in a higher force exerted on the submerged surface [16]. This experiment further illustrates how water pressure impacts the flow of fluids, reinforcing the theoretical concept that pressure differences drive water movement in hydraulic systems [17]. It emphasizes the importance of factoring in hydrostatic pressure when designing submerged structures, as failing to account for pressure variations can result in serious structural vulnerabilities [18,19]. By integrating hydrostatic principles into engineering practices, the creation of stronger hydraulic structures has been advanced, enhancing safety, durability, and efficiency in practical aquatic settings [20]. The knowledge derived from experimental modeling has enhanced the understanding of hydrostatic pressure behavior in real-world scenarios, aiding future investigations aimed at improving structural designs for hydraulic purposes. This is depicted in Figure 1, which shows the center of pressure applied while disregarding the area.

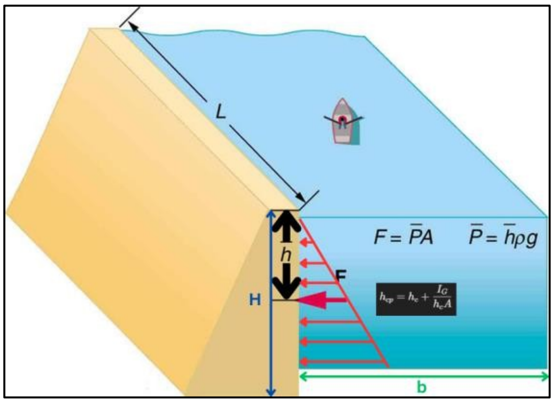


Fig. 1. Diagram of centre of pressure applied with the area being neglected

2. Methodology
2.1 The Geometry of the Experiment

This part discusses the geometry of the experiment to obtaining accurate results overall. Thus, in the next section we will discuss the experimental setup and analysis from what we get regarding this study.

2.1.1 Exact 3D model of container

The container used for this project is not square shape overall. It does have a spherical or curvelike shape and the right side as shown in Figure 2. Autodesk inventor used in creating modelling the 3D model.

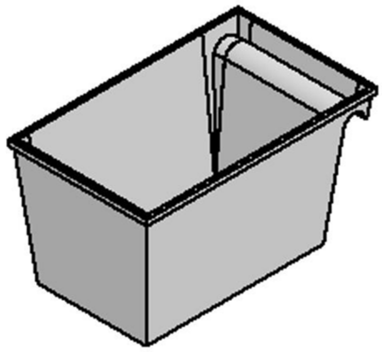
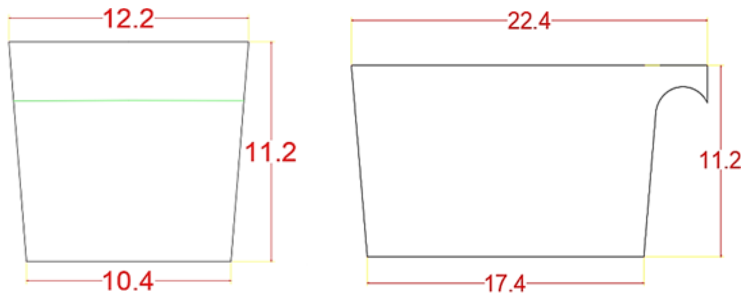


Fig. 2. 3D drawing to actual show the shape of the container

2.1.2 Container dimensions

The non-equivalent containers used in this experiment where for the side 1 the bottom horizontal length is 10.4 cm while the horizontal top is 12.2 cm. For the vertical length at side 1 at 90° angle is 11.2 cm. Meanwhile for side 2, the length for bottom horizontal one is 10.4 cm and 22.4 cm at the horizontal's top. The same vertical 90° length as side 1. The curved path at the end of side 2 was ignored since it does not affect anything at any point. This was shown in Figure 3.



(a) (b)

Fig. 3. Container dimensions (a) Container side 1 (b) Container side 2

2.1.3 Dam modelling

A gravity dam model was built to conduct the experiment as shown in Figure 4. The material used is modelling clay, cardboard, adhesive tape and super glue. The modelling clay is shaped as desired. The clay then combined with cardboard to make the flat dam shape. This combination is fully wrapped with adhesive tape making it water resistance. The dam is then being fit into the container as shown in Figure 4 and then being glued on the surface container, making sure the gaps is sealed surely. Dry the glue with medium heat of hair blower to get rapid result.

(a) (b) (c)

Fig. 4. Dam modelling (a) Modelling clay and super glue b) Cardboard and adhesive tape (c) Dam model fitting in container

2.1.4 The measurement for depth

The depth is being measured using a measuring device(ruler) in centimeter (cm) as unit (Figure 5). The depth chosen for this experimental setup, which is 3 cm, 5 cm, 7 cm. This depth represents as h where being used to calculate the pressure using formula mentioned in introduction (1). In addition, different depths will create different pressures as theoretically expected.

Fig. 5. Straight marking line represent depth

2.2 Experimental Setup

The experimental setup was designed and constructed to determine the relationship between depth-pressure on submerged planes based on hydrostatic pressure principle. The materials that are being constructed are affordable, simple yet safe to use. In addition, measurement device make is super easy to get the precise value of model. Thus, steps involved in assembling and preparing the experimental setup are shown below:

i. Make sure the container is clear enough to detect the water level.
ii. Examine the entire section of the container, ensuring no crack ed parts that could cause leakage.
iii. Re-evaluate the measuring part at least 3 times to get the most accurate readings.
iv. Draw straight line using ruler for the depth mark.
v. Fit the dam model into a container.
vi. Fill the one side of container with water steadily until it reaches the first depth mark (3 cm).
vii. Make sure the fluid is at rest. Repeat step at VI. for 5 cm and 7 cm of depth.

2.3 Analysis of the Experiment

This part is about inspection that has been observed in this experiment regarding the key while diving through in fluid mechanics. Not only does this experiment provides understanding, but it also enhances our experience in real world applications which may give benefits soon.

2.3.1 Pressure-depth relationship

The pressure on the submerged plane is determined by the depth using the formula from Eq. (1) where:

$$P = \rho g h \tag{1}$$

where ρ is the density of the fluid, g is gravitational acceleration ($9.81 m/s^2$) and h is the depth water submerged in fluid.

2.3.2 Density of the fluid (ρ)

In water (density ≈ $1000 kg/m^{3)}$ where the pressure is relatively high compared to light fluids such as oil (density <$1000 kg/m^{3)}$ which is lower.

2.3.3 Force-depth relationship

The force acting on submerged plane increases quadratically with depth calculated by the Eq. (2).

$$F = \rho g h_C A \tag{2}$$

where h_C is the depth to the centroid of the submerged plane and A is the area of the submerged plane. The quadratic relationship arises from the increasing hydrostatic pressure with depth and the submerged plane's larger effective area.

2.3.4 Center of pressure

The centre of pressure, the point of application of the resultant force, was determined using the Eq. (3).

$$h'_c = h_c + \frac{I_G}{h_c A} \quad (3)$$

where is the second moment of area of the submerged surface. The centre of pressure shifts downward with increasing depth due to the higher pressure acting at greater depths.

3. Results

3.1 Effect of Depth to the Pressure

The relationship between pressure and depth is linear, as predicted by the hydrostatic. The table below summarizes the calculated using Eq. (1) pressures at depths of 0.03 m, 0.05 m and 0.07 m. Table 1 summarize the result of the calculation. Figure 6 show that the pressure increases linearly with the depth. The more the depth the high the pressure. Depth at 0.03 m have the lowest pressure meanwhile the depth at 0.07 m have the highest pressure

Table 1
Value of pressure and depth

Depth (m)	Pressure (Pa)
0.03	294.3
0.05	490.5
0.07	686.7

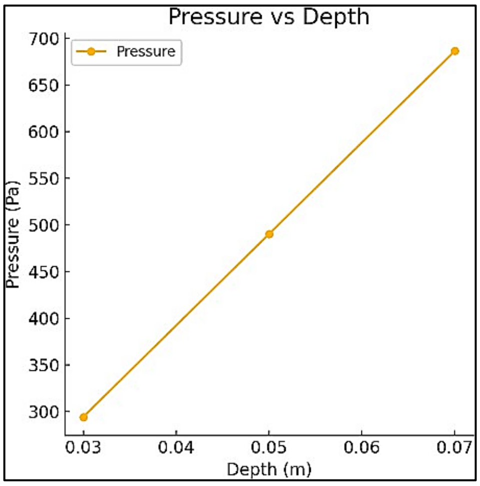


Fig. 6. Pressure vs depth graph

3.2 Effect of the Depth to the Force Exerted by the Water

The force acting on the submerged plane increases quadratically with depth due to the relationship between depth, pressure, and the submerged area. Table 2 below summarizes the forces at each depth. Figure 7 show quadratically graph showing the effect of depth to the force exerted by the water to the submerged body. This result calculated using Eq. (2) and summarized in Table 2.

Table 2
Value of depth and force

Depth (m)	Force (N)
0.03	1.08
0.05	2.99
0.07	5.86

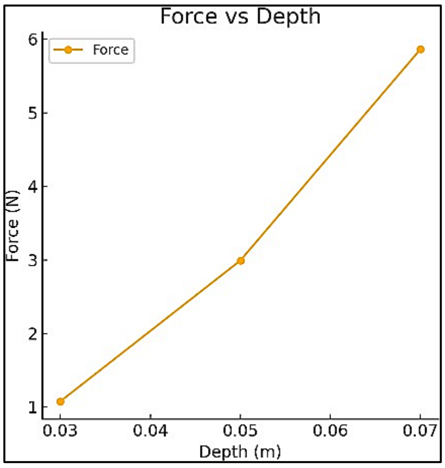


Fig. 7. Force vs depth graph

3.3 Effect of Depth to the Centre of Pressure

The centre of pressure is the point where the resultant force acts on the plane. It shifts slightly downward as depth increases. The Table 3 below summarizes the centre of pressure values. Figure 8 show that center of pressure increse as the depth increase. The graph is plotted using the summarize result in Table 3. The result is calculated using Eq. (3).

Table 3
Value of depth and center of pressure

Depth (m)	Centre of pressure (m)
0.03	0.020
0.05	0.033
0.07	0.047

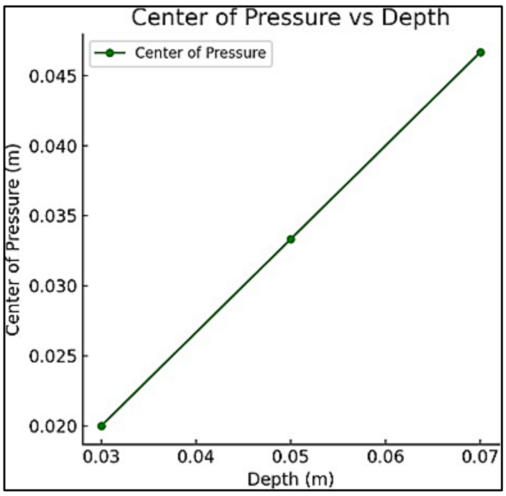


Fig. 8. Center of pressure vs depth graph

3.4 Experimental Error

Minor experimental errors were observed, including slight water leakage due to nonuniform adhesion of glue and minor discrepancies in measurements. These factors, however, did not significantly affect the validity of the results. Potential improvements include better sealing methods and more precise measurement tools to enhance accuracy. The findings underscore the importance of depth and fluid density in determining hydrostatic pressure, force, and center of pressure. These principles are crucial for designing stable hydraulic structures such as dams, where understanding pressure distribution ensures structural safety and efficiency.

4. Conclusions

The experiment effectively illustrated that hydrostatic pressure rises proportionally with increasing water depth, as evidenced by the recorded pressures at depths of 3 cm, 5 cm, and 7 cm, confirming the theoretical assertion that pressure increases directly with depth. The force acting on submerged surfaces demonstrated a quadratic relationship with depth due to the interplay of rising pressure and the area submerged. As depth increased, the center of pressure showed a downward movement, consistent with theoretical predictions. At a depth of 0.03 m the pressure is 294.3 Pa, at depth 0.05 m the pressure is 490.5 Pa and at depth 0.07 m the pressure is 686.7 Pa. This reading shows that this experiment is successfully conducted true to theoretical result that as the depth increases, the pressure increases.

Next the experiment on effect of depth shows that at depth 0.03 m, 0.05 m and 0.07 m the force obtains was 1.08 N, 2.99 N and 5.86 N that prove the more the depth of the submerged body, the more force will be exerted on the submerged body. For the last investigation on the relationship between depth with center of pressure the result obtains at depth 0.03 m, 0.05 m and 0.07 m the center of pressure was 0.020 m, 0.033 m and 0.047 m. This proves that the more depth, the more the center of pressure. From all the results obtained, it was concluded that this experiment successfully conducted with the experimental result align with the theoretical result. The depth of the submerged body indeed affects the pressure, the force and the center of pressure.

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