Birzeit university– faculty of engineering and technology

Department of mechanical engineering

Fluid Mechanic Laboratory

ENME312

Section 1

Experiment No.1

"The center of pressure"

Instructors:

Dr. Adel Dweik

Eng. Alanoud Muadi

Group 5:

Majd Raddad 1201196

Qais Samara 1202956

Mohammad Abu Ayyash 1182690

Prepared by: Majd Raddad- 1201196

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Abstract

When examining the behavior and characteristics of fluids, the concepts of pressure and forces generated by these fluids are essential because many applications, like wells, dams, gates, etc., are designed to preserve fluids (mostly water). In the analysis of these applications, the forces generated by these fluids must be resisted for them to be effective, so fluid forces and pressure need to be understood and estimated. Forces are usually calculated in another term, called a center, or point of action. This is the point on which the resultant forces act; in the case of fluids, this point is referred to as the hydrostatic pressure point.

This experiment demonstrates the hydrostatic forces concepts, its point of action, and the unit weight of water. The hydrostatic force is the pressure exerted by a fluid at equilibrium on both fully and partially submerged surfaces. This is achieved using a quadrant-shaped tank, which can hold variable heights of water and pivots on a smooth bar. To estimate the force, the tank is set at specific angles (0, 20 degrees) for the experiment. The angle adjustment is done by unscrewing the tank and tilting it to the desired position, then securing it in place with added weights as necessary. Additional weights are placed at the end of the smooth bar to create a moment at the pivot that lifts the tank. The tank is then filled with water to a height that brings it back to the initially set angle. For each combination of weight and height, the moment is calculated as the weight multiplied by the moment arm. Graphs are then plotted to show the relationship between the moment and the height, allowing for the estimation of the unit weight of water.

The results of where (θ =0°) part obtained for the unit weight of the fully submerged surface to be 9253.3 N/m^3, and 14690.4 N/m^3 for the partially submerged surface, which leas an average unit weight of water equal to 11971.85 N/m^3.

Objectives

- Explore the concept of fluid hydrostatic forces on gates, reservoirs, and dams.
- Measure the moment caused by fluid thrust on a Fully or partially submerged plane surface.
- Estimate hydrostatic force, its point of action, and the unit weight of water.

Sample calculation.

Moment M=W× (R3) …… (1)

M= (Mass*9.81) × R3

Where:

W : The weight of the weights added to the arm (kg)

R3: Arm radius (mm)

For fully submerged:

$$M = \frac{\gamma\, B\, R_2^3 \cos\theta}{3} - \frac{\gamma\, B\, R_2^2\, h}{2} + \frac{\gamma\, B\, h^3 \sec^2\theta}{6}$$ **……………………….. (2)**

θ: Tilting angle [Degrees]

γ: Specific weight, which equals ρg [N/m3] and will be determined experimentally

h: Water depth [mm].

R1.R2 values are given in table 1 below. for θ= 0

Average slope (constant) =- $\frac{\gamma * \mathrm{B}(R2^2 - R1^2)}{2}$

-10.41= - $\frac{\gamma * 0.075(0.2^2 - 0.1^2)}{2}$

γ =9253.3 N/m^3

For partially submerged:

$$M = \frac{\gamma\, B \cos\theta}{3}(R_2^3 - R_1^3) - \frac{\gamma\, B\,(R_2^2 - R_1^2)\, h}{2}$$ **…………………… (3)**

for θ= 0

Equation constants = $\frac{M\prime}{h^3}$ = $\frac{\gamma 2\ \mathrm{B} * \sec^2(\theta)}{6}$

183.63= $\frac{\gamma * 0.075 * \sec^2(0)}{6}$

γ_2= 14690.4 N/m^3

Same goes for θ= 20 but using cosine of 20°. .

Ycp = $\frac{M}{F}$

Where Ycp is the location of the hydrostatic pressure center

F is the force acting on the fully/partially submerged plane of the tank

The force can be calculated as follows.

$$F = \frac{\gamma_{avg} \times B \times COS\theta}{2}(R_2^2 - R_1^2)$$

$$\gamma_{avg} = \frac{\gamma_{fully} + \gamma_{partially}}{2} = \frac{9253.3 + 14690.4}{2} = \mathbf{11971.85\ N/m^3}$$

Calculating the center of pressure for fully and partially submerged case of h= 0.156 m and h=0.095 for θ=0.

Theoretical Moment at this height = (0.123 N.m for partially submerged) and (0.622 N.m for partially submerged).

$$\text{Force} = \frac{11971.85 * 0.075 * (0.2^2 - 0.1^2)}{2} = 13.5\ \text{N}$$

$$\text{Ycp} = \frac{0.622}{13.5} = 0.0461\ \text{m}$$, for h=0.095, Fully submerged.

$$\text{Ycp} = \frac{0.123}{13.5} = 0.00912\ \text{m}$$, for h=0.156, Partially submerged.

Table (1): Given Parameters (Inner Radius, Outer Radius, Width, Arm Radius).

parameter	Value (mm)
R1	100
R2	200
B	75
Arm radius (R3)	250

Results

- **For Fully submerged θ = 0 ° and (h< 0.1) :**

Table (2): Data and Calculations for Calibration Angle θ = 0 °

Angle = 0					
Weight (g)	h (mm)	Weight (Kg)	h (m)	100 cos 0	M
270	95	0.27	0.095	100.000	0.233
290	89	0.29	0.089	100.000	0.218
310	82	0.31	0.082	100.000	0.201
330	80	0.33	0.08	100.000	0.196
350	74	0.35	0.074	100.000	0.181
380	70	0.38	0.07	100.000	0.172
400	63	0.4	0.063	100.000	0.155

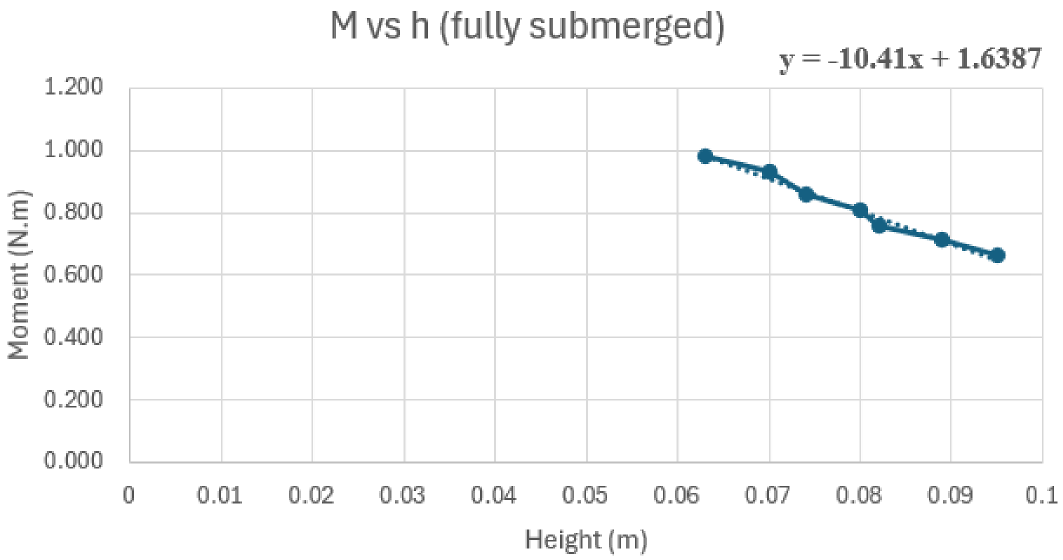
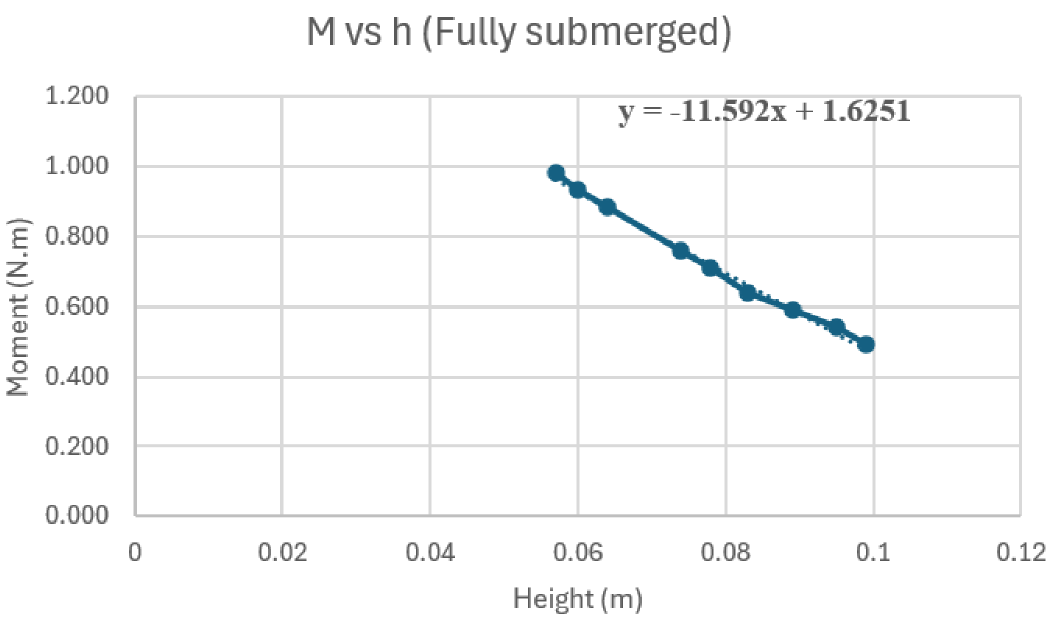


Fig (1): Moment M (N.m) Vs. Water Depth h (m), for θ= 0° Fully submerged.

- **For Fully submerged θ = 20 ° and (h< 0.093969) :**

Table (3): Data and Calculations for Calibration Angle θ = 20 °

Angle = 20					
Weight (g)	h (mm)	Weight (Kg)	h (m)	100 cos 0	M
200	99	0.2	0.099	100.000	0.491
220	95	0.22	0.095	100.000	0.540
240	89	0.24	0.089	100.000	0.589
260	83	0.26	0.083	100.000	0.638
290	78	0.29	0.078	100.000	0.711
310	74	0.31	0.074	100.000	0.760
360	64	0.36	0.064	100.000	0.883
380	60	0.38	0.06	100.000	0.932
400	57	0.4	0.057	100.000	0.981



Fig(2): Moment M (N.m) Vs. Water Depth h (m) for 20°, Fully submerged Plane.

Table (4): Unit Weight Calculations for Fully Submerged Plane.

Parameter	**Value**
slope for (θ = 0)	10.41
slope for (θ = 20)	11.592
Unit Weight (γ_1), θ = 0 N/m^3	9253.3
Unit Weight (γ_1), θ = 20 N/m^3	10304

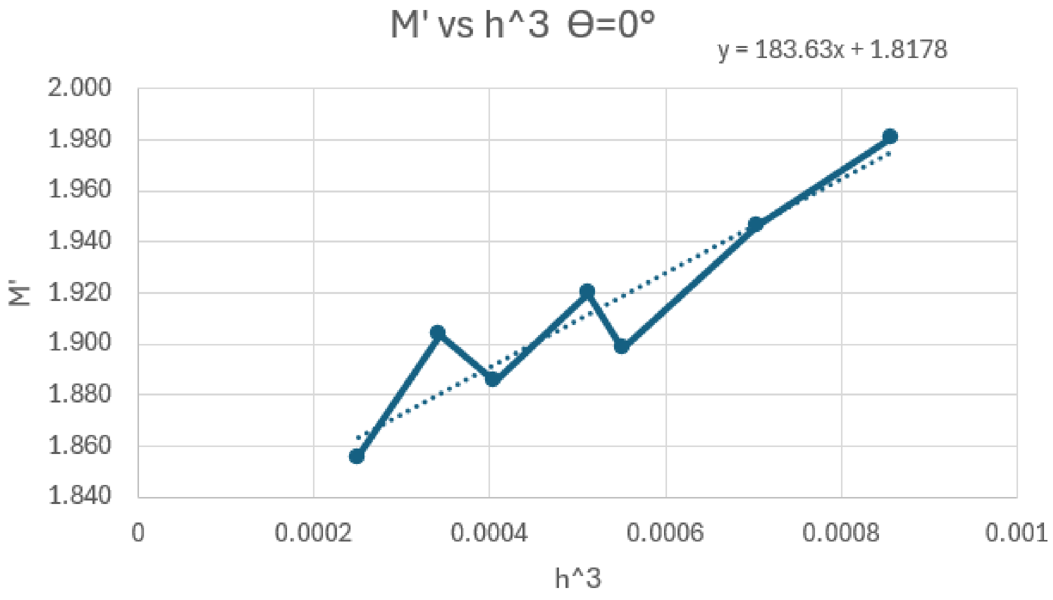


Fig (3): Relationship between (M') against (h^3) for θ=0.

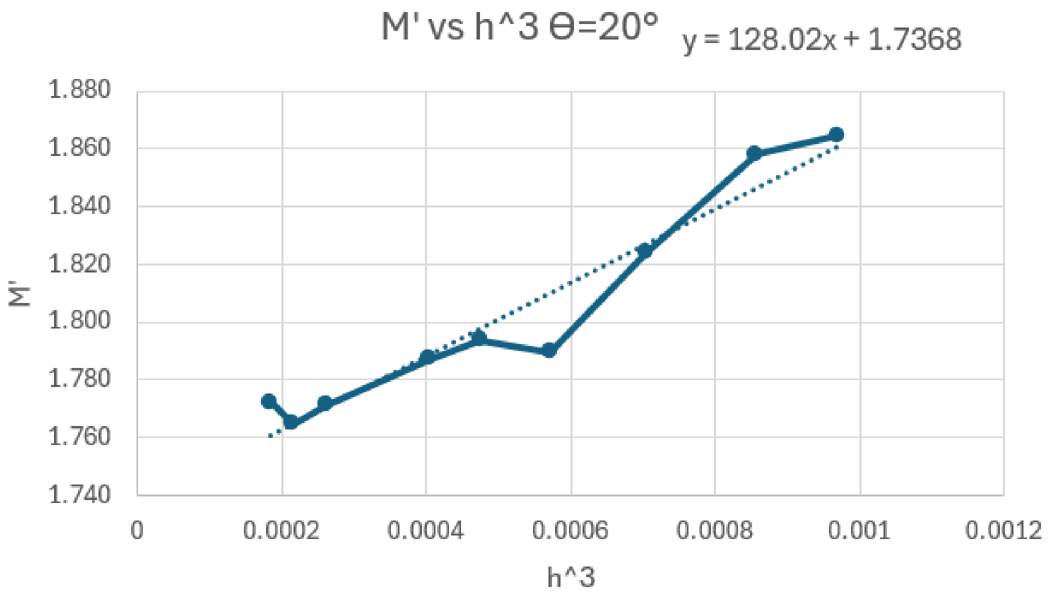


Fig (4): Relationship between (M') against (h^3) for θ=20.

- **For Partially submerged: -**

- **For h>0.1:**

Table (5): Data and Calculations for Calibration Angle Ө = 0 °.

Angle = 0					
Weight (g)	h (mm)	Weight (Kg)	h (m)	100 cos 0	M
50	156	0.05	0.156	100.000	0.383
70	142	0.07	0.142	100.000	0.348
90	140	0.09	0.14	100.000	0.343
110	130	0.11	0.13	100.000	0.319
130	123	0.13	0.123	100.000	0.302
150	120	0.15	0.12	100.000	0.294
180	112	0.18	0.112	100.000	0.275
200	109	0.2	0.109	100.000	0.267
250	101	0.25	0.101	100.000	0.248

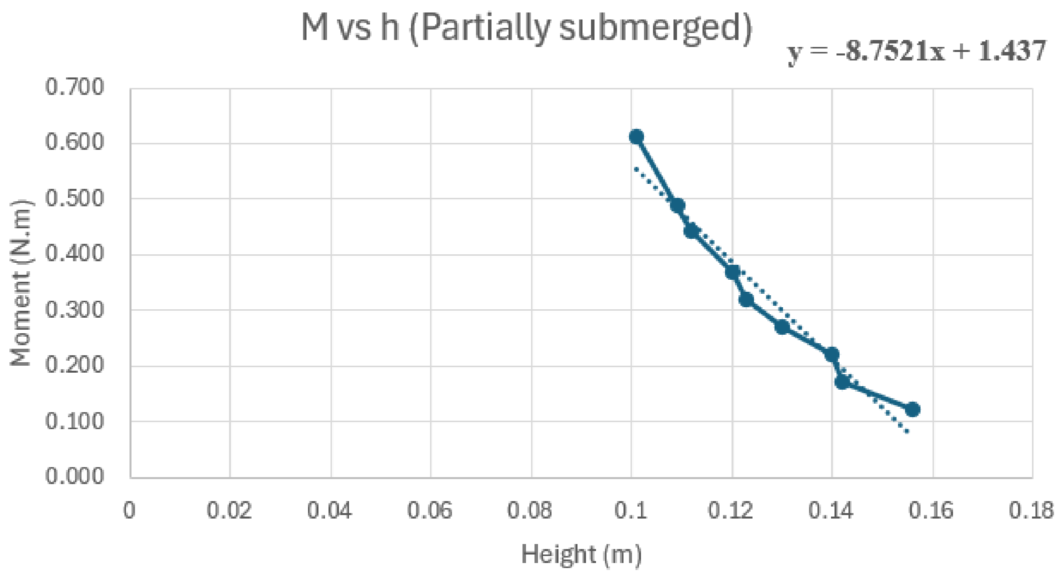


Fig (5): Moment M (N.m) Vs. Water Depth h (m), for θ= 0° Partially submerged.

- **<u>h >0.093969</u>:**

Table (6): Data and Calculations for Calibration Angle Ɵ = 20 ° .

Angle = 20					
Weight (g)	h (mm)	Weight (Kg)	h (m)	100 cos 0	M
20	155	0.02	0.155	100.000	0.049
40	149	0.04	0.149	100.000	0.098
60	135	0.06	0.135	100.000	0.147
90	129	0.09	0.129	100.000	0.221
110	121	0.11	0.121	100.000	0.270
160	111	0.16	0.111	100.000	0.392
180	103	0.18	0.103	100.000	0.441

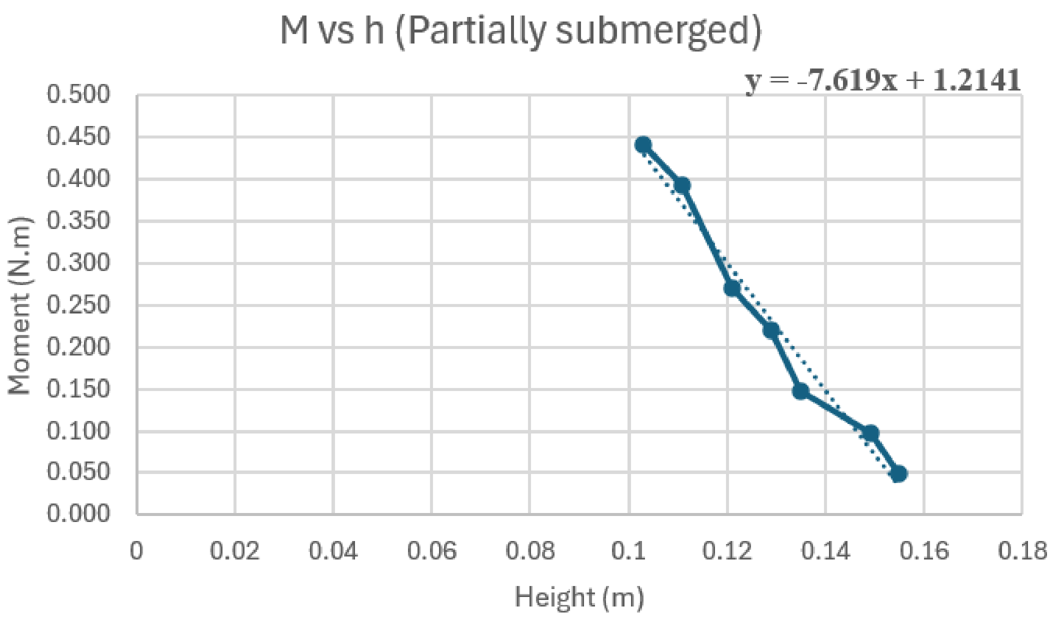


Fig (6): Moment M (N.m) Vs. Water Depth h (m) for 20° Partially submerged.

Table (7): Unit Weight Calculations for Partially Submerged Plane.

Parameter	Value
Constant for (θ = 0°)	8.7521
Constant for (θ = 20°)	7.619
Unit weight for (**γ2**) (Ɵ = 0°)	14690.4
Unit weight for (**γ2**) (Ɵ = 20°)	9043.56

Average Unit Weight (for θ = 0°) = $\frac{\gamma 1+\gamma 2}{2}$ **= 11971.85** N/m^3
Average Unit Weight (for θ = 20°) = $\frac{\gamma 1+\gamma 2}{2}$ **= 11866.98** N/m^3

Discussion of results

The objectives of the experiment included exploring the concept of the "center of hydrostatic pressure" and introducing key terms such as hydrostatic pressure, hydrostatic force, and unit weight. The experiment successfully achieved its goal by calculating these various parameters to approximate the value of the center of hydrostatic pressure.

The results section Tables 2, 3, 5, and 6, representing the experimental data and the calculated moments. These tables categorize the data based on whether the tank plane was fully or partially submerged at varying weights. Additionally, Tables 4 and 7 summarize the outcomes for the unit weight of water, derived by applying the necessary equations. The experimental results indicate that the average unit weight of water is 11971.85 N/m^3at 0 degrees (θ=0°) and 11866.98 N/m^3at 20 degrees (θ=20°).

Furthermore, the data from the tables mentioned above were used in graphs shown in Figures (1, 2, 5, and 6), which illustrate the relationship between the water height and the moment at these heights. Four graphs were plotted from different angles to represent both partial and full submersion scenarios.

Finally, upon comparison, there was no big difference in the behavior of the trendlines for the same cases of partial and full submersion when the tilting angle was altered.

Conclusion

In conclusion, the experiment aimed to explore the concept of the "center of pressure" and its significance for understanding fluid dynamics. By using a quadrant-shaped tank that was subjected to different levels of submersion and tilt angles.

The obtained value for the unit weight is 11971.85 N/m^3, compared to the actual unit weight of water (9810 N/m^3), resulting in an error of 22%. This error can be attributed to several factors, notably when comparing the results of fully submerged and partially submerged cases. The unit weight obtained from fully submerged cases (9253.3 N/m^3) is nearly accurate, whereas for partially submerged cases, the yielded unit weight (14690.4 N/m^3) exhibits a noticeable difference. This discrepancy arises from fitting the data into a quadratic trend, whereas the real behavior follows a cubic equation. Despite these challenges, the results are deemed acceptable given the complexity of the experiment. Factors such as the repetitive process of height reading, potential misreading due to the quadratic shape of the tank, and the necessity of taking readings perpendicular to the water level all contribute to the margin of error, making the observed error value acceptable.

References

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- Hsu, T.-J., & Chiang, H.-L. (2007). Estimation of the Center of Pressure for a Floating Body. Journal of Ship Research, 51(3), 243–250.
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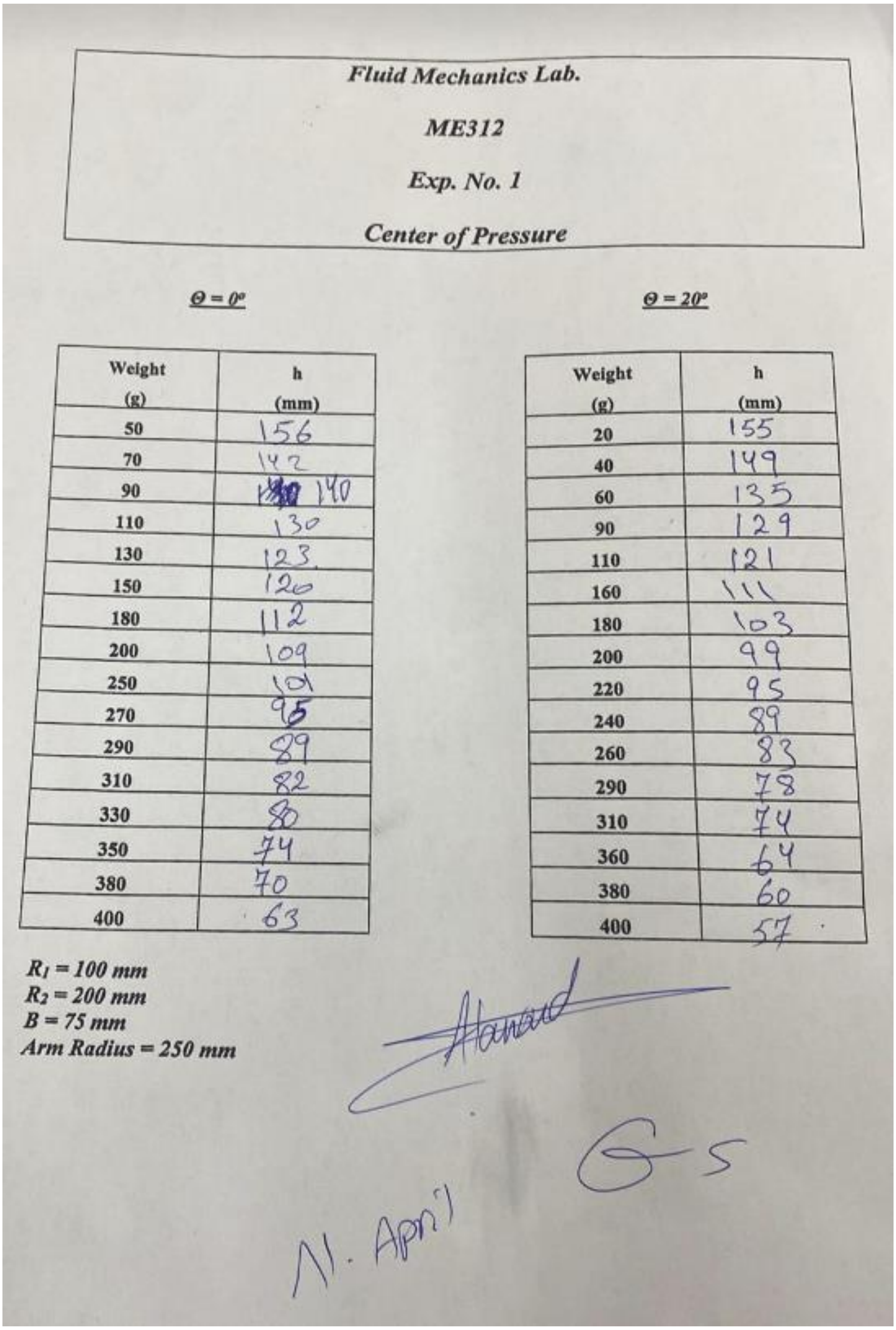
Appendices



Fluid Mechanics Lab.

ME312

Exp. No. 1

Center of Pressure

$\Theta = 0°$

Weight (g)	h (mm)
50	156
70	142
90	140
110	130
130	123
150	120
180	112
200	109
250	101
270	95
290	89
310	82
330	80
350	74
380	70
400	63

$\Theta = 20°$

Weight (g)	h (mm)
20	155
40	149
60	135
90	129
110	121
160	111
180	103
200	99
220	95
240	89
260	83
290	78
310	74
360	64
380	60
400	57

$R_1 = 100$ mm
$R_2 = 200$ mm
$B = 75$ mm
Arm Radius = 250 mm

11. April