



THE UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CE369- FLUID MECHANICS I

Lab 2. Centre of Pressure

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OBJECTIVE:

1. To determine the centre of pressure of a wholly submerged body and to compare these with theoretically obtained values.
2. To estimate relative errors in determining of centre of errors

THEORY:

The total hydrostatic forces exerted on either a submerged surface or on a portion of fluid isolated as a free body can be determined by means of calculation.

The force and intensity of pressure exerted by a fluid on an immersed surface increases with depth.

For a plane surface, the force exerted by a fluid on each differential element of the surface area is given by ;

$$dF = \rho gh \cdot dA = \gamma h \cdot dA \dots \text{equation 1}$$

Where, $\gamma = \text{specific weight of fluid}$

$h = \text{depth of element below the surface of fluid}$

The total sum of the pressure force is found by integrating the differential force over the area of the submerged body:

$$\int dF = \int \gamma h dA$$
$$F = \gamma \bar{h} A \dots \text{equation 2}$$

Where, $\bar{h} = \text{depth of centroid of submerged body}$

$A = \text{area of submerged body}$

The resultant hydrostatic force acts at a point called the centre of pressure.

Theory shows;

$$x_p = \bar{x} + \frac{I_G}{A \cdot \bar{x}} \dots \dots \dots \text{Theoretical Determination of } x_p$$

Where $\bar{x} = \text{centroidal distance of submerged object from surface}$

$I_G = \text{second moment of area of immersed body about surface of liquid through C.G}$

Experimental Determination of x_p ;

$$y = \frac{W.s}{F} \quad y = \text{distance from pivot to centre of pressure}$$

$W = \text{weight added to hangar}$

$s = \text{distance of pivot to hangar}$

But $y = x_p + r - \frac{h_1}{\cos \theta}$

$h_1 = \text{depth of water to rectangular surface top}$

$r = \text{distance from pivot to rectangular surface}$

$\theta = \text{angle of inclination}$

THEREFORE, $x_p = y - \left(r - \frac{h_1}{\cos \theta}\right)$

DESCRIPTION OF APPARATUS:

The apparatus permitted the moment due to the total fluid thrust on a wholly or submerged plane surface to be measured directly and compared with the Theoretical Analysis. Provision was made for varying the inclination with the vertical of the plane surface subjected to the fluid pressure so that the general case may be studied.

The water was contained in a Perspex quadrant, the cylindrical sides of which had their axes coincidental with the centre of rotation of the tank assembly. The total fluid pressures on these curved surfaces therefore exerted no moment about the centre, the only moment present being that due to the fluid pressure on the plane test surface.

This moment was measured experimentally by applying weights to the weight hanger mounted on an arm on the opposite side of the quadrant tank. The head of water in the tank was measured directly against a transparent scale mounted on the apparatus.

PROCEDURE:

Initially, the quadrant was set in the first required angular position $\theta = 0^\circ$ using a balancing weight on the same side of the assembly as the weight hanger.

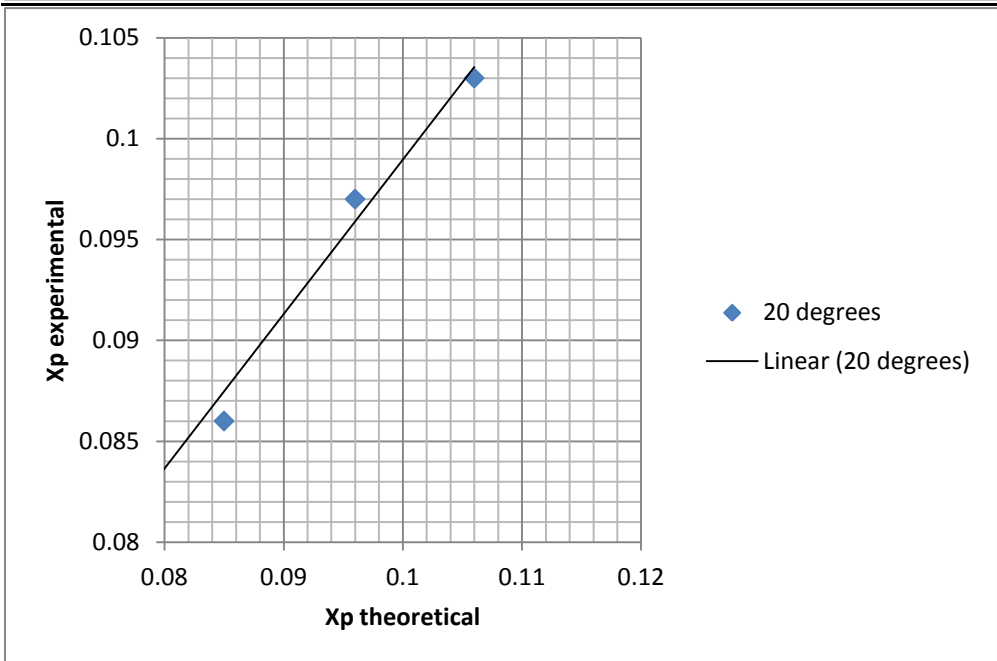
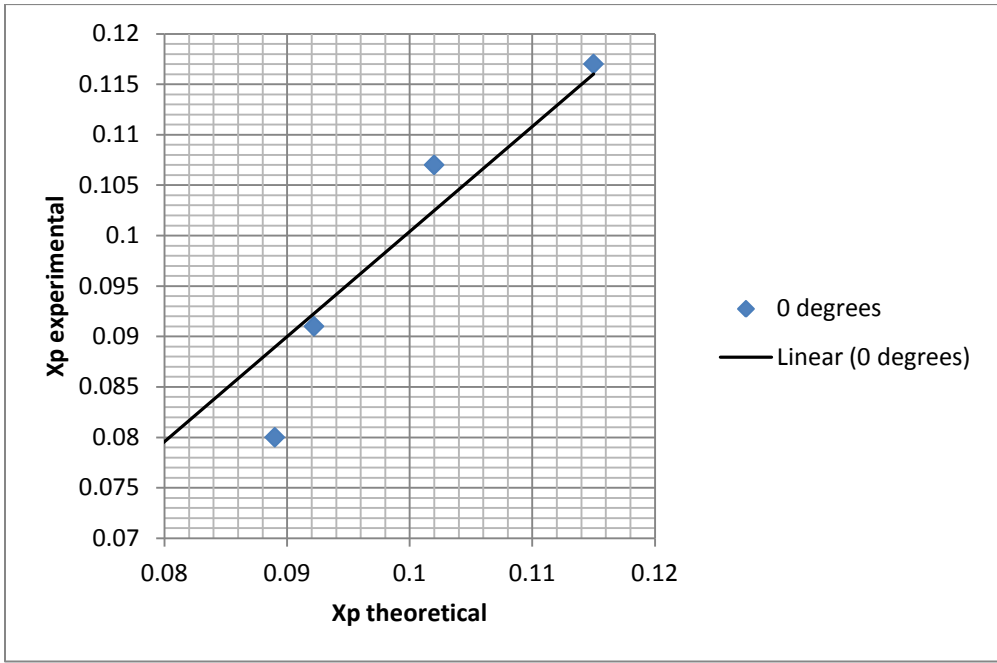
Subsequent results were taken by balancing incremental weights placed on the hanger with extra quantities of water. The depths h_1 and h_2 were measured against each weight used. The procedure was repeated for angles 20° and 30° .

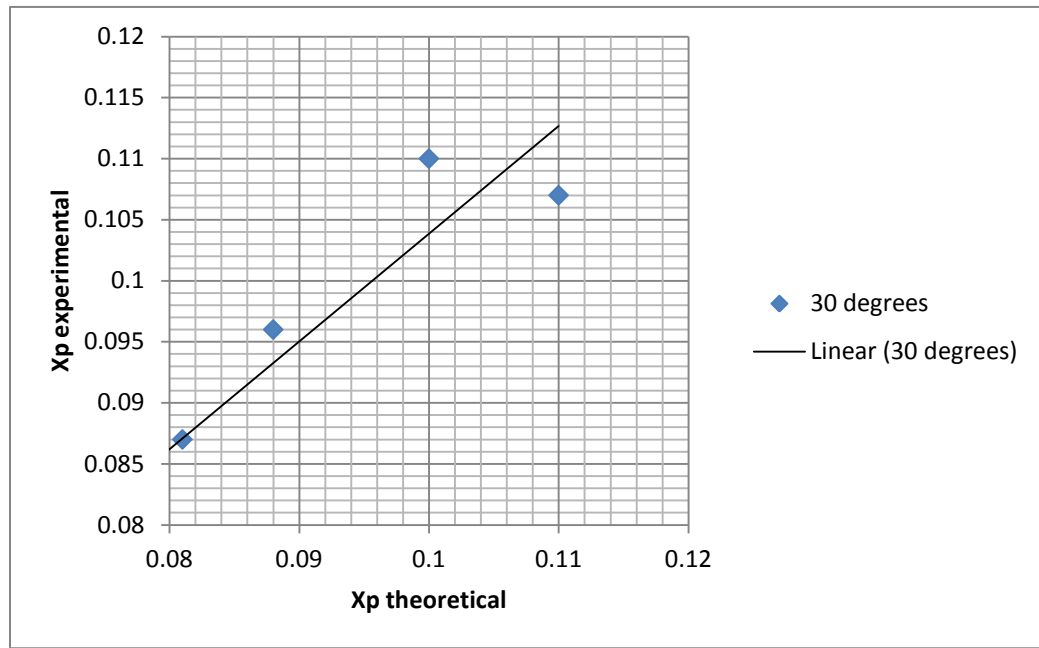
RESULTS:

The table below shows the results obtained from the experiment.

Table1:

		h_1	h_2	\bar{h} (m)	$F(N)$	$\bar{x} = \bar{h}/\cos\theta$	ICG /Ax	$x p$ THEORY	W	$y = W*s/F$	$h_1/\cos\theta$	$x p$ EXP	% error
		m	M	m	N	m		m	N	m	m	m	
1	30	0.005	0.092	0.049	3.6	0.057	0.015	0.072	2.453	0.17	0.0058	0.076	-5.56
2	30	0.017	0.107	0.061	4.48	0.07	0.019	0.089	2.943	0.16	0.02	0.08	10.11
3	30	0.027	0.114	0.071	5.22	0.082	0.0102	0.0922	3.434	0.16	0.031	0.091	1.3
4	30	0.037	0.124	0.081	5.95	0.094	0.0087	0.102	3.924	0.16	0.0427	0.107	-4.9
5	30	0.049	0.136	0.093	6.84	0.107	0.0078	0.115	4.415	0.16	0.057	0.117	-1.74
6	20	0.003	0.097	0.049	3.6	0.052	0.016	0.068	2.453	0.17	0.0032	0.0732	-7.65
7	20	0.011	0.105	0.057	4.19	0.061	0.014	0.075	2.943	0.17	0.012	0.082	-9.33
8	20	0.024	0.118	0.07	5.15	0.074	0.011	0.085	3.434	0.17	0.026	0.086	-1.18
9	20	0.035	0.129	0.081	5.95	0.086	0.0097	0.096	3.924	0.16	0.037	0.097	-1.04
10	20	0.045	0.139	0.091	7.13	0.097	0.0086	0.106	4.415	0.15	0.053	0.103	2.83
11	0	0.006	0.107	0.057	4.25	0.057	0.015	0.072	2.943	0.17	0.006	0.076	-5.56
12	0	0.017	0.118	0.068	5.06	0.068	0.013	0.081	3.434	0.17	0.017	0.087	-7.41
13	0	0.026	0.127	0.077	5.73	0.077	0.011	0.088	3.924	0.17	0.026	0.096	-9.09
14	0	0.04	0.141	0.091	6.78	0.091	0.0094	0.1	4.415	0.17	0.04	0.11	-10
15	0	0.047	0.151	0.101	7.52	0.101	0.0085	0.11	4.905	0.16	0.047	0.107	2.73





DATA ANALYSIS:

L=10cm

b=7.5cm

r=10cm

s=25cm

Sample calculation for 30°; experiment trial no.1

$$\text{Area } A = Lb = 0.100m \times 0.075m = 7.5 \times 10^{-3}m^2$$

THEORETICAL DETERMINATION OF x_p ;

$$\bar{x} = \frac{\bar{h}}{\cos \theta} = \frac{0.049}{\cos 30^\circ} = 0.05658m \approx 0.057m$$

$$I_{CG} = \frac{1}{12} bL^3 = \frac{1}{12} 0.075 \times 0.1^3 = 6.25 \times 10^{-6}m^4$$

$$\frac{I_{CG}}{A\bar{x}} = \frac{6.25 \times 10^{-6}m^4}{7.5 \times 10^{-3}m^2 \times 0.057m} = 0.0146m$$

$$x_p = \bar{x} + \frac{I_{CG}}{A\bar{x}} = 0.057m + 0.0146m = 0.0716m \approx 0.072m$$

EXPERIMENTAL DETERMINATION OF x_p ;

$$y = \frac{2.453 \times 0.25}{3.6} = 0.1703m$$

$$x_p = y - \left(r - \frac{h_1}{\cos \theta} \right); \quad \frac{h_1}{\cos \theta} = \frac{0.005m}{\cos 30^\circ} = 0.00577m \approx 0.0058m$$

$$\text{thus, } x_p = 0.1703 - (0.1 - 0.0058) = 0.0761m$$

$$\%error = \left[\frac{x_p(\text{theory}) - x_p(\text{experimental})}{x_p(\text{theory})} \right] \times 100\%$$

$$[0.072 - 0.076/0.072] \times 100\% = -5.56\%$$

DISCUSSION:

The graphs plotted the results as x_p *experimental versus theoretical* for each respective angle of inclination. A visual display of the correlation between the two methods was achieved by the plotting of these graphs.

The experiment was subject to parallax errors during the reading of water heights. Caution was taken to reduce such errors.

Average values taken might have also been a reason to lesser accuracy. Recommendations are for the experimental setup to be replaced by a latest one. Generally there were small percentage errors implying that data obtained is reasonably accurate to make valid deductions such as the correlation factor between the two methods is *approximately* 1.

CONCLUSION:

The centre of pressure of a completely submerged surface was successfully determined experimentally and was easily compared to that obtained by theory.

It was concluded that the centre of pressure of an immersed body lies below the centre of gravity of the surface or body submerged.

The objectives of the laboratory experiment were achieved.

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1. Kothandaraman C.P & Rudramoorthy R. (1999), **Fluid Mechanics and Machinery** (2ND edition), New Age International Ltd., Publishers, New Delhi, India.
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3. White F.M (2011), **Fluid Mechanics** (SIE,7th edition),McGraw-Hill companies, Inc, New York, United States of America