Experiment (2): Metacentric height of floating bodies

Introduction:

The Stability of any vessel which is to float on water, such as a pontoon or ship, is of paramount importance. The theory behind the ability of this vessel to remain upright must be clearly understood at the design stage. Archimedes' principle states that the buoyant force has a magnitude equal to the weight of the fluid displaced by the body and is directed vertically upward. Buoyant force is a force that results from a floating or submerged body in a fluid which results from different pressures on the top and bottom of the object and acts through the centroid of the displaced volume.

Apparatus:

1. Flat bottomed pontoon (Figure 1).
2. Hydraulic bench.

Figure 1: Flat bottomed pontoon

Equipment set up:

The flat bottomed pontoon is constructed from non-ferrous materials and has a detachable bridge piece and loading system. Provision is made to alter the keel weight and the mast weight so obtaining a variety of loading conditions. For off balance loadings, the degree of list can be directly measured using the plumb-bob line attached to the mast and swinging over a scale mounted on the

bridge piece. The floatation experiments can be carried out using the measuring tank of the hydraulics bench.

Floatation characteristics of flat bottomed pontoon.

Depth H = 170mm.

Length L = 380mm.

Width D = 250mm.

Distance from pontoon center line to added weight x = 123mm.

Center of gravity of vessel with mast OG_{vm} = 125mm approximately from outer surface of vessel base.

Weight of vessel with mast W_{vm} = 3000g.

Height of mast loading position above water surface of vessel base = 790mm.

Theory:

Consider a ship or pontoon floating as shown in figure 2. The center of gravity of the body is at G and the center of buoyancy is at B. For equilibrium, the weight of the floating body is equal to the weight of the liquid it displaces and the center of gravity of the body and the centroid of the displaced liquid are in the same vertical line. The centroid of the displaced liquid is called the "center of buoyancy". Let the body now be heeled through an angle θ (Figure 6), B_1 will be the position of the center of buoyancy after heeling. A vertical line through B_1 will intersect the center line of the body at M and this point is known as the metacenter of the body when an angle θ is diminishingly small. The distance GM is known as the metacentric height. The force due to buoyancy acts vertically up through B_1 and is equal to W. The weight of the body acts downwards through G.
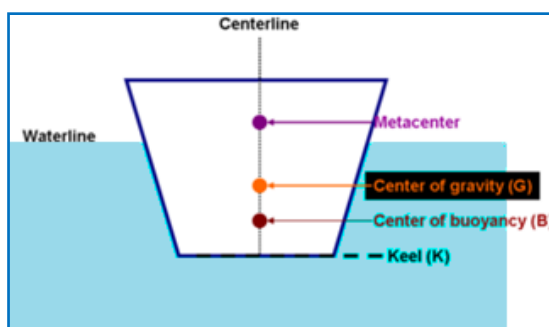

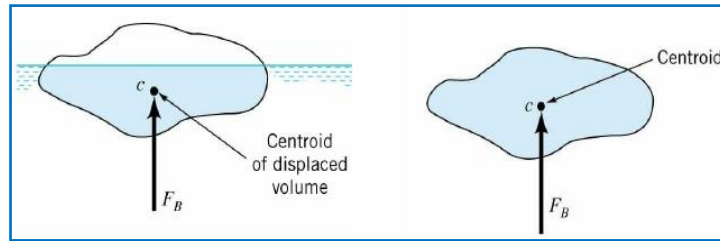**Figure 2: Illustrative figure of flat bottomed pontoon**

Figure 3: Centers of buoyancy of floating and submerged objects

Stability of submerged objects:

Stable equilibrium: if when displaced, it returns to equilibrium position.

If the center of gravity is below the center of buoyancy, a righting moment will produced and the body will tend to return to its equilibrium position (Stable).

Unstable equilibrium: if when displaced it returns to a new equilibrium position.

If the Centre of Gravity is above the centre of buoyancy, an overturning moment is produced and the body is (unstable).

Note : As the body is totally submerged, the shape of displaced fluid is not altered when the body is tilted and so the center of buoyancy unchanged relative to the body.
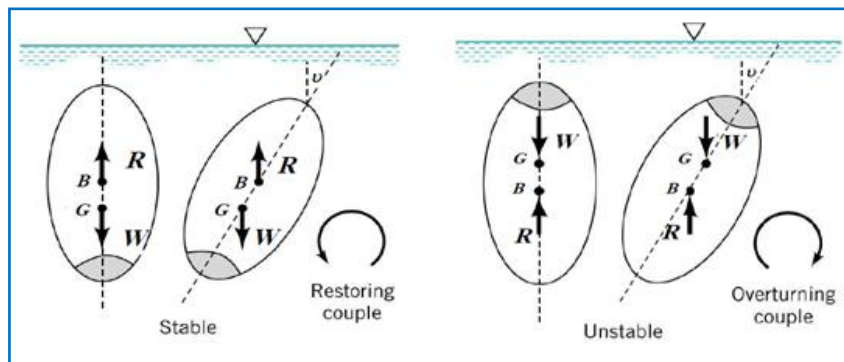

Figure 4: Stability of submerged objects

Stability of floating objects:

Metacenter point M: the point about which the body starts oscillating.

Metacentric height GM: is the distance between the center of gravity of floating body and the metacenter.

If M lies above G a righting moment is produced, equilibrium is stable and GM is regarded as positive.

If M lies below G an overturning moment is produced, equilibrium is unstable and GM is regarded as negative.

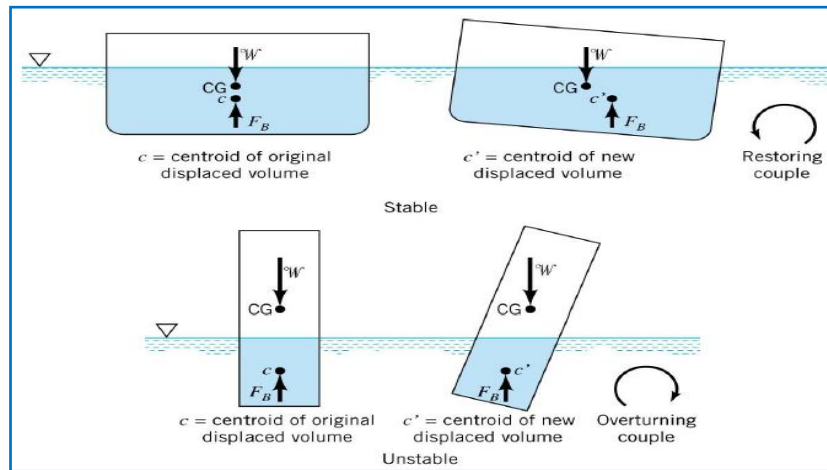If M coincides with G, the body is in neutral equilibrium.

Figure 5: Stability of floating objects

Determination of Metacentric height

1- Practically

$$WGMsin(\theta) = Px$$

$$GM = \frac{Px}{Wsin(\theta)}$$

Where x = distance from pontoon centerline to added weight.

Where W = weight of the vessel including P.
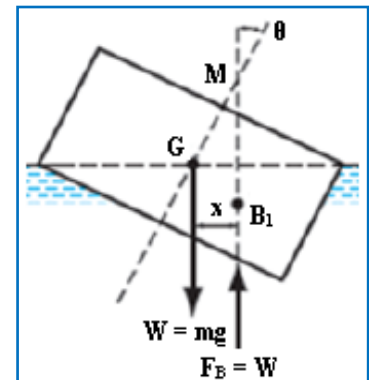
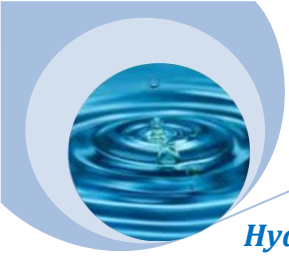**2- Theoretically**

$$GM = BM + OB - OG$$

$$BM = \frac{I}{V}$$

$$OB = 0.5\frac{V}{L \times D}$$

Where V = volume of displaced liquid

$$I = \frac{DL^3}{12}$$

Exercise A

Purpose:

To determine the floatation characteristics for unloaded and for loaded pontoon.

Procedures:

1. Assemble the pontoon by positioning the bridge piece and mast i.e. locate the mast in the hole provided in the base of the vessel and clamp the bridge piece fixing screws into the locating holes in the sides of the vessel.
The 'plumb-bob' is attached to the mounting dowel located on the mast and is allowed to swing clear of and below the scale provided

2. Weigh the pontoon and determine the height of its center of gravity up the line of the mast by balancing the mast on a suitable knife edge support and measuring the distance from knife edge to outside base of pontoon.

3. Fill the hydraulic bench measuring tank, or other suitable vessel, with water and float the pontoon in it. Trim the balance of the pontoon by applying one of the small weights provided to the bridge piece at the required position so that the vessel floats without any list, this condition being indicated by the plumb-bob resting on the zero mark.

4. Apply a weight of 50g on the bridge piece loading pin then measure and record the angle of list and value of applied weight.

5. Take readings of list angle and applied weight (100, 150 & 200g). Repeat the procedure for lists in the opposite direction i.e. apply the weights to the opposite side of the bridge piece.

6. Calculate GM practically. Draw a relationship between θ (x-axis) and GM (y-axis), then obtain GM when θ equals zero.

7. Calculate GM theoretically.

8. Repeat the above procedures for increasing ballast loading conditions i.e. 2000 and 4000g.

Results:

Bilge Weight W_b (gm)	Off balance wt. P (gm)	Mean Defln. θ (degree)	Exp. GM (mm)	GM at $\theta = 0$ from graph	BM (mm)	OB (mm)	Theo. GM (mm)
0.00	50						
	100						
	150						
	200						
2000.00 x_1 = 30mm	50						
	100						
	150						
	200						
4000.00 x_1 = 37.5mm	100						
	150						
	200						
	250						

Conclusion:

Comment on the closeness or otherwise of the practically acquired values of metacentric height against theoretically derived results.

Exercise B

Purpose:

To determine the effect on floatation characteristics of altering the center of gravity of the pontoon, with given total loading.

Procedures:

1. Replace the large bilge weights by 4×50g weights.
2. Apply a weight of 300gm on a height of 190 mm from the pontoon surface.
3. Using the method of exercise A, determine the metacentric height GM (using applied weights 40, 80 &120g).
4. Move one 50g bilge weight to the mast head and once again determine GM.
5. Repeat 100, 150 and 200g moved from the bilge weight to the mast head. Measure the position of the center of gravity from the base of the pontoon for each loading condition.
6. Determine the theoretical GM for each condition and also a height of a metacenter above water level.

Note 1: BM & OB values are constants for all loading conditions, since the dimensions & the weight of a pontoon do not alter.

Note 2: Once the center of gravity of the unloaded pontoon has been determined, then the center of gravity for other loaded conditions can be evaluated by taking moments about the base of the pontoon.

$$OG = \frac{3000(125) + W_b(35) + 300(190) + W_m(790 + \frac{L}{2})}{3500}$$
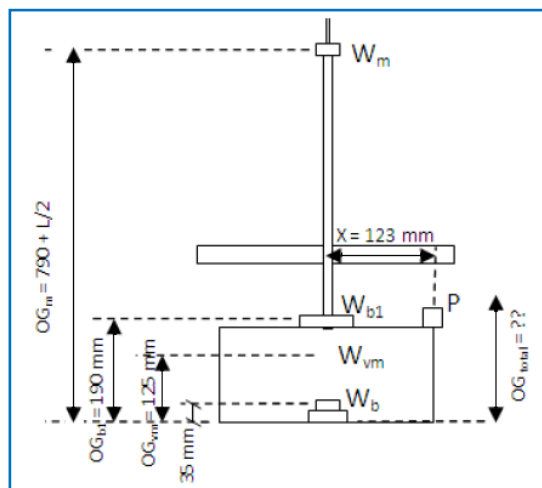
Where : $W_b + W_m = 200g$

        L = 10 mm when $W_m = 50g$

        L = 20 mm when $W_m = 100g$

        L = 30 mm when $W_m = 150g$

        L = 40 mm when $W_m = 200g$

Results:

Off balance wt. P (gm)	Mean Defln. θ (degree)	Exp. GM (mm)	BM (mm)	OG (mm)	Theo. GM (mm)	M above water level (mm)
Mast Weight = 0.0						
40						
80						
120						
Mast Weight = 50.0						
40						
80						
120						
Mast weight = 100.0						
20						
40						
80						
Mast Weight = 150.0						
10						
20						
40						
Mast weight = 200.0						
Unstable						

Conclusion:

Show the variation of depth of submergence and position of metacentric height under different loading conditions

Discuss what will happen if the ballast weights were added at the center of gravity so that the resultant center of gravity was unchanged.