DETERMINATION OF VESSEL WEIGHT AND COORDINATES OF ITS CENTRE OF GRAVITY BY USING OF ELASTIC INFLATABLE TANKS

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Abstract: The methods of experimental determination of the vessel weight and the coordinates of its center of gravity without launching using inflatable elastic containers are shown in this article.

KEYWORDS: VESSEL, INCLINING, TEST, ELASTIC, TANKS

1. Introduction

The calculations of weight displacement of the empty vessel and coordinates of its centre of gravity are performed when the vessel is under project. But never the less there is an inclining test which is performed after the vessel launch for determining the characteristics of the vessel.

The modernization and re-equipment often take place during vessel operations. These actions are accompanied with dismantling the existing equipment and designs and installation of the new ones. It leads to considerable changing of weight characteristics of a vessel. Calculations of changing of the specified characteristics of a vessel are carried out at performance of similar reconstructions to have a clear idea about its stability to vessel descent.

A new method of experimental determination of a vessel weight and coordinates of its center of gravity before ships launching by using of elastic inflatable cylindrical tanks (EICT) is presented in this article.

A method of transporting vessels on land with inflatable elastic tanks is widely used in the countries of South-East Asia.

Elastic cylindrical tanks are made of rubber and are equipped with fitting for connection to compressed air system and pressure gauges to monitoring the internal pressure.

The tanks are stowed across vessels hull under the bottom between keelblocks. When the pressure is increased the tanks abut against the bottom and lift the vessel above the keelblocks. After that the keelblocks are removing (fig.1 - 2).

After that the vessel is towed in longitudinal direction. Herewith the cylindrical inflatable tanks act as rinks. Rinks that go out from the bottom in aft end are transported into the forepart.

Inflatable elastic tanks lay directly between bottom and building ways if the vessel has flat bottom (fig.1,2,5)

If the vessel has raise of floor or sharp curved contours then it is necessary to use special intermediate flat platform (fig.3,4,6,7).

2. Weighing of the vessel
   (Determination of vessel weight and abscissas of its centre of gravity)

The vessel is set on keelblocks on the building ways (fig. 8a). Inflatable tanks are lay down across vessels hull on building ways between keelblocks symmetrically about vessels centre line (fig. 8b).

Then tanks are filled with compressed air until the vessel is not raised above the keelblocks till complete lack of them (fig. 8c).

There are list of characteristics such as: internal pressure, contact area of bottom with tank, and abscissas of center of gravity of contact area in reference to chosen readout system (for example - the midship section plane) are measured for each tanks (fig.9).
where \( G \) – vessel weight, \( \Delta = \sum Q \) – maintaining force (equal the displacement). Then vessel weight can be determined by equation

\[
G = \sum p_i F_i.
\]

(1)

When the trim is missing absissa of vessels center of gravity equal to absissa of fulcrum support can be determined by the expression.

\[
x_a = \frac{\sum Q x_a}{\sum Q}.
\]

Or finally, after appropriate substitutions

\[
x_a = \frac{\sum p_i F_i x_a}{\sum p_i F_i}.
\]

(2)

3. Inclining of vessel
(Determination of vessel weight and applicates of its centre of gravity)

The vessel is set on keelblocks on building ways as during weighing (fig 8a). The tanks are lay transverse under e bottom between keelblocks (fig 8b). When the pressure increases the tanks about against the bottom and lift the vessel above the keelblocks. The lifting of vessel should be such to avoid contact of vessel with keelblocks while inclination to the required angles (fig 8c).

There is a fixed-ballast with weight lay on upper deck in midship section on height above principal plane with offset to one side from centre line on distance. As a result the heeling moment which lead to the ship heeled to the angle appears (fig 10).

Because of it, deformation of an inflatable elastic tank asymmetrically about centre line.

There are list of characteristics such as: internal pressure, contact area of bottom with tank, and ordinate of center of gravity of contact area in reference to centre. (fig 11).

In the heeled condition (fig 10) the value of arm of heeling moment can be determined by equation

\[
e_i = e_i^0 \cos q + b \sin q.
\]
Rise of center of gravity of solid ballast above the center of gravity of the vessel

\[ b = H_{Gp} - Z_g \]

In the equilibrium heeled condition (fig.10, 12) at \( Q \) angle the heeling moment can be determined by equation

\[ M_{KP} = \rho \cos \alpha \cos q + b \sin q \]

Or finally, after appropriate substitutions

\[ M_{KP} = \rho \left[ \cos \alpha \cos q + \left( H_{Gp} - Z_g \right) \sin q \right] \]

Fig. 10. Definition of arm of heeling moment

Fig. 11. Determination of the weight of the ship and its center of gravity

Reducing moment in heeled condition of equilibrium in considering with \( \Delta = \Delta' \cos q \) (fig.12)

\[ M_{B} = \rho' = \Delta = \rho' \cos q \]

The ratio at equilibrium condition it’s necessary \( M_{KP} = M_B \) and \( G + P = \Delta \). After substitution values we get the equation

\[ P \left[ \cos \alpha \cos q + \left( H_{Gp} - Z_g \right) \sin q \right] = \rho' \cos q \]

Introduce notion of conditional metacentre, conditional arm of static stability and conditional metacentric height.

As it’s known the metacentre is a center of curvature the trajectory at which the center of buoyancy moves when vessel heeled. Characteristics of this trajectory depends on dimensions and form of the displacingment part of the vessel.

If the vessel is set on the building ways on elastic tanks then hull form does not affect stability of the system. General principles of interaction of vessels hull and elastic foundation essentially equal.

The hull will get heel when the heeling moment is applied. As a result the reaction of elastic foundation appears.

Resulting reactions of elastic foundation will move in the direction of that board in which the vessel heeled. It will lead to appearance of the restoring moment.

Point of intersection of action line of resulting reactions of elastic foundation with projection of centre line is a conditional metacentre. (Point M on fig.12).

Appropriate rise of conditional metacentre above the centre of gravity is a conditional metacentric height.

And distance along the normal between lines of action the forces of vessel weight \( G \) and maintained force \( \Delta \) - is a conditional arm of static stability.

It should be noted that the above characteristics have nothing to do either qualitatively or quantitatively with the same true parameters of the vessel afloat.

However, they enable us to determine the \( z \) center of gravity of the vessel, which has nothing to do with hydrostatic characteristics of the vessel hull.

From the previous formula we get the value of the conditional shoulder static stability

\[ I' = \frac{P \left[ \cos \alpha \cos q + \left( H_{Gp} - Z_g \right) \sin q \right]}{\Delta' \cos q} \]

or

\[ I' = \frac{P \left[ \cos \alpha \cos q + \left( H_{Gp} - Z_g \right) \sin q \right]}{\Delta' \cos q} \]

whence

\[ I' = \frac{P}{\Delta'} \left[ \cos \alpha + \left( H_{Gp} - Z_g \right) \sin q \right] \] (3)

In a simplified version, taking into account the fact at low angles of \( \theta \) we can write

\[ I' = \frac{P}{\Delta'} \left[ \cos \alpha + \left( H_{Gp} - Z_g \right) q \right] \] (37)

The conditional metacentric height(fig.12) can be determined by equation

\[ h' = \frac{I'}{\sin q} \]

whence

\[ h' = \frac{P}{\Delta' \sin q} \left[ \cos \alpha + \left( H_{Gp} - Z_g \right) \sin q \right] \] (4)

In a simplified version, taking into account the fact at low angles of \( \theta \) we can write

\[ h' = \frac{P}{\Delta'q} \left[ \cos \alpha + \left( H_{Gp} - Z_g \right) q \right] \] (47)
Value of applicate of conditional metacentre comparatively principal plane (fig.12).

\[
H' = \frac{e}{\text{tg} q}.
\]  

(5)

The applicate of centre of gravity vessel comparatively principal plane can be determined by using the (4) and (5) equation.

\[
z_g = H' - H = \frac{e}{\text{tg} q} - \frac{P}{\Delta' \sin q} \left( \varepsilon' + (H_{GP} - z_g) \text{tg} q \right):
\]

\[
z_g = \frac{e}{\text{tg} q} - \frac{P}{\Delta' \sin q} \left( \varepsilon' + H_{GP} \text{tg} q \right) + \frac{P \text{tg} q}{\Delta' \sin q} z_g.
\]

We solve the resulting equation for \(z_g\)

\[
z_g = \frac{P \text{tg} q}{\Delta' \sin q} z_g = \frac{e}{\text{tg} q} - \frac{P}{\Delta' \sin q} \left( \varepsilon' + H_{GP} \text{tg} q \right),
\]

whence

\[
z_g \left( 1 - \frac{P}{\Delta' \sin q} \right) = e \cos q - \frac{P}{\Delta' \sin q} \left( \varepsilon' + H_{GP} \text{tg} q \right)
\]

or finally

\[
z_g = \frac{e \cos q - \frac{P}{\Delta' \left( 1 - \frac{1}{\cos q} \right)} \left( \varepsilon' + H_{GP} \text{tg} q \right)}{\sin q}
\]

(6)

In a simplified version, taking into account the fact that at low angles \(\text{tg} q = \sin q = q\), and \(\cos q \approx 1\), equation (6) becomes

\[
z_g = \frac{e - \frac{P}{\Delta'} (\varepsilon' + H_{GP} \cdot q)}{q \left( 1 - \frac{P}{\Delta'} \right)}.
\]  

(6?)

There is calculation result of \(Z_g\) using (6) and (6a) equations at various angles of heel presented in the table below.

Calculation errors when using a simplified formula are also defined in the table.

For the calculation used the following data \(\Delta' = 3000\) ton; \(P = 5\) ton; \(H_{GP} = 10\) m; \(\varepsilon' = 7\) m; \(e = 0.3\) m.

Calculations have shown that at heeled within \(3^\circ\), the maximum error in the determination of the by approximate formula (6a) does not exceed 0.15%.

Given the fact that the metacentric height is usually order of magnitude smaller than , that is defined as a small difference of large values, the approximate version of the formula is quite applicable to an angle of heel of \(3^\circ\).

In this case the error of determination of metacentric height associated with the calculation error will be no more than 1.5%.

The weight characteristics of the flat intermediate platform(fig. 3.4.5.6.7) must be determined earlier and then must be considered with calculations.

These methods of determining the vessel weight and the coordinates of its centre of gravity are the subject of invention, the application for which are sent in patent organizations of leading shipbuilding companies.

### Table 1

<table>
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<th>Q, degree/radian</th>
<th>0.5/0.00873</th>
<th>1.0/0.01745</th>
<th>1.5/0.02618</th>
<th>2.0/0.03491</th>
<th>2.5/0.04363</th>
<th>3.0/0.05236</th>
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<td>(Z_g), (6)</td>
<td>33.08</td>
<td>16.53</td>
<td>11.01</td>
<td>8.251</td>
<td>6.596</td>
<td>5.491</td>
</tr>
<tr>
<td>(Z_g), (6?)</td>
<td>33.07</td>
<td>16.53</td>
<td>11.02</td>
<td>8.256</td>
<td>6.603</td>
<td>5.499</td>
</tr>
<tr>
<td>(\Delta), %</td>
<td>0.03</td>
<td>0</td>
<td>0.09</td>
<td>0.06</td>
<td>0.11</td>
<td>0.15</td>
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