Determination of the stability parameters and the position of a ship in the condition of flooding of the watertight compartment

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Abstract

This paper presents the results of stability calculations in the case of damaged watertight compartment during flooding. Working out these calculations there have been applied the constant displacement method and the method of established volume. The work has contributed to the analysis of changes of metacentric height, angles of heel and angles of trim, which may occur during flooding of the watertight compartment.

The method of determination of the position of a ship during the flooding of the watertight compartment and computer programmes elaborated might be exercised on training stability and survivability simulator which is being prepared to be executed at The Naval University of Gdynia. These calculations might be of some help in training midshipmen and functional persons who are responsible for safety of floating.

1 Introduction

A Navy ship is endangered by different damage during the operation. It might occur as a result of fires, mistakes in navigation, operational mobility, manoeuvrability, enemy’s affecting and so on. Moreover, research and analysis show [4,6,7,9], that the human factor (mistakes, recklessness, negligence, poor working conditions, overload of work, stress) determines influence on damage and failures of vessels. It means, that stress should be put on experience and habits of the people who are responsible for safety of floating in the earliest stages of training. These who are already operating on the ships should have
possibility to deepen their knowledge through exercises provided and propped up by using computer programmes, simulation of the situation of damage on prepared stands, which can show how models of the ship and their conducting give possibility to analyse the situation which may occur in reality, and undertake quick decision to prevent crisis situation. The project of work station concerning stability and survivability problems, is being prepared for operation stage in The Naval University of Gdynia. It assumes establishing the post of (basins, models) instrumentation of posts – connecting models with computer posts of operator and practises, suitable software to simulate the situations of damage which might occur on a ship [9,10]. Fig.1 shows the example of schematic diagram for providing exercises.

The model of stability calculation of a ship has been made in the Construction and Propulsion Institute of The naval University of Gdynia. There were done stability calculations in the case of the damaged watertight compartment or compartments, and what is more the computer programmes and calculations of the volume of displacement and coordinates of centre of buoyancy. For the
calculation authors have used numerical methods of calculation of the area and moments of plane figures. It was used for calculations of the amount of water in an optional watertight compartment as well as after damage of two optional compartments which are adherent to each other. The calculations of increase of draught using curves of the volume of displacement and curve of mass of water filling watertight compartment has been carried out. In order to work out changing of draught, metacentric height $GM$, angles of heel, angles of trim which might occur during particular phases of flooding of the watertight compartment, computer program and calculations have been made. Furthermore, the constant displacement method and the method of established volume have been employed.

2 Calculations of stability during flooding of the watertight compartment

Within the realization of the problem there has been calculated stability during particular phases of flooding of the bigger watertight compartment chosen near midship section for the worst stability reasons state of loading, which is shown by figure 2.

![Schematic picture of flooding of the watertight compartment in the chosen state of loading of a ship](image-url)

**Figure 2.** Schematic picture of flooding of the watertight compartment in the chosen state of loading of a ship
After selection of the watertight compartment which has been damaged the waterline sections for growing height of water in the compartment have been provided. For each of this case there have been calculated the volume of flooding of a part of the compartment, coordinates of geometrical centre of the flooded part of the compartment: \( x_g, z_g \), and volume and amount of water in the compartment. The calculations were supported by computer programme, which were prepared at the Naval University of Gdynia for calculating the volume of displacement and coordinates centre of buoyancy of a chosen ship type and to estimating amount of water in optional damaged watertight compartment \([5,10]\). The problem has been solved for cases in which the level of the water in damaged compartment maintains on the level of the sea water, and the bulkheads are situated between distance \( x_r \) and \( x_d \) from midship section:

where:
\( x_r \) – length of stern bulkhead from midship section;
\( x_d \) – length of bow bulkhead from midship section;

The example of integral curves of areas of section lines and the watertight compartment damaged in the midship section is shown by fig.3.

![Integral curves of areas of section lines of the damaged compartment](image)

Figure 3. Visualisation of integral curves of areas of section lines of the damaged compartment between frames 35 – 50.

In the subsequent stages transverse moment of inertia of waterline of the compartment \( I_{bt} \), moment of free surface of liquid in the compartment, weight of the ship after flooding of the watertight compartment a new fore and aft draughts and metacentric height \( G_upMu \) have been calculated. In the work, however angles of heel have not been taken into consideration, because flooding of the watertight compartment has been damaged symmetrically. For determination of the final state of flooding of the compartment for each waterlines sections mentioned there has been computed the mean draught on the level of the centre.
of gravity of the water in the damaged compartment $T_w$. Next the level of the water in the compartment, at which the level of sea water is equal to the final state of flooding of the watertight compartment has been calculated. During the flooding of the compartment curves in function of the level of water in the compartment have been determined as follows:

- metacentric height $G_{up}Mu$;
- height of centre of gravity of water $z_g$ and its distance from plane one of bulkhead $x_g'$;
- amount of water in the compartment $p$.

The results of calculations and their visualisation are presented by Table 1 and fig.4.

Table 1. The results of calculations basic stability parameters during flooding of the watertight compartment.

<table>
<thead>
<tr>
<th>$t_{prz}$ [m]</th>
<th>$p$ [t]</th>
<th>$Z_g$ [m]</th>
<th>$G_{up}Mu$ [m]</th>
<th>$T_w$ [m]</th>
<th>$x_g'$ [m]</th>
<th>$T_{du}$ [m]</th>
<th>$T_{ru}$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.5730</td>
<td>3.575</td>
<td>-4.700</td>
<td>3.510</td>
<td>3.641</td>
</tr>
<tr>
<td>0.250</td>
<td>12.058</td>
<td>0.125</td>
<td>0.3738</td>
<td>3.600</td>
<td>-4.660</td>
<td>3.512</td>
<td>3.667</td>
</tr>
<tr>
<td>0.500</td>
<td>22.540</td>
<td>0.250</td>
<td>0.3940</td>
<td>3.610</td>
<td>-4.650</td>
<td>3.520</td>
<td>3.692</td>
</tr>
<tr>
<td>1.000</td>
<td>61.600</td>
<td>0.500</td>
<td>0.1880</td>
<td>3.700</td>
<td>-4.590</td>
<td>3.550</td>
<td>3.800</td>
</tr>
<tr>
<td>1.500</td>
<td>103.103</td>
<td>0.750</td>
<td>0.2020</td>
<td>3.770</td>
<td>-4.540</td>
<td>3.660</td>
<td>3.890</td>
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<tr>
<td>2.000</td>
<td>153.777</td>
<td>1.000</td>
<td>0.1820</td>
<td>3.860</td>
<td>-4.520</td>
<td>3.620</td>
<td>4.030</td>
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<td>2.500</td>
<td>199.240</td>
<td>1.250</td>
<td>0.1990</td>
<td>3.930</td>
<td>-4.507</td>
<td>3.685</td>
<td>4.130</td>
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<tr>
<td>3.000</td>
<td>246.070</td>
<td>1.500</td>
<td>0.2260</td>
<td>4.040</td>
<td>-4.503</td>
<td>3.696</td>
<td>4.278</td>
</tr>
<tr>
<td>3.500</td>
<td>293.400</td>
<td>1.930</td>
<td>0.2000</td>
<td>4.133</td>
<td>-4.562</td>
<td>3.737</td>
<td>4.398</td>
</tr>
<tr>
<td>4.000</td>
<td>345.190</td>
<td>2.000</td>
<td>0.2540</td>
<td>4.210</td>
<td>-4.502</td>
<td>3.777</td>
<td>4.520</td>
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<tr>
<td>4.500</td>
<td>389.700</td>
<td>2.400</td>
<td>0.1900</td>
<td>4.320</td>
<td>-4.510</td>
<td>3.810</td>
<td>4.640</td>
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<tr>
<td>5.000</td>
<td>440.600</td>
<td>2.500</td>
<td>0.2376</td>
<td>4.400</td>
<td>-4.500</td>
<td>3.840</td>
<td>4.780</td>
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</tbody>
</table>

Fig.4. Diagram of determined level of the water in the compartment at which the level of sea water is remains.
After completing these calculations, it was assumed, that the flooded compartment had direct connection with the sea water and the level of water in the compartment was placed at the same level as the level of sea water. Calculations have been done by means of constant displacement method and using theoretical lines of the chosen ship and its hydrostatic curves. The fore and aft draught, metacentric height have been calculated and the results received by constant displacement method are shown by table 2.

Table 2. The results of calculations of basic stability parameters using constant displacement method

<table>
<thead>
<tr>
<th>Lp</th>
<th>Calculated state</th>
<th>$\Delta Tn$</th>
<th>GM0</th>
<th>GMb</th>
<th>$\varphi$</th>
<th>$\psi$</th>
<th>$T_{du}$</th>
<th>$T_{nu}$</th>
<th>$T_{tr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Damaged watertight compartment between frames 35–50</td>
<td>0.75</td>
<td>0.202</td>
<td>88.77</td>
<td>0</td>
<td>0°50'</td>
<td>3.78</td>
<td>4.76</td>
<td>4.27</td>
</tr>
</tbody>
</table>

For the time being on the basic of the theoretical lines there has been prepared (to practical application) three dimensional geometry of construction of a chosen real ship type with the aid of professional CAD programmes which can improve accuracy of calculations of stability of a ship in damage condition and survivability of a ship. Furthermore, it can be helpful in comparing the results of calculations with those received at the first approximation.

3 Conclusions

The presented method of ship stability calculations in the case of flooding of the watertight compartment and its computer visualisation allows for carrying out preliminary analysis in convenient way, without making time-consuming calculations. The results of the work converge with these in ship’s documentation of this kind of ship.

The authors of the work treated these calculations (or results of calculations) as a first approximation based on approximated formulas [1,3,8]. Soon there will be made accuracy calculations of buoyancy and coordinates centre of buoyancy, additional geometrical characteristic buoyancy and area of floatation. It would provide for stating precisely subsequent approximation of calculations, which would increase accuracy of the applied method. In order to check, whether after flooding of compartment stability requirements are fulfilled, curves of heeling moment of damaged ship will be executed and in this case coordinates centre of buoyancy (longitudinal and vertical position centre of buoyancy) of undamaged ship, with trim and coordinates centre of gravity of water in the damaged compartment will be computed according to e.g. Wlasow method. The next stage will be calculations of righting arms for particular angles of heel and adequate moments. This subject will cover the next work. The results of the work might be used in educational training and exercises on the ready for
practical application training simulator for water fighting, as an aid to functional persons on ships in fighting for keeping up stability and survivability of a ship.

References
