Changing stability of the ship while flooding compartments in the aspect of the maritime transport safety

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Abstract: - The paper contains the computational stability issues after flooded ship's compartment. Watercrafts, especially warships, due to the tasks they perform, are exposed to fires. The main extinguishing agent used on ships is usually seawater, which in large quantities poses a threat to the ship's stability and subdivision. During the putting out of marine fires the ship's compartments are flooded with this extinguishing agent. A free surface effect appears after a partial submersion of the compartment. It has influence on the deterioration of the stability of the entire ship and in particular cases may lead to its sinking. The threat to the ship's stability is influenced by the flooding of high located compartments. Therefore, the main focus of the work was to determine the impact of the high-located ship compartment on the boat deck for the stability of the ship. The method of assumed mass and the algorithm of calculating the righting levers with respect to the free surface effect were used for the determination of stability parameters. The results of the calculations presented in the paper contain information about the amount of water in the range causing deterioration of the stability of the ship. The usefulness of the presented method is based on a quick assessment of stability while course of extinguishing and thus affects the safety of the ship. Usually, during the firefighting, the ship's crew is focused on extinguishing a fire, not on assessing the stability of a ship. Based on the results of the graphical calculations, appropriate conclusions were done.

Keywords: ship stability, angle of heel, safety of warship

1 Introduction

Increase in migration of people and in trade by sea have contributed to substantial increase in traffic on sea lanes and progress in technology has made it possible to build ships having big displacement. More than 80% of the world trade makes use of maritime transport, which has become one of the pillars of international trade. Apart from many advantages, this has created several hazards to safety in maritime transport and to natural environment.

Special role, having impact on maritime safety, is played by naval ships. Due to the nature of missions they carry out they are exposed to damage, fires and even sinking. A naval ship is a complex technical system whose combat capability depends on her reliability. The analysis of literature and maritime practice shows that even the best organized naval fleets suffer from accidents and ship malfunctions. They can be hazardous to lives and health of a ship crew or result in the ship's total loss.

Fire presents serious hazard to a ship when at sea. It results in her sinking rarely, however the left devastation is usually very serious and, as ever, depending on the level of the crew training in respect to the damage control plan. During peaceful operation of the combat vessel, short-circuits in electrical installations, failures of devices and mechanisms, self ignition of pure oxygen when contacted with petroleum materials and so on make most sources of fires. Seawater is usually the main extinguishing agent used on ships and high volumes of the water are hazardous to the vessel stability and subdivision. Therefore, in the paper, the main emphasis has been made on defining the impact of high located and flooded compartments on the ship stability safety. Results of calculations presented in the elaboration contain information regarding volumes of water in the compartments causing deterioration of the ship stability.

2 Defining stability parameters of the ship

For Water broken into the vessel's hull and the flooded compartment or tank result in deeper draught of the ship, possible heel and trim as well as a change in her stability. The change may improve or aggravate operational conditions of the boat. In some case, lower stability may be serious enough to endanger safety of the ship and her crew as well as it may cause overturning of the vessel. To avoid accidents of such a kind, it is necessary to check stability of the damaged ship and apply appropriate remedial measures that would stop its lessening.

Flooding of high situated compartment or several compartments always results in aggravation of the vessel's stability. As a consequence, a heel or trim of the ship, change in the metacentric height and the righting levers may occur.

A vessel of standard displacement D for which a mass m is loaded in the point A (X, Y, Z) as in the Figure 1 [1,2,3] has been taken into consideration in the stability calculations.

At the beginning, acceptance of the mass was assumed so that to have its centre vertically above the centre of water-plane section's surface WO in the point A_1 (X_S, 0, Z). For this cause the draught increase and the new transverse metacentric height were calculated [1,2,3].

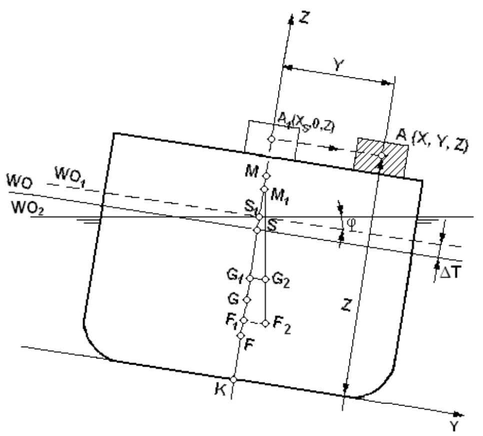

Figure 1. Scheme of the ship situation after acceptance of the mass m in the point A [1,2,3]

In the next step, the mass was moved from the imaginary position onto the place occupied in reality:

- towards the transverse direction by a distance of

$$e = Y\text{-}Y_1 = Y\text{-}0 = Y,$$

- towards the longitudinal direction by a distance of

$$l = x\text{-}x_S.$$

Than, the angle of heel, the angle of trim and the new bow and stern draughts of the ship has been calculated.

For large angles of heel (above 7°), the ship stability is defined based on the righting lever curves (Reed's curve). This curve allows determining dimensions of the righting lever for any angle of heel of the given ship, at invariable displacement and position of the gravity centre.

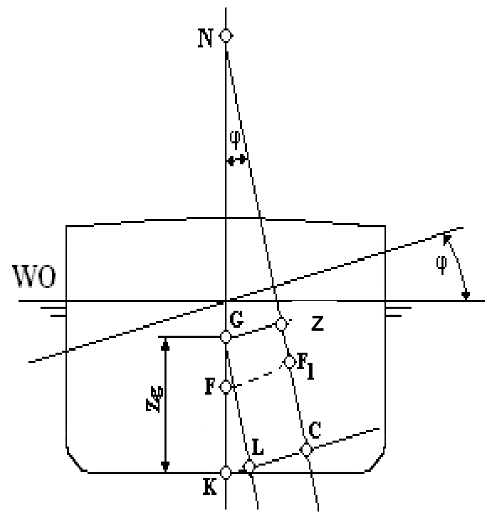

Figure 2. Righting lever of the form and weight [3,12,13]

Value of the righting lever $\overline{GZ}$ is determined with the following formula applied [3, 12, 13]:

$$\overline{GZ} = \overline{KC} - \overline{KL} \qquad (1)$$

where:

$$\overline{KL} = Z_g \sin\varphi \qquad (2)$$

Z_g – the gravity centre height [m],

$\overline{KL}$ – the weight stability lever [m],

$\overline{KC}$ – the form stability lever [m].

The formula (1) may be presented in the following way:

$$\overline{GZ} = \overline{KC} - Z_g \sin\varphi \qquad (3)$$

For the determination of the righting lever for any angle of heel it is necessary to know the form stability lever that changes depending on the angle of heel. This value is read from the so-called Pantecaren graph, which is developed during the design phase of the ship.

Reed's curve which is a graph of righting levers provides information about the basic parameters of the stability of the ship, such as:

φ GZmax – heeling angle at the maximum value of the righting lever occurs [deg],

GZmax – the maximum righting lever [m],

φr – the angle of vanishing stability [deg],

GM – the metacentric height [m].

3 Impact of free surface on the ship stability

Presence of fluid free surface after partial flooding of compartment always results in reduction of the vessel's metacentric height. This decrease depends, among the others, on the shape and magnitude of this surface.

Receipt of liquid cargo on board of a ship, accompanied by occurrence of the free surface, has influence on change of position of the vessel gravity centre and thus on the metacentric height $\overline{GM}$. Hence usage of, for instance, larger quantities of water for fire-fighting purposes on upper decks results in shifting the boat's gravity centre up, and – if connected with occurrence of free surfaces – it may cause the loss of stability and overturning of the ship.

Impact of inertia moment derived from the free surface of the flooded compartment has been taken into account in the calculations of the metacentric height. It has been assumed that surface of the compartment under flooding is rectangular. The moments of inertia of the permanent constructional elements present in the compartment have been taken into consideration in calculations regarding the inertia moment of the entire body.

Influence of the free surface effect on the righting levers' curve (the Reed's curve) has been taken into account by implementing an allowance marked with an X symbol [1,2,3].

$$X = \left[y_{G1}(\varphi)\cos\varphi + z_{G1}(\varphi)\sin\varphi\right] \quad (4)$$

where:

$y_{G1}(\varphi)$ and $Z_{G1}(\varphi)$ – constituents of shift of the vessel's mass centre, at the heel to the angle φ[m],

$$y_{G1}(\varphi) = \frac{\sum_{i=1}^{n} m_i \left[y_g(\varphi)\right]_i}{D} \quad (5)$$

$$z_{G1}(\varphi) = \frac{\sum_{i=1}^{n} m_i \left[z_g(\varphi)\right]_i}{D} \quad (6)$$

D – ship displacement together with liquid cargo [t],

m_i –mass of the liquid cargos in particular tanks [t],

$[y_g(\varphi)]_i$ and $[z_g(\varphi)]_i$ – constituents of shifts of the fluid gravity centres in the flooded compartments at the heel to the angle φ [m] [10].

These parameters have been calculated with a used of an elaborated computer programme. This software is adapted to calculate stability parameters for a floating structure of rectangular shape.

After defining the allowance from the free surface effect, the new GM is:

$$GM = G_1M_1 - X \quad (7)$$

Where:

GM – the metacentric height [m].

Based on the formula 7, the calculations and analyses of the vessel's metacentric height after flooding the ship compartment have been made.

3 Characteristics of the research object

The training vessel selected for the tests is a flagship of the training and research ships' wing of our fleet. This ship operates on different seas in hazard, changeable weather conditions where is the high propability it's damage. The analysis of damage stability after flooding high located compartments is necessary for the maritime transport safety. The boat is divided, with ten transverse watertight bulkheads, into 11 watertight compartments located on the frames: 3, 16, 25, 35, 50, 60, 71, 80, 91 and 101. Such division ensures maintenance of unsinkability when two neighbouring compartments have been flooded, excluding main engine room and adjoining compartment.

General characteristics of the vessel:

- main dimensions:
  - overall length: L_c = 72,20 m,
  - length between perpendiculars: L_{pp} = L = 64,20 m,
  - maximal breath: B_{max} = 12,00 m,
  - breath: B = 11,60 m,
  - height: H = 5,55 m.

The calculations have been made for load displacement and no icing. These conditions are characterized by the following quantities:

- displacement: D = 1745,34 t,
- ordinate of the mass centre from the main plane: z_G = 4,31 m,
- stern draft: T_R = 3,97 m,
- bow draft: T_D = 4,05 m,
- average draft: $T_{śr}$ = 4,01 m,
- trim: t = 0,08 m,
- metacentr height from the base plane: z_M = 5,44 m,
- metacentric height: GM = 1,13 m,
- speed: V =16,8 w
- coordinates of the mass centre:
  - x_G = 29,649 m from the after perpendicular,

- y_G = -0,007 m from the plane of symmetry,
- z_G = 4,314 m from the base plane [1].

Figure 3. Picture of the training vessel [9]

4 Results of calculation the vessel stability with flooded compartment

The ship's stability calculations have been performed for two high altitude, flooded ship compartments. The first one was located at a height of 8,1m from the base plane. This range of dimensions: beam 8.67 m and a length of 36,78 m have the surface area, taking into account its equipment, equal to 188.5 m^2. The second compartment dimensions: beam 8.64 m and a length of 19,49 m was at a height of 10.2 m from the base plane. This compartment had a surface area, taking into account its equipment, even 147,6m^2. Both compartments during tests poured into previously established water height H = 0.1 m, H = 0.4 m, and H = 0.8 m. Stability calculation were conducted for both parameters: metacentric height and righting levers assuming flooding of compartments to the same water level H.

The results of the calculations of matacentric height and maximum values of righting levers taking into account the free surface effect of the considered amount of water in the range shown in the table 1 and Figure 4 and 5 *[7,8,9]*.

Table 1: Result of matacentric height calculation

H [m]	**0,1**	**0,4**	**0,8**
GM [m]	1,01115	0,7274	0,6587
G_1M_1 [m]	-0,2251	-0,4577	-0,4632

Table 1 presents the results of the metacentric height calculations before (GM) and after taking into account the free surface effect (G1M1) for the considered water level in the compartments.

A negative value of the metacentric height is already present when the compartments are flooded to a height of H = 0.1 m.

The dependence of the metacentric height GM and G_1M_1 on the water level inside a flooded compartments shows Figure 5.6.

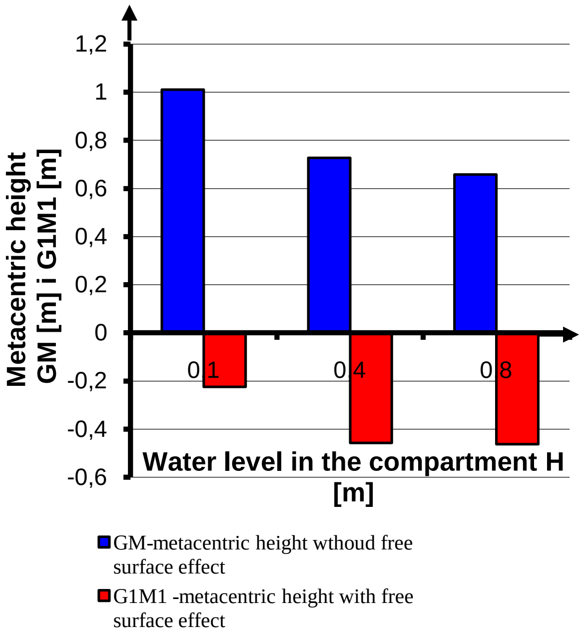

Figure 4. Result of metacentric height calculation depending on the water level inside a compartment [9]

The figure above shows that with the increase of the water level H in the compartments, the value of the metacentric height G_1M_1 decreases.

Figure 5 presents changes of righting levers (Reed's curve) as a function of the angle of heel of the ship for selected water levels in the flooded ship compartments.

The analysis of the results of righting lever calculations presented in the Figure 5 shows a clear decline in the value of the maximum righting lever depending on the water level in the flooded ship compartments. For the amount of water in the compartment H = 0.1 m the maximum righting lever had value GZ = 0.91 m. However, after increasing the level of water in the compartment to H = 0.8 m the maximum righting lever significantly reduced until the value to 0.04 m.

The angles of steady heel of the ship, resulting from flooding of the vessel compartment under discussion, amount respectively: φ_{S1} = 12° for the water level in the compartment equal H = 0,4 m and φ_{S2} = 40° for H= 0,8 m. The metacentric heights for these cases display negative values. But for the amount of water in the compartments H = 0.8 m the angle of vanishing stability reduced from approx. φr = 100° to approx. φr = 60 °.

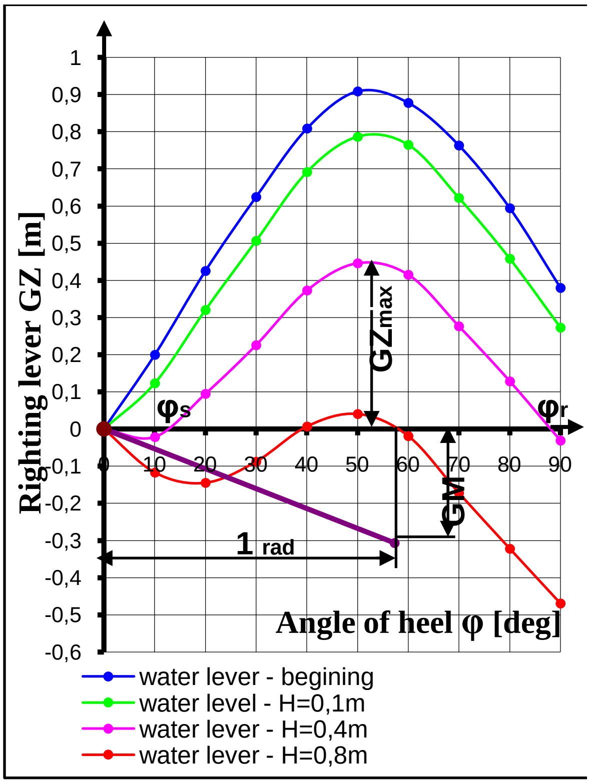

Figure 5. Influence of the amount of water in the compartment on the Reed's curve

5 Conclusion

As a result of analysis of the ship's stability after flooding a high situated compartments provides the following conclusions:

Flooding of high located compartments results in:

- a reduction in a value of metacentric height,
- a reduction in a value of righting levers,
- a reduction in the angle of vanishing stability φr,
- an increase in a value of steady heel angle φ_S.

The analysis of changes in the stability of the ship shows, that the worst option is the simultaneous flooding of two compartments have to height H = 0.4 m. It causes a loss of initial stability of the ship. The recovery of stability followed by an inclination of the ship equal φs = 12 °.

At the lower level of the water in the ship's compartments retains a positive initial stability.

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