

# Influence of flooding boat deck ship compartment on the changing of a righting lever as a sea safety

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*Abstract:* - The paper contains the computational stability issues with high flooded ship compartment on the boat deck. Defined righting lever calculation algorithm with the free surface effect after flooding high located ship compartments was taking into account. Based on results of the calculations presented in the graphical form suitable conclusions were done.

*Key-Words:* - ship stability, angle of heel, safety of warship

## 1 Introduction

As Ship is a compound technical system operated intensively in particular during military activities. Her combat abilities depend, first of all, on munitions with which the vessel is equipped and on the remaining technical measures ensuring her way [5]. Damages caused to those measures result in deterioration of the boat military capabilities and they may be followed by various reasons. 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 compartment causing deterioration of the ship stability.

## 2 Research object characteristics

The training vessel selected for the tests is a flagship of the training and research ships' wing of our fleet. The said 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. Analysis of the damage stability after flooding high located compartments has been justified because the ship sails in different sea waters, so in various and dangerous weather conditions where the risk of damages is high. 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.



Fig. 1. Picture of the training vessel [9]

These conditions are characterized by the following quantities:

- displacement:  
 $D = 1745,34 \text{ t}$ ,
- ordinate of the mass centre from the main plane:  
 $z_G = 4,31 \text{ m}$ ,
- stern draft:  
 $T_R = 3,97 \text{ m}$ ,
- bow draft :  
 $T_D = 4,05 \text{ m}$ ,
- average draft:  
 $T_{sr} = 4,01 \text{ m}$ ,
- trim:  
 $t = 0,08 \text{ m}$ ,
- metacentr height from the main plane:  
 $z_M = 5,44 \text{ m}$ ,
- metacentric height:  
 $GM = 1,13 \text{ m}$ ,
- speed:  
 $V = 16,8 \text{ w}$
- coordinates of the mass centre:
  - $x_G = 29,649 \text{ m}$  from the after perpendicular,
  - $y_G = -0,007 \text{ m}$  from the plane of symmetry,
  - $z_G = 4,314 \text{ m}$  from the main plane [9].

### 3 Defining the metacentric height and the righting levers of the ship

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 2 [1,2,3] has been taken into consideration in the stability calculations.

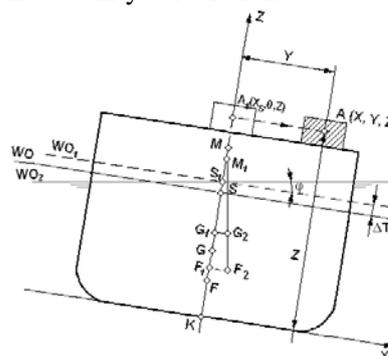


Fig. 2. Scheme of the ship situation after acceptance of the mass  $m$  in the point  $A$  [1,2,3]

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  $A_1 (X_S, 0, Z)$ . Then, it is possible to calculate [1,2,3]:

- the draught increase, as per the formula:

$$\Delta T = \frac{m}{\rho F_{WO}} \tag{1}$$

- the new transverse metacentric height, as per the formula:

$$\overline{G_1 M_1} = \overline{GM} + \frac{m}{D+m} \left( T + \frac{\Delta T}{2} - Z - \overline{GM} \right) \tag{2}$$

- the new longitudinal metacentric height, as per the formula:

$$\overline{G_1 M_{L1}} = \frac{m}{D+m} \overline{GM_L} \tag{3}$$

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  $e = Y - Y_l = Y - 0 = Y$ ,
- towards the transverse direction by a distance of  $l = X - X_s$ .

The angle of heel of the ship has been calculated with the below formula:

$$tg\varphi = \frac{mY}{(D+m)\overline{GM}_1} \quad (4)$$

and the trim of the vessel from:

$$tg\Psi = \frac{m(X - X_s)}{DGM_L} \quad (5)$$

The new draughts of the bow and stern are defined from the following equations:

$$T_{d1} = T_d + \Delta T + \Delta T_d \quad (6)$$

$$T_{r1} = T_r + \Delta T + \Delta T_r \quad (7)$$

The final results are as follows:

$$T_{d1} = T_d + \frac{m}{\rho F_{wo}} + \left(\frac{L}{2} - X_s\right) \frac{m(X - X_s)}{DGM_L} \quad (8)$$

$$T_{r1} = T_r + \frac{m}{\rho F_{wo}} + \left(-\frac{L}{2} - X_s\right) \frac{m(X - X_s)}{DGM_L} \quad (9)$$

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 mass centre.

Value of the righting lever  $\overline{GH}$  is determined with the following formula applied [14]:

$$\overline{GH} = \overline{KC} - \overline{KL} \quad (10)$$

where:

$$\overline{KL} = Z_g \sin\varphi \quad (11)$$

- $Z_g$  – the mass centre height [m],
- $\overline{KL}$  – the weight stability lever [m],
- $\overline{KC}$  – the form stability lever [m].

$$e = Y - Y_l = Y - 0 = Y$$

$$l = X -$$

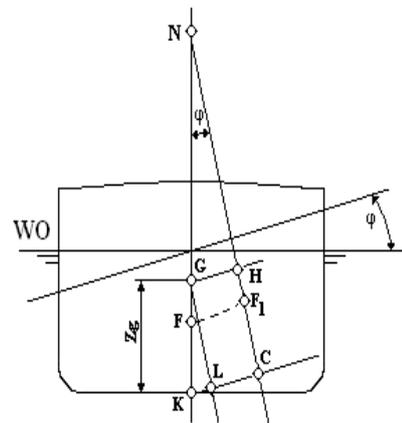


Fig. 3. Righting lever of the shape and mass [1]

The formula (10) may be presented in the following way:

$$\overline{GH} = \overline{KC} - Z_g \sin\varphi \quad (12)$$

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:

- $\varphi_{Gzmax}$  – heeling angle at the maximum value of the righting lever occurs [deg],
- $GZ_{max}$  – the maximum righting lever [m],
- $\varphi_r$  – the angle of vanishing stability [deg],
- $GM$  – the metacentric height [m].

#### 4 Free surface effect

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

$$X = [y_{G1}(\varphi)\cos\varphi + z_{G1}(\varphi)\sin\varphi] \tag{13}$$

where:

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

$$y_{G1}(\varphi) = \frac{\sum_{i=1}^n m_i [y_g(\varphi)]_i}{D} \tag{14}$$

$$z_{G1}(\varphi) = \frac{\sum_{i=1}^n m_i [z_g(\varphi)]_i}{D} \tag{15}$$

$D$  – 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 mass centres in the flooded compartments at the heel to the angle  $\varphi$  [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 fluid free surface, the new GM is:

$$GM = G_1M_1 - X \tag{16}$$

Based on the formula 16, the calculations and analyses of the vessel's metacentric height after flooding the ship compartment have been made.

### 5 Results of the vessel stability with a ship compartment flooded

The calculations have been made for a compartment located at the height of 8,10 m from the main plane.

This compartment, of the dimensions: width 8,67 m and length 36,78 m, is represented by a plane surface, after considering its equipment, equal 188,5 m<sup>2</sup>. It was undergone flooding up to the water height H previously assumed.

The results of the righting levers calculations, with the free surface effect, for the considered water heights in the compartment, was taken into consideration. A course of changes of the righting levers' curve (the Reed's curve) versus the heel angle of the ship is presented in the Figure 4. The angles of steady heel of the ship, resulting from flooding of the vessel compartment under discussion, amount respectively:  $\varphi_{S1} = 12^\circ$  for the water level in the compartment equal  $H = 1,0$  m and  $\varphi_{S2} = 18^\circ$  for  $H = 1,6$  m. The metacentric heights for these cases display negative values.

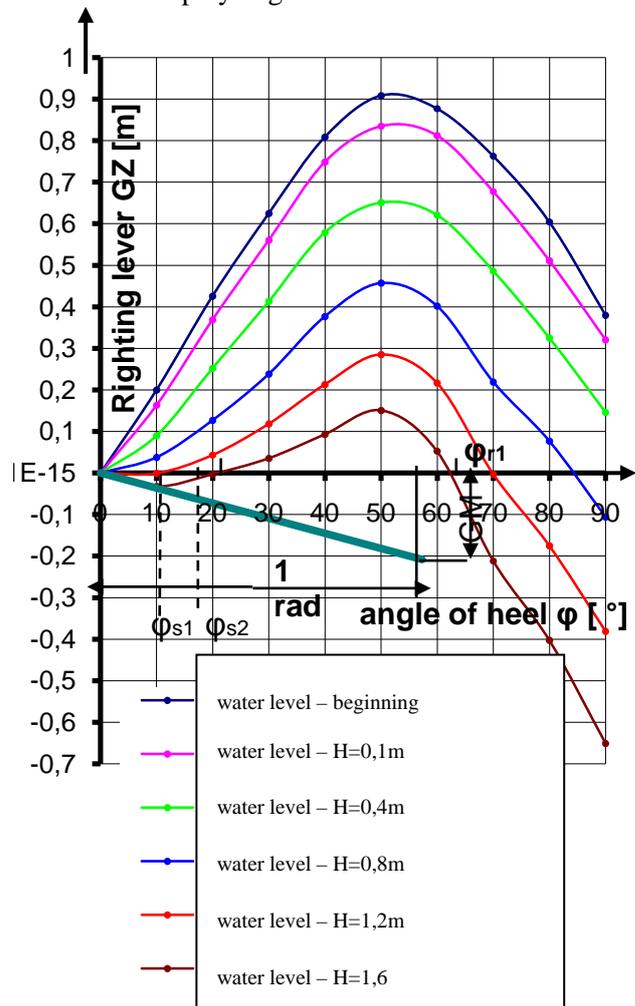


Fig. 4. Influence of the amount of water in the compartment on the Reed's curve

For the amount of water in the compartments  $H = 1.6$  m angle range of righting lever reduced from approx.  $\varphi_r = 100^\circ$  to approx.  $\varphi_r = 60^\circ$ .

## 4 Conclusion

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

Flooding of high located compartment results in:

- a reduction in a value of metacentric height,
- a reduction in a value of righting levers,
- a reduction in the angle range righting lever  $\varphi_r$ ,
- an increase in a value of steady heel angle  $\varphi_s$ .

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  $H = 1.2$  m. It causes a loss of initial stability of the ship. The recovery of stability followed by an inclination of the ship equal  $\varphi_s = 12^\circ$ .

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