INFLUENCE OF FLOODING BOAT DECK COMPARTMENT ON THE SHIP'S SAFETY

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Abstract

At any time whether during combat or non-combat, naval ships are susceptible to damage. During combat, navy ships are susceptible to suffer damage to a particular degree on its hull, armament or even its technical equipment. The damages occur at specific places on the ship and are of specific nature. A navy ship can suffer damage from torpedoes and mine explosions, impact resulting from artillery shells, missiles or airborne bombs or even due to effects from weapons of mass destruction. This damage results in flooding of the affected areas. During the ship's operation at sea a significant threat to its safety is fire. Although fire rarely causes the ship to sink, the damage that it leaves is usually very serious, though the extent of the damage depends on the level of crew training in the area of emergency response[1]. The main extinguishing agent used on ships is usually sea water, which in large quantities poses a threat to the safety of the ship. It affects changes in the stability and position of the ship. Determination of these changes is the basis for the sub-capacity calculations related to the operation of a damaged ship. Therefore, the main focus of the work was to determine the impact of flooding of high-located compartments on the safety of a ship[2]. The results of the calculations presented in the paper include information about the amount of water in the range causing deterioration of the stability of the ship..

1 INTRODUCTION

Any occurrence of a ship accident is a nightmare to many sea crews and seafarers. Marine accidents affect not only humans but also the properties and activities onboard the ship, functionality of ashore as well as the marine environment. These accidents are not only limited to navy ships but also cargo, fishing, and cruise ships to. Over the past decades, various navy ships have experienced various accidents, some of which have been minor while others have been fatal. Some of these accidents have led to some navy ships sinking while others have been grounded for many years before being reintroduced or replaced with new ones[3,4].
Each warship 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's military capabilities and they may be followed by various reasons. Events causing damages to the ship, as to a technical system[6], are presented in Figure 1. Fire presents a serious hazard to a ship when at sea. It rarely results in her sinking, but the destruction it may leave behind is usually very serious though as always, this depends 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 are the most common causes of fires. Seawater is usually the main extinguishing agent used on ships, but high volumes of the water are hazardous to the vessel's 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 contain information regarding volumes of water in the compartment causing deterioration of the ship's stability.

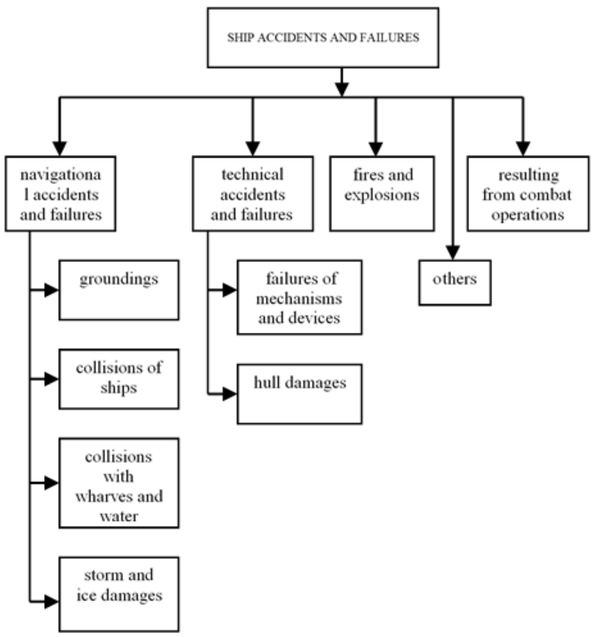

Fig. 1 Break-down of ship accidents and failures [4,6]

2 CHARACTERISTICS OF RESEARCH OBJECT

The training vessel selected for the tests is a flagship of the training and research ships 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[8]. Such division ensures maintenance of unsinkability when two neighbouring compartments have been flooded, excluding the main engine room and adjoining compartment. Analysis of the damage stability after flooding high located compartments can be justified by the fact that the ship operates in different sea waters, and therefore in various and dangerous weather conditions where the risk of damages is high. General characteristics of the vessel - main dimensions [8]:

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:	$H = 25{,}55$ 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,
- middle draft:	$T_{śr} = 4{,}01$ m,
- trim:	$t = 0{,}08$ m,

- metacentr height from the main plane: zM = 5,44 m,
- metacentric height: GM = 1,13 m,
- speed: V =16,8 w

-coordinates of the centre of gravity "G":

xG = 29,649 m distance from the after perpendicular,
yG = -0,007 m distance from the center plane,
zG = 4,314 m distance from the base plane [8].

Fig. 2 Picture of the training vessel

3 DEFINING THE METACENTRIC HEIGHT AND THE STATIC STABILITY CURVE 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 cases, lower stability may be serious enough to endanger the ship and her crew as well as potentially causing overturning of the vessel. To avoid accidents of this kind, it is necessary to check stability of the damaged ship and apply appropriate remedial measures that would stop its lessening.

Flooding of a high situated compartment or several compartments always results in aggravation of the vessel's stability. As a consequence, a trim or heel of the ship, change in the metacentric height and the static stability curve 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 3 [9, 10] has been taken into consideration in the stability calculations. The training vessel selected for the tests is a flagship of the training and research ships' wing of our fleet.

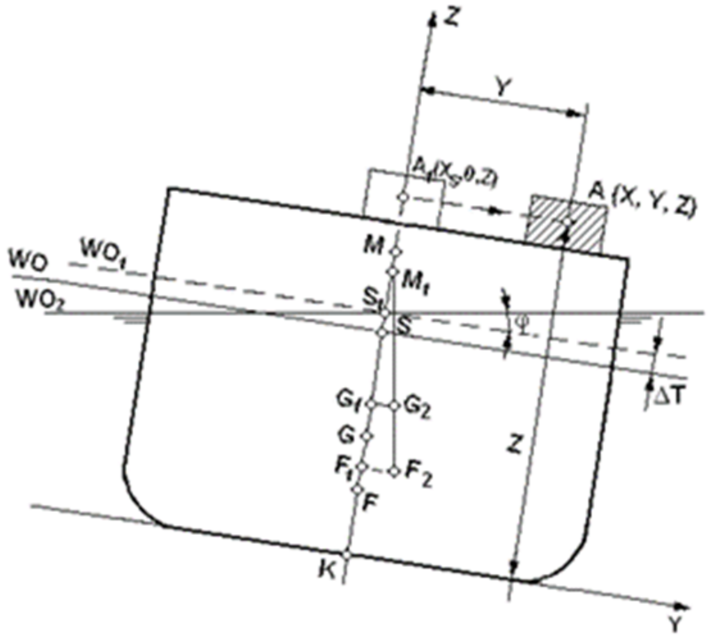

Fig. 3 Scheme of the ship situation after acceptance of the mass m in the point A [11]

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 A1 (Xs, 0, Z). Then, it is possible to calculate [10,11,12]:
- the draught increase, as per the formula:

the end of the table caption. Footnotes to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data) and included beneath the table body.

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

(1)

ρ – density of the sea water [t/m^3]
- the new transverse metacentric height, as per the formula:

$$\overline{G_1M_1} = \overline{GM} + \frac{m}{D+m}\left(T + \frac{\Delta T}{2} - Z - \overline{GM}\right)$$

(2)

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

$$\overline{G_1M_{L1}} = \frac{m}{D+m}\overline{GM_L}$$

(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-Y1 = Y-0 = Y,
- towards the transverse direction by a distance of l = X-XS,
  Where: Xs – centre of flatation.

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

$$tg\varphi = \frac{mY}{(D+m)\overline{G_1M_1}}$$

(4)

and the trim of the vessel from:

$$tg\Psi = \frac{m(X - X_S)}{D\overline{GM_L}}$$

(5)

The new draughts of the bow Td1 and stern Tr1 are defined from the following equations:

$$T_{d1} = T_d + \Delta T + \Delta T_d$$

(6)

$$T_{r1} = T_r + \Delta T + \Delta T_r$$

(7)

The final results are as follows:

$$T_{d1} = T_d + \frac{m}{\rho F_{WO}} + \left(\frac{L}{2} - X_S\right)\frac{m(X - X_S)}{D\overline{GM_L}}$$

(8)

$$T_{r1} = T_r + \frac{m}{\rho F_{WO}} + \left(-\frac{L}{2} - X_S\right)\frac{m(X - X_S)}{D\overline{GM_L}}$$

(9)

For large angles of heel (above 7°), the ship stability is defined based on the static stability curve (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 is determined with the following formula applied [13]:

$$\overline{GZ} = \overline{KC} - \overline{KL}$$

(10)
where:

$$\overline{KL} = Z_g \sin\varphi$$

(11)

Zg - the height of gravity centre [m],
$\overline{KL}$ - the weight stability lever [m],
$\overline{KC}$ - the form stability lever [m].

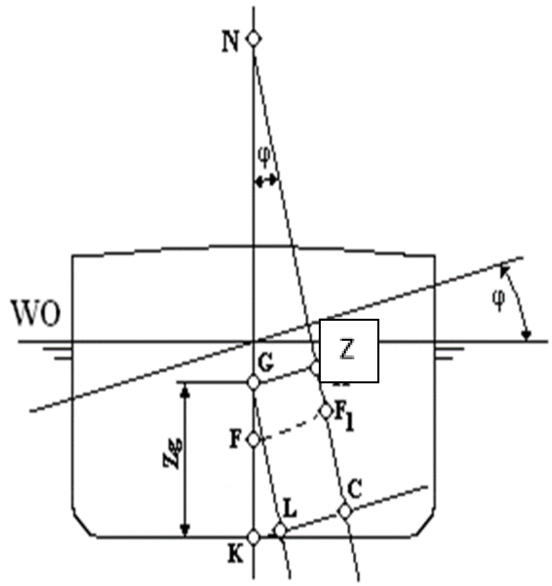

Fig. 4 Righting lever of the shape and mass [14]

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

$$\overline{GZ} = \overline{KC} - Z_g \sin\varphi \tag{12}$$

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 Cross curves of stability graph, which is developed during the design phase of the ship.
The static stability curve which is a graph of righting levers provides information about the basic parameters of the stability of the ship, such as:

φ GHmax - 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].

4 FREE SURFACE EFFECT

The presence of fluid free surface effect after the partial flooding of a compartment always results in a reduction of the vessel's metacentric height. This decrease depends, among other factors, 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 an influence on the change of position of the vessel centre of gravity and thus on the metacentric height and righting lever. Hence usage of, for instance, larger quantities of water for firefighting purposes on upper decks results in shifting the boat's centre of gravity up, and – if connected with occurrence of free surfaces – it may cause the loss of stability and overturning of the ship.
The 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 the 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.
Determining the influence of the free surface effect of the liquid on the ship's stability the ship has been tilted by an angle φ. The layout of the partially filled liquid tank with a specific density ρ1 and volume v is shown in Figure 5. The liquid mass in the tank is calculated [9,10,12]:

$$m = \rho_1 * v$$

(13)

At any angle of heel the liquid in the tank is poured overboard and its surface is parallel to the sea water, assuming the position of WO1. The center of liquid mass, which in the upright position of the ship was at the point g, will move to the point g1 as a result of the change in shape of the fluid filled volume. The shape of the tank in the transverse section of the ship resembles a cuboid. The center of fluid mass g moves over the circle with the center at the point n. So the distance can be expressed by an equation [10,12,14]:

$$\overline{gn} = \frac{i_b}{v}$$

(14)

where:

ib – interia moment of a free surface effect [m4],
v – volume of the liquid inside the tank [m3].

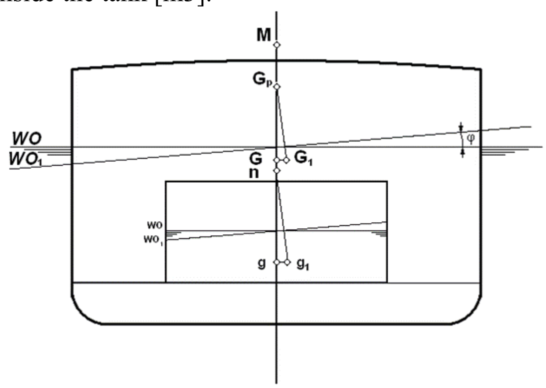

Fig. 5 Ship with free surface [13]

Because at low heel angles the direction of gravity of the liquid passes through the point n, so that the influence free surface effect of the liquid in the tank on the metacentric height of the ship will be identical to the effect that would induce the shift of the constant mass (equal to the weight of the liquid), whose center of gravity has gone from point g to point n. Actual movement the center mass of the fluid will cause a parallel displacement of the centre of gravity of the ship from point G to point G1, resulting in a reduction of the righting lever and thus a reduction in ship stability. The direction of gravity force in the tilt will thus pass through G1, crossing the symmetry plane of the ship at point Gp. For small angles of heel, the Gp point is constant. The reduction of the metacentric height due to the movement of the centre of gravity of the ship from point G to point G1 will be the same as the shift of centre of gravity to point Gp. For this reason, this point is called the apparent medium of mass. The apparent displacement of the centre of gravity of a ship from G to Gp is caused by the apparent center of mass displacement from g to point n. Therefore, the distance is calculated by the formula [10,12,13]:

$$\overline{GG_p} = \frac{\rho_1 * v}{\rho * V} * \overline{gn} = \frac{\rho_1 * v}{\rho * V} * \frac{i_b}{v} = \frac{\frac{\rho_1}{\rho} * i_b}{V}$$

(15)

where:
ρ1= density of the water inside the tank,
ρ = density of the sea water,
V= volume of ship displacement.

Since the arbitrary movement of the liquid mass is always vertically directed and directed upwards, it is accompanied by a decrease in the metacentric height [1,2,3]:

$$\overline{G_pM} = \overline{GM} - \overline{GG_p} = \overline{GM} - \frac{\frac{\rho_1}{\rho} * i_b}{V}$$

(16)

where:

$\overline{G_pM}$ – reduced matacentric height[m].

With bigger number of tanks not completely filled with liquids of different densities, the effect of free surfaces is summed up according to the formula:

$$\overline{G_pM} = \overline{GM} - \frac{\sum_{k=1}^{n} \frac{\rho_{pk}}{\rho} i_{bk}}{V}$$

(17)

where:

ibk – subsequent interia moments of a free surface effect [m4].

As can be seen from the above formulas, the presence of a free surface reduces the metacentric height of the ship, the reduction being dependent on the moments of inertia of the free surfaces.

Influence of the fluid free surface on the static stability curve (the Reed's curve) has been taken into account by implementing an allowance marked with an X symbol [10,12,13].

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

(18)

where:

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

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

(19)

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

(20)

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

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

$[y_g(\varphi)]_i$ and $[z_g(\varphi)]_i$ – coordinates 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 program. 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:

$$GM = G_1M_1 - X$$

(21)

Based on the formula 21, 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 FLOODED SHIP COMPARTMENT

The calculations have been made for a compartment located at the height of 8,12 m from the base plane. This compartment, of the dimensions: width 8,67 m and length 36,7 m, is represented by a plane surface, after considering its equipment, equal 188,6 m2. 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 static stability curve (the Reed's curve) versus the heel angle of the ship is presented in the Figure 6. The angles of steady heel of the ship, resulting from flooding of the vessel compartment under discussion, amount respectively: $\varphi S1 = 12°$ for the water level in the compartment equal H = 1,0 m and $\varphi S2 = 18°$ for H = 1,6 m. The metacentric heights for these cases display negative values.

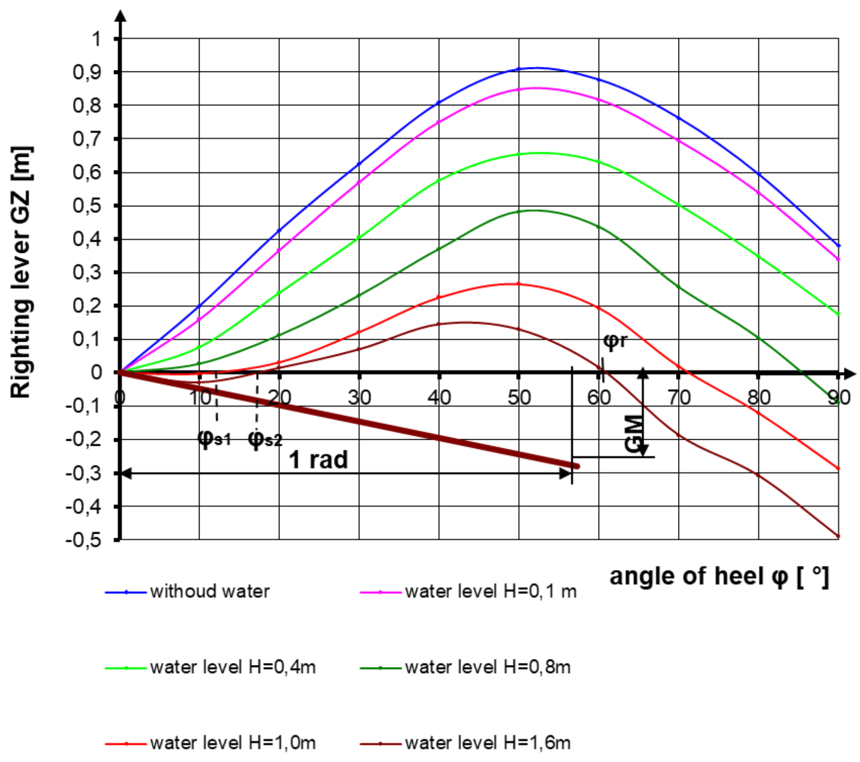

Fig.6 Influence of the amount of water in the compartment on the righting levers

The results of the calculations of matacentric height taking into account the free surface effect of the considered amount of water in the range shown in the table 1.

H [m]	**0,1**	**0,4**	**0,8**	**1**	**1,2**	**1,6**
GM [m]	1,071	0,916	0,716	0,629	0,530	0,353
G_1M_1 [m]	0,339	0,206	0,034	-0,041	-0,127	-0,281

Table 1: Result of the matacentric height calculation

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 compartment. A negative value of the metacentric height is already present when the compartment is flooded to a height of H = 1.0 m.
The dependence of the metacentric height GM and G1M1 on the water level inside a flooded compartment shows Figure 7.

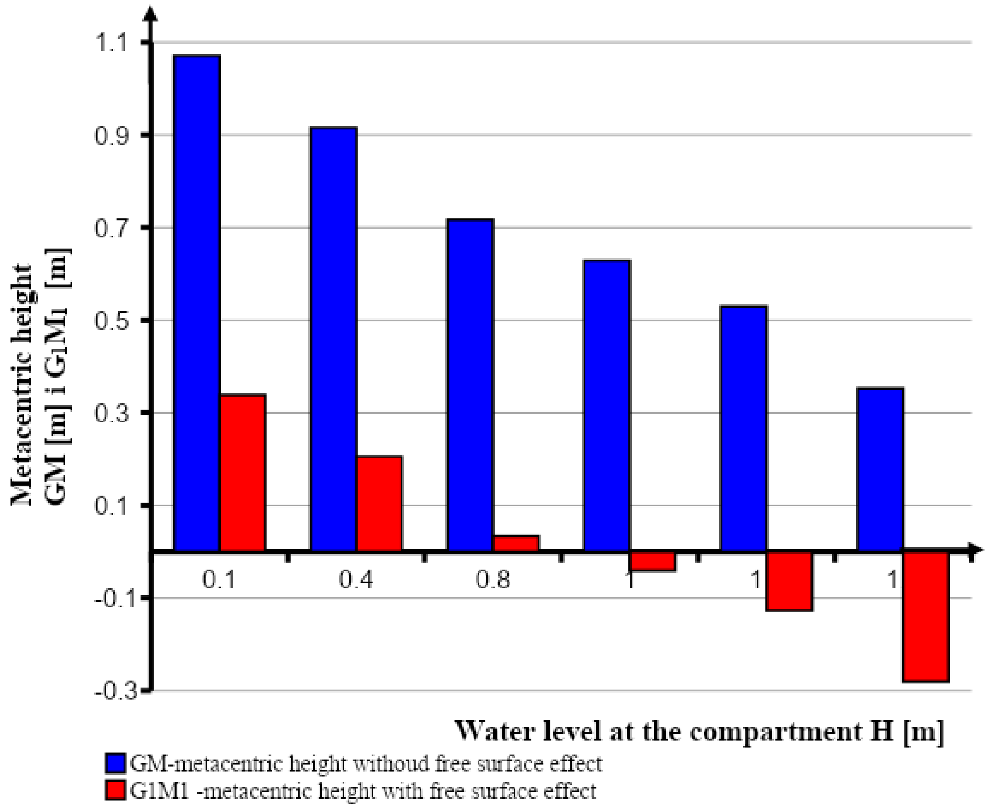

Fig. 7 Influence of the amount of water in the compartment on the metacentric height

The figure above shows that with the increase of the water level H in the compartment, the value of the metacentric height G1M1 is reduced.
Analysis of Fig. 6 shows clear variety values of the maximum righting levers depending on the water level in the flooded compartment. The values of righting levers show a decreasing tendency for an increasing water level in the compartment from GZ = 0.85 m for water level H = 0.1m to GZ = 0.15 m for water level H = 1.6m. Based on the worked up graph, it is possible to read the permissible value of the water level in the flooded compartment, which will reduce the righting lever to the minimum value required by the IMO (International Maritime Organization)[15], i.e. to GZ = 0.2 m. For the studied case, the water level in the range should not be greater than H = 1,0 m. A larger amount of water in the compartment may lead to the loss of stability of the ship and in a special situation it may even lead to the sinking of the ship.

6 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 φr,

- an increase in a value of steady heel angle φS.

The analysis of changes in the stability of the ship shows, that the worst option is the simultaneous flooding of the compartment have to height H = 1.0 m and more. It causes a loss of initial stability of the ship. The recovery of stability followed by an inclination of the ship equal φs = 12 °.

In a future work, I intend to analysis the stability of the ship after flooding several high located compartments.

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