The Evolution of the Formula for Estimating the Longitudinal Extent of Damage for the Hull of a Small Ship of the Transitional Mode

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SUMMARY

Old and new requirements of the High Speed Craft Code, and the methods of some researchers for calculating the damage length for a ship's hull, are considered in this article. Damage occurs more often in small vessels than in large vessels. Collisions between ships and ship's grounding are two of the main reasons for the loss of ships. The damage to the vessel is determined, for the worst case scenario. Long and narrow damage ("raking"), which absorbs the kinetic energy of the vessel, is the worst case scenario. Small high speed craft were selected for analysis. This article describes the requirements of the High Speed Craft Code related to high-speed vessels. Small vessels of the transitional mode are a category of high-speed vessels, as operated at relative velocities $1 \leq Fr_V \leq 3$, where $Fr_V = \frac{v}{\sqrt{g\sqrt[3]{V}}}$ - the Froude number based on volume. The formula for calculating the length of the possible damage of hull should take into account data on the material, the thickness of the plating, the width of the damage, the vessel's speed and its displacement. This paper proposes a comparative analysis of the size of the possible length of the hull damage, which has been calculated using different methods. The formula for calculating damages is proposed for small high speed vessels, but is possible to use this formula to other types of ships.

1. INTRODUCTION

Ships of the transitional mode belong to the category of high-speed vessels, because they are operated at relative velocities $1 \leq Fr_V \leq 3$. In the High Speed Craft Code 1994 [1]: "High speed craft" is defined as a craft capable of maximum speed (m/s) equal to or exceeding: $v_{max} \geq 3{,}7V^{0{,}1667}$, where V is the displacement corresponding to the design waterline (m^3). After the transformation of the Froude number, velocity is $v = 3{,}13Fr_V V^{0{,}1667}$. From this inequality and the equation, it can be concluded that the vessel is at high speed at $Fr_V \geq 1{,}18$. The term "small" ship of the transitional mode is defined in article [2] and in accordance with the data of this work such vessels have lengths less than 40 m and a displacement less than 190 t. These data were obtained on the basis of the requirements of the strength of the vessel, vertical accelerations, the optimal relative dimensions of the high-speed vessel and the comparison of two energies: the energy of the moving ship and the energy of the sea wave. The causes of the loss of ships remain steady over the years [3]. In this paper, several types of the collisions are considered: collisions between ships and the ship's grounding. These are the two main causes of loss of ships; accounting for 10.3% and 33.1% of annual losses respectively. For small ships, the probability of damage is three times more, than for large ships. It is necessary to consider the data and methods, which are offered by different researchers, for calculation of the length of the possible damage of the hull of small high speed ship, as a result of collisions with an undersea object.

2. THE DATA ON POSSIBLE EXTENT OF DAMAGE

One of the variants in calculating the extent of damage was offered by W. Hovgaard [4]. He noted that the length of damage, caused by blast of the torpedo, ranges from 8 to 17 m. The average length of the damage is taken as 11 m. According to the IMO data the average length of damage is: for vessels less than 70 m. - 2.5 m; for vessels (70-108 m.) - 6.2 m; for vessels (109-131 m.) - 7.8 m; for vessels (132-145 m.) - 9.5 m; for vessels with a length over 145 m. - 11.8 m. This information does not take into account the speed of the vessel [5].

The HSC Code [1] proposes a possible length of bottom or side damage equal to 10% of the length of the vessel, L, or $3m + 0,03L$, or 11 meters, whichever is the least. For a large passenger vessel (category "B" craft), which, after the flooding of one compartment retains the capability to navigate safely, there is a requirement to increase the possible length of the bottom damage by 50%, in the case of damage to the bow of the vessel.

This Code [1] defines two types of vessels. These categories are listed below in a short form. "Category A craft" is high-speed passenger craft operating on a route with high probability of the evacuation at any points of the route all passengers and crew. They can be rescued with the time to prevent persons in survival craft from exposure causing hypothermia or 4 hours and carrying not more than 450 passengers. "Category B craft" is any high-speed passenger craft other than a category "A" craft.

The length of the damage, according to the formula $l_d = 3m + 0,03L$, for a vessel with length 145 m, is equal to 7.4 m. This value corresponds to the Hovgaard's assumptions. Information about the speed of the ship, hull material, thickness of the plating and the width of the damage is absent in these data.

Some of the accidents which occurred with the high-speed vessels have shown that damage equal to 10% of the length of the ship did not give a good picture of the damage. The paper [6] demonstrated more probability of full length damage, for craft with length about 60 m, than for craft with length about 30 m. In this paper, the researchers took into account the material of the hull, the speed of the ship and others parameters. The proposals for predicting the extent of the damage to the hull in a collision with an underwater object have been developed. It is noted that the main difficulty in the theoretical analysis of the probable collision is the choice of scenario for the events. It is shown that the length of the relative damage for high-speed vessels is several times greater than for conventional vessels.

Some variants of the characteristics of possible damage are described below [6]. The long and narrow damage ("raking") is driven by the kinetic energy of the ship. The wide damage after collision with a rock is driven by the kinetic energy of the ship also. After this type of damage the ship may be lifted vertically. Side damage will occur after incorrect maneuvering. The driving energies for this damage process are the wind and the waves. The greatest length of the damage will be in the first variant. In this paper, a formula for determining the length of possible damage, which includes the kinetic energy of the vessel and the "raking" force, is proposed, but this proposition does not contain practical guidance for calculating the length of the damage based on different hull materials, plating thickness and damage width.

In the HSC Code [7] there is a new assumption about the possible length of the side damage equal to $l_d = 0,75V^{1/3}$ or (3 m + $0,225V^{1/3}$), or 11 m, whichever is the least. V - volume of displacement corresponding to the design waterline (m^3). The main difference between new and old rules is the use in calculating formulas of volume of displacement instead of the length.

Any part of the hull is considered to be vulnerable to raking damage if it’s in contact with the water at speed in smooth water and it also lies below two planes which are perpendicular to the craft middle line plane and at heights as shown in figure 1.

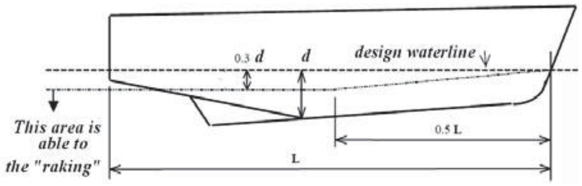


Figure 1. The area vulnerable to “raking”.

Two different longitudinal extents are considered. The first is 55% of the length, measured from the forward point of the underwater volume. The second is a percentage of the length, applied anywhere in the length of the craft, equal to 35%. For craft with length less than 50 m the extent equal to (L/2 + 10) %. In areas not vulnerable to “raking”, the damage must be taken to be the same as for the sides.

V.U.Minorsky, in work [8], suggests that the length of the damage can be calculated by the formula, $l_d = a\sqrt{dE}$, a - the coefficient of the local strength of the damaged vessel, dE - the energy of the collision. These calculations using this formula are based on the collision with two ships. In an accident that occurs due to contact with an underwater object and ship, calculations with these formulas are difficult.

3. THE METHOD FOR CALCULATING THE LENGTH OF POSSIBLE DAMAGE FOR THE HULL OF A HIGH-SPEED VESSEL

The force of the resistance of the hull material can be written as:

$$R = E\frac{l_d}{L}bt \tag{1}$$

where E - Young's modulus, kN/m^2; b - the width of the damage, m; t - the thickness of the plating, m; l_d - the length of the damage, m.

The kinetic energy of the vessel is equal to the work of the resistance of the hull’s material, at the part of the vessel.

$$\frac{mv^2}{2} = Rl_d \tag{2}$$

Some ship’s hull can not be damaged, after collision, but it is better to consider a more dangerous case, with damage. The case of cutting the plating of the vessel, without the effect of frames, has more dangerous, because it would lead to greater damage length.

In these calculations it is assumed that the engine is stopped and the speed of the vessel at the end of the process equals to zero. A variant of the collision is contact with an underwater object, “raking”.

$$l_d = \sqrt{\frac{mv^2L}{2Ebt}} \tag{3}$$

where m - the mass of the ship, t; v - the speed, m/sec; L - the length of the ship, m.

For example, the calculation of the possible length of the damage of high-speed vessel, with relative speed $Fr_V = \frac{v}{\sqrt{g\sqrt[3]{V}}}$ = 1.6, the width of the damage is 0,01 m; length of ship 40 and 60 m were made, Figure 2 (formula).

The results of calculations by different methods are presented, Figure 2.

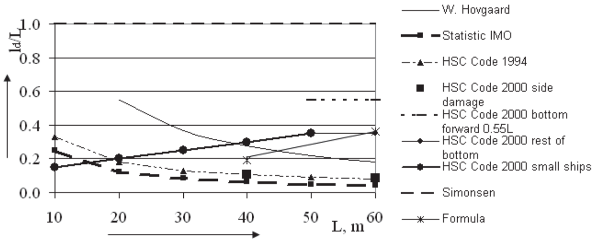
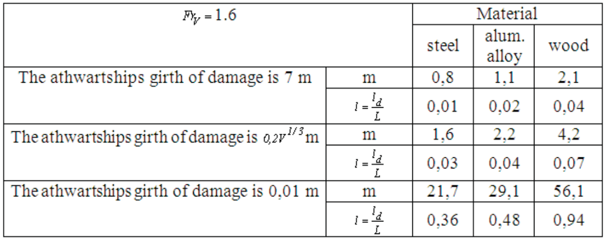


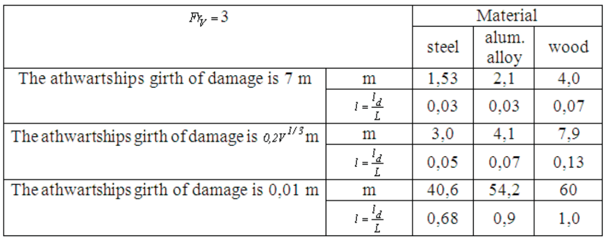
Figure 2. The relative length of the damage $l = \frac{l_d}{L}$ and the ship length.

The proposed scheme, for calculating the length of the damage, can be applied to vessels of various designs: with a double bottom and without it. Vessels may have restrictions navigation area, and may not have [9]. Proposed formula makes it possible to determine the length of damage to ships with different materials and different Froude number based on volume. The following tables show the calculations for the vessel, which has steel, aluminum alloy or wood hull. The athwartships girth of damage are 7 m [10], $0{,}2V^{1/3}$ [7] и 0.01 m. The last value corresponds approximately to the average thickness of the shell plating of the ship and in the case of landing on an underwater obstacle, which has the same width; this obstacle will be damaged rather than the vessel's hull. For example, the calculations of possible length of the damage for vessel with length 60 m, at the relative speeds 1.6 and 3, with different hull's materials (steel, aluminium alloy, wood) were made, figures 3 and 4.



$Fr_V = 1.6$		Material		
		steel	alum. alloy	wood
The athwartships girth of damage is 7 m	m	0,8	1,1	2,1
	$l = \frac{l_d}{L}$	0,01	0,02	0,04
The athwartships girth of damage is $0{,}2V^{1/3}$ m	m	1,6	2,2	4,2
	$l = \frac{l_d}{L}$	0,03	0,04	0,07
The athwartships girth of damage is 0,01 m	m	21,7	29,1	56,1
	$l = \frac{l_d}{L}$	0,36	0,48	0,94

Figure 3. The length of the damage, $Fr_V = \frac{v}{\sqrt{g\sqrt[3]{V}}} = 1.6$.



$Fr_V = 3$		Material		
		steel	alum. alloy	wood
The athwartships girth of damage is 7 m	m	1,53	2,1	4,0
	$l = \frac{l_d}{L}$	0,03	0,03	0,07
The athwartships girth of damage is $0{,}2V^{1/3}$ m	m	3,0	4,1	7,9
	$l = \frac{l_d}{L}$	0,05	0,07	0,13
The athwartships girth of damage is 0,01 m	m	40,6	54,2	60
	$l = \frac{l_d}{L}$	0,68	0,9	1,0

Figure 4. The length of the damage, $Fr_V = \frac{v}{\sqrt{g\sqrt[3]{V}}} = 3$.

The formula (3) can be used for small high speed vessels, but is possible to use this formula to other types of ships.

4. CONCLUSIONS

The length of damage significantly depends on the hull's material and the width of the damage. For a high speed vessel collision with an underwater object is the most probable. The formula for calculating the length of the possible damage, that takes into account data on the material, the thickness of the plating and the width of the damage, can give more accurate data on the extent of the damage. Until now, such a differentiated method for the determination of the extent of the ship's hull damage have not been used.

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