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GENERAL STRENGTH, ENERGY EFFICIENCY (EEDI), AND ENERGY WAVE CRITERION (EWC) OF DEADRISE HULLS FOR TRANSITIONAL MODE

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ABSTRACT

In the modern world, environmental issues come to the fore. The document of MARPOL for reducing the emission of pollutants into the atmosphere relates to the energy efficiency coefficient $EEDI$. This coefficient is directly related to the power of the main engine and, accordingly, to the water resistance. The way to reduce the energy efficiency factor $EEDI$ by increasing the relative length $\frac{L}{\sqrt[3]{V}}$ of the ship was proposed in this article. To determine the maximum value of the relative length, knowledge of the general strength of the vessel is required. The value of the relative section modulus of an equivalent girder for a small vessel of transitional mode is defined. The result of the graphic solution of two equations is the value of such a relative section modulus. This parameter is required to determine the limiting value of the relative length and to find solutions to reduce the coefficient $EEDI$. Comparative analysis of the obtained data with the data of the strength and weight of the H-girder with a length similar to the ship was conducted. The formula for determining the limiting value of the relative length was obtained from the equation of general strength. For a preliminary assessment of the future project of the ship, in terms of permissible design accelerations and the possibility of the ship moving against a sea wave of a certain height, a graph was built based on the application of the energy wave criterion EWC and the requirements of various classification societies.

Keywords: Energy wave criterion, energy efficiency factor, design accelerations

NOMENCLATURE

$\Delta = \gamma V$ – displacement of the ship
γ – density of water
β – deadrise angle, degrees
$Fr_V = \frac{v}{\sqrt{g\sqrt[3]{V}}}$ – volume Froude number
W – section modulus
$\frac{W}{\Delta}$ – relative section modulus
$\frac{L}{\sqrt[3]{V}}$ – relative length
$EEDI$ – energy efficiency index
D – depth of the ship
B – width of the ship
d – draft of the ship
c_b – block coefficient
$n = 1 + a_{CG}$ – summary acceleration
a_{CG} – design vertical acceleration (expressed in g)
σ_a – allowable compression stress for the material
t – thickness of the plating
Ω – area of the cross section of the ship
R – total resistance
$\frac{R}{\Delta}$ – relative total resistance

R_o – residuary resistance

$\frac{R_o}{\Delta}$ – relative residuary resistance

EWC – energy wave criterion

η – efficiency coefficient

INTRODUCTION

Three modes are distinguished in the theory of ship design. The character of these modes is determined by the nature of the forces of maintenance. If the weight of the vessel Δ is completely balanced by the hydrostatic force, this mode is called displacement $\Delta = \gamma V$, volume Froude number $Fr_V < 1$.

With further increase in the vessel speed, the bow rises and the bottom of the vessel will be moved with the angle of attack to the surface of the water. An additional force directed perpendicular to the bottom of the vessel develops. This force can be decomposed into two components: hydrodynamic resistance of water and the hydrodynamic lift force Y. The transitional mode begins. The weight of the ship is balanced by two forces: the hydrostatic and hydrodynamic $\Delta = \gamma V_1 + Y$, $1 < Fr_V < 3$. The hydrostatic force γV_1 is created by the part of the body of the craft V_1 that is submerged in the liquid. The transitional mode has not been extensively studied because the elements of displacement and planing are parts of the forces. Another difficulty for the study is a variable position of the vessel relative to the water at various speeds.

The increase in the speed leads to a further growth of the hydrodynamic force, emersion of the vessel, and accordingly a reduction in the hydrostatic force. The planing mode is the regime when the hydrodynamic lift forces Y fully support the weight of the craft $\Delta = Y$, $Fr_V < 3$.

When a high-speed vessel is moving in the transitional mode with a volume Froude number , loads increase from the interaction of the bottom of the vessel and the waves. Accelerations increase accordingly, which adversely affects the health of the passengers and crew. Hull structures and equipment may also be damaged. The acceleration that is considered to be acceptable from a physiological point of view is limited to a value of 0.2g. In reality, the acceleration on board the high-speed vessel reaches high values. Modern requirements of classification societies significantly raise the level for permissible accelerations on board high-speed vessels. Various methods are used to reduce shock loads. One of them is an increase in the deadrise angle β. Vessels with a deadrise angle $\beta > 20°$ are often called "monohull deep V". To evaluate the project of the ship in terms of design accelerations and the ability of the ship to move against the wave, it is possible to build a graph based on the energy wave criterion EWC and requirements of classification societies. This criterion is based on the energy of the sea wave and the kinetic energy of the vessel with the added masses of water. The problem of ship motion on the head wave is considered in [1]. In this work, the authors improved the existing methods of the theory of the ship but did not give an answer to the question of whether a ship with kinetic energy can move towards the wave. In [2], the theoretical basis for describing the wave energy is considered in detail and the ship's roll parameters are calculated, but there are no recommendations for assessing the decrease in the ship's speed on a head wave.

In the transitional mode, the water resistance increases significantly. A decrease in resistance is possible by increasing the relative length $\frac{L}{\sqrt[3]{V}}$ of the vessel, which can lead to problems in ensuring general strength. To determine the maximum possible value of the relative length, knowledge of the relative section modulus is required. There is a lack of information about the relative section modulus of an equivalent girder of the vessel $\frac{W}{\Delta}$ in various studies. The choice of the relative length of the vessel is associated with such qualities as propulsion and many others. Sometimes, the shipbuilder's desire to reduce water resistance by increasing this parameter is limited by the difficulties of ensuring general strength. There is a need to find the limiting values of the relative length, ensuring the strength of the vessel, while maintaining acceptable propulsion. The value $\frac{L}{\sqrt[3]{V}}$ is associated with propulsion or rather with the relative resistance of water $\frac{R}{\Delta}$.

Also, this indicator has an impact on the energy efficiency index $EEDI$. Thus, in this study, an attempt will be made to combine the requirements for general strength, propulsion, and energy efficiency in order to create new and improved existing ships.

THE RELATIVE SECTION MODULUS OF AN EQUIVALENT GIRDER FOR A VESSEL

Values characterizing various types of girders are sometimes given in different literature. Some books propose a coefficient of the structural quality of a girder $\frac{W}{F}$ as the ratio of the section modulus W to the area of its cross section F. In other sources, the dependence of the weight of one linear meter of the girder on the section modulus is presented. From this information, it is clear that each type of beam is characterized by its own dependence. For research, it is possible to apply knowledge about the section modulus of the small vessel, as given in [3]. The minimum section modulus of a small vessel (with deadrise angle $\beta = 0$, depth D, width B, thickness of plating t) is described by the formula $W = D(B + \frac{D}{3})t = (0.33D^2 + DB)t$. As noted above, deadrise hulls are widely used in transitional motion. In this paper, the forms with deadrise angle will be considered, Fig. 1.

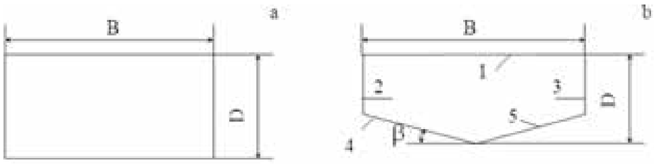

Fig. 1. Sections of the hull.

Writing the elements in Table 1, it is possible to obtain a formula for the section modulus of the hull with a deadrise angle β = 25°.

$$W = (0.33D^2 + 0.015B^2 + 0.82DB - 0.028\frac{B^3}{D})t \quad (1)$$

When applying the value of the deadrise angle β = 0° in the calculations, the following formula was obtained

$$W_{\beta=0} = D(B + \frac{D}{3})t = (0.33D^2 + DB)t \quad (2)$$

This formula is similar to the formula presented in [3] and mentioned above in this article.

Equations of a similar type for deadrise angles from 0° to 30° can be obtained. The results of the calculations were used to determine the coefficient of the profile u in the formula $W = \frac{u}{2} D\Omega$, which includes the depth D and the area of the cross section of the ship Ω, after equating the right sides of the equations described above. Using this data, it is possible to find out how the section modulus of the deadrise hulls differs from the flat bottom, Fig. 2.

Sometimes, in the early stages of a project when there is no complete data on the projected vessel, there is a need to assess the general strength of the vessel. In such cases, some simplifications are applied in the calculation, and the cross-section of the vessel appears as the cross-section of an equivalent H-girder. In these cases, the formula $W = \frac{u}{2} D\Omega$ is usually used.

Tab. 1. Elements of the cross section of the vessel in Fig. 1b

Numbers of elements corresponding to Figure 1b	Area, F	The distance between the center of gravity of the element and the central axis, z
1	2	3
1	tB	$\frac{D}{2}$
2, 3	$(D - \frac{B}{2} tg\beta)t$	$\frac{B}{2} tg\beta$
4, 5	$\frac{Bt}{2\cos\beta}$	$\frac{D}{2} - \frac{B}{4} tg\beta$

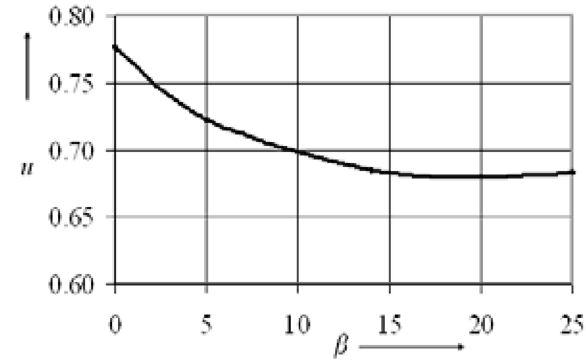

Fig. 2. The dependence of the coefficient of the profile u on the deadrise angle.

For the calculations, it is assumed that the position of the central axis passing through the centre of gravity of the cross section of the vessel is in the middle of the depth. This assumption is based on the fact that the bottom deadrise will shift the position of this axis towards the deck, and the stronger and heavier construction of the bottom will lower the axis towards the bottom. Sometimes in assessing the general strength, simplification is used to find the minimum acceptable value. The thickness of the girders is distributed over the thickness of the vessel plating. For further calculations, the thickness of the steel plating is assumed to be 6 mm, as an average value for transitional mode vessels with a length of about 30 m.

Information about the structural quality of a girder $\frac{W}{F}$ can be projected on the calculations of the relative section modulus of an equivalent girder for a vessel $\frac{W}{\Delta}$. In approximate calculations of strength, the shape of the profile, which corresponds to the equivalent girder of the vessel, is an H-girder, Fig. 3, and, taking into account the direct dependence of the cross-sectional area on the length of the vessel, we can assume the presence of such a value of the relative section modulus $\frac{W}{\Delta}$, which is characteristic for a specific type of ship. This value retains approximately the same value for ships of the same type; the same hull material and speed mode.

Formula (2) can be represented in the form,

$$\frac{W}{\Delta} = \frac{D(B + \frac{D}{3})t}{\gamma c_b LBd} = \frac{k_D t(1 + 0.07k_D)}{\gamma c_b L} \quad (3)$$

taking into account the geometry of the hull and the fact that $k_D = \frac{D}{d}$ and $\frac{B}{d} = 4.7$ (such a relative width valuecorresponds to the minimum water resistance in the speed range $2 \le Fr_V \le 3$).

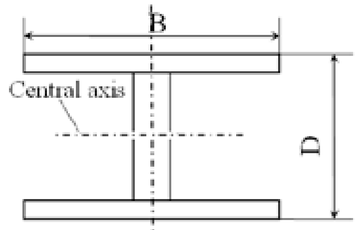

Fig. 3. The equivalent girder for calculating the section modulus of the ship (H-girder).

The relative section modulus, in m³/t, can also be found from the equation of general strength based on the bending moment due to still water loads, wave induced loads, and impact loads, $M = W\sigma_a = \frac{\Delta L}{k} n$

$$\frac{W}{\Delta} = \frac{L}{k\sigma_a} n \tag{4}$$

where $n = 1 + a_{CG}$ is the summary acceleration, L is the vessel length in m, σ_a is the allowable compression stress for material of the hull in t/m², and k is the coefficient characteristic for the type of vessel.

For crafts of different types of service (passenger, ferry, cargo), an acceleration greater than a_{CG} = 1.0 may not be adopted for the purpose of defining limit operating conditions [4]. In the calculations, a fixed value $n = 1 + a_{CG}$ = 2 was adopted. In Rules [5], it is proposed he summary acceleration $n = 1 + a_{CG}$ for passenger ships n = 2 and $n = 1 + a_{CG}$ = 2.3 for pleasure boats. In real conditions, the summary acceleration will be connected with the relative speed Fr_V.

The coefficient k for pleasure boats can be obtained from the formula for the bending moment due to still water loads, wave induced loads, and impact loads $M = \frac{\Delta}{2}(m - 0.17c_b L)(g + 1.3g)$ [5]. The value of m= - 0.05 L is the average arm of the loaded ship, reference point is middle For value of block coefficient c_b= 0.55, the formula will be in the form $M = -\frac{\Delta L}{20}(g + 1.3g)$in kNm or $M = -\frac{\Delta L}{20}(1 + 1.3)$ in tm. Same considerations for passenger ships at n = 2. The value of the coefficient k is assumed to be equal 20.

The allowable compression stress is assumed to be equal to 0.8 of the yield strength of the material, in this case, steel. The researcher can apply the materials and the requirements of any rules chosen by him to solve the task in the proposed method.

After a joint graphical solution of two equations (3) and (4), as shown in Fig. 4, it is possible to determine a value $\frac{W}{\Delta}$ = 0.0003 m³/t for steel hull, satisfying the requirements of general strength and taking into account the geometry of the hull. It is interesting to note that the Bureu Veritas Rules are created specifically for vessels less than 65 m in length [5].

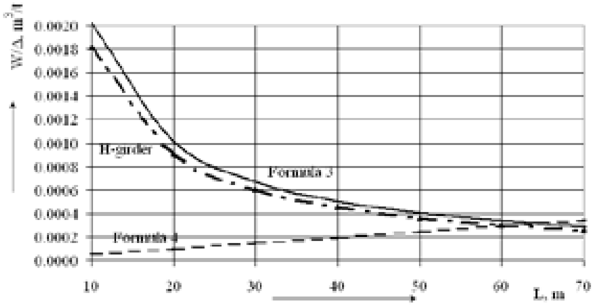

Fig. 4. The value of the relative section modulus.

The solution obtained by the graphical method does not take into account the case of deadrise. Next, an analysis will be made of how much the section modulus of hulls with different deadrise differs from the section modulus of the hull without deadrise. Based on the analysis of the coefficient of the profile u in the formula $W = \frac{u}{2} D\Omega$, which includes the depth D and the area of the cross section of the ship Ω, it can be assumed that the difference in the value of the section modulus for deadrise hull and for non-deadrise hull is, on average, about 10%, as shown in Fig. 2. Taking into account this fact, the value of the relative section modulus of the deadrise steel hull taken for further calculations can be considered to be about $\frac{W}{\Delta}$ = 0.00027 m³/t. To check the obtained values $\frac{W}{\Delta}$, it is possible to conduct an additional calculation. As noted above, the type of the balk, which corresponds to the equivalent girder of the hull of the vessel, is the H- girder in the approximate calculations. Using the data n the dependence of the weight of 1 m of an H-girder on its section modulus and adopting various lengths of the beam, it is possible to get a value close to 0.0003 m³/t for a balk with a length of 64 m, as shown in Fig. 4.

THE MAXIMUM VALUE OF THE RELATIVE LENGTH OF THE SHIP AND THE ENERGY EFFICIENCY DESIGN INDEX

Using the obtained information about the value of $\frac{W}{\Delta}$, it is possible to determine the relative length $\frac{L}{\sqrt[3]{V}}$ of the vessel from the conditions of general strength $\sigma_a W \geq \frac{\Delta L}{k} n$.

The values of the summary acceleration n can be presented as the dependency on the Froude numbers in the speed range $2 \leq Fr_V \leq 3$, $n = 0.3Fr_V^2 = 0.3\frac{v^2}{g\sqrt[3]{V}}$. This formula was obtained on the basis of data from classification societies and data provided by various researchers.

After substituting the formula for summary acceleration n into the general strength condition $\sigma_a W \geq \frac{\Delta L}{k} n$, the inequality for relative length is

$$\sigma_a \frac{kgW}{0.3v^2\Delta} \geq \frac{L}{\sqrt[3]{V}} \tag{5}$$

The relative length $\frac{L}{\sqrt[3]{V}}$ depends on the relative residuary resistance $\frac{R_o}{\Delta}$. The relative total resistance of water $\frac{R}{\Delta}$ is included in the simplified equation for the calculation of the energy efficiency design index $EEDI = \frac{aR}{k_1 k_2 \eta \Delta}$ [6], where the coefficient a depends on the type of ship. The way to obtain this formula is described below.

The MARPOL'S formula for the calculation of the attained $EEDI$, in its shortened form, is:

$$EEDI = \frac{(\prod_{j=1}^{n} f_j)(\sum_{i=1}^{nME} P_{ME(i)} C_{FME(i)} SFC_{ME(i)})}{f_i f_c Capacity f_w v_{ref}} \quad (6)$$

Other absent elements of this formula are connected with the power of the auxiliary engines, shaft motor, and engines with innovative technology. The factor f_j is related to the ice reinforcement of the hull and can take a value no greater than 1. The factor f_i is a capacity factor and must not be less than 1. The coefficient f_c depends upon the deadweight and volume of cargo tanks for gas carriers and chemical tankers, but for other types of ships, it is equal to 1. f_w is a weather factor and depends on the sea conditions. It can be taken as equal to 1.

The P_{ME} is taken as 75% of the power of the main engine P_{ME} = 0.75N, where $N = \frac{Rv}{\eta}$, so $P_{ME} = 0.75 \frac{Rv}{\eta}$.

For calculations using formula (6), the velocity of the ship v is taken as that when using 75% power of the main engine. To account for this fact, the factor k_1, $v_{ref} = k_1 v$ must be used in the equation.

The part of equation (6) *capacity* is the deadweight (for non-passenger ships) or gross capacity GT for passenger ships. Basically, ships of the transitional mode are used for transporting passengers (passenger craft, passenger ferries, etc.). The approximate formula for calculating the capacities is $GT = k_2 \Delta$.

The next factor is C_{FME}, which is termed the carbon emission coefficient. The last of the considered factors is SFC_{ME}, which is characterized by the specific fuel consumption of the engine. The values of these factors can be accepted as 3.1144 g CO_2/g fuel and 190 g/kWh, respectively.

After transformations, the formula $EEDI = \frac{aR}{k_1 k_2 \eta \Delta}$ is obtained.

For approximate estimation of $\frac{R}{\Delta}$, in transitional mode, data received from different researchers were analyzed. The data from towing tanks at SSPA and NPL came from Brown, Volodin, Nordstrem, and Groot. The tests included a range of $\frac{L}{B}$, $\frac{B}{d}$, c_b values, different hull forms, and different angles of entry for the waterlines [7]. The results of the study of the relationships of residuary resistance $\frac{R_o}{\Delta}$ against $l = \frac{L}{\sqrt[3]{V}}$ in transitional mode are shown in Fig. 5. The residuary resistance R_o has most of the total resistance value in this mode.

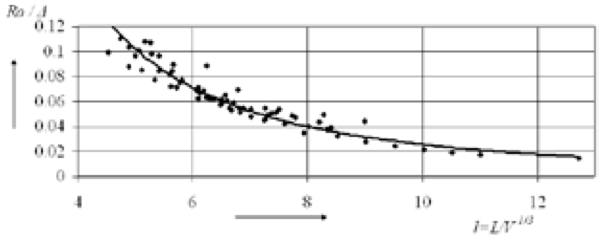

Fig. 5. The dependence of the relative residuary resistance on relative length at Fr_V = 2.

Using the least squares method and Fig. 5, formula 7 was derived for Fr_V = 2.

$$(\frac{R_o}{\Delta}) = 2.53(\frac{L}{\sqrt[3]{V}})^{-1.99} \quad (7)$$

The coefficient of determination for the data has a value of more than 0.83.

The following results were obtained after differentiation of equation (7)

$$d(\frac{R_o}{\Delta}) = -5.03(\frac{L}{\sqrt[3]{V}})^{-2.99} d(\frac{L}{\sqrt[3]{V}}) \quad (8)$$

Equation (8) helps to analyze the influence of the change in the relative length on the relative residuary resistance and $EEDI$.

THE ENERGY WAVE CRITERION EWC

In the previous sections of this article, the design accelerations and the determination of the relative length of the vessel have been described. When designing a vessel, it is already useful at the first stages to have information about the possibility of the vessel moving towards a wave of a certain height [1] and the permissible values of design accelerations that occur during such movement. To study these issues, it is possible to use the energy wave criterion EWC and formulas of classification societies.

The energy wave criterion $EWC = \frac{\gamma g k_w h_w^3 B}{4.4 m v^2}$ contains the following parameters: water density γ; acceleration of gravity g; coefficient $k_w = \frac{L_w}{h_w}$ relating the length L_w and height h_w of the wave; ship width B; speed V; and mass displacement of the vessel m. This criterion was derived from the inequality containing the wave energy $E_w = \frac{\gamma g k_w h_w^3}{8} B$ and the kinetic energy of the ship (vessel parameters: block coefficient c_b, length L, width B, and draft d) with the added masses of water $E_s = 1.1 \frac{mv^2}{2} = 1.1 \frac{\gamma c_b L B d v^2}{2}$. The coefficient EWC is similar to

Newton's criterion $Ne = \frac{PL_N}{mv^2}$; in this equation, P is the force and L_N is the linear size [8].

This criterion EWC was applied to solve the task for determining the maximum value of the wave height at which the ship will be able to move against the wave. If the value of this criterion is close to 1 or exceeds the value of 1, then it is possible to predict a significant decrease in the speed of the vessel or its inability to move against the wave.

Accelerations arising from such a movement can be estimated using the recommendations of various classification societies. The relationship between design acceleration values, ship characteristics, and the maximum wave height that the ship can meet during the voyage is based on the GL [4] and RINA [9] formula $H_{sm} = 5\frac{a_{CG}}{v}\frac{L^{1.5}}{6+0.14L}$. The calculation was made following the scheme. Froude number values and ship length options were given. The speed of the ship was then determined, which corresponds to these Froude numbers and the lengths of the ship. Using the iteration method, the length of the vessel and the Froude numbers were determined, which correspond to a given wave height and to the value of a_{CG}.

APPLICATION OF THE OBTAINED FORMULAS IN PRACTICE

So, the opportunity appeared to apply the presented formulas in practice on an example of a real ship. For the calculation, the high-speed small vessel "Length 28" was chosen, the length of ship is 28 m, the width is 7.2 m, the speed is 30 knots, $Fr_V = 2.2$. The material of the hull is glass reinforced plastic. The summary acceleration n of the vessel in the example has a value $n = 0.3Fr_V^2 = 0.3\frac{v^2}{g\sqrt[3]{V}}$ = 1.45.

The researcher can apply the materials, value n, and the requirements of any rules chosen by him to solve the task in the proposed method. After the joint solution of formulas (3) and (4), the value $\frac{W}{\Delta}$ = 0.0009 m3/t was obtained (glass reinforced plastic).

The real value of the relative length $\frac{L}{\sqrt[3]{V}}$ of this vessel is about 5.5. The maximum allowable value calculated by formula (5) is $\frac{L}{\sqrt[3]{V}}$ = 8.2 (hull material and thickness were taken into account when performing the calculation). If we assume that this value will be increased by one unit, it will take the value $\frac{L}{\sqrt[3]{V}}$ = 6.5, and then the relative residual resistance will decrease $d(\frac{R_o}{\Delta}) = -5.03(\frac{L}{\sqrt[3]{V}})^{-2.99} d(\frac{L}{\sqrt[3]{V}}) = -0.031$ or about 35%, as shown in Fig. 5. An increase in the relative length of the ship was achieved, for example, by increasing its length and reducing its block coefficient, and the displacement value will remain close to the original. This approach involves the choice of the relative length of the vessel at an early stage of the project. Considering the fact that the residual resistance at $Fr_V = 2.2$ has a large part of the total resistance, the overall decrease in the relative total resistance $\frac{R}{\Delta}$ can be significantly reduced. The residual resistance has a dominant part in the total resistance in the transitional mode. The residual resistance is about 70% of the total resistance in this mode. The friction resistance will also change after changing the relative length but will have less impact on the total resistance because the residual resistance is dominant.

An approximate formula for estimating the energy efficiency factor is $EEDI = \frac{aR}{k_1 k_2 \eta \Delta}$. Consequently, as a result of the performed operations, a significant reduction in the carbon dioxide emissions into the atmosphere is possible.

The information in Fig. 6 shows the results of the calculation using the equation $1.1\frac{\gamma c_b LBdv^2}{2} = \frac{\gamma g k_w h_w^3}{8} B$, which is the basis of the energy wave criterion EWC. This equation includes the kinetic energy of the vessel with the added masses of water (left part) and the full energy of the wave (right part). The energy of the vessel with the added masses of water is spent to overcome the barrier, and in accordance with the principle of change in kinetic energy, the speed of the vessel is reduced to zero.

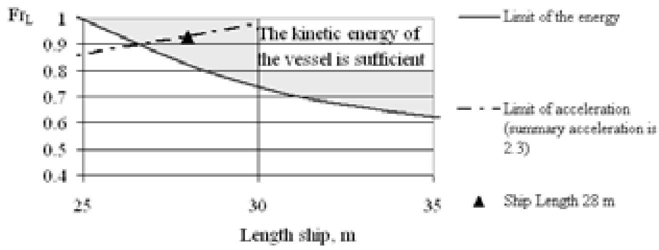

Fig. 6. Comparison of the energies of the ship and the energy of a wave with a height $h_{3\%}$ = 4.3 m, $\frac{L_w}{h_{3\%}}$ = 20.

The movement of the vessel "Length 28" towards a wave with a heights of $h_{3\%}$ = 4.3 m is possible with a significant speed reduction. With a higher wave height $h_{3\%}$ = 4.5 m, the ship will not be able to move against the wave. y. The points located above the curve characterize the vessels having enough kinetic energy for movement. The ship "Length 28" has the enough kinetic energy for movement with such a wave.

Fig. 6 shows the line for the limit of permissible design accelerations at such a wave. The line is built on the basis of the RINA and GL requirements for the maximum wave height that the ship can meet during the voyage $H_{sm} = 5\frac{a_{CG}}{v}\frac{L^{1.5}}{6+0.14L}$. The length of the vessel and the Froude numbers were determined, which correspond to a wave height, subject to the condition a_{CG} = 1.3, for pleasure boats [5].

CONCLUSIONS

To solve the problem of determining the relative section modulus of an equivalent girder for a small vessel, the methods of structural mechanics and the theory ship design were applied: the equation of general strength, taking into account the summary acceleration, and the method of the preliminary calculation of the section modulus.

The joint solution of the above-mentioned equations gives the value of the relative section modulus of a transitional mode small vessel equal to 0.0003 m^3/t for a steel hull. Taking into account the deadrise of the hull, a value of $\frac{W}{\Delta} = 0.00027\ m^3/t$ can be adopted. The data of the verification calculation of the relative section modulus for the H-girder confirmed the obtained results. When using other materials, the relative section modulus will take on different values, as shown in the example of a vessel with a glass reinforced plastic hull.

The maximum value of the relative length of a small high-speed vessel $\frac{L}{\sqrt[3]{V}}$, taking into account summary accelerations and $\frac{W}{\Delta}$, can be found from the inequality $\sigma_a \frac{kgW}{0.3v^2\Delta} \geq \frac{L}{\sqrt[3]{V}}$. Increasing the value of the relative length of the vessel leads to a decrease in water resistance, which in turn positively reduces the value of the factor $EEDI$ and therefore reduces carbon dioxide emissions into the atmosphere.

Combining the three qualities of a ship: the general strength, propulsion, and energy efficiency presented in this article will help create safer and more energy efficient ships.

The use of the energy wave criterion EWC at an early stage of the project makes it possible to assess the possibility of a vessel moving towards a wave with a certain height or to predict a decrease in the vessel's speed. The proposed version of the graph, which demonstrates the relationship between the parameters of the future ship with the characteristics of sea waves and design accelerations, can be useful when creating a ship project. Such an assessment is extremely useful for certain categories of ships, such as rescue crafts. The criterion EWC contains ship data and sea wave characteristics, which allows the designer to evaluate various ship operation options.

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