“ONE DIGIT” ESTIMATION OF NAVIGATION AREA PARAMETERS FOR A MONOHULL FAST FERRY

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Abstract. In modern versions of the Directive 2009/45/EC of the European Parliament and of the Council on safety rules and standards for passenger ships and in some rules of classification societies, for example Registro Italiano Navale, options for the designation of the navigation area for passenger ships are proposed.

Fast ferries carry not only Ro-Ro cargo, but also a large number of passengers and therefore belong to the type of passenger ships. Considering the high speed of these vessels, up to 40 knots and the short distance from the port of refuge during the voyage, liferafts are the main life-saving appliances on board the high-speed ferry but the main parameter regarding the safety is the possibility for the passengers to be rescued by a “rescue vessel” or the distance from a safe port. By the rules of the International Code of Safety for High-Speed Craft, the time for rescuing people from aboard a high-speed passenger ship is limited. In this article, the characteristics of the rescue vessel for rescuing passengers from the ferry will be determined. The worst case for a rescue craft at moving against a wave, with a typical wave height for this area, will be considered. The permissible value of the width of the navigation zone will be determined, taking into account the survival time of a person at the water temperature of a given area.

When designing a high-speed passenger ferry, it is very important to know at an early stage of the project about a possible decrease in speed when moving on a sea wave. This speed reduction can be predicted at an early stage of the project based on the data on the wave parameters in the region and the characteristics of the fast ferry.

In this way the safety of the primary vessel will be enhanced by the fact that the estimated time for rescue or to reach a safe port will be evaluated in a realist way and not only with a theoretical parameter.

To solve these problems at the first stages of the project, for a “One digit” assessment, Energy Wave Criterion (EWC) will be used that takes into account the kinetic energy of the vessel and the energy of the wave.

Keywords: Energy wave criterion (EWC), monohull fast ferry, navigation area.

1. Introduction

The issue of assigning a navigation area to a vessel remains relevant, because it is based on the desire of shipowners and shipbuilders to combine several conflicting factors: to expand the range of operation of the vessel and create safe conditions for the crew and passengers. This is especially important for fast ferries, as these vessels operate over short distances, at high speeds, and often do not have lifeboats on board.

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Such vessels are equipped with life rafts. In such a situation, the requirements of the International Code of Safety for High-Speed Craft regarding the time during which people can be rescued must be taken into account. For high-speed craft, the time to assist people is limited to four hours or exposure to hypothermia [1]. This period of time must be taken as the maximum duration of the rescue operation, taking into account the reduction in the speed of the rescue vessel in the head wave in this area. The following factors also influence the designation of a navigation area for a ship: the height of the waves in the area, the distance from the port of refuge, the strength of ship structures, unsinkability and stability. Given these factors, various regulatory documents give different recommendations for assigning a navigation area to a vessel. Directive 2009/45/EC of the European Parliament and of the Council [2] defines four navigation areas for passenger ships:

- Class A is a passenger ship engaged on domestic voyages other than voyages covered by Classes B, C and D;
- Class B is a passenger ship engaged on domestic voyages in the course of which it is at no time more than 20 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height;
- Class C is a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 2,5 metres significant wave height …in the course of which it is at no time more than 15 miles from a place of refuge, nor more than 5 miles from the line of coast..;
- Class D is a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 1,5 metres significant wave height… in the course of which it is at no time more than 6 miles from a place of refuge, nor more than 3 miles from the line of coast….

As an example for the fast ferry "Guizzo" Registro Italiano Navale has assigned a navigation area NAV.S (100) or one hundred nautical miles from a place of refuge. The classification society Det Norske Veritas proposed the navigation area R1 for the ferry “Albayzin” - 100 nautical miles from a place of refuge in winter time.

Limitations for high-speed vessels, in terms of design accelerations for ship structures and the highest wave height that a ship can overcome will be discussed in this article, in order to give a safer definition of the operational area, this because a generic evaluation of the distance from a safe port can be not enough without taking in due consideration the state of sea and the speed reachable by the vessel in situation of emergency.

To create high-quality projects of high-speed ferries, with different relative speeds and different sizes, it is necessary to predict the possible decrease in the speed of the vessel in the head wave already at the first steps of the project, using a one-digit (preliminary) method. Such a method can be presented in the form of graphs, for sea areas with different wave heights. From the point of view of the authors, the method can be based on a comparison of two energies: the energy of the wave and the kinetic energy of the ship. The result of such a comparison is the energy wave criterion EWC described in [3] and [4]. In the case of dominance of the wave energy over the kinetic energy of the vessel, it is possible to predict the complete stop of the vessel. If the vessel's energy exceeds the energy of the wave, it is possible to estimate the decrease in the vessel's speed in the head wave.

2. Decreasing the speed of the vessel in the head wave

The criterion EWC was applied to solve the above tasks. The 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 $Ne = \frac{P L_N}{m v^2}$, in this equation P is the force, L_N - the linear size.

When conducting various scientific studies, it is especially important to be able to compare theoretical and practical results. Data on speed reduction at wave 7 points are described in [5] for the high-speed ferry “Guizzo”. In good weather, the speed of the ferry reached 42 knots. When moving on a rough sea with a wave height $h_{1/3}$ = 5.1 m, which corresponds to $h_{3\%}$ = 6.8 m, the ship speed decreased to 33.3 knots. Figure 1 shows the dependence of the speed reduction in the head wave on the criterion EWC and plotted a point characteristic of the vessel "Guizzo". The formula $Speedr\,reduction(\%) = 180EWC^3 - 522EWC^2 + 496EWC - 54$ describes this dependence, which was obtained on the basis of tests in towing tanks. Tests were carried out in several towing tanks [6] and [7] on a regular wave, at various ratios of height and wavelength, as well as at various ratios of vessel length and wavelength. It can be assumed that such test results can be extended to study the behavior of a ship on an irregular wave.

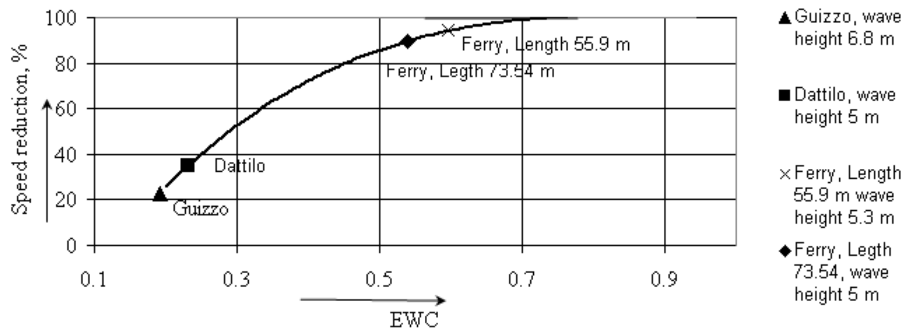

Figure 1. Criterion EWC for various vessels, wave heights $h_{3\%}$.

The coefficient EWC, for the ferry "Guizzo", equals to 0.19 and is calculated for the state of the sea described in [8], for the ratio of the wavelength L_w to its height $h_{3\%}$, $\frac{L_w}{h_{3\%}} = 10$. The ship speed will decrease by 23% and its predicted value will be 32.3 knots. The value of the reduced speed described in [5] was equal to 33.3 knots. As can be seen from the above reasoning, the reduced speed and the predicted speed differ by 3%.

The authors considered also other vessel, with dimensions representative of the present tendency in the design of fast ferries, to extend and explore the validity of the method. As well know the "Guizzo" was an extremely fast ship, with a top speed of 40 knots, in order to increase the application field of the method the authors investigated also different hulls, a ferry with a L.o.a of about 80 m, a fast ferry with a L.o.a. of about 60 m and the Italian Coast Guard patrol ship "Dattilo – CP 940".

For a ferry with a length L = 73.54 m, with a wave height $h_{3\%}$ = 5 m, which corresponds to $h_{1/3}$ = 3.8 m, the speed of the ship will be close to zero. The same graph shows the data for the vessels: the rescue ship "Dattilo" (length 80 m, speed 18 knots) and ferry (length 55.9 m, speed 25.5 kn.). The wave height for these vessels is assumed to be 5 m and 5.3 m (respectively), the ratio of the wave length L_w to its height $h_{3\%}$ is $\frac{L_w}{h_{3\%}} = 15$. Such a wave height was chosen in accordance with the data of [9], for the third region of the Mediterranean Sea, Figure 2.

Figure 2. Geographic area taken for calculations.

Wave height $h_{3\%}$ from 4 to 5 m ($h_{1/3}$ from 3 to 3.76 m) has a probability of less than 10% during the year. This approach to the choice of the estimated wave height is based on the requirements [9], in which, when assigning a navigation area to passenger ships, the probability of exceeding the specified wave height is less than 10% within one year.

The height chosen has been also compared with the significant wave height data, usually communicated by the DM 750/2005 for "Ministero dei trasporti e delle Infrastrutture" referring the wave height data to be considered for the Ro-ro Pax ferries [10]. This document proposes to take into account the wave height for region 3 $h_{1/3}$ = 2.5 m.

3. The choice of characteristics of the vessel for a given area

Figure 3 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 criterion EWC. This equation relates the kinetic energy of the vessel with the added masses of water and the energy of the wave. The kinetic energy of the vessel with the added masses of water $E_s = 1.1\frac{\gamma c_b LBdv^2}{2}$ 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.

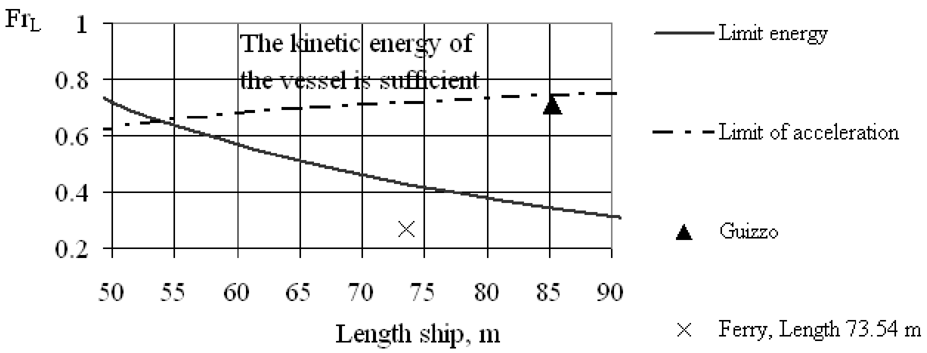

Figure 3. Comparison of the energies of the "Guizzo", the ferry with a length L = 73.54 m and the energy of a wave with a height $h_{3\%}$ = 6.8 m, $h_{1/3}$ = 5.1 m, $\frac{L_w}{h_{3\%}} =$ 10.

The point characteristic of "Guizzo" is located above the line showing the sufficiency or insufficiency of the vessel's energy. In this case, the ferry has the kinetic energy necessary for movement, with such a wave. The point for a ferry with a length L = 73.54 m is below this line and this is a case of insufficient vessel energy. Additionally, figure 3 shows a line for the limit of permissible design accelerations. This line is built on the basis of the Germanischer Lloyd requirements for the maximum wave height that the ship can meet during the voyage

$H_{sm} = 5 \frac{a_{CG}}{v} \frac{L^{1.5}}{6 + 0.14L}$ [11]. Quote from [11]: “For craft with type of service “Passenger, Ferry, Cargo” an acceleration greater than a_{CG} = 1,0 g may not be adopted for the purpose of defining limit operating conditions”. 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 wave height $h_{3\%}$ = 6.8 m, subject to the condition a_{CG} = 1.0 g.

For a high-speed ferry project with length L = 55.9 m, width B = 9.43 m, depth D = 5 m and draft d = 2.17 m (Figure 4), similar calculations were made, Figure 5.

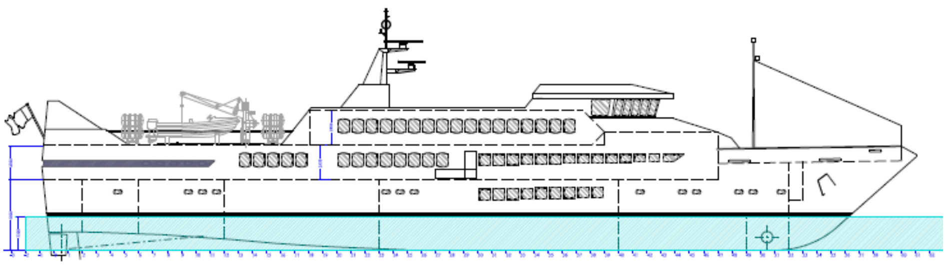

Figure 4. General arrangement of the fast ferry, length L = 55.9 m.

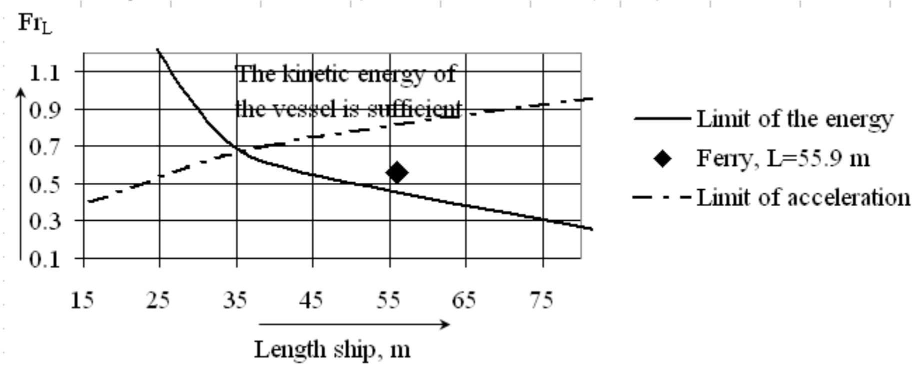

Figure 5. Comparison of the energies of a fast ferry with a length L = 55.9 m and the energy of a wave with a height of $h_{3\%}$ =5.3 m ($h_{1/3}$ =4 m), $\frac{L_w}{h_{3\%}} = 15$.

It can be seen from the figure that the movement of this ferry towards a wave with a height of $h_{3\%}$ =5.3 m ($h_{1/3}$ = 4 m) is possible with almost a complete decrease in speed. This is confirmed by the data in Figure 1, the predicted drop in the speed of this vessel is about 94%.

4. Determination of the navigation area for the ferry, taking into account the time of human survival in the water.

For calculations of this type, it is necessary to have information about the average water temperature in a given area and the survival time of a person in water with such a temperature. In region 3, in January, the average water temperature is about 12ºC. A person, at this temperature, can survive in water for about 3 or 4 hours. This period of time should be taken for further calculations as the period during which people should be helped. It is noteworthy that the requirements of the Code [1] suggest the same time interval for rescuing people from a sinking high-speed vessel, type A, which carries less than 450 passengers. During this time, assistance must be provided by a rescue vessel.

One of the modern vessels is the offshore patrol vessel “Dattilo”. The maximum capacity for rescued people is about 600 people. Vessel length L = 80 m, width B = 16.6 m, speed v = 18 knots. The wave height in region 3, as mentioned above, is from 4 to 5 m and has a probability of less than 10% during the year. With a wave height of $h_{3\%}$ =4.5 m, the rescue ship “Dattilo” will lose about 16% of speed and will move at a speed of 15.2 knots. In 4 hours “Dattilo” will cover about 61 nautical miles. Such a distance from the place of basing of rescue ships may be assigned to fast ferry.

5. Bow Freeboard estimation

This part is more relevant for the fast ferries, which are engaged only in the carriage of passengers. The freeboard of this type of crafts will be smaller than for ferries that are engaged in transportation of passengers and vehicles. For further calculations, a high-speed ferry with a length of 55.9 m was selected. The bow height is about 4 m, with a draft of 2.17 m.

Figure 6 shows the main components of a ship's bow dive.

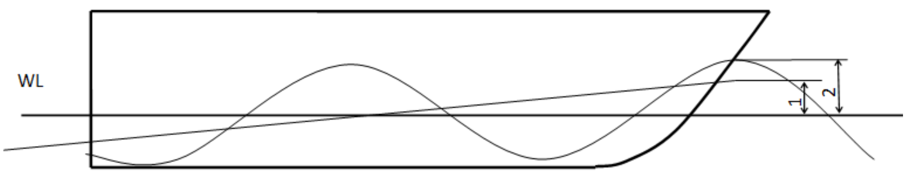

Figure 6. The parts of submersions of the fore end of ship: 1 - pitch; 2 - sea waves.

The important factor influencing to the choice of the value of the bow height is the amplitude of the pitching. For small passenger vessels, on a wave of up to 4 points, the amplitude of the pitching can reach 7°, the minimum value is 3° [6]. Bureau Veritas offers value for amplitude of pitching $A_r \leq 0{,}2$ radian. For the selected ferry, like an assumption, the amplitude φ is about 3º, taking into account that the ship has good maritime qualities.Trim t is calculated from the expression $t = L \times tg\varphi$ = 2.9 m. Immersion of the bow, as a result of pitching will be equal to 1.45 m.

The second component of dive of bow is sea waves. When the ship moves against a wave $h_{3\%}$ = 5 m ($h_{1/3}$ = 3.8 m) high, the bow will sink about 2.5 m. The sum of the two components of the dive is 3.95 m. This value is less than the bow height 4 m.

The third component, formed waves, occurs when the ferry moves at high speed. In this calculation, the variant of the movement of the vessel on the wave is considered, taking into account the pitching.

6. Conclusions

A “One digit” project assessment is an opportunity to determine the size and speed of the future vessel already at the first stages of the project, for operation in a certain navigation area. It is possible to predict design accelerations for a future project.

The result of such a study: a high-speed ferry with a length L = 55.9 m practically cannot move against a wave with a height $h_{3\%}$ = 5.3 m ($h_{1/3}$ = 4 m), $\frac{L_w}{h_{3\%}} = 15$. If the restriction of the navigation area to this vessel is considered from the point of view of preventing deck wetness of the bow, then the maximum wave height should be taken as $h_{3\%}$ = 5 m ($h_{1/3}$ = 3.8 m). The distance from the base of the rescue vessel, type “Dattilo”, for this ferry, is 60 nautical miles. This distance is related to the time requirements in which people must be rescued. This period, about 4 hours, is associated with the lifespan of a person in outboard water, in winter. When operating the ferry in the warm season, it is possible to expand the navigation area of the vessel. Design accelerations are within the established norms.

Important information is the data on the decrease in the speed of the ship on the head wave. Such data is presented in this article in the form of a graph and a formula. The formula is based on the results of tests in the towing tanks and verified using data on the speed reduction of the fast ferry “Guizzo”. The calculation error is about 3%. The forecast of the decrease in the speed of the rescue vessel “Dattilo”, during the rescue operation, taking into account the height of the wave, is made in the article. The speed of this vessel will decrease to 15.2 knots when moving against a $h_{3\%}$ = 4.5 m high wave. Consequently, in 4 hours, during this maximum time of the rescue operation, the rescue ship will be able to cover about 60 nautical miles, which will be the boundary of the navigation area for a high-speed passenger ferry.

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