Contributions to Improve Ships Safety and Construction

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Abstract. Construction safety of the ships is a central objective in the concerns of all the actors involved in shipbuilding and operation of ships, of this depending their survival and therefore, the purpose of my doctoral thesis [10] was the analysis of some technical requirements concerning the construction safety of the ships, stipulated by the main international regulations and following theoretical and laboratory research, to make proposals for improvement of these requirements, thus contributing to technical progress in the field.

1. Introduction

Construction safety of the ships is a central objective in the concerns of all the actors involved in shipbuilding and operation of ships, of this depending the integrity of ships, the life of crews and passengers, the integrity of the goods transported, and the environment protection. The safety construction is achieved by meeting some technical requirements from international regulations as well as from the classification societies rules and industry standards, in all phases of the ship's life, from design, construction and operation to scrapping.

A lower level of safety construction can lead to material losses and failures, human life losses or ecological disasters. Among the lost ships, a significant share was represented by the bulk carriers and oil tankers, some of them by the collapse of the longitudinal structural elements of the hull and its breaking into two parts, as can be seen in fig. 1, 2 and 3. By these activities, the following were achieved:

- Development of 4 computational tools for assessing of the longitudinal strength of the ships in still and bad sea condition which allow carry out of studies and research to improve shipbuilding regulations on safety construction or of ship’s projects by the doctoral thesis;
- Development an original method of nonlinear calculation of ship’s oscillation parameters at the dynamic layout on wave, considering the quadratic damping can be generalized throughout the theory of oscillation and vibration mechanics, because the damping can be considered dependent upon any function of the oscillation velocity and even other parameters.
- Substantiated proposal for improving the IACS requirements on longitudinal strength of seagoing ships in intact condition;
- Development of a method of probabilistic assessment of longitudinal residual strength of the seagoing ships in damaged condition;
- Development of a method of probabilistic assessment of overall survival of the seagoing ships in damaged condition.

Through the topics treated, the thesis opens new perspectives for future research regarding ship’s safety construction.
Therefore, the purpose of my doctoral thesis [10] was the analysis of some technical requirements concerning the construction safety of the ships, stipulated by the main international regulations and following theoretical and laboratory research, to make proposals for improvement of these requirements, thus contributing to technical progress in the field.

In this respect it has been established the following objectives:

- Development of computational tools for assessing the construction safety of the ships on longitudinal strength;
- Improving the requirements on longitudinal strength of seagoing ships in intact condition;
- Development of a method of probabilistic assessment of longitudinal residual strength of the seagoing ships in damaged condition;
- Development of a method of probabilistic assessment of overall survival of the seagoing ships in damaged condition.
2. Computational tools for assessment the construction safety of the ships on longitudinal strength

To analyze the construction safety of the ships, the following 4 computational codes which allow conducting studies and research to improve shipbuilding regulations on safety construction or of ship’s projects were developed:

A code for calculation of the sectional efforts and of the elastic line of the ship’s hull at the static position in still-water and at the quasi-static position on the head wave having cosine or trochoidal form (RLS-V1). The code allows determining the floating parameters for the equilibrium position of the ship in still-water and the quasi-static position on the wave for different cases of loading conditions, as well as the sectional efforts and the elastic line of its hull under such conditions. Based on the classical calculation method in "Ship’s Theory," adapted and developed by the author in a specific way to automate calculations, the code introduces several innovative elements. The method adopted and the calculation code were validated by direct manual calculations on a parallelepiped barge. This tool has proved to be particularly effective in the research work being to establish proposals to improve the ship's safety regarding longitudinal strength;

A code for linear calculation of the ship’s oscillation parameters and of the additional sectional efforts in its hull induced by the head wave (RLD-V1). This code was developed based on the classical method in „Ship’s Theory”, using the „Ordinary Strip Theory” and the „Modified Strip Theory”, developed by the author in a specific way to automate calculations, introducing several new considerations.

The tests on a series of 3 models validated the adopted method and the calculation code:

- Wigley III experimental model of the Ship Hydrodynamics Laboratory of the University of Technology in Delft (fig.4);
- Seatech-D model (representing a RoPax ship at 1:39.024 scale), within the LAINNE project carried out by VTT in Merike (Finland) (fig.5);
- The experimental model of 6 m length of Mejiro test basin from Tokyo (fig.6).

In fig. 7, the results of the pitch measurements and calculations with the RLD-V1 code for the Wigley III model are presented graphically, noting that the differences are generally less than 30% considered by the literature as acceptable and only in isolated cases such as the areas resonance, this limit is exceeded. These differences are justified by the complexity of the ship's hydrodynamics, in which the additional masses of water are difficult to predict accurately and the phenomena of damping are equally difficult to determine. Due to the large number of validations they has undergone the RLD-V1 code, this has been a benchmark for the other methods and codes;
A code for non-linear calculation of the ship’s oscillation parameters and of the additional sectional efforts in its hull induced by the head wave (RLD-V1N). The code was developed based on the classical method in „Ship’s Theory”, using the „Ordinary strip theory” and the „Modified strip theory” developed by the author in a specific way to automate calculations taking in account linear dumping depending on the oscillation speed of the ship and applying the successive approximation method,. The method adopted and the calculation code were validated on the basis of the Mejiro tests. In fig.8, the results of deck stress measurements and calculations with the RLD-V1N code of model are presented graphically, noting that the differences are generally less than 20% considered by the literature as acceptable and only in isolated cases such as the resonance areas, this limit is exceeded.

A program for non-linear calculation of the ship’s oscillation parameters and of the additional sectional efforts in its hull induced by head waves, considering quadratic damping (RLD-V2). The code was developed based on a new method proposed by the author, considering the non-linear damping depending on the square of the ship's oscillation velocity. Taking into account the damping in this way and using the β-Newmark time integration method, is a novelty in the study of the ship's heave coupled with the ship's pitching, being an appreciation of the phenomenon closer to reality. The method adopted and the calculation code were validated on the basis of the Mejiro tests. In fig.9, the results of deck stress measurements and calculations with the RLD-V2 code of model are presented graphically, noting that the differences are generally less than 10% considered by the literature as acceptable and only in isolated cases such as the resonance areas, this limit is exceeded. This tool allows a better assessment of the ship's dynamics and sectional efforts in its body, ensuring the achievement of particularly interesting results in the research carried out in order to improve the safety of the ship's construction.

Fig. 6 – The experimental model of 6 m length of Mejiro test basin
To improve the construction safety of ships on the longitudinal strength in intact condition, it carried out a comparison of wave-induced sectional efforts, determined according to IACS regulations, with those obtained with the codes presented in chapter 2. It was found that the IACS efforts are smaller than the real ones, particularly in the case of shear forces for several representative ship types, as can be seen from fig. 10 and fig. 11 in the case of a bulk carrier of 65000 tdw. This situation can lead to the realization of bad scantling of ships vessels confirmed by the loss of many bulk carriers of single skin construction. To avoid such losses, appropriate corrections are proposed for IACS formulas to obtain the more accurate values for the sectional efforts and to built safer ships, as following:

- the factor $k_H$ to be increased by approximately 10%, that is, to have the value of 210 instead of 190;
- the factor $k_S$ to be increased by approximately 20%, that is, to have the value of 130 instead of 110;
- the factor $k_Q$ to be increased by approximately 50%, that is, to have the value of 50 instead of 30;
- the formulas will be multiplied by the factor $k_F$ which introduces the dependence of Froude number $F_n$:

$$k_F = \max(1, \sqrt{0.5 + 6 \cdot F_n - 11 \cdot F_n^2})$$

so these formulas become:

- for hogging bending moment:

$$M_{NV,H} = \kappa_F \cdot \kappa_H \cdot F_M \cdot C \cdot L^2 \cdot B \cdot C_P \cdot 10^{-3} \ [\text{kN m}]$$

- for sagging bending moment:
\[ M_{WV,S} = \kappa_F \cdot k_S \cdot F_M \cdot C \cdot L^2 \cdot B \cdot (C_B + 0.7) \cdot 10^{-3} \text{ [kN m]} \]  

\[ Q_{WV} = \kappa_F \cdot k_Q \cdot F_Q \cdot C \cdot L \cdot B \cdot (C_B + 0.7) \cdot 10^{-2} \text{ [kN]} \]  

By applying these revised formulas, for the bulk carrier of 65000 tdw, the new values of IACS wave-induced sectional efforts are shown graphically in fig.12 and fig.13 compared to the values determined by direct calculations.

From the analysis of these graphically presented results it is found that the revised IACS formulas sufficiently cover the values determined by direct calculations.

These conclusions are also confirmed by the IMO’s decision to require bulk carriers over 150 m in length to be with double skin.

Fig. 10–Maximum values of the additional wave-induced shear forces in the hull of 65000 tdw bulk carrier, depending on ship speed.
Fig. 11–Maximum values of the additional wave-induced bending moments in the hull of 65000tdw bulk carrier, depending on ship speed
Fig. 12 – Revised maximum values of the IACS additional wave-induced shear forces in the hull of 65000 tdw cargo ship, compared to the values determined by direct calculations.
Fig. 13 – Revised maximum values of the IACS additional wave-induced bending moments in the hull of 65000 tdw cargo ship, compared to the values determined by direct calculations

3. **Probabilistic assessment of the longitudinal residual strength of the seagoing damaged ships**

To improve the safety of the construction of damaged ships, it is proposed to apply a probabilistic concept to treat the construction safety of the ship after damage in terms of longitudinal residual strength, which is based on the ability of survival after damage, as a measure of ship safety assessment in damaged
conditions hereinafter referred to as the effective longitudinal residual strength index $R_L$, determined with the relation:

$$R_L = \sum p_i r_i$$ (5)

where:

\begin{itemize}
  \item $i$ is the index of each compartment or group of compartments considered,
  \item $p_i$ indicates the probability that only the considered compartment or group of compartments will be damaged;
  \item $r_i$ indicates the probability of survival after damage to the considered compartment or compartment group.
\end{itemize}

For survival of the ship, it is required as this effective index $R_L$ to be greater than a minimum value called the required residual longitudinal strength index $R_{LO}$. The taking into account a large number of crash cases whose influence is found in the actual residual longitudinal strength index $R_L$, depending on the occurrence probability and the probability of survival after damage, allows a better assessment of the construction safety to ship damaged. Such assessment of the residual longitudinal strength of damaged ships is a modern, elegant and synthetic way of assessing of their construction safety.

This assessment method was applied to a cargo of 2400 tdw, resulting $R_{LO} = 0.43275$, and $R_L = 0.9156$ and proving that the ship is very robust, being with the double skin.

The same method was applied to the bulk carrier of 65,000, resulting $R_{LO} = 0.68473$ and $R_L = 0.605241$ and proving that the ship not meet the safety criterion, as expected, because it has a single side and the collision shear area is decrease by 32%.

4. Probabilistic assessment of overall survival of the seagoing damaged ships

To improve the construction safety of the damaged ship, it is proposed to complement the SOLAS probability concept for assessing the stability of the damaged ship, with survival in respect to the hull ultimate girder strength, so that the assessment is based on the survival of the ship after damage as a measure of ship safety regarding residual longitudinal strength and stability, hereinafter referred to as actual overall survival index $S_G$, determined with the relation:

$$S_G = \sum p_i r_i s_i$$ (6)

where:

\begin{itemize}
  \item $i$ represents index of each compartment or group of compartments under consideration,
  \item $p_i$ indicates the probability that only the considered compartment or group of compartments will be damaged;
  \item $r_i$ indicates the probability of survival after damaging residual longitudinal strength to the considered compartment or compartment group;
  \item $s_i$ indicate the probability of survival after damaging strength to the considered compartment or compartment group.
\end{itemize}

For survival of the ship, it is required as this effective overall survival index $S_G$ to be greater than a minimum value called the required overall survival index $S_{GO}$. The taking into account a large number of crash cases whose influence is found in the actual overall survival index $S_G$, depending on the occurrence probability and the probability of survival after damaging residual longitudinal strength and stability, allows a better assessment of the construction safety to ship damaged. Such assessment of the overall survival of damaged ships is a modern, elegant and synthetic way of assessing of their construction safety.
5. Comments and conclusions

The main scop of my doctoral thesis [10] was, as a result of documentation and research, to make proposals to improve the requirements on construction safety of the ships set out in international regulations and to develop methods and calculation tools that allow assessment of the construction safety of the ships. In this respect, the following were achieved:

1. substantiated proposals to improve the construction safety of the seagoing ship by:
   - increasing the longitudinal strength of their hull as a result of the revision of the current IACS method on calculating the wave-induced sectional efforts;
   - the probabilistic evaluation of their longitudinal residual strength in damage situations;
   - the probabilistic evaluation of their overall survival in damage conditions;
2. development of 4 computational codes which allow carry out of studies and research to improve shipbuilding regulations on safety construction or ship’s projects;
3. development of an original method of nonlinear calculation of ship’s oscillation parameters at the dynamic layout on wave, considering the quadratic damping which can be generalized throughout the theory of oscillation and vibration mechanics, because the damping can be considered dependent upon any function of the oscillation velocity and even other parameters.

At the same time, through the topics treated, the thesis opens new perspectives for future research from the ship’s hydrodynamics and longitudinal strength regarding safety construction.

6. References

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