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DESIGN AND OPERATIONAL PROBLEMS OF SAFETY OF SURFACE NAVAL AND MERCHANT SHIPS IN DAMAGED CONDITIONS

ABSTRACT

The paper regards various design and operational problems associated with survivability of surface naval and merchant ships using an alternative probabilistic methodology. This methodology is based on application of the performance-oriented and risk-based approaches. The performance-based approach requires to use the design and hydromechanics-based application methods. A measure of a ship safety in damaged conditions is either a risk or risk level. The risk is estimated using the risk analysis. Between the most important elements of risk analysis are the hazard identification, scenario development, quantitative risk assessment and risk control. The assessment of safety is based on the total risk management TRM approach including the risk assessment and risk management. The detailed discussion regarding the method and modeling will be submitted for publication by the Gdansk University of Technology in separate publication.

Keywords:

ships' safety, damage.

INTRODUCTION

The paper presents some information on modeling safety of ships in damaged conditions at the preliminary design stage or for the salvage-oriented purposes. Generally, the method can be called as an alternative performance-oriented risk-based method in comparison with the method included in SOLAS.

The current method of assessment of safety of ships in damaged conditions is based on the harmonized SOLAS Chapter II-1 Parts A, B and B-1 [1]. These regulations are prescriptive in their character and are based on the semi-probabilistic and fully probabilistic approaches. Application of the requirements included in those regulations to certain types of ships e.g. large passenger vessels, Ro-Ro vessels or car-carriers may lead to insufficient level of ship safety or provide unnecessary design restrictions. IMO has decided to improve the prescriptive regulations and

create the sets of new rules based on the risk assessment technology. Such the rules should be directed towards satisfying the objectives. For the whole process of improving the rules IMO has recommended an application of the Formal Safety Assessment FSA methodology published as MSC Circ. 1023 [2].

CURRENT METHOD OF ASSESSMENT OF SAFETY OF SHIPS IN DAMAGED CONDITIONS

The current method for safety assessment of ships in damaged conditions is based on the regulations included in the SOLAS Chapter II-1 Parts A, B and B-1. Using the current methodology the measure of safety of a ship in damaged conditions is the attained subdivision index 'A'. It is treated as the probability of survival of flooding any group of compartments. The basic design criteria is the condition as follows [1]:

$$A > R \quad (1)$$

where: A – attained subdivision index calculated according to the formula:

$$A = \sum p_i s_i \quad (2)$$

where: p_i – probability of flooding the group of compartments under consideration;
 s_i – probability of survival after flooding the group under consideration;
 R – required subdivision index.

Both the indices A and R are calculated according to the well known formulae accepted by IMO [1]. A typical process of assessment of safety of a ship in damaged conditions may be as it was introduced by Gerigk in 2005 [3], [4], [5], [6]. The calculations of the attained subdivision index A are connected with the large scale numerical calculations and they are time consuming. In practice, even if the criteria (1) is satisfied there can be serious doubts if a ship is really safe from the operational point of view. Of course, the optimization of the attained subdivision index A can be applied to increase the safety of ship at the design stage. Another technique which can be implemented for the same purposes is the optimization of the local safety indices. These techniques are prescriptive in their nature as well and do not guarantee a substantial increase of a ship safety [3], [4], [5], [6]. The primary analysis associated with using such the techniques was conducted at the University of Newcastle upon Tyne in 1991 by Gerigk and published by Sen and Gerigk in 1992 [7].

PERFORMANCE-ORIENTED RISK-BASED DESIGN

The risk-based design is a formalized design methodology that systematically integrates the risk analysis in the design process with the prevention/reduction of risk as a design objective [8]. This methodology applies a holistic approach that links the risk prevention/reduction measures to ship performance and cost by using relevant tools to address ship design and operation. As indicated by the Ship Stability Research Centre in Glasgow, this is a radical shift from the current treatment of safety where safety is a design constraint included within the rules and regulations. The risk-based design should offer freedom to the designer to choose and identify optimal solutions to meet safety targets. For the risk-based design safety must be treated as a life cycle issue. The following steps are needed to identify the optimal design solution [8]: set objectives, identify hazards and scenarios of accident, determine the risk, identify measures and means of preventing and reducing risk; select designs that meet objectives and select safety features and measures that are cost-effective, approve design solutions or change the design aspects.

AN ALTERNATIVE METHOD

The modern approach to ship safety is connected with combining the elements of system approach to safety and Formal Safety Assessment (FSA) methodology [2], [3], [4], [5], [6]. The major elements of FSA are as follows: hazard identification, risk analysis, risk control options, cost-benefit assessment, recommendations for decision making. The above steps have been combined with the modern ship design spiral as presented in fig. 1.

The following methods are used for the risk assessment: hazard identification, frequency assessment, consequence assessment and risk evaluation. Within the hazard/risk analysis the following methods have been investigated [9]: preliminary hazard analysis (PHA), preliminary risk analysis (PRA), what-if checklist analysis, failure modes and effects analysis (FMEA), hazard and operability analysis (HAZOP), fault tree analysis (FTA), event tree analysis (ETA), relative ranking, coarse risk analysis (CRA), pareto analysis, change analysis, common cause failure analysis (CCFA) and human error analysis (HEA).

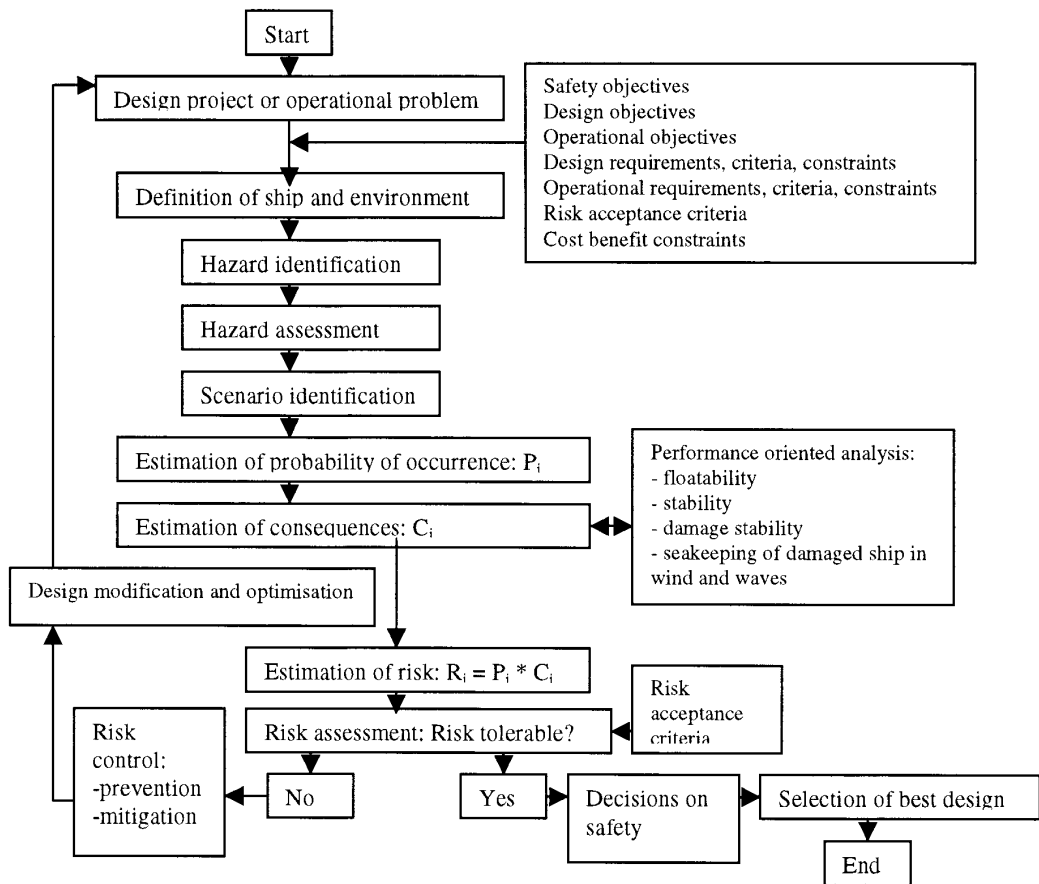


Fig. 1. Logical structure of the risk-based design method

The key issue within the proposed method is to model the risk contribution tree. The risk associated with the different hazards and scenario development is estimated according to the well known formula:

$$R_i = P_i \times C_i \quad (3)$$

where: P_i – probability of occurrence of a given hazard;

C_i – consequences following the occurrence of the data hazard and scenario development, in terms of fatalities, injuries, property losses and damage to the environment.

The logical structure of the risk contribution tree is presented in fig. 2. Three categories of accidents which may potentially cause a damage to the ship were taken into account during the investigations: collision, stranding and grounding. According to statistics these categories are the main reasons of accidents at sea. As indicated in fig. 2 the risk contribution trees for the collision, stranding and grounding were prepared separately. Finally, the complex risk contribution tree was worked out for all these categories of accidents.

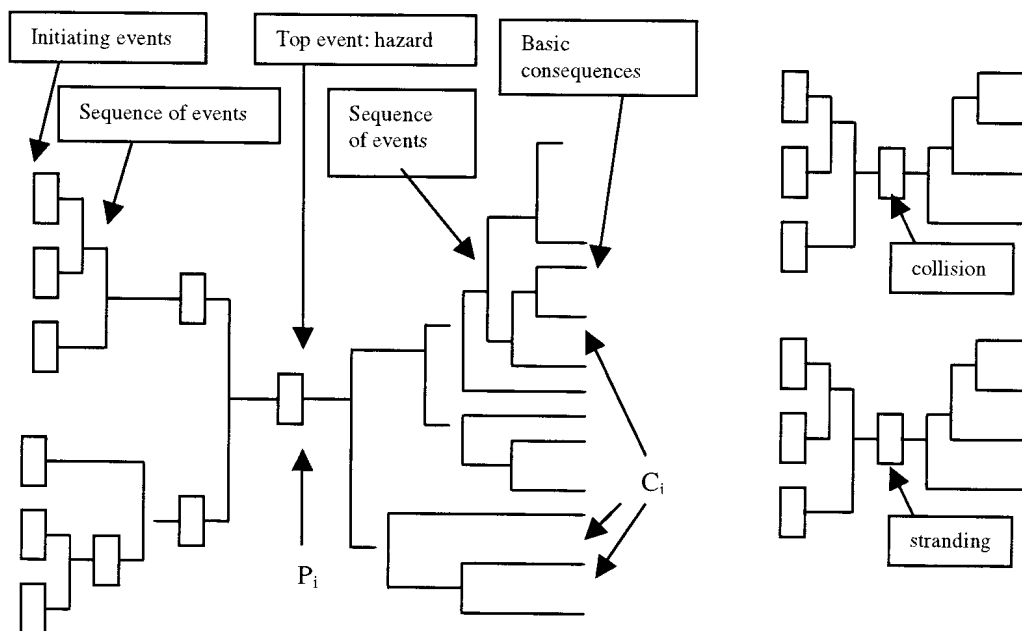


Fig. 2. Logical structure of a risk contribution tree and examples of models of risk contribution trees for the collision, grounding and stranding

A good example of the risk and safety assessment according to the proposed method is the design analysis conducted for the container ship presented in fig. 3. The hazards and scenarios concern flooding of the following damage zones (groups of compartments) due to collision, stranding or grounding: 1, 2, 3, 4, 5, 6, 7, 8, 9, 1 + 2, 2 + 3, 3 + 4, 4 + 5, 5 + 6, 6 + 7, 7 + 8, 8 + 9, 1 + 2 + 3, 2 + 3 + 4, 3 + 4 + 5, 4 + 5 + 6, 5 + 6 + 7, 6 + 7 + 8, 7 + 8 + 9.

The P_i probabilities of occurrence of the collision, grounding and stranding events were obtained by applying the Monte-Carlo generated scenarios [10]. Comparing

the distribution of P_i values in comparison with the data obtained using the IMO-based formulae the influence of uncertainties was observed. In the case when the risk is estimated according to the formulae:

$$R_i = F_i \times C \quad (4)$$

where: F_i – frequency of occurrence of a given hazard;

C_i – consequences following the occurrence of the data hazard and scenario development, it is difficult to take the uncertainties into account or estimate them.

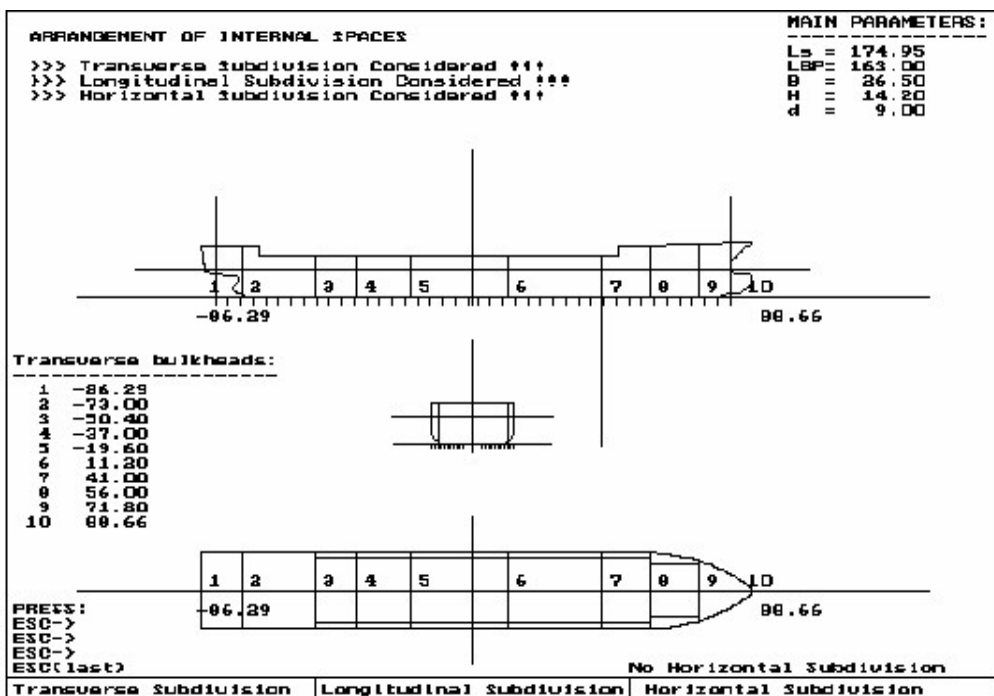


Fig. 3. Arrangement of internal spaces for a container ship [11], [12]

Simulating the P_i and C_i values using the Monte Carlo method the influence of different impacts (water on deck, wind, cargo shift) on safety of the ship was taken into account. An example of the risk distribution in terms of surviving the collision, stranding or grounding is presented in fig. 4.

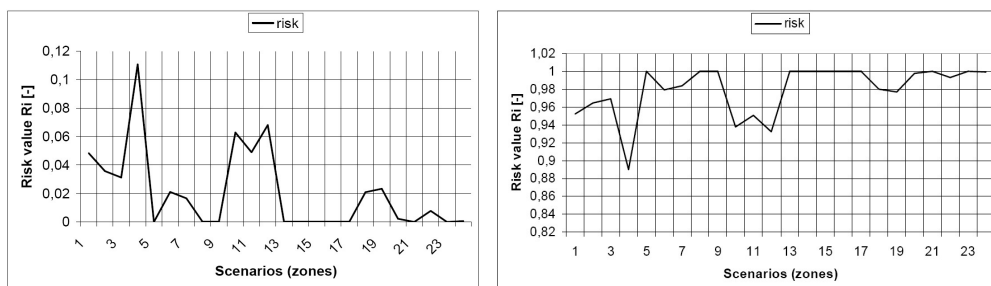


Fig. 4. Relative risk distribution presented either as $R_i = P_i \times C_i$ or $R_i = 1 - (P_i \times C_i)$ values

CONCLUSIONS

The performance-oriented risk-based method for assessment of safety of damaged ships is briefly presented in the paper. The current work regarding the method is associated with integrating the performance-oriented and risk-based analyses into the system introduced in fig. 1. The method uses the performance-oriented risk-based approach to safety. The risk analysis is based on the FSA methodology. The hazard identification, estimation of the probability of occurrence and estimation of consequences are the base for the risk assessment. The method can be implemented for the design and operational purposes.

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