Model of identification of events and accident scenarios for a method of risk and safety assessment of ships in damaged conditions

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ABSTRACT

The paper regards some problems associated with identification of events and accident scenarios and modeling of risk for the alternative method of risk and safety assessment of ships in damaged conditions. The various problems associated with modeling the survivability of ships using a performance-oriented risk-based approach are considered. It is taken into account to apply the methodology within the decision making processes for either the design, operational or salvage-oriented purposes.

KEYWORDS

Ship safety, safety of ships in damaged conditions, safety assessment, risk analysis, ship design for safety, safe operation of ships.

INTRODUCTION

The paper presents some information on modelling the risk and safety assessment of ships in damaged conditions for the design, safe operation or salvage-oriented purposes. The research concerns development of an alternative performance-oriented risk-based method for assessment of safety of ships.

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, IMO (2005), IMO (2007). These regulations are prescriptive in their character and are based on the fully probabilistic and semi-probabilistic approaches to safety. Application of the requirements included in these 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. Between the standard design objectives the sufficient level of safety should be included. 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, IMO (1997, IMO (2002a). The proposed alternative method is a kind of performance-oriented risk-based analysis to be included in either the design operation processes with the reduction of risk and sufficient level of safety as an objective. The methodology adopted can easily be adopted for assessment of safety of undamaged ships as well as it very much depends on the problem (system) definition. In the paper the performance-oriented risk-based method of assessment of safety of ships in damaged conditions is briefly discussed because of limited space available. Some examples of assessment of safety using the method are presented. The detailed discussion regarding the method will be published by the Gdansk University of Technology later this year.

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-I. Using this method 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 criterion is the condition as follows, IMO (2005), IMO (2007):

$$A > R \tag{1}$$

where:

A - attained subdivision index calculated, for the draughts d_s, d_p and d_l defined in regulation 2, according to the formula, IMO (2005):

$$A=\sum p_i s_i \tag{2}$$

p_i - probability that only the compartment or group of compartments under consideration may be flooded, as defined in regulation 7-1;

s_i - probability of survival after flooding the compartment or group of compartments under consideration, as defined in regulation 7-2;

R - required subdivision index.

The probabilities p_i and s_i are calculated according to the well known formulae accepted by IMO, IMO (2005), IMO (2007). The typical process of assessment of safety of ships in damaged conditions at the design stage or when the survivability of existing ships is considered is directed to satisfy the criteria (1). As an example the final results of survivability assessment for the 1100 TEU container ship can be introduced. The main data of this ship necessary to conduct the survivability assessment are as follows, Gdynia Shipyard (1999-2005):

-length between perpendiculars L_{BP}=145.00 m,

-subdivision length L_s=158.66 m,

-deepest subdivision draught d_s=10.20 m,

-light service draught d_l=7.56 m,

-lightweight = 6800.00 tonnes,

-coordinates of centre of gravity: LCG=58.10 m from A.P., VCG=11.10 m above B.P.

The calculations of the attained subdivision index "A" are connected with the large scale numerical calculations and they are time consuming. The final results of the probabilistic survivability assessment for the 1100 TEU container ship are as follows, Gdynia Shipyard (1999-2005), Gerigk (1999-2005), Gerigk (2005b), Gerigk (2006), Woznicki (2005):

$$A = \sum \Delta A_i = 0.52605 \tag{3}$$

$$R = 0.52510 \tag{4}$$

$$\text{Then } A>R \text{ as } 0.52605>0.52510 \tag{5}$$

Even if the criterion (1) is satisfied, by formulae (5), there are serious doubts if the ship could really be safe in operation. Of course, the optimisation of the attained subdivision index "A" can be applied to increase the safety of ships in damaged conditions. The optimisation may concern the optimisation of the so-called local safety indices. However these techniques should be considered as prescriptive as the method itself. Some example calculations associated with using these techniques were conducted at the University of Newcastle upon Tyne in 1991 by Gerigk and published in 1992, Sen et al. (1992).

PERFORMANCE-ORIENTED RISK-BASED DESIGN

As it was introduced by Vassalos, Skjong and the others, 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 embedded as a design objective, along standard design objectives. 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, Vassalos et al. (2005a), Vassalos (2005b), Vassalos (2006), SSRC (2006), Skjong (2004), Skjong (2005), Skjong et al. (2006).

The following steps were introduced to be needed to identify the optimal design solution, SSRC (2006): 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.

A similar approach to assessment of safety of ships for design, safe operation and salvage has been applied for the method presented in the paper. The approach is similar but there are the differences in methods, models, solutions and details. The original structure of the method and proposed risk-based design system for assessment of safety of ships in damaged conditions is presented in Figure 1. Because of the limited space available in the paper more details regarding the method will be presented during the Workshop.

PROPOSED METHOD

The modern approach to ship safety is connected with combining the elements of system approach to safety and Formal Safety Assessment (FSA) methodology, IMO (1997), IMO (2002a). The major elements of the FSA methodology 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, Gerigk (2005a), Gerigk (2005b), Gerigk (2006).

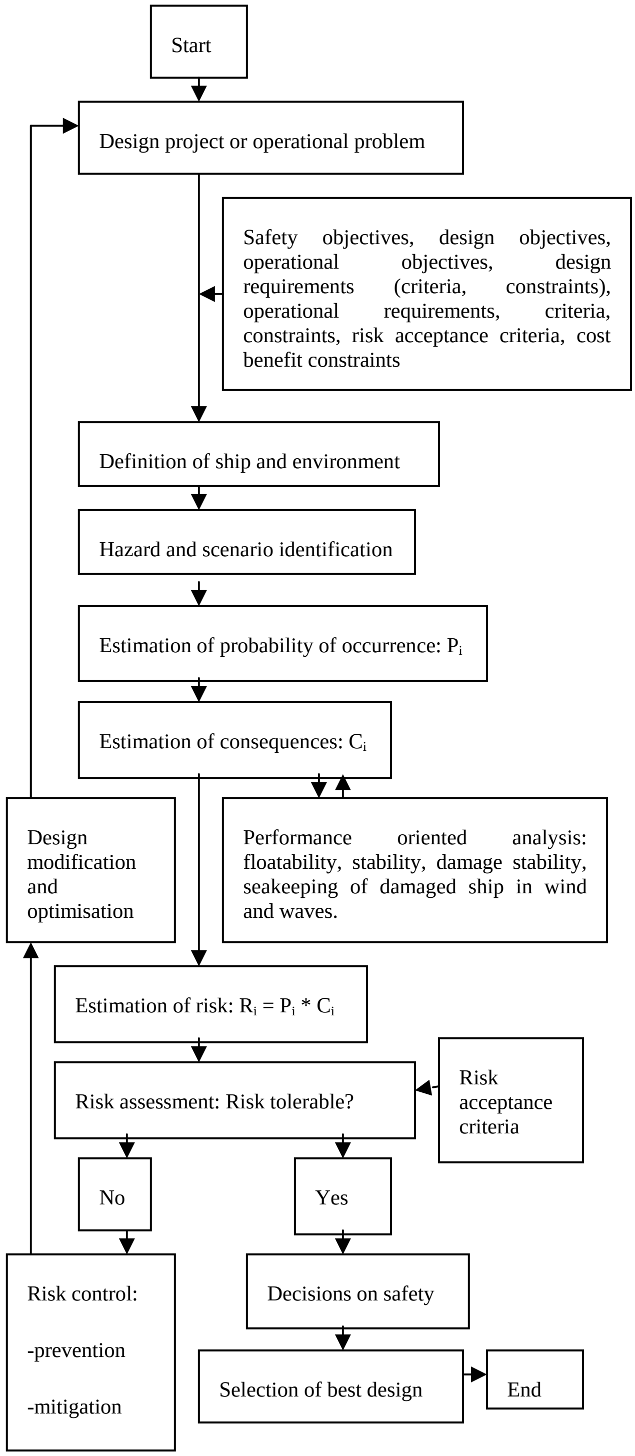

Fig. 1: Structure of the risk-based design system for assessment of safety of ships in damaged conditions.

The following methods have been used for the risk assessment including the hazard identification methods, frequency assessment methods, consequence assessment methods and risk evaluation methods, ABS (2000), Gerigk

(1999-2005): 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).

The risk reduction principle and main strategy adopted for the method was reducing the probability of consequences of accident, Grabowski et al. (2000), Gerigk (2005b), Gerigk (2006).

A method for assessment of safety of ships in damaged conditions is associated with solving a few problems regarding the naval architecture, ship hydromechanics and safety and it is novel to some extent. When preparing the method the global and technical approaches were used, Barker et al. (2000). The global approach mainly regards the problems associated with the development of risk assessment methodology. The technical approach concerns developing either the design, operational or salvage-oriented procedure including the structure of system (method), computational model, design requirements, criteria and constraints, library of analytical and numerical methods and library of application methods, Gerigk (2005a), Gerigk (2005b), Gerigk(2006). There are two approaches to risk management: bottom-up approach and top-down. For example, the top-down risk management methodology has been applied for design for safety. This approach should work in the environment of performance-based standards and help designing the ships against the hazards they will encounter during their operational life, Gerigk (1999-2005), Gerigk (2005a), Gerigk

$$R=P_c \text{ x } P_{c/fdpe} \text{ x } P_{c/fdpe/ns} \text{ x } P_{c/fdpe/ns/tts} \text{ x } C \quad (7)$$

(2005b).

MODELING RISK

The key issue when using the proposed method is to model the risk contribution tree for the risk assessment. Three categories of accidents which may potentially cause a damage to the ship were taken into account: collision, stranding and grounding. According to the statistics these categories are the main reasons of accidents at sea. They constitute about 53% of the whole number of accidents, Kobylinski (2001). The risk contribution trees for the collision, stranding and grounding were developed separately according to the general fault tree FTA and event tree ETA structures. The holistic approach to ship safety has been applied. According to this two major assumptions have been done. First assumption is that the system failures can be either the hardware, software, organizational or human failures. Second concerns the holistic risk model to be applied for assessment of safety of ships in damaged conditions. The Total Risk Management TRM approach should be

$$R_i = P_i \text{ x } C_i \quad (6)$$

implemented as a systematic and holistic approach that builds on the quantitative risk assessment and risk management. The risk associated with the different hazards and scenario development was estimated according to the well known general formulae:

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 holistic risk model for the assessment of safety of ships in damaged conditions is as follows, Jasionowski et al. (2006), Skjong et al. (2006), Gerigk (2005b), Gerigk(2006):

where: P_c - probability of collision (hazard); $P_{c/fdpe}$ - probability of flooding having the ship hit from given direction at data position with given extent conditional on collision; $P_{c/fdpe/ns}$ - probability of not surviving conditional on having flooding when the ship is hit from given direction at data position with given extent conditional on collision; $P_{c/fdpe/ns/tts}$ - probability of given time to sink conditional on not surviving the conditional on having flooding when the ship is hit from given direction at data position with given extent conditional on collision; C - consequences regarding the fatalities, property (cargo, ship) and/or environment.

The risk model (7) is different from the model presented by Skjong et al. as it does not use the conditional probability of sinking given by the P_{sink}=1-A complement probability of the attained subdivision index "A", Skjong et al. (2006).

A good example of the risk and safety assessment according to the proposed method is the design analysis conducted for the container ship as follows:

-length between perpendiculars L_{BP}=163.00 m,

-subdivision length L_s=174.95 m,

-breadth B=26.50 m,

-deepest subdivision draught d_s=9.00 m,

-tonnage P_N=22286.00 DWT.

The hazards and scenarios concern flooding of the following damage zones (presented in Figure 2) due to collision: 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.

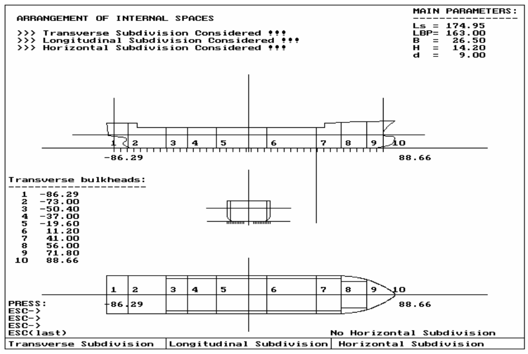

Fig. 2: Arrangement of internal spaces for a container ship, Gerigk (1999-2005), Gdynia Shipyard (1999-2005).

For calculation of the probabilities of occurrence including the uncertainties the Monte-Carlo techniques have been used to obtain the different scenarios, Gerigk (1999-2005), Woznicki (2005). In the case when the risk is estimated according to the formulae:

$$R_i = F_i \text{ x } C_i \tag{8}$$

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.

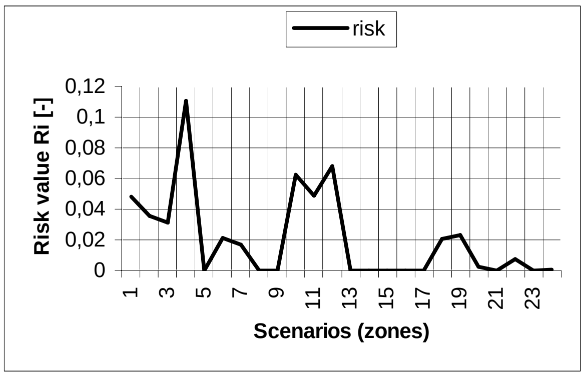

Fig. 3: An example distribution of the risk ($R_i = P_i * C_i$) values.

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 can be taken into account. An example of the risk distribution ($R_i = P_i$ x C_i) in terms of surviving the collision is presented in Figure 3.

SHIP SALVAGE USING THE PROPOSED METHOD

In operation the factors affecting safety of a damaged ship may follow from three major sources: design (engineering), operation and management (ship management, safety management). The harmonized SOLAS Chapter II-1 is mainly related to design. The aspects connected with the operational and management issues are marginally underlined in these regulations. The other regulations better reflect the operation and management as well as the human factor.

Even if the current regulations are based on the probabilistic approach to safety they still are prescriptive in their nature. As indicated before, applying these regulations to certain types of ships the insufficient level of ship safety or unnecessary design restrictions can be observed. Despite many advantages from the ship design point of view the current regulations do not enable to conduct the safety analysis according to the complex sequence of real events which may occur at sea. Within the SOLAS based methodology the objective is survivability that is connected with estimation the attained subdivision index A and satisfying the criteria "A>=R". The index "A" may not reflect to the real level of safety of a damaged ship at sea. There is a problem if the results obtained during the performance-oriented investigations (using the physical and/or numerical simulations) can fully support the assessment of safety of a damaged ship in real sea conditions. Can the risk-based analysis guarantee that the risk level predicted at the design stage could be the same in ship operation. The assessment of safety of a damaged ship in operation requires a rapid modelling of situation. The proposed method enables to use the risk analysis as a salvage-oriented procedure which should be integrated with the risk control (prevention, reduction) embedded as the main objective. The risk analysis regards identifying all the possible hazards, describing all the possible scenarios development and calculating the risk (in terms of probabilities of hazard occurrence and consequences). It is followed by assessing the means of controlling (preventing, reducing, mitigating) the risk. The risk control options are the integrated parts of the method together with the decisions on safety. The multi-level safety assessment can be applied using the risk evaluation criteria.

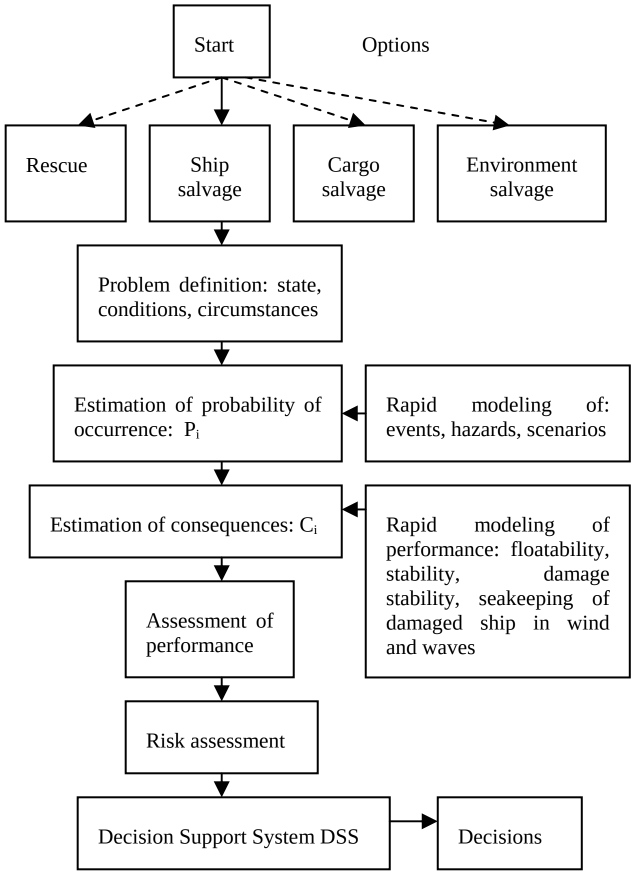

Fig. 4: Structure of the salvage-oriented method.

The main steps of the method as a salvage-oriented procedure are the hazard identification, hazard assessment, scenario development and risk assessment. The hazard and risk assessment are supported by modelling the uncertainties. The risk assessment can be done using the statistical method, analyst judgment, formal expert elicitation and Bayesian analysis.

The basic structure of the salvage-oriented method is presented in Figure 4. Despite of having the rapid modeling possibilities the most important feature for such the method is to have the components associated with the making decisions on safety. The modern decision support tools for salvage purposes can be the fuzzy logic and neural-net techniques. Because of the limited space in the paper the further information on the salvage-oriented method will be presented during the Workshop.

CHALLENGES REGARDING FURTHER INVESTIGATIONS

Currently, there are a few problems under consideration regarding the safety of ships in damaged conditions which are associated with the existing prescriptive method included in the SOLAS Chapter II-1. The first problem concerns how to obtain the same level of safety for different types of ships. The second regards updating the statistical data for the p_i factor estimation. The next problem which can probably not be solved using the prescriptive approach is calculation of the s_i factor taking into account the possible hazards and scenarios.

The new formula for the s_i factor should include the components following from the fact that there are a few stages during the flooding process, IMO (2002b), Dudziak et al. (2001), Gerigk (1999-2005), Santos et al. (2005): creation of damage (stage 1), transient heel and intermediate flooding (stage 2), progressive flooding (stage 3), final stage (stage 4). During the above mentioned stages the internal and external impacts may appear according to the following: wind heeling moment, action of waves, ballast/cargo shift, crowding of people, launching life saving appliances, etc. The combinations of the above mentioned may create the sequences of events (scenarios) which are not taken into account within the current regulations. The alternative methods can be useful for developing the future regulations.

CONCLUSIONS

The performance-oriented risk-based method for assessment of safety of ships in damaged conditions 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 Figure 1. The method uses the performance-oriented risk-based approach to safety. The risk analysis is based on the FSA methodology. The current research requires the further development of modelling the risk. The method can be implemented for the design, operational and salvage-oriented purposes.

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