Mirosław Gerigk
Gdańsk University of Technology

A RISK MODEL FOR ASSESSING THE SHIP SINKABILITY IN UNCERTAIN CONDITIONS

Abstract: The paper concerns the ship safety in damaged conditions. The existing methods of safety assessment of ships in damaged conditions are devoted to design and are very difficult to apply in operational conditions. A method based on the risk and safety assessment of ships in damaged conditions is briefly presented in the paper. The level of risk is the measure of safety. The method applies the ship performance approach together with the risk assessment. The risk analysis is based on application of the matrix type risk model. The risk model enables to take into account the uncertainties connected with the possible scenarios of an accident consisting of combinations of the hazards, intermediate events, additional events (releases) and consequences.
Keywords: safety of ships in damaged conditions, ship salvage, risk assessment

1. INTRODUCTION

The paper presents a few problems regarding a method of risk and safety assessment of ships in damaged conditions where the key issue concerns the risk model. This model should take into account the uncertainties connected with the possible scenarios of an accident. The scenarios consist of combinations of hazards, intermediate events, additional events and consequences. The research is connected with development of a performance-oriented risk-based method for assessment of safety of ships in damaged conditions [1].

The current methods of assessment of safety of ships in damaged conditions are mainly based on the regulations included in the SOLAS convention (Chapter II-1) [2][3]. These methods are more directed towards solving the design problems than those connected with operation or salvage. It follows from many reasons. First of all, these methods are prescriptive in their character. Generally, these methods are based on the probabilistic approach to safety but in some cases the semi-probabilistic components are included. These methods do not take into account all the possible scenarios of an accident. Application of some of these methods to certain types of ships e.g. car-carriers, ro-ro vessels or passenger ships may lead to insufficient level of safety or provide unnecessary design or operational restrictions.

The following methods rely on the regulations included in the SOLAS convention and may be considered for application to the design, operational and salvage purposes.

The first method is based on the holistic risk model for the assessment of safety of ships in damaged conditions which can presented as follows [4][5]:

$$R=P_{c} \times P_{c/fdpe} \times P_{c/fdpe/ns} \times P_{c/fdpe/ns/tts} \times C \quad (1)$$

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 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 second method is based on concepts of : casualty threshold, time to capsize and return to port, where the basic ship safety objectives have been divided into three categories [6]:

-category I - vessel remains upright and afloat and is able to return to port under own power (RTP – Return To Port);

-category II - vessel remains upright and afloat but unable to return to port under own power and is waiting for assistance (WFA – Waiting For Assistance);

-category III - vessel likely to capsize/sink and abandonment of the ship may be necessary (AS – Abandonment of the Ship).

The third method is based on a concept of an absolute survivability where the Safe Return to Port (SRtP) attained subdivision index A_{SRtP} should be calculated according to the ship residual stability characteristics [7]:

$$A_{SRtP} = 0{,}4\, A_{SRtP,s} + 0{,}4\, A_{SRtP,p} + 0{,}2\, A_{SRtP,l} \quad (2)$$

where the subdivision indices $A_{SRtP,s}$, $A_{SRtP,p}$ and $A_{SRtP,l}$ regard the subdivision (s), partial (p) and light ship (l) loading conditions. The $A_{SRtP,s}$, $A_{SRtP,p}$ and $A_{SRtP,l}$ indices should be calculated according to the following formula [7]:

$$A_{SRtP,lc} = \sum_{i=1}^{n} p_i\, s_{SRtP,i} \quad (3)$$

where lc – loading index (lc = s, p, l); p_i - probability that only the compartment or group of compartments under consideration may be flooded, as defined in regulation 7-1 [2][3]; $s_{SRtP,i}$ - probability of survival after flooding the compartment or group of compartments under consideration, in the final stage of flooding only, as defined in [7].

2. THE NEW METHOD OF RISK AND SAFETY ASSESSMENT OF SHIPS IN DAMAGED CONDITIONS

The methodology where the risk-based design and a formalized design methodology were integrated together in the design process with the prevention/reduction of risk as a design objective, along with the standard design objectives was introduced by Vassalos and the others [5][11][12].

The proposed method is a kind of performance-oriented risk-based procedure which enables the risk and safety assessment at the design stage, in operation or during the ship salvage. Within the method the holistic approach to safety assessment of ships is applied. It is based on application of a risk model which includes all the possible scenarios of events during an accident. The method takes into account an influence of design and operational factors on safety and safety management related factors as well. The method is based on implementation of the system integrated approach to safety, elements of Formal Safety Assessment FSA, ship performance-oriented approach and risk-based approach to safety [1]. For the ship performance evaluation the statistics, investigations using the physical models and numerical simulation techniques can be applied. The ship performance evaluation enables to determine the intermediate events, additional events (releases) and consequences and risk of each accident scenario. The aim is to achieve an adequate level of risk by reducing the risk if necessary. Providing a sufficient level of safety based on the risk assessment is the main objective. It is either the design, operational or organizational objective. Then, safety is not a limitation any more, existing in the regulations. It is just the objective. The measure of safety of a ship in damaged conditions is the level of risk. The proposed method may be used at any ship's life circle, including safety assessment of the ship during a catastrophe. Some elements of the method can be used for safety assessment of different means and systems of seaborne transportation. In the future the method can be useful in elaboration of a new methodology of safety assessment of ships, which bases on the application of risk analysis. The method is based on the following steps: setting the objectives, hazard identification, scenarios development, risk assessment, risk control (prevention, reduction), selection of designs (operational procedures) that meet the objectives. The structure of the method is presented in [1].

3. THE RISK ANALYSIS USING THE MATRIX TYPE RISK MODEL

The safety case considered in the paper regards the safety of a ship in damaged conditions when the ship skin is damaged due to the following hazards: collision, grounding, stranding or another reason. The risk and safety assessment for a ship in damaged conditions starts from the modeling of the risk contribution tree. For each hazard a separate event tree should be modeled using the Event Tree Analysis ETA.

Generally, sixteen safety functions have been used for each event tree from the ship safety in damaged conditions point of view. These functions are as follows [1]: function1 (avoiding the hazard); function 2 (hull skin damage (flooding)); function 3 (position and extension of damage); function 4 (equalization of the ship heel at the preliminary stage of flooding); function 5 (loss of the ship stability at the preliminary stage of flooding); function 6 (loss of the ship stability during the intermediate stages (and phases) of flooding; function 7 (loss of the ship stability at the final stage of flooding); function 8 (loss of the ship floatability at the final stage of flooding); function 9 (ship is waiting for assistance); function 10 (ship returns to port under own power); function 11 (ship returns to port by taking in tow); function 12 (ship is continuing the mission); function 13 (mustering and abandonment of the ship (evacuation)); function 14 (SAR action); function 15 (fire and/or explosion); and function 16 (emergency cargo unloading (pollution of the environment)). A position of each function can easily be found in Figure 1 where the basic event tree for the safety assessment of ships in damaged conditions is represented. It is important to notice that each event tree may have a dynamical character.

The holistic approach to ship safety has been applied. According to this approach two major assumptions have been done. First that the system failures can be either the hardware, software, organizational or human failures. The second assumption was that the risk model for assessment of safety of ships in damaged conditions should be the holistic risk model.

The risk associated with the different hazards and scenario development was estimated according to the well known general formulae [1]:

$$R_i = P_i \text{ x } C_i \tag{4}$$

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.

As it is mentioned in (1) the risk model may have four different kinds of losses regarding the human fatalities (HF), cargo and ship losses (CS), environment pollution (E) and financial losses ($) ($C = C_{HF/C}, C_{CS/C}, C_{E/C}, C_{\$/C}$).

The risk analysis requires to calculate the conditional probabilities regarding the initial events ZI_i, major events (hazards) ZG_j, intermediate events ZP_k and final events ZK_l which can be treated as consequences. The basic mathematical formulae are as follows [1]:

$$P(ZI) = P(ZI_i) = \left[P(ZI_1), P(ZI_2), \dots, P(ZI_n)\right] \text{ for i=1 to n} \tag{5}$$

$$P(ZG_j/ZI_i) = \begin{bmatrix} P(ZG_1/ZI_1) & P(ZG_2/ZI_1) & \dots & P(ZG_m/ZI_1) \\ P(ZG_1/ZI_2) & P(ZG_2/ZI_2) & \dots & P(ZG_m/ZI_2) \\ \dots & \dots & \dots & \dots \\ P(ZG_1/ZI_n) & P(ZG_2/ZI_n) & \dots & P(ZG_m/ZI_n) \end{bmatrix} \tag{6}$$

for j=1 to m.

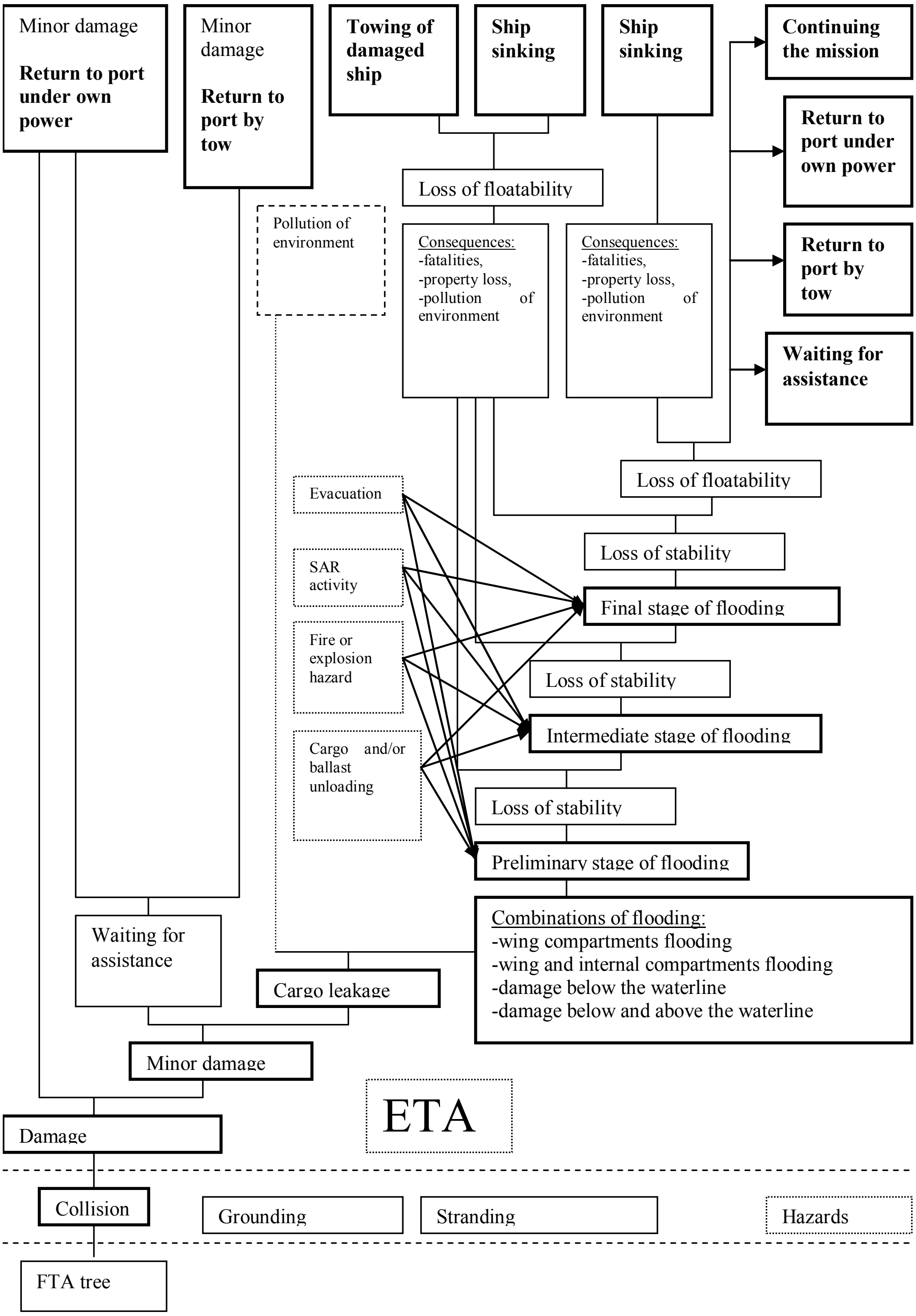

Fig. 1. A basic event tree for the salvage purposes

$$P(ZP_k/ZG_j)=\begin{bmatrix} P(ZP_1/ZG_1) & P(ZP_2/ZG_1) & \dots & P(ZP_{m1}/ZG_1) \\ P(ZP_1/ZG_2) & P(ZP_2/ZG_2) & \dots & P(ZP_{m1}/ZG_2) \\ \dots & \dots & \dots & \dots \\ P(ZP_1/ZG_m) & P(ZP_2/ZG_m) & \dots & P(ZP_{m1}/ZG_m) \end{bmatrix} \quad (7)$$

for k=1 to m1.

$$P(ZK_l/ZP_k)=\begin{bmatrix} P(ZK_1/ZP_1) & P(ZK_2/ZP_1) & \dots & P(ZK_{m2}/ZP_1) \\ P(ZK_1/ZP_2) & P(ZK_2/ZP_2) & \dots & P(ZK_{m2}/ZP_2) \\ \dots & \dots & \dots & \dots \\ P(ZK_1/ZP_{m1}) & P(ZK_2/ZP_{m1}) & \dots & P(ZK_{m2}/ZP_{m1}) \end{bmatrix} \quad (8)$$

for l=1 to m2.

Because of the above mathematical model used the entire risk model is called as the matrix type risk model. The risk model enables to consider many possible scenarios of an accident using the event tree like presented in Figure 1. In the case when the additional events occur the probability of occurring the given consequences $PoC(C_i)$ can be calculated according to the formulae presented in [1]. The typical additional events may concern the water on deck, air cushions, cargo leakage, additional heeling occurrences, and passenger behavior.

4. APPLICATION OF THE METHOD AND RISK MODEL FOR THE SHIP SALVAGE

The ship accidents at sea may lead to the loss of life, loss of properties (ship and cargo) and pollution of environment. The modern approach to safety of seaborne transportation requires to apply the so-called life-circle approach by integrating the design for safety, safe operation and safe salvage methods. Most of the salvage activities have been associated with using the rules of thumb without a support based on the safety assessment process. The effective and safe ship salvage requires to develop the methods, models and tools for the assessment of risk and safety of ships in damaged conditions.

The proposed method of risk and safety assessment of ships in damaged conditions together with the matrix type risk model enables to assess a ship survivability at each stage of flooding including the preliminary, intermediate and final stages of flooding. Such an assessment is necessary to predict any further deterioration of the damage condition. It may be connected with further flooding of compartments and ship listing increase. This assessment also regards predicting how long it would take the ship to capsize or sink. If the ship survives flooding (a ship remains upright (or heeled) and afloat) and is unable to return to port under own power it is necessary to solve the problems associated with the towing when waiting for an assistance. The number of towing points and towing speed in the calm and rough weather conditions should be evaluated. During the towing the risk and safety assessment of the ship should be permanently conducted.

Two different examples of a ship performance data (in the physical model scale) regarding the ship roll function in time domain and a concept of the ALARP risk evaluation criteria applied for assessment of safety of the ship in damaged condition are presented in Figure 2.

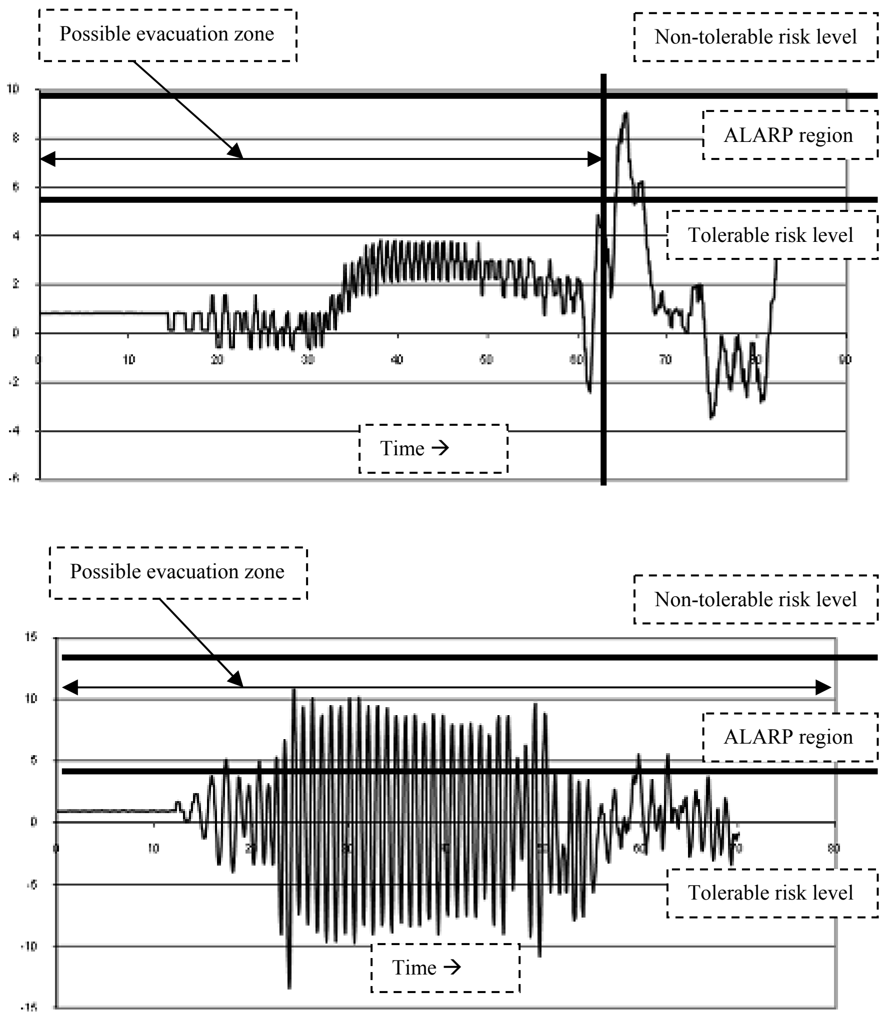

Fig. 2. Two examples of a ship performance data (a ship roll in damaged conditions (in degrees) in time domain (in seconds)) and ALARP risk acceptance criteria application

5. CONCLUSIONS

Some elements of the method of risk and safety assessment of ships in damaged conditions together with the matrix type risk model are presented in the paper. The proposed risk model is much more complicated than the model given by Skjong et al. [4][5][11][12]. By using (5), (6), (7) and (8) the proposed risk model enables to estimate the risk level for all the possible scenarios of an accident when ship is in damaged conditions.

The current research is associated with further developing the risk models necessary for the ship performance-oriented and risk-based assessment. From the practical point of view the research should bring a model for the computer simulation of the ship salvage process.

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MODEL RYZYKA OCENY ZATAPIALNOŚCI STATKU W WARUNKACH NIEPEWNOŚCI

Streszczenie: Artykuł dotyczy bezpieczeństwa statków w stanie uszkodzonym. Obecne metody oceny bezpieczeństwa statków w stanie uszkodzonym są ukierunkowane na projektowanie i trudno je zastosować w warunkach operacyjnych. Opisano metodę oceny ryzyka i bezpieczeństwa statku w stanie uszkodzonym, w której miarą bezpieczeństwa jest poziom ryzyka. Zastosowano podejście oparte na ocenie zachowania statku i ocenie ryzyka wypadku. W analizie ryzyka wykorzystano macierzowy model ryzyka, umożliwiający analizę scenariuszy wypadku przy uwzględnieniu niepewności związanych z wystąpieniem zagrożeń, zdarzeń pośrednich, zdarzeń dodatkowych i konsekwencji wypadku.

Słowa kluczowe: bezpieczeństwo statków w stanie uszkodzonym, ratowanie statków, ocena ryzyka