Concept of implementation of open water model tests for assessment of safety of ships in damaged condition

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Abstract

The paper presents the preliminary information on the concept of open water model tests for assessment of safety of ships in damaged conditions. The need to develop the concept follows from the fact that the current regulations for assessment of safety of ships in damaged conditions require to consider an influence of many factors coming from different sources. Among the most important factors are those which come from the ship itself and the environment. Of course, the current regulations take into account the impacts which follow from the stages of flooding and progressive flooding but not all the possible impacts are taken into account. The open water model tests may enable to verify the existing regulations and model some phenomena associated with flooding. The open water model tests can be an important alternative method for the assessment of ship safety. The current method and some elements of the new approach to the safety of ships in damaged conditions are briefly described in the paper. A concept of the open water model tests for assessment of the safety of ships in damaged conditions are introduced. Some details regarding the research stand are given. The preliminary programme of investigations is presented as well. Because of the limited space available in the paper more details regarding the concept of open water model tests will be given in the POWER POINT presentation during the Symposium and in the final version of the paper.

Keywords: *assessment of safety, model tests, safety of ships, safety of ships in damaged conditions*

INTRODUCTION

The current requirements regarding the safety of ships in damaged conditions are included in the harmonized SOLAS chapter II-1 parts A, B and B-1 and are still based on the IMO Resolution A.265 (VIII). In comparison with the previous version of SOLAS in these regulations more factors affecting safety of ships in damaged conditions are taken into account. It was possible due to the outcome of HARDER project and extensive work of the IMO SLF Sub-Committee during its 46, 47 and 48 sessions. In May 2005 the IMO Maritime Safety Committee (MSC) approved the revised and harmonized SOLAS chapter II-1 and it will be put into force together with the Explanatory Notes in 2009.

The current regulations are prescriptive in their character and are based on experience. The changes in legislation are difficult to proceed and time consuming. The expectations of the maritime sector are that they will meet new needs and challenges. The current regulations do not enable to meet them and there is no possibility to apply the pro-active approach to safety. Safety still becomes a constraint included in the prescriptive regulations.

The current work on safety of ships in damaged conditions concentrates on development of the Expalantory Notes for the harmonized SOLAS chapter II-1. Although the new SOLAS chapter II-1 is accepted by the IMO MSC Committee there is a necessity to continue the work on modelling the behaviour of ships in damaged conditions because of many reasons. One of them is that using the current regulations the assessment of safety of ships in damaged conditions requires to conduct the computer based calculations of performance of a ship in damaged conditions. The model tests of ships in damaged conditions can be treated as an alternative method and are very usefull for validation purposes when assessment of safety of ships in damaged conditions is done according to the current regulations.

Current method

According to the current SOLAS based regulations the assessment of safety of a ship in damaged conditions is associated with estimation of the subdivision index A value which should be checked against the required subdivision index R value. The design criterion is as follows:

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

The subdivision index A value should be calculated according to the formula:

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

where:

- pi - probability of flooding of the group of compartments under consideration;
- si - probability of survival after flooding of the group under consideration.

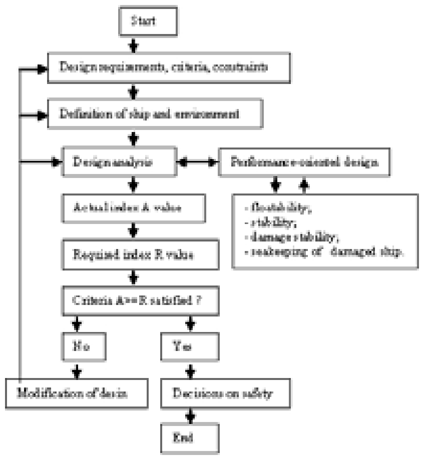

Fig. 1 *logical structure of procedure for assessing the criteria (1) according to the current solas based methodology*

The procedure of estimation of the index A value is associated with conducting the calculations including:

1. floatability;
2. stability;
3. damage stability;
4. dynamical stability of damaged ship;
5. behavuiour of damaged ship in wind and waves (seakeeping of damaged ship).

When predicting the motions of the damaged ships in waves the main contributing factors are as follows:

1. the flooding process;
2. the floodwater effects on the ship motions;
3. mass inertia and hydrodynamic mass effects;
4. potential and viscous damping;
5. restoring effects;
6. wave induced forces.

The performance-oriented design requires assessing the behaviour of a given ship in a given set of environmental and operational scenarios on the basis of her performance in terms of hydromechanical characteristics of a damaged ship in waves. During the design analysis regarding the damaged ship an influence of parameters associated with the hull form, arrangement of internal spaces, loading conditions, position and extent of damage, cargo shift and weather impacts can be taken into account.

The general major parameters associated with estimation of the index A value are the following: hull form, arrangement of internal spaces, loading conditions, position and extension of damage, environment (waves), flooding including the stages of flooding, impacts following from different sources.

The general major parameters associated with estimation of the required index R are as follows: size of ship, number of passengers.

New approach to safety

The new approach to safety is closely associated with the risk-based design. The risk-based design is a formalized design methodology that integrates systematically risk analysis in the design process with the prevention/reduction of risk embedded as a design objective, along the 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. 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 offers freedom to the designer to choose and identify optimum solutions to meet safety targets. For the risk-based design safety must be treated as a life cycle issue.

Regarding the current work on safety of ships in damaged conditions conducted at the Chair of Naval Architecture, Faculty of Ocean Engineering and Ship Technology, Gdansk University of Technology it is associated with the development of a method for assessment of safety of ships in damaged conditions which is a performance-oriented risk-based method. Within this method a measure of safety of ships in damaged conditions is either the risk or level of risk.

The risk is defined as follows:

$$R = P * C \tag{3}$$

where:

P – probablity of a hazard occurrence;

C – consequences of a given hazard occurrence.

The risk is estimated using the risk analysis. The risk analysis requires to perform the hazard identification, scenarios development, hazard assessment, risk assessment and risk control.

The risk analysis is combined together with the performance-oriented investigations. It follows from the fact that there is a need to consider all the possible fault trees (sequence of events) to define the hazards, first of all. When the hazards are found, all the possible consequences of an accident should be defined by developing the event trees (another sequence of events). It should be noted that the different consequences may follow from the different hazards or combination of hazards.

Such an approach to ship design and safe operation has been applied for the method presented by the author. Because of the limited space available the particulars of the performance-oriented risk-based method will be omitted in this paper.

Model tests of ships in damaged conditions

Despite all the developments associated with the current regulations regarding the safety of ships in damaged conditions included in the harmonized SOLAS chapter II-1 parts A, B and B-1, there is still a need to apply the model tests of ships in damaged conditions.

The reasons are as follows:

1. model tests of ships in damaged conditions can be treated as an alternative method of safety assessment of ships in damaged conditions;
2. model tests of ships in damaged conditions enable to verify the results obtained using the SOLAS based procedure of estimation of the index A value;
3. model tests of ships in damaged conditions enable to verify the results obtained using the different codes of computer simulation of a ship performance in damaged conditions;
4. model tests of ships in damaged conditions enable to verify and develop the new models for assessment of safety of ships in damaged conditions.

In the early 2004 the 24th ITTC Specialists Committee on Stability in Waves initaiated the study on stability of ships. Between the problems the stability of damaged ships was indicated. The activities were completed at the end of year 2004. The participants of the study were the following:

1. National Technical University of Athens, Ship Design Laboratory, Greece;
2. Ship Stability Research Centre SSRC, Universities of Glasgow and Strathclyde, United Kingdom;
3. Marine Research Institute, MARIN, The Netherlands;
4. Instituto Superior Tecnico IST, Lisbon, Portugal;
5. Korea Research Institute of Ships and Ocean Engineering KRISO, Korea.

The major objectives of the study were as follows:

1. to provide a thorough insight into the fundamental properties of the benchmark numerical methods presented in Table 1;
2. to assess the performance of each numerical method with respect to the available experimental data and the other methods;
3. to assess the overall efficiency of the investigated methods.

The method of study was such that the numerical methods were assessed by a series of tests of various complexity. The model tests were selected in order to enable to the extent feasible the isolation of the basic component of the problem. The sensitivity of the numerical methods as well as their absolute efficiency were assessed.

Hydrostatic forces by direct pressure integration
Potential strip theory
Potential 3D panel method
Incident wave forces by direct pressure integration
Memory effects
Semi-empirical roll viscous damping
Roll viscous damping analysis in components
Floodwater assumed as a horizontal free surface
Floodwater assumed as moving plane free surface
Internal water motion by shallow water equations
Numerical method
Ship motion degrees of freedom
Flooding by simple hydraulic model

***Table 1** the benchmark methods used during the 24th ittc benchmark study*

The investigations were conducted for the following ships:

1. passenger Ro-Ro ferry (PRR01) of LBP = 170.00 meters (model scale: 1:40);
2. tanker of LBP = 310.20 meters (model scale: 1:82.5);
3. passenger Ro-Ro ferry (PRR01) of LBP = 174.80 meters (model scale: 1:38.25).

The results of study were the following:

1. modelling of the inertia and restoring forces was generally correct;
2. model tests confirmed that the viscous roll damping by semi-empirical coefficients can be usefull;
3. deviations between the results obtained by different numerical methods (Table 1) are caused by the fact that different approaches were used to determine the effect of floodwater on ship motions;
4. there is a necessity to improve the modelling of the flooding process and progressive flooding effects.

Concept of open water model tests of ships in damaged conditions

In Poland, the open water model tests of ships in damaged conditions can be conducted at the Ship Handling Resarch and Training Centre in Ilawa. The objectives of the open water model tests of ships in damaged conditions could be the following:

1. alternative method of safety assessment of ships in damaged conditions;
2. verification of results obtained using the SOLAS based procedure of estimation of the index A value;
3. verification of results obtained using the different codes of computer simulation of a ship performance in damaged conditions;
4. verification and development of new models for assessment of safety of ships in damaged conditions;
5. training of masters, ship officers, naval architects and students.

The logical structure of the risk-based design/operational procedure (method) is introduced in Figure 2. The performance-oriented open water model tests of ships in damaged conditions which can be a part of the entire research activities should cover the following characteristics of ships in damaged conditions:

1. floatability;
2. stability;
3. damage stability;
4. dynamical stability of damaged ship;
5. seakeeping of damaged ship.

The idea of the performance-oriented open water model tests of ships in damaged conditions is based on the following assumptions:

1. all the necessary data regarding the characteristics of the ships used during the tests are generated using the numerical and computer simulation;
2. ship models used during the tests may be as follows:
   · struck model (damaged ship);
   · striking model;
3. the struck model should always be a full size model;
4. striking model can either be a full size model or a bow-section model;
5. structure of the research stand, equipment and system of indicators involved during the investigations depend on the test variant;
6. the tests should be conducted according to a programme;
7. results of investigations should be worked out and verified using the numerical and computer simulation
.

Research stand

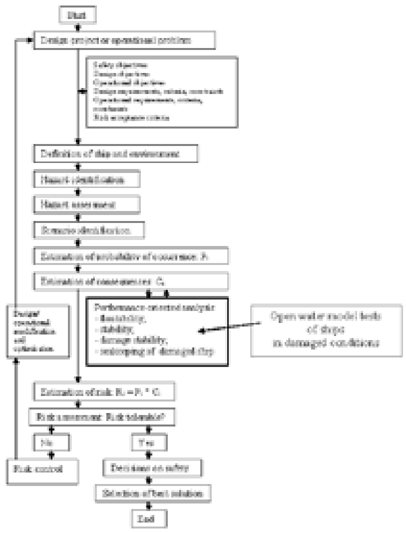

***Fig. 2** Logical structure of the risk-based design/operational procedure (method).*

The general structure of the research stand is presented in Figure 3.

One of the major characteristics which has to be known to

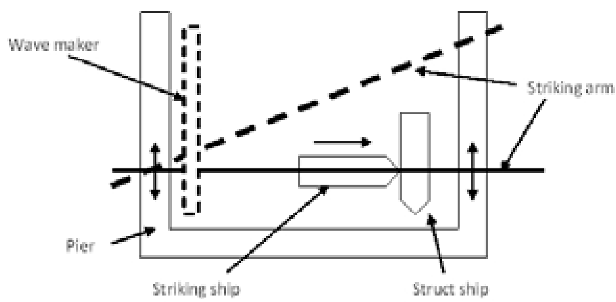

***Fig. 3** General structure of the ship survivability research stand*

determine the energy of the striking ship is the towing force along the striking arm. Using the gravitational dynamometer, the towing force can be calculated according to the formula:

$$F = m\,(dv/dt) + R_T(v) \qquad (4)$$

where:

- F– towing force;
- m – total mass including the mass of model, added mass, mass of weights and mass of inertia of the rotating parts of dynamometer;
- R_T– total resistance of model;
- v – velocity of model.

Assuming that the total resistance of the model is proporcional to the exponent of velocity:

$$R_T = c_T\ v^2 \qquad (5)$$

The formula (3) may be expressed as follows:

$$F = m\,v\,(dv/ds) + c_T\ v^2 \qquad (6)$$

where:

s – distance passed by model.

To decrease the distance between the struck and striking models/ships the additional accelerating force has to be implemented according to the formula:

$$F + F_a = m\,v\,(dv/ds_a) + c_T\ v^2 \qquad (7)$$

where:

- F_a – additional accelerating force;
- s_a – distance when the model accelerates.

Solving the formula (7), the distance sa can be estimated.

The general structure of the gravitational type striking arm is presented in Figure 4.

Background for investigations

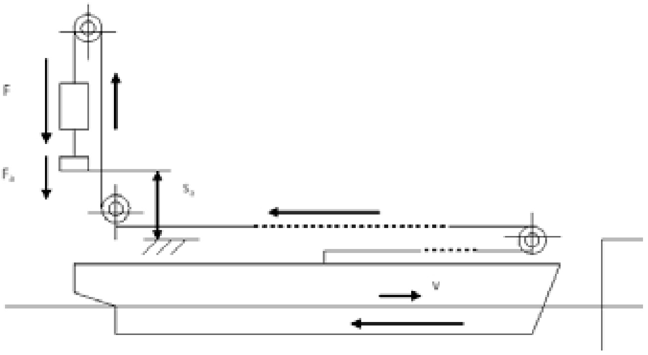

***Fig. 4** General structure of the gravitational type striking arm*

The background of the tests are the risk analysis of collisions, external dynamics of ship collisions, internal mechanics of ship collisions, deterministic and probabilistic analysis of collisions and ship survivability.

During the tests, the model of the ship collision probability can be based on the number of possible ship collisions and can be estimated as follows:

$$P[\text{collision}] = 1 - \exp(-\text{Nship-ship}) \qquad (8)$$

where:

Nship-ship – expected number of ship to ship collisions determined as follows:

$$\text{Nship-ship} = \text{Pc Na} \qquad (9)$$

where:

- Pc – the causation probability;
- Na – number of possible ship collisions.

The waterway intersection using the definition of collision diameter is taken from Petersen (1995).

The collision risk factors can be divided into three main groups:

1. waterway system including environmental conditions;
2. involved vessels;
3. human factors.

During the tests, the possible consequences of a collision can be as follows:

1. minor damage - economic consequences;
2. severe damage:
3. oil spill – environmental consequences;
4. capsizing – total loss of vessel.

Program of open water model tests of ships in damaged conditions

The behaviour of damaged ships in the calm water conditions have been well investigated according to the damage stability model tests. Such tests enable to determine if a ship would survive or not after flooding of a single watertight compartment or group of adjacent watertight compartments according to its reserve buoyancy, draft and trim and damage stability characteristics.

Predicting the behaviour of damaged ships in rough seas is much more difficult than in the calm water conditions. It follows from the fact that there are a few factors affecting the motion of a damaged ship in waves.

They are as follows:

1. ingress/egress of external water into and out of the damaged compartment or group of compartments under consideration;
2. impact of air cushions;
3. impact of heeling moments from different sources (cargo shift, launching the life saving appliances, passengers behaviour, etc.).

The program of the open water model tests of dynamics of damaged ships should consist of the following tests:

1. intact model tests;
2. investigations of influence of the position (longitudinal, vertical) and extent (shape) of damage on rolling / sway / heave motions;
3. investigations of influence of the quantity of water in damaged compartment on rolling/sway/heave motions;
4. investigations of influence of the quantity of water in damaged compartment under the deck (perforated deck) on rolling/sway/heave motions;
5. investigations of influence of the initial angle of heel due to asymmetric loading on rolling/sway/heave motions during flooding;
6. investigations of influence of the leeward (windward) side, when damage is sealed, on rolling/sway/heave motions;
7. investigations of influence of the bottom damage on rolling/sway/heave motions.

	Stage 1	Stage 2	Stage 3	Stage 4
wind heeling moment	X	X	X	X
action of waves	X	X	X	X
ballast/cargo shift			X	X
Crowding of people		X	X	X
launching life saving aids		X	X	
air-flow bags action			X	X

***Table 2** an example matrix of events during flooding*

Research problems for further investigations

There are many problems included in the regulations which require further development as either the short or long term actions.
Among the problems are the following:

1. intermediate stages of flooding;
2. equalization after flooding;
3. water on deck and progressive flooding;
4. impact of air cushions;
5. impact of the heeling moments due to the cargo shift, passengers behaviour or lauching of the life saving appliances.

When predicting the motions of the damaged ships in waves, the main contributing factors are the following:

1. the flooding process;
2. the floodwater effects on the ship motions;
3. mass inertia and hydrodynamic mass effects;
4. potential and viscous damping;
5. restoring effects;
6. wave induced forces;

Evaluating the performance of numerical methods it can be underlined that regarding the free roll decay of the damaged ship the key results are non-satisfactory. The same applies to the damaged ship motions taking into account the regular (large) wave excitations.

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