On a risk-based method for safety assessment of a ship in critical conditions at the preliminary design stage

Current report

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ABSTRACT

The paper presents some current results of the research on development of a method for safety assessment of ships in critical conditions at the preliminary design stage. The method is expected to make it possible to perform the multi-objective and multi-parametric investigations to achieve the required and optimum levels of safety by using the risk-based and formal approaches to ship safety. During the design analysis influence of parameters associated with the hull form, arrangement of internal spaces, loading conditions, position and extent of damage, cargo shift and weather impacts on safety of ships in critical conditions will be taken into account. Current capabilities of the method are illustrated by several calculation examples of influence of different arrangements of internal spaces of a cargo ship on values of the IMO formal subdivision indices such as the "Attained Subdivision Index A" and "Local Subdivision Indices ΔA_j". The method is still under development and its final structure will be presented in the near future.

Key words : ship safety, formal safety assessment, design for safety, ship hydromechanics, survivability

INTRODUCTION

During the last decade many European institutions conducted the investigations related to the ship safety problems [1, 2, 3, 4, 5]. Recently, the HARDER research programme has been set up to revise the SOLAS Convention, (Chapter II-1 Parts A, B and B-1), it has been aimed at solving the following problems [8] :

- reviewing model tests and methods concerning safety evaluation and assurance including the development of the methods contained in A.265 IMO document [14], and also that applicable to Ro-Ro ships
- survival prediction for various ships in waves including observed mechanisms of capsize
- estimation of probability of sea state occurrence at the time of a casualty
- development of the so called survival factor "s".

Also, at the Chair of Ship Hydromechanics, Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology two projects have been conducted regarding a new method and model for the safety estimation of ship in critical conditions, as well as a model for direct risk assessment of ships in critical conditions [6 , 7]. The major research issues associated with the above mentioned projects were :

- damage stability modelling methods
- large scale flooding
- dynamic effects due to internal (ballast and/or cargo shift) and external (waves, wind) impacts
- development of survival criteria for the ships in damage condition
- investigations on the safety assessment
- and example preliminary designs.

The critical conditions have been defined as the ingress of external water into any group of watertight compartments of a ship, associated with both internal (cargo and/or ballast shift) and external (waves and wind action) impacts.

The knowledge base for the research includes: naval architecture, ship hydromechanics, system approach to safety, safety case/formal safety assessment (FSA) methods, IMO regulations for ship safety.

This paper is devoted to presentation of some current results of the conducted research projects regarding development of a method for safety assessment of ships in critical conditions at the preliminary design stage.

MAJOR ASSUMPTIONS FOR THE MODERN APPROACH TO SHIP SAFETY IN CRITICAL CONDITIONS

The modern approach to ship safety in critical conditions is based on the general assumption as follows :

The first assumption

The factors affecting the ship safety in critical conditions may result from different sources : design, operation and management.

The second assumption

The factors affecting the ship safety may come from different groups of factors such as :

- 1st - the external factors not related to the environment :

general human factor, control systems, technical means, legislative actions.

- ♦ 2nd - the environmental factors including the wind, waves and current.
- ♦ 3rd - connected with the ship :
  - ⇨ ship including hull, propeller and rudder
  - ⇨ cargo including arrangement of internal spaces, cargo and ballast distribution and loading condition
  - ⇨ inter-related parameters and characteristics directly connnected with ship safety: intact stability, damage stability, dynamical stability in damage condition, and survivability.
- ♦ 4th - connected with ship operation: the ship management system including the ship safety system.
- ♦ 5th - connected with the shipping company's safety management system and safety culture.
- ♦ 6th - the human factor including both the psychological and physical predispositions, character, morale, integrity, knowledge, experience and training degree.

In the current work the factors of the first four groups have been taken into account in the method for assessment of ship safety in critical conditions.

The third assumption

The modern approach to ship safety is connected with combining: the system approach and Formal Safety Assessment (FSA) method which contains : hazard identification, risk assessment and risk reduction.

By taking into account these elements the method in question has gradually been developed to include the following components (shown also in Fig.1) :

- design requirements, criteria and constraints
- risk acceptance criteria
- safety objectives
- ship and environment definition
- design analysis :
  - ⇨ hazard identification
  - ⇨ hazard assessment
  - ⇨ scenario development
  - ⇨ hydromechanical design analysis (intact stability, damage stability, dynamical stability in damaged condition)
- risk assessment
- risk acceptance criteria
- risk reduction (mitigation measures)
- modification of design
- ship safety assessment
- decisions on ships safety.

For estimating the risks the following techniques have been selected to be used within the method :

- ⇨ ALARP (As Low As Reasonable Possible) concept
- ⇨ F-N curve : the frequency of fatalities in function of number of fatalities
- ⇨ Risk acceptance matrix.

For the hazard identification the hazard and operability (HAZOP) studies have been used as the most effective technique. The event tree analysis (ETA) has been used for the scenario identification.

The statistics and investigations into serious casualties, documented in [9], have been assumed the major source of information on hazards and risks involved in shipping. It has been further assumed that the design method should combine both global approach and technical approach [13].

The global approach has concerned the method framework containing the elements just above enumerated. The technical approach has been connected with the developing of :

- ✧ logical structure of design system
- ✧ design requirements, criteria and constraints
- ✧ logical structure of computational model
- ✧ analytical and numerical methods
- ✧ application methods regarding the intact stability, damage stability, dynamical stability in critical and damage condition.

For risk management considerations the top-down risk management method has been applied which is suitable for design for safety at the preliminary design stage.

METHOD OF SHIP DESIGN FOR SAFETY IN CRITICAL CONDITIONS

A worked-out safety estimation method for ships in critical conditions is associated with solving a few problems regarding the naval architecture, ship hydromechanics and ships safety, and it is novel to some extent.

The logical structure of the method and design system combining the global approach and technical approach is presented in Fig.1.

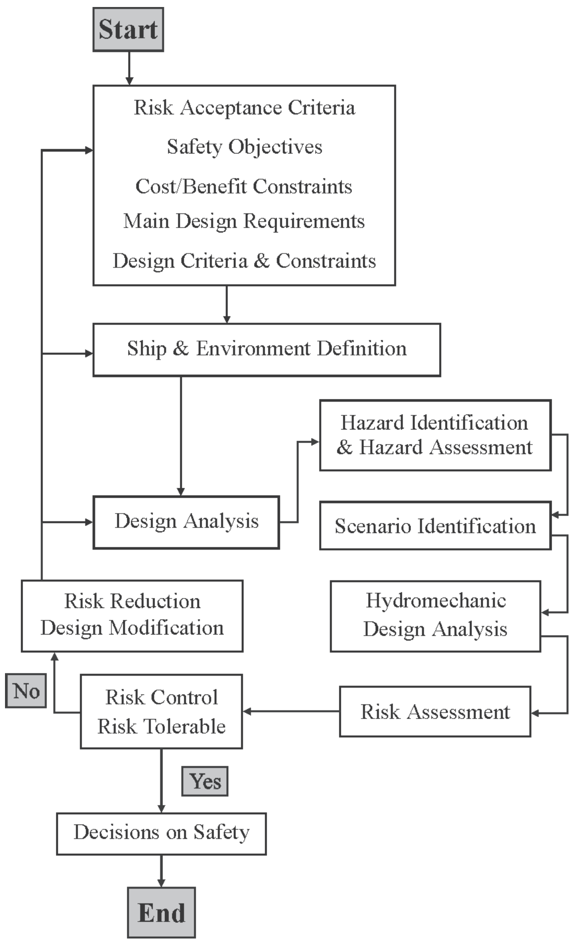

Fig.1. *Logical structure of the design system and computational model combining the global approach and technical approach*

According to Fig.1, the ship and environment are defined as objects of hydromechanics, described by a set of parameters. The "Hydromechanic Design Analysis" module contains the design methods in which both the functions and procedures associated with solving particular ship hydromechanics problems are used. The "Risk Assessment" module includes the methods which combine both the "hydromechanics" and "risk assessment" functions and procedures. The "Main Design Requirements" module is intended to be consisted of :

- general requirements
- IMO regulations
- requirements of classification societies and
- requirements of conventions (SOLAS`90 and SOLAS`95.

The current set of requirements included into the database has so far concerned the IMO regulations only. The database will eventually include both the risk acceptance criteria, safety objectives, main requirements and design criteria and constraints.

By using the method
two separate design processes can be initiated:

- iterative approach
- parametric investigations.

From the design process point
of view the method consists of two sub-methods [10]:

- parametric method - when intact stability and damage stability characteristics are calculated
- semi-probabilistic or probabilistic method - for solving the problems related to the survivability and risk assessment.

The following design options of the computational model, based on the IMO regulations [15], are currently offered :

- calculation of the "Attained Subdivision Index A"
- calculation of the "Local Subdivision Indices ΔA_j"
- calculation of the "Probability of Oil Out-flow"

Moreover it is possible to use the option : calculation of the "Probability of Capsizing in Critical Conditions", not covered by the IMO regulations, i.e. the direct risk assessment method which is still under development.

At the current stage of development of the method
it has been assumed that the method :

- has scientific and research features rather than purely design one
- is useful for design of the conventional cargo vessels only.

The method is still under development
and its final structure will be presented in the near future.

COMPUTATIONAL MODEL OF SHIP DESIGN FOR SAFETY IN CRITICAL CONDITIONS

The most important features
of the computational model in question are as follows :

- it is open
- it has a hybrid-modular structure
- it has a common library of analytical and numerical methods
- it has a common library of application methods.

From the practical point of view the computational model is based on a dynamical database concept, and it is original to some extent. The database is modular and related to the logical structure of the computational model. The database enables to provide the safety estimation when ship's hydromechanical characteristics are estimated by using : the numerical calculations (direct methods), model tests results, results from the full scale trials, combined empirical and numerical calculations (semi--direct methods) or empirical calculations (indirect methods).

The computational model has been prepared for the PC Windows–based workstations. The application software is programmed in Fortran, Pascal and C++ languages. The detail structure of the data base including the input data, outputs, graphics and ship design data will be presented in the near future.

At the current stage of work it is possible to use the method and computational model for the research purposes only. A version for implementation for the research and design purposes would be available soon.

SOME EXAMPLES OF CURRENT CAPABILITIES OF THE METHOD IN QUESTION

Below presented are a few examples of using the method for calculation the probability of flooding any group of compartments, optimisation of the "Attained Subdivision Index A" and calculation of the "Local Subdivision Indices ΔA_j" in compliance with IMO relevant regulations.

Example 1

Calculation of the probability of flooding any group of compartments

At the design stage the estimation of the probability of survival of flooding any group of compartments is connected with calculation of the "Attained Subdivision Index A" [15]. The risk assessment is associated with satisfying the criterion :

$$A \geq R$$

where :

$$A = \Sigma\, p_i\, s_i$$

Both the indices, A and R, are calculated according to the formula accepted by IMO. In the presented example the formula given by the Resolution MSC 19/58 – "Subdivision and damage stability of cargo ships over 100 m" has been applied.

A typical set of ship initial data
for the given ship may look as follows :

- main parameters
- stability data, hull form
- arrangement of internal spaces (like the presented in Fig.2)
- loading condition
- set of permeabilities.

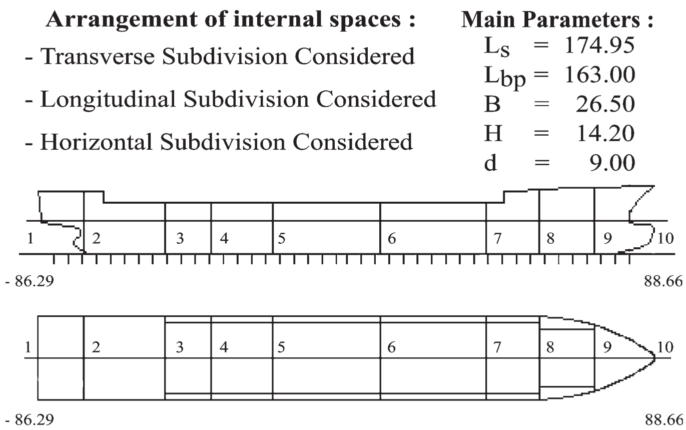

Fig.2. *An example arrangement of internal spaces of a containership*

According to the performed calculations value of the "Attained Subdivision Index A" is as follows [16] :

$$A = \Sigma \Delta A_{pi} = 0.5501$$

The Required Subdivision Index is:

$$R = (0.002 + 0.0009 \cdot L_S)^{1/3} =$$

$$= (0.002 + 0.0009 \cdot 174.98)^{1/3} = 0.54230$$

where :

$$L_S = 174.98 \text{ [m]}$$

The final result satisfies the relation A > R, as :

$$0.5501 > 0.5423.$$

Example 2

Optimisation of the "Attained Subdivision Index A"

For more advanced procedures of design for safety of a ship in damage condition the following approach can be applied. In Fig.3 the arrangement of internal spaces of a cargo ship is presented. During the computer simulation three design versions regarding the number and position of transverse bulkheads were taken into account. Tab.1 presents the results of optimisation of the "Attained Subdivision Index A" for all the design versions (Fig.3). During the optimisation process the preliminary positions of some bulkheads were significantly changed.

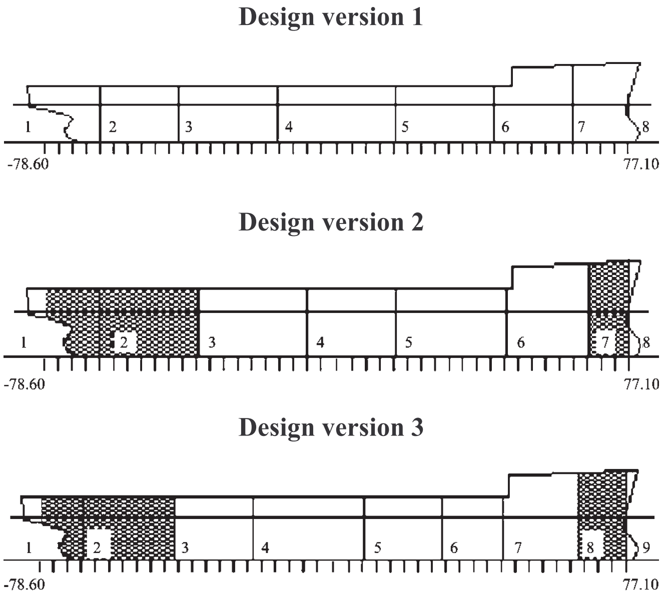

Fig. 3. Three different preliminary arrangements of internal spaces of the considered cargo ship

The optimisation method consited in maximization of the objective function represented by the "Attained Subdivision Index A". Its aim concerned reaching possible maximum values of the $p_i \cdot s_i$ factors for each group of the watertight compartments. One of the constraints was that the s_i value should never be equal to null. The major starting design conditions were : number and positions of bulkheads.

The investigations showed that a larger number of bulkheads not necessarily guarantee much higher values of the index "A". Moreover, by applying one bulkhead more the p_i values become greater for the groups including two or more single compartments, but in the same time the conditional probabilities s_i decrease. The values of p_i and s_i factors are interrelated

Tab. 1. *Results of optimisation of the "Attained Subdivision Index A"*

Ship type: general cargo Design criterion: optimisation of the "Attained Subdivision Index A"		
Design version 1	**No. of iteration**	**Index A value [-]**
	I	0.6560
	II	0.7181
	III	0.8162
	IV	0.8171
	V	0.8174
	VI	0.8177
Design version 2	**No. of iteration**	**Index A value [-]**
	I	0.6050
	II	0.7261
	III	0.7951
	IV	0.7974
	V	0.7976
Design version 3	**No. of iteration**	**Index A value [-]**
	I	0.6690
	II	0.8210
	III	0.8225
	IV	0.8278
	V	0.8233

but in an irregular manner. In general, one bulkhead more or less may only slightly affect the "Attained Subdivision Index A" values. The small changes in the positions of bulkheads do not give much different values of the index "A", but the local subdivision indices may be changed significantly.

Example 3

Calculation of the „Local Subdivision Indices ΔA_j"

The calculation of the local subdivision indices is a kind of optimisation procedure which may provide the same level of safety for each of the considered watertight compartment. The local subdivision indices were calculated according to the following formula [11]:

$$\Delta A_j = (\Sigma\, p_i\, s_i) / (\Sigma\, p_i)$$

The optimisation process of the indices ΔA_j is connected with the iterative shifting of the bulkheads against each other until the ΔA_j values become more or less equal, possibly for all the compartments. In Tab.2 the local subdivision indices ΔA_j are presented for four performed design iterations. The calculations concerned the design version "1" of the general cargo ship presented in Fig. 3.

	Comp. no. 1	**Comp. no. 2**	**Comp. no. 3**	**Comp. no. 4**	**Comp. no. 5**	**Comp. no. 6**	**Comp. no. 7**
x_1 [m]	-78.60	-60.00	-40.00	-15.00	15.00	40.00	60.00
x_2 [m]	-60.00	-40.00	-15.00	15.00	40.00	60.00	77.10
ΔA_j [-]	**0.8363**	**0.4953**	**0.3522**	**0.4311**	**0.3521**	**0.6080**	**0.9140**
x_1 [m]	-78.60	-60.00	-40.00	-15.00	15.00	38.40	60.00
x_2 [m]	-60.00	-40.00	-15.00	15.00	38.40	60.00	77.10
ΔA_j [-]	**0.8363**	**0.4953**	**0.3539**	**0.6239**	**0.5478**	**0.6270**	**0.9286**
x_1 [m]	-78.60	-60.00	-40.00	-16.69	15.00	38.40	60.00
x_2 [m]	-60.00	-40.00	-16.69	15.00	38.40	60.00	77.10
ΔA_j [-]	**0.8979**	**0.8137**	**0.6104**	**0.7457**	**0.6724**	**0.6453**	**0.9286**
x_1 [m]	-78.60	-60.00	-40.00	-17.14	15.00	38.40	60.00
x_2 [m]	-60.00	-40.00	-17.14	15.00	38.40	60.00	77.10
ΔA_j [-]	**0.8979**	**0.9096**	**0.6228**	**0.7415**	**0.6726**	**0.6453**	**0.9286**

Tab.2. *Results of the optimisation of the local subdivision indices ΔA_j for the design version "A" is presented in Fig. 3*

In Fig. 4 the graphical results of the computer simulation in question are presented.

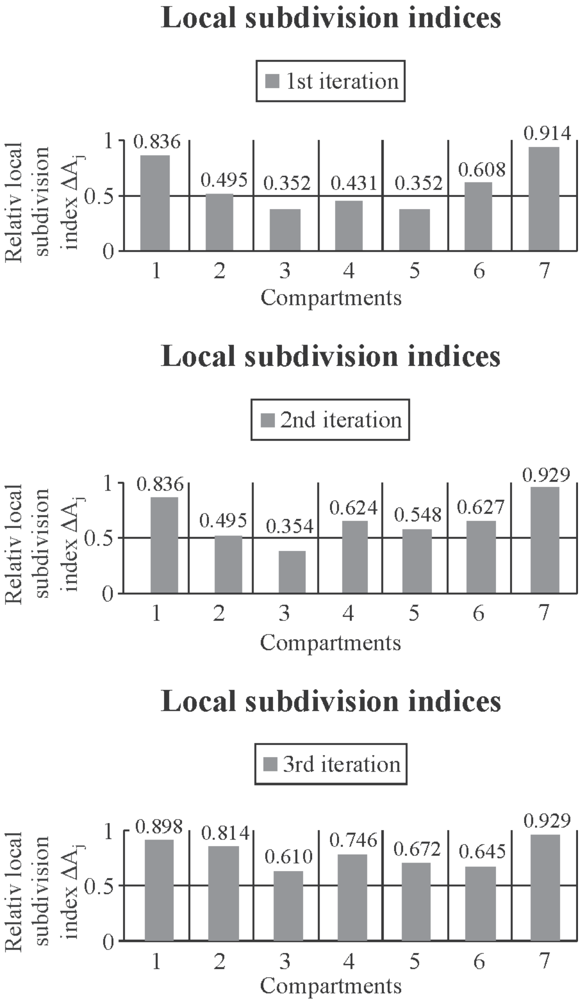

Fig. 4. *Results of the optimisation of the local subdivision indices ΔA_j for the design version "1" of the general cargo ship, presented in Fig. 3*

RESEARCH PROJECTS UNDER WAY

One of the projects concerns estimation of the probability of capsizing a ship in critical conditions by using the direct risk assessment method applied to stability problems.

Another deals with consideration of a few novel safety assessment approaches with a view of implementing them into a safety system for ships in critical conditions to support the application of formal safety assessment. The following novel safety assessment and decision-aiding tools applicable to safety management system are considered [14]:

- ✰ expert judgements based on the Taguchi method
- ✰ a safety based decision support system using either knowledge-based expert systems or artificial neural network techniques
- ✰ a fuzzy-logic-based synthesis incorporating the Dempster Shafer approach for making multiple-attribute decision
- ✰ an integration of approximate reasoning approach and evidential reasoning method in design evaluation.

SUMMARY

Some results of the research projects on an integrated safety estimation method and model for assessing the safety of a ship in critical conditions has been reported. The method is directed towards the ship safety estimation in critical conditions at the preliminary stage of design. By using the method/ /model the hazard and risk assessment may be performed according to the IMO regulations for cargo ships.

So far, the method and model have been used for investigating the ship safety from the damage stability and survivability point of view. The method/model can be used for guiding ship subdivision for safety. Example results of the investigations of different arrangements of internal spaces of a cargo ship including either transverse or combined subdivision, have been presented. The damage stability, survivability and risk assessment calculations were carried out for each case.

The method is still under development and its final structure will be published soon.

Acknowledgement

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NOMENCLATURE

A	- attained subdivision index
L_S	- subdivision length
p_i	- probability of flooding the group of compartments under consideration
R	- required subdivision index
s_i	- probability of survival after flooding the group of compartments under consideration
ΔA_j	- local subdivision index related to each group of compartments under consideration
ΔA_{pi}	- components of the "Attained Subdivision Index A" for each group *i* of compartments
x_1 , x_2	- positions of bulkheads aft and fore, respectively

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Conference

24th Symposium of Ship Power Plants

On 27 and 28 November 2003 in Świnoujście, a Polish port town on the Baltic Sea coast , was held 24th international meeting of the scientific workers engaged in the designing, testing and operating of ship power plant devices. The meeting was organized by the Institute of Technical Operation of Ship Power Plants, Maritime University of Szczecin.

The Symposium's agenda contained presentation of 44 papers split into 5 topical groups :

- Design and operation of ship power plants (18 papers)
- Renovation of ship power plants (2 papers)
- Failures, tribology and diagnostics (10 papers)
- Control of working processes and computer simulation (9 papers)
- Solid/liquid separation (5 papers).

The authors of the papers represented 7 Polish coastal scientific research centres and 3 Russian ones. Maritime University of Szczecin, Gdańsk University of Technology and Technical University of Szczecin most contributed to preparation of the conference materials. The participants had the opportunity of being acquainted with current production achievements of such companies as : MAN-B&W, Caterpillar, Alfa Laval, Bosch Rexroth, Volvo Penta and Olympus, and of visiting floating objects of Polish Navy Base in Świnoujście.

Miscellanea

Agreement on cooperation

In July 2003 the agreement on scientific technical cooperation in the area of ship electric engineering between Polish Register of Shipping (PRS) and the Department of Ship Electric Engineering, Gdynia Maritime University, was signed by Mr. J. Jankowski, D.Sc., General Director of PRS, and Prof. J. Mindykowski, Head of the Department.

Realization of the cooperation is intended on one hand to support developments in the field of ship electric power engineering, and on the other hand to help in developing and modernizing rules for construction and classification of ships and floating objects for sea and inland navigation.

The common activity to be undertaken will concern :

- production and distribution of electric energy
- quality parameters of the energy
- influence of electric energy consumers on its quality
- influence of quality of electric energy on operation of its consumers
- instrumentation for measurement and control of electric energy quality.

Within the scope the cooperation will be realized by means of :

- reviewing topics proposed by each of the parties and common choice of priorities
- common carrying out measurements of electric energy parameters on selected objects
- determining research directions on the basis of earlier obtained results
- common analyzing research results from the point of view of their possible application into PRS rules and instructions
- analyzing possible improvements of ship electric plant control & measurement systems, resulting from research work
- elaboration of a portable electric power analyzer applicable to the new and existing ships not equipped with a modified permanent measurement & control system of electric power plant.

Finally common publishing activity in the range of the cooperation topics has been agreed.