HYBRID PROBABILISTIC APPROACH TO WATERTIGHT SUBDIVISION OF PASSENGER SHIPS – APPLICATION OF 'LOCAL SUBDIVISION INDEX'

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Abstract

The international regulatory framework of subdivision and damage stability of passenger ships and more in particular passenger ships with a considerable number of persons at risk on board is a major aspect to be considered in terms of safety. The main reason for addressing this issue should be considered in the light of ongoing activities within the International Maritime Organization (IMO) which effectively means that harmonization of the probabilistic approach for watertight subdivision and damage stability of both passenger ships and dry cargo ships is envisaged.

In the context of the probabilistic methodology the accidental outflow performance of an oil tanker is outlined also to some extent because international regulations on this subject are under development for MARPOL (International Convention for the Prevention of Pollution from Ships, 1973) and the accidental oil outflow performance is based on a simplified approach different from the subdivision index.

The paper briefly discusses the basic principles of the probabilistic approach to watertight subdivision and damage stability and subsequently concentrates on the present calculation methodology in the context of the current revision of SOLAS (International Convention for the Safety of Life at Sea). In this respect the role in the process and contributions of the EU-sponsored project HARDER (Harmonization of Rules and Design Rationale) is also amplified to some extent. The next topic is the consideration of the relevant parameters to describe the safety performance following a collision, such as the attained/required subdivision index and further the local subdivision index. The basic philosophy for the mathematical model describing both the attained subdivision index 'A' and in particular the proposed (attained) local subdivision index 'a_k' for an arbitrary compartment k is outlined. The main part of the paper is devoted to the analysis and corresponding discussion of the local subdivision index a_k and the associated requirements in terms of the required subdivision index 'R' and the required local survivability index 's_k' in relation to the number of persons at risk 'N'.

An important aspect related to the calculation of the local subdivision index is that statistical data (probability density functions) on the vertical zone (extent and location in the vertical direction) of the damage should be available. The introduction of the local subdivision index a_k additional to the subdivision index A may lead to a substantial increase of the calculation effort, however the calculation procedure is improved as deterministic elements such as 'minor' damage become redundant.

The paper is concluded with a summary consisting of conclusions and recommendations which are deemed useful in the light of further long term development of international regulations on watertight subdivision and damage stability of passenger ships along the lines of the 'hybrid' probabilistic approach.

1. INTRODUCTION

Since the introduction of the probabilistic method in the context of subdivision of ships [1] the concept as such has steadily gained international recognition although the different approach required another way of thinking. Within the scope of international safety legislation the first resolution based on the probabilistic concept of subdivision and damage stability of passenger ships produced by IMO [2] was accepted as an equivalent to SOLAS which was entirely deterministic in nature. Quite recently [3] requirements also based on the probabilistic concept were introduced in SOLAS for cargo ships above a certain size. Currently a harmonized version based on the probabilistic concept and in principle applicable to all ship types is under development within IMO with the aim to be incorporated in SOLAS and to supersede existing legislation, both deterministic and probabilistic, on subdivision and damage stability of ships.

This harmonization process is supported by an extensive research program carried out by the HARDER-consortium. The 'deliverables' generated in the HARDER-project [4] are mainly used for an up-date of the formulae for p_i and s_i describing the risk for an arbitrary damage scenario i. This output is based on a more extensive analysis of damage statistics resulting in more reliable probability density functions for most damage parameters (location and extent). Likewise additional model experiments have been carried out in order to come up with a modification for the survivability. A further contribution may be expected to cover the result from test calculations for the purpose of validation of the calculation methodology and determining the equivalent level of safety by means of A/R.

The harmonized version of the probabilistic concept of subdivision and damage stability of both passenger ships and dry cargo ships is however still characterized by some deterministic elements (e.g. minor damage).
In principle the harmonization process for the probabilistic evaluation of watertight subdivision and damage stability of both passenger ships and dry cargo ships is limited to collision damage, whereas damage due to grounding is covered in a different manner.

It was also recognized that the concept could be extended to describe the accidental outflow performance of oil tankers in the probabilistic sense. Within the scope of international legislation on pollution prevention the first draft resolution [5] based on the probabilistic concept of oil outflow performance applicable to new double hull oil tankers has been finalized recently within IMO.

In general the international legislation addressing the maritime environment is covered by the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). Currently a 'review of hypothetical oil outflow parameters' is subject of study [6] within IMO with the view to establish a proposal for modification of regulations 22-24 of Annex I of MARPOL 73/78 to be based on a probabilistic methodology to the maximum extent possible. The result will be reflected in the accidental oil outflow performance characterized by the mean oil outflow parameter O_m and based on the 'simplified' probabilistic calculation method.

2. CALCULATION METHODOLOGY

The level of safety associated with a ship following a collision damage is defined by the attained subdivision index A and may be calculated as:

$$A = \Sigma(p_i s_i) \qquad (1)$$

where:

- i represents each compartment or group of compartments under consideration
- p_i accounts for the probability that only the compartment or group of compartments under consideration may be flooded
- s_i accounts for the probability of survival after flooding the compartment or group of compartments under consideration

In principle the summation has to be carried out over all damage cases i resulting in a positive contribution $(p_i s_i) > 0$ to the attained subdivision index A.

The oil outflow performance index is defined by the parameter of the mean oil outflow O_m following a tanker accident and may be calculated as:

$$O_m = \Sigma(p_k v_k)/V_c \text{ with } V_c = \Sigma(v_k) \qquad (2)$$

where:

- k represents each cargo tank under consideration
- p_k accounts for the probability that cargo tank k is damaged
- v_k volume of oil in cargo tank k

In principle the summation has to be carried out over <u>all</u> cargo tanks k designed for the carriage of oil.

The simplified approach, see e.g. [7], is based on the 'linear' properties of the system where it is assumed that the entire volume of oil of cargo tank k will be released if cargo tank k is involved in damage scenario i. This allows the transformation from the i-system requiring a summation over the damage scenarios to the k-system requiring a summation over the cargo tanks:

$$\Sigma(p_i v_i) = \Sigma(p_k v_k) \qquad (3)$$

where:

- v_i volume of oil in cargo tanks assumed to be damaged in damage scenario i

The simplified approach however is not applicable to the determination of the attained subdivision index A because of the inequality:

$$\Sigma(p_i s_i) \ \& \ \Sigma(p_k s_k) \qquad (4)$$

3. LOCAL SUBDIVISION INDEX

The local subdivision index a_k for an arbitrary compartment k is defined as follows:

$$a_k = \Sigma(p_i s_i)/p_k \text{ with } p_k = \Sigma(p_i) \qquad (5)$$

where:

- a_k local subdivision index for compartment k corresponding with the probability of survival calculated by the weighted values of the probability of occurrence p_i of <u>all</u> possible damage cases when compartment k is involved in a collision damage
- k subscript denoting the compartment under consideration
- Σ symbol for the summation to be carried out over all possible damage cases involving compartment k
- p_i probability of occurrence of damage case i involving compartment k
- s_i probability of survival of damage case i involving compartment k
- i subscript denoting the damage case under consideration

- p_k accounts for the probability that compartment k is flooded

Note: the parameter p_k for compartment k shall be calculated entirely independent from the p_i-contributions (Σp_i) i.e.:

$$p_k = 1 - p_j \qquad (6)$$

where:

- p_j accounts for the probability that compartment k is <u>not</u> flooded

In principle the concept of the local subdivision index may be applied for any compartment k yielding a 3-dimensional safety picture of the ship where compartments may be identified with the associated values of p_k and a_k. It is recommended that for this purpose an algorithm is developed in order to streamline the computation procedure.

By way of a 'lower cargo hold' present in some ro-ro passenger ships this typical design arrangement may be demonstrated in somewhat more detail (see also Figure 1). If such a lower cargo hold is assumed to be located within the traditional B/5 longitudinal bulkheads extending over a considerable length (say $L_s/4$) the probability that this particular compartment is involved in a collision damage p_k may be calculated being in the order of 13%. If such damage scenarios are associated with a very low survival capability e.g. $a_k \approx 0$ than such a design arrangement should be considered to represent a very high risk.

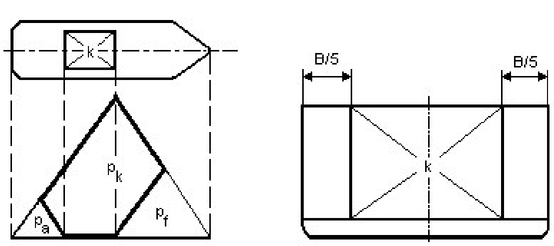

Figure 1: Outline of configuration of 'lower cargo hold' arrangement.

The application of the local subdivision index may meet the need to identify and solve the problem of such 'weak spots'.
It is acknowledged that proposals (see in this respect e.g. [8]), based on the probabilistic approach but different from the concept reflected in equation 5 of the paper, on the topic of local damage have been submitted to IMO/SLF. However all these proposals were not accepted for various reasons.

4. REQUIREMENTS FOR INDICES A AND a_k

Generally speaking the subdivision index has to comply with the following requirements:

$$A \geq R \qquad (7)$$

and

$$a_k \geq s_k \qquad (8)$$

The required subdivision index R is usually a function of ship size expressed by the subdivision length L_s and the number of persons (or passengers) N allowed to be carried on board the ship. This function may for instance be written as:

$$R = 1 - 1/(c_1 L_s + c_2 N + c_3) \qquad (9)$$

where c_1, c_2 and c_3 are positive constants.
It should be noted that the function for R has the property that $0 < R < 1$ (see also Figure 2).

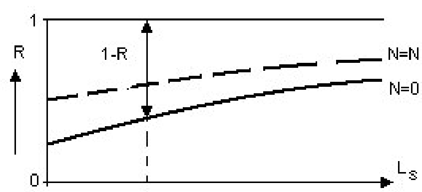

Figure 2: Diagram for the required subdivision index R as function of L_s

The required local subdivision index is basically an 'effective' probability of survival when compartment k is involved in a collision damage and for this reason it is denoted by the survivability index s_k. However the requirement given in equation (7) should only be applicable to compartments exceeding a critical value p_0:

$$p_k \geq p_0 \text{ with } p_0 = c_0.\{1-1/(c_2N+c_3)\}.(1-R_0) \quad (10)$$

where:

- c_0 coefficient to be determined by test calculations
- R_0 required subdivision index for non-passenger ships e.g. as given by the modified formula by putting N = 0 yielding:

$$R_0 = 1 - 1/(c_1L_s + c_3) \quad (11)$$

and

where it is assumed that the critical value p_0 is proportional to the maximum allowable extent of unsafety $1-R_0$.

In this way a 'hybrid' computation method is introduced where the required subdivision index R is dependent on the variables L_s and N in an uncoupled way.

5. GENERAL DISCUSSION

The practical application of the local subdivision index as outlined in this document requires the introduction of assumed probability density functions of the vertical extent of damage and the centre of the vertical extent of damage in order to arrive at a technically sound methodology. Provided the damage in the vertical direction is not correlated with the damage in the longitudinal direction the following formula for p_k may be derived:

$$p_k = p_{k/l}.p_{k/v} = (1-p_a-p_f)(1-p_l-p_u) \quad (12)$$

where:

- $p_{k/l}$ probability of occurrence of damage case involving compartment k in the longitudinal direction
- $p_{k/v}$ probability of occurrence of damage case involving compartment k in the vertical direction
- p_a, p_f, p_l and p_u denote the (negative) contributions of the 'undamaged' parts of the ship to p_k and where the subscripts a, f, l and u denote respectively aft, forward, below and above compartment k (see also Figure 3)

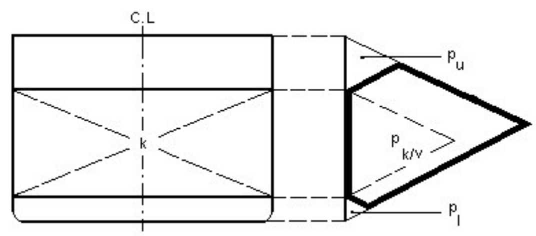

Figure 3: Integration domains for the computation of probability $p_{k/v}$

A similar method has been used in the development of the draft regulation on 'accidental outflow performance' for oil tankers (see e.g. [6]). Further the damage should necessarily be assumed to be of the form of a parallelepiped in order to establish an unambiguous calculation method for the local subdivision index.

Statistical data, see also [9], on the vertical zone (extent and location in the vertical direction) are relatively scarce. This in combination with the effect of non-rectangular section form and the occurring 'end-effects' at the ship's bottom and the bulkhead deck may lead to less accurate probability density functions. As the probability of damaging the bulkhead deck is rather accurate (the probability that the damage will not extend above the waterline is only about 13%) and the probability that the bottom is damaged is of less importance a pragmatic approach based on an educated guess may be preferable.

In the legislation currently under development there are still some elements covered by the deterministic approach:
- ramming damage: in principle a requirement $a_k \geq s_k$ may be formulated for the compartment(s) aft of the collision bulkhead in addition to the requirement $s_i = 1$ for the compartment forward of the collision bulkhead.
- raking damage: in principle a requirement $a_k \geq s_k$ may be formulated for any outboard compartment assuming a damage penetration of a very limited extent and having regard to the maximum damage length of 0.5L as defined in IMO document SLF 45/3/5 of reference [4].
- lesser damage: in principle a requirement $a_k \geq s_k$ may be formulated for any outboard compartment not extending over the full depth.
- minor damage: in principle a requirement $a_k \geq s_k$ may be formulated for any outboard compartment assuming very limited damage extents. Since this is applicable to the entire hull this implies that bottom damage is also considered. In general this specific aspect boils down to a requirement for two adjacent compartments.

With respect to the required local subdivision index s_k it is observed that a distinction may be made between outboard compartments adjacent to the hull and inboard compartments.

For the outboard compartments the requirement for s_k should be expressed as a function of N as this criterion should at least be equivalent to the deterministic concept of the factor of subdivision.

For the inboard compartments the requirement may be written as e.g. s_k = [0.5] or be expressed as a function of N.

The basic philosophy of a local subdivision index a_k based on the probabilistic methodology is equivalent with the evaluation of local subdivision in a quantitative way and this leads to additional requirements for the distribution of the safety and/or the unsafety of the ship after collision damage.

If the concept of the local subdivision index in the long term should be introduced in the international regulatory framework it should be emphasized that a great number of test calculations has to be carried out in order to quantify the associated computation methodology of the proposed local subdivision index and more in particular the parameters p_0 and s_k as defined in section 4.

6. CONCLUSIONS

The local subdivision index a_k is dependent on the subdivision arrangement and not on the dimensions of the damage and in this respect it is a performance type of index. Such a performance type of requirement is, in addition to the overall performance of the ship characterized by the attained subdivision index A, an excellent instrument for judging the local survival capability and at the same time it has the potential to cover deterministic requirements related to e.g. minor damage.

The local subdivision index a_k for an arbitrary compartment k is defined in equation (5) of the paper.

In the paper an outline is given how the concept of the local subdivision index could be incorporated in the calculation methodology for the overall safety level of the ship. In this approach the parameters representative for the required safety level have been considered independent as far as practicable. However another approach for the incorporation of the local subdivision index in the calculation methodology is quite conceivable.

It is recommended that a pragmatic approach should be followed to develop the probability density functions covering the vertical extent of damage.

It should be emphasized that a great number of test calculations has to be carried out in order to quantify the proposed local subdivision index and the associated computation methodology.

7. REFERENCES

[1] K. Wendel: "*Subdivision of ships*", Paper presented at the Diamond Jubilee International Meeting of the Society of Naval Architects and Marine Engineers, 1968.

[2] IMO-document: "*Regulations on subdivision and stability of passenger ships as an equivalent to Part B of Chapter II of the International Convention for the Safety of Life at Sea, 1960*", Resolution A.265(VIII), 1973.

[3] IMO-document: "*Subdivision and damage stability of cargo ships*", SOLAS 1974, Chapter II-1, Part B-1.

[4] IMO-documents: "*SLF 45/3/3 and SLF 45/3/5*".

[5] IMO-document: "*Interim Guidelines for the approval of alternative tanker designs under regulation 13F of Annex I of MARPOL 73/78*", 1994.

[6] IMO-document: "*BLG 8/4, Annex 1, Regulation 21*".

[7] H. Vermeer: "*International regulations based on a probabilistic approach of accidental outflow performance of oil tankers*", Proceedings of the International Conference on Technologies for Marine Environment Preservation (MARIENV95), September 1995.

[8] IMO-documents: "*SLF 36/4/5 and SLF 37/4/7, 8 and 9*", submitted by respectively the Netherlands and Poland.

[9] Herbert Engineering Corp. – Technical support to HARDER: "*Vertical extent of damage analysis*", HEC Report No. 9933-2, February 2001.