

# Design Implications of the New Harmonised Probabilistic Damage Stability Regulations

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## ABSTRACT

In anticipation of the forthcoming new harmonised regulations for damage stability, SOLAS Chapter II-1, proposed in IMO MSC 80 and due for enforcement in 2009, a number of ship owners and consequentially yards and classification societies are venturing to exploit the new degrees of freedom afforded by the probabilistic concept of ship subdivision. In this process, designers are finding it rather difficult to move away from the prescription mindset that has been deeply ingrained in their way of conceptualising, creating and completing a ship design. Total freedom it appears is hard to cope with and a helping hand is needed to guide them in crossing the line from prescriptive to goal-setting design. This will be facilitated considerably with improved understanding of what this concept entails and of its limitations and range of applicability. This paper represents an attempt in this direction, based on the results of a research study, financed by the Maritime and Coastguard Agency in the UK, to assess the design implications of the new harmonised rules on passenger and cargo ships.

**Keywords:** *probabilistic rules, damage stability, ship design*

## 1. INTRODUCTION

From a ship stability viewpoint, the most fundamental goal to be achieved is for a ship to remain *afloat* and *upright*, especially so after an accident involving water ingress and flooding. Regulations to address the former are targeting subdivision and the latter damage stability. More recent instruments in the regulatory process tend to cater for both issues whilst contemporary developments have adopted a more holistic approach to safety that encompasses considerations of all principal hazards over the life-cycle of the vessel.

Notably, the first Merchant Shipping Act of 1854 is the first known legal requirement addressing safety at sea concerning watertight

bulkheads, leading eventually and after heavy loss of life to the adoption of the first internationally agreed system of subdivision in SOLAS 1929.

The first damage stability requirements, on the other hand, were introduced following the 1948 SOLAS Convention and the first specific criterion on residual stability standards at the 1960 SOLAS Convention with the requirement for a minimum residual GM of 0.05m. This represented an attempt to introduce a margin to compensate for the upsetting environmental forces. "Additionally, in cases where the Administration considered the range of stability in the damaged condition to be doubtful, it could request further investigation to their satisfaction". Although this was a very

vague statement, it is representative of the first attempts to legislate on the range of stability in the damaged condition. It is interesting to mention that a new regulation on "Watertight Integrity above the Margin Line" was also introduced reflecting the general desire to do all that was reasonably practical to ensure survival after severe collision damage by taking all necessary measures to limit the entry and spread of water above the bulkhead deck.

The first probabilistic damage stability rules for passenger vessels, deriving from the work of Kurt Wendel on "Subdivision of Ships", [1] were introduced in the late sixties as an alternative to the deterministic requirements of SOLAS '60. Subsequently and at about the same time as the 1974 SOLAS Convention was introduced, the International Maritime Organisation (IMO), published Resolution A.265 (VIII). The next major step in the development of stability standards came in 1992 with the introduction of SOLAS part B-1 (Chapter II-1), containing a probabilistic standard for cargo vessels, using the same principles embodied in the 1974 regulations. The same principle was used in launching at IMO the regulatory development of "Harmonisation of Damage Stability Provisions in SOLAS, based on the Probabilistic Concept of Survival" in the belief that this represented a more rational approach to addressing damage stability safety.

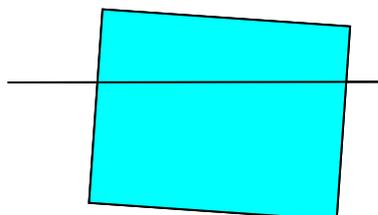
Evidence, however, of "common sense" driving rule making is very scarce; with accidents providing the main motivation for rule making, emphasis has primarily been placed on reducing consequences, i.e., on cure rather than prevention. Against this background, it is widely believed that the prevailing situation could be drastically improved through understanding of the underlying mechanisms leading to vessel loss and to identification of governing design and operation parameters to target risk reduction cost-effectively. This in turn necessitates the development of appropriate methods, tools and techniques capable of meaningfully addressing the physical phenomena involved.

Having said this, it was not until the early 90s when **dynamic** stability pertaining to ships in a **damage** condition, was addressed by simplified numerical models, such as the numerical model of damaged Ro-Ro vessel dynamic stability and survivability [2]. The subject of dynamic ship stability in waves with the hull breached received much attention following the tragic accident of Estonia, to the extent that led to a step change in the way damage stability is being addressed, namely by assessing the performance of a vessel in a given environment and loading condition on the basis of first principles. In parallel, motivated by the compelling need to understand the impact of the then imminent introduction of probabilistic damage stability regulations on the design of cargo and passenger ships and the growing appreciation of deeply embedded problems in both the rules and the harmonisation process itself, an in-depth evaluation and re-engineering of the whole probabilistic framework was launched through the EC-funded €4.5M, 3-year project HARDER [3]. The overriding goal of the HARDER project was to develop a rational procedure for probabilistic damage stability assessment, addressing from first principles all relevant aspects and underlying physical phenomena for all types of ships and damage scenarios. In this respect, HARDER became an IMO vehicle carrying a major load of the rule development process and fostering international collaboration at its best – a major factor contributing to the eventual success in achieving harmonisation and in proposing a workable framework for damage stability calculations in IMO SLF 47.

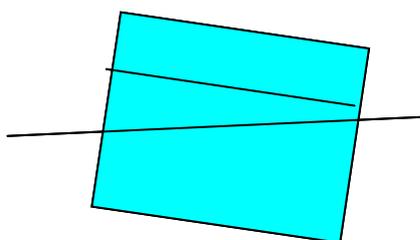
Deriving from developments at fundamental and applied levels in project HARDER as well as other EU projects such as NEREUS, ROROPROB and SAFEVSHIP and other international collaborative efforts (e.g., work at ITTC), a clearer understanding of damage stability started to emerge together with a confidence in the available knowledge and tools to address the subject effectively, even at design concept level. More importantly, the knowledge gained can be used

to address critically all available regulatory instruments and to foster new and better methodologies to safeguard against known design deficiencies in the first instance, until safer designs evolve to reflect this knowledge.

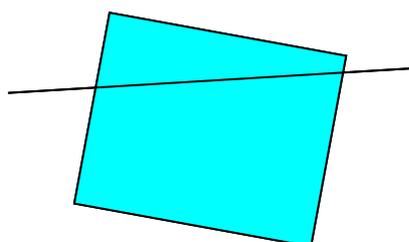
At this point in time, it is known for example that damaged ships in waves may capsize in one of the following modes (the first three after the final equilibrium condition is reached post-damage):



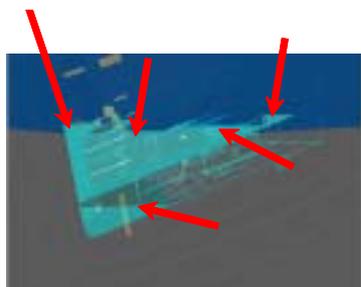
High freeboard ships: Provided there is some minimal positive righting lever and range of stability the ship will not capsize in moderate waves. Wave impacts on the side of the ship will induce some rolling in marginally stable cases, which could result in capsize at the larger sea states. Often ships are more vulnerable with the damage to leeward, since the GZ levers are typically less in the damaged direction and the induced dynamic roll is typically somewhat greater leeward.



Low freeboard Ro-Ro ships: This is the typical mechanism of capsize for Ro-Ro ships. The wave action gradually pumps water up onto the vehicle deck. The height of the water gradually increases until either a reasonably stable equilibrium level is reached where inflow is approximately equal to outflow for ships with sufficient reserve stability, or if stability is inadequate, the heeling moment of the water will cause a capsize to windward. In some rare cases Ro-Ro vessels may heel to leeward after the first few wave encounters with an insufficient freeboard on the weather side to prevent further water accumulation and the ship will continue to take water on the vehicle deck until a capsize results.



Low freeboard conventional ships: This is the typical mechanism of capsize for non-Ro-Ro ships. The highest waves will form boarding seas and will pile-up on the windward side of the deck, inducing roll and capsize, usually to windward. The weather deck tends to drain quickly if there is no capsize, and there is no build-up or accumulation of water as seen with enclosed Ro-Ro decks. One or two high waves in close succession are often sufficient to cause capsize.



Multi-Free-Surface Effect: This mechanism of capsize is relevant to ships with complex watertight subdivision such as cruise ships. As the hull is breached, water rushes through various compartments at different levels, substantially reducing stability even when the floodwater amount is relatively small. As a result the ship can heel to large angles, even for small damage openings, letting water into the upper decks that spreads rapidly through these spaces and may lead to rapid capsize at any stage of the flooding.

The aforementioned mechanisms of vessel capsize help to judging how relevant or effective available regulatory instruments are,

in being able to prevent or mitigate disasters, as indicated in the following for the instruments currently in use or due to be enforced:

- SOLAS 74: 1-compartment standard (prevent ship from sinking if one compartment is breached; resistance to capsize in waves unknown)
- SOLAS 90: 2-compartment standard (prevent ship from sinking if any two compartments are breached; resist capsize of 2-compartment worst damage in sea states with  $H_s$  approximately 3m – Ro-Ro vessels)
- Stockholm Agreement (as above but with a pre-defined level of water on deck depending on freeboard and in operational sea states of up to 4m  $H_s$ ), [4 ]
- Harmonised SOLAS Chapter II-1(SOLAS 2009 – equivalent to SOLAS 90; such equivalence to be addressed here)

Concerning the latter, a stage has now been reached where the draft text of the major revision to the subdivision and damage stability sections of SOLAS Chapter II-1 based on a probabilistic approach has been completed following final amendments in January 2005 to Regulation 7-1 involving calculation of the “p” factor. The revised regulations were adopted in May 2005 at the IMO MSC and will be entering into force for new vessels with keels laid on or after 1st January 2009. The new regulations represent a step change away from the current deterministic methods of assessing subdivision and damage stability. Old concepts such as floodable length, criterion numeral, margin line, 1 and 2 compartment standards and the B/5 line will be disappearing.

With this in mind there appears to be a gap in that, whilst development of the probabilistic regulations included extensive calculations on existing ships which had been designed to meet the current SOLAS regulations, little or no effort has been expended into designing new ships from scratch using the proposed regulations. It is this gap that the research study is aiming to address and constitutes the kernel for this paper. In particular, the UK Maritime and Coastguard Agency (MCA) wished to address the following concerns:

- Equivalence between the new rules and the existing damage stability regulations i.e. do the new rules allow more flexibility and hence result in less safe designs?
- The effect different design options may have on the performance of a vessel under the new rules.

The paper starts by introducing briefly the framework of the new probabilistic rules before considering the limitations inherent in this latest regulatory instrument in its current form; ways of overcoming these are then proposed as well as offering a helping hand to the designers for taking full advantage of the flexibility of the new rules whilst making full use of existing knowledge and experience with deterministic rules-based design; the design implications deriving from the implementation of the new rules are then examined by using three case studies: a cruise ship, a Ro-Pax and a container feeder; the paper concludes by summarising the key points emerging from the work presented.

## 2. THE PROBABILISTIC CONCEPT OF SHIP SUBDIVISION

One of the fundamental assumptions of the probabilistic concept of subdivision of ships is that the ship under consideration is damaged or more precisely that the ship hull is breached and there is (large scale) flooding. This implies that the interest focuses not on absolute collision damage safety of a ship but on *conditional* safety (relative measure of safety). In other words, irrespective of the collision risk (in terms of probability) that ends in hull breaching and flooding, it would be important to know whether the ship will survive accidental collision damage. For this reason, the regulations require the same level of “safety” irrespective of the area of operation that can be of varying density of shipping (congestion of traffic), or indeed ship type and all that this entails and irrespective of the ensuing consequences, all of which might imply considerably different levels of actual risk. However, other aspects of shipping (e.g. environmental hazard due to harmful cargo,

size of ship, number of persons on board and so on) can be accounted for in the expression for the Required Index of Subdivision (R). Under such circumstances the probability of ship surviving collision damage is given by the Attained Index of Subdivision, A, using the following expressions:

$$A = \sum_{j=1}^J \sum_{i=1}^I w_j \cdot p_i \cdot s_{ij} \quad ; \quad A > R \quad (1)$$

Where,

- A/R Attained/Required Index of Subdivision  
 j loading condition (draught) under consideration  
 J number of loading conditions considered in the calculation of A (normally 3 draughts)  
 i represents each compartment or group of compartments under consideration for each j  
 I set of all feasible flooding scenarios comprising single compartments or groups of adjacent compartments for each j  
 w weighting factor for each j  
 p<sub>i</sub> probability that only the compartment (s) under consideration is (are) flooded  
 s<sub>ij</sub> (conditional) probability of surviving the flooding of compartment(s) under consideration for given j

It is clear that the summation in equation (1) covers only flooding scenarios for which both p<sub>i</sub> and s<sub>i</sub> are positive (i.e., survivable scenarios – which contribute to the summation). In other words, A is the weighed average “s-factor”, with “p-factors” and “w<sub>j</sub>s” being the weights, i.e.:

$$A = \hat{E}(s) \quad (2)$$

Put differently, using the notion of risk as discussed in [5], the Index A is an aggregate probability of survival for all possible damage scenarios reflecting ship collision statistics worldwide. Consequently, (1-A) is the cumulative probability of (sinking/capsize) of

these scenarios or a *relative measure of collision damage risk*. The required index R on the other hand cannot be assigned such precise terminology other than by association to Index A (R is derived principally from regression on A). Otherwise, all that can be said is that R represents an “indicative level of collision damage safety” that is deemed to be acceptable by society.

### 3. INHERENT LIMITATIONS IN THE NEW RULES

#### (i) s-factor formulation (final equilibrium)

$$s_i \approx K \cdot \left[ \frac{GZ_{\max}}{0.12} \cdot \frac{Range}{16} \right]^{\frac{1}{4}} \quad (3)$$

where:

GZ<sub>max</sub> is not to be taken as more than 0.12 m;

Range is not to be taken as more than 16 degrees;

K = 1 if θ<sub>c</sub> ≤ θ<sub>min</sub>

K = 0 if θ<sub>c</sub> ≥ θ<sub>max</sub>

K =  $\sqrt{\frac{\theta_{\max} - \theta_c}{\theta_{\max} - \theta_{\min}}}$  otherwise;

“θ<sub>min</sub>” is 7 degrees for passenger ships and 25 degrees for cargo ships, and

“θ<sub>max</sub>” is 15 degrees for passenger ships and 30 degrees for cargo ships.

The process of derivation of model (2) entailed a series of experiments were designed and undertaken in project HARDER, using a large array of Ro-Ro vessels and a few cargo vessels, as well as numerical simulations performed that were used as reference for relating the proposed regression formulation to sea states and time [3]. This process involved testing scale models in worst SOLAS 90 damage cases over 30 minutes duration and noting the sea state resulting in capsizing (critical sea states). The additional information used was the cumulative distribution of sea states recorded at the instant of collision (Figure 1). Thus, the “s-factor” formulation encodes implicitly the

information on sea state as well as the time the vessel is expected to survive after a flooding event.

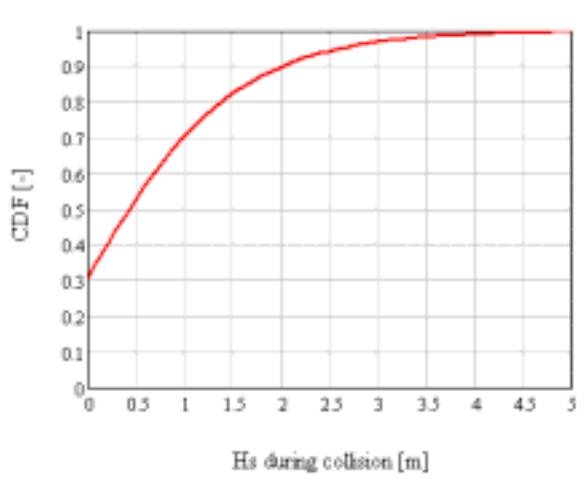
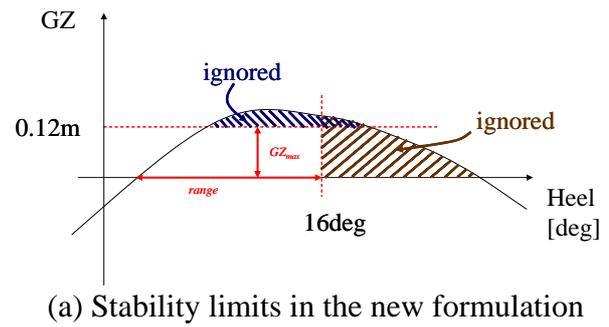


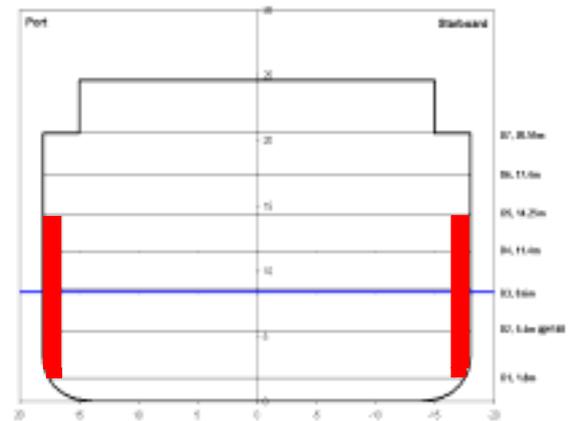
Figure 1: CDF of significant wave heights at the instant of collision, [9]

However, because of the rather simplistic manner of combining all this information, the accuracy and reliability of the proposed model are not established. Moreover, an alternative formulation developed in project HARDER, using the SEM methodology [6] and capable of directly accounting for pertinent physical phenomena, hence used in designing novel concepts, was never adopted. This being the state of affairs, it is of paramount importance to appreciate the usefulness of more advanced numerical simulation tools capable of addressing the real problems of damage survivability, thus aiding decision making in the design stage. A number of limitations of model (2) can be outlined as follows:

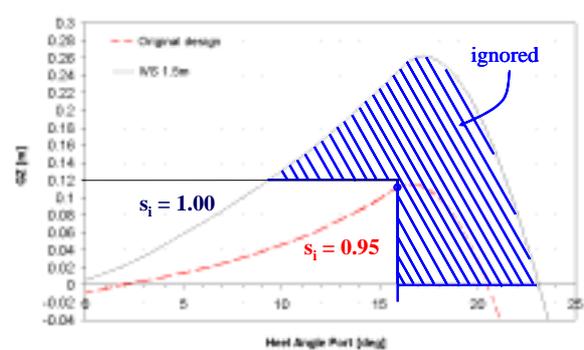
- Ship geometry partly ignored: The limits in the restoring curve parameters used in the formulation (Figure 2a), ignore partly ship geometry, particularly so geometry that is known to lead to high survivability ships, such as side casings (Figure 2b). In the latter case, although the  $s_0$  factor is increased from 0.95 to 1.0, the real benefit resulting from considering side casings is largely unaccounted for (Figure 2c); hence there is no real incentive for the designer to go down this route.



(a) Stability limits in the new formulation



(b) High survivability measures



(c) Real survivability enhancement ignored

Figure 2: Ship geometry partly ignored by s-factor formulation

- Intermediate stages of flooding: the  $s$ -factor formulation provided in the new rules, does not account for the process of transient flooding as noted for ships with complex geometry such as cruise ships and as outlined in the foregoing. This is a severe limitation that requires close attention when designing this type of ship as detailed in [7].

- Applicability to all ship types: The majority of model experiments and numerical simulations used in the derivation of the s-factor formulation were focused on Ro-Ro vessels. As such, for the range of ships represented in the data set considered, it is reasonable to expect an accurate estimate of the relative probability of survival for this ship type. For other ship types, in particular cruise ships, the ability to accurately predict survivability is questionable to say the least. Differences in ship geometry and internal arrangements necessitate attention to problems different to those encountered in Ro-Ro vessels, as outlined earlier. Again a large scale study in [7] helps to highlight this problem.

## (ii) Insurgence of determinism within the probabilistic rules

As it is impossible to model every single collision damage scenario systematically; the choice adopted is to include all historically probable scenarios that contribute in determining Index A. In this respect and to ensure that a rational provision is taken in ensuring a minimum *acceptable risk level*, deterministic merits are being made use of such as Regulation 6 (par.1) and Regulation 8.

Regulation 8 in particular, requiring a 2-compartment standard with an s-factor equal to 0.9 and a penetration depth at B/10 is literally throwing the spanner in the works. Strictly speaking equivalence with SOLAS 90 goes out of the window in that:

- The penetration depth is B/10 rather than B/5
- S=0.9 implies in essence survival for 30 minutes up to a critical sea state with  $H_s=2m$  (some kind of reduced Stockholm Agreement compliance)
- This 2-compartment damage statistic bears no resemblance to the SOLAS 90 2-compartment standard.

This arbitrary deterministic criterion is expected to have serious design implications.

## (iii) Conceptual design gap

Based on the fact that only survivable scenarios contribute to the value of Index A, it is implied that even if a vessel achieved the required index of subdivision, there may be cases which are likely and which have a low probability of surviving – hence a high relative risk of sinking/capsize in scenarios, which are implicitly assumed to be acceptable. Figures 3 and 4 next serve to demonstrate this point, showing results of probabilistic damage stability calculations for a passenger ship and a Ro-Pax vessel.

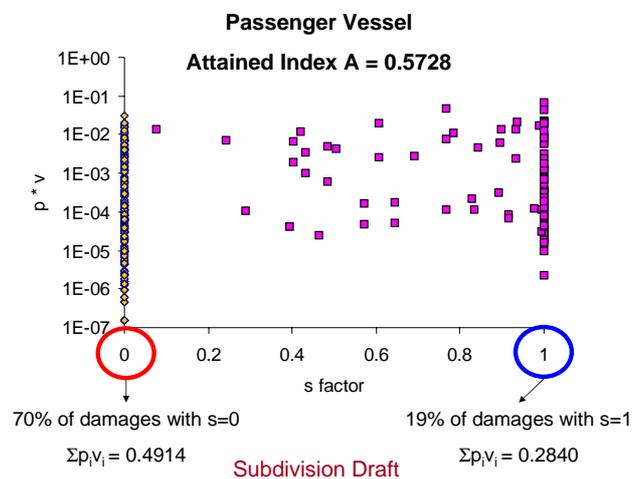


Figure 3: Probabilistic Damage Stability Calculations (Passenger Vessel)

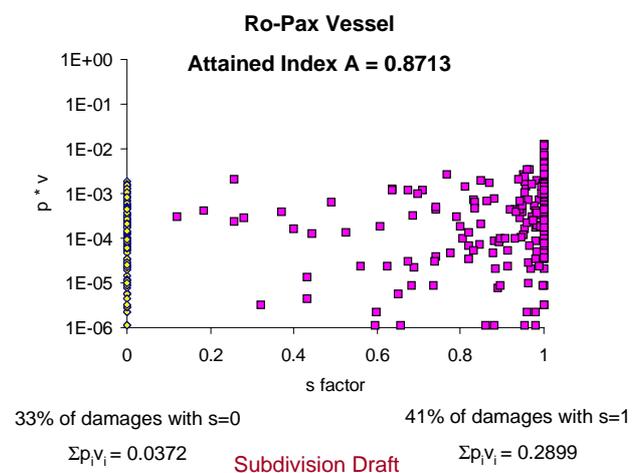


Figure 4: Probabilistic Damage Stability Calculations (Ro-Pax Vessel)

These results highlight a number of points:

- One could speculate that the value of A is a good indicator of the vessel relative collision damage safety, on the basis of the observed reduction of non-survivable scenarios and the higher survival probability of the remaining scenarios.
- But, even with  $A=0.8713$ , implying a rather small (acceptable according to the new rules) collision damage risk, there are 33% of non-survivable scenarios.
- In both ships non-survivable scenarios are among the most probable.
- Wendel's probabilistic concept of ship subdivision is conceptually flawed, allowing for a potentially large (and hence unacceptable) number of non-survivable scenarios or worse leading to design changes that do little to improve actual safety.
- As such, there is an obvious need for implementing a scheme, deriving from deeper understanding of what A represents in a quantitative sense, to take advantage of the opportunities presented by the new probabilistic framework whilst overcoming fundamental inherent weaknesses

An attempt in this direction is presented in the next section.

#### 4. CROSSING THE LINE IN SHIP DESIGN FROM DETERMINISTIC TO PROBABILISTIC RULES

In the simplest of levels, the dilemma of prescriptive SOLAS-minded designers can be demonstrated in Figures 5 and 6 below:

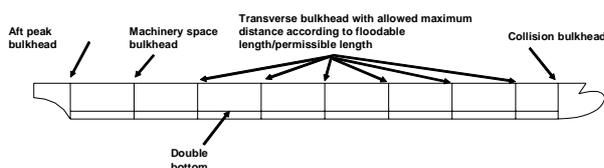


Figure 5: Prescriptive subdivision (Deterministic rules)

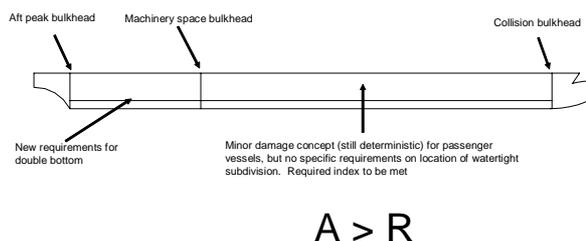


Figure 6: Largely "unguided" subdivision (Probabilistic rules)

It is obvious that internal subdivision arrangement is a key issue affecting ship performance, functionality and safety, all of which have to date been catered through the provision of rules and regulations, reflecting in essence codification of best practice. Throwing this away and leaving on the table a blank sheet, makes ship subdivision a very difficult problem indeed. This was essentially the problem addressed in the EU project ROROPROB [8].

Principally, building on the understanding of Index A as outlined in Section 2 , affords a straightforward way of determining the relative (collision damage) risk profile of a vessel at an early design stage and hence devise an effective means of risk reduction by focusing primarily on the high risk scenarios. This concept is illustrated in Figure 7 for a large cruise liner.

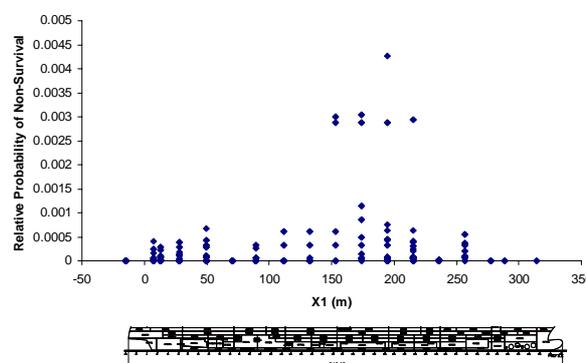


Figure 7: Risk Profile of a large cruise liner

In Figure 7, the longitudinal location (on the horizontal axis) corresponds to the aft-most coordinate of the flooded compartments. The

relative “risk” of non-survival (product of probability of damage and probability of non-survival [ $p*(1-s)$ ]) is plotted on the vertical axis. For a specific damage location, there may be several damage case scenarios depending on the extent of flooding (longitudinally, vertically and transversely). The non-survival probability (“risk”) can be used to identify high-risk areas of the watertight subdivision; changes made in those areas will be the most effective in reducing the risk, and of course in improving the subdivision index. Numerical simulations are then used to establish the exact flooding mechanism and identify cost-effective changes for the local watertight arrangement (at design stage) or active damage control measures (during operation). In the light of the harmonised probabilistic rules, such an approach was developed by the Ship Stability Research Centre (SSRC) and is being used by Safety At Sea and Deltamarin in ship concept design to optimise the watertight subdivision arrangements for complex ships such as large cruise liners and Ro-Ro passenger ships.

In line with the risk-based approach outlined above, an internal watertight subdivision arrangement of the ship can be designed to minimise the probability of sinkage/capsize. This will lead to a ship design with a known level of risk that can be optimised for safety and cost-effectiveness

whilst achieving other functionality and performance objectives such as lane meters, size of fire zones, length of compartment, number-position-height of watertight bulkheads, etc. In order to achieve the above, a parametric model of the watertight subdivision should be available. This is easily achieved with commercially available software packages. The developed probabilistic methodology can then be implemented using established optimisation algorithms, such as Genetic Algorithm tailored to this application.. The fully automated optimisation procedure typically produces several thousand design alternatives depending on the complexity of the ship’s layout and the number of variables.

The actual process used by Safety at Sea and Deltamarin for platform optimisation is illustrated in Figure 8 (left). A sample of the optimisation problem variables is also shown (right). In order to make the process effective, the participation of all decision-makers (the designer, the owner, the yard) is essential to properly define the optimisation variables, objectives and constraints. Using this approach, high survivability internal ship layouts have been developed, without deviating much from the current SOLAS practice, this making it easy for ship designers to relate to the proposed practice. The level of progress achieved is shown in Figure 9,( contrast with Figure 4).

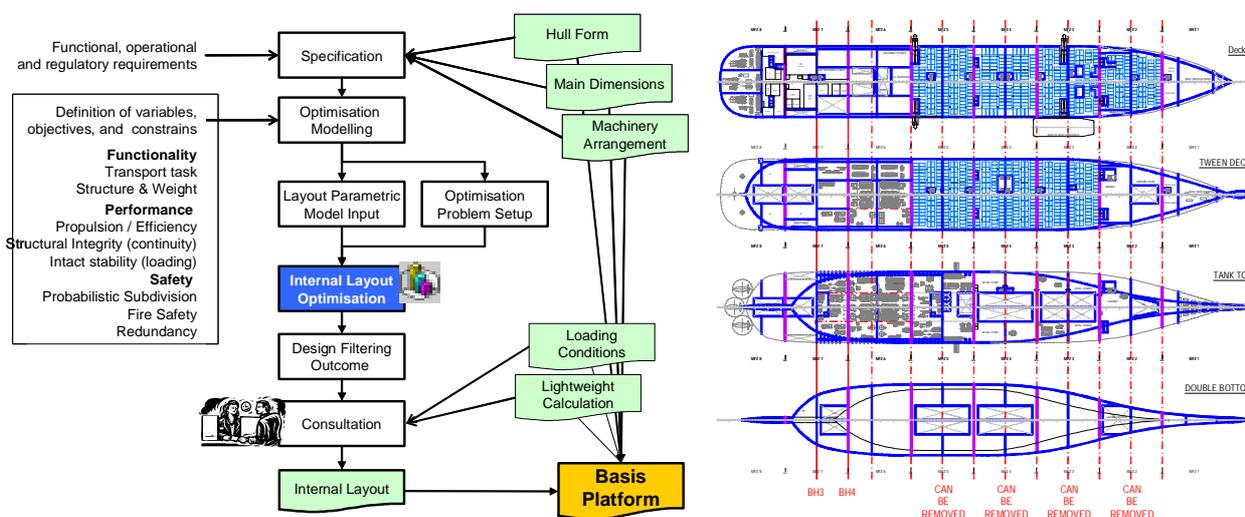


Figure 8: Platform optimisation – probabilistic rules-based ship subdivision

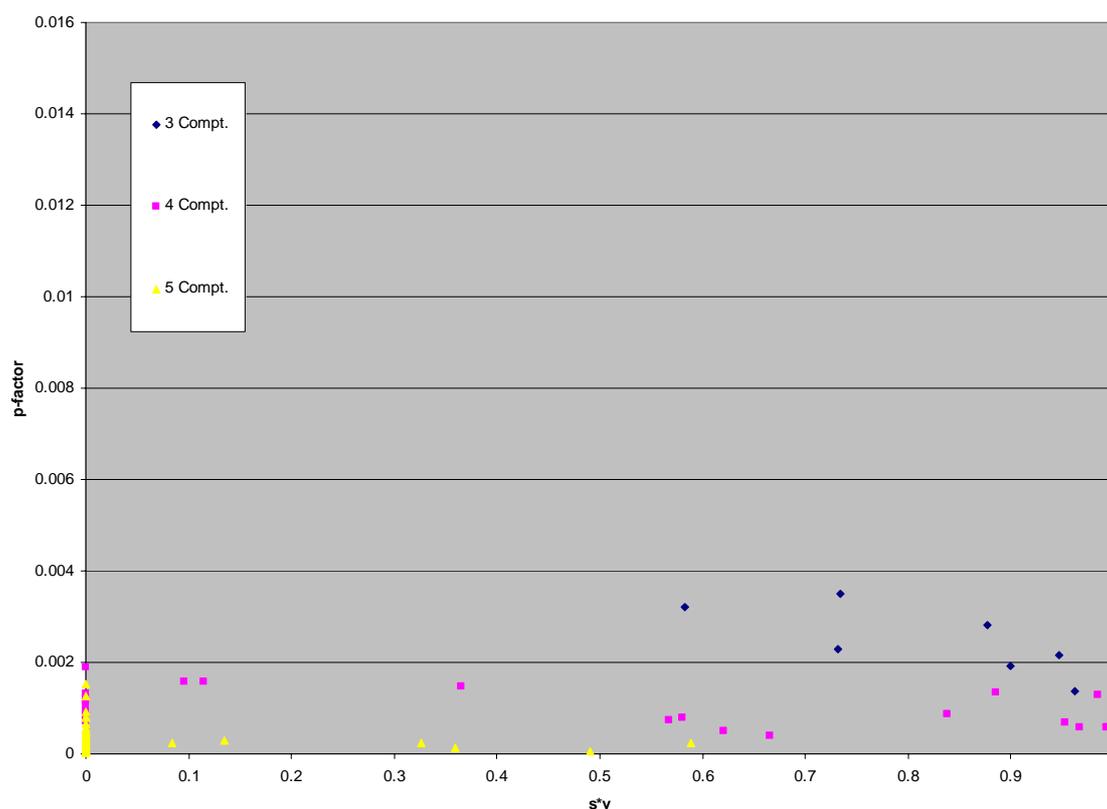


Figure 9: High survivability ship layout (Attained index  $A=0.97$ )

## 5. DESIGN IMPLICATIONS OF THE NEW PROBABILISTIC RULES

### Approach

To address the issues raised by MCA, the following approach was adopted for a selection of vessel designs:

- Analyse an existing SOLAS'90 design to the new MSC 194(80) rules using existing limiting curve operational envelope.
- Propose a new design based on the same operational envelope and design specifications but designed purely to the new MSC 194(80) rules e.g. A-value and Regulation 8.
- Analyse new design for existing SOLAS'90 rules
- Compare the limiting curve results from the two designs

The aforementioned rules can be summarised as follows:

### Existing Stability rules (SOLAS'90):

- Passenger ships demonstrate compliance using a deterministic set of criteria, pertaining to evaluating the GZ curve of a damage case after flooding.
- Damage case is either one or two compartments with a penetration to B/5.
- Cargo ships demonstrate compliance using a probabilistic set of criteria where contributions from single and multiple compartment damages including penetrations past B/5 are summed to give an Index A which must be greater than a Required Index R based on parameters such as  $L_s$ .

### New Stability rules (MSC 194(80)):

- Passenger and Cargo ships demonstrate compliance using a probabilistic set of

criteria where contributions from single and multiple compartment damages including penetrations past B/5 are summed to give an Index A which must be greater than a Required Index R based on parameters such as Ls and number of lifesaving appliances.

- This new set of probabilistic regulations differ from the existing cargo ship rules in the number of draughts used for the calculation, permeabilities, formulation of the required index R and also in the formulation of the p, s, and v factors used in the calculation of A for each damage case.

From the vessels considered in the MCA study, results from the following 3 designs are presented and discussed:

- PANAMAX Cruise Liner (SOLAS'90 deterministic)
- Large RO-PAX ferry (SOLAS'90 deterministic)
- Container Feeder (SOLAS'90 probabilistic REG 25)

## PANAMAX Cruise Liner

### Existing Ship Design

A standard SOLAS'90 compliant PANAMAX cruise liner was chosen for the basis ship; approximately 300m long and carrying roughly 3350 passengers and crew. The results of the analysis are given in Figures 10-11 next.

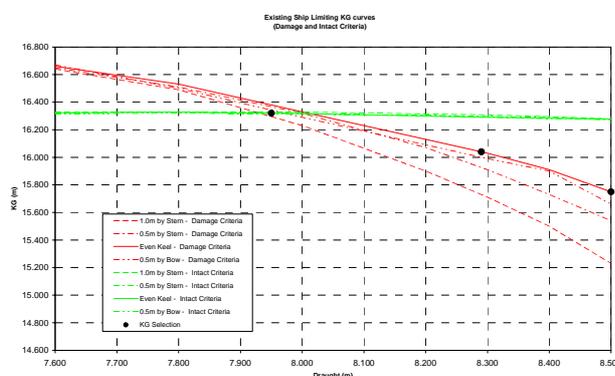


Figure 10: Existing Ship Limiting Curves and A-value KG selection

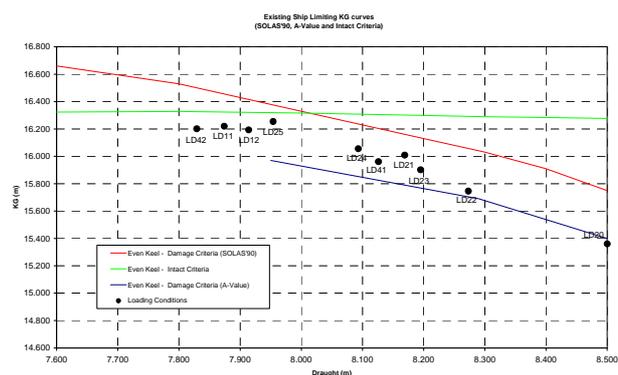


Figure 11: Existing Ship A-value Limiting curve with loading conditions

Figure 11 illustrates that the existing ship requires a reduction in limiting KG of 0.350m to obtain  $A=R$ , resulting in only one loading condition falling marginally under the allowable curve. This poor A-value performance is due to static heel angles caused by large tank asymmetries in the DB and B/5 tanks on Deck 00.

### New Ship Design

Using the platform optimisation approach described in the foregoing, the following objectives were set for the new design:

- Must be compliant with R-value
- Must be compliant with Regulation 8
- Approximately same tank volume and similar distribution in vessel
- Maintain or increase anti-heeling capacity
- Approximately the same internal area for service spaces e.g. sewage treatment rooms
- Approximately the same positions for Main Fire Bulkheads
- Same spacing for Main Engine Room Bulkheads
- Similar door arrangement on the bulkhead deck and above as on the existing ship
- Minimize Steel weight

The results of the analysis are given in Figures 12 and 13 next:

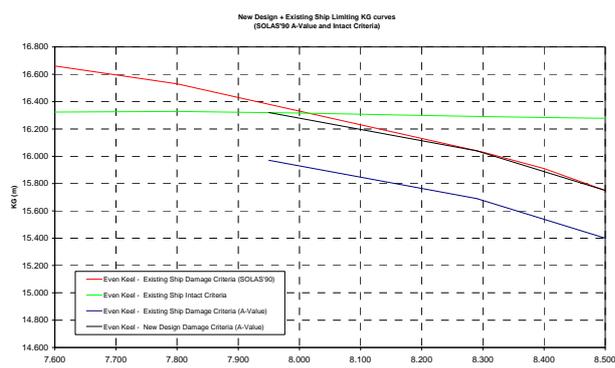


Figure 12: New Design A-value Limiting curve

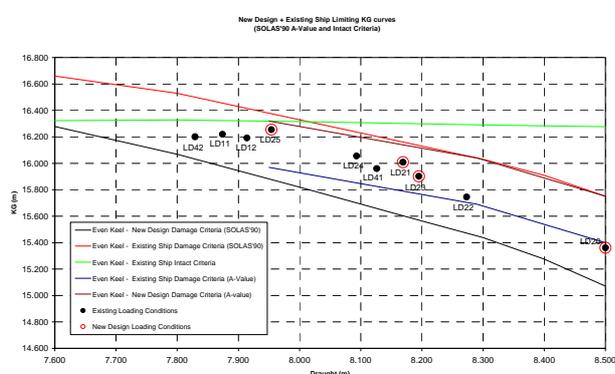


Figure 13: New Design SOLAS'90 Limiting Curve

Figure 13 shows that the new design requires a big reduction in limiting KG (a maximum of 0.680m at 8.500m draught at even keel) to comply with SOLAS 90 criteria, resulting in all existing loading conditions exceeding the new allowable curve. This poor SOLAS'90 performance is due to changes in the adopted subdivision principles (larger compartment lengths – which are not permitted under the existing deterministic SOLAS'90 regulations).

Concerning the latter point, additional calculations were carried out to assess whether this effect was purely down to the “margin line” criteria in the SOLAS'90 calculations, resulting from the increased compartment lengths in the new design. The results of the calculations for a SOLAS'90 limiting curve, with the “margin line” criteria removed, is shown in Figure 14. As can be seen, the limiting curve is greatly improved at the deeper

draughts where the “margin line” criterion is dominant but as the draught reduces, additional criteria such as “GZmax” start to gain importance, thus resulting in the limiting curve dropping again.

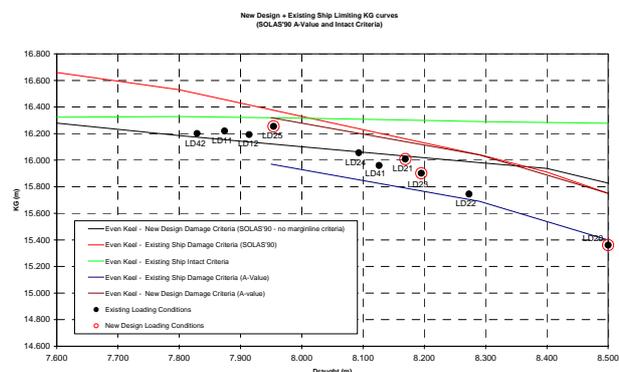


Figure 14: SOLAS'90 design comparison

The results from this study indicate that it is possible to produce two designs which do not show equivalence with regards to the two stability standards adopted. The difference in the results for the two designs is directly linked with the flexibility regarding the design features permitted in the two rules in question. Interestingly, the deterministic Regulation 8 appears to dominate calculations in so far as the limiting KG curve is concerned to the extent that the labour-intensive probabilistic rules calculations could in principle be dispensed with!

## Large Ro-Pax Derry

### Existing Ship Design

A standard SOLAS'90 compliant Ro-Pax ferry was chosen for the basis ship; approximately 290m long and carrying roughly 2500 passengers and crew.

The results of the analysis are given in Figures 15-61 next.

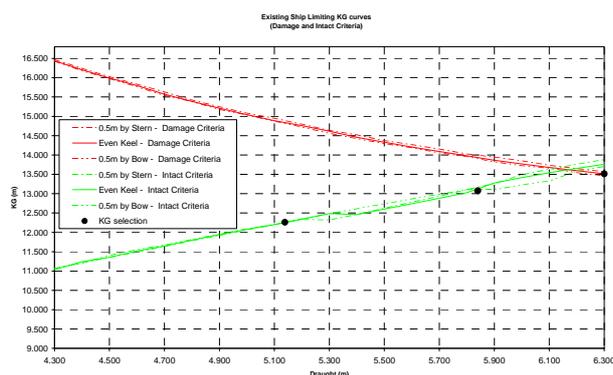


Figure 15: Existing Ship Limiting Curves and A-value KG selection

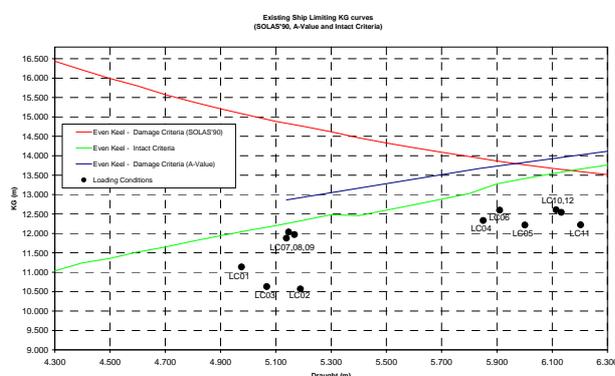


Figure 16: Existing Ship A-value Limiting curve with loading conditions

To resulting damage limiting KG curve for the vessel using  $A=R$  as the criterion, display a margin of some 0.6m throughout the draft range as shown in 16. However, since the intact stability limiting curve is dominant over the entire draught range, this additional margin is of no benefit in the operation of the vessel. This good A-value performance is due to the large WT barriers on the port and starboard of the car deck resulting in reduced amount of water on the vehicle deck.

### New Ship Design

Using the platform optimisation approach described in the foregoing, the following objectives were set for the new design:

- Must be compliant with R-value
- Must be complaint with Regulation 8

- Approximately same tank volume and similar distribution in vessel
- Maintain or increase anti-heeling capacity
- Approximately the same internal area for service spaces e.g. sewage treatment rooms
- Approximately the same positions for Main Fire Bulkheads
- Same spacing for Main Engine Room Bulkheads
- Maintain vehicle lane capacity
- Minimize Steel weight

The results of the analysis are given in Figure 17 next:

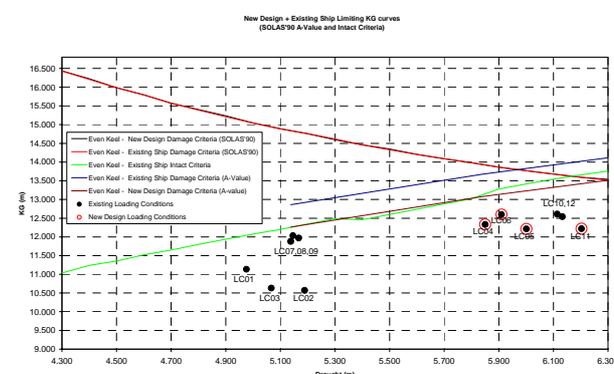


Figure 17: New Design SOLAS'90 Limiting Curve

Figure 17 shows that the new design gives an identical limiting KG curve as the existing vessel, demonstrating that it is possible to produce two designs which show equivalence with regards to the two stability standards adopted. The similarities in the results from the two designs can be attributed to the design constraints, mainly linked with the purpose of the vessel i.e. large vehicle lane capacity. The results from this study highlight the issue of the intact stability criteria since in both designs it is these criteria which are dominant. This result is due to both vessels using the same hull form and the fact that the criteria for intact stability are the same irrespective of which damage stability rules are used

Finally, the results help to show the flexibility in the way the designer can apply the new probabilistic rules in that the resultant damage

limiting curve shape can be adapted to follow that of an intact curve to ensure that a more optimised design is produced (something which is not possible in the traditional deterministic SOLAS'90 criteria).

### Container Feeder ship

A standard SOLAS'90 (probabilistic REG 25) compliant Container Feeder was chosen for the basis ship; approximately 130m long and 1400 tonnes displacement.

The results of the analysis are given in Figure 181 next.

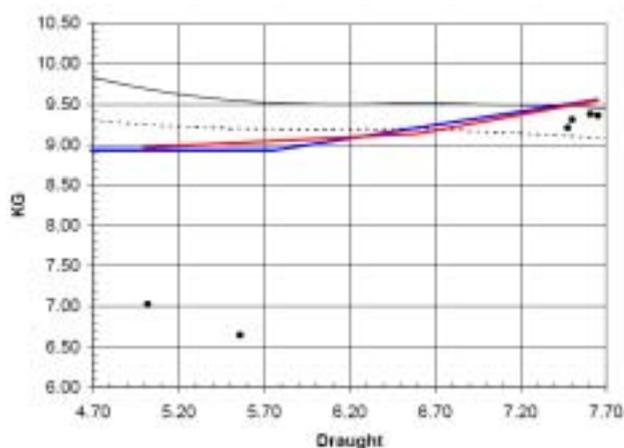


Figure 18: Existing Ship A-value Limiting curve with loading conditions

The existing SOLAS'90 (probabilistic REG 25) and new MSC 194(80) regulations result in similar operational envelopes for this type of vessel, indicating no real effect, in this case, from the changes introduced in the harmonized regulations. The same was the case with the other cargo vessels considered in the study.

## 6. CONCLUDING REMARKS

Based on the work presented in the foregoing, the following concluding remarks may be drawn:

### Specific

- Wendel's concept of ship subdivision is incongruent with modern concepts of risk

and risk analysis. This deficiency is greatly exacerbated by add-ons and quick fixes that lack rigour and credibility (e.g., deterministic merits).

- In this respect, designing (upgrading) ships to high Index A-values to comply with high (er) required Index R-values can be grossly misleading and dangerous.

### General

- With a clear trend towards probabilistic and risk-based frameworks to addressing ship safety in a holistic manner, it is important to base such developments on clear understanding of the underlying principles and of the intention of the ensuing rules and regulations and/or criteria.
- The need to inculcate all major stakeholders in these new developments must remain a priority and clear targets set to facilitate the transition from prescriptive to goal-setting regulations.
- The probabilistic framework of the new harmonised rules for damage stability calculations offer flexibility and added degrees of freedom for designers to enhance safety cost-effectively whilst embracing innovation.

## 7. ACKNOWLEDGMENTS

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