SOLAS '90, Stockholm Agreement, SOLAS 2009 – The False Theory of Oranges and Lemons

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ABSTRACT

In anticipation of the forthcoming new harmonised probabilistic damage stability regulations during a period when existing deterministic instruments are still being enforced, namely SOLAS '90 (globally) and Stockholm Agreement (in Europe), questions concerning multi-instrument compliance in newbuilding projects are being raised by industry and regulators alike. These are fuelled by uncertainties concerning the derivation of the SOLAS 2009, lack of experience in their implementation, but more importantly by the determinism that has prevailed in the industry to this date. The argument of mixing "oranges" and "lemons" when it comes to combining probabilistic and deterministic rules has given the impetus to writing this paper, aiming to demonstrate that the argument has no relevance, as both sets of regulations address statistical damages to a lesser or fuller extent.

KEYWORDS

SOLAS '90, Stockholm Agreement, SOLAS 2009, damage survivability, probabilistic rules

INTRODUCTION

In January 2009, the new harmonised probabilistic rules for ship subdivision will become mandatory, replacing their deterministic counterparts, namely SOLAS '90 and Stockholm Agreement (SA) and initiating a new era in rule-making in the maritime industry in line with contemporary developments, understanding and expectations. This will be the culmination of more than 50 years of work, one of the longest gestation periods of any other safety regulation. Considering that this is indeed a step change in the way safety is being addressed and regulated, "taking our time" is well justified. However, close scrutiny of the work that led to the current formulation of the s-factor gives rise to concerns that a series of unjustified compromises have crept in during the rule-making process. This was reported in the stability workshop in Hamburg, [Vassalos 2007].

Contemporaneously, doubts from other sources surfaced to indicate that the SOLAS 2009 rules were in some respects not providing as high a safety level as the deterministic rules being replaced. This particularly related to the ingress of water on Ro-Pax car decks, which was not specifically addressed in SOLAS 2009. As a result, the European Commission sought the views of industry on the possible problems and solutions regarding the two sets of rules in relation to Ro-Ro passenger vessels. Two opposing views emerged: the first [Hildingsson 2005; [Schreiber 2006], suggesting that SOLAS2009 constitutes at least an equivalent stability standard and that the underlying method for assessing the probability of survival, the “ s ” factor, accounts for the effects of water on deck (WOD) on Ro-Ro ships, as concluded during the HARDER project, [HARDER 2003]; the second supporting that in view of the facts presented in [Vassalos 2007], it will be difficult to dispense the current provisions for damage stability until the new rules were suitably amended.

Following a number of meetings involving the European Maritime Safety Agency (EMSA, the maritime industry and Member States, it was decided that despite the fact that all parties were fully supportive of the probabilistic approach of SOLAS 2009, the European Commission will be requesting IMO to re-examine the new rules (particularly the WOD problem with Ro-Pax) under a new work programme and, in the meantime, allow a temporary continuation of the regional measures in line with the Stockholm Agreement. Member States remain divided, one of the main worries being that in practical terms it would not be feasible in the future for shipbuilders to design ships to two sets of rules.

In line with the views expressed above, this paper advances the strong belief housed at SSRC and SaS that the probabilistic framework for damage stability calculations constitute the most significant single development in the rule making history. However, implementation of the rules to designing a number of newbuildings (cruise and Ro-Pax), evaluation of a number of existing vessels and, finally, FSA studies performed under the IP SAFEDOR [SAFEDOR 2005-2009] for both cruise and Ro-Pax, reveal that the safety standard implicit in these rules leaves passenger ships vulnerable to damage scenarios that could be safeguarded by their deterministic counterparts. Hence, to achieve real progress in ridding off determinism for good whilst meeting contemporary societal expectations as regards human life safety, the standard in the forthcoming rules MUST BE RAISED SIGNIFICANTLY. The paper provides evidence in support of this claim by presenting a series of results addressing the issues raised during recent debates. More specifically:

Using Ro-Pax and cruise vessels designed to either or both deterministic and probabilistic rules, the latter with the Required Index R varying from the level currently proposed to almost 1, it is clearly demonstrated that deterministic rules comprise specific subsets from the ensemble of all probable damages as well as the contribution of these subsets to Index-A, thus providing a means for comparing the three instruments in relative and absolute terms.

A judicious selection from the above set of results is then used to highlight and explain the likely possibility of not being able to satisfy one of the two sets of criteria when using the other to design these ships. Emphasis is placed in particular on the weakness of using an aggregate statistic (Index-A), in that it “shields” possible design vulnerabilities through what is known as “compensation effect”. There are two ways to avoiding this. The first and least efficient is to utilise deterministic safeguards, the normal step followed by the deterministically-minded rule makers (for example, Regulation 8.2 for minor damages) or to raise the standard so as to cater for such weaknesses implicitly.

The paper concludes by echoing the IMO Secretary General that “the future is (indeed) probabilistic” and that there are no oranges and lemons among the damage stability instruments; only engineers with poor “vision”!

DETERMINISTIC AND PROBABILISTIC INSTRUMENTS OF DAMAGE STABILITY

As the forthcoming probabilistic rules were developed as equivalent to SOLAS ’90, in the sense of utilising the calculated A-values of marginal SOLAS ‘90 vessels to derive the safety standard (R Index), demonstrating such equivalence would be very important. In this respect, the following are noteworthy.

SOLAS '90:

For most ships, this standard prevents them from capsizing if any two compartments are flooded in any sea conditions encountered during a collision. As a deterministic instrument deriving from consideration of calm water stability parameters of ships deemed safe to operate, the level of safety (risk content in the rule), is at first sight, unknown. For comparison purposes, however, a performance criterion may be used, such as the maximum sea state (as characterised by Hs) a marginal SOLAS '90 Ro-Ro passenger 2-compartment standard ship could survive. These results demonstrate than on average, SOLAS '90 ships survive a worst-2-compartment damage is sea states of 2.5m Hs.

Stockholm Agreement:

This is known as SOLAS '90 plus water on deck criterion and is the first performance-based criterion ever devised in the maritime industry. More specifically, ships complying with Stockholm Agreement requirements could survive a worst-2-compartnent damage, with a pre-defined level of water on deck, in sea states up to 4m Hs, depending on freeboard and area of operation. Hence, it is readily amenable to comparison when the equivalent route to compliance by model experiments (IMO '95 Regulation 14) is followed; note that Stockholm Agreement compliance by calculation considerably underestimates survival (see Figure 1).

SOLAS 2009

This is a probabilistic instrument reflecting the "aggregate" probability of survival, considering all pertinent collision→flooding scenarios as derive from such accident statistics. These address loading condition, damage characteristics and sea state at the instant of collision. Therefore, it offers a rational basis for establishing the level of safety (by quantifying the associated risk) of the vessel in question. The safety standard in this rule is represented by the Required Index of subdivision R, whilst the safety level is inferred by using the Attained Index of subdivision A. For comparison purposes, in the first instance, a relationship between Index-A and sea state (as characterised by Hs) could again be considered as shown in Figure 2.

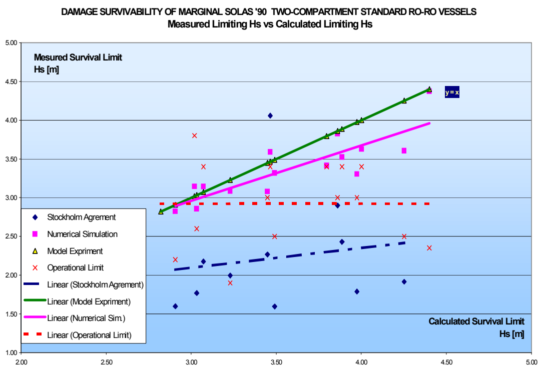

Figure 1: Survival sea states for Stockholm Agreement Ro-Ro passenger ships (experiment and calculation routes)

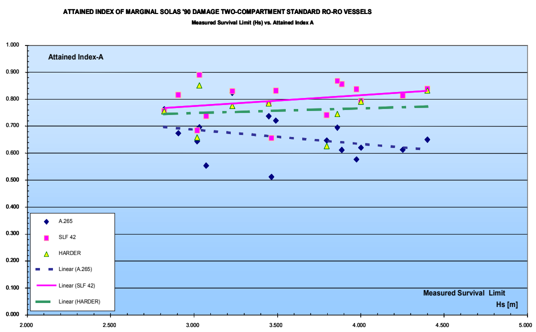

Figure 2: Comparison of Index-A by various probabilistic instruments

The new regulations represent a step change away from the current deterministic methods of assessing 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.

Hence attempting to compare these rules with their deterministic counterparts as described above can only support a general argument. For a more direct and specific comparison, it would be necessary to consider all three under the same framework, namely the probabilistic framework for ship subdivision as described next.

THE PROBABILISTIC CONCEPT OF SHIP SUBDIVISION

One of the fundamental assumptions of the probabilistic concept of the ship subdivision in the proposed regulations is that the ship under consideration is damaged, that is the hull is assumed breached and there is (large scale) flooding. This implies that the cause of the breach, the collision event with all the circumstances leading to its occurrence, are disregarded, and hence the interest focuses on the *conditional* probability of the loss of stability.

In other words, risk to life is assumed to be irrelevant on the likelihood of occurrence of a collision event that ends in hull breaching and flooding. For this reason, the regulations imply the same level of "safety" irrespective of the mode of operation that can e.g. take place in area of varying density of shipping (congestion of traffic), or indeed can be so different depending on ship type, or can involve vastly different consequences, etc, all of which might imply considerably different levels of actual risk. This said, all risk-related factors (e.g. size of ship, number of persons on board, life saving appliances arrangement, and so on) are meant to indirectly be accounted for by the Required Index of Subdivision, R. Summarizing, the probability of ship surviving collision damage is given by the Attained Index of Subdivision, A, and is required not to be lesser than the Required Index of Subdivision, R, as given by expression (1):

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

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
- I set of all feasible flooding scenarios comprising single compartments or groups of adjacent compartments
- w_j probability mass function of the loading conditions (draught)
- p_i probability mass function of the extent of flooding (that the compartments under consideration are flooded)
- s_{ij} probability of surviving the flooding of the group of compartment(s) "i", given loading (draft) conditions j occurred

The index A can thus be considered as the expected value of the "s-factor", with "p- and w-factors" being the respective likelihoods, reflected in worldwide ship collision statistics:

$$A = E(s) \qquad (2)$$

Consequently, (1-A) can be considered as the marginal probability of (sinking/capsize) in these scenarios, and as such it can be used for deriving the collision-related risk contribution, [Vassalos 2004].

The Required Index of Subdivision, R (derived principally from a regression on A-values of representative samples of existing ships) represents the "level of safety" associated with collision and flooding events that is deemed to be acceptable by society, in the sense that it is derived using ships that society considers fit for purpose, since they are in daily operation. Additional pertinent information relates to the formulation of the s-factor itself, namely (at final equilibrium), with a number of inherent limitations as detailed in [Vassalos 2006]:

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

where:

GZ_{max} 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 $\theta_e \leq \theta_{min}$

K= 0 if $\theta_e \geq \theta_{max}$

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

"θ_{min}" is 7 degrees for passenger ships and 25 degrees for cargo ships, and

"θ_{max}" is 15 degrees for passenger ships and 30 degrees for cargo ships.

The process of derivation of model (2) entailed a series of experiments, 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. This process involved testing scale models in worst SOLAS 90 damage cases over 30 minutes duration and noting the sea state resulting in capsize (critical sea states). The additional information used was the cumulative distribution of sea states recorded at the instant of collision (Figure 3). 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.

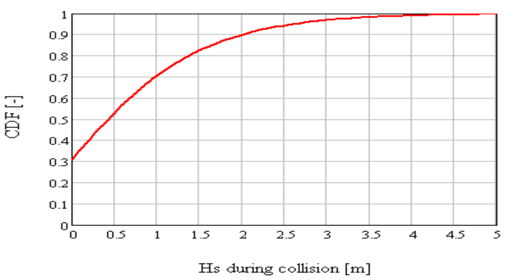

Figure 3: CDF of significant wave heights at the instant of collision

A CONSISTENT FRAMEWOTK FOR SOLAS '90, SA AND SOLAS 2009

On the basis of the foregoing and considering Figures 1-3, the following observations can be made:

- SOLAS '90 provisions cater for all 2-compartment damages, in sea states with Hs of approximately 2.5, corresponding roughly to a survival factor of 0.9.
- For SA, the same applies but limiting Hs is now 4m, hence an s-factor of 1.0.

Therefore, the following notation for Index A, can be adopted:

$$A_K = \sum_{j=1}^{J} \sum_{i=1}^{I} w_j \cdot p_i s_{ji} \quad ; \quad A > R \qquad (3)$$

Where, K=1,2,3, … implies sts of damages of 1, 2, 3, … compartments respectively and $I \in K$.

$$A_{SOLAS\ '90} = A_1 + A_2,\ \text{for all } s_{ji} \geq 0.9 \qquad (4)$$

Hence A_1+A_2, for all $s_{ji} \leq 0.9$ will represent contribution to A from damage scenarios where a SOLAS 2009 ship will fail to comply with SOLAS '90 provisions.

Similarly,

$$A_{SA} = A_1 + A_2,\ \text{for all } s_{ji}\text{-}1.0 \qquad (5)$$

Again, A_1+A_2, for all $s_{ji} \leq 1.0$ will represent contribution to A from damage scenarios where a SOLAS 2009 ship will fail to satisfy SA requirements pertaining to Hs=4m.

Different penetration depths, being applicable to deterministic and probabilistic instruments, will distort comparisons, but if emphasis is placed on the intent of the rule (namely SOLAS '90 safeguards against any 2-compartment damage, i.e., not necessarily B/5 damages) it will now be possible to compare all three by considering the risk contribution of all pertinent damage scenarios in each of instruments, using expressions (1), (3) and (4). This will be considered in the next section, following some preliminary results of research projects undertaken on behalf of the UK Maritime and Coastguard Agency (MCA).

COMPARATIVE ASSESSMENT BETWEEN DETERMINISTIC AND PROBABILISTIC INTRUMENTS FOR DAMAGE STABILITY

MCA Research Projects

Considering that, whilst development of the probabilistic regulations included extensive calculations on existing ships which had been designed to meet the current SOLAS regulations, little effort had been expended into designing new ships from scratch using SOLAS 2009 regulations. It is this gap that the research study UK MCA RP552 aimed to address, in particular, 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 designs with a lesser safety level?
- The effect different design options may have on the performance of a vessel under the new rules.

To address these issues, the following approach was adopted for a selection of vessel designs comprising passenger and cargo vessels [Vassalos 2006]:

- Analyse an existing SOLAS '90 design using SOLAS 2009 rules with the existing limiting curve operational envelope.
- Propose a new design based on the same operational envelope and design specifications but designed purely for compliance with SOLAS 2009 rules.
- Analyse new design using SOLAS'90 rules.
- Compare the limiting curve results from the two designs

The results from this study can be summarised as follows:

Cruise ship

- The SOLAS 90' design did not comply with SOLAS 2009, mainly due to static heel angles caused by large tank asymmetries in the DB and B/5 tanks on Deck 00.
- Similarly the SOLAS 2009 design did not comply with SOLAS '90, mainly due to changes in the adopted subdivision principles (larger compartment lengths – which are not permitted under the existing deterministic SOLAS'90 regulations).
  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 de dispensed with!**.**

RoPax

- The SOLAS '90 design complied with SOLAS 2009 with some margin, mainly 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.
- The SOLAS 2009 design produced an identical limiting KG curve as the existing vessel, demonstrating that it is possible to produce two designs which show equivalence.

Cargo ships

- Designing to either of the two sets of rules resulted in similar operational envelopes for all cargo ships, indicating no real effect from the changes introduced in the harmonized regulations.

The overriding conclusion from this study points to the fact that a new design that meets one set of rules may or may not comply with the other, simply because the parameters chosen to measure the standard are different in the two sets of regulations

SaS Case Studies

To advance the argument deriving from expressions (3) to (5), some results are presented here for case studies performed by SaS in support of the EMSA discussions. Four from 4 SOLAS '90 RoPax vessels were used, designed to SOLAS '90 that were upgraded to SA by model tests. These are shown in Table 1 and Figure 4 below.

Table 1: A-value Comparisons between SOLAS '90, SA and SOLAS 2009 RoPax designs

RoPax Vessel	R-value	A-value SOLAS '90	A-value SA	Oper'al Hs	s-factor (Fig. 3)
SaS1	0.789	0.827	0.827	3.0	0.968
SaS2	0.779	0.846	0.846	2.8	0.960
SaS3	0.778	0.817	0.841	4.0	0.990
SaS4	0.801	0.821	0.821	3.8	0.988

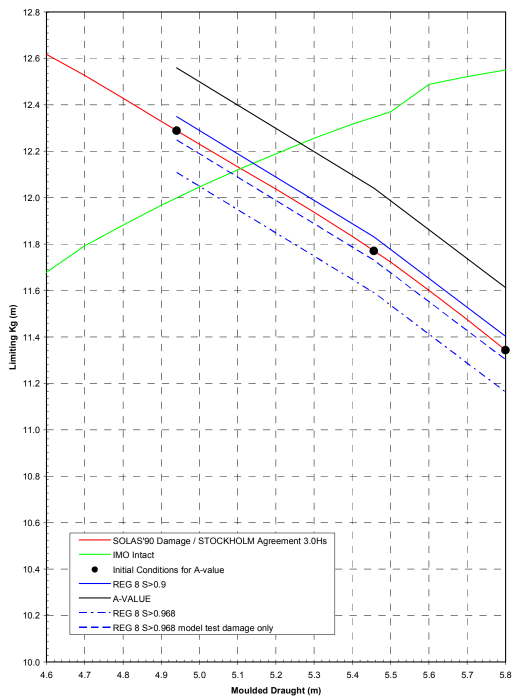

Figure 4: Limiting KG Curves for SaS1

"A-value SOLAS'90" denotes SOLAS2009 calculations performed for loading conditions derived from the KG limiting curves implied by SOLAS '90. Likewise "A-value SA" denotes the SOLAS2009 calculations performed for loading conditions derived from the KG limiting curves implied by Stockholm Agreement with the relevant Hs verified experimentally (the "dots" shown in Figure 4). The "s-factor" corresponds to relevant factor obtained from Figure 3 for the operational Hs required by Stockholm Agreement.

These results are indicative of the following:

- The R-Index needs to be increased by 3%-10%, depending on the vessel for compliance with SOLAS '90 and SA requirements.
- Similar to conclusions derived from the MCA study it would seem that SOLAS 2009 designs may not comply with SOLAS '90 and SA requirements BUT it could certainly be made a stricter requirement if the standard (R-value) is raised sufficiently.

  The difference between A-value in columns (3) and (4) of Table 2 and the R-value in column (2), reflects damage scenarios not complying with the deterministic standards that can be accommodated in the new rules through the "compensation" effect.

Newbuilding Design Experience

<u>Early Results</u>

In the quest to explore equivalence between probabilistic and deterministic rules, a set of calculations were completed using a SOLAS '90 PANAMAX cruise liner and a SOLAS 2009 post-PANAMX cruise ship.. The objective of the exercise was to identify the required limiting KGs (hence computed the R-value) in both vessels so that the SA is complied with, namely, s=1.0 for all 2-compartment damages (observing the B/5 and B/10 penetration depths in the two vessels as required by each applicable set of regulations).

However, this proved more difficult than originally anticipated. The problem in all cases relates to the design of the vessel in specific areas and not the rule in general. In all cases the vessels have been designed to meet the requirement, thus if the requirement for the s-factor increased to 1.0 for the 2 compartment B/5 in the PANAMAX cruiser and B/10 cases in the post-PANAMAX both started to fail readily. Attempting to increase GM to comply with the s=1.0 requirement leads to large increases in the attained index. This, however, does not reflect the real required increase in A-value due to s=1.0 for 2-compartment damages since in all cases the problem is down to the design. In the case of the PANAMAX cruise liner it is the position of the openings, meaning that it is almost impossible to obtain s=1.0 for the 2-compartment damages unless modifying the opening arrangements on the vessel. In the case of the post-PANAMAX the situation is again similar, the problem being a cross connection which could not equalise quickly enough to allow s=1.0. Clearly, with the vessel designed for 2-compartment B/10 damages the s-factor factor targeted was 0.9 and not 1.0.

The point emerged from this study is that each rule leads to designs, which are optimised/refined to a level where they meet the rule requirements as they stand. If a higher standard for the 2-compartment cases were introduced then designs fail because of localised rather than global "deficiencies"; hence localised changes to the internal arrangement or cross flooding layouts should be enough to raise the standard, rather than changing KGs.

In the knowledge that localised modifications do not have a significant impact on the overall attained index it is unlikely that the A-value would increase in the same proportions as it would if the KG were reduced, such reduction having probably the greatest overall effect in raising the A-value.

A way out of this dilemma would be to design a vessel to comply with the requirements of both deterministic and probabilistic instruments (hence ensuring the highest level of safety allowed by the rules) until understanding of what level of safety is needed and how best to achieve it were in place. Adopting, for example, the approach described in [Vassalos 2006] as "Platform Optimisation", where the vessel subdivision problem is solved as an optimisation problem, the deterministic requirements are simply added as additional constraints with the ensuing design complying with both sets of instruments. Indeed, this has already been undertaken in a number of newbuildings (cruise and RoPax). This is presented next for three new designs alongside the vessels discussed in the foregoing.

One-Rule and Two-Rule Designs

Seven ship designs were analysed on the basis of expressions (3) to (5), including existing and new designs, some of the latter designed to comply with both SOLAS 2009 and SA. The analysis relates to all damages covered by the probabilistic rules. The results are presented in Table 2 and Figure 5 as approximate probabilities for the vessel to capsize in the said scenario in less than 3 hours [Jasionowski and Vassalos 2006], in an attempt to relate all results to the notion of risk and hence attempt direct comparisons in an absolute sense.

The results presented in Figure 5 designate contributions to "risk" by zone rather than compartment but in the majority of cases the two coincide.

Table 2: Analysis Results

A **A value = 0.80059** PANAMAX Cruise Ship SOLAS '90

ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.80059	0.95251	0.15191		
1 ZONE	0.23861	0.23864	0.00003	0.00000	0.00053
2 ZONE	0.28115	0.28396	0.00281	0.01050	0.04096
3 ZONE	0.16970	0.19788	0.02818		
4 ZONE	0.09275	0.13808	0.04533		
5 ZONE	0.01546	0.06545	0.04999		
6 ZONE	0.00292	0.02850	0.02558		

B **A value = 0.70905** ROPAX SOLAS '90 - Long Lower Hold

ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.70905	0.90660	0.19755		
1 ZONE	0.29685	0.29716	0.00031	0.00078	0.00387
2 ZONE	0.29849	0.35577	0.05728	0.07828	0.11156
3 ZONE	0.09691	0.16325	0.06633		
4 ZONE	0.01480	0.05829	0.04350		
5 ZONE	0.00188	0.02393	0.02206		
6 ZONE	0.00012	0.00819	0.00807		

C **A value = 0.81658** Post-PANAMAX Cruise Ship - SOLAS 2009 & SA

ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.81658	0.99172	0.17514		
1 ZONE	0.27316	0.27316	0.00000	0.00000	0.00000
2 ZONE	0.34929	0.36230	0.01300	0.02635	0.04234
3 ZONE	0.15318	0.20393	0.05075		
4 ZONE	0.03881	0.09644	0.05762		
5 ZONE	0.00190	0.04164	0.03974		
6 ZONE	0.00023	0.01426	0.01403		

D **A value = 0.90170** Post-PANAMAX Cruise Ship - SOLAS 2009 & SA

ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.90170	0.99915	0.09745		
1 ZONE	0.36509	0.37538	0.01029	0.04851	0.12732
2 ZONE	0.36022	0.37388	0.01365	0.04916	0.16378
3 ZONE	0.13145	0.16826	0.03681		
4 ZONE	0.03513	0.06210	0.02697		
5 ZONE	0.00944	0.01717	0.00772		
6 ZONE	0.00036	0.00236	0.00200		

E **A value = 0.91191** RoPax - SOLAS 2009 & SA

ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.91191	0.98667	0.07476		
1 ZONE	0.31950	0.31951	0.00001	0.00000	0.00197
2 ZONE	0.37238	0.37882	0.00644	0.01018	0.06587
3 ZONE	0.14612	0.17629	0.03017		
4 ZONE	0.05585	0.07989	0.02404		
5 ZONE	0.01806	0.03215	0.01410		
6 ZONE	0.00000	0.00000	0.00000		

F	A value = 0.79814		SaS Design - SOLAS 3009 &SA		
ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.79814	0.92346	0.12532		
1 ZONE	0.28883	0.28883	0.00000	0.00000	0.00000
2 ZONE	0.35327	0.35683	0.00356	0.00815	0.03800
3 ZONE	0.13873	0.18668	0.04796		
4 ZONE	0.01711	0.07114	0.05403		
5 ZONE	0.00020	0.01998	0.01978		
6 ZONE	0.00000	0.00000	0.00000		

G	A value = 0.97881		SaS Design (Lifebelt) - SOLAS 2009 & SA		
ZONE	A-VALUE Σ P*S*V*W	MAXIMUM Σ P*V*W	PROB TO CAPSIZE IN 3 HR	s<0.9 Σ P*W	s<1 Σ P*W
TOTAL	0.97881	0.99850	0.01969		
1 ZONE	0.33039	0.33039	0.00000	0.00000	0.00000
2 ZONE	0.37256	0.37256	0.00000	0.00000	0.00000
3 ZONE	0.19775	0.19785	0.00010		
4 ZONE	0.06552	0.07614	0.01061		
5 ZONE	0.01259	0.02157	0.00898		
6 ZONE	0.00000	0.00000	0.00000		

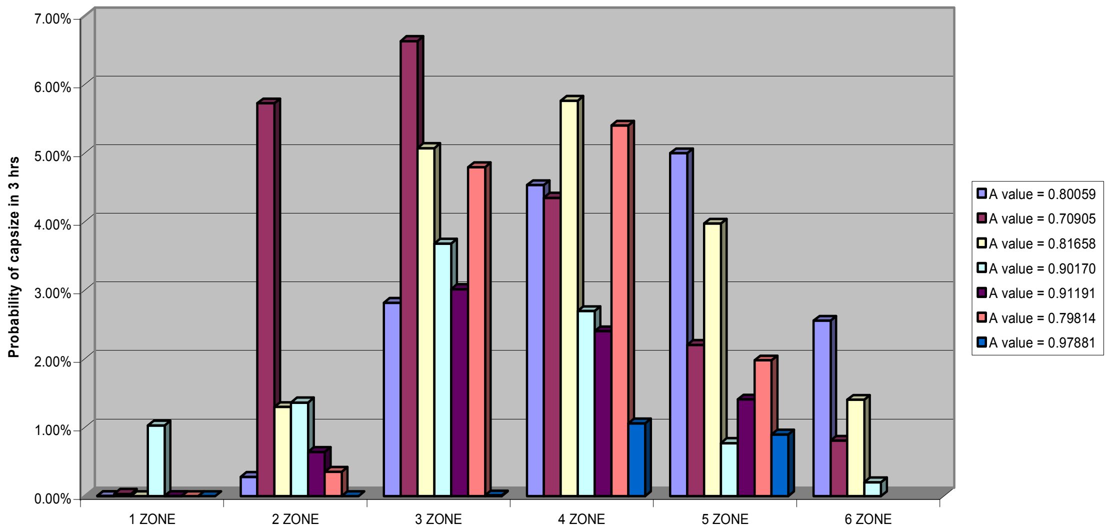

Figure 5: SOLAS '90 and SA "Deficiencies" in SOLAS 2009.

An examination of Figure 5 leads to the following noteworthy points:

- Having ships designed to survive any 2-compartment damages up to Hs=4.0m (s=1.0) is not a mean task, especially for penetrations up to centre line. This is a severe test for a vessel's survivability.
- All one- and two-zone damages that "fail" refer to centre line damages that introduce asymmetry with the exception of vessel B, which has a long lower hold. It should be noticed that vessel D with A-Index over 0.9 still fails to survive one zone damages at 4.0m Hs.
- The RoPax with A=Index of 0.912 (the second largest of the ships presented) fails

only marginally in having all two-zone damages with an s=1.0. This is a design in the making, so that this small deficiency will be taken care of.

- Designs F and G represent a SaS proposal for high survivability concept designs, included here to demonstrate that (a) such designs can be realised and (b) that the standard ought to be raised substantially before anyone can claim that SOLAS 2009 is stricter than SOLAS ’90 or SA.

SAFEDOR FSA Studies

It would be worthwhile mentioning that the EU IP SAFEDOR has produced FSA studies for RoPAx and Cruise ships, which are being submitted to IMO and will be published in the SAFEDOR web site for public access. The recommendations from these studies strongly suggest that the standard (R-value) for both vessel categories ought to be raised substantially and what is more important, it is cost-effective to do so.

Related to this, an EU project proposal is currently being prepared by selected partners from the SAFEDOR consortium to formulate and benchmark such a standard, with the view to submitting the results to IMO.

CONCLUDING REMARKS

Based on the results and discussion presented in this paper the following remarks can be made:

- In anticipation of the forthcoming probabilistic rules, due to be adopted in January 2009, concerted effort is required to ensure the use of collective wisdom in all undertakings involving new designs.

- This is particularly important in view of the fact that the new rules were found to be in need of major revision before they can be confidently applied to the design of passenger ships.

- Until such time, the use of suitable tools (numerical or experimental) ought to be used to safeguard against unsafe designs, coupled with the use of deterministic instruments, which provide a worthy safeguard against deficient rules and designers lacking experience and understanding in designing to new rules.

- The freedom afforded by the new regulations must be harnessed and the ensuing capability directed to realise much safer designs that has thus far been the case.

- Indeed, work undertaken to date strongly suggests that the standard implied by the new rules in their current formulation is not sufficient but using the new framework for damage stability calculations wisely could lead to high survivability designs that meet societal expectations cost-effectively.

- Concerning the argument on “oranges” and “lemons”, it would appear that key differences between probabilistic and deterministic rules can only be found in production designs, deriving from localised details and not at conceptual level. As a result direct comparisons at concept level could produce conflicting results. SOLAS ’90 and SA requirements are nothing more than constraints in the general problem of damage survivability of ships, which can be adequately addressed through the probabilistic framework of SOLAS 2009. Such constraints appear to be “stretching” the standard put forward by the current rules, thus providing more evidence of the need to raise the standard for ship damage stability.

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