Investigation of the Impact of the Amended S-Factor Formulation on ROPAX Ships

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ABSTRACT

The adoption of the probabilistic framework in the 2009 Amendments to SOLAS, was a major change against the deterministic approach used for the damage stability assessment of passenger and dry cargo ships. Over the last years, a number of serious concerns have been raised regarding the survivability of SOLAS 2009 ships in comparison with the requirements of Stockholm Agreement (Directive 2003/25/EC). A number of studies and discussions exist along the marine industry and IMO of how the water on deck effect could be incorporated under the SOLAS regulations. Recently, the SDC Sub-Committee at its first session has agreed in principle to the proposed amendments to SOLAS chapter II-1, including the survivability assessment of ROPAX ships. The main objective of this paper is to investigate the impact of the revised s-factor formulation on existing designs.

Keywords: *damaged ship stability, ROPAX ship, probabilistic assessment*

1. INTRODUCTION

The 2009 amendments to SOLAS and the adoption of the harmonized probabilistic damage stability regulations for dry cargo and passenger ships (SOLAS 2009), was a significant step towards a more rational approach for the assessment of ship's survivability after damage. The EU-funded research project HARDER (1999-2003) investigated all elements of the existing approach and proposed new formulations for the damage and survival probabilities and for the maximum acceptable risk level (minimum safety requirements) taking into consideration enhanced probabilistic data. The final recommendations submitted to SLF 46 and the new harmonized regulations adopted by Marine Safety Committee on May 2005 (Resolution MSC.194(80)) and entered into force on 1 January 2009.

Since the harmonised probabilistic damage stability regulations became mandatory there is a continuous process in the international and national maritime regulatory bodies of developing amendments to SOLAS chapter II-1 and of the associated explanatory notes (resolution MSC.281(85)). A number of regulations have been identified as needing for improvement as realised over the years that the new SOLAS could not cater for the expeditious developments in the design of large passenger ships. Moreover, concerns were expressed by EU member states and the Maritime Safety Agency (EMSA), regarding the safety equivalence between SOLAS 2009 and the provisions of Stockholm Agreement (Directive 2003/25/EC) for RoRo passenger ships. It is noted that SOLAS 2009 was not aiming to include water-on-deck (WoD) effects on RoPax ships because the Stockholm Agreement was not part of the SOLAS 90 standard then in force [Papanikolaou, 2013].

Last year IMO SDC Sub-Committee at its first session (SDC 1) has agreed in principle to the proposed amendments to SOLAS chapter II-1, including a revised formulation for the survivability assessment of ROPAX ships. This paper aims to identify the impact of the revised s-factor formulation on existing designs.

2. REGULATORY FRAMEWORK

2.1 The current s-factor formulation

The s-factor represents the probability of survival after flooding a compartment or group of compartments after collision damage and its current formulation as found in SOLAS II-1 Reg.7-2 is based on the concept of critical significant wave height H_{Scrit}, as derived from the original HARDER project:

$$H_{Scrit} = 4\frac{\max(GZ,0.12)}{0.12}\frac{\max(Range,16)}{16} = 4s^4 \quad (1)$$

In order to account transient capsize phenomena in the calculation of the survival probability and prevent asymmetric flooding, a factor K is applied to the final stage of flooding as a function of the final heeling angle at the equilibrium θ_e ($K = 1$ if $\theta_e \leq 7°$, 0 if $\theta_e \geq 15°$ and $[(15 - \theta_e)/(15-7)]^{1/2}$ elsewhere).

Therefore, the s-factor at the final stage of flooding is determined as:

$$S_{final} = \mathrm{K}\left[\frac{GZ_{max}}{0.12}\frac{Range}{16}\right]^{1/4} \quad (2)$$

where:

$GZ_{max} \leq 0.12m$ and $Range \leq 16°$

For passenger ships, SOLAS 2009 requires the calculation of s_{mom} at the final equilibrium, which is the survival probability considering the maximum transverse moment at the damaged condition resulted by the wind force and the evacuation of the ship (passengers movement to one side and lifeboats lunching). In addition, for passenger ships only, where the intermediate stages of flooding may be critical, it is required the calculation of the ship's survival probability ($s_{intermediate}$) before the final equilibrium is reached. Where cross-flooding fittings are required, the time for equalization shall not exceed 10 min. When the heel angle at any intermediate stage exceeds 15° the value of $s_{intermediate}$ is zero. In any other case it is calculated as follow:

$$S_{intermediate} = \left[\frac{GZ_{max}}{0.05}\frac{Range}{7}\right]^{1/4} \quad (3)$$

where:

$GZ_{max} \leq 0.05m, Range \leq 7°$

The s-factor for any damage case is then obtained from the formula:

$$s = \text{minimum}\{s_{intermediate}, s_{final} \cdot s_{mom}\} \quad (4)$$

The value of s-factor is also depending on the floatability of the ship at the final equilibrium and the immersion of critical points like horizontal evacuation routes, vertical escapes, control stations, etc. The immersion of any of the critical points result s=0.

2.2 The Stockholm Agreement

The Stockholm Agreement (SA) applies to RoRo passenger ships operating on regular scheduled voyages or visiting designated ports in North West Europe and Baltic Sea. The requirements of SA aim to increase ship's safety by accounting the risk of accumulation of water on the RoRo deck; water on deck (WoD) effect. The regulatory framework is based on a deterministic approach having as main parameters the residual freeboard (F_B) in the way of damage and the sea state, by means of significant wave height (H_s). The ship shall meet the survival criteria as described in SOLAS 90 Ch.II-1 Reg.8 paragraphs 2.3 to 2.3.4 when a hypothetical amount of water accumulated on the RoRo deck. If $F_B \geq 2.0$m no water is assumed while if $F_B \leq 0.3$m the height (h_w) of water on deck is taken as $h_w = 0.5$m. Intermediate heights of water are obtained by linear interpolation. With respect to the sea conditions, if the significant wave height in the voyage area is $H_s \leq 1.5$m then no water is assumed to be accumulated on the RoRo deck due to damage while if $H_s \geq 4.0$m the height of the water is based on the residual freeboard and calculated as above. Intermediate values are determined by linear interpolation. It is noted that, as an alternative to the above compliance with SA requirements can be demonstrated by carrying out model tests based on the specific method described in Directive 2003/25/EC.

2.3 The amended s-factor formulation

The SDC sub-committee at its first session on January 2014 finalized the draft amendments to SOLAS Ch. II-1 based on the report of the working group at SLF55 and of the correspondence group (SDC 1/WP.5/Add.1). According to the agreed amendments the survival probability for ROPAX ships is calculated using the formula:

$$S_{final} = \mathrm{K}\left[\frac{GZ_{max}}{TGZ_{max}}\frac{Range}{TRange}\right]^{1/4} \quad (5)$$

where:

$GZ_{max} \leq TGZ_{max}$ and $Range \leq TRange$

$TGZ_{max} = 0.20m$ and $TRange = 20°$

for each damage case that involves a RoRo space,

or

$TGZ_{max} = 0.12m$ and $TRange = 16°$ otherwise

3. APPLICATION OF THE AMENDED FORMULATION

Two existing ROPAX designs are used in order to investigate the impact of the amended survival probability on the stability characteristics, with respect to the attained subdivision index (*A*), and damage stability requirements, in terms of the minimum required intact metacentric height (*GM*). It is noted that for both ships the requirements of Reg.7 were more onerous than those of Reg.8 and Reg.9 when either the existing or the amended s-factor formula was used. All ships have been designed according to SOLAS 2009 and SA stability requirements.

3.1 Ship 1

The first ship is a large sized RoRo passenger day/night ferry which can accommodate 1900 passengers, is fitted with one lower hold and is divided into 18 watertight zones along the subdivision length of 200.8m.

In total 1146 damaged conditions are investigated for the three intact draughts (light, partial and deepest) with the damages to extend up to four zones. At 840 cases, at least one RoRo space is involved in the damage scenario Figure 1. For the most of them the vessel has sufficient GZ and Range in order to achieve s=1 or not enough stability and/or floatability leading to s=0 when both the existing and the revised s-factor formulation is considered.

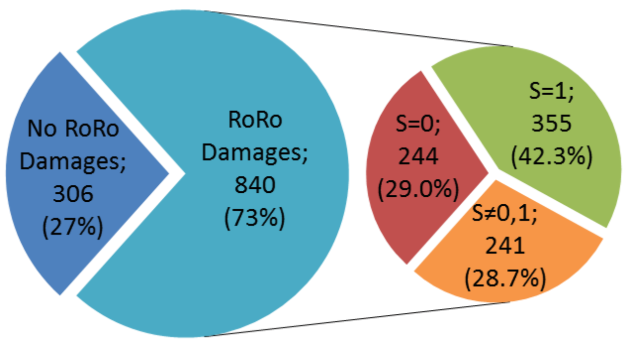

Figure 1: Damaged conditions studied, Ship 1

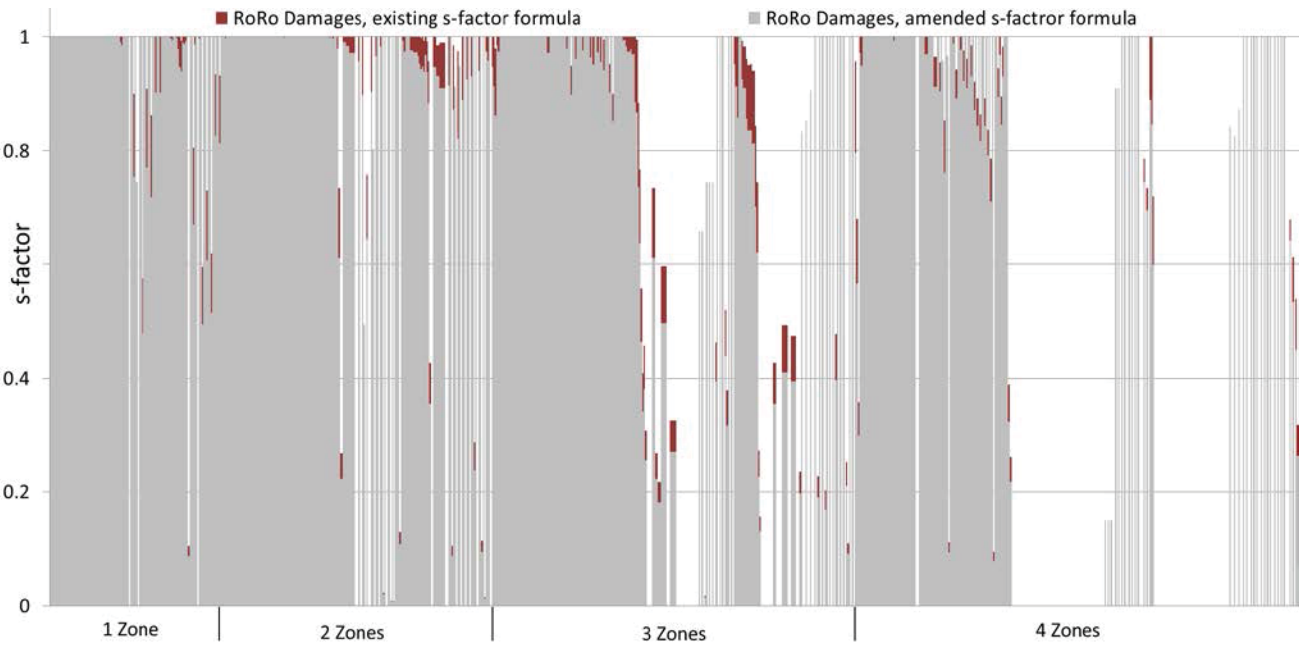

Figure 2: Survival probability of RoRo damages based on the existing and amended formula, Ship 1

For the rest 355 cases a mean reduction 8.7% occurred in the survival probability. If all 840 cases where a RoRo space is involved are accounted then the mean reduction to the s-factor is 2.5%. The Figure 2 shows the differences in the s-factor values for all damages where a RoRo space is involved when the existing and amended formula is used. It is also noted that for 88 or 10% of these cases the survival probability was one when calculated with the existing formula but reduced after the Equation 3 is used.

The required subdivision index according to SOLAS II-1 Reg.6, is R=0.79108. The calculations show that when the revised s-factor formulation is used, the attained index is reduced per 1.6%, decreased from A=0.79164 to A^*=0.77915, where A and A^* are the attained subdivision index according to the existing and amended Reg.7, respectively. As can be seen from Table 1, the minimum GM values need to be increased per 7cm in order the vessel to achieve compliance with Reg.6. For the calculation of the new GM, the values at partial (DP) and deepest subdivision draught (DS) equally increased while the GM value at the light service draught (DL) remained constant.

According to the approved stability information, the ship complies with the requirements of Stockholm Agreement (WoD) for a significant wave height of 4.0m at the light, partial and deepest draughts when the metacentric height values are at least those shown on the Table 1. It can be seen that the amended s-factor formulation for ROPAX ships, which leads to more onerous requirements, is able to draw up the water on deck effect, in terms of minimum required GM.

Table 1: Minimum required GM values, Ship 1

	Existing s-factor	Amended s-factor	WoD
Initial Condition	GM (m)	GM_S (m)	GM_W (m)
DL 5.10m, TR-0.3m	5.180	5.180	2.440
DP 6.00m	1.760	1.830	1.850
DS 6.60m	1.760	1.830	1.850
A	0.79164	0.79169	-
R	0.79108		-

3.2 Ship 2

The second ship is a large sized RoRo passenger day ferry with the capability to accommodate 300 passengers and transport vehicles on the main and upper garage decks and in one lower hold. The subdivision length of 211.9m is divided into 18 watertight zones while the required subdivision index is lower in comparison with the first ship (R=0.70036) because of the significantly smaller number of passengers.

The total number of the damage conditions investigated for the light, partial and deepest draughts was 1353 assuming the ship damaged up to four zones. As can be seen on Figure 3, the 81% of the examined cases involve a RoRo space. More than half of them did not have sufficient stability or enough floatability and result a zero survival probability regardless of the formulation used. On the other hand, 18% of them result s=1 based on both the existing and revised s-factor formula. For the rest 262 cases a mean reduction of 10.2% occurred in the s-factor values. If all 1098 cases involving a RoRo space are considered, then the mean reduction to the s-factor is 2.4%. It is also noted that 79 or 7% of the cases with a damaged RoRo space had a unitary probability of survival when calculated with the existing formula but reduced after the amended formula used.

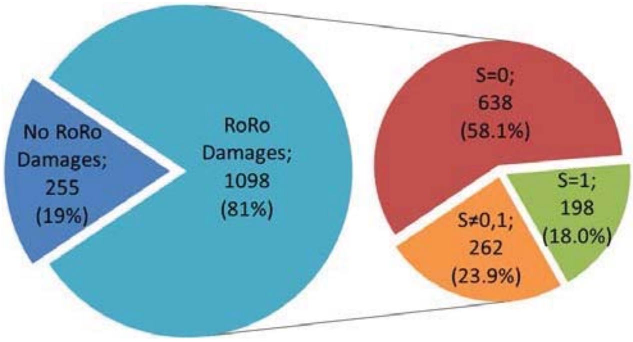

Figure 4: Damaged conditions studied, Ship 2

The impact of the amended s-factor formulation on the survival probabilities for all damages involving a RoRo space can be seen on Figure 4. The subdivision index of the ship has been reduced from A=0.70245 to A^*=0.68265 or 2.8%, where A and A^* are the attained subdivision indices according to the existing and the amended s-factor formulation, respectively. In order the vessel to achieve A=R the intact GM values need to be increased per 11cm equally for both the partial (DP) and deepest subdivision conditions (DS). As per the first ship, the GM value corresponding to the light service condition (DL) remains constant (Table 2).

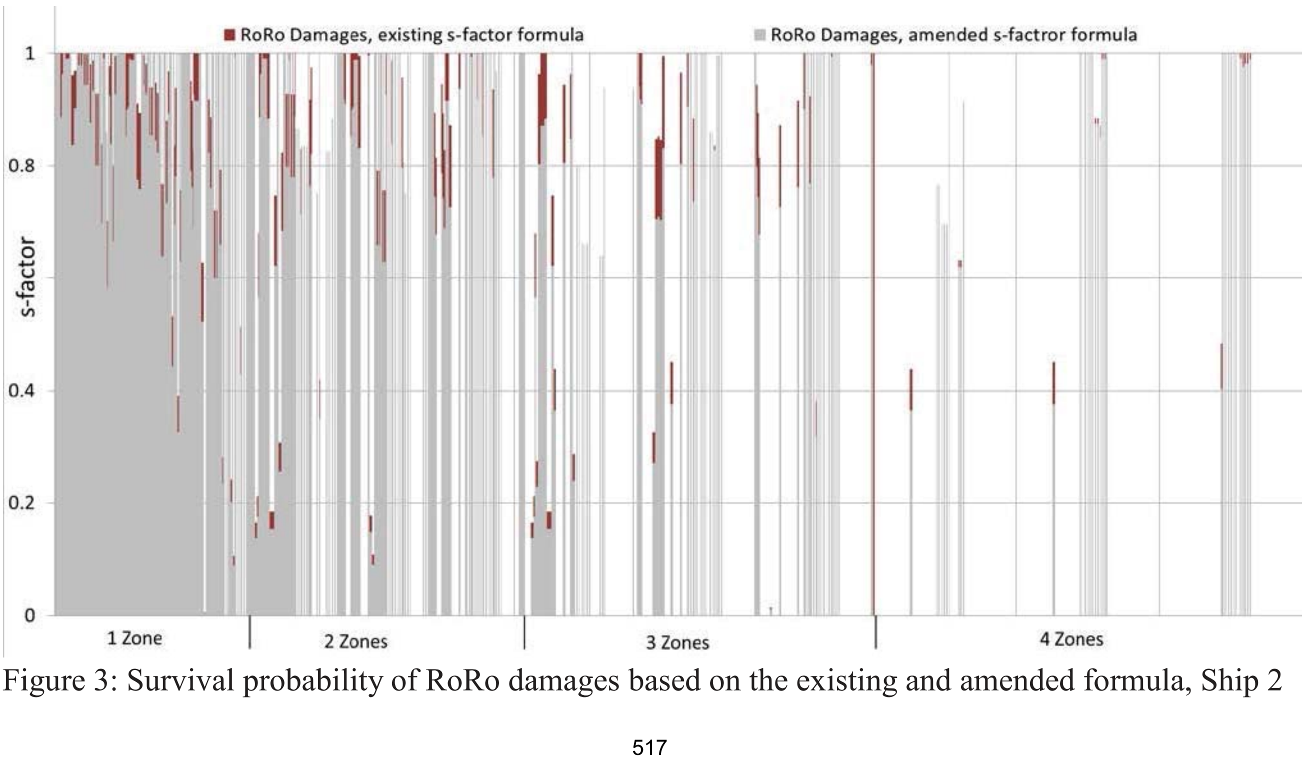

Figure 3: Survival probability of RoRo damages based on the existing and amended formula, Ship 2

Table 2: Minimum required GM values, Ship 2

	Existing s-factor	Amended s-factor	WoD
Initial Condition	GM (m)	GM_S (m)	GM_W (m)
DL 5.01m, TR-0.2m	4.610	4.610	2.141
DP 5.79m	1.500	1.610	1.611
DS 6.30m	1.900	2.010	2.024
A	0.70245	0.70213	-
R	0.70036		-

4. CONCLUSIONS

Following many discussions within the maritime community, last year the SDC subcommittee finalised the draft amendments to SOLAS Ch.II-1. A brief study for the effect of the amended survival probability for ROPAX ships has been presented in this paper.

The results show that, with respect to the requirements of Stockholm Agreement, the amended SOLAS Ch.II-1 was able, in terms of minimum required GM, to draw up the water on deck effect for the vessels under investigation. On the other hand, and due to the nature of the probabilistic approach, it is recognised that it is difficult to figure out possible critical damage cases and identify potential vulnerabilities in design with regard to damage cases involve a RoRo space. It is important to note that as the number of the vessels investigated is rather small the generalisation of the above outcomes is not possible.

5. ACKNOWLEDMENTS

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