COMPARATIVE STUDY OF DAMAGE STABILITY CALCULATIONS FOR SOLAS 2009 AND SOLAS 2020 OF RO-RO PASSANGER VESSEL

K Malinowska, Deltamarin.Sp. z o.o, Poland

SUMMARY

This paper presents a comparison of damage stability calculations results for ro-ro passenger vessel according to the requirements contained in SOLAS 2020 and SOLAS 2009 conventions. The calculations have been made in Napa software. The goal of this article is to show quantitively how significant is the increase of safety standards as per SOLAS 2020 revision, and what impact it will have on the ro-ro passenger vessel design.

NOMENCLATURE

[Symbol]	[Definition] [(unit)]
N	Total number of persons on board
R	Required index
A	Attained index of subdivision
EMSA	European Maritime Safety Agency
SOLAS 2009	International Convention for the Safety of Life at Sea dated/introduced by 2009
SOLAS 2020	International Convention for the Safety of Life at Sea dated/introduced by 2020
MSC	IMO's Maritime Safety Committee
S_{final}	Survivability factor (s factor) representing expected probability of survival
K	Coefficient depending on heeling angle
Range	Range of positive stability of the damaged ship (^{0})
GZmax	Maximum righting lever within the Range (m)
TGZmax	Target values for the maximum righting lever (m)
TRange	Target values for the maximum range (m)
Θmin	Minimum heel angle (^{0})
Θmax	Maximum heel angle (^{0})
Θe	Equilibrium heel angle in any stage of flooding (^{0})
N1	Number of persons with lifeboat provided
N2	Number of persons (including officers and crew) the ship is permitted to carry in excess of N1
Ls	Subdivision length (m)
DL	Light service draught
DP	Partial subdivision draught
DS	Deepest subdivision draught

1. INTRODUCTION

On 13th of January 2012 a passenger ship Costa Concordia grounded in the Mediterranean Sea, which resulted in the sinking of the vessel . This accident was an inspiration for EMSA to conduct a damage stability study concerning passenger ships, which was completed in 2016. This research led to the amendments to the International Convention for the Safety of Life at Sea (SOLAS 2020) that raised the damage stability requirements for the passenger ships in case of flooding caused by a collision. There are significant changes between the old and new SOLAS requirements. First one introduces a new definition of the required subdivision index R for passenger ships. The new definition is more rigorous than before for vessels carrying up to 1200 person on board. Secondly, a stricter formulation of the survivability s-factor for damages including ro-ro spaces is defined. Additionally, a survivability factor for minor damages is reformulated. New passenger ships constructed on or after 1st of January 2020, or with keel laid after 1st of July 2020, or delivered after 1st of January 2024 will be designed according to SOLAS 2020. Meeting new regulations along with the new approach to cross flooding calculations makes a design of a ro-ro passenger vessels really challenging. To better understand a need for a new SOLAS regulations it is good to go back to the history. The International Convention for the Safety of Life at Sea is one of the oldest conventions concerning safety of the marine traffic. It is a set of rules which determines minimum safety standards in the construction, equipment and operation of the merchant vessels. The first version of SOLAS was passed in 1914 as a result to the sinking of the RMS Titanic. After that six SOLAS conventions entered into force before SOLAS 2009. In SOLAS 2009 convention probabilistic method was taken into use as a lead calculation method for passenger ship (IMO, 2009). Moving from the deterministic methods as it was done in the previous versions of SOLAS to probabilistic method, it was important to keep safety at the same level. In the probabilistic method, R-index (setting Required level of safety) and A-index (describing Attained level of safety) are calculated, for the ship to be stable and safe it must be ascertained that A≥R. The probabilistic method is based on statistical data from damages to other ships. It takes into account all possible damage combinations of length, height, penetration depth and survivability.

2. SOLAS 2020

During the development of SOLAS 2009 rules and after they came into force there were number of critical issues concerning regulations for large passenger ship sector, which was and still is growing fast in the last years. To check if damage stability rules were sufficient several research projects were conducted. The conclusion from those analysis was showing that there is a possibility to design a vessel that fulfills SOLAS 2009 rules, but she may still sink and/or capsize even in calm water. Some proposals for improvement of R formula were made. The final decision was made at the 98th meeting of MSC on 15 June 2017, and a new R formula (Table 1) was approved in amendments for SOLAS II-1 within resolution MSC.421(98).

Table 1: [SOLAS 2020 subdivision index R for passenger vessel]

Persons on board	R
N < 400	R = 0.722
400 ≤ N ≤ 1350	R = N / 7580 + 0.66923
1350 ≤ N ≤ 6000	R = 0.0369 x Ln (N + 89.048) + 0.579
N > 6000	R = 1 – (8525.5 + 0.03875 x N) / (N + 5000)

The main differences between the R-index definitions in SOLAS 2009and SOLAS 2020 are:

- the formula no longer depends on the subdivision length,
- N in SOLAS 2020 represents a total number of persons on board, unlike SOLAS 2009 where it depended on a number of persons for whom the lifeboats were provided,
- R is constant for passenger vessels with less than 400 people onboard.

Not only R formula changes in SOLAS 2020, also the survivability factor s for ro-ro passenger vessel was revised. The reason for this was GOALDS project (Luhmann, 2015). The main objective of GOALDS was enhance collision and grounding casualty's database which lead to statistical analysis of data concerning the location and extend of hull breach and check the validity of SOLAS 2009 assumptions for passenger ships. Those data showed difference compered to old research project HARDER (Cichowicz, 2019). Similar as it was which GOALDS, the intent of this project was to establish the regulatory survivability safety level which result s-factor formula. As it can be seen in Figure 1 a correlation between waive height Hs and GZ max is different for ro-ro passenger vessels, compared to cargo vessels.

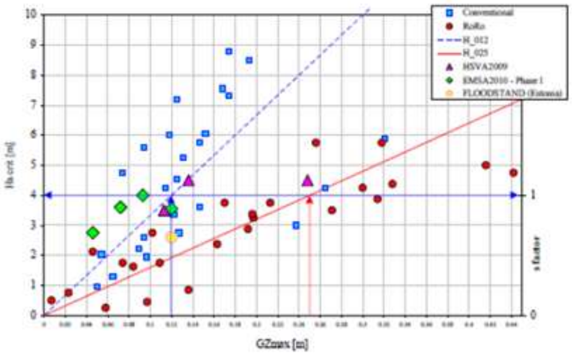

Figure 1:[Model test results for ro-ro passenger vessel (Cichowicz, 2019)]

Based on those data a new s factor formula for ro-ro cargo hold was defined. Additionally, GZ and range requirements have been increased for the final stage of flooding to achieve s=1:

$$S_{final,j} = K\left(\frac{GZmax}{TGZmax} \cdot \frac{Range}{TRange}\right)^{\frac{1}{4}}$$

where:

TGZmax = 0.20m, for ro-ro passenger ship for each damage case that involves a ro-ro space,
= 0.12m , otherwise;
TRange = 20^0, for ro-ro passenger ships for each damage case that involves a ro-ro space,
= 16^0, otherwise;
K = 1 if $\theta_e \leq \theta_{min}$
K = 0 if $\theta_e \geq \theta_{max}$

$$K = \sqrt{\frac{\theta\, max -}{\theta\, max - \theta min}}$$

Θmin is 7^0 for passenger ships and 25^0 for cargo ships.
Θmax is 15^0 for passenger ships and 30^0 for cargo ships.

The biggest difference between the requirements for new R formula is for vessels between 400 and 1350 persons on board, as it can be seen in Figure 2.

The information on this chart shows that fulfilling the SOLAS 2020 requirements will be the most demanding task for this group. For this reason, the article concentrates on a ro-ro passenger vessel with 1250 people on board.

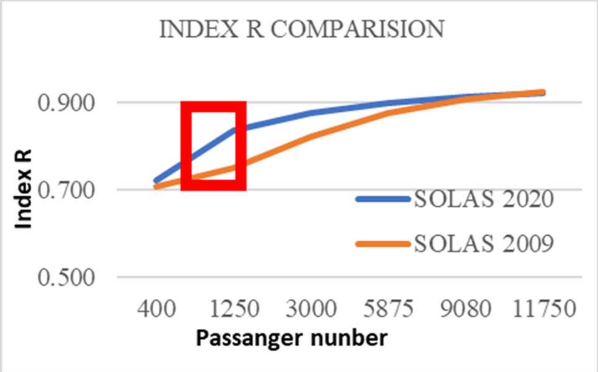

Figure 2:[Index R comparison for passenger vessel]

3. BASIC DESIGN

The basic design used in this paper is a typical ROPAX ship with transverse subdivision and a lower hold. Vessel is fitted with three vehicle decks. For better unloading and loading process there are aft side ramp as well as fore side ramp. The vessel can load trailers on two decks, private cars are fitted in lower hold on Deck1 and Deck2. The ship is subdivided into 18 watertight zones by 17 main transverse bulkheads. Figure 3 shows Napa model which represents watertight subdivision up to Deck 5.

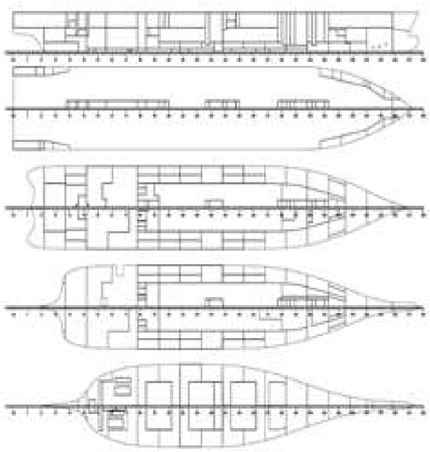

Figure 3: [Basic layout or ro-ro passenger vessel]

Main dimension of the vessel:

Length overall	230 m
Breadth	30 m
Height of bulkhead deck	10 m
Draft	7 m

4. INDEX RESULTS FOR SOLAS 2009

The main tool used to calculate damage stability was Napa 2019.2x64. Each damage scenario considered that have sufficient floating position gives a positive contribution and is summed up in the attained index A. Depending on the length of the vessel and a number of passengers on board a required subdivision index R is defined. The final criteria is that the index A must be bigger than R.

Subdivision index R is calculated according to SOLAS 2009:

$R = \frac{1-5000}{L_S+2.5N+15225}$, where

N1 = 600
N2 = 650
N= N1 +2N2
N=1900
Ls= 229.168m

For the purpose of the calculations three initial conditions were defined as required in SOLAS. The initial conditions are shown below. For all the initial conditions, the trim is zero.

DL: for T=5.50m Gm =5.0m
DP: for T=6.46m Gm =2.8m
DS: for T=7.10m Gm =3.0m

Attained subdivision index **A: 0.77454**
Required subdivision index **R: 0.75253**

Table 2:[Detailed index result SOLAS 2009]

Damages	W*P*V*S
1 Zone damages	0.30311
2 Zone damages	0.32396
3 Zone damages	0.11035
4 Zone damages	0.02775
5 Zone damages	0.00817
6 Zone damages	0.00119
Total A index	**0.77454**

According to the results from Table 2, attained subdivision index A is bigger than the required value R. This means that the vessel fulfils both Regulation 6 and 7 from SOLAS 2009.

The chart below represents the s factor values for all the penetrations in both single and multiple zone damages. It can be observed that 50% of all damage cases have survivability s=1, while 34% are the damage cases that have s=0. We can also see that 10% of all cases are damage cases with 0.8<s<1. It means that we can work on those cases, and improved their survivability to s=1, which will give us a higher volume of value A.

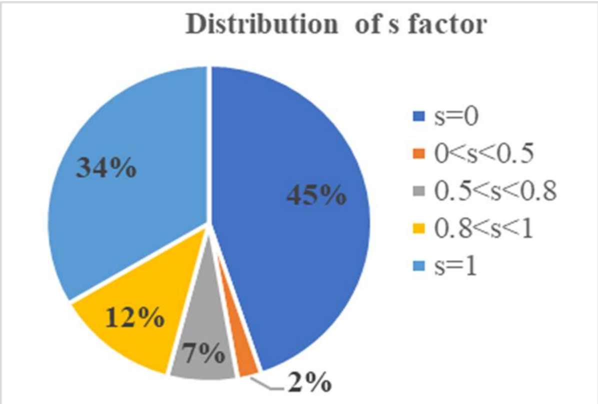

Figure 4: [Distribution of s factor]

5. INDEX RESULTS FOR SOLAS 2020

Subdivision index R calculated according to SOLAS 2020:

$$R = \frac{N}{7580} + 0.66923$$

Initial conditions were the same as for SOLAS2009 calculations

Required subdivision index **R**: **0.83414**
Attained subdivision index **A**: **076410**

Detailed index results are shown in table 3.

Table 3: [Index results for SOLAS 2020]

Damages	W*P*V*S
1 Zone damages	0.30129
2 Zone damages	0.31830
3 Zone damages	0.10783
4 Zone damages	0.02737
5 Zone damages	0.00812
6 Zone damages	0.00119
Total A index	**0.76410**

According to the results from table 4, the attained subdivision index A is smaller than the required value R, which means according to SOLAS explanation, that subdivision of ship is considered not sufficient.

Figure 5 shows a comparison between attained index A for SOLAS 2020 and SOLAS 2009. It can be seen that the difference between values is very small. The reason for that is new s-factor formula in SOLAS 2020 used for ro-ro spaces.

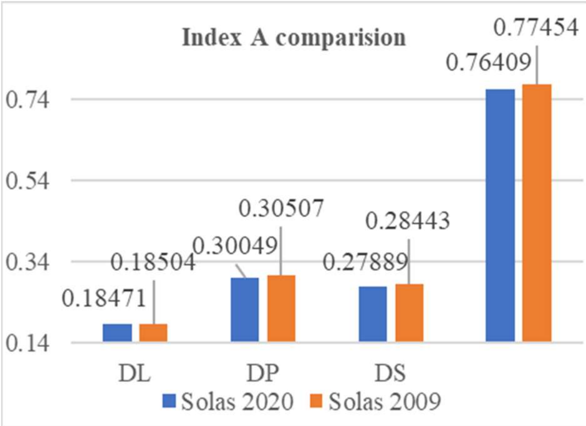

Figure 5: [Comparison of index result for SOLAS 2020 and SOLAS 2009]

The figure 6 shows s-factor distribution for SOLAS 2020 calculations. It can be seen that the difference between old and new SOLAS for s=0 is more than 10%, the same is with s=1. It means that s factor formula is stricter than previous one.

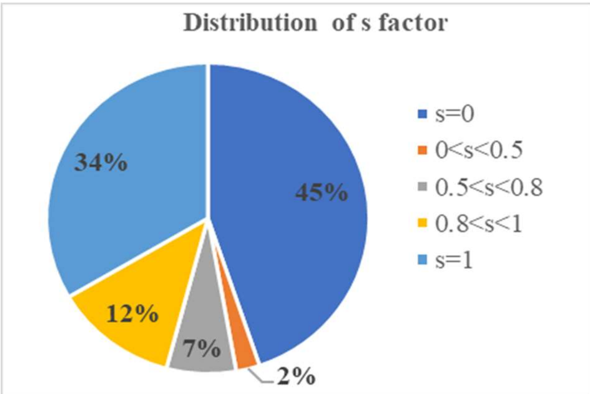

Figure 6: [Detailed distribution of s factor for SOLAS 2020]

6. PROPOSED SOLUTION TO FULFIL SOLAS 2020 REQUIREMENTS

Changing the Initial GM values

For the first damage stability calculations the GM limits values for the three loading conditions are usually taken from intact stability GM limit curve. When required index A is not met, the GM values may be increased to closer match actual, feasible loading conditions. Increasing the GM values should be done implying that intact loading condition still met new GM. In case GM values from actual loading conditions are still not enough to reach A=R these need to be revised - this usually leads to significant lose of cargo capacity or to increasing draft with additional water ballast

Dividing lower hold by watertight doors.

The added benefit of this solution is that the additional watertight barriers means that damages that include lower hold results in bigger s factor value. The reason for it is that when the undivided lower hold is damaged a big volume is flooded and the vessel have too small GZ to achieve positive s factor value, but when we divide the lower hold into separate watertight spaces, there is a chance that its s factors will be bigger than zero. A negative consequences of this solution are extra costs for the vessel owner, both due to the construction costs as well as due to the loading/unloading operations taking more time

U-deck

Another possible solution is to create additional void spaces in the double sides above the U-shaped voids, see Figure 7.

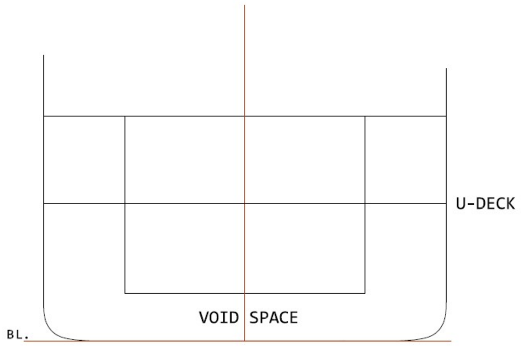

Figure 7: [U-voids]

These so-called U-decks are designed to increase the survivability of the ship in damage condition. They are reducing the amount of water that floods the U-tanks and are therefore increasing survivability before the cross-flooding takes place. The higher the sea water level in the U-tanks, the bigger is the stabilizing effect of the U-deck spaces.

Reduce unsymmetrical flooding and need for cross flooding arrangement

Cross flooding ducts are used to provide equalization across the ship in order to decrease the heeling angle. In the past few years when passenger vessel market increased, the use of high capacity cross flooding ducts started to be a popular solution in order to achieve the required value of subdivision index A. Due to the increased requirements for the required index R for passenger ship from 2020 the interpretation of the instantaneous flooding changed. For some time, the official interpretation of the SOLAS regulation II-1/7-2.2 which allowed the intermediate stages of flooding to be disregarded as instantaneous, in case when fluid equalization is achieved in 60s or less, was already source of the discussion. In the SOLAS 2020 requirements concerning the cross flooding one can read that GZ value before the cross flooding need to be positive, which means that we need to include all the cross flooded voids into the index calculations in the intermediate stages. In this case the U-shaped voids need to be small, in order to have small heeling angle before cross flooding.

7. CONCLUSION

An impact of the new survivability s-factor formulas on the attained index of subdivision is relatively small, resulting in a decrease of A index below few percent. Despite the sample ship calculations shown that in order to fulfil the requirements of R index, a new vessel design approach is needed. Some proposals for the design changes were presented in the article. Further investigations are needed to identify the most effective approach.

8. ANCKNOWLEDGMENT

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9. REFERENCES

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