A Performance-Based Survivability Assessment of Regulatory Frameworks

Nikolaos Tsakalakis, Romanas Puisa, Khaled Mohamed and Dracos Vassalos
The Ship Stability Research Centre, Department of Naval Architecture and Marine Engineering, University of Strathclyde, Glasgow, UK

Cantekin Tuzcu
UK Maritime and Coastguard Agency

ABSTRACT

Deterministic regulatory frameworks of the past could only provide information of whether a vessel could comply with a pre-determined set of criteria but failed to provide information on the level of safety pertinent to a specific design. Probabilistic frameworks by definition can provide such sort of information, necessary for comparison in an optimisation process. SOLAS 2009, as a probabilistic framework, entails this capability but failed to inspire confidence in the maritime industry due to a series of misconceptions and inherent drawbacks in its formulation and application. The latest developments in survivability assessment have provided the ability to measure the survivability of any design, irrespective of which standard it is developed to comply with. To this end, this paper is aimed at conducting a direct comparison of probabilistic and deterministic regulatory frameworks for damage stability on a selection of Ro-Ro passenger vessels of various sizes. Both numerical and analytical performance-based assessment methods will be utilised, highlighting in the process any inherent inconsistencies in each framework, in an attempt to restore confidence in state-of-the-art on damage stability assessment. Specific attention is to be paid to the controversial design feature of the long lower hold.

KEYWORDS

Performance-Based; Survivability Assessment; Regulatory Frameworks; SOLAS ’90; SOLAS 2009; Index A;

INTRODUCTION

The introduction of the probabilistic framework for damage stability was a step change in the way the industry understandsand executes ship design. The freedom for innovation allowed by SOLAS 2009, though, was quickly replaced with concern when certain issues surfaced regarding inconsistencies inherent in the formulation. As a result, industry lost confidence in the new regulations, fearing that certain commercial features of ships, such as a long lower hold (LLH) are not properly taken care of. This study focuses on the level of safety implied by current and past regulations, overall as well as regarding such specific features, in an attempt to estimate their contribution to survivability and restore confidence in overall probabilistic frameworks.

METHOD OF APPROACH

Numerous different designs, of 3 sizes of RoPax ships have been generated and their survivability measured by means of performance-based assessment (PBA). The study has been separated in two parts, the first being targeted at evaluating the accuracy of Index A as an analytical tool for PBA, while during the second part, the design alternatives developed would form the basis for a statistical evaluation of the regulatory instruments in question.Due to the increased time and effort required by the numerical PBA tool to evaluate the survivability of a design, it would have been impossible to repeat the procedure for each one of the hundreds of different designs developed for the second part, thus rendering the analytical model (i.e., Index A), albeit not as accurate, the only choice.

Performance-Based Assessment Methods

Performance-Based Assessment approaches (PBA) can provide an objective tool of estimating the survivability of any vessel, irrespective of which regulatory instrument has been used to design, build and operate (Vassalos et al. 2008). They come in opposition to deterministic approaches in the fact that instead of providing information on whether the studied scenario complies with a set of requirements, there is the potential to provide quantitative results about the performance of the vessel in question with respect to a specified mode of failure, in this case loss (Vassalos, 2006). There are two principal ways of carrying out a performance-based assessment; analytical and numerical. The latest regulatory instrument for damage stability, namely SOLAS 2009, has been developed in this scope and as such it can be used as an analytical method for this reason. The numerical, time domain simulations carried out by PROTEUS3 (Fig. 1) (Jasionowski, 2001) can provide a more accurate tool for the estimation of survivability but are more costly in terms of both time and effort to perform than analytical calculations.

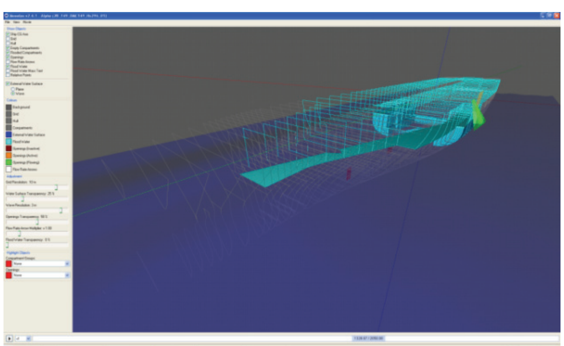

Fig. 1: Visualization of simulation with PROTEUS3

Numerical PBS Assessment

PROTEUS3 is a state-of-the-art time-domain numerical simulation tool capable of handling complex geometries such as the ships used in the study. Each ship variant is simulated for 30 minutes in a number of randomly generated damage scenarios. Scenarios include damage opening size and location as well as environmental conditions. 300 scenarios are automatically generated for each ship, using Monte Carlo sampling technique. The probability distributions used for this purpose are the same that were used for the development of the P-factor currently in SOLAS 2009, derived from EU-funded project HARDER (1999-2003).

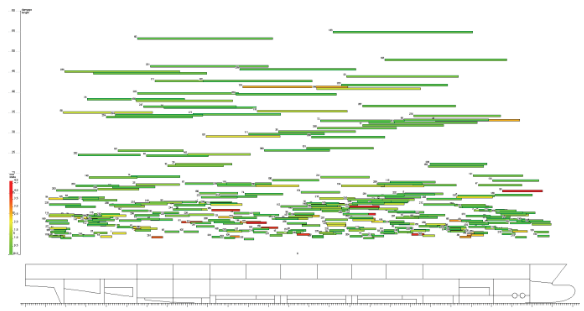

Fig.2: 300 damage scenarios generated for the testing of one variant

The result of a series of simulations can be seen in Fig. 3. Both the probability density and the cumulative distribution functions for time to capsize are visible. The information acquired from the marginal value of the cumulative distribution function (CDF) is the probability of the vessel to capsize in 30 minutes given a specific loading condition, or the vessel's vulnerability to flooding (Jasionowski, 2007).

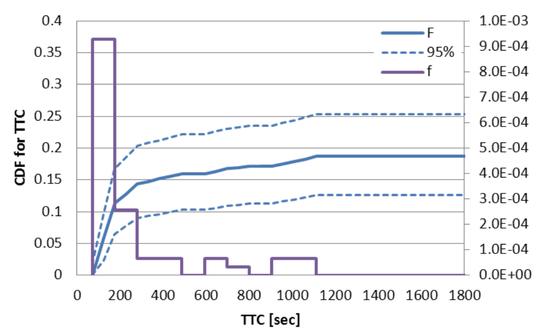

Fig. 3: Probability distribution for Time to Capsize given specific loading condition and 30 minutes

The compliment of this value represents the vessel's survivability and is the value against which the Index A for every vessel is going to be compared in a bid to measure its accuracy. Numerical PBS assessment is the most accurate measure of survivability readily available now.

SAMPLE VESSELS

On the basis of this study lie3 different parametric models of typical RoPax ships, of small, medium and large size. Details of their principal dimensions can be found in table 3. Based on these initial designs, 15 models were generated for the first part of the study, 5 for each size, each one complying with a different set of regulations. The regulations taken into account are:

A. SOLAS '90 (Ch. II-1 Reg. 4-12)

B. SOLAS '90 (Ch. II-1 Reg. 8-12)

C. A.265 (Regulation 1-11)

D. SOLAS 2009 (Ch. II-1 Reg. 5-9)

E. SOLAS '90 (Ch. II-1 Reg. 8-12) + MCA additional requirements

A sample arrangement of ship 3 can be seen in Fig. 4. The vessels were prepared with high accuracy and detail, although as concept designs their survivability performance might be slightly higher than that of a built ship, due to asymmetries and several other compromises that inevitably reach production.

Table 3: principal dimensions of study ships

Parameter	Ship 1	Ship 2	Ship 3
Length (BP)	105 m	150 m	200 m
Breadth (moulded)	18.6 m	26.5 m	29.4 m
Depth (moulded)	12.8 m	14.3 m	15.3 m
Draught (design)	4.8 m	6.2 m	6.7 m
Displacement	5955.68 t	16653.4 t	26090.7 t
Passengers	600	1400	2000

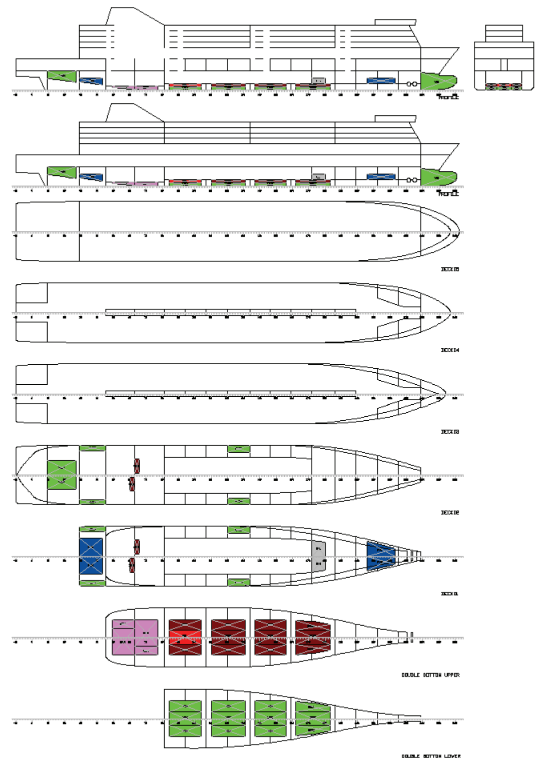

Fig. 4: General Arrangement of an alternative of ship 3

The calculations were carried out for two loading conditions for each vessel. The first was the same for all vessels of the same size and the second for limiting conditions according to the regulation in question. The results were quite interesting as they demonstrated how operation can affect the survivability of the vessel. Limiting KG value (maximum allowable) has been applied for deterministic regulations while A=R was sought for probabilistic ones.

COMPARISON OF INDEX A WITH PBS

The results of this first part of the study were very encouraging regarding the validity of Index A. overall it presented a positive relation with PBS, increasing confidence in the use of the index for the next stage. Fig. 5 demonstrates how Index A was mostly within the 5% confidence interval of PBS assessment. The correlation was strong enough for the data to be regressed in an attempt to reduce the error of prediction. The error of the distribution before and after regression can be seen in Fig. 6 where error dropped from 16.8% to 7.6%.

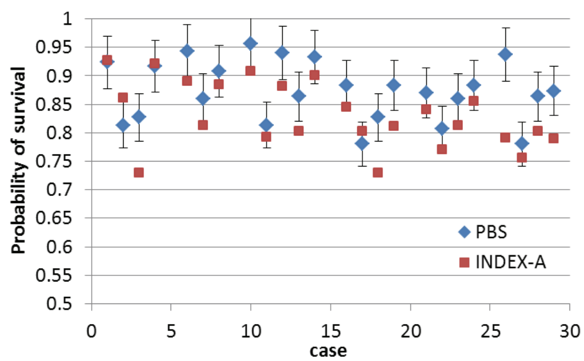

Fig. 5: Comparison of Index A against numerical PBS assessment

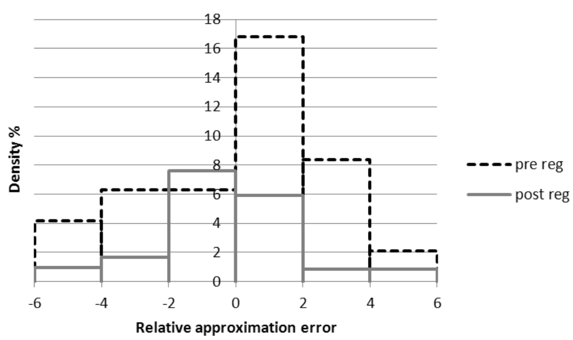

Fig. 6: Error distribution before and after regression

RESULTS

Since Index A has proven to be an accurate measure of survivability, it can be safely used in the second part of the study as a PBA tool for the large number of variants needed for statistical investigation of the regulations (Puisa, 2011). Each variant was checked for its compliance with each regulation set thus resulting in compliant vessels that had the same PBS with non-compliant ones. In fact the level of overlap between compliant and non-compliant variants was, particularly in the case of the small vessel, alarming. A typical case of overlap is shown in Fig. 7, where medium ship variants are checked against their compliance with SOLAS '90. It appears that, while a ship that complies with any deterministic regulation does have a high level of survivability, the opposite is not guaranteed, meaning that if a ship is not compliant with a deterministic regulation doesn't necessarily have low survivability. Fig. 8 depicts the percentage of overlap for all studied ship variants, separated by size and regulation.

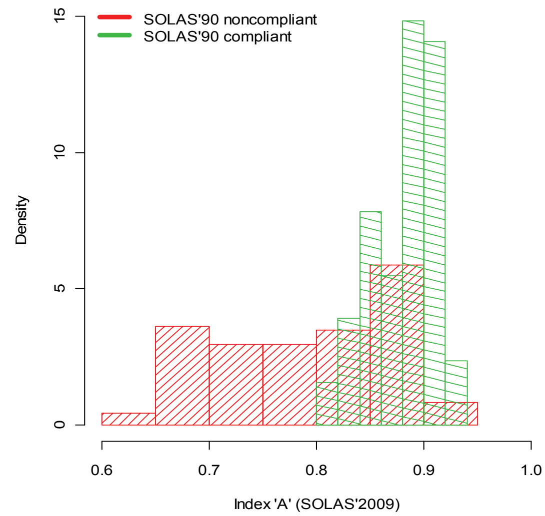

Fig. 7: typical overlap between compliant and non-compliant with SOLAS '90 variants of the medium ship[Puisa, 2011]

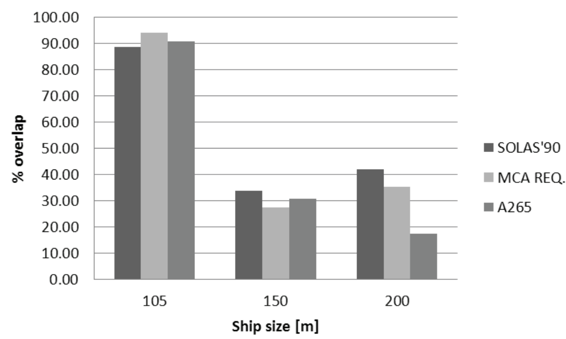

Fig. 8: Percentage of overlap of compliant and non-compliant variants with respect to size and regulation[7]

Regarding the variants that comply with the regulations, the results seem to be rather consistent. Generally, when the additional MCA requirements are applied to SOLAS '90 ships these appear to have the highest survivability, followed closely by A.265 as can be seen in Fig. 9 that shows the expected mean Index A given size and regulation. Another fact also apparent in the same figure is that in order for compliance with

[7]Note that, although A.265 is also a probabilistic regulation, it too demonstrates a level of overlap due to the difference of SOLAS 2009 with respect to how performance is measured.

SOLAS 2009 to guaranty as high a level of survivability as the previous regulations, required index of subdivision, R, will need to be increased.

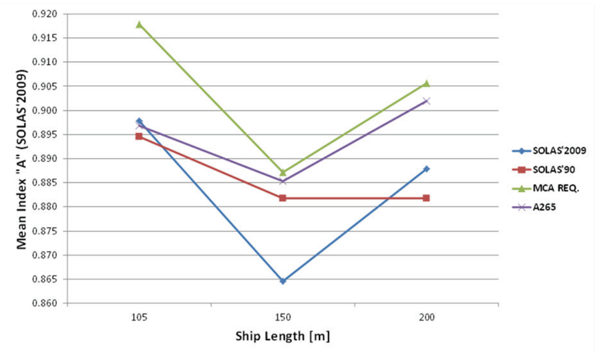

Fig. 9: Expected mean Index A given size and regulation (Puisa, 2011)

Due to the complications involved, limiting loading conditions were only applied for the initial 15 designs used for the evaluation of Index A as a measure of survivability. The bars on the left of Fig .10 correspond to the PBS of ships without a long lower hold and it can be seen that SOLAS 2009 and MCA additional requirements guaranty that a ship equipped with a lower hold has comparable risk level to ships that don't. The reason for this seems to be that SOLAS '90 (Ch. II-1, Reg. 8-12) is virtually "blind" to the feature of the lower hold, while MCA requirements take it into consideration and the fact that a LLH would penalize Index A massively, its size is indeed effectively kept under control.

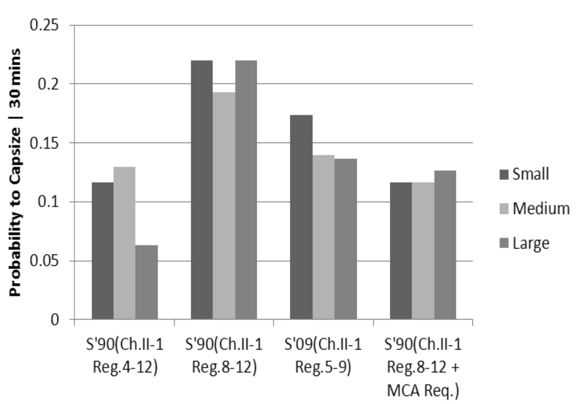

Fig.10: PBS results for 4 of the regulations performed under limiting loading conditions

CONTRIBUTION OF LLH

The LLH is highly valued in the industry for commercially utilizing spaces that would otherwise have no use. However, it is a large un-subdivided space low in the ship making it particularly vulnerable in case of flooding. Should the LLH be flooded it essentially means that there wouldn't be enough residual buoyancy to stay afloat. That said, if the residual buoyancy exists, the decreased centre of gravity that is the result of flooding of a lower space would mean that the ship would have no problem of stability. The probability of damaging the LLH is proportional to its size compared to the size of the vessel as visible in Fig. 11. The following figures show the distribution of probability of the s-factor with the contribution of the LLH.

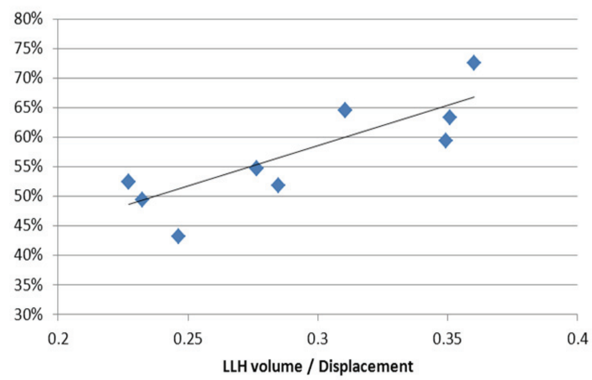

Fig. 11: Percentage of damages involving LLH over total number of damages

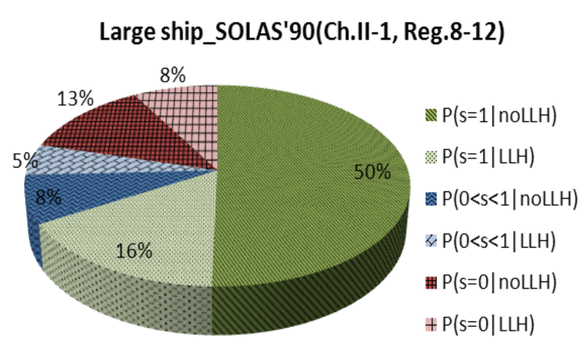

Fig. 12: Distribution of probability of s_i additionally separated with respect to involvement of LLH

The example of Fig. 12 demonstrates that the LLH is damaged in approximately 40% of the cases that have no stability whatsoever (s=0) but is also involved in roughly 25% of the cases that have GZ_{MAX} and Range of stability larger than 0.12 m and 16 deg. respectively. Overall, the cases resulting in no stability and contain the LLH decrease as ship size increases as can be seen in Fig. 13. Numbers 1,2 and 3 represent small, medium and large ship respectively, while letters stand for regulation as per previous paragraph (ref. “sample vessels”).

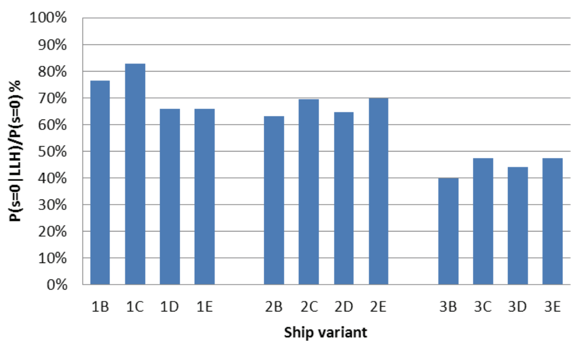

Fig. 13: Percent involvement of LLH per size and regulation

INCREASING SURVIVABILITY

Abandoning traditional concepts like the margin line, the probabilistic framework for damage stability has introduce the freedom and incentive to extend watertight subdivision above the bulkhead deck in an attempt to provide extra buoyancy and stability in case of extensive flooding. So long as it is economically viable, this could potentially balance the negative effect of the LLH. To this end, an extra assessment has been carried out in this study to demonstrate the application an extended watertight envelope. One of the variants was modified to incorporate watertight casings in the ro-ro deck space and its survivability was measured as described previously. The modified car deck of the study vessel can be seen in Fig. 14. The side casings introduced were placed in such a way so they are cost effective and have little influence on the capacity of vehicles.

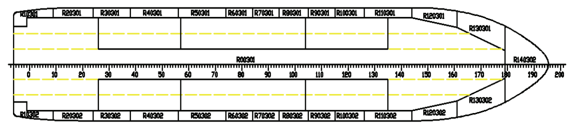

Fig. 14: Modified car deck of the study vessel

The new configuration resulted in 75% reduction of risk for this particular vessel (see fig. 15) with only 3 out of 200 simulated damages to result in capsize.

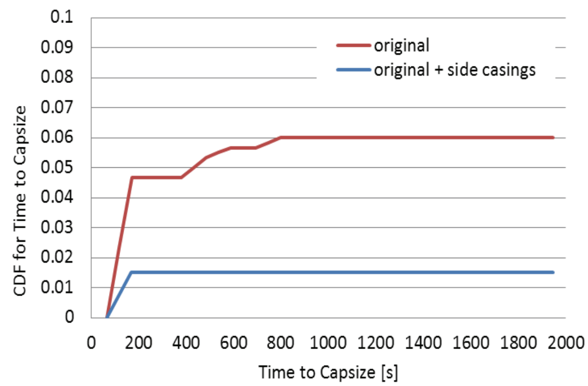

Fig. 15: Result of numerical PBS for the original and modified design

The Index A calculation of the vessel demonstrates a significant decrease of the number of cases that had no residual stability even for 5 compartment damages (see fig. 16).The modified vessel had an Index A of 0.9651 compared to 0.8415 of the original one.

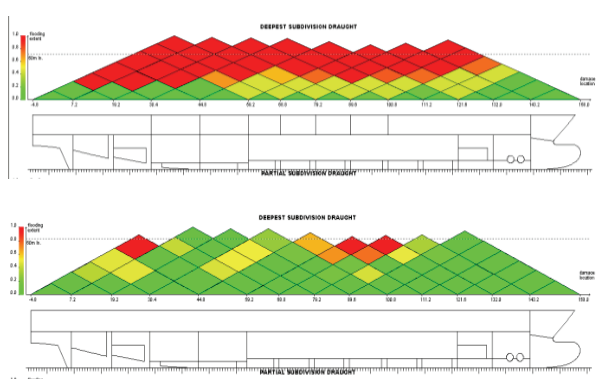

Fig. 16: Comparison of distributions for unconditional probability survivability given 3 hours for original (upper) and modified vessel

CONCLUSIONS

The first conclusion out of this study is that the probabilistic index of damage stability is an accurate enough measure, for the ship sample used in this project. As such it can be used as a performance-based assessment method for e.g. optimization purposes where positive correlation is more important than absolute accuracy. It can also be deducted that, on average, regulations that somehow controlled the size of the LLH proved to provide a higher level of survivability than SOLAS '90 (ChII-1, Reg. 8-12) that doesn't do so. More importantly it has been shown that deterministic regulations have a large degree of inconsistency in them as they might render ships with equal survivability as both complying and non-complying. On the other hand, ships that do comply with those regulations have, again on average, a slightly higher survivability than ships complying with SOLAS 2009 as a result of the value of required Index R. To finalise, the probabilistic framework for damage stability allows for the consideration of watertight spaces higher in the subdivision so that the negative effect of the flooding of the LLH can be counteracted.

ACKNOWLEDGMENTS

The authors would like to thank Mr Anthony York (Safety at Sea Ltd, Glasgow) for preparing the parametric models and designing the study ships. We would also like to thank the UK Maritime and Coastguard Agency for giving us the opportunity to undertake this project.

REFERENCES

HARDER (1999-2003): "Harmonisation of Rules and Design Rationale". EC funded project, DG XII-BRITE, 2000-2003

Jasionowski, A., "An integrated approach to damage ship survivability assessment", PhD Thesis, University of Strathclyde, 2001

Jasionowski et al.: "Ship Vulnerability to flooding", Proc. 3rd Intl Conf for Maritime Safety, Berkeley, California, 2007

Jasionowski, A., York, A.: "Investigation into the safety of RO-RO passenger ships fitted with long lower holds" Report of research project UK MCA RP564, 20 Jan 2008

Puisa, R., Mohamed, K.: "A critical look At SOALS Ch. II-1 with respect to floodable length of compartments in passenger ships", Work Package 3 report, UK MCA Research Project 625, 2011

Tsakalakis, N., Puisa, R., Chen, Q.: "A critical look At SOALS Ch. II-1 with respect to floodable length of compartments in passenger ships", Work Package 2 report, UK MCA Research Project 625, 2011

Vassalos, D., Jasionowski, A.: "Conceptualising Risk", 2006, Proc of the 9th Intl Conf. on Stability of Ships and Ocean Vehicles, Rio-de-Janeiro, Brazil

Vassalos, D., Jasionowski, A., Tsakalakis, N., York, A. (2009) "SOLAS '90, Stockholm Agreement, SOLAS 2009 – The false theory of oranges and lemons", Proc of the 10th Intl Ship Stability Workshop, Daejon, Korea.