Defining Rational Damage Stability Requirements

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ABSTRACT

The major benefit of switching from the deterministic frameworks for damage stability of the past to the current performance-based state of the art is the ability to have a measurement of the level of survivability of any given design. The required level of survivability is probably the key parameter in any probabilistic framework, in essence answering the question “how safe is safe enough?”. To this end, survivability analysis results on representative cruise and Ro-Pax ships can be related to design and operational parameters with a view to define and quantify the relationships between damage survivability characteristics following a collision and time available for evacuation with potential outcomes in terms of people potentially at risk. For this paper, established numerical methods for the measurement of performance-based survivability have been utilized and used as benchmark against available analytical methods in an attempt to define a rational requirement for the level of survivability.

KEYWORDS

Damage Stability; Survivability Assessment; SOLAS 2009; Safety level; Passenger Ships; Evacuation; Risk; Index A;

INTRODUCTION

A comprehensive performance-based survivability assessment of 4 passenger vessels has taken place within EU funded project GOALDS. The target was to provide an answer regarding the safety level offered by modern, state-of-the-art ships, firstly for the development of an analytical methodology for the estimation of risk from flooding but also for the development of a rational level for the required index of subdivision. Independent as well as in-house developed tools provided us with the capability to perform the survivability assessment in various ways and compare them against each other, thus securing a reliable result.

The R-Factor

The minimum level of survivability a vessel should offer is postulated by the R-factor. This applies either to new ship designs or existing ships and should reflect the societal acceptance of risk from loss of life. A typical F-N diagram contains 3 zones according to severity as can be seen in figure 1. A common mistake between the people in the industry is the perception that if the F-N curve lies within the boundaries of the ALARP region the design is acceptable. Cost-benefit analysis though, could as well prove that the F-N curve should in fact be as noted by the acronym: As Low As Reasonably Practicable, thus not low enough in the example of the figure. The ALARP region boundaries have been obtained by Skjong et al. [2007] and could change.

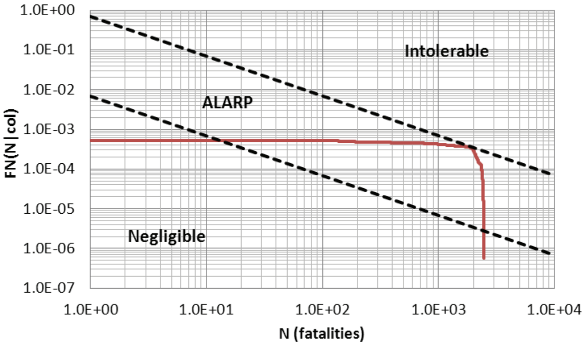

Fig. 1: Typical F-N diagram where the distinction between the consequences can be seen

METHOD OF APPROACH

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 the Monte Carlo sampling technique (see figure 2). 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).

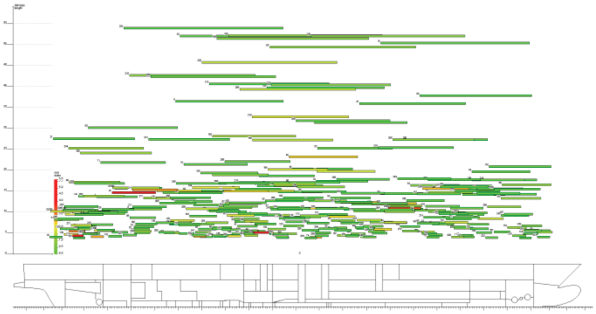

Fig.2: 300 damage scenarios generated for the testing of sample vessel EUGD01-R1

The result of a series of simulations can be seen in figure 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 CDF is the probability of the vessel to capsize in 30 minutes given the specific loading condition.

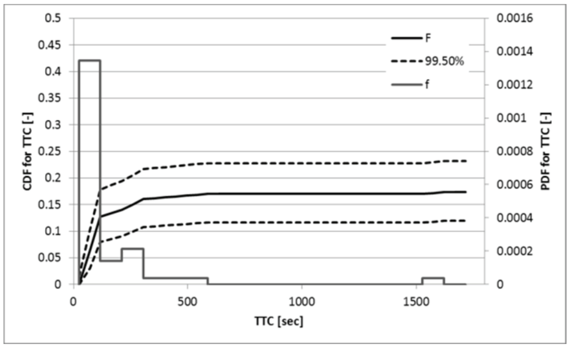

Fig.3: Probability distribution for Time to Capsize given specific loading condition and 30 minutes

The vessel's survivability is given by the compliment of this value and should correspond to the Index A for the specific loading condition. Numerical PBA is the most accurate measure of survivability readily available now.

Analytical PBS Assessment

Due to the complexity and time involved with numerical simulations, an easier method has been devised, namely UGD (Jasionowski, 2007). It is based on an analytical model for the estimation of time to capsize and results in the same marginal probability for time to capsize as given from Numerical PBSA, thus the two can be directly compared. The results of the analytical method are not quite as accurate as those of the numerical one but they have through various studies proven to be of comparable value (Jasionowski, 2008, Tsakalakis, 2011). Given the significant reduction in calculation time, the analytical method can be considered as a reasonable alternative. When combined with information on time needed to evacuate the studied vessel, the analytical software can provide information on potential loss of life as well. Typical results of UGD can be seen in figure 4 and figure 5 where the comparison with the CDF for time to capsize of numerical PBSA of figure 3 can be made.

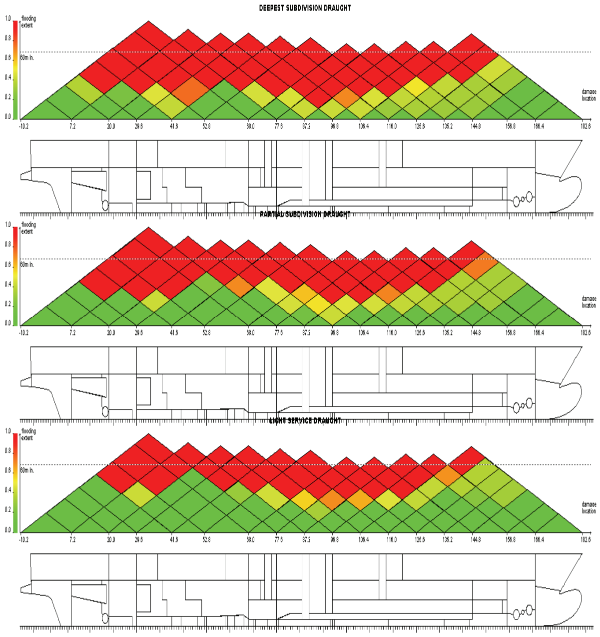

Fig. 4: Distribution of conditional probability for time to capsize, given loading conditions and damage extent occurred.

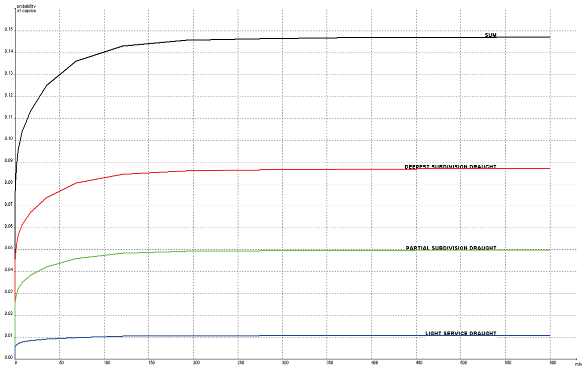

Fig.5:Distributions of probability for time to capsize: Unconditional (Top) and conditional, given loading condition.

Evacuation and Potential Loss of Life

The concept of potential loss of life is summarized in equations 1, 2 and 3 [Vassalos, 2007 & Jasionowski, 2007]

$$Risk_{PLL} \equiv E(N) \equiv \sum_{i=1}^{N_{\max}} F_N(i) \tag{1}$$

$$F_N(N) = \sum_{i=N}^{N_{\max}} fr_N(i) \tag{2}$$

$$fr_N(N) = \sum_{j=1}^{n_{hz}} fr_{hz}(hz_j) \cdot pr_N\left(N \mid hz_j\right) \tag{3}$$

This can be demonstrated graphically by figure 6. In short the number of fatalities is the number of people that failed to evacuate when the capsize event took place.

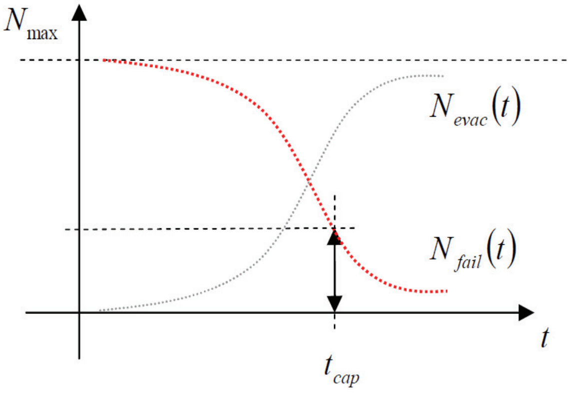

Fig.6: Interplay between Time to Capsize and Evacuation Time

The evacuation analysis has been performed by means of EVI, a software package developed at the Ship Stability Research Centre, which uses as input a number of parameters such as ship geometry, passenger demographics and ship motions due to environment, to determine the time required to evacuate (Vassalos, 2001). It has been used for a number of years in a wide variety of studies and has been benchmarked against available real data. A typical model of a RoPax ship as used in EVI® can be seen in figure 7 while figure 8 shows an example of an objective completion curve.

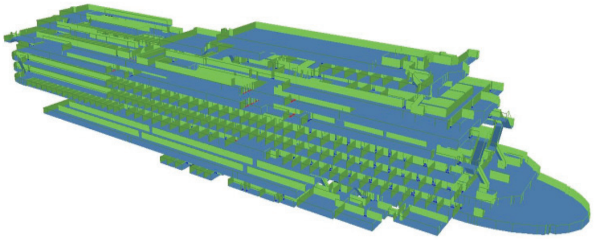

Fig.7: Geometry of a RoPax ship as modeled in EVI®

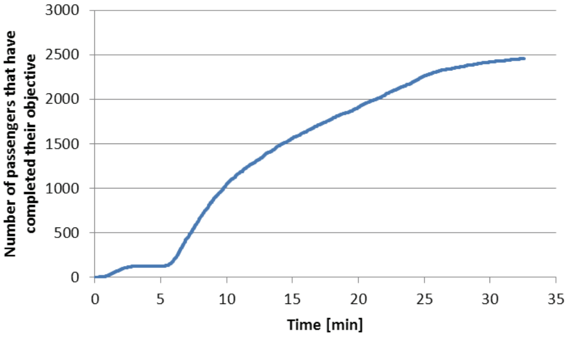

Fig.8: Objective completion curve; note the approximately 5 minute lag in the beginning of the simulation due to response time of passengers sleeping in their cabins.

Objective completion curves have been obtained with EVI® for all vessels in day and night conditions. The objective used in this study is mustering and not abandonment of ship as shown in figure 9 (SAFEDOR, 2006). This would additionally involve embarkation and launching of the lifeboats and clearing the vessel, which are all very crucial elements of ship abandonment that wrongfully tend to be overlooked at the moment since they would require separate measurements and models.

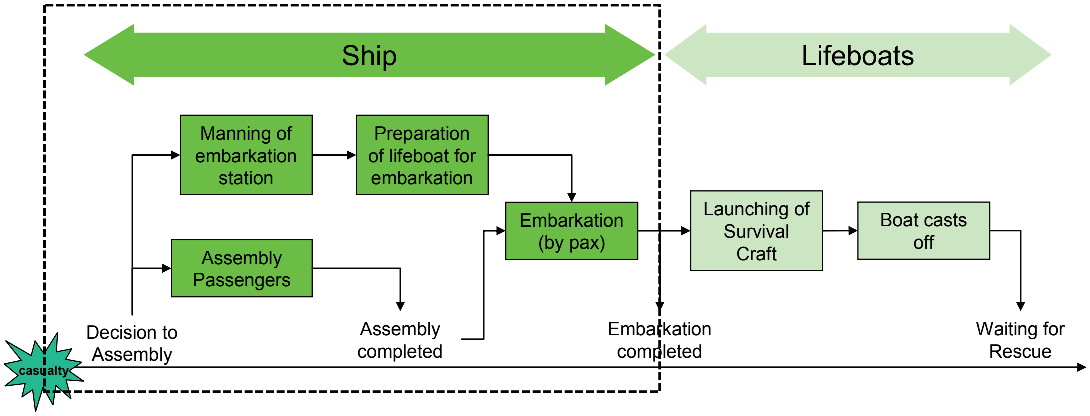

Fig.9: Total evacuation process and mustering part.

SAMPLE VESSELS

The study vessels consist of two RoPax ships and two cruise ships, the attributes of which can be seen in table 1. The ships have been selected in such a way as to ensure coverage of the design space. This also ensures that should any similarities or differences exist between these ship types they would be pronounced so as to be dealt with accordingly.

Table 1: principal dimensions of study ships

	R1	R2	C1	C2
Number of passengers	1400	800	3840	2500
L_{OA} [m]	194.3	97.9	311	295
L_{BP} [m]	176.0	89.0	274.7	260.6
Breadth moulded [m]	25.0	16.4	38.6	32.2
Deepest subdivision load line [m]	6.55	4.0	8.6	8.0
Depth to bulkhead deck	9.1	6.3	11.7	10.6
Displacement [tn]	16,6	3,4	62,5	45.0
Service speed [kn]	27.5	19.5	22.6	22.0

RESULTS

The study involved getting the F-N curves and PLL values for various collision frequencies for the study ships that range from 5.0E-04 to 1.0E-02. It appears though that no matter the frequency, the potential loss of life is quite high, not only for the vessels carrying thousands of passengers (figure 10) but also for smaller vessels as pictured in figure 11.

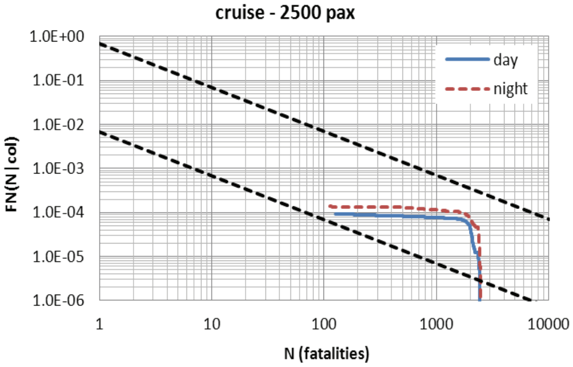

Fig.10: F-N diagram for one of the cruise vessels with frequency of collision equal to 1.0E-03. ALARP region obtained from Skjong (2007)

One could easily argue that both these cases definitely require risk control options irrespective of cost effectiveness. The resulting PLL for all the ships and frequencies is visible in table 2.

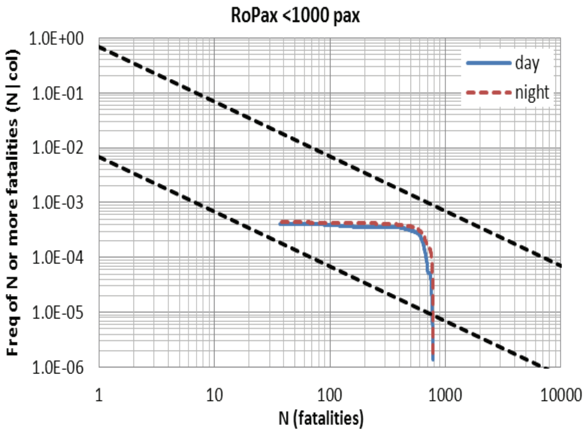

Fig.11: F-N diagram for the smaller one of the RoPax vessels with frequency of collision equal to 5.0E-03. ALARP region obtained from Skjong [2007]

Table 2: Resulting PLL for the ships, frequencies and cases tested

Day

f	C1	C2	R1	R2
1.0E-02	2.22E+00	4.20E+00	1.44E+00	1.57E+00
5.0E-03	1.13E+00	2.16E+00	7.19E-01	7.37E-01
1.0E-03	2.19E-01	4.02E-01	1.43E-01	1.46E-01
5.0E-04	1.08E-01	2.10E-01	7.18E-02	7.62E-02

Night

f	C1	C2	R1	R2
1.0E-02	2.84E+00	5.92E+00	2.94E+00	1.37E+00
5.0E-03	1.52E+00	2.81E+00	1.40E+00	7.22E-01
1.0E-03	2.89E-01	6.01E-01	2.91E-01	1.41E-01
5.0E-04	1.49E-01	2.89E-01	1.46E-01	6.92E-02

It can be generalized that PLL is increased according to the order of magnitude of passengers carried by the vessel. What is more, it appears that the effect that frequency has on PLL is linear as can be seen in figure 12, where the average PLL values for night and day cases have been plotted against frequency.

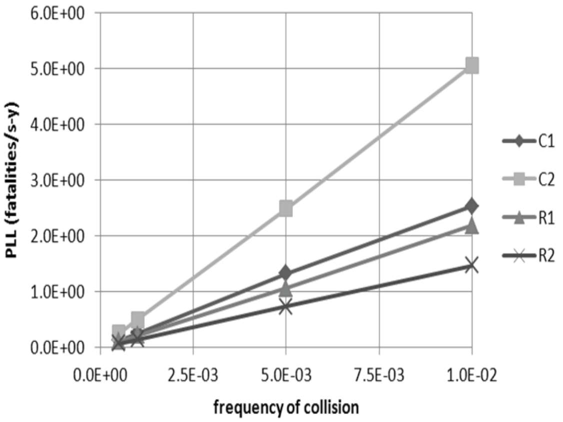

Fig.12: Average PLL for day and night vs. frequency of collision.

CONCLUSIONS

Although there is still a great distance to be covered with respect to establishing a reasonable required level of survivability, this study has provided with a few insights to the right direction. The most important of those is probably that no matter what the frequency of incident compromising the ship safety, the large number of guests in modern ships suggest that if the potential is there the consequences will be catastrophic. Adding the fact that there are experiments that suggest that modern ships could capsize within a few minutes thus leaving little time for evacuation only strengthens the suggestion that the required index should be revised. Furthermore, this study has shown that irrespective of how safe a ship is, risk will always increase as the number of passengers carried increases.

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