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Passenger Ship Safety – Science Paving the Way

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ABSTRACT

The prevailing regulatory framework addressing ship safety originates in some distant past and carries a heavy “baggage” of experiential determinism and rules of thumb; all throwing a smoke screen onto science and quenching most attempts to dealing with safety in a scientific, all embracing and systematic approach. Goal-Based Standards are meant to provide anew impetus to achieve this but experience so far suggests if anything even more determinism and even less science in the strife to face uncertainty and complexity with only “crumbs” of understanding of the real issues at hand. There is only one real exception, giving science the opportunity and all of us hope that scientific approaches to addressing safety will at long last be called upon to pave and lead the way: [Large] Passenger Ship Safety. Nothing is meant to be preconceived here; safety can have a field day before it is cut down to face reality and cost. Goal-Based Approaches, *Casualty Threshold, Safe Haven, Safe Area, “Zero” Tolerance in human life loss, De-risked Ships*; all goes and is being seriously discussed at IMO. This paper presents a critique of recent developments at IMO, in particular the new probabilistic rules of damage stability calculations, in an attempt to demonstrate the need to use knowledge in all its forms to make a difference in safety improvement before proceeding to suggesting a workable approach to address one exciting development in the regulatory front: Casualty Threshold. Emphasis is placed on explaining the framework that could embrace and support such development and on the pre-requisite scientific knowledge to realise it.

1 Introduction

Since 1959, when the International Maritime Organisation (IMO) first met, improving safety at sea has been continuously on top of its agenda. One of the major targets and achievements of the IMO has been the development of international regulations that are followed by all shipping nations. In this respect, one of IMO’s main objectives has been “*to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships*”. As a result of IMO efforts, shipping is today regulated by numerous pieces of legislation, among which SOLAS, is generally regarded as “the most important of all international treaties concerning the safety of merchant ships”. Notwithstanding this, the prescriptive nature of SOLAS and its implications to innovation in ship design is a well discussed topic in no need of convincing.

Encouraging however is the increasing tendency to adopt a “**goal-based**” approach to regulation in general and the fact that there appear to be good technical and commercial reasons for believing this approach is preferable to more prescriptive regulation. A commonly found reference to “goal-based regulation” is that it does not specify the means of achieving compliance but sets goals that allow alternative ways of reaching the goal [1]:

Prescriptive

"*You shall install a 1 metre high rail at the edge of the cliff*"

Goal-based

"*People shall be prevented from falling over the edge of a cliff*"

Such an approach simply defines clearly the safety expectations that are deemed to be appropriate, without providing a solution in itself. It has been this "rationality" principle that has driven the adoption in IMO MSC.99(73) 2001 of "alternative design and arrangements for fire safety" (regulation 17 of SOLAS II-2). The same intention was implicit in the early developments on probabilistic damage stability regulations and other pieces of legislation developed under the "equivalent safety" principle. It is also in this context that in May 2000 the IMO Maritime Safety Committee agreed to undertake a holistic consideration of safety issues pertaining to passenger ships, with particular emphasis on large cruise ships. As stated in [1] the outcome, to date, of this effort has resulted in an entirely new regulatory philosophy for the design, construction and operation of passenger ships that will better address the future needs of the cruise industry. In relation to this, the Committee adopted a "guiding philosophy" that is now viewed as a "vision statement" to provide an idealised view of where the international community would like to be in the future regarding the regulatory framework – at least for large passenger ships. With the approval of the guiding philosophy, the Committee, in effect, also agreed to a new way of viewing the regulatory development process as well. Traditionally, issues related to fire protection, marine engineering, naval architecture and other maritime disciplines would, in most circumstances, be considered in isolation of each other and, after deliberations, prescriptive regulations would be prepared on a piecemeal basis to address each specific area of safety. However the new regulatory approach is holistic in nature and focuses on achieving goals such as

> "*a ship should be designed for improved survivability so that, in the event of a casualty, persons can stay safely on board as the ship proceeds to port*".

The above reflects recognition that ship design has always been "goal-based" (the goal being to meet owner's requirements and SOLAS rules!) hence a more rational approach to ship safety regulation is to specify safety goals that reflect modern safety expectations. Furthermore, and perhaps, more importantly, an "outside-the-box" thinking in ship design would be allowed, bringing alongside the opportunity to use developments in science and technology to the benefit of the shipping industry and for safety's sake.

Damage ship stability is one of the fundamental areas of safety legislation as it deals with mitigating the consequences (hence the risk) of collision and/or grounding. Stability deterioration resulting from hull breach and subsequent flooding to internal compartments, had led in the past to major loss of life on passenger ships [2]. The history of SOLAS developments in this respect is well known and yet, when looked through the prism of modern safety expectations, damage stability is an area of ship safety legislation in which prescription has managed to achieve its most irrational example. Luckily enough, a drastic deviation from this "traditional" approach, is the current developments on [large] passenger ships at IMO which seem likely to provide the opportunity to start from scratch, with rationality and science paving the way – or so it is hoped. This paper elaborates on this issue, from the point of view of (but not limited to) large passengers ships, based on recent and current work at SaS and SSRC by addressing both prescriptive and goal-based approaches.

2 Ship Stability – the Prescriptive Approach

From a ship stability viewpoint, the most fundamental goal to be achieved is for a ship to remain *upright* and *afloat*, especially so after an accident involving water ingress and flooding. . The means to achieve that goal have been prescribed by SOLAS since 1929:

- SOLAS 74: 1-compartment flooding standard
- SOLAS 90: 2-compartment standard (in essence)
- Harmonised SOLAS Chapter II-1, [3]

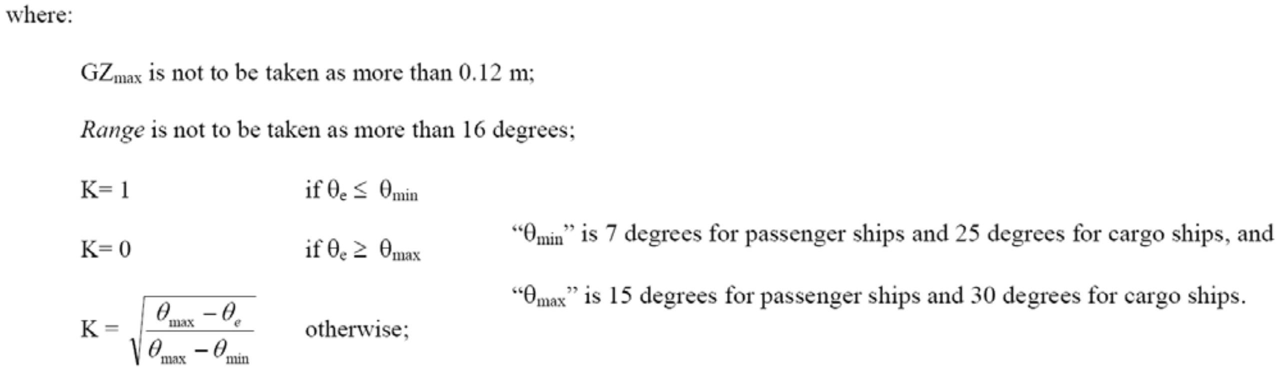
In relation to the latter, the new harmonised SOLAS Chapter II-1 consolidates the probabilistic concept of ship subdivision in an attempt to move away from prescription, a step that has to be commended, despite the fact that some of the most irrational "baggage" of previous SOLAS provisions is being kept in. The new regulations require that an attained index of subdivision, A is at or above some level R, the formulation of which can be found in IMO MSC79, 2004. Although R is assumed to reflect a level of safety, very little can be ascertained on the actual level that these new regulations provide.

Whilst the probabilistic concept of subdivision, conceived nearly 40 years ago, is plausible from a practical point of view, the phenomena of flooding and subsequent loss of stability in extreme environments … and ultimately life, seem to involve issues far more complex than the rationale implicit in A and R formulations.

However, all the "imperfections" of the probabilistic subdivision index calculations apart, it is fair to say that in an era where high-value ships, sometimes carrying thousands of people onboard and featuring an arsenal of state-of-the-art technology on board (propulsion, energy production, automation, control and communication systems, among others), it is difficult to understand that to ensure basic safety expectations in the event of - say, a collision, not so "state-of-the-art" knowledge and methods (conceived in Archimedes epoch, e.g. GZ curve) are still the basis for evaluating ship "survivability" and ensuring safety. In relation to the above and in the context of the probabilistic subdivision index, the survival factor (s_i) can be singled out for this discussion.

As it is well known, the factor s_i, represents the (conditional) probability of surviving the flooding of compartment(s) under consideration for a given loading condition, and it has been formulated on the basis of empirical relationships between traditional vessel stability parameters and survivability tested for a small number of cases with specific damage characteristics. Equation (1) is the formulation of factor s_i for final equilibrium.

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



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;

"$\theta_{\min}$" is 7 degrees for passenger ships and 25 degrees for cargo ships, and

"$\theta_{\max}$" is 15 degrees for passenger ships and 30 degrees for cargo ships.

The traditional stability parameters involved in this expressions pertain to characteristics of the GZ curve in still water, calculated by assuming that floodwater reaches the state of minimum entropy at every stage of flooding, i.e. that the lowest-most spaces within the damaged zone flood instantly, and that static balance between mass properties of the vessel, the displaced water and the floodwater describes fully the vessel stability.

To gain better understanding of the meaning of the above approximation, and in general of stability of modern passenger ships, a study **[4**] was undertaken including probabilistic damage stability calculations, numerical time-domain simulations and scaled-model tank testing of three cruise ship designs as described in Table 1, considered representative of modern passenger ships. Table 2 and Figure 1 and Figure 2 provide an overall summary of the study.

On the basis of the validation studies, it was carried out, it was concluded that whilst some discrepancies between the results of experiments and numerical simulations exist, the numerical simulations are capable of capturing the dominant physical phenomena driving vessel response during progressive flooding through the complexity of internal layout of the type of vessels considered, and in the environment of random waves. As shown in Table 2, altogether 33 different damage cases of three vessels were investigated. The cases were chosen, in principle, *ad hoc*, with the only objective of having a range of *s* factors and distribution of damages along the whole length of the vessel.

The damage openings were chosen with a level of "high severity" in mind, hence their characteristics were: either from bulkhead to bulkhead spanning the flooded spaces in case of C1 vessel, or spanning the distance between the centres of the furthermost compartments in the damage, C2 and C3 vessels. Vertically, the damage opening was modelled from the base plane to the top of the geometry being modelled. Penetration-wise, the damages were assumed to have only the shell removed. Overall, it is clear that a far more thorough study would be required to properly quantify the average survival rate in each of the scenarios. Simulations would have to be carried out for a range of environmental conditions, for longer periods of time, a number of repetitions would need to be considered, and most importantly a large number of damage openings would need to be addressed for each flooding scenario. Only then a good estimate of the average survival rate "*s*" could be derived and compared with the current proposals, or indeed, a suitable proposal for calculating *s* be formulated. Nevertheless, some observations can be made and trends deduced on the basis of the work performed, as outlined next.

It can be seen that of the 33 cases considered, 16 were found to lead to vessel capsizing within two hours, sometimes very rapidly. Of the 16 "capsizing" cases, 10 had the "s" factor higher than 0, and some had s=1.0. Of the remaining 17 "surviving" cases, 7 had the s factor equal to zero!

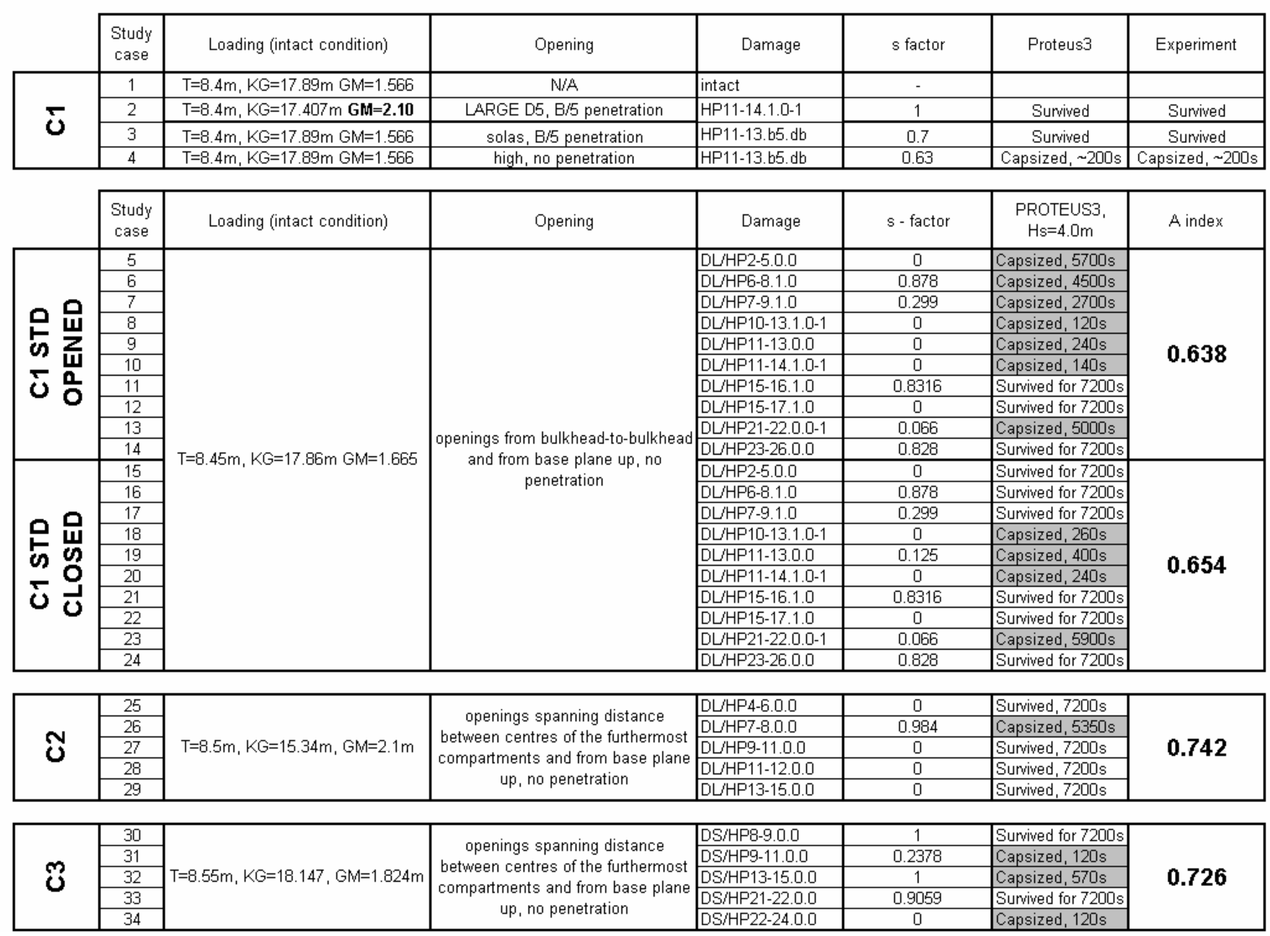
Although limited, the study demonstrates that traditional GZ-curve characteristics cannot adequately describer the behaviour (and hence the destiny) of a damaged ship with the complexity in watertight subdivision of internal spaces found on a typical cruise vessel, and consequently, that the formulation for the "s" factor in its present form cannot meaningfully represent the average resistance of such ships to capsize when subjected to flooding, following collision damage. The primary reason for this deficiency derives from explicitly neglecting the presence of multiple free surfaces (MSF effect), a phenomenon specific to ships with complex watertight subdivision, which substantially weakens or indeed leads to complete erosion of stability at any of the stages of flooding.

As the ship's hull is breached, water rushes through various compartments at different levels, see Figure 3, rather than flowing instantaneously to the lowest-most space, as is assumed in traditional stability calculations. As a result vessel stability can be substantially impaired even when the floodwater amount is relatively small, see Figure 5 for a sample of hypothetical cases, and subsequently the ship can heel to angles far larger than those predicted by a conventional approach; compare Figure 4 and Figure 5. As the vessel attains large angles of heel, of the order of **20deg** even for small damage openings, see for instance Figure 6 and Figure 7, the water reaches the upper decks, whether via the main damage opening or other openings, such as door O250 (aft-port-deck5) of C1 vessel, and then spreads rapidly through these spaces, see Figure 8.

Table 1 Particulars of test ships

	Description	Gross tonnage (gt)	No Passengers / No Crew / (total No People)
C1	large cruise ship	109,000	2,600 / 1,100 / (3,700)
C2	panamax cruise ship	90,090	2,500 / 860 / (3,360)
C3	large cruise ship	113,000	2,670 / 1,100 / (3,760)

Table 2 Summary of the results of numerical simulations and probabilistic calculations



	Study case	Loading (intact condition)	Opening	Damage	s factor	Proteus3	Experiment
C1	1	T=8.4m, KG=17.89m GM=1.566	N/A	intact	-		
	2	T=8.4m, KG=17.407m **GM=2.10**	LARGE D5, B/5 penetration	HP11-14.1.0-1	1	Survived	Survived
	3	T=8.4m, KG=17.89m GM=1.566	solas, B/5 penetration	HP11-13.b5.db	0.7	Survived	Survived
	4	T=8.4m, KG=17.89m GM=1.566	high, no penetration	HP11-13.b5.db	0.63	Capsized, ~200s	Capsized, ~200s

	Study case	Loading (intact condition)	Opening	Damage	s - factor	PROTEUS3, Hs=4.0m	A index
C1 STD OPENED	5	T=8.45m, KG=17.86m GM=1.665	openings from bulkhead-to-bulkhead and from base plane up, no penetration	DL/HP2-5.0.0	0	Capsized, 5700s	**0.638**
	6			DL/HP6-8.1.0	0.878	Capsized, 4500s	
	7			DL/HP7-9.1.0	0.299	Capsized, 2700s	
	8			DL/HP10-13.1.0-1	0	Capsized, 120s	
	9			DL/HP11-13.0.0	0	Capsized, 240s	
	10			DL/HP11-14.1.0-1	0	Capsized, 140s	
	11			DL/HP15-16.1.0	0.8316	Survived for 7200s	
	12			DL/HP15-17.1.0	0	Survived for 7200s	
	13			DL/HP21-22.0.0-1	0.066	Capsized, 5000s	
	14			DL/HP23-26.0.0	0.828	Survived for 7200s	
C1 STD CLOSED	15			DL/HP2-5.0.0	0	Survived for 7200s	**0.654**
	16			DL/HP6-8.1.0	0.878	Survived for 7200s	
	17			DL/HP7-9.1.0	0.299	Survived for 7200s	
	18			DL/HP10-13.1.0-1	0	Capsized, 260s	
	19			DL/HP11-13.0.0	0.125	Capsized, 400s	
	20			DL/HP11-14.1.0-1	0	Capsized, 240s	
	21			DL/HP15-16.1.0	0.8316	Survived for 7200s	
	22			DL/HP15-17.1.0	0	Survived for 7200s	
	23			DL/HP21-22.0.0-1	0.066	Capsized, 5900s	
	24			DL/HP23-26.0.0	0.828	Survived for 7200s	
C2	25	T=8.5m, KG=15.34m, GM=2.1m	openings spanning distance between centres of the furthermost compartments and from base plane up, no penetration	DL/HP4-6.0.0	0	Survived, 7200s	**0.742**
	26			DL/HP7-8.0.0	0.984	Capsized, 5350s	
	27			DL/HP9-11.0.0	0	Survived, 7200s	
	28			DL/HP11-12.0.0	0	Survived, 7200s	
	29			DL/HP13-15.0.0	0	Survived, 7200s	
C3	30	T=8.55m, KG=18.147, GM=1.824m	openings spanning distance between centres of the furthermost compartments and from base plane up, no penetration	DS/HP8-9.0.0	1	Survived for 7200s	**0.726**
	31			DS/HP9-11.0.0	0.2378	Capsized, 120s	
	32			DS/HP13-15.0.0	1	Capsized, 570s	
	33			DS/HP21-22.0.0	0.9059	Survived for 7200s	
	34			DS/HP22-24.0.0	0	Capsized, 120s	

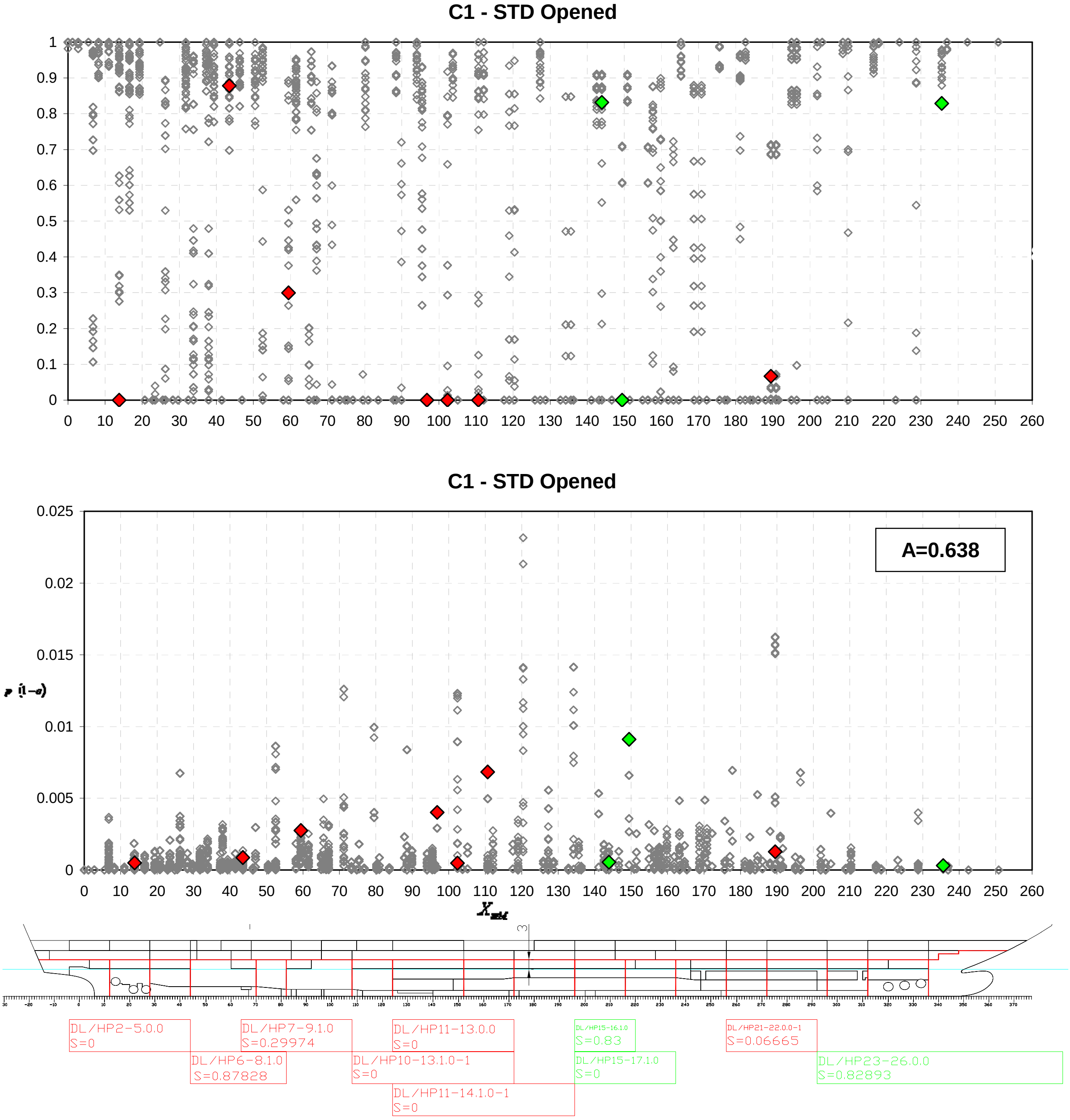


Figure 1: Side view of the vessel, C1-STD Opened, with a map of "s" factors (upper plot) and the expression $p \cdot (1-s)$, for all damage cases considered as a function of the damage locations. The red boxes in the lowest-most plot indicate cases where the ship capsized within 2 hours simulation time, whereas green boxes indicate survival cases.

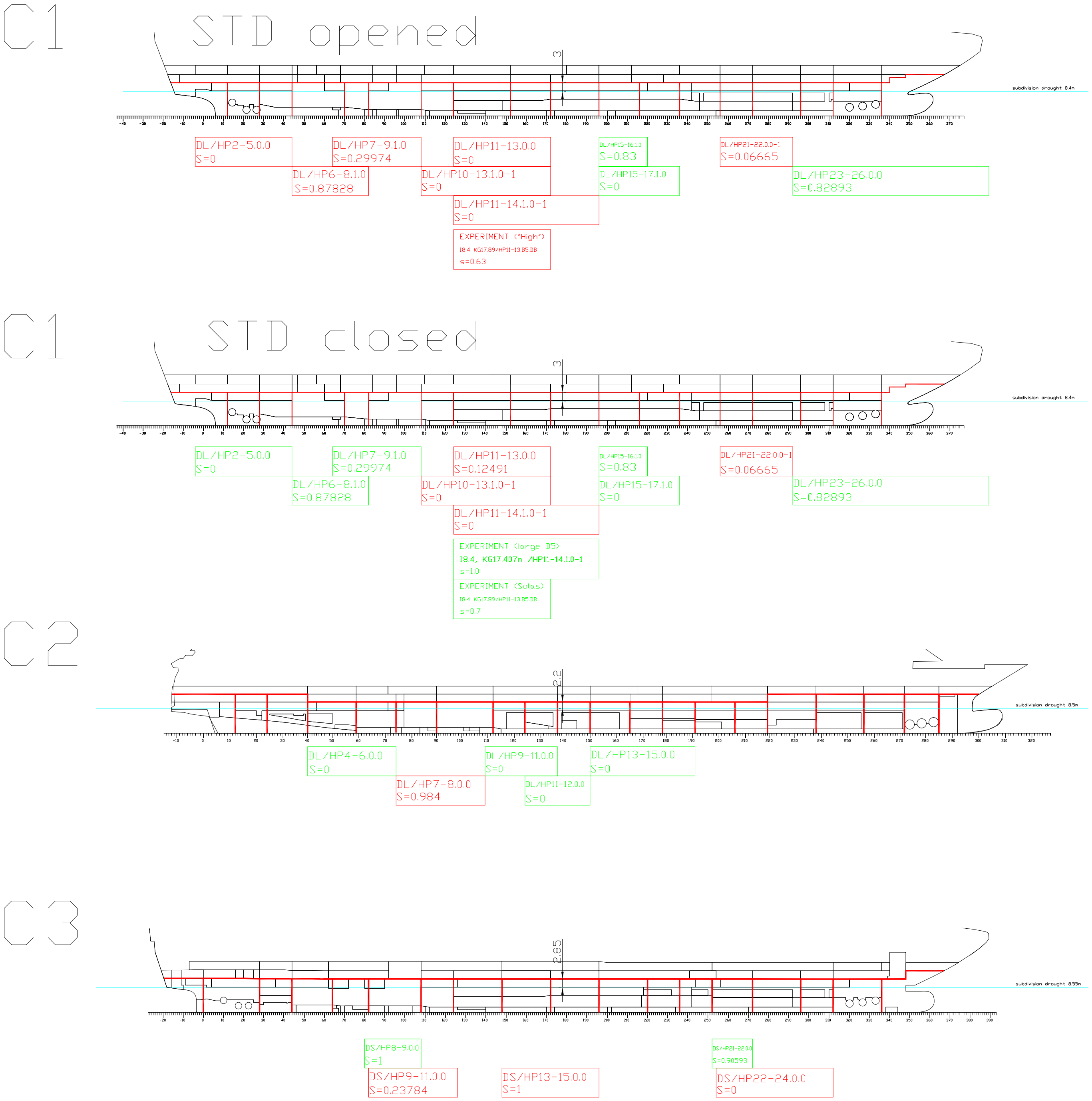


Figure 2: Side view of the general watertight subdivision of the test vessels considered. Indication of the damage cases considered with calculated "s" value: red boxes signify cases where the ship capsized within 2 hours simulation time, whereas green boxes indicate survival cases.

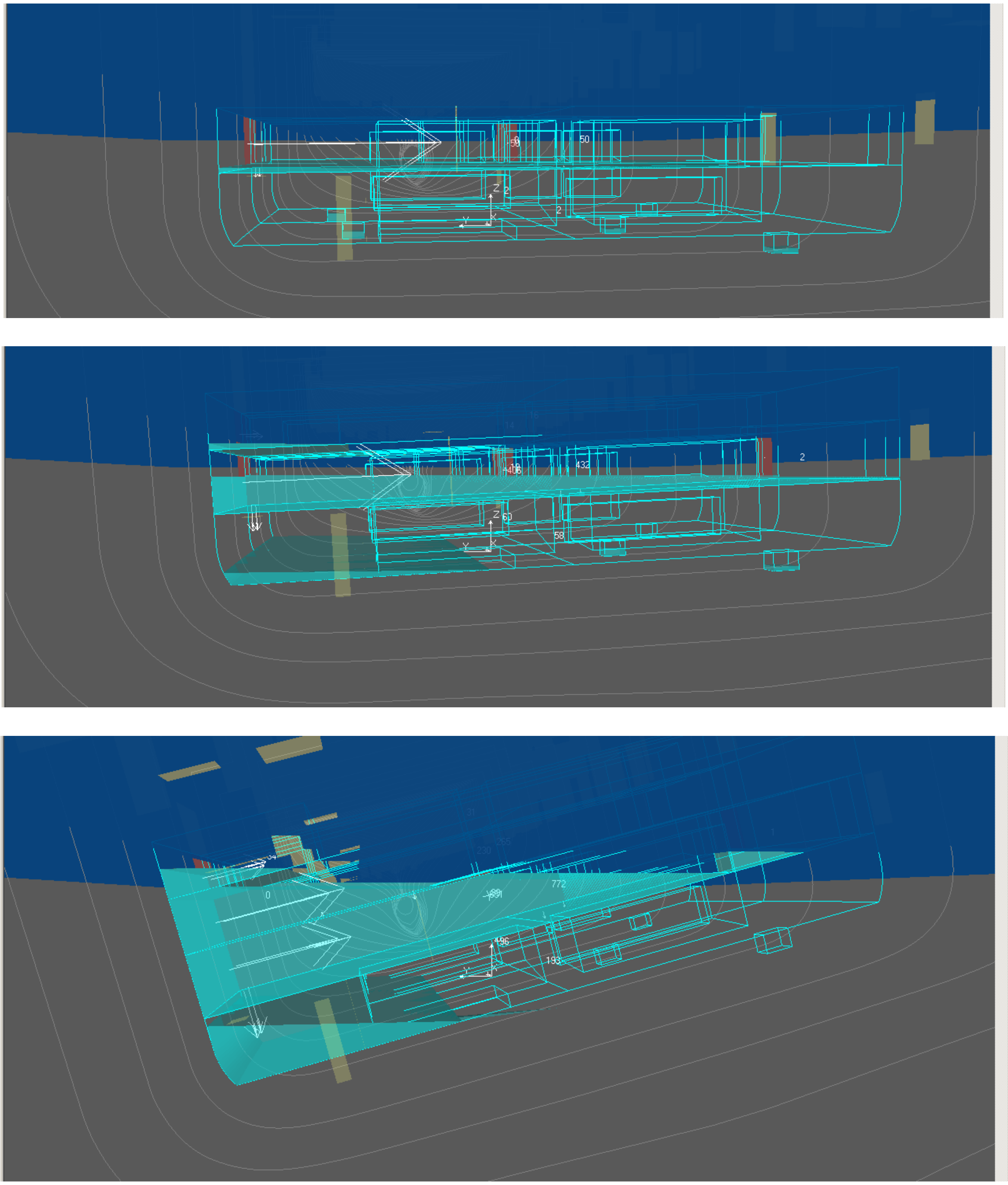


Figure 3: Intermediate stages of flooding compartments at frame 148 of C1 vessel, damage p11-13-b5-db; a typical process of heeling/capsizing takes some 2-3 minutes from the instant of hull breach.

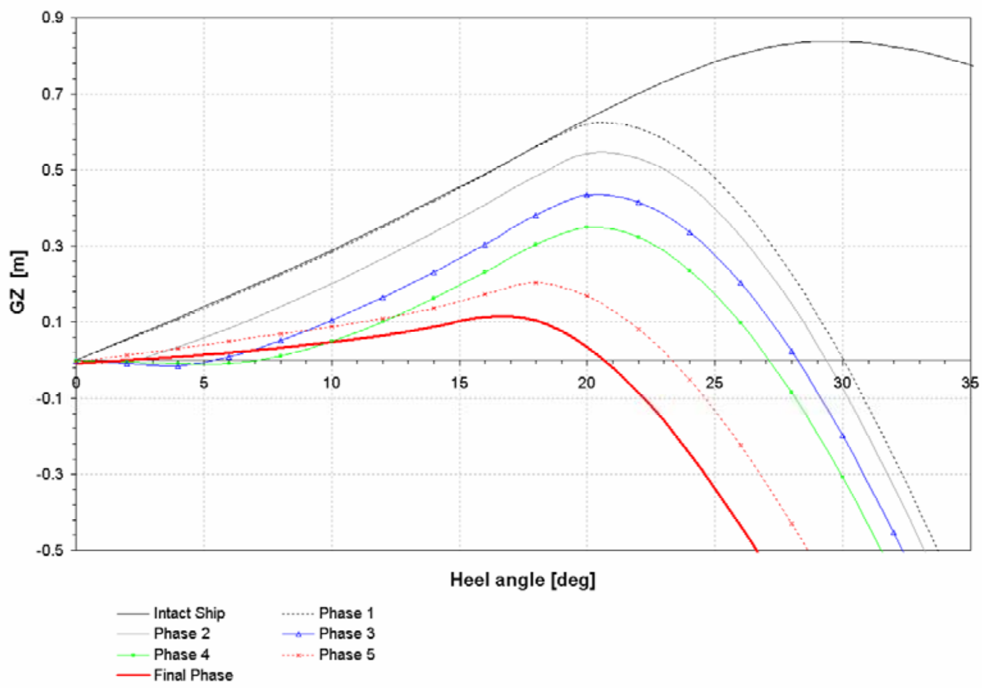


Figure 4: GZ curves for various transient flooding stages, p11-13-b5-db

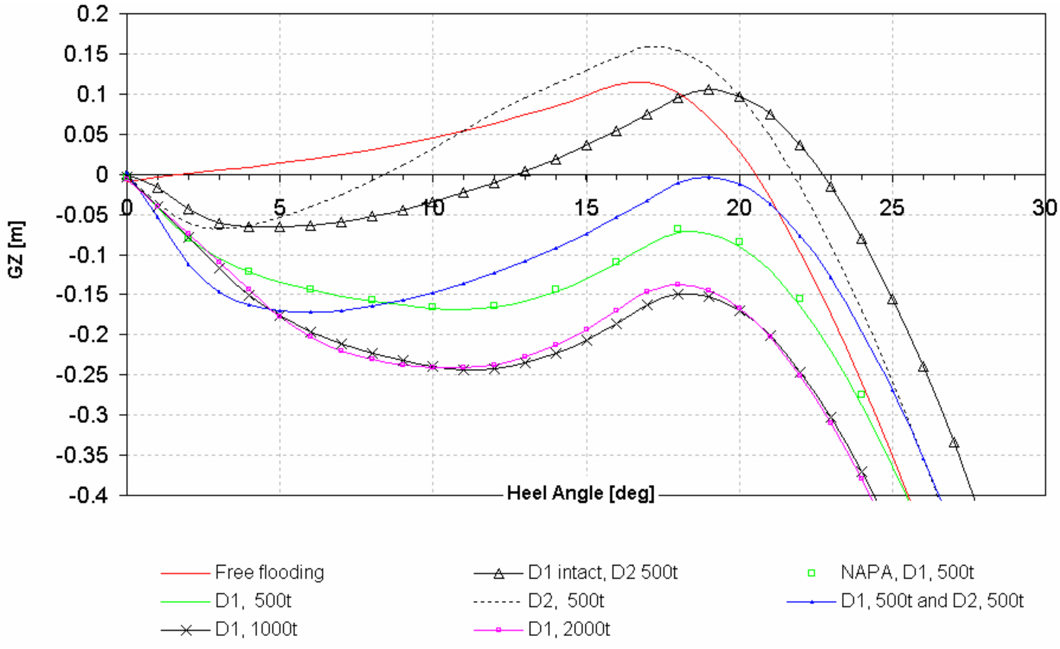


Figure 5: Righting levers for a damaged ship, case p11-13-b5-db
Effects of various stages of transient flooding Decks 1 and 2

Figure 6: Damaged vessel (**STD opened**).

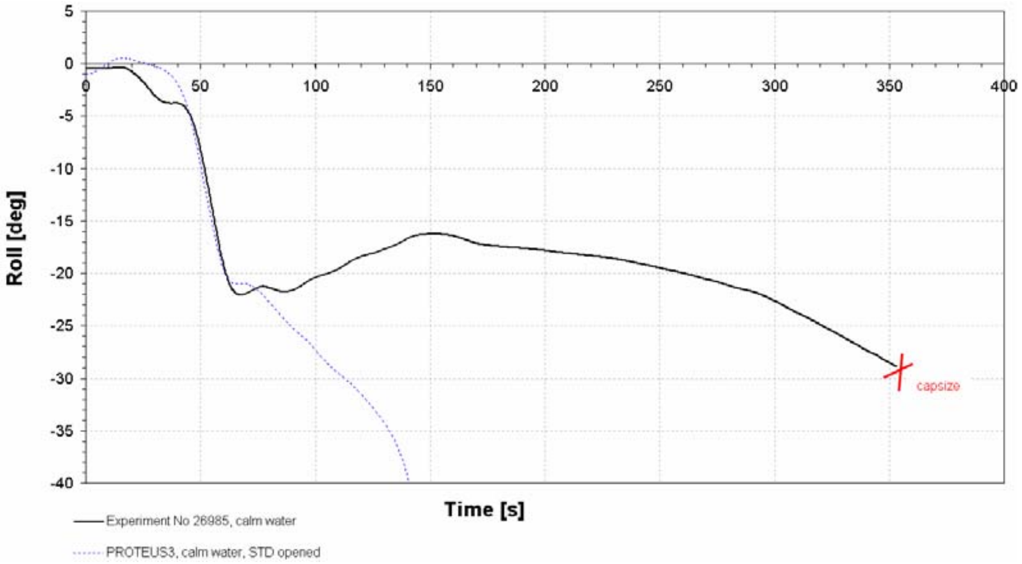


Figure 7: Damaged vessel (**STD opened**), test in calm sea, D=8.4m, KG=17.89m
Comparison between model experiment results and numerical simulations

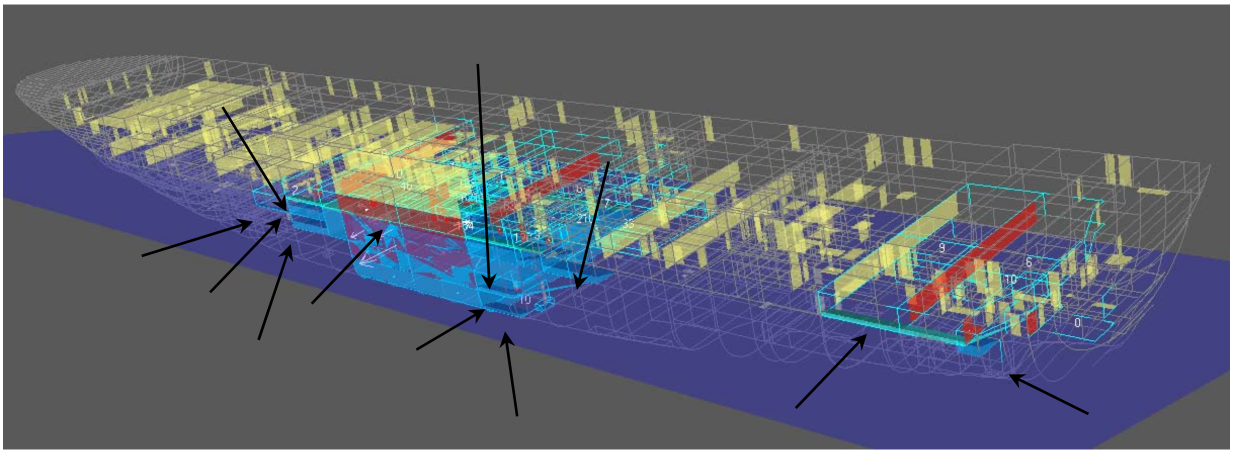


Figure 8: Multi-free surface (MFS) effect during flooding in waves, C1, Case DL/HP11-13.0.0.

Summarising this section, the following observations are noteworthy:

- The development of probabilistic rules to provide safety "equivalent" to SOLAS has in a way imposed all the prescriptive SOLAS "baggage" onto the new rules thus "quenching" the advantage expected to be derived from adopting a rational probabilistic framework to address ship subdivision
- State of the art tools are needed to understand ship behaviour in different damages (location, length, penetration), particularly time evolution of damage involving progressive flooding that may lead to vessel sinking/capsize; perhaps extensive studies could allow identification of parameters (e.g. properties of GZ curve, given also the curve is derived with some specific assumption on distribution of water, etc) that govern survivability of these damages
- Such capability would allow quantification of risk levels associated to different damages and hence ranking of damage scenarios and risk assessment for design and regulatory purposes.

3 Ship Survivability – the Goal-Based Approach

The difficulty with the safety "equivalence" principle is that it is not possible to quantify safety in the current requirements; therefore it is difficult to demonstrate equivalence. A deviation from this and the first opportunity in the rule making history to "do things right" relates to the safety of [large] passenger ships. In May 2000, the IMO Secretary-General called for a general review of the safety of these ships noting that "what merits due consideration is whether SOLAS and, to the extent applicable, the Load Line Convention requirements, several of which were drafted before some of these large ships were built, duly address all the safety aspects of their operation – in particular, in emergency situations". This visionary prompt led IMO MSC to adopt a new "philosophy" and a working approach for developing safety standards for [large] passenger ships. In this approach modern safety expectations are expressed as a set of specific safety goals, listed below – among various proposals to the Committee:

- The ship should be designed for improved survivability so that, in the event of a casualty, persons can stay safely on board as the ship proceeds to port
- The ship should be crewed, equipped and have arrangements to ensure the safety of persons onboard for survival in the area of operation, talking into account climatic conditions and the availability of SAR functions.
- The ship should be crewed and equipped to ensure the health, safety, medical care and security of persons on board until more specialised assistance is available.
- etc…

The list is long but a consistent “whole” is identifiable. Achievement of these goals would ensure safety of human life and the ship that is commensurate with the safety expectations of today, including environmental concerns. In this context, safety goals need to be generic - hence applicable to all ship types. The implementation of such an approach requires also more specific requirements related to ship-type specific hazard categories and ship functions that are verifiable during design – these are referred to as “functional requirements” and for addressing the risk of flooding; the following functional requirements - among others, can be listed (from various proposals):

- When a watertight compartment (below the bulkhead deck) is flooded, there should be efficient down- and cross-flooding arrangements for the water to flood freely the entire compartment, with no air pockets or other obstacles delaying flooding or leading to multiple free surfaces.
- The ship should remain sufficiently upright and afloat to allow for emergency operations to be carried out onboard. The vessel shall be able to return to port by own means, to wait for assistance or be towed to a port of refuge. In such cases appropriate habitability and redundancy arrangements should be in place to be able to sustain all people on board.
- If the vessel cannot be prevented from sinking, it should survive for as long as necessary to allow safe and orderly abandonment by all people on board.
- Undivided spaces running along a significant length of the vessel intended for housing pipes / cables should be located so that the risk of damage following a grounding/collision incident is minimised.

The above safety goals and functional requirements, in one way or another were the inspiration for most of the current prescriptive requirements in SOLAS. However, their application to constantly evolving ship design concepts is not justified nor appropriate anymore. All these requirements can be addressed during early design stages if the right knowledge is available to the designer and incorporated in the design concept: Questions such as those listed below need to be addressed form first principles:

- How to minimise the risk of progressive flooding should water ingress occur?
- How to ensure efficient down-flooding arrangements without compromising fire protection?
- What vessel attitude is safe for assembling passengers and carrying out emergency operations?
- What sea severity is the vessel expected to withstand in damage conditions and for how long?
- How much time is needed for abandoning the vessel?

Prerequisite knowledge to addressing this type of questions during design or for rule-making purposes derives either experientially or through numerical modelling and systematic investigation using verified/calibrated models. In this sense, and in the absence of experience particularly with new vessel types, advanced simulation tools should be used for gaining such knowledge and ultimately for <u>verification</u> purposes, in the same way as model testing is used today to gain better understanding” and to verify specific performance achievements. No doubt such a verification process requires clear and quantifiable [performance] criteria that can be evaluated with available tools and methods. However, the ultimate *goal* is to verify that the functional requirements are met and hence, the safety goals will be achieved. The verification process can also provide the means to categorise the outcome of different design scenarios, information useful if one (designer, legislator, and decision-maker) wants to know the safety boundaries of specific ship designs, a notion that is gaining momentum under the term “casualty threshold” also among the item list of the [large] passenger ships discussions. In the knowledge that prescription may spoil, yet again, what can be a totally exciting development for naval architects, the authors take a proactive step (leap) to suggest a credible way of carrying out such verification along with some thoughts on its relevance for determining what a casualty threshold in the context of damage survivability may be. A comparable approach is applicable to other hazard categories (safety concerns, safety drivers).

3.1 Identification of critical scenarios

For verification to be practical, a limited (critical) number of “design” scenarios must be addressed. Hence their selection must be made on some form of synthesised knowledge leading to realistic and relevant scenarios contributing to the majority of the risk associated with, in this case, survivability in damage conditions. In this context, a combination of the factors p_i and s_i (from the probabilistic subdivision index calculations) could form the basis of preliminary ranking of damage cases provided that at least the formulation of s reflects better the physics of flooding phenomena. One such formulation for Ro-Ro vessels is the SEM [5]. This may lead to a number of scenarios involving water ingress and flooding into one-, two- or more compartments, of any penetration, depth and vertical extent. In the nascence of simple formulations, tedious numerical simulations are the only substitute.

3.2 Verification of functional requirements and performance criteria

Quantifiable performance criteria shall reflect the specific functional requirements. In relation to survivability, these may relate to – for instance, instantaneous heeling angle (at all stages of flooding), equalisation times, etc (see for instance [6]). In relation to habitability, the criteria may relate to required water demand per person for say [5] days; similarly, performance criteria for ensuring basic services and functions can be developed. Eventually, it is suggested that the outcome of each evaluated scenario could be classified in the following terms:

- Type I: a casualty in which damage survivability functional requirements can be met. The ship is able to return to port under own means and all basic functions and services (habitability) can be provided to people on board.
- Type II: casualty in which damage survivability functional requirements can also be met, albeit the extent of damage may lead to limited availability of basic functions, resulting for example to having the ship to be towed to port.
- Type III: casualty in which damage survivability functional requirements can be met only for a limited period of time or cannot be met at all – commensurate with the time required for safe and orderly abandonment of the vessel.

Theoretically, most of the casualties should result in Type I or II consequences. Only a few cases should result in Type III consequences, in which case adequate design solutions (passive measures) should be in place to improve survivability enough to mitigate consequences to category I/II or otherwise to ensure orderly abandonment of passengers and crew (see Figure 9). This approach is in line with the ALARP principle, and it has no direct need of risk acceptance criteria. Yet, it can be said that a ship concept developed under such a framework, is de-risked, at least as far as human life loss is concerned and of course, within the assumptions implicit in the verification process. The outcome of such a process is simplistically illustrated in Figure 9. What solutions and to what extent designers, yards and the industry in general is prepared to incorporate such solutions in the context of other design trade-offs, is a matter to be explored and gauged on the way.

It is important to add here that in the light of the findings presented in the previous section, it is rather obvious that using a deterministic criterion to portray the casualty “threshold” as, say, a given flooding damage extent, in attempting to categorise a priory the severity of the consequences of specific design scenarios, is not very rational indeed (SOLAS determinism all over again).

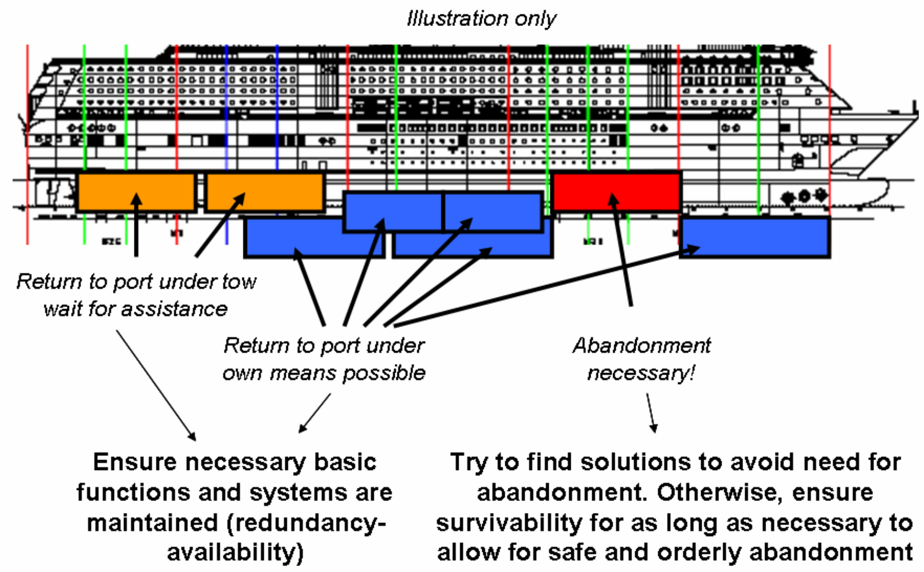


Figure 9: Illustration of the proposed casualty threshold analysis

These deliberations have a strong relationship with the framework outlining the development of new goal-based ship structural construction standards as illustrated in Figure 10. .

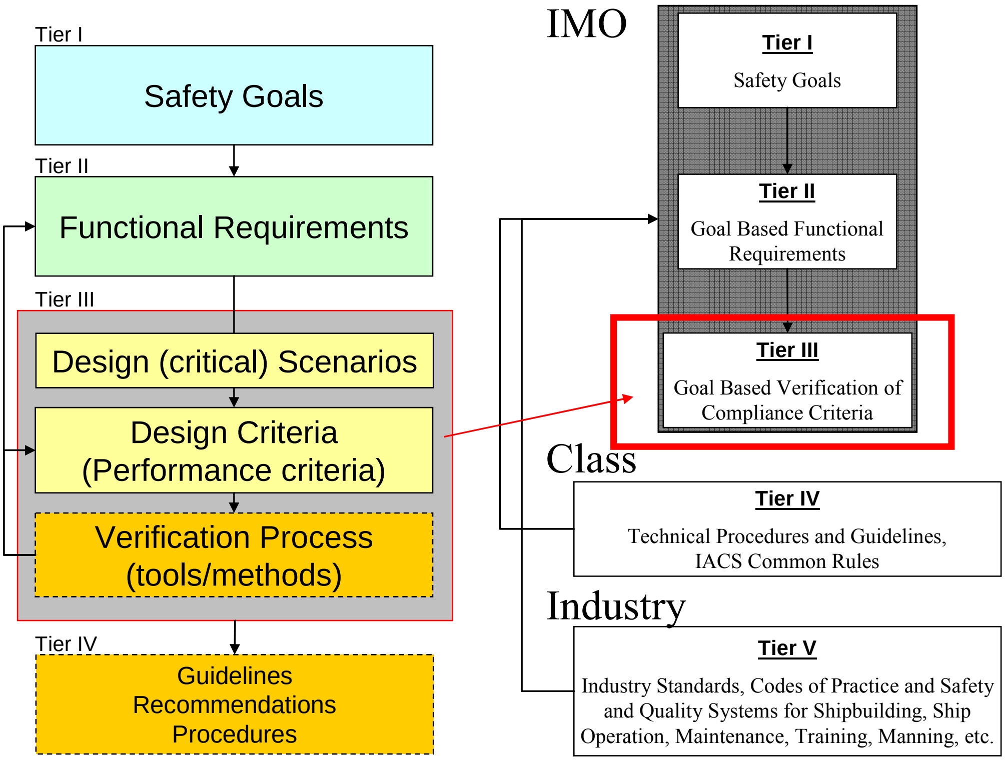


Figure 10: Approach to goal-based design and regulation
(in the light of IMO Goal-based ship construction standards)

Notwithstanding the potential for unprecedented safety improvements by adopting a framework that embraces science and nurtures rational decision making, the industry's response is still governed by a mind set that upholds prescription and understands only deterministic regulation. Ibis being the case, it fights in every step on the way to put deterministic "markers" so that it does not loose touch with experiential knowledge, fearing the new learning curve presented by open-ended, goal-based approaches.

4 Concluding Remarks

On the basis of the foregoing discussion and results presented, the following concluding remarks can be made:

- The new probabilistic framework for damage stability offers the potential to achieving much better standards than those set out by deterministic regulations and without doubt constitutes a significant and long awaited step towards improved safety, particularly if state-of-the-art knowledge and tools are utilised to address damage stability safety in a meaningful manner.
- Moreover, frameworks proposed by IMO and others soon to be embarked upon provide the right platform to accommodate and promote scientific approaches to dealing with ship safety.
- However, **c**ompared to modern risk assessment methods and tools used in other industries, the new harmonised regulations for damage stability calculations are far from complete, necessitating a number of steps for direct implementation to be deemed appropriate. The formulation for the "s" factor for [large] passenger ships in particular does not meaningfully represent the average resistance of such ships to capsize; the primary reason for this inadequacy derives from underlying assumptions pertaining to the properties of traditionally derived GZ curve, explicitly neglecting phenomenon of multi-free-surface effect.
- This paper argues that this fundamental weakness derives from the compulsion to introduce deterministic prescription in the rule making, even within a probabilistic framework. The justification of targeting "equivalent" safety to SOLAS seems to be so overpowering that the industry is prepared to accept patently irrational formulations and results that clearly undermine safety and ignore scientism reasoning and know-how.
- Addressing safety of [large] passenger ships appears to be the only exception to the rule, offering a platform for scientific knowledge in all its forms in attempting to ensure that safety of these ship concepts remains tolerable and ALARP even in all plausible damage scenarios.
- Yet, it is still early times and determinism is proving too strong and too hard to kill!

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