Probabilistic rules for damage stability – current status

A personal review of what has been achieved through the new harmonized standard in SOLAS 2009, by Mikael Huss

Introduction about rules and standards

The general purpose of technical rules should be to define minimum requirements necessary to assure public wellbeing (including safety of lives, health, property, environment, functionality etc.).

The purpose of technical standards is more targeting the need for a common understanding of how things are to be done and for facilitation of interchange and communication. Many standards are developed primarily to facilitate fulfillment of requirements, but other essential standards are developed without any direct coupling to safety, although their existence does indirectly contribute to safety by creating common references.

Traditionally the technical rules for international shipping have been directly formulated in terms of prescriptive standards in IMO conventions and codes. This has indeed facilitated the implementation of an equal basic shipping safety independent of where the ship has been built or by whom it is operated. Fulfillment of the society requirements has been considered identical to compliance with a certain standard, no less – no more.

However, this mixture of different purposes (safety and facilitation) into one regulatory regime has also some major drawbacks, which have become clearer and clearer as society develops faster and faster. New technology, new markets and public requirements on increased safety have become difficult to handle within a prescriptive regime built on existing technology and market and with inherent but not explicitly stated safety level. Anyone, being politicians who want to implement higher safety or ship designers/operators who seek innovative solutions, will find it extremely difficult to challenge the prescribed standard.

The goal-based standard initiative is a rational step forward into a new regime that will meet the requirements of the changing future without losing the experience gained from standards developed during centuries.

From my perception, the core essence of goal-based standards is to explicitly formulate objectives, functions and solutions separate from each other so that the fulfillment of objectives can be measured independently of the used technology. This separation is important for validation of the existing standards and will open up for alternative standards or new innovative solutions based on risk-based design etc.

It is in this context of existing and future rules and standard regimes I will try to make a brief review of what actually has been achieved through the new harmonized damage stability rules in SOLAS 2009.

Major impact of SOLAS 2009

The harmonized regulations on subdivision and damage stability adopted as amendments to SOLAS Chapter II-1, (Res. MSC.216(82), in the following referred to as SOLAS 2009) was the final outcome of decades of discussions and development. The most significant change was that these amendments finally ended a century long era of prescriptive requirements on transverse bulkheads and subdivision of passenger ships based on floodable length and margin line criteria. The ability to withstand one, two or three compartment side damages, which had been the common standard of expressing passenger ship safety, was now replaced by something more difficult to perceive – the ability to withstand a certain percentage of all possible damages described by probability functions. This incorporates two changes of directions, from design towards performance, and from deterministic towards probabilistic standards.

It must be emphasized that the main objective of the amendments was not to introduce a new methodology, nor to change the current level of safety. It was rather to harmonize damage stability assessment under one rationally based methodology from a situation where two fundamentally different approaches and principles were living in parallel.

The probabilistic methodology to assess subdivision and damage stability had already been introduced in the, at that time, very innovative alternative regulations for passenger ships, Res. A.265 (VIII) from 1973, and in existing mandatory SOLAS regulations for dry cargo ships in Chapter II-1, Part B-1 from 1992. At the same time the traditional deterministic subdivision standards had developed further by adding additional stability requirements to the old SOLAS floatability standard for passenger ships and by many other requirements for specific ship types.

This divergence in methodology and principles made any comparison of safety level very difficult. An overall harmonized standard would actually have been a significant step towards goal-based standards in this area. However, SOLAS 2009 did not achieve this full harmonization; it did merely change the mandatory regime for passenger ships.

During the process of benchmarking the new regulation with the existing it was found that the safety level of existing ships built according to deterministic requirements showed a very large scatter when measured according to the new methodology. By all reasonable assumptions it can therefore be said that SOLAS 2009, even if it allows for a more flexible designs, will result in a more consistent minimum level of safety.

Especially large passenger ships and ro-ro cargo ships built according to the, at that time, existing standard, were found to diverge from the trend of attained indices calculated for all types of ships under consideration for the new regulations. By a special decision in MSC, the new requirements were allowed to be stricter specifically for these ship types in order to keep a common general formula for the required index.

Core components of the probabilistic damage stability standard

As already stated, the probabilistic damage stability standard can be seen as a performance standard rather than a design standard. Instead of stipulating how the ship should be subdivided, the performance of a proposed subdivision arrangement is evaluated for typical damage scenarios. This is much alike other test performance standards like the fire test procedures referred to in SOLAS Chapter II-2 or the NCAP collision test rating used to rank new cars. However, instead of using a few well defined scenarios and perform detailed destructive testing of one or a few samples, the probabilistic methodology is introduced in the definition of numerous scenarios for which the performance is evaluated in a more generic way.

Both these approaches have some advantages and disadvantages. The introduction of a large variety of damage cases weighted with their probability assures that the subdivision is not "paragraph-optimized" that could be the case if just one or a few representative cases were chosen. The B/5 limit of penetration in the old passenger ship regulations is one such example. On the other hand generic performance criteria, i.e. survivability in this case, may of course not fully represent the possible outcome of every individual ship or incident. In real critical situations (as well as in destructive performance testing) it is often a sophisticated and partly unforeseeable chain of events that may be crucial for the final result. Whatever performance standard used, there will always be elements of assumptions, generalization and simplification. Even if every reasonable effort is made to lessen the influence from these simplifications, a technical standard needs to be based on a fair balance between unified applicability and scattered reality. Other measures such as local risk assessment and safety management systems are better suited to take care of the differences between individuals of the same category.

The three core components of the probabilistic subdivision and damage stability regulations are:

1. Required overall level of survivability accounting for any foreseeable situation where the ship has lost some of its watertight integrity (index R).

2. Distributions describing the degree of survivability under a specific damage (s).

3. Distributions describing damage position and extent (p,r,v).

Even though the regulations themselves look very complicated in their formulation and lead to extensive analysis, this fundamental structure gives an extraordinary clear and rational separation between different stakeholders interest. The public interest is covered by the overall level of survivability, which should be addressed by political decisions. The designers need only to care about how to achieve sufficient survivability with full freedom to choose the subdivision arrangement. And the damage distributions are totally independent of any technical solution or required safety level.

However, this theoretically clear structure is in reality affected by the inherent assumptions and simplifications as well as by other requirements that do not strictly follow the same approach. On top of the probabilistic collision performance standard, additional design requirements have been added for side and bottom damages, which cover other contact situations in a traditional deterministic way.

What do we have and what can be further improved?

Let us start looking at the principal components from bottom. The distributions describing damage position and extent are based on statistics from ship to ship collisions including a variety of ship types, sizes and conditions. The number of reported collision damages is relatively small and the quality of the documentation is varying. All damage extension data have been normalized with regard to the ship main dimensions and take no account on differences in structures and subdivision. Whatever distributions fitted to this set of data will include a significant scatter and shall be treated as a representative model rather than precise description of reality. It is therefore reasonable to stick to robust and simple distributions from the perspective of a technical standard.

The natural step forward would be to include all other causes of large scale flooding below the waterline into the same probabilistic framework. The GOALDS initiative on grounding is in this respect very welcomed. Collision and grounding will probably together cover all necessary conditions to be accounted for even if flooding due to structural failure without contact may contribute to some extent.

When it comes to flooding caused by deficiencies in the watertight boundary above the waterline, the number of causes may be much larger and probably most of the statistics will not be available. In a number of fatal accidents this has been the final cause of flooding leading to capsize or sinking even if it was not the initial event. However, an analysis of the effect of such second stage flooding requires a completely different set of scenarios that will be difficult to incorporate in the standard damage stability concept at this stage.

The distribution of survivability after damage is mainly described by ordinary stability characteristics: range of positive stability, *GZ*-max and angle of heel at final equilibrium. Full survivability at equilibrium is assumed achieved when *GZ*-max is at least 0.12m, the range is at least 16° and the heel is less than 7° for passenger ships and less than 25° for cargo ships. For passenger ships there are additional requirements regarding intermediate stages of flooding and ability to withstand heeling moments from wind, passengers and survival crafts. Evacuation is accounted for both in the equilibrium heel angles and in requirements on non-flooded evacuation routes, escape hatches and control stations.

The survivability criteria were developed and verified based on calculations and model tests for various ship types. They are not necessary representing every realistic event but are similar both to the previous damage stability criteria and to the intact stability criteria, describing a general capability to withstand a variety of situations. It may be somewhat misleading in the present regulations that the quantitative value $s = 1$ is reached at a rather moderate level of stability that would perhaps not be sufficient under all circumstances. At this stage, also s must be interpreted as another part of the standard model and not a strict measure from direct assessment.

Within the present probabilistic framework, the survivability criteria could well be further developed and differentiated between more ship types if found necessary. Also in this respect, the GOALDS initiative is important. The better survivability may be understood and described, the better can we accept the separation between political decisions on safety level from technical solutions. In the future we may well extend this level to include, in addition to survivability, also other functions and consequences of flooding such as ability to return to port and even oil spill from tankers.

The high-level component of the regulatory structure is the safety requirement expressed as index *R*. Due to the original mission to maintain the safety level from previous standards, this is presently not harmonized between passenger ships and dry cargo ships. Instead we have the somewhat disturbing situation that a cargo ship without passengers may have significantly higher required index than a passenger ship with the same length and a few passengers.

I see possibilities in the future to improve the formulation of index *R*. If we believe to have representative models for both probability and consequences then we could also pinpoint the targets regarding safety of lives, health, property, environment, functionality etc. and these targets should as far as possible be formulated in terms of harmonized required levels independent of ship categorization and technology.

In the calculation of total attained index *A* the present rules use the weighted sum from calculations from three loading conditions. As far as I can recall the distribution between these is an ad hoc standard not based on detailed statistics nor correlated to damage conditions. If index *R* were to be revised as suggested above, I would also recommend revising this calculation scheme. I see no firm argument why not a similar approach as in the intact stability code could be used, namely to state that the minimum required index should be obtained under all operating conditions including various trim and draughts.

How is then SOLAS 2009 working as a design standard?

Performance based standards or test based standards are not ideal for easy design optimization purposes since they require a trial and error procedure. On the other hand, they have the advantage over prescriptive standards that they actually can be used for finding safety critical design “spots”. The introduction of a probabilistic event description increases dramatically the extent of calculations/ tests but also opens up for a variety of solutions. For advanced designers SOLAS 2009 is therefore probably a challenge, but a positive one.

Still, if one looks back on the long development of the new harmonized probabilistic standard, it is possible to identify parts that could have been simplified and/or made more explicit without sacrificing any significant principle. As with most IMO regulations, it came in the end out as a compromise between different opinions and aspects. Due to its complicated formulation the development was probably dominated little too much by scientists and technical experts. Unfortunately this may have lead to a general perception that the standard is a “black box” rather than the transparent, rational and well-structured standard it should be. In the coming revision that is scheduled for the SLF sub-committee I see opportunities to improve the text further and incorporate some important clarifications that were identified during the work with the Explanatory notes.

Safety level inherent in SOLAS 2009

One clearly stated objective for the development of the new regulation was to maintain the inherent damage stability safety in the existing regulations.

For cargo ships, not much was changed in principles and the benchmarking between new and old formulations showed, as could be expected, rather consistent correlation. Except for ro-ro cargo ships where the required safety level definitely was increased by the harmonization.

For passenger ships that previously were designed based on a deterministic standard such a comparison is more complicated. One may find designs that fulfill the new requirements but would not have been allowed under the “old” SOLAS and vice versa, and could argue that the safety level has been decreased or increased. But such examples are in isolation not a rational measure of the standard. Going from prescriptive design requirements to probabilistic performance-based requirements has most likely lessened the scatter in “real safety” among new ships and raised the minimum level for larger ships.

The complete SOLAS 2009 including probabilistic damage stability assessment, deterministic requirements of side and bottom protection together coming requirements of flooding detection systems and redundancy of essential systems will in my personal view significantly increase the safety level with regard to flooding of passenger ships in general.

For ro-ro passenger ferries that have to fulfill the additional deterministic water-on-deck performance standard in accordance with the regional Stockholm agreement (SA), the question of equal safety is still under discussion and will most likely never be fully settled due to the completely different assessment principles. There are indications that the requirements of new SOLAS 2009 compared to previous SOLAS+SA are on average about the same, but also that the scatter among such comparisons is significant. I trust that the ongoing SLF work and the supporting GOALDS project will eventually lead to a unified international standard for ro-ro passenger ships where all necessary survivability considerations are incorporated into the probabilistic standard.

The final and crucial question to ask is of course whether the present safety level of SOLAS 2009 is sufficient? I will not present any personal opinion on that, since it is of little interest.

As with all rules the resulting safety should be continuously monitored and the regulations and standards validated based on experience and analysis. IMO has procedures and recommendations on how proposals and revisions should be put forward today and I believe that a goal-based framework could facilitate this on a more regular basis in the future. I understand that this is also in line with the main objective of the GOALDS project. My only recommendation to the project is therefore to seek to maintain and further strengthen the core structure of the SOLAS 2009 damage stability standard. The milestone we have passed here is important not only for subdivision and stability but also for the principles of future rule development in general.