Comparison of survivability between SOLAS 90/95 and SOLAS 2009 ships - A retrospective view 10 years on from project HARDER

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Abstract: This paper takes a look back at the process leading up to the new SOLAS 2009 damage stability regulations. The work of the HARDER project is reviewed and the findings, controversial and non-controversial are discussed. Except for a few noteworthy ship types, for the most part these new regulations have had minimal impact on overall safety level and the design of new ships. The impacts on several ship types are significant, and are discussed. But the major unresolved question raised by SOLAS 2009 is how to deal with a significant number of existing large passenger liners that currently operate with lower safety levels, with risk levels for ship loss due to a collision likely exceeding the societal and IMO acceptable mark. Some possible ways forward are suggested.

Introduction & History

Probabilistic damage standards were originally considered by IMO (then IMCO) at the 1960 SOLAS Convention, based on the pioneering work of Wendel [1]. However it was not until 1971 that, culminating many years of research, the IMCO Sub-Committee on Subdivision and Stability completed new probabilistic passenger ship rules, which were adopted in 1974 as Assembly Resolution A.265 as an "equivalent" alternative to the deterministic provisions of SOLAS 1960. (These rules were rarely ever used in practice.)

In 1983 the IMCO formally decided that all future regulations for subdivision and damage survivability standards for ships should be modelled after the probabilistic principles of the alternative passenger ship regulations. Following many years of effort and development a draft set of probabilistic regulations for cargo ships were developed in 1987 and approved in 1988. The then renamed International Maritime Organization (IMO) adopted these probabilistic subdivision and damage stability regulations for dry cargo ships which were then incorporated as part of SOLAS '90 Chapter II-1, Part B-1, which became effective for all cargo ships over 100m in length in 1992. SOLAS '90, following the Herald of Free Enterprise casualty in 1987, also included considerably increased damaged stability standards for new passenger ships as part of the deterministic passenger ship regulations.

The 1995 SOLAS Convention considered proposals to account for water on deck effects, which were instrumental in the loss of the Estonia in 1994, as well as the previous Herald of Free Enterprise casualty. While improvements in watertight integrity and bow door standards were adopted, the water on deck component of the damage stability regulations was not agreed to by IMO and was approved only as a regional "opt-in" standard applicable to the northern European nations only, the so-called SOLAS 90+. In 1998 the B-1 cargo ship regulations were also extended down to ships of 80m in length.

At this stage there were two sets of probabilistic rules, optional as an equivalent for passenger ships, and mandatory for dry cargo ships. They were similar, but there were significant differences between the two regulations. Bearing these differences in mind, in 1995 IMO launched an effort to harmonize the passenger and dry cargo ship regulations into a single standard that might eventually be extended to all types of vessels covered by IMO conventions.

Research on the harmonized regulations remained ongoing through independent national activities, and was given a major boost by the European Union funded project HARDER. This research eventually culminated in new regulations for both dry cargo and passenger ships that were approved in 2005 [2], and came into force following SOLAS convention in 2009.

Basis of the SOLAS 2009 Upgrade

Prior to SOLAS 2009 the requirements concerning subdivision and damage stability for ships were contained in multiple separate mandatory IMO instruments, referring to specific ship types (SOLAS, Load Lines Convention, MARPOL, and the IBC, IGC and HSC Codes); plus the alternate probabilistic regulations for passenger ships, Resolution A.265(VIII). In addition there were non-mandatory provisions applicable to offshore supply vessels, special purpose ships, and mobile offshore drilling units (MODUs).

The main task of IMO's harmonization effort was to bring together the SOLAS 1990/95 passenger regulations with more modern probabilistic regulations used for the cargo vessels in B-1, and the rarely used A.265 for passenger ships.

The guiding principal and instructions from IMO regarding harmonization and the overall safety level were clear. To harmonize the separate damage stability regulations as far as practical for new ships, while maintaining the overall safety standard level from current regulations. This implied that IMO considered that the safety level of the current regulations were within acceptable societal levels.

Project HARDER

In 2000 project HARDER was launched as a consortium of 19 organizations from industry and academia in Europe. This project aimed to systematically investigate using first principles, the validity, robustness, consistency and impact of the harmonized probabilistic damage stability regulations on the safety of existing ships and on the design evolution of new ship concepts for various types of cargo and passenger ships.

The intent of the HARDER project with respect to overall safety level substantially followed IMO guidelines with a view towards having their findings accepted with little changes for new international ship safety regulations.

The planned methodology to establish the regulatory survivability safety level was generally based on the following principles:

1. To refine and improve the methodology to calculate the Attained Subdivision Index (A), as a consistent way to evaluate a ships survivability, which would be as close as practical to a surrogate measure of risk. (Index A actually represents the conditional probability of a ships loss given that it is involved in a collision damage, with breached and flooded compartments.)

2. To then develop the formulation for the Required Subdivision Index (R), which would be generally equivalent to SOLAS 90/95, B-1, and A.265 standards. This was to be accomplished by the establishment of basic safety level from a regression of existing ships meeting the current regulations.

3. It was generally accepted that ships representing a greater loss consequence (larger ships or more passengers) should meet progressively higher safety standards.

HARDER Findings

For the most part, the proposed methodology and findings based on the extensive 3-year HARDER research project generally resulted in an uncontroversial updating and overall improvement of the regulatory framework the damage survivability for most ship types:

- The damage statistics were significantly updated, but were found to be generally consistent with the overall trends observed 40 years earlier [3].

- The recommended methodology for determining the probability of damage cases from the damage statistics was conceptually similar to the B-1 regulations (however including the addition of a third operational draft).

- For conventional non-RoRo vessels the probability of survival after damage (the s-factor) could generally be predicted using readily calculated quasi-static GZ properties traditionally used in the current damage stability regulations.

- For many ship types the safety level could be established as planned, by a regression on ships length based on A levels calculated with the proposed regulations.

However there were some areas where the HARDER findings were inconsistent and not universally supported within the HARDER group, or where the findings lead to conclusions that were in conflict with the IMO guidelines [4]:

- For RoRo cargo ships, the vertical extent of damage statistics showed that the then current B-1 regulations significantly underestimated the upper vertical extent of damage, see Fig. 1. This resulted in this type of cargo ship showing significantly reduced levels of safety compared to other cargo vessels when evaluated with the new vertical extent probabilities.

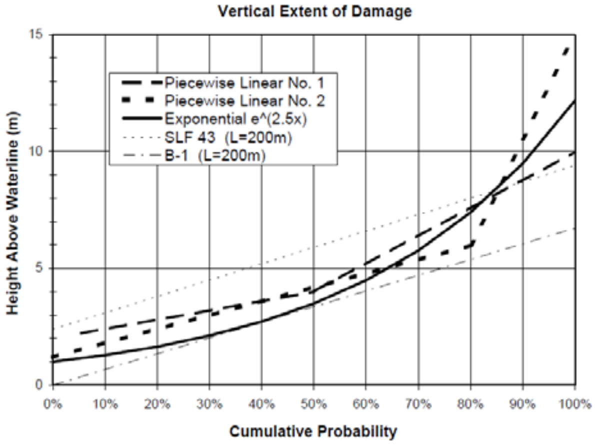

Fig. 1 - Proposals for alternative "v" formula [5]

- For RoRo passenger ships, the HARDER group considered a modified Static Equivalent Method (SEM) to account for the probability of capsizing considering water on deck effects [6], which was to be used as a replacement or addition to the traditional survivability criteria for this type of ship. This separate water on deck s-factor for low freeboard RoRo passenger ships helped to retain consistency with the SOLAS 95 North Europe regulations (SOLAS 90+) and the Stockholm Agreement.

- For large passenger liners the damage statistics for mean damage length were inconsistent with current regulations (particularly SOLAS 90), where mean damage length was shorter and remained constant for ships over a specific length, see Fig. 2. It was well understood that these damage length statistics from the HARDER re-analysis could have a significant impact on survivability, but many were quite surprised to see the resulting trend of reduced levels of safety for the very longest passenger ships, see Fig 3. The recognition that existing regulations resulted in large ship which could be less safe was an issue that could not be ignored.

  (In general the low indices SOLAS 90 ships evaluated against the SOLAS 2009 standard are due to heel angles from flooding the spaces outside the B/5 limits, with ineffective cross-flooding connections. Subsequent studies have shown that things may not be as dire as indicated since the s-factor, derived from cargo ship studies, may be conservative for large passenger liners.) [7]

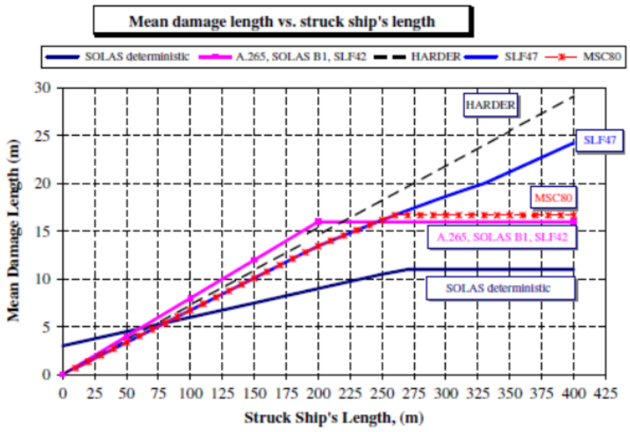

Fig. 2 - Mean Damage Length [8]

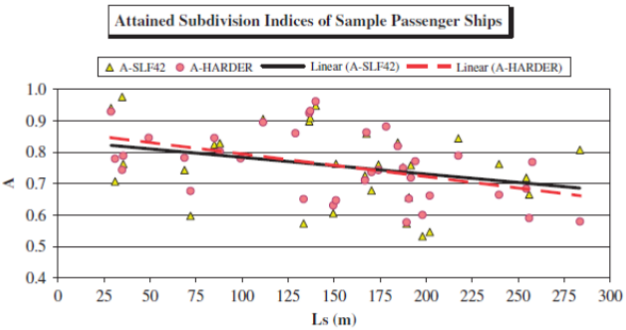

Fig 3 - Attained indices of passenger ships vs. length [8]

Resolution of Issues at IMO

In 2005 the new damage stability regulations were approved at IMO. [2] The previously mentioned controversial aspects of the HARDER findings were 'resolved' in the intervening time since the completion of the HARDER project as follows:

- For RoRo cargo ships the new vertical extent of damage statistics were accepted and RoRo cargo ships were included as part of the standard cargo ship group subject to the same R requirements as all other cargo ships.

- For RoRo passenger ships the SEM methodology was not accepted and RoRo passenger ships are subject to the same survivability methodology (s-factor) and same safety level (R) as all other passenger ships. At the time, and even now, some were convinced that water on deck effects were adequately handled by the proposed cargo ship based s-factor based on GZ properties. But subsequent studies have clearly confirmed that this is not the case. [7]

- For large passenger ships it was recognized that a simple regression of existing sample ships, see Fig. 3, would not be an acceptable outcome, and a rising standard for larger ships was required to meet societal safety levels. To accomplish this, a controversial compromise was reached, where basically the required safety level was based on a regression analysis of just the "reasonably good" existing vessels in the sample (defined as within the ALRP risk region, see Fig. 5). Other ships outside this ALRP region were excluded from the regression. The resulting Required Index (R) formulation, the bold line in Fig. 4, was in the end considered acceptable.

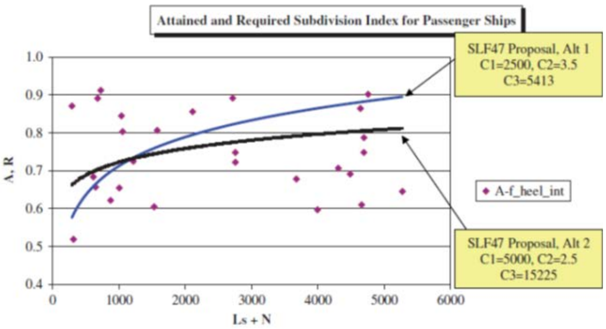

Fig 4 - R-index proposals for passenger ships [8]

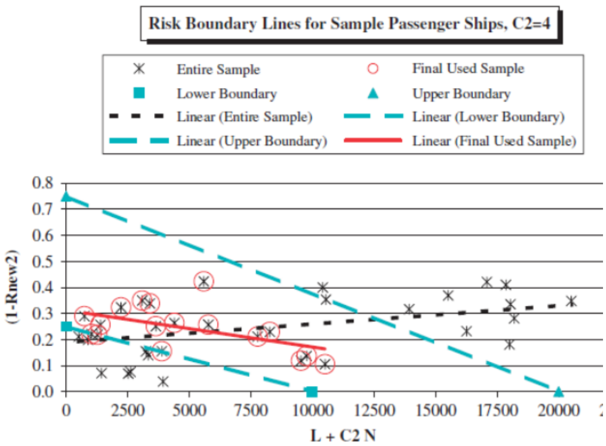

Fig 5 - Risk assessment of passenger ship [8]

Consequences of the new SOLAS 2009 Regulations

While there are many regulatory changes and improvements in the new SOLAS 2009 regulations, for many ship types the overall level of safety did not substantially change. There was also broad concurrence that, in general, the level of safety in the new regulations was at an acceptable level.

However in these three areas, the SOLAS 2009 regulations have some additional consequences for new ships:

- Many new RoRo cargo ships (particularly PCC, PCTC, and other large RoRo vessels) survivability has been significantly upgraded by compliance with the new vertical extent of damage regulations. Compliance is typically accomplished by raising the height of the freeboard deck. Existing ships not required to meet the new requirements are of significantly lower survivability standard and are gradually being retired from the world fleet.

- SOLAS 2009 regulations for many RoRo passenger ships may be less stringent than the old, deterministic rules according to either the SOLAS 95 regional agreement (SOLAS 90+) or the Stockholm agreement [7] [9]. Ongoing efforts are still underway in Europe and at the IMO to resolve these issues.

- For new large passenger liners, the new SOLAS 2009 R index is set at approximately 0.80, and gradually raising for larger ships, and ships for larger numbers of passengers (see Fig. 4). In contrast existing pre-2009 large passenger liners have A indices over a wide scatter between 0.60 and 0.90 as also seen in Fig. 4.

  The survivability of new passenger liners in general, and of new large (over 200m) passenger liners in particular have been able to (with some difficulty) comply with the new regulations [10] and are believed to be on average significantly safer than their existing (pre-2009) counterparts which exhibit a wide and inconsistent level of survivability.

Considerations for Exiting Ships

In retrospect 10 years on, the HARDER project accomplished most of its goals. It validated the overall risk based methodology for an updated framework of ship damage stability regulations, harmonized the regulations for several ship types, and produced a package which could be readily adopted by IMO as the basis the new SOLAS regulations.

This paper has identified three areas that had some impact on specific ship types in the new SOLAS 2009 regulations:

- For RoRo cargo ships it has been accepted that the new regulations represent a higher standard, but there seems no compelling need to address the safety level of existing ships at this time considering the limited number of ships, the limited consequences, and the rate at which the older ships are being removed from the world fleet from scrapping levels.

- For RoRo passenger ships it is generally accepted that the existing Stockholm agreement represents the current highest standard and there is considerable ongoing work in this area for potential future regulations. In retrospect, the IMO efforts of SOLAS 2009 on RoRo passenger ships falls short of providing a reasonable safety standard.

In addition to RoRo passenger ships, the major unaddressed issue arising from SOLAS 2009 is regarding the older passenger ships.

The risk level for survivability after a flooding event, we believe, is proportional to 1-A. Based on this assumption, the risk level for some SOLAS 90/95 based existing passenger liners can be twice as high as the current SOLAS 2009 standard. Note at the time of implementing the 2009 regulations, the data indicated (see Fig. 5) that many, approximately 30% of the sample evaluated, of the existing large passenger ships had risk levels above the upper ALRP level risk boundary.

Note that while the risk assessment comparison between Pre-SOLAS 90 (basically SOLAS 74) and SOLAS 90 for all passenger ships is not available, it is widely accepted that the residual stability extensions of SOLAS 90 resulted in a significant improvement in the risk levels. SOLAS 90 Ro-Ro passenger vessels have been shown to meet a substantially higher standard than SOLAS 74 ships. [11]

A rough estimate of the composition of the world fleet of cruise liners:

Pre-SOLAS 90	210
SOLAS 90/95	290
SOLAS 2009 (approx.)	20
Total	520

Table 1 – Approximate world passenger ship fleet

The following conclusions are offered for existing passenger ships. (Note that since the SOLAS 2009 regulations are quite new, the ‘existing’ ship fleet currently comprises over 95% of the ships in service):

- SOLAS 2009 represents a reasonably high and attainable survivability standard for all ship types (other than RoPax) including large passenger ships. (Some have suggested that this standard is also too low for passenger ships, and recent FSA studies indicate that this standard can and should be raised to even higher levels.) [12]

- Existing SOLAS 90/95 and pre-SOLAS 90 large passenger ships on average meet significantly lower survivability standards than new SOLAS 2009 ships, with as much as half of the current operating fleet (perhaps 30% of the SOLAS 90 fleet, and probably most of the SOLAS 74 fleet) below the ALRP safety standard currently considered appropriate at IMO.

- It is assumed that individual formal safety assessments (FSA) of these lower standard pre-SOLAS 2009 ships would confirm the compelling need to consider retroactive regulations to improve their risk levels.

- It is recommended that all existing large passenger vessels be re-asses using the procedures according to SOLAS 2009. Ships that show Attained Subdivision Indices (A) significantly below the current requirements (R) should be considered candidates for the application of risk reduction measures as a high priority.

- The other remaining SOLAS 74 passenger ships still in service should be retired on the fastest agreeable timeframe. (The Pre-SOLAS 90 RoRo passenger ships were subject to an A/Amax upgrade initiative in the mid-1990s with many older ships being upgraded or retired.)

- Since it may be difficult, or impractical, to upgrade these lower standard SOLAS 90 ships with design measures alone, operational risk control measures including passive and active damage control, and collision avoidance measures should be encouraged to bring these ships to the equivalent of the overall SOLAS 2009 safety levels.

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