Regulatory, Design, Operational and Emergency Response Measures for Improving the Damage Survivability of Existing RoPax

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Abstract This paper describes the background and provides the rationale and the framework to embrace the whole spectrum of measures (regulatory, design, operational and emergency response) for improving the damage survivability of existing RoRo passenger vessels. The damage stability workshop elaborated here is the first step of a process initiated by INTERFERRY Europe to assess impact on/options for existing ships of increasing the required subdivision index R should IMO decide to apply new damage stability requirements retrospectively. This, in turn, would provide the motivation for instigating and establishing a framework and propose an approach for alternative compliance to account for the contribution made to damage survivability by operational and active damage control measures that could be undertaken in case of a flooding accident. This represents a step change both in the mind-set of naval architects and in safety legislation but the impact will be immense and mostly positive.

Keywords RoPax damage stability · Alternative means of compliance · Vulnerability management

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1 Introduction

Recent discussions at IMO on the safety of passenger ships include a potential increase in the required subdivision index for all passenger ships. An initiative, started by INTERFERRY Europe, seeks to assess the impact of the above on existing vessels (if such changes were applied retrospectively) and propose an approach for alternative compliance based on a fair recognition and credit of the contribution to risk reduction afforded by operational and active damage control measures that would be undertaken in case of a flooding accident. This should be accounted for, in addition to the contribution made by traditional design measures. This approach was first presented in the 13th ISSW in BREST 2013 [1]. To this end, a tentative plan of action was prepared to carry out a study aimed at quantifying and validating the risk-reduction effectiveness potential of such measures. The proposal included a one-day workshop to discuss the context and the relevant issues on the subject as a first step in the process. This took place in London on 22 January 2014 with a participation of 19 persons representing 5 ferry operators, 1 class society, 1 yard, 2 Flag Administrations and a number of damage stability experts.

Following a brief description of the rationale in support of adopting an alternative compliance approach that accounts for all meritorious contributions to enhancing damage survivability, the paper focuses on the objectives of and the key outcomes from the damage stability workshop.

2 Background

Every time there is an accident with passenger ships, exposing their vulnerability to flooding as a result of collision/grounding accidents, societal outcry follows and industry and academia “buckle up”, delving for design improvements to address the Achilles heel of this ship type, namely inadequate damage stability. However, any such improvements are targeting mainly newbuildings, which comprise a small minority of the existing fleet. Therefore, state-of-the-art knowledge on damage stability is all but wasted, scratching only the surface of the problem and leaving thousands of ships with severe vulnerability, that is likely to lead to further (unacceptably high) loss of life. This problem is exacerbated still further, today more rapidly, as the pace of scientific and technological developments is unrelenting, raising understanding and capability to address damage stability improvements of newbuildings cost-effectively, in ways not previously considered. As a result, SOLAS is becoming progressively less relevant and unable to keep up with this pace of development. This has led to gaps and pitfalls, which not only undermine safety but inhibit progress.

However, lack of retrospectively applied legislation (supported by what is commonly known as the Grandfather Clause) is not the only reason for damage stability problems with passenger ships. Tradition should share the blame here. In the quest for damage stability improvement, design (passive) measures have traditionally been the only means to achieve it in a measurable/auditable way (SOLAS 2009, Ch. II-1). However, in principle, the consequences from inadequate damage stability can also be reduced by operational (active) measures, which may be very effective in reducing loss of life (the residual risk). There are two reasons for this. The first relates to the traditional understanding that operational measures safeguard against erosion of the design safety envelop (possible increase of residual risk over time). The second derives from lack of measurement and verification of the risk reduction potential of any active measures. In simple terms, what is needed is the means to account for risk reduction by operational measures as well as measures that may be taken during emergencies. Such risk reduction may then be considered alongside risk reduction deriving from design measures.

Therefore, new measures for risk reduction (operational and in emergencies) should be considered in addition to design measures. What needs to be demonstrated and justified is the level of risk reduction and a way to account for it, the latter by adopting a formal process and taking requisite steps to institutionalise it.

3 Life-Cycle Risk Management

Traditionally regulations, as a risk control measure for damage stability improvement, always focus on design solutions, normally referred to as passive measures (**category 1 measures**), Fig. 1 [1]. Operational/active measures (**category 2 measures**) whilst abundant in SOLAS Ch. II-2 (e.g. damage control), have not been validated to the same level of rigour as category 1 measures. Finally, measures/systems focusing on emergency response (**category 3 measures**), such as Decision Support Systems for Crisis Management, Evacuation, LSA, Escape and Rescue, whilst fuelling debates on being effective risk control measures or not, the cost-effectiveness of their risk reduction potential has never been measured nor verified. One of the reasons for this, arguably, derives from the fact that because these measures are there to address ‘residual’ risk and residual risk is by definition small, therefore risk reduction is also perceived to be small. However, this could not be further from the truth. The second is again lack of measurement and verification of such risk reduction.

Considering the above, a life-cycle perspective offers a framework for a holistic approach to damage stability, focusing on life cycle and encompassing all 3 categories of risk control options, accounting for these based on IMO cost-effectiveness criteria. This assumes that the risk reduction potential of all measures in the three categories is known and this is where there is a big gap in this approach that needs to be overcome before such a process can be formalised and adopted. This constitutes the kernel of the work to be undertaken, with the workshop described in the following constituting and facilitating the first step.

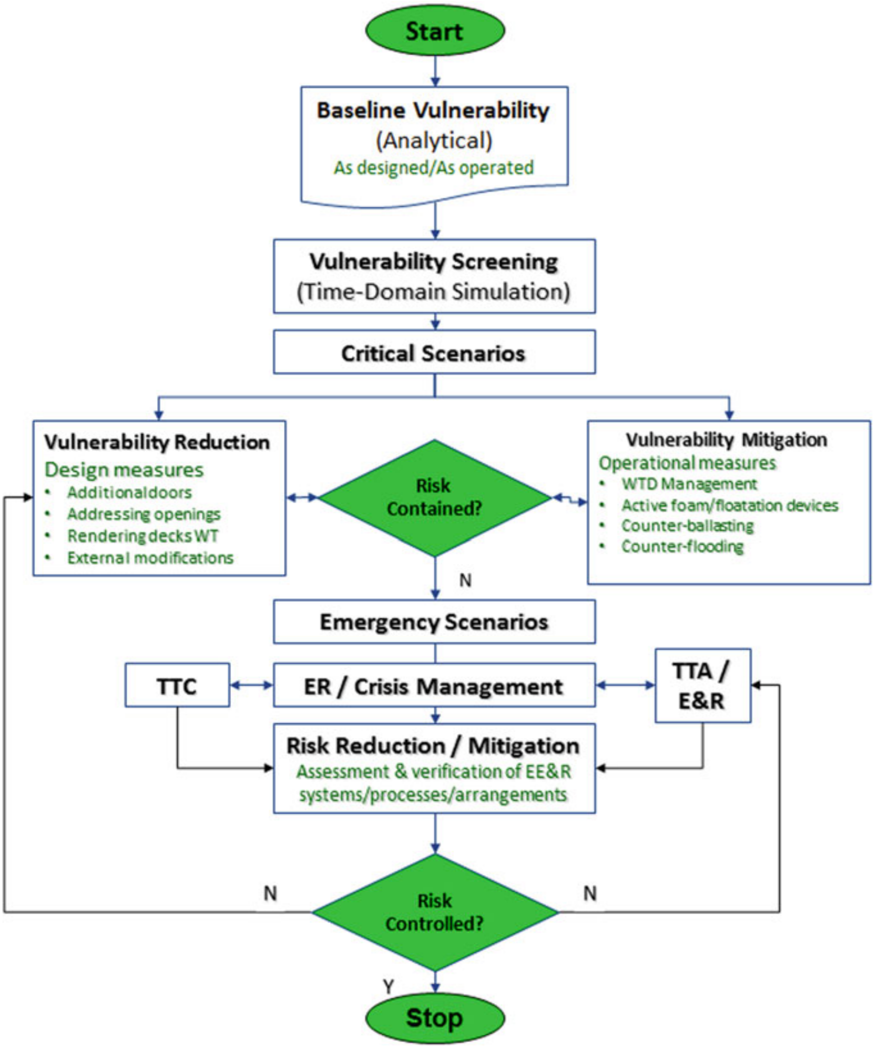

Fig. 1 Vulnerability management [1]

4 Workshop—Brainstorming Session

The brainstorming session was conducted on the basis of a number of basic premises related to risk as defined below. Mind maps were used to record the views of the participants. Whilst this method is relatively unstructured, it allows recording of high-level discussions of hazards, influencing factors and risk control measures.

Risk

- Risk can be quantified by the likelihood of undesirable consequences (e.g. fatalities per ship year, total losses per year, etc.)
- The range of undesirable consequences includes: impact on human life (fatalities and injuries) and impact on property (loss of and/or damage to the ship).
- For the purposes of this workshop, the accidental event that may lead to undesirable consequences is "flooding".

Accidental flooding events

- Water ingress and flooding may be the result of casualty incidents or systems failure including—but not limited to the following:

  1. Collision
  2. Contact (e.g. with quay)
  3. Bottom/side raking damage
  4. Failure (e.g. crack) of hull envelope
  5. Failure of overboard valve

- Incidents resulting in internal flooding (ballast water, fuel oils, etc.) may be the result of the following types of systems failures

  6. Internal structural failure (e.g. ballast tank, manhole, structural degradation, etc.)
  7. Failure of fire mains valve.

Risk Reduction

In order to reduce the risk associated with flooding, the likelihood of occurrence and/or the severity of the consequences need to be reduced.

Reducing the likelihood of a flooding event

- Although, it was agreed that this is an important element of the risk associated with flooding, this is out with the scope of the workshop. However, some of the factors affect both likelihood and consequences (e.g. crew competence).

Reducing the severity of the consequences of a flooding event

- The internal watertight subdivision is a passive barrier or risk control measure, the objective of which is to reduce the severity of the consequences should a flooding event occurred.
- However, as indicated in the foregoing, there are other measures that may reduce the severity of the consequences (mitigation) of a flooding event. Those measures are of operational and/or active nature and as such less amenable to statutory verification unless an alternative method is applied.

Table 1 Generic sequence of events that may occur after a flooding event (typical muster list)

Stage 1	Stage 2	Stage 3
INCIDENT (1) Detection & Alarm	(2) Damage control (3) Muster of Passengers (4) Preparation of LSA	(5) Abandon Ship (6) Rescue

Risk Contributing Factors

- There are also other factors that can influence the severity of the consequence of flooding. These factors influence the sequence of events that occur after the accidental event. This sequence can be generalised in terms of the following activities, see Table 1:
    1. Flooding detection and alarm
    2. Damage control
    3. Muster of passengers
    4. Preparation of LSA
    5. Abandon ship
    6. Rescue to a place of safety
- *Identification of the factors that influence the outcome of each of the above stages, is one of the key objectives of the brainstorming session.* These factors can be of the following types:
    1. Human (crew, passengers)
    2. Hardware (e.g. ship, systems, equipment)
    3. Organisational (e.g. procedures)
    4. External (e.g. weather-related, SAR assets)
- In addition, human and organisational factors are significant in terms of Damage Control and Emergency Response performance.

5 Identification of Hazards

Risk contributing factors and potential hazards were identified as listed below. These lists only reflect the scope of the discussions and therefore are not exhaustive; they can however be regarded to be representative.

Stage 1: Detection and Alarm

Relevant hazards identified during the brainstorming session include:

1. Flooding in space not fitted with water alarms
2. No/difficult access for validation of alarm

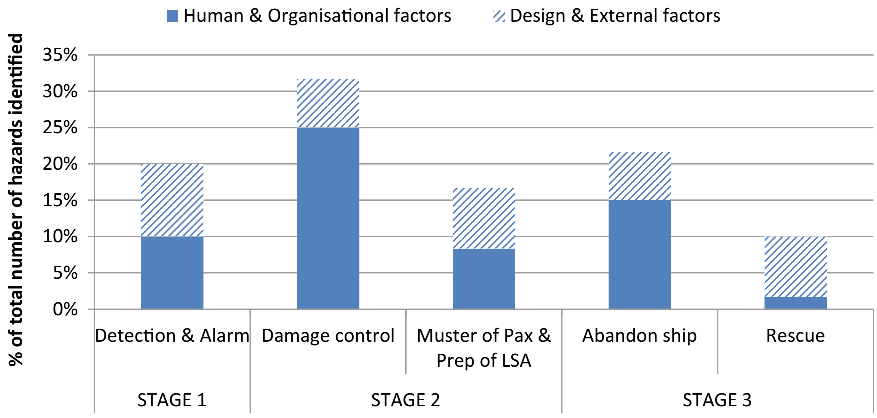

Fig. 2 Breakdown of identified hazards (60 hazards in total)

3. Failure or impairment of automatic means of detection
4. Not effective (slow) means of detection
5. Trips, falls, exposure to flood water when trying to validate an alarm
6. Crew not familiar with layout of the ship
7. No information or uncertainty about the location and the extent of the damage
8. Unclear, ineffective procedures (reference to muster list)
9. Poor competence of crew—lack of training in flooding detection
10. Lack of crew preparedness in searching for water
11. Poor/ineffective internal and/or external communications
12. Initiation of mustering (general alarm) too soon—this will create MUSTERING hazards unnecessarily (Fig. 2).

Stage 2: Damage Control

Relevant hazards identified during the brainstorming session include:

1. High vulnerability of watertight subdivision & arrangements to flooding
2. Impairment of watertight subdivision & arrangements (due to accidental event)
3. Ineffective/blocked scuppers in car deck
4. No/difficult access for effective damage control (e.g. vehicles on car deck, voids)
5. No/difficult access to damage control equipment
6. Additional hydrostatic pressure on internal structures, doors and bulkhead penetrations
7. No redundancy of essential ship systems after flooding
8. Crew not prepared/not able to reconfigure systems for damage control
9. Trips, falls, exposure to flood water when trying to deploy damage control measures
10. Ship systems not dimensioned for dealing with damage control (e.g. pumps)
11. No information or uncertainty about the location and the extent of the damage, especially if flooding is escalating

12. Crew not able to effectively assess the criticality of the damage
13. Poor competence of crew—not trained in damage control
14. Lack of crew preparedness in damage control
15. Crew not familiar with layout of the ship
16. Crew not available for damage control (low crew redundancy)
17. Lack of effective leadership in an emergency situation
18. Breakdown of internal communication (due to language barriers, inappropriate use or failure of communications equipment)
19. Ineffective/unhelpful external support
20. Rough weather, cold climates.

Stage 2: Muster of Passengers & Preparation of LSA

Relevant hazards identified during the brainstorming session include:

1. False alarm—muster initiation too soon, creating unnecessary hazards for passengers
2. Impairment of escape routes, muster areas and/or LSA systems (due to accidental event)
3. Impairment or failure of lighting along escape routes and/or muster areas (e.g. due to blackout as a result of the flooding)
4. Impairment or failure of internal communication systems (e.g. due to blackout as a result of flooding)
5. Ship motions, heel, trim—making moving to muster areas difficult and hazardous
6. Trips and falls when moving to muster area
7. Exposure to weather (to passengers if mustering externally; to crew when preparing LSA)
8. Inefficient internal communication (with passengers)
9. Difficult in managing passenger behaviour—crew not prepared in crowd control
10. Not sufficient crew numbers available to assist passengers (e.g. due to damage control efforts) and control of mustering.

Stage 3: Abandon Ship

Relevant hazards identified during the brainstorming session include:

1. Fast ship capsize
2. Poor/delayed decision by the Master
3. Impairment of embarkation areas and/or LSA (due to accidental event)
4. Failure of deployment of LSA systems
5. Impairment or failure of emergency abandonment systems (e.g. due to blackout as a result of flooding)
6. MOB situation
7. Lack of key crew redundancy
8. Rough weather
9. Large heel and trim angles (in excess of LSA design criteria)

10. Poor competence of crew—not trained in deployment and use of all LSA on-board
11. Lack of crew preparedness in LSA deployment and embarkation
12. Not sufficient competent crew numbers available to deploy and control LSA units
13. Poor/ineffective passage planning (with SAR in mind).

Stage 4: Rescue to Place of Safety

Relevant hazards identified during the brainstorming session include:

1. Ineffective/no SAR planning
2. Safe place (to transfer people) not available
3. Unavailability of adequate SAR assets (for the number of persons)
4. Lack of crew preparedness
5. Poor/ineffective communication with external stakeholders (safe port, class, Coastal and Flag State)
6. Rough weather.

6 Flooding Risk Mitigation Options

Although it was acknowledged that it is always preferable to have passive or semi-automatic measures in place, the discussion was focused on active and operational damage mitigation options including the following (see Fig. 1):

Design Modifications (Category 1)

The following observations are made:

- Passive measures providing additional buoyancy (sponsons, ducktails, buoyancy tanks, etc.)
- The performance of design modifications is related to the effectiveness of flooding mitigation
- The effectiveness of design modifications does not depend explicitly on crew performance
- Design modifications reducing the inherent vulnerability to flooding; from all mitigation measures, these may have the highest potential for improving the value of the A-index (Fig. 3).

- Well known solutions and their implications—relating to the following
  - Double hull machinery room → may introduce flooding asymmetry and maintenance/rust problems
  - Rendering decks watertight → not always possible
  - Relocation of openings → not always possible or effective
  - SWT/Splash-tight doors (Fire doors); not always possible or effective

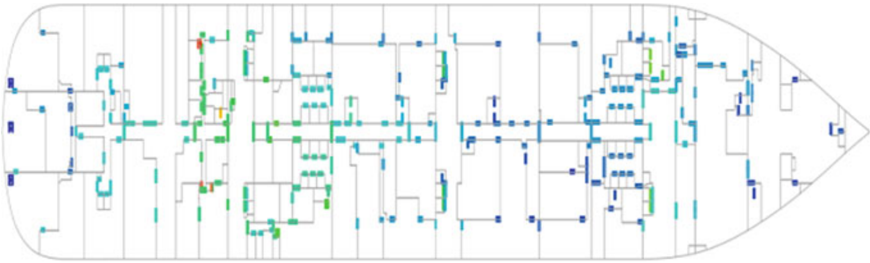

Fig. 3 Vulnerability screening in a passenger ship (identification of focal areas for improved survivability; in this case deck openings with high frequency and high volume of floodwater during progressive flooding scenarios)

- Buoyancy tanks

Operational Measures (Category 2)

In relation to containment actions, the following observations are made:

- Containment actions limit the severity of the consequences of a flooding accident by preventing progressive flooding
- Limited experience on merchant ships—better experience on naval vessels
- Simple tools and equipment available on-board
- Crew competence and preparedness is a significant influencing factor in ensuring containment actions are effective
- However, in terms of statutory A index calculations or flooding simulations, it is assumed that the existing watertight integrity performs as expected, e.g. watertight doors do not leak, penetrations in watertight bulkheads do not leak, etc.

In relation to *active damage* control, the following observations are made:

- Counter ballasting and/or counter flooding measures limit the severity of the consequences of a flooding accident by preventing excessive heel/trim of the ship (Fig. 4). However, timing of this action might be an issue.

- Damage-specific measures not possible in all cases
- Depends on tank and internal arrangements
- Relies on the *availability of relevant ship systems* (bilge, ballast, power, among others)
- Large number of possibilities—difficult to assess and execute by the crew without support
- Hazard of significant hydrostatic loads on internal structures
- Potential for using new materials/technologies (e.g. foams, inflatable devices):
  - Fast semi-automatic deployment, essential
  - To be effective in critical damages where time to capsize less than say 20 min
  - Requires type approval and additional maintenance and training

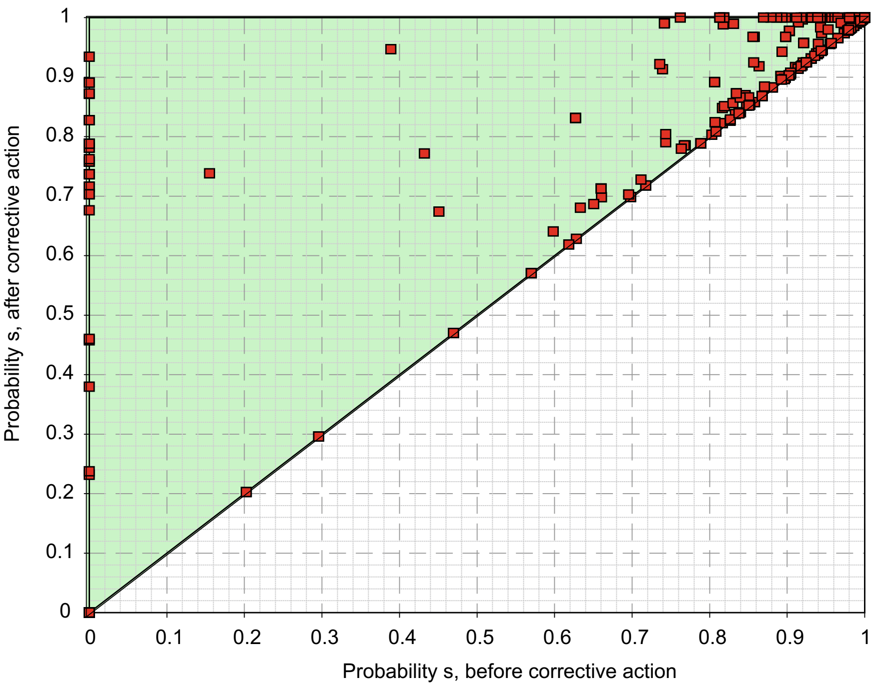

Fig. 4 Counter-ballasting capacity post-casualty (typical example)

- Crew competence and preparedness as well as availability of relevant ship systems are significant influencing factors for ensuring that active damage control actions are effective
- The contribution to A-index can be assessed by means of flooding simulations (not by statutory calculations). However, in order to ensure that the actions can be accomplished effectively, crew performance and availability of relevant ship systems needs to be demonstrated.

Some *radical* actions were identified, for which the following observations are made:

- Running the ship aground when/if possible
- Unloading cargo overboard when/if necessary
- Such actions will require additional planning and crew preparedness.

Emergency Response Measures (Category 3)

These relate mainly to escape, evacuation and rescue arrangements; for which the following comments are made:

- Measures reducing the severity of the consequences of a flooding accident by allowing the persons on-board to abandon the vessel

- Effective evacuation requires the vessel to remain afloat and upright—to the limits of LSA systems
- Crew competence and preparedness as well as availability of relevant ship systems are significant influencing factors for ensuring that people on-board can be evacuated effectively.

7 Workshop Outcome

The outcome of the workshop discussions and subsequent analysis is presented under the following headings:

- Long-terms goals
- Ship vulnerability to flooding
- Active flooding mitigation
- Risk reduction.

Long-term Goals

Although in the short to medium term, the goal of the initiative started by INTERFERRY EUROPE is related to the potential retrospective application of increased R-Index requirements, the participants of the workshop agreed that the long-term goals and implications of the issues addressed in the workshop need to be established.

Key items that will be affected include:

1. Alternative arrangements and means for assigning credit to operations/emergency response measures
2. Definition and interpretation of required subdivision index R, SOLAS Ch.II-1 Regulation 6
3. Alternative methodology for the calculation of the A index value—in accordance with SOLAS Ch.II-1 Regulation 4
4. Verification of essential ship systems redundancy for existing ships. This is in line with SOLAS Ch.II-2 Safe return to Port requirements for ship systems
5. Evacuation and LSA arrangements—considering that SOLAS Ch.III is under revision
6. Verification and validation of crew preparedness and performance. ISM Code implementation is the minimum level or performance expected
7. Contribution from INTERFERRY on potential changes to SOLAS and the ISM Code.

Ship Vulnerability to Flooding

In terms of the subdivision index, used for design verification of ship damage stability, the following observations are made:

1. The required index of subdivision R expressed the accepted probability of a ship surviving a collision incident for 30 min or more. Consequently, the attained

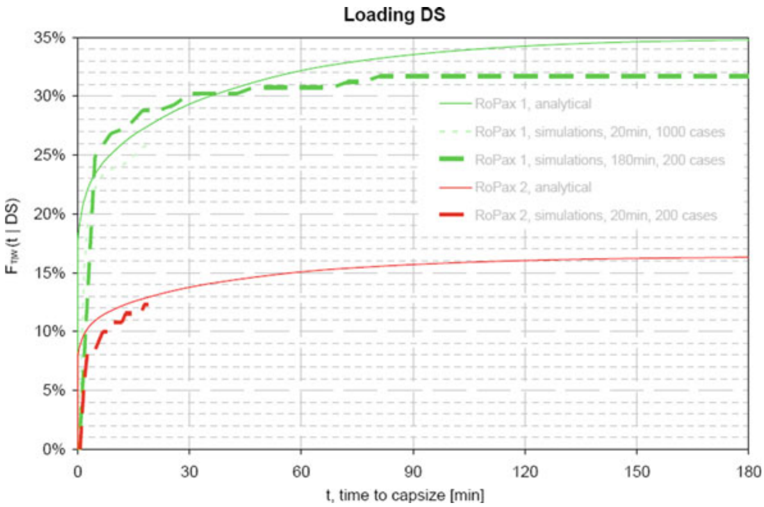

Fig. 5 SOLAS versus numerical simulations (Reg. 4, Part B)—simple internal architecture

index A reflects the average probability of a ship surviving 30 min or more, such average deriving from consideration of damage statistics as described in SOLAS 2009.

2. On this basis, a ship attaining a value of A = 0.8, implies that the ship has a 20% average probability of capsize within 30 min, following flooding of ship spaces as a result of collision damage.
3. The statutory calculation[1] of A-index encompasses many empirical approximations (e.g. s-factor, p-factor) and conservative assumptions, some of which are not justified in practice (e.g. loading conditions, damage statistics).

   Moreover, there is extensive knowledge and evidence to make the following assertions:

4. A method based on numerical (flooding) simulations and Monte-Carlo sampling techniques can be used reliably as an alternative approach to the statutory calculation of the A-index, in accordance with SOLAS Ch.II-1 Regulation 4.2.
5. Previous studies have shown that by using this alternative method, the simplicity and conservatism implicit in the statutory calculations may, in some cases lead to underestimation, while in other cases lead to overestimation of the attained index A (Figs. 5 and 6).
6. Furthermore, regarding these flooding cases in which a ship is likely to capsize within 30 min, it has been shown that in some cases, (i) the ship will have no damage stability at all: i.e. the ship will capsize fast, whilst in other cases (ii) the ship may be recovered with effective active damage control: i.e. the ship can be saved or the time to capsize can be extended to allow for safe evacuation of passengers and crew (Fig. 4).

[1] Referred to as 'SOLAS2009' calculation.

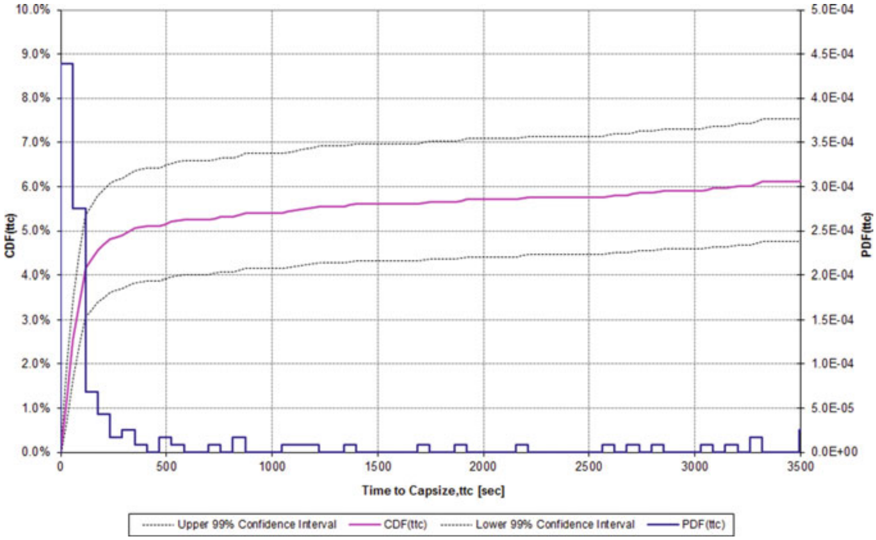

Fig. 6 SOLAS versus numerical simulations (Reg. 4, Part B)—medium complexity internal architecture

7. The alternative approach is a better method for assessing the vulnerability of a ship to flooding, regardless of the type of accident (collision, grounding, raking damage, etc.).
8. The use of the alternative approach to assess ship vulnerability has many benefits; it allows the incorporation of realistic operating conditions and it allows for verification of active damage control actions such as counter-ballasting and counter-flooding. Moreover, by providing information on the time line of events, it allows assessing the effectiveness of the evacuation arrangements.

Active Flooding Mitigation

Assuming that an alternative method for assessing ship vulnerability to flooding is adopted, active flooding mitigation options for which credit can be obtained in terms of the attained A-index (by simulation), include the following:

1. Design modifications—although not the preferred option for existing ships unless they are easy to implement and are cost-effective
2. Active, counter-ballasting, counter-flooding measures—these are damage-specific therefore, verification may be extensive. In order to realise the potential gains, additional verification is required:

   (a) Relevant ship systems must be demonstrated to be available (Safe Return to Port concept of SOLAS Ch.II-2)—note that 16% of the hazards related to damage control relate to ship systems redundancy in case of flooding
   (b) Crew competence and preparedness must be demonstrated (objective evidence as per or beyond SOLAS and ISM Code requirements). Note that

32% of the hazards identified relate to damage control. Of those, the majority (78%) can be controlled by effective crew performance and/or effective operating procedures.

Risk Reduction

Effective evacuation and rescue (EER) arrangements also reduce the risk to people. These measures can be successful only if the ship remained afloat and upright for as long as necessary to complete the ship abandonment process. Therefore, the following is required to demonstrate risk reduction:

1. Time line of key events in the flooding process—e.g. time to reach a heel angle of, say 20°. This can be provided by the numerical flooding simulations (alternative approach)
2. A verification of the time required to carry out ship abandonment as per the ship's muster list. This includes quantification of the time for general alarm, response and mustering, embarkation of LSA, deployment of LSA and sail away from vessel
3. Crew competence and preparedness must be demonstrated (objective evidence as per or beyond SOLAS and ISM Code requirements)—Note that 32% of the hazards identified relate to ship abandon and rescue. Of those, the large majority (86%) can be controlled by effective crew performance and/or effective operating procedures.

8 Conlcuding Remarks

1. Building on the knowledge and understanding of damage stability fundamentals, a process has been elucidated to address the vulnerability to flooding of passenger ships from a life-cycle perspective and with focus on operational and emergency response measures alongside the more traditional design measures, with emphasis of application on existing ships.
2. An initiative undertaken by INTERFERRY Europe is putting this concept to test, starting with a workshop to assess the impact of possible changes in the required subdivision index R and the potential implications for existing vessels should IMO decided to apply the new requirements retrospectively.

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