Life-cycle risk (damage stability) management of passenger ships

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ABSTRACT

Inadequate damage stability, the Achilles heel of passenger ships, has been a critical research objective that industry and academia delved to improve every time following accidents with passenger ships. Most achievements focused on design phase, either for the new-made regulations or rather novel pro-active methodology of risk-based design, which ignored thousands of existing ships and wasted state-of-art knowledge on damage stability. Considering this situation, a framework of life-cycle risk (damage stability) management of passenger ship and its related damage stability verification framework were introduced and established in this paper.

Keywords: damage stability, risk management, damage control

1. INTRODUCTION

Accidents of passenger ships, involving thousands of lives on broad, are a matter of grave concern, consequences of which from time to time irritate and astonish the public. As a result, industry and academia's endeavour to improve safety of passenger ships never stops and much of it targets the inadequate damage stability, the Achilles heel of passenger ships. For centuries, traditional passive way of establishment and modification of safety regulations and rules in the aftermath of tragic accidents stays as the dominant method to help control the risk but nowadays it becomes difficult to catch up with the unrelenting pace of ship technology. In contrast, pro-active risk reduction ideas were put forward and various related methods are under development and tentatively expanding into the ship industry. The typical representative, risk-based ship design method, integrating safety assessment procedure into the ship design process, widens the design envelope and inspires innovations on the new specifications while proactively controlling the risk. Moreover, along with traditional regulations, it focuses on the improvement of damage stability in the design phase, which serves only for the newbuildings, leaving thousands of existing ships still confronted with uncontrollable risk and with state-of-art knowledge on damage stability wasted.

Given the background introduced above, it is not sensible to limit the research of damage stability improvement in ship design phase. Besides the risk control options (RCOs) in design phase, throughout a ship's life, effective operational (active) measures and measures conducted during emergencies could also serve to improve damage stability and efficiently reduce the loss of lives. This gives birth to the idea of establishment of a complete framework for life-cycle risk (damage stability) management. Built on the life-cycle perspective, this framework is a holistic approach to improve damage stability cost-effectively through risk control measures in design, operation and emergency stages. As the building block of the framework, the risk reduction potential of risk control measures should be known. This could be accomplished by a damage stability verification framework which aims at the verification and measurement of the risk reduction measures in ship's whole life cycle via auditable and measurable means. And this paper would introduce the establishment of these two frameworks respectively.

2. SAFETY MANAGEMENT SYSTEM

The safety management system introduced by HSE (Health and Safety Excursive) in its guide -- *successful health and safety management* has served as a mainstream methodology for risk management and has been employed in various different industry fields managing risks and solving safety problem in a holistic view. The system comprises five steps, namely, policy, organizing, planning and implementing, measuring performance, reviewing and auditing (shown in figure 1). 'Policy' describes the corporate approach to safety; 'Organizing' describes the management hierarchy relating to safety with responsibilities defined at each level; 'Planning' shows the safety tasks to be targeted at each stage and 'Implementing' is to conducting measures to reduce or mitigate risks; 'Measuring performance' refers as measurement and verification of the effectiveness the implemented measures; 'Reviewing and Auditing' belongs to the system of continuous improvement, ensuring new hazards identified, near miss incidents considered and the SMS kept up to date. The importance of this safety management system lies on the classification of a rather complicated situation which includes huge numbers of different aspects into systematic and reasonable five steps.

Based on the HSE's Safety Management System (SMS) guideline, the damage stability risk management framework in this paper also followed the holistic idea of HSE's SMS and utilized the steps in the guideline. Given the particular situation of damage stability problems discussed in the paper, the main concerns of the framework focus on the last three steps which specifically are planning and implementation of risk control measures, measurement of the performance and effectiveness of implemented risk control measures, and acquisition of reviews and suggestions from the former two processes.

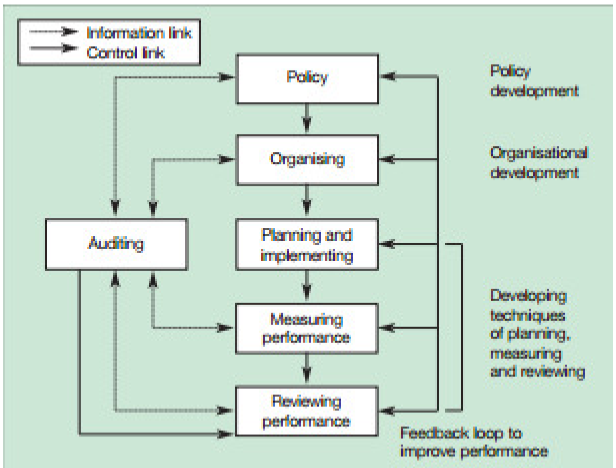

Figure 1: Key Elements of Successful safety management

3. LIFE-CYCLE RISK (DAMAGE STABILITY) MANAGEMENT FRAMEWORK

A literature review on life-cycle risk management (LCRM) for ships would tell us that LCRM is still a developing and immature subject. Plenty of ideas merged and attempts of managing the overall risk from a life-cycle view have been made. The main target and challenging part of a primary thinking pattern is establishment of linkages among different life periods and among different risk control processes to order to integrate different life periods, safety essentials and risk-based methodologies together in a whole risk management system. A review and feedback system is prone to be established based on this kind of risk management system. However, it seems that this research direction builds on the hypothesis that appropriate measures would be conducted to reduce or mitigate risks and threats to tolerable level during operation and emergency stages, which is not often the case. Complementarily, the objective of the life-cycle risk management framework presented in this paper is assurance of risk being under control in every period of ship's life by managing the risk in ship's different life periods. Disassembly of this holistic goal indicates that target for each life period is the verification of risk reduction or mitigation in this period.

Establishing on a life-cycle perspective, the framework comprises three dominate phases in the life of a ship, namely design, operation, and emergency. The operation stage defined here is from an incident happened to the moment before the ship is going to be abandoned. And emergency stage starts from the moment ship is decided to be abandoned. Correspondingly, risks are divides in terms of life periods into three parts, risk in design, residual risk in operation and residual risk in emergency situation. In each life-cycle phase, three essential safety management steps mentioned in the first section are conducted respectively, reducing and mitigating the risk in every stage and ensuring an overall safety environment.

Verification of the risk control options in each life phase is most direct way to ensure risk reduction or mitigation in every life period. Risk control options in each stage are distinctive from each other. In design phase, traditionally rules always focus on design solutions, serving as passive risk control measures for damage stability improvement. Operational measures, referred as active risk control measures, are abundant in SOLAS Ch. II-2 (e.g. damage control). In emergency stage, effective risk control measures are mainly systems and measures focusing on emergency response, such as Decision Support Systems for Crisis Management, Evacuation, LSA (Life Saving Appliances), Escape and Rescue.

Whilst a substantial amount of options for planning and implementation of risk control measures exist, measurement of the performance and effectiveness of these risk control measures still remains as a big gap in this approach. Contrary to passive design solutions which has stayed as a primary research target for centuries, operational measures have not been rigorously validated yet. Moreover, the cost-effectiveness of emergency risk reduction potential was never measured nor verified before, since risk reduction of 'residual' risk in this stage falsely perceived to be small by definition. These problems need to be overcome before the overall risk management process can be formalized and adopted. This issue was considered in the next section.

4. DAMAGE STABILITY VERIFICATION FRAMEWORK

In addition to traditional design modifications, identification of alternative means and arrangements such as operational measures and emergency response measures gives credit to their benefit based on their verifiable contribution in improving stability levels. Damage stability verification framework is established, targeting on identification, quantification and validation of the risk-reduction potential of all such measures.

Damage stability verification framework encompasses one proposal for each life stage. The goal for design and operation stage is to assess the ship vulnerability to flooding, while assessing effectiveness of emergency response is the target for emergency phase. To achieve the goal, objective of the proposal for design stage (Item 1) is establishment of baseline vulnerability and assessment of impact of design measures. Quantitative analysis, including damage stability statutory assessment and damage stability alternative method, are planned to conduct to acquire the effectiveness of various risk control options in design. Correspondingly, assessment of impact of active damage control measures by crew is the objective for operation proposal. Quantitative analysis to fulfill this objective includes damage stability alternative method and ship systems operability assessment, while qualitative analysis, namely assessment of crew performance, could serve as supplementary. Similarly, proposal objective for emergency stage is assessing impact of emergency responses measures. Escape and evacuation analysis and assessment of crew performance are the quantitative and qualitative analysis respectively.

4.1 Proposal for the design phase

The work in design phase comprises the following activities:

Statutory (SOLAS2009) damage stability assessment: The following actions describe in-house developments targeting design vulnerabilities and cost-effective design measures to reduce these.

1. Statutory A-value index calculation (basis calculations) in accordance with SOLAS Ch.II-1 (SOLAS 2009).

2. Vulnerability screening and identification of design modifications aimed at increasing the level of index A as high as it is practicably attainable.

3. The results of the vulnerability screening will be used to define appropriate design modifications on the basis of risk-reduction potential and cost effectiveness.

4. Taking into account the results of the vulnerability screening, simple solutions (such as closing openings) as well as a number of alternative ship watertight arrangements will be used for further analysis for each ship.

Operational data: The following actions target to identify ship specific data and conditions for use in the stability assessment (rather than the generalised average values used in the probabilistic rules)

5. Collection and analysis of real life on-board data for an agreed period of operation. The data relate to loading conditions, stability parameters, quantity and distribution of loads, etc. Use will be made of any data that already exists.

6. Readily available stability improvements can be specified by reviewing the quantity and distribution of fluid loads (fuel, ballast water, heeling water, fresh water, grey water).

7. Realistic operational data need to be used as a basis for numerical flooding simulations.

Alternative assessment of damage stability: The following actions describe the use of first-principles tools as a supplementary means to assessing damage stability.

8. Alternative assessment based on Monte Carlo (MC) sampling in conjunction with numerical flooding simulations (referred to subsequently as MC simulation). This approach reflects explicitly the damage statistics and accounts realistically for the physics of stability deterioration following a collision event. The MC simulation is a viable technique for stability assessment in accordance with SOLAS Chapter II Part B Regulation 4.2 (alternative method).

9. For the purposes of comparison, the alternative assessment will be carried out for the same basis design and alternative watertight arrangements developed as part of the statutory damage stability assessment.

10. The MC simulations will allow identification of weak “spots” (e.g. local architecture) contributing to stability deterioration when subject to flooding as a result of water ingress following a large number of collision events.

11. The study will be performed for (a) three watertight arrangements per ship, and (b) two loading conditions, comprising one

regulatory condition, and one real life loading condition. In total six cases per ship will be analysed.

4.2 Proposal for operation stage

The work comprises the following activities, carried out for the same sample ships referred to in Item 1. Measures related to damage stability assessment encompass active damage control which is STAGE 2 activity in a typical muster list.

<table>
<tr><th>STAGE 1</th><th>STAGE 2</th><th>STAGE 3</th></tr>
<tr><td rowspan="3">INCIDENT happens

(1) Detection & Alarm</td><td>(2) Damage control</td><td rowspan="3">(5) Abandon Ship
(6) Rescue</td></tr>
<tr><td>(3) Muster of Pax</td></tr>
<tr><td>(4) Preparation of LSA</td></tr>
</table>

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

Qualitative analysis includes:

1. Definition of active damage control options by the crew. It is envisaged that for this, a one-day meeting with active crew members (Master, chief engineers, deck hands, etc.) involved in damage control duties on-board the vessels under evaluation will be conducted.

2. Definition of human and organizational (procedural) factors affecting the effectiveness of damage control actions.

3. Effectiveness of crew actions for flooding control will highly depend on the level of crew preparedness and competence necessary to carry out the actions safely, timely and effectively.

4. A qualitative measure reflecting the objective evidence in terms of crew competence and preparedness will be developed

Quantitative analysis includes:

1. One of the watertight arrangements defined in Item 2 will be used as platform to quantitatively assess the impact of possible active flooding control measures by crew when a flooding incident moves to damage control stage (see Table above).

2. The quantitative analysis will be based on the alternative MC simulation method described in Item 1. This entails identification of flooding scenarios where counter-ballasting is effective and feasible, the latter implying availability of ship systems to enable this action.

3. Crew actions to be analysed will comprise counter-ballasting operations. This is based on the premises that available options will be computed, defined and executed in a timely manner.

4. Effectiveness of crew actions for flooding control will depend, in addition to the necessary ship systems being available, on the possibility of active reconfiguration for that purpose if the systems are impaired by the flooding.

5. The availability of relevant ship systems will be verified by using a design verification tool that allows modeling ship systems architecture, in topological and functional form. The tool is used for verification and analysis of essential ship systems redundancy when applying Safe Return to Port requirements of SOLAS Ch.II-2.

4.3 Proposal for emergency phase

The research comprises the following activities, carried out for the same sample ships referred to in Item 1. Measures related to evacuation include: muster of passengers, preparation of LSA, abandon ship and rescue operations, namely STAGE 2 and 3 activities in a typical muster list.

Qualitative analysis includes:

1. Definition of evacuation-related duties and activities by the crew. It is envisaged that for this, evacuation activities on-board the vessels under consideration will be conducted.

2. A hazard identification type of exercise needs to be conducted with a view to defining human and organisational (procedural) factors affecting the effectiveness of the evacuation process.

3. Effectiveness of crew actions for evacuation purposes will highly depend on the level of crew preparedness and competence necessary to carry out the actions safely, timely and effectively.

4. A qualitative measure reflecting the objective evidence in terms of crew competence and preparedness will be developed

Quantitative analysis (Evacuation analysis) includes:

5. Evacuation analyses of the ships in question will be conducted with an advanced evacuation analysis tool (as defined in MSC\Circ.1238)

6. The evacuation analysis will cover the mustering and ship abandonment process;

7. Human and LSA systems performance data for the analysis will be collected and validated prior to use on the basis of existing IMO instruments and operators experience

8. The evacuation time will be assessed in the context of the survival time (time to capsize) derived from the damage stability assessment (Items 1 and 2) for all critical emergency scenarios (where damage stability may be compromised)

9. Effectiveness of crew actions for evacuation will depend on the availability of necessary emergency ship systems or the possibility of active reconfiguration for that purpose if the systems are impaired by the flooding.

10. The availability of relevant ship systems will be verified as described in Item 2(9) above.

5. CASE STUDY

Here presented a simplified case study of the damage stability assessment for damage control process. The objective of the study is to identify and qualify the impact of damage control measures. The overall procedures are shown in Figure 2.

Firstly, the original geometry data and loading conditions of representative ship are given and recorded. Monte Carlo simulation method is employed to generate different damage extents and sea states which would later be applied on the representative ship resulting piles of damage scenarios. By calculating the probabilities of survival under random sea states for each damage extent, critical scenarios that the probability of survival indicates an intolerable chance of capsize could be elected as research objects in the next step. For each critical scenario, corresponding risk control options are generated, with an alternative loading condition and geometry data comparing to the original one. Then Monte Carlo simulation needs to be employed again to generate random sea states, and with the help of PROTEUS program the motion responses of the damage ship under current circumstances could be obtained. Finally, the probabilities of survival under random sea states for three hours are calculated again, and the differences between the original and new survival probabilities could be counted as the impact of the related risk control options for a certain damage case.

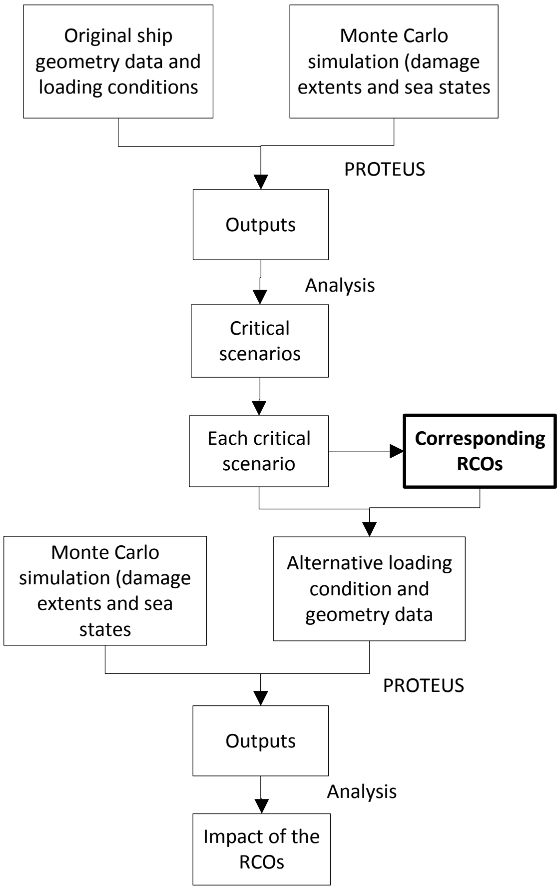

Figure 2 Overall procedures of damage control verification process

The damage control measures considered in this case study mainly include counter-ballasting plans. It is multi-objective optimisation process, and various algorithms could be proposed to determine the most effective risk control option based on both a list of performance and safety criteria.

6. CONCLUSIONS

This paper presented a hostile framework for life-cycle risk (damage stability) management of passenger ships which particularly emphasizes on the benefits and importance of identification and verification of the risk control measures in operation and emergency phases. Correspondingly, as the building block, a damage stability verification framework was established and specific proposals for each life stage were raised. And the last section of the paper outlined a related case study aiming at qualifying and verifying the impact of damage control measures. Further study might include development of the algorithms of generation of damage control measures under various performance and safety criteria at the same time.

7. REFERENCES

Vassalos, D., Konovessis, D., Jasionowski, A. (2013), "Life-cycle risk management: a safety case approach", Proceedings of the IDFS 2013, pp. 37~42, 25-27 November, Shanghai, China

Martins, P.T. (2011), "Real-Time Decision Support system for managing ship stability under damage", OCEANS, 2011 IEEE – Spain, ISBN: 978-1-4577-0086-6

Qi Chen (2012), "Uncertainty Quantification in Assessment of Damage Ship Survivability", University of Strathclyde, Glasgow, May 2013

Papanikolaou, Apostolos (Ed.) (2009), "Risk-based ship design – Methods, Tools and Applications", ISBN: 978-3-540-89041-6

Health and Safety Executive (1997), "Successful health and safety management", ISBN 978 07176 1276 5