FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management

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ABSTRACT

This paper presents an overview of the research project FLOODSTAND, which is targeted to develop and increase reliability of flooding simulations and of assessments of large passenger ship performance in safety-critical crises. The gaps in existing data will be filled and uncertainties in the current knowledge can be rectified by experiments and computational methods. The aim of the project is to develop guidelines and standards, in connection to damage stability, a crucial element of ship safety. This paper presents the background, objectives and structure of the project as well as the applied methods and expected results.

KEYWORDS

damage stability, progressive flooding, time-to-capsize, decision support, rescue, passenger ship

INTRODUCTION

The size of large passenger ships has grown up to measures that are bigger than ever. Thus, the need to develop assessments related to ship safety has also become more important than ever. Simulations are widely used today to support decision-making in various problems, related to some special issues e.g. in the design process of a large cruise passenger ship or a ROPAX-vessel. If the calculation routines are reliable and fast enough, they may offer help in potential crises, too. The growing need and interest for flooding simulations has increased the requirements regarding the capability and the reliability of many elements in simulations.

General arrangement of a large passenger ship is very complex. Internal subdivision of a watertight compartment of a cruise vessel with all the non-watertight boundaries has some effect on the progress of flooding, but today it is yet almost practically an impossible task to be exhaustively modelled; this may also be meaningless. However, the behaviour of some leaking structures, whether described by the rate of their leakage and/or by their collapse at a certain level of loading, may have a definite effect on the ship's survivability, in damaged condition. Thus, it is an important topic for experimental research, like the behaviour of a damaged vessel in waves is. Research, related to the known lacks of knowledge, to required data and to novel methods to facilitate reliable assessments of ship safety, on various levels of detail, is carried out in this project.

Guidelines and standards, based on reliable data and methods, following commonly agreed & accepted criteria, form a solid base for sound development. The expected results of the new FP7 project FLOODSTAND are planned to help in, and they also form part of the development of flooding simulations and of ship safety assessments. Multifaceted contemplation and utilisation of both bottom-up and top-down approaches, on various levels of detail and for various purposes will further improve the evolution of methodology and standards used to guarantee ship safety.

DESIGN AND APPLICATION (WP1)

The main objective of the first Work Package, WP1, of project FLOODSTAND is to produce sufficient amount of documentation and data of the selected sample ships of different size for further use in WP2 and WP3. The shipyards developed and provided two representative sample ship designs for typical state-of-the-art cruise vessels to be used for flooding simulation purposes, see Fig. 1.

The new concepts of inner design will be developed considering the weak points of the original designs. Naturally, they have still to comply with actual statutory rules but the real flooding behaviour has to be improved.

The main focus is on two different aspects;

1. Flooding of void spaces through structural ducts
2. Flooding of cabin structures

New arrangements of voids and cabins, staircases and other non watertight spaces will be developed and considered, too.

The different new concepts will be analyzed further with the flooding simulation tools and compared with the design practises in current use. The main objective for the judgement of the designs is the stability during and after the flooding as well as the remaining time to escape from the flooded rooms.

Based on the conclusions of the other work packages, different design concepts for spaces below and on the bulkhead deck will be analysed at a later stage of the project.

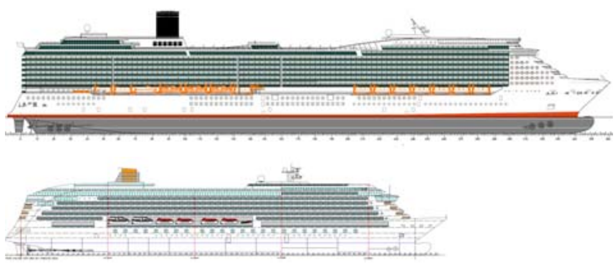

Fig. 1: Above: Post-Panama sized cruise ship; 125000 GT, L = 327 m, B = 37.4 m, T = 8.8 m, and below: a medium sized cruise vessel: 63000 GT, L = 238 m, B = 32.20 m, T = 7.4 m.

EXPERIMENTAL AND NUMERICAL TESTS (WP2)

Flooding progression modelling is studied in several ways in FLOODSTAND. The scope of modelling extends from single openings and structural elements to partitions and compartments up to a whole ship section. The applied approaches to produce new knowledge include experimental and numerical methods.

The behaviour of many structures, typically used in passenger ships, like semi-watertight doors, cross-flooding hatches, wall panels and windows, is not always well known in the case of flooding. Numerical data, related to the actual leakage and/or collapse under water pressure, does not exist or has not been known widely enough to make it possible to be taken into account in flooding simulations, see IMO SLF47/INF.6 (2004). Therefore, experimental research on the leakage and collapse of such structures, under controlled conditions of a test laboratory, was considered to be an important topic to be investigated.

A watertight tank, that would facilitate tests with many interchangeable structures under relevant water pressure and destructive loading, was designed and built. It was fitted with a system for static water pressure adjustment and equipment for measurements and monitoring arrangement for acquiring stress distribution within the tested structure and for measuring of the flow rate through the leakages during the phases of the tested structure's collapse.

Two shipyards provided ship structures that were prepared beforehand for testing, as well as information and data related to them. The results of these tests (see Fig. 2), soon fully completed, will be published soon.

Fig. 2 A non-weatertight wall panel leaking in the tests at CTO.

Numerical methods offer another important research method related to the mechanisms of failure of the doors and the other structural components for the assessment of their effects on the flooding. Thus, simulations, carried out using explicit finite element (FE) codes (LS-Dyna, MSC Patran/Nastran) were included in the research program. Utilization of explicit code provides much efficient opportunities of modeling of the failure propagation.

It is expected that two main pressure values will describe the failure process. The failure process begins when the structure loses its watertight integrity and starts to leak - this stage is described by the leakage pressure. Failure process continues until the collapse of the structure, which is described by the collapse pressure. At any time, the extent of failure can be described by the area of leakage opening. Computations will be validated with the experiments conducted. Based on the experiments and the FE-simulations, estimated risk criteria for leakage and collapse of doors and other structural elements will be proposed.

Experimental and computational studies on pressure losses

Experimental studies on the pressure losses in manholes were performed in scales: 1:1, 1:2 & 1:3, to obtain numerical data for validation of CFD-calculations. These test were continued by systematic tests with different modifications of a typical arrangement of a cross-flooding duct of a large passenger ship, with the interest in deriving conclusions on the effects of some parameters, such as the number of girders and openings on the pressure loss.

A number of CFD computations on the previously described parts of the ship have been carried out. These CFD computations will be used to provide a global and simplified flooding simulation tool with unknown coefficients (e.g. pressure loss in various openings). Both RANSE solver ISIS-CFD of CNRS and Fluent will be used.

Dedicated CFD simulations will be also carried out in order to assess the pressure losses in typical air pipes from the voids since during flooding the counter pressure of air can have a significant effect on the cross-flooding time.

Effects of air pressure, level of detail, scale etc.

Air compression inside the damaged ship can have a notable effect on the flooding progress. In model tests this factor has usually been neglected by using large ventilation pipes. In the novel model tests at MARIN a large vacuum tank is used to properly scale the air pressure outside the model. This provides a unique opportunity to test the air compression effects on flooding in model scale. The floating position is kept fixed but several combinations of heel and trim angles are tested. Water heights and air pressures are measured in many compartments. In addition also the forces and moments acting on the model are recorded. The results of these challenging tests will provide data for further validation of numerical simulation codes. Two models with different levels of detail are used.

Input parameters of flooding simulations will be systematically varied in order to assess the sensitivity of the simulation results on these parameters. The sample ship designs produced in the WP1 will be used for this purpose. Guidelines for the preferred accuracy of the input data along with simple error estimations will be provided.

FLOODING CONTROL ONBOARD (WP3)

Currently the available tools for damage control onboard the ships are mainly papers showing pre-calculated results of pre-defined damage cases. Obviously, the real damage is arbitrary. In addition the loading condition and the statuses of the doors (open/closed) can be different. In fact, the number of combinations is practically unlimited. This means that the starting point for the assessment of damage and flooding extent has to be based on the information from various monitoring systems (flood sensors, tank sounding devices, door status, etc.).

The WP3 focuses on studying how the limited information, received from flood level monitoring systems, can be utilized in the assessment of damage extent and time-domain flooding simulation for estimating the time-to-flood and the stability of the ship. The objective is to develop a flood sensor data interpreter for instantaneous use in flooding prediction tools, as well as to derive methods for assessment of uncertainty in such data interpretation. Furthermore, based on the improved knowledge in assessing leaking and collapsing of non-watertight structures and pressure losses in various openings (WP2), the results of the flooding simulation tool are expected to be much more reliable.

Finally, some guidelines and principles for the design of flood water sensor systems will be developed. The main task is to find the optimum locations for the sensors. Some preliminary results are presented in Penttilä and Ruponen (2010). The developed methods will be implemented in a decision support system for demonstration and testing purposes.

STOCHASTIC SHIP RESPONSE MODELLING (WP4 & WP6)

Current damaged ship stability standards represent some consensual degree of ability for a ship to attain a state of functional equilibrium if disturbed from it; however, this ability has never been resolved into practical information, such as:

(a) Should the ship return to port after a collision incident when it is half a nautical mile from the port or should it be abandoned immediately? Or

(b) Should the ship return to port after a collision in a "bad" weather when it is 200 miles from the nearest port, e.g. northern ice regions, or should the potentially thousands of persons onboard be asked to abandon the vessel?

Weighing of information for a decision in both these cases will be different and must be precise. And today such weighing for a decision is left to the discretion of ship's crew with similarly discretionary advice from far-away onshore supporting teams.

The FLOODSTAND project sets to devise basis, *a standard*, for such decisions, so that either the crew or the on-shore team advises accordingly to rigorous criteria accommodating for all information that is relevant to such decision making at every instant of time, as well as for all the uncertainties associated with eventually committing to this decision. The decision making process will thus be limited to providing with accurate assessment of all the relevant input information, rather than judgement if these or the other ship states are better for this or the other decision. The judgement element will be replaced with reading of the standard's recommendation. The crew's responsibility would thus be limited to provision of as representative information of the casualty as is possible and then timely execution of the recommendation.

It is proposed that the judgement standard is based on the concept of *conditional risk*. The decision to be executed will always be that which results in the least risk at given instant of time. From the point of view of development within the proposed project, the risk will be considered as a mathematical expectation of the loss conditional on a specific decision option available and relevant to a specific casualty case (damage characteristics, ships systems availability, evacuation systems, rescue proximity, ship state e.g. watertight doors closed, etc), as is shown schematically in Figure 4 and concept equation (1).

$$E(loss|decision_i) = \sum_j loss(j) \cdot p_{N|i}(j|decision_i) \qquad (1)$$

For $j = 1 \ldots N_{\max}$ and where $N_{\max}$ is total number of persons onboard.

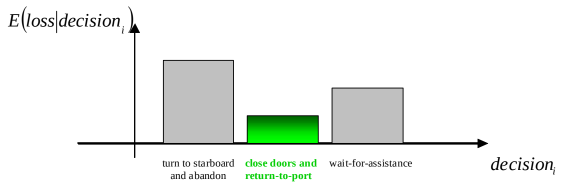

Fig. 3: The FLOODSTAND concept of the "least risk" to be used as the decision merit function.

Furthermore, it is proposed that this casualty mitigation standard be directly used for revision or, indeed, setting of design standards. For instance it could be required that a ship is designed so, that the expected loss for every one of a set of specific damage cases (e.g. every damage leading to 3-compartment flooding) and given specific mitigation action (e.g. stay onboard) is not more than a given acceptable level.

Such precise estimates of underlying stochastic process of capsize, supported with precise estimates of actual conditions, also accounting for expected uncertainties in assessing such actual flooding states, can be built into a rational standard for decision making during crises as well as for informing the crew at all times of ship criticality during operation, so as to enhance crew preparedness for such crises.

MUSTERING-ABANDONMENT-RESCUE MODELING (WP5)

One of the tasks to be carried out in the project FLOODSTAND is to determine standards for developing Mustering, Abandonment and Rescue models that would integrate the most significant factors accounting for the potential degradation of people's health and eventually provide as an output, the risk (in terms of safety) for passengers to abandon the ship. This risk should be easily converted into an input for a decision support system aiming at helping masters to adopt the best options for ensuring passengers' safety in case of a flooding event onboard a large passenger vessel. Moreover, standards for assessing the uncertainty bounds associated with the models will also be determined since a decision support system can be considered effective at the condition that it provides the decision-maker with a clear indication of the uncertainties attached to its output information/ advice.

Concerning the aspects focussed on in this section, the first year of the project FLOODSTAND was mainly dedicated to collecting and analysing data from different sources in order to address the different aspects of evacuation in case of a flooding event. Amongst these aspects are the detection of flooding, the assessment of damage by the crew, the assessment of the situation by the master, the decision to stay onboard or abandon the ship, the effects of flooding on evacuation, the launching of life-saving appliances (LSA) while the vessel is listing because of flooding or the recovery of LSA by the Search and

Rescue (SAR) services. During this period several passenger ships' masters and SAR personnel were interviewed and/or answered a questionnaire. This feedback from 'in field' people brought precisions on the actual decision making process in case of flooding as well as the practical needs faced by these persons when it comes to real massive evacuations of cruise and passenger ferry ships. Accident and evacuation drill reports were also analysed and a regulatory review, setting the minimum regulatory requirements for crisis management onboard passenger ships, was performed.

Moreover, the core concepts underpinning the development of the mustering, abandonment and rescue (MAR) models were also defined. They were adapted from a combination of the SAFECRAFTS FP6 EC funded project's results (SAFECRAFTS, 2008 & SAFECRAFTS, 2008), and the current state-of-the art practice for ship evacuation simulation. They are based on the principle that health can be a relevant indicator of the success of the ship abandonment. During the process of mustering, abandonment and rescue, the health of passengers and crewmembers is a variable that is likely to degrade as they go through MAR obstacles. At the end of the process, the final health of passengers is compared to their initial one, which provides a good indication on how risky it is to abandon the ship. The potential number of fatalities is directly derived from this indicator and will be the preferred input for the loss function embedded in the decision support system.

DEMONSTRATION (WP7)

The last WP of the project deals with the demonstration and exploitation and dissemination of results. In the framework of project's demonstration activities, it is planned to test within a realistic working environment the effectiveness of the developed standard in rating different decisions for various casualty cases and for a series of hypothetical as well as real-life (historical) scenarios; independently, demonstration and testing should include the implementation of the approach in the design process.

WP7 is composed of three tasks referring to the benchmarking of data on casualty mitigation case, the demonstration of the casualty mitigation standard and the demonstration for use as a design standard. In this respect, characteristic benchmark scenarios will be developed, that will be used in the testing of the standard in typical ship operational conditions and in the ship design process. The results will provide feedback to other WPs for modification, improvements or fine-tuning of the proposed standard.

As the basic criterion for the crisis management the *loss function L* will be used:

$$L = TTE - TTS, \qquad (2)$$

where TTS: Time to Survive;

TTE: Time to Evacuate

Time data for ship flooding and probability of survival, evacuation, abandonment and rescue of people on board will put together to derive the loss function in terms of a balance between survive and evacuation time, for given casualty scenario.

The benchmark scenarios will address characteristic time aspects of the ship flooding process. The basic frame of each scenario is determined by the set of parameters that will remain fixed throughout the testing process, e.g. ship type (ROPAX and cruise ship), damage type (collision and grounding), hull subdivision, etc., whereas other parameters are characterized by increased uncertainty will be emulated, e.g. damage size, sea state, internal openings, time to evacuate, etc. The available information during an emergency situation, like flooding, forms the actual conditions for which a decision support has to be developed. Without such conditional environment any decision remains rather generic and consequently of low practical usefulness.

CONCLUSIONS

The objectives of project FLOODSTAND include development of new data to improve the knowledge related to damaged ship stability and progressive flooding. Its purpose is to create useful data and methods, apply the new information in developing new guidelines and decision support tools for both designers and operators. The project was started in 2009. So, some of the results of the project[1], described just briefly above, have already been generated and the dissemination process, via various publications etc., has started.

ACKNOWLEDMENTS

Allthough the opinions professed in this paper represent those of the individual authors, the team of which was selected from each WP-leader organisation of FLOODSTAND, the paper strives to objectively describe the whole collaborative project. The project would not have been possible without the efforts of the whole Consortium[1] or without the financial support from the EC to this three-year research project FLOODSTAND (Grant Agreement Number 218532, SCP7-GA-2009-218532), making the described work possible, and that the authors want to express their gratitude for.

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[1] For more information of the project FLOODSTAND, it's results and the Consortium (consisting of: AALTO University (ex. Teknillinen korkeakoulu, previously also known as Helsinki University of Technology), Finland; STX Finland; CNRS, France; CTO, Poland; DNV, Norway; BMT, United Kingdom; MARIN, The Netherlands; MEC Insenerilahendused, Estonia; Meyer Werft GmbH, Germany; Napa Ltd, Finland; SSPA, Sweden; SF-Control, Finland; NTUA, Greece; Bureau Veritas, France; SSRC, United Kindom; S@S, United Kindom; Maritime and Coastguard Agency, United Kindom), see the web-site: http://floodstand.tkk.fi/ .