FLOODSTAND

PROJECT FINAL REPORT

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Project acronym: FLOODSTAND

Project title: Integrated Flooding Control and Standard for Stability and Crises Management

Funding Scheme: Collaborative Small or Medium Scale Focused Research Project

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4.1 Final publishable summary report

4.1.1 Executive summary

A crucial question onboard any passenger ship in crisis is related to the safety and the risk involved. As the size of the new ships has increased remarkably during the past decades, these issues have become even more important. When a larger number of passengers get onboard the same vessel the risk to life increases, and hence new insights and methods to deal with it need to be explored. As it is known that the major risk to persons onboard is posed by the hazard of flooding, FLOODSTAND was planned to respond to this need by deriving new detailed, more reliable information and modeling principles on the process of ship flooding and by developing new methods for analysing the flooding extent onboard and by developing a standard for a more comprehensive measure of damaged ship stability than standards in use today.

In passenger ships, the non-watertight subdivision in the watertight compartments is usually rather dense. Consequently, the structures involved will have a large effect on the progress of the floodwater in the event of breach and leakage. Until now, there has not been available reliable data for assessing the response and strength of widely used structures (such as fire doors) under the pressure of floodwater. However, in flooding simulation, it is necessary to include also the leakage through closed doors since the simulated time-to-flood depends heavily on the applied model for the leakage. Through various analyses carried out in FLOODSTAND the modeling of the flow through typical doors stands now on a much more reliable basis than before. With the new data and guidelines prepared the flooding simulations can serve the needs of designers and operators better than before.

Since the flooding simulations usually require a long time for computing, simplified approaches for calculations, e.g. for modeling the flows inside the damaged ship or for the further assessment of the status of the vessel, are often favored. The applied methods have been validated with experiments. This approach is used in all flooding simulation tools. Experimental discharge coefficients that take into account the pressure losses in the openings have widened and deepened the knowledge and understanding related to proper values for discharge coefficients. They are now better known for various typical openings and structures in a modern passenger ship. Little knowledge has been available with respect to the survivability of damaged cruise ships at calm water and in waves. Some interesting efforts towards this research area have now been directed in FLOODSTAND. These efforts have increased the knowledge and understanding of the related phenomena and the outcome, although in practice it may still be a challenging effort to model a whole ship with every detail.

FLOODSTAND was set out to derive missing data for flooding simulations, for the validation of time-domain numerical tools for the assessment of ship survivability, rescue and to develop guidelines as well as a standard for a comprehensive measure of damaged ship stability, addressing the risk of flooding in passenger ships, cruise liners and ROPAX-vessels. The project has reached these goals fairly well.

Guidelines and uncertainty bounds have been established, and many simulations for assessing the damage and extent of flooding onboard a damaged ship or assessments of the time-to-capsize have been carried out. FLOODSTAND also aimed at establishing methods for instantaneous classification of the severity of ship flooding casualty with an expected performance in reaching the related objectives.

FLOODSTAND will contribute in reducing the risk to human life, by ensuring that the level of safety of the transport system will respond to the increasing demand, featured by large passenger ships. Prospects for this development look encouraging, based on the results achieved during the course of the project. The impact of FLOODSTAND is notable and it will most probably grow considerably with time.

Results of the project are available via the project website: **http://floodstand.aalto.fi**

4.1.2 Description of project context and objectives

<u>Context</u>

The size of the biggest new passenger ships has increased continuously. Bigger size offers bigger opportunities and economics of scale, but when a bigger ship accommodates more passengers there may be a higher risk, if evacuation is needed. Thus, new approaches have to be used and further developed in order to have the flooding under control if the watertight integrity of the ship is lost.

In the worst case, all flooding accidents may lead to the capsizing or sinking of the ship within a highly variable time frame. The need to ensure safe return to port or at least sufficient time for abandonment will form major challenge in ship design.

However, the assessment of the available time and the evacuation decision are not easy tasks. This process is complicated and there is a notable lack of data. Thus, guidelines and methods to tackle these problems must be developed. New tools are required in order to increase the designers' and operators' possibilities to reliably evaluate the ship's capability to survive in flooding accidents.

Reliable simulation of flooding of passenger ships in damage conditions is one of the most topical issues related to the development of methods for their safety assessments. The importance of this matter involves both design and operation, and it is a high priority issue also for the Sub-committee on Stability and Load Lines and Fishing Vessels Safety (SLF) of the International Maritime Organization (IMO). The project FLOODSTAND has aimed at development and increase reliability of flooding simulations with many of its sub-topics, e.g.: cross flooding, pressure losses in openings and cross flooding ducts, leakage and collapse of non-watertight doors, flooding progression and time-to-capsize. This research area (not limited solely to the above list) is highly valued by SLF.

The results of the project will be taken into account in development and amendment to IMO instruments, both mandatory and recommendatory. They also show directions for further work in these matters.

<u>Objectives</u>

The main objectives of FLOODSTAND are to increase the reliability of flooding simulation tools in design and onboard use by establishing modelling principles and uncertainty bounds, in particular by:

- establishing guidelines for modelling leaking through closed doors (e.g. non-WT doors, semi-WT doors) and the critical pressure head for their collapse under the pressure of floodwater;
- simplified modelling of pressure losses in flows through typical openings;
- feasible and realistic modelling of compartments with complex layouts (cabin areas) for flooding simulation tools;
- the use of flooding monitoring systems and simulation for assessing the damage and extent of flooding onboard the damaged ship.

The research efforts in FLOODSTAND, especially in Work Packages: WP1-WP3, aim at the above objectives, by representing a bottom-up approach, supported by experimental research (tests with real ship structures, such as doors, cabin wall panels etc., and model tests) and computational studies.

FLOODSTAND also aims to establish methods for instantaneous classification of the severity of ship flooding casualty, with the following objectives:

- establishing requirements and uncertainty bounds for methods for the prediction of the time it takes a ship to capsize or sink after damage.
- establishing requirements and uncertainty bounds for models of mustering. abandonment and rescue operations.
- deriving a standard for decision-making in crises.
- developing an implementation system and testing the effectiveness of the standard in rating different decisions for various casualty cases, as well as testing the approach in design.

The latter objectives are of special interest in WP4-WP7 with more focus on top-down approach.

Work performed since the beginning of the project and the main results

The contents of the whole project is presented in a summary table, see Table 1 below.

Table 1 The Contents of the Work Packages and Tasks in project FLOODSTAND

WP	WP/Task Contents	Lead organisation*
WP1	**WP1 Design and application**	**STX Finland**
	Task 1.1 Development of basic design of passenger ships	STX Finland
	Task 1.2 Analysis of the real flooding effects on design	STX Finland
WP2	**WP2 Flooding Progression Modelling**	**AALTO**
	Task 2.1 Experiments with leaking and collapsing structures	CTO
	Task 2.2 Numerical modeling and criteria for leaking and collapsing structures	MEC
	Task 2.3 Experimental studies on pressure losses	AALTO
	Task 2.4 Computational studies & RANSE CFD	CNRS
	Task 2.5 Model tests for cabin areas	MARIN
	Task 2.6 Sensitivity of simulation model	AALTO
WP3	**WP3 Flooding Simulation and Measurement Onboard**	**NAPA**
	Task 3.1 Development of flood sensors data interpreter	NAPA
	Task 3.2 Impact of ship dynamics	AALTO
	Task 3.3 Design of flood sensor systems	NAPA
WP4	**Stochastic ship response modelling**	**SSRC**
	Task 4.1 Benchmark data on time to capsize, ttc	SSPA
	Task 4.2 Test/develop analytical time to capsize model	SSRC
	Task 4.3 Test/develop numerical time to capsize model	NTUA
	Task 4.4 Test/develop hybrid time to capsize model	SSRC
	Task 4.5 Establish uncertainty bound on ttc models	SSRC
WP5	**Rescue process modelling**	**BV**
	Task 5.1 Benchmark data on mustering/abandonment/rescue	BV
	Task 5.2 Test/develop mustering (M) model	BMT
	Task 5.3 Test/develop abandonment (A) model	BV
	Task 5.4 Test/develop rescue (R) model	BV
	Task 5.5 Establish uncertainty bounds on M-A-R models	SSRC
WP6	**Standard for decision making in crises**	**SSRC**
	Task 6.1 Develop loss function	SSRC
	Task 6.2 Develop likelihood function	SSRC
WP7	**Demonstration**	**NTUA**
	Task 7.1 Benchmark data on casualty mitigation cases	NTUA
	Task 7.2 Demonstration of a casualty mitigation standard	BMT
	Task 7.3 Demonstration for use as a design standard	NTUA

* The FLOODSTAND Consortium members' acronyms, full names and country are: **AALTO**: Aalto-korkeakoulusäätiö (=operating as Aalto University), Finland, **STX**: STX Finland Ltd (Finland), **CNRS**: Centre National de la Recherche Scientifique, France, **CTO**: Centrum Techniki Okretowej Spolka Akcyjna, Poland, **DNV**: Det Norske Veritas AS, Norway, **BMT**: BMT Group Limited, UK, **MARIN**: Stichting Maritiem Research Instituut Nederland, NL, **MEC**: MEC Insenerilahendused, EST, **MW**, MEYER WERFT GmbH, Germany, **NAPA**: Napa Ltd, Finland, **SSPA**: SSPA Sweden AB, Sweden, **RTR**: Rosemount Tank Radar, Sweden (RTR became a Consortium member, when SFC, SF-Control Oy, Finland, ceased to exist as it was merged to its mother company 1.1.2011), **NTUA**: National Technical University of Athens - Ship Design Laboratory, Greece, **BV**: Bureau Veritas – Registre International de Classification de Navires et d Aeronefs SA, France, **SaS**: Safety At Sea Limited, UK, **MCA**: Maritime and Coastguard Agency, UK, **SSRC**: University of Strathclyde, UK.

4.1.3 The main S&T results/foregrounds

4.1.3.1 Design and application[2]

In WP1, Design and application, two cruise ship designs of different size were produced. These ship designs were then used in other work packages for flooding calculations and assessments. The applicability of the findings of other work packages, mainly WP2, on the design of modern cruise ships was investigated. Consideration was used to take the advantage of most of the results of the other work packages, however. Main focus was laid on the results of the full scale flooding tests and simulation work of WP2, but also the design targets presented in WP6 have been considered.

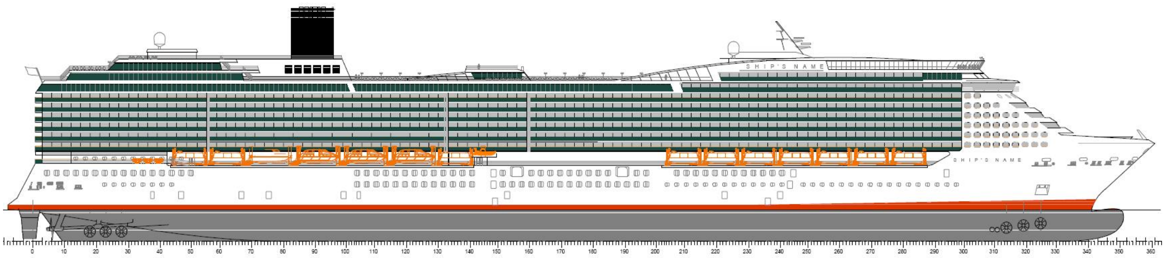

Figure 1 Side view of the post-Panama sized cruise ship design created by STX in FLOODSTAND WP1/Task 1.1; 125.000 GT, L = 327 m, B = 37.4 m, T = 8.8 m (Source: Deliverable D1.1a)

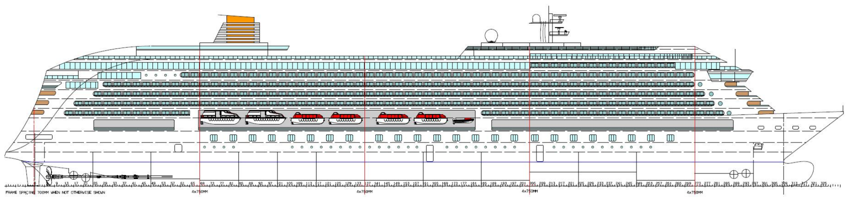

Figure 2 Side view of the medium sized cruise vessel design created by MW in FLOODSTAND WP1/Task 1.1; 63.000 GT, L = 238 m, B = 32.20 m, T = 7.4 m (Source: Deliverable D1.1b)

It was shown, that the results found in these work packages do not have a significant influence on the global design of cruise ships, as many of the assumptions defined in the explanatory notes of SOLAS could be confirmed in this project. However,

- the results obtained in project FLOODSTAND give more precise input data and thus, more reliable basis for time domain flooding simulations used for stability studies and assessments.
- Significant details in the design of the watertight subdivision of cruise ships can now be improved to enhance safety and to consider the physical behavior of the ship.
- A number of items have been identified, which need to be addressed to the Regulatory Bodies to improve the SOLAS convention and its explanatory notes.

[2] Lead beneficiary: STX Finland, Other participants: Meyer Werft GmbH (MW), AALTO, DNV

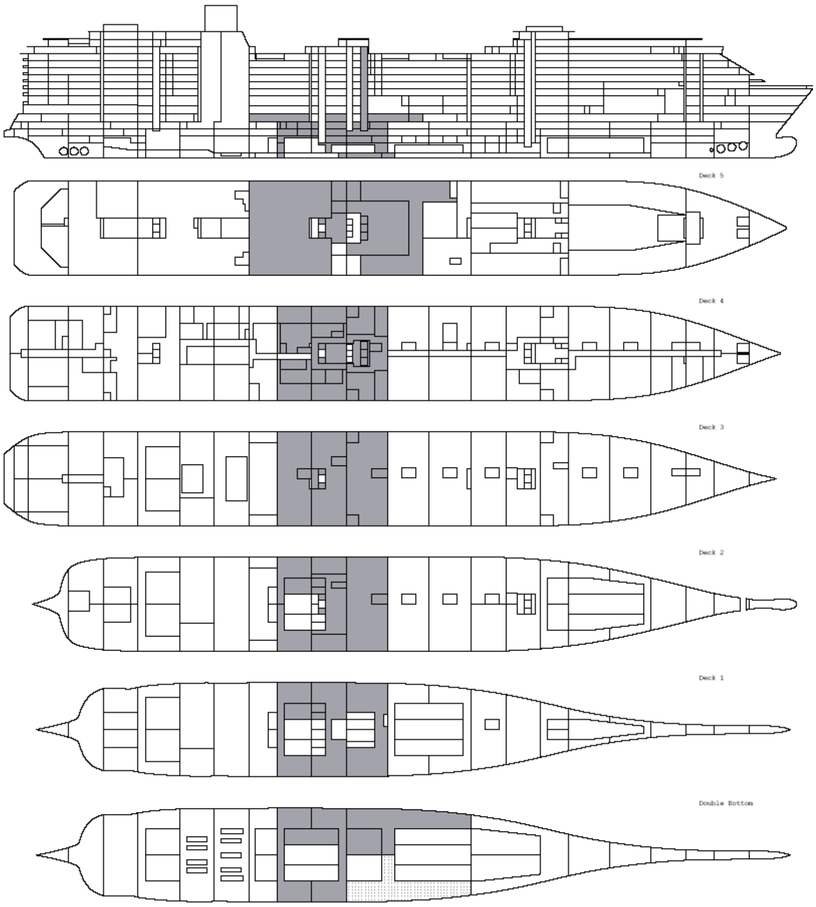

Figure 3 Damage case; instantaneous cross-flooding in large DB dry tank (Source: Deliverable D1.2)

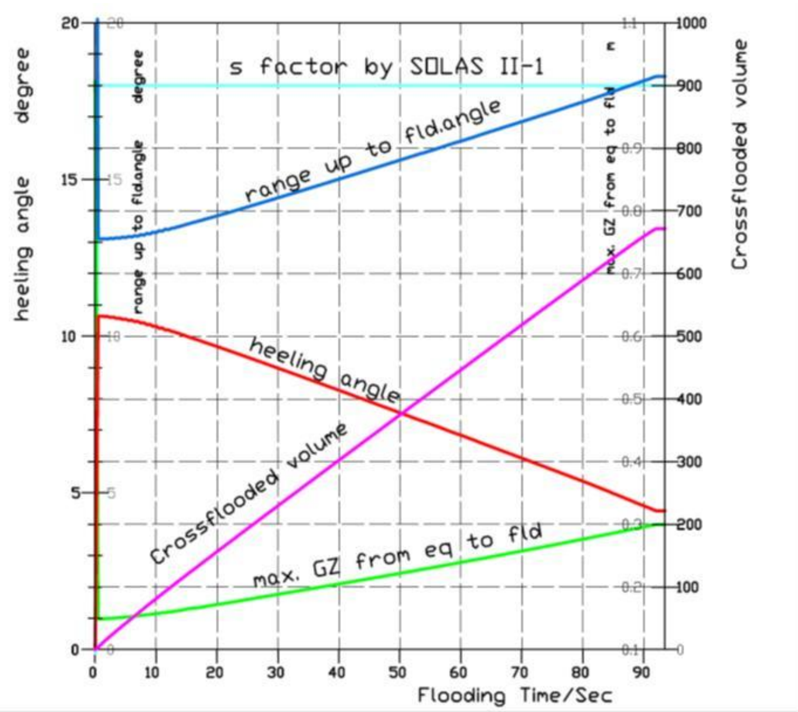

Figure 4 Floating position and s-factor during instantaneous cross-flooding (Source: Deliverable D1.2)

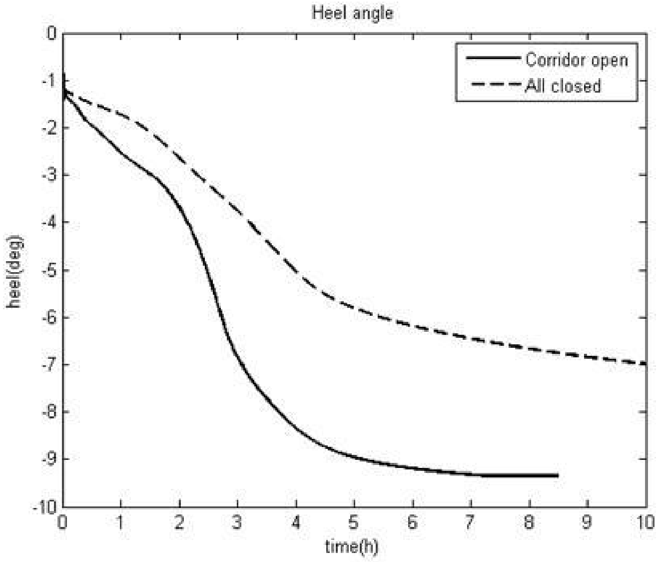

Figure 5 Effect of the status of fire doors on bulkhead deck: Change of heel angle in another damage case, with the service corridor doors open (solid line) and with all service corridor doors closed (dashed line). (Source: Deliverable D1.2)

4.1.3.2 Flooding progression modelling[3]

Flooding progression modelling and all the work carried out within its context was a large work package. It included several tasks and sub-tasks ranging from the planning and execution of various experimental tests, but also several numerical tests, applications of CFD and FEM. As described earlier these research efforts were directed to produce new data and knowledge related to the following topics: cross flooding, pressure losses in openings and cross flooding ducts, leakage and collapse of non-watertight doors, flooding progression and time-to-capsize.

The tests with non-watertight doors at CTO started with the design of the test stand for static pressure loading of the ship structure mock-ups (e.g. walls with cabin, fire doors or SWT-doors). This sub-task included the preliminary planning of the tests and planning & decisions on the structures to be tested as well as the planning & development & construction of the new test stand & equipment needed for the tests and the planning of the test procedures.

One of the most important parts of the test stand was built in the form of a watertight tank with one exchangeable wall where each structure to be tested (i.e. the test specimen) was installed (see Figure 6). The tank was fitted with piping system for static pressure adjustment with pumps. Other elements of the test stand design included the measurement and monitoring equipment arrangement for stress distribution within the structure and for obtaining of the flow rate through the leakages during the structure collapse.

[3] Lead beneficiary: AALTO, Other participants: CTO, CNRS, MARIN, MEC, NAPA, STX Finland, MW.

Figure 6 Test stand with a test specimen (in a frame) attached for the test in WP2/Task 2.1. In this case the test specimen is: cabin wall panel. (Photo: Deliverable D2.1b)

The general descriptions of the mock-up and test procedure as well as the list of structures to be tested, being most important for the other participants (especially shipyards) was available already at an early phase of the project. Potential misunderstandings between CTO and other parties involved in the planning of the tests were avoided by meetings and close contacts by other means. Co-operation was essential for attaining a common understanding and agreement about many issues related to the tests and their preparations. The decision to build the test pieces in standard frames (see Fig. 7) at the shipyards before shipping them to CTO was made in a meeting in autumn 2009 at the STX shipyard in Turku.

The design & production & outfitting of the test stand was a challenging task, not least due to all safety aspects. However, the test stand was completed in early spring 2010. At that time test specimens from STX had already been delivered to CTO. MW delivered the next test specimens a bit later.

a) A-class fire door, double leaf *b) B-class door*

Fig. 7 a & b: Some examples of test specimens (doors & other structures to be tested) attached to the test frames, specially manufactured by STX, waiting for transportation to Gdansk, Poland, to be tested at CTO in WP2/Task 2.1. (Photos by STX)

A model basin in Gdansk at CTO was used for the experiments enabling controlled conditions of the water level and flow. Furthermore the capabilities provided by the model basin infrastructure enabling the construction of the pressure piping installation at least 7 m above the basin bottom level as well as the effective operation of the mock-up. The tightened requirement for a higher pressure head up to 15-20 m was a challenge, but it could be solved. During the measurements the test stand/mockup was filled with water, gradually increasing the pressure up to the level with starting leakage and structure collapse. (See Figure 8)

The tested structures were monitored with respect to the loading (pressure) and stress distribution. A laser equipment was found necessary for recording the deflections. After the start of the test the pressure, the deflections of the tested structure and the leakage rate were measured, until the tested structure collapsed or until the maximum leakage rate, the test setup could counteract, was attained. A total number of 20 tests were carried out, the number of tests was slightly smaller than originally planned due to combining of some doors with the neighbouring wall panels and the incurred costs.

- Significant results attained were:

- Test methodology developed
- Test stand/mock-up
- Test results of the unique destructive tests carried out

a) SWT-door, sliding *b) Cabin wall*

c) Close-up of the bottom part of a door in a test (Door deflection at points 4, 5 and 6 were measured with laser equipment)

Figure 8 a, b &c (above): Some test specimens (= test objects or stuructures) during the experiments at CTO in WP2/Task 2.1. (Photos: Deliverable D2.1b, CTO)

Test methodology developed in Task 2.1, the test stand/mock-up itself and the test results, described in the public reports D2.1a & D2.1b are clearly significant results of the project. To our knowledge the results of the tests in Task 2.1 are unique. A short overview of the experimental tests in T2.1 was included in a general presentation of FLOODSTAND in the 11th International Ship Stability Workshop in Wageningen, The Netherlands, in June 2010. Results of the tests in Task 2.1 have also been introduced to IMO in SLF53 in January 2011, together with a short overview of project FLOODSTAND and some other results of WP2, and also in SLF54 in January 2012.

The work to design and manufature the test frames, into which the test specimens were attached, increased the amount of work at the shipyards and the transportation costs. However, this choice confirmed well-fitting parts (with test specimens) to be easily attached to the test stand for the tests and thus a clearly shorter delivery cycle of the actual tests.

Numerical studies and analysis of leaking and collapsing structures were alsocarried out. The numerical studies in sub-task 2.2.1 involved analyses where the standard doors and lightweight walls were subjected to hydrostatic pressure. The aim was to estimate the collapse pressure for named structures and understand their behaviour. This knowledge helps to develop simplified formulas for collapse pressure estimation that can be used later on in flooding simulation.

Four types of structures were studied: cold-room structure (including wall and door), cabin wall, A-60 hinged door and A-60 semi-watertight sliding door. All these structures were analysed with non-linear finite element method. As a result, the collapse pressure was determined. The study included determination of material mechanical properties through testing. In order to validate the finite element results (see e.g. Figure 9) full-scale laboratory test were carried out on cold-room and cabin wall panels.

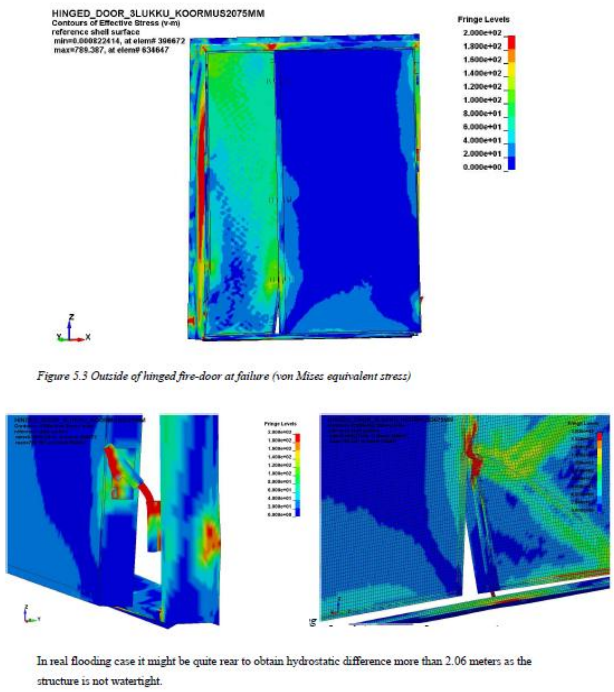

Figure 9 Numerical test on water pressure effects on a hinged fire-door; WP2/Task 2.2 (Photo: Deliverable D2.2a)

For cold room panel and for cabin wall panel the analytical models where developed in order to estimate the critical pressure heads. For standard door solutions the use of analytical methods is not practical as door failure often depends rather on the strength of joints (like screws, rivets, supporting profiles) as on the strength of the door itself. As a result of analyses critical pressure heads for above mentioned partitions were determined.

In all cases the critical pressure heads are well estimated as they coincide with the tests performed at CTO. The cold room panel sustains approximately 2.7 m of water pressure. A-60 SWT sliding door will collapse at water height 8.1 m where CTO tests indicated collapse at 8.36 m of water height.

According to simulation A-60 door will collapse at approximately 2 m of water level due to deformation of door joints. However, in tests CTO pointed out that the leakage limit was reached at 1 m of water level. Tests conducted in MEC and simulation on single cabin wall panel indicates that the panel will fail due to bending already at 1.1 m of water level. However, the panel will not collapse at that point as at the membrane forces start carry the load. Therefore, the final failure occurs at point where the total shear force reaches to value equal to the shear strength of the panel-deck connection. According to CTO the cabin wall panel can carry the load up to 1.2-1.4 m of water level.

• Significant results attained so far in this task (T2.2) were:

- Results from the laboratory tests carried out by MEC and published in deliverable D2.2a.
- Results obtained by comparing the results of the tests in Task 2.1&2.2 and those of the numerical analyses indicate that with the proper modelling technique the collapse of partitions due to water pressure can be estimated quite well. The modelling accuracy less than 20 % compared to test results can be achieved. However, this means that very detailed models must be analysed and material properties have to be known on stress-strain curve level.
- A short overview of T2.2 will be introduced to IMO in SLF53 in January 2011 (together with an overview of project FLOODSTAND and some other results of the project).

• The reason for a minor deviation (~1M) from the original schedule of the delivery of the first draft of D2.2a was related to the minor deviation from the original schedule of the availability of some of the test results from T2.1. The first draft of D2.2a was sent to the coordinator already in the end of August and for SC's comments on 16.9.2010. The latter delay was caused by the coordinator's sick leave. The complete draft version of D2.2a was available for the SC on 6.10.2010 and the final version of D2.2a was published on the project's web site on 25.10. 2010. No big impacts on other tasks or on available resources and planning are expected.

Definition	Action/Performance	Description	Conditions of use
Watertight	To withstand constant pressure[2] ($p > p_L$)	Under bulkhead deck	To be kept closed during navigation (special exceptions may be applied)
Light watertight	To withstand constant water pressure[3] ($p < p_L$)	On Bulkhead deck	To be kept closed during navigation (special exceptions may be applied)
Semi Watertight	Weathertight to provide positive residual stability[4]	On bulkhead deck and above	May be kept open during navigation

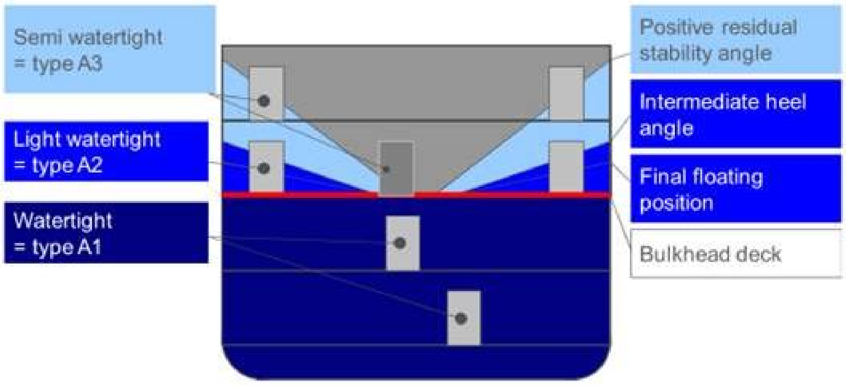

Figure 10 Category A doors in passenger ships
(Source: STX Finland, *used in Deliverable D1.2)*

One important part of the research on non-watertight structures involved was the development of easy-to-use criteria for the flooding simulation. Based on the experiments and the finite element simulations in Sub-Task 2.1.2 and in Sub-Task 2.2.1, the estimated risk criteria of leakage and collapse of doors and other structural elements needs to be known and proposed. This was done in deliverable D2.2b, published during the second 18-month period of the project.

- Significant results attained in the latter part of this task (T2.2) were:

- The guidelines in D2.2b were developed. They were based on the results of the experimental tests in Task 2.1 and of the numerical analysis in Sub-Task 2.21. Results from the laboratory tests carried out by MEC and published in deliverable D2.2a.

- A short overview of T2.2 was introduced to IMO in SLF53 in January 2011 (together with an overview of project FLOODSTAND and some other results of the project).

- The results of collapse/leakage pressure heads of non-watertight doors to simulate flooding of water through fire-rated doors along bulkhead deck have already been used in real ship design within the industry.

The experimental studies related to pressure losses in openings, e.g. in cross-flooding ducts, were carried out by AALTO (ex. TKK), with support from both shipyards, STX Finland and Meyer Werft GmbH. Important support in some special questions was also provided by the assisting Technical Coordinator for WP1-WP3 (NAPA), who acted as the host of the first planning meeting for T2.3 (and partially T2.1, too) on the 27.3.2009, soon after the official start of the project.

Figure 11 Flooding through a full-sized manhole in a flume tank tested in WP2/Task 2.3(Photo: Aalto University)

Valuable comments on the plans and details of the model of the cross-flooding duct to be built by AALTO were received from all partners (STX, MW and NAPA). Experimental studies on the pressure losses in man-holes were performed in scales: 1:1, 1:2 & 1:3, to obtain numerical data for validation of CFD-calculations. The full scale manhole for the tests (see Figure 11) was provided by STX Turku shipyard.

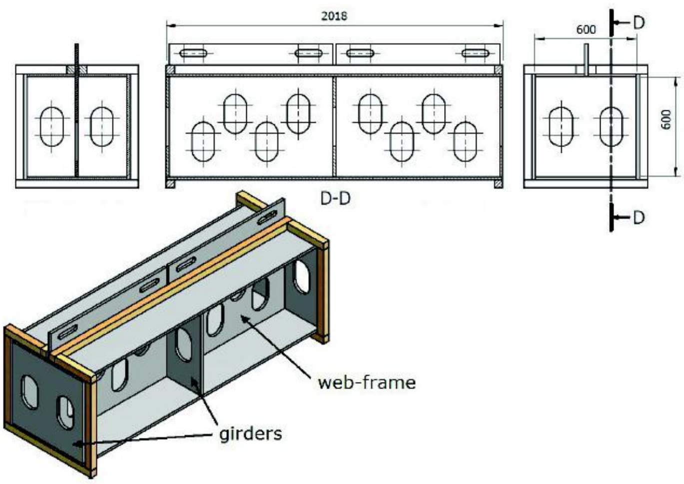

Figure 12: The dimensions of one 1:3 scale model cross-duct module with a web frame in the middle of the cross-duct built in WP2/Task 2.3
(Note! The web-frame was not present in the model during most tests. Stiffeners are not included in this figure, although present in most of the tests. See Fig. 11 for comparison)

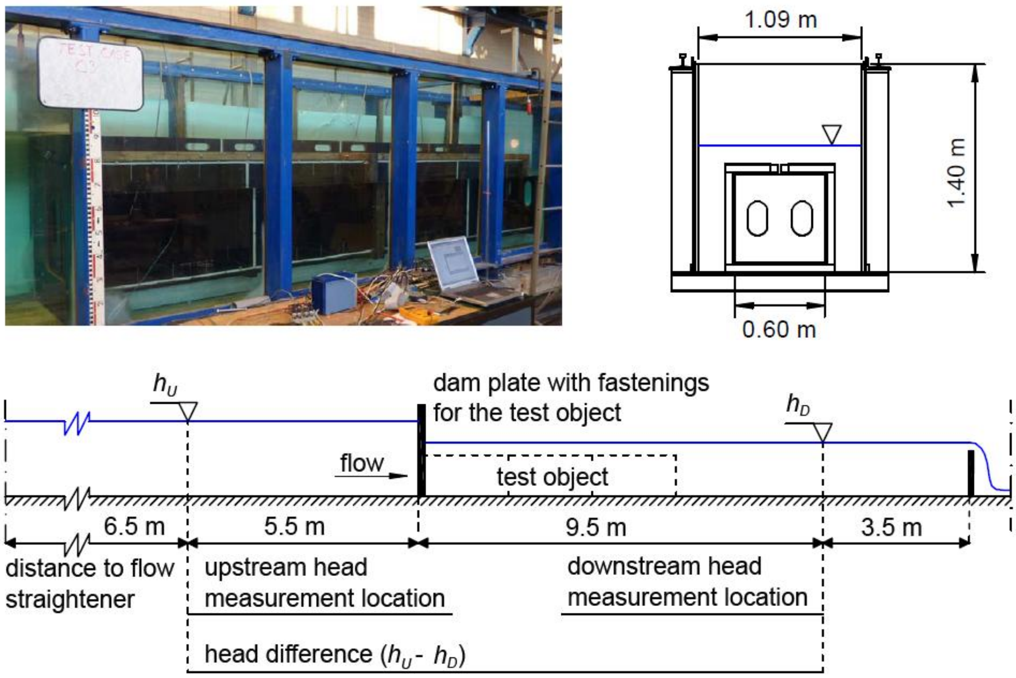

Figure 13 Longitudinal and cross-sectional views of the experimental set-up in the flume for cross-flooding duct tests in WP2/Task 2.3 (Aalto University/TKK)

The test were continued by systematic model tests with different modifications of a typical arrangement of a cross-flooding duct (see Fig. 12 & Fig 13) 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. Preliminary results were exchanged with Task 2.4 (CNRS). A demonstration of a test in the flume was arranged for the Task-participants in December during a Task-level meeting. Tests were completed before the project meeting in Gdansk, 9.-10.3.2010, where the results were presented. The full draft deliverable D2.3 was completed & submitted for the comments of the project Steering Committee on 27.4.2010, and the final version of it was published on the project's public web site later in May 2010.

- Significant results attained in this task (T2.3):

- Results from all laboratory tests carried out by AALTO are published in D2.3
- Key results:
  -- The structural stiffeners inside the cross-duct and on the single girders were found to significantly increase the value of the discharge coefficient CD.
  -- The influences of the web frame and the inclination of the cross-duct on the value of the discharge coefficient were negligible.
  -- There is a risk that the discharge coefficients of cross-ducts are overestimated if the guidelines of the IMO Resolution MSC.245(83) are applied without properly considering the geometrical properties of the girders in the cross-ducts (see Fig. 10).
- Results of the tests in Task 2.3 will be introduced to IMO in SLF53 in January 2011 (together with a general overview on project FLOODSTAND and with some other results of the project)
- A journal paper related to these tests has been submitted to Ocean Engineering
- A short overview of the tests in T2.3 was included in a general presentation of the project FLOODSTAND, too, in the 11th International Ship Stability Workshop in Wageningen, The Netherlands, in June 2010

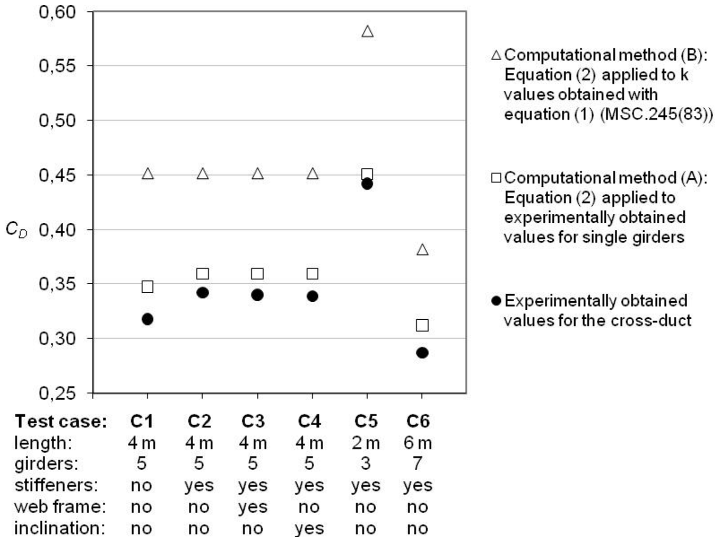

Figure 14: Comparison between the experimentally obtained discharge coefficient for the crossduct and the corresponding computed value (Source: Deliverable D2.3 v.1.2.1)

CFD computations on detailed parts of the ship using the configurations chosen in Task 2.3 were also made. The list of openings etc. to be studied was also originally planned in the first planning meeting for T2.3 (and partially T2.1, too) on the 27.3.2009, soon after the official start of the project. However, the detailed research objects were confirmed later, during the second 6-months period of the project, when EC had signed the contract with the Consortium and CNRS could start their efforts (after summer vacations).

The CFD computations can be used to provide a global and simplified flood-simulation tool with unknown coefficients (pressure loss in various openings, for instance). Since the number of configurations of interest is very large, these computations were distributed among two CFD partners, CNRS using their in-house RANSE solver ISIS-CFD and CTO using Fluent. The CFD computations made are reported in D2.4a. (Some Figures of this report are presented below in Figs. 15 and 16).

Some test cases were computed in model scale in order to study the scale effects. Test cases, with three different water elevations were computed by both project participants.

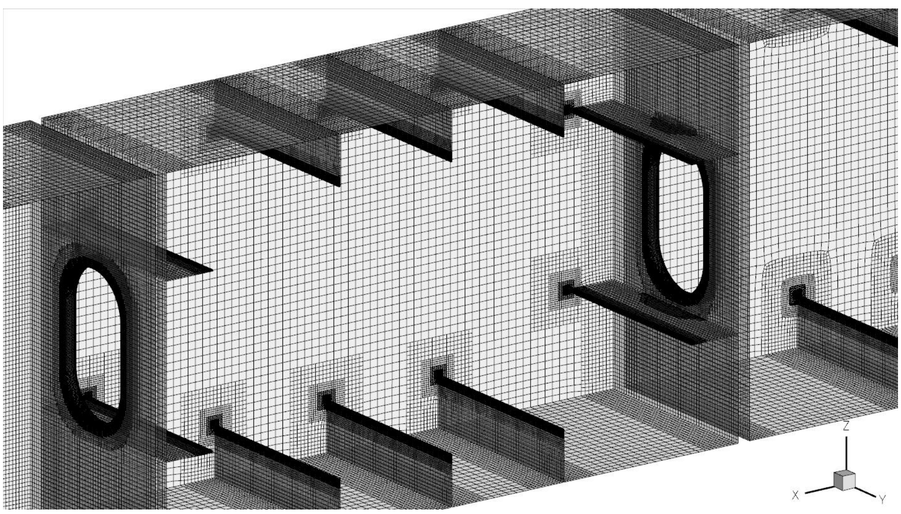

Figure 15: Surface grid details illustrating part of the surface grid in the middle region

of the cross-duct (Source: Deliverable D2.4a)

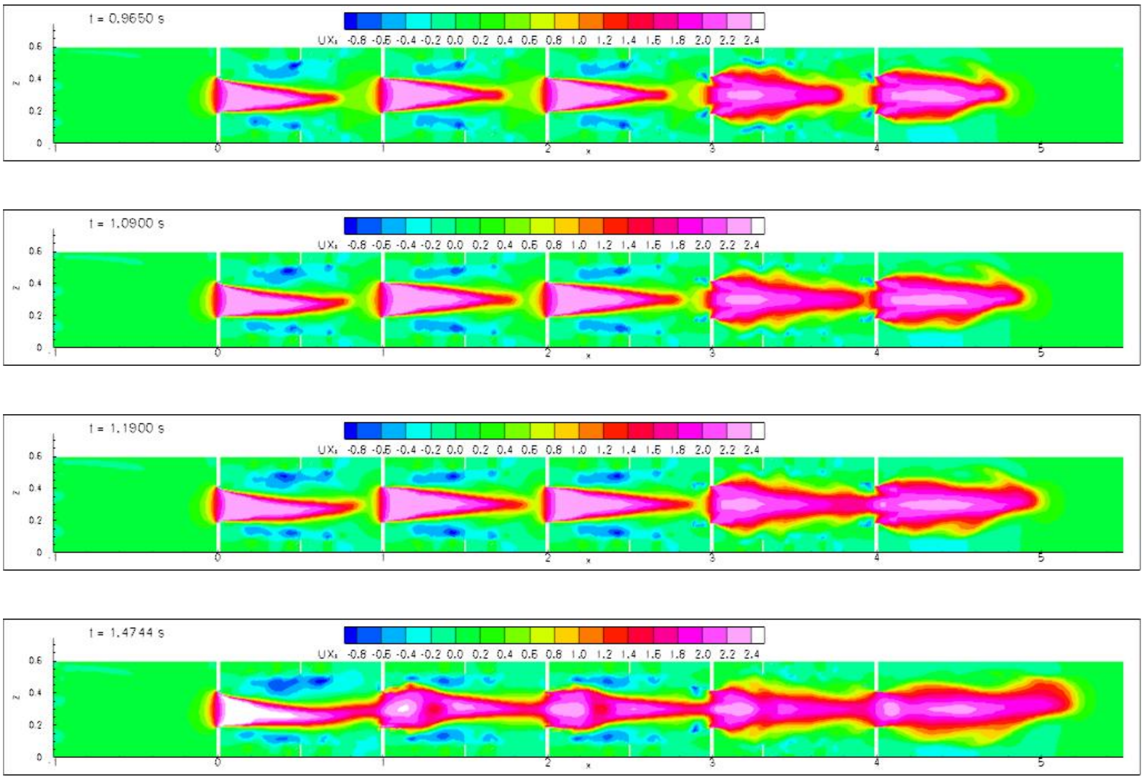

Figure 16: Time history of iso-U distribution in Y middle cut plane of a cross-flooding duct composed of three modules, one of which is presented in Fig. 8, without stffeners (Source: Deliverable D2.4a)

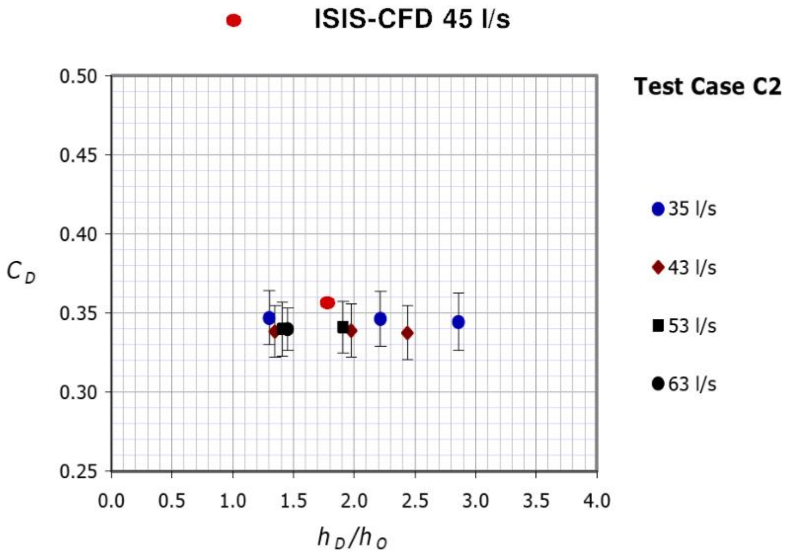

Figure 17 Plot of the discharge coefficient and the downstream head to opening; a comparison between CFD & model test results (Sub-Task 2.4.1 & Task 2.3)

• Significant results attained in this sub-task (Sub-Task 2.4.1):

- Results from these studies, carried out by CNRS & CTO, are published together in D2.4a
- The CFD simulation of the model-scale cross-duct is in good agreement with the experimental results (see Fig. 17). Furthermore, calculations for full-scale duct with high pressure heads at the inlet (5 m and 10 m) resulted in very similar discharge coefficients. This supports the application of CFD, allowing studies with much higher pressure heads than in the experiments (carried out)

- A short overview of these studies, based on the D2.4a will be introduced to IMO in SLF53 in January 2011 (together with the project FLOODSTAND and some other results of the project). An annex to the relevant Inf.-paper has already been submitted to IMO. Further publications in journals etc. are planned/developed.

The effects of air compression are an important topic, but often neglected although the effects of air ventilation can have impacts on progressive flooding. A systematic analysis on the ventilation in a typical tank compartment of a modern passenger ship was performed by dedicated CFD simulations carried out by CTO in order to assess the pressure losses in typical air pipes from the voids since the counter pressure of air can have a significant effect on the cross-flooding time. The air compressibility is taken into account in the computations.

The analyses apply to a situation described as follows (D2.4b): flooding of the ship's double bottom causes air compression in the compartments located far from the damage region, and the effect of air cushion appears. The air discharge through the air pipes of the compartment venting system influences the flooding rate. The computational models are reduced to the air pipes only, with prescribed overpressure at the inlet and atmospheric pressure at the outlet. Such model allows for evaluation of the pressure loss coefficient as a function of over-pressure for particular air pipes.

Two types of air pipes were considered: an air pipe with free outlet and air pipe with air cap on the outlet (the air cap closes the pipe outlet in case of water on deck). The presented results include:
- Visualization of the pressure and velocity distribution in the air pipes;
- Values of air mass flow rate for given overpressures;
- Derived quantities: speed reduction factor & pressure loss coefficient for given overpressures.

The CFD results (pressure loss coefficient) for the air pipe with free outlet were compared with the results of simplified calculation based on the IMO resolution No. MSC.245(83). This comparison shows that the simplified approach yields considerably higher values of pressure loss coefficient than CFD computations.

• Significant results attained in this sub-task (Sub-Task 2.4.2):

- The dependency on the overpressure difference seems to be marginal, and consequently it is reasonable to apply constant factor in cross-flooding time calculations.
- All results of the studies carried out by CTO are published in D2.4b
- A short overview of the studies in T2.4 will be introduced to IMO in SLF53 in January 2011 (together with the project FLOODSTAND and some other results of the project).
- The results have affected on the air pipe designs on planned newbuildings
- The final report, deliverable D2.4b, has been published on the public web site of project FLOODSTAND.

Model tests for cabin areas were carried out during the first 18-month period of the project and they have been discussed in deliverable D2.5b.

• Significant results attained in this task (T2.5):

- The lessons learned from the model tests are listed in the report and are valuable results as such
- An other remarkable result is the experience from special model tests of this particular type that they proved to be even much more complicated than originally foreseen. The test type and the environment, in which the model tests were carried out, form together an extremely challenging combination
- All deliverables related to this task were published before autumn 2011

Sensitivity studies of simulation model were scheduled to be started in the second 18-month period of the project, because of the need for results from the previous tasks in this and the previous WPs (WP1 and WP2). Therefore, the research related to this task was carried out mainly during the second 18-month period.

• Significant results attained in this task (T2.6):

- In the studies (reported in D2.6), no parameter variation whatsoever seemed to have any significant effect on the maximum transient heel[4] in the beginning of the flooding

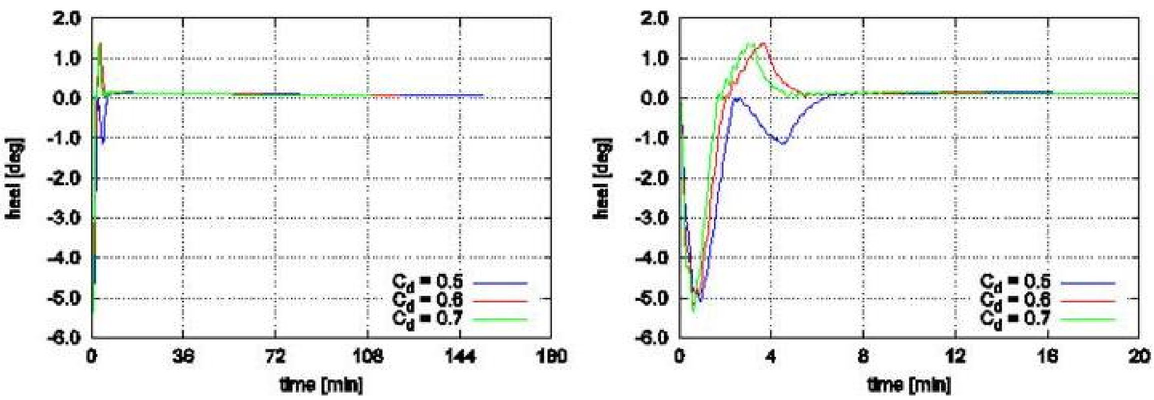

Figure 18 Time history of heel with different discharge coefficients (Source: Deliverable D2.6)

- The applied parameters had notable effects on the time-to-flood and on the progress of flooding and the heeling after the transient phase. For example, variation of discharge coefficient affected directly the flooding time and indirectly the collapses of doors

- Variation of critical pressure head for collapse had the most apparent effect on the way the flooding progressed. In this way it affected the nature of the heeling behaviour, but it also had an effect on the flooding rate and thus on the time-to-flood

- Leakage area modelling had a clear effect on the time-to-flood. This effect became apparent after the early flooding phases when most of the flooding was based on leaking through

[4] The transient heel angle at the beginning of the flooding may become very important if it can cause excessive transversal shift of heavy items onboard introducing a constant list of the ship or if it may act as a cause of additional (and consequently progressive) flooding through some openings above waterline.

closed doors. If the variation of A_{ratio} did not have an effect on the collapse of doors, the consequent effects especially on heel were almost non-existent

- In a flooding case, where most of the flooding is leaking through closed doors the applied leakage area ratio seemed to have a significant effect on the time-to-flood. E.g. underestimation by 50% can lead to up to 50% overestimation in the time-to-flood. However, the effects on the behaviour of flooding (e.g. order of flooded compartments) were minimal. Thus, the conservative approach is to use slightly too large leakage area ratios in order to avoid the over-estimation of time-to-flood

- Based on the presented studies, it seems to be well justified to use the industry standard discharge coefficient 0.6 for all openings, except the pipes and cross-flooding devices. Based on the CFD and model tests in Tasks 2.3 and 2.4 of the FLOODSTAND project, this value is very realistic

- The simplified formula for calculation of cross-flooding time, MSC.245(83) provides very similar results as detailed time-domain flooding simulation. However, the effective discharge coefficient for the duct should be determined with Eq. (7)[5] or with CFD since the use of the regression Eq. (6)[3] results in significantly too fast cross-flooding times

- One task of next SDS Correspondence group is to update draft amendments to the Recommendation on a standard method for evaluating cross-flooding arrangements (resolution MSC.245(83) and review equations 2.4 and 2.5 of the annex and figures 13 and 14 shown in the appendix 2 of the Recommendation. This review of MSC. 245(83) is based on the results received from project FLOODSTAND (and reported to IMO in SLF54/4)

- Deliverable D2.6 was published during this 18-month period

All deliverables of this part of the work (Work Package 2) have been completed within the scope of the project.

4.1.3.3 Flooding Simulation and Measurement Onboard[6]

In Task 3.1: Development of flood sensors data interpreter, a new inverse method for definition of flooding and damage extents based on flood level sensor data has been developed and documented. The accuracy of the method has been verified against accurate time domain simulation and even full scale test and the results were found good. However, the calculation took too much time to be able to apply for use on board ships.

Improved method for prediction of progressive flooding has been developed and reported. Computational performance has significantly improved from the initially used time-domain simulation without significant sacrifice of accuracy. This method forms a solid basis for decision making applications to be used on board ships.

[5] in deliverable D2.6
[6] Lead beneficiary: NAPA, Other participants: AALTO, STX, DNV, MARIN, RTR

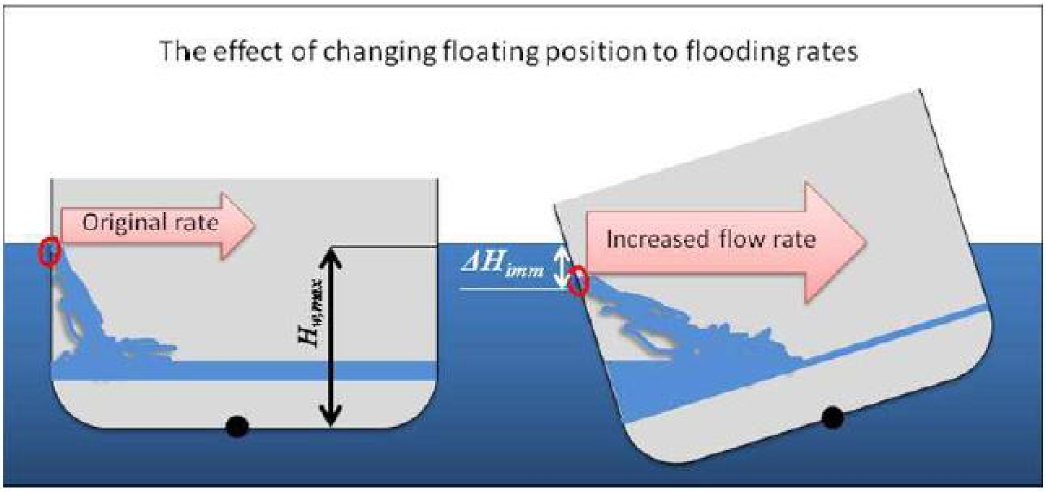

Figure 19 The effect of changing floating position on the flooding rate through the breach (Source: Deliverable D3.1)

In Task 3.2: Impact of ship dynamics, a new approach on calculation of the motions of a damaged ship has been developed by combining NAPA and LAIDYN software.

In Task 3.3: Design of flood sensor systems, a guideline for design of flood sensor systems to be used for decision making systems has been developed. The guideline discusses the type, required number and location principles of flood water sensors to achieve sufficient accuracy of the flooding prediction calculations (Task 3.1).

Significant achievements in WP3 were:

In Task 3.1: Development of flood sensors data interpreter: Computational performance and accuracy of the improved method for prediction of progressive flooding has reached acceptable level for analysing of real time accident scenarios. This method forms a solid basis for decision making applications to be used on board ships.

In Task 3.2: Impact of ship dynamics: Combining NAPA and LAIDYN software makes it possible to take into account the effect of sea state in the flooding prediction calculations. After some further development, this can be integrated into the decision making system to be used on board ships.

In Task 3.3: Design of flood sensor systems: A clear guideline for design of flood sensor systems makes it easier for the shipyards and ship owners to define the required level of instrumentation needed for successful application of flooding prediction calculations. The guideline forms a solid basis for further discussion at IMO targeting to revised requirements for passenger ships.

All reports of this part of the work (WP3), deliverablesD3.1, D3.2 and D3.2, have been completed and published.

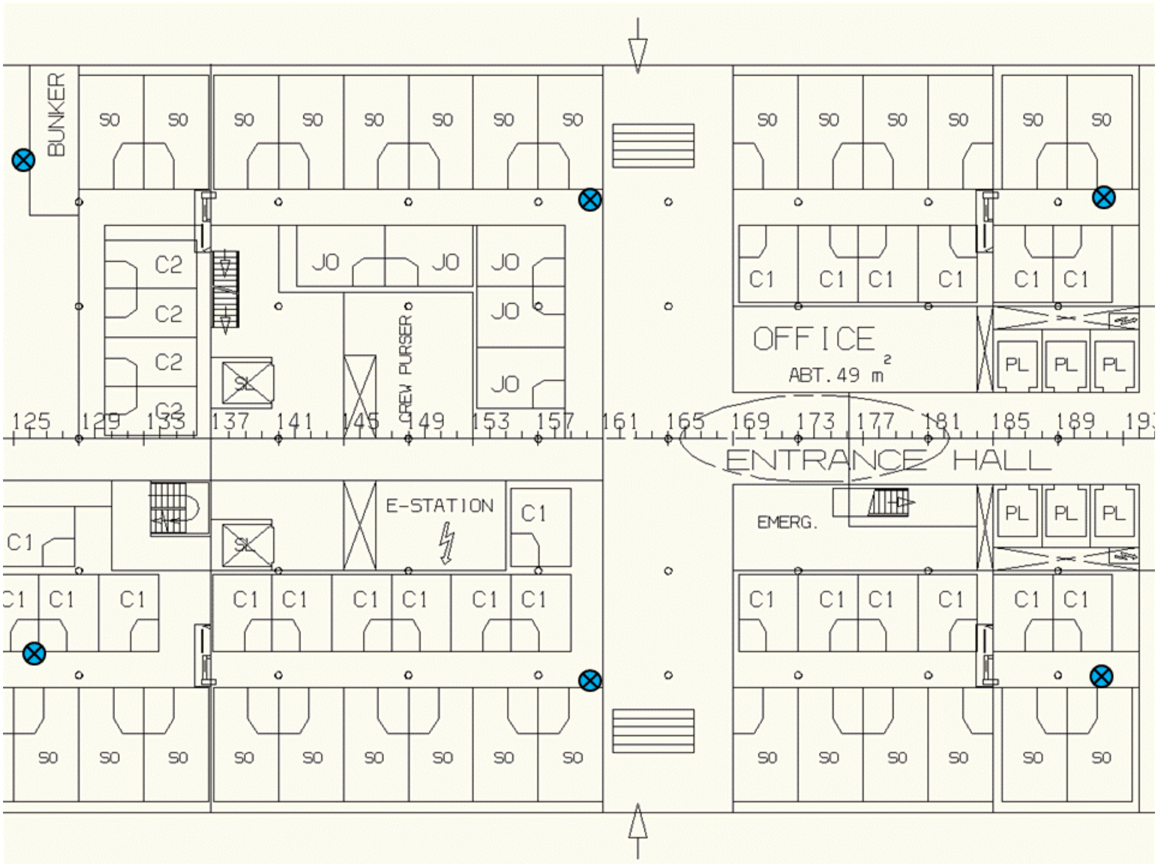

Figure 20 Sensors above bulkhead deck (Source: Deliverable D3.3)

4.1.3.4 Stochastic ship response modelling[7]

Analytical model for prediction of the time to capsize after flooding has been derived as follows.

$$F_{cap}\left(t \mid Hs\right) = 1 - \left[1 - \Phi\left(\frac{Hs - \left(H_{crit} - \varepsilon\right)}{0.061 \cdot \left(H_{crit} + \varepsilon\right)}\right)\right]^{\frac{t}{t_0}}$$

$$H_{crit} = 4 \cdot \left(\frac{GZ_{\max}}{0.25} \cdot \frac{Range}{25}\right), \; t_0 = 30\,\text{min}\,, \; \varepsilon = 10^{-12}$$

Extensive discussion on the relationship between ship stability, legislative methods available and the process of ship stability deterioration observed in experiments have been presented. Based on an extensive validation studies for RoRo passenger type ships the model seems to be adequate to represent survivability for any type of hull damage of such ships which results in a known flooding extent, thus narrowing down information needed for quantitative assessment of time available before capsize.

Considering sensitivity to input information, especially concerning the extent of flooding, it is proposed that even though core validation study is performed for a RoPax ship case only, the proposed method may be applied to any type of vessel, e.g. cruise ships, as the key functionality of the solution is differentiation between completely survival and non-survival states valid equally for any ship, and despite the fact that some conservatism deriving from epistemic uncertainty pertaining to the model may be expected.

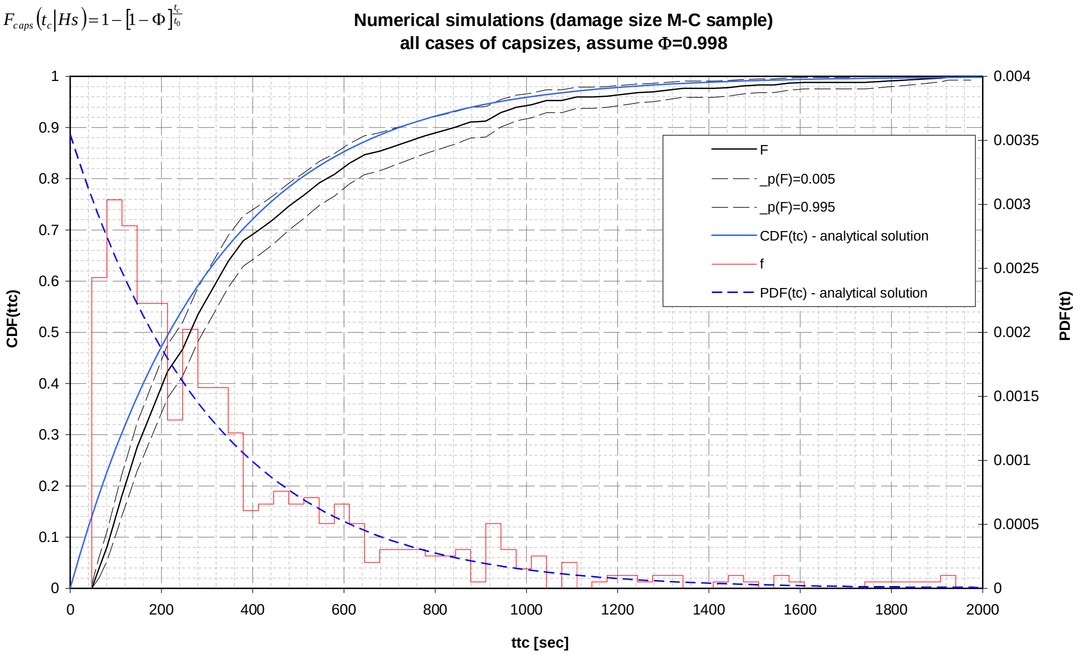

Figure 21 Results of numerical simulations of the distribution of ttc, Time to Capsize (Source:A. Jasionowski: Presentation in the final Workshop/Seminar of project FLOODSTAND, in Espoo 7.2.2012, available 25.2.2012 at: "http://floodstand.aalto.fi/Info/examples/final_workshop.htm")

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[7] Lead beneficiary: SSRC (The Ship Stability Research Centre), Other participants: SSPA, NTUA, SaS, MCA

The uncertainty analysis indicated that the **extent of flooding,** affecting parameters of GZ_{max} and Range, seems to be one of the most critical information needed for confident assessment of criticality of flooding situation. The precision or lack thereof in estimating the extent of flooding experienced during crises seems to be an overriding uncertainty datum, on the basis of which the epistemic uncertainties of the modelling itself should be considered acceptable for engineering purposes of decision making during crises

A hybrid model of ship stability deterioration process, combining numerical simulations with analytical projections, was developed based on Bayesian inference framework.

$$F_{T|\Phi}\left(t_c \middle| \varphi(t)\right) = \sum_i \frac{p_D(d_i) \cdot F_{\Phi|D}\left(\varphi(t) \middle| d_i\right)}{\sum_j p_D(d_j) \cdot F_{\Phi|D}\left(\varphi(t) \middle| d_j\right)} \cdot F_{T|D\&\Phi}\left(t_c \middle| d_i \cap \varphi(t)\right)$$

A case study indicated that little or no enhancement on projections of the situation evolution can be attained during crises through observing ship angle of heel.

This result implies that judgements based on perceptions or measurements of angle of heel might be misleading in both directions, (a) when an angle of heel is observed it might not mean that the situation is critical and (b) when no angle of heel is observed might not imply that the situation is “safe”. It must be noted, however, that these observations are based on only small sample of numerical experiments, and that therefore further studies are needed to understand better the nature of inferences that can be drawn from real-life information during evolving crises.

Therefore, any assessment must strive to minimise the uncertainty (predominantly the extent of flooding) to minimum and methods, perhaps such as derived in this project, must be used for systematic judgement on criticality of the situation rather than rely on subjective judgement of the crew.

These conclusion could not have been obtained readily based on pure numerical simulations, model experiments or pure analytical solutions, and hence the hybrid modelling proves to add value to studies on the process of stability deterioration after flooding.

Main achievements:

- All model test results with the model of Estonia, from Task 4.1, Part a, Part b and Part c are now available and reported in D4.1
- Demonstrated the reliability of numerical simulations (WP4)
- Identified robust modeling principle for use in any decision support system
- An analytical model for ttc was developed
- A hybrid model of ship stability deterioration process, combining numerical simulations with analytical projections, was developed
- All deliverables were finally produced

4.1.3.5 Rescue process modelling[8]

The progress towards objectives included gathering benchmark data on mustering/abandonment/rescue and the

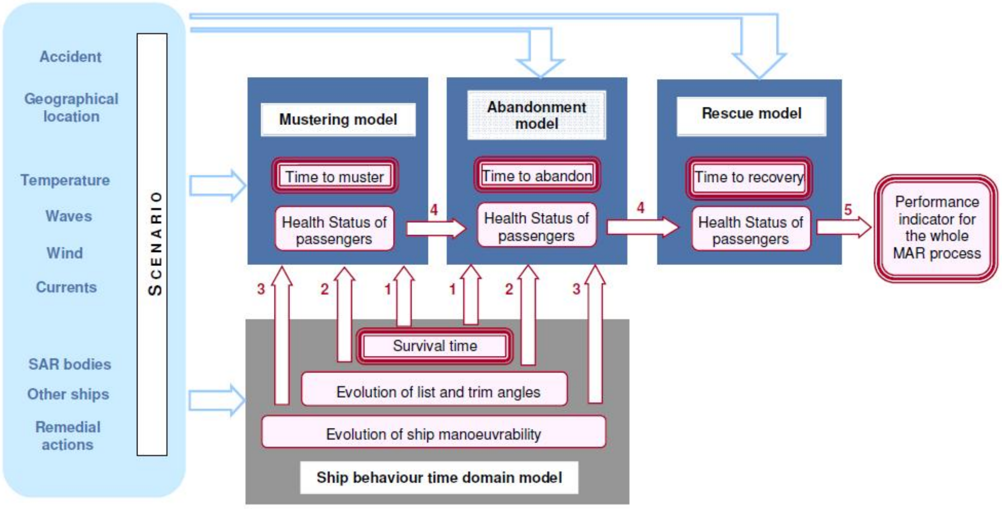

Figure 22 A schematic view of the M-A-R model to be developed in WP5 (Source: Deliverable D5.1)

Task 5.1 has been finalised and the work is described in deliverable D5.1 published on the public web site of FLOODSTAND on 15.3.2010.

Test/develop mustering (M) model

Tasks 5.2, 5.3 and 5.4 have exactly the same architecture. Therefore, the activities performed in Tasks 5.2, 5.3 and 5.4 are run in common.

The sub-task related to the refinement of the scenarios was completed by obtaining the data concerning the two demonstration cases were gathered concerning the type and number of Life-Saving Appliances, their characteristics (capacity and internal arrangement), the characteristics of the means of rescue used, etc.).

Definition of the main obstacles, phenomena, and significant parameters was completed. A final consolidated list of obstacles for the Mustering phase has been agreed between partners. The significant parameters of the models for assessing those obstacles have been defined.

One part of the research was the definition of the analyses to be performed. The sub-task is completed. The tools that have been used to perform the analysis have been defined. Scenarios (list angles, time of day…) have all been listed.

A model for the further analysis was defined. All simulations have been carried out on the software Evi by SSRC. Time to Muster for both reference ships and for all scenarios been calculated.
The model was tested and the results have been developed in Deliverable 5.5.

[8] Lead beneficiary: BV, Other participants: BMT, SSRC, SaS, MCA

Task 5.2 has been finalised. The complete draft version of the corresponding deliverable D5.2 was submitted to the coordinator with a delay on the schedule (on the 9th of November 2011). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.2 was published on the public web site of FLOODSTAND on 03.01.2012.

Test/develop abandonment (A) model

Sub-task 5.3.1: Refine scenarios

This sub-task is completed and was carried out together with Sub-task 5.2.1 (see above).

Sub-task 5.3.2: Define main obstacles, phenomena, and significant parameters

This sub-task is completed. The obstacles associated to the Abandonment phase were listed, the phenomena to be modelled in order to assess their influence were identified.
The relevance and significance of the obstacles were discussed by all partners.
A final consolidated list of obstacles for the Abandonment phase has been agreed between partners. The significant parameters of the models for assessing those obstacles have been defined.

Sub-task 5.3.3: Define analyses to be performed

This sub-task is completed. The tools that need to be use to perform the analysis have been defined. Parameters influencing each obstacle have all been listed.

Sub-task 5.3.4: Develop one model

This sub-task is completed. A model has been developed for each obstacle and each EU FP6 Safecrafts project result that can be reused has been adapted to FLOODSTAND scenarios and reference ships. All matrices associated with each obstacle have been calculated.

Sub-task 5.3.5: Test the model

This sub-task is completed. Results have been developed in Deliverable 5.5.

Task 5.3 has been finalised. The complete draft version of the corresponding deliverable D5.3 was submitted to the coordinator with a delay on the schedule (on the 9th of November 2011). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.3 was published on the public web site of FLOODSTAND on 03.01.2012.

Test/develop rescue (R) model

Sub-task 5.4.1: Refine scenarios

This sub-task is completed and was carried out together with Sub-task 5.2.1 (see above).

Sub-task 5.4.2: Define main obstacles, phenomena, and significant parameters

This sub-task is completed. The obstacles associated to the Rescue phase were listed, the phenomena to be modelled in order to assess their influence were identified.
The relevance and significance of the obstacles were discussed by all partners.

A final consolidated list of obstacles for the Rescue phase has been agreed between partners. The significant parameters of the models for assessing those obstacles have been defined.

Sub-task 5.4.3: Define analyses to be performed

This sub-task is completed. The tools that need to be use to perform the analysis have been defined. Parameters influencing each obstacle have all been listed.

Sub-task 5.4.4: Develop one model

This sub-task is completed. A model has been developed for each obstacle and each EU FP6 Safecrafts project result that can be reused has been adapted to FLOODSTAND scenarios and reference ships. All matrices associated with each obstacle have been calculated.

Sub-task 5.4.5: Test the model

This sub-task is completed. Results have been developed in Deliverable 5.5.

Task 5.4 has been finalised. The complete draft version of the corresponding deliverable D5.4 was submitted to the coordinator with a delay on the schedule (on the 29th of November 2011). After the time reserved for comments by the Steering Committee and consequent revisions, the final version of D5.4 was published on the public web site of FLOODSTAND on 03.01.2012.

Uncertainty bound

The scope of this task have been slightly shifted from original plan as uncertainty bound were difficult to assess due to the generic nature of the models developed in this work package, more information about this change can be found in the Deliverables.

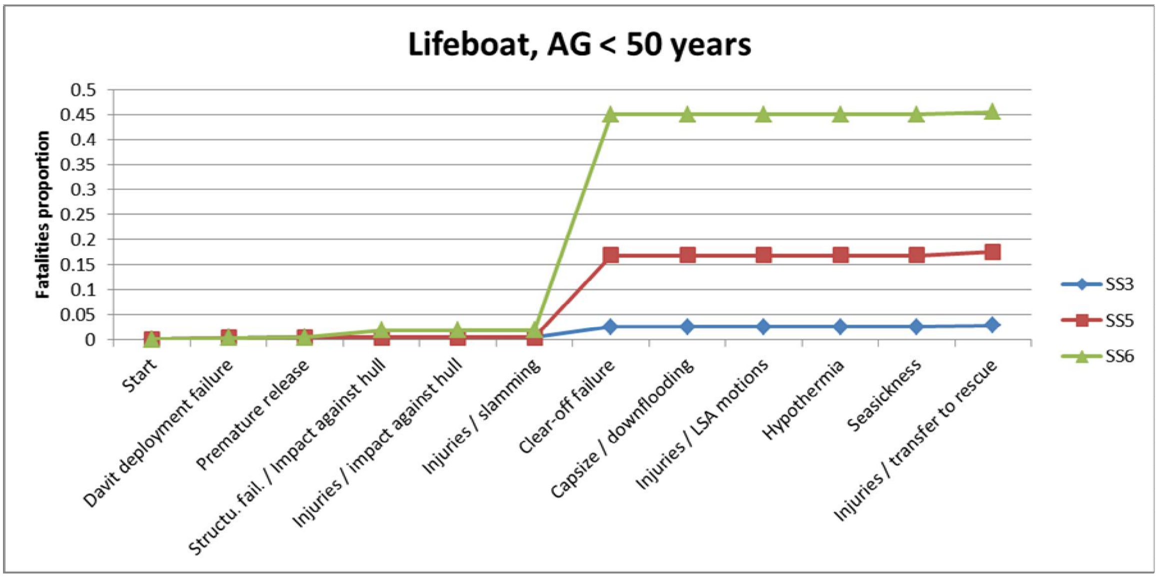

Figure 23 Expected casualties through the MAR process, influence of sea state, Lifeboat, <50 year old group (Source: WP5 Presentation in the Final Public Workshop of project FLOODSTAND)

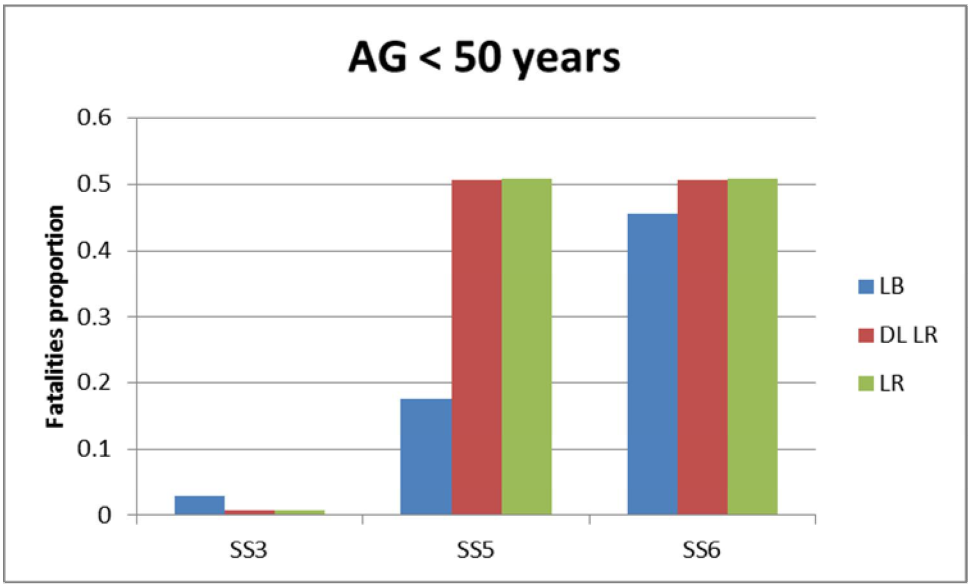

Figure 24 Expected casualties through the MAR process, influence of LSA type, <50 year old group

(Source: WP5 Presentation in the Final Public Workshop of project FLOODSTAND)

The main goal of the task 5.5 was to assess the MAR process as a whole using the results from all previous tasks as well as the software "Casualty calculator", developed by BMT (and described in deliverable D5.2).

• Significant results in WP5:
- A list of obstacles has been defined.
- All obstacle matrices have been calculated
- Several key parameters have been derived from WP5 results that have a significant influence on the expected number of casualties.

4.1.3.6 Standard for decision making in crises[9]

Models for loss function and likelihood functions have been proposed, and an integrated format of decision making process addressing ship's residual stability, the abandonment and the rescue operations, as well as dominant inherent uncertainties have been proposed, was given (in Deliverable D6.2) as follows:

Step 1 - Order mustering and follow with situation assessment at the first sign of distress
Step 2 - If flooding extent not determinable or escalating then abandon

Step 3 - Else if [$\min(0.125 \cdot Hs, 1) \cdot < F_{cap}(3hrs|Hs)$] then abandon [10]

Step 4 - Else stay onboard

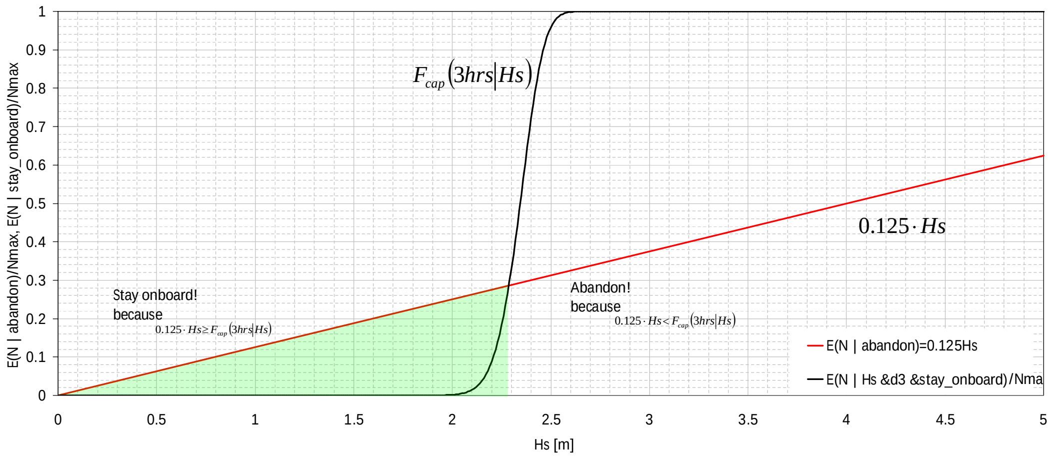

Figure 25 The decision making process, accommodating for key uncertainties. (Source: Deliverable D6.2)

Some fundamental uncertainties related to the assessment of the extent of flooding do not seem resolvable at present, and given considerable level of typical ship vulnerability to flooding with possible rapid capsize, it is recommended in the above process that the order to muster is an automatic and immediate crew reaction to first report or a sign that distress occurs. During the mustering time all efforts to assess the extent of flooding must be made, and in case doubts remain as to the scenario, or in case the flooding is escalating, an order to abandon should be given. In case flooding situation is well established, a quantitative criterion is given to make judgement on the risk balance between decisions of abandonment and staying onboard.

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9 Lead beneficiary: SSRC, Other participants: SaS, NTUA, MCA

10 Thus, according to the standard proposed in Deliverable D6.2, the order to abandon the ship is tightly coupled to the significant wave height (Hs) and to the applied models of:

- the expected losses in case of abandonment: min(0,125•Hs, 1)

and

- the expected losses in case of capsize in 3 hours: Fcap (3 hrs|Hs)

On the basis of a decision expected to lead to least expected casualties, Step 3, as given in Jasionowski (2012c), simply suggests to abandon, if the latter value is higher.

Naturally, the above process is susceptible to subjective interpretations as to what constitutes "doubt" or "well established" situation awareness, and these are proposed to remain discretionary judgements of the crew.

It follows that technologies (better sensors, their denser distribution and good maintenance) and procedures for monitoring of all of ship spaces should be developed, so that this fundamental uncertainty is resolved. However the proposed above procedure would seem competent and generic independent of the state of technology.

The process highlights the important decision making elements, which when used in training may allow the crew to better understand importance of their preparedness for handling crises.

Assessment of the likelihood function is proposed to be adopted for any type and size of the vessel, even though its key validation was performed for RoPax type ships only, as the formulation is based on generic parameters of residual stability, as well as generic assumptions on the impact of the process of floodwater progression ("GZ cut-off at down-flooding points"), with the latter mitigating the mentioned expected uncertainties of situation assessment.

Additionally, a mathematical model for an instantaneous stability monitoring paradigm has been proposed, facilitating efficient upkeep of crew preparedness for handling crises, should these occur. Such preparedness is possibly the most effective means of handling crises or its prevention in the first place.

The proposed prototype of the standard seems robust and reflective of the identified physics prevailing during flooding, loss of stability and abandonment, as well as the state of today's infrastructure available for establishing ship's status.

4.1.3.7 Standard for decision making in crises[11]

WP7, coordinated by NTUA, was organized with the aim of testing the FLOODSTAND approaches in view of the mitigation of the casualty risk of passengers onboard ships associated with the ship flooding hazard; the testing was understood within laboratory environment. The two developed approaches of FLOODSTAND, to be tested, were those of the "FLOODSTAND for crisis management", as elaborated in WP4-6, and the "FLOODSTAND for flooding control" approach, as elaborated in WP1-3.

The test conditions (benchmark scenarios for testing) were defined in task 7.1 for the ship in 'operation' (work of Task 7.2) and the ship in 'design' stage (work of Task 7.3). For the testing in the 'operation' mode (7.2), specific casualties and damage extents are considered, whereas differently in the 'design' mode some wider range of probable casualties was considered. The main challenges for the operational problem are the onboard detection of the damage case and subsequently the estimation of the ship's survivability for the particular damage detected. The challenge for the design problem regards the assessment of the full, as much as possible, range of probable casualties throughout ship's life. Operational problem may yield advice related to the evacuation of the damaged ships, whereas the design problem may drive decisions related to the watertight subdivision of the ships. The "FLOODSTAND for crisis management" was tested for both operational and design conditions (Tasks 7.2 and 7.3) according to the original work plan, whereas "FLOODSTAND for flooding control" was tested in operational only (Task 7.2) according to the modified work plan.

The "FLOODSTAND for crisis management" approach was tested by SSRC and BMT (Task 7.2), as implemented with the FLOODSTAND-ISTAND software, and was used to analyze two ships, one ROPAX (Estonia) and one cruise (Monarch), in real accident conditions. The conducted studies demonstrated that the results could be assumed as well correlated to the reported findings from the corresponding accident investigations; therefore they proved satisfactory for the developers (SSRC, BMT). However, due to the large uncertainty related to the detection of the damage extent, the onboard prediction remains accordingly of limited confidence. Furthermore, the studies put emphasis on the monitoring of the vulnerability of the ships due to the subdivision relaxations, which may result from the open watertight doors during ship operation. Thus, the associated risk might be well reduced before any flooding occurrence. This proactive function is considered of major importance particularly in view of the limited time for orderly abandonment, which is further confirmed in this project. The detailed work was reported with the deliverable D7.2a.

The "FLOODSTAND for flooding control" approach was tested by NAPA (Task 7.2), as implemented with the NAPA-Onboard software, and was used to analyze the flooding of two grounding casualties for one cruise ship, as they were defined in D7.1. The tests assumed some off-board setup (i.e. without estimations for the damage case/extent) for training purposes, and the collected results were to the satisfaction of the developers (NAPA). The method might be extended by exploiting additional information from water detection measurements, however it was not demonstrated. The consequences to the damage stability because of specific ship flooding could be computed with the tested tool, and awareness to the training crew could be provided. This was nicely demonstrated with the impact of watertight doors on the sinking of the damaged cruise vessel. The time performance of the flooding prediction tool needs still some improvement. The graphical user interface may improve functionality of the tool however contributes further to the computational requirements. The detailed work was reported with the deliverable D7.2b.

The "FLOODSTAND for crisis management" was also tested for ship design practice (Task 7.3). For this purpose the two passenger ships one RoPax (Estonia) and one cruise ship

[11] Lead beneficiary: NTUA, Other participants: SSRC, BMT, NAPA, SaS, BV, MCA

(concept design B, WP1) were tested by NTUA. Monte Carlo simulations were carried out to assess the probabilistic properties of the time to capsize, which is the fundamental variable of the approach, within a probabilistic design environment for collision side damages. The results enhanced evidences that that capsize events in collision damages systematically occur in short time (roughly 30 min) after the damage incident for both studied ships. This is quite short time to manage an orderly evacuation and abandonment of the ships, and particularly for the larger passenger ships. In this context, the applicability of the tested approach could not be concluded as the approach found to be insensitive in the range of the short times and for the generic probabilistic environment assumed. No remarkable impact of the alternative subdivision scenarios on the probabilistic properties the time to capsize could be detected. The detailed work was reported with the deliverable D7.3.

Significant results of this Work Package were:

- The onboard detection of the damage extent, which determines the ability to assess the ship’s survivability, remains an open challenge for the onboard applications that deal with the survivability of the ship in flooding casualties.

- Additional evidences were generated indicating that the available time for orderly evacuation of both RoPax and cruise ships engaged in flooding incidents is much shorter than it is currently assumed. This may significantly affect the regulatory assumption for the safe evacuation of passenger ships.

4.1.3.8 Conclusion

The progress of the work has been quite good and almost all of the objectives set to the first half and on the second half of the project were met. Project FLOODSTAND was established to derive most of the missing data for validation of time-domain numerical tools used in the assessment of ship survivability and to develop a standard for a comprehensive measure of damaged ship stability by concentrating on the risk of flooding. The results of the project obtained satisfied almost all of the identified objectives.

Nearly all of the scheduled RTD-deliverables could be produced in each Work Package and approved by the Steering Committee (SC) as originally planned. The total number of these deliverables was 32. [12] The list of these deliverables can be found below, at the end of this report (see: 4.1.3.10 References).

The concept cruise ship designs in WP1were developed as planned, which gives good prospects for their further analysis during the second half of the project. In spite of the intentionally front heavy schedule of the experimental part of the work in WP2 and WP4, almost all of the scheduled tests could be made and reported during the first half of the project. The results from the model tests, and from the tests in real scale, as well as from the numerical analysis, and from all the other reported parts of the project, can be considered to be a good groundwork for further analysis, and thus, a promising outcome of the project.

A standard for decision making in crises should be simple. In this respect the objective was met well. The proposed standard is simple. However, the other side of the coin should not be forgotten either. Unfortunately, a thoroughly made assessment of all the implications would

[12] Note! Part of the work in WP3 was moved to WP7. This work, consisting solely of work efforts of NAPA, and its results are reported in partial deliverable D7.2b. Deliverable D7.2 is considered here to be one deliverable, as it officially should, composed of two partial deliverables D7.2a and D7.2b, and a cover document. (Similar approach was applied here on D4.1 and the partial deliverables D4.1a, D4.1b and D4.1c.)

require a multidisciplinary approach, possibly utilizing the methodology of Formal Safety Assessment, which was outside the scope of this Work Package and project.

The results of this project are published at the public website: **http://floodstand.aalto.fi**.

Additionally, several journal articles and conference/workshop papers have been published, too, as well as documents for IMO's consideration (in SLF). All these results are part of and support pre-normative research towards guidelines, standards and regulations, and explanatory measures to assess their impact. The flooding calculations will be more reliable/easier for the ship designers to select novel design options. In this way the project helps the designers to better protect the vulnerable persons onboard. The improvement of the reliability of flooding simulations will increase the quality of onboard real time damage stability assessments and estimates of the safety onboard, which may be a very demanding task for any operator faced by the rare, but hazardous event of flooding.

Ship designers, builders & ship owners, and the scientific community at large, on relevant workshops, journal and conference publications, as well as at scheduled presentations to the IMO, has formed the media of the results. The reception in all venues has proved to be encouraging.

FLOODSTAND will contribute in reducing the risk to human life, by ensuring that the level of safety of the transport system will respond to the increasing demand, featured by large passenger ships. Prospects for this development look encouraging, based on the results achieved during the final (second) 18-month period of the project.

4.1.3.9 The potential impact

The project FLOODSTAND contributes towards the impacts listed in the work programme in relation to the topic or topics in question:

The European shipbuilding industry is the undisputed market leader in the sector of cruise ships due to its specialisation to high-quality and high-technology vessels. Almost all large cruise ships of today are built in Europe and it is a well-known fact that the shipyards building these vessels have a major influence on the welfare of the surrounding society. The current total order book value of this particular sector is counted in billions of euros. However, it is not an easy task to maintain the leading position in this limited branch. Tough competition from outside Europe must be beaten recurrently. The only way to make it possible is a continuous process of development, search for new possibilities in design by considerable efforts in R&D. New innovative solutions that may break old limits can be found, but this process must be carried out in a controlled way. Otherwise it may not be possible to guarantee the safety.

The world's cruise sector is big and its growth rate has been propitious. Cruising is a major source of inbound tourism for European countries, according to the European Cruise Council. Between 1995 and 2005, demand for cruising worldwide more than doubled from 5.7 million to 14.4 million passengers. Over the same period the number of Europeans taking cruise holidays around the world more than trebled from 1 million to 3.3 million. Based on the latest figures[13], the number of Europeans taking a cruise

[13] Source: News Release of the European Cruise Council, Miami, Florida, 12.3.2012: Cruising in Europe continues to grow steadily ("http://www.europeancruisecouncil.com/content/Cruising in Europe continues to grow steadily_ECC News Release.pdf")

holiday has continued. The number exceeded 6 million for the first time in 2011, with an increase of 9% from 2010. The growth is expected to continue in future.

It can be concluded, that passenger ship sector is, in short, a major industry in and for Europe. By the results of this project, new data is publicly available to support pre-normative research towards standards and regulations, and explanatory measures to assess their impact. The flooding calculations will be easier and more reliable for the ship designers to select novel design options. In this way the project has helped the designers to better protect the vulnerable persons on board. The improvement of the reliability of flooding simulations will also increase the quality of on board real time damage stability assessments and estimates of the safety on board, which may be a very demanding task for any operator faced by the rare, but hazardous event of flooding. Guidelines as well as improved knowledge and understanding of the phenomena involved will help both designers and operators now and in the future.

By the generation of more reliable and new data and methods for flooding simulation tools, and incorporation such with an advanced water level monitoring system, the project FLOODSTAND has enhanced the development of new tools for crisis management. Also a proposal for a related standard to support decision-making on board has been developed. The improvement of safety is a continuos process, so, in spite of the many steps forward now taken in project FLOODSTAND, this work has to be continued.

The participation of two major shipyards, building about 65 % of the large passenger cruise ships of today, has given guarantees that this new development will serve the need of design, too. On the other hand, the involvement of the large cruise ship operators in the Advisory Committee will cater for the needs from the operational aspects. Maritime authorities and classification societies are the most important organisations when the measures at policy and regulatory measures are considered. Therefore it was important to have them included in the Consortium and the Advisory Committee, too. By close cooperation with the other participants of the project they have given considerable support to the project, but they will also be better informed of the project results, both as WP participants as well as members of the Advisory Committee.

Thus, the research project FLOODSTAND will contribute in reducing the risk to human life associated to the context of maritime transport by ensuring that the level of safety of the transport system will respond to the increasing mobility demand, featured by the ever increasing size of large passenger ships. This development will be achieved in the project by the development of more reliable data and advanced modelling to be used in flooding simulation methods. Such tools can be developed to a design environment facilitating virtual testing, becoming possibly a basis for new goal based standards and regulations.

The Expected Impact of the relevance of project FLOODSTAND has been assessed with reference to some important context areas:

Based on technological and operational advances and on the European transport policy, develop integrated, safer, “greener” and “smarter” pan-European transport systems for the benefit of all citizens and society and climate policy, respecting the

environment and natural resources; and securing and further developing the competitiveness attained by the European industries in the global market:
The impact of FLOODSTAND: DIRECT/HIGH

Developing technologies and intelligent systems to protect vulnerable persons such as passengers, crew: The impact of FLOODSTAND: DIRECT/HIGH

Advanced engineering systems and risk analysis methodologies will be developed for the design and operation of vessels: The impact of FLOODSTAND: DIRECT/HIGH

Emphasis will be placed on integrative approaches linking human elements, structural integrity, preventive, passive and active safety including monitoring systems, rescue and crisis management: The impact of FLOODSTAND: DIRECT/HIGH

Safety will be considered as an inherent component of the total transport system embracing infrastructures, freight (goods and containers), transport users and operators, vehicles and vessels and measures at policy and legislative levels, including decision support and validation tools: The impact of FLOODSTAND: DIRECT/HIGH

Contribute towards further reducing the risk to human life and environment associated to maritime transport: The impact of FLOODSTAND: DIRECT/HIGH

Ensuring that the level of safety and security of the transport system will respond to the increasing mobility demand and crime emergence:
The impact of FLOODSTAND: DIRECT/ HIGH

Decrease the level of human error: The impact of FLOODSTAND: DIRECT/HIGH

Recent evidence from early 2012[14] has proved, once again, that the topic discussed and its importance has not lost its relevance. Important results have been achieved in this project[15], but the core of the matter, improvements in the support to decision-makers in the reality of often unpredictable situations and outcomes (in almost every accident) must still be continued.

[14] Reference is made here to the recent accident of Costa Concordia (13.1.2012).

[15] Direct results of the project, e.g. in the form of research reports, are available on the project web-site: "http://floodstand.aalto.fi/Info/public_download.html"

4.1.3.10 References

The main results/foreground is publicly available in the research reports (deliverables) available on the project web-site "**http://floodstand.aalto.fi/Info/public_download.html**".

RTD-deliverables of the project FLOODSTAND (218532) produced and approved include the following deliverables from Work Packages 1-7:

Del. no	Deliverable name	WP no.	Lead beneficiary	Nature
D1.1a	Concept Ship Design A	1	STX	R, P
D1.1b	Concept Ship Design B	1	MW	R, P
D1.2	Analysis and applicability of alternative design	1	STX	R
D2.1a	Description of the mockup and test procedures; List of structures to be tested	2	CTO	R, P
D2.1b	Experimental study on the critical pressure heads	2	CTO	R, P
D2.2.a	Numerical study on the critical pressure heads	2	MEC	R, P
D2.2.b	Guidelines and criteria on leakage occurrence modelling	2	STX	R
D2.3	Results of the experimental study on the pressure losses in openings	2	AALTO	R, P
D2.4.a	Results of the computational study on the pressure losses in openings	2	CNRS	R, P
D2.4.b	Results of the studies of pressure losses in air pipes and effects of ventilation	2	CTO, STX	R, P
D2.5a*	Draft report on flooding tests on detailed cabin arrangements	2	MARIN	R, P
D2.5b	Report on flooding tests on detailed cabin arrangements and on the effects of different scale	2	MARIN	R, P
D2.5.c*	Guidelines on modelling principles for cabin areas	2	MARIN	R, P
D2.6	Sensitivity analysis for the input data in flooding simulation. Criteria for floodwater flow modelling	2	AALTO	R
D3.1	Flood sensors data interpreter	3	NAPA	R
D3.2	Impact of ship dynamics	3	AALTO	R
D3.3	Design guidelines for disposition of flooding sensors	3	NAPA	R
D4.1 [16]	Report on physical model experiments with ship model	4	SSPA	R
D4.2	Report on validation and sensitivity testing of an analytical method for characterising ttc	4	SSRC	R, P
D4.3	Report on validation and sensitivity testing of a numerical method for characterising ttc	4	NTUA	R, P
D4.4	Report on validation and sensitivity testing of a hybrid method for	4	SSRC	R, P

[16] Note! This deliverable includes a cover document and separate partial deliverables

	characterising ttc			
D4.5	Report on the method for assigning of uncertainty bounds for methods for characterising of ttc	4	SSRC	R, P
D5.1	Report on the data collection on mustering/abandonment and rescue	5	BV	R
D5.2	Report on validation and sensitivity testing of methods for assessing effectiveness of mustering process	5	BMT	R, P
D5.3	Report on validation and sensitivity testing of methods for assessing effectiveness of abandonment process	5	BV	R, P
D5.4	Report on validation and sensitivity testing of methods for assessing effectiveness of rescue process	5	BV	R, P
D5.5	Report on the method for assigning of uncertainty bounds for methods for M-A-R assessment	5	SSRC	R, P
D6.1	Report on the details and the rationale of the loss function	6	SSRC	R, P
D6.2	Report on the details of the likelihood function	6	SSRC	R, P
D7.1	Report on the benchmark data on casualty mitigation	7	NTUA	R
D7.2 [15]	Report on the tests of the standard in a Functioning Crises Management System	7	BMT	R, P
D7.3	Report on the applicability of the standard for design practice	7	NTUA	R, P
	*Note! This is not a public report			

Scientific publications of the project:

- Jalonen, R.P.S., Jasionowski, A., Ruponen, P., Mery, N., Papanikolaou, A., Routi, A.L., (2010), FLOODSTAND – Integrated Flooding Control and Standard for Stability and Crises Management, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

- Jalonen, R., Ruponen, P., Jasionowski, A., Maurier, P., Kajosaari, M., Papanikolaou, A. (2012) FLOODSTAND – Overview of Achievements, *Manuscript submitted to be published in the Proceedings of the 11th International Conference on the Stability of Ships and Ocean Vehicles, 23-28 September 2012, Athens, Greece.*

- Jasionowski, A., (2010), Decision Support for Crises Management and Emergency Response, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

- Jasionowski, A, “Decision Support for Ship Flooding Crisis Management”, Journal of Ocean Engineering, 38 (2011) pp. 1568-1581.

- Manderbacka, T.L., Matusiak, J.E., Ruponen, P.T. (2011) Ship Motions Caused by Time-Varying Extra Mass on Board. Proceedings of the 12th International Workshop on Ship Stability, Washington, D.C. USA - 12-15 June 2011, pp. 263-269.

- Penttilä, P., Ruponen, P. (2010), Use of Level Sensors in Breach Estimation for a Damaged Ship. Proceedings of the 5th International Conference on Collision and Grounding of Ships ICCGS, June 14th - 16th 2010, Espoo, Finland, pp. 80-87.

- Qi Chen, Jasionowski, A, “A New Methodology for Modelling Stochastically the Time to capsize”, 4th International Maritime Conference on Design for Safety, October 18-20, 2010 in Trieste, ITALY.

- Ruponen, P., Queutey, P., Kraskowski, M, Jalonen, R., Guilmineau, E. 2012a. On the calculation of cross-flooding time. Ocean Engineering Vol. 40, 27-39

- Spanos, D.A., Papanikolaou, A.D., On the Time Dependent Survivability of ROPAX Ships, Proc. of the 10th Inter. Workshop on Ship Stability, Wageningen, The Netherlands, June 21-23.

- Spanos, D., Papanikolaou, A. (2011) On the time dependence of survivability of ROPAX ships, Journal of Marine Science and Technology, Vol. 17, pp. 40–46, DOI: 10.1007/s00773-011-0143-0

- Stening, M., Järvelä, J., Ruponen, P., Jalonen R., (2010), Determination of discharge coefficients for a cross-flooding duct, Ocean Engineering, Vol. 40 (2012), pp. 27–39

More publications are expected …