FLOODSTAND-deliverable:

Benchmark Data on Casualty Mitigation Cases

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Abstract:
This deliverable defines a set of comprehensive benchmark tests (case studies) that will be used to demonstrate the methodological approaches of the FLOODSTAND project with respect to the assessment of the casualty risk of passengers on board a ship against the ship flooding hazard. The effectiveness of the FLOODSTAND approaches (tools for the crisis management and flooding control) will be tested in operational conditions, whereas the 'crisis management tool' will be also tested in ship design scenarios.

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1 CONTENTS

Page

2 EXECUTIVE SUMMARY

WP7 of FLOODSTAND research project has been defined with the aim to demonstrate developments and achievements of the project with respect to the assessment and mitigation of the casualty risk of passengers onboard a ship against the ship flooding hazard. The effectiveness of developed methods should be tested in both ship operational and ship design conditions. Therefore a set of comprehensive benchmark tests are being developed in this work package and this is in fact the objective of task 7.1, presented in this report. Following the present specification of benchmarks, the developed FLOODSTAND approaches will be applied to the defined benchmark casualties and useful results will be generated, which will provide a feedback for improvement of the effectiveness of the methods and even more for identifying necessary modifications and improvements of presently available approaches.

In the FLOODSTAND project two alternative approaches to the casualty mitigation are investigated: the "FLOODSTAND for flooding control" and the "FLOODSTAND for crisis management", each of them elaborated in WP1-3 and WP4-6 respectively. The above alternative approaches were due to the merging of two originally separate projects proposals into one, namely FLOODSTAND at the request of EC. Thus, whereas the work of WP7 was initially planned for demonstration of the second approach only, namely "FLOODSTAND for crisis management" [1], the need to include in the demonstration both above approaches was identified at an early stage of the project and the 'FLOODSTAND for flooding control" approach was also included in WP7 to the extent possible by available project resources, [2].

The developed benchmark tests are outlined including the various design considerations which were taken into account in the process of their development, following also an analysis of ship capsize scenarios on the basis of numerical simulations of ship capsize and the time to capsize. The time to capsize is a central parameter of the FLOODSTAND approaches, therefore detailed analysis of this time parameter was carried out. Taking also into account the estimated time dependence of the survivability of the damaged ship, six benchmark tests were designed for two different ship types, namely one ROPAX and one cruise vessel. The scenario conditions were complemented in the way to account for the rescue of people as well.

For each case study vessel, two casualty scenarios are defined for testing the ship in operational conditions, and one more benchmark scenario for testing her in ship design stage. Collision and grounding damage scenarios were developed for the ROPAX and cruise ship respectively, as they were the most hazardous events for these ship types. The design scenarios were directed towards testing the effect of provision (by design measures) of additional watertight spaces above the water line and the subdivision deck.

The herein reported results were derived during the first half period of the FLOODSTAND project, when the "FLOODSTAND for crisis management" approach was not entirely defined and reported. Therefore, the designed benchmarks are considering the early status of this FLOODSTAND approach, as it could be defined so far. Refinements of the benchmarks might be required during the testing work so that the demonstration of the final developments is enhanced to the best possible level.

3 INTRODUCTION

The main objective of WP7, as described in the project technical annex [1], is to test within working environment the effectiveness of the “FLOODSTAND for crisis management” approach in rating different decisions for various casualty cases as well as to test the approach in the design process.

The objective of the Task 7.1 is to combine input data from previous WPs, (WP4, WP5, WP6) and to develop a set of casualty scenarios appropriate for testing this FLOODSTAND approach.

The need to demonstrate the “FLOODSTAND for flooding control” approach as well, which is elaborated in WP3, was recognized at an early stage in the FLOODSTAND project, [2]. Therefore this approach will be tested too, in ship operational conditions (Task 7.2), which extended the objective of Task 7.1 accordingly.

It is noted that numerical simulations may contribute to an enhancement of the benchmark data set and this will be exploited to enable a more comprehensive design basis for the set-up of the final benchmark scenarios.

The next Fig.1 illustrates the structure of the work within WP7 and the position of the Task 7.1.

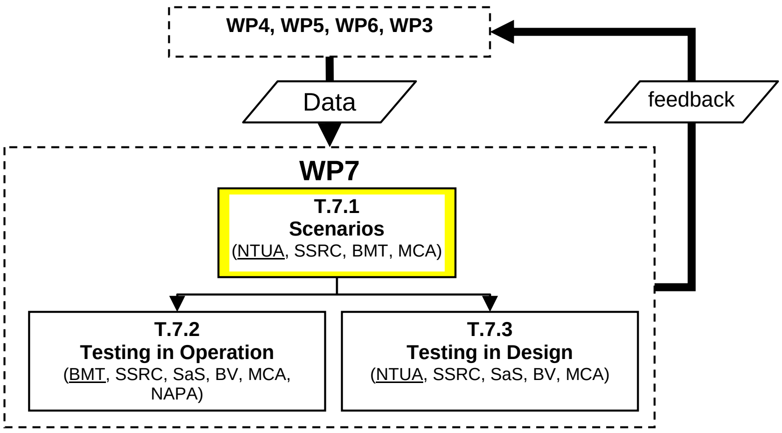

Fig.1 WP7 structure

In accordance to the work plan of WP7 [4], which was developed by the WP7 leader in consultation with all WP7 partners, the development of the benchmark scenarios followed the below four basic activities:

- Information flow in real life casualties
- Generation of random casualties
- Develop casualty scenarios
- Selection of benchmark scenarios

The available information during an emergency situation, like the ship flooding and evacuation, 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.

The basic features of each scenario are determined by the set of those parameters that will remain fixed throughout the testing process, e.g. ship type (RoPax and cruise ship), damage type (collision and grounding), hull subdivision, the passenger population distribution (mainly age categories), etc. Other parameters being characterized by increased uncertainty should be assumed in a probabilistic context (described with some probability model) e.g. damage size, sea state, internal openings and time to evacuate. These parameters are randomly generated through the assumed probabilistic environment.

The benchmark scenarios should deal with the characteristic time aspects of the ship flooding process. Therefore numerical simulations, additionally to the experimental data, could guide the development of benchmarks with respect to time.

A comprehensive set of benchmarks will be proposed which will be investigated in the subsequent Tasks 7.2 (testing in operation) and 7.3, (testing in design), according to the elaborated WP7 development plan [4].

In Task 7.1 four partners were planned to contribute as below.

NTUA task coordinator; generation of random casualty data and damage scenarios; numerical simulation of typical damage scenarios; definition of benchmark scenarios matrix; Reporting

SSRC comparative numerical simulations of typical damage scenarios

BMT Information flow in realistic casualties

MCA Review of report

4 DESIGN CONSIDERATIONS

The “FLOODSTAND for crisis management” approach being developed in WP4-6 of the project will be initially evaluated within the research project on the basis of the herein developed/defined specific tests, the benchmark scenarios. The considerations applied to the design of the benchmark scenarios are summarized in this section.

Survival time

Since the “FLOODSTAND standard for crisis management” is mainly founded on survival time considerations of damaged passenger ships, namely the assessment of the time the ship may survive after an assumed damage incident, a primary characteristic of the test scenarios should be the differentiation with respect to time to survive, or the time to capsize, namely whether the ship survives for infinite time or it sinks/capsizes in a fast or a slow mode. Benchmark scenarios should provide the mean to demonstrate how well the standard may assess the differentiation in time to capsize. For this purpose, experimental data available from the tank measurements (if not real life casualty data) was a valuable source of data for the evaluation of the standard’s performance.

On board casualty assessment

Another basic characteristic of the benchmark scenarios is the details in their specification. A certain scenario might be determined in full details so that a specific event will be evolving, which would be fully measurable and then directly evaluable. However, such test definition would be literally useful only for some validation purposes of the tools that are employed and how well a specific case might be reproduced. For the actual response of the ship master in a collision or grounding casualty, the conditions of the ship and events that take place during an accident are not known with confidence. The information suffers of much uncertainty and in most cases there are several critical conditions that can not be determined at all.

Two basic categories of information may be identified, which are necessary for the assessment of the survivability of the flooded ship:

- all information that specifies ship’s operational condition at the time of the assumed damage incident and
- information which determines/defines the damage case itself.

Operational data

The operational status of the ship can be determined by information which is practically available on board and can be gathered and uploaded on the decision support system that supports the FLOODSTAND approaches. Such data regard ship’s loading condition, passengers’ age distribution, the weather and route data, in addition to the means of rescue available in the area of operation. These data can be generally assumed available, even with some uncertainties, at any time and ready for use by the decision system.

Damage data

The information related to data defining the damage case suffers most by uncertainty, practical limitations and constraints for its processing by ship board systems. This information is essentially born during the accident incident, hence could become available only after the damage. This regards the damage opening in terms of location and extent and subsequently the extent of possible flooding which is related to the potentially flooded compartments and the possibility of progressive flooding to adjacent compartments. The later is determined by the conditions of the connecting openings like the watertight doors.

Damage case

The assessment of the hull breach opening is of high difficulty and its precise description can be generally available only long after the damage event with close inspection and measurements (if possible at all). Alternatively, the assessment of the damage case, namely to detect which compartments are, and could be, flooded after the damage, can be managed with inspection of the spaces by the crew, and nowadays by use of automatic water detection systems. As soon as the ship is getting flooded the number of the flooded compartments and the flooding rates can be assumed as available information for further processing. Together with the information about the condition of the compartments' connecting openings, the final flooding condition may be identified within short time and with reasonable confidence.

Multiple damage openings

A special case that needs caution is that of the multiple openings. Sometimes after a collision or grounding more than one hull openings (hull damages) may occur. There are dangerous events even if some of these openings are located above the wetted part of the ship hull (above ship's operational waterline). Through these openings, there is no sea water ingress at the time of the accident; hence, no flooding can be detected within the related damaged rooms. However, after some time and as the flooding of the ship goes on through other openings, the above waterline openings may also immerse and flooding will increase accordingly. Only after these (*above operational waterline)* openings come into water the flooding rate will notably change and then the ship master may realize that the ship sustains different flooding conditions, compared to what has been initially assessed.

Thus, a careful inspection of the above operational waterline parts of the hull is imperative after a collision (with side damage due to, e.g., protruding rocks to which the ship may come into contact). Only when relevant information about the likely above waterline openings can be available, they can be taken into account. A full hull inspection is assumed to be managed not earlier than about *20-30 minutes* after the damage incident, thus only after that period of time a clear picture of ship's damages can be expected and be processed.

Ship types

The FLOODSTAND project and related development work aims also at contributing to an improvement of current stability regulations of SOLAS and their implications on passenger ship design and operation; they follow also the need for new methods for assessment of the damaged ship survivability. In this respect, two prototype ships were assumed for the benchmarking of developed methods in the present research. They are a ROPAX ship and a Cruise ship.

ROPAX designs suffer in general by possible flooding of the large open space for RoRo cargo (car deck). This space (or spaces) is generally located on and above the subdivision deck and ship's operational waterline (except for ROPAX ships with *lower holds,* situated below above boundaries); thus, a flooding of these above water large open spaces may be expected mainly as a result of waves and ship motion action. Thus, the testing scenarios for this type of vessel should be considering the action of sea waves within the damage scenario.

Cruise ship designs are in generally of finer subdivision, even for large spaces above the subdivision deck. Thus, they do not directly suffer by extended flooding of some large open spaces, though multiple decks flooding may occur resulting to multi free-surface problems. However, their finer subdivision may result to complicated arrangements which make rather difficult a fast assessment of the final flooding condition of the ship. The flooding may evolve in quite different ways depending on the actual status of the multiple connecting openings. The action of waves and ship motion may be also of importance for the flooding of higher decks, however not to the same degree as for ROPAX ships.

<u>Damage type</u>

The assumed damage openings may vary with respect to size and location. Collision damages form the basis for ship's damage stability analysis according to SOLAS. Following available statistics of collision damages for a struck ship, these openings may occur at any position along the ship, whereas for striking ship damages mainly occur forward of the collision bulkhead; In damage stability considerations the stuck vessel is taken as reference. The length of struck ship's damage openings may be up to 30% of the ship length (for ship lengths up to 260 m) and they are extending vertically from the base line up to a height well above ship's waterline (following the shape of the bow of a striking ship of comparable size). Such damages are practically side damages, which may indeed result to large openings reaching the height of the car deck. Therefore, the risk of capsize for ROPAX ships is directly related to collision damages and may significantly increase under the action of waves, which excite ship motions that effectively lower the car deck to seawater level and cause its flooding.

Another type of damage which presently is of central interest for passenger ships, because of frequent accidents of this type, is that of ship grounding. These damages result to fracture of hull bottom structure which by definition is limited to below the waterline. The fundamental safety provision against the grounding is the construction of double bottom, a design detail already present from the days of the first steam ships. Thus, the required height for the double bottom has been regulated accordingly (in SOLAS, through the *minor damage* provisions). However recent reviews of the damage statistics for grounding casualties (research project GOALDS [13]) evidenced a large probability for the penetration of the double bottom. In such cases, flooding of the rooms above the double bottom occurs through an up-flooding process[1]. In up-flooding, the sea water enters from the ship bottom and the waves' action result of less significant. Hence, an assumption for the grounding damage scenarios could be the calm water condition, which may simplify the related analysis without loss of the generality.

Random damage openings

Two types of damage conditions that of collision and grounding will be included in the benchmark tests. In both cases, related damage statistics will be the basis for their definition, since the openings (size and location) suffer of notable uncertainty in realistic casualty situation. Hence, based on the statistical data and corresponding probability distributions the damage openings may be created in a random way for the present need of the benchmark tests.

Real accidents

The early plan of the present research was to try to develop benchmark scenarios on the basis of past real accidents. Eventually, it proved more efficient and of higher value to develop new theoretical damage scenarios. Real loss accidents have been already well investigated and in principal they provide a good reference for evaluation of the FLOODSTAND approaches, since there is much analysis and information for ship's loss. With the intention to include as much possible versatility in the benchmark tests, it proved more efficient to design new theoretical scenarios by exploiting results of the conducted physical model tests (WP4) and then building scenarios on this ground basis of higher confidence, instead of assuming an event of a real ship sinking, that could be derived from real accidents but sometimes uncertainty with respect to the full damage conditions.

[1] Cruise ship *MS Sea Diamond* sunk in 2007

5 TANK MODEL TESTS

The tank model tests of a ROPAX vessel, carried out by SSPA in WP4, [6], form the experimental basis for the present work. Relevant measurements were uploaded on the FLOODSTAND project website (http://floodstand.tkk.fi) for use by the project partners.

The model tests characterize the stochastic process of the time to capsize of the damaged ROPAX ship. Tests were carried out at scale 1:40, and regard a two compartments damage case, with a SOLAS damage amidships of V-cut shape. So far, two test series were carried out, both in stationary beam waves. In the first [6], the ship model was free to drift downstream and the survivability was assessed at 30 min, while in the second [8], the ship model was moored with soft springs and could not drift downstream hence up to 3 hours test records could be achieved.

The main useful outcome of these tank tests is the measured probability to capsize over the incident wave height, shown in Fig.2 below, which is re-produced from the report of SSPA [6]. This detailed probability provides a good reference for validation of the numerical tools that were employed for the design of the herein benchmark tests as well as for the evaluation of the selected scenarios.

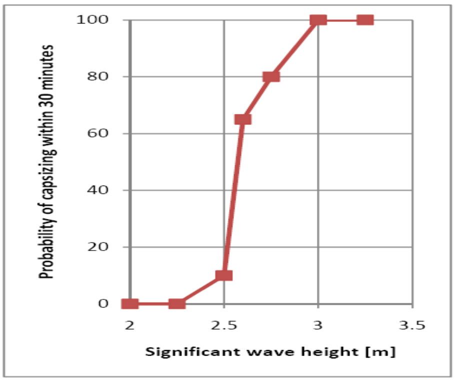

Fig.2 Probability to capsize over the significant wave height, SSPA [6]

For the above tank tests, capsize events were assumed when the average heel angle exceeds 20 degrees within a time duration of 30 min in full scale. The likelihood of capsize for a specific wave height was estimated on the basis of 20 measurements. Hence, the same capsize criteria should be also applied in the benchmark testing in order to get comparable conditions to the tank data.

6 MAR MODEL

Ship passengers' safety is directly dependent on ship's survivability and eventually on ship's safety. Ship's survival time in case of an accident leading to flooding is a fundamental index for passengers' safety too. However, in a wider view considering the full transportation, the safety of passengers may be extended to include risks associated to the mustering, abandonment and rescue.

Even before the ship loss event the people onboard are exposed to hazards related to the their moving towards the muster stations, like fall injuries caused by severe ship motion or delayed mustering due to complex arrangements or low visibility when lights off. Ship abandonment is still a hazardous operation, particularly when the ship sustains a heavy list and/or responds to severe waves. As soon as people have abandoned the ship, they are exposed to other hazards, which are associated generated by the harsh weather and environmental conditions and the availability and proximity of rescue services. The people that eventually will fall into the water, and might drown or suffer hypothermia, increase the level of urgency for the rescue services. A MAR (Mustering, Abandonment and Rescue) model is being elaborated in WP5 of FLOODSTAND, [7].

The total casualty risk of people onboard is related to both ship's loss as well as to risks related to likely obstacles that people may have to surpass throughout their rescue. In case of accidents in which ship's abandonment is inevitable, the abandonment could be held off the longer possible in order to provide sufficient time to organize the rescue. Under mild weather situations or when fast loss of the ship is expected such delay is of less importance or not relevant. However, when the risk of the people getting exposed to the sea is high while the ship is sinking in a slow mode, then the passengers should stay onboard until the risk at sea becomes less than the risk onboard.

The benchmark scenarios for the operational testing (task 7.2), elaborated in the following sections, prescribe parameters that pertain to the evaluation of the FLOODSTAND MAR model as well. The wind speed, the air temperature and the day/light condition in the region of the assumed accident are determined. The coordinates of the accident and the distance to the nearest ship or shore that could straight come for help are also determined.

Therefore the detailed MAR (mustering, abandonment and rescue) model [7] for the evaluation of rescue can be applied in the benchmark scenarios as well. When long survival times for the damaged ship may occur in some countable probability, then the detailed MAR model may provide guidance for an improved abandonment and consequently additional mitigation of the casualty risk. The demonstration of the MAR model for one of the defined benchmark tests is assumed sufficient for demonstration purposes.

7 DEMONSTRATION PLATFORMS

7.1 Platform 1

A software platform that may accommodate the FLOODSTAND approach to crisis management is necessary for testing and demonstration purposes in WP7.

The prototype software *iStand* is being developed by SSRC, it was presented by SSRC during the WP7 meeting at BMT [3] as candidate platform for the needs of WP7; it was considered appropriate for the demonstration of the FLOODSTAND approach to crisis management.

Two main components are included in *iStand*, namely those of the mathematical model for the survivability assessment and the necessary software infrastructure for the implementation of the model onboard a ship. The software may support the analysis of the survival time, estimate the flooding extent and evaluate evacuation and potential casualties. Specific modules can be employed for demonstration in ship operational conditions and ship design, Fig.3.

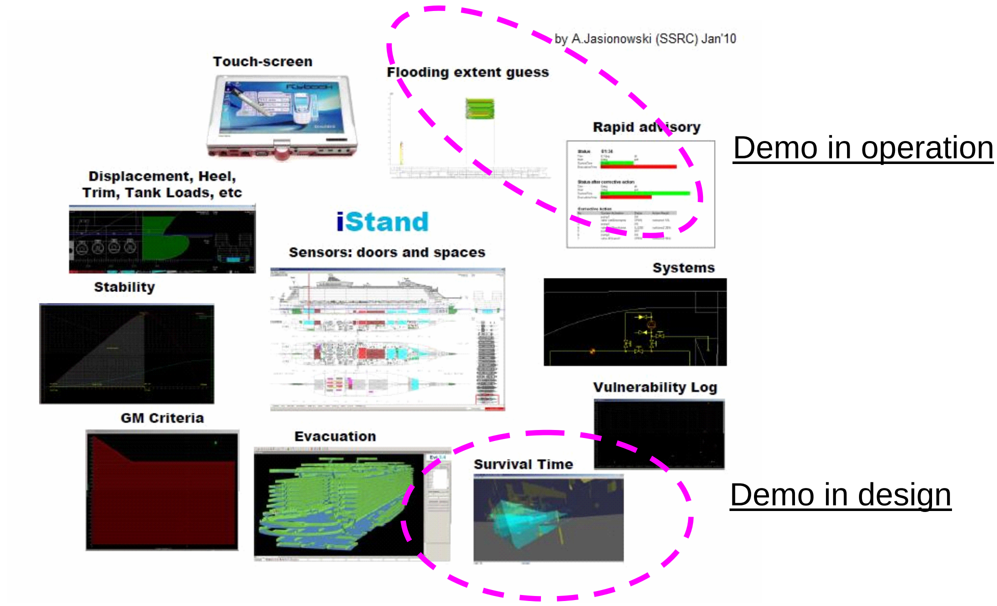

Fig.3 *iStand* software demonstrated by SSRC, [3]

7.2 Platform 2

Additionally to the above demonstrator, a second platform for the demonstration of the “FLOODSTAND for flooding control” approach is adopted. For this scope the software *Onboard-NAPA* by NAPA will be the employed, as discussed during the held WP7 meeting [3]. This software incorporates a wide range of features, including the Decision Support for Flooding Control (DFC) which provides an approach to the handling of flooding emergency situations.

DFC evaluates counteracts against the ship flooding and integrates water level gauging system, where the location and quantity of floodwater can be detected and measured in real time.

This software provides a ready solution for the implementation of the second platform, and will be employed for testing the developments of WP3 with the herein benchmark scenarios designed for the ship operational conditions (Task 7.2, as agreed in Steering Committee [2]).

8 DEMONSTRATION OBJECTIVES

In this section the demonstration objectives are summarized, namely the necessary and meaningful issues of the developed approach that the demonstration should be directed towards.

FLOODSTAND approaches will be applied for the casualty mitigation in the case of specific damages that result to ship flooding as well as will be used in ship design process, to test whether it could be an effective approach for the safety improvement of people on board. Both approaches will be demonstrated in ship operational conditions, namely *ship in operation*, whereas the “FLOODSTAND for crisis management” will additionally be tested in design conditions, namely *ship in design*.

When in operation, the change of the safety level due to a hull breach and flooding incident is questioned. A fast and accurate assessment of the passengers’ risk should be applied just after the damage occurrence. Hence the prime property to be demonstrated is that the method and the related computations could be completed fast enough and <u>the results could be timely provided</u> to the ship master for subsequent use in the decision making process.

The determination of the damage case suffers by uncertainty. Although the uncertainty can be limited to some extent with information gathered on the bridge, it is assumed that damage conditions are only incompletely known during the assessment process. So an objective of the FLOODSTAND approaches is to estimate the damage extent on the basis of the available data, regarding mainly the flooding rooms and the flooding rates. The <u>estimation of the damage extent</u> is rather critical for the full assessment and should be well detailed in the investigation of the benchmark scenarios.

Having estimated the damage case then it follows the essential part that of the <u>estimation of potential casualties</u> related to the specific damage scenario. Apparently the safety level of the people on board is deteriorated in the event of a ship flooding. However the flooding might remain within the safety margins inherent to the ship. The objective is to evaluate to what degree the safety margins will be exceeded, which is equivalent to the actual risk of casualties because of ship capsize or sink.

In accordance to the “FLOODSTAND for crisis management” approach the balance between the time to capsize (TTC) and the time to evacuate (TTE) mostly determines the actual safety level. However the related rescue time and constraints will eventually fully complete the safety estimations. Therefore the demonstration should also focus on the key variable of TTC and some validation tests for the estimation of TTC should be included. (Herein it is reminded that the ship's TTC equals the ship's survival time.)

The last and quite valuable objective is the demonstration of any counter act/measures that the FLOODSTAND approaches could advise. Based on the analysis of the actual damage events and the gathered information the ship flooding and the safety might be possible to be controlled with specific actions that could measurably mitigate the probability of casualties. Such actions might be related directly to the flooding control (counteracts), however they might be of proactive nature (countermeasures) which improve the safety margins by mitigating casualties before the damage incident.

While the demonstration in ship operational conditions is related to the assessment and mitigation of casualties for specific damage scenario, the demonstration in ship design is related to the improvement of safety by changes and modifications of the ship design and particularly the ship watertight subdivision. In design the time of the computational efforts is not a strict constraint like in operational conditions however the approach should be still perform in practical design times.

The selected benchmark scenarios for the demonstration in design principally improve the safety of the ship and the passengers. Applying the "FLOODSTAND for crisis management" the identification of the factors/cases that dominate the general safety and improvement might be achieved. After that, the interest can be concentrated on these dominant cases and their impact on the safety. The estimated impact on the safety is to be justified and validated. Then the confidence for the overall assessment of casualties will depend on the successful validation of this approach to these specific cases.

9 SHIP PROTOTYPES

9.1 ROPAX Ship

The ROPAX ship *MV Estonia*, which sunk in September 1994 due to rapid loss of stability after loss of her hull integrity and ingress of sea water on the car deck through the bow ramp, was used as a study ship in FLOODSTAND project and was also tested in the model basin in WP4, [6]. This vessel has a standard ROPAX subdivision that the present research is interested to. The vessel complied with damage stability requirements of SOLAS'74 (it launched in 1980), while compliance with the latest SOLAS'90 is unsure (the ship was treated as an *existing ship* in terms of compliance with latest regulations).

Main Dimensions	
Lpp	137.4 m
B	24.2 m
T	5.39 m
D_{DECK}	9.1 m
Displ.	12300 tn

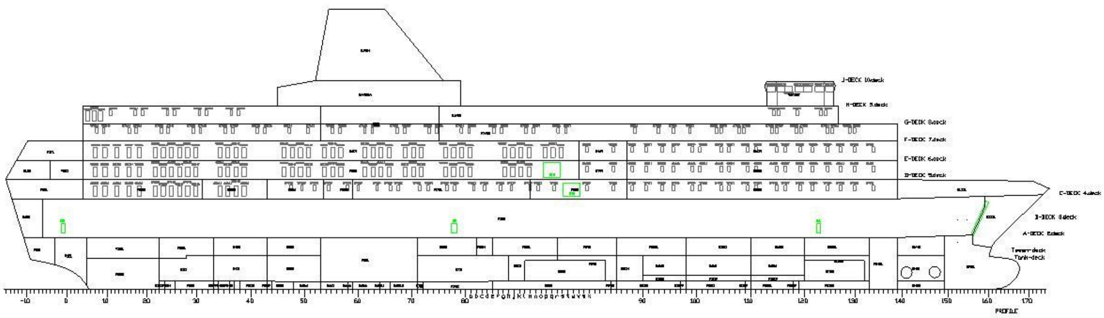

Fig.4 Profile of 1st FLOODSTAND benchmark ship: ROPAX vessel

9.2 Cruise Ship

A medium sized modern cruise vessel, with 63000 GT tonnage, which represents a state of-the-art cruise ship concept in the last years, is the 2nd prototype ship for the FLOODSTAND benchmarks. This ship design was introduced to the FLOODSTAND project through WP1 [5].

The watertight subdivision below the bulkhead deck complies with SOLAS regulations (SOLAS'74 and SOLAS 2009 including safe return to port provisions).

Main Dimensions	
Lpp	216.80 m
B	32.20 m
T	7.20 m
D_{DECK}	9.80 m
Displ.	35000 tn

Fig.5 Profile of the of 2nd FLOODSTAND benchmark ship: Cruise ship

10 ANALYSIS OF THE TIME TO CAPSIZE

FLOODSTAND project aims, among others, at the development of methods appropriate for the casualty mitigation related to hull damages and of consequent ship stability changes. The ship survival time after the damage incident is a central variable in such methods. The longer the ship survival time is the higher the probability the passengers to survive. Trivially, if the ship survival time is infinite, namely no capsize or sinking, then full safety for the passenger can be assumed.

The “FLOODSTAND for crisis management” is based on an analytical formulation of time to capsize, which is expected to be reported in [9]. Analytical model permits a fast estimation of the time to capsize for a given ship damage condition. Therefore massive estimations and probabilistic analysis can be performed in short time. To accomplish the probabilistic analysis in short time is the very important prerequisite of the system in order to make advices for the risk mitigation in limited times during an accident.

In parallel to the analytical model a detailed numerical simulation model is applied for the estimation of the time to capsize. This approach results to more accurate estimations for the time; however, the computational cost is largely increased. Hence the detailed numerical simulation could not be appropriate for the casualty mitigation in ship operational cases, where fast computational methods are necessary.

Detailed numerical simulations are elaborated in WP4 by NTUA-SDL and expected to be reported in [10]. Initial results [11] are already available and they are taken into account for the herein development of benchmark test.

The time to capsize has been analyzed with detailed numerical simulations for the range of damage openings that follow from the corresponding damage statistics. Statistics of collision damages regarding the location and size were updated and elaborated in the past research project HARDER (2000-2003) and are reported in [12]. A new update is presently in progress in the research project GOALDS [13].

Damage statistics show an even distribution for the damage location and damage length up to 30% of the ship length. For these statistics and applying a Monte Carlo simulation method, damage openings could be randomly generated along the ship. A sample of damage cases is shown in Fig.6. This corresponds to the ROPAX vessel which is modeled up to the deck above the car deck. For each damage opening (which is shown in red color) the damaged compartments are identified (shown in blue). The cars’ space might also become damaged if the opening height exceeded the car deck. In the bottom image of Fig.6 a small opening is limited below the car deck and above the double bottom, resulting to one compartment damage case.

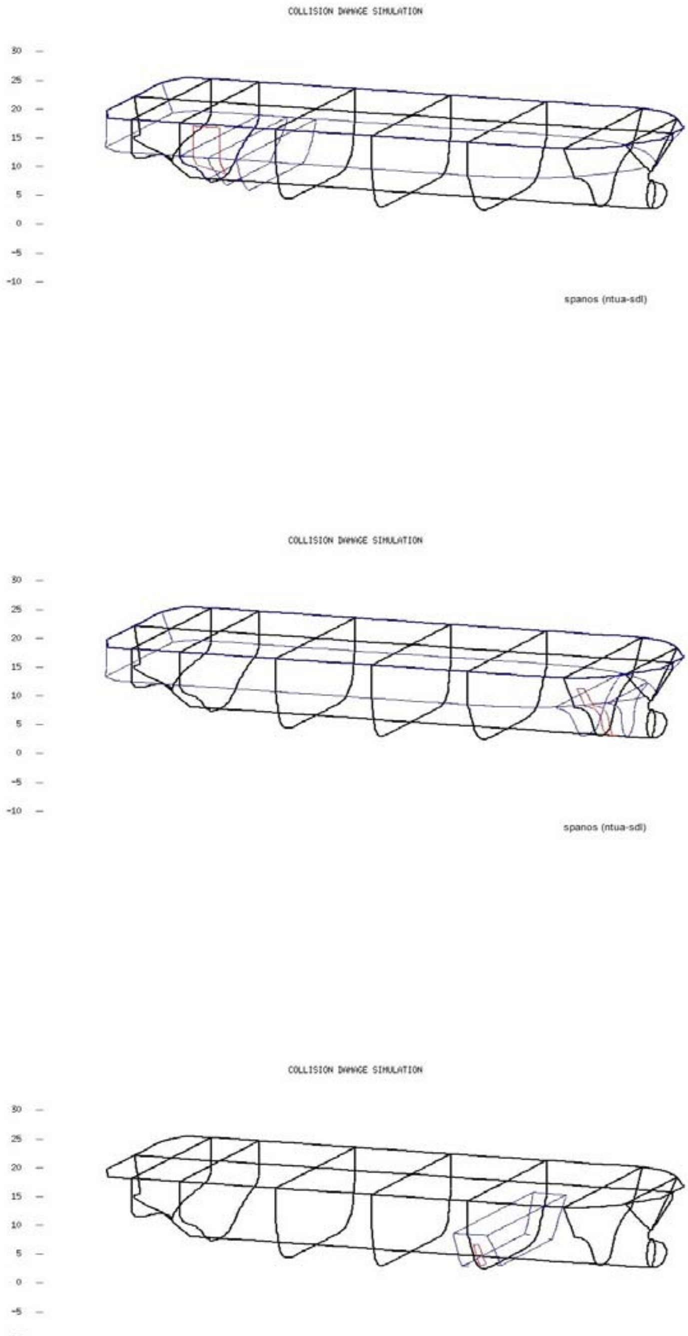

Fig.6 Random generation of damage cases (red: damage opening, blue: damaged compartments)

Each damage case is simulated in sea waves which are also randomly generated. Sea waves of JONSWAP spectrum are assumed. The assumed probability for the significant wave height is that of the collision damage statistics, namely what was the wave height during collision casualties of the past. This distribution has been extensively used and yet forms the background of the SOLAS 2009 revision.

The ship loading conditions as it is described through the ship displacement and the integral parameters of KG, and radii of gyrations are also randomly sampled. This means that for a specific damage case, e.g. two compartments damage amidships, could be tested for several ship loading conditions, and wave environments, e.g. moderate waves of Hs=1.5 m with ship displacement of 9000 tn for one simulation test and later rough waves of Hs=3.5 m with displacement of 12000 tn.

For each simulation the time to capsize was recorded. Fig.7 below demonstrates a typical simulation for a case which lasted long enough (more than 1 hour) until the ship capsized. The roll motion and the floodwater on the deck are plotted. There are three characteristic time phases in this test. In the first approximately 10 minutes after the assumed collision damage the water is gradually accumulated on the deck and the ship heels towards the damaged side (port side) approximately 5 degrees. Thereafter the second phase can be observed where an average balance takes place. The ship rolls around 5 degrees and a some average water of 150 tn seems to be trapped on the deck. This condition lasts almost for 1 hour and it seems that vessel has reached a stable condition and may survive for even longer. However in the third phase, after 1 hour from the collision a sequence of waves has caused a further gradual increase of floodwater on the deck and the heeling angle. When floodwater on deck exceeded 250 tn then instability conditions were developed and the ship soon capsized.

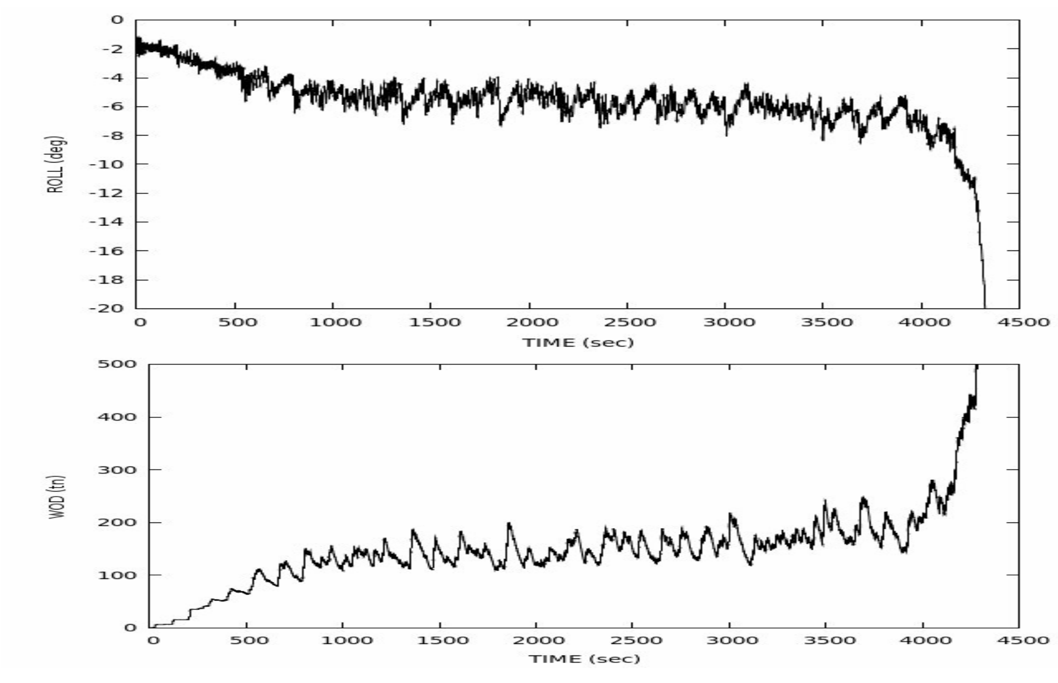

Fig.7 Numerical simulation (capsize at 1hr 10 min)

The simulation of Fig.7 is a typical case that clearly depicts the three characteristic phases over the time, and mainly the second one that of the average balance. However, long capsize time is a rather rare event for a capsizing ROPAX ship as explained in [11] and demonstrated with the present results summarized in Fig.8.

The probability density distribution of the time to capsize for the capsizing cases is estimated in Fig.8. This is actually the statistical result for the cases that eventually capsized. According to this result only rarely the ship may capsize later than 20 minutes, while the test of Fig.7 lies out of the upper boundary.

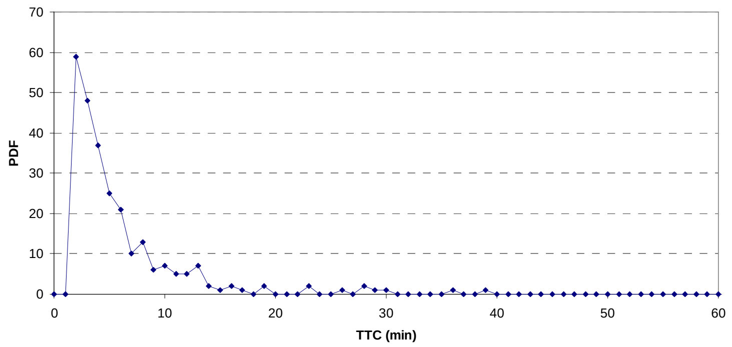

Fig.8 The estimated probability of time to capsize

The above information evidences that for a capsize/non-survive damage case there is practically no time to manage any ordered evacuation. If capsize will occur it will happen within 30 min. On this basis the survivability of the ship can be reduced to the question whether it will survive or capsize. If the stability of the damaged ship is sufficient then the ship will survive with a very high probability. If otherwise is going to capsize then there are no time margins for some ordered evacuation.

This behavior is tightly connected to the ROPAX vessel and the mode of capsize due to the flooding of the car deck. In absence of the large car space, like a cruise ship, then the time to capsize is expected to be distributed also to longer times. Especially when progressive flooding of multiple rooms is necessary until the ship lose her stability.

11 BENCHMARK SCENARIOS

Taking into account the design considerations and analysis of the time to capsize specific casualty scenarios are proposed in this section. Four scenarios appropriate for testing in operational conditions and two scenarios for testing in design stage are defined.

11.1 ROPAX in operation

The ROPAX vessel is assumed to be damaged in side collision, where the car deck is damaged too. The damage case is shown in Fig.9 below, where the potentially flooded spaces through the damage opening are highlighted. The herein assumed benchmark scenarios are irrelevant to the actual sinking scenario for this ship.

The assumed side damage openings are of low penetration therefore the double bottom remains intact. Flooding may occur through the damage opening into the damaged compartments No 5 (aft), No 6 (fore) and into the car deck. The two scenarios differ with respect to the opening size and location, which differentiate the flooding rates to each room. The number of persons on board is also different.

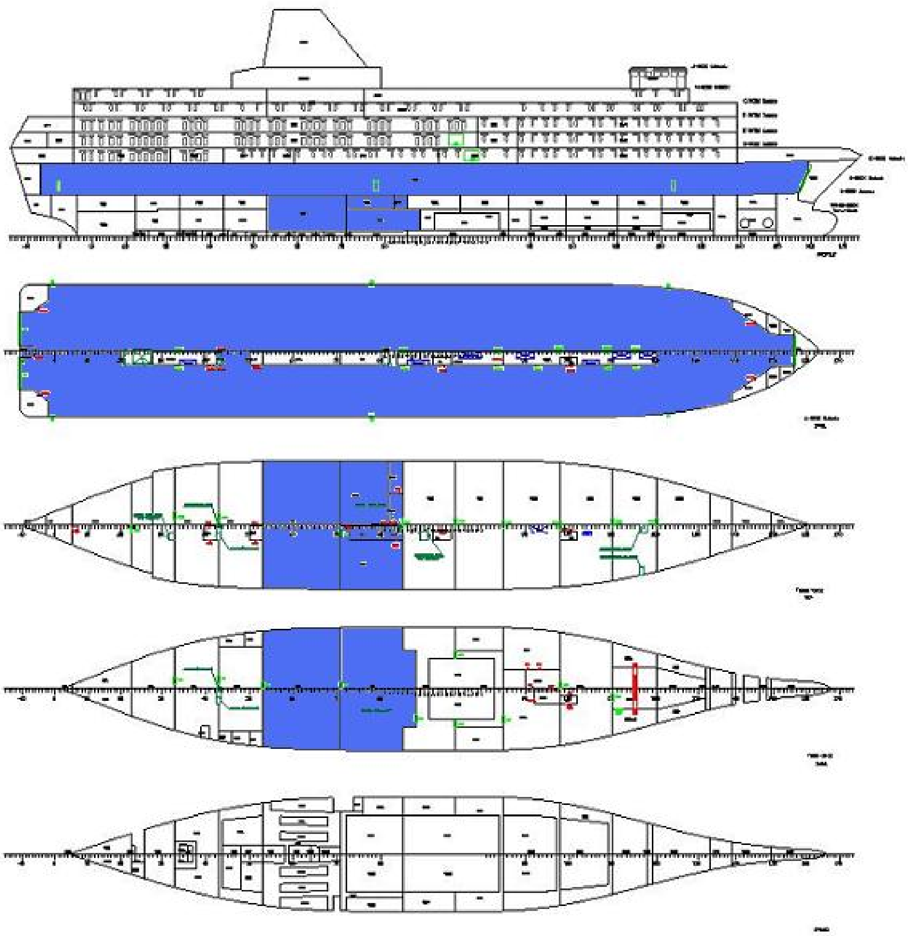

Fig.9 Collision damage scenarios A1 & A2

Casualty scenario A1

CASUALTY SCENARIO A1	
Location	57° 0' 00" N, 1° 0' 00" E
Time (day/night)	14:00 (local time) / day
Season	Winter
Distance to nearest ship	100 sm
Ship loading condition	
Passengers and crew	1200
Displacement	11350 tn
KG	10.25 m
GM	1.25 m
i_{xx}/B	0.34
Roll natural period	16.1 sec
Damage opening	
Location	-31.6 from midship
Length	5.80 m
Penetration	0.85 m
Height	9.7 m from BL
Damaged compartments	No 5, 6 & car deck, intact double bottom
Permeability	
Compartment No 5	0.85
Compartment No 6	0.95
Car space	0.95
Environmental conditions	
Moderate-rough waves	
Significant wave height	2.65 m
Wave spectrum	JONSWAP

Spectrum peak period	8.4 sec
Ratio (roll / waves) period	2 (approx.)
Wave direction	Beam waves, heading damaged side
Wind (mean)	20 kn (strong breeze)
Air Temperature (mean)	+0.0 Celsius

Casualty scenario A2

CASUALTY SCENARIO A2	
Location	42° 00' 00'' N, 5° 00' 00'' E
Time (day/night)	22:00 (local time) / night
Season	Winter
Distance to nearest ship	50 sm
Ship loading condition	
Passengers and crew	800
Displacement	10800 tn
KG	9.70 m
GM	2.25 m
i_{xx}/B	0.34
Roll natural period	12.1 sec
Damage opening	
Location	-29.3 from midship
Length	7.50 m
Penetration	0.20 m
Height	8.5 m from BL
Damaged compartments	No 5, 6 & car deck, intact double bottom
Permeability	
Compartment No 5	0.85
Compartment No 6	0.95
Car space	0.95
Environmental conditions	
Rough waves	
Significant wave height	3.90 m

Wave spectrum	JONSWAP
Spectrum peak period	11.5 sec
Ratio (roll / waves) period	1 (approx.)
Wave direction	Beam waves, heading damaged side
Wind (mean)	30 kn (near gale)
Air Temperature (mean)	-4.0 Celsius

11.2 ROPAX in design

Assuming that the “FLOODSTAND for crisis management” may satisfactory assess the effect of the design elements on the time to survive of the damaged passenger ship and considering that the capsize mode of ROPAX which is related to the flooding of car deck the herein design scenario deals with a subdivision of the car deck.

Watertight side casings are defined on the car deck as shown in Fig.10. The casings area is 10% of the deck area available for car stowage. Thereby the large deck space can be supported with these intact spaces which may provide additional buoyancy in case of large heeling angles of the damaged ship. The available space for the floodwater on deck is reduced and the corresponding free surfaces, consequently the heeling moment on the ship by the floodwater is reduced accordingly.

Such favorable impact on the survivability of the ROPAX is achieved in direct loss of the payload by 10% as well as the increase of construction cost. Within the ship design process the assessment of the survivability improvement with the FLOODSTAND approach may enable rational decisions for the definition of side casing on the ROPAX.

The breadth of the assumed casings is 2.40 m (or B/10). Casings are extended vertically up to deck 4 (namely the top the vehicle space). The longitudinal distance between the aft and fore pair of casings exceeds 1/3 of the ship length which is the longest damage size expected for the ROPAX according to the damage statistics. In the cases of collision event amidships all these four casings will remain intact. While in case of collisions that damage one casing, then the other three remain intact. Therefore at least three casings will be always available.

Design scenario A3

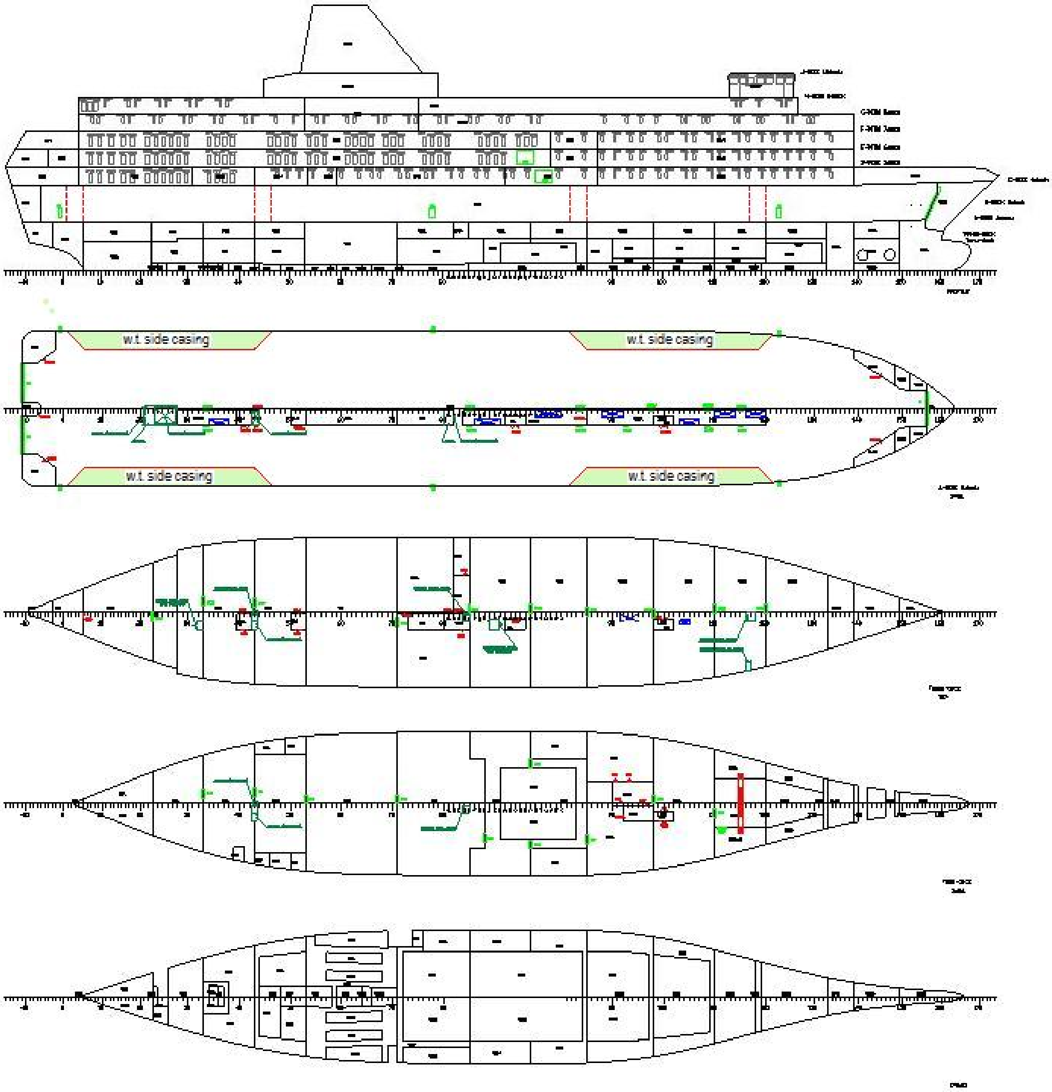

Fig.10 Design scenario A3, Deck side casings

11.3 Cruise ship in operation

The cruise ship is primarily suffering by extended flooding within the complicated arrangement of rooms. The two benchmark scenarios proposed below deal with grounding damages in calm water. In both cases up-flooding occurs and rooms are sequentially flooded through connecting internal openings assumed existing within the damages compartments. The final extent of flooding is determined here, while the details of the openings should be specified within Task 7.3, when design details will be available.

Casualty scenario B1

In the first scenario two compartments are assumed damaged from a bottom opening symmetrical to CL. The flooding may happen up to one deck over the subdivision deck (deck 5) and assumed limited within the two zones as in Fig.11. A connecting opening is also assumed at deck 4. Through that opening the two forward compartments may also be flooded with down flooding from deck 4. Therefore these two forward compartments are potentially flooded; however, they remain intact at the time of damage incident.

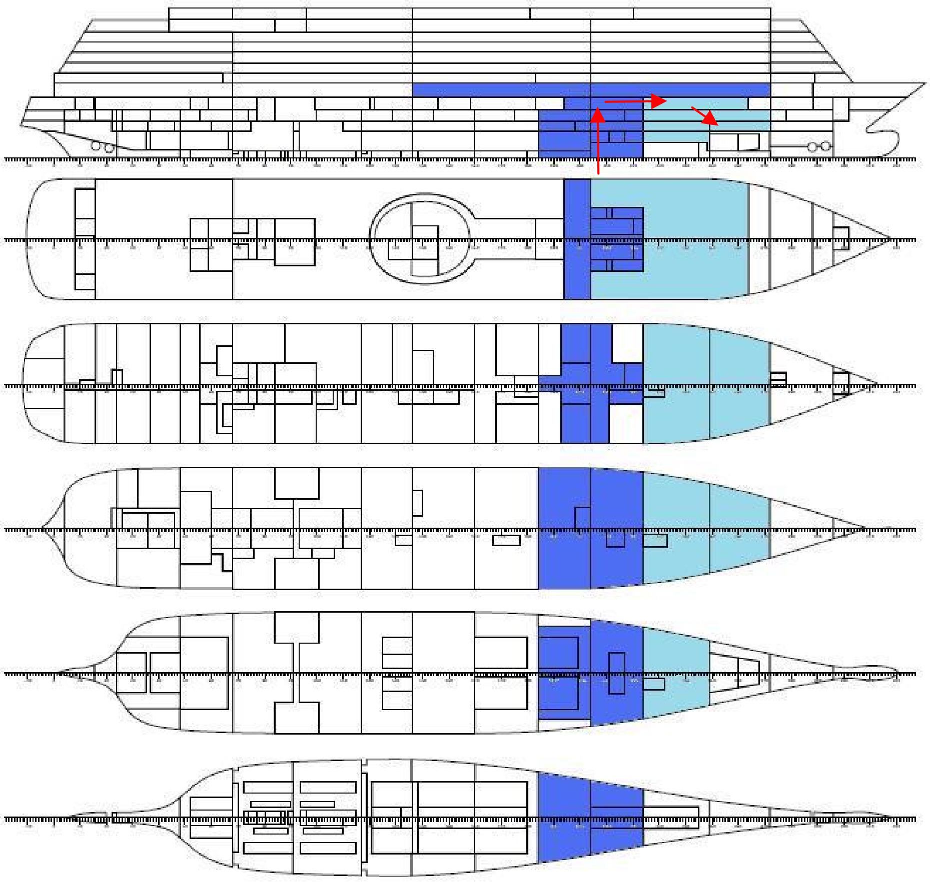

Fig.11 Grounding scenario B1

CASUALTY SCENARIO B1	Grounding of Cruise vessel
Location	61°20'10"N, 6°39'30"W
Time (day/night)	9:00 (local time) / day
Season	Winter
Distance of nearest ship	150 sm
Ship loading condition	
Passengers and crew	2400
Displacement	35400 tn
GM	2.5 m
Damage opening	
Location	+35.8 FWD from midship
	0.0 m from CL
Length	11.0 m
Penetration	1.5 m
Breadth	4.0 m from BL
Damaged compartments	No 9, & 10 (11 & 12) (as in Fig.11)
Environmental conditions	
Waves	Calm water
Wind (mean)	2 kn (light air)
Air Temperature (mean)	-5.0 Celsius

Casualty scenario B2

In this scenario long slide grounding is assumed to happen with the starboard side of the bottom. As a result a long raking damage results which is deep enough to penetrate the double bottom as well. Four sequential compartments get damaged and up-flooding may occur simultaneously for all these compartments leading to an asymmetrical flooding, which is extended as shown in Fig.12.

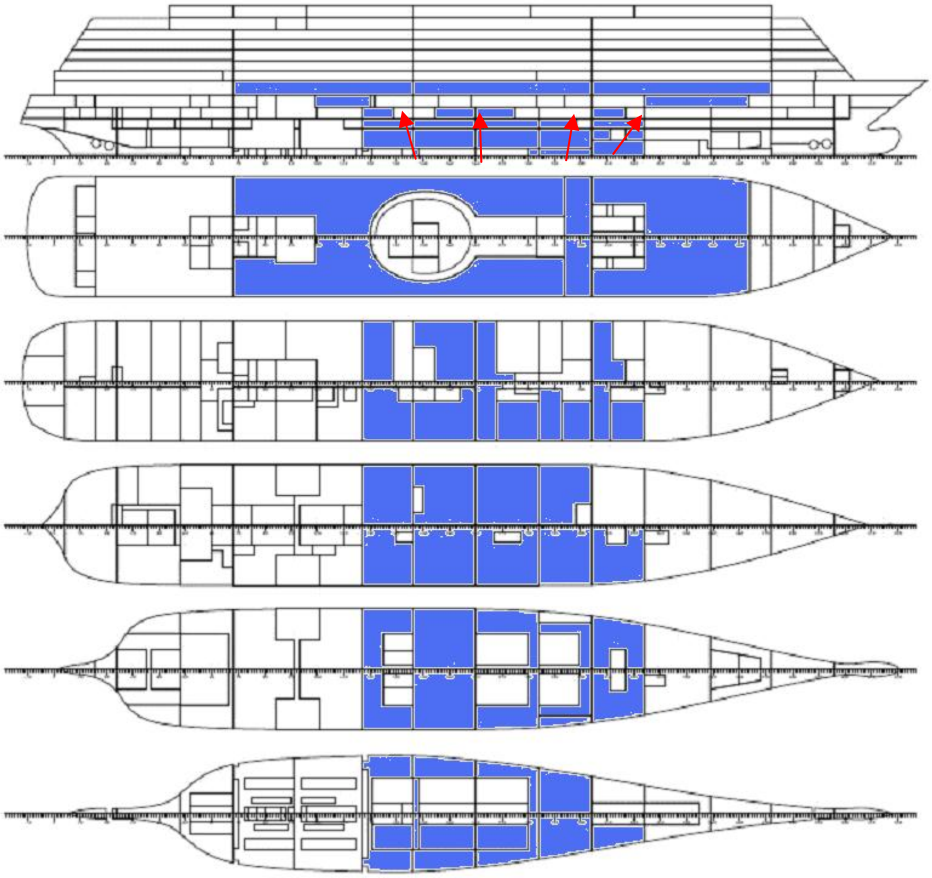

Fig.12 Long raking grounding scenario B2

CASUALTY SCENARIO B2	Extensive grounding of Cruise vessel
Location	30° 9' 00" N, 15° 51'10" W
Time (day/night)	17:00 (local time) / early dusk
Season	Summer
Distance of nearest ship	10 sm
Ship loading condition	
Passengers and crew	1600
Displacement	34000 tn
GM	2.1 m
Damage opening	
Location	+7.0 m FWD from midship
	+9.6 m STRB from CL
Length	40.0 m
Penetration	0.6 m
Breadth	0.6 m from BL
Damaged compartments	No 6, 7, 8 & 9 (as in Fig.12)
Environmental Conditions	
Waves	Calm water
wind	5 (light breeze)
Air Temperature (mean)	+20.0 Celsius

11.4 Cruise ship in design

The design scenario for the cruise vessel considers the upwards extension of the main watertight subdivision. If two decks (designated for public use) above the subdivision deck will be considered watertight and be subdivided with four transverse bulkheads at the limits of the subdivision zones then survivability of the damaged cruise ship can be significantly improved. In the design process it is questioned to what degree the survivability improvement may be justified by cost increase. By use of the "FLOODSTAND for crisis management" approach the expected improvement in survivability might be estimated and provide clearer guidance to the ship designers.

Design scenario B3

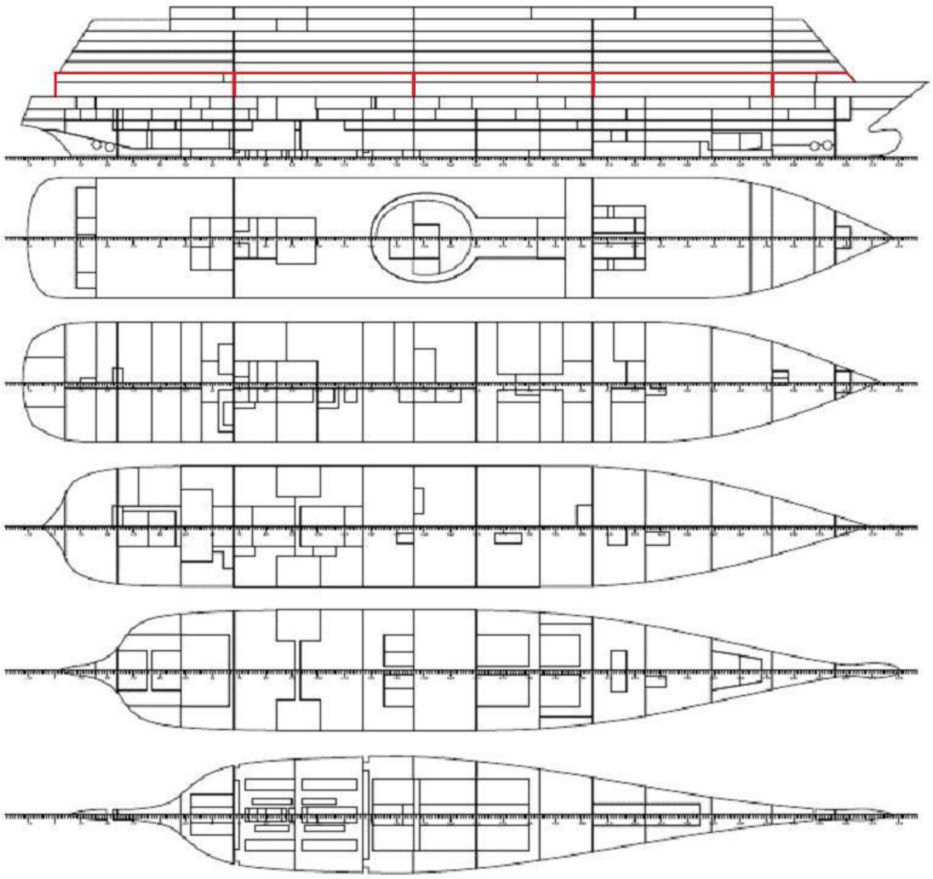

Fig.13 Design scenario B3: consider watertight subdivision above the main deck.

12 SUMMARY OF BENCHMARK SCENARIOS

The six (6) benchmark scenarios defined in Task 7.1 and analyzed in above sections are summarized in the next Table 1. With this set of scenarios the FLOODSTAND approaches will be tested in ship operation conditions, for both ship types, in both collision and grounding incidents, in sea waves and in calm water, winter and summer, day and night, in different modes of flooding, namely flooding of deck and progressive flooding. The “FLOODSTAND for crisis management” will be tested in ship design as well.

All the scenarios are appropriate for the developed approach in WP4-6. Additionally the scenarios B1 and B2 are also appropriate for testing the “FLOODSTAND for flooding control” approach developed within WP3.

Operational scenarios (A1, A2, B1 & B2) will be investigated in Task 7.2 while the design scenarios (A3 & B3) will be investigated in Task 7.3 of the FLOODSTAND project, [4]. The work of both tasks is planned for the second half of the project [4].

Table 1 Summary of benchmark scenarios

<table>
<tr><td></td><td colspan="3">Scenarios for Testing in</td></tr>
<tr><td>Ship</td><td colspan="2">Operation</td><td>Design</td></tr>
<tr><td>ROPAX</td><td>A1
Collision in waves
(see § 11.1)</td><td>A2
Collision in waves
(see § 11.1)</td><td>A3
Side casings on the car deck
(see § 11.2)</td></tr>
<tr><td>CRUISE</td><td>B1
Grounding in calm water, with progressive flooding
(see § 11.3)</td><td>B2
Grounding in calm water, with long raking opening
(see § 11.3)</td><td>B3
Watertight spaces above the subdivision deck
(see § 11.4)</td></tr>
<tr><td colspan="4">[green] “FLOODSTAND for crisis management” approach only
[blue] Both “FLOODSTAND for crisis management” and “FLOODSTAND for flooding control”</td></tr>
</table>

13 REFERENCES

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