SAFE STAB 2021
Stability and Safety of Ships and Ocean Vehicles

Proceedings of the 1st International Conference on the Stability and Safety of Ships and Ocean Vehicles, 7-11 June 2021, Glasgow, Scotland, UK

Benchmark Study on Simulation of Flooding Progression

Pekka Ruponen, *NAPA & Aalto University* pekka.ruponen@napa.fi

Rinnert van Basten Batenburg, *MARIN* r.v.bastenbatenburg@marin.nl

Henry Bandringa, *MARIN* h.bandringa@marin.nl

Luca Braidotti, *University of Trieste* lbraidotti@units.it

Shuxia Bu, *CSSRC* bushuxia@cssrc.com.cn

Hendrik Dankowski, *University of Applied Science Kiel* hendrik.dankowski@fh-kiel.de

Gyeong Joong Lee, *KRISO* gjlee@kriso.re.kr

Francesco Mauro, *MSRC* francesco.mauro@strath.ac.uk

Alistair Murphy, *Brook's Bell* alistair.murphy@brookesbell.com

Gennaro Rosano, *University of Naples Federico II* gennaro.rosano@unina.it

Eivind Ruth, *DNV* eivind.ruth@dnv.com

Markus Tompuri, *NAPA* markus.tompuri@napa.fi

Petri Valanto, *HSVA* valanto@hsva.de

Riaan van't Veer, *MARIN* r.vantveer@marin.nl

ABSTRACT

Several time-domain flooding simulation codes have been developed and improved over the past decade, after the previous international benchmark study in 2007. Consequently, within the ongoing EU Horizon 2020 project FLARE, a new benchmark study was organized. The first part of this study focuses on different fundamental flooding mechanisms, characteristic for progressive flooding in damaged passenger ships, including up- and down-flooding, as well as extensive horizontal flooding along a typical deck layout. Numerical results are carefully compared against measured water levels at different locations. Similarities and differences between the codes and applied modelling practices are discussed, and the reasons for observed deviations are analysed.

Keywords: *progressive flooding; simulation; benchmark; validation; damage stability*

1. INTRODUCTION

Development of time-domain simulation methods for flooding and motions of damaged ships has enabled advanced survivability assessments, especially for passenger ships. Over the past two decades, several codes have been developed. Mostly, these methods are based on hydraulic models, with flooding progression calculated by using Bernoulli's equation. Recently also computational fluid dynamics (CFD) tools have been applied, as presented e.g. by Ruth et al. (2019) and Bu and Gu (2019, 2020).

Earlier international benchmark studies have been organized within the International Towing Tank Conference (ITTC). The first two concentrated on flooded ship motions in waves, Papanikolaou and Spanos (2001, 2005), while the third one, van Walree and Papanikolaou (2007), focused on progressive flooding with experimental data on model tests with a box-shaped barge, Ruponen et al. (2007), concluding that prediction of the flooding rates and transient phenomena is not yet satisfactory in general. Since then, the same box-model case has also been used for validation of several new simulation methods, including CFD tools.

Based on the recommendations of the previous benchmarks and the fact that several new codes have been introduced, a new open benchmark, with extensive set of different flooding cases, was considered essential. The FLARE benchmark consists of three separate parts. In this paper, the results of the first part are presented, focusing of various typical flooding mechanisms. The latter parts will deal with cruise and ropax ships, focusing on transient and progressive flooding in both calm water and in waves, and the findings will be presented later.

2. BENCHMARK STRUCTURE

2.1 Test Cases

The coupling between the flooding process and damaged ship motions is extremely complex, especially when the damage occurs in waves. Figure 1 illustrates the couplings between the flooding and damaged ship motions in waves. The whole FLARE benchmark is divided into separate parts, eventually, covering the whole process, including flooding of a floating ship both in calm water and in irregular waves.

Recently, Ypma and Turner (2019) have presented an approach to validation of flooding simulation considering also captive model tests, and a somewhat similar methodology has been adopted, with the first part of the benchmark focusing on the accuracy and performance of the simulation tools for various typical flooding mechanisms. Simplified geometries and flooding scenarios are used in captive model tests, so that the floating position of the model is fixed. The follow-up studies, with focus on transient and progressive flooding in both calm water and in waves, will be published later, once all results have been analysed.

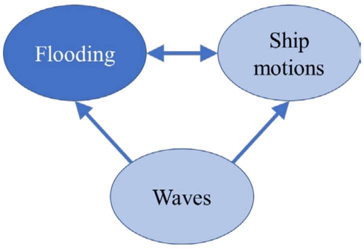

Figure 1 Couplings between flooding, ship motions and waves, the present study focuses on flooding

In the first part of the benchmark study three different flooding scenarios are investigated:

- Up-flooding in a box model with two compartments
- Down-flooding in the same box model with different openings
- Extensive progressive flooding on a typical deck layout of a cruise ship

2.2 Participants

In total 11 organizations provided numerical results for the benchmark study, as summarized in Table 1. Some participants used more than one code. In addition to the FLARE consortium, also external participants were invited, based on recent publications on the topic. Most of the codes are based on hydraulic models using Bernoulli's equation. CSSRC, DNV and MARIN used CFD tools, based on volume of fluid (VOF) method, and HSVA applied shallow water equations (SWE) for flooding along the deck, combined with Bernoulli-based calculation of flow through the internal openings. A short description of each code, with key references, is presented in Table 2.

Table 1. Overview of the benchmark study participants

Participant			Code	up flooding	down flooding	deck flooding
BROO	Brooks Bell	UK	PROTEUS	✓	✓	✓
CSSRC	China Ship Scientific Research Center	China	Star-CCM+	–	✓	✓
			wDamstab	✓	✓	✓
DNV	DNV	Norway	OpenFOAM	–	✓	✓
HSVA	Hamburgische Schiffbau-Versuchsanstalt GmbH	Germany	HSVA-Rolls	–	–	✓
KRISO	Korea Research Institute of Ships & Ocean Engineering	Rep. of Korea	SMTP	✓	✓	✓
MARIN	Maritime Research Institute Netherlands	Netherlands	XMF	✓	✓	✓
			ComFLOW	✓	✓	✓
MSRC	Maritime Safety Research Center	UK	PROTEUS	✓	✓	✓
NAPA	NAPA	Finland	NAPA	✓	✓	✓
UAK	University of Applied Science Kiel	Germany	E4 flooding	✓	✓	✓
UNINA	University of Naples Federico II	Italy	FloodW	✓	✓	–
UNITS	University of Trieste	Italy	LDAE	✓	✓	✓

Table 2. Summary of the simulation code features

BROO & MSRC	In-house code **PROTEUS** owned by Safety at Sea Ltd, a subsidiary of BROO. Originally developed at University of Strathclyde (MSRC). Flooding rates are calculated applying Bernoulli's equation with a hard-coded discharge coefficient of 0.6. Floodwater motions are modelled as a pendulum (Free-Mass in Potential Surface). Resolution of a multi-body multi-degrees of freedom system, with 6-DOF for ship motion and 3-DOF per each flooded compartment. Regular and irregular waves. Froude-Krylov and restoring forces integrated up to the instantaneous wave elevation. Radiation and diffraction are derived from 2D strip theory. Hydrodynamic coefficients vary with the attitude of the ship during the flooding process (heave, heel and trim). Details presented in Jasionowski (2001).
CSSRC CFD	Commercial CFD software **Star-CCM+** is used, with volume of fluid (VOF) approach for floodwater. Six degrees of freedom ship motions can be considered. Both regular and irregular waves can be considered by instantaneous integral of pressure along the wet surface. Details of the method are presented in Bu and Gu (2019, 2020). For decks and bulkheads, also "slip" boundary condition was applied since plexiglass surfaces of the models are smooth. Simulations were done also with the normal "no-slip" condition.
CSSRC Meth1	In-house code **wDamstab**. Bernoulli for flooding rates with horizontal surface for floodwater. Four degrees of freedom (Sway-heave-roll-pitch) can be considered. Ship motion is calculated based on the potential flow theory (STF). regular waves, Froude-Krylov and hydrostatic forces can be calculated based on the integration of pressure along instantaneous wet surface.
DNV	**OpenFOAM** CFD toolbox is used. The air and water flows are resolved by a finite volumes formulation to solve the Reynolds-Averaged Navier-Stokes (RANS) equations. For details about using CFD in flooding analyses, see Ruth et al. (2019).
HSVA	In-house version code the Rolls code, **HSVA-Rolls**. The ship roll motion and surge are solved with ordinary differential equations using nonlinear hydrostatics in waves (NAPA based) + linear strip theory for wave excitation and for RAOs (response amplitude operators) of other four Degrees of Freedom (DOF); altogether 2 non-linear DOF + 4 linear DOF solved in time domain. Flooding rates are calculated with Bernoulli, using empirical discharge coefficients. Floodwater is treated either with a pendulum model, or with shallow-water-equations (SWE).
KRISO	In-house code **SMTP**. Flooding rates calculated with Bernoulli, using empirical discharge coefficients. Floodwater has either horizontal surface or pendulum model appropriate at each compartment. The program provides several kinds of types for compartments and openings, and their numbers are unlimited. Ship motions are calculated by 6-DOF non-linear equations in time-domain, the hydrodynamic forces are calculated by strip method. Details presented in Lee (2015).
MARIN	The Extensible Modeling Framework (XMF) is a software toolkit on which all MARIN's fast-time and real-time simulation software is based applying Newtonian dynamics, of which Fredyn and ANySim are known examples. XMF is recently extended with a flooding module library (XHL) based on Bernoulli's equation with empirical discharge coefficients, using generic 3D defined floodable objects. A graph-solver technique is utilized to capture the complexity of entrapped air in compartments and for hydrostatic pressure-corrections from fully flooded compartments.

MARIN CFD	The CFD code **ComFLOW** is a Cartesian (cut cell) grid-based Volume of Fluid (VOF) CFD solver, using a staggered finite-volume discretization of the Navier-Stokes equations. Geometrically reconstruction of the free surface interface. Automatic grid refinement by means of surface and object tracking criterion and explicitly integrating the free surface in time using a variable time step. Details are given by Veldman et al. (2014) and Bandringa et al. (2020).
NAPA	Commercial software **NAPA** is used. The flow rates calculated from Bernoulli's equation, with user-defined discharge coefficient for each opening. Horizontal free surface assumed in all flooded rooms. Pressure-correction algorithm applied to solve the governing equations (continuity and Bernoulli). Ship motions are either fully quasi-static (heel, trim & draft) or with dynamic roll motion. Effect of waves (regular or irregular) on flooding can be considered. Details are presented in Ruponen (2007, 2014).
UAK	In-house code **E4 Flooding Method**, with flooding calculated by using Bernoulli's equation with horizontal surface and flooding path modelled as directed graphs. Ship motions either 3-DOF quasi-static or 6-DOF dynamic, with support for regular waves and other effects e.g. interaction with cargo and seabed, Dankowski and Dilger (2013), conditional openings and leakage, Dankowski et al. (2014) and cargo shift. Details of the simulation method are presented in Dankowski (2013) and Dankowski and Krüger (2015).
UNINA	In-house tool **FloodW**, coded in Matlab-Simulink. Flooding rates are calculated based on Bernoulli's equation with empirical discharge coefficients. Floodwater is treated as a non-horizontal flat surface, in agreement with the pendulum model. Regular and irregular wave effects are modelled, accounting for all pertinent nonlinearities. Details are presented in Acanfora and Cirillo (2016, 2017) and Acanfora et al. (2019).
UNITS	In-house code **LDAE**. The flooding process is modelled using a DAE system based on the Bernoulli equation, which is linearized and solved analytically. A flat horizontal free surface is assumed for the sea and waterplanes inside flooded rooms. An adaptive integration time step, based on floodwater level derivatives, is adopted. The model does not include dynamic ship motions. Only quasi-steady change of heel, trim and sinkage is considered. Details in Braidotti and Mauro (2019, 2020).

2.3 Benchmark Methodology

Details on the geometry of the models and some videos on the tests were provided in advance to all participants. In addition, some measurement results on the water levels were shared in graphical format, to ensure fair and equal conditions between the participants.

2.4 Discharge Coefficients

Most of the participating codes use a hydraulic model, based on Bernoulli's theorem, for calculation of the flow rates through the openings. This approach is computationally efficient, when compared to the CFD tools, but it requires semi-empirical discharge coefficients for modelling the flow losses in the openings. For full-scale simulations, the "industry standard" value of 0.6 has proven to be reasonably accurate, Ruponen et al. (2010). Although the generally applied value 0.6 is valid for most cases, it is not realistic e.g. for cross-flooding ducts and pipes.

Since frictional losses are proportional to the Reynolds number, somewhat larger discharge coefficient is characteristic for model-scale openings, Idel'chik (1960). This has also been observed in the previous experimental studies, e.g. Katayama and Ikeda (2005) and Ruponen et al. (2007). Consequently, all participants using Bernoulli's theorem, were recommended to use discharge coefficients given in Table 3. The values were obtained from analysis of dedicated tests carried out at MARIN for different openings.

Most codes include a possibility for manual definition of discharge coefficients for each opening. However, PROTEUS, used by both BROO and MSRC, has a hard-coded discharge coefficient 0.6. In view of a proper benchmark comparison, it was necessary to compensate this by adjusting other opening characteristics, in order to achieve the same effect on flooding progression. The alignment was required BROO modelled the effect by considering the openings as leaking doors with a large leakage area ratio, while MSRC modified the opening areas.

Table 3 Recommended discharge coefficients based on model tests

Case	Opening	Cd
Up & Down	80 mm × 80 mm	0.65
Up	80 mm × 40 mm	0.65
Down	40 mm × 40 mm	0.70
Deck	Narrow (width < 30 mm)	0.73
Deck	Wide (width ≥ 30 mm)	0.70
Deck	Breach	0.65

3. UP-FLOODING

Calculation of flooding progression through a compartment that is filled-up with water is known to be challenging for simulation codes since the effective hydrostatic pressure is higher than the top of the filled-up compartment. Therefore, the first benchmark case focuses on up-flooding with extremely simple geometry.

The box-shaped model has two sub-compartments that are separated by a deck with a 40 mm × 80 mm hole in the middle. There is a breach hole of size 80 mm × 80 mm in the side of the lower compartment. Draft is constant 400 mm. A sketch of the test case is presented in Figure 2.

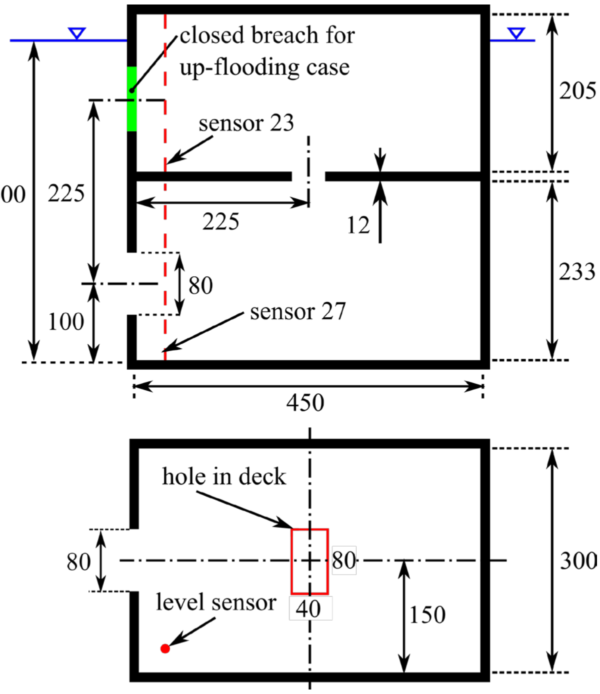

Figure 2 Box model arrangement and dimensions for the up-flooding case

The lower compartment is vented through a pipe and the upper compartment has an open top and is thus vented as well. A snapshot from ComFLOW simulation by MARIN, visualizing also the ventilation arrangement, is shown in Figure 3 below.

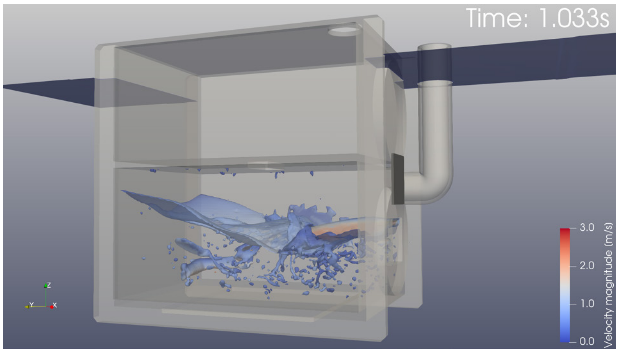

Figure 3 Snapshot of ComFLOW simulation of up-flooding by MARIN

Most codes can predict the flooding progression rather well, and hence each code is compared separately against the measured water levels in Figure 4. In general, the rising of the water level in the lower compartment during the first 3.5 s is slightly underestimated. For the upper compartment, the simulation results match well with measurement. Only the code PROTEUS, used by both BROO and MSRC, predicts much slower up-flooding through the fully flooded lower compartment. Based on analysis by MSRC, this is a problem in core level implementation, and can currently be overcome only by artificial changes to geometry to avoid up-flooding through a completely filled-up room.

Eventually, only MARIN provided CFD results for this case, showing very good correlation with the measurements. CFD captures the fluctuations in the water levels, but the general development is the same as with Bernoulli-based codes.

4. DOWN-FLOODING

Like up-flooding, also down-flooding is a fundamental flooding process that is very typical, especially in case of extensive progressive flooding in passenger ships. Therefore, the second part of the benchmark focuses on simulation of this simple flooding mechanism.

The compartment geometry is the same as in the up-flooding case, Figure 2, but the breach opening (size 80 mm × 80 mm) is now located in the upper compartment and the hole in the deck is smaller, 40 mm × 40 mm.

Most codes can accurately predict the increase of the water level in the upper compartment. In general, the down-flooding rate is slightly under-estimated, Figure 5. The small increase in the water level in the upper compartment when the lower compartment is filled-up is also captured.

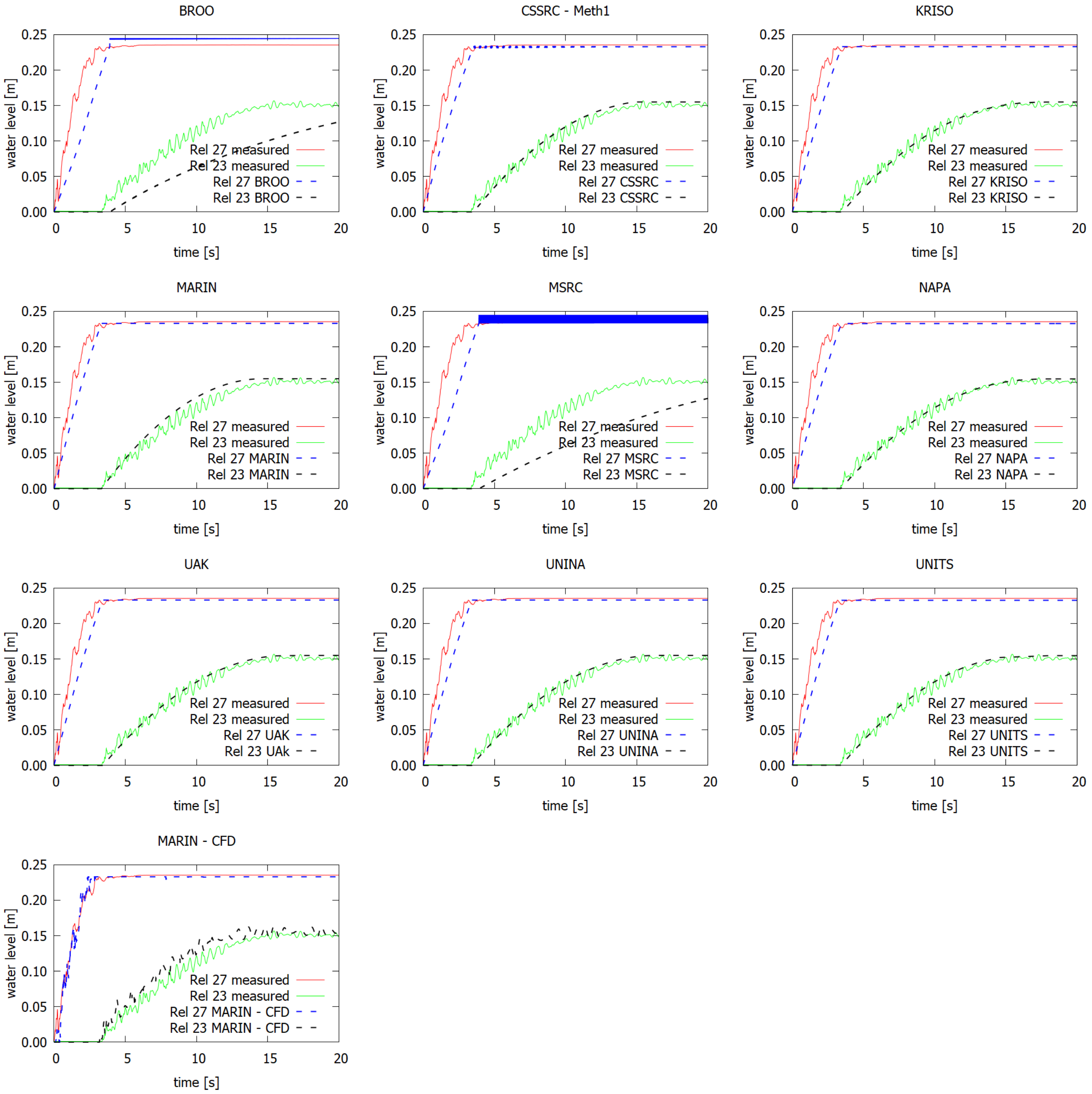

Figure 4 Comparison of water levels in the up-flooding case at Rel 27 in the lower compartment and Rel 23 in the upper compartment

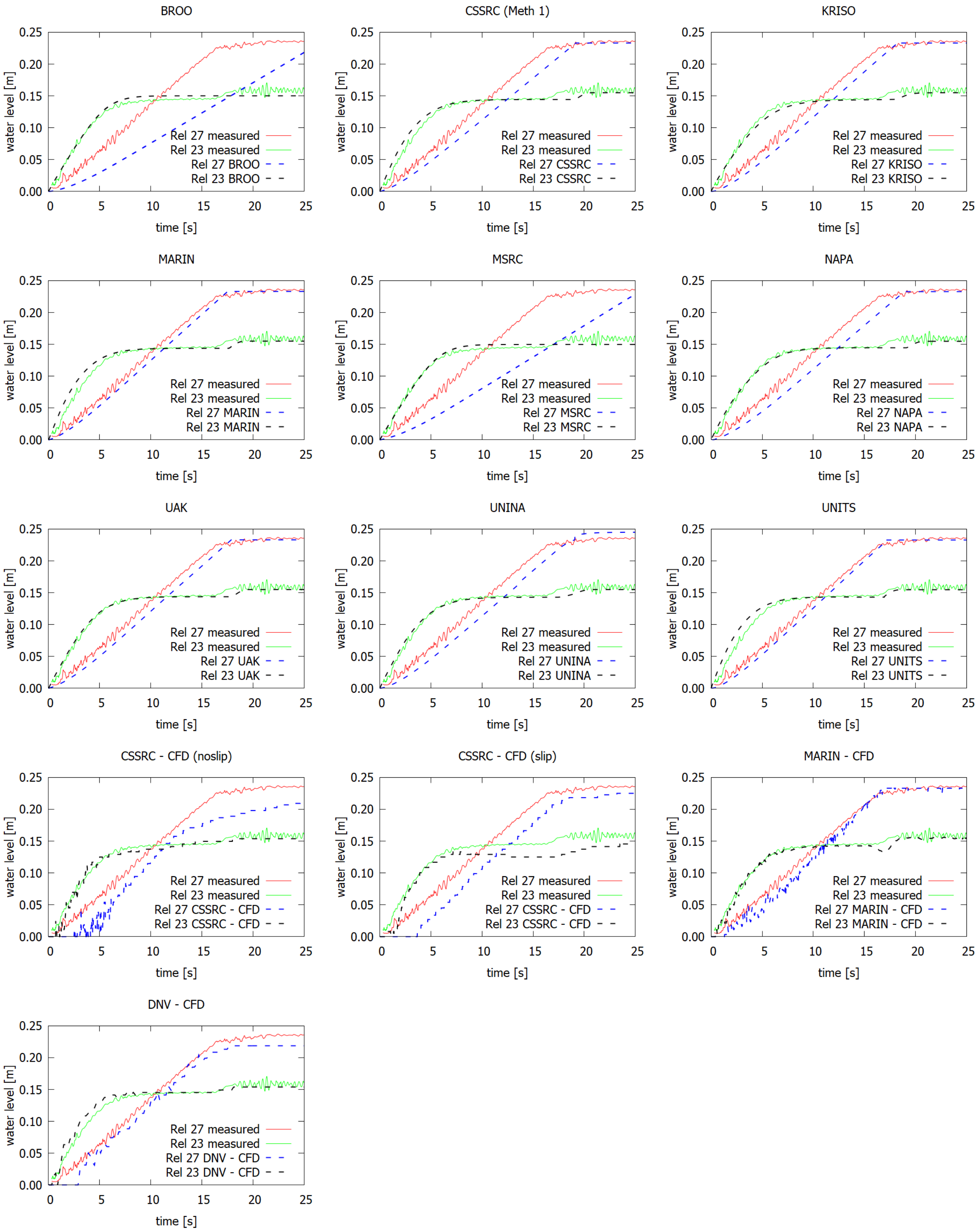

Figure 5 Comparison of water levels in the down-flooding case

All simulation codes with a hydraulic Bernoulli-based flooding model provide good results, except PROTEUS, used by BROO and MSRC. This code can predict the flooding of the upper compartment, but the down-flooding rate is seriously underestimated. Similar problems are not encountered with the other Bernoulli-based simulation codes. According to the code analysis by MSRC, this results from a hard-coded ramp function for down-flooding openings that unrealistically reduces the flow rate.

With CFD methods "no-slip", i.e. wall condition is normally used for decks and bulkheads. Since in the physical model the plexiglass surfaces are much smoother than the steel structures in full-scale ship, CSSRC decided to study separately also "slip" condition, i.e. a perfectly smooth surface, considering only the normal pressure without tangential force. The "no-slip" condition results in better match with the measurements, indicating the frictional effects on the surfaces are notable. Furthermore, CSSRC applied Realizable $k-\varepsilon$ two-layer turbulence model. DNV and MARIN considered laminar flow, which seems to provide more realistic results, at least in model scale. The beginning of the down-flooding is visualized in Figure 6 from the OpenFOAM simulation by DNV.

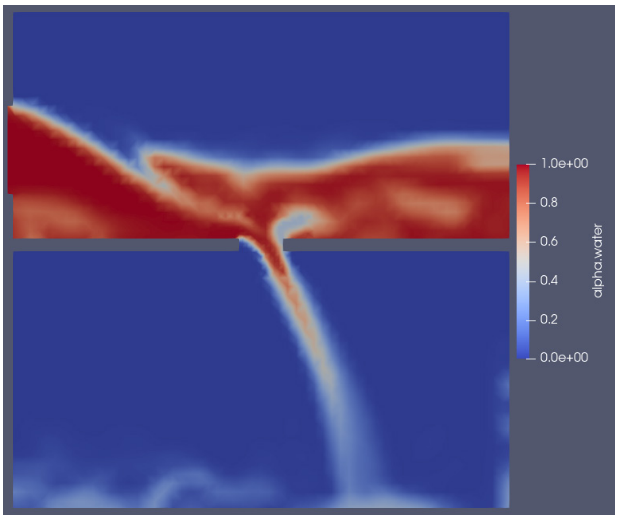

Figure 6 Visualization of the beginning of the down-flooding at 2.0 s in simulation by DNV

5. DECK FLOODING

The third case considers extensive progressive flooding along a typical deck layout of a cruise ship, including a long central service corridor, Figure 7. The scale of the model is 1:60, and the draft of the model is constant 0.03 m above deck level (in model scale). The breach on the side of one compartment is opened instantly, causing the flooding of the deck. For Bernoulli-based codes, a common modelling practice for the corridor was adopted, by dividing the long corridor into five adjacent rooms with division at the locations of the partial bulkheads. A discharge coefficient 1.0, i.e. no flow losses, was applied for these artificial openings.

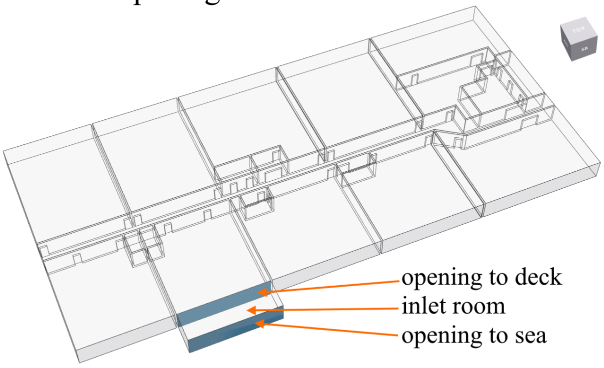

Figure 7 Arrangement for deck flooding case

HSVA applied Bernoulli's equation for real physical openings only, and the deck was divided into a grid of 38 × 78 cells for solution of the shallow water equations. CSSRC used a grid of 1 080 000 cells with realizable $k-\varepsilon$ two-layer turbulence model. Moreover, both slip and no-slip boundary conditions for the decks and bulkheads were applied separately. DNV used a grid of 165 000 cells with laminar flow model, while the MARIN CFD simulation was based on a local refined grid, solving between 505 186 and 1 196 604 cells

Simulation results are compared to measured water levels at various locations on the deck, Figure 8. Results are presented in Figures 9 – 13. Excluding the CFD codes, the participants performed calculations in full scale, but all results are presented in model scale for consistency.

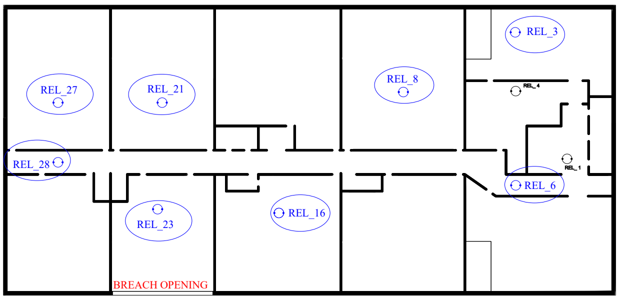

Figure 8 Locations of selected water level sensors

The breached room is flooded rapidly, with a clear decaying wave, sensor REL 23, that is captured only by the CFD and SWE codes, Figure 9. Floodwater progresses rapidly along the long corridor. Consequently, flooding to the rooms along the corridor, e.g. at REL 16 in Figure 10, is initially slow, but after about 45 s water level starts to increase more rapidly. The CFD tools by CSSRC, DNV and MARIN, as well as the SWE simulation by HSVA, capture this phenomenon rather well. This behaviour is even more pronounced at sensor REL 8, Figure 11, where the flooding of the room from the corridor is notably delayed. This is properly predicted only by the CFD codes and by the hydraulic model of KRISO.

In general, the Bernoulli-based codes predict much faster flooding of these compartments. Despite of the unified modelling principles, the scatter of the results is very wide. The code by KRISO provides very good results, likely due to the newly implemented “corridor room model” that considers the momentum of the flow along the long corridor. The details of this new feature have not yet been published by KRISO.

Water elevation at the aft end of the corridor, sensor REL 28, is predicted rather well by the simulation codes, Figure 12. However, the fluctuations in the beginning of flooding are captured only by the CFD and SWE methods.

The sensor REL 3 is furthest away from the breach in the forward part of the deck. The trend is well captured by all codes, but the variation in the results is notable, Figure 13.

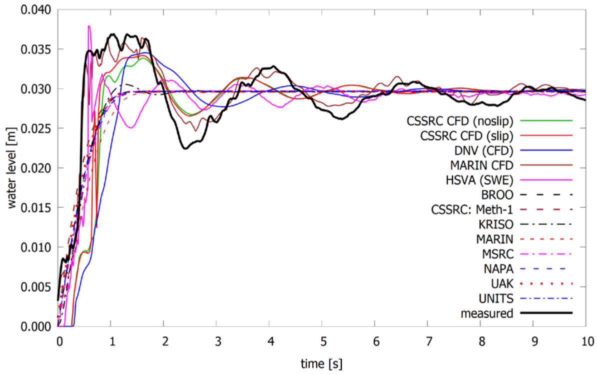

Figure 9 Water level in the breached room at sensor REL 23

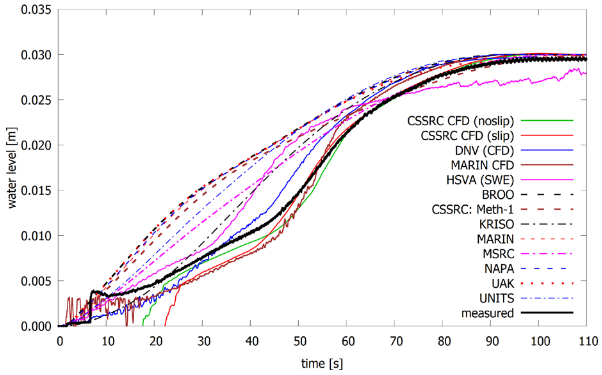

Figure 10 Water level at REL 16 in a room at the middle of the corridor

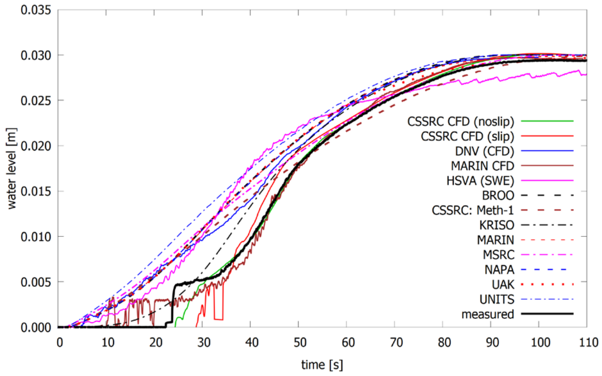

Figure 11 Water level at REL 8, in a room along the corridor

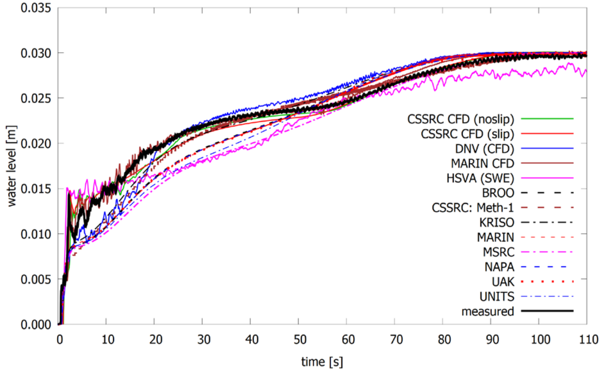

Figure 12 Water level at REL 28 located in the aft end of the corridor

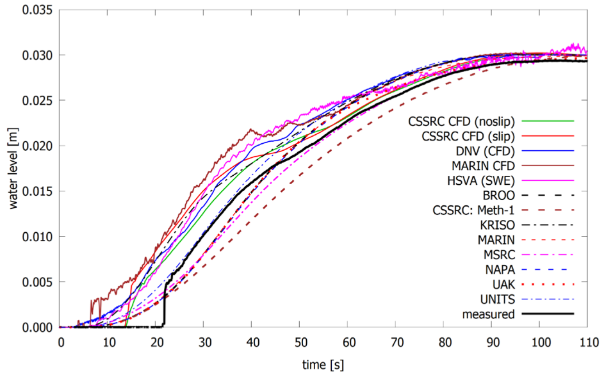

Figure 13 Water level at sensor REL 3, furthest distance to the breach

The scale of the model was small (1:60) and surface tension effects caused notable step in the level sensor data, Figures 10, 11 and 13. This behaviour was captured in the CFD simulations. The flooding progression in visualized in Figure 14, using CFD results by CSSRC with the no-slip boundary condition. The effect of the long corridor on flooding of the rooms is clearly visible.

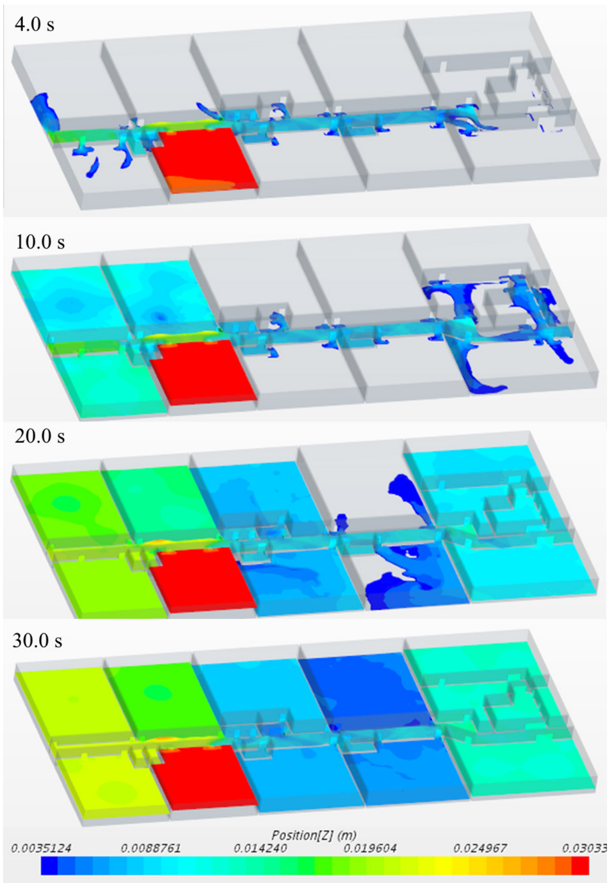

Figure 14 Visualizatoin of deck flooding from CFD simulation by CSSRC (no-slip)

With the CFD codes the computation time for the deck flooding case was about 100-1000 times slower than real time (in full-scale), whereas the Bernoulli and SWE methods were all faster than real time, albeit with quite notable range as the most efficient code is about 50 times faster than the slowest Bernoulli-based code. Applied code level implementation, such as time discretization and integration methods for volumes, can have a notable effect on the performance.

6. DISCUSSION

Most codes with a hydraulic model correctly predicted the flooding progression for the simple up and down-flooding cases in close agreement to model tests. Use of CFD tools provided more additional information on the details, especially during the initial flooding process, but for rather simple cases the CFD tools hardly provide a better prediction of the water level height development when compared to the Bernoulli-based methods (CSSRC-Meth1, KRISO, MARIN, NAPA, UAK, UNINA, UNITS). Only the code PROTEUS, used by both BROO and MSRC, predicted severely underestimated flooding rates for both up- and down-flooding. Based on investigations by MSRC, this resulted from built-in ramps for flooding rates and problems with fully filled-up compartments, so the problem is in the code implementation, not in the Bernoulli-based methodology for flooding progression, and not initiated by the prescribed discharge coefficient.

The deck flooding case is characterized by progressive flooding along the long service corridor. In the experiments, the rooms adjacent to both ends of the corridor were flooded much faster than the rooms in the middle. This phenomenon was properly captured by the CFD codes and the SWE method used by HSVA. In addition, the newly developed extension of the SMTP simulation code by KRISO, considering the momentum of the flow in a long compartment, provided very promising results.

In general, the variation on the results in the deck flooding case with simulation codes based on hydraulic model was much larger than expected, especially when considering that the corridor was divided into smaller rooms at same locations and that the same discharge coefficients were applied. This indicates differences in the numerical methods for time integration.

7. CONCLUSIONS

The benchmark cases have provided valuable information on the performance and characteristics of different time-domain flooding simulation codes. Obvious errors in implementation were found for one code. The deck flooding case demonstrated that transient flooding progression along a long corridor can be captured, not only with CFD tools, but also with SWE model of HSVA and with Bernoulli based methods, when the momentum of the flow is considered, as in the simulation by KRISO.

Due to the large variation in the simulation results for the deck flooding case, a new set of experiments on progressive flooding of several compartments with fixed floating position could be valuable. In the present study, some scale effects were noticed, and therefore, in future model tests a large scale should be used.

This benchmark study with the simplified test cases paves way for more extensive benchmarking of the same codes for simulation of flooding and motions of damaged ships in calm water and in waves, which will be studied and reported in the latter part of the FLARE benchmark.

8. ACKNOWLEDGMENTS

The research presented in this paper has received funding from European Union project FLooding Accident REsponse (FLARE) number 814753, under H2020 program, which is gratefully acknowledged. The CFD calculations by CSSRC were conducted in Wuxi National Computing Center. UNINA would like to acknowledge the kind support of Prof. Riccardo Martino in updating the FloodW tool. All opinions are those of the authors.

9. REFERENCES

Acanfora, M., Cirillo, A. 2016. A simulation model for ship response in flooding scenario, Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ., Vol. 231 (1):. 153-164.

Acanfora, M., Cirillo, A. 2017. On the development of a fast modeling of floodwater effects on ship motions in waves, Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ., Vol. 231(4): 877-887.

Acanfora, M., Begovic, E., De Luca, F. 2019. A fast simulation method for damaged ship dynamics, J. Mar. Sci. Eng., Vol. 7(4):1-14.

Bandringa, H., Helder, J.A. and van Essen, S. 2020. On the validity of CFD for simulating extreme green water loads on ocean-going vessels. OMAE 2020 39th Int. Conf. on Ocean, Offshore and Arctic Eng.

Braidotti, L., Mauro, F. 2019. A new calculation technique for onboard progressive flooding simulation, Ship Technology Research, Vol. 66, no. 3, pp. 150-162.

Braidotti, L., Mauro, F. 2020. A Fast Algorithm for Onboard Progressive Flooding Simulation, J. Mar. Sci. Eng., 8(5):369.

Bu, S., Gu, M. 2019. Study on damaged ship motion coupled with damaged flow based on the unified viscous and potential model, Proceedings of the 17th International Ship Stability Workshop, 10-12 June 2019, Helsinki, Finland, pp. 209-220.

Bu, S., Gu, M. 2020. Unified viscous and potential prediction method for the coupled motion of damaged ship and floodwater in calm water, Ocean Eng., Vol. 210, Article 107441.

Dankowski, H. 2013. A Fast and Explicit Method for the Simulation of Flooding and Sinkage Scenarios on Ships, PhD Thesis at Hamburg University of Technology.

Dankowski, H., Dilger, H. 2013. Investigation of the mighty servant 3 accident by a progressive flooding method. Int. Conf. on Offshore Mechanics and Arctic Eng.

Dankowski, H., Russell, P., Krüger, S. 2014. New insights into the flooding sequence of the Costa Concordia accident. Int. Conf. on Offshore Mechanics and Arctic Eng.

Dankowski, H., Krüger, S. 2015. Dynamic Extension of a Numerical Flooding Simulation in the Time-Domain, 12th Int. Conf. on the Stability of Ships and Ocean Vehicles STAB2015, Glasgow, UK.

Idel'chik, I. E. 1960. Handbook of Hydraulic Resistance (translated from Russian), Published for the U.S. Atomic Energy Commission, Washington D.C.

Lee, G.J. 2015. Dynamic orifice flow model and compartment models for flooding simulation of a damaged ship, Ocean Eng., Vol. 109, pp. 635-653.

Jasionowski, A. 2001. An integrated approach to damage ship survivability assessment, PhD thesis, University of Strathclyde.

Katayama, T., Ikeda, Y. 2005. An Experimental Study of Fundamental Characteristics of Inflow Velocity from Damaged Opening, Proc. of the 8th Int. Ship Stability Workshop, Istanbul, Turkey.

Papanikolaou, A., Spanos, D. 2001. Benchmark Study on the Capsizing of a Damaged Ro-Ro Passenger Ship in Waves – Final Report.

Papanikolaou, A., Spanos, D. 2005. The 24th ITTC Benchmark Study on Numerical Prediction of Damage Ship Stability in Waves – Final Report.

Ruponen, P. 2007. Progressive Flooding of a Damaged Passenger Ship, Dissertation for the degree of Doctor of Science in Technology, TKK Dissertations 94, 124 p.

Ruponen, P., Sundell, T., Larmela, M., 2007. Validation of a simulation method for progressive flooding. Int. Shipbuild. Prog., Vol. 54, pp. 305-321.

Ruponen, P., Kurvinen, P., Saisto, I., Harras, J. 2010. Experimental and Numerical Study on Progressive Flooding in Full-Scale, RINA Transactions, Vol. 152, Part A4, Int. J. Marit. Eng., pp. A-197-207.

Ruponen, P. 2014. Adaptive time step in simulation of progressive flooding, Ocean Eng., Vol. 78, pp. 35-44.

Ruth, E., Olufsen, O., Rognebakke, O. 2019. CFD in damage stability, Proc. of the 17th Int. Ship Stability Workshop, 10-12 June 2019, Helsinki, Finland, pp. 259-263.

Veldman, A. E., Luppes, R., van der Heiden, H. J., van der Plas, P., Düz, B., Huijsmans, R. H. 2014. Turbulence modeling, local grid refinement and absorbing boundary conditions for free-surface flow simulations in offshore applications. ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering.

van Walree, F., Papanikolaou, A. 2007. Benchmark study of numerical codes for the prediction of time to flood of ships: Phase I, Proc. of the 9th Int. Ship Stability Workshop, Hamburg, Germany.

Ypma, E.L., Turner, T. 2019. An approach to the validation of ship flooding simulation models, Contemporary Ideas on Ship Stability. Springer, Cham, pp. 637-675.