CFD in damage stability

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ABSTRACT

This paper presents some of the key learnings from CFD simulations of flooding events following a collision damage, as gained during the corresponding research and development activity carried out within the eSAFE project. The software STAR-CCM+ was used and allowed for full-scale simulations of the fully-coupled behaviour of the vessel, and of external and internal flows. All stages of the flooding process were included: i.e., transient and progressive flooding. The captured effects include the water inside the vessel propagating through corridors, ducts and other openings, dynamic response of the vessel due to water ingress, and waves influence. It was concluded that CFD simulations is generally a satisfactory tool for simulating flooding events. However, the simulation time was an issue, particularly for progressive flooding and statistical evaluations where many damage cases have to be evaluated.

Keywords: *eSAFE, Dynamic stability, CFD, simulations.*

1. INTRODUCTION

Software tools for simulation of flooding (e.g. PROTEUS3 [1], FREDYN [2][3], ROLLS [4][5], NAPA [6] and others) have been under development and put to practical use for many years. In connection with the eSAFE project [7][8] it was suggested to use CFD as a means to validate the simulation tools. It was recognised that while there are several results from model tests available for roro passenger vessels, there is very little data available for cruise ships. eSAFE used CFD to study the behaviour of a cruise ship during transient flooding in calm water and regular waves as well as progressive flooding in regular waves. The definition of the flooding stages is shown in Figure 1.

In the process of planning the extent and scope of CFD simulations, the ITTC recommendations on Numerical simulations of Capsize behaviour of damaged ships in irregular beam seas [9] was referred to.

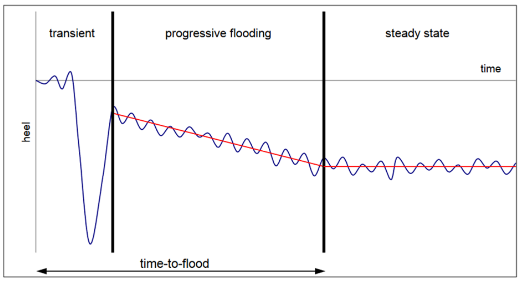

Figure 1: Phases of flooding process (from Ruponen [6]).

2. SELECTED FLOODING CASES

The main objective of the CFD work was to validate the results provided by the simulation software PROTEUS3 [1][10]. Based on initial PROTEUS3 simulations, a limited number of damage cases were selected to cover the relevant physics during flooding. Two cases where capsize could occur in the transient phase and two cases where capsize could occur in the progressive phase were selected. It should be noted that the selected damage cases were severe, affecting at least three vertical zones.

3. MODELLING

The geometry models used in the CFD calculations were taken from the NAPA model used by the shipyard for conventional damage stability calculations. In addition, structures restricting the flow in cross ducts and air vents were included. A-class bulkheads and hypothetical subdivision in way of e.g. cabin areas were not included. The assumed damage was limited in extent vertically up to deck 4, two decks above the bulkhead deck. Damages were imposed by removing structure in the damage definition volume.

The simulations were performed with STAR-CCM+ 9.04.011. Initial simulations were performed to derive a set of reasonable simulation parameters. The work on roll damping in Kristiansen et. al. [11], validated by model tests, was used as starting point. It was found possible to coarsen both mesh and time step, and still achieve reliable results. An example of meshing in way of cross flooding ducts is shown in Figure 2. In addition, important observations were that compressibility and air vents were important, and that the viscosity model was less important.

In the progressive flooding case the mesh and time step were coarsened further to allow for a very long simulation time. Simulating 30 minutes of progressive flooding in waves still took 50 days on 200 CPUs.

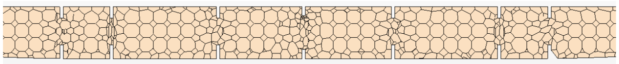

Figure 2: Example of cross-flooding duct and mesh.

4. TRANSIENT FLOODING IN CALM WATER

When a large portion of a ship, at or below the waterline is opened to the sea, a violent dynamic response due to sea water rapidly entering the ship will occur. This can result in rather extreme angles of heel during the first roll cycles that could lead to capsize. This is called transient flooding, see Figure 1, and has been subject to substantial research efforts e.g. Manderbacka [12] and Vassalos [13].

Two damage cases that by use of PROTEUS3 indicated capsize were simulated by CFD, for which one case is presented here. As a basis for comparison both results from using PROTEUS3 and NAPA for the same damage case are presented in Figure 3. Quasi-static NAPA calculations are performed with two different virtual transverse subdivisions of the machinery and cabin space. The finer division is denoted as "NAPA_1" in Figure 3, whereas the case indicated as "NAPA_2" is based on a coarser modelling. In PROTEUS3, two different properties of deck 4 were simulated. In one case the deck was completely transparent to water (denoted by "_1" in Figure 3), and in the other case completely watertight (denoted by "_2" in Figure 3). Deck 4 was barely touching the water at the maximum roll angle, but still produced a significant difference with respect to survivability. All NAPA and CFD simulations were performed with a completely watertight deck 4. The same CFD case was calculated by both LR and DNVGL giving similar results. It is worth noting that all software provided approximately the same maximum angle of heel. However, there appeared to be a difference in the dynamic behaviour after the initial transient.

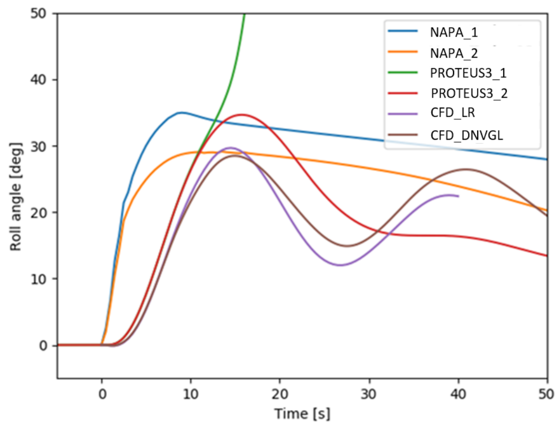

Figure 3: Transient flooding – response from various simulations.

A screenshot of the situation close to the maximum angle of heel is shown in Figure 4. The left side shows the portion of the ship opened to the sea. It was observed that the water level on the opposite side is higher due to the rolling of the vessel. This contributes to reduced transient roll angle. A significant advantage of the CFD simulations is the ability to accurately simulate and visualize the internal flow as opposed to only simulating filling levels under the assumption of a horizontal free surface.

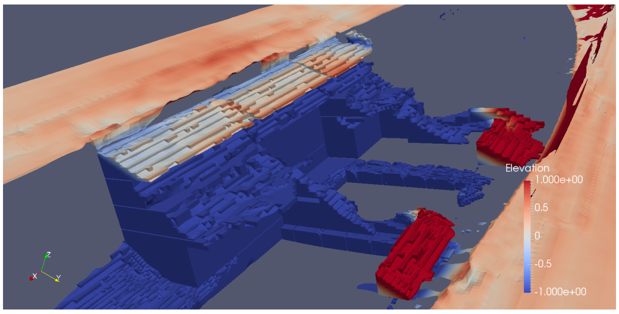

Figure 4: Screenshot - transient flooding.

5. TRANSIENT FLOODING IN WAVES

The same transient flooding damage case was simulated in regular beam sea waves to study the effect of waves in the transient phase. A wave height of 8m was found reasonable for the transient case, representing an "extreme" wave in 4m significant wave height. Steep waves are believed to be worse. Hence, the wave period was set to 7s.

The vessel was allowed to reach stationary behaviour in the waves prior to introducing the damage. The damage was imposed at four different positions (90 deg out of phase) in the wave to check the importance of phasing between wave and damage. The resulting roll time series are seen in Figure 5. Run_35 is the calm water and run 37 to 40 are the same damage introduced at different positions in the wave. It is observed that for this case the maximum roll angle shows small dependency on wave phasing or if the waves were present at all,

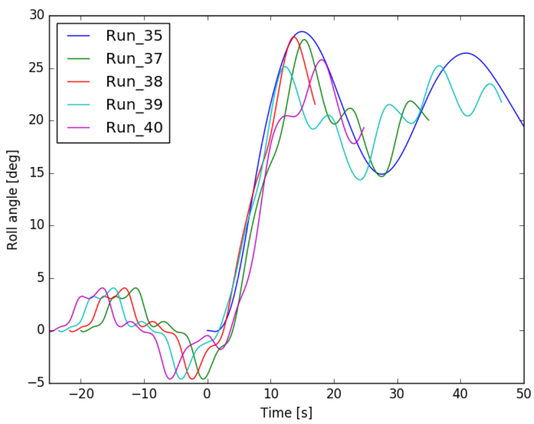

Figure 5: Opening to the sea at various phases of the waves.

6. PROGRESSIVE FLOODING IN REGULAR WAVES

The damage cases selected for validation of progressive flooding were among those where PROTEUS3 simulations resulted in capsize. The affected compartments are visualised in Figure 6. To ease comparison, regular waves were used. The wave height was set to 4 metres and the wave period to 5 seconds, to approximate a reasonable probable steep sea state lasting for an hour.

The simulation in waves was run for some time (to get realistic vessel motion) before the damage was introduced. Run 4100 shows the result in calm water. In Run_4108 the damage is introduced after 9s, and in Run_4107 after 11.5 seconds. The resulting roll angles are seen in Figure 7. Apparently, the starting point was not important for this case where the waves are relatively small, and the transient was not a problem in calm water. The initial transient is, in this case, reduced when the waves are present.

In Figure 8 and Figure 9 the progressive flooding in PROTEUS and CFD is compared. The PROTEUS3 results show that the flooding develops to an excessive angle of heel while the CFD calculations result in a steady state or slowly increasing angle of heel. The reason for the different behaviour is not clear but could be caused by different modelling assumptions.

It is believed that the resulting vessel motion from the waves is not significant for the progressive flooding phase. From the videos, it seemed like the effect from waves pushing water into the vessel was more important.

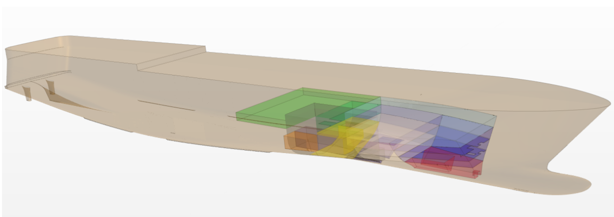

Figure 6: Illustration of ship model and flooded space.

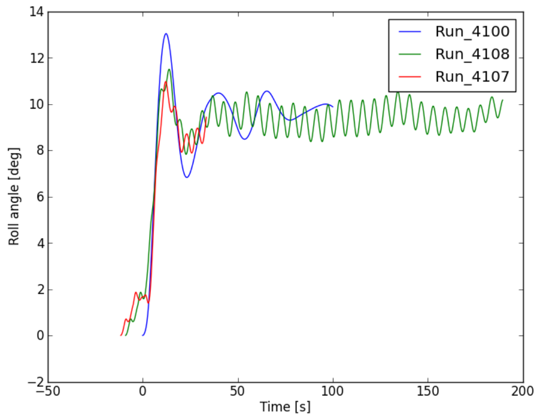

Figure 7: Introduction of damage at various time steps.

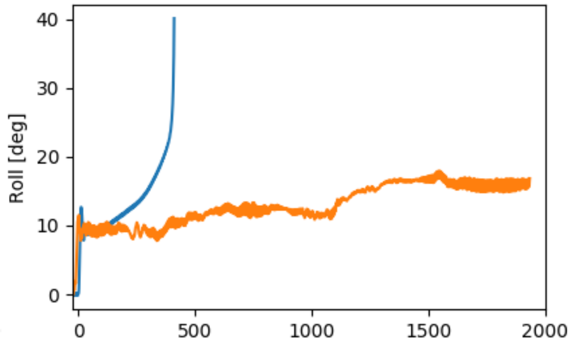

Figure 8: Comparison roll – PROTEUS3 (blue) and CFD (orange).

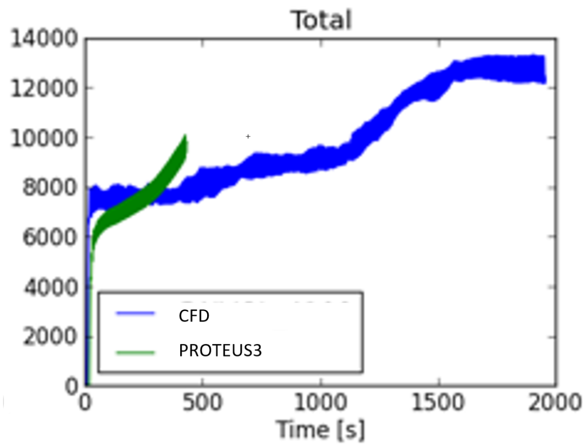

Figure 9: Comparison – flooded volume.

7. SOME THOUGHTS ON FUTURE USE OF CFD FOR DAMAGE STABILITY

In the presented work, CFD has been applied to complex damage stability cases and has given reasonable results. With respect to applicability of CFD in damage stability calculations, it is foremost the computational cost and time that are limiting.

CFD can be efficiently applied to selected parts of the damage stability assessment. For instance, CFD can be used to simulate:

- Wind forces on the superstructure
- Drag forces on the underwater hull
- Drift speed
- Wind heeling angle
- Cross flooding ducts

These kinds of simulations are significantly simpler and can be performed within a reasonable cost and time frame.

Simulating the entire problem of vessel motions, external and internal flows, is currently deemed reasonable for a limited selection of transient flooding cases. Progressive flooding in CFD is considered research scope.

Model tests may be cost efficient when performing parameter studies. Although some effects like wind are hard to model, most real physics may be accurately accounted for. The cost of preparing a vessel model with complex internal compartmenting is very high, and significant simplifications are normally required. CFD is already a preferred alternative when a low number of short duration events are studied for each damage case with specific flooded compartments.

If CFD is used for validation purposes, the damage cases selected for comparison should not be too complicated. Differences in assumptions or simplifications should be avoided when considering the basic capability of the simulation software. When relevant, CFD may be a useful tool to validate the effect of any simplification in the simulation tool.

Visualization is an important advantage of CFD. In the CFD simulation all physical quantities are known in the entire domain. This can be used to investigate and learn about detailed flow patterns or special effects.

8. CONCLUSIONS

CFD simulations of selected severe damage stability cases have successfully been performed. Both transient and progressive flooding in calm water and in waves were evaluated. For many cases PROTEUS3 compared well with CFD. However, for the progressive flooding simulation, there were significant differences. This is not necessary a shortcoming of one of the tools, but could also be caused by modelling differences.

The main advantage of CFD is the ability to visualize and investigate detailed flow patterns and include arbitrary geometrical models. Currently, CFD can efficiently be applied to study specific details or parts of the damage stability assessment like wind forces or cross flooding ducts. The main challenge with respect to full damage stability simulations is currently simulation time and cost, however future developments in computational power might help to overcome this.

ACKNOWLEDGEMENTS

This work was carried out in the framework of the project "eSAFE – enhanced Stability After a Flooding Event – A joint industry project on Damage Stability for Cruise Ships". The funding partners of eSAFE are: Carnival Corporation Plc, DNV GL, Fincantieri, Lloyd's Register, Meyer Werft, RINA Services, Royal Caribbean Cruises Ltd. and STX France. The financial support from the eSAFE funding partners is acknowledged.

DISCLAIMER

The information and views as reported in this paper are those from the authors and do not necessarily reflect the views of the eSAFE Consortium.

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