SPH-BASED MODELLING OF SHIPS AND OCEAN PLATFORMS OPERATING IN EXTREME ENVIRONMENTS

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I. INTRODUCTION

The demand for accurate predictions of current, waves and ice interactions with ships and ocean platforms is growing exponentially due to the ever-growing size of ships and ocean structures and increased operations in harsh environments. Violent free surface flows in an extreme wave environment can produce a tremendous pressure load on ships and ocean platforms by slamming or due to large motions and structural movements, resulting in elastic and even plastic deformations. Using traditional CFD methods, modelling hydro-elastic problems with structure deformations and a free surface breakup is difficult. The presence of ice pieces in this complex environment adds to complications in the modelling. Capabilities in numerical modelling of hydro-elastic structures and ice-like material must be developed parallel to physical modelling. The Smoothed Particle Hydrodynamics (SPH) methods have shown promises to accurately model the interactions between rigid and hydro-elastic structures, ice and violent free-surface flows, particularly with GPU-accelerated computational environment.

In recent times, the Ocean Coastal and River Engineering Research Center of the National Research Council Canada (the NRC-OCRE) has shown interest in the novel, meshless, and Lagrangian technique-based SPH method for modelling of rigid and hydro-elastic structures operating in complex wave-current environments with the presence of complex materials like ice and their mutual interactions. In the current endeavour, the author utilized the open-source SPH code DualSPHysics to model and predict the hydrodynamic characteristics of ships and ocean platforms interacting with rigid ice blocks and large waves. The main goal is to build confidence in the versatility of the open-sourced SPH-based tool for utilizing it as a complementary tool to the physical model testing capabilities to support research need for the performance evaluation of ships and ocean platforms exposed to an extreme and harsh environment and use it as a platform for further development of modelling hydro-elastic structures and realistic ice.

In the next section, the author presents several simulation test cases of ships and ocean platforms operating and interacting in different wave and ice environments.

II. NAOE APPLICATIONS OF DUELSPHYSICS

This section presents three test cases demonstrating the utilization of DualSPHysics for modelling and simulating complex floating structures operating in wave and ice environments. The applicability and rationale for each test case are presented in the following sub-sections. Details of the modelling techniques, simulation setup parameters and quantitative validations are not given. The target is to demonstrate the capabilities of the SPH tool for modelling the cases of ships and ocean platforms operating in representative moderate to extreme wave environments in areas where limited research is published.

Higher-resolution (final) simulations for each test case, focusing on the effects of environmental impacts on multiple operational scenarios, are currently being completed. The details of simulation conditions and setup parameters, the predicted results, and the comparison between the predictions and the corresponding measurements for each application case will be published in individual and separate research articles.

A. High-Speed Trimaran Hydrodynamics in Extreme Environments

The increasing demands for high-speed and economical operations in the recreation, ferry, windfarm, patrol, research, oil spill response industries, and navies worldwide have been met by narrow mono-hulls and multi-hull ships such as catamarans and, more recently, by novel hull forms such as trimarans. Mono-hulls and catamarans perform well in calm water and low sea states. However, excessive motions of these vessels and slamming events are driving the industry to look into alternative hulls, especially the trimaran hulls. The slenderness of the component hulls of a trimaran results in significant reductions in the wave-making resistance and improved motions in a seaway. At present, SPH-based models have yet to be tried to predict the hydrodynamics of such hulls despite their high potential.

In the current endeavour, the author validated the SPH-based tool by modelling and predicting the hydrodynamic performance and the 3D wave pattern generated at several high speeds of a Trimaran in calm water and waves and comparing the hull forces and motions with corresponding measurements conducted in a towing basin with wave generation capability. This purpose is very demanding in the SPH framework since the use of varying spatial discretization is not done in the current framework. This means a substantial computational burden to have sufficiently fine particle resolutions to capture the wave pattern. The parametric setup of the SPH models is confirmed using an extensive convergence study of the particle resolutions and smoothing distances. The final SPH results are then compared with the corresponding experimental measurements.

The SPH predicted calm water and wave resistances were within ±5% of the measurements at the high-speed range. The velocity and pressure distribution over the free surface and the surface elevation depict realistic interactions between the water and the hulls. Figure 1 presents representative examples of the trimaran under a high-speed condition in calm water and waves, showing the velocity fields on the free surface. The analysis also offered a better understanding of the dynamics of the ship's bow waves, how the bow wave breaking process develops and modifies the wakefield, and mainly how the overturning bow waves generate intense splash-up cycles.

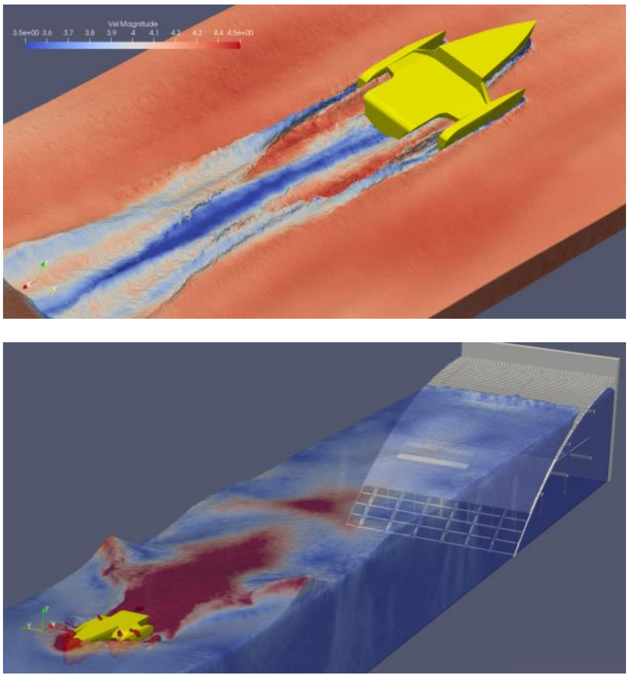

Figure 1. SPH Modelling of the Trimaran hull in Current (top) and in waves (Bottom).

B. Ship and Bergy Bit Interactions in Waves

Wave-driven growlers and bergy bits' impact load on floating and moving ships and ocean platforms is a critical design concern. The impact load is primarily influenced by the hydrodynamic interactions between the two bodies, mainly when they are close. This research aims to develop an SPH-based numerical tool to investigate the hydrodynamic influence on impact forces imparted to floating and moving ships and offshore platforms resulting from a collision with an ice mass of arbitrary size and shape in the presence of massive waves.

In this case study, DualSPHysics was utilized to model and predict the hydrodynamic interactions of a 6-DOF ship and bergy bits. The study involved modelling a generic drillship and simplified bergy bits in floating and towing scenarios and in regular and irregular wave conditions. The predictions were validated using the model-scale measurements on a moored ship towed at multiple oblique angles approaching a floating bergy bit in waves. Overall, this study thoroughly compares the model scale measurements and the prediction outcomes from the SPH tool for performance and accuracy. The SPH predicted ship motions and forces were primarily within ±10% of the measurements. The velocity, pressure distribution, and wave characteristics over the free surface depict realistic interactions of the wave, ship, and the bergy bit. This work identifies and presents several challenges in preparing the input file, particularly while defining the mass properties of complex geometry, the computational requirements, and the post-processing of the outcomes. Figure 2 presents a representative example simulation of the drillship and the cylindrical bergy bit interactions in a regular wave condition, showing the velocity fields on the free surface.

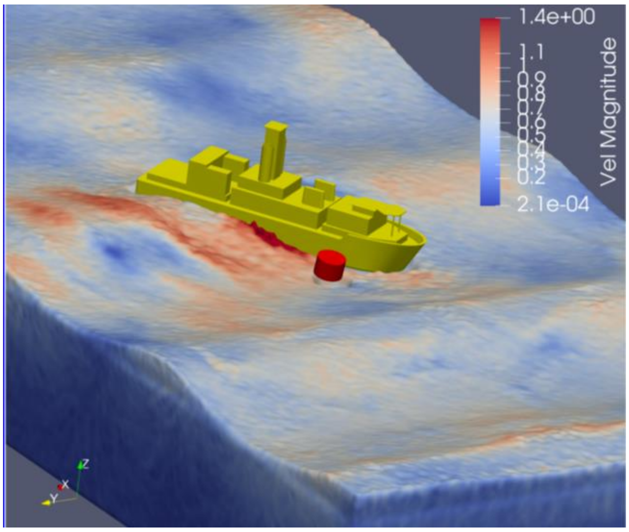

Figure 2. SPH Modelling of a 6-DOF Moored Drillship and Drifting Bergy Bit Interactions in Waves.

C. Ocean Platforms and Ice Pieces Interactions in Waves

This test case demonstrated the utilization of DualSPHysics in modelling and simulating ocean platforms interacting with ice blocks and ice floes in the presence of an extreme wave environment, which is prevalent in the Marginal Ice Zone (MIZ) of Arctic and Sub-Arctic regions. The ice and wave interaction is important in the MIZ for two primary reasons: firstly, ocean waves influence the sea ice cover, which then affects large-scale wind patterns and ocean currents; secondly, ice floes scatter and dampen waves, which has to be taken into account in forecasts of wave heights [1].

Two simulation cases are studied: a free-floating semi-submersible operating in a large wave field with multiple bergy bits and secondly, an offshore supply vessel transiting through a pack ice field in large waves. The work is motivated by the need to develop a numerical tool to predict the motions and environmental loads on commonly used floating offshore wind turbine (FOWT) platforms and offshore support vessels. All FOWT platforms and support vessels in sub-arctic areas are susceptible to various environmental loadings and motions due to massive waves, bergy bits, and pack ice fields that can substantially impact their operational activities. Notably, a semi-submersible carrier structure may encounter high waves, and moving bergy bits and the interactions with local hydrodynamic elements may create hazardous operating conditions. Likewise, the support vessels that facilitate the operations and maintenance of the FOWTs often encounter pack ice fields on top of waves, and understanding the loads due to these harsh environments is paramount for safe and efficient operations.

The free-floating semi-submersible encountering a large wave in the presence of multiple bergy bits of different sizes were modelled utilizing DualSPHyscis to investigate the motions of the platform, as well as the loads caused by the waves, moving ice blocks, and their interactions. To examine various operational situations, the incidence wave and bergy bits numbers and locations were systematically altered in the simulations while keeping the shape of the semisubmersible, airgap, and still water depth constant. Figure 3 shows semi-submersible interacting with the ice blocks in large waves as a representative simulation case.

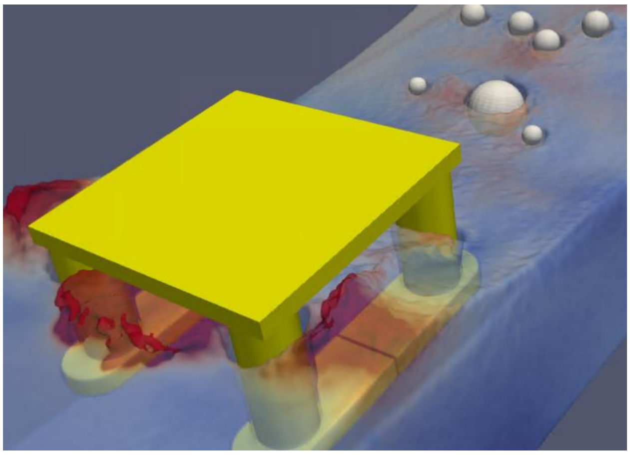

Figure 3. SPH Modelling of Ice Blocks of several sizes approaching a 6-DOF semi-submersibles under significant wave actions.

In the second simulation scenario, realistic pack ice fields consisting of various ice floe sizes (25 m to 75 m), ice concentration (70% to 90%) and ice height (0.5 m to 1 m) were modelled in the presence of large waves through which a generic OSV transited through at 5 to 10 knots. This simulation evaluates the interactions between the OSV and ice floes in the presence of waves of different ice fields and wave parameters. Another target is to gain insights into the wave-ice interactions and wave attenuation effects. Figure 4 shows the OSV transiting through and interacting with the ice floes in large waves as a representative simulation case.

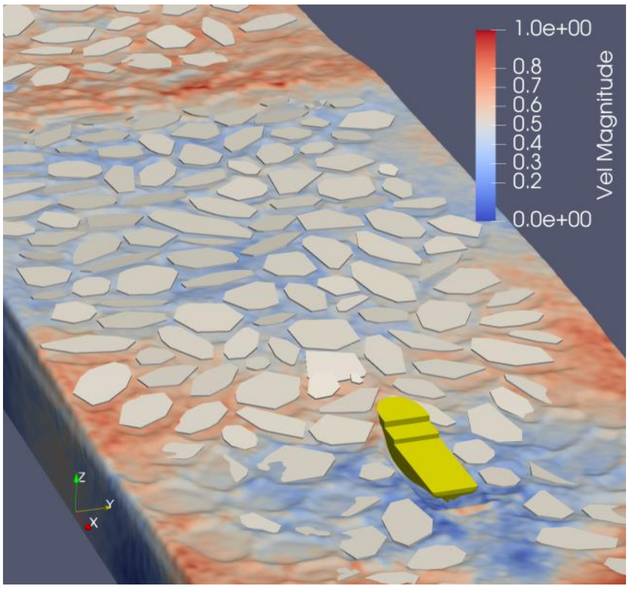

Figure 4. SPH Modelling of an OSV transiting through a pack ice field under significant wave actions.

III. Conclusion

This study demonstrated the capabilities of DualSPHysics for modelling multiple cases of ships and ocean platforms with complex geometry operating in representative moderate to extreme wave environments in the presence of ice in areas where limited research is published.

Due to its high computational cost, the author found the SPH-based tool inappropriate and impractical for predicting typical displacement hulls' performance at low to moderate speeds. However, this tool can be an alternative solution for high-speed scenarios, particularly for complex hulls like a trimaran in waves, where strong wake interactions occur between the hulls and the complex surrounding environment.

The SPH tool has shown promise in modelling and predicting complex interaction scenarios comprising free-floating and transiting ships and ocean platforms in wave and ice environments. The need for SPH-based tools to model hydroelastic structures and realistic ice will be paramount in the near future.

In-depth validations of the SPH tool for several naval architectures and ocean engineering-related applications are ongoing and will be published soon.

Acknowledgment

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References

[1] J. Mosig, Contemporary wave-ice interaction models, Doctoral Thesis, University of Otago in Dunedin, New Zealand, (2018).