



**University
of Victoria**

Graduate Studies

Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

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MSc (Sharif University of Technology, 2009)

**“A Parallel Explicit Incompressible Smoothed Particle Hydrodynamics
(ISPH) Model for Nonlinear Hydrodynamic Applications”**

Department of Mechanical Engineering

Tuesday, December 6, 2016

9:30 A.M.

Engineering and Computer Science Building
Room 468

Supervisory Committee:

Dr. Curran Crawford, Department of Mechanical Engineering, University of Victoria (Co-Supervisor)

Dr. Peter Oshkai, Department of Mechanical Engineering, UVic (Co-Supervisor)

Dr. Johannes Gemmrich, School of Earth and Ocean Sciences, UVic (Outside Member)

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Dr. Ioan Nistor, Civil Engineering, University of Ottawa

Chair of Oral Examination:

Dr. John Dower, School of Earth and Ocean Sciences, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

Fluid structure interactions in the presence of a free surface includes complex phenomena, such as slamming, air entrainment, transient loads, complex free surface profiles and turbulence. Hence, an appropriate and efficient numerical method is required to deal with these type of problems (efficient both in problem setup and numerical solution). Eulerian mesh-based methods can be used to solve different types of problems, however they have difficulties in problems involving moving boundaries and discontinuities (e.g. fluid structure interactions in the presence of a free surface). Smoothed Particle Hydrodynamics (SPH) is a mesh-less Lagrangian particle method, ideal for solving problems with large deformation and fragmentation such as complex free surface flows. The SPH method was originally invented to study astrophysical applications and requires modifications in order to be applied for hydrodynamics applications. Applying solid boundary conditions for hydrodynamic applications in SPH is a key difference to the original SPH developed for astrophysics. There are several methods available in literature to apply solid boundaries in SPH. In this research, an accurate solid boundary condition is used to calculate the pressure at the boundary particles based on the surrounding fluid particles. The two main methods to calculate the pressure in the SPH method are the weakly compressible SPH (WSPH) and the incompressible SPH (ISPH) approaches. The WCSPH uses the equation of state while ISPH solves Poisson's equation to determine the pressure. In this dissertation, an explicit incompressible SPH (ISPH) method is used to study nonlinear free surface applications. In the explicit ISPH method, Poisson's equation is explicitly solved to calculate the pressure within a projection based algorithm. This method does not require solving a set of algebraic equations for pressure at each time step unlike the implicit method. Here, an accurate boundary condition along with an accurate source term for Poisson's equation is used within the explicit method. Also, the sub-particle turbulent calculation is applied to the explicit ISPH method (which handles large-scale turbulent structures implicitly) in order to calculate the flow field quantities and consequently forces on the device more accurately.

The SPH method is typically computationally more expensive than Eulerian-based CFD methods. Therefore, parallelization methods are required to improve the performance of the method, especially for 3D simulations. In this dissertation, two novel parallel schemes are developed based on Open Multi Processing (OpenMP) and Message Passing Interface (MPI) standards. The explicit ISPH approach is an advantage for parallel computing but our proposed method could also be applied to the WCSPH or implicit ISPH. The proposed SPH model is used to simulate and analyze several nonlinear free surface problems. First, the proposed explicit ISPH method is used to simulate a transient wave overtopping on a horizontal deck. Second, a wave impacting on a scaled oscillating wave surge converter (OWSC) is simulated and studied. Third, the performance and accuracy of the code is tested for a dam-break impacting on tall and short structures. Forth, the hydrodynamic loads from the spar of a scaled self-reacting point absorber Wave Energy Converter (WEC) design is studied. Finally, a comprehensive set of landslide generated waves are modeled and analyzed and a new technique is proposed to calculate the motion of a slide on an inclined ramp implicitly without using a prescribed motion.