Numerical Simulation of Breaking Waves Using Hybrid Coupling of FNPT and NS Solvers

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ABSTRACT

In recent years, our research group has been developing a meshfree method based on Meshless Local Petrov Galerkin Method using Rankin source function (MLPG_R) and recently improved the methodology for the smooth pressure evaluation (IMLPG_R), as reported in the previous ISOPE conference papers. As it is well known that the particle methods that solve Navier Stokes (NS) equation is time consuming when the waves propagate over a long tank or for a long simulation time. One way to overcome this is to couple the NS solver with the solver based on Fully Nonlinear Potential Theory (FNPT). In this paper, novel algorithms were employed to couple the FNPT solver (based on Finite Element method developed by Sriram et al., 2006) and NS solver (Sriram and Ma, 2010). The new coupled model has been applied to a regular wave simulation. The applications of the developed model for solitary wave overtopping and shallow water freak waves breaking are presented.

KEY WORDS: FNPT; Hybrid coupling; IMLPG_R; breaking waves; shallow water freak waves.

INTRODUCTION

The available numerical models for the simulation of nonlinear wave and structure interactions are currently based on solving either the fully nonlinear potential flow theory (FNPT) or using the Navier Stokes (NS) equations. The test cases reported in the literatures using these models showed a good agreement with the experimental measurements. However, the application of these numerical models to the more general purpose cases are limited, for example reproducing the wave scenarios from offshore to coastal zone, to reproduce large scale test cases like one of the world largest wave channel in Hannover (GWK tank). The reason is that one needs to capture both non-breaking and breaking process accurately as close as possible, so the applicability of the either of these two models are limited due to the physical assumptions involved in the model. Therefore, using FNPT one can simulate highly stable and long time simulations with longer computational domain, but holds good only till the waves overturns. Whereas, in NS solver one can model the small scale phenomenon like viscous effects, turbulence, however it require finer mesh/nodes and a long computational time.

Thus, neither one of the two types of wave models is suitable for large scale wave propagation incorporating both the non-breaking and breaking processes in the simulations. Based on our experience, the numerical water wave model should meet two criteria: firstly, both the non-breaking and breaking processes and its interaction with the structure must be taken care satisfactorily in the simulation, and secondly, the simulation must be computationally efficiently.

Hence to meet the above criteria, either a new model which has both capabilities should be developed or a method should be developed to couple the two individual numerical models. The second option is attempted in this paper, by coupling the FNPT models with the NS models. The big challenge for coupling the models is that both models are different in theory/physics: i.e. non-viscous and viscous, and further, it employs different numerical treatments/algorithms.

As to the coupling of these two types of models, we found a few references. Fujima et al. (2002) developed the 2-D/3-D hybrid model intended for numerical tsunami simulation around structures. Comparison with the laboratory experiment showed that the hybrid model was able to reproduce the 3-D characteristics of flow around structure, and comparison with similar simulation using full 3-D model proved that the hybrid model could reduce the computational time significantly. Lachame et al. (2003), Grilli et al. (2004), and Biausser et al. (2004), discussed the coupling of the fully nonlinear potential flow model based on a Boundary Element Method (BEM) and VOF/NS model for the simulation of solitary wave breaking over the slopes. Two methods of coupling were proposed: weak and strong coupling. In the first method, the solution of the BEM model is used as an initialization of the VOF/N-S solver, with no feedback. In the second method, both models are exchanging information at every time steps. Sitanggang (2008) developed a hybrid coupling between Boussinesq model and RANSE model. In coupling, mesh based methods with meshless methods, Sueyoshi et al. (2007) used BEM and MPS (Moving Particle Semi-implicit method) for the two way coupled algorithm, taking the considerations of water wave kinematics the first half of the domain (free surface) was modeled using MPS and the second half of the domain (bottom part) is modeled using BEM. Narayanaswamy et al. (2010) and Kassiotis et al. (2011) used one way coupling between booussinesq model and SPH for solitary wave simulations.