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Numerical Study of 2-D Vertical Water-entry Problems Using Two-phase SPH Method

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A two-phase Smoothed Particle Hydrodynamics (SPH) method is used to simulate the early stage of the water entry of a 2-D wedge or a ship-section structure. From a comparison of the numerical results and the measured data, it is found that good agreement can be achieved. The variation of the velocity field, the pressure distribution, and the total hydrodynamic loads on the wedge are presented and discussed. The later stage of the cavity evolution for the wedge water entry and the formation of the entrapped air cavity for the ship-section water entry are simulated well by the two-phase SPH method.

INTRODUCTION

Slamming on ships and offshore structures can induce local and global structural responses (Faltinsen, 2015). The mortal slamming force can damage the ships or offshore structures. A better understanding of the slamming force on the structure and the pressure distribution on the structure is important for the design and operation of ships and offshore platforms. The slamming stage is the initial stage of the water-entry problems, which includes the water landing of the spacecraft, aircraft ditching, and other applications in naval architecture and ocean engineering (Streckwall et al., 2007). The period of the slamming stage is extremely short, basically in the order of milliseconds, so the modelling slamming process requires pressure sensors with high-frequency responses in experiments and the high temporal resolution model in the numerical simulation.

In marine hydrodynamics, the entrapped air at the impact belongs to one of the important hydrodynamic phenomena associated with the water-entry-induced slamming of the ship, the sloshing-induced slamming in a liquefied natural gas (LNG) tank, and the steep-wave-induced impact on a vertical wall (Gao et al., 2012; Lugni et al., 2010a, 2010b; Gong et al., 2011). In recent years, mesh-free methods have played an important role in modelling hydrodynamic flows with the free surface. The Smoothed Particle Hydrodynamics (SPH) method is one of the mesh-free methods and has advantages in dealing with large deformation and breaking of the free surface (Oger et al., 2006). It was first utilized by Lucy (1977) to solve astrophysical problems. The applications of the SPH are mainly focused on fluid-dynamics-related areas including heat transfer, mass flow (Cleary, 1998), and multi-phase flows (Monaghan and Kocharyan, 1995). The SPH method has been developed into a competitive approach dealing with impulsive loading and large deformation events. Gong et al. (2009) adopted the SPH method with an improved approach for computing the pressure of the particles on the wall boundary condition. Shao (2009) developed a version of the incompressible SPH method to simulate the water entry of a wedge and validated the model with the experimental data available. Recently, the two-phase SPH model has been implemented to simulate the deformation of the free surface and the evolution of the cavity induced by the wedge entering the water from the air (Gong et al., 2016).

For multiphase flows characterized by high-density ratios at the phase interface, there have been several attempts to propose stable multiphase methods. Liu et al. (2005) proposed a hybrid particle-mesh method to simulate unsteady multiphase flows in which a sharp interface separates incompressible fluids of different densities and viscosities. Lind et al. (2016) developed a new two-phase incompressible-compressible SPH method where the interface is discontinuous in density. Khayyer and Gotoh (2013) presented an enhanced stabilized Moving Particle Semi-implicit (MPS) method for the simulation of multiphase flows characterized by high-density ratios. Khayyer and Gotoh (2016) presented a novel compressible-incompressible multi-phase projection-based particle method for the prediction of water-slamming pressures. In this paper, following Colagrossi and Landrini (2003), a background pressure is added to the equation of state to avoid the tensile instability at the water-air phase interface.

On the basis of the experimental data of the hydrodynamic loads provided by the Wave Induced Loads on Ships Joint Industry Project-III (WILS JIP-III), the two-phase SPH method is used to predict the slamming pressures, is validated by the measured pressures for the cases of the wedge released at a given drop height, and has only one degree of freedom in the vertical direction. The total weight of the wedge, triangular frame, and vertical rod is 68.3 kg. The length of the wedge is 0.6 m, and the breadth is 0.8 m. The deadrise angle is 30 degrees. Two pressure sensors and one force sensor are placed on the wedge, as shown in Fig. 1. The wedge water entry with tilting angles of 20 degrees is also investigated, as shown in Fig. 2. The ship section is partly in the water at the initial time and is released at a given drop height. Three pressure sensors and three force sensors are placed on the

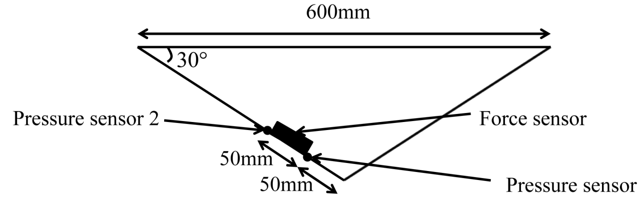

Fig. 1 Section of the wedge

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KEY WORDS: Water entry, wedge, SPH, two-phase.