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Prediction of Forces and Pressures on a Wedge and a Ship Section with CIP-Based Methods

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This paper presents improved numerical methods to predict slamming forces/pressures on a wedge with different tilted angles and on a ship section with various drop heights. The water-entry problem was solved by using a constrained interpolation profile (CIP) method on a fixed Cartesian grid. Both incompressible and compressible solvers and three interface capturing schemes were used to examine their effects on the solutions. Effects of prescribed and free fall motions on the solution were investigated. Convergence studies were carried out using various domain sizes, grid sizes, and time steps. The grid convergence index was employed to estimate the uncertainties due to spatial discretization. Validation studies were performed by comparing numerical solutions with experimental data.

INTRODUCTION

The water-entry or slamming problem is highly nonlinear since it involves breaking water surfaces and air bubbles. The water-entry problem of wedges has been extensively studied by many researchers. The theoretical analysis of the similarity flow induced by the wedge entry was pioneered by Von Karman (1929) and Wagner (1932). A review of earlier research on the theoretical analysis of water-entry problems was given by Korobkin and Pukhnachov (1988).

Various numerical methods have also been developed to address water-entry problems. The potential flow theory has been applied to solve water-entry problems of wedges, for example, by Vinje and Brevig (1981), Greenhow (1987), Zhao and Faltinsen (1993), and Zhao et al. (1996). Chuang et al. (2006) developed a boundary element method (BEM) based on the desingularized Cauchy formula and removed the corner singularity at the intersection point of body and water surface. Xu et al. (2008) simulated oblique water entry of an asymmetrical wedge based on a BEM with an analytical solution for the jet. Xu and Wu (2015) used a BEM with vortex shedding to simulate the oblique water entry of a wedge. The pressure jump was addressed by imposing the Kutta condition at the wedge apex. Bao et al. (2016, 2017) studied the oblique water entry of a 2-D wedge with prescribed and free fall motions. Wang and Faltinsen (2017) improved the numerical method proposed by Zhao and Faltinsen (1993) and presented the results for wedges with small dead-rise angles. Although the water-entry problem can be solved successfully in various degrees by the potential flow theory, there are difficulties in treating distorted free surfaces. Special treatments are usually needed, for example, for detached flow jets. Most of the studies based on the potential flow theory are limited to short-time simulations and simple 2-D geometries.

The computational fluid dynamics (CFD) methods have been increasingly employed to overcome the difficulties in treating highly nonlinear free surfaces. For example, Kleefsman et al. (2005) applied the volume-of-fluid (VOF) method to simulate a 2-D symmetric slamming problem. Kim et al. (2007) applied the smoothed particle hydrodynamics (SPH) method to solve 2-D water entry of asymmetric bodies. Wang and Guedes Soares (2014) investigated the water impact of 3-D buoys by using an explicit finite element method with an arbitrary Arbitrary Lagrangian Eulerian (ALE) solver. Zhang et al. (2015) studied the effect of compressibility on pressure distribution based on a finite element method solver. Benchmark studies on the water entry of a wedge and a ship section were carried out by Hong et al. (2017). In their work, results from a number of participants and based on various numerical methods were compared. It was found that CFD methods are promising for the cases of the wedge with zero tilted angle and the ship section with smaller drop heights. There is a need to further investigate the asymmetric water entry of the wedge and the symmetric water entry of the ship section with larger drop heights.

The constrained interpolation profile (CIP) method, originally developed by Takewaki et al. (1985), Yabe (1991) and Yabe et al. (2001), has also been used in water-entry studies. Hu and Kashiwagi (2004) further developed the CIP combined and unified procedure (CCUP) to simulate violent free surface flows. The robustness and the stability of the CCUP method has been demonstrated in multiphase flow simulations. Zhu et al. (2007) applied the CCUP method to simulate the water entry and the exit of a 2-D circular cylinder. In the work of Yang and Qiu (2012b), the CIP method was extended to solve the water-entry problems of 3-D bodies based on their studies of 2-D problems (Yang and Qiu, 2012a). Wen and Qiu (2015, 2016) further developed the CIP method by implementing the parallel computation algorithm and applied it to 2-D and 3-D slamming problems. Wei et al. (2015) studied the water entry of 2-D wedges with a CIP-based method. The tangent of hyperbola for interface capturing (THINC) method was used for interface capturing. In the work of Kim et al. (2017), the 2-D water entry of a symmetric wedge and a ship section with a low drop height was also studied with a CIP-based method and other methods.

In this paper, the water-entry problem is further studied with CIP-based methods. The present study focused on the prediction of local pressures/forces on wedges with different tilted angles and a ship section with different drop heights. Three different schemes

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