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Numerical Study of Sloshing in Baffled Tanks by MPS

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ABSTRACT

The effects of the baffle in rolling rectangular tank are investigated numerically by a particle solver MLParticle-SJTU based on MPS (Moving Particle Semi-implicit) method. Firstly, the liquid sloshing flow in a rolling rectangular tank without baffle is carried out to validate the reliability of the present solver. The numerical impact pressure on the measuring probe by the MLParticle-SJTU solver shows a favorable agreement with the experimental data together with the VOF results. In addition, the effects of baffle height on liquid sloshing are analyzed by considering five baffle heights. Numerical results show that the baffle significantly effects the motion of the fluid. Violent flow phenomena such as breaking wave and impacting the top wall of the tank can be observed in cases with small baffle height (or no baffle), while the fluid becomes weaker when increasing the baffle height. At the same time, the impact pressure decreases with increasing the baffle height.

KEY WORDS: MPS (Moving Particle Semi-Implicit); Liquid sloshing; Baffle; Free surface flow.

INTRODUCTION

Sloshing flow problem is commonly encountered in the shipping industry such as larger membrane-type liquefied natural gas (LNG) carries and LNG floating-production-storage-offloading (FPSO) vessels. When the tank is filled partially, high sloshing-induced oscillating impact loads on ship structures and large amplitude free surface displacement may occur, which can lead to the structure fatigue damage. Furthermore, when the frequency of excitation is close to one of the natural frequencies of liquid fluid, resonance will occur and larger sloshing amplitudes can also be expected. Therefore, there is a strong need to predict the impact loads on the structure and suppress the sloshing amplitude.

Sloshing flow is a highly nonlinear problem involving complicated phenomena such as breaking wave, overturning of free surface, splashing and high-speed impact on the tank wall. Due to its complexity, analytical solution (Faltinsen, 1974) can be given under the strong hypothesis such as irrotationality and simple geometry of tank, but it is difficult to describe the effect of energy dissipation due to viscous effect and flow separation. Recently, CFD (Computational Fluid Dynamics) has been proved an effective tool to predict impact load induced by liquid sloshing. Armenio et al. (1996a, 1996b, 1996c) investigated the sloshing flows in unbaffled and baffled tanks by RANSE (Reynolds Averaged Navier Stokes Equations) model together with experimental validation. Xue et al. (2011) employed large eddy simulation (LES) combining with volume of fluid (VOF) to study the liquid sloshing in a tank with baffles. Liu and Lin (2008) developed a 3D two phase fluid flow solver combining LES approach and VOF method to deal with violent forced sloshing flow with breaking up of free surface, and then they (2009) discussed the effects of baffles in the sloshing tank based on their solver. Chen et al. (2009) analyzed the accuracy of numerically predicting impact pressure on the walls based on level-set method. Akyildiz et al. (2005, 2006) carried out a number of experiments to investigate the pressure distribution on a rectangular tank induced by liquid sloshing. Later Akyildiz (2012) studied the effects of the vertical baffle on liquid sloshing in 2D rolling rectangular tank based on volume of fluid together with finite difference approximation. Cho et al. (2004) introduced a velocity-potential-based nonlinear finite element method for liquid sloshing in 2D baffled tank subject to horizontal forced excitation. Hu et al. (2004) employed an improved constraint interpolation profile (CIP) method to investigate violent sloshing flow in a sway tank.

All the numerical studies mentioned above are based on mesh method. Recently an alternative tool to study the sloshing flow is the meshless particle method. MPS (Moving Particle Semi-Implicit) is one such method, first proposed by Koshizuka (1998) to simulation the incompressible flow with large free surface deformation. Similar to SPH (Smoothed Particle Hydrodynamics), the fluid is presented by particles carrying physical properties such as pressure and mass, and there is no constant topology relationship between particles. One main advantage of particle method is the ability of handing flows with large interface movement and free surface deformation without any special treatment. Up to now, there has been some excellent work on liquid sloshing based on particle method. Shao et al. (2012) modelled the liquid sloshing by an improved SPH method, in which modified schemes for density correction and kernel gradient correction are both