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Investigation of Excitation Period Effects on 2D Liquid Sloshing by MPS Method

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ABSTRACT

In this paper, liquid sloshing in a 2D rectangular tank under harmonic rotational excitation is simulated by a meshless method solver MLParticle-SJTU, which is based on Moving Particle Semi-Implicit (MPS) method. Validation is performed by comparing the flow pattern and impact pressure with the corresponding experimental data. MLParticle-SJTU is proved to be reliable and efficient to solve 2D sloshing problem. In addition, the effect of excitation period on liquid sloshing is investigated. Sloshing cases under different excitation periods are taken into account. The evolution of flow patterns and impact pressure for these cases are analyzed. It is shown that sloshing is significantly affected by excitation period: Four types of sloshing waves can be observed for different excitation periods; Impact event takes place earlier with the increase of excitation period; Maximum of pressure occurs at a period lower than the first-mode natural period (T/T_0=0.8, T_0 is the first-mode natural period); The profile of "church roof" can be observed in the pressure curve when impact events occur under certain excitation periods.

KEY WORDS: MPS; 2D sloshing; rolling motion; excitation period; impact pressure; flow pattern.

INTRODUCTION

Liquid sloshing is of significant importance in coastal and offshore engineering and marine industry. Violent liquid sloshing in an oil or liquefied natural gas (LNG) ship can result in local breakage and global instability to the ship, and can then further lead to leakage of oil, and capsizing of ship (Shao et al., 2012). The amplitude of sloshing depends on the amplitude and period of the tank motion, liquid-fill depth, liquid properties and tank geometry. When the external forcing period is close to the highest natural period of the liquid, sloshing will be violent, which is called resonance phenomenon. So it is essential to avoid the vessel first natural frequency being close to the dominant frequency of the environment condition to achieve a good vessel motion performance.

Due to the importance of the sloshing problem, many researchers have conducted researching work, including theoretical analysis (Faltinsen, 1978; Faltinsen and Timokha, 2001), experimental research (Akyildiza and Unal, 2005; Lugni et al., 2006; Bulian et al., 2014) and numerical simulation. Due to its relatively low cost and the fast development of computer, computational fluid dynamics (CFD) has become an effective approach to study sloshing problem. In the past two decades, there have been many studies on sloshing based on CFD. Wu and Chen (2009) employed a finite difference method (FDM) solver to investigate sloshing waves in 3D liquid tank subjected to a range of excitation frequencies with motions that exhibit multiple degrees of freedom. Chen et al. (2009) analyzed the accuracy of numerically predicting impact pressure on the walls and ceiling of tanks based on level-set method. Kim (2001) applied the SOLA-SURF method to simulate sloshing flows in 2-D and 3-D containers and adopted a buffer zone concept to calculate the impact pressure on the tank ceiling. Hu et al. (2004) employed an improved constraint interpolation profile (CIP) method to investigate violent sloshing flow in a horizontally oscillating rectangular tank. By now, grid-based methods still play the dominant role in numerical research. However, due to the restriction of the grid, these methods may face some difficulties dealing with problems with large deformation and complex free surfaces, such as the violent sloshing problem (Chen et al., 2013).

Recently, an alternative approach to study the sloshing flow in CFD approach is the meshless method, such as SPH (Smoothed Particle Hydrodynamics, Gingold and Monaghan, 1977; Lucy, 1977) and MPS (Moving Particle Semi-Implicit, Koshizuka and Oka, 1996; Koshizuka et al., 1998). In meshless method, the flow field is represented by a set of interacting particles, which have mass, momentum and energy, etc. As particles have no fixed topography, meshless method is capable of handling large-deformed free surface problems. The fragmentation and coalescence of fluid can be naturally simulated in meshless methods (Zhang and Wan, 2011a). Another advantage for meshless method is that there is no numerical diffusion near the free surface since the particles are traced based on Lagrangian representation (Zhang and Wan, 2012).

In the present study, 2D liquid sloshing in a forced rolling tank is simulated. Numerical results, including the free surface deformation and impact pressure, are compared with experimental data. Then, sloshing cases under different excitation periods are simulated. The