Numerical Simulation of Shallow Water Sloshing Characteristics in a Rectangular Tank

Mi-An Xue a,b, Jinhai Zheng a,b, Xiaoli Yuan a,b,c, Pengzhi Lin a, Yuxiang Ma a, Wei Zhang a,b
a State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University. Nanjing, Jiangsu, China
b College of Harbor Coastal and Offshore Engineering, Hohai University. Nanjing, Jiangsu, China
c College of Mechanics and Materials, Hohai University. Nanjing, Jiangsu, China
d State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University. Chengdu, Sichuan, China
e State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology. Dalian, Liaoning, China

ABSTRACT

Sloshing flows can create significant global and local loads on the tank wall due to the impact of traveling hydraulic jump which is usually generated and observed in shallow water sloshing. This study therefore presents a numerical investigation of the shallow water sloshing characteristics in a rectangular tank. An in-house two-phase flows model is employed to simulate liquid sloshing phenomena with small fluid depth by changing the forcing frequency. The present numerical results are validated and in good agreements with the available experimental data from Bouscasse et al. (2013). The dominant response frequencies identified from the amplitude spectrum are presented for the different forcing frequency. The shallow water sloshing profile of the response amplitude operator is also obtained in a wide range of frequencies. The resonant frequency is shifted to a higher value than predicted by linear theory, which is like the response of hardening spring.

KEY WORDS: Shallow water; sloshing flows; rectangular tank; numerical simulation; forcing frequency.

INTRODUCTION

Sloshing is the violent motion of the free surface of a fluid in a partially filled container. The principal factors that affect the characteristics of a free surface sloshing waves in a tank are the tank shape, fill height and the tank motions including forcing amplitude and forcing frequency. Among the sloshing flows, low filling depth conditions are attractive due to the wave systems that are generated under these deep conditions. At low fill heights, the free surface motion due to sloshing typically takes the form of a travelling wave or bore wave, characterized by high velocities and low impact angles against the side or end tank walls and low air entrainment in the fluid. These bore waves can result in higher impact loads on the tank walls than occur with standing waves (Lloyd’s Register, 2009).

The study of shallow water sloshing, in general, is motivated by a number of applications such as sloshing on the deck of fishing vessels and offshore supply vessels, sloshing in wing fuel tanks of aircraft, green-water effects, sloshing in a swimming pool on deck, sloshing in fish tanks onboard fishing vessels and sloshing in automobile fuel tanks (Ardakani and Bridges, 2011). Verhagen and Wijngaarden (1965) conducted theoretical and experimental studies of finite amplitude shallow fluid sloshing in a rectangular tank harmonically excited by surge. Ockendon et al. (1986) developed a model for shallow water sloshing and presented the response diagrams describing periodic sloshing in a shallow rectangular tank. Faltinsen and Timokha (2002) developed an asymptotic modal approximation of nonlinear resonant sloshing in a rectangular tank with small fluid depth. It is noted that there are numerical difficulties for strong shallow fluid sloshing for the depth to length ratio h/L < 0.05, where h is the water depth and L is the tank length.

Cox et al. (2005) constructed the amplitude-frequency diagram, the hysteresis loops, and the stable equilibrium solutions associated with those loops which exist for the same forcing frequency for liquid sloshing in a shallow water tank. Gardarsson and Yeh (2007) experimentally investigated the wave response to relatively large shaking amplitude near the resonant frequency in a rectangular tank. In their investigations, they also explored that there is the hysteresis phenomenon associated with the bifurcation of the nonlinear system in shallow water sloshing in horizontally excited tank. In other words, it is not possible to define a unique jump frequency as it depends on the direction of the frequency tuning.

Ardakani and Bridges (2012) studied shallow water sloshing in vessels undergoing prescribed rigid-body motion in two dimensions. Chern et al. (2012a) simulated fully non-linear second-order resonance waves in a three-dimensional shallow water rectangular tank using a pseudospectral σ-transformation model. They demonstrated that second order resonance can be very pronounced in shallow water sloshing. Chern et al. (2012b) developed a pseudospectral σ-transformation model for simulating sloshing waves in a three-dimensional rectangular tank. A parameter study was conducted for sloshing in a shallow water tank by varying the excitation frequency, base aspect ratio, and excitation amplitude in their investigations. They show that contrary to the situation in deeper water tanks, sloshing in shallow water strongly

www.isope.org

Proceedings of the Twenty-fourth (2014) International Ocean and Polar Engineering Conference Busan, Korea, June 15-20, 2014 Copyright © 2014 by the International Society of Offshore and Polar Engineers (ISOPE) ISBN 978-1 880653 91-3 (Set); ISSN 1098-6189 (Set)