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A numerical study of the effects of the vertical baffle on liquid sloshing in two-dimensional rectangular tank

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ABSTRACT

The liquid sloshing in a moving partially filled rectangular tank with a vertical baffle is investigated. A numerical algorithm based on the volume of fluid (VOF) technique is used to study the nonlinear behavior of liquid sloshing. The numerical model solves the complete Navier–Stokes equations in primitive variables by using of finite difference approximations with the moving coordinate system. The ratio of baffle height to the initial liquid depth has been changed in the range of $0 \leq h_B/h \leq 1.2$. The critical baffle height to reach the roof of the tank and the baffle height beyond the liquid does not get over the baffle anymore have been investigated. The vortex originated by the flow separation from the baffle tip became weaker with increasing the baffle height. In order to assess the accuracy of the method used, some results with baffle height are compared with the experimental results. Comparisons show good agreement for slosh loads in the cases investigated. The free surface elevation and the time variations of pressures have been also presented.

1. Introduction

Liquid sloshing in a moving tank constitutes major components in a number of dynamical systems such as aerospace vehicles, road tankers, liquified natural gas carriers, elevated water towers and petroleum cylindrical tanks . Fluid motion in partially filled tanks can cause large structural loads if the period of tank motion is close to the natural period of fluid inside the tank [1,2]. The amplitude of the slosh, in general, depends on amplitude and frequency of the tank motion, liquid-fill depth, liquid properties and tank geometry. These parameters have direct effects on the dynamic stability and performance of moving tanks. The baffle inside a tank has investigated many researchers and the several recent studies on the effect of baffle on liquid sloshing are summarized as follows.

There has been a considerable amount of work on liquid sloshing. Some of these studies are reported by Ibrahim et al. [3], Faltinsen and Timokha [4]. Faltinsen and Timokha [4] analyzed the two-dimensional nonlinear sloshing of an incompressible fluid with irrotational flow in a rectangular tank by a modal theory. The theory they used is in good agreement with experimental results but the model assumes infinite tank roof height.

Akyildiz and Unal [5,6] investigated the pressure variations in both baffled and unbaffled rectangular tank numerically and experimentally. They observed that the effects of the vertical baffle are most pronounced in shallow water and consequently the pressure response is reduced by using the baffles. When an internal element is put into a tank, the liquid

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viscosity cannot be neglected and energy is dissipated by viscous action. Celebi and Akyildiz [7] revealed that flow over a vertical baffle produces a shear layer and energy is dissipated by viscous action. They concluded that, in an increased fill depth; the rolling amplitude and frequency of the tank with or without baffle configurations directly affect the degrees of nonlinearity of the sloshing phenomena. As a result of this, a phase shift in forces and moments occurred

Kim [8] analyzed the sloshing flows with impact load in the two- and three-dimensional containers based on a finite difference method. In this study, the Navier–Stokes equation with free boundary was solved using the SOLA scheme and the free surface profile was assumed to be a single-valued function. Armenio and La Rocca [9] adopted the finite difference method to solve the 2-D RANS equations to overcome the strong interaction between vorticity and free surface motion. The control of the sloshing behavior with baffles is also a subject of interest in the recent years, because of the complexity and highly nonlinear nature of the problem. Some researches carried out the experimental and numerical studies and pointed out the above mentioned characteristics [6,10–12].

Cho and Lee [13] denoted that the liquid motion and the dynamic pressure distribution above the baffle are more active than those below the baffle by carrying out the parametric study on two-dimensional liquid sloshing. They used the baffled tank under forced horizontal excitation considering potential flow theory. Cho et al. [14] carried out a numerical method to analyze the resonance characteristics of liquid sloshing in a 2-D baffled tank. They cannot resolve the viscous and the rotational motion of the liquid sloshing because of the potential flow theory. Pal and Bhattacharyya [15] carried out the numerical and experimental studies of liquid sloshing for 2-D problem. The resulting slosh heights for various excitation frequencies and amplitudes are compared with the data obtained numerically. It was concluded that the little variations in the data are due to the ineptness of the experimental setup and the input parameters. Younes et al. [16] investigated the hydrodynamic damping experimentally in rectangular tanks with vertical baffles of different heights and numbers. It is pointed out that the damping ratio increases by increasing the baffle numbers.

Liu and Lin [17] studies 3-D liquid sloshing in a tank with baffles using the numerical approach. They showed that the vertical baffle is more effective than the horizontal baffle in reducing the amplitude and the pressure on the wall. The commercial CFD code has been utilized to investigate the liquid sloshing recently [18–21]. They showed good agreement with the experimental data.

In this study, the effects of the vertical baffle height on liquid sloshing in a rolling rectangular tank have been investigated. A numerical algorithm based on the volume of fluid (VOF) technique is used to study the nonlinear behavior of liquid sloshing. The numerical model solves the complete Navier–Stokes equations in primitive variables by using of finite difference approximations with the moving coordinate system. The main purpose of this study is to assess numerically how the height of the baffle relative to the initial liquid depth affects liquid sloshing. The vertical baffle is located at the center of the bottom of the tank which is excited with the same frequency. Thus, this study presented provides an investigation of the free surface elevation according to the baffle height and the pressure distributions on the tank wall.

2. Mathematical formulation and numerical approach

The fluid is assumed to be homogenous, isotropic, viscous and Newtonian. Tank and fluid motions are assumed to be two-dimensional. The domain considered here is a rigid rectangular container partially filled with liquid, as shown in Fig. 1.

The governing equations (namely Navier–Stokes and continuity equations) are solved simultaneously with the corresponding boundary conditions and free surface kinematics and dynamic boundary conditions in the fluid domain

$$\nabla \mathbf{U}(u,v) = 0 \tag{1}$$

$$\frac{\partial \mathbf{U}}{\partial t} + \mathbf{U}\cdot\nabla\mathbf{U} = -\frac{1}{\rho}\cdot\nabla\mathbf{P} + \mathbf{F} + v\nabla^2\mathbf{U} \tag{2}$$

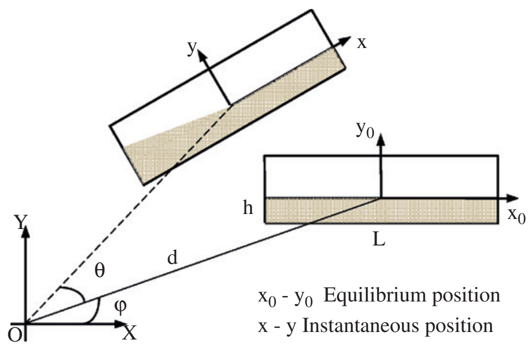

Fig. 1. Moving coordinate system.