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Liquid moment amplitude assessment in sloshing type problems with smooth particle hydrodynamics

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Abstract

Sloshing moment amplitudes in a rectangular tank for a wide range of rolling frequencies are investigated both experimentally and numerically. In a previous paper, Souto et al. [2004. Simulation of anti-roll tanks and sloshing type problems with smoothed particle hydrodynamics. Ocean Eng. 31 (8–9), 1169–1192] numerical results obtained with a 3-D Smooth Particle Hydrodynamics (SPH) formulation were presented. These only corresponded to the phase lag between the tank motion and the liquid response moment. This paper is aimed at improving those results by obtaining accurate values for the moment amplitudes. We present the corrections with respect to the aforementioned implementation that focus on the time integration scheme and on the treatment of the boundary conditions. In addition better quality experimental results are presented.

Keywords: SPH; Free-surface flows; Sloshing; Tuned liquid damper; TLD; TSD; Particle method; Phase diagram; Roll

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1. Introduction

The sloshing phenomenon can be defined as the highly nonlinear movement of the free-surface of liquids inside tanks. It generates dynamic loads on the tank structure and thus becomes a problem of relative importance in the design of marine structures in general and an especially important problem in some particular cases such as membrane system LNG vessels (Tveitnes et al., 2004). In these cases, the loads affect not only the structure of ships but their movement on waves (Kim et al., 2003b). This issue is crucial in the understanding of passive anti-roll tanks which are used mainly to dampen the roll movement of fishing vessels (Bass, 1998). Another types of tuned liquid dampers used in engineering correspond to the devices placed in tall buildings aimed at suppressing wind and earthquake induced vibrations in their structures. Very important examples are the Shin Yokohama Prince Hotel or the Hobart Tower in Tasmania (Kareem et al., 1999).

In the present paper the question of estimating the overall water moment inside rectangular tanks is addressed with respect to rolling motion and to ensure accurate validation, we cover a very wide range of experimental case studies. In a previous paper (Souto et al., 2004) a numerical technique was introduced to perform these calculations. In the experiments, the water moment signal is filtered to have the first harmonic (the one corresponding to the tank motion). In the numerical simulation the same process is performed. Results regarding the phase lag between both components were quite accurate but the ones corresponding to the moment amplitude were not so precise. In this paper we report the actions that have been taken to overcome these limitations and that advance the technique to a very mature stage in the design of unbaffled 2-D liquid dampers.

The sloshing problem has been to a great extent investigated in the last 50 years. The first attempts were based on mechanical models of the phenomenon by adjusting terms in the harmonic equation of motion (Graham and Rodriguez, 1952; Lewison, 1976). These types of techniques are used when time-efficient and not very accurate results are needed (Aliabadi et al., 2003). The second series of investigations solves a potential flow problem with a very sophisticated treatment of the free-surface boundary conditions (Faltinsen et al., 2005) that extends the classical linear wave theory by performing a multimodal analysis of the free-surface behavior. This approach is very time efficient and accurate for specific applications but it cannot handle overturning waves and neither is it clear how it could resolve the flow for generic geometries and baffled tanks. The third group of methods solves the nonlinear shallow water equations (Stoker, 1957) with the use of different techniques; Lee et al. (2002) use Glimm's method whilst Verhagen and Van Wijngaarden (1965) use a gas analogy formulation, both with respect to the 2-D rolling problem.

The fourth and most important group of techniques used to deal with highly nonlinear free-surface problems is aimed at solving numerically the incompressible Navier–Stokes equations. We will group them by using the term CFD. Frandsen (2004) solves the nonlinear potential flow problem with a finite difference method in a 2-D tank that is subjected to horizontal and vertical motion. Her results are very