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Experimental study of liquid sloshing dynamics in a barge carrying tank

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Abstract

An experimental work has been carried out to study the phenomena of sloshing of liquid in partially filled tanks mounted on a barge exposed to regular beam waves. Three liquid fill levels with liquid depth, h_s to length of tank, l ratio (h_s/l) of 0.163, 0.325 and 0.488, are studied. The time histories of sloshing oscillation are measured along the length of container at predefined locations. The nonlinear behaviour of sloshing oscillation is observed for the regular wave excitation. The spectra of the sloshing oscillation and their qualitative assessment are reported. Attempts are made to evaluate the harmonics present in the sloshing oscillation and compare with the results of earlier studies. The effects of wave excitation frequency and wave height on the sloshing oscillation as well as on the response of the barge are studied.

Keywords: Barge responses; Liquid sloshing; Secondary resonance; Modal sacrifice; Parametric resonance

1. Introduction

Liquid oscillation in a partially filled tank is associated with various engineering problems and dynamical systems. Liquid oscillation due to forced excitation is called sloshing. In maritime applications, it is experienced in LNG-FPSO/FSRU units, barges/ships equipped with oil tanks, storage tanks in compliant offshore platforms and in water ballasting tanks. The violent sloshing of liquid creates highly localized impact pressure on the container walls, which may in turn cause structural damages and may even create

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sufficient moment to destabilize the vessel that carries the liquid container. In order to design the tank walls for loads due to sloshing action and to study the stability of floating vessels, it is necessary to predict the liquid motion either using numerical simulation or experimental measurements. In view of the importance of the liquid sloshing dynamics in all engineering applications, several studies have been carried out to understand the said phenomena in a tank through analytical, numerical and experimental methods. The review of the literature categorized under single degree of excitation (translation or rotational), combined degree of excitation and sloshing due to interaction of the container and the vessel are discussed below.

Faraday (1831) explored the free surface waves in vertically oscillating basins. Benjamin and Ursell (1954) studied the linearized sloshing oscillation on the stability of the plane free surface of liquid subjected to vertical periodic motions. Moiseyev (1958) has initiated the study on nonlinear resonant sloshing of liquid in a horizontally excited tank. A third order hydrodynamic theory for steady state sloshing induced by small amplitude sway/roll excitation was reported by Faltinsen (1974). Further, Faltinsen (1978) presented a nonlinear numerical model for predicting the sloshing in a rectangular tank subjected to forced harmonic oscillation in the sway mode. In late eighties, considerable research has been devoted to predict sloshing surface elevation in the liquid tank subjected to translational/rotational excitation. Ockendon et al. (1986, 1993, 1996) explored the existence of multiple periodic solutions and shock wave information present in the shallow water sloshing using analytical approach. Lui and Lou (1990) have carried out a linear analytical study to signify the importance of dynamic coupling of a roll-excited liquid-tank system. Waterhouse (1994) elucidated the importance of critical depth (h_s/l) of 0.337 in the field of liquid sloshing dynamics. Extensive studies on modal analysis of liquid sloshing have been carried out (Faltinsen et al., 2000; Faltinsen and Timokha, 2001, 2002). The possible harmonics present in the system for the aspect ratio (ratio of the liquid depth, h_s and the tank length, l) ranging between h_s/l of 0.1 and 1.0 were explored. In general, the modal theories were limited without considering the liquid impact on the top deck of the tank, wave breaking and excessive run-up on tank walls.

Several studies were carried out on the numerical simulation of sloshing motion in tanks excited in one degree of excitation. Nakayama and Washizu (1980) carried out numerical analysis based on the finite element method (FEM) for the unsteady surface motions of liquid in a rectangular tank subjected to pitching oscillation. Armenio and La Rocca (1996) carried out numerical study based on the shallow water hypothesis and validated with experimental work for the roll excitation. Kim (2001) reported the simulation of the sloshing flows in 2D and 3D tanks as well as for the impact load on tank top panel due to sloshing flows at higher fill levels based on the finite difference method. Frandsen (2003) developed the finite difference based numerical scheme and sigma-transformation mapping technique to simulate sloshing motion in the vertically excited containers. The importance of wave steepness on the initial perturbation and the associated nonlinear behaviour in free surface elevation has been discussed. Thus, most of the work focused on the sloshing oscillation due to individual sway, heave or roll excitation.

Moving on to the studies related to combined degree of excitation, Frandsen (2004) developed a numerical wave tank (sigma-transformation method) and reported the possibility of infinite resonance frequencies for the case of combined (horizontal and vertical) excitation in contrast to unique resonance frequency observed in the horizontal excitation. Kim et al. (2003) reported the 2D (sway) and 3D (six degrees of freedom of excitation) sloshing behaviour in a rectangular tank by using volume of fluid (VOF) based numerical algorithm. The report revealed that, in addition to the translational accelerations, the rotational accelerations made an unpredictable run-up behaviour, which would lead to unexpected reaction force against the oil tanker. Wu et al. (1998) reported the occurrence of travelling waves and