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Investigation of Finite Water Depth Sloshing in a Tank in the Presence of Slat Screens Using Model Test and CFD

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Experiments and computational fluid dynamics (CFD) are used to study the effect of slat screens with three different solidity ratios *Sn* (the ratio between solid area and total area of the screen under the mean free surface) on sloshing in a two-dimensional tank in finite water depth ($h/l = 0.4$, with h and l the water depth and length of the tank, respectively). The steady-state responses of the waves and horizontal forces are analyzed. The effect of the solidity ratio on the natural/resonant frequency of sloshing is addressed. In addition, the effect of initial conditions on the steady-state results is also depicted.

INTRODUCTION

Swash bulkheads and baffles are used to diminish sloshing in the cargo and fuel tanks of ships. Faltinsen and Timokha (2009) give a thorough investigation of the effectiveness of these devices using theoretical/empirical methods. Large solidity ratio slat screens similar to swash bulkheads alter the resonant sloshing frequencies, shifting them to higher values (slat screens used in this study are made of a limited number of horizontal slats). This is of interest if the new higher sloshing frequencies are away from the energetic frequency range of the typical sea states, which in fact reduces the risk of occurrence of large pressures due to sloshing. This effect has been investigated for finite water depth using experiments and linear and nonlinear modal methods where the effect of the screen was introduced into the modal equations as a quadratic pressure loss term (Faltinsen et al., 2011a; Faltinsen et al., 2011b; Faltinsen et al., 2011c). In shallow water, Love and Tait (2010) modified the multimodal method of Faltinsen and Timokha (2001) to include damping terms that account for the screen in a tuned liquid damper (TLD). The latter work and similar works on TLDs consider small solidity ratios *Sn* (typically smaller than 0.5). This means that the lowest natural frequency does not experience a substantial change (essential for a TLD) and the screen acts more like a damping device. In marine applications, however, it is of interest to consider large solidity ratios to modify the natural/resonant sloshing frequencies.

Sloshing is a highly nonlinear phenomenon, and in the presence of screens the order of nonlinearity as a function of forcing amplitude changes. When screens have small solidity ratios of approximately 0.5, the hysteresis effect, which causes multiple solutions with steady-state jumps near the lowest natural frequency, is weakened, and the steady-state jumps do not occur (Firoozkoohi, 2013). However, as shown in Firoozkoohi and Faltinsen (2014) and Firoozkoohi (2013), the screen causes new nonlinear phenomena such as secondary resonance of higher sloshing modes due to nonlinear energy transfer from higher harmonics of forcing motion to the higher modes of sloshing. The nonlinear multimodal analysis of sloshing in screen-equipped tanks has shown (Faltinsen et al., 2011c) that the mathematical system expressing the modal system has to include the screen effect by considering its effect on the natural frequencies and the interaction of the screen with the modes through the order of nonlinearity of each mode. Additionally, it should also include many sloshing modes. Finding out the nonlinear ordering of the sloshing modes can be very complex. However, once the equation system is established, large numbers of simulations can be done in a short time. In Faltinsen et al. (2011c), the nonlinear modal method was not applied to frequencies larger than the second mode of sloshing in a clean tank (i.e., a tank without a screen) due to extreme complexities regarding the modal expansion. Screens also introduce other nonlinear phenomena such as three-dimensional effects, including wave breaking accompanied with turbulence, and local effects, such as liquid-to-gas jet flows through screen openings and run-ups on the screen that are difficult to include in the nonlinear multimodal method. Computational fluid dynamics (CFD) is used here to include the above-mentioned effects and to extend the range of frequencies to frequencies larger than the third natural frequency of sloshing. The extensive experimental work reported in Firoozkoohi (2013) has shown that unequal sloshing responses may also occur on the opposite sides of the tank due to a local transient effect near the screen. (In a linear system, one expects equal responses due to symmetry.) This paper shows that the unequal response effect is captured by CFD.

Numerical works of this kind have been performed by Maravani and Hamed (2011) for shallow water that has been applied for frequencies around the lowest natural frequency and for solidity ratios smaller than 0.5. Lu et al. (2015) studied the effect of baffles on two-dimensional sloshing using a Navier–Stokes viscous type of solution and addressed the effect of baffles on damping of sloshing waves and resonant sloshing frequencies.

Some recent works by Molin and Remy (2015) and Molin et al. (2015) should be noted here, where simplified potential flow

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KEY WORDS: Sloshing, nonlinear, screen, CFD, natural frequency.