Experimental and Numerical Investigation of the Effect of Swash Bulkhead on Sloshing

Reza Firoozkoohi and Odd Magnus Faltinsen
Center for Ships and Ocean Structures & Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

ABSTRACT

The effect of swash bulkheads on sloshing in a two-dimensional rectangular tank is studied. Damping due to the bulkheads and change in the lowest natural sloshing frequencies are accounted for using the quasi-linear modal theory by Faltinsen and Timokha (2009) and compared to new experimental results. An objective is to find which solidity ratio1 (Sr) gives the smallest sloshing waves at the two lowest natural sloshing frequencies. This solidity ratio is a function of non-dimensional lateral excitation amplitude and liquid depth-to-tank breadth ratio. In fact the quasi-linear modal theory (Faltinsen and Timokha, 2009) is justified and the conditions of applicability of the theory are determined.

KEY WORDS: Sloshing; swash bulkhead; linear modal theory; experiments.

INTRODUCTION

Sloshing matters in the design of ship tanks transporting liquids and fuels like LNG, LPG and oil. Sloshing means in our context “Violent or resonant motion of a liquid free surface inside a storage tank of a ship due to an excitation load with a frequency close to the lowest natural frequencies of the tank-liquid system”. There is a mutual interaction between ship motions and sloshing. Liquid impact on the tank walls and the roof can happen as results of different sloshing scenarios. Sloshing-induced slamming and resulting structural stresses is of particular concern for prismatic LNG tanks. As a consequence, there are limitations on the filling depth of the tanks.

Internal structures such as baffles, columns and swash bulkheads2 cause dissipation of the kinetic and potential energy by means of flow separation. The consequence is damping of the sloshing. A swash bulkhead has the additional important effect of changing the natural sloshing frequencies to a frequency domain where less severe ship motions occur.

Baffles have in general a small damping effect on sloshing relative to swash bulkheads (Faltinsen and Timokha, 2009). Swash bulkheads can be optimized to minimize sloshing. The result depends for instance on the tank motion, the liquid depth and the solidity ratio (Sr).

An early study about swash bulkhead in the marine field was by Akita (1967). He showed from a non-impact hydrodynamic pressure point of view how different shapes of perforations and different solid area percentages can reduce the pressure forces on the tank walls. In spacecraft applications, the effect of perforated walls on sloshing has been studied experimentally by Garza (1964) and Abramson and Garza (1965) for forced horizontal excitation of a vertical circular tank that is compartmented into sectors by means of radial walls 45°, 60° and 90° sector tanks. Their lateral excitation amplitudes were low relative to ship sloshing applications. Both the excitation amplitude and perforation of the sector walls affect the damping and the highest natural period. The natural period is here defined to correspond to when the liquid response has a maximum as a function of the forcing period. The fact that the excitation amplitude matters is a nonlinear effect associated with the cross-flow empirical quadratic nonlinear damping associated with the cross-flow through the swash bulkhead that can provide useful information on the effectiveness of swash bulkheads. The investigation begins by describing the theoretical method. The results of this numerical method will be compared with new experimental results.

NUMERICAL INVESTIGATION

The numerical analysis is developed for a 2D rectangular tank without chamfers and infinite tank roof height. The tank is laterally excited. The method is described in detail by Faltinsen and Timokha (2009). Here a summary of the theoretical model is given.

Summary of the Mathematical Procedure

The liquid domain is split into two equal domains $Q_1^-$ and $Q_1^+$ by a

---

1 The ratio between the solid area and the total projected area of the swash bulkhead
2 Perforated bulkheads inside ship tanks used for damping the resonant liquid motion
3 Germanisher Lloyds