Investigation of the effectiveness of a slat-type baffle in mitigating sloshing in a rectangular tank

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1. INTRODUCTION & OBJECTIVE

Liquid sloshing in containers is known to pose significant challenges in the storage and transportation of hazardous chemicals. Sloshing also occurs in spacecraft and various fluid-based mechanical systems, wherein it leads to undesirable effects (see Akyildiz 2005). Sloshing in tanks can be mitigated to a large extent using a baffle with slots (referred to as slat-type baffle), as shown in Fig. 1. Here, we present some preliminary results from our ongoing work in which we investigate the fluid flow in a rectangular tank fitted with a slat-type baffle (see Fig. 1). An important parameter in this analysis is the solidity ratio, defined as $\gamma = n_s A_s / A_b = n_s h_s / h_b$, where n_s is the number of slats, $A_s = W h_s$ is the cross-sectional area of each slat, $A_b = W h_b$ is the cross-sectional area of the baffle (see Marivani and Hamed, 2011). We are interested in investigating the effect of solidity ratio on the pressure caused due to sloshing, at a specific location on the tank's right wall. To obtain results, we consider three distinct values of $\gamma = 0.67,\ \gamma = 0.89,\ \gamma = 1$, corresponding to low, medium, and high solidity ratios. The tank is allowed to be oscillated with a known amplitude in a direction parallel to its length. The baffle is designed to have a height of h_b = 90 mm, a width of W = 300 mm (equal to the tank width), and a thickness of t = 20 mm. The effect of solidity ratio on sloshing dynamics was investigated using OpenFOAM.

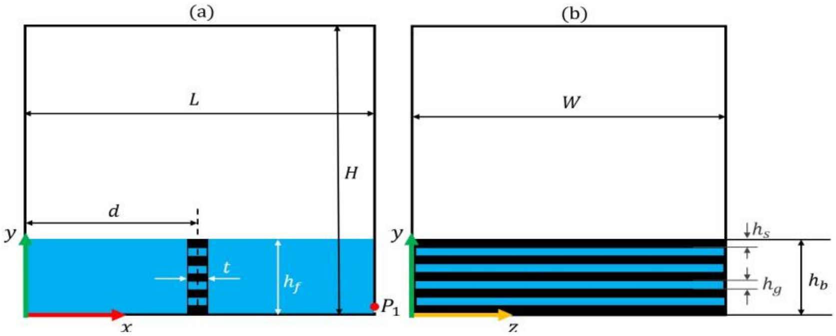

Figure 1. Geometry of the tank used in our simulations. (a) Front view. (b) Side view. The depth of water is h_f, and the height of the baffle is h_b. Regions shaded in black indicate the slats, each having a thickness of h_s.

Our simulations are motivated by the results of (i) Chen (2018), who numerically simulated 3D sloshing in a rectangular tank using OpenFOAM to study the effect of increasing the amplitude of oscillation on wall pressure; (ii) Marivani and Hamed (2011), who studied the effects of two different slat-type baffles on tuned liquid dampers (TLDs) using a finite difference method based laminar computational fluid dynamics (CFD) model; and (iii) Firoozkoohi *et. al.* (2013, 2016), who performed experimental and numerical analyses to study the forces on tank walls.

Assuming incompressible, laminar flow, we performed numerical simulations to investigate the effect of solidity ratio on mitigating sloshing for different modes (n) of oscillation, where n represents the n^{th} mode, for which the dispersion relation is $\omega_n^2 = g k_n \tanh(h_f k_n)$, where ω_n is the frequency of oscillation, k_n is the wave number, g is the acceleration due to gravity, and h_f is the water depth. The flow is governed by the continuity equation and Navier-Stokes equations. We specified appropriate boundary conditions and used the volume of fluid (VOF) method to capture the air-water interface. We also performed a grid independence study to arrive at an optimum mesh size for our simulations. The preliminary results of this work are presented in Section 2.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

In Fig. 2, we present our numerical results for the gauge pressure at a specific point (point P_1 in Fig. 1) in the tank. To understand the effectiveness of the slat-type baffle, we obtained time histories of the pressure at P_1 for three different values of the solidity ratio. Figures 2(a) and 2(b) show the gauge pressure at P_1 as a function of time for $n = 1$ and $n = 2$ respectively. From Fig. 2(a), we observe that for $n = 1$ the range of pressure variation at point P_1 is on the order of 1 kPa when $\gamma = 0$ (no baffle, green solid curve); whereas it is on the order of 0.1 kPa both when $\gamma = 0.89$ (baffle with slots, black solid curve) and when $\gamma = 1$ (baffle without any slots, red solid curve). This indicates that the presence of a baffle can reduce the pressure fluctuations by approximately one order of magnitude for this tank when $n = 1$. From Fig. 2(b), we observe that for $n = 2$ the range of pressure variation at point P_1 is on the order of 0.1 kPa when $\gamma = 0$ (no baffle, green solid curve), whereas it is on the order of 0.2 kPa when $\gamma = 0.89$ (baffle with slots, black solid curve), and on the order of 0.3 kPa when $\gamma = 1$ (baffle without any slots, red solid curve). This shows that the baffle is not effective in mitigating the effects of sloshing in the tank when $n = 2$. We are currently performing more simulations to understand this trend. Results of our extensive simulations will be reported elsewhere.

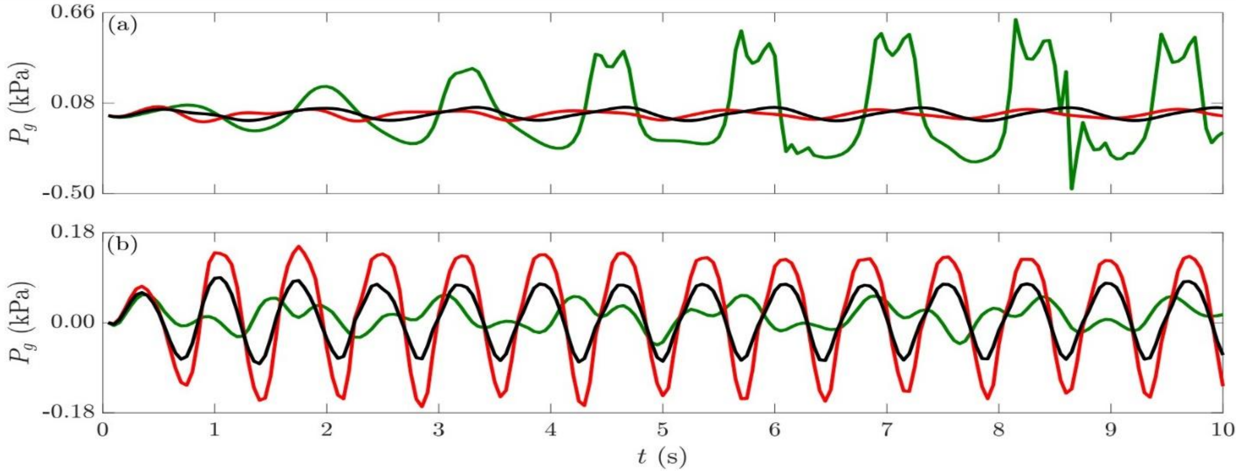

Figure 2. The temporal evolution of gauge pressure at point P_1 in the tank. Panels (a) and (b) present results for modes $n = 1$ and $n = 2$. The green, black, and red solid curves represent results for $\gamma = 0$, $\gamma = 0.89$, and $\gamma = 1$ respectively.

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