Experimental Investigation For Liquid Sloshing In Baffled Rectangular Tanks

M.F. Younes, Y.K. Younes

Abstract: Liquid sloshing is a kind of very complicated free surface flow and exists widely in many fields. In this paper, the sloshing phenomenon in a partially filled rectangular tank under a sway excitation is studied experimentally. A small scale test rig is designed and constructed to measure the dynamic tank wall forces and interaction forces, the baffles are fitted to attenuate the lateral motion of the liquid slosh. Lower mounted and upper mounted vertical baffles of different heights are tested. Lower mounted vertical baffles with central hole of different sizes are considered. The results show that the size and position of the vertical baffles significantly improve damping.

Keywords: Baffles, Sloshing, Rectangular tank, Liquid vibration

1 INTRODUCTION

Sloshing is a potential source of disturbance in liquid storage containers. One important issue in the liquid sloshing is that when the sloshing frequency is close to the natural frequency of the system the sloshing force and sloshing moment are so large that they lead to safety problems. Sloshing is not a gentle phenomenon even at very small amplitudes. The liquid motion can become very non-linear, surface slopes can approach infinity. The most interested parameters of liquid sloshing are sloshing frequency and damping. Usually a good frequency calculation result can be achieved but it is difficult to obtain a reasonable result for damping calculation. As a result, an experimental method is often used to determine the sloshing damping. Ranganathan [1] and Nickkawde et al. [2] have simulated the movement of the liquid with a regular pendulum and a fixed mass. The mass of the pendulum simulated the effects of the first mode of the fluid in movement. The fixed mass simulated the inertia and the weight of the remaining liquid. Alyildiz and Unal [3,4] investigated the pressure variations in both baffled and unbaffled rectangular tank numerically and experimentally. They observed that the effects of the vertical baffle are more pronounced in shallow water and consequently the pressure response is reduced by using the baffles. Celebi and Alyildiz [5] revealed that flow over a vertical baffle produces a shear layer and energy is dissipated by viscous action. They concluded that, in an increased fill depth; the rolling amplitude and frequency of the tank with or without baffle configurations directly affect the degrees of nonlinearity of the sloshing phenomena. As a result of this, a phase shift in forces and moments occurred. Cho and Lee [6] denoted that the liquid motion and the dynamic pressure distribution above the baffles are more active than those below the baffle by carrying out the parametric study on two-dimensional liquid sloshing. They used the baffled tank under forced horizontal excitation considering potential flow theory. Liu and Lin [7] studies 3-D liquid sloshing in a tank with baffles using the numerical approach.

They showed that the vertical baffle is more effective than the horizontal baffle in reducing the amplitude and the pressure on the wall. Khalifa et al. [8] presented numerical (FEM) and experimental investigations of liquid sloshing in a partially-filled rigid rectangular tank fitted with a vertical baffle mounted on its bottom, under horizontal base excitation. Younes et al. [9] presented an experimental study of the hydrodynamic damping provided by using lower and upper mounted vertical baffles in partially filled rectangular tanks, and evaluated the effects of baffle dimensions, shape, number, and arrangement on the damping. Araf [10] developed a finite element formulation to investigate the sloshing of liquids in partially filled rigid rectangular tanks, with a bottom-mounted vertical rigid baffle as well as side-mounted rigid baffle, undergoing steady-state harmonic or arbitrary horizontal base excitation. Biswal et al. [11, 12] presented the natural frequencies of liquid in a liquid-filled cylindrical rig tank with or without baffles. The authors used an annular plate as a baffle, which was fitted to the inner periphery of a cylindrical tank. Both rigid and flexible baffles were considered into the computation. Finite element technique was used to solve both the liquid and the structural domain. In this paper, the problem was confined to liquid sloshing in a rectangular tank under harmonic sway excitations to investigate the variations of the dynamic forces and the effectiveness of vertical baffles on damping liquid sloshing forces. Tests are carried out for a tank with and without baffles. Lower mounted, upper mounted and central hole vertical baffles are tested. For each filling ratio, the excitation frequency is chosen close to the fundamental frequency of oscillation of the contained liquid to provide maximum slosh forces. The different design parameters of the baffles and tank have been tested in order to provide quantitative measures for practical favorable designs. These include the tank filling ratio, excitation amplitude, excitation frequency, baffle size and baffle configuration.

2 EXPERIMENTAL AND INSTRUMENTATION SETUP

Referring to Fig. 1, the test rig consists of three main parts: the shaking table, the exciter and the rectangular tank. The shaking table is specially designed for sloshing experiments and it is moved in the longitudinal direction by using a Scotch Yoke mechanism.

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An electrical frequency inverter is used to change the excitation frequency from 0 to 1.2 Hz. A 60x60 cm model tank, width of 40 cm constructed from Plexiglas 1 cm thick are fixed on to the shaking table by four screw rods. An aluminum C-beam are fixed on the inner surface of the tank wall and used to support the different vertical baffles. For the measurement of the sloshing force applied to the tank walls, a force transducer is fixed on the inner surface of the tank wall. The excitation force taken as an indication to the force transmitted of the main structure is measured by using S-force transducer (II). The output signals are fed to the data acquisition card and then transmitted to a PC. The LabJak stream software is used to analyse the digital data.

### 3 RESULTS AND DISCUSSION

Tests are carried out under a horizontal harmonic motion for a liquid height $H=15, 30$ and $45$ cm corresponding to filling ratios $F_r=1/4, 1/2$ and $3/4$. The excitation frequency varies from $f_x=0$ to $1.1$ Hz. From primary tests, the excitation amplitude of $3$ cm has been selected to provide large slosh forces which can be accurately measured for the cases of lower filling ratios and does not create violent liquid oscillations for the cases of higher filling ratios. Tests are carried out for a tank with and without baffles. Lower mounted, upper mounted and central hole vertical baffles are tested (table 1).

**Table 1**

<table>
<thead>
<tr>
<th>Layout of experimental cases</th>
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<tbody>
<tr>
<td>Lower mounted vertical baffle</td>
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<tr>
<td>Upper mounted vertical baffle</td>
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<tr>
<td>Baffle with a central hole</td>
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</tbody>
</table>

For each test run, the tank starts from rest for selected excitation frequency, liquid height and baffle configuration. The tank is let to run for about 30 sec before data recording. This time was found suitable to reach steady state. After a period of 60 seconds, the data are recorded by the automatic data acquisition system. Figs. 2 and 3, show the dynamic forces for unbaflled tank in time domain. The excitation force ($F_{ex}$) and the dynamic force acting on the tank walls ($F_{w}$) are increasing with the excitation frequency and the maximum force takes place at an excitation frequency ($f_x=1.1$) close to the natural frequency of the liquid ($f_n=1.09$ Hz).
3.1 Effect of the Lower Mounted Vertical Baffle

Figs. 4 and 5, show the variation of the relative maximum wall force $F_{w,r}$ obtained for filling ratios $F_r=0.25$ and 0.5 for different excitation frequencies. These figures indicate that the maximum wall forces in a baffled tank decreases as the excitation frequency increases compared to that in an unbaffled tank. It may be concluded that the baffle located vertically on the center on the bottom of the tank has a greater influence on the dynamic forces on the sides of the tank when placed closer to the liquid free surface. The effect of the lower mounted baffle on the dynamic forces is gradually reduced when the baffle is moved towards the bottom of the tank and is almost negligible when it is placed closer to the bottom. The results illustrated in Fig. 6, show that the non-dimensional excitation force decreases with the baffle height due to the increase of damping ratio. Furthermore, the maximum excitation force occurs at an excitation frequency greater than that of the unbaffled tank.

3.2 Effects of the Upper Mounted Vertical Baffles

In Fig. 7, it can be noticed that the non-dimensional maximum wall forces are decreasing with the baffle depth. When the baffle depth relative to the liquid height is very small $h_u/H=1/6$, there is no great difference between the baffled and unbaffled responses. The same observation can be noticed in Fig. 8 for the non-dimensional maximum excitation forces for baffle depths $h_u=10, 15$ and 20 cm.
The maximum contribution of the baffle occurs at higher baffle depths. From these figures it can be observed that the forces are increasing slightly for small values of frequency ratio \((r<0.6)\). For higher values of frequency ratio \((r>0.6)\), the forces are increasing sharply and reach their maximum value at \(r=0.9\) – 0.95 for un baffled tanks. Finally, the forces magnitudes drop, it can be concluded that the upper mounted baffle located at the center of the tank reduces the dynamic forces acting on the structure and tank wall.

For a higher baffle depth \((h_u/H=2/3)\) the maximum forces increase slightly and in a linear trend for a wide range of the excitation frequencies. As shown in Figs. 9 and 10, the minimum forces occur at relative baffle depth \(h_u/H =0.7\) \((H_u/H=0.85)\), for the selected excitation frequency and filling ratio. Therefore, this type of baffles is suitable for chargeable tanks because when the liquid height changes, the baffle depth changes by the same ratio.

### 3.3 Effect of the Baffles with a Central Hole

From figs. 11 and 12, it can be noticed that increasing the hole diameter leads to a decrease in the dynamic wall forces for any liquid height, due to the increase in the damping ratio. For a certain value of hole diameter (above \(d=10\) cm), the hole diameter becomes large and the relative velocity between the liquid and the baffle decreases, therefore, the dynamic force decreases with an increase in the hole diameter and the tank may be treated as an open tank. for filling ratio \(F_r=0.25\) and frequency ratio \(r=0.9\), when the hole diameter increases from 10 to 18 cm, the wall force increases from 17% to 22% from its value in unbaffled tank case.

The effect of the hole area relative to the liquid projected area \(A_L\) on the dynamic wall force is illustrated in figure 13, for filling ratios \(F_r=1/4\) and 1/2, and the frequency ratios \(r=0.5\), 0.9 and 1. From this figure, it can be noticed that the maximum reduction of the dynamic wall forces occurs at relative area \(A_r=0.12\) with filling ratio \(F_r=1/2\) and at relative area \(A_r=0.2\) with filling ratio \(F_r=1/4\) irrespective of the value of the excitation frequency. It can be concluded that the maximum contribution of this type of baffles occurs at \(F_r=1/2\) \((A_r/A_L=0.12)\). This is due to the position of the hole relative to the liquid surface.
CONCLUSIONS

The dynamic wall forces reduction achieved by a single hole baffles is more suitable for a wide range filling ratios applications than the lower mounted baffle arrangement. For the tested model, for baffle with $d/H_0=0.16$ the dynamic wall force is reduced by 88 % and 80 % from its unbaffled values for $Fr=1/4$ and $Fr=1/2$ respectively. The maximum reduction in the dynamic wall forces occurs when the hole position is close to the liquid free surface. This type of baffles is recommended to be used in large semi chargeable tanks where high dynamic forces are expected. The dynamic wall forces reduction achieved by a single upper mounted vertical baffle is greater than that of the other studied cases for $Fr = 0.5$. It can be noticed that the minimum forces occur at relative baffle depth $h_u/H =0.7$ ($h_u/H_t=0.85$), for the selected excitation frequency and filling ratio. The upper mounted baffle reduces the dynamic wall forces by 90% from its unbaffled values. This type of baffle is more suitable for changeable tanks.

5 REFERENCES


