Experimental Investigation on the Effect of Liquid Fill Level in a Container to Liquid Sloshing

M.A.M. Irwan[1,*], M.M. Syahrail[1], P. Azma[1], A.M. Fudhail[1], M.Z.M. Rody[1], R. Nadlene[1], S. M. Adrinata[1] and M.N.N. Rashid[2]
[1]Faculty of Mechanical Engineering, UTeM
[2]Faculty of Engineering Technology, UTeM

*Corresponding email: mohdirwan@utem.edu.my

Abstract

Liquid sloshing is any motion of free liquid surface inside its container. Sloshing may generate hydrodynamics loads that can be dangerous to structural integrity and stability of moving containers. In this study, liquid sloshing in containers with 50% and 90% fill level were investigated. The containers with liquid inside were excited sinusoidally by using an electrodynamics shaker while the free liquid surface level change was captured by using high speed camera**.** The free liquid surface amplitude difference obtained for containers with 50% and 90% fill level were compared. Results show that sloshing is more vigorous in containers with 50% fill level compared to 90% fill level. Liquid transportation should be done at an almost full fill level to minimize sloshing.

Keywords: electrodynamics shaker, high speed camera, 50% and 90% fill level.

1. INTRODUCTION

Liquid sloshing is any motion of free liquid surface inside its container. It can be initiated by any disturbance to a partially filled liquid container [1]. These motions may generate hydrodynamics loads that can be dangerous to structural integrity and stability of the container [2]. The liquid sloshing phenomena is illustrated in Fig. 1:

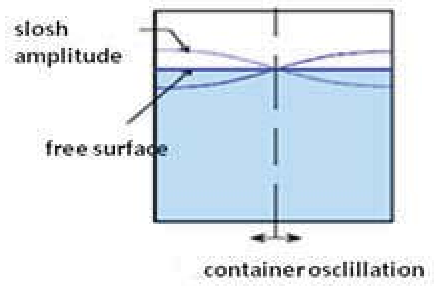

Fig. 1 Schematic illustration of liquid sloshing

Study of liquid sloshing is very important in applications involving moving containers with liquid inside. Some of the applications include tank trucks on highways, liquid tank carriages on railroads, sloshing of liquid cargo in ocean-going vessels and propellant tanks in liquid rocket engines [3]. These applications involve various types of liquid being transported around the world. Common types of liquid important to our daily lives are petroleum products and clean supply of water.

It is common to see these types of liquid being transported by trucks on the road every day. Therefore, study of liquid sloshing in liquid cargo transportation is very important. By understanding liquid sloshing, damage to structure and instability of moving containers can be reduced.

Liquid cargo can either be transported in a cubical shaped or cylindrical shaped container as shown in Fig. 2 and Fig. 3. Selection of which container to be used is made according to the industrial needs. Regardless of which container is used for transportation, liquid sloshing may still influence the stability of both containers while the cargo is being transported.

There are several parameters that may influence the stability of containers while liquid is transported such as the amplitude and natural frequency of the container motion excitation, filled liquid properties, container geometry and liquid fill level in the container [4].

Liquids may be transported at different fill levels to various destinations depending on delivery constraints and demand. Therefore, it is also important to study the effect of having voids in the containers if the liquid fill level is too low. It is important to insist transportation to be done in the safest possible condition. In this study, liquid sloshing in containers with 50% and 90% fill levels were investigated by using relatively smaller scale models which resembles the common container shapes used for liquid cargo transportation.

Fig. 2 Liquid cargo transporter – Cylindrical Shape

Fig. 3 Liquid cargo transporter – Cubical Shape

2. METHODOLOGY

The experiments were conducted by using smaller container models at the scale of 1:10 with reference to road tankers. The container geometry studied were cubical and cylindrical types which resemble actual liquid containers used during liquid transportation.

Each container was installed and positioned on a horizontal rolling table which will move the container. The rolling table was positioned on a support table. The support table could be adjusted vertically to align the table with an electrodynamics shaker head, as shown in Fig. 4. The rolling table was coupled to the electrodynamics shaker. A single-axis accelerometer was also mounted on the rectangular enclosure to measure the lateral acceleration imparted on the selected tank. The electrodynamics shaker was set to generate harmonic excitation at frequency 10 Hz and amplitude of 1.8.

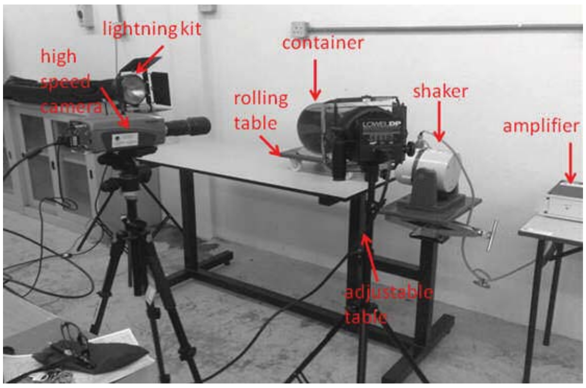

Fig. 4 Experimental Set Up

High speed camera was used to capture the image of free surface amplitude change. The high speed camera was positioned in front of the experiment set up and was focused on the containers. Once the shaker moves the rolling table, the high speed camera records the amplitude change when the required container acceleration is achieved at steady state condition. The lightning kit is used in order to provide some lightning and produce clearer image.

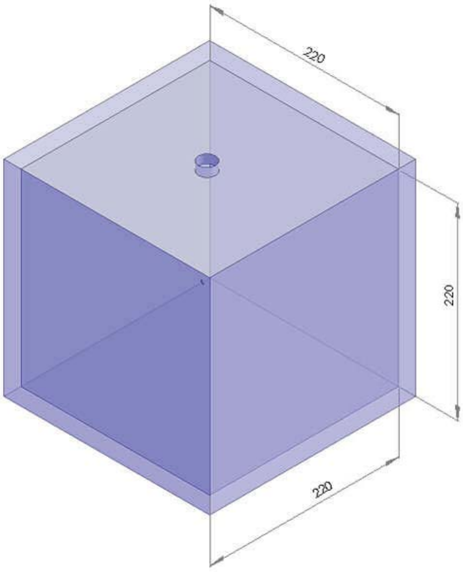

Fig. 5 Cubical container (220mm x 220mm x 220mm)

On the other hand, the accelerometer that was installed will measure the acceleration of the moving container and sent it to RT Photon software. From the software, the nature and acceleration of excitation can be verified.

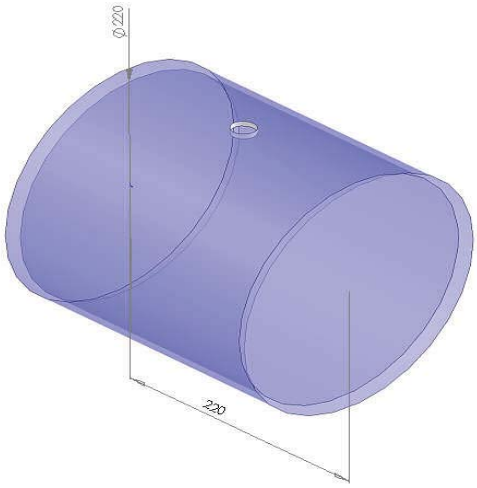

Fig. 6 Cylindrical container (D: 220mm x L: 220mm)

3. Experiment Results And Discussion

3.1 Liquid Sloshing in Cubical Containers

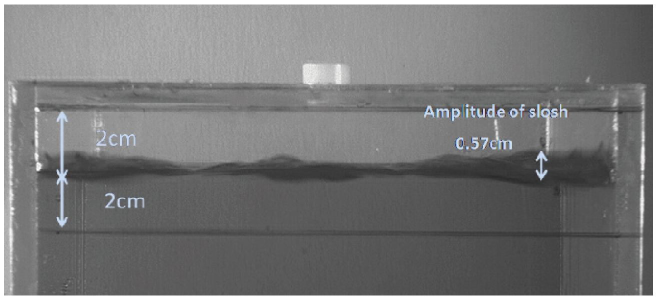

Fig. 7 Liquid Slosh Amplitude at 90% fill level

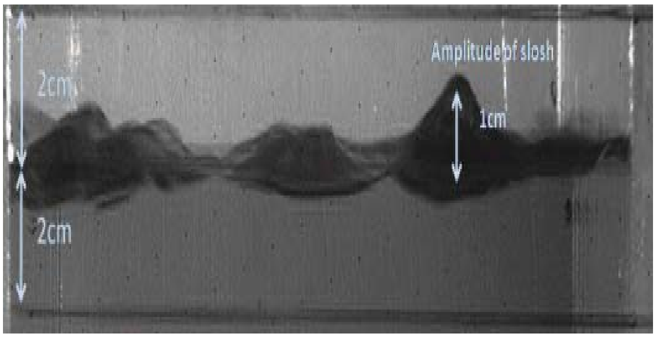

Fig. 8 Liquid Slosh Amplitude at 50% fill level

Table 1: Comparison of Liquid Slosh Amplitude for Cubical Containers

Container	Amplitude (cm)
90% fill level	0.57
50% fill level	1

Liquid sloshing depends on the liquid fill level. This can be described in Fig. 7 and Fig. 8. Both figures show the highest level of free liquid surface at steady state condition during excitation. It is obvious that the amplitude at 50% liquid fill level is higher.

3.2 Liquid Sloshing in Cylindrical Containers

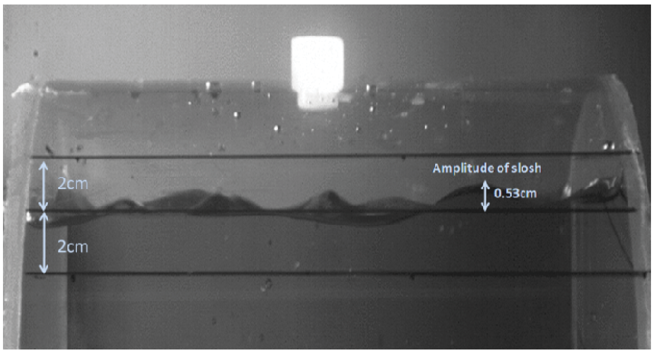

Fig. 9 Liquid Slosh Amplitude at 90% fill level

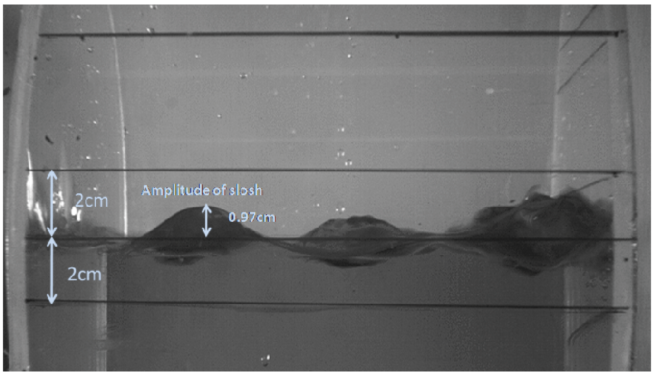

Fig. 10 Liquid Slosh Amplitude at 50% fill level

Table 2: Comparison of Liquid Slosh Amplitude for Cylindrical Containers

Container	Amplitude (cm)
90% fill level	0.53
50% fill level	0.97

The same observation can be made for cylindrical containers in Fig. 9 and Fig. 10. The highest level of free liquid surface was recorded for 50% liquid fill level.

3.3 Discussion

Liquid sloshing is more vigorous for both containers when the liquid fill level is 50%. This is indicated by the highest level of free liquid surface recorded during the excitation for all containers at similar condition. When liquid level is low, the motion on the surface is easier to be triggered although the frequency of motion applied to container is not changed.

Besides that, when the liquid level is low, the stability of container is also affected because the hydrodynamics load generated during sloshing produces unwanted momentum to the container. Therefore, higher liquid level fill is better for liquid cargo transportation. However, it is impossible to fill the containers to its full capacity with liquid due to liquid vaporization and expansion depending on the surrounding temperature.

4. CONCLUSION

Liquid sloshing is more rigorous for low liquid fill level. Therefore, liquid cargo transportation should be done at the highest possible liquid fill level to minimize sloshing.

ACKNOWLEDGMENT

The authors wish to thank Ministry of Higher Education Malaysia (MoHE) and Universiti Teknikal Malaysia Melaka (UTeM) for providing financial support through PJP/2010/FKM(21B)S735.

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