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ANALYSIS OF SLOSH IN TANK WITH DIFFERENT FILLING PERCENTAGE

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Abstract

The problem of sloshing in closed vessels has been subjected of several studies over the past few decades. The phenomenon of sloshing involves free surface movement of the fluid in the container due to sudden loads. Free surface liquid motion is very important factor in liquid storage tanks, Free surface liquid motion is very important factor in liquid storage tanks, airplanes fuel containers, space vehicles, missiles and satellites. Forces on liquid container's wall and moments will be severe when they are excited by frequencies near to resonant. Thus to avoid failures, estimation of dynamic loads is necessary. Numerical methods for solving free surface problems are of great importance in many engineering applications. The objective of this work is to study the slosh in tank when the tank volume is 50% fill, 60% fill and 80% fill without baffles. The numerical analysis has been performed using CFD technique and FLUENT tool.

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Keywords:

Slosh;

Tank;

CFD;

FLUENT.

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1. Introduction

In fluid dynamics, slosh refers to the movement of liquid inside another object, the liquid must have a free surface to constitute a slosh dynamics problem, where the dynamics of the liquid can interact with the container to alter the system dynamics significantly. Important examples include propellant slosh in spacecraft tanks and rockets especially upper stages, and the free surface effect cargo slosh in ships and trucks transporting liquids for example oil and gasoline. Sloshing behavior of liquids within tanks represents thus one of the most fundamental fluid-structure interactions. Free surface flows find large number of industrial interests like, liquid sloshing in LNG tankers, chemical and food industry, diesel injectors, atomization, droplet-wall interaction, cavitation, Ink-jets and similar devices and involved complex. Initially aeronautics was the major field of interest, where the motion of fuel is studied in tanks that would adversely affect the dynamics and stability of a plane. Fuel tanks in rockets were also a major topic for study of sloshing initially. More recently, the motion of liquids, including fuels, in several naval applications and its structural & enormous effects attracted much attention.

1.1 Sloshing Dynamics

In mechanical engineering sloshing is considered coupled with the container motion when assessing vehicle dynamics. As the experience with road tanker design indicates, it may be necessary to join sloshing and vehicle dynamics in one model when there is strong coupling between the motion of the tank and the sloshing fluid. Figure 1 (a) shows a schematic of the full sloshing problem: the ship is disturbed by the wave excitation Ewave, which in turn moves the tank resulting in sloshing. The sloshing and wave excitation forces act at the tank boundary. The traditional approach splits the system above into a pure sloshing problem shown in figure 1(b) and a sea keeping problem shown in figure 1(c). However, this approach does not take cross-coupling between ship motion and sloshing into account

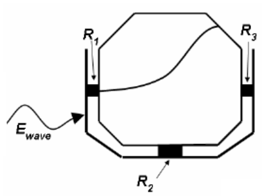
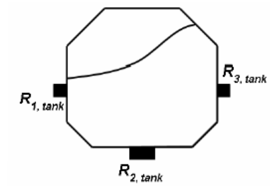
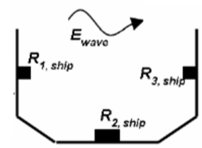
 1 (a): The full sloshing system	 1(b): The sloshing problem	 1(c): The seakeeping problem

Fig 1: The sloshing problem for LNG tankers

1.2 **Literature**

When a tank is partially filled with a fluid and subjected to an external excitation force, sloshing occurs [1]. Ships with large ballast tanks and liquid bulk cargo carriers (e.g. oil tankers) are at risk of exposure to sloshing loads during their operational life [2]. The inclusion of structural members within the tanks dampens the sloshing liquid sufficiently in all but the most severe cases. This approach can not be used for liquefied natural gas (LNG) carriers and sloshing has thus evolved into a design constraint for this type of vessel [3,4]. Natural gas, consisting of typically 90% methane, is transported in liquefied form over long distances (>1600 km) as it is more economic than building a pipeline [5]. The liquefaction temperature of _163 _C requires a combination of suitable insulation and structural material to minimise heat transfer and withstand the applied loads. The accurate calculation of the sloshing loads is an essential element of the LNG tank design process [6]. The work of Abramson [7] underpins sloshing analysis and [8] gives a survey of sloshing modelling techniques. Three approaches are usually used to determine sloshing loads in naval architecture. Experimentation is used by classification societies, among them Det Norske Veritas, Lloyd's Register and the American Bureau of Shipping [6]. Correct scaling of the model sloshing loads is often difficult [7]. Theoretical fluid dynamics models have been developed. A linear model for the aerospace industry was given by Graham and Rodriguez [9]. Faltinsen [10] developed a third order theoretical sloshing model. The restriction imposedby the tank shape complexity has been overcome using boundary element methods.

2. Steps in analysis

2.1 Modeling and meshing of tank

The physical model used for present study is shown in figure. Present model consists of a 3-dimensional liquid storage rectangular tank which is partially filled with water (ρ=999.98 kg/m3, μ=0.00103 kg/m-s). The tank dimensions are 1.2*0.6*1.2 m3. Water fill level in tank is 60% and 80% of total height of tank and the rest part is occupied with air. During the seismic excitation mode, tank is supposed to go under sloshing effect which creates pressure and forces on tank wall. A quadrilateral mesh has been adopted with 10976 elements and 20854 nodes as shown in figures 3. Model with dimentions and domain names are shown n figures 2 and 4.

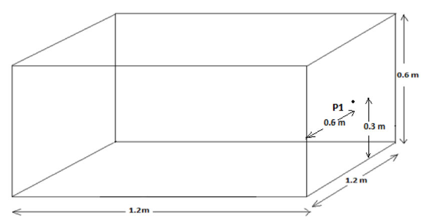


Fig 2. Tank without baffles

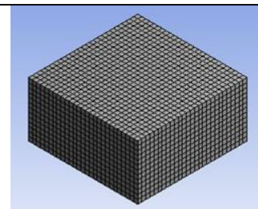


Fig 3. Mesh of tank without baffles

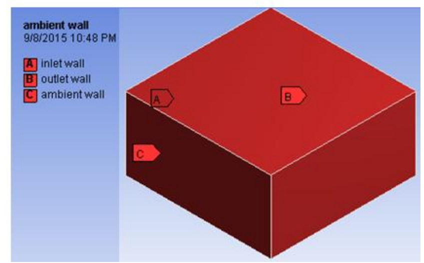


Fig 4. Boundary names

2.2 Large amplitude slosh

A rectangular container is considered. It is subjected to a periodic displacement in xdirection.

This is achieved by treating the horizontal motion of the finite element nodes at the vertical boundaries of the container in a lagrangian manner. The x- velocity of these nodes is prescribed as $u \; A \sin(\; t)$. The horizontal position of the container oscialltes with the amplitude A and the frequency $f \, / \, (2 \;)$. Initiallt, the fluid is at rest and in equilibrium. The motion of the mesh is based on the pseudoelastic methodology. We have plotted the figure for the configuration of the mesh and pressure isolines at different time instants. We also have plotted a graph for y v/s $\acute{\omega}$

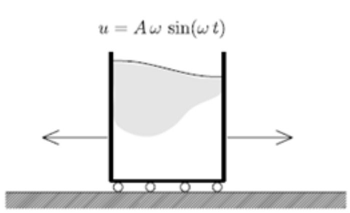
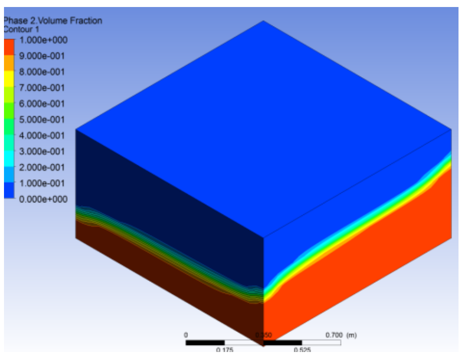
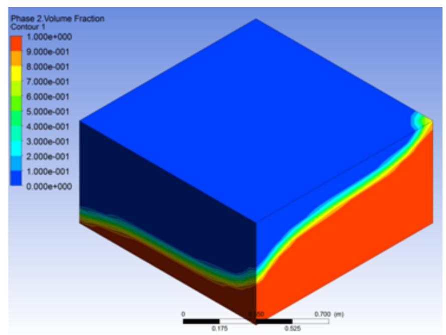
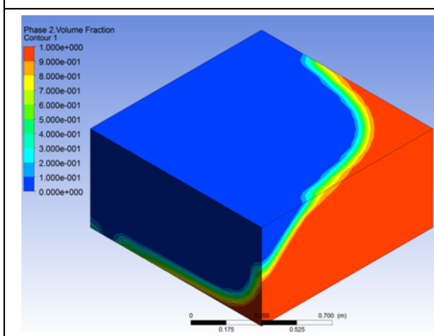
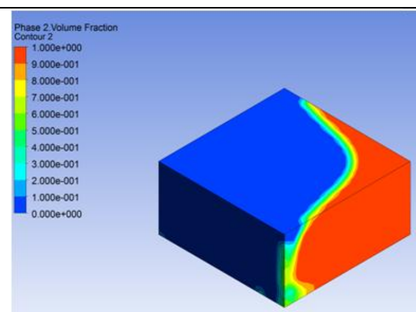


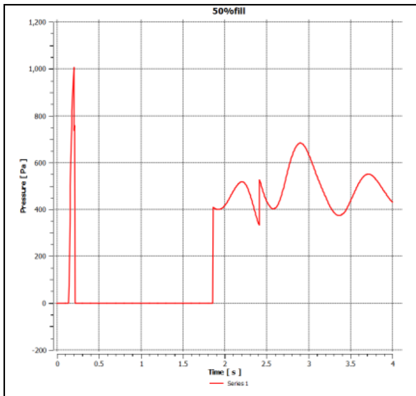
Fig 5. Large Amplitude Sloshing, Problem description

3. Results and Discussion

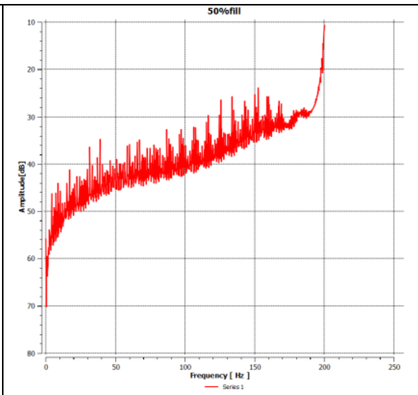
Case 1: Without baffle 50% fill

The sloshing of kerosene in tank filled with 50% volume before acceleration and after acceleration which is applied with time steps showed in figures: 6 and 7. The figures shows the motion of fluid occurs immediately after vehicle accelerated as half of the tank is empty. In this case, the filling level is reduced to 50% of the tank height, which results in the formation of a travelling wave and large air pockets are observed when the wave breaks into a tank side wall.

 0.1sec	 0.15sec
 0.25 sec	 0.4sec



Pressure variation with time



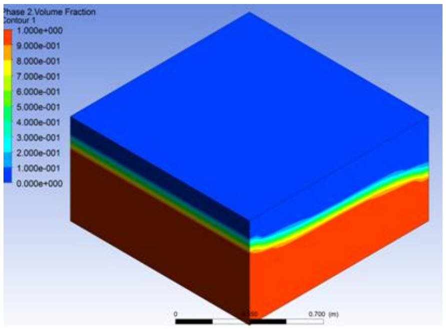
Oscillation frequency

Fig 6. Without baffle 50% with time 0.1sec to 0.4sec

Pressure variation and oscillation frequencies are shown in figure.5.8 and 5.9 During and immediately after impact, air and kerosene are mixing with a wide range of air particles entrained in the kerosene. The air bubbles increase the compressibility of the impacting fluid mixture (Dias et al., 2008) and consequently a lower pressure is observed. Therefore, the pressure magnitudes and oscillation frequencies are investigated in the air bubble rather than the initial point of impact. the flow field becomes periodic after about 20 oscillations. The initial transient stage lasts approximately ten oscillations and a secondary transient stage is observed between oscillations 20 and30.

Case 2: Without baffle 60% fill

The below figures shows the impact of slosh on tank walls when tank is filled with 60% in its hight. In this case, the filling level is increased to 60% from 50% of the tank height, which results in the formation of a travelling wave and large air pockets are observed when the wave breaks into a tank side wall observed to be reduced as a function of time. The fluid oscillating wave reduced as filling level is increased. The fluid compression started between 0.5 sec to 0.7 sec as shown in Figure 7 compared to 50% fill, where impact of slosh is continued after 0.4 sec.



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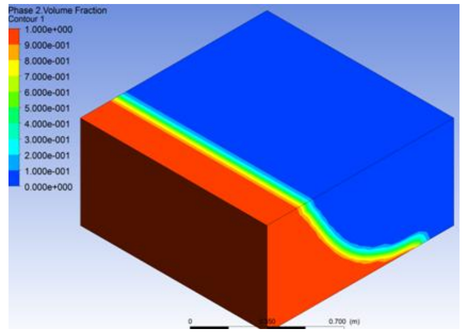

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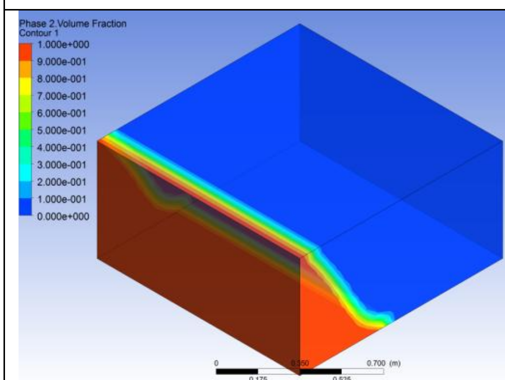
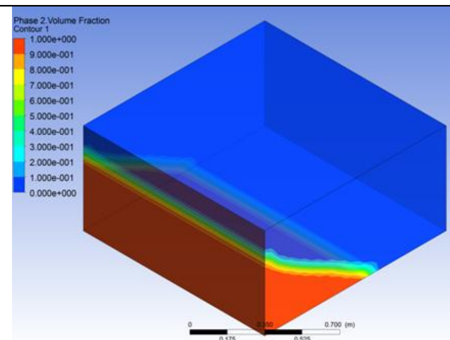
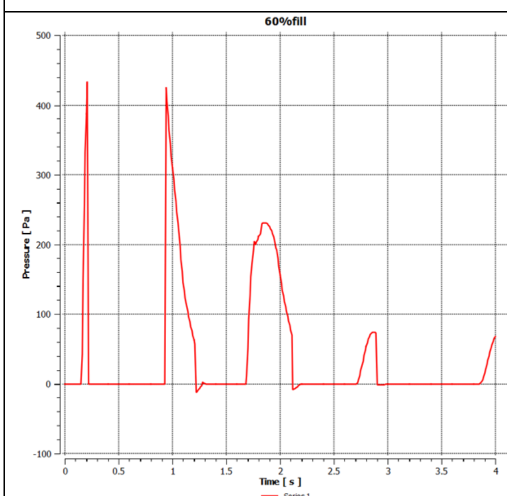


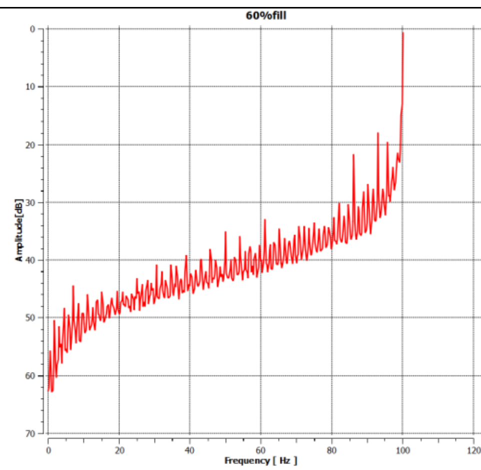
1 sec



1.3sec



Pressure variation with time



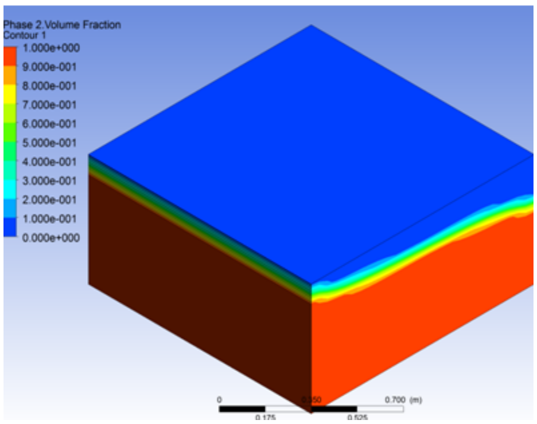
Oscillation frequency

Fig 7. Without baffle 60% with time 0.1sec to 1.3sec

It is clear that maximum amplitude of longitudinal forces is higher at low fill level, because at higher fill level of fluid, slosh does not occur heavily. It is also shown when the tank is excited by natural frequency with excitation amplitude of 0.015 m/s^2.

Case 3: Without baffle 80% fill

The figure 8 shows the impact of slosh on tank walls when tank is filled with 80% in its height.



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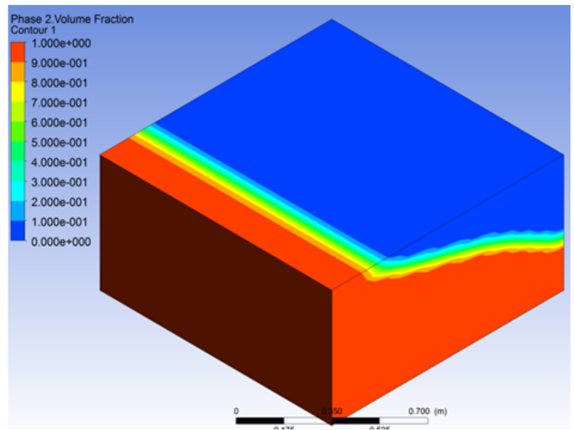

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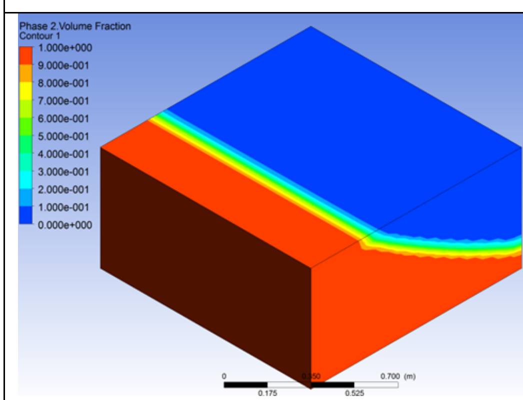

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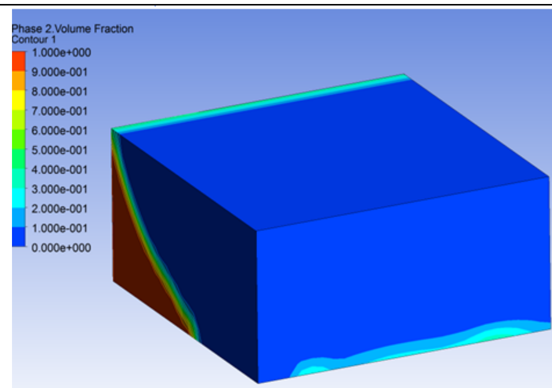

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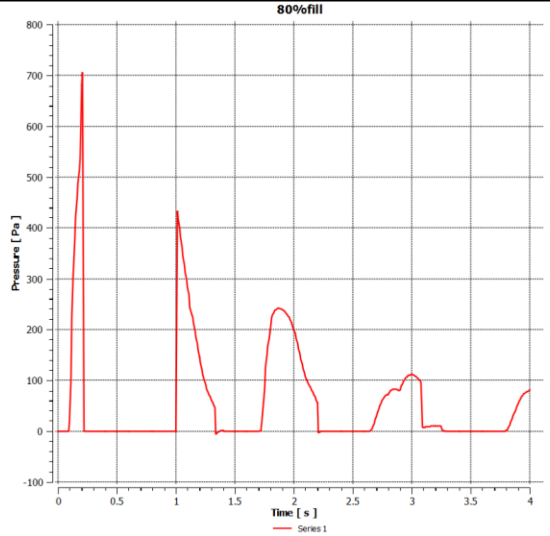
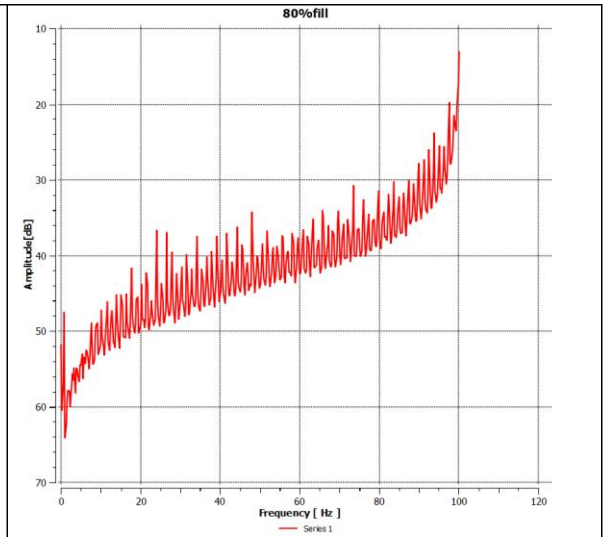


Pressure variation with time



Oscillation frequency

Fig 8. Without baffle 80% with time 0.1sec to 1.8sec

Figure 8 shows pressure variation on tank walls with respect to time when baffles were not inserted in the tank. The overall pressure variation pattern is uniform till 0.5 sec.With about zero pressure during the start, the maximum pressure exerted is 450Pa. The maximum pressure on the tank surface is seen between 0.2 to 1 seconds. It is observed that there is no much difference in pressure and amplitude for different filling heights of fluid in tank. The uniformity of oscillating pressure pulse is increased with increase of filling level.

4. Conclusion

It is observed from the simulation that the filling height in tank affects the occurance of slosh. 80% fill has less amplitude compared to 60% and 50% fill and the starting time of slosh also less. The overall pressure variation pattern is uniform till 0.5 sec.With about zero pressure during the start, the maximum pressure exerted is 450Pa. The maximum pressure on the tank surface is seen in between 0.2 to 1. As vertical height increases the free surface behavior of liquid is found to be stable without reaching top surface of the tank. It was observed that the maximum sloshing of the liquid occurred at 0.5m2/sec accelerationNominal deference was found for the amplitude change with respect to frequency for both the acceleration cases.The results showed that the acceleration is directly proportional to the inclination angle of the liquid surface in a partially filled moving tank. The inertia of the liquid is decreasing when acceleration is increasing

Future scope

By considering the maximum sloshing of the liquid which was obtained at $0.5m^2/sec$ the sloshing effect of the same liquid can be studied by varying the liquids and effect of density of the liquid can be studied on sloshing phenomenon.

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