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SLOSHING ANALYSIS OF MEMBRANE TANK FOR MALAYSIA LNG CARRIER

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ABSTRACT

The use of liquefied natural gas (LNG) in industry for generating electricity and power make the transportation between the nations increased especially from Malaysia to the Eastern nations such as Japan and Korea. The research objective is to analyze data of the sloshing effect on the LNG membrane containment system. The computation had been done to different pressure between different filling levels inside the tank. Data from previous model experiments are used to make the comparison with calculated data. The use of computational fluid dynamics (CFD) is discussed.

Keywords: *LNG carrier, sloshing effect, membrane containment system, filling levels, CFD*

1.0 INTRODUCTION

Since Malaysia is one of the biggest LNG exporters, study about the sloshing effect is important for better LNG transportation, see Figure 1. Within a range of tank filling levels, the natural pitching and rolling movement of the ship at sea, and the liquid free surface effect, can cause the liquid to move within the tank. It is possible for considerable liquid movement to take place, creating high impact pressure on the tank surface. This effect is called "sloshing" and can cause structural damage [1].

Fig. 1 MISC LNG Carrier

Sloshing is a problem that affects membrane constructed tanks. Independent containment systems such as the spherical Moss design and the IHI prismatic design are not subject to the same sloshing impact, see Figure 2. Partial loading at any tank filling level is inherent in the design of Moss design tanks, giving them distinct advantages over membrane containment systems, when handling spot trading and offshore loading or unloading.

When the tank motion is large, the front of the "hydraulic jump" (when the motion within the tank causes the liquid to create a wave action) becomes steeper, developing a breaking wave. If the hydraulic jump hits the bulkhead before breaking, a large impact can occur.

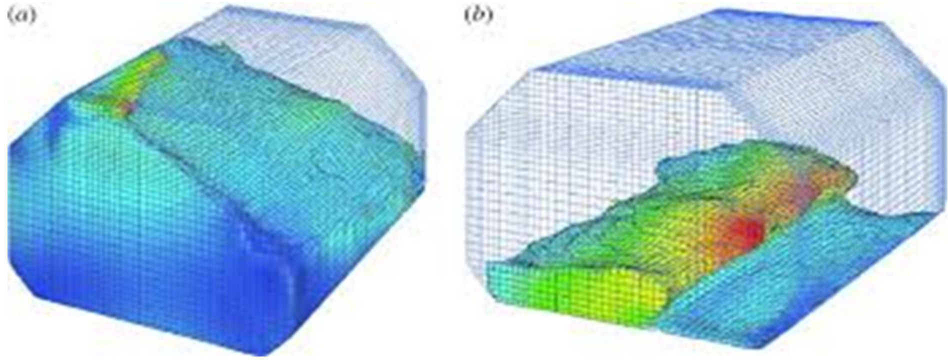

Fig.2 The movement of liquid in LNG tank simulation

2.0 OBJECTIVES AND SCOPE OF THE RESEARCH

The objective of the research is to study the data taken from previous model experiments and examine the data to prove the parameter of filling levels. The research will also determine different sloshing pressure base on different filling levels by using Bureau Veritas (BV) guideline to make comparison between different filling levels.

In order to achieve the objectives of the research, there are several scopes and limitation that had been outlined. The scope and limitation of the research include:

- The research from previous model testing experiments;
- Simulation by means of computational fluid dynamics (CFD) method.

3.0 LITERATURE REVIEW

Large number of LNGC were built or under construction with the capacities which had almost doubled as compared to the classical LNG carriers (from 138,000 m^3 to 266,000 m^3). The most common LNG ships belong to the so-called membrane type. Within the membrane type concept, which is of main concern here, the LNG is kept liquid at very low temperature (-160^0C) by complex insulation system that is attached to the ship structure.

Sloshing is a highly stochastic phenomenon, see Figure 3.1 [4]. This highly stochastic behaviour is clearly observed in the few sloshing events that occurred at sea and during the sloshing model tests (pressures do not repeat themselves even under the same drive motions). Moreover, sloshing phenomenon is also complex from a thermodynamics point of view. Indeed, partial condensation of the LNG vapour (depending on the speed of condensation and impact duration) may happen during the impact. Due to the violence of the impact, the hydrodynamic pressure will often depend on the structural response so that fully coupled hydro-structure modelling is imperative.

The membrane type LNG containment system consists of thin metal membranes to prevent cargo leakage, foam or powdery insulation material to maintain the low temperature to keep the LNG cargo in liquid state and associated structure to retain the membrane and insulation material and to secure them to the hull structure.

Two types of membrane containment systems are most often used in modern LNG carriers that are layered foam type containment system (GTT MARK III) and box type containment system (GTT No. 96), see Figure 3.2. Both containment system provide primary and secondary barriers in compliance with the International Gas Code (IGC) and SOLAS 1974. See Table 3 to see the difference between the two containment systems.

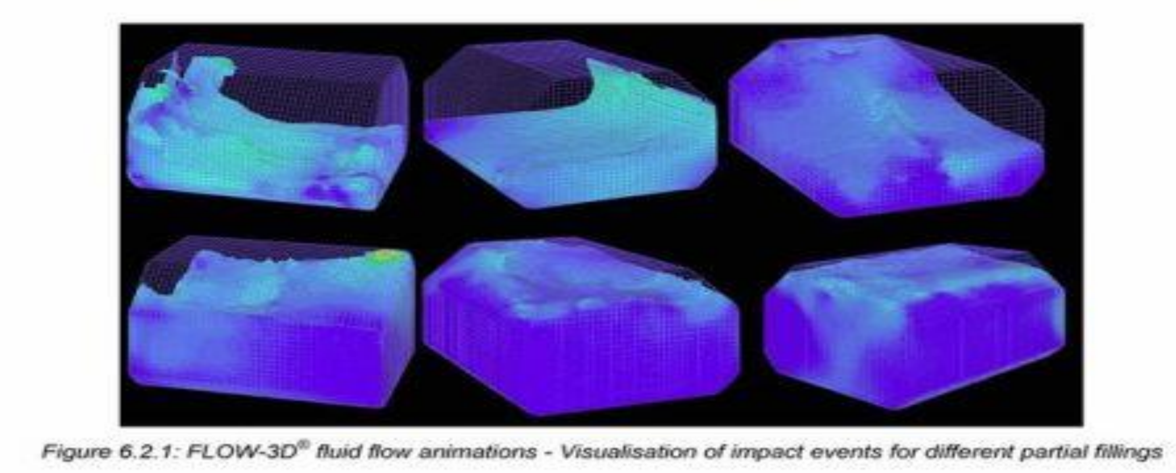

Fig. 3.1 FLOW-3D Fluid flow animations

Table 3: Differences between GTT Mark III and GTT No. 96

Tank type	GTT MARK III	GTT No. 96
Primary barrier	Corrugated membrane made of thin low carbon stainless steel.	Membrane made of thin metallic sheet of high nickel alloy (Invar).
Secondary barrier	Layer of triplex system made of thin aluminium foil glued with glass cloth both sides.	Barrier made of thin metallic sheet of high nickel alloy (Invar) of same thickness and material of primary barrier.
Insulation	Consists of polyurethane foam with glass fibre (R-PUF). Two layers of R-PUF are glued to both side of secondary barrier. Upper surface is glued to primary barrier plywood sheet while lower surface is glued to plywood sheet that is attached to the inner hull. The lower plywood sheet is attached to the inner hull by using strips of mastic material.	Consists of two layers of wooden boxes made of plywood filled with powdery insulation material, Perlite. Internal member of parallel plywood is used to support the box surface and Invar membrane. Resin rope is used for box side that is in contact with the inner hull. The box connects to inner hull through a system of bolts and studs welded to the inner hull.

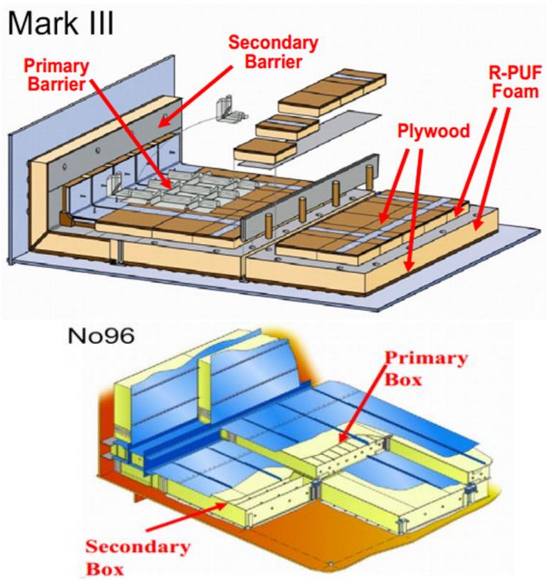

Fig. 3.2 Schematic Drawings of Containment Systems: MARK III and GTT No. 96

4.0 SEAKEEPING ANALYSIS AND HYDRODYNAMIC COMPUTATIONS

Seakeeping analysis is a key point in each particular sloshing study, with an objective to determine ship motions. The objective of seakeeping analysis is aimed at determining wave induced loads and ship responses under a prescribed sea state. Directly calculated ships motions determined by such analysis are used as sloshing excitation for CFD computations and sloshing model tests.

The purpose of the hydrodynamic calculations is mainly aimed to determine Response Amplitude Operators (RAOs) of the six degrees of freedom motion, representing the ship response on the wave of unit amplitude as a function of wave frequency.

Hydrodynamic computations are generally performed by means of 3D-panel diffraction/radiation potential theory within the frequency domain software. This software has to be fully validated through the comparison with semi-analytical studies, numerical results from recognized numerical tools and experimental results.

5.0 CFD COMPUTATIONS

The objectives of the CFD numerical sloshing simulations is to evaluate the overall fluid kinematics, to provide independent verification of sloshing effects on cargo tank walls, to evaluate the representative design loads on ship inner-hull structure and to provide fluid velocities and accelerations at the pump mast location for its strength assessment, see Figure 5.

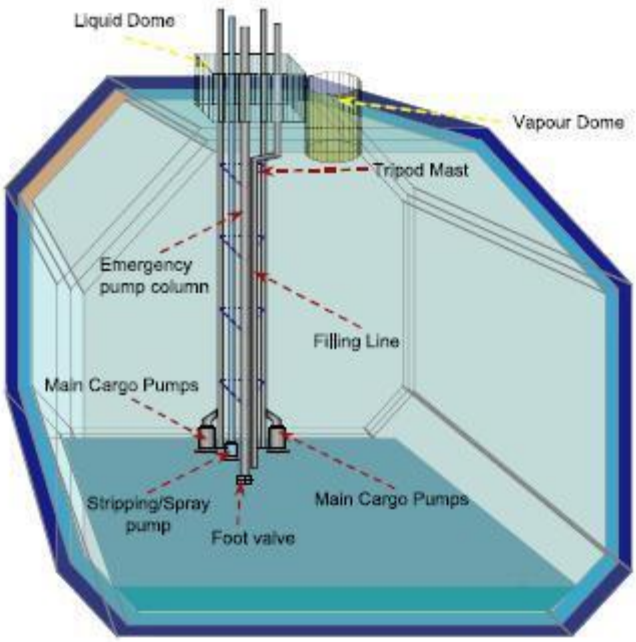

Fig. 5 Pump mast location in membrane tank

The sloshing CFD analysis is to identify type and nature of the impact, to correctly evaluate kinetic energy of the liquid and quantify impact by the impact normal velocity with respect to the wall at distinct locations (predefined hot-spots). This information is of fundamental importance for the independent review of the sloshing model tests and for the comparative analysis with reference vessels.

6.0 PRESSURE SENSORS ARRANGEMENT

Impact velocities and quasi-static forces (per m^2, i.e. quasi-static pressures) are examined in predefined zones inside the tank (similar to the definition of pressure sensor location inside the physical small-scale model tank). Each hot spot is defined by a zone composed of several cells, usually nine of the same size. Location of these hot spots depends on filling height and sloshing excitation imposed on the tank.

The default hot spot zones are located on (See Figure 6):

- Transverse bulkheads above the lower chamfer's height, to investigate the consequence of longitudinal sloshing flows, including the phenomena of longitudinal progressive wave;
- Side-walls above the lower chamfer's height, to investigate the consequence of transverse sloshing flows, including the phenomena of transverse progressive wave;
- Each corner between the upper chamfer and the ceiling, to investigate the consequence of standing and breaking waves in interaction with the tank top.

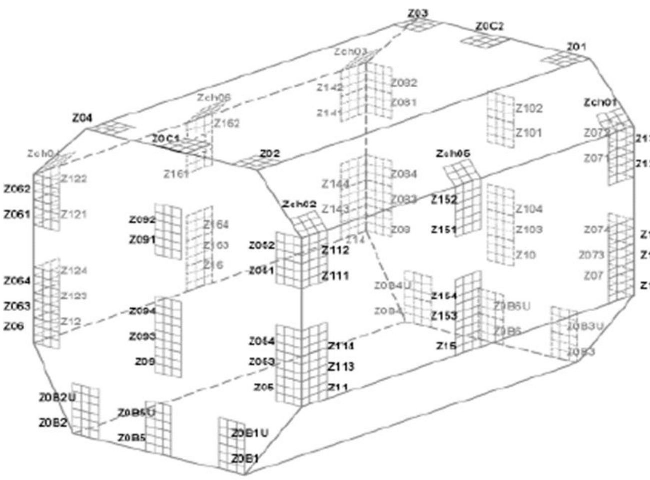

Fig. 6 Default hot spot zones in the membrane tank: Sensors arrangement

7.0 DATA PROCESSING OF IMPACT PRESSURES

Depending on the pressure sensor characteristics, pressure results can include noise, hydrostatic pressure, low (wave) frequency fluid oscillations and high frequency sloshing impact pressures. Only high frequency impact pressures are of interest. Thus, a high pass filter of 4 Hz is to be used in order to eliminate hydrostatic pressure (if any) and low (wave) frequency fluid oscillations. This filtered signal is to be used for the subsequent numerical analysis.

Indeed, working on the raw signal and on the possible slow drift that it may contain could lead to erroneous statistical post processing.

8.0 METHODOLOGY AND FLOW CHART

A methodology is usually a guideline system for solving problem, with specific components such as phases, tasks, methods, techniques and tools. There were two modes of methodology applied which were data collection and analysis data from the study experiments. The flow chart for the research is shown below in Figure 8.

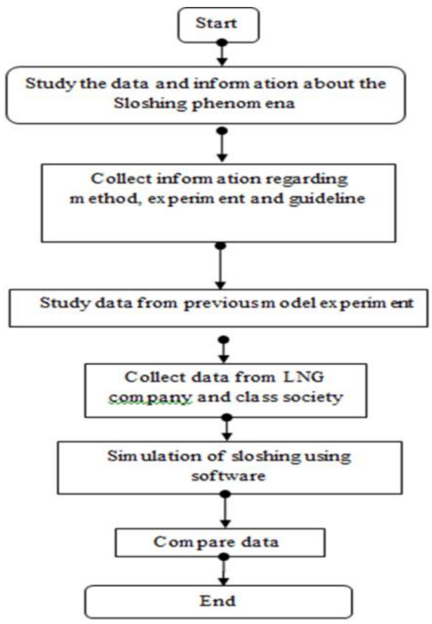

Fig. 8 Flow chart for the research

9.0 RESULTS AND DISCUSSIONS

Based on calculations by using Bureau Veritas (BV) guidance, sloshing impact for 50% of filling level is higher than impact produced in 80% of filling level. For the result of inclined condition pressure, only 80% filling level meet the criteria to be evaluated. The pressure obtained in the inclined condition is higher, i.e. 184.13 kN/m^2.

From model testing experiment, the pressure is detected by sensor that is located at the same height of every filling level. In this case, filling level of 20% generate the highest pressure with maximum pressure at 6.5 second of impact time. This proves that at 20% of filling level, the productivity of standing wave is very high. For 50% and 80% of filling level, the pressure produced is quite similar to each other.

The impact load on the bulkhead is maximum at the low filling level (20% of tank width). It has also been found that the spatial and temporal pattern of the impact pressure at the low filling is quite different from the high filling case. The wider effective area of the impact pressure at the low filling level indicates that the calibration of the impact pressure should be made more carefully for the strength of the insulation system and bulkheads.

From the data, it is proved that filling level of 20% cannot be used during transportation of LNG.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research is to study about the sloshing phenomena in LNG membrane tank which can cause untoward incident to the tank structures and boundaries. From the study, improvement of tank design and tank filling level can be determined to reduce the sloshing effect inside the tank.

Determine how the results and conclusions from this study could be used for the continued development of requirements from Classification societies, including SCM (Ships Classification Malaysia). Expand the study to cover tank parts that are likely to experience sloshing impact loads for lower filling levels since they are quite different in their characteristics.

Sloshing generate different impact pressure at different filling level. Data about sloshing is very stochastic because sloshing impact is different for different tank sizes.

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