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DESIGN OF PRISMATIC PRESSURE VESSEL WITH STIFFENERS CONSIDERING SLOSHING LOAD

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Abstract - In 2012, the International Maritime Organization (IMO) maintained the emissions of Sulphur oxides and Nitric oxide by setting the emission control area and regulations on ship operations. Recently, with the increasing price of the crude oil and consideration of environmental pollution, LNG has gained more importance as a relative economical and environmentally friendly energy. Liquefied Natural Gas is used in propulsion system of ships. Therefore, it is necessary to design the LNG storage tank, which is one of the significant components of LNG fuel supply systems. This paper presents design of prismatic pressure vessel with stiffeners for LNG storage for application in ships. 9% Nickel steel is used for the construction of pressure vessel which having high strength and toughness at relatively low cost. Prismatic pressure vessel consists of stiffeners, beams and flat plated shells. Nowadays with the increasing size of LNG tanks, sloshing load is an important design parameter. For LNG storage tanks on ships, rolling and pitching motion of ship cause the largest sloshing load. Computational fluid dynamics is used for modelling and simulation of the sloshing motion. For static structural analysis of prismatic pressure vessel, Finite element analysis is used. The computational analysis result shows that the prismatic pressure vessel satisfies the design acceptance criteria.

Keywords - LNG, Prismatic Pressure Vessel, Stiffeners, Sloshing Load, Finite Element Analysis.

I. INTRODUCTION

In 21 centuries, Liquefied natural gas has turned into an imperative piece of the world vitality expend. Initially, it's critical to discover the substitution of the crude oil since the fast utilization of this non-sustainable power source. Natural gas is a clean and naturally well-disposed vitality when contrasted with raw petroleum. Now a day, in transportation of liquefied natural gas, maritime transportation plays a critical role. For transport LNG on the ocean, LNG carrier as the storage tanker has to be designed and fabricated particularly to conquer a few specialized challenges. At present just a couple of nations, for example, The United States, China, Japan, Korea and some Europe nations are equipped for building this sort of storage tank [2].

LNG is a cryogenic fluid. It is utilized as a fuel in ship propulsion systems. One of the imperative difficulties of LNG propulsion system is the design of LNG storage tank. Conventional pressure vessels were utilized for storing the LNG on the ships, however they have some constraint: low volume efficiency. Prismatic pressure vessel having 25-50% higher volume efficiency than the conventional pressure vessels so called cylindrical pressure vessels [7]. The installation space and capacity of pressure vessel represent essential variables to consider when these vessels are utilized as a part of offshore industries and ships. These LNG storage tanks are placed on the deck of ships. On-board vessels include equipment for operations, and their exceptional prerequisites are larger than the vessel itself because there is necessity of inspection and maintenance by the maintainer. So because of this necessity, there is diminishing in cargo space on the deck of ships and lessen the benefits that can be earned by ship owner. As needs be design of LNG storage tank must incorporate the minimum space for on-board marine instruments, which offers rise to the idea of prismatic pressure vessel. Moreover, various attempts have been made to maximize the capacity of the pressure vessel. Considering manufacturing point of view, Conventional pressure vessels for high capacity with high pressure have confinements due to restrictions in the thickness of the shell plates. Accordingly, various kinds of pressure vessels have been considered. Senjanovic et al. (2005) proposed an outline application utilizing bi-lobe tanks in which two parallel barrels cover [7]. Bergan and Madsen (2006) built up a cellular organized tank as a type of multi lobe tank structure [7]. Rammo et al. (2011) proposed cubic-form pressure vessel that over-lap 12 similar barrels and resulted in large gas carrier [7]. These methodologies applied to expand the capacity of a traditional vessel within limited space. Notwithstanding, these designs, nevertheless, have drawbacks as to their functional applications. To meet the prerequisites of expanding limit; studies have revealed the design of Prismatic pressure vessels. This paper proposes design of a prismatic pressure vessel with stiffeners considering sloshing load by using finite element analysis.

II. GEOMETRY

The prismatic pressure vessel storing the liquefied gas-fuel mounted on the deck of ship. The ship has the subsequent principle dimensions: length of 313m, breadth of 50m, height of 40m, and draught of 27m. The service speed is generally 19.5 knots on the open ocean. The ship demands $3700m^3$ of LNG fuel for 30 days of transport. In general, the LNG is stored at −163°C near atmospheric pressure in a liquid state. The dimensions of the vessel are length of 33m, breadth of 15m, and height of 9m. The pressure vessel wall thickness and stiffener thickness are chosen based on manufacturing concerns. In any case, deciding the thickness of these materials presents restrictions in light of the fact that the shells are commercial steel plates for use as a development material. Typically, the plate thickness is less than 40 mm [6], and stiffeners are attached to the vessel wall with a fitting shape to resist the bending of the shell. The thickness of pressure vessel is 30mm. The pressure vessel has internal rectangular beam members. The rectangular beam members are arranged 3m apart from the adjacent member. The rectangular beam has thickness 40mm. The rectangular stiffeners attached outside of the vessel wall having height of 400mm and thickness of 40mm. Figure 1 shows CATIA model of a prismatic pressure vessel.

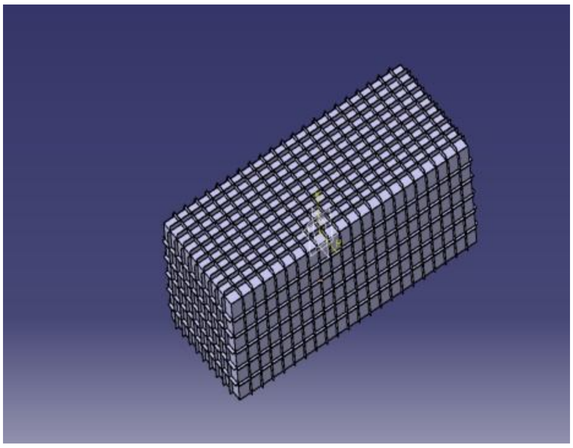


Figure 1: CATIA model of prismatic pressure vessel

III. SLOSHING ANALYSIS OF LNG IN PRISMATIC PRESSURE VESSEL

In fluid mechanics, movement of two or more incompatible phases (generally gas and liquid) inside another object which is normally experiencing movement. Sloshing happens effectively in somewhat partly filled tank, particularly LNG storage tanks which are utilized as a part of ship applications. These days with the expanding use and size of LNG, sloshing phenomenon turns out to be increasingly critical design parameter. For LNG storage tanks on ships, rolling and pitching movement of ship cause the largest sloshing load [3]. Serious sloshing motions will generates massive impact force on tank wall and structure; it'll damage the whole structure. At the point when the sloshing movement is serious with extensive amplitude, development of free surface is exceptionally nonlinear. In this paper, Computational Fluid Dynamics (CFD) techniques are utilized for modelling and simulation of sloshing in tank. Simulation is carried out for transient condition. Furthermore, if done all the modelling and simulation in three dimensions, an excess of time and memory will be expended [3]. In this study, two dimensional simulations are carried out using ANSYS Fluent. Filling ratio 50% is considered for sloshing simulation. Two-dimensional simulations are performed for the pitching motion with the tank rotating about its y-axis, positioned 16.5 m from the left tank wall (half of width), and 4.5 m above the tank bottom (half of height). Internal pressure of 2.9 Bar is applied on the tank. The motion was sinusoidal with amplitude of 11^0 and period of 10.22 s. We considered a filling level of 50% of LNG and 50% of air. 21500 quadrilateral cells and 21851 nodes are generated using structured mesh. Maximum pressure value obtained in this simulation is 0.4 Bar. This is due to there is adequate amount of space available for travelling the fluid wave, so that it has more impact on the tank walls. More turbulence is generated in this case As the tank moved upward, LNG began sliding down the front wall and afterward running back toward the opposite wall. A steep overturning wave was created. Some fluid again hits the top wall. Once the tank achieved its highest position and began moving down, fluid kept running down the wall and toward the opposite side, overturning again. Fig. 2 shows that peak pressures varied strongly from period to period due to the stochastic nature of violent splashing. Fig. 5 shows free surface shape of LNG for particular time period in pitching.

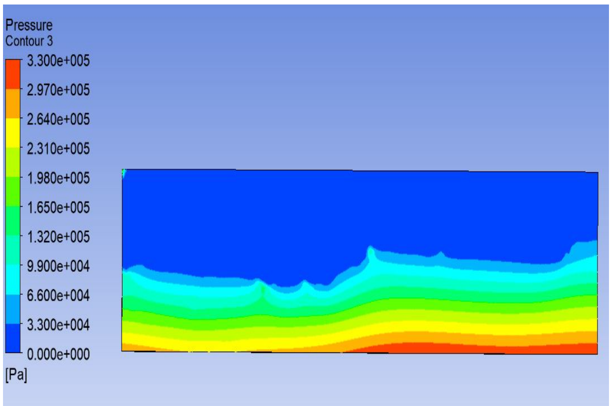


Figure 2: Pressure variation contour for pitching condition with 50% filling level

We performed two-dimensional sloshing simulations of the rolling tank rotating sinusoidal about its x-axis, positioned 7.5 m from the left tank wall (half of length), and 4.5 m above the tank bottom (half of height). The motion was sinusoidal with amplitude of 15^0 and period of 5.1s. 13500 quadrilateral cells and 13741 nodes are generated using structured mesh. Maximum pressure value obtained in this simulation is 0.3 Bar. In this case, for generating the turbulent wave amount of fluid is adequate and sufficient amount of space is available for travelling the generated wave. So that, wave having high velocity impact on the vessel walls. Further, this maximum sloshing load can be evaluated for determining design pressure of prismatic pressure vessel. Fig. 3 shows that pressures variation for rolling condition. Fig. 4 shows free surface shape of LNG for particular time period in rolling.

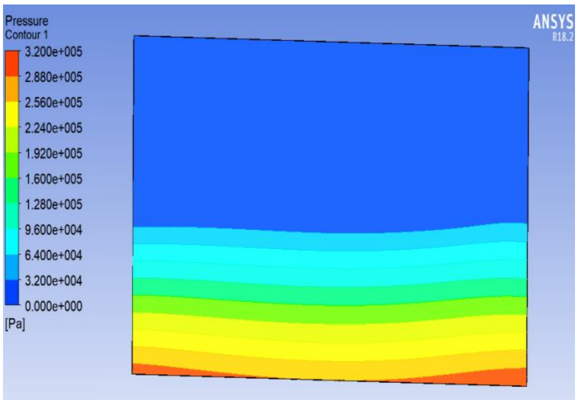
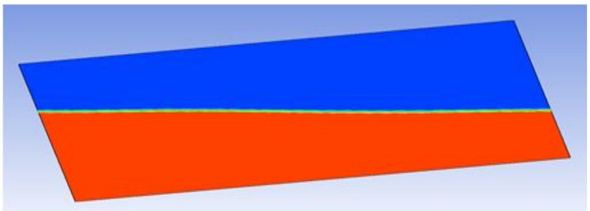
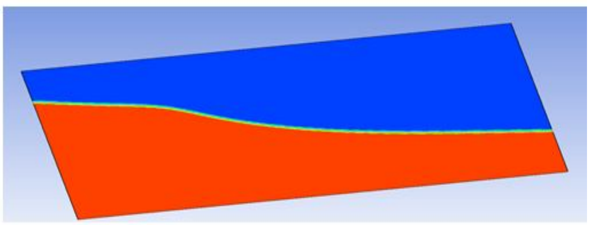


Figure 3: Pressure variation contour for rolling condition with 50% filling level

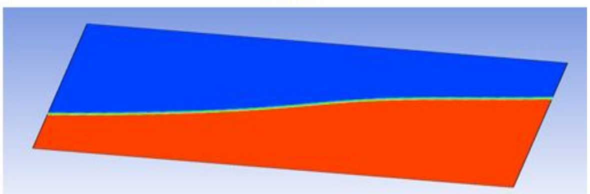
(a) At rest position



(b) At time 1s



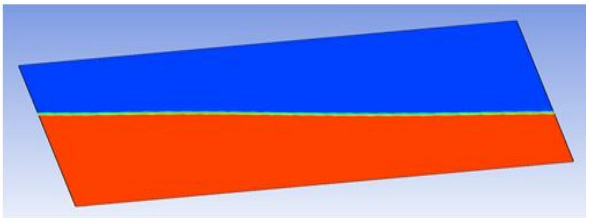
(c) At time 2s



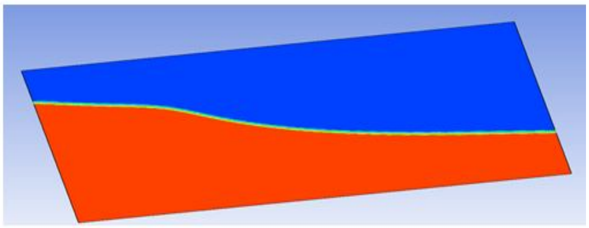
(d) At time 4s

Figure 4: Free surface shapes of LNG for 50% filling level (rolling)

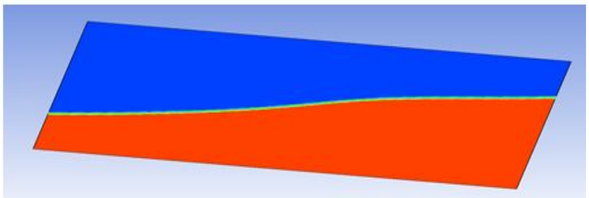
(a) At rest position



(b) At time 2s



(c) At time 4s



(d) At time 9s

Figure 5: Free surface shapes of LNG for 50% filling level (pitching)

IV. STATIC STRUCTURAL ANALYSIS USING FINITE ELEMENT METHOD

The prismatic pressure vessel is used in propulsion system of ships. Due to massive impact on ship and also on LNG storage tank due to sea waves, it is very important to design a pressure vessel having good structural stability. For static structural analysis, finite element method is used. 9%Nickel steel plate is used for the construction of Liquefied Natural Gas. Table 1 shows mechanical properties of 9%Nickel steel. Fully ductile at -196°C, well below the boiling point of liquid methane, the traditional 9%Ni steel grade combines high strength, high toughness and weld ability provides at relatively low cost. Fig. 1 shows the CATIA model of prismatic pressure vessel. Finite element method reduces degrees of freedom from infinite to finite with the help of discretization. i.e. meshing (nodes and elements). Meshing is any typical FEA software is discretization. In ANSYS, coarse mesh is applied. Total number of nodes are 1137526 and no. of elements are 583108.

This LNG storage tank has application ships. It is kept on deck of ship while operations. It has large bottom surface area, so that it can be easily mounted on the upper surface of deck. This prismatic type pressure vessel doesn't require any supporting system for stability. After selecting the static analysis the boundary conditions are applied as fixed at all sides of the bottom plate. Thickness of vessel and its manufacturing is mainly influenced by a design pressure of prismatic pressure vessel. It is characterized by including the liquid pressure of 2.2 Bar, vapour pressure of 0.7 Bar [2] and maximum sloshing load for pitching and rolling condition of 0.7 Bar. The estimation of the design pressure is a simple step to scheme a storage vessel. The pressure vessel is subjected to design pressure 3.6 Bar.

After applying all the boundary conditions and pressure loading, the model is prepared for the solution for obtaining the deformation and the related stress of the pressure vessel. Von-Mises equivalent criteria are used for evaluating stresses in a pressure vessel. The overall stresses are significantly lower than the allowable stress. The maximum equivalent stress is 213.49 MPa which is below than the allowable stress of material which is 230 MPa shown in fig. 6. The location of maximum equivalent stress is at the rectangular beam near the top shell plate of prismatic pressure vessel shown in fig. 7. The beam structures are under tensile stress to sustain the pressure within the shell plates. Rectangular stiffeners experiences lower stress than the internal beam sections. At the stiffeners, the average equivalent stress distribution value is 50 MPa, which is well below than the allowable stress. As compared to beam structures, tank shell was stronger to carry internal applied pressure. The maximum deformation is takes place at the top shell plate of pressure vessel. The value of maximum total deformation is 12.402 mm shown in fig. 8. According to ASME Code, the deformation larger than the half of the wall thickness of non-circular pressure vessel is permissible [4]. Here, pressure vessel deformation is less than the wall thickness. Hence, the design of prismatic pressure vessel under static loading is safe.

Parameter	Unit	Value
UNS Code	-	K81340
ASTM Specification	-	A553 Type I
Density	Kg/m^3	8000
Ultimate strength	MPa	690
Yield strength	MPa	585
Elastic modulus	MPa	185000
Allowable stress	MPa	230
Thermal conductivity	W/m_^{0}C	21

Table 1: Mechanical properties of 9% nickel steel [6]

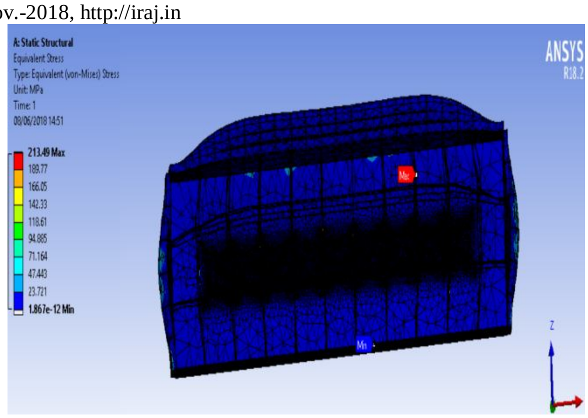


Figure 6: Equivalent (Von-mises) stress distribution under a design pressure of 3.6 bar

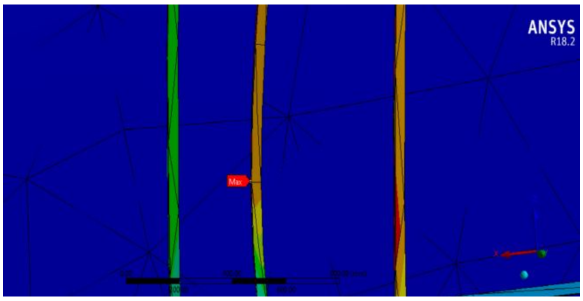


Figure 7: Location of maximum equivalent (Von-mises) Stress in pressure vessel

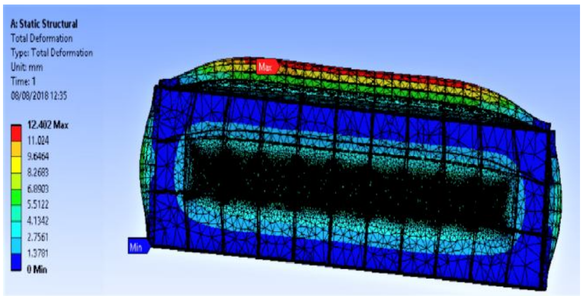


Figure 8: Total deformations plot under applied design pressure of 3.6 bar

CONCLUSION

- The prismatic pressure vessel counts as an effective design because it replaces the conventional vessel. Conventional pressure vessels for high capacity storage with high pressure have restrictions because of limitations in thickness.
- The volume efficiency of a prismatic pressure vessel is 45% higher than that of cylindrical pressure vessel.
- Pressure vessel reinforcement can be done by using attaching different type of stiffeners to wall of the pressure vessel and internal load carrying beam members. Adding stiffeners to the pressure vessel, increases stiffness and used to reduce the weight of vessel.

- The study of sloshing phenomenon of fluid-structure interaction is of great practical significance for the LNG pressure vessel which is operating on ships. For designing rectangular pressure vessel, Sloshing load is an important design parameter.
- The Overall stresses are significantly lower than the allowable stress of material. Hence structural reliability encounters no significant difficulties.

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