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Design of Liquefied Natural Gas (LNG) Storage Vessels

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Abstract: Pressurized vessels are one of the equipment, which has the most important and special application in oil and petrochemical industries and in most of the major industries, such as power plants and transportation. The finite element method is a process in which the specified domain is expressed as a combination of fixed domains called finite elements, so that there is the possibility of regular formation of approximation functions in the residual weight approximation to solve one problem on each element. In addition, the highest stress according to Van-Mises theory related to the lower corners of the vessel, but due to uncertainty and after applying it, as shown in Figure 1, the stress level varies in different probabilities and reached from a stress of 2.97×10^{8} Pascal at a probability level of 0.001 to 6.90×10^{8} Pascal at a probability level of 0.999. In this research, a concave wall with a curvature radius of 2334.3 m was proposed to investigate Van-Mises stress, which results indicate 30% reduction in stress. Figure 2 illustrates the result of the Van-Mises stress for the concave wall proposed. As known, the calculated stresses in the software completely correspond to the values obtained from the equations, which indicates the accuracy of distribution of the stress in the vessel wall.
Keywords: Design , Liquefied Natural Gas , Storage Vessels

INTRODUCTION

We know that pressurized vessels are one of the equipment, which has the most important and special application in oil and petrochemical industries and in most of the major industries, such as power plants and transportation. Therefore, paying the attention to design and construct of them has particular importance. Products with a high vapor pressure up to 100 pounds per square inch are stored in spherical or cylindrical vessels. Spherical or cylindrical vessels are used to withstand high pressures and can withstand pressure up to 100 pounds per square inch or more. These types of vessels are used for maintenance of butane and propane and liquefied gas and light petrol and generally light chemicals. Among storage vessels with fixed roofs, vessels that are used to store liquid gases (LNGs) are more important and more complex. One of the causes of this complexity is very low operating temperature, so that this temperature is -162 ° C for LNG vessels. The wall of these vessels is in double-wall and nickel and magnesium alloy steels constructed to improve efficiency and especially increase the impact resistance at low temperatures. Two intervals between the two walls, thermal insulations are used. Pressurized vessels are designed and built according to ASME SEC, VIII DIV1 standard (Godoy & Sosa, 2003). Liguefied Natural gas has a volumetric gas equivalent of 1/600 of natural gas volume in gas mode. Liquid gas is colorless, non-toxic, and non-corrosive gas. The dangers that this gas can cause is flaring, freezing, and choking. The energy density of the natural gas is 60% of diesel fuel. The condensation process involves the removal of certain compounds such as dust, acid gases, helium, water, and heavy hydrocarbons, which cause problems in the downstream flow (gas transfer in pipes) for gas. Natural gas is cooled after removing the above cases at a pressure equivalent to atmospheric pressure and temperatures of -162 ° C (maximum gas pressure for transfer applications at pressure 25 kPa or 36 psi). Reducing gas volume in conditions pipelines are not available will save money in long paths. In cases where the transfer of natural gas through an economic or operational pipeline is not possible, it can be transported by sea vessels carrying natural gas designed for this purpose or by road vessels. In consumption markets, liquid natural gas converts again to gas mode (Licai Yang & Zhiping Chen, 2013). The density of liquid natural gas varies from about 0.41 to 0.5 kg / l, which is a function of temperature, pressure and its composition. The amount of liquid natural gas at the highest level reaches to 24 megajol / liter at temperature -164 ° C. The lowest amount of natural gas heating is 21 megajol. Liquid natural gas contains more methane (more than 90%) and low levels of ethane, propane, butane, and some other heavy alkanes (Malhotra, Wenk, Wieland, 2000). The LNG refinement can be designed in such a way that the finished product contains 100% methane. In the design of liquid natural gas vessels, based on the initial information that process section provides for mechanical section that in this design the thickness of the sheet used to construct the pressurized tank, including shell and the head based on ASME (American Society of Mechanical Engineers), calculation of wind load, earthquake and seismic load are carried out based on UBC (Uniform Building Code). To design, a suitable constructor material must be selected and then shaped on the basis of it. The design is carried out based on longitudinal and lateral stresses that remain in the vessel like a thin shell. These stresses can be achieved by having internal pressure and having the thickness and diameter of the vessel. However, these stresses are not the total stress applied to vessel, but other lateral forces such as wind force and earthquakes, etc., increase these stresses (Livaoglu & Dogangun 2007). Investigating pressurized vessels and storage and calculating them and existing standards for the design of such vessels are discussed in this project, so that designer engineer must have complete information about the types of joints, welding joints, test required and welding design to design pressurized vessels with high reliability. It is obvious that lack of accuracy during design will result in financial losses and waste of time in the production line of a manufacturing plant (Grange, Kotronis, Mazars, 2008). In today's industrial world, pressurized vessels have found much importance, especially in refineries. Pressurized vessels were firstly used only for storage, but now in various types of these vessels, they perform converting crude oil to refined oil, and generally that are used widely in the refining of oil and its derivatives, and servicing at the fueling stations (Curadelli, 2013). Pressurized vessels are made in any size and shape. The smallest diameter of them may be a fraction of an inch and the largest of them is 150 feet in diameter. Some of them are located deep in the ground or in the ocean, but they are often installed on the ground or protected on platforms. The internal pressure range is also wide in vessels. The relative internal pressure equivalent to the height of water in a tank may be about one inch of water, or it can impose a power about 300,000 Psi or more in another vessel, as lack of attention in this regard will lead into explosion and irreparable financial and physical losses (Zhang & Weng, 2014). For this reason, the industrialized countries of the world have established industrial associations consisting of engineers, experts and researchers to harmonize what is called as standardizing the vessels construction in order to pass standard rules in this area. One of the best of these standards is the ASME code (Hamdan, 1999). Therefore, in this research, the researcher intends to design LNGs using the software through temperature, pressure, forces, maximum permissible stresses, shell under internal pressure and high pressure vessels.

METHODOLOGY

The finite element method is a process in which the specified domain is expressed as a combination of fixed domains called finite elements, so that there is the possibility of regular formation of approximation functions in the residual weight approximation to solve one problem on each element. Therefore, the finite element method with traditional Galerkin methods, least squares and other residual weight methods differs from the viewpoint of the formulation of approximate functions.

Three features of finite element method

Dividing the whole into elements: it allows providing a domain with complex geometries as a combination of simple geometric simple domains and allows for systematic extraction of approximation functions.

Extracting approximation functions for each element, the approximation functions are often algebraic polynomials that are extracted using the interpolation theory.

Summing up of elements, which is based on the continuity of the response and the balance of internal fluxes

These three features, which form the main steps in extracting finite element relationships, are closely interlinked. The geometry of the elements used to express the domain of the problem should be such that the approximation functions can be exclusively extracted. Approximation functions depend not only on geometry, but also on the number and location of points or nodes in the element and the interpolated quantities (Wing Kam, 1981).

Finite Element Method

Preprocessing: Dividing the domain of the problem into finite elements (discretization)

Element relationship making: Providing the governing equations on an element.

Assembeling: Obtaining the equations governing on the domain of the problem by assembling the equations governing each element.

Solving equations

Post-processing: Obtaining the required quantities, such as speeds and pressures.

In a simple mode such as systems involving the springs or trusses, it is possible to define the behavior of the element directly and there is no need to consider the governing differential equation.

Domain meshing

The division of the domain into finite elements is due to the fact that the response of problem is obtained for each element with high precision and then by assembling the response in the whole element, the overall response of the problem is determined. The general rules for creating a network for finite element relationships are as follows:

The number, shape, and type (that is linear or quadratic) of the elements must be such that the geometry of the domain to be divided with the desired accuracy and precision.

The density of elements should be such that the areas with large gradient of the problem variable are properly simulated (that is high-order elements should be used in areas with large gradients).

The mesh arrangement should gradually shift from areas with high density to areas with low density.

The geometry of the problem must be completely covered by elements.

Showing a domain by a set of finite elements requires compliance with many points. The number, type (for example, linear or quadratic), shape (for example, triangular or rectangular) and density (that is network modification) of the used elements in one problem depend on the following considerations:

The division of the domain into acceptable elements, as close as possible to each other.

The second consideration that requires engineering precision is the division of the object or part of the object into relatively small elements so that the response gradients to be precisely calculated.

For example, viscous fluid flow around a cylinder in a channel is considered. The flow enters to channel from the left side, and after passing around the cylinder, it leaves the channel from the right side. Since the cross-sectional area of the cylinder is smaller than the cross-section of the channel, it is expected that the flow to accelerate around the cylinder. Additionally, the speed at the distance away from cylinder (for example, in the input entry) is basically uniform, as this qualitative knowledge of flow behavior forms a coarse mesh (that is, the elements are relatively large in size) in a space roughly far from the cylinder, and a delicate mesh at close intervals of the cylinder.

The following three conditions must be met to modify the mesh

A. The geometric structure of the problem does not change.

B) The position of the previous nodes does not change.

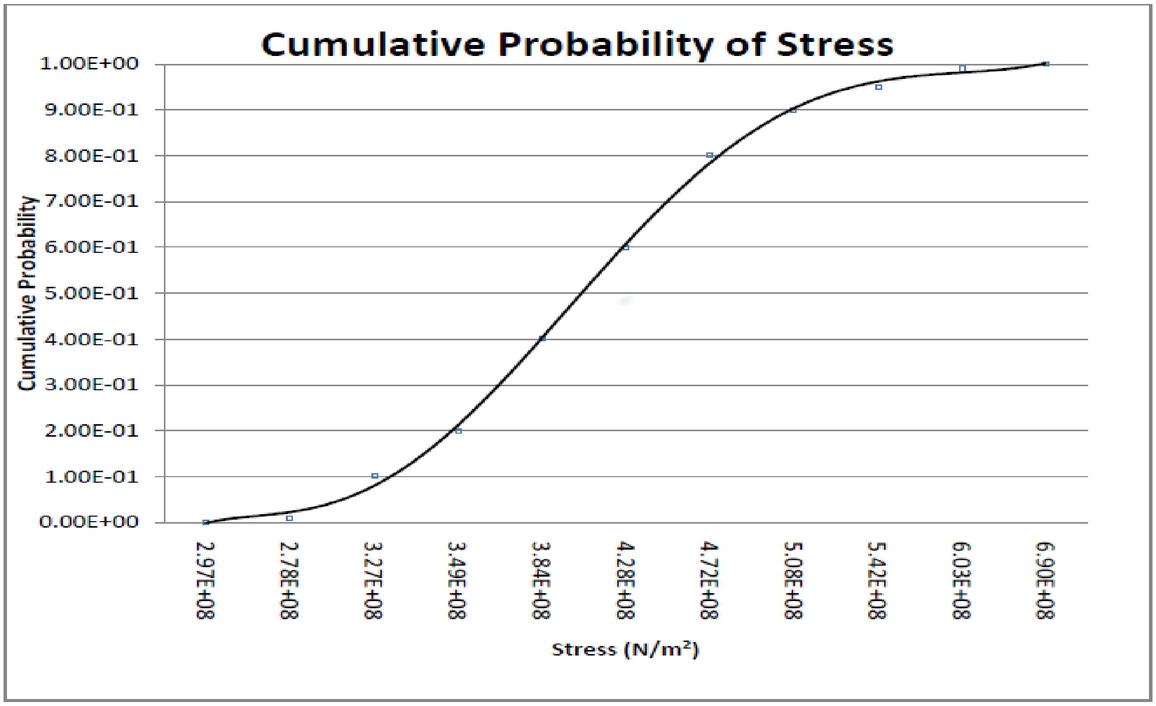
C) The same approximating time to remain at all stages of the modification process (James I. Chang, Cheng-Chung Lin, 2005).

An important part of modeling finite element is meshing, which consists of numbering nodes and elements and creating node coordinates and connection matrix, while creating such information is quite simple, the type of information affects the computational efficiency and accuracy. The accuracy of finite element solving also depends on the selection of finite element elements. For example, if the selected mesh disturbs the symmetry of the problem, the response will be less accurate than the response obtained using its physical symmetry. Geometrically, a triangular element has less symmetry lines compared to a rectangular element, so triangular elements' meshes should be used with higher accuracy. The accuracy of the finite element responses method depends on the size of its meshing. If responses are converged to a certain value by fragmenting the meshing, is said that the response has convergence. Selection of test responses as well as weight functions is effective in the convergence of finite element solving. Weight functions as well as test response should be sufficiently soft. This softness depends on the derivatives appeared in the weak form of the governing equation. In finite elements, weight functions, as well as test response and their derivatives must be able to accept fixed values (DiGrado & Thorp. 2004).

Findings

The results of stress testing on the uncertainty of the variables studied

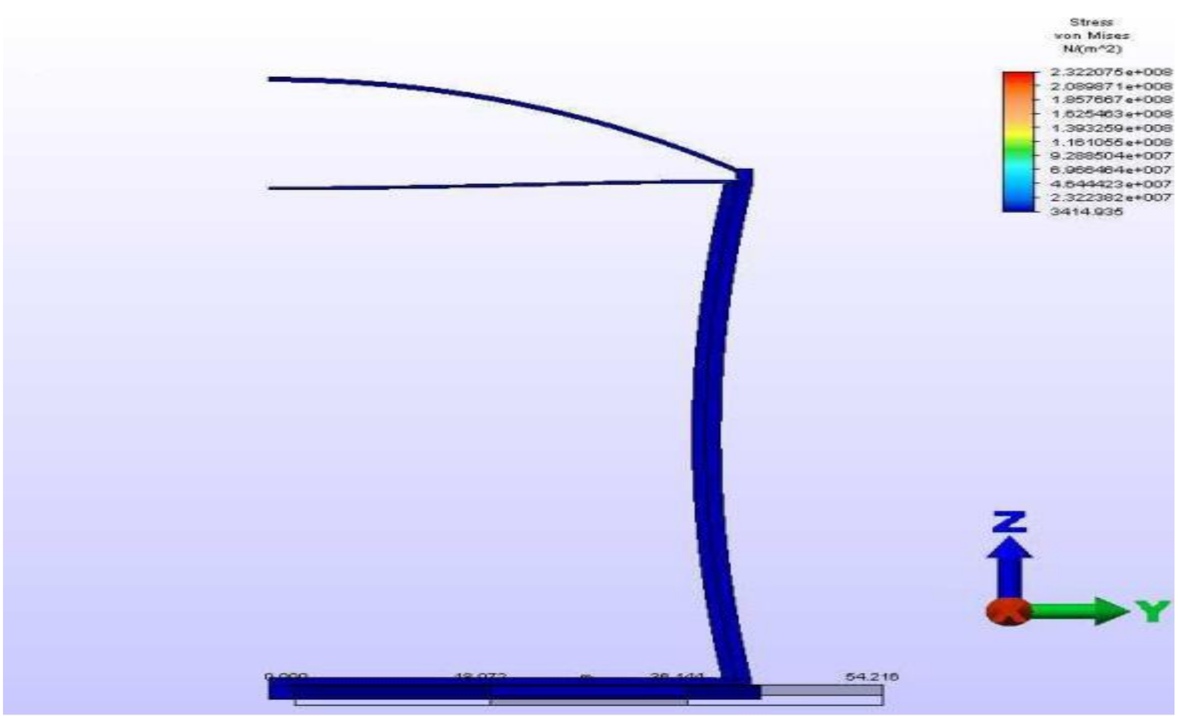
As shown in Figure 1, the stress level varies in different probabilities and reached from stress $2.98*10^8$ Pascal at a probability level of 0.001 to ٦/٩٠×١٠^٨ Pascal at a probability level of 0.999 percent.



Figur 1: stress investigation in different uncertainties of LNG vessel

Results of the proposed form for the LNG vessel

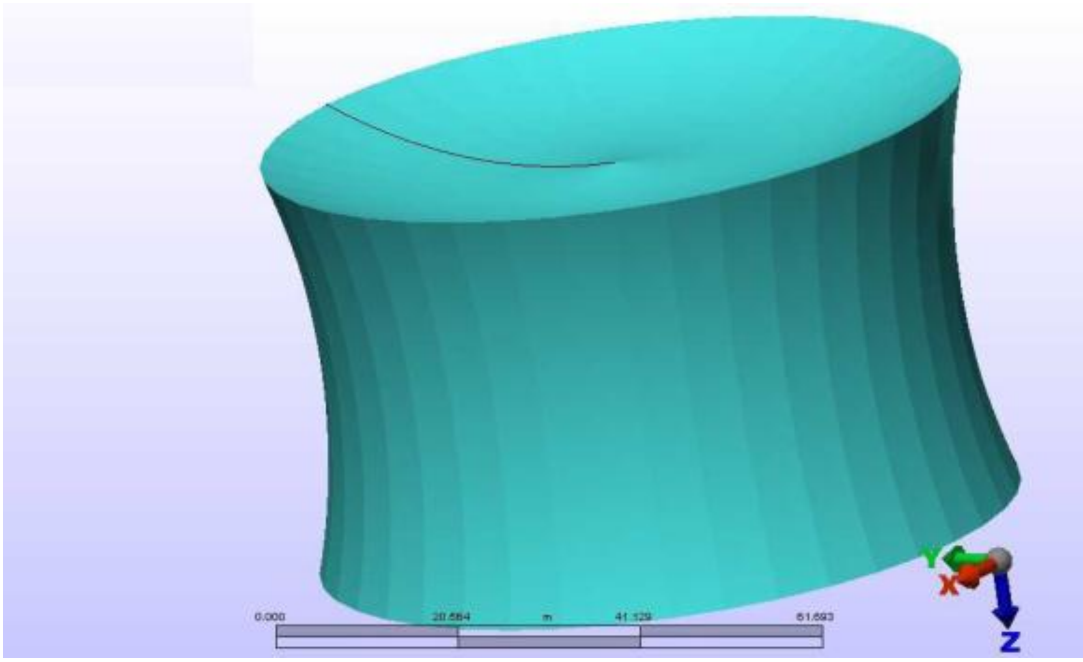
In this research, a concave wall with a curvature radius of 2334.3 m was proposed to investigate Van-Mises stress, which results of this study show a 30% reduction in stress. Figure 2 shows the results of the Van-Mises stress for the proposed concave wall.



Figur 2: Investigating LNG vessel stress by concave tank wall

Concave wall results for LNG vessel

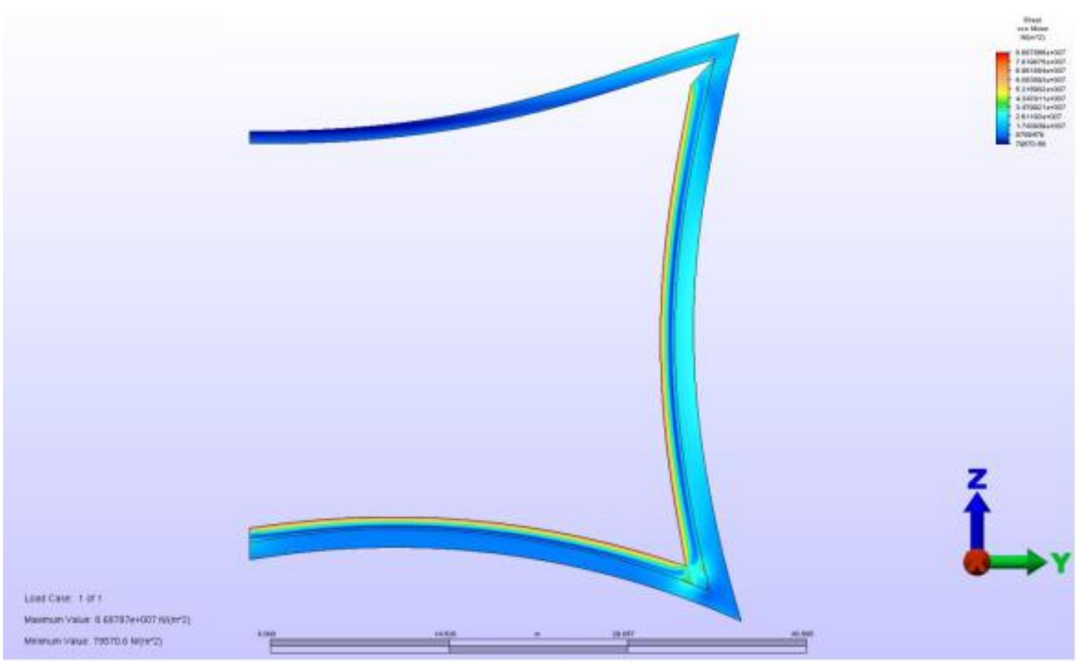
The overall shape of the concave wall is shown in Figure 3, which is designed by the software at a curve radius of 234 m.



Figur 3. LNG vessel with concave vessel wall

Concave wall stress results for LNG vessel

The concave wall stress is shown in Figure 4, which is designed by the software at a curve radius of 234.3 m.



Figur 4: Investigating LNG vessel stress with concave vessel shell

Investigating the amount of environmental stresses created in the vessel crust

By applying the hydrostatic pressure on the wall of the vessel in this wall, circular stresses are created. Knowing the amount of hydrostatic pressure and the radius of the vessel and its thickness, we can calculate the amount of these circular stresses using solid theories.

$$\sigma = \frac{P \times R}{t}$$

In the above equation, σ is the circular stress created in the vessel wall. P is the amount of hydrostatic pressure at each depth of the fluid, and R represents the radius of the vessel and also t is the wall thickness of the vessel. In order to investigate the accuracy of distribution of stress in the vessel wall, we apply a constant hydrostatic pressure (maximum hydrostatic pressure in the vessel) uniformly within 3 seconds into internal wall of vessels then hold the pressure constant for 1 second. In addition, for this purpose, only the wall of the vessels is modeled to prevent the interference of any other factor. In addition, it should be noted that the software offers the amount of pressure on both sides of the shell, which must be averaged first and then compare with the value obtained from the equation.

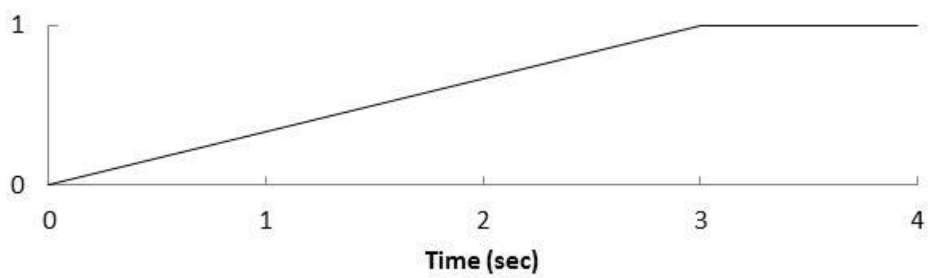


Figure 5. Hydrostatic pressure increase rate

Due to the fluid height in the vessel, the maximum fluid hydrostatic pressure in the vessel floor is calculated as follows.

Now, we apply this amount uniformly and within 3 seconds to the internal wall of the vessel. The amount of stress in different parts of the vessel wall with different thicknesses can be calculated as follows:

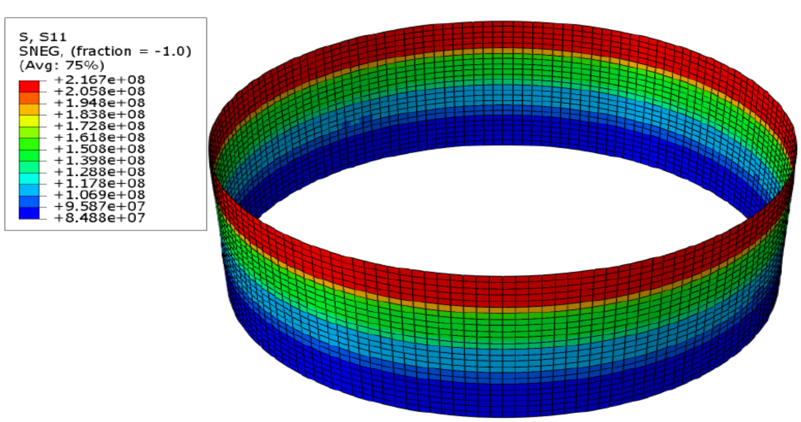
$$\sigma = \frac{P \times R}{t} = \frac{98100 \times 17.5}{0.02} = 85837500\ Pa = 85.8375\ M\ Pa \qquad \text{t=20mm}$$

$$\sigma = \frac{P \times R}{t} = \frac{98100 \times 17.5}{0.016} = 107296875\ Pa = 107.2969\ M\ Pa \qquad \text{t=16mm}$$

$$\sigma = \frac{P \times R}{t} = \frac{98100 \times 17.5}{0.012} = 143062500\ Pa = 143.0625\ M\ Pa \qquad \text{t=12mm}$$

$$\sigma = \frac{P \times R}{t} = \frac{98100 \times 17.5}{0.008} = 214593750\ Pa = 214.59375\ M\ Pa \qquad \text{t=8mm}$$

Now, we can compare the obtained values with the values obtained from the software.



In addition, elements are considered in the middle of each row of the vessel wall sheets and compare the increasing trend of circular stress with theoretical value.

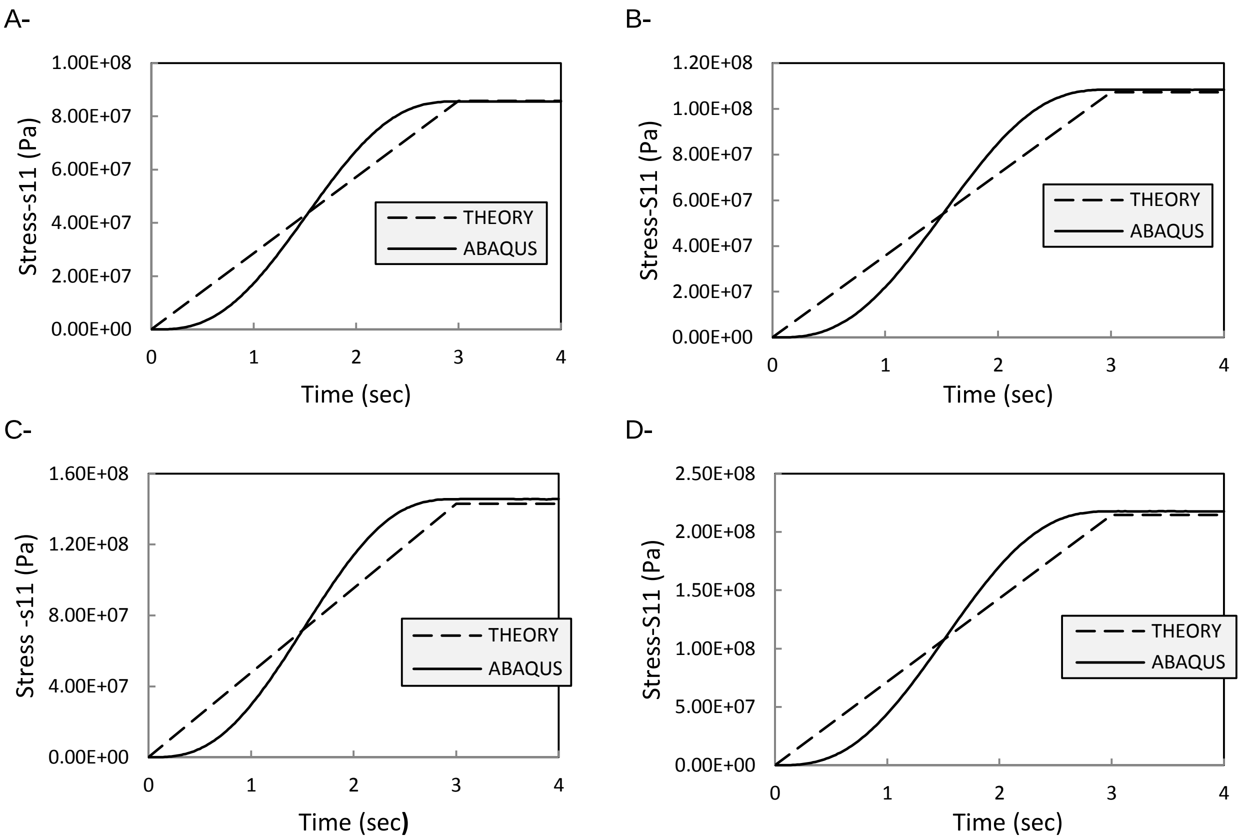


Figure- 6 Comparison of the increasing trend of circular stress in the middle elements of the width of the sheets in the vessel a) mm t=20 b) t = 16) c) t=12 mm d) t= 8mm

As known, the calculated stresses in the software completely correspond to the values obtained from the equations, which indicates the accuracy of distribution of the stress in the vessel wall.

CONCLUSION

In this research, a vessel was designed, but the design of the LNG vessel, in addition to the structural issues, requires thermal discussions due to the very low temperature of natural gas storage. In addition, the highest stress according to Van-Mises theory related to the lower corners of the vessel, but due to uncertainty and after applying it, as shown in Figure 1, the stress level varies in different probabilities and reached from a stress of 2.97×10^{8} Pascal at a probability level of 0.001 to 6.90×10^{8} Pascal at a probability level of 0.999. In this research, a concave wall with a curvature radius of 234.3 m was proposed to investigate Van-Mises stress, which results indicate 30% reduction in stress. Figure 2 illustrates the result of the Van-Mises stress for the concave wall proposed. As known, the calculated stresses in the software completely correspond to the values obtained from the equations, which indicates the accuracy of distribution of the stress in the vessel wall.

REFERENCES

F.H. Hamdan,1999, Seismic behaviour of cylindrical steel liquid storage tanks, Journal of Constructional Steel Research, vol.53, pp.307-333.

James I.Chang, Cheng-Chung Lin , 2005, A study of storage tank accidents, Journal of Loss Prevention in the Process Industries.vol.19,pp51-59

L.A. Godoy, E.M. Sosa, 2003, Localized support settlements of thin-walled storage tanks, Thin-Walled Structures.vol.41,pp.941-955.

Licai Yang, Zhiping Chen, 2013, An analytical formula for elastic-pelastic instability of large oil storage tanks, International journal of Pressure vessels and piping, Vol 101, pp 72-80.
Malhotra, P.K., Wenk, T., Wieland, M, 2000, Simple procedure for seismic analysis of liquid storage tanks, Structural Engineering International, vol.10, pp197-201.
O.Curadelli, 2013, Equivalent linear stochastic seismic analysis of cylindrical base isolated liquid storage tanks, Journal of Constructional steel research, vol 83, pp 166-176.
R. Livaoglu, A. Dogangun, 2007, Effect of foundation embedment on seismic behavior of elevated tanks considering fluid–structure-soil interaction, Soil Dynamics and Earthquake Engineering, vol.27, pp855–863.
Ruifu.Zhang, Dagen Weng, 2014 , Assessment of the seismic effects of isulation on extra-large cryogenc liquid natural gas storage tanks, Journal of loss prevention in the process industries, Vol.30, pp9-16.
Stéphane Grange, Panagiotis Kotronis, Jacky Mazars, 2008, A macro-element for a shallow foundation to simulate Soil–Structure Interaction considering uplift, C. R. Mecanique, vol.336, pp.856-862.
Wing Kam LIU, 1981, Finite element procedures for fluid-structure interactions and application to liquid storage tangs, Nuclear Engineering and design, vol.65, pp.221-238