Finite Element Simulation of Inner Tank of LNG Full Capacity Storage Tank

Juan Su, Xu Chen, Cheng Chen, Shuqian Tong, and Ye Chen

Abstract The inner tank of LNG storage tank is an important part of LNG storage tank, and its mechanical characteristics are very important to the safety of engineering operation and maintenance. Considering the high price of the inner tank material (9% Ni steel plate), it is difficult to practically carry out large-scale or equal-scale experimental research in batches. Therefore, using finite element software to conduct research on the LNG inner tank can not only obtain reliable results, but also save a lot of cost. In this paper, the design and calculation of the wall thickness of the inner tank are first carried out, and on this basis, the numerical model of the designed 200,000 m^3 full-capacity storage tank is established by using the finite element software ANSYS, and then the water pressure condition and the maximum operating conditions are simulated and calculated. Liquid level conditions, external pressure buckling conditions. The research results show that the maximum stress is located at the bottom of the inner tank and is less than the allowable stress un-der the condition of hydraulic pressure and maximum operating liquid level; buckling occurs at the bottom of the inner tank under the condition of external pressure buckling.

Keywords LNG storage inner tank · Water pressure · Maximum operating liquid level · Buckling analysis · Finite element modeling

1 Introduction

As an efficient and clean energy, natural gas plays an increasingly important role in modern industry. However, its storage and transportation are often faced with greater challenges due to gas phase characteristics. Liquefied natural gas (LNG) technology can transform free gas into liquid phase with smaller volume and safer property for

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storage and transportation. As the most widely used LNG storage tank in China, the research on the inner tank of LNG full capacity storage tank is conducive to ensuring the stability of natural gas storage. Considering the high price of the inner tank material (9% Ni steel plate), it is difficult to practically carry out large-scale or equal-scale experimental research in batches. While using finite element software for simulation calculation is not only reliable, but also can save a lot of costs. Therefore, it is widely applied as a common method for pre-research analysis.

Certain basic studies have been carried out in the past decades. Chen [1] conducted finite element simulation research on the inner tank of LNG storage tank based on ANSYS finite element software, mainly studied the influence of different temperatures on different areas of the inner tank, and the results showed that the ambient temperature has a greater influence on the tank roof. Gao [2] used ANSYS software to analyze the strength of LNG storage tanks. Liu [3] analyzed LNG storage tanks by using finite element software, and the results showed that the stress concentration phenomenon in the discontinuous area is more obvious under the static force; the response difference is larger under different seismic waves. Yang [4] used ABAQUS finite element software to establish a finite element model of LNG storage tanks and analyzed the mechanical properties of storage tanks under different construction conditions. Luo [5] studied the shock-absorbing effect of the insulation layer of LNG storage tanks, and the results showed that the insulation layer has a shock-absorbing effect on the seismic response of the inner tank and has a shock-absorbing effect on the acceleration of the outer tank. Li [6] conducted stress analysis on the concrete outer tank of LNG storage tanks. Under the condition of empty tank, the maximum compressive and tensile stress at the top of the tank occurred at the pressure ring of the storage tank, and the maximum compressive stress of the bearing platform under the condition of empty tank, The maximum tensile stress is located at the outer edge of the connection between the bottom of the tank and the cap. Some researchers have conducted relevant research on the key technologies and materials used in storage tank design [7–13]. Foreign researchers have also conducted a lot of research on LNG storage tanks and achieved many results [14–16]. However, there are few related studies and reports on the inner tank design of LNG full-containment storage tanks, especially the buckling.

Taking the design and calculation of a 200,000 m^3 LNG full-capacity storage tank as a typical calculation case, this paper establishes a three-dimensional model and conducts finite element research to verify the reliability of the design and provide reference for the further engineering applications. For the convenience of analysis, only statics condition is studied here.

2 Basic Parameters

See Table 1.

Table 1 Basic design parameters of inner tank

Heading level	Example	Font size and style
Nominal diameter of inner tank	D	85,000 m
Tank wall height	H	42,720 m
Medium height	Hp	37,740 m
Medium density	Wp	480 kg/m^3
Test water level (fresh water)	Hw	23,110 m
Density of test water (fresh water)	Ww	1000 kg/m^3
Corrosion allowance	CA	0 mm
Material density (steel)	ρ	7890 kg/m^3
Design allowable stress	Sd	268 N/mm^2
Test allowable stress	St	340 N/mm^2
Minimum allowable wall thickness	tmin	10 mm
Welded joint coefficient	JE	1

3 Model Building

3.1 Calculation of Inner Tank Wall Thickness

According to EN 14620, the wall thickness design formula is:

$$\mathrm{td} = \mathrm{D}/[(20)(\mathrm{Sd})(\mathrm{JE})] \cdot \left[(98)(\mathrm{Wp})(\mathrm{Hp} - 0.3) + \mathrm{Pd}\right] + \mathrm{CA} \tag{1}$$

The wall thickness formula for hydraulic test is as follows

$$\mathrm{tt} = \mathrm{D}/[(20)(\mathrm{St})(\mathrm{JE})] \cdot [(98)(\mathrm{Ww})(\mathrm{Hw} - 0.3) + \mathrm{Pt}] \tag{2}$$

The calculation results are shown in the Table 2.

3.2 3D Model Building

The analysis object of this paper is a full capacity LNG tank with a volume of 200,000 m^3. The diameter of the inner tank of the tank is 85,000 mm, the height of the inner tank is 42,720 mm, the maximum design liquid level is37,740 mm, and the maximum operating liquid level is 37,800 mm. The inner tank of LNG tank is made of 9% Ni steel plate, which is welded by 12 layers of steel plates. The height of each layer of steel plate is 3650 mm. An equal-scale 3D model of the inner tank of 200,000 m^3 LNG tank is established using 3D modeling software, as shown in Fig. 1.

Table 2 Calculation sheet of inner tank wall thickness

Number of layers	Distance to upper design liquid level/m	LNG working condition/mm	Hydraulic test/mm	Selected wall thickness/mm
1	37.74	28.22	27.10	28.9
2	34.25	25.59	22.87	26.2
3	30.76	22.96	18.64	23.7
4	27.27	20.33	14.41	21.0
5	23.78	17.70	10.18	18.8
6	20.30	15.07	5.95	16.5
7	16.81	12.44	1.72	14.2
8	13.32	9.81	–	11.8
9	9.83	7.19	–	10.0
10	6.34	4.56	–	10.0
11	2.85	1.93	–	10.0
12	– 0.64	– 0.70	–	10.0

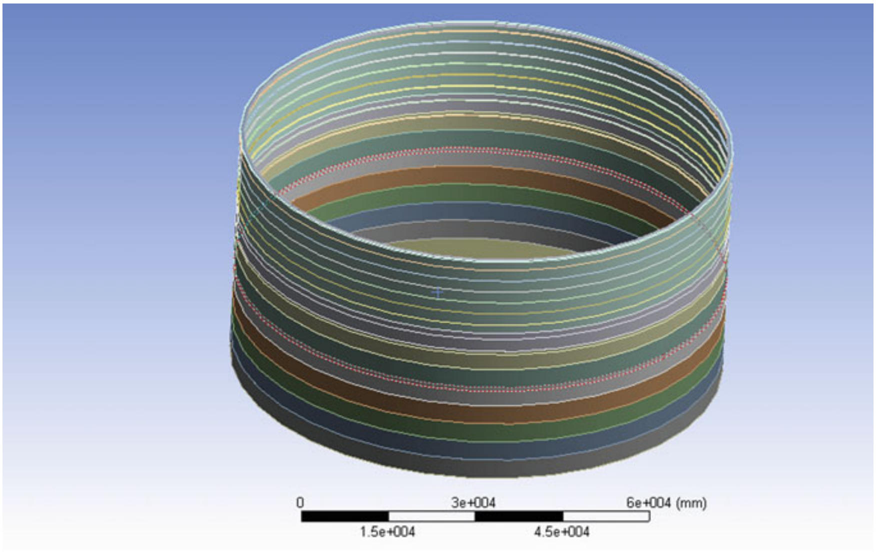

Fig. 1 3D model of inner tank of LNG storage tank

3.3 *Meshing*

The inner tank is modeled with shell elements, and the mesh division is shown in Fig. 2.

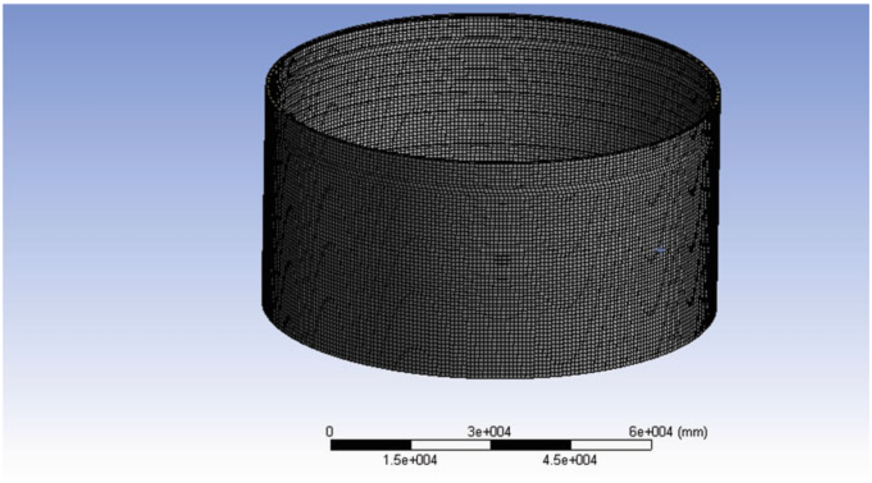

Fig. 2 Finite element mesh division of inner tank model

4 Result Analysis

4.1 Hydrostatic Test Condition

In the hydrostatic test, the water level is 23.11 m, and the pressure on the bottom of the tank is 0.227 MPa, which decreases linearly from bottom to top. Figures 3 and 4 show the stress distribution and total deformation results of the inner tank subjected to the static pressure of the stored liquid. It can be seen from the stress distribution diagram that the maximum stress is 329.22 MPa (located at the bottom of the tank), which is less than the allowable stress of 340 MPa.

In the hydrostatic test, the maximum deformation is 65.85 mm, which is relatively consistent with the reference [1], verifing the correctness of the result.

4.2 Buckling Analysis

The inner tank of the LNG storage tank is a thin-walled structure, so it is easy to buckle when the tank is empty. In actual engineering, the inner tank of the LNG storage tank is mainly subjected to gravity and perlite lateral pressure when the tank is empty. Therefore, the perlite lateral pressure is studied. And buckling under gravity are of great significance.

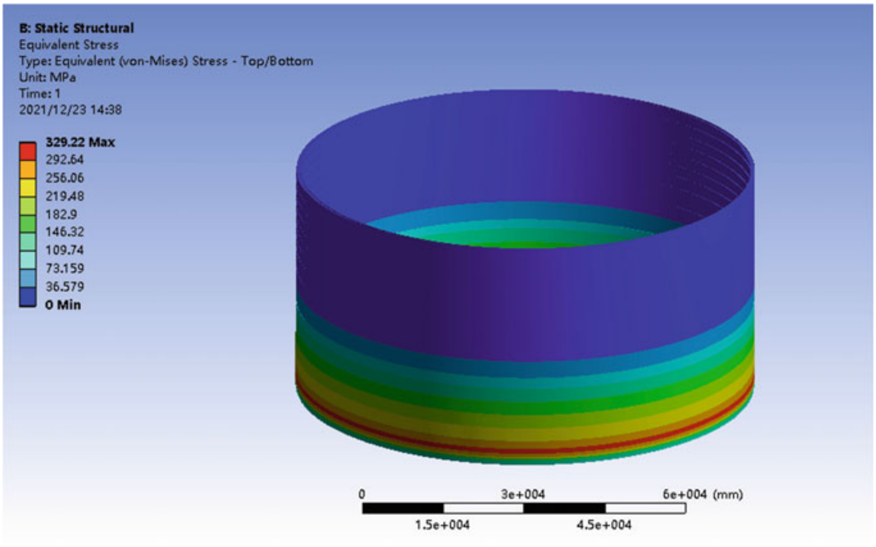

Fig. 3 Stress cloud diagram of inner tank during hydrostatic test

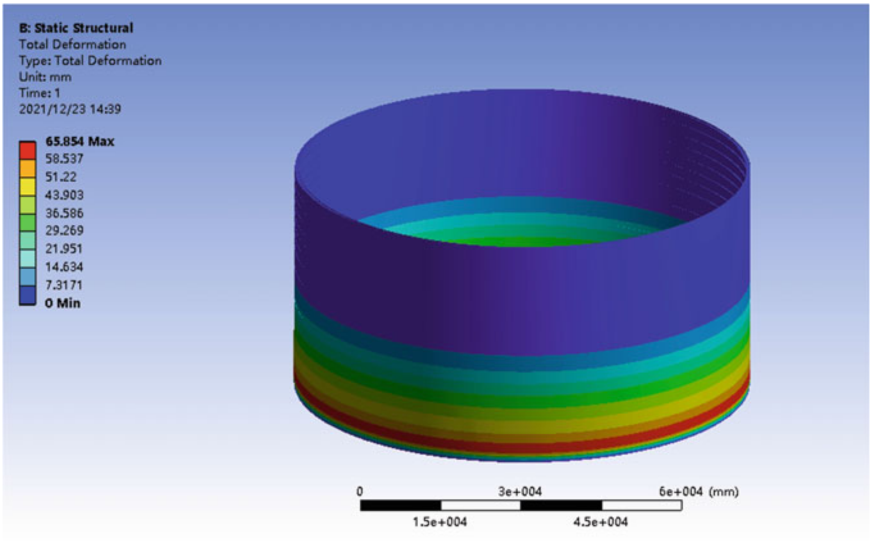

Fig. 4 Deformation cloud diagram of inner tank during hydrostatic test

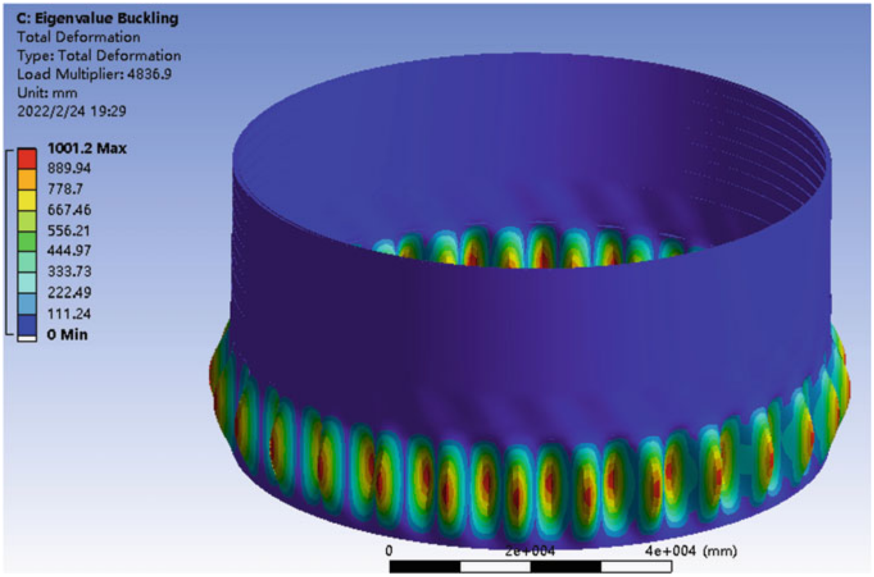

Fig. 5 Buckling cloud diagram of inner tank

When the storage tank is in an empty state, according to the perlite pressure calculation results, the maximum perlite pressure is 1201 Pa. This pressure is applied as an external pressure to the outside of the inner tank, and the buckling analysis of the inner tank is carried out. The buckling analysis results are shown in the Fig. 5. When the external pressure is 4836.9 Pa, the critical buckling state of the inner tank is reached (4836.9 is larger than 3 times of 1201), and the safety factor is greater than 3, which meets the design requirements.

5 Conclusions

1. The 200,000 m^3 storage tank designed in this paper meets the strength requirements, and the maximum stress is less than the allowable stress under different working conditions;
2. Under the action of external pressure and gravity, the buckling of the inner tank of the LNG storage tank occurs when the tank is empty. At the bottom, the inner tank designed in this paper meets the design requirements.

References

1. Chen, W.: Simulation Research on Static Force Field and Temperature Field of Large LNG Storage Tank Based on ANSYS. Qingdao University of Science and Technology, Qingdao (2019)
2. Yan, G., Min, L.: Application of ANSYS in strength analysis of LNG storage tanks. Ship Sci. Technol. **42**(22), 214–216 (2020)
3. Liu, D.: Structural Analysis and Performance Research of LNG Storage Tanks. Northwest University, Xi an (2018)
4. Yang, W.: Research on Mechanical Properties of LNG Storage Tank Multi-point Overall Lifting Process. Industrial Architecture (1) (2022)
5. Luo, D., Sun, J., Liu, C., Cui, L., Wang, Z.: Research on shock absorption effect of LNG storage tank insulation layer. J. Vib. Eng. **33**(5), 885–900 (2020)
6. Li, Z., Tao, J., Leng, M., Li, X., Zhang, N.: Load and stress analysis of LNG storage tank concrete outer tank under stable conditions. Nat. Gas Ind. **38**(11), 89–96 (2018)
7. Xia, M.: Key technology for design and calculation of large LNG storage tanks. Chem. Manage. **14**, 68–71 (2022)
8. Zhang, B., Huang, H., Chen, T., Xia, M., Ji, N.: Stress analysis of LNG storage tank based on numerical simulation. Petroleum Chem. Equip. **25**(03), 24–27 (2022)
9. Zhang, W., Tian, G., Zhao, G., Yin, X., Han, G.: Research on the cold insulation performance of large LNG storage tanks. Gas Heat **42**(01), 24–31 (2022)
10. Jiang, B.: Analysis of design points in the process of localization of 9Ni steel plates for LNG storage tanks .Chem. Equip. Pipeline **58**(06),15–19 (2021)
11. Li, J., Li, J., Xu, H.: Finite element static analysis of the overall structure of 3000 cubic LNG storage tank .China Chem. Equip. **22**(03),19–25 (2020)
12. Liu, Y., Xiao, L., Yang, F., Zhang, B., Huang, H.: Static analysis of 160,000 m^3 large fully contained LNG storage tank. Ganggong Technol. **57**(S1), 85–90 (2020)
13. Zhang, N.: Numerical Simulation Research on Inner Tank Leakage of LNG Storage Tanks. China University of Petroleum Beijing (2020)
14. Haddar, M., Hammami, M., Baccar, M.: Numerical parametric study of a cooling system for an LNG storage tank. Oil Gas Sci. Technol. **74** (2019)
15. Effendy, S., Khan, M.S., Farooq, S., Karimi, I.A.: Dynamic modelling and optimization of an LNG storage tank in a regasification terminal with semi-analytical solutions for N2-free LNG. Comput. Chem. Eng. **99** (2019)
16. Kim, J.H., Kang, S.K., Kim, Y.G., Jo, Y.: An assessment of carbonation and chloride attack for outer concrete of LNG storage tanks. Korean J. Hazardous Mater. **3**(1) (2015)