Finite Element Analysis and Test Verification of Super-Large Vertical Steel Storage Tank

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Abstract. In order to master the static characteristics of the super vertical steel storage tank structure, based on the potential flow theory, the fluid structure coupling element and contact element are introduced, and the three-dimensional finite element model of 150000m³ super large steel storage tank system is established by using the finite element software ADINA. The static analysis of the tank structure under different water filling height is carried out, and the circumferential and axial stress and distribution at different height of the tank wall structure are obtained. The results are in good agreement with the experimental results, and the rationality of ADINA finite element modelling method is verified. Finally, the stress nephogram and design suggestions of the wall of the super vertical steel tank are given, which lays the foundation for the further static and dynamic nonlinear analysis of the tank.

1. Introduction
With the need of strategic oil reserves, the number of large oil storage tanks in the world is increasing year by year, and the volume of tanks is also increasing [1]. The research on super large storage tanks in foreign countries started earlier and developed relatively fast. Since the early 1960s, 100 thousand cubic meters of floating roof tanks have been built successively in the United States, the Middle East, Western Europe, Japan and other places. By the end of 1960s, Venezuela has built a floating roof tank with a volume of 150 thousand cubic meters. In 1971, Japan successfully built a floating roof tank with a volume of 160 thousand cubic meters. At the end of the 20th century, a large oil producing country in the Middle East adopted advanced technology and materials to build a 240 thousand cubic meters floating roof tank[2]. With the rapid development of China's economy, the continuous improvement of high-strength materials, advanced design methods and manufacturing methods, more and more large-scale steel tanks are built in practical projects. In the aspect of research, P. K. Malhotra[3] put forward a simplified design method of storage tank for rigid foundation in 2000, and investigated the influence of convection quality and pulsation quality on concrete or flexible tank wall, which was adopted by European code. In 2008, Y. Shoichi[4] used the axisymmetric shell finite element method for numerical analysis, and proposed the buckling strength of the floating platform under the cyclic bending load and the cyclic compression load. In 2015, E. Azzuni[5] conducted linear analysis on the wall thickness of steel cylindrical tank based on three analysis methods of API 650 Standard Specification, and developed a basic thin wall theory based on elastic matrix method, which can optimize the design of wall thickness of large steel tank. C.Q. Yuan discussed the detection
methods of different tank liquid levels in 2011. In the same year, the finite element analysis was carried out for 50000 m³ LNG tank, and the tensioning sequence of its vertical prestressed reinforcement was given. X.Y. Sheng used ABAQUS finite element software to analyze the stress of 150000 m³ double disk floating roof crude oil storage tanks of four schemes, and determined a more reasonable design scheme through comparison. Z. Wang used the finite element software ADINA to study the static performance and seismic response of the reticulated shell storage tank, which verified that this structure has a large rigidity, can effectively reduce the thickness of the tank wall and the bottom plate, and has a good economy. In 2014, J. Ji proposed the structure and construction method of Super Large FRP composite tank with floating roof. In 2015, Y. Zhang carried out the design and finite element analysis of vertical GFRP storage tank, and gave the design suggestions of this type of tank. Although there are a lot of documents about finite element analysis of storage tank, there are few tests to verify the results of finite element analysis. Based on this, ADINA finite element analysis of super large steel storage tank is carried out to obtain the stress distribution of the pipe wall under the self weight of storage tank. The correctness of finite element simulation is verified through tests, which lays a foundation for further static and dynamic analysis of various combined storage tanks.

2. Survey and test of vertical steel tank engineering

In October 2004, two 150 thousand m³ floating roof crude oil tanks were built in Yizheng transmission and distribution station of Sinopec pipeline storage and transportation company. Designed by Sinopec Engineering & Construction Corporation, the tank is the largest vertical cylindrical crude oil tank built in China. Its appearance is shown in figure 1. In order to verify the rationality of the design and the reliability of the theoretical calculation during the design, Professor Z.P. Chen of Zhejiang University tested the stress of the bottom plate edge plate of one tank (T1 tank), the outer surface stress of the lower three-layer wall plate, the inner surface stress of the bottom wall plate and the stress at the entrance hole during the water filling test of the tank. The two-way strain gauge used was pasted on the test part along the axial direction and the circumferential direction, as shown in figure 2. Through measurement, the circumferential and axial stress distribution curves of the outer wall of T1 storage tank are shown in figure 5.

3. Finite element analysis of T1 tank

3.1. Basic parameters of T1 tank

The basic parameters of 150000 m³ floating roof tank (T1 tank) are listed in table 1. The density and bulk modulus of water are $1 \times 10^3$ kg/m³ and $2.0 \times 10^8$ N/m², and acceleration of gravity is 9.8 m/s². The density and modulus of elasticity of steel plate is $7.85 \times 10^3$ kg/m³ and $2.06 \times 10^5$ MPa, and yield strength and shear modulus is 490 N/mm² and $7.92 \times 10^4$ MPa, respectively.
Table 1. Geometric parameters of 15×10⁴ m³ storage tank and material

| Tank location          | Cycle number | Height H(mm) | Wall thickness δ(mm) | Material  |
|------------------------|--------------|--------------|----------------------|-----------|
| Tank wall panel        | 1            | 2980         | 40                   | SPV490Q   |
|                        | 2            | 2680         | 33                   |           |
|                        | 3            |              | 26                   |           |
|                        | 4            | 2680         | 17                   | SPV490Q   |
|                        | 5            |              |                      |           |
|                        | 6            |              |                      |           |
|                        | 7            | 2660         | 12                   | 16MnR     |
|                        | 8            |              |                      | Q235-B    |
| Base plate             | Edge plate   | 23mm         | SPV490Q              |           |
| (thickness)            | Middle panel | 11mm         | Q235-B               |           |

3.2. coordinate system

The cylindrical coordinate system adopted by the tank is shown in figure 3, and the origin of the coordinate is at the center of the bottom plate. The radius, the height and the thickness of the tank are \( R \), \( H \) and \( \delta \), respectively. The height of the liquid is \( h_w \). The bottom of the tank is in contact with the basis.

![Figure 3. The cylindrical coordinate system for tank](image)

3.3. Establishment of finite element model

3.3.1. Element selection. Both the tank wall and the bottom plate adopt 4-node isoparametric shell units, which can be used to simulate thin shell structures. The liquid adopts an 8-node three-dimensional solid unit, the liquid surface is a free-surface unit, and the other is fluid-surface unit. The basis adopts an 8-node three-dimensional solid unit. Face-face contact should be used according to the contact between the tank bottom and the foundation, and the contact element and target element that match with the shell element and solid element are selected. The target unit and the contact unit are set at the bottom of the tank and the base.

3.3.2. Finite element model of T1 storage tank. Taking into account the characteristics of the complicated stress on the lower part of the tank wall, the mesh division adopts the way of top-down encryption. The finite element model after grid division is shown in figure 4.
4. Comparison between finite element results and measured values

For large oil tanks, the maximum stress of the tank wall occurs in the lower part of the tank, generally on the first or second ring wall plate, and this area is also the most prone to elephant foot buckling, so the stress characteristics of the two-ring siding are studied. For the 15×10^4 m^3 finite element model of the storage tank established above, the static analysis under the self-weight load is carried out at the water filling heights of 20.18 m and 6.13 m, respectively, and the simulated values of the circumferential and axial stresses of the outer wall of the storage tank obtained is compared with the measured value as shown in figure 5. It can be seen from figure 5 that the distribution trends of the two curves are consistent, and the error is within the required range. The agreement between the stress value and the finite element analysis curve is basically good, which verifies the rationality of the establishment of the finite element model and analysis method of the steel storage tank by ADINA.
5. Conclusions

Based on the ADINA finite element software, this paper carried out numerical analysis of the static performance of the existing 150,000 m$^3$ super-large steel storage tank, and obtained the distribution law of the stress of the wall of the storage tank with different filling water height. By comparing with the test results, the agreement is good, which verifies the rationality of the ADINA finite element modeling method. Finally, the stress cloud diagram and design suggestions of the super-large vertical steel storage tank wall are given, which lays the foundation for the static and dynamic nonlinear analysis for the storage tank in further.

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