Analysis of Uneven Settlement of Large Oil Storage Tank

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Abstract. The uneven settlement of large oil storage tank will not only cause the tank wall to be elliptical and the upper floating plate to be blocked, but also cause the tank body to fall. In order to study the influence of uneven settlement on the tank structure, this paper takes 50000m³ oil storage tank as an example, uses the finite element simulation method to explore the influence of uneven settlement of different scales of large tank foundation on the overall stress characteristics of the tank, and obtains the storage. The influence of uneven settlement of tank foundation on the mechanics of tank body, tank bottom and large corner joint. It can provide some guidance for tank management and evaluation.

1. Introduction
In recent years, with the increase of the number and capacity of crude oil storage tanks, large-scale tank accidents often occur, resulting in disastrous consequences [1-4]. As many tanks are built in coastal, soft soil and other areas with poor geological conditions, with the increase of service life of tanks, the tank foundation is prone to local settlement, resulting in tank tilt, wall plate deformation buckling, floating chuck and other safety accidents [5,6]. Reference[7] uses the measured settlement data to analyze the deformation of the floating roof tank. Reference [8] analyzes the structural mechanical characteristics of large storage tank under the foundation settlement. The maximum settlement standard of tank foundation is studied by numerical method in reference [9]. In order to study the influence of uneven settlement of oil tank on the tank, a finite element model is established to analyze the consequences of uneven settlement of 50000 m³ tank.

2. Simulation model

2.1. Modeling
Taking a 5×10⁴m³ floating roof oil tank as an example, the tank model is established by SOLIDWORK software, including tank body, foundation and foundation, backfill tamping foundation, etc. Then it is imported into ANSYS / workbench finite element analysis software, as shown in Figure 1. And the tank body includes tank wall, stiffening ring, tank bottom and large corner seam, as shown in Figure 2.
In order to simulate the uneven settlement of tank foundation, the foundation structure is refined. The foundation is divided into concrete ring beam, cement levelling layer, concrete cushion (100 mm), asphalt sand (100 mm), sand cushion (900 mm) and gravel with coarse sand (1000 mm grade), as shown in Figure 3.

The solid model of compacted foundation of backfill is shown in Figure 4.
2.2. Mesh generation
Using ANSYS / workbench finite element structural analysis software, the tank model is divided into three-dimensional finite element mesh, with 1573805 nodes and 428864 three-dimensional finite element elements, as shown in Figure 5.

2.3. Boundary condition setting
For a 5×10⁴ m³ large floating roof oil tank, the maximum water injection height is 16.3m and the maximum filling speed is 3500m³/h. The mass of floating roof is 1.4386e⁵ kg and the pressure is 487.832953N/m². The net pressure (0.1622mpa) of the maximum reserves and the surface pressure (487.8pa) generated by the floating roof. In engineering practice, due to various reasons, local weakening may be caused in the process of tank foundation backfilling, resulting in uneven settlement of tank foundation. The elastic modulus of the quarter sector of the tank foundation is reduced by 50%, as shown in Figure 6. The backfill compacted foundation adopts the sandstone material given by ANSYS/workbench software, and its elastic modulus is 3.4E10. Considering the local uneven settlement of partially backfilled compacted foundation caused by various external factors, it is assumed that the elastic modulus of the quarter sector green part is greatly reduced due to softening, which is set as 1.7e10. The static analysis of large storage tank is carried out under the boundary condition of backfill tamping foundation and fixed support at the bottom.

3. Analysis
The Mises stress distribution diagram of tank structure under the combined action of its self-weight, liquid pressure, floating plate and uneven settlement is shown in Figure 7. And the deformation distribution diagram of tank structure under the combined action of its own weight, liquid pressure, floating plate and uneven settlement is shown in Figure 8.
Figure 7. Mises stress distribution diagram of tank structure.

(a) Total deformation
(b) Deformation in Y direction

Figure 8. Structural deformation distribution of tank.

The Mises stress distribution diagram of tank wall, stiffening ring, tank bottom and large corner joint is shown in Figure 9 respectively.

(a) Mises stress distribution of tank wall
(b) Mises stress distribution of stiffening ring

(c) Mises stress distribution at tank bottom
(d) Mises stress distribution of corner seam

Figure 9. Mises stress distribution of tank structure.

The maximum Mises stress is located on the second stiffening ring, as shown in Figure 10.
The maximum Mises stress (the 2nd stiffening ring) is shown in Figure 10.

The comparison of the maximum Mises stress of each part of the tank structure under normal condition and uneven settlement condition is shown in Table 1.

**Table 1. The maximum Mises stress for parts (Mpa)**

| Structure                  | tank wall | stiffening ring | tank bottom | large corner joint |
|----------------------------|-----------|-----------------|-------------|--------------------|
| Normal working condition   | 330.80    | 688.46          | 44.28       | 46.05              |
| Uneven settlement condition| 331.02    | 688.46          | 46.86       | 46.05              |

The comparison between the maximum total deformation value of tank body and the maximum deformation value in Y-direction under normal working condition and uneven settlement condition is shown in Table 2. The maximum total deformation occurs in the middle of the bottom of the tank wall and the first stiffening ring, and the maximum deformation in the Y-direction of the tank body occurs in the outer edge of the first stiffening ring.

**Table 2. Maximum total deformation and in Y-direction of the tank (mm)**

|                           | Total deformation | Deformation in Y direction |
|---------------------------|------------------|----------------------------|
| Normal working condition  | 39.106           | -21.897                    |
| Uneven settlement condition| 39.099           | -21.895                    |

Figure 11 and Figure 12 shows the Y-direction deformation of the tank wall and the tank bottom under normal working conditions and uneven settlement working conditions.
Figure 12. Deformation in Y-direction under Uneven settlement condition.

Figure 13 and Figure 14 shows the X-direction deformation diagram of the tank under normal condition and uneven settlement condition.

Figure 13. X-direction deformation of tank under normal condition.

Figure 14. X-direction deformation of tank under uneven settlement condition.

Figure 15 shows the total deformation of the tank body under normal working condition by 60 times magnification. It can be seen from the figure that the bulge on the lower tank wall of the first stiffening ring is relatively prominent. It is also obvious from the figure that the deformation form of the stiffening ring (especially the first stiffening ring).
4. Conclusion
The paper mainly simulated the uneven settlement of large oil storage tanks, and explored the response of main components such as tank wall, tank bottom and large corner seam under uneven settlement. The main conclusions are as follows:

(1) The maximum Mises stress in the local area of the tank wall is 330.80MPa, which is larger than the allowable stress of 261MPa. The larger Mises stress (688.46MPa) of the bracket under the stiffening ring will cause adverse effect on the structure, and the attention should be paid when the reservoir reaches the maximum value.

(2) Compared with the stress and deformation under normal condition and uneven settlement condition, it can be seen that the local stiffness softening of the compacted backfill foundation has little effect on the stress and deformation of the tank body.

(3) Because the large angle seam structure mainly bears extrusion pressure, the mismatch of the rigidity between the large angle seam and the base metal will not cause the interface fracture mechanics phenomenon of the large angle seam structure.

(4) In the actual operation process, when the reservoir height reaches the design height, there will be certain risks. It is suggested to reduce the reservoir height appropriately.

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