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Large-scale Simulated Storage Tank Settlement and Strain Simulation

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Introduction

The first batch of four national strategic petroleum reserve bases is located in coastal landfill plots or island areas, where the foundations are mostly soft soil foundations. Under the gravitational influence of the storage tanks and the liquid inside them, the foundations of large petroleum storage tanks will experience varying degrees of settlement. Typically, foundation settlement is divided into base slab settlement and tank perimeter settlement. For base slab settlement, soil mechanics is commonly used for prediction, and research in this area is relatively mature[1-5]. However, research on tank perimeter settlement is relatively less, and this type of settlement is greatly influenced by the actual conditions of the foundation. Currently, actual measurements are mainly used to obtain relevant settlement data.

Uneven settlement is generally the component with the smallest numerical value in tank perimeter settlement, but it has a significant impact on storage tanks. Even if the uneven settlement value is small, it can still cause a significant radial displacement of the shell [7,8], adversely affecting the normal lifting and lowering of the floating roof.

In order to obtain the magnitude and distribution pattern of stresses on the tank wall after uneven settlement of the storage tank, and to assess the rationality of the finite element analysis method, strain testing experiments were conducted on the key areas of the tank wall of a 1:16 scaled model storage tank at different water levels using Fiber Bragg Grating measurement technique. The experiments aimed to acquire the strain distribution patterns and perform data analysis.

Research objectives

- Determine the magnitude and distribution of stresses on the tank wall following uneven settlement of the storage tank.
- Assess the rationality of the finite element analysis method.

Methods

Using the finite element analysis software Ansys, the stress distribution of the tank wall under third-order harmonic uneven settlement was simulated to determine the lifting and lowering displacements of each column of the settlement operation platform, as well as the approximate orientations of six key areas of the tank wall. Under the premise of evenly selecting measurement points along the tank wall, one measurement point was chosen at 25cm and another at 83cm from the tank base plate in each of the six key areas. The twelve measurement points were numbered in a counterclockwise sequence, with odd numbers corresponding to the points 83cm from the tank base plate and even numbers to those 25cm from the tank base plate. Moreover, these points corresponded to the 48 outer lifting columns, with numbers 1 and 2 being the measurement points at the locations where the lifting columns were raised the most. At each measurement point, three Fiber Bragg Grating (FBG) strain sensors were arranged in a delta configuration (i.e., vertical, diagonally up to the right at 45°, and horizontal) to form a strain rosette.

Numerical simulation

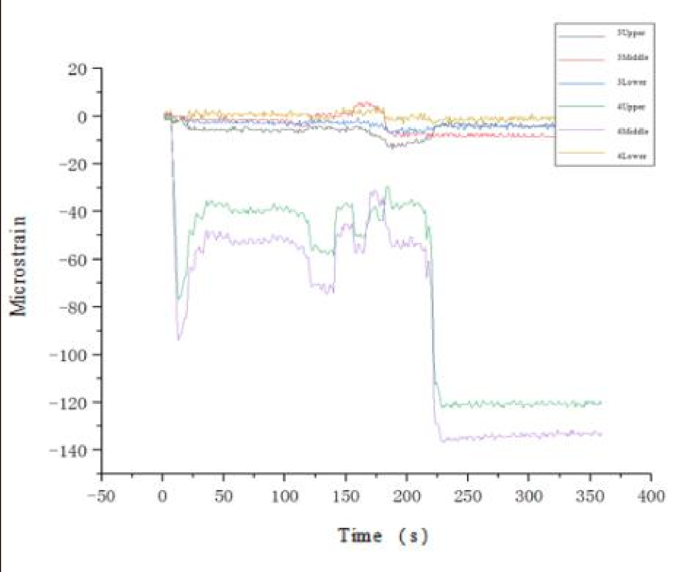

Figure 1. Strain values of sensors at measurement points 3 and 4 at a water level of 30cm

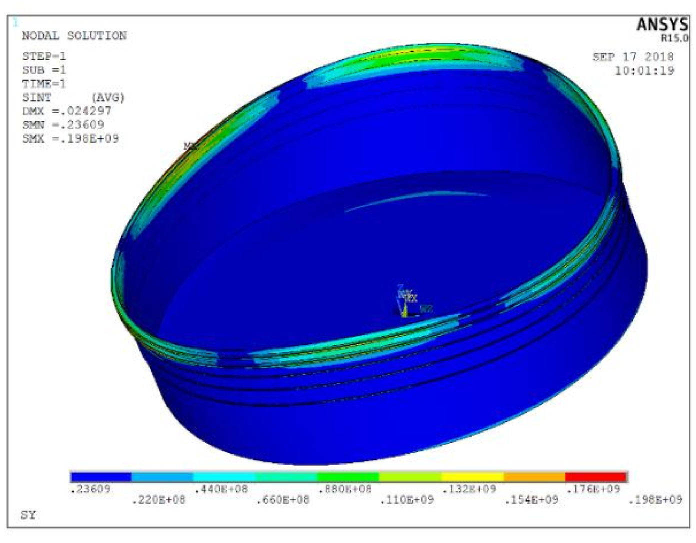

Figure 2. Contour map of stress intensity distribution at a water level of 30cm.

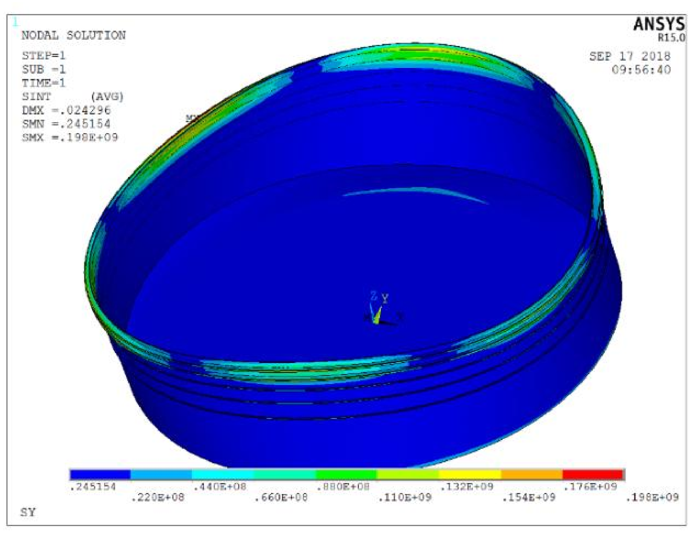

Figure 3. Contour map of stress intensity distribution at a water level of 70cm.

Results

Comparing the maximum shear stress values obtained from experiments at water levels of 30cm and 70cm with the stress intensities (equivalent stresses under the third strength theory) simulated using finite element analysis software, it was found that the errors between the experimental data and simulated values at the same point on the tank wall ranged from -90.5% to 2596.2%.

Conclusions

- The maximum stress on the tank wall during uneven settlement occurs within the process of settlement, not after reaching a stable state. This necessitates the need for real-time monitoring of the tank's condition on-site. Given the rate at which settlements occur and historical instances of tank settlement accidents in the country, it is advisable to perform dynamic testing every three years to ensure that the stress on the tank wall remains below the tank's yield strength throughout its service life.
- Stress variations on the tank wall due to uneven settlement can be effectively simulated using finite element analysis software. While there is a discrepancy between the simulated values and the experimental data, it falls within an acceptable margin of error.

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