High Temperature Salt Tank Buckling Failure

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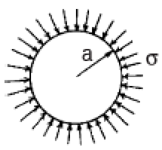
1. Introduction

The basic commercial proposition of CSP technology is its ability to store energy in the form of heat at elevated temperatures. The current state of the art is using molten nitrate salts stored in large cylindrical tanks. These tanks have proven to be highly reliable when constructed for use in Parabolic Trough plants. Mehos et al (1), however, have reported two known failures of the hot tanks when employed in use in Central Tower Receiver projects. This paper covers some of the findings of work that has been conducted in the investigation of these failure modes.

2. Buckling as a Failure Mode

From confidential discussions about the failure modes experienced in industrial projects buckling of the tank floor as a constrained diaphragm was postulated as a basis for the failure mode. Tests at the Queensland University of Technology confirmed that the frictional properties of the materials used in these designs at these temperature are extremely high. as the tank floor expands during the commissioning the phase it is restrained by these frictional forces. Additionally, the outer rings of these may be cooler than the central part of the floor plate.

This generates compressive forces in the floor plate. Rourke (2) defines the critical buckling stress for isotropic circular plate (fixed support) :



$$\sigma' = 1.22 \frac{E}{1-\nu^2}\left(\frac{t}{a}\right)^2$$

From this it can be seen at the very large diameter to thickness ratios, the critical stress is extremely low resulting in a very high probability of failure

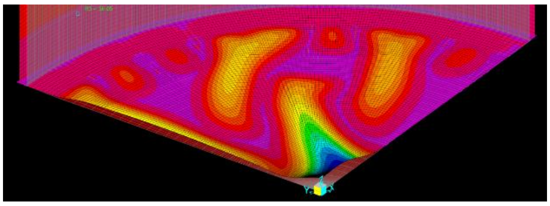
2 FEA Modelling

Traditionally commercial tanks use the API 650 code to design such tanks. This approach was used to model the Vast Solar NWQHPP Project 50 MW's salt tank. Certain residual deformations were assumed in the tank after welding of the plates. The tank was then modelled using a non-linear FEA model to determine how the tank floor would be deformed. The tanks were simulated to be heated up to an industry standard of 350 degrees under a constrained frictional resistance applied to the tank annular ring below the tank walls. The frictional forces are significant as these areas carry the full load of the tank walls and roof along with the tank insulation.

3 Results

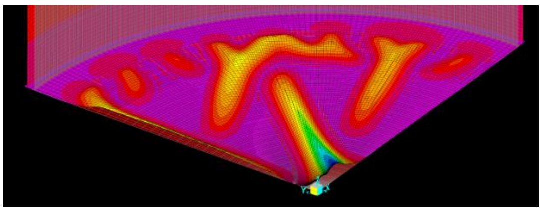
Pre Heating

During the pre-heating stage, hot air is blown into the tank. It is reasonable to assume that the tank's temperature distribution is not uniform. In the chosen case temperature difference of 50 degrees was selected between the outer annular ring (cooler) than the central part of the floor plate. Additionally, a coefficient of friction of 0.8 was chosen. It should be noted that this is not a conservative value compared to the empirical results. As can be seen in the below-mentioned simulation, the increased differential expansion caused by both temperature and friction effect results in the floor plate showing buckling patterns as follows :



Salt Filling

Once the tank has been heated, they are filled with molten salt. The hydrostatic pressure placed on the now deformed floor plate pushes the plate further down and sharpens the ridges.



Analysis of the ridges or creases showed that extremely high strain rates applied to the material. These materials would likely fail under cycling loading applied to these highly deformed areas.

Summary

The failure of tanks on so-called ridges formed in the tank floor has been successfully modelled and understood. Whilst information about these tanks in commercial CSP power plants is confidential, the authors have confirmed that these ridges are the cause of failure in the commercial plants. This is a significant understanding. The current floor designs cannot accommodate the compressive forces, and alternate designs that eliminate these compressive forces have been developed. These designs allow the expansion of the floor around flexible geometries that do not crease significant compressive stresses. A testing program has been proposed to confirm the failure mode in scaled-down tests and validate new designs that are intended to solve these problems.

References

[1] Mehos, M., et al., (2020). Concentrating Solar Power Best Practices Study, NREL, Golden, CO.

[2] Roark's Formulas for Stress and Strain, The McGraw-Hill Companies, 1938