VAST SOLAR

High Temperature Salt Tank Buckling Failure

SolarPaces 2022

Partners

We want to acknowledge the collaborative effort that has been put into this process.

QUT Queensland University of Technology

SolarDynamics

CD CONTRATOS Y DISEÑOS INDUSTRIALES S.A.

ASTRI Australian Solar Thermal Research Institute

VAST SOLAR

Alia Energy Consulting

Advisian Worley Group

ANSTO

Promat

CSP 1.0 – Parabolic Troughs

Bankable but too expensive

Positives

- Extremely high reliability
- High utilisation helped by modular array with HTF loop
- Local controllability possible within each component of the modular array
- Mixing effect to mitigate thermal transients

but slow deployment due to…

Issues

- Limitation on Rankine cycle efficiency at lower temperatures
- Very low temperature differences across Thermal Energy Storage (TES) which increases costs (low molten salt utilisation across possible operating range)

Push to increase power cycle temperature

CSP 2.0 – Central Towers

Unsolvable thermal control issues and single point of failure risk

Positives

- High efficiency power cycle drives down LCOE
- Better utilisation of salt storage (higher TES temperature difference)

but significant technical challenges remain…

Issues

- HTF freeze risk
- Low controllability
- Limited ability to deal with transients

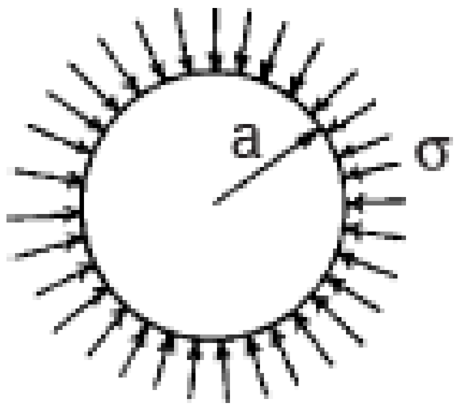
and these lead to…

Consequences

- Performance – significantly smaller operating windows
- Availability – components failures due to inability to control thermal transients:
  - Tank failures
  - Heat exchanger failures
- Risk – challenges with daily pre-heat / salt melting

Roark’s Critical Buckling Stress

For circular membrane under compression the thickness to diameter ratio shares how sensitive these structures are to buckling



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

Causes of the Failures

If the probability of compressive stresses exists what are potential causes of the failures.

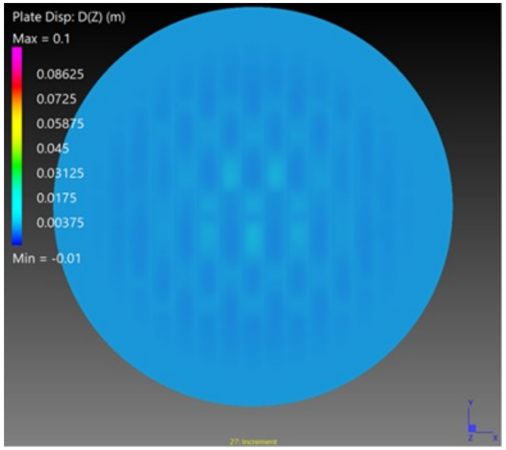
- NREL CSP Best Practices :

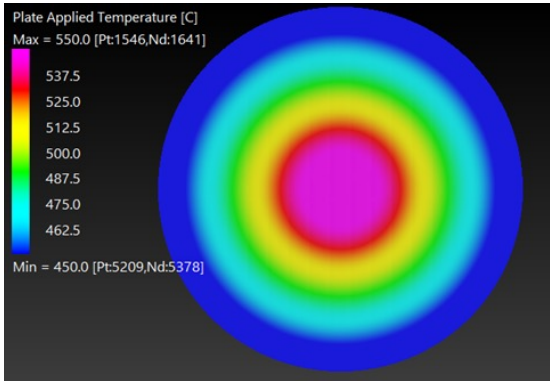
"There is no design code for molten-salt tanks. The American Petroleum Institute (API) Standard 650 is limited to 2.5 psi and 200°F and is the closest design code for these tanks. The industry should develop a design standard for hot- and cold-salt tanks."

- Friction – Research at QUT has shown that the friction factors are significant at the higher temperatures. This led to friction being a key driver of the failures.
- Temperature gradient has been shown to be the main driver of the compressive stress, this is heightened by :
  - Higher temperatures differences (560/280 Tower Systems vs 380/280 PTC) result in a greater radial gradient.
  - Process control issues related to Central Tower Receivers a major driver of these variations.

Thermal Gradients

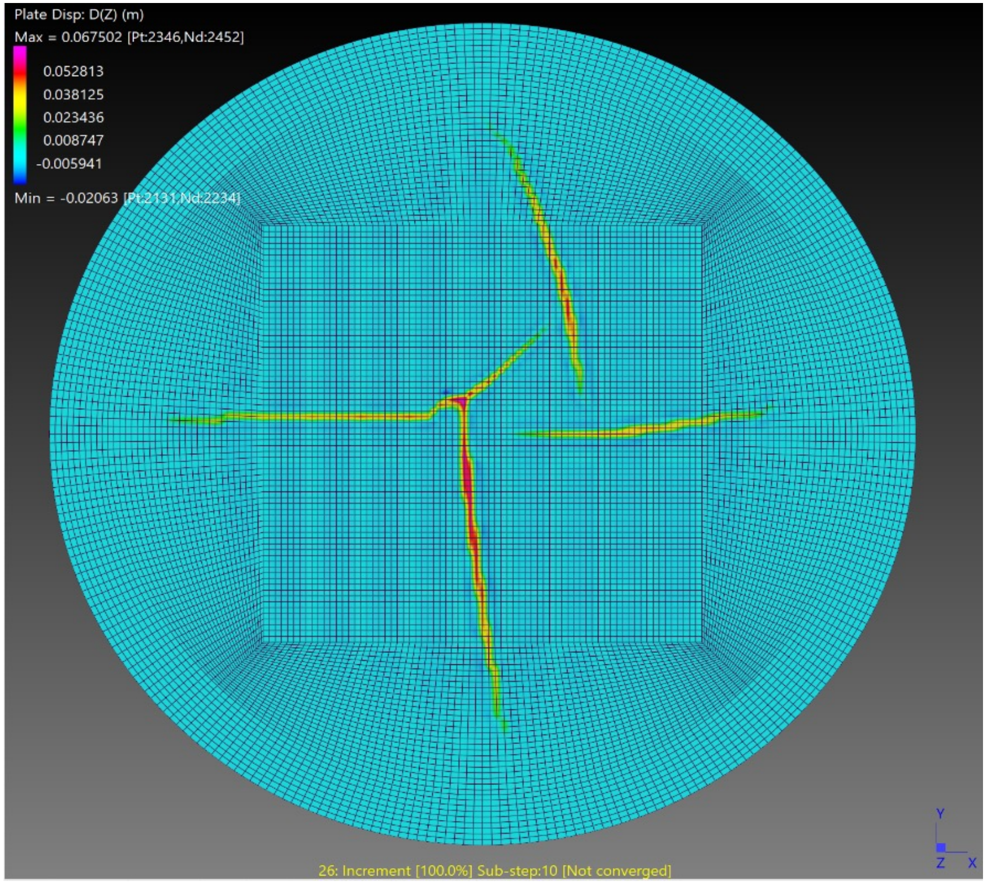
The potential expected deformation of a rectangular arrangement





FEA Results

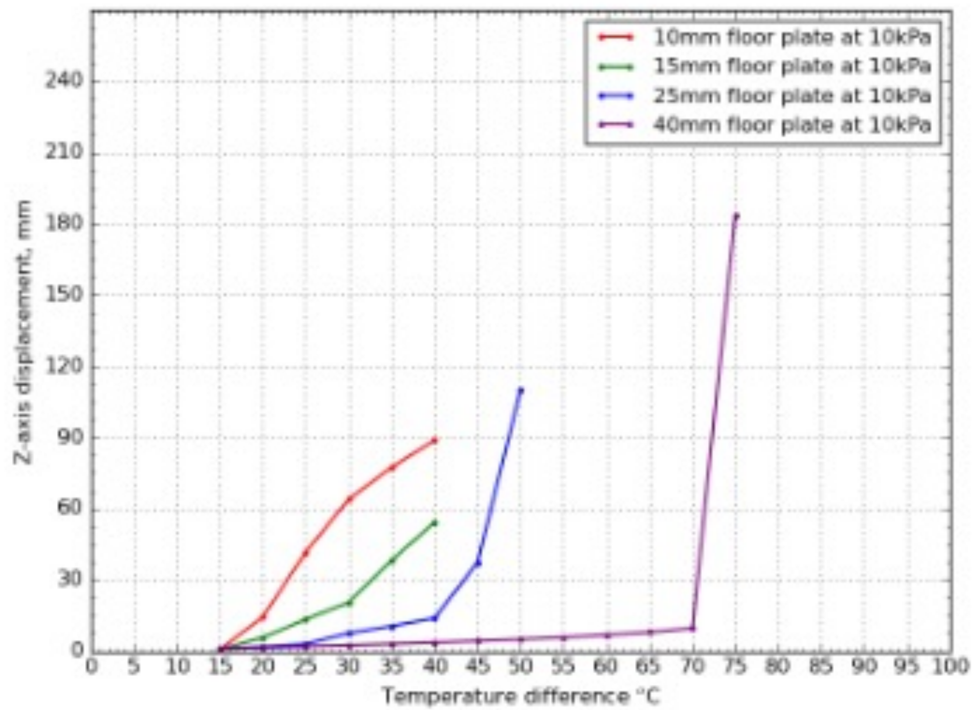
These closely match failure modes realised in several CSP plants.*.



* Analysis background is successively apply salt pressure load, temperature difference, remove temperature load, remove pressure and look at final, permanently deformed floor shape. The height of the ridges in the plot are approximately the same as the height of the ridges in the photo a couple of slides before

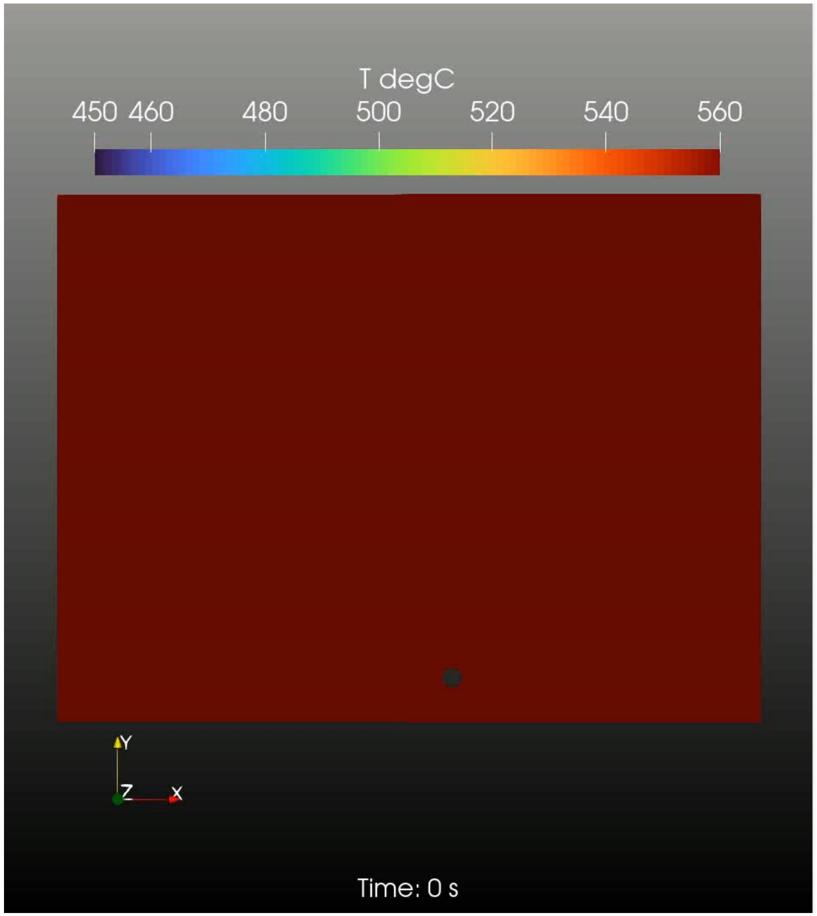
Improvements in the Tank Floor

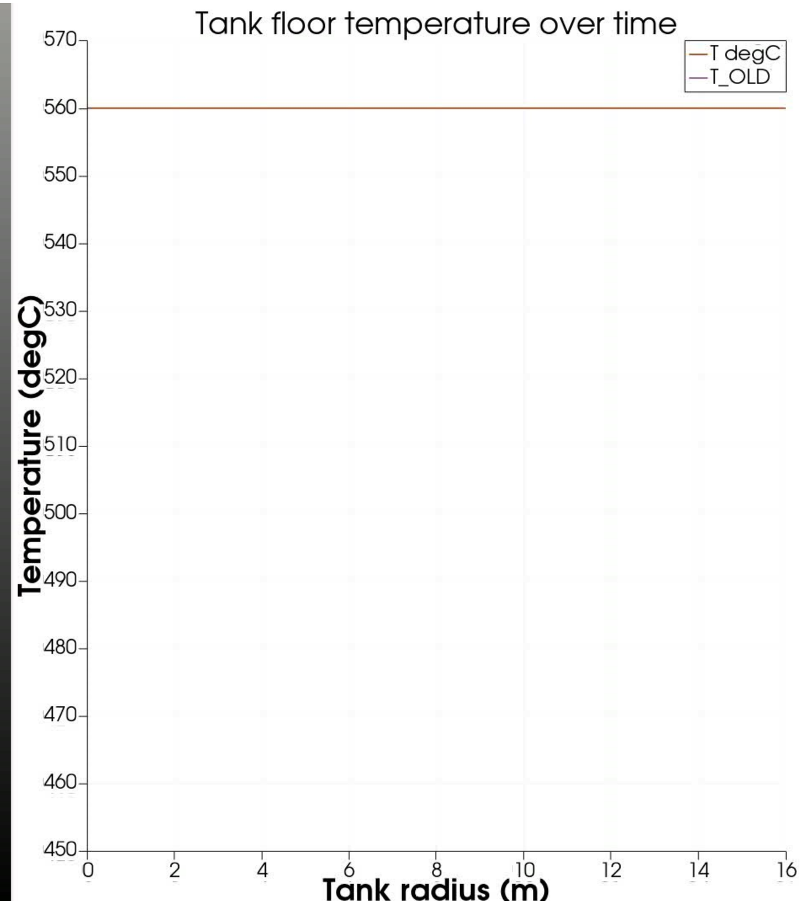
Depending on plate thickness the buckling can be initiated at very lower temperature variations.



Transient Analysis

Process temperature deviation will have major impact.





Layer of Protection Approach

The solution to protect tanks requires multiple layers of protection.

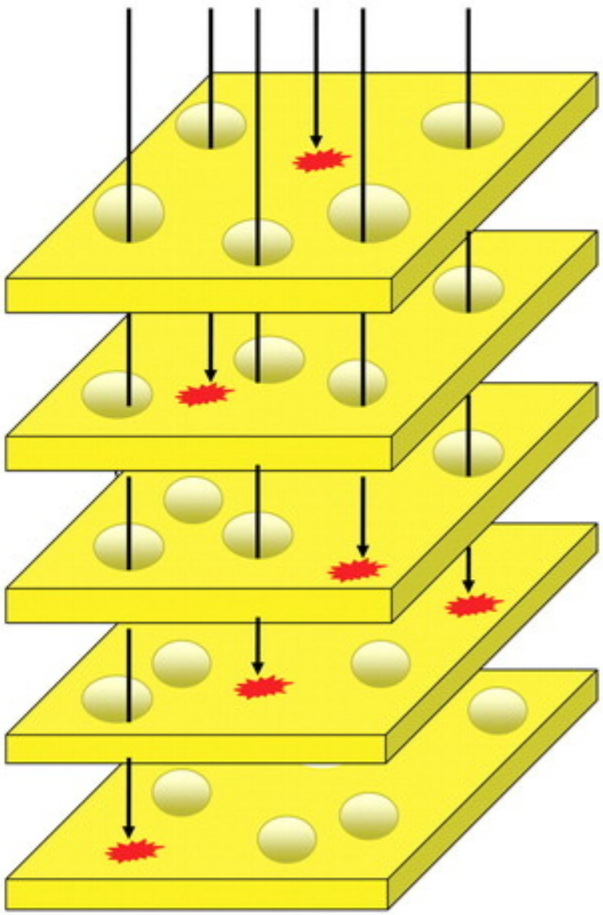
Improved Mechanical Design

Temperature Process Control
(incl Smart Cross Over)

Improved Thermal Insulation

Improved Commissioning
Sequences (Prov Patent)

Plant Trip under out of process
conditions



Conclusions

- Collaboration with partners that have deep experience in these components and systems has facilitated these insights
- Transient management is a fundamental critical factor to be considered in design and operation.
- Spatial thermal management within the tank need to be considered
- Models meet practice – theory understood
- Pathway to develop resistant designs.
- Down select form 4 advanced designs that have shown significant improvement in resistance to these process variations.