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Finite Element Analysis Application in Cryogenic and Refrigerated Storage Tank Design

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Finite Element Analysis Application in Cryogenic and Refrigerated Storage Tank Design

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a member of TGE / CIMC group

Technodyne International Ltd (a member of TGE group), is a world leader in the design of cryogenic and refrigerated storage tanks with more than 20 years experience of designing in excess of 100 storage tanks world wide.

As part of the design verification and optimization process, Technodyne International has developed a number of techniques to analyse critical components of the storage tanks, some of which are briefly presented.

- Liquefied gases & storage facilities.
- Full containment storage tank.
- Selection of finite element analysis:
  - Outer containment tank analysis
  - Spill analysis
  - Wall liner analysis

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Liquefied Gases

- Refrigerated temperatures generally refer to 0 to -150˚C
- e.g. Liquefied Propane Gas (LPG), Ethylene, Ethane, Butane, Ammonia.

- Cryogenic temperatures generally refer to below - 150˚C
- e.g. Liquefied Natural Gas (LNG).

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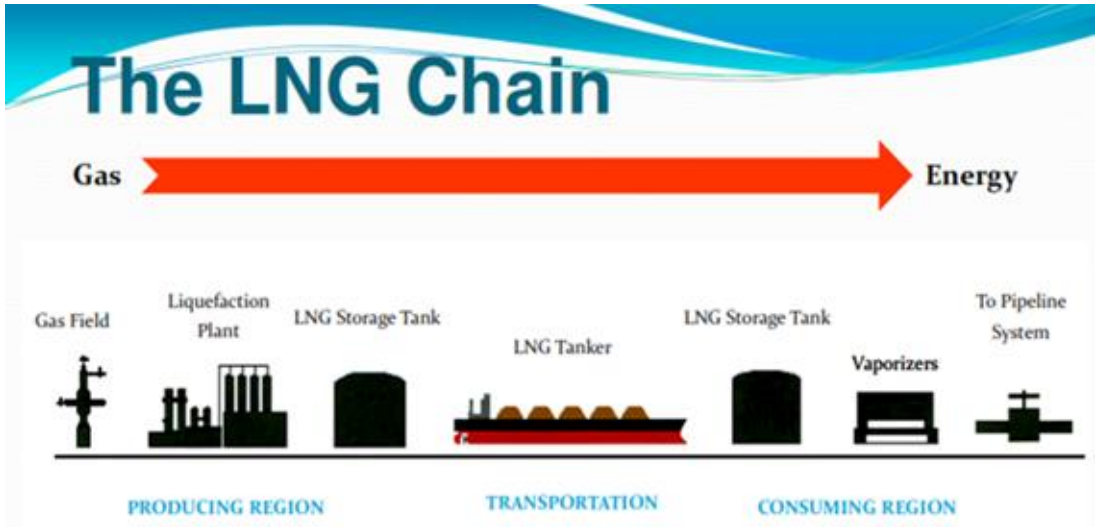
Liquefied Natural Gas (LNG)

- Cooled and liquefied at -165˚C.
- Takes up to 600 times less space than natural gas.
- Transported and shipped in specialized LNG carriers.
- To regions not connected to pipeline network.
- It can be used as: fuel for power generation, heating and as transportation fuel.



Picture is taken from: LNG overview, John. A. Sheffield, WIGLOX

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Importance of LNG storage

- To provide a reserve capacity so that a continuous supply of gas can be maintained.
- To provide a strategic stock of gas so that peak demands and opportunities can be met.
- To provide the appropriate conditions to maintain the liquid state of the fuel.

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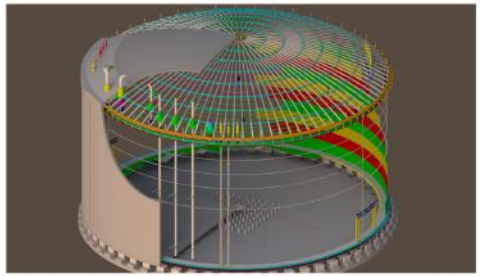
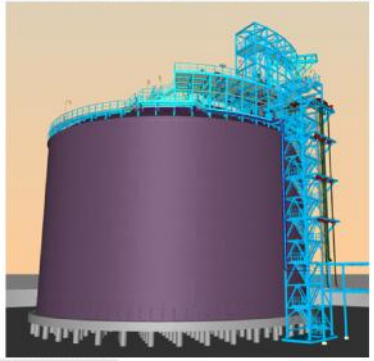


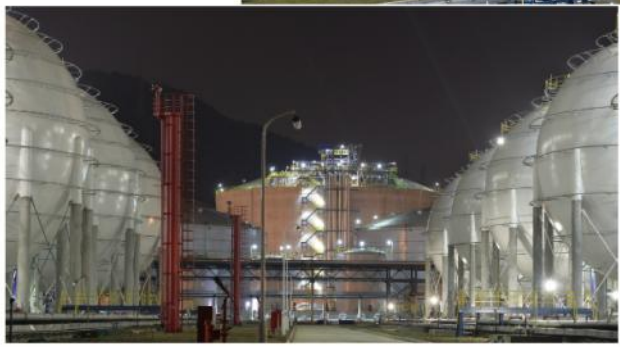

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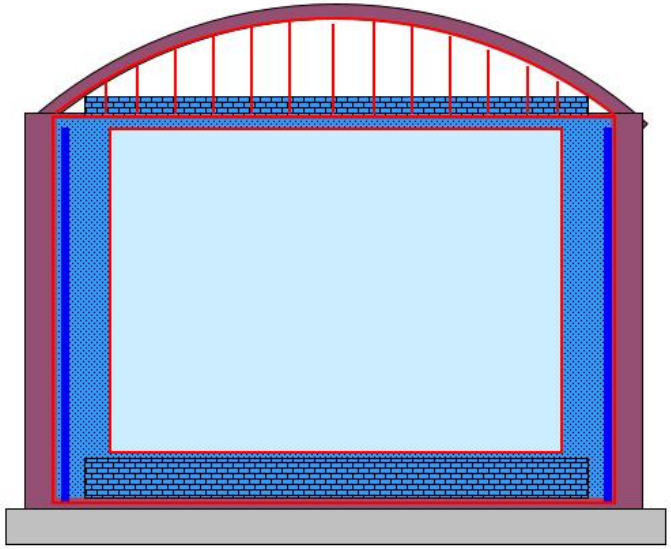
- **Full Containment Tank**

- Both the inner and outer tank are capable to contain the liquid stored.
- The low temperature steel inner tank contains the liquid under normal operating conditions.
- The outer roof is supported by the outer tank.
- The outer tank is intended to hold liquid and control venting of the vapour resulting from a product leakage.



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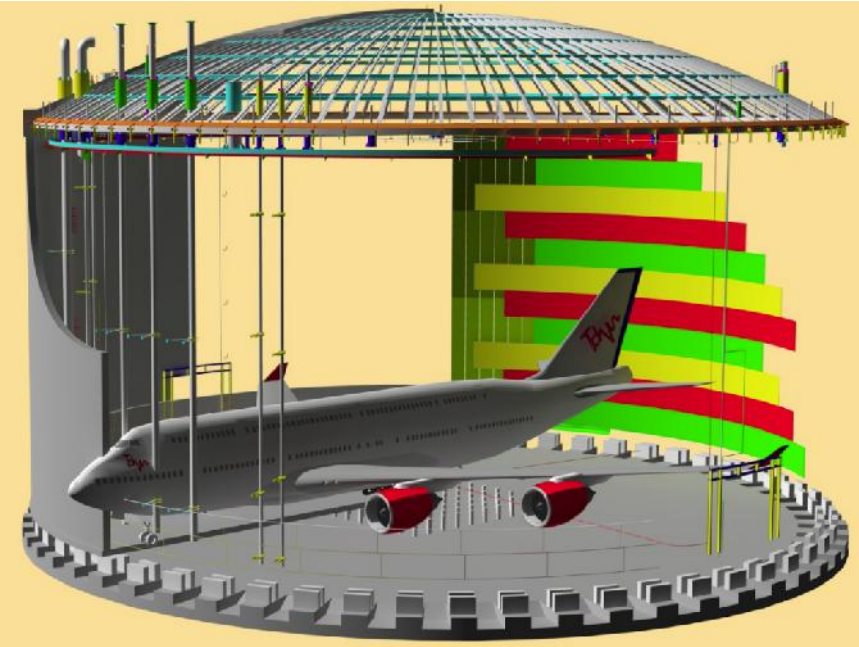

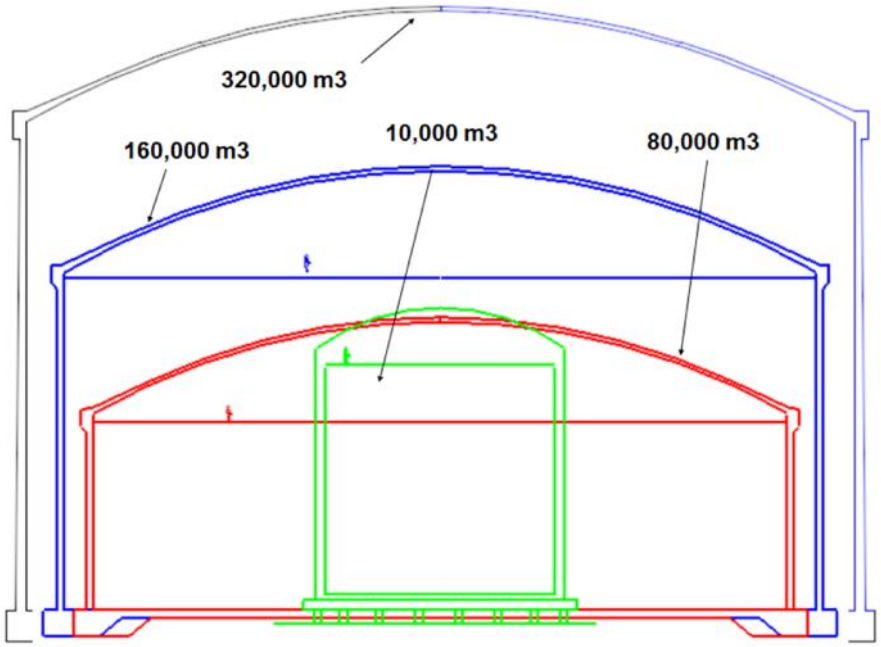

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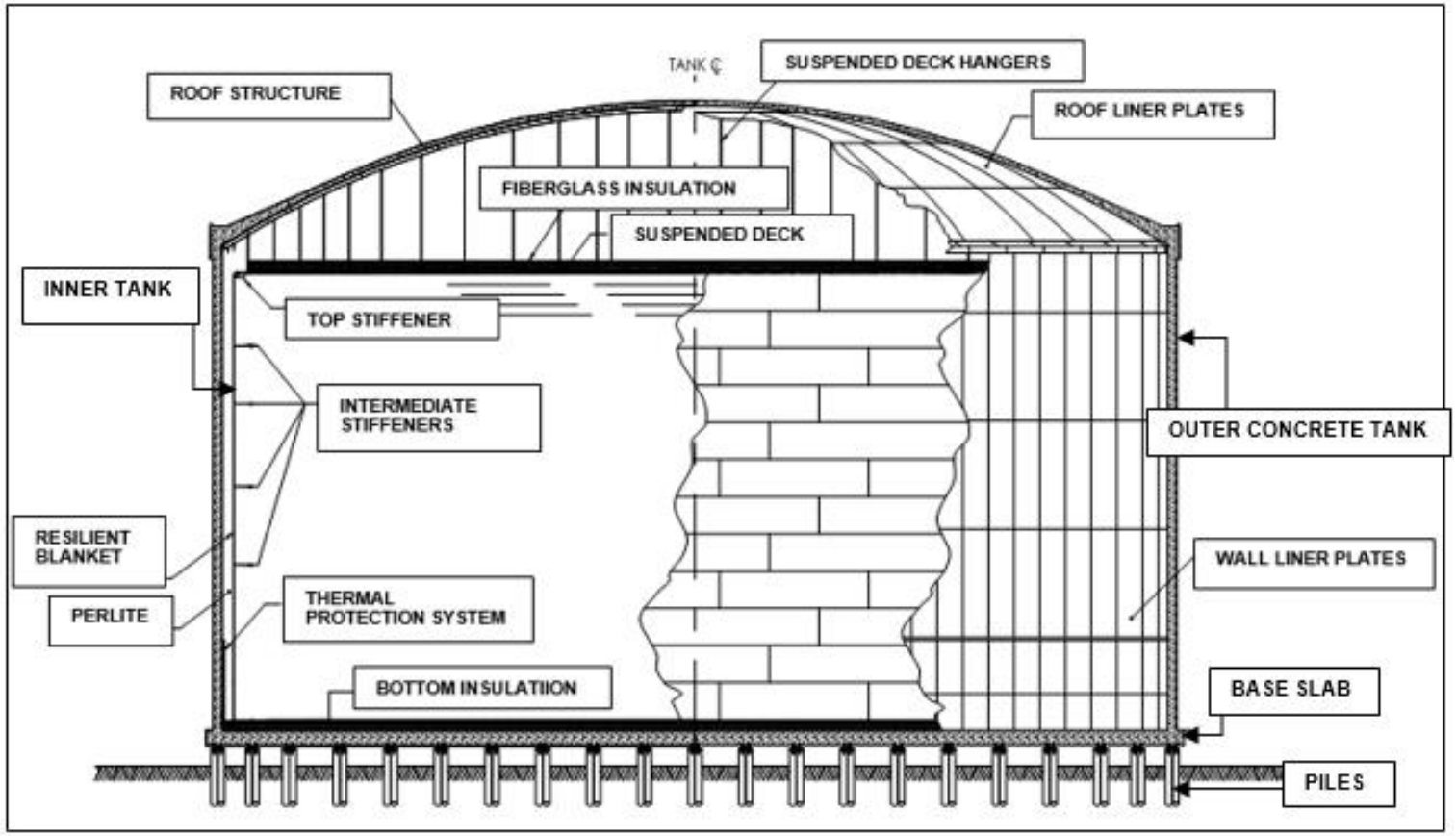

General arrangement for full containment LNG storage tank

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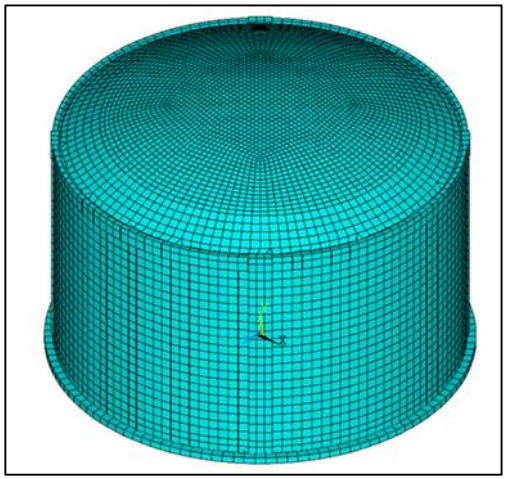
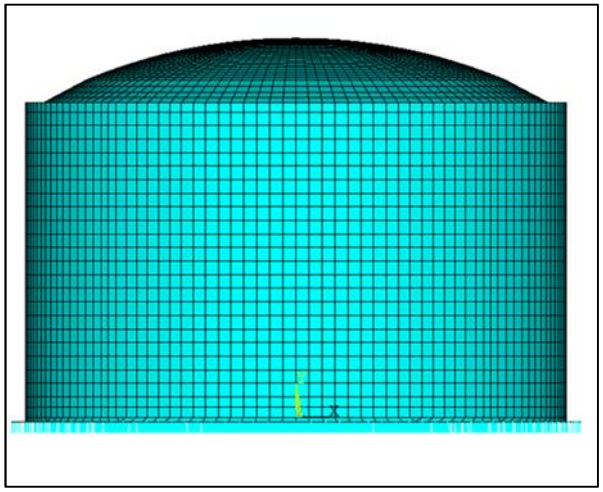
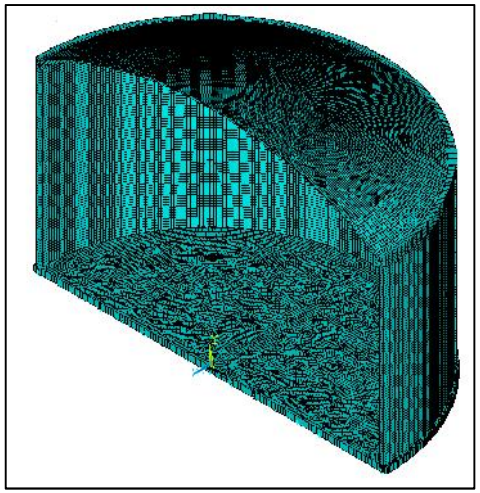
FEA of Outer Containment Tank

- 3D finite element model is created in ANSYS.
- Effect of concrete cracking incorporated.
- Normal, seismic and accidental loads are applied.
- Ultimate Limit State and Serviceability Limit State checks carried out.
- Results verified against calculated ultimate section capacities.





Typical finite element model for a storage tank



A cross-section through the tank showing the shell thickness defined for the slab, walls and roof

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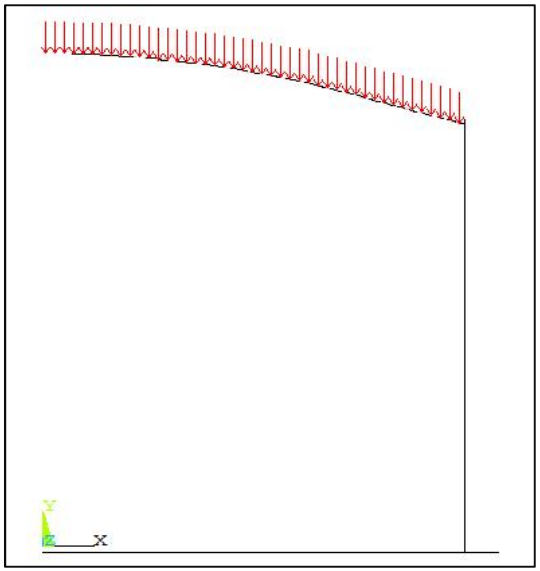
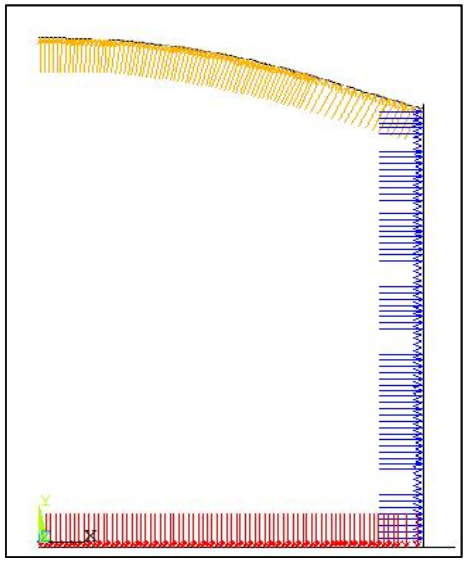
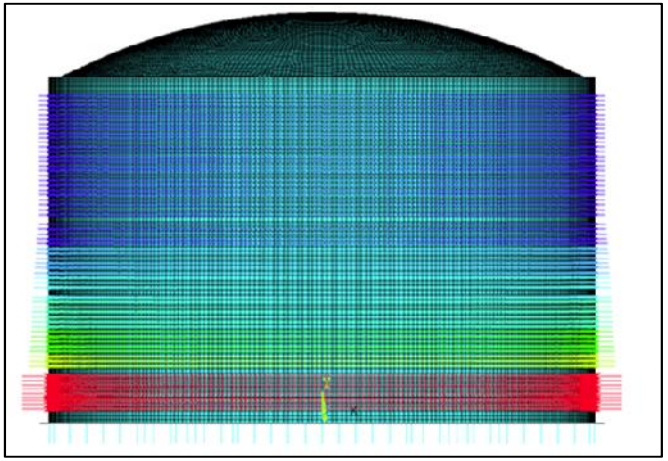


Live load on the roof



Internal pressure



Post tensioning tendons on wall

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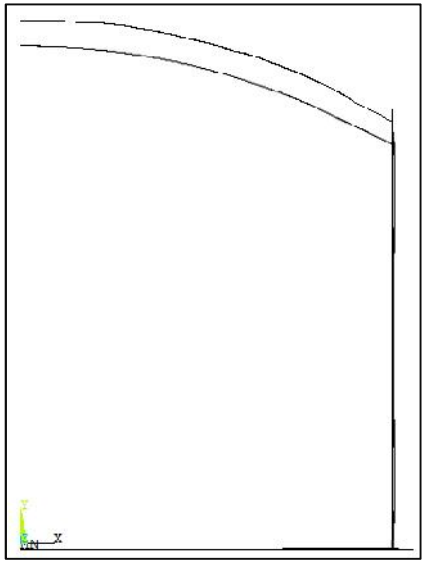
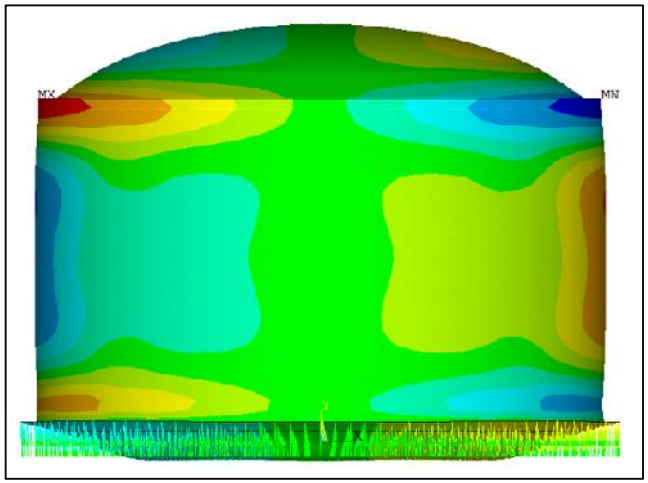
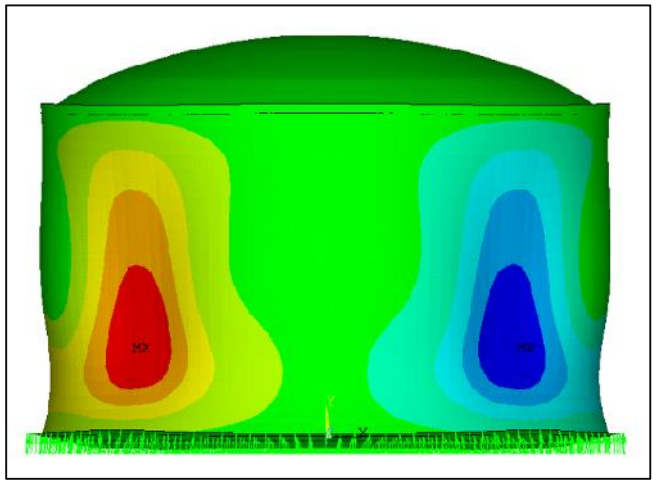


Deformation due to live load on the roof



Deformation in horizontal direction due to internal pressure



Deformation due to post-tensioning tendons on wall

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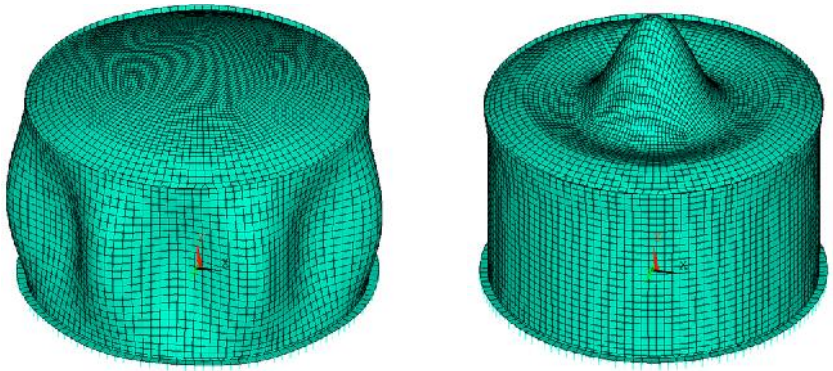
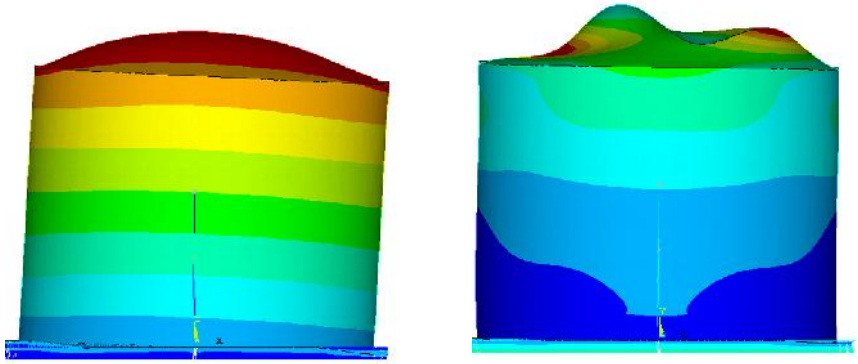
Seismic Analysis

- Modal Analysis: to determine natural frequency and mode shapes of the tank.
- Spectrum Analysis: to assess the response of the outer tank to earthquake loading.



Mode shapes of the outer containment tank



Deformed shapes of the outer containment tank

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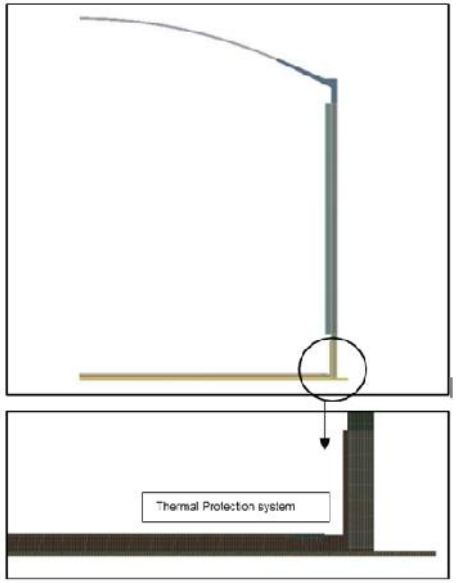
Spill Analysis

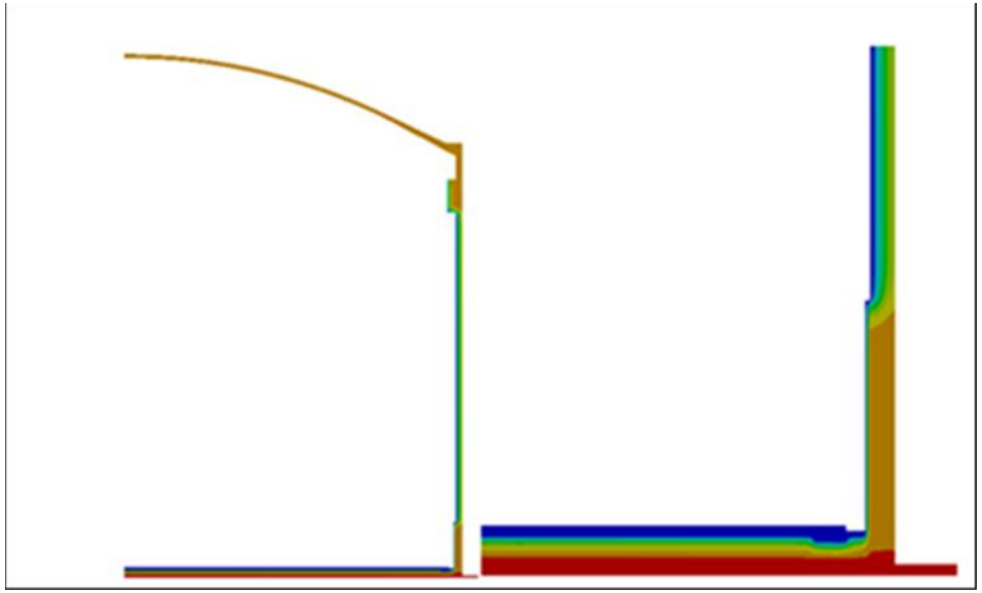
- To ensure the liquid tightness of the concrete wall by means of maintaining minimum compression zone specified by codes.

Thermal Model

- 2D axisymmetric finite element model with temperature dependant material property created in ANSYS.
- Conduction and atmospheric convective effects incorporated.
- Solar radiation, summer & winter conditions and transient effects are considered.



2D finite element model



Thermal profile in the concrete wall and slab

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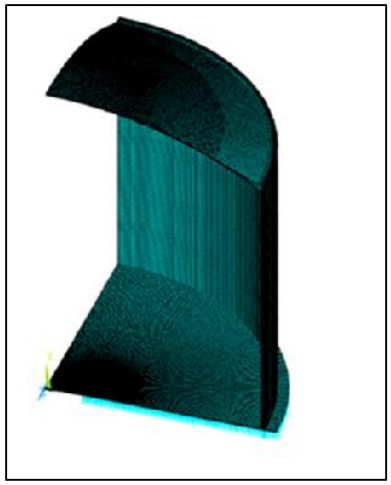
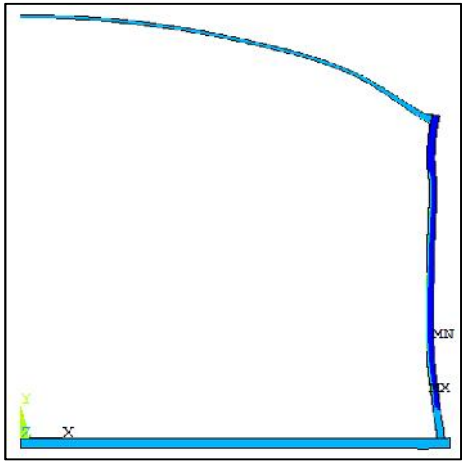
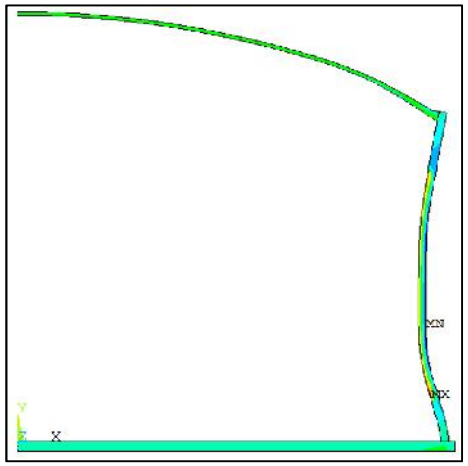
Structural Model



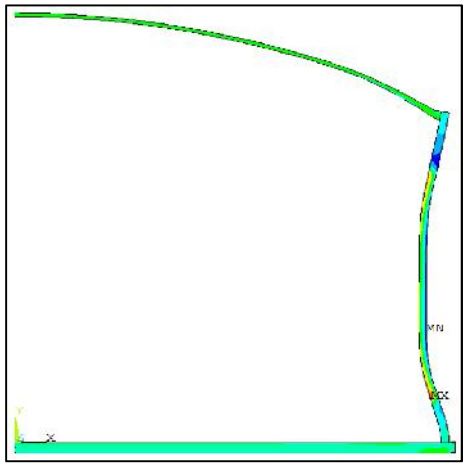
- 3D finite element model created.
- Non-linear properties of the concrete are modelled.
- Microplane model used to simulate stiffness degradation after crack initiation.
- Maximum degradation and rate of damage evolution are defined.
- Thermal & non-thermal loads e.g. hydrostatic pressure are applied.
- Compression zones are identified.
- Principal stresses compared with maximum stresses allowed.



Summer 1hour
(stress plot)



Summer 1day
(stress plot)



Summer 3days
(stress plot)

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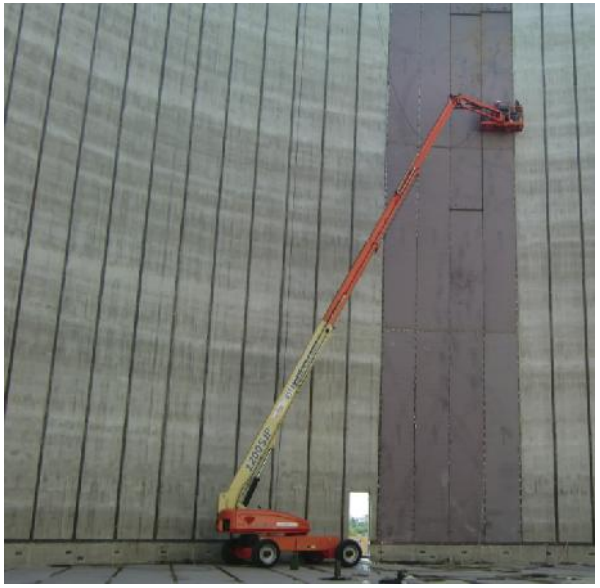
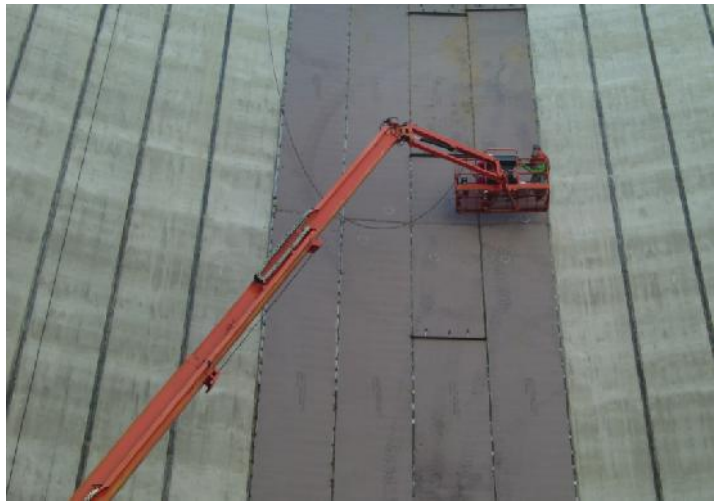
Steel Wall Liner Analysis

- The liner serves as the vapour barrier to ensure tank is vapour tight.
- The carbon steel liner plate is fillet welded to the embedments.
- Concrete wall is subject to compression from a post-tensioning system followed by long term creep and shrinkage.
- Wall moves radially inwards and imposes stresses on the liner plates and welds.
- Test pressure, design pressure and vacuum pressure are also applied.





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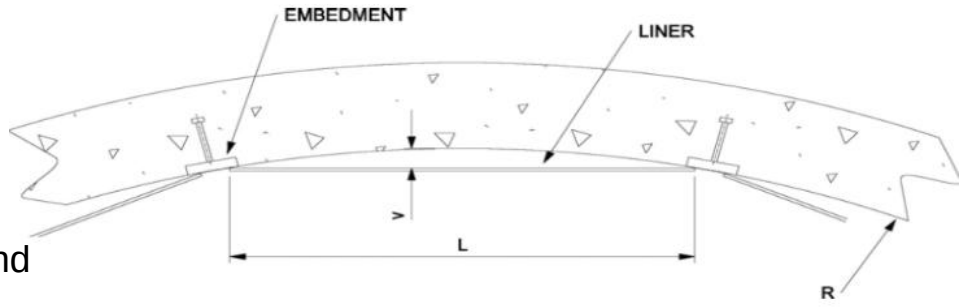
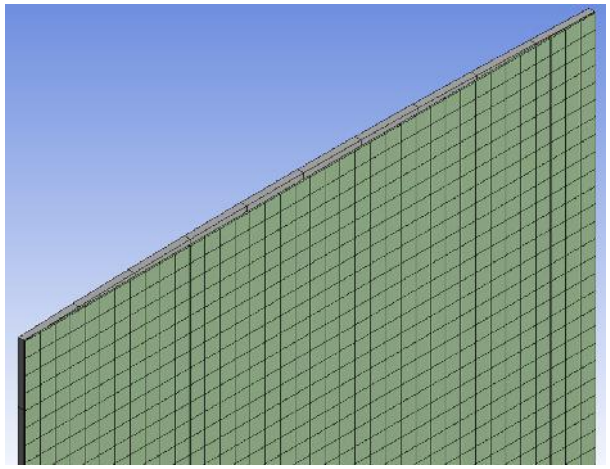
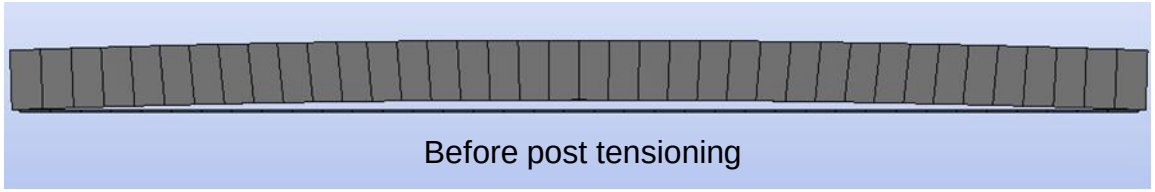
Wall Liner Analysis for Perlite Tank

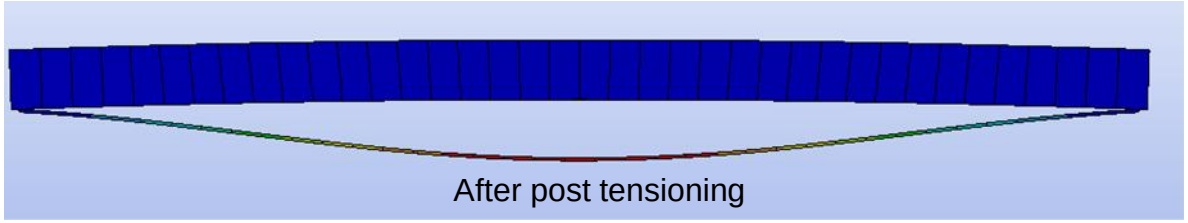
- 3D finite element model is created in ANSYS.
- Torsional stiffness of the welds is incorporated.
- Wall radial movement is applied.
- Different range of pressures applied.
- Primary and secondary stresses are identified and checked against corresponding allowable stress.
- Liner displacement predicted by FEA verified by hand calculations.







Before post tensioning



After post tensioning

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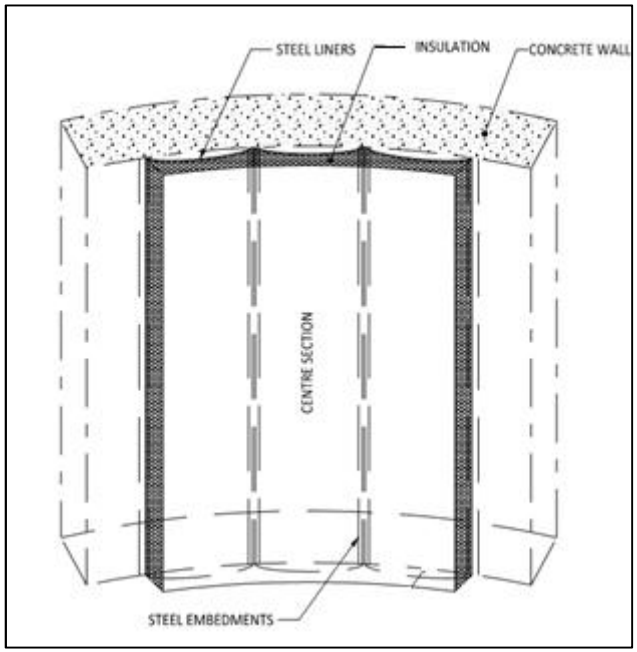
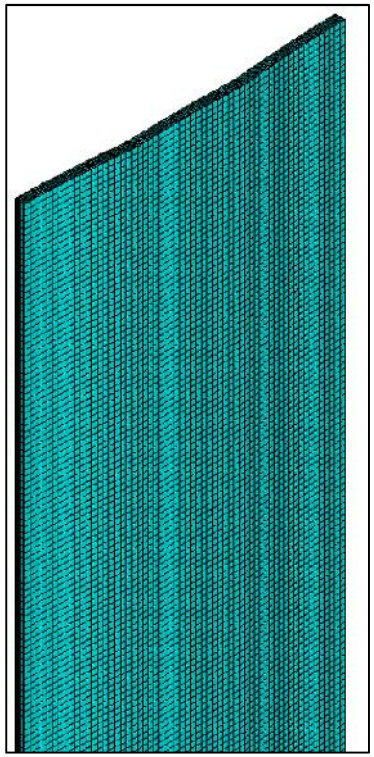
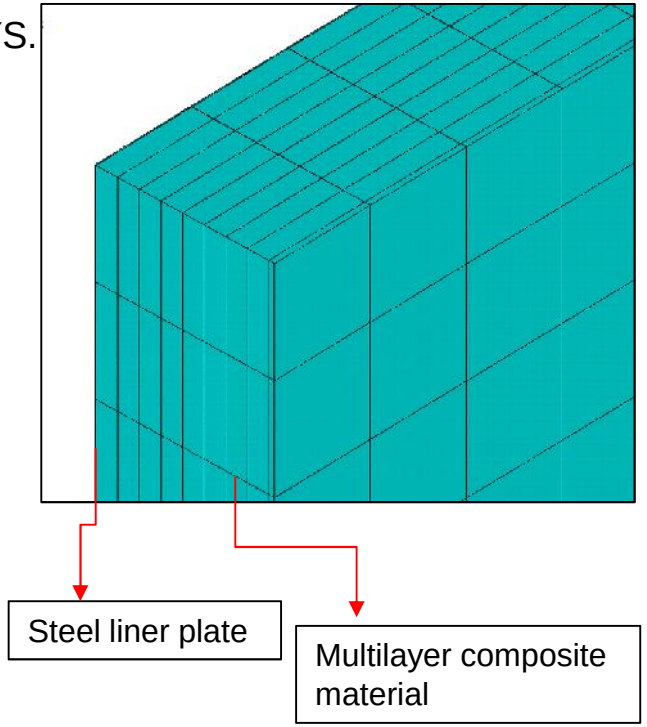
Analysis for Refrigerated Tank Composite Insulation

- Steel liner plate insulation composite model created in ANSYS.
- Mesh sensitivity run is performed.
- Membrane stress through thickness is checked.
- Interlaminar shear stress is checked.
- Direct stresses is checked.







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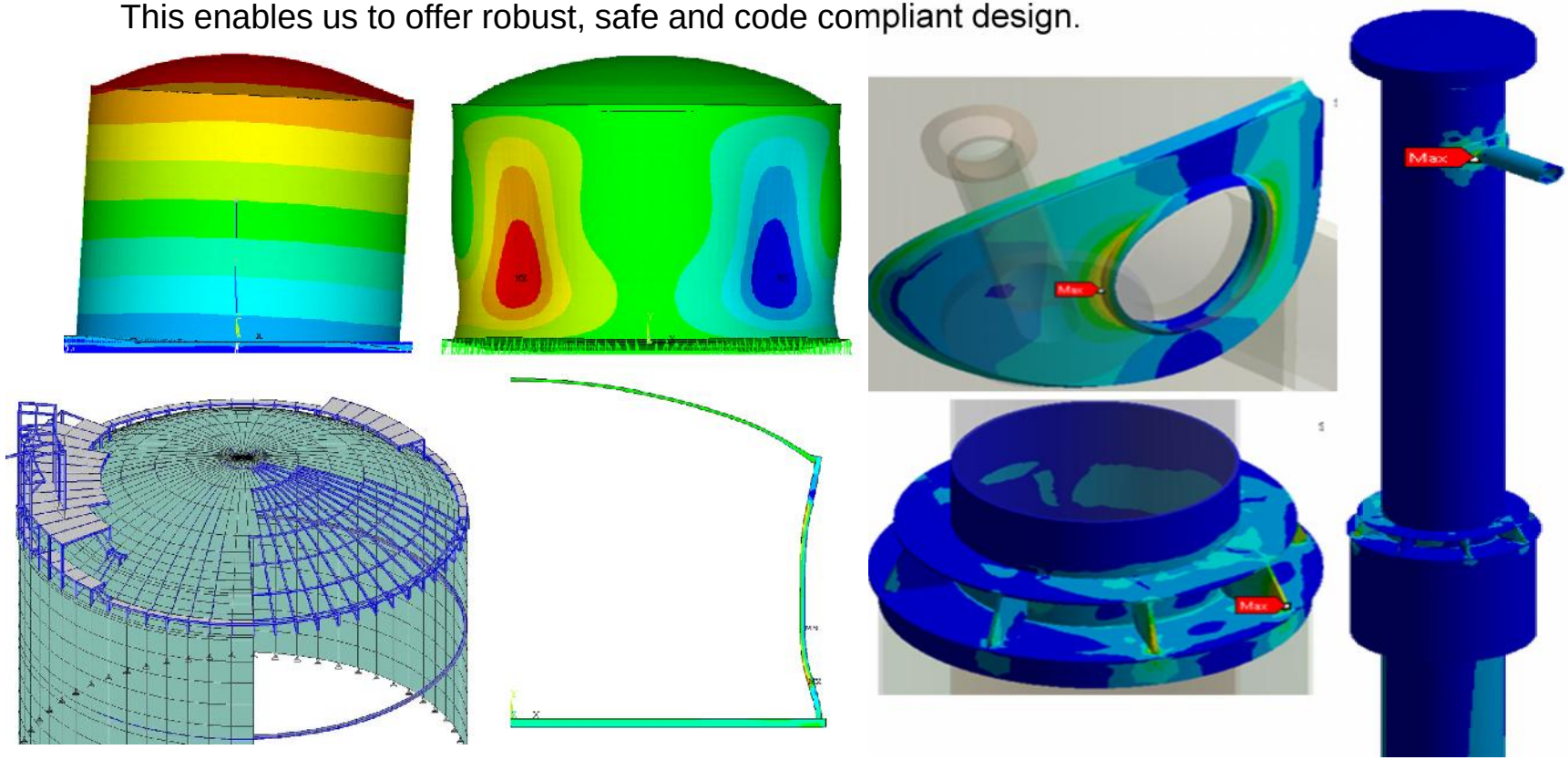
Conclusion:

The experience of Technodyne International Ltd has shown that the application of FEA modelling is an efficient and effective method of verifying cryogenic and refrigerated storage tank design. This enables us to offer robust, safe and code compliant design.



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