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Design of LPG mould billet using FEM

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ABSTRACT:

The significance of the title of the project comes to front with designing structure of a 1000 mt capacity of LPG mounded bullet pressure vessel for static loading, is basically a project concerned with different design variables, thickness of shell, elliptical head, operating manhole and stiffners under load case of high pressure test and working fluid with standards of ASME codes and its assessment is carried out in CATIAV5 for modeling and analysis in HYPERMESH/ANSYS. it is employed on practical design of LPG pressure vessel as per required by the industry.

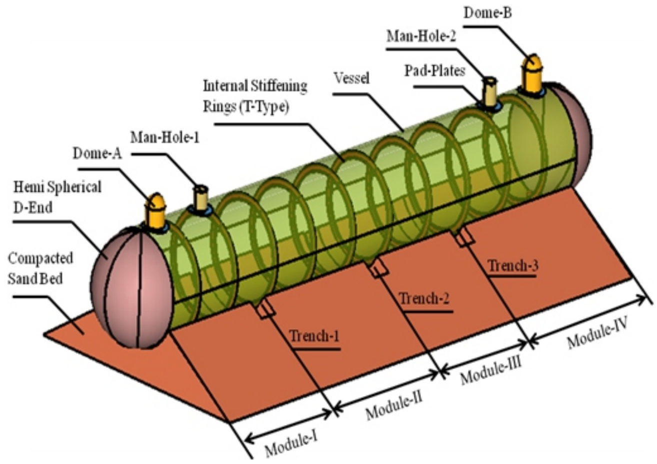
INTRODUCTION:

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure. They are used to store fluids under pressure. The pressure vessels are designed with great care because rupture of pressure vessels means an explosion which may cause loss of life and property. The material of pressure vessels may be brittle such that cast iron or ductile such as mild steel. And pressure vessels are classified mainly into two types, (a) According to Dimensions (b) According to end Construction.The pressure vessels, according to the dimensions are classified as thin and thick shells. The ratio of internal diameter and wall thickness is the factor which differentiates between thin and thick shells. If the ratio d/t is more than 10, then it is called thin shell and if this ratio is less than 10 it is said to be thick shell. The examples of the thin shells are pipes, boilers and storage tanks while the thick shells are used in pressure cylinders, Gun barrels, etc.The pressure vessels according to end construction are classified as open end and closed end. A simple cylinder whit a piston is an example of closed end vessel. In case of open end vessels the circumferential stress is induced in addition to the circumferential stress.

And according to role of process vessels are mainly classified into four types:

(a)Reaction pressure vessel.
(b)Heat exchanger pressure vessel.
(c)Separation pressure vessel.
(d)Storage pressure vessel.

The objective of this project is to design a Horizontal storage pressure vessel which can store LPG (liquid petroleum gases). In general storage pressure vessels are used to hold liquid or gaseous materials, storage media or container to balance the pressure from the buffering effect. In order to achieve better design results, ASME boiler codes were taken into consideration.



Typical Horizontal LPG Storage Vessel Assembly.

Objectives and Scope:

A Finite element model is developed to analyze the behavior of Horizontal mounded LPG Vessel subjected to Hydro test condition, and Operation Condition. In Hydro Test condition, water is used to test the vessel as its density is higher than the LPG. Following are the loads considered in Hydro Test Condition:

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-Pressure inside the vessel.
Hydro Test Pressure.
Pressure Due to Head (100 % head of water).
-External Pressure on the vessel.
-Self weight due to gravity.

In Operating Condition, LPG is used and the vessel is subjected to varying pressure at different heads as 25%, 50%, 75%, 90%. Following are the loads considered in Operating Condition:

-Internal Pressure
-Pressure due to head (25%, 50%, 75%, 90%)
-External pressure

-Mound pressure at dome ends
-Mound pressure on cylinder
-Self weight due to gravity.

The Primary Objective of this research is to build a pressure vessel with design parameters and to validate the results using finite element method. Scope of designing a pressure vessel covers the design basis for following equipment:

-Vessel
-Stiffeners
-Domes / Hemispherical D-ends
-Sand filling in differential settlements.
-Man-holes
-Pad-Plates
Design of Pressure Vessel

2.1 Codes and Standards:

Following are the codes and standards had been used to design the Horizontal pressure vessel:
ASME SEC. VIII DIV.1 /
For Pressure vessels
IS: 2825

ASME SEC. VIII DIV.2
For Pressure vessels (Selectively for high pressure / high thickness / critical service)

ASME SEC. VIII DIV.2
For Storage Spheres

ASME SEC. VIII DIV.3
For Pressure vessels (Selectively for high pressure)

2.2 Types of Storage Vessels:

2.2.1 Selection of storage vessel type:

In addition to mounded storage, other types of vessel may also be used to store LPG under pressure at ambient temperature.

- Spheres
- Bullets (above ground)
- Submerged storage vessels

The principle of the design of the vessel is that the axisymmetrical loads are carried by the shell plates, while bending stresses due to non-symmetrical loads are carried by the shell plates, while bending stresses due to non-axisymmetrical loads are carried by stiffening rings (except for small diameter, unstiffened vessels).

MINIMUM SHELL/HEAD THICKNESS

Minimum thickness shall be as given below
a) For carbon and low alloy steel vessels- 6mm (Including corrosion allowance not exceeding 3.0mm), but not less than that calculated as per following:
For diameters less than 2400mm
Wall thickness = Dia/1000 +1.5 + Corrosion Allowance
For diameters 2400mm and above
Wall thickness = Dia/1000 +2.5 + Corrosion Allowance
All dimensions are in mm.
b) For stainless steel vessel and high alloy vessels -3 mm, but not less than that calculated as per following for diameter more than 1500mm.
Wall thickness (mm) = Dia/1000 + 2.5
Corrosion Allowance, if any shall be added to minimum thickness.
c) Tangent to Tangent height (H) to Diameter (D) ratio (H/D) greater than 5 shall be considered as column and designed accordingly.

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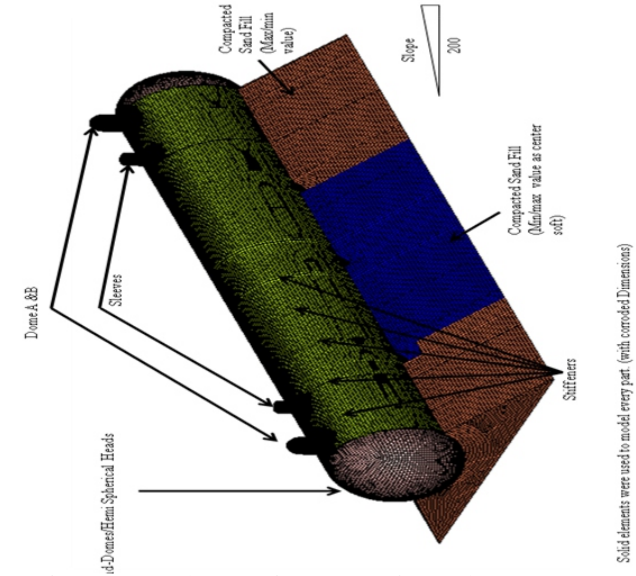
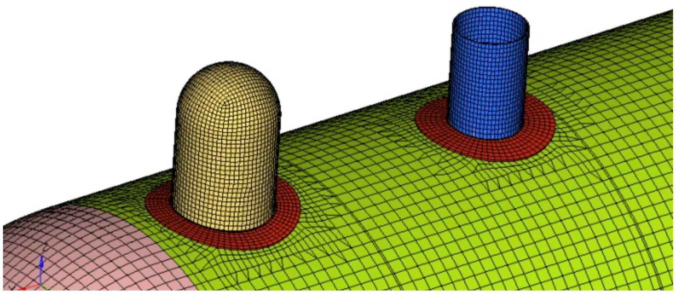
d) For carbon and low alloy steel columns / towers -8mm (including corrosion allowance not exceeding 3.0mm.
e) For stainless steel and high alloy columns / towers -5mm. Corrosion allowance, if any, shall be added to minimum thickness.

2.3.2 Vessel sizing:

All Stiffeners
Based on inside diameter
All Clad/Lined Vessels
Based on inside diameter
Vessels (Thickness>50mm)
Based on inside diameter
All Other Vessels
Based on outside diameter
Tanks & Spheres
Based on inside diameter
FE Model Preparation / Results:



Mesh is created using hypermesh, and an average element size of 20 mm is used for modeling. Hexa / Penta element configurations are used in building this model. And to capture the surfaces stresses, we had extracted skin as shell elements.



Boundary Conditions (Hydro Test Condition):

4.2.1 Constraints:

Vessel is supported by the Sand fill, and sand fill is constructed on the ground, hence all the base nodes of the mound are constrained in all degrees of freedom (123456). The arrow marks detailed below represents constraints on the base.

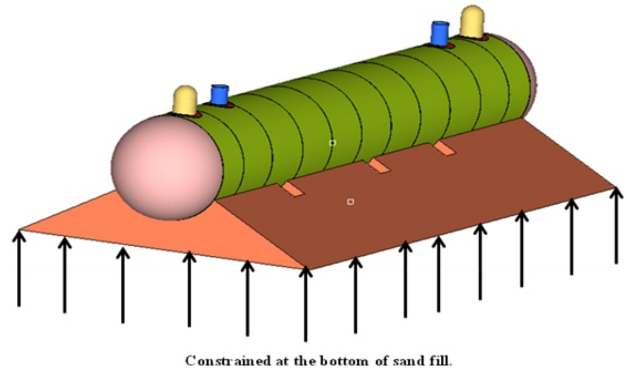


Fig: 4.4 Constraints (SPC loactions)

Since the vessel is installed on the ground, Gravity of 9810 mm /s2 has been considered over the entire model. Other Boundary conditions are loads applied internally and externally. Below are the details of other load cases carried out to find the performance of the Vessel Design.

Pressures inside the Vessel:

With regard to the stiffener design, the internal pressure only affects the normal force N3 in the stiffening ring, not the bending moment of the shear force. Part of the shell plates will act together with the ring to carry the load to which the rings are subjected. This part, the working width w, is:
$w = 2 \times 0.78 \times \sqrt{(R \times t)}$
The internal pressure, acting on the working width, will cause a normal tensile load N3 which is carried by the combination of stiffening ring and working width of the shell plate.
$N_3 = p_3 \times w \times R$
Where p_3 = the internal design pressure.
Hydro Test Pressure : 19.75 kg/cm2 or 1.93668 MPa
Pressure due to head : 0.75 kg/cm2 or 0.073575 MPa (at 100% head of water)

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4.2.3 Pressure outside the Vessel:

External Pressure : 1.856 kg/cm2 or 0.1819994 MPa
Gravity is considered to capture the self weight of the vessel.

4.3 Boundary Conditions (internal pressure + liquid weight + mound weight + load due to thermal expansion with center soft) at Operating Conditions:

4.3.1 Pressures inside the Vessel (fig: 4.5):Internal Pressure: 14.5 kg/cm2 or 1.42187 MPa

4.3.2 Pressure due to head (LPG):

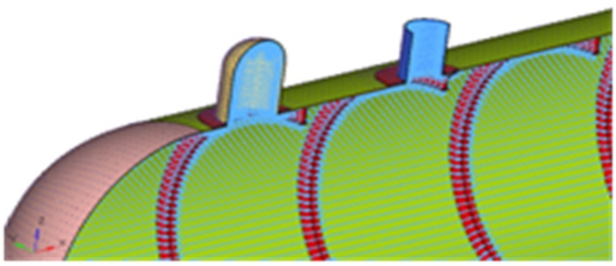


Fig: 4.5

25% head: 0.103 kg/cm2 or 0.0101165 MPa
50% head: 0.103 kg/cm2 or 0.020233 MPa
75% head: 0.103 kg/cm2 or 0.03034 MPa

4.3.3 Pressure Outside the Vessel:

External Pressure : 1.856 kg/cm2 or 0.1819994 MPa
Mound Pressure at Dome Ends: 0.1647 MPa

Mound Pressure on Cylinder:

The weight on the mound assumed to be in a radial pressure q on the cylinder, as shown in the below figure (ψo = 90°): At angle ψ: qψ = qo cos ψ,
Where qo (kN/m2) is the maximum pressure at ψ = 0
q0*Cos = 0.035146 MPa
q10*Cos = 0.034612 MPa
q20*Cos = 0.033027 MPa
q30*Cos = 0.030438 MPa

q0*CosΘ = 0.035146 MPa

q10*CosΘ = 0.034612 MPa

q20*CosΘ = 0.033027 MPa

q30*CosΘ = 0.030438 MPa

q40*CosΘ = 0.026924 MPa

q50*CosΘ = 0.022592 MPa

q60*CosΘ = 0.017573 MPa

q70*CosΘ = 0.012021 MPa

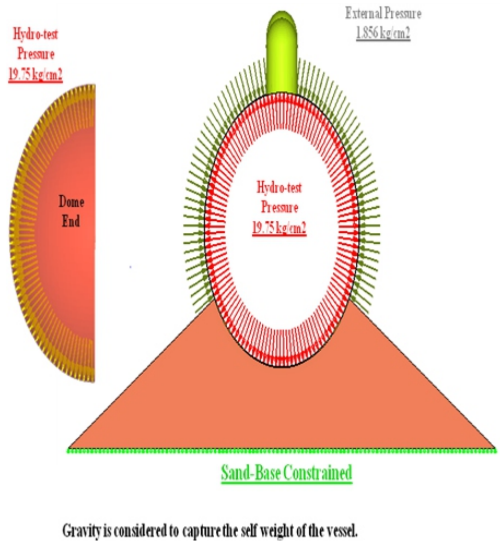
q80*CosΘ = 0.006103 MPa

q90*CosΘ = 0 MPa

Fig: 4.6 Mound weight

Following are the Load-Cases Analyzed:
Hydro Test Condition :

Generally hydro test conditions are tested at 90% head of the volume being filled in the vessel, so that it lets us know the ability to sustain for high pressure.Below are the Load cases done for operating Conditions:



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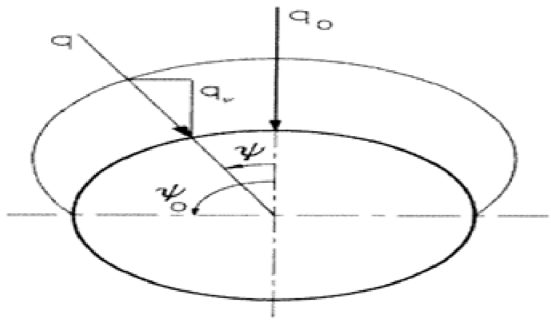

Fig:4.7a HydroTest Condition

Load Case-1: Internal Pressure + liquid weight + mound weight + Load due to thermal expansion with centre soft.

LoadCase-2: Internal pressure + liquid weight + mound weight + Load due to thermal expansion with end soft.

LoadCase-3: liquid weight + mound weight + Load due to thermal expansion with centre soft.

LoadCase-4: liquid weight + mound weight + Load due to thermal expansion with end soft.

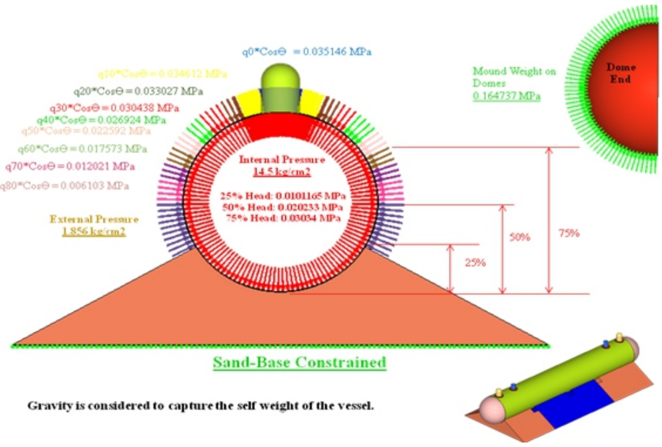

Fig: 4.7b LoadCases - 1 to 4

4.5 SCL: Stress Classification Lines:

This SCL information gives various details across the cross-sectional thickness, mainly these scl plots are detailed in the welding regions. So that we can calculate the strength of the weld joint in the vessel to ensure that there are no pressure leakages. These plots are defined by displacement in X-Dir and Stress in Y-Dir.

SCL Plots at various junctions are defined below and each SCL plot had been compared with the allowable stress at those maximum points in the below locations :

SCL-1 : Dome to Shell
SCL-2 : Shell to Nozzle
SCL-3 : Shell to stiffeners at ends
SCL-4 : Shell to Stiffeners-at center
SCL-5 : Shell to Dome-A

SCL Locations:

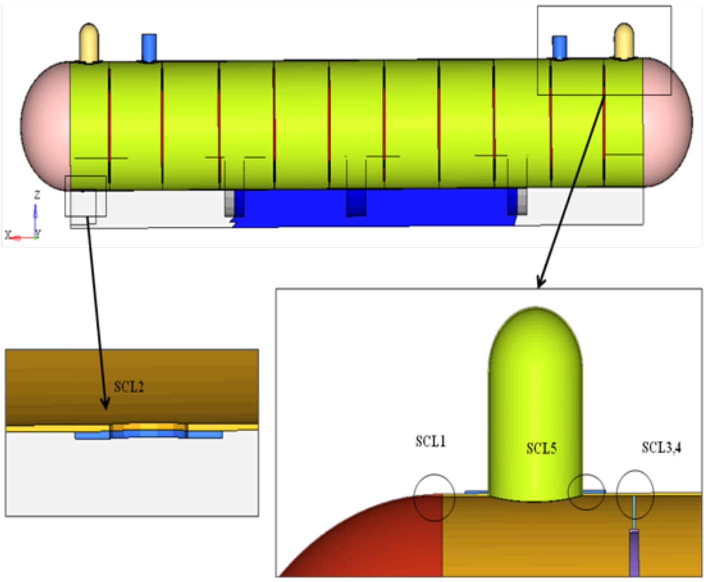

Fig: 4.8 SCL Loacations

SCL's had been plotted from the above some locations where the stress are maximum. Hence the analyst has to take SCL at all critical location near discontunity. With experience and looking at geometry and stress contour, and expert will be able to make out which SCL gives maximum membrane or bending stress. In other words considering that SCL which gives maximum membrane and bending stress to arrive at PL or Q as the case may be helpful.

4.6 Results:
HYDRO –TEST Condition:

Displacement & Stress Contours at 90% LPG Head:

Z-Displacement at 100 % water filled condition:

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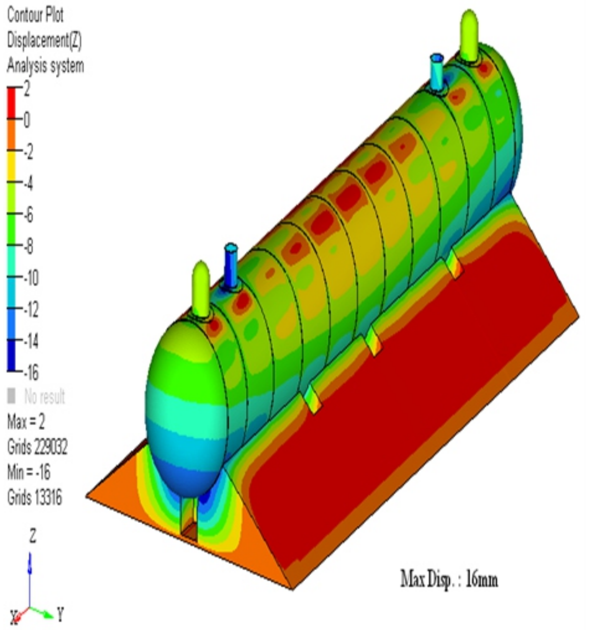


Fig: 4.9b Stress Plot (Hydro Test Condition)

Overall Stress contour at Yield Strength (345 MPa):

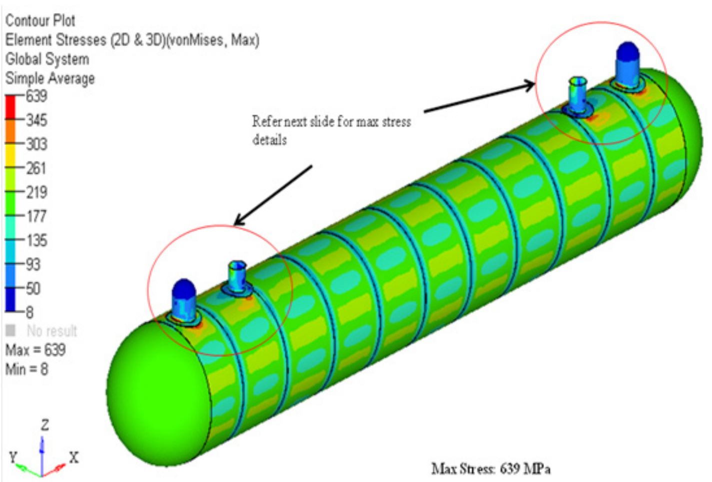
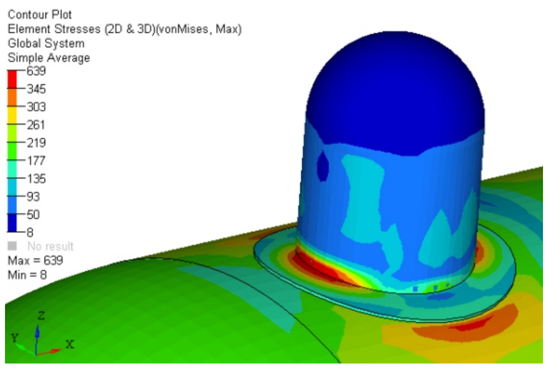


Fig: 4.10a Overall Stress Plot (Hydro Test Condition)

The stresses above the allowable limit are



in red ranging from 345-639 MPa.

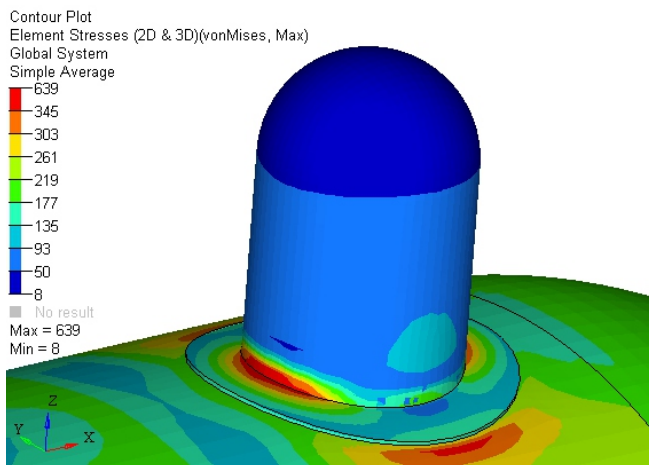
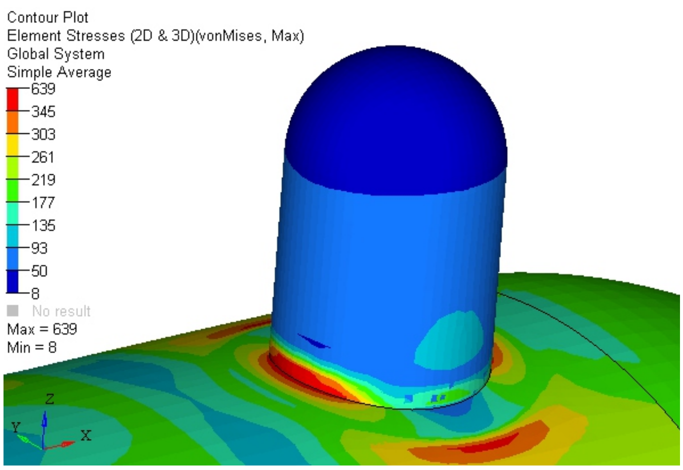


Fig: 4.10b Stresses between Domes(A&B) to Vessel (Hydro Test Condition) with pad plates.

Above stress between Dome A to Vessel and Dome B to Vessel. These are the locations where the stresses are very high and above the yield limit, but below the ultimate stress for the material being used. To reduce the stresses over this region, pad plates are used.



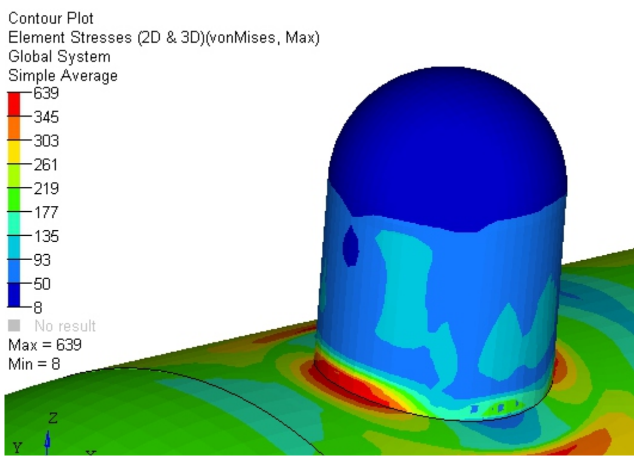


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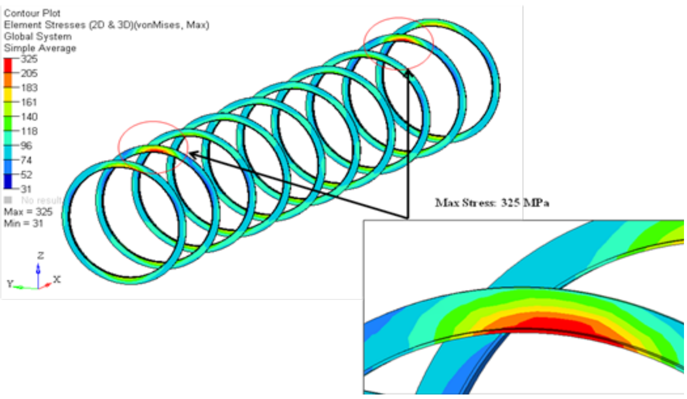
Fig: 4.11 Stresses between Domes to Vessel (Hydro Test Condition) without pad plates.

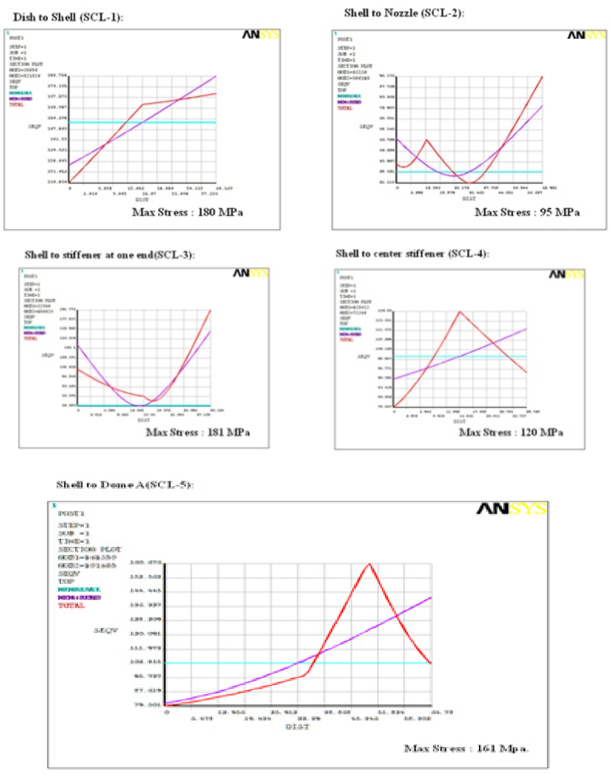
A localized stress is formed below the pad plates. (Max Stress: 639 MPa) Stress contour at allowable stress (205 Mpa) for stiffeners:



4.12 Stress Plots in Stiffener locations

Stiffeners are in allowable range at 100%head+Hydro Test Pressure. Except in the regions of stiffeners just below the pad-plates. Thus there is a local stress which is less than the minimum yield strength (< 345MPa).

SCL Info for Hydro Test Condition:



4.13 SCL plots for Hydro Test Condition.

Summary of SCL Data extracted for Hydro Test Condition (Table 4.1):

SCL	Stress Intensity (Mpa)	Allowable Stresses (Mpa)	Descriptions	Result
1	150	205	PM (S)	ok
	181	307.5	PL +PB (1.5 x S)	ok
	168	615	PL +PB +Q (3xS)	ok
2	24	205	PM (S)	ok
	72	307.5	PL +PB (1.5 x S)	ok
	95	615	PL +PB +Q (3xS)	Ok
3	55	205	PM (S)	ok
	150	307.5	PL +PB (1.5 x S)	ok
	190	615	PL +PB +Q (3xS)	ok
4	99	205	PM (S)	ok

SCL	Stress Intensity (Mpa)	Allowable Stresses (Mpa)	Descriptions	Result
1	150	205	PM (S)	OK
	181	307.5	PL +PB (1.5 x S)	OK
	168	615	PL +PB +Q (3xS)	OK
2	24	205	PM (S)	OK
	72	307.5	PL +PB (1.5 x S)	OK
	95	615	PL +PB +Q (3xS)	OK
3	55	205	PM (S)	OK
	150	307.5	PL +PB (1.5 x S)	OK
	190	615	PL +PB +Q (3xS)	OK
4	99	205	PM (S)	OK
	119	307.5	PL +PB (1.5 x S)	OK
	107	615	PL +PB +Q (3xS)	OK
5	101	205	PM (S)	OK
	125	307.5	PL +PB (1.5 x S)	OK
	160	615	PL +PB +Q (3xS)	OK
	PM = Membrane	PL+PB = Membrane + Bending	PL+PB +Q = Total	

	119	307.5	PL +PB (1.5 x S)	ok
	107	615	PL +PB +Q (3xS)	ok
5	101	205	PM (S)	ok
	125	307.5	PL +PB (1.5 x S)	ok
	160	615	PL +PB +Q (3xS)	ok
PM =				

Membrane
PL +PB = Membrane + Bending
PL +PB +Q = Total

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5. CONCLUSION:

Finite element model is developed to analyze the behavior of Horizontal mounded LPG Vessel subjected to Hydro test condition, and Operation Condition. Aim is to design and validate a pressure vessel that can store 1000 metric tons (MT) of LPG in it (either in gaseous state or in liquid state). SA-537-cl1 material had been used for all components in the model. This design has been validated for various conditions and passed successfully.

1.Hydro Test Condition: As briefed earlier any pressure vessel constructed shall be tested for Hydro Test as a mandatory. In this test 90% of water will be filled in the vessel and subjected to internal pressure of 19.75 kg/cm2 and an external pressure of 1.85 kg/cm2 (obtained from design calculations) and also self weight due to gravity. Below is the results summary (Table 4.6):

SCL-1 : Dome to Vessel
SCL-2 : Vessel to Nozzle
SCL-3 : Vessel to stiffeners at ends
SCL-4 : Vessel to Stiffeners-at center
SCL-5 : Vessel to Dome-A/B

Whole model cannot be taken into considered for finding stresses due to assumptions made to minimize the model to main components of a vessel. Stress intensities are calculated in only the welded locations and joints, where the bullet has to sustain for higher stresses. As per the above table, model is passed for all the membrane and bending stresses (~280 MPa < Yield strength 50000 psi / 345 MPa). All the obtained stresses for the design are less than the allowable stresses.

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