Determination of Safety of Inclined Leg Support for Pressure Vessel Subjected to Arbitrary Wind Load Using FEA

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Abstract- The vertical pressure vessels in market comes in either leg support or skirt support. In leg support legs are symmetrically distributed along the circumference and are vertically mounted. The requirement of support for pressure vessel for production of phenol and acetone is to have more floor space below the vessel and opening angle between first two leg is of 80.^{0}Thereforthe aim of this paper is to check the safety of pressure vessel for inclined and asymmetrically distributed legs. Therefore in this paper it is determined that whether we can support the pressure vessel with inclined and asymmetrically distributed legs or not.

Keywords – FEA, Inclined leg support, pressure vessels, and unsymmetrical legs support.

I. Introduction

The pressure vessels and support to be design for current work is for production of phenol (C_6H_5-OH) and acetone (CH_3-$COCH_3$) from benzene (C_6H_6) and propene (C_3H_6). This process illustrates the benefit of chemical engineering in merely converting two relatively cheap starting materials, benzene and propene into two more valuable ones, phenol and acetone. Other reactants required are oxygen from air and small amounts of a free radical initiator. Most of the worldwide production of phenol and acetone are now based on this method. The current range of Pressure Vessels in the market come either in skirt support or supported by 8 legs equidistance from each other. However, a pressure vessel is to be designed for the industries producing phenol and acetone (Cumene process) for more structural stability. The stability of pressure vessels is mainly depending on operating conditions and support of pressure vessels. The pressure vessel has to have a lot of controls for the cumene process due to operating conditions inside vessel; hence 8 legs are not feasible. Six legs support with a non symmetric distribution was tried out initially. The current requirement is to provide more floor space below the vessel; it is done by making legs of pressure vessel inclined to vertical. However, making some changes in symmetric distribution of legs and mounting in inclined position structural stability of vessel can be affected. Therefore structural stability of vessel is checked by checking the deflection and stresses in leg support by using FEA for unsymmetrical leg distribution and 0^0, 5^0, 10^0 and 15^0 inclined legs.

II. DESIGN CALCUATIONS

The support is to be design for the following operating conditions;
1. Maximum allowable pressure inside pressure vessel = 1.03421 N/mm^2
2. Vessel weight (approximate, dry) = 2721.55 kg
3. Vessel weight (approximate, full) = 8619 kg

The dimensions of vessel used for modeling of vessel are shown below;

1. Vessel inner diameter = 1.524 m
2. Length of cylindrical portion = 3.048 m

3. Height of vessel from ground = 1.1125 m

2.1 wind loads–

The direction of wind force is unknown; wind can come from any direction. Therefore in this paper the arbitrary direction of wind is considered.
Wind Load calculations

Table -1 wind load calculations factors

Description	Symbol	Value	Unit
Structure Category		**III**	
Exposure category		**D**	
Basic Wind Speed	**V**	**40**	**mph**
Importance Factor	**I**	**1.15**	
Gust response Factor	G_f	**1.15**	
Force coefficient	C_f	**0.9**	

$$F = q_Z \times G_f \times C_f \times A_f \quad (1)$$

Where $q_Z =$ Velocity pressure at height Z above ground

F = Force acting on pressure vessel.

$$q_z = 0.0156KzIV2 \quad (2)$$

G_f = gust response factor for flexible vessels.

C_f = force coefficient, shape factor 0.7 to 0.9

A_f = projected area, sq meter

For the pressure vessel having height in the above range the above factor is

$G_f = 1.15$

$C_f = 0.9$

Projected area, $A_f = 3.048 \times 1.524 = 3.645152$ sq meter (3)

Hence from equation 1, 2,3 force calculation is

$F = 0.0156\times 1.4506 \times 1.15\times 40^2\times 1.15\times 0.9 \times 50$

$= 9584.83$ N

$= 11000$ N For analysis (For worst conditions)

2.2. Design of Leg Support –

The dimensions of leg support are found out by considering the pressure vessel as a cantilever beam Subjected to axial lading at its centre of gravity and subjected to bending load of wind. The free body diagram for above mention loading condition and considered I section will be as follows-

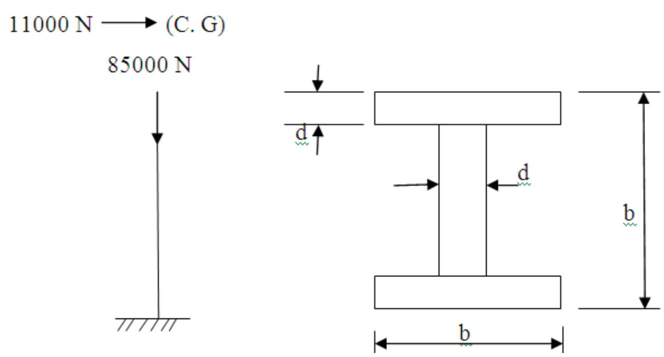


Fig 1 Free body diagram and cross section of Leg

Assumptions for above I section are as follows

Width = height of I section = b (mm)

Thickness of web = d (mm) = 0.1 b

Distance between ground and CG = 1113 + 15242637 mm

The area of cross section (A) for above section will be

$A = 2 \times bd + [(b - 2d) \times d)]$

$= 0.2\ b^2 + [0.8\ b\ d]$

$=0.2\ b^2 + 0.8 \times 0.1\ b^2$

$= 0.016\ b^2 \quad mm^2$ (5)

Moment of inertia (I) can be found as

$I = 2\ bd^3 /12 + [d\ (b - 2d)^3\ ]/12$

$= 1/12 \times [(2\times 10^3\ b^{40}) + (0.1\ b\ (0.8\ b)^3)]$

$= 6.83 \times 10^{-3}\ b^4 \quad mm^4$ (6)

Section modulus for above section (Z)

$Z = I / Y = (6.83 \times 10^{-3}\ b^4\ )/ [b/2]$

$= 0.01367\ b^3$ mm3 (7)

Bending moment M = 11000×1113 Nmm (8)

The material used for design of leg is structural steel with following properties

$E = 200 \times 10^3\ N/ mm^2$

Poisson's ratio $\mu = 0.3$

Yield stress $\sigma_{yt} = 250\ N/ mm^2$

The factor safety (fos) considered = 2

Therefore actual allowable stress ($\sigma_{all)}$ = 125 N/ mm^2

The leg is subjected to axial load and bending moment therefore the equation for calculating dimensions of leg is

$$\sigma_{all} = \frac{P}{A} + \frac{M}{Z}$$

Where; P – Axial load acting on leg due to full weight of vessel (N)

A - The area of cross section for above section (mm^2)

M – Bending moment created due to wind load (N)

Z – Section modulus of above section

Putting values from equation

$$125 = \frac{85000}{0.016\,b^2} + \frac{11000 \times (1113+1524)}{0.01367\,b^3}$$

Solving above equation for b we get the value of b as

b = 311 mm

Therefore area of cross section which can sustain above loading will be from eq (5)

$A = 0.016\,b^2 \quad mm^2$

$= 0.016 \times 311^2 \qquad = 1547 \quad mm^2$

This area is to be divided among the six legs therefore area of cross section for one leg will be

A1 = 1547/6 = 257 mm (consider for design)

From this area of cross section we can determine the dimension of I – section for one leg

$A1 = 0.016\,b1^2$

$257 = 0.016 \times b1^2$

b1 = 126.73 = 130 mm

The Legs of the Vessel are I section beams with dimensions as shown below in table II.

Table -2 D*imension of legs*

Description	**symbol**	**Value (mm)**
Depth	**G**	**130**
Width	**H**	**130**
Thickness mean	**I**	**13**
Web thicknes	**J**	**13**

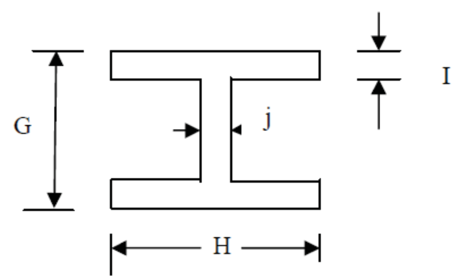


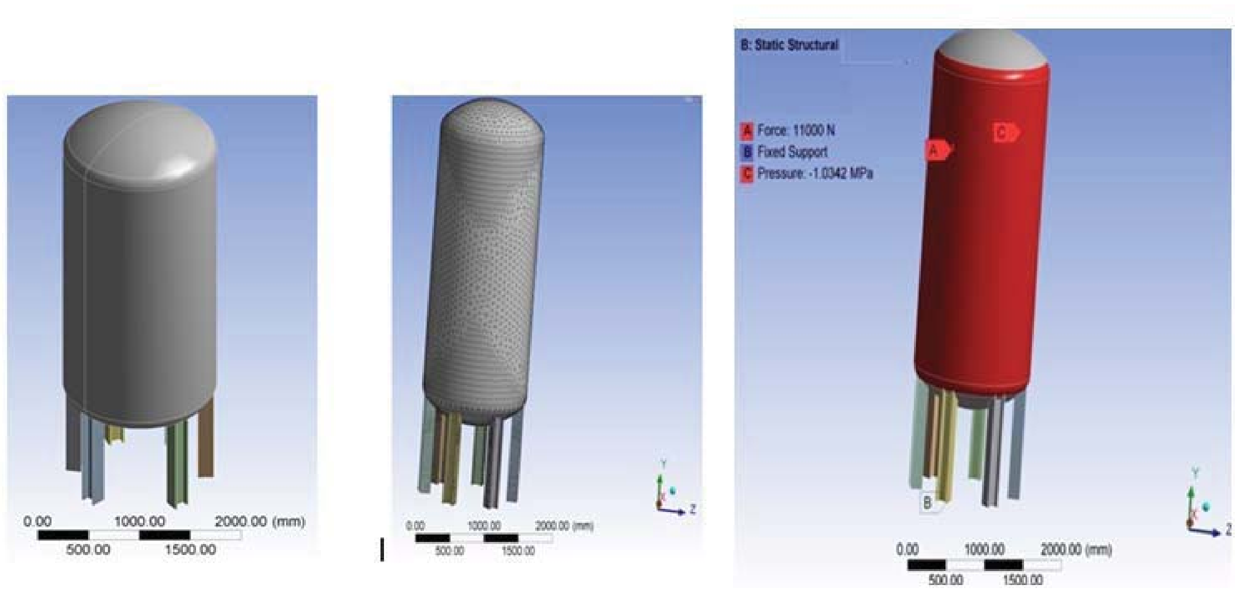
Fig. 2 leg dimension

III. SOFTWARE ANALYSIS

The modeling and analysis of pressure vessel and required leg support is done in Ansys .

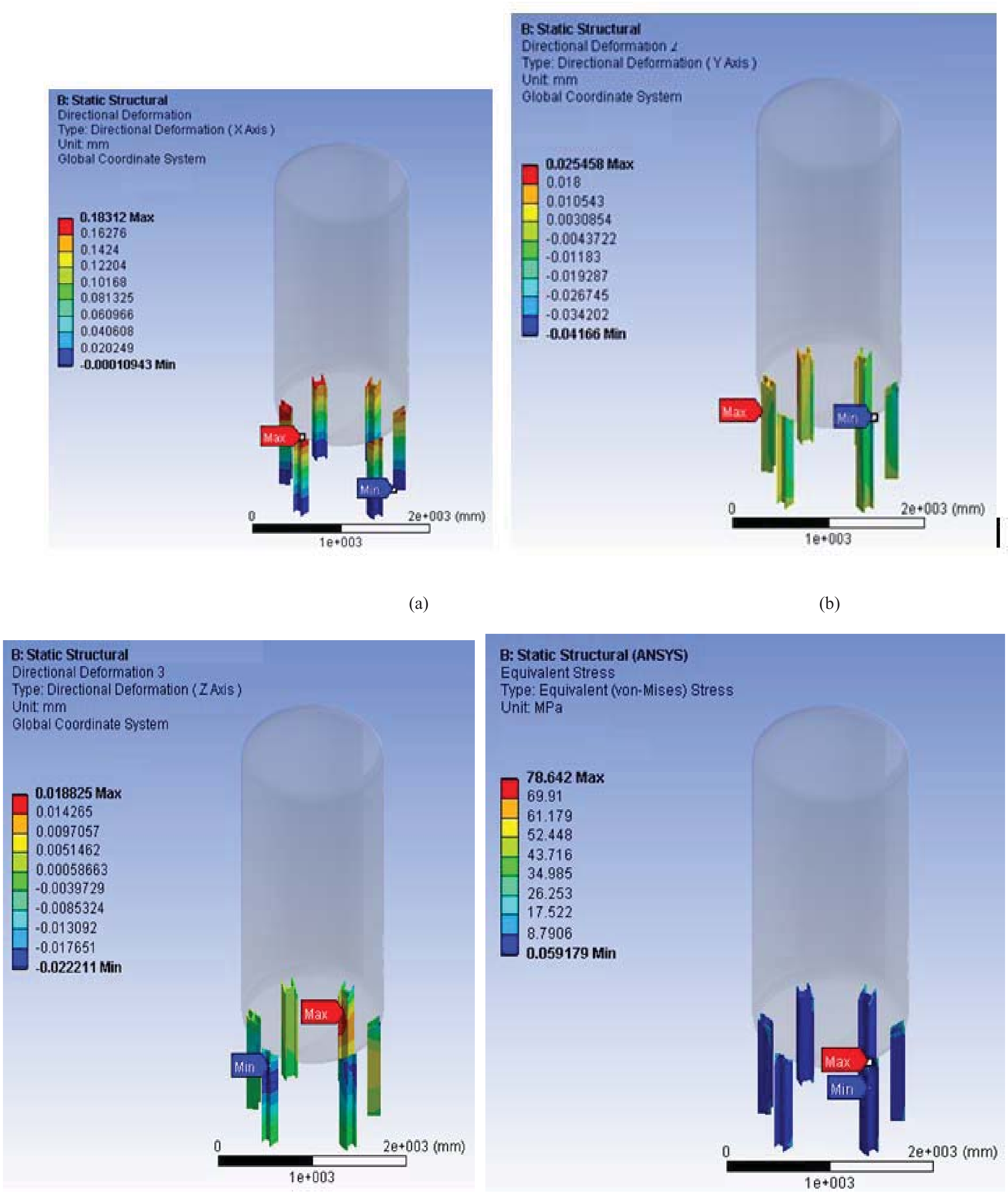
1. Element used for meshing are 10 node tetrahedron
2. 10 node tetrahedron elements are used for leg support and pressure vessel meshing.
3. Sizing for tetrahedron element for vessel is 150mm and 180mm.
4. Sizing for tetrahedron element for leg support is 100mm and 120mm
5. pressure inside pressure vessel 1.03421 N/mm2
6. All the support is fixed.
7. Wind load of 11,000 N is applied.

8. Finding out total deformation in Leg support.
9. Stresses created in leg supports.
10. The Model for pressure vessel and leg support assembly is shown in fig. 3(a)
11. The meshing of pressure vessel is done as shown in fig. 3(b)
12. The boundry conditions applied for model are shown in fig. 3 (c)
13. The directional deformation of leg support along X, Y, Z- axis and vin-mises stresses created in legs are shown in fig.4 (a), (b), (c) and (d)
14. Likewise the analysis is done for 0^0, 5^0,10^0 and 15^0 inclined legs to vertical and all the results are shown in result table.



(a) (b) (c)

Fig.3 (a) Modeling of Pressure vessel (b) Meshing of vessel and support assembly (c) Boundary conditions



(a) (b)

(c) (d)

Fig. 4 (a) X-Directional deformation legs for mesh size 100mm, (b) Y-Directional deformation legs for mesh size 100mm, (c) Z-Directional deformation legs for mesh size 100mm, (d) vin-mises stresses created in legs for mesh size 100mm

IV. RESULTS & DISCUSSION

1. The results of unsymmetrical distributed legs with combination of 0^0, 5^0, 10^0 and 15^0 inclined legs with respective mesh size are shown in table III.
2. From the result table III we can clearly see that the deformation of legs along X, Y and Z-axis is very smaller
3. The von-mises stresses created in legs are also within the permissible limits.

Table -2 Result of 0^0, 5^0, 10^0,15^0 inclined legs

Sr No	Angle (Degree)	Mesh Size mm	No of Nodes	Max deformation mm			Stresses Mpa
				X	Y	Z	
1	**0^0**	**100**	**27156**	**0.1677**	**0.0239**	**0.0241**	**58.34**
2	**0^0**	**120**	**20132**	**0.1831**	**0.0254**	**0.0188**	**78.64**
3	**5^0**	**100**	**27203**	**0.1405**	**0.0157**	**0.0234**	**60.7**
4	**5^0**	**120**	**20200**	**0.1321**	**0.0150**	**0.0276**	**61.40**
5	**10^0**	**100**	**27743**	**0.1071**	**0.0164**	**0.0277**	**98.20**
6	**10^0**	**120**	**20259**	**0.1013**	**0.0178**	**0.0299**	**65.58**
7	**15^0**	**100**	**26740**	**0.079**	**0.0166**	**0.0315**	**117.0**
8	**15^0**	**120**	**19958**	**0.07467**	**0.0189**	**0.0316**	**66.28**

V. CONCLUSIONS

From the above results we conclude that the deformation of legs support for unsymmetrical and inclined legs is very small and stresses are also within the permissible limits. Therefore the requirement of more floor space below the vessel for cumene process can be achieved by making legs unsymmetrical distributed and inclined to some suitable angle and the designed support is safe.

REFERENCES

[1] Cai Zengshen, Lin Jun, "*Support leg stress in pressure vessels mounted on arbitrary legs subjected to lateral loadings*", International Journal of Pressure Vessels and Piping, Vol-68, pp 13-22, 1996.

[2] Deniss R Moss, Pressure Vessel Design manual 2004 (third edition)

[3] Ansys 11 Manual

[4] D V Hutton, fundamental of finite element analysis.