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Finite Element Analysis of Elliptical Pressure Vessels

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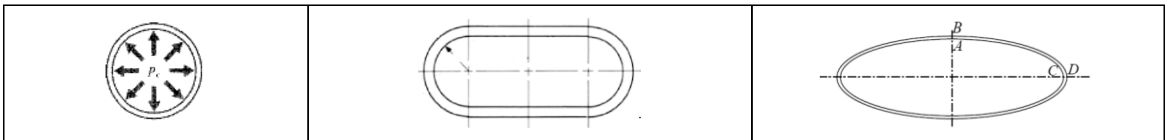
***Abstract:* -** This paper presents the work carried out for determination of stresses in an open ended pressure vessel of elliptical shape. In some situations, due to the limited space available, exit pipes are made of elliptical or obround shape. In this study, the stresses in the elliptical pressure vessel are determined using finite element method. The material of the vessel is aluminum alloy. Internal pressure is applied to the vessel. Software 'ANSYS' is used for modeling & analysis purpose. Considering the symmetry about both axes, only quarter model is prepared. PLANE82 elements are used for the analysis. Firstly analysis of circular pressure vessel is done. The results of the circular vessel are validated by analytical solution. Then using the same type of element & mesh density, analysis of elliptical pressure vessel is done. During the study, different parameters were varied & their effect on the stresses was observed.

***Keywords:* -** *Elliptical Pressure Vessel, Finite element analysis, ANSYS.*

I. INTRODUCTION TO PRESSURE VESSELS

Pressure vessels are a commonly used device in engineering. Cylindrical or spherical pressure vessels (e.g., hydraulic cylinders, gun barrels, pipes, boilers and tanks) are commonly used in industry to carry both liquids and gases under pressure. When the pressure vessel is exposed to this pressure, the material comprising the vessel is subjected to pressure loading, and hence stresses, from all directions. The normal stresses resulting from this pressure are functions of the radius of the element under consideration, the shape of the pressure vessel (i.e., circular, obround or elliptical) as well as the applied pressure.



Circular Pressure Vessel	Obround Pressure Vessel	Elliptical Pressure Vessel

Figure.1 Types of Pressure Vessels

II. PROBLEM DEFINITION

Analysis of a circular pressure vessel is done for a certain pressure. Hoop stresses are determined for this geometry. Analytical solution of the same is determined. Comparison of the results is done. Then keeping the area of flow same, the shape of the pressure vessel is changed to elliptical. To maintain the flow rate constant, the area of flow is kept same & the stress analysis is done for this vessel. Following data is used for the analysis work.

Inner Diameter (D) = 200 mm, Thickness of vessel (t) = 2.5 mm
Pressure applied (P) = 0.1 MPa
Material Properties: Material selected is Aluminum alloy used in aircraft.

Table.1 Material Properties

Young's Modulus	1.03458 e5 MPa
Poisson's Ratio	0.33

III. ANALYTICAL SOLUTION

Analytical solution is determined for circular pressure vessel using Formula,
Hoop Stress = (P x R) / t = (0.1 x 100) / 2.5 = 4 MPa

IV. FINITE ELEMENT ANALYSIS

Circular Pressure Vessel:

Taking the advantage of symmetry about both the axes, a quarter model is prepared & the analysis is done using Finite Element Method based software ANSYS.

Meshing: For meshing quadrilateral elements with mid-side nodes are used. The details of this element are as below.

PLANE82:- It is a higher order version of the 2-D, four-node element PLANE42. It provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries.

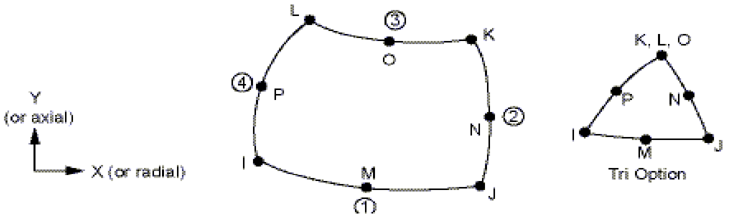


Figure.2 Structure of PLANE82 element

The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an axi-symmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

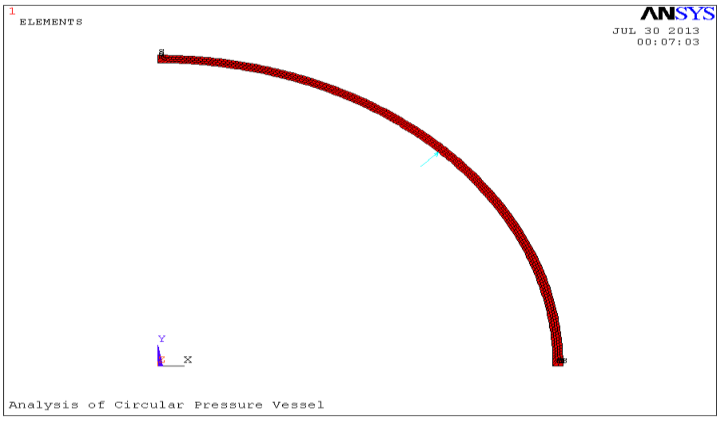


Figure.3 Circular Pressure vessel with load condition & boundary condition

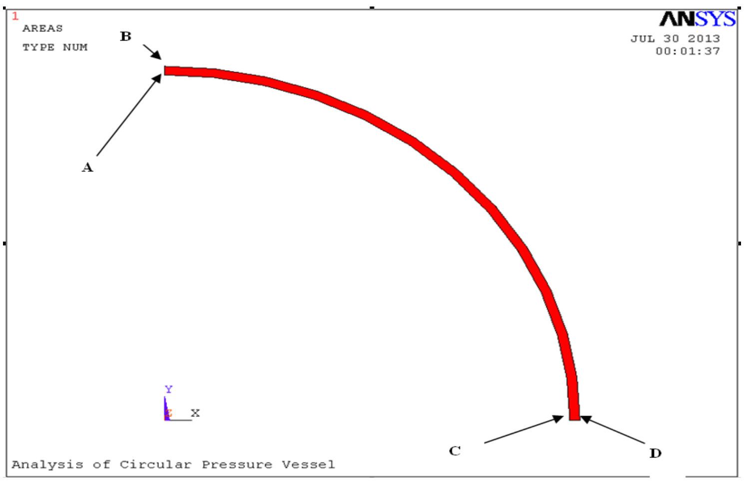


Figure.4 Location of Points A, B, C & D

The various points of interest are as shown in the above figure.
Elliptical Pressure Vessel: Keeping the cross section area constant, the dimensions of the major & minor axis are determined. Also variation in major & minor axis of ellipse is done & effect is observed. The following figures show model, meshing, load & boundary conditions of the elliptical vessel with a ratio of Major axis (X) to Minor axis (Y) equal to 2.816613

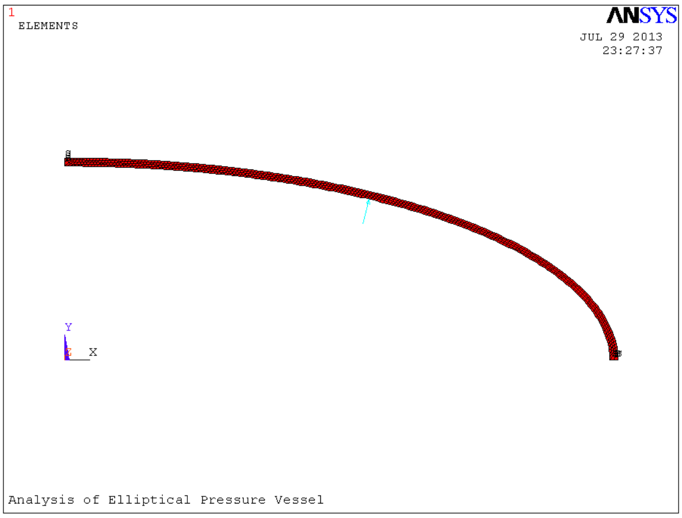


Figure.5 Meshed model of elliptical pressure vessel with boundary condition & Load Conditions

V. RESULTS & DISCUSSIONS:

Circular Pressure Vessel: Initially for circular pressure vessel, trials are taken to see the effect of mesh density. It is seen that using edge length of 1.25 mm for small edges & edge length of 1 mm for curved edges, we get more accuracy. Hence the same is finalized for further analysis. Following table gives the details of the results obtained with the above mesh density.

Table.2 Values of Principal Stresses

Stress at A	Stress at B	Stress at C	Stress at D
4.0504MPa	3.9506MPa	4.0504MPa	3.9506MPa

Figure 6 indicates the deformed shape, along with un-deformed shape of the circular pressure vessel. I can be seen that the maximum deformation is only 0.003947 mm. Figure 7 indicates the values of principal stresses in this circular pressure vessel.

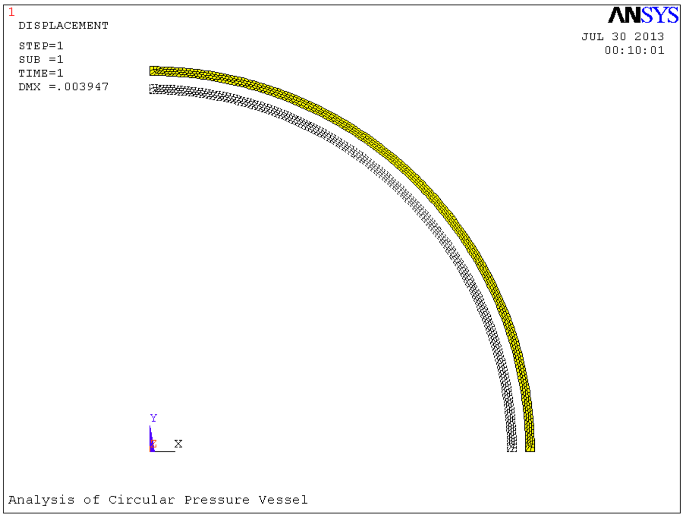


Figure.6 Deformed shape along with undeformed shape (Circular Pressure Vessel)

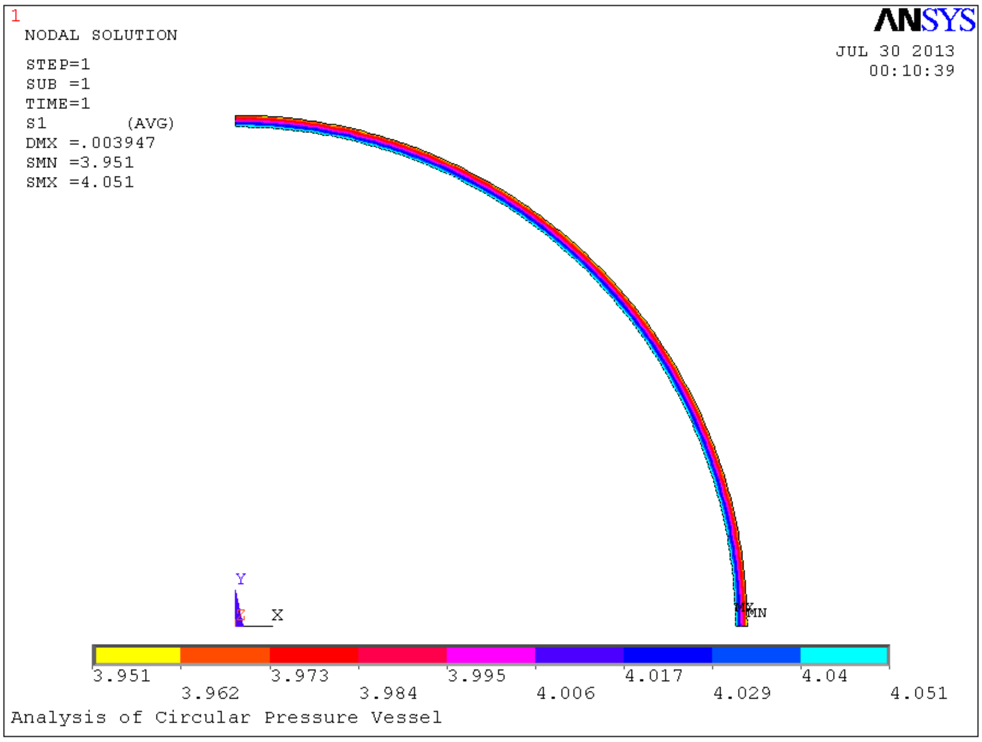


Figure.7 Principal stresses (Circular Pressure Vessel)

Stresses at A, B, C & D points: The output of nodal solution is listed & observation of the stresses at A, B, C & D points is done. The values obtained are as below.

Table.3 Principal Stresses at A, B, C & D for Circular Pressure Vessel

Node Position	Point	Node Number	Stress (ANSYS) MPa	Hoop Stress (Analytical) MPa
Inner - Upper Side	A	326	4.0506	4
Outer - Upper Side	B	2	3.9506	
Inner - Lower Side	C	330	4.0506	
Outer - Lower Side	D	1	3.9506	

Elliptical Pressure Vessel:

Following figure 8 indicates the deformed & un-deformed shape of the elliptical pressure vessel.

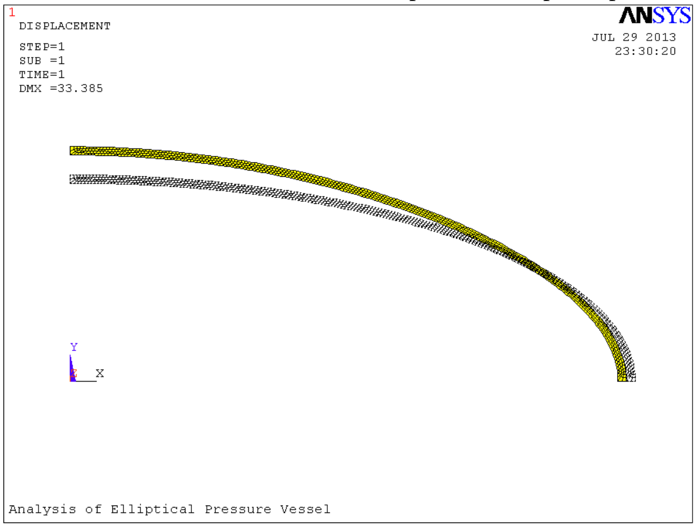


Figure.8 Deformed shape & Un-deformed shape of obround pressure vessel

Figure 9 shows the first principal stresses & Figure 10 gives Third Principal Stress. The maximum stress values are-

Table.4 Principal Stresses at A, B, C & D for elliptical Pressure Vessel

Stress at A (in MPa)	Stress at B (in MPa)	Stress at C (in MPa)	Stress at D (in MPa)
-497.85	502.62	714.24	-663

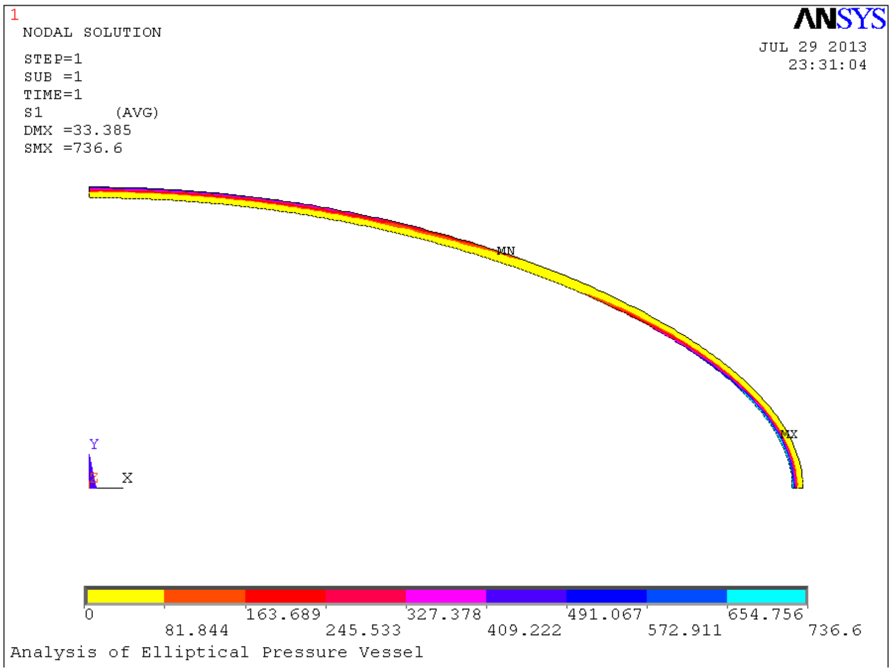


Figure.9 First Principal Stresses (Elliptical Pressure Vessel)

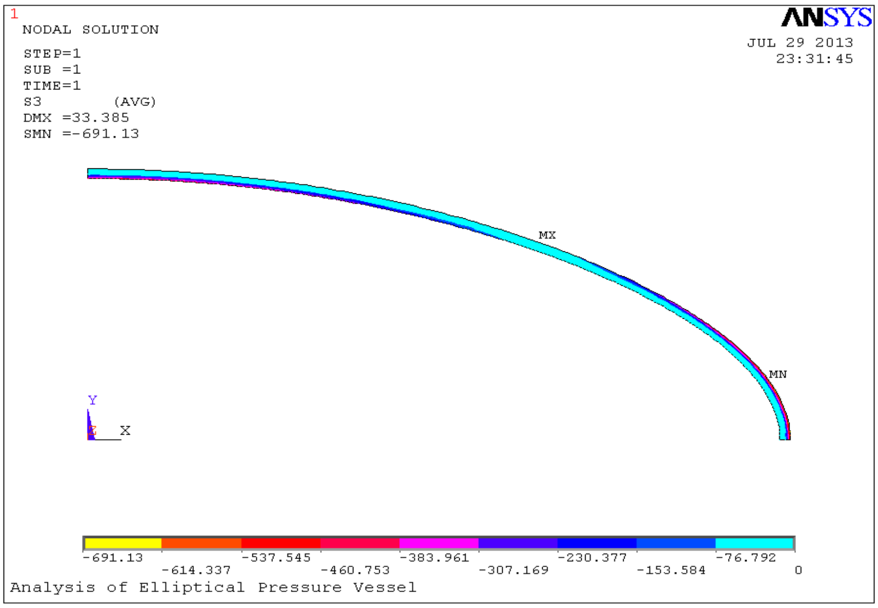


Figure.10 Third Principal Stress (Elliptical Pressure Vessel)

From the above study, it is seen that values of hoop stresses are very much higher than that of the circular pressure vessel. Also the maximum deformation is 33.385 mm which also is very much higher than that of circular pressure vessel.

Following table gives the details of the values of stresses at A, B, C & D points for values of a/b ratio (Ratio of major axis to minor axis) of elliptical pressure vessel.

Table.5 Results of Hoop Stresses in Elliptical Pressure Vessel

(a/b)	A	B	C	D
	Stress (MPa)	Stress (MPa)	Stress (MPa)	Stress (MPa)
10.21318	-2495.3	2496.9	2856.5	-1910
7.19752	-1613.9	1615.9	2013.7	-1581.6
5.379901	-1122.7	1124.4	1527.6	-1261.4
4.200951	-821.83	826.69	1150.4	-1023.5
3.393437	-630.23	634.96	902.17	-824.18
2.816613	-497.85	502.62	714.24	-663
2.067435	-326.05	331.1	450.24	-423.99
1.618629	-213.32	218.87	276.14	-259.9
1.330351	-127.34	133.57	155.38	-143.73
1.135794	-56.28	63.332	68.41	-59.103
1.061958	-24.863	32.377	33.863	-25.299

The following graph indicates the variation of stresses with references to the change of a/b ratio.

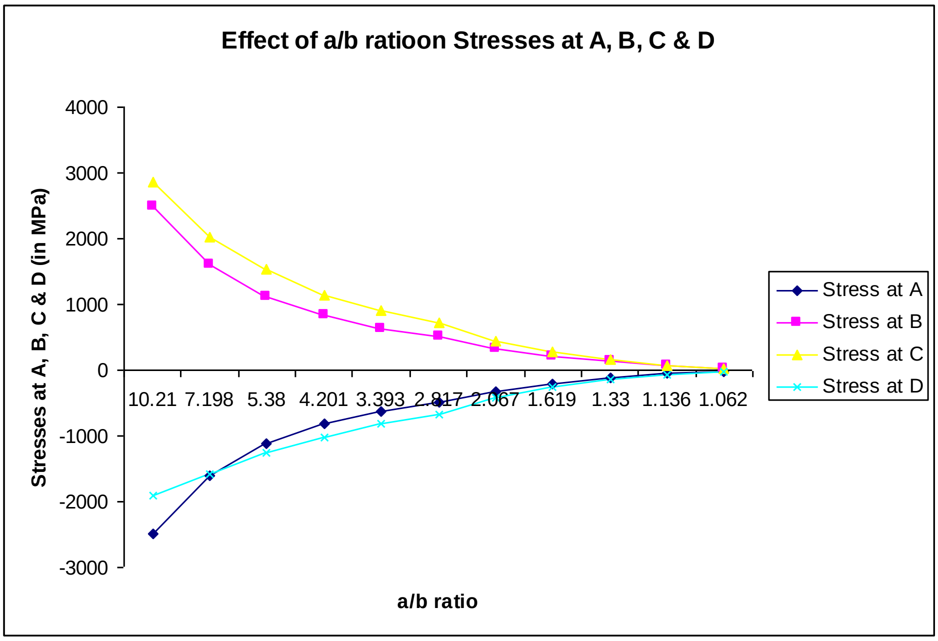


Figure.11 a/b ratio Vs. Hoop Stresses at A, B, C & D

From all the above figures, it can be said that as radius of curved portion of obround pressure vessel goes on increasing, the hoop stresses go on reducing. The reduction is as per the curves indicated above.

Effect of thickness of Elliptical Pressure Vessel on the values of the Hoop Stress: The effect of thickness on the values of the stresses is also observed. Following table indicates the values of the hoop stresses at different thickness of the pressure vessels.

Table.6 Stresses at different thicknesses of Pressure Vessel

Thickness (mm)	Stress (Mpa)	Stress (Mpa)	Stress (Mpa)	Stress (Mpa)
2.5	-821.83	826.69	1150.4	-1023.5
3	-572.06	576.48	819.31	-700
3.5	-422.56	424.3	615.03	-508.89
4	-322.85	325.4	477.52	-383.56
4.5	-255.44	257.57	382.89	-299.69
5	-207.84	209.02	316.97	-240.19

From the table it is seen that as the thickness of vessel goes on increasing, stresses go on reducing.

VI. CONCLUSIONS

- The hoop stresses in the elliptical pressure vessel are very much higher as compared to the stresses in circular pressure vessels.
- Deformation in the elliptical pressure vessel is also very much higher as compared to the deformation in circular pressure vessels.
- As a/b ratio (ratio of major axis to minor axis) of elliptical pressure vessel goes on increasing, the hoop stresses go on increasing.
- As the thickness of vessel goes on increasing, stresses go on reducing.

VII. ACKNOWLEDGEMENT

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