

# Design & Analysis of Pressure Vessel with Hemispherical & Flat Circular End

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## Abstract

A thin cylindrical pressure vessel has been analyzed for different end connection using analytical and finite element analysis. The main objective of this paper is to compare stress distribution over pressure vessel for end connection viz. hemispherical and flat circular. This paper designs the pressure vessel according to the pressure vessel handbook for both hemispherical and flat circular end pressure vessel so as to determine the most economic and efficient design. The various dimensions of pressure vessel like internal diameter and thickness of vessel and end connections has been decided using analytical design whose three dimensional model is prepared in modeling software Pro-Engineer 5.0 and analyzed using FE tool Ansys 12. The analysis has been carried out for two dimensional axisymmetric analysis, three dimensional horizontal pressure vessel with saddle support and vertical pressure vessel over stand.

**Keywords:** Stress, hemispherical end, flat circular end, ANSYS

## I. INTRODUCTION

Tanks, vessel and pipelines that carry, store or receive fluids are called as pressure vessel. A pressure vessel is defined as a container with a pressure differential between inside and outside. The inside pressure is usually higher than the outside. The fluid inside the vessel may undergo a change in state as in the case of steam boiler or may combine with other reagent as in the case of chemical reactor. Pressure vessel often has a combination of high pressure together with high temperature and in some cases flammable fluids or highly radioactive material. Because of such hazards it is imperative that the design be such that no leakage can occur. In addition vessel has to be design carefully to cope with the operating temperature and pressure.

Pressure vessel are used in a number of industries; for example, the power generation industry for fossil and nuclear power, the petrochemical industry for storing and processing crude petroleum oil in tank farms as well as storing gasoline in service station, and the chemical industry. Their use has expanded throughout the world. Pressure vessel and tank are in fact essential to the chemical, petroleum, petrochemical and nuclear industry. It is in the class of equipment that the reaction, separation and storage of raw material occur. In the same word, pressurized equipment is required for a wide range of industrial plant for storage and manufacturing purpose.

Pressure vessels are usually spherical or cylindrical with dome end. The cylindrical vessels are generally preferred because of the present simple manufacturing problem and make better use of the available space. Boiler, heat exchanger, chemical reactor and so on, are generally cylindrical. Cylindrical vessels are design and manufactured with different end connections viz. hemispherical, flat circular, ellipsoidal and dished shape. Hemispherical and flat circular ends are popular end connections used for petrol and diesel fuel tank, water and milk tanks. Spherical vessels have the advantages of requiring thinner walls for a given pressure and diameter than the equivalent cylinder. Therefore they are used for large gas or liquids container, containment buildings for nuclear plant and so on.

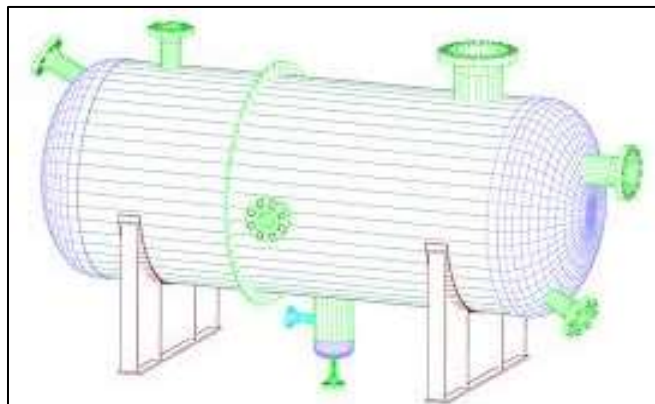


Fig. 1.1: Horizontal Pressure Vessel

In the design of pressure vessel safety is the primary consideration, especially for nuclear reactor vessels, due the potential impact of a possible accident. In generally however, the design is a compromise between consideration of economics and safety. The possible risks of a given failure and its consequent are balanced against the effort required for its prevention; the resulting design should achieve an adequate standard of safety at minimum cost.

The pressure vessels, according to their dimensions, may be classified as thin shell or thick shell. The pressure vessels, according to the end construction, may be classified as open end or closed end. In case of vessels having open ends, the circumferential or hoop stresses are induced by the fluid pressure. A simple cylinder with a piston, such as cylinder of a press is an example of an open end vessel. In case of vessels having close ends, longitudinal stresses in addition to circumferential stresses are induced. When a thin cylindrical shell is subjected to an internal pressure, it is likely to fail in circumferential and longitudinal stress. Tensile stress acting in a direction tangential to the circumferential is called circumferential or hoop stress. In other words, it is a tensile stress on longitudinal section or on the cylindrical walls. It may fail along the longitudinal section (i.e. circumferentially) splitting the cylinder into two troughs, as shown in Fig. 1.2 (a). Tensile stress acting in the direction of the axis is called longitudinal stress. In other words, it is tensile stress acting on the transverse or circumferential section or on the ends of the vessel. It may fail across the transverse section (i.e. longitudinally) splitting the cylinder into two cylindrical shells, as shown in Fig. 1.2(b).

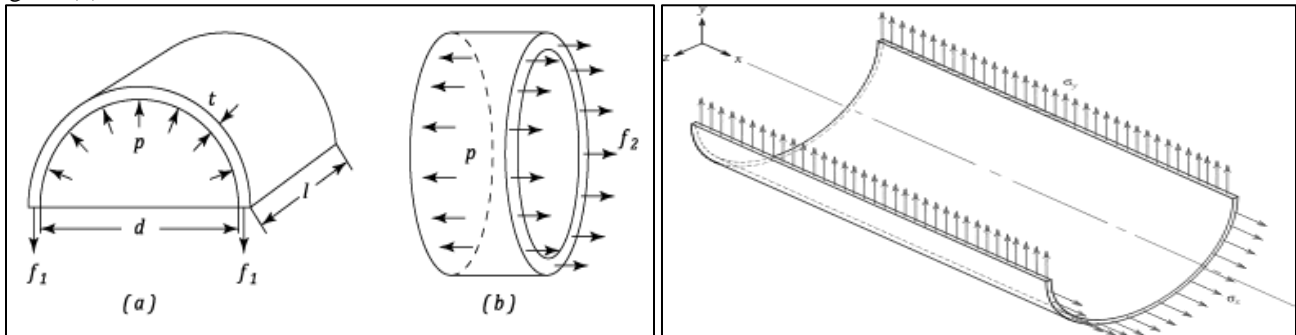


Fig. 1.2: Failure of pressure vessel along longitudinal section and transverse section

## II. LITERATURE REVIEW

Adithya M, M. M. M. Patnaik [1] horizontal pressure vessel supported on saddles is designed and analysed. The FEA for different configurations of pressure vessel on saddle supports is done using ANSYS. The stress intensities in various cases are analyzed and the optimal location when the saddles are placed away from heads is considered as the most suitable design for the large horizontal vessels. The effect of stiffening is also considered in three cases. The reduction in stress intensity is found for one of the cases. For this the optimization of thickness was done which resulted huge reduction of weight.

PallaviJ.Pudke[2] the stress distribution of various geometric parameters of gussets and number of gussets of saddle is observed to select the optimal size of saddle. He shows that the design by analysis is the most desirable method to evaluate and predict the behavior of different configurations of saddle supports. The comparison of these results helps to provide the most optimized design with an ability to meet the requirements. He suggested stress values obtain by empirical method and analysis stresses are below allowable limits which are acceptable.

TapanMajumder[3] multilayer compound cylinders are suitable for high operating pressures, indicated results for an optimum condition, the stress at the inner surfaces of all cylinders become equal to the yield stresses of the materials used for multilayer compound cylinders. There is saving in material by using multilayered compound cylinder as compared to solid walled cylinder. This decreases not only weight of compound cylinder but also the cost of the material required to manufacture of multilayered compound cylinder.

Sagar P. Tiwatane[4] analysis throws light on various stresses encountered in the skirt to dished junction which makes its design critical. After this analysis optimum parameters considered which can minimize stresses in junction. This helps in increasing life of pressure vessel & reduces its cost. He concluded that stress and other parameters are also decreased by changing weld size of skirt to dished end junction.

Sunil Kumar D [5] designed and evaluated the pressure vessel and determined the static and thermal analysis considering for a given pressure and temperature design conditions. Stress linearization values greater than the allowable stresses of the material and the min fatigue life is obtained less than  $1e6$  cycles, factor of safety of less than 1 considered for fully reversal cycle, hence designed fail. Then modified pressure vessel has an increased thickness of pressure vessel and shell by 5mm in accordance to ASME sec VIII Division 2 rules. After increasing the thickness of vessel the stress linearization results for modified design and hence obtained the induced stress values below the allowable stress limits of the materials and obtained the min fatigue life cycle greater than  $1e6$  cycles for infinite life design and with factor of safety more than 1 to achieve fatigue life greater than  $1e6$  cycles for considering fully reversal cycle.

VinodKumar[6] he did comparative study on stresses by using mathematical approach and by ANSYS software. He did modifications in present design, reduced maximum stress value at critical zone and optimizes the cost of equipment. Some

modifications are done like inserted wear plate between saddle and vessel, made saddle support radius greater than vessel outer radius and made it flexible at the saddle horn.

Zick[7] Find out the stresses in cylindrical vessels at various locations which are supported on saddles. Zick analyzed that which vessels should be designed for internal pressure alone and how much stiffness is required for the vessels, by knowing the stresses and a chart is given which covers support designs for pressure vessels made of mild steel for storage of liquid weighing 42 lb. per cu. ft.

BhagatMeghrajVitthal [8] for calculating deflections and stresses in each nodes, he did finite element analysis. Comparison is done between bilinear and quadratic ranges for same element number. He found that bilinear is showing more variation than quadratic from the exact values. For same element type with different numbers results were expected that is results converge to exact values when number of element increases.

Dr. D. V. Bhope [9] He did FE analysis of horizontal and vertical pressure vessel and found out that magnitude of stresses is high for flat circular end pressure vessel while magnitude of stresses is lower in case of hemispherical and dished end pressure vessel. Flat circular end is not preferred for pressure vessel and hemispherical and dished ends are considered for better end connections. Lengths of leg support have effect in vertical pressure vessel and arc length of saddle support does not have much effect on stresses for horizontal pressure vessel.

V. V. Wadkar [10] He did analysis of cylindrical pressure vessels with hemispherical head type .By ANSYS he calculated maximum equivalent stress and compared results with theoretical values. In his paper he concluded that smaller values of equivalent stresses are appearing in pressure vessel with hemispherical heads and equivalent stress distribution is advantageous in case of head geometry.

Chandrakant R Kini [11] By using FEA analysis and by analytically he calculated maximum equivalent stress (Von Mises Stress) and also prepared a three dimensional model for finite element analysis. He found deviations in both the results. The maximum equivalent stress obtained for the designed three dimensional model was less than the yield strength of the material SA 283 C grade that is 132.9742025 MPa < 245 MPa, thereby advocating that the pressure vessel design was correct and also that the three dimensional model could withstand the operating temperatures and pressures. The deviation of 2.4860% was least among all the meshes that were applied on the pressure vessel for analysis. The mesh size for which this least value of deviation was obtained was 0.002m. The mesh size for which this least value of deviation was obtained was 0.002m. Therefore this design of flat dish end pressure vessel is safe and can be put to use.

### III. IDENTIFIED GAPS IN LITERATURE

- Pressure vessel length increases. Now its three time of diameter. Previously it was two times.
- Shape of pressure vessel changes. Now it like a water or oil tanker.
- Analysis has been carried out with two saddle support and with three saddle support.
- Analysis has been carried out also for three vertical leg and four vertical leg.
- Axisymmetric analysis has been carried out.

### IV. PROBLEM FORMULATION

A study for the stress analysis of pressure vessel involves the study of longitudinal and circumferential stresses induced due to fluid pressure. The stresses in pressure vessel will vary with respect to its design consideration corresponding to its application. Here the pressure vessel with single opening at center and along its length has been analyzed for various cases and compare its stresses for hemispherical and flat circular end connection. The analysis involves the use of saddle support for horizontal vessel and leg support for vertical vessel.

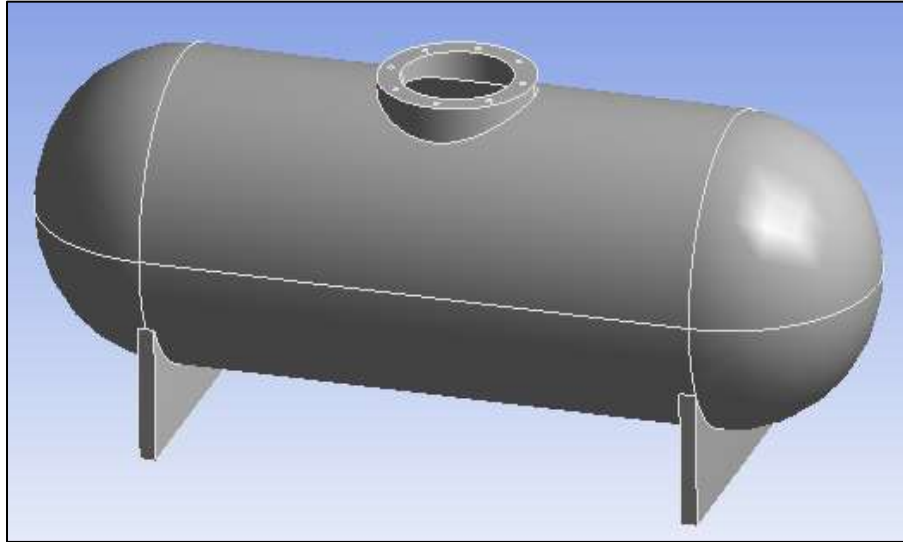
### V. OBJECTIVE

The part model is converted into IGS file format to import the geometry in ANSYS. ANSYS 12.0 is the finite element analysis software which is used for the analysis of pressure vessels. In design simulation 10-node tetrahedral SOLID187 element is used for meshing of three dimensional vessel and 8-node PLANE 183 element is used for meshing of two dimensional axisymmetric pressure vessel. SOLID187 element is a higher order 3-D, 10-node element and PLANE183 is a higher order 2-D, 8-node or 6-node element. SOLID187 and PLANE 183 has a quadratic displacement behavior and is well suited to modeling irregular meshes (such as those produced from various CAD/CAM systems).

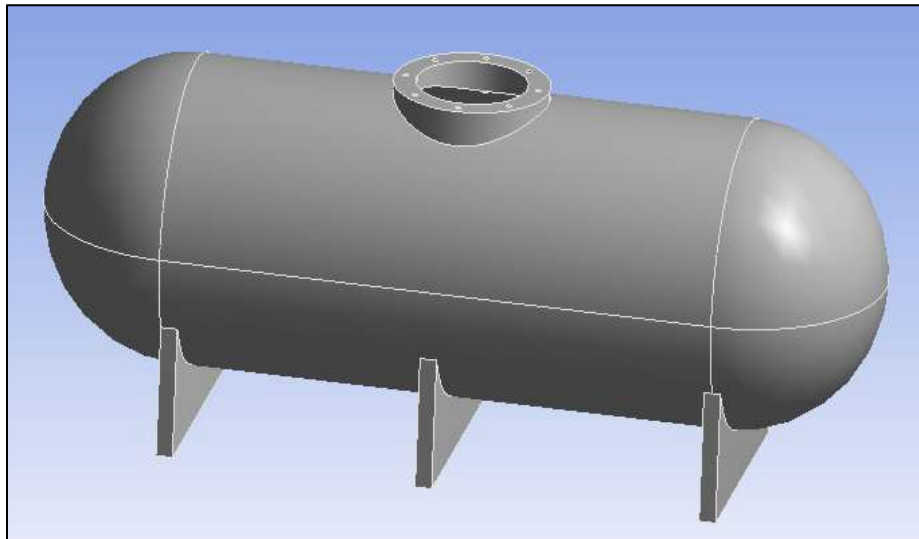
A SOLID 187 is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.

PLANE 183 element is defined by 8 nodes or 6 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 (plane stress, plane strain and generalized plane strain) or as an axisymmetric element. This element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic

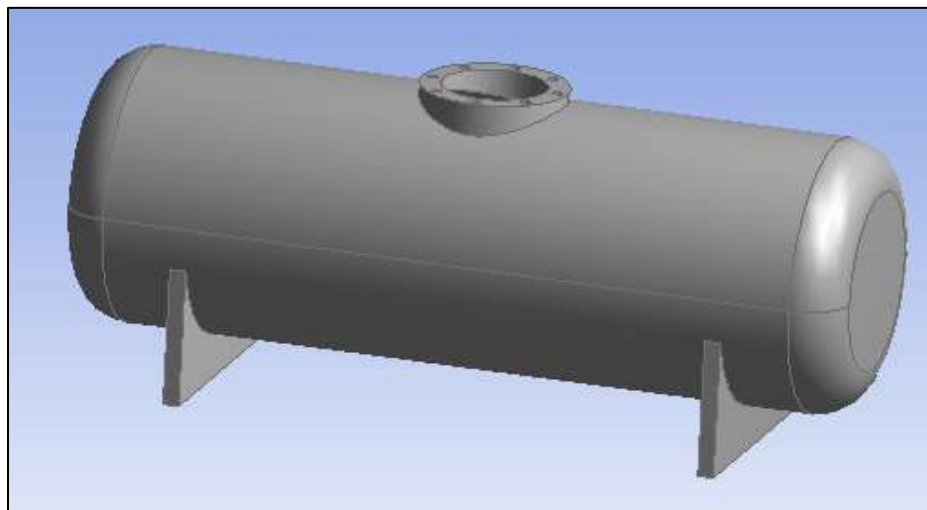
materials, and fully incompressible hyperelastic materials. Figure 4 shows the 10 node tetrahedral SOLID 187 element and 8 node PLANE 183 element.



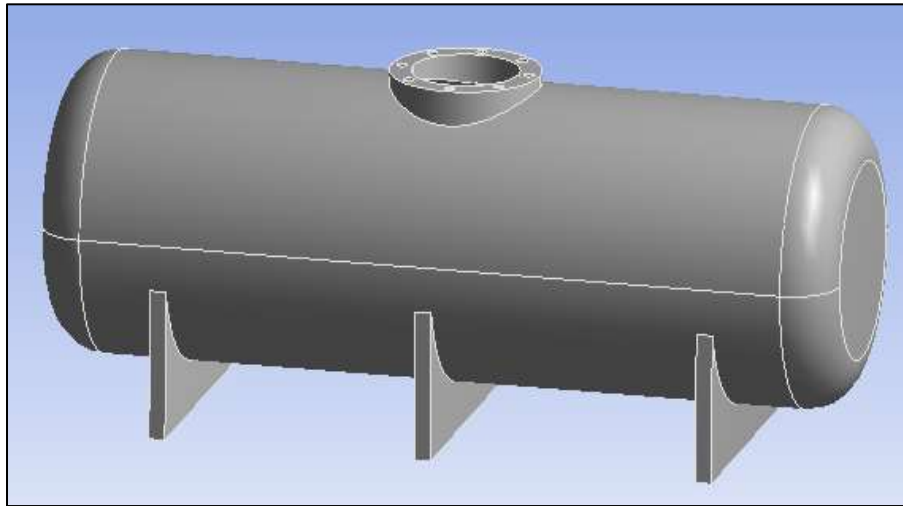
(a) Hemispherical head vessel with two saddle support



(b) Hemispherical head vessel with three saddle support

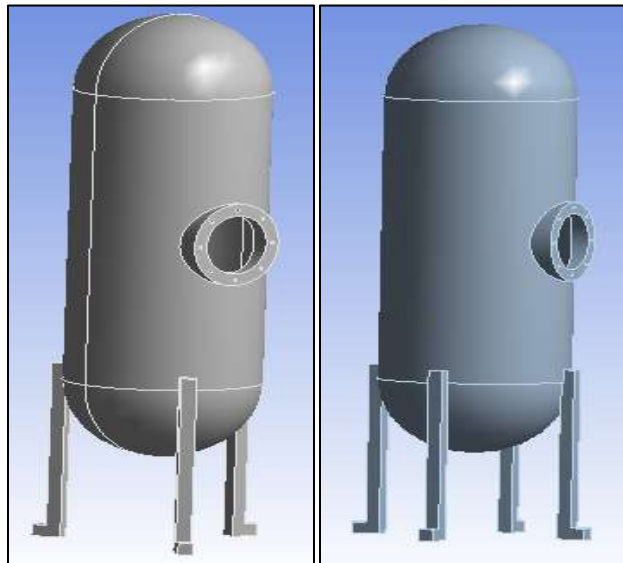


(c) Flat Circular Head with two saddle support

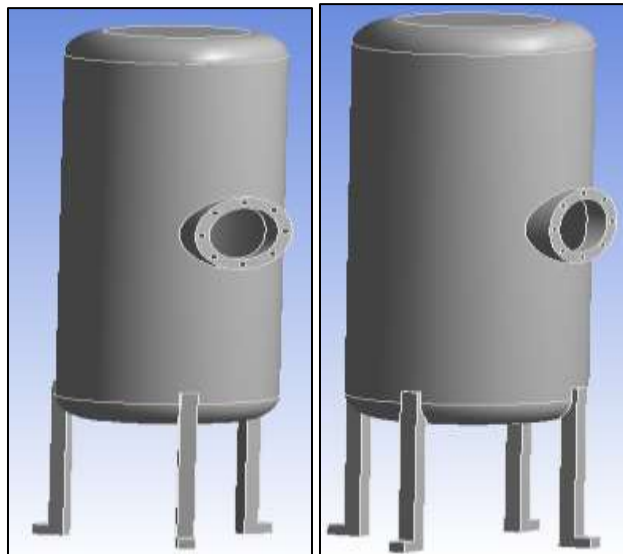


(d) Flat Circular Head with three saddle support

Fig. 1: Pro/E model of horizontal pressure vessel with saddle support



(a) Hemispherical head with three and four leg support



(b) circular head with three and four leg support

Fig. 2: Pro/E model of vertical pressure vessel with leg support having

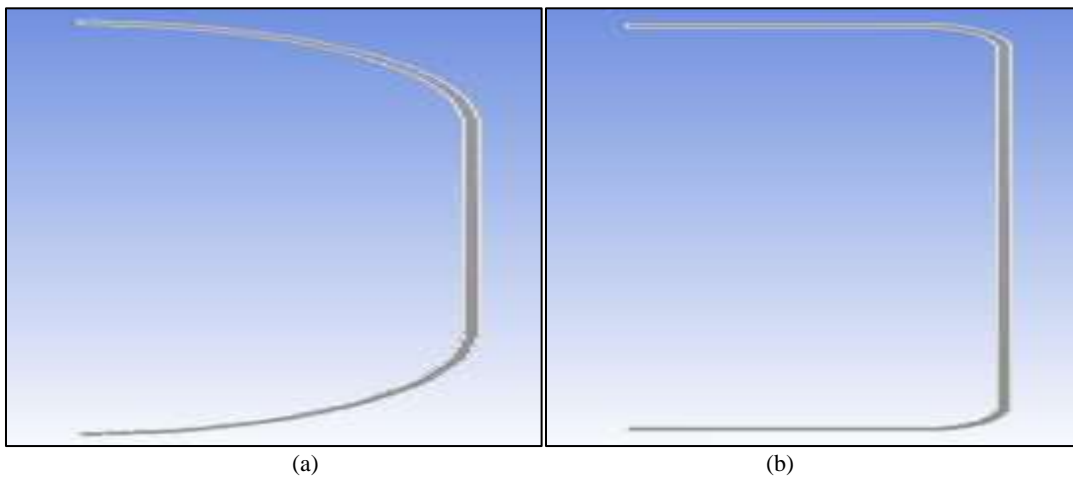


Fig. 3: Axisymmetric model of (a) hemispherical head (b) circular head

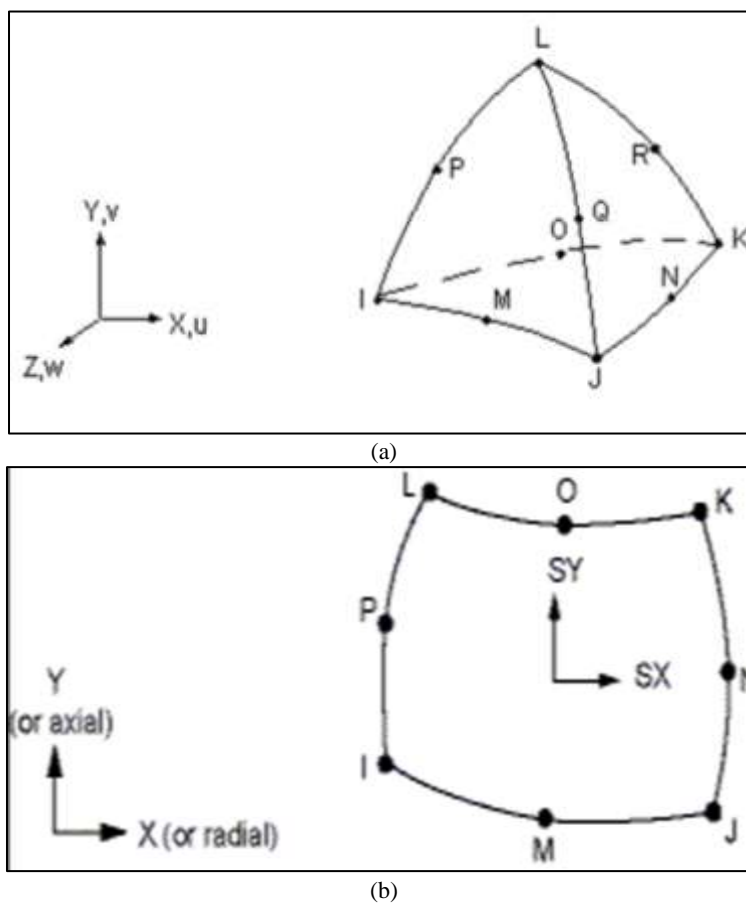
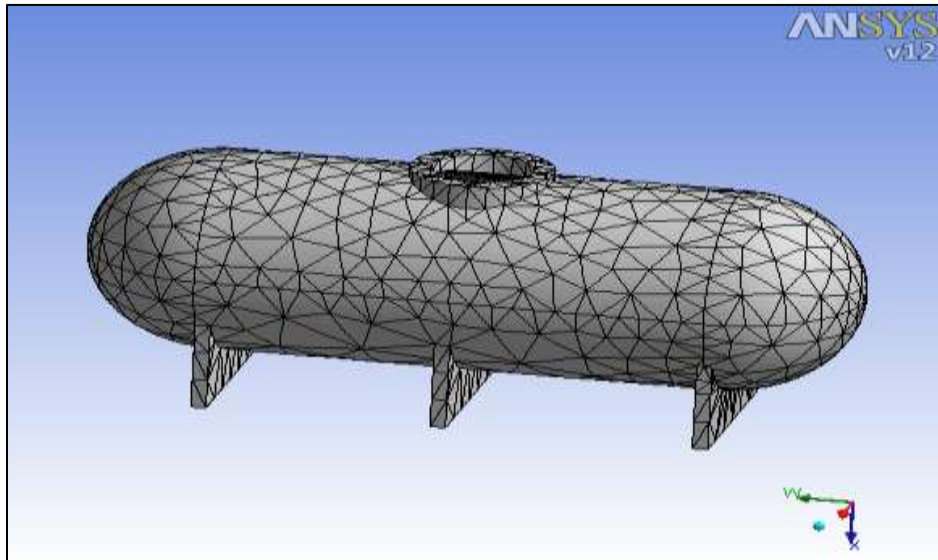
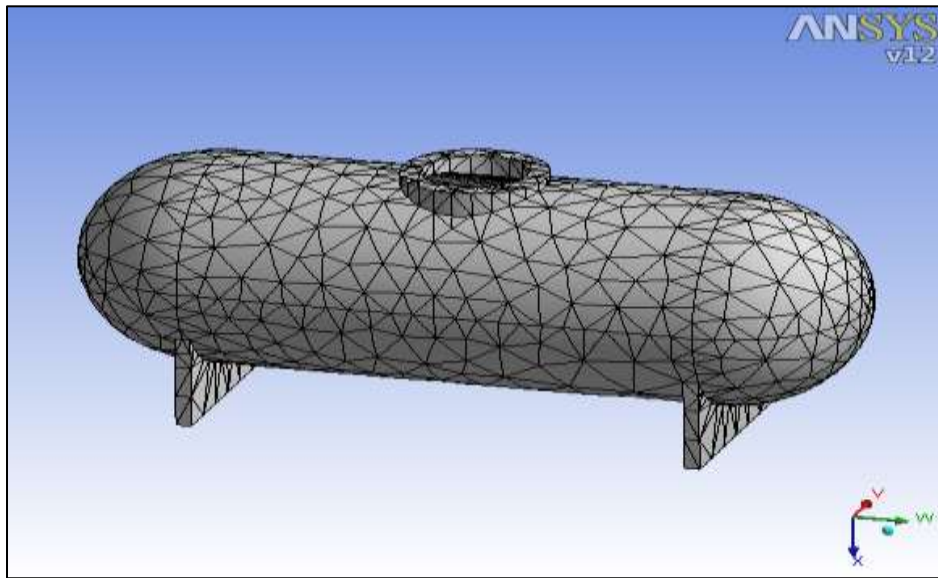
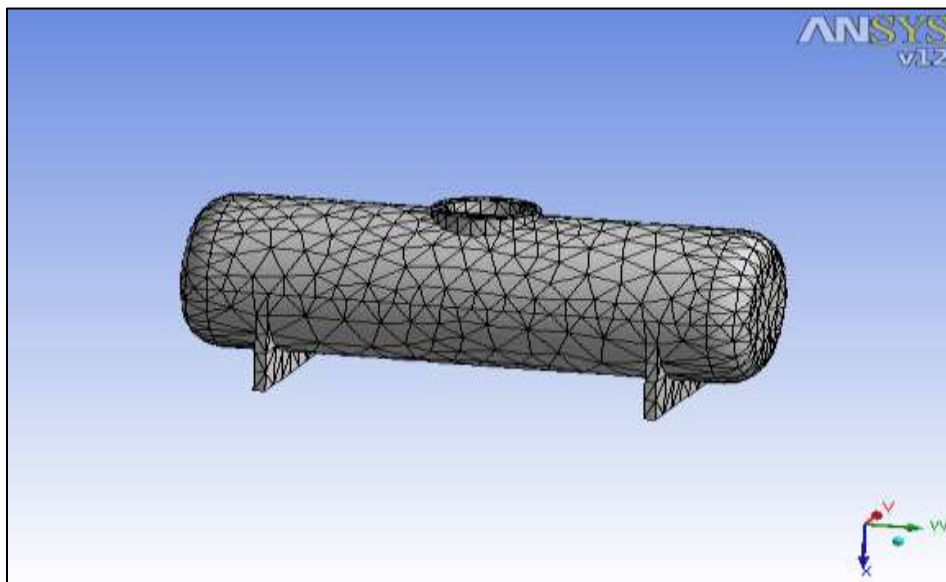


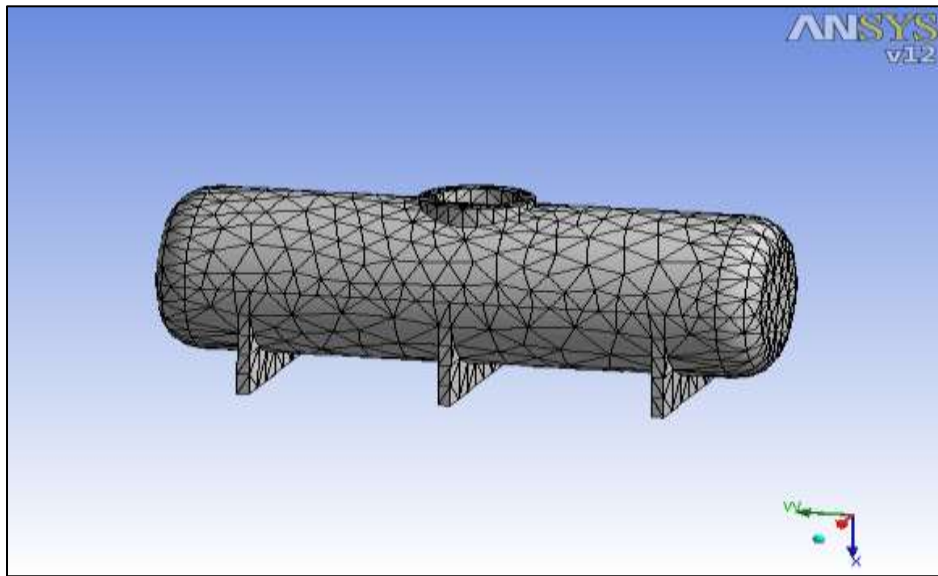
Figure 4: (a) 10 Node Tetrahedral SOLID 187 element (b) 8 Node PLANE 183 element

For the meshing of three dimensional horizontal and vertical pressure vessels, the above described 10 node tetrahedral element is used and for two dimensional axisymmetric model, above describe 8 node PLANE 183 element is used with course meshing. The material properties like modulus of elasticity and poisons ratio is assign to the vessel in engineering data in Ansys. The modulus of elasticity and poisons ratio for the structural steel material is  $200 \times 10^3 \text{ N/mm}^2$  and 0.3 respectively. The FE analysis has been carried out for various saddle supports and for different leg support. Figure 5 shows the mesh model of horizontal pressure vessel with saddle support, figure 6 shows the mesh model of vertical pressure vessel with leg support and figure 7 shows the mesh model of an axisymmetric pressure vessel with different end connection.



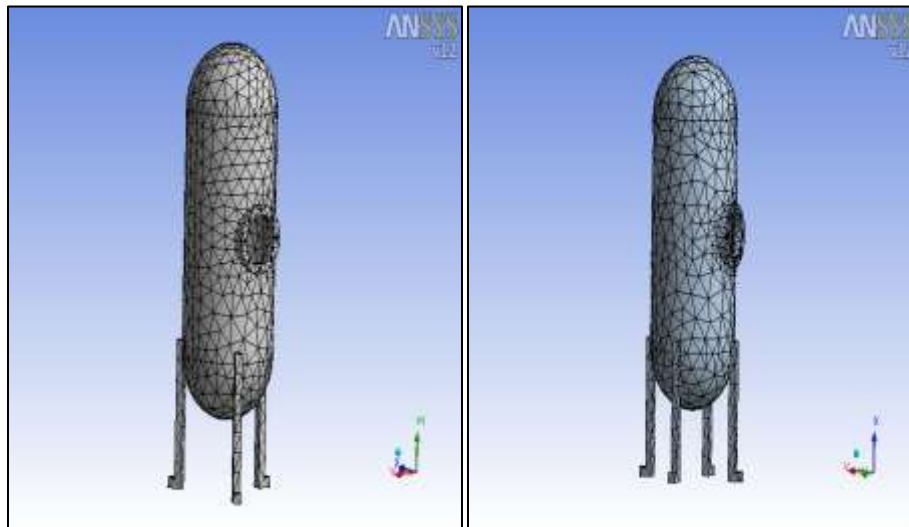
(a) Hemispherical head vessel



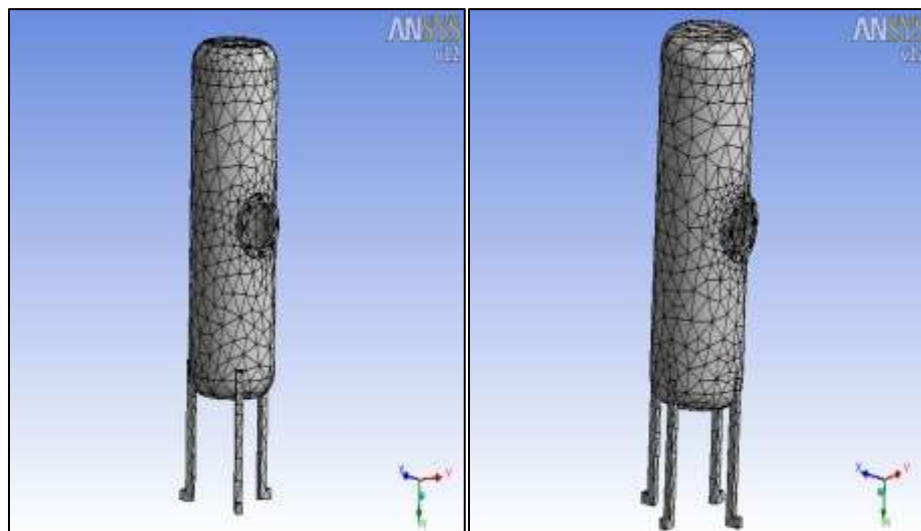


(b) Flat Circular Head

Fig. 5.5: Mesh model of horizontal pressure vessel with saddle support



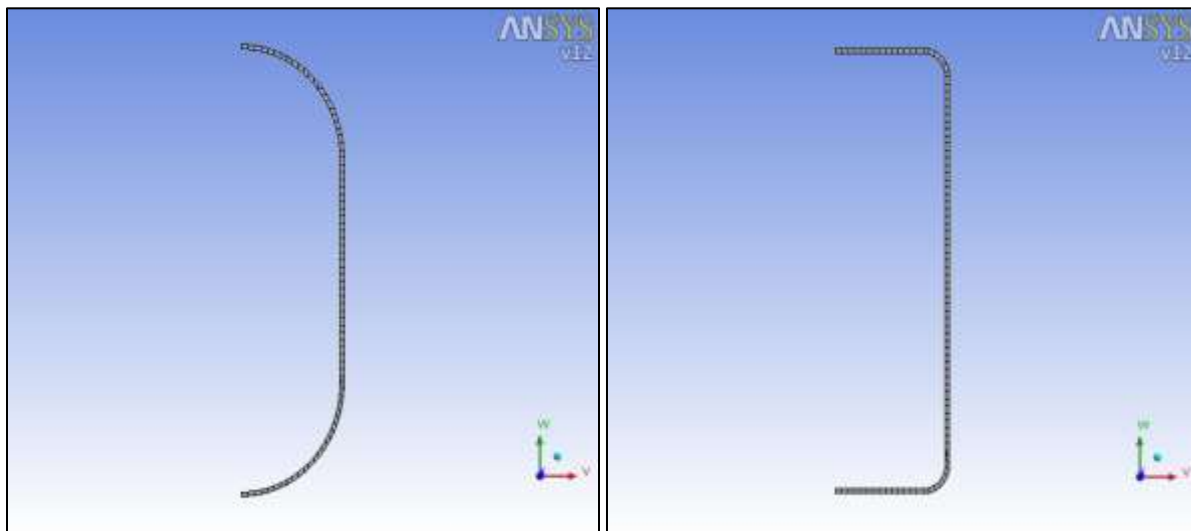
(a) Hemispherical head vessel



(b) Flat Circular Head

Fig. 5.6: Mesh model of vertical pressure vessel with leg support



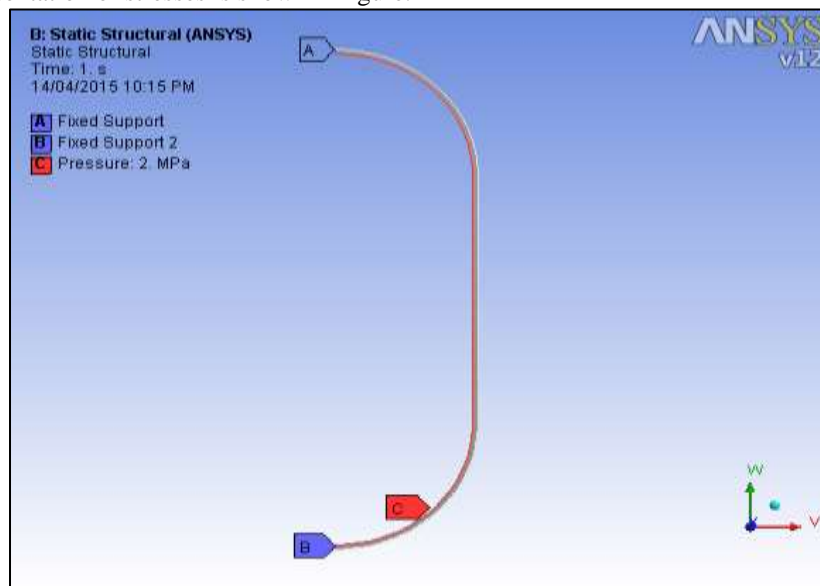


(a) Hemispherical head vessel (b) Flat Circular Head  
Fig. 5.7: Mesh model of axisymmetric pressure vessel

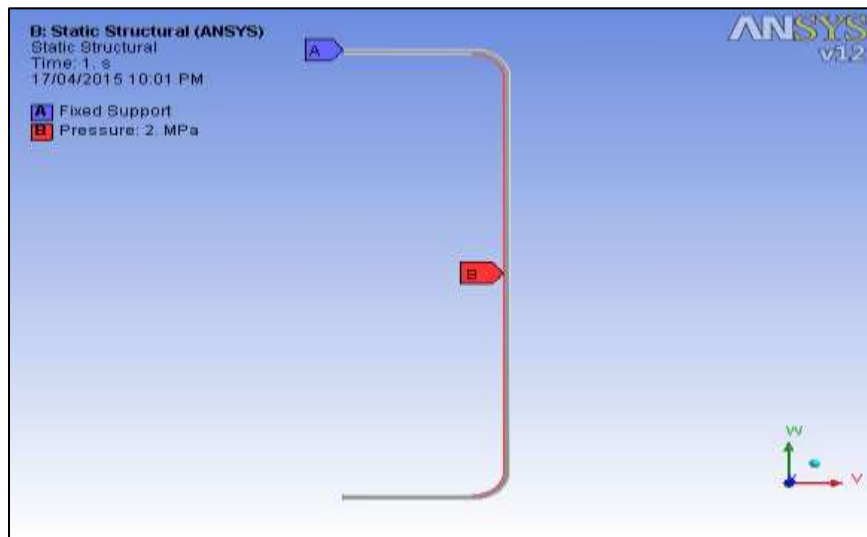
## VI. FE ANALYSIS OF PRESSURE VESSEL

### A. Finite Element Analysis of Axisymmetric Pressure Vessel with Different End Connections

The FE analysis starts with an axisymmetric analysis of pressure vessel. The two dimensional model is prepared in the geometry environment of Ansys 12 which is mesh with 8-node PLANE 183 element. The FE analysis has been carried out on four end connection pressure vessel. In boundary condition, the vessel is supported at the end corners and internal pressure of 2MPa is applied at the inner surface. The boundary condition for hemispherical and flat circular end connection pressure vessels are shown in the figure. The results computed is in the form circumferential and longitudinal stresses shown in figures which indicates for axisymmetric analysis, hemispherical and ellipsoidal end pressure vessel acquires less stress than other ends. The results also computed in equivalent (von mises) stress, maximum principal stress and minimum principal stress are shown in table and graphical representation of stresses is shown in figure.

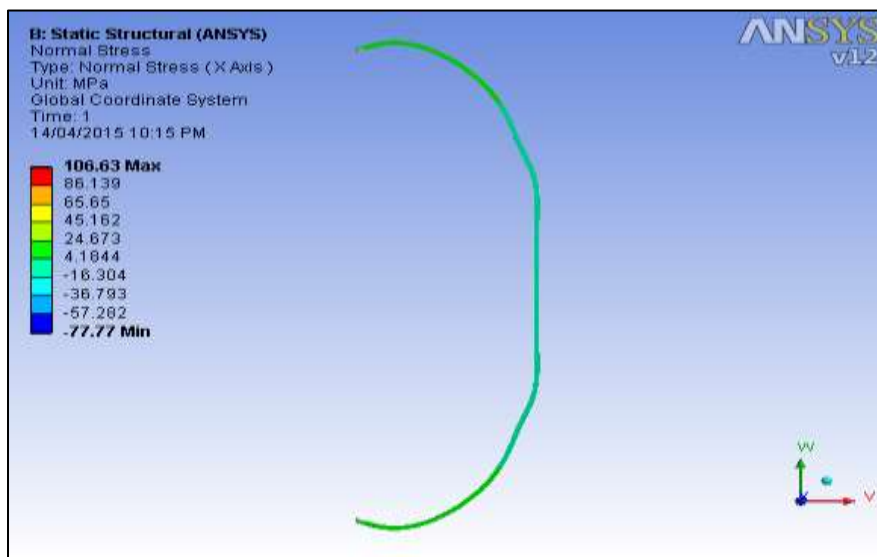


(a) Hemispherical end

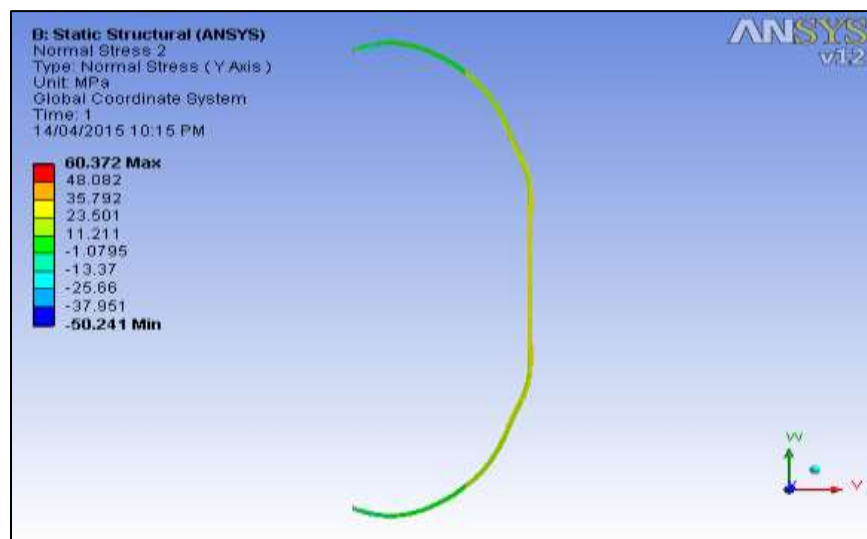


(b) Flat circular end

Fig. 1: Boundary condition for axisymmetric pressure vessel



(a) Circumferential Stress



(b) Longitudinal Stress

Fig. 2: Circumferential and longitudinal stress on hemispherical end pressure vessel

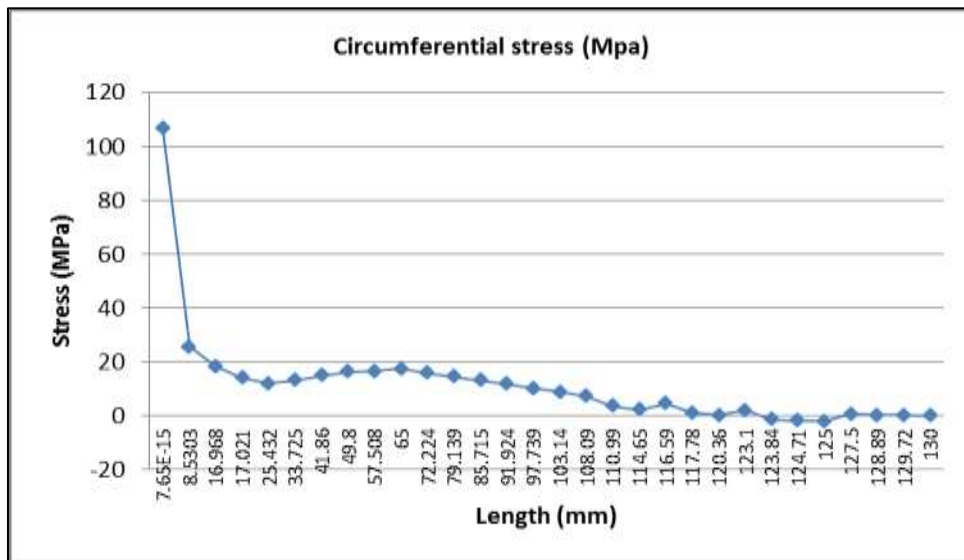


Fig. 3: Circumferential stress (Mpa)

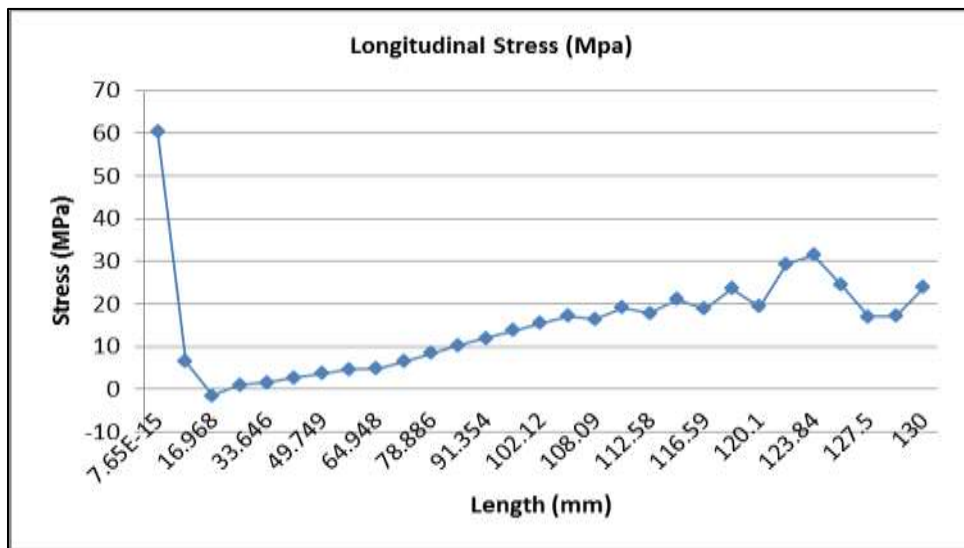
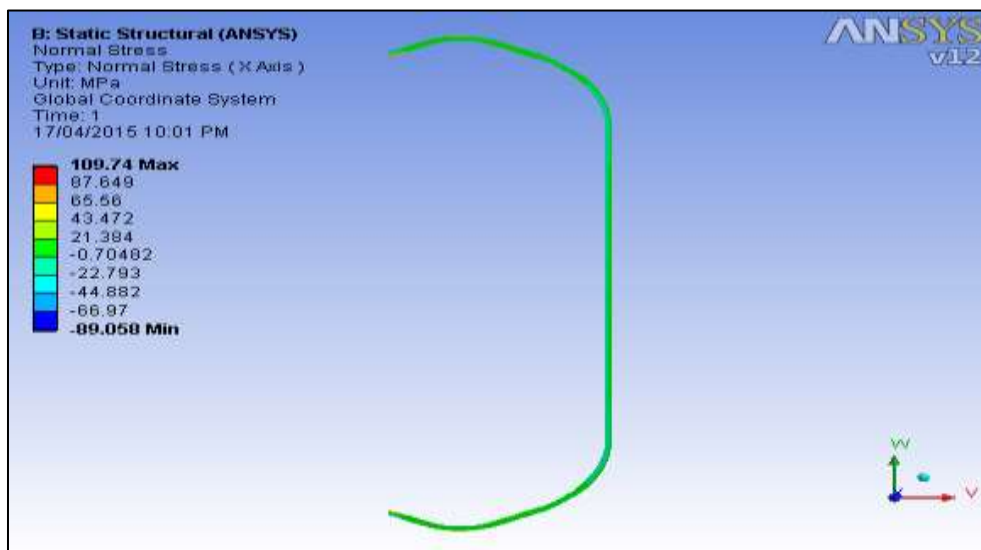
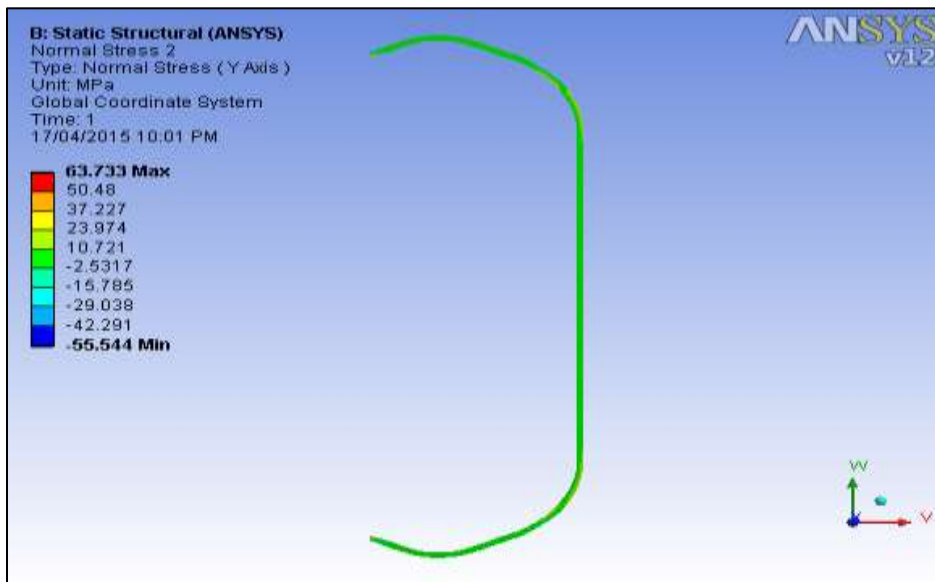


Fig. 4: Longitudinal Stress (Mpa)



(a) Circumferential Stress



(b) Longitudinal Stress

Fig. 5: Circumferential and longitudinal stress on flat circular end pressure vessel

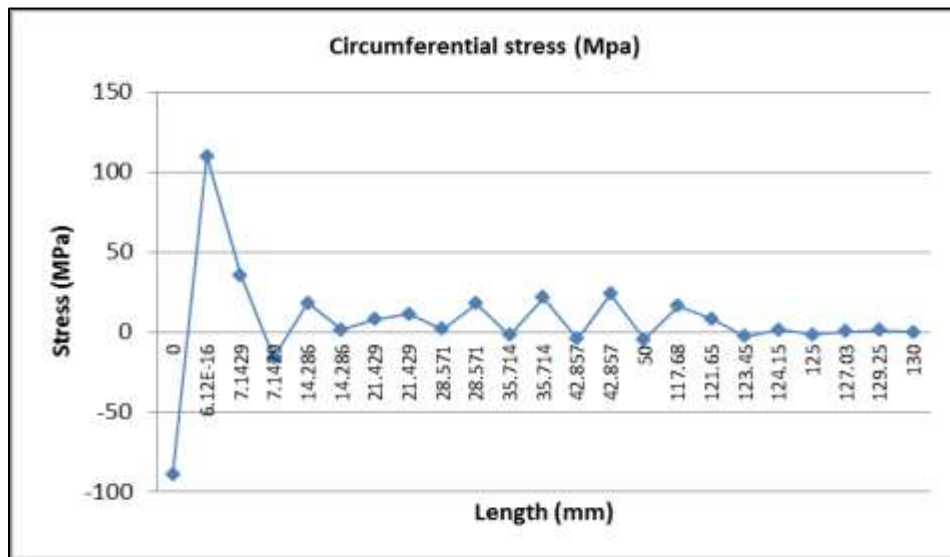


Fig. 6: Circumferential stress (Mpa)

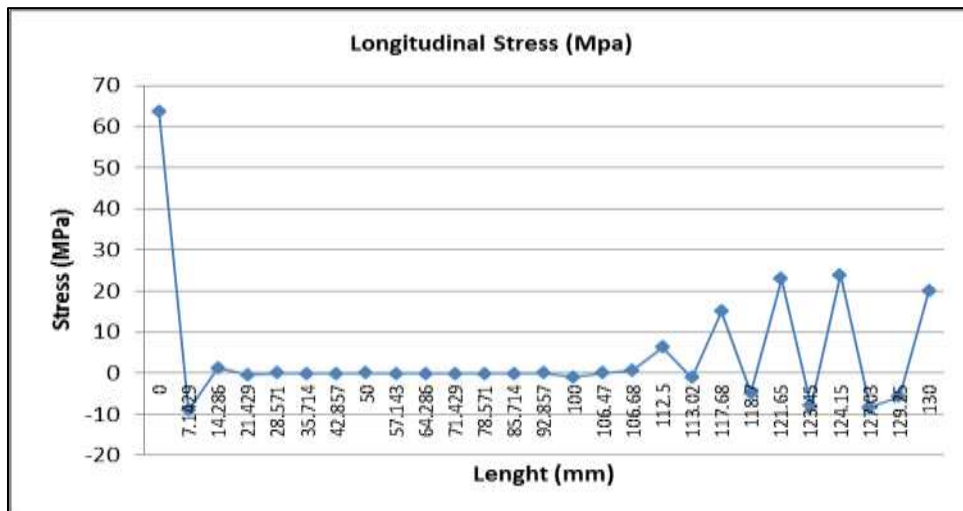


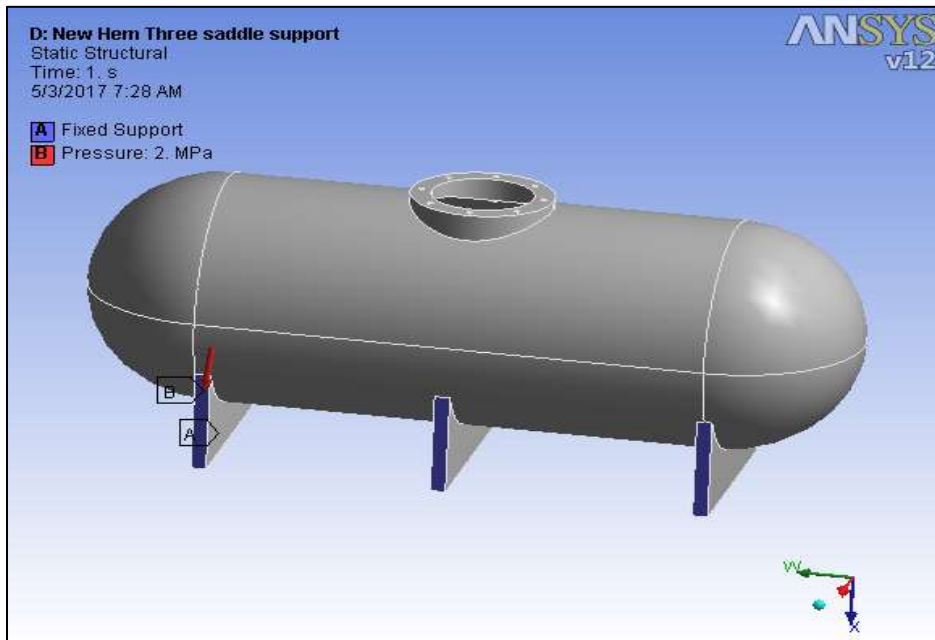
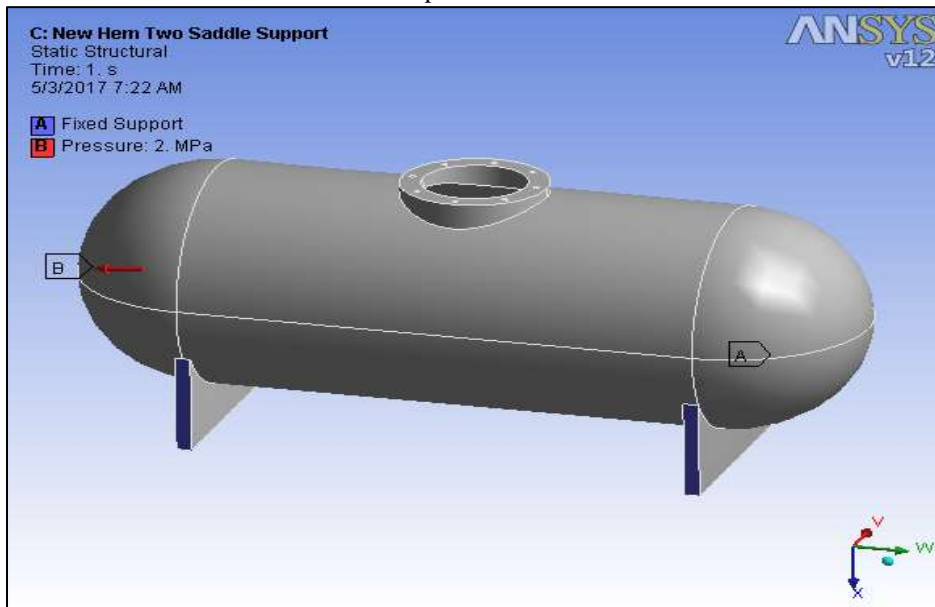
Fig. 4: Longitudinal Stress (Mpa)

Table – 1  
Finite Element Analysis of 2-D Axi-symmetric Pressure Vessel using Ansys

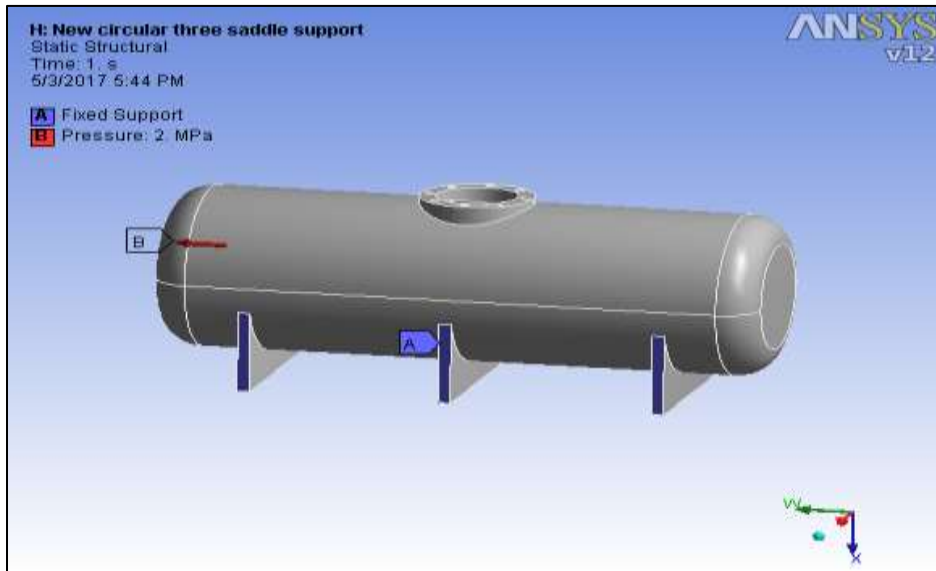
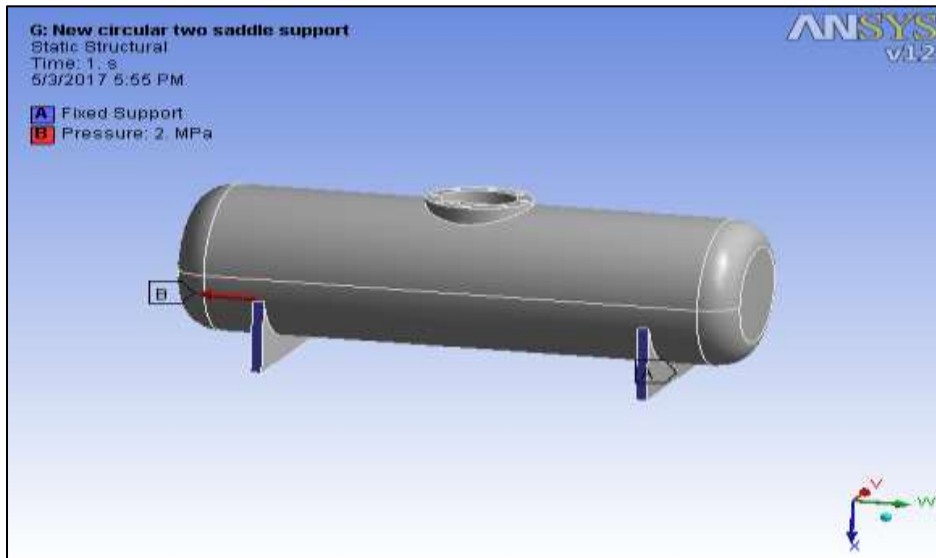
Sr. No.	Type of Pressure Vessel	Von mises stress (MPa)	Normal Stress (x) MPa	Normal Stress (y) MPa	Maximum Principal Stress (MPa)	Minimum Principal Stress (MPa)	Stresses on end connection
1	Hemispherical	71.35	106.63	60.372	125.05	41.95	48.075
2	Flat Circular	75.121	109.74	63.73	128.02	45.45	101.76

**B. Finite Element Analysis of Horizontal Pressure Vessel with Saddle Support**

At first, FE analysis of horizontal pressure vessel with saddle support having distance of 500 mm between two saddle has been carried out by applying boundary condition of fixed support at bottom and side face of saddle and pressure of 2 MPa is applied at internal diameter of vessel normal to the surface. Boundary condition for all ends is shown in figure and results obtained is in the form of circumferential and longitudinal stress is shown in figure for hemispherical and flat circular end vessel respectively. Also FE analysis of horizontal pressure vessel with three saddle support with distance of 250 mm each has been carried out and the results are compared. The results are shown in table and graphical representation of stresses for all end connections is shown in figure which shows that the stresses are minimum for hemispherical end.

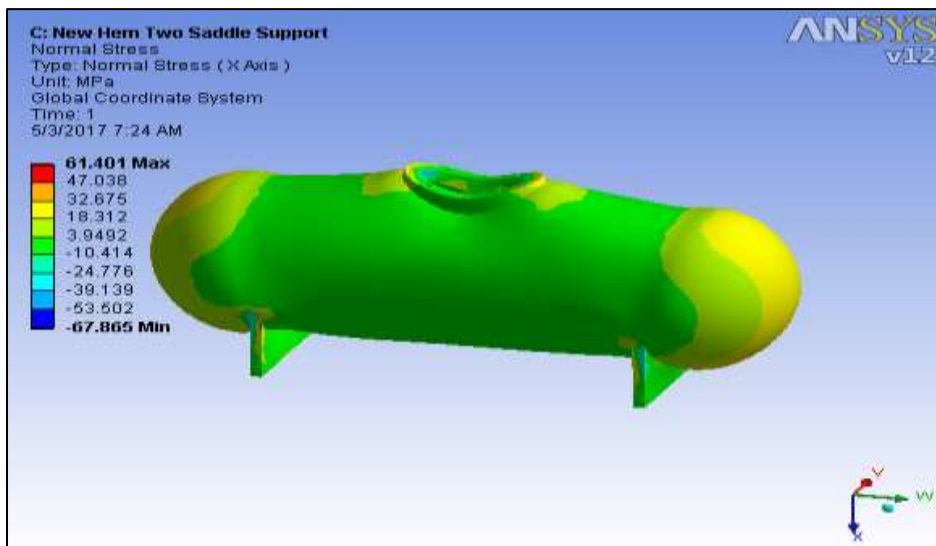


(a) Hemispherical end

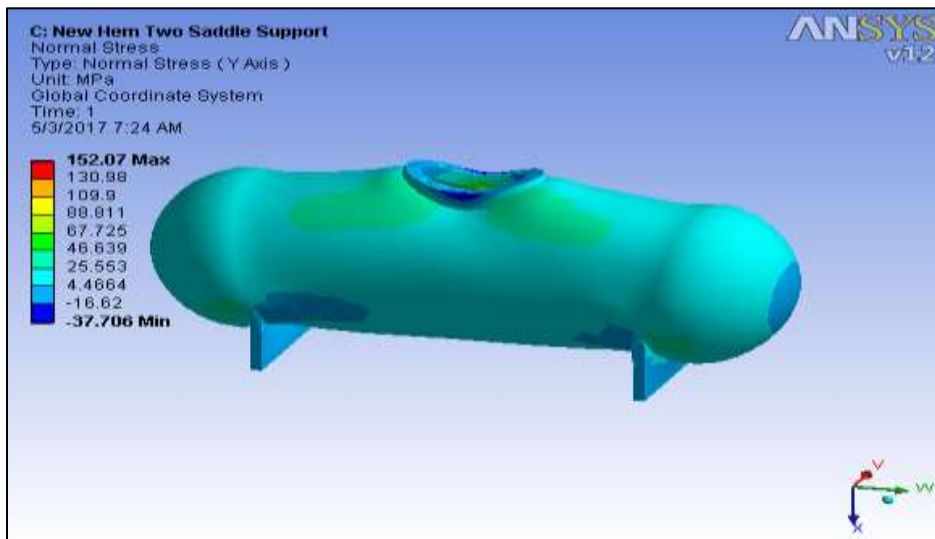


(b) Flat circular end

Fig. 6.7: Boundary condition for axisymmetric pressure vessel

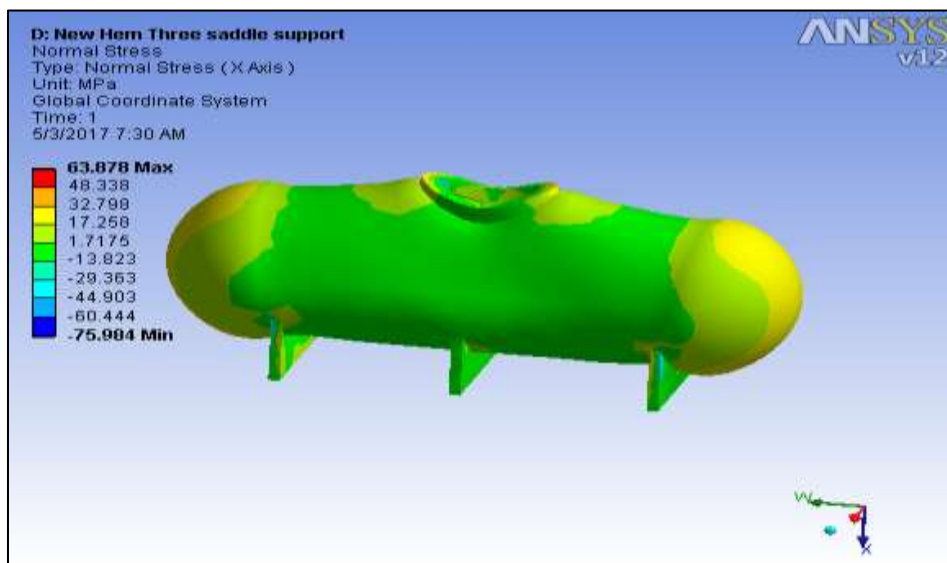


(a) Circumferential stress

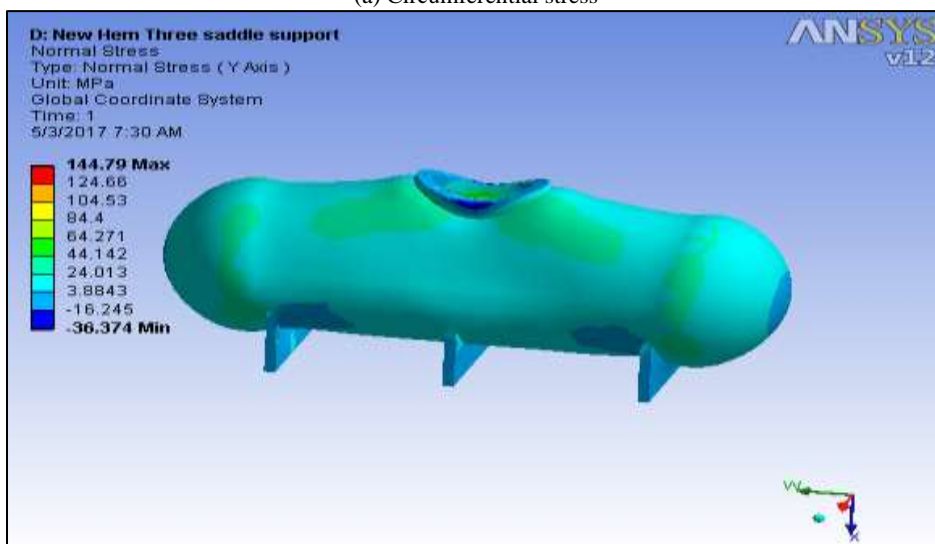


(b) Longitudinal stress

Fig. 6.8: Circumferential and longitudinal stresses on hemispherical end pressure vessel with two saddle support



(a) Circumferential stress



(b) Longitudinal stress

Fig. 6.8: Circumferential and longitudinal stresses on hemispherical end pressure vessel with three saddle support

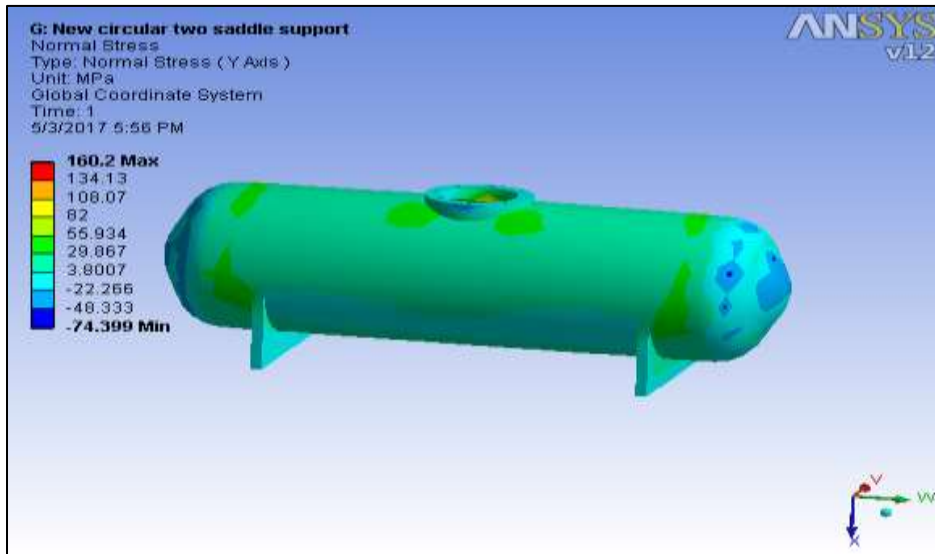
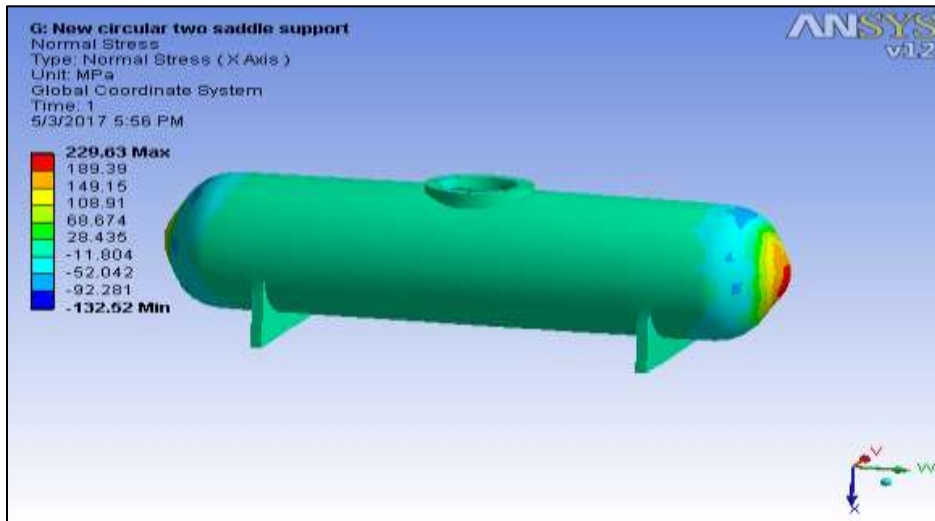
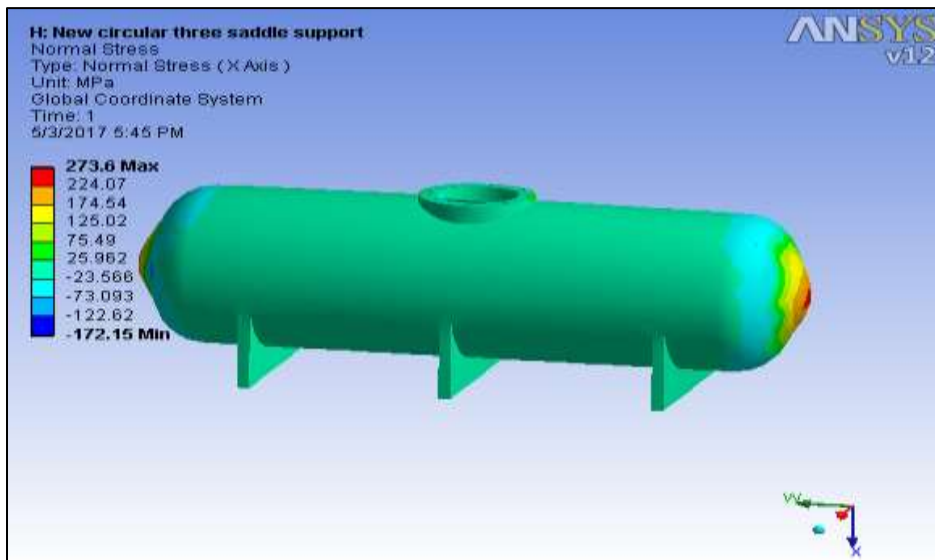
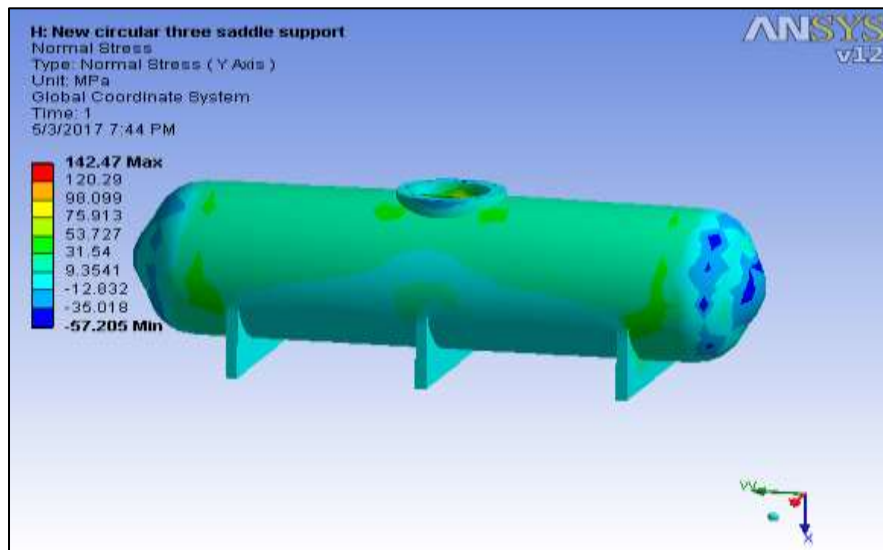


Fig. 6.9: Circumferential and longitudinal stresses on flat circular end pressure vessel with two saddle support







(b) Longitudinal stress

Fig. 6.10: Circumferential and longitudinal stresses on flat circular end pressure vessel with three saddle support

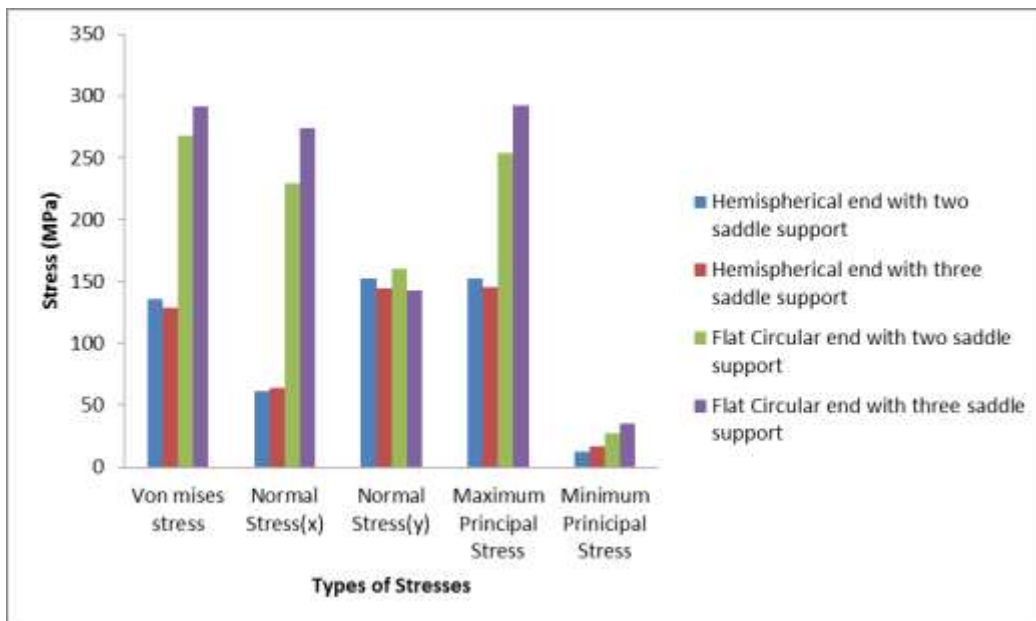


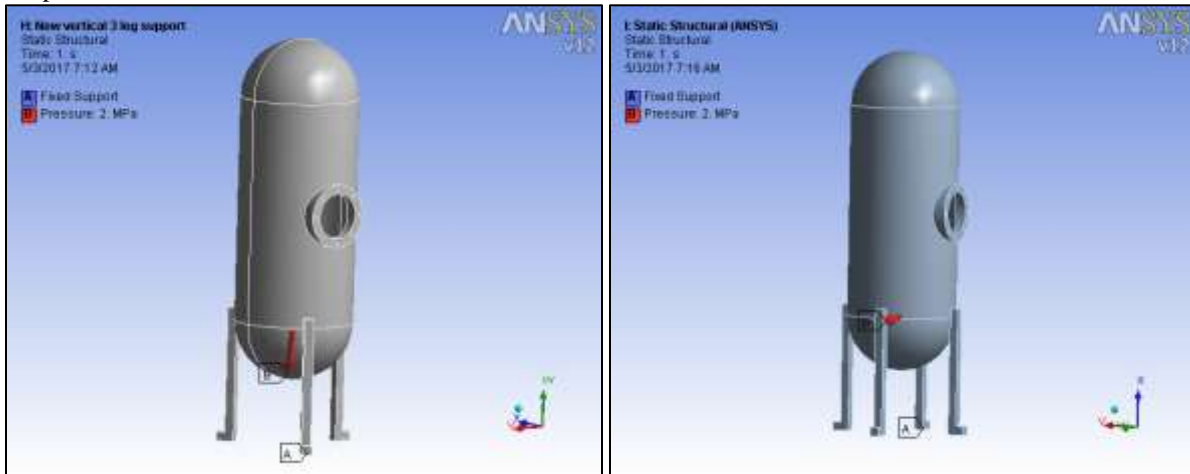
Table 2: Finite Element Analysis of Horizontal Pressure Vessel with Saddle Support

Sr. No.	Type of Pressure Vessel	Von mises stress	Normal Stress(x)	Normal Stress(y)	Maximum Principal Stress	Minimum Principal Stress
1	Hemispherical end with two saddle support	135.54	61.401	152.07	152.46	12.4
2	Hemispherical end with three saddle support	128.83	63.878	144.79	145.15	16.986
3	Flat Circular end with two saddle support	268.18	229.63	160.2	254.23	27.573
4	Flat Circular end with three saddle support	291.09	273.6	142.47	292.09	34.708

## VII. FINITE ELEMENT ANALYSIS OF VERTICAL PRESSURE VESSEL WITH STRAIGHT LEG SUPPORT

After stress distribution over horizontal pressure vessel, the FE analysis has been carried over vertical pressure vessel having three and four straight legs support. The legs are attached to the cylinder at equal angular interval which are fixed at the bottom end and pressure of 2MPa is applied at inside surface of vessel during boundary condition. Figure 6.18 shows boundary condition for hemispherical and flat circular end vertical pressure vessel. Due to internal pressure, circumferential and

longitudinal stresses are acting along the x and y axes normally on each vessel are shown in following figure. The tabulated result shown in table indicates that flat circular vertical pressure vessel acquires very high stress on the body. So it is permissible to use hemispherical end for vertical vessel.

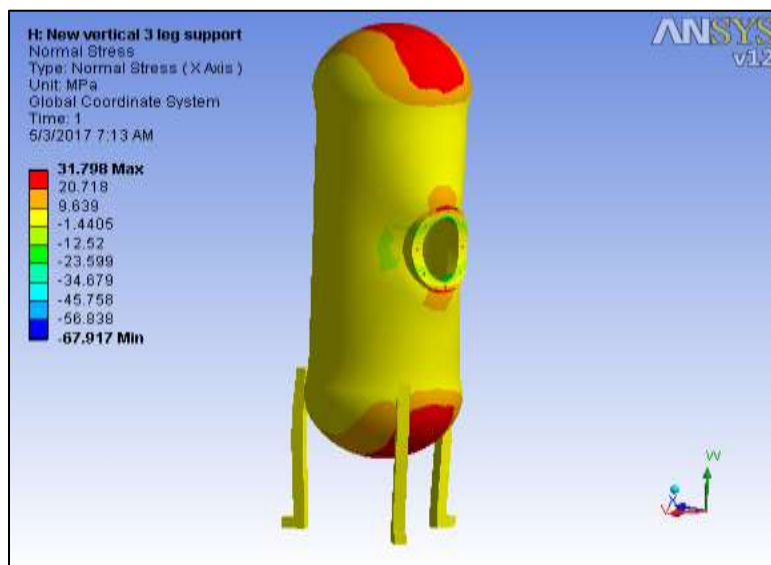


(a) Hemispherical end



(b) Flat circular end

Fig. 6.18: Boundary condition for vertical pressure vessel having different hemispherical and flat circular connections with three and four leg support



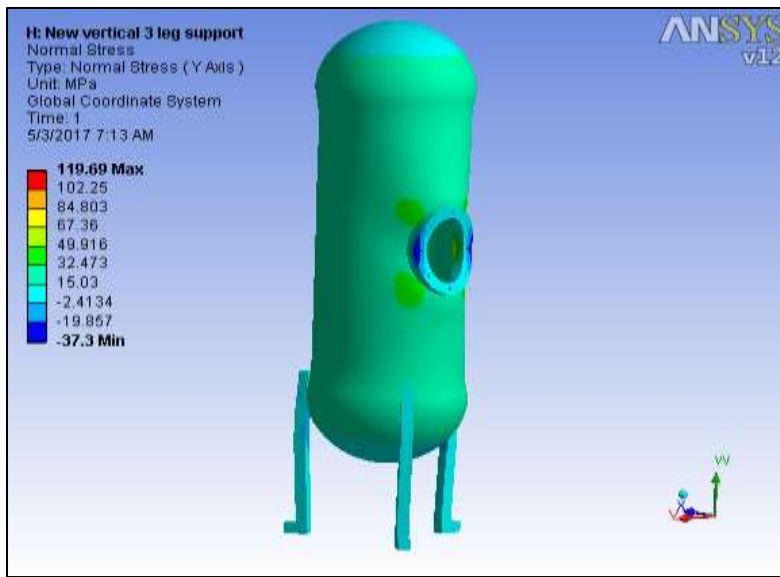


Fig. 6.19: Circumferential and longitudinal stress on hemispherical end vertical pressure vessel with three leg support

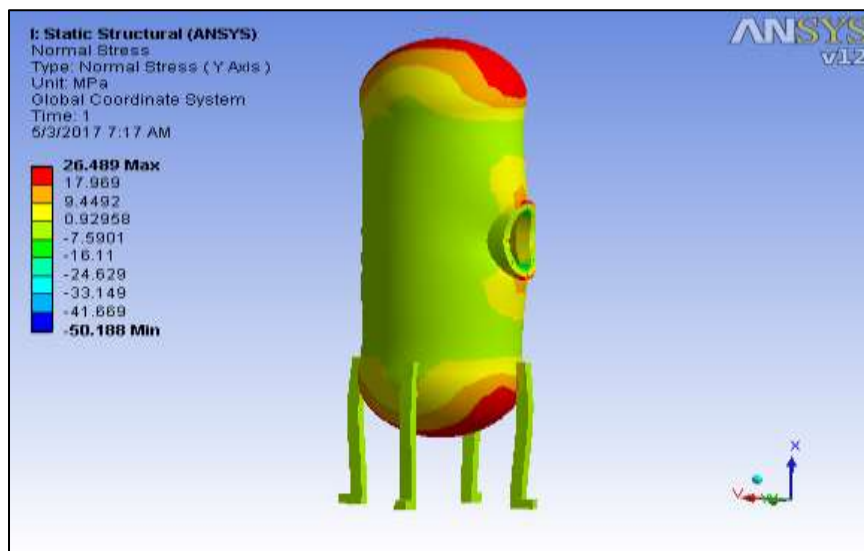
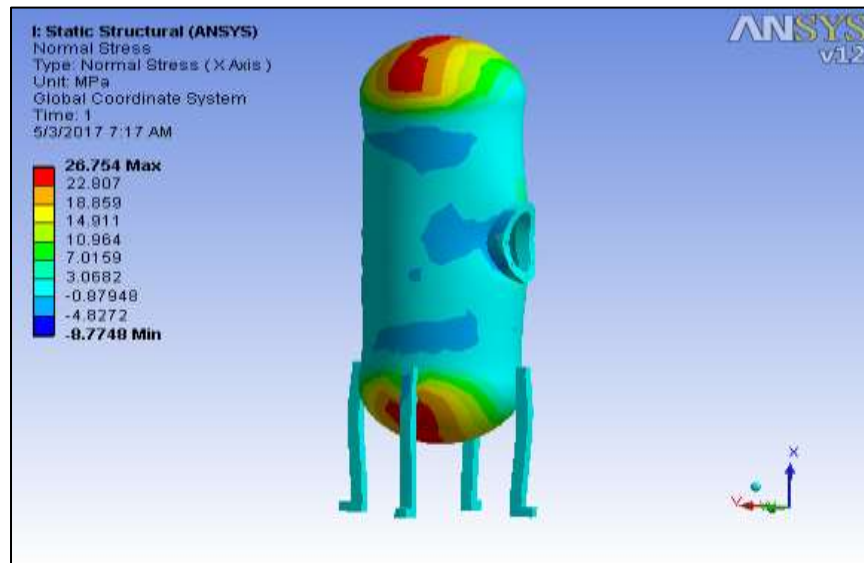


Fig. 6.20: Circumferential and longitudinal stress on hemispherical end vertical pressure vessel with four leg support

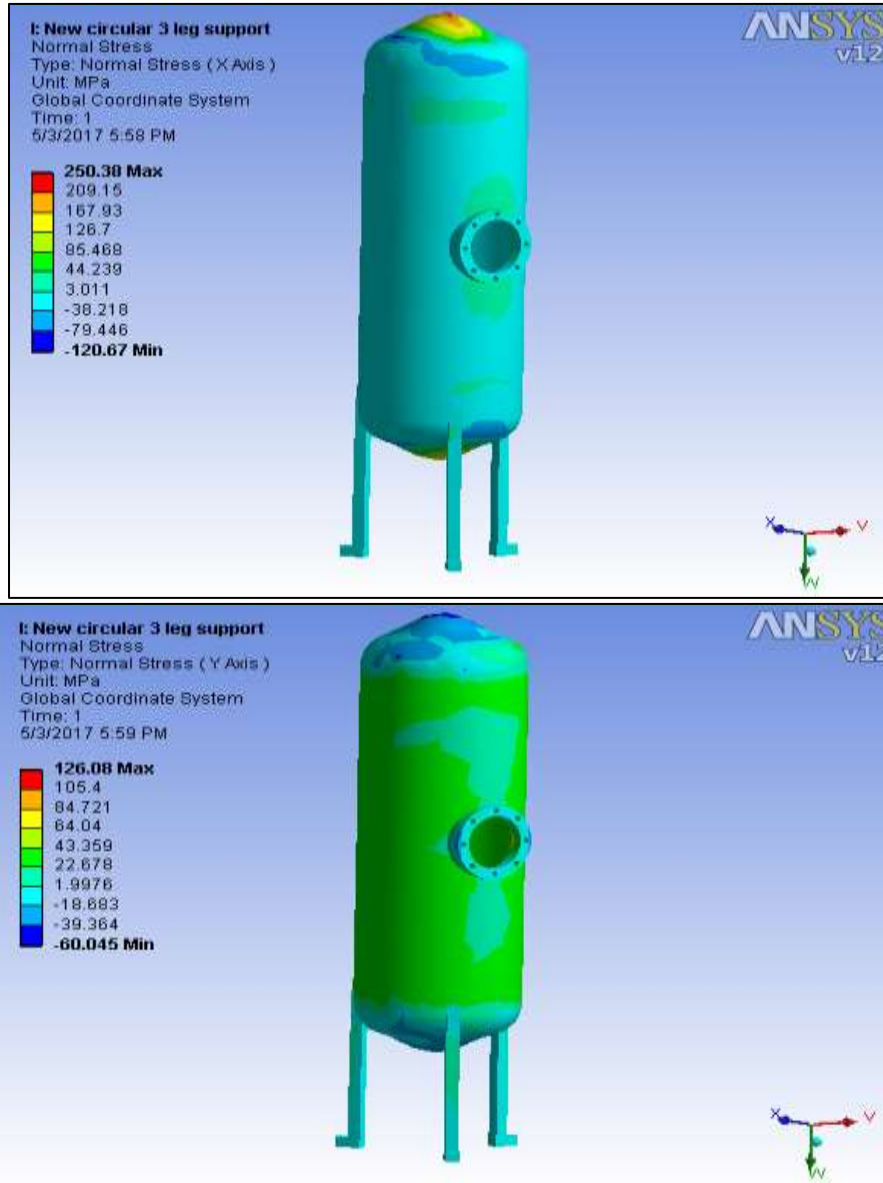


Fig. 6.21: Circumferential and longitudinal stress on flat circular end vertical pressure vessel with three leg support

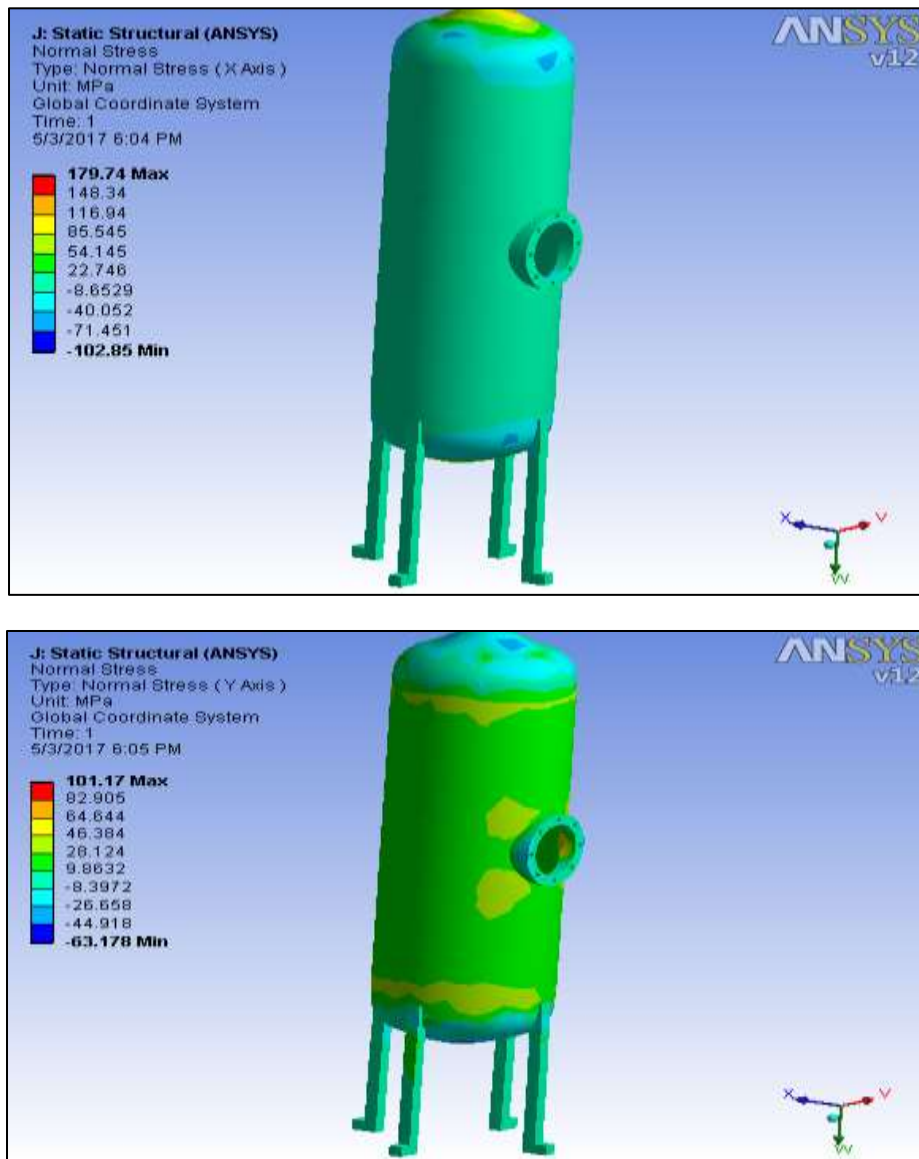
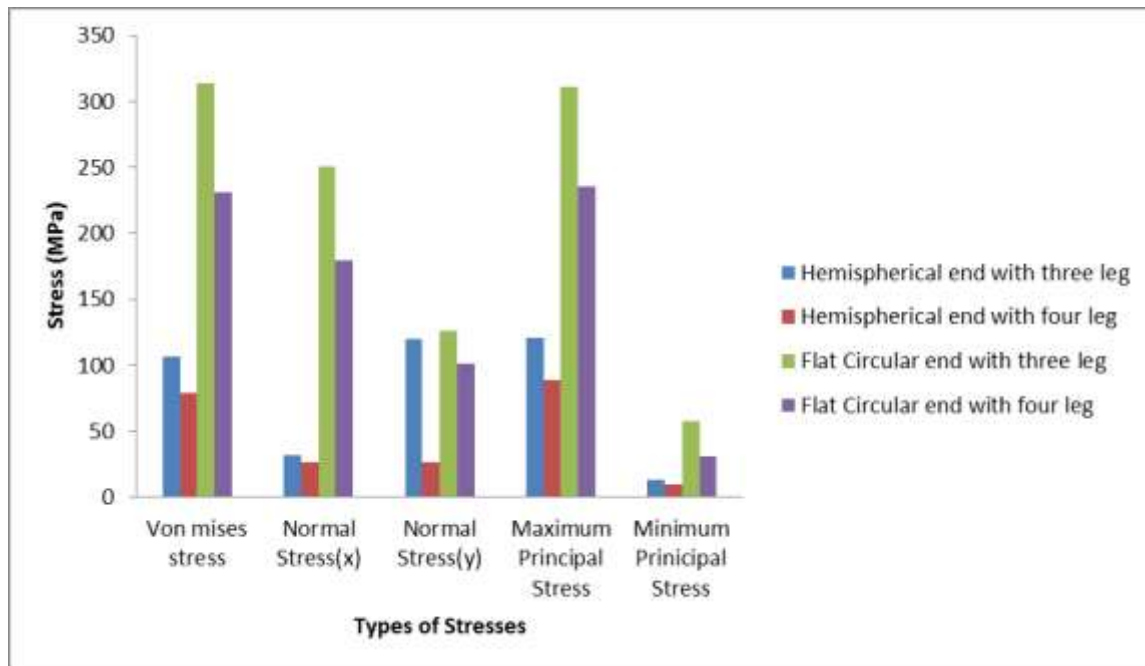


Fig. 6.22: Circumferential and longitudinal stress on flat circular end vertical pressure vessel with four leg support

Table - 6.4  
Finite Element Analysis of Vertical Pressure Vessel with three Leg Support

Sr. No.	Type of Pressure Vessel	Von mises stress	Normal Stress(x)	Normal Stress(y)	Maximum Principal Stress	Minimum Principal Stress
1	Hemispherical end with three leg	106.77	31.798	119.69	120.37	13.044
2	Hemispherical end with four leg	79.038	26.754	26.489	88.996	9.75
3	Flat Circular end with three leg	313.3	250.38	126.08	311.05	57.401
4	Flat Circular end with four leg	230.71	179.74	101.17	235.53	30.864



### VIII. RESEARCH METHODOLOGY

This section highlights the research methodology for the present study. It explains the research objectives and a suitable methodology to achieve those objectives. The objective of this research is to study the effect of fluid pressure on end connection of pressure vessel specifically on hemispherical and flat circular using analytical and numerical techniques. The possible reason of failures in pressure vessel is mainly due to material composition/defects, noncompliance with design specifications, variable loads and its effects. The various stages of present research and methods used for the analysis are as follows.

- Study of different pressure vessels with different end connections and observations of its design consideration.
- Selection of pressure vessel for analysis purpose with its technical specifications.
- Static stress analysis of pressure vessel with hemispherical and flat circular end.
- For static analysis, analytical equations based on design of machine elements are used. For numerical analysis, finite element method is used.
- Finite element method is used to determine the longitudinal and circumferential stresses in pressure vessel.
- For CAD modeling of pressure vessel, modeling software Creo- Parametric 2.0 from PTC Enterprises and for finite element analysis, ANSYS 12.0 from ANSYS, Inc. is used.

### IX. CONCLUSION

In this project the various activities that are involved are:

- The various types of end connections are studied and required modifications are done for better functioning of pressure vessels.
- Horizontal pressure vessels are analysis for three different curved saddle supports and vertical pressure vessels for three different lengths of legs.
- CAD model generation.
- Finite element model generation (Pre-Processing).
- FE analysis of two dimensional axis symmetric and 3-D analysis of pressure vessel for flat circular and hemispherical end connections.
- Finite Element analysis of pressure vessel with hemispherical and flat circular end.
- FEA of the updated design.

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