# Analysis of Toroidal Pressure Vessels with and without holes Using PreWin

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***Abstract* - The design of pressure vessels for operating at very high pressure is a complex problem. The pressure vessels used in wide applications such as in thermal and nuclear power plants, in chemical industries, in space and ocean depths, in hydraulic units of aircrafts and fluid supply systems in industries. The pressure vessels have different shape of opening like manholes, hand holes, and nozzles and have different size of opening such as small drain to full vessel size opening with body flange. The opening cannot be avoided in the pressure vessels because of various piping attachment. Due to openings in the vessels shell around the opening are weakened. This cause stress concentration because of geometrical discontinuity in the vessels. Such discontinuities are called as stress raiser and region in which they occur is called the area of stress concentration. Stress concentration factor is used to quantify how the stress is concentrated in a component. So the present study makes an attempt to find the effect of diameter and position of openings on toroidal pressure vessels. The pressure vessels shall be analyzed by using PreWin, a graphical pre and post processor for the structural analysis software FEAST (Finite Element Analysis of Structures). The toroidal shell is idealized with various elements like 4 / 8 noded solid of revolution and shell/ solid elements using FEAST and results compared with those obtained using analytical values. This paper is an attempt to study of the effect of openings of 10 mm to 150 mm on toroidal pressure vessels. Also find out the variation of stress concentration factor for different diameter of hole. To find the effect of position of hole, the holes of different diameters are placed at two different locations of the shell.***

***keywords* - FEASTSMT, PreWin,stress concentration, stress concentration factor,shell element,openings, toroidal pressure vessels.**

## INTRODUCTION

PRESSURE vessel is defined as a container with a pressure differential between inside and outside. Pressure vessels often have a combination of high pressures together with high temperatures and in some cases flammable fluids orhighly radioactive materials. The design is such that the pressure vessels should withstand design pressure without any leak. Pressure vessels are used in a number of industries like, power generation industry for fossil and nuclear power, the petrochemical industry for storing, in hydraulic units for aircraft and Solid Rocket motor cases, liquid pressure vessels as storage tanks for launch vehicles in space industry, and processing crude petroleum oil in tank farms as well as storing gasoline in service stations.
Toroidal vessels are commonly used for the storage of pressurized fluids in automotive and aerospace applications due to their optimal use of space. Here, the aim is to provide insight into the effect of openings on toroidal pressure vessels.

Openings in pressure vessels in the regions of shells or heads are required to serve the following purposes;
i) Man ways (for maintenance and repair),
ii) Holes for draining or cleaning the vessel,
iii) Hand hole openings (for inspecting the vessel from outside,
iv) Nozzles attached to pipes to convey the working fluid inside and outside of the vessel. The stress levels at the opening will be peak due the removal of the material and hence will lead to weak region of the total structure. So the stress concentration at these locations should be estimated for the safe design of pressure vessels. The amount of weakening is dependent on (i) Diameter of hole, (ii) The number of holes, (iii) Spacing of holes (iv) Location of hole.

## OBJECTIVES

Familiarization of software PreWin, the Graphical User Interface (GUI) based pre & post Processor of FEAST$^{SMT}$ , structural analysis software developed by scientists of VSSC/ISRO based on Finite Element Method (FEM).
To conduct structural analysis using PreWin for toroidal pressure vessel by varying the diameter of hole.
Conduct a study on the effect of diameter of hole on stress concentration factor around the holes.
To study the effect of position of openings on displacement and stress around the hole region.

## METHODOLOGY

Toroidal shell without hole and the loads (ie. internal pressure) is axisymmetric in nature was analyzed and the results were compared with theoretical values available in literature survey. The analysis was performed for both 4 noded and 8 noded shell element and the results were compared so that the suitable element can be selected for further analysis. Then the analysis is done for toroidal shell with hole diameters varying from 10 mm to 150 mm at two locations were selected for placing these holes. Here the assumption is that the toroidal shell is planned to made of top/bottom half of the shell and then welded in the inner / outer curvature. These positions are called the long seam inner (LSI) and outer(LSO) portions.

## MODEL

In order to calculate the stresses in the region of hole, three finite element models have been used.

Toroidal pressure vessel one quarter portion without hole (shown in Fig.1, 2) Toroid with circular holes of diameters 10 mm to 150 mm placed at outer (LSO) region (shown in Fig.2), 3) Toroid with circular holes of diameters varying from 10 mm to 150 mm placed at inner(LSI) region of the pressure vessel(shown in Fig.3).

Toroid without hole is an example for axisymmetric shell of revolution. So it can also be modeled as axisymmetric shell of revolution.

## MESHING

For uniform toroid hole, both 4 noded and 8 noded elements are used for meshing. For toroid without hole only 4 noded shell element is used for meshing.

**Table 1: Inputs for Finite Element Analysis**

| | |
|---|---|
| Toroid Major Radius | 1500 mm |
| Toroid Minor Radius | 250 mm |
| Shell thickness | 2.4 mm |
| Material | AA6061 Al. Alloy |
| Modulus of elasticity | 70 GPa. |
| Poisson's ratio | 0.3 |
| Internal pressure | 0.575 MPa |

Fig.2: Toroid with hole at outer region of pressure vessel

Fig.3: Toroid with hole at inner region of pressure vessel shell

## BOUNDARY CONDITIONS

The pressure vessel is analyzed for an internal pressure of 0.575 MPa. In order to avoid rigid body motion, both the ends were symmetrically constrained.

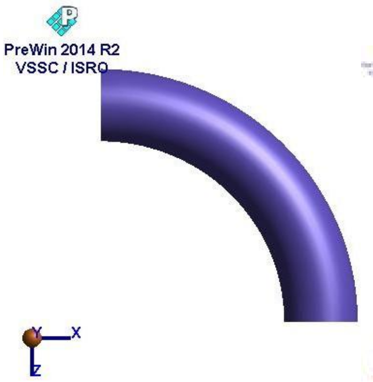
## RESULTS & DISCUSSION

The maximum stress values and displacement values are obtained from the analysis as follows.

### *Toroid without hole*

As toroid without hole can be modeled as an axi-symmetric shell of revolution, it is modeled with axisymmetric element with as a chord of radius 250 mm, mean radius as 1500 mm and thickness 2.4 mm.

### Toroidal shell with axisymmetric 4 noded shell element



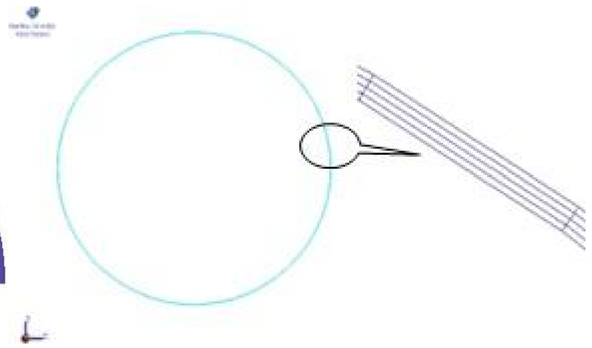


Fig.1: Toroid without hole (One quarter portion) Fig.4: FE Idealisation Deformed Undeformed

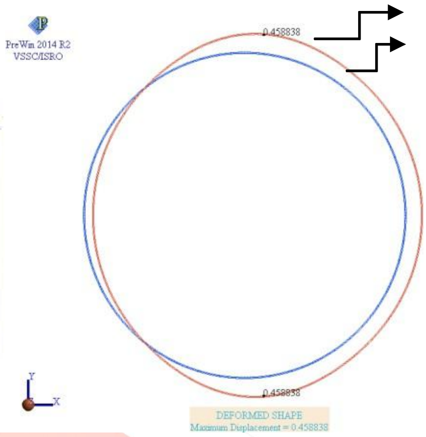
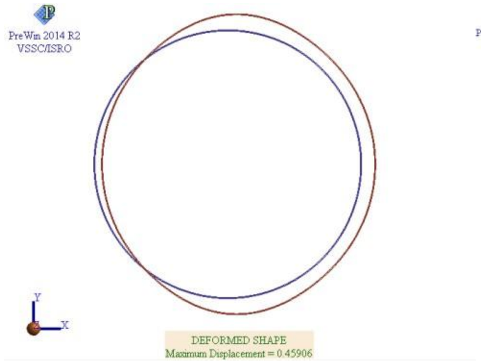


Fig.5: Deformed shape (4 noded axisymmetric element)

Fig.6: First Principal stress

The analysis results for 4 noded axisymmetric shell element is shown in fig.5 &6.Fig.5 shows the maximum displacement as 0.458838 mm at two locations as shown in figure.Fig.6 shows the principal stress contour, which shows the maximum value of 66.661 MPa at LSI.

### Toroidal shell with axisymmetric 8 noded shell element



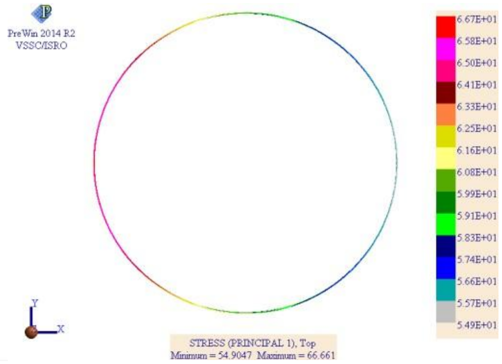
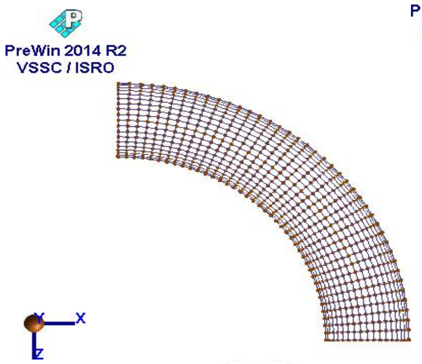


Fig.7: Deformed shape (8 noded axisymmetric element) Fig.8: Principal stress

Fig.7 shows the maximum displacement as 0.45906 mm at two locations of the shell. Fig.6 shows the principal stress contour, which shows the maximum value of 66.661 MPa at LSI. The displacement and principal stress values btained using 4 noded and 8 noded axisymmmetric shell elements are almost the same.

Toroid (without hole) quarter model-**4 noded shell element**



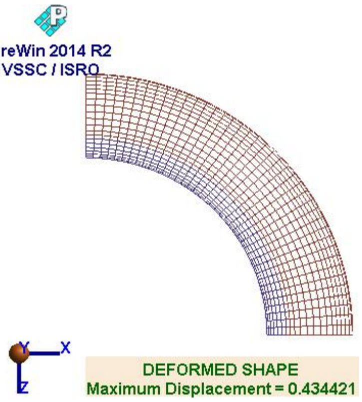


Fig.9: FE Idealisation Fig.10: Deformed shape (4 noded shell element)

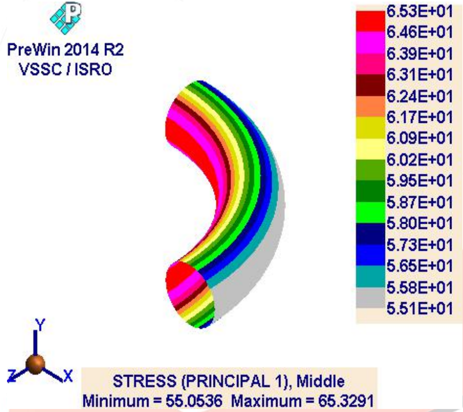
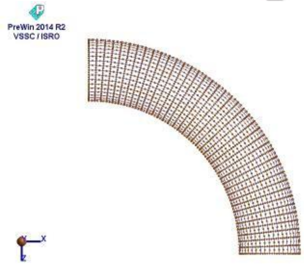
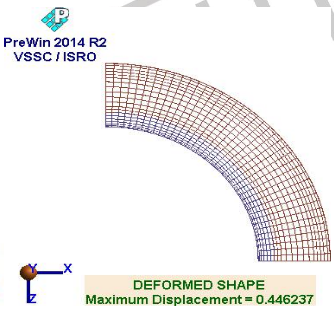


Fig.11: Principal stress(Mid layer)

Fig.9 shows FE idealization for quarter portion model of toroid without opening using 4 noded shell element. The maximum deformation is observed as 0.434421 mm as shown in Fig.10. From Fig.11 the maximum stress occur at the LSI of toroidal shell, and the maximum value of principal stress obtaines as 65.3291 MPa.

**Toroid (without hole) quarter model -8 noded shell element**





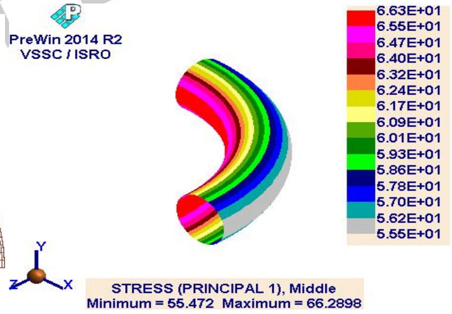


Fig.12: FE Idealisation Fig.13:Deformed shape(8 noded shell element) Fig.14:Principal stress

Fig.12 shows FE idealization for quarter portion model of toroid without opening. The maximum deformation is observed as 0.46237 mm (Fig.10). From Fig.11 the maximum stress occur at the LSI of toroidal shell, the maximum value of principal stress obtaines as 65.3291 MPa.

Table.2: Displacement and stress for various elements

By comparing the results obtained by 4 noded and 8 noded elements it is seen that the stresses are comparable.

### *Toroid with hole*

#### Hole at outer region of shell

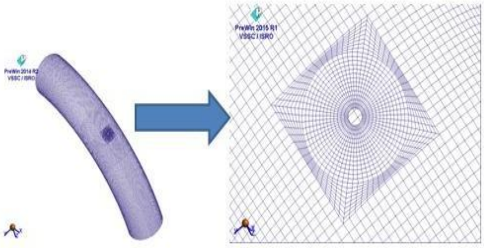
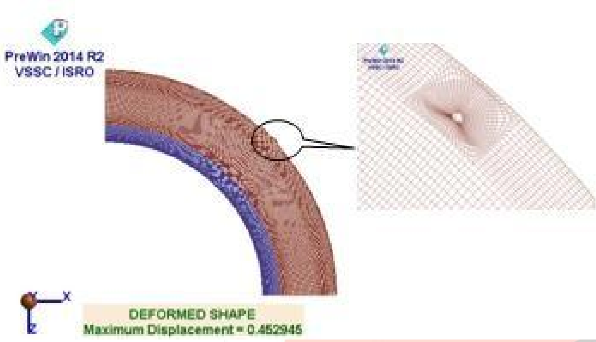


Fig.15: FE Idealisation for opening diameter 20 mm

Finite element idealization for toroidal shell with 20 mm opening is shown in Fig.13, which shows a continous uniform mesh at the region of opening.

| Element type | Maximum displacement (mm) | Principalstress(MPa) |
|---|---|---|
| 4 noded axisymmetr ic element | 0.458838 | 66.661 |
| 8 noded axisymmetr ic element | 0.45906 | 66.661 |
| 4 noded shell element | 0.434421 | 65.3291 |
| 8 noded shell element | 0.446237 | 66.2898 |



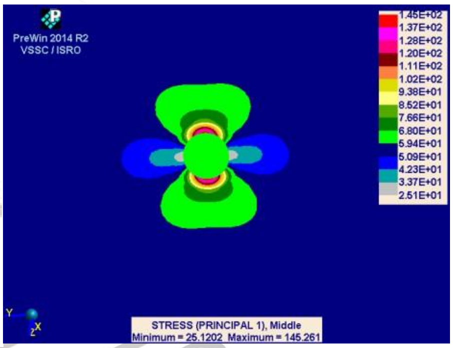


Fig.16: Deformed shape for hole dia.20mm Fig.17: First Principal stress (Mid layer)

Fig. 16 shows that the maximum displacement i.e. 0.452945 mm which occur at the region of opening. The maximum principal stress of 145.261MPa also occurs near the vicinity of the hole, it is due to weakening of toroidal shell at the location of opening (Fig.17).

For toroid with hole, stress concentration factor is calculated to to quantify how the stress is concentrated in the region of opening.Stress concentration factor (K), is a dimensionless factor. It is defined as the ratio of the highest stress in the element to the reference stress.

$$\text{SCF},K = ?_{\text{max}}/?_{\text{ref}}$$

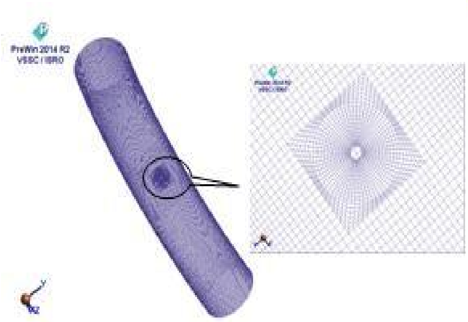
| Hole diameter(mm) | Displacement (mm) | Principal stress(MPa) | SCF |
|---|---|---|---|
| WITH OUT HOLE | 0.458838 | 55.62 | |
| 10 | 0.451448 | 125.352 | 2.25 |
| 20 | 0.452631 | 145.261 | 2.61 |
| 30 | 0.530433 | 159.762 | 2.87 |
| 40 | 0.461843 | 174.377 | 3.14 |
| 50 | 0.541132 | 188.468 | 3.39 |
| 60 | 0.659661 | 201.594 | 3.62 |
| 70 | 1.11873 | 216.964 | 3.90 |
| 80 | 1.66317 | 224.979 | 4.04 |
| 90 | 2.39773 | 235.505 | 4.23 |
| 100 | 3.30914 | 249.200 | 4.48 |
| 110 | 4.42039 | 267.594 | 4.81 |

| | | | |
|---|---|---|---|
| 120 | 5.75301 | 289.136 | 5.20 |
| 130 | 7.33294 | 313.567 | 5.64 |
| 140 | 9.18294 | 338.740 | 6.09 |
| 150 | 11.3372 | 360.557 | 6.48 |

Reference stress is the total stress within an element under the same loading conditions without the stress concentrators, meaning the total stress on the material where the material is free from holes, cuts, shoulders or narrow passes.

Table.3: Variation of SCF for opening at LSO

### 7.1.2. Hole at LSI of shell.



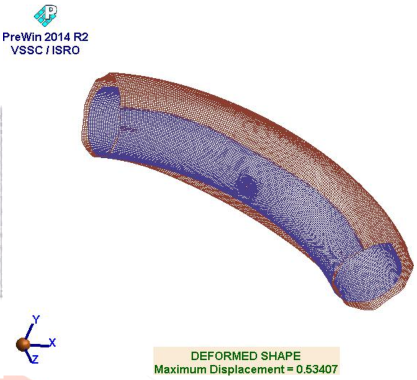
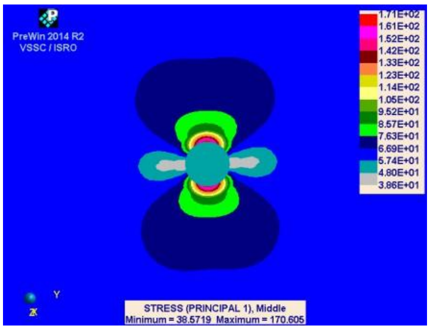


Fig.18: FE Idealisation Fig.19: Deformed shape for 20 mm diameter opening

Table.4: Variation of SCF for opening at LSI

| Hole diameter(mm) | Displacement (mm) | Principal stress(MPa) | SCF |
|---|---|---|---|
| WITH OUT HOLE | 0.458838 | 65.885 | |
| 10 | 0.457512 | 149.863 | 2.27 |
| 20 | 0.528992 | 170.605 | 2.59 |
| 30 | 0.958607 | 178.771 | 2.71 |
| 40 | 1.55793 | 181.239 | 2.75 |
| 50 | 2.31493 | 179.001 | 2.72 |
| 60 | 3.2156 | 181.294 | 2.75 |
| 70 | 4.25299 | 195.202 | 2.96 |
| 80 | 5.39398 | 212.618 | 3.23 |
| 90 | 6.62933 | 234.207 | 3.55 |
| 100 | 7.95609 | 255.830 | 3.88 |
| 110 | 9.35507 | 278.601 | 4.23 |
| 120 | 10.815 | 301.634 | 4.58 |
| 130 | 12.3259 | 323.498 | 4.91 |
| 140 | 13.881 | 342.753 | 5.20 |
| 150 | 15.4777 | 352.13 | 5.34 |



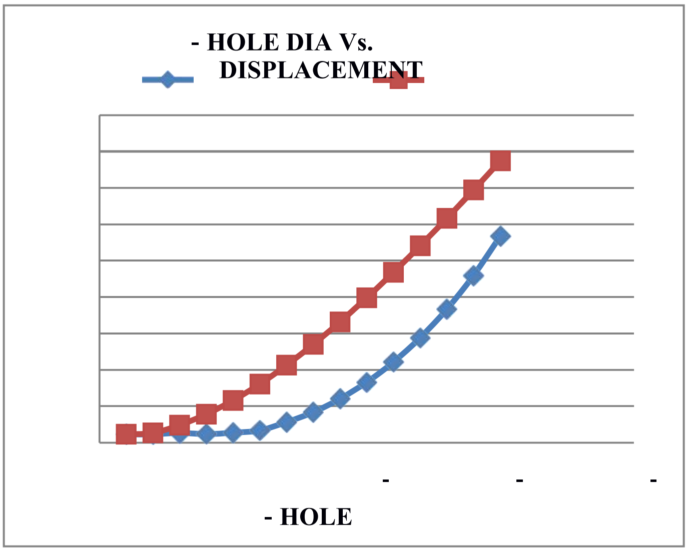


Fig.20: Principal stress for 20 mm dia. Hole. Fig.21: Hole dia. Vs Displacement

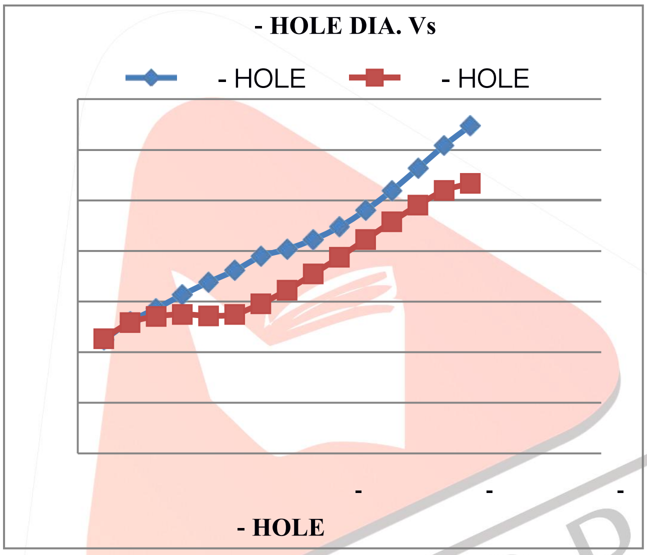


Fig.22: Hole dia. Vs SCF

## CONCLUSIONS

From the results obtained through the analysis of toroid without hole it can be observed that the maximum stress occurs at the inner region of the torus and the minimum stress occurs at outer region of torus.

The stress concentration factor increases with increase in diameter of the hole.

For toroid with hole at inner region have higher displacement than toroid with hole at inner region for every diameters of the hole.

For toroid with hole at outer region have higher stress concentration factor than toroid with hole at inner region for all hole diameters.

## SCOPE FOR FUTURE WORK

Proper stiffening at the openings have to be worked for all cases to keep the stress levels within acceptable limits.

It can be further studied to find the effect of the position of openings at mean radius and multiple openings and on SCF.

There is a scope for further studies on variation of stress concentration factor on elliptical holes.

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