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FEA of Cylindrical Pressure Vessels with Different Radius of Openings

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Abstract: Pressure vessels have to be designed in such a way that they are able to bear high pressure and extreme level of temperature. In pressure vessels openings are required for inlet and outlet purposes. These openings can cause geometric discontinuity of the vessel wall, so a stress concentration is created around the opening. Hence a detailed analysis is required. In this study behavior of a cylindrical pressure vessel wall for increasing diameter of holes are considered to find out the diameter of opening with minimum stress concentration. 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) and the results are compared with the analytical solutions and the results obtained using ANSYS.
Keywords: Finite element analysis, Geometric discontinuity Pressure vessel, stress concentration.

I. INTRODUCTION

Pressure vessels which holds liquids or gases well above, or below, ambient pressures are everywhere in manufacturing and process equipment, refineries and petrochemical plants, submarines, spacecraft and, more generally, in all hydraulic and pneumatic systems. They may be of any shape and range. High pressures, extremes of temperature and severity of functional performance requirements pose exacting design failure problems. That includes (1) The reasoning that established the most likely mode of damage or (2) methods of stress analysis employed and significance of results.(3)Selection of material, type and its environmental behavior. Pressure vessels usually have the shape of spherical, cylindrical, ellipsoidal or some composites of these. Pressure vessels are usually spherical or cylindrical with dome end. The cylindrical vessels are generally preferred because they present simple manufacturing problem and make better use of the available space. Solid Rocket motor cases, liquid pressure vessels as storage tanks for launch vehicles, boiler, heat exchanger, chemical reactor and so on, are generally cylindrical. Evaluation of failure pressure that a cylindrical pressure vessel can withstand is an important consideration in the design of pressure vessels.

II. SCOPE OF STUDY

When openings are provided on the walls of the pressure vessels they results in the penetration of pressure restraining boundary and hence causes a discontinuity. Stress concentration can occur due to existence of this void. Hence integrity of the structure in the presence of these openings has to be assessed and adequate margins have to be ensured. This project aims at studying the effects of openings of varying diameters on the cylindrical pressure vessels.

III. OBJECTIVES

To study the variation of stresses in the vessel wall due to varying diameter of openings. Finite element modeling and analysis are performed using a new structural analysis software FEAST^{SMT}/PreWin developed by the scientists of VSSC/ISRO. The main goal is to calculate the stresses by hand and compare them with the Finite Element Analysis results. Also analysis is performed using another structural analysis software ANSYS and the results obtained using FEAST^{SMT}/PreWin are compared with those obtained from ANSYS.

IV. METHODOLOGY

Studies on various previous methods used for the design and analysis of pressure vessels were conducted. Finite element packages

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FEAST[SMT]/PreWin was selected for modeling and analysis of the structure. Initially cylindrical conditions were generated on a flat plate and its analysis under different radius of openings were done to get familiarized with the variation of stress concentration factor in cylinder. Further analyses were performed on cylinder for two cases, firstly for cylinder with hole and secondly for cylinder with different radius of openings.

V. STRESSES IN CYLINDRICAL PRESSURE VESSELS

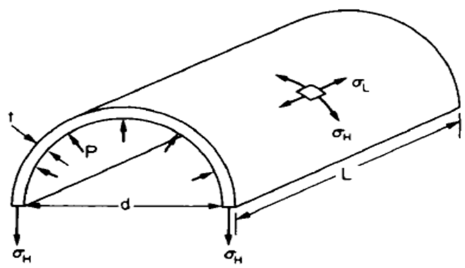

Figure 1 Half of a thin cylinder subjected to internal pressure

Stresses set up in the walls of a thin cylinder due to internal pressure *p* are:
Circumferential stress (or) hoop stress,

$$\sigma_1 = \frac{pr}{t}$$

Longitudinal (or) axial stress,

$$\sigma_2 = \frac{pr}{2t}$$

Where, p is internal pressure, r is the radius of the cylindrical shell and t is the thickness provided. Fig 1 shows half of a thin cylinder subjected to internal pressure.

VI. FINITE ELEMENT MODELING

The Finite Element Method (FEM) is a technique that is currently used to solve engineering problems in a variety of fields such as solid mechanics, fluid mechanics and heat transfer. FEA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes. Mathematical equations help predict the behavior of each element. A computer then adds up all the individual behaviors to predict the behavior of the actual object.

A. Description of model

The cylindrical pressure vessel is modeled as a shell structure. Modeling was carried out with the following parameters (Table 1).

Table 1 Inputs for modeling

Radius	79.1 mm
Height	500 mm
Thickness	4 mm
Material	Steel
Young's Modulus	206010 N/mm^2
Poisson's Ratio	0.3

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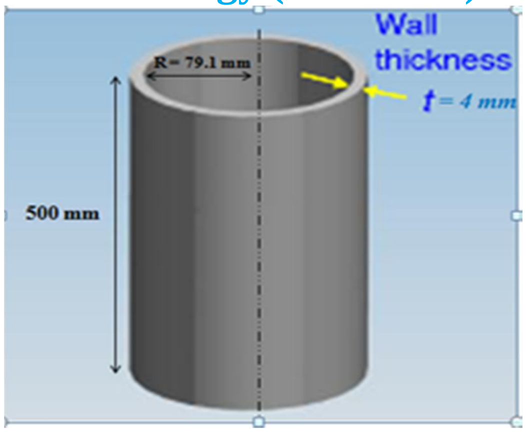

Figure 2 Layout of model

Fig 2 shows the layout of model selected for analysis.

B. Element selection and meshing

For most pressure vessels element selection is made from three categories of elements: Axis-symmetric solid elements, shell or plate elements, and 3D-brick elements.

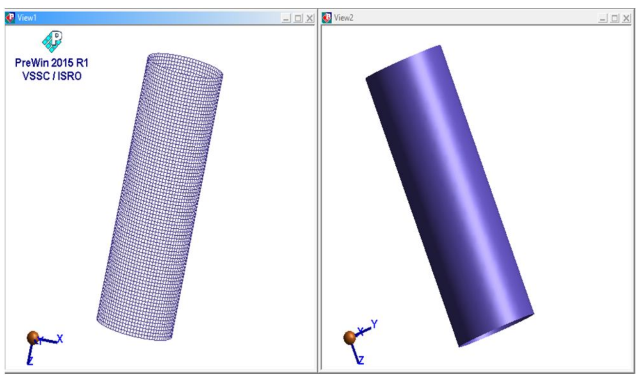

Figure 3 Different views of meshed model generated using FEAST^{SMT}/PreWin

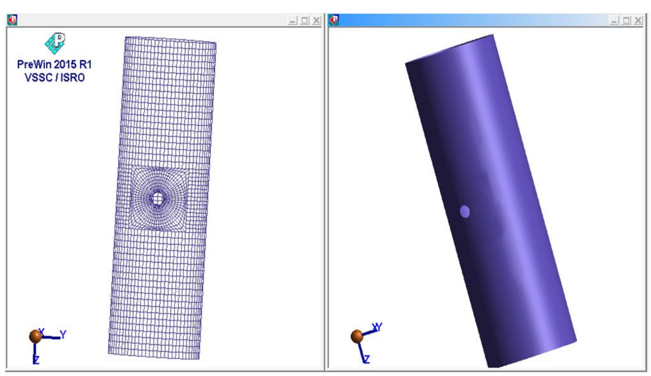

Figure 4 Different views of model with opening generated using FEAST^{SMT}/PreWin

In order to identify the element that gives the best results in minimum time, model with 4-noded shell element and 8-noded shell elements are analyzed separately. Values of principle stress obtained using 4-noded element and 8-noded element were almost the same, But with 4-noded element the analysis took lesser runtime. Hence 4-node element, Shell-181(Fig 5) was selected for the present analysis.

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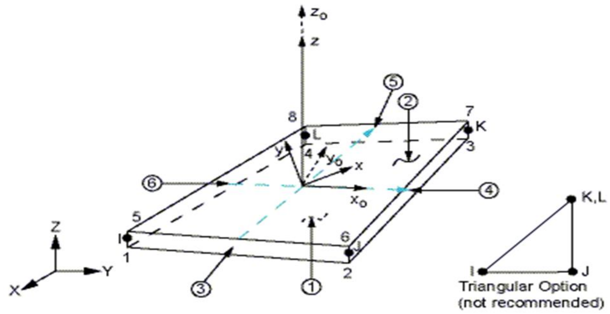
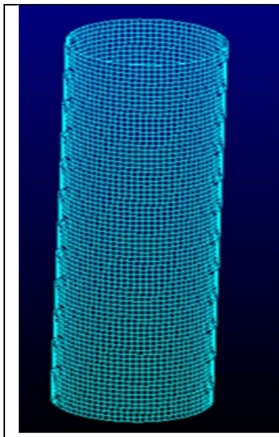
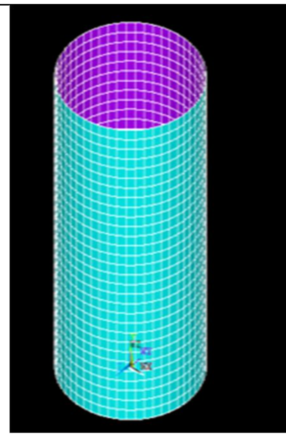


Figure 5 Geometry of SHELL 181

A. Meshing in FEAST ^{SMT} *and ANSYS*

	
FE Mesh (PreWin)	FE Mesh (ANSYS)

SHELL 181 which is used to model thin to moderately thick shell structures are used in this study because this element gave the best results in minimum run time. It is a 4noded element with six degrees of freedom at each node. It is well-suited for linear, large rotation, and/or large strain nonlinear applications. Figure 3 and 4 shows different views of meshed model without opening and with opening generated using FEAST^{SMT}/PreWin.

Modeling and meshing in FEAST^{SMT}/PreWin was much easier compared to ANSYS. Using FEAST^{SMT} more uniform mesh can be created around the opening that is the area where maximum stress concentration is expected(Fig 6).

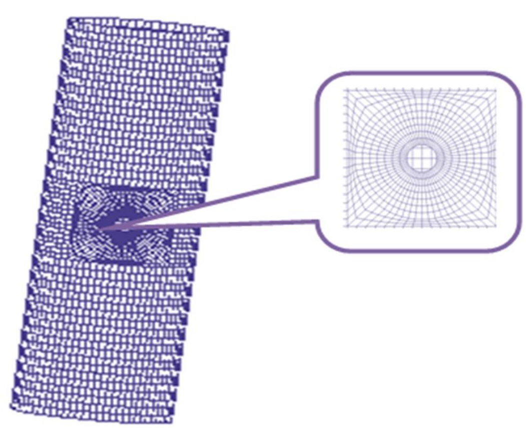


Figure 6 Uniform mesh around opening obtained in Feast

VII. FINITE ELEMENT ANALYSIS AND RESULTS

A static analysis is conducted to obtain the stress distribution across the structure, two cases where considered:
case 1 : without opening
case 2 : with varying opening diameters

A. Case 1

Full cylindrical shell is modeled without opening is analyzed using FEAST^{SMT}/PreWin. The maximum values of principle stresses obtained matched with the theoretical value of 90.68 MPa.

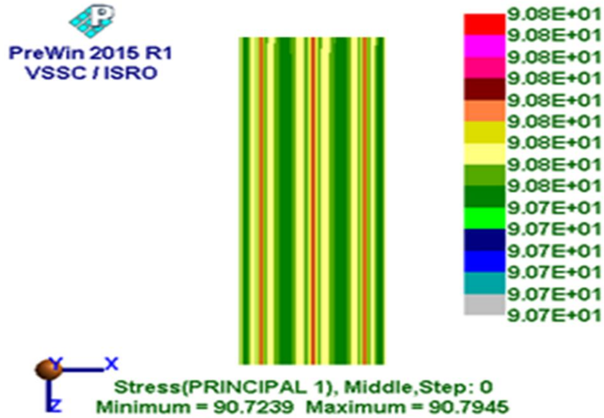


Figure 7 Principal stress pattern in FEAST^{SMT}/PreWin.

Figure 7 shows the values and pattern of principal stress obtained in FEAST^{SMT}/PreWin.

B. Case 2

Analysis of cylindrical shell with different radius of hole 10mm to 45 mm in steps of 5.mm, were performed. In order to understand and get familiarize with the variation of stress
pattern in a cylindrical pressure vessel, analyses were conducted initially on a plate. The cylindrical shell with opening and was considered as a flat plate with a hole at its centre (Fig 8).

The stress concentration about a circular hole in a cylinder or a sphere with stress applied by internal or external pressure can be obtained from the cases of simple tension or compression by using the method of superposition. In case of a cylinder stressed by pressure longitudinal stress is half the hoop stress, Therefore maximum stress at point n near to the opening on longitudinal axis is,$3\sigma_y - \sigma_x = 3\sigma_y - \frac{1}{2}\sigma_y = 2.5\sigma$, and at the point m near the opening on the circumferential axis is$3\sigma_x - \sigma_y = \frac{3}{2}\sigma_y - \sigma_y = \frac{1}{2}\sigma_y$, here σ_x is the stress applied along the longitudinal axis and σ_y is the stress applied along the circumferential axis.

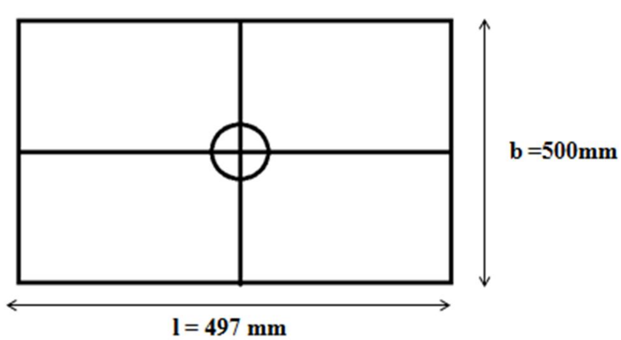


Figure 8 Layout of plate with hole

Utilizing the symmetry of the structural component and the loading, a quarter section of the plate was modeled and the symmetric

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boundary conditions are applied for the nodes lying in plane of symmetry. The plate dimensions were $248.5mm \times 250mm$. Cylindrical conditions was generated by applying σ (i.e. hoop stress in cylindrical shell) along Y direction and σ/2 (i.e. Meridional stress in cylindrical shell) along X direction. i.e. stress along Y direction is $4.6 N/mm^2$ and along X direction is $2.3 N/mm^2$ applied respectively as shown in the following figure 9.

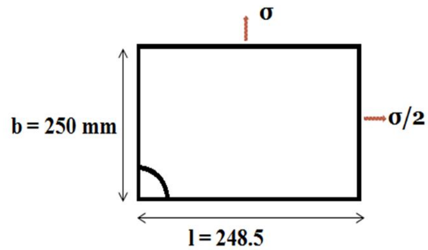

Figure 9 Quarter section of plate taken for analysis

Table 2 Values of SCF for different radius of opening

Hole Radius(mm)	1st Principal stress(N/mm^2)	S.C.F
Without hole	4.6	
10	4.6	2.51
15	11.62	2.53
20	11.69	2.54
25	11.78	2.56
30	11.89	2.58
35	12.01	2.61
40	12.17	2.64
45	12.34	2.68

Increasing values of stress concentration factor is shown in Table 2. The graph (Fig 10) confirms that the stress concentration factor increases with increasing radius of openings.

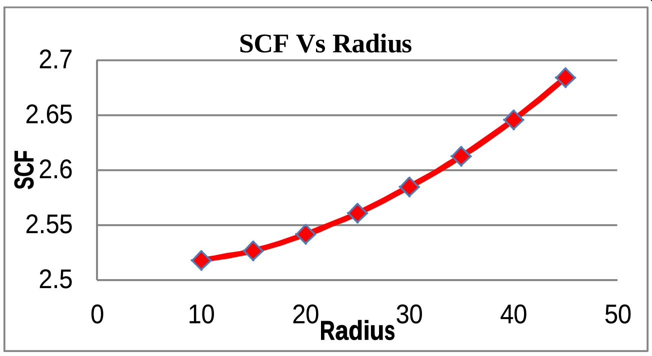

Figure 10 Variation of SCF with radius

From the above results on the analysis of plate, it is understood that the stress concentration factor is found to be constant close to the analytical value[[1]John. F. Harvey] of 2.5 and then increases with increasing diameter of openings. So Further analyses were performed on cylindrical shell with different hole radius.

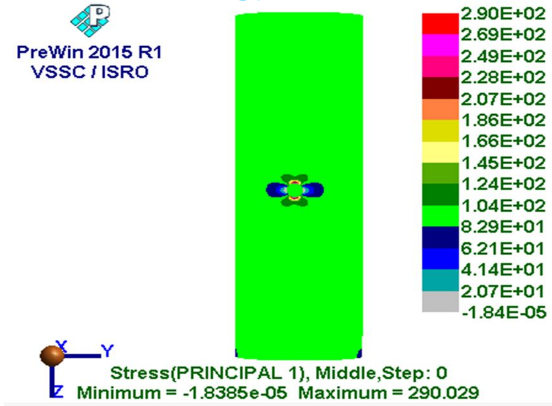

Figure 11 1st Principal Stress pattern around 10mm opening using PreWin/FEAST^{SMT}

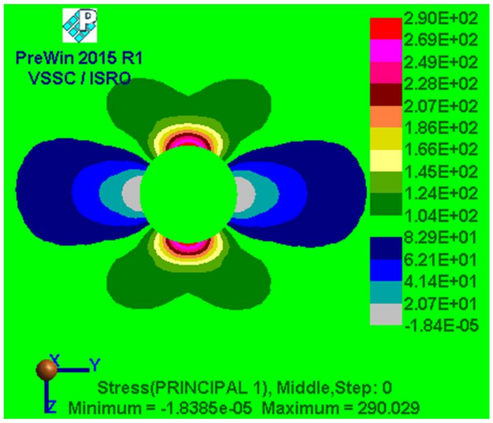

Figure 12 Maximum value of stress occurs around opening

From Figures 11 & 12 it is observed that the maximum stress concentration occurs around the vicinity of opening.

Table 3 Variation of SCF with radius in cylindrical vessel

Hole Radius(mm)	1st Principal stress(N/mm^2)	SCF(P1)
Without hole	90.9807	
10	290.029	3.1943455
15	318.633	3.5093866
20	320.03	3.524773
25	344.989	3.7996685
30	429.006	4.7250219
35	580.537	6.3939666
40	738.935	8.1385436
45	925.539	10.193778

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It was observed that as the diameter of the opening increases principle stress increases.

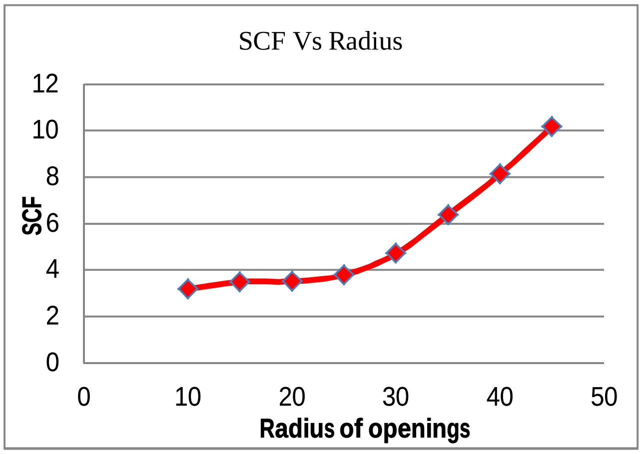

Figure 13 Variation of S.C.F with radius

Fig 11 shows the increasing pattern of Stress Concentration Factor (SCF) with increasing radius of opening. Initially the value of stress concentration factor for 10mm radius of opening is 2.82 increased to 7.02 when the radius is 45mm. This may be due to the curvature effect of the cylindrical shell with opening, which is not accounted in the analytical expression.

Variation of principal stress around the circumference of opening is observed to be cyclic for all radius of openings as shown in Fig 14.

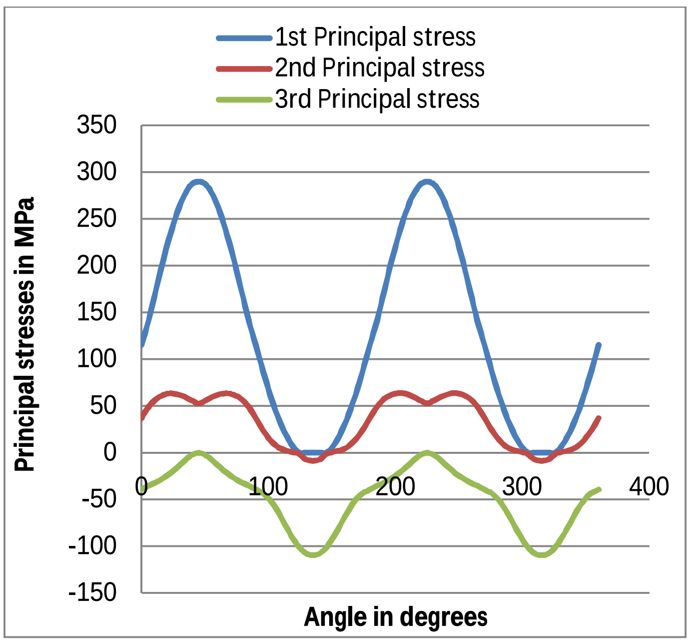

Figure 14Variation of principal stresses around 10mm opening.

Finite element analysis of same model with different diameters of openings is performed in ANSYS to compare the results. The results matched well with that of FEAST^{SMT}.

VIII. CONCLUSIONS

From this study it can be concluded that

A. FEAST^{SMT} Can be used as competent software to model the geometry, mesh it and perform post processing on the results.

B. Stress concentration is one of the important factors in pressure vessels, the study performed allowed evaluation of stress concentration factor.

C. Stress concentration factor increases by increasing the opening size in geometry.

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APPENDIX

A sample macro for creating a cylinder without hole using FEAST^{SMT}

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SURFACE,CYLINDER,0/0/0,79.1,500,8,,1,1
FEM,QUAD,all,,,10/80,/0/0/0,1/1,0
MATERIAL,ISO,all,210000/0.3/0/0,1
THICKNESS,ADD,all,4,1
PRESSURE,ADD,all,4.6,0,0,1
BC,ADD,1T11/892T901/1782T1791/2672T2681/3562T3571/4452T4461/5342T5351/6233T6241,3/0/4/0/5/0,0,1,0
BC,ADD,881T891/1772T1781/2662T2671/3552T3561/4442T4451/5332T5341/6222T6231/7113T7121,1/0/2/0/3/0/4/0/5/0/6/0,0,2,0
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