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Numerical Stress Analysis of Uniform and Stiffened Hydraulic Cylinder

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Abstract: ***This study deals with the stress analysis of thick cylinder using Finite Element Method. The analysis was carried out in commercially available software ANSYS^{TM} 15.0. The proposed work is aimed to analyze the cylinder with the stiffener under static load conditions for different cross-section geometries for the same area. In this study the effect of various stiffener on cylinders for Von-Misses stress (VM), Circumferential stress (σ_θ) has been investigated.***

Keywords: Static loading, stiffener stress analysis, thick cylinder

1. Introduction

Thick walled cylinders are widely used in chemical, petroleum, military industries as well as in nuclear power plants. They are usually subjected to high pressures which may be in constant or cyclic loading conditions. The conventional elastic analysis of thick walled cylinders to final radial & hoop stresses is applicable for the internal pressures up to yield strength of material. But the industrial cylinders often undergo pressure about yield strength of material. Hence a precise elastic-plastic analysis accounting all the properties of material is needed in order to make a full use of load carrying capacity of the material & ensure safety with respect to strength of cylinders.

Shuan-qiang Xu and Mao-hong Yu (2005), [1] Carried down shakedown analysis of an internally pressurized thick walled cylinders, with material strength differences. Through elasto-plastic analysis, the solutions for loading stresses, residual stresses, elastic limit, plastic limit & shakedown limit of cylinder are derived, in their study. Zengliang Gao, Gangsi Cai, Lihua Liang and Yuebao Lei (2008), [2] presented limit load solutions for thick-walled cylinders with fully circumferential inner/outer cracks under combined internal pressure and axial tension have been derived, considering the elastic–perfectly plastic material properties and von Mises yield criterion. In this work A. B. Ayob, M. N. Tamin, and M. Kabashi Elbasheer (2009), [3] two-dimensional FE simulations of the thick-walled cylinder were carried out to validate the analytical optimum autofrettage pressure and radius. The effects of autofrettage level parameters on the pressure capacity of cylinders were studied. J.P. M. Whitty, B. Henderson, J. Francis and N. Lloyd (2010), [4] this paper has investigated the effects of changing the Poisson's ratio in a thick-wall cylinder subjected to internal pressure conditions. Numerical and analytical modelling has shown that the stress distributions of unconstrained systems are independent of the mechanical properties, while constraining/encapsulating causes these distributions to become Poisson's ratio dependent. Yuebing Li, Yuebao Lei and Zengliang Gao (2013), [5] studied limit loads for thick-walled cylinders with circumferential internal/external surface/through-wall defects under various combinations of positive/negative axial force, positive/negative global bending moment and internal pressure have been investigated using the 3D elastic-perfect plastic finite element method. In this work Neetesh N. Thakre, Dr. D. V. Bhope (2014), [6] studied the buckling load capacity of cylinder increases with increase in number of stiffeners. So, the stiffeners are recommended to reduce the deformation and to increase the buckling pressure capacity.

In all mentioned research work, investigation gap found for thick wall cylinder is to study of stresses induced in uniform thick wall cylinder and stiffener on thick wall cylinder, so its seems necessary to study the stresses in case of different stiffener geometries with circularly mounted and longitudinally mounted stiffener and their co-relation. Therefore, in this paper the numerical analysis of with and without stiffener cylinder are performed. For longitudinally and circularly mounted stiffener and different stiffener geometries viz. rectangular, triangular and semi-circular stiffener keeping cross-section area constant for all.

2. Stiffener Geometries

In the present work cylinder with stiffener varying dimensions at different locations under static loading conditions is analyzed using FE approach. The proposed analysis involves different cross-section stiffener for same area for each of the cases. The cross-sectional view of the cylinder with stiffener ring for three cases shown in figure 1, 2, and 3 for rectangular, triangular and semi-circular stiffener respectively.

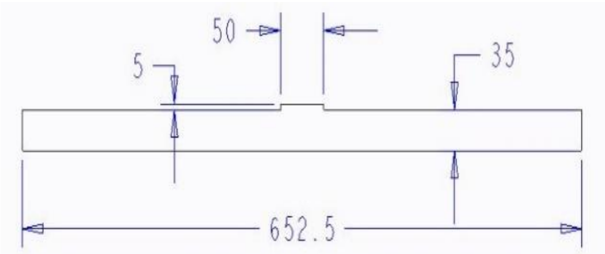


Figure 1: Cylinder with Rectangular stiffener

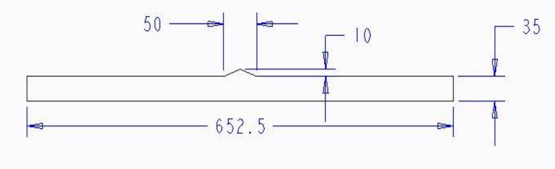


Figure 2: Cylinder with Triangular stiffener

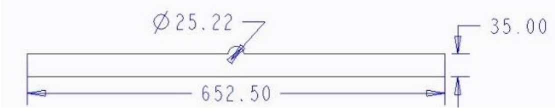


Figure 3: Cylinder with Semi-circular stiffener

Considering, cylinder of R_O = 217.5mm and R_i = 182.5mm, L = 3 R_O that is L = 652.5mm generally L > 2 R_O according to St. Venant's principle [5], we considered L=3R_O. The material of the test specimen is steel st52. Material data:- density ρ = 7800kg/m^3, Young's modulus (E) = 2.1*10^5MPa, Poisson's ratio (μ) =0.3, Yield stress (σy) = 345MPa.

3. Numerical Model

In this paper commercially available FE software ANSYS[TM]15.0 is used for 3-D stress strain calculation. The test specimen model is generated in PTC CREO 1.0 modelling software. The test specimen cylinder model is 3sD, 4-node mixed u-P element. The element has a linear displacement and hydrostatic pressure behavior. The element is suitable for modeling irregular meshes (such as those generated by various CAD/CAM systems) and general materials (including incompressible materials). The element is defined by four nodes having four degrees of freedom at each node: three translations in the nodal x, y, and z directions, and one hydrostatic pressure (HDSP) for all materials except nearly incompressible hyperelastic materials. For nearly incompressible materials, instead of hydrostatic pressure, the volume change rate is used at each node together with the three translation degrees of freedom. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It is capable of simulating deformations of nearly incompressible elastoplastic materials, nearly incompressible hyperelastic materials, and fully incompressible hyperelastic materials.
The geometry and node location for this element are shown in fig.4

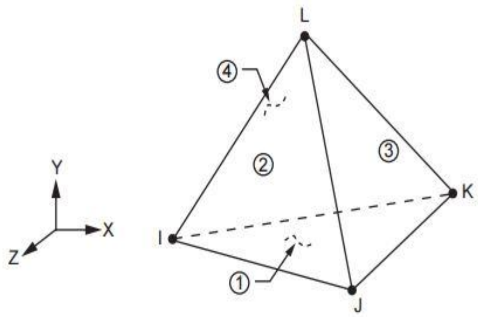


Figure 4: Geometry and node location for element Solid285

The applied free mesh model consists of 1572 nodes and 4487 element for the case of uniform cylinder without stiffener. Structural material properties are given above. To investigate stress parameter in an elastic range, the cylinders are modeled as a linear elastic material. The fig.5 shows the loading and boundary condition model of cylinder

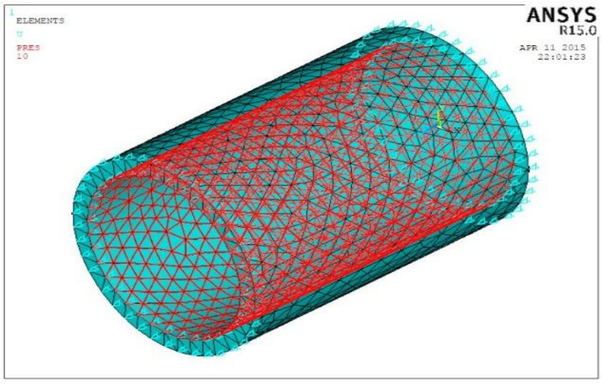


Figure 5: cylinder without stiffener and its loading condition

The main criteria for failure chosen are maximum strain energy criterion or von misses failure criteria. It says that the material will fail when the equivalent stress exceeds the yield point limit. The main criteria for failure chosen are maximum distortion energy criterion or von Misses yield criteria. Cylinder is then subjected to an internal pressure varying gradually (increased in steps) and corresponding maximum von Misses stress values are noted from the analysis results. The iterative procedure is continued till the von Misses stress reaches near about yield strength values.

There is an important pressure limit to study the thick walled cylinders. This is internal pressure required at the onset of yielding of inner bore surface. That is the load to initiate the plasticity at the internal cylinder radius, often expressed as Elastic load capacity.

$$\gamma 0=\frac{1-\beta^2}{\sqrt{3}}=\frac{p_o}{\sigma_y} \text{ [5]}$$

$\gamma 0$ is the load capacity, β is the radius ratio (Ri/RO), Po is the pressure where plasticity begins at internal walls of cylinder, σy is the yield strength of material.

Therefore, an internal pressure of cylinder maximum 60MPa was considered and tested the different stiffener cylinder with varying pressure from 10MPa-60MPa

While the both face of the cylinder are fixed and zero degree of freedom in z-direction. Finally, the static finite element analysis is performed.

4. Result and Discussion

This paper discusses the stresses involved in uniform and stiffened hydraulic cylinder. Two different mounting for the stiffener are studied in longitudinal and circumferential position with 4 and 5 numbers of stiffeners each. The cross-section area geometry for rectangular, semi-circular, triangular stiffener are kept constant for all i.e. A=250mm^2. The results obtained after FE analysis for whole study are discussed in next section.

A. Uniform Cylinder

As mentioned previously uniform cylinder of 35mm thickness studied. For different varying pressure of 10MPa to 60MPa.

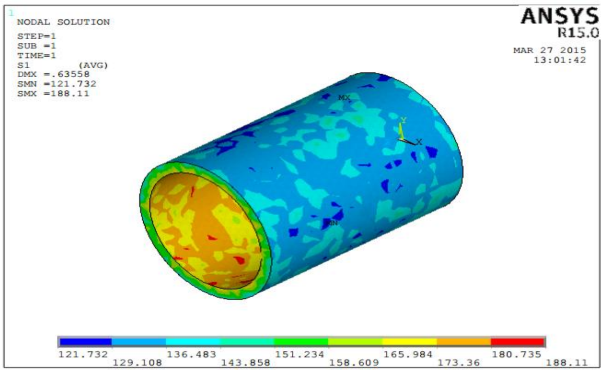


Figure 6: von-misses stress for 30MPa pressure

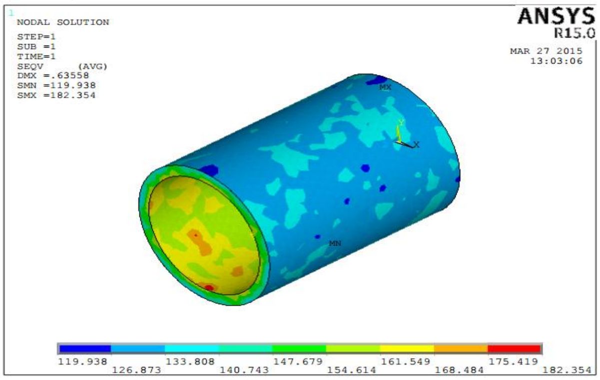
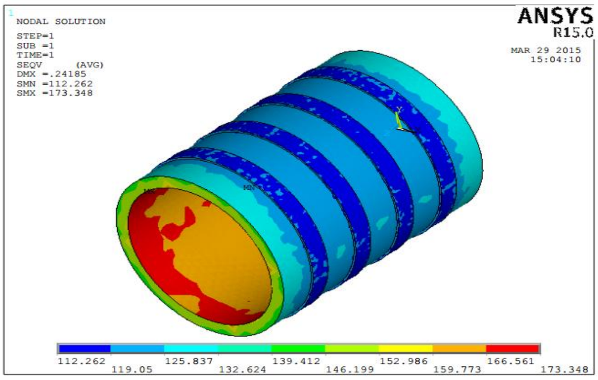


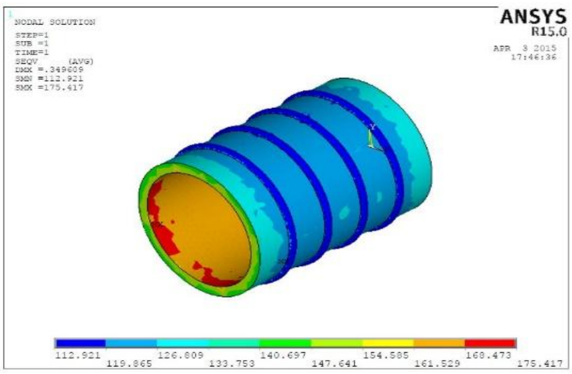
Figure 8: Circumferential stress for 30MPa pressure

B. Stiffened Cylinder

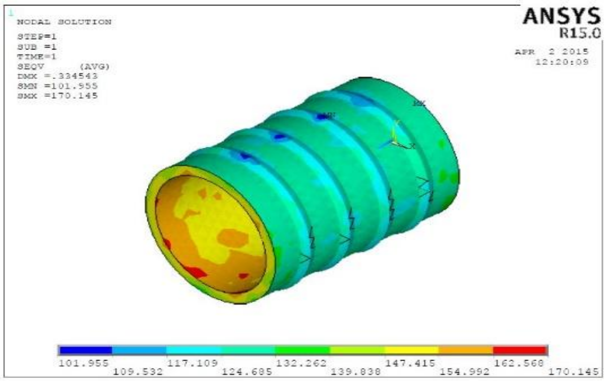
Circumferential and longitudinal stiffeners have been considered for cylinder. FE analysis is carried out by using ANSYS™ considering different types and location of stiffener. The stress contours for various stiffeners on cylinder are shown for pressure 30MPa in figure 9 and figure 10.



(a) Rectangular stiffener

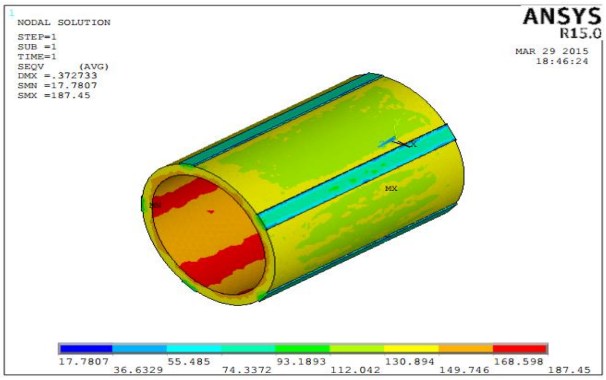


(b) Semi-circular stiffener

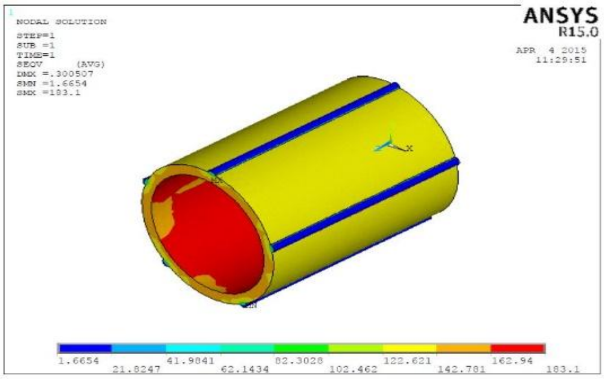


(c) Triangular stiffener

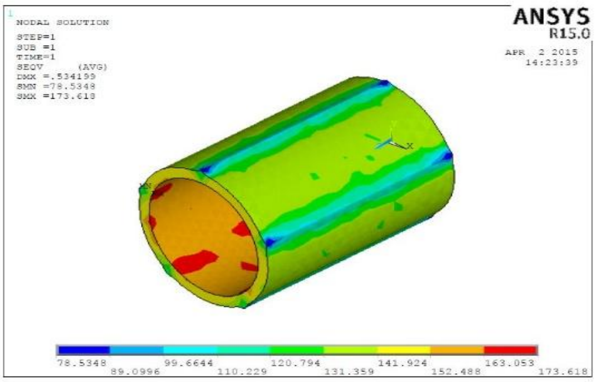
Figure 9: Maximum VM stress, number of stiffener=4 for circumferentially mounted stiffener.



(a) Rectangular stiffener

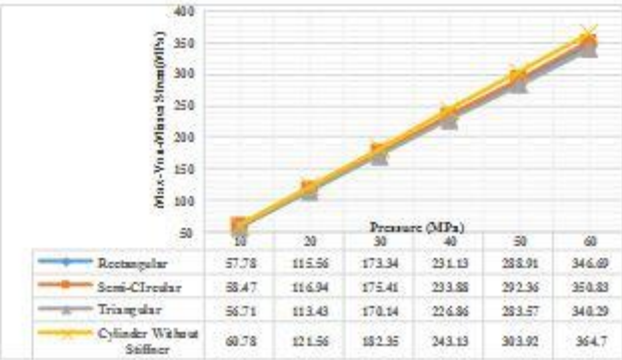


(b) Semi-circular stiffener



(c) Triangular stiffener

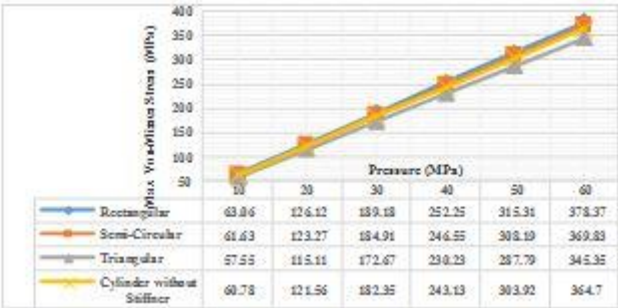
Figure 10: Max VM, number of stiffener=5 for longitudinal mounted stiffener.



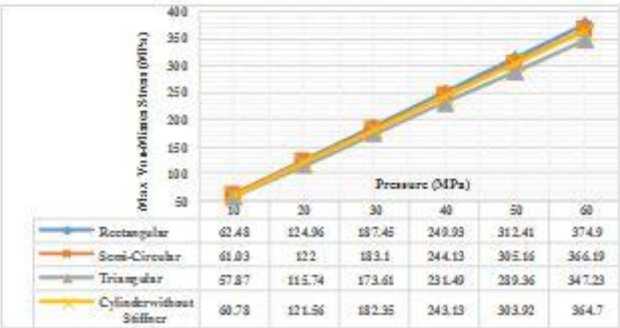
(a) When number of stiffener are 4

(b) When number of stiffener are 5

Figure 11: Max VM stresses with respect to pressure on circumferentially mounted stiffener

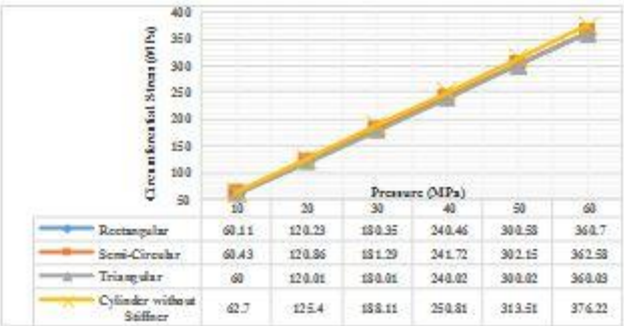


(a) When number of stiffener are 4

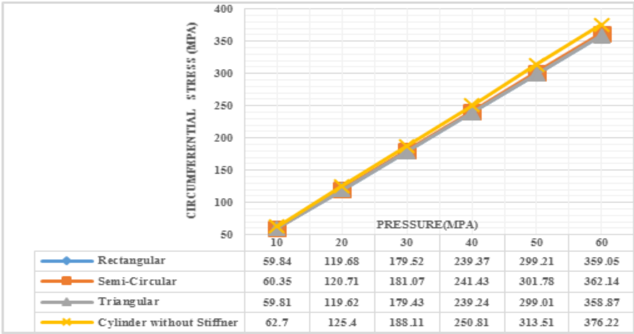


(b) When number of stiffener are 5

Figure 12: Max VM stresses with respect to pressure for longitudinally mounted stiffener.



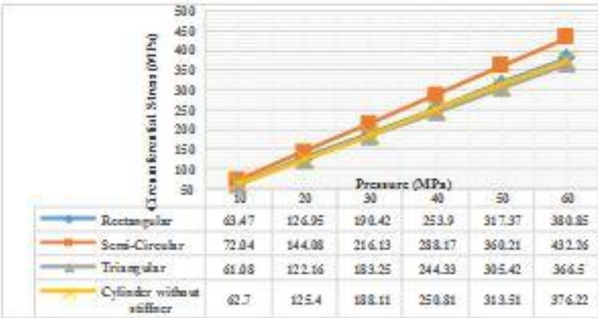
(a) When number of stiffener are 4



(b) When number of stiffener are 5

Figure 13: Circumferential stress with respect to pressure for circularly mounted stiffener.

(a) When number of stiffener are 4



(b)When number of stiffener are 5

Figure 14: Circumferential stress with respect to pressure for longitudinally mounted stiffener.

It is observed from the figure 11, 12, 13 and 14 that triangular stiffener shows the minimum values of stresses in all cases because the residual area between two consecutive triangular stiffeners is less than semi-circular stiffener. And the height of triangular stiffener is twice than the square stiffener. Study also shows that effect of number of stiffener also plays a vital role. For number of stiffener 5 seen less level of stress in all condition.

5. Conclusion

The study presents maximum Von-Mises and circumferential stresses for uniform and stiffened cylinder. Two different orientation and various geometries for stiffener were considered. Steel st52 was selected for the analysis. The observations made through the study are:

Circumferential mounting for stiffener are better than longitudinally mounted cylinder for all stiffener geometries.

Number of stiffener 5 is most effective for minimizing the VM and circumferential stress compared with 4 number of stiffener.

Triangular stiffener shows the minimum values of Von-Mises and circumferential stresses in all cases. Hence it is comparatively better than semi-circular and rectangular stiffeners.

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