Buckling Analysis of Thin Walled Cylinders Subjected to Axially Compressive Load by ANSYS

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Abstract

Buckling is a critical phenomenon in structural failure under compression load. Buckling strength of structures depends on many parameters like supports, linear material, composite or nonlinear material etc. Buckling behavior is also influenced by thermal loads and imperfections. Analyzing all these conditions is difficult task. So few parameters are considered for the present work. Due to the advances in the Finite element techniques, analysis of these problems is possible which is difficult in earlier days. In the present work thin-walled cylinders are considered for buckling analysis. Shell63 element from ANSYS software in elastic range is used .

***Keywords:**- Critical buckling, Linear Buckling, Eigen value, Thin shells buckling, ANSYS.*

1. Introduction

When a structure undergoes visibly large displacements transverse to the load then it is said to buckle. Buckling may be demonstrated by pressing the opposite edges of a flat sheet of cardboard towards one another. Local buckling of cylindrical shells is indicated by the growth of bulges, waves or ripples, and is commonly encountered in the component plates of thin structural members. If buckling deflections become too large then the structure fails this is a geometric consideration, completely separated from any material strength consideration. If a component or part therefor is prone to buckling then its design must satisfy both strength and buckling safety constraints that is why Buckling is important.

Thin-walled cylinders of various constructions find wide uses as primary structural elements in simple and complex structural configurations. The round cylinder is popular in column design, in tubing and piping, and in offshore platforms. Stiffened and unstiffened metallic and laminated composite thin (large diameter to thickness ratios) shells are used extensively in underwater, surface, air, and space vehicles as well as in the construction of pressure vessels, storage bins, and liquid storage tanks.

Thin-walled cylindrical tanks are prone to buckling collapse due to accidentally induced internal vacuum. While internal under-pressures can be generated for a variety of reasons, the condensation of steam in the vessel results in a particularly rapid and severe level of vacuum loading. The particular motivation for this research is tank collapse or pressure vessel failure in the food, pharmaceutical and biotechnology industries. These vessels are routinely filled with saturated steam as part of cleaning, sterilization or purging cycles. Condensation of the steam if accompanied by inadvertent closure of all vessel valves will lead to a rapid drop in internal pressure and vessel failure. Such a collapse, if it occurs, tends to be catastrophic resulting in the complete destruction of the vessel. Two hypotheses regarding the type of material modeling are used, linear buckling analysis and nonlinear buckling analysis.

2. Analytical solution

A Thin-walled cylinders simply supported at the ends is uniformly compressed in the axial direction as shown in Fig. 1.

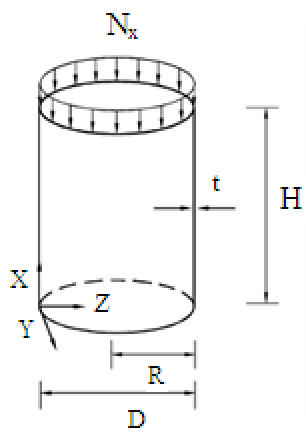

Figure 1: Thin-walled cylinders subjected to axial load

Using equation of stress can be compared with theoretical results

$$\sigma = \frac{Nx}{t} = \frac{R\,E}{S(1-\nu^2)} \tag{1}$$

where

$$R = (1-\nu^2)\lambda^4 + \alpha\left[\left(n^2+\lambda^2\right)^4 - (2+\nu)(3-\nu)\lambda^4 n^2 + 2\lambda^4\left(1-\lambda^2\right) - \lambda^2 n^4(7+\nu) + \lambda^2 n^2(3+\nu) + \eta^4 - 2n^6\right] \tag{2}$$

$$S = \lambda^2\left\{\left(n^2+\lambda^2\right)^2 + \frac{2}{1-\nu}\left(\lambda^2+\frac{1-\nu}{2}n^2\right)\left[1+\alpha\left(n^2+\lambda^2\right)^2\right] - \frac{2\nu^2\lambda^2}{1-\nu} + \frac{2\alpha}{1-\nu}\left(\lambda^2+\frac{1-\nu}{2}n^2\right)\left[n^2+(1-\nu)\lambda^2\right]\right\} \tag{3}$$

$$\alpha = \frac{t^2}{12R^2} \tag{4}$$

$$\lambda = \frac{mR\pi}{H} \tag{5}$$

The simplified forms of eq.1 is

$$\sigma_{cr} = \frac{N_x}{t} = \frac{1-\nu^2}{E}\left(\alpha\frac{\left(n^2+\lambda^2\right)^2}{\lambda^2} + \frac{(1-\nu^2)\lambda^2}{\left(n^2+\lambda^2\right)^2}\right) \tag{6}$$

When the value of n in eq.6 is equal to zero, axisymmetric buckling occurs, and eq.6 is simplified as

$$\sigma_{cr} = \frac{N_x}{t} = D\left(\frac{m^2\pi^2}{tH^2} + \frac{EH^2}{R^2Dm^2\pi^2}\right) \tag{7}$$

The stress equation as follows

$$\sigma = \frac{Et}{R\sqrt{3(1-\nu^2)}} \tag{8}$$

3. Numerical analysis

The structural static analysis capabilities in the ANSYS program are used to determine the displacements, stresses, strains, and forces that occur in a structure or component as a result of applied loads. Static analysis is appropriate for solving problems in which the time-dependent effects of inertia and damping do not significantly affect the structure's response. Static analysis in the ANSYS program can also include nonlinearities such as plasticity, creep, large deflection, large strain, and contact surfaces. A nonlinear static analysis is usually performed by applying the load gradually so that an accurate solution can be obtained.

A: Element Type

This analysis considers the shell 63 element which has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses. Fig. 2. shows the details of shell 63 element.

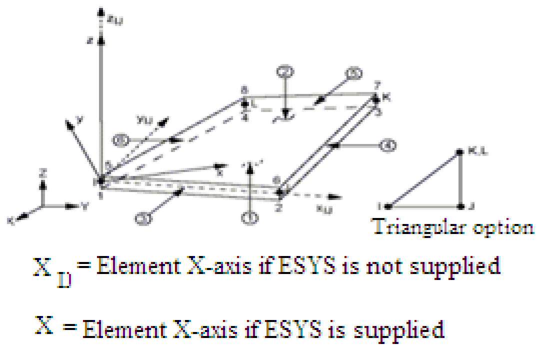

Figure 2: Shows The details of shell 63 element

B: Boundary conditions and modeling of cylinder

For each of the two ends, two different types of boundary conditions (Fig 3) are used. At the fixed end, displacement degrees of freedom in 1, 2, 3 directions (U_1, U_2, U_3) as well as rotational degrees of freedom in 1, 2, 3 directions ($\theta_1, \theta_2, \theta_3$) were restrained to be zero. At the movable end, load was exerted with an even stress distribution in the longitudinal direction U_1.

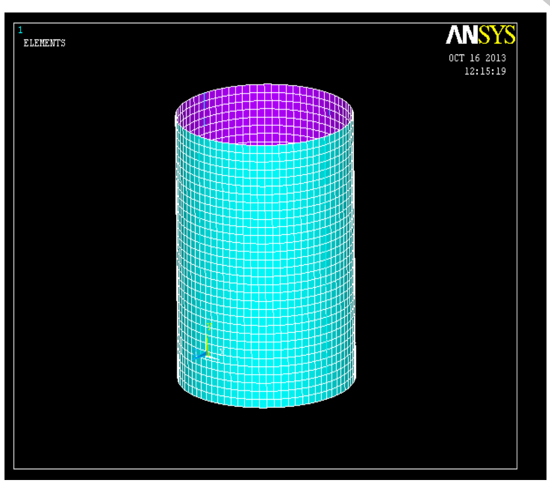

Figure 3: Modeling of cylinder

4. Mathematical Modeling

Buckling analysis is used to determine:

1) The load level at which a structure becomes unstable.

2) Whether or not a structure is stable at a particular load level.

This analysis type is important for determining buckling load-carrying capacity of the structure. Two types of buckling analyses are available in the ANSYS program: linear (Eigen value) buckling and nonlinear buckling. In the present paper we investigate the linear buckling analysis (Eigen value).

A. Linear Buckling Analysis

Linear buckling analysis depends on material linearity and follows the Hooks Law and the geometrical non-linearity follows the stress-strain and load-displacement curves. Linear, or Eigen value, buckling accounts for stress stiffness effects where compressive stresses tend to lessen a structure's ability to resist lateral loads. As the compressive stresses increase, the resistance to lateral forces decreases. At some load level, this negative stress stiffening overcomes the linear structural stiffness, causing the structure to buckle. Eigen value buckling analysis predicts the theoretical buckling strength (the bifurcation point) of an ideal linear elastic structure. Thus, Eigen value buckling analysis often yields un conservative results, and should generally not be used in actual day-to-day engineering analyses. The following cases of thin-walled cylinders are solved by the ANSYS software and results are tabulated, Table 1. shows the geometric and material properties which are used in the analysis.

Table 1: Geometric and Material Properties

Sr.No.	Components	Dimensions
1	Radius	88.2mm
2	Thickness	0.22mm
3	Height	230mm
4	Young's Modulus	205Gpa
5	Poison's ratio	0.3
6	Density	78000N/m^3

Case1: Linear Elastic Buckling Analysis

Fig. 4. Shows the deformation Plot of linear elastic Buckling analysis. The maximum deformation is 0.00511mm for the linear Elastic buckling analysis. Maximum deformation can be observed at the free end and minimum displacement can be observed at the constraint end. The status bar indicates varying displacements across the problem. Fig. 5. Shows the Buckling stress of around 19.87 Mpa due to elastic buckling analysis. and Fig. 6. Shows the mode shape of the cylinder.

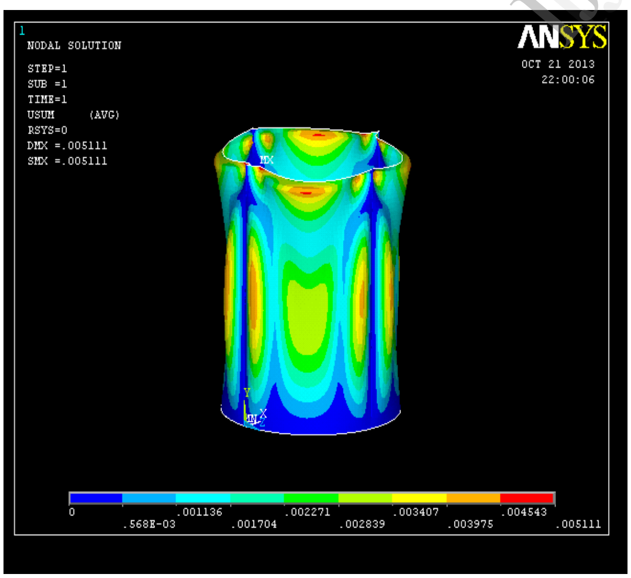

Figure 4: Deformation plot for linear elastic buckling analysis

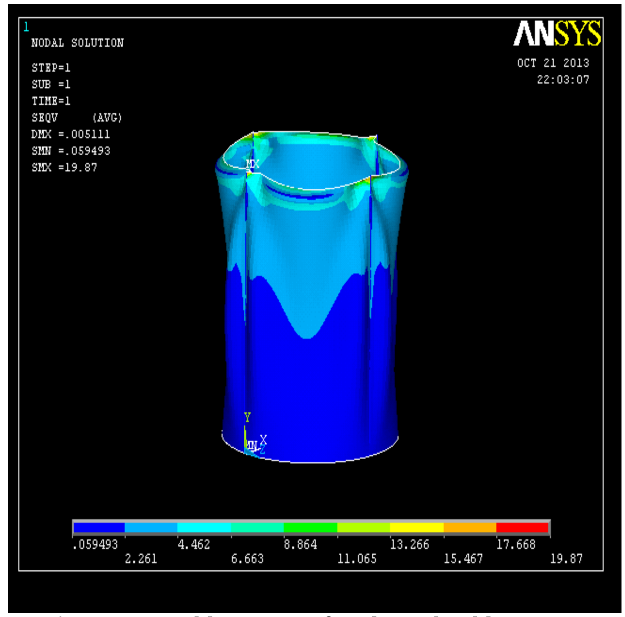

Figure 5: Buckling stress for elastic buckling

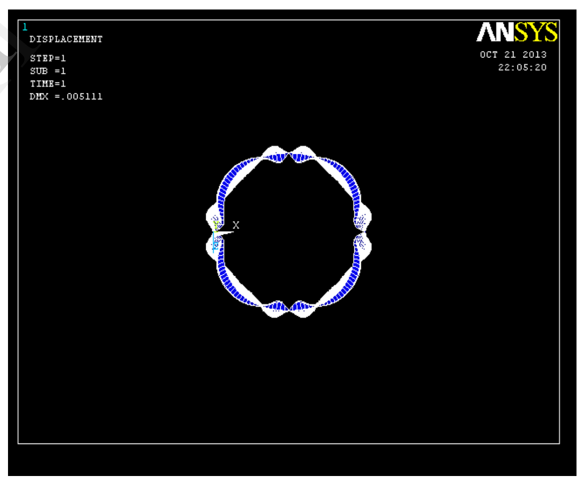

Figure 6: Mode shape

Convergences Study and Validation:-

Buckling stresses were obtained using different numbers of elements in both the circumferential and axial direction and analysis results shows in the Table 2. The result is compared with the MATLAB results of Ref [11] and in good agreement.

Table 2: Convergences Study and Validation

No. of elements	Buckling stress(N/mm^2)	Element Size(mm)	Aspect ratio
8x18	5.072	29.76	1.07
16x35	13.47	15.1	1.1
32x70	19.87	7.5	1.1
Ref[11]	23.17	–	–

Case2: Eigen value buckling Analysis

The Fig 7, shows maximum deformation is 0.004869mm for the Eigen value buckling analysis. Maximum deformation can be observed at the free end and minimum displacement can be observed at the constraint end. The status bar indicates varying displacements across the problem. The Fig 8 shows a buckling stress of around 13.47MPa due to Eigen-Value buckling analysis. Fig. 9. Shows the mode develop due to eigen value buckling analysis.

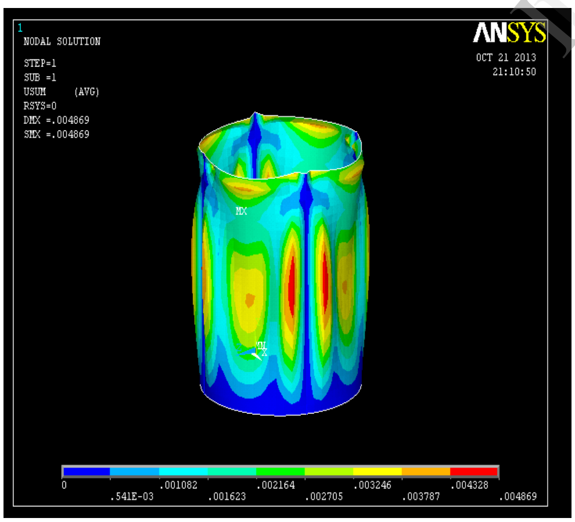

Figure 7: Deformation plot for eigen-value buckling analysis

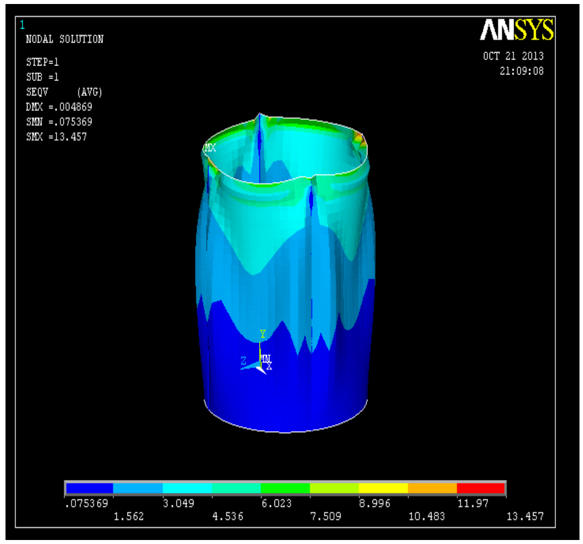

Figure 8: Buckling stress for eigen-value buckling analysis

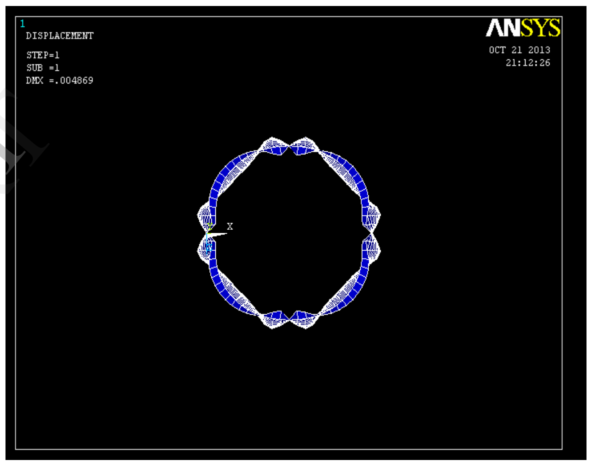

Figure 9: Mode shape

The two cases solved till now are summarized in Table 3.

Table 3: Comparison of linear elastic analysis And Eigen Value Buckling Analysis

Analysis type	Axial displacement (mm)	Buckling stress (Mpa)
Linear elastic analysis	0.005111	19.87
Eigen value buckling analysis	0.004869	13.457

5. Conclusions

A Finite element analysis is carried out to find buckling strength of thin-walled cylinders. The buckling may be due to compressive loads created due to self weight or outer members or internal pressure or may imperfections in the structure.

1. Shell63 is a linear element and does not support nonlinearity in the problem where as shell43 is a nonlinear element supports plasticity in the problem.

2. Convergence study of elastic buckling analysis of shell 63 element shows good convergence with aspect ratio of 1.1 and Element size about 7.5mm. Convergence study shows when the number of elements in circumferential and axial direction increases the load carrying capacity of the structure converges to the true value.

3. A comparison between linear elastic analysis and eigen value shows that the response reduces in later case and the same is observation in Ref[1] . Analysis does not predict the actual behavior of structure, it just gives an mathematical solution and eigen value buckling analysis gives the unconservative results.

6. References

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