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Finite Element Analysis of Torispherical Shell

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Abstract:
Pressure vessels with torispherical heads are used in several engineering applications particularly in rocket motor casting; LPG storage cylinder and fuel storage tanks, and Also used to minimize the length of the storage tanks and launch vehicle. The torispherical pressure vessel head has been taken for stress analysis. From strength point of view, in torispherical head, the knuckle region becomes critical and controls the design. Effect of torispherical head on the buckling of pressure vessels was investigated by finite element (FE) method. The FE method with use of nonlinear buckling analysis was applied to predict the critical buckling Load. The influences of geometrical parameter such as thickness, knuckle radius and diameter of cylindrical part, on the buckling of heads have been studied.

The ax symmetric four node and incompatible solid elements are used in commercial ANSYS 12.0 FEA package for analysis.

For torispherical head with cylindrical vessel carried out an experiment studies on torispherical head models by photo elastic method. Using their nominal dimensional parameter r/D, t/D, R/D and h/D the shell is modeled. Axial stress and hoop stress and deflection values of inner and outer surface of the vessel are plotted near the junction of the crown to the knuckle to cylinder.

1. Introduction

Theories of thin-walled structures applied on pressure vessels were reviewed by Teng et al [1]. Results of numerical evaluation of buckling by using linear and non-linear theories of thin-walled shells of revolution have been presented. Regarding to existence of non-continue stress in cylinder-head intersection, the choice of head considering the geometrical limitation and production facilities is the most important point in designing of pressure vessels. Torispherical heads are used commonly in pressure vessels because of their simple manufacturing and good strength in high pressure condition. The buckling strength is one of the most important points in design of pressure vessels [2]. Internal pressurization is often an important loading condition for pressure vessels. Finite element method is often used in the buckling analysis of pressure vessels due to its capability. The hydrostatic buckling of shells under different boundary conditions has been investigated by using energy method [3]. Results showed that in shells with medium height, under different boundary conditions buckling load is obtained by applying a scalar coefficient to the buckling load of the pin ended case, but this method is not applicable for the long shells for which the occurred circumferential waves from buckling. Teng et al [4] have introduced a numerical model, aided by the method of Eigen mode-affine, in the non-linear analysis of elastic shells. As the shells are sensitive to initial geometrical imperfections, predicting of their buckling resistance would be precise if those imperfections are taken into account. In torispherical heads by increasing the ratio of knuckle radius per vessel diameter (r/D), dimension of spherical part decreases. Thus, the spherical part as part of the head becomes weaker and in a defined r/D a notable fall in buckling resistance is occurred [5]. European recommendation ECCS [6] had introduced several experimental relations for design of spherical shells. In following we are discussed about the buckling load and influence of different parameters on it.

2. Geometry of Pressure Vessel Heads with Torispherical Shell

This chapter presents the geometrical heads of torispherical pressure vessels. The torispherical head with cylindrical pressure vessel is composed of two circular arcs, crown of radius (R_D) at the top and knuckle of radius (R_K). This is fitted on the cylinder of radius (R_C) there is no discontinuity in slope at either the cylinder-knuckle junction or the knuckle-crown junction, for uniform thickness in knuckle region, the geometry of torispherical headed vessel is presented in Figure 1.

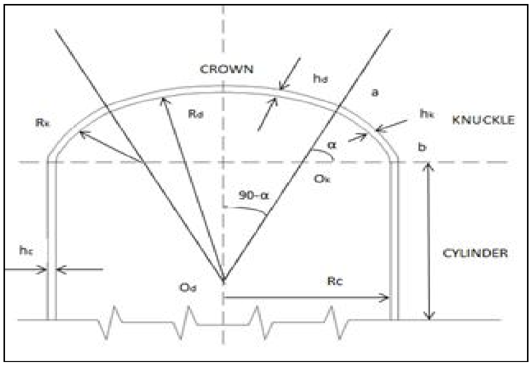

Figure 1: Geometry of a typical pressure vessel

The torispherical head geometry is composed of two circular arcs, crown of radius (R_D) at the top and knuckle of radius (R_K). This is fitted on the cylinder of radius (R_C) with reference to Figure 1 (O_d) is the center of curvature of the crown and (O_k) is the center of curvature of the knuckle.

The angle subtended by the knuckle at (O_k) is computed as

$\alpha = \cos^{-1}((R_c - R_k) / (R_d - R_k))$ ----------------- (1)

This ensure the continuity of slopes at 'a', the junction of crown and knuckle. The rise of head, H is computed as

$$H = R_d - \sqrt{\left((R_d - R_k)^2 - (R_c - R_k)^2\right)}$$ ---------------- (2)

h_c, h_d and **h_k** are the thickness of cylinder, crown and knuckle respectively. For the case of uniform wall thickness, **$h_c = h_d = h_k$**

3. Method of Analysis

The following analysis using ANSYS solver are performed on the spherical shell model created by the material of mar aging steel and wrought iron, ie.

- Static analysis and
- Buckling analysis

3.1. Static Analysis

Static analysis deals with the condition of equilibrium of the bodies acted upon by forces and the result obtained from static analysis for structure or component caused by loads will give a clear idea about whether it will withstand for applied maximum forces or not. If the stress values obtained in this analysis crosses allowable values, it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary. For this case the 2D FE model is developed and typical meshing is generated by using solid 42 elements. The shell is fixed at both end and the internal pressure of 1.0Mpa is applied and obtained deformed shape, stress and strain of the spherical shell.

3.2. Buckling Analysis

Eigen value buckling analysis predicts the theoretical buckling strength of an ideal linear elastic structure. Bifurcation buckling refers to the unbounded growth of a new deformation pattern. Imperfection and material non-linearity cannot be included in this analysis. Thus, the buckling strength obtained by Eigen value buckling analysis may differ from that of a real structure and often yield non conservative results. Therefore, care is needed when using this method in actual evaluation of buckling strength. Non-linear buckling analysis including geometric and material non-linearity is usually the more accurate approach and is therefore recommended for design or evaluation of actual structures. There are two methods for obtaining buckling strength by non-linear buckling analysis. One basic approach is to constantly increment the applied loads until the solution begins to diverge, which can be obtained from load-controlled buckling analysis. In this approach, a simple static analysis will be done with large deflection extended to a point where the structure reaches its limit load.

4. Modelling

Non-linear finite element method with large deflection analysis was performed using commercial Ansys software. A three dimensional finite element model was generated using Ansys 12.0. For studying of buckling of pressure vessel with torispherical head; we modeled intersection of cylinder head. The influence of welding and forming on material property were neglected while the effect of welding can be accounted for by modifying the yield stresses. The length of the cylinder was kept at 4□□ (□□is the linear elastic meridian bending of half-wave length given by 2.44 Rt) to ensure that the boundary effects at the far end of the cylinder do not interfere with the behavior of the intersection. The model was meshed with shell 93 element. SHELL93 is particularly well suited to model curved shells. 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. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The material of the intersections was assumed to have typical properties of steel: an elastic modulus of 1.9 □10^5 MPa; a Poisson's ratio of 0.26, and yield stress of 206 MPa,

5. Numerical Data

The numerical parameters of storage tanks are used for the present analysis, the storage tanks are used in launched vehicle. It is made of steel. Generally, the geometry of storage tanks is composed of circular cylindrical shell with torispherical heads. The numerical parameters of torispherical shell have taken from standard references. Numerical parameters of the torispherical head vessel from standard Parameters.

Geometrical parameters are:

- R_c = 800 mm
- R_d = 2456.6 mm
- R_k=147.2mm
  h_c =h_d = 241.6 mm
- L_c = 1000 mm.

MATERIAL PARAMETER	MARAGING STEEL	WROUGHT IRON
Young Modulus, (E)	E= 2.1*10^5 GPA	E= 2.0*10^5 GPA
Poisson's Ratio, (V)	V = 0.3	V = 0.29
Yield Stress, σ_y	σ_y = 360 MPa	σ_y = 360 MPa
Internal Pressure, (P)	P = 1.5 MPa	P = 1.5 MPa

Table 1

6. Result and Discussion

6.1. Static Analysis of Steel and Wrought Iron

Static analysis is carried out with both end is fixed and internal pressure of 1.0MPa is applied in the shell. The result obtained from FEA solve for deflection of steel and wrought iron material are tabulated below and it is more in mar aging steel than wrought iron. Figure. 6.1 to 6.12 are showing that deformed shape, x- component of stress and strain in steel and wrought iron materials.

Sl. No.	Material	Deformed shape	Stress	Strain
01.	Mar aging steel	511384	-340E+07	15.364
02.	Wrought Iron	447461	-345E+07	13.585

Table 2

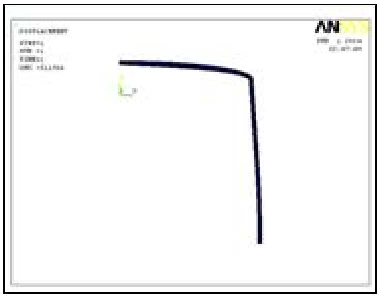

Fig 6.1 Deformed shape of shell

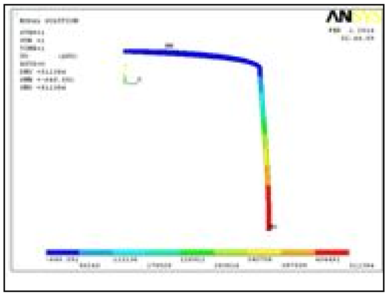

Fig 6.2 DOF at X comps, of shell

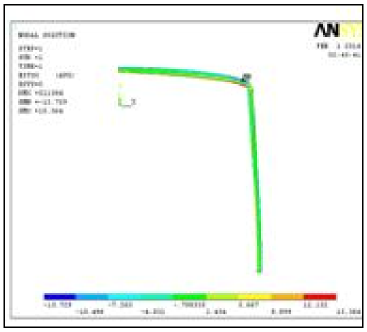

Fig 6.3 Strain at X comps, of shell

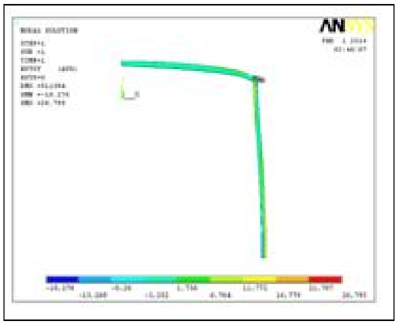

Fig 6.4 Strain at Y comps, of shell

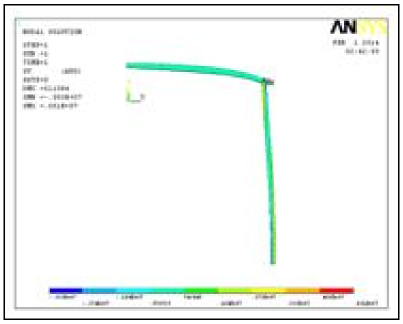

Fig 6.5 Stress at X comps, of shell

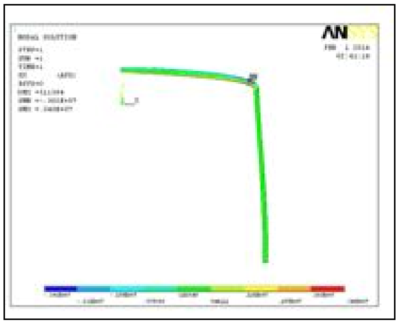

Fig 6.6 Stress at Y comps, of shell

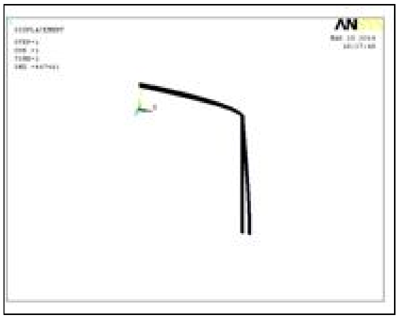

Fig 6.7 Deformed shapes in wrought iron

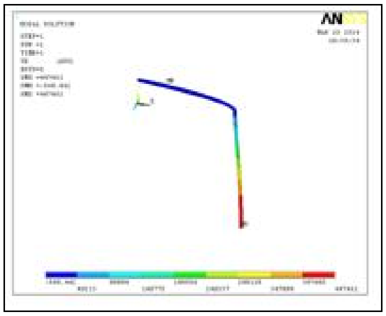

Fig 6.8 DOF at X comps, in wrought iron

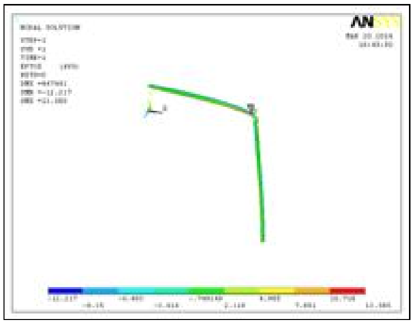

Fig 6.9 Strain at X comps, of shell

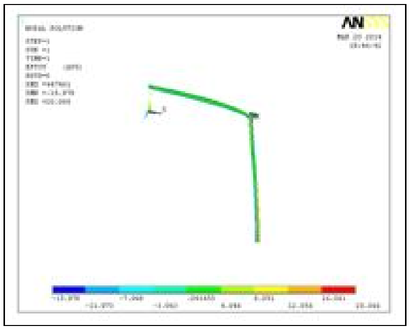

Fig 6.10 Strain at X comps, of shell

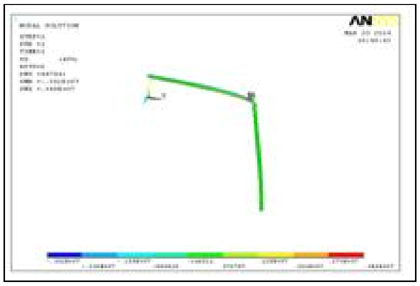

Fig 6.11 Stress at X comps, of shell

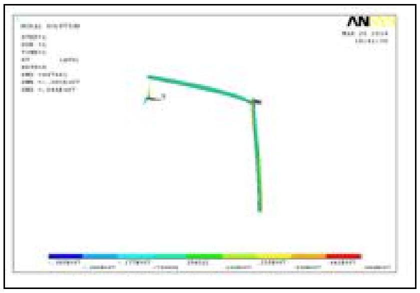

Fig 6.12 Stress at X comps, of shell

6.2. Buckling Analysis of Steel And Cast Iron

Buckling analysis is performed to get critical internal buckling load. The buckling frequency and its corresponding mode shapes obtained for mar aging steel and wrought iron material using ANSYS V 12 are shown in figure. 6.2.1 and 6.2.2. The Table 3 shows the comparison of buckling load obtained the value, and it is more in wrought iron than mar aging steel.

Sl. No.	Material	Buckling load in-MPa
01.	Mar aging steel	127.543
02.	Wrought Iron	146.207

Table 3

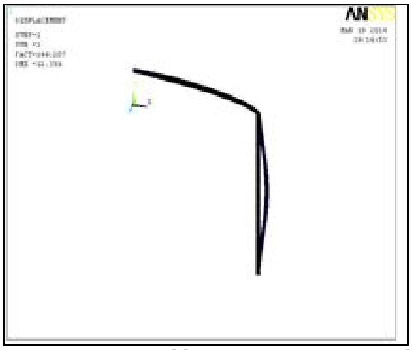

Fig. 6.2.1 Buckling in Mar aging steel

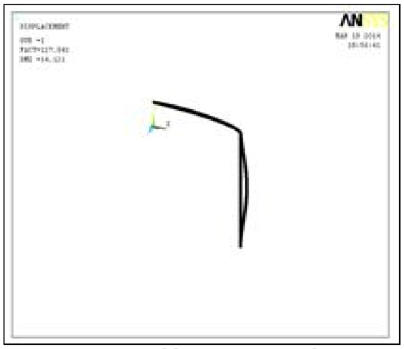

Fig. 6.2.2 Buckling in Wrought iron

7. Conclusion

In this analysis, a numerical method for buckling problems of the general axisymetric shell, considering nonlinearity in the prebuckling state, is proposed. To show the validity of this method the buckling problem of a partial spherical shell subjected to uniform pressure upon the convex side of its surface is solved by the present method and the calculated results are compared with those by other researchers.

The present method is used to solve the buckling problem of the torispherical head of a circular cylindrical pressure vessel subjected to internal pressure.

8. References

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