A Study on Moment Attenuation Characteristics of Thin Shell Structures of Launch Vehicles

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Abstract: ***Thin shell structures near the structural interfaces have local bending moments induced due to local load eccentricity. Thin shells have the unique feature of attenuating the edge moment loads by virtue of its geometry, allowing local deformations. This paper aims to study the moment attenuating characteristics of thin shell structures used in Launch vehicles. Theoretical and numerical solutions techniques are used to study the shell behavior under edge moment loads. Theoretical solutions are derived based on the shell-bending theory and are validated with detailed finite element analyses.***

Keywords: Thin shells, Launch Vehicle Structures, Edge Moment, Moment attenuation, Bending theory, Behavior of thin shells

1. Introduction

Inter-stage structures of launch vehicles near the structural interface have local moments generated due to the eccentricity created by the joint (flanged joint or lap joint). Similarly, in tank structures (fuel or oxidizer tank), near the cylinder to dome joint, due to the change in geometry, local edge moments are generated. Thin shell structures, unlike thick shell have a unique feature of faster attenuation of local moment loads.The purpose of this study is to investigate the edge moment attenuating characteristics of thin shell structures used in launch vehicles. Analytical and numerical studies are carried out to understand the behavior of thin shell structures under edge moment loading.

2. Objective

1) To understand the moment attenuation behavior of thin shells near the structural interfaces.
2) Theoretical and numerical study of thin shell characteristics for different shell thickness

3. Literature Review

Suhrabuddin et al [5] in their work, explains the general formulation for the curved, arbitrary shape of thick shell finite elements along with a simplified form for axisymmetric situations. Reddy J.N. and Chandrashekhara [4] describes a nine-nodded finite element and reported both the geometrically linear and nonlinear transient response of laminated composite cylindrical and spherical shells. Chakravorty D et al [3] represented variation of vibrational stiffness of conoids with boundary condition, aspect ratio and truncation ratio. Altenbach H et al [1] proposed a variational method for refining the shell theory which was based on Kirchhoff-Love hypothesis.

4. Theoretical Study

4.1 Model Configuration

Most of the launch vehicle inter-stage structures are thin walled cylindrical structures. Hence a simple monocoque cylindrical shell configuration is chosen for the analysis/study as shown in Figure1.

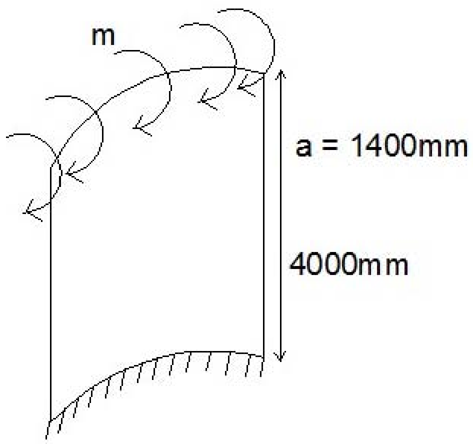

Figure 1: Monocoque Cylindrical shell

4.2 Material Properties

Table 1: Material Properties

Properties	Aluminium
Modulus of elasticity, E	67680 N/mm^2
Poisson"s ratio	0.3

Using the bending equation,

$$M_x = -D \, {d^2 w}/{dx^2} \quad (1)$$

$$D = {Eh^3}/{12(1-\mu^3)} \quad (2)$$

D is the flexural rigidity of the shell and h is the thickness of the shell

$$\frac{d^4 w}{dx^4} + 4\beta^4 w = \frac{Z}{D} \tag{3}$$

Where $\beta^4 = \dfrac{3(1-\mu^2)}{a^2 h^2}$ (4)

$$\beta = \frac{0.0343539}{h^{1/2}}$$

The geometric parameter β is the reciprocal of length

$$\frac{d^2 w}{dx^2} = \frac{-1}{2\beta D}\left(2\beta m_0 \psi(\beta x) + 2Q_0 \xi(\beta X)\right) \tag{5}$$

$$\left.\begin{aligned} \varphi(\beta x) &= e^{-\beta x}(\cos\beta x + \sin\beta x) \\ \psi(\beta x) &= e^{-\beta x}(\cos\beta x - \sin\beta x) \\ \theta(\beta x) &= e^{-\beta x}(\cos\beta x) \\ \zeta(\beta x) &= e^{-\beta x}(\sin\beta x) \end{aligned}\right\} \quad 6$$

unit edge moment m_0 = 500N-mm

Moment variation along the length of the cylindrical panel is derived as

$$M = 500 \times e^{-0.03435 \times k^{-0.5} x}\left(\cos 0.03435 \times h^{-0.5} x + \sin 0.03435 \times h^{-0.5} x\right) \quad 7$$

The variation of moment along the length of thin shell near the structural interfaces under the influence of thickness is investigated. The thicknesses of shell are 0.5, 1, 1.5… 5mm. The shell is subjected to a load of 500Nmm at the fore end. Based on equation (7), the variation of moment is plotted along the length of the cylinder for various thicknesses as shown below:

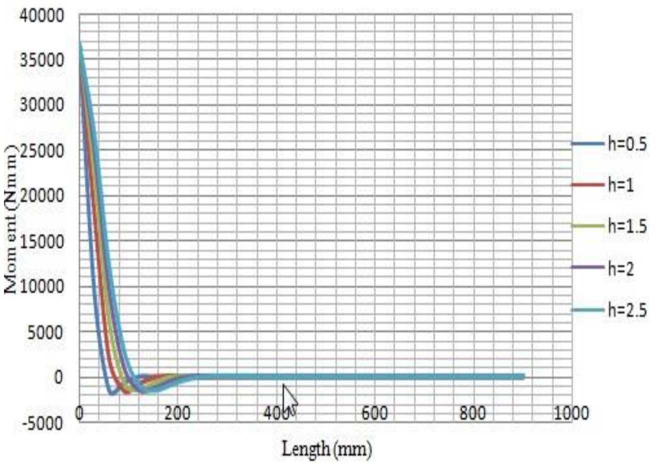

Figure 2: Variation of Moment along Length for 500 Nmm Moments (t = 0.5 to 2.5 mm)

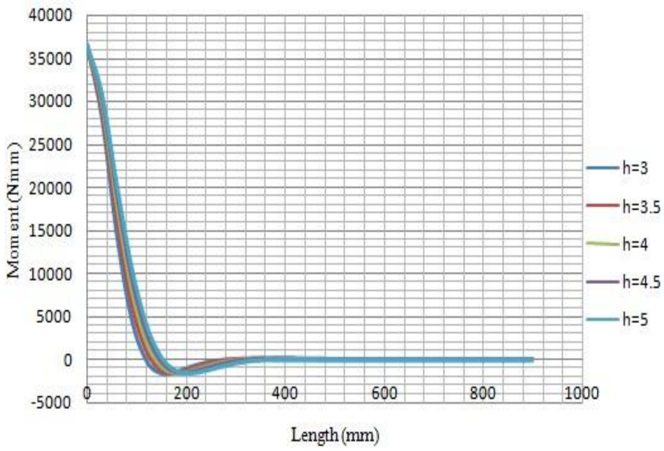

Figure 3: Variation of Moment along Length for 500 Nmm Moments (t = 3 to 5 mm)

The Figure 2 and Figure 3 shows how the bending moment vary along the length of the cylindrical shell. In this case, the moment gradually decreases as we move from the edge where local edge moment is applied to the fixed edge. As a result the bending moment is maximum at the free edges of the cylinder and vanishes towards the supporting edge. It is the general trend of the variation of moment along the length of the cylinder as predicted by the theory.

5. Numerical Validation

The numerical validation is carried out by Finite Element Method (FEM) The structure under consideration is a simple monocoque cylinder, which has a quarter symmetry, under the proposed loads and boundary conditions. Hence modeling of one-fourth of the geometry is adequate to simulate the problem as shown in Figure 4.

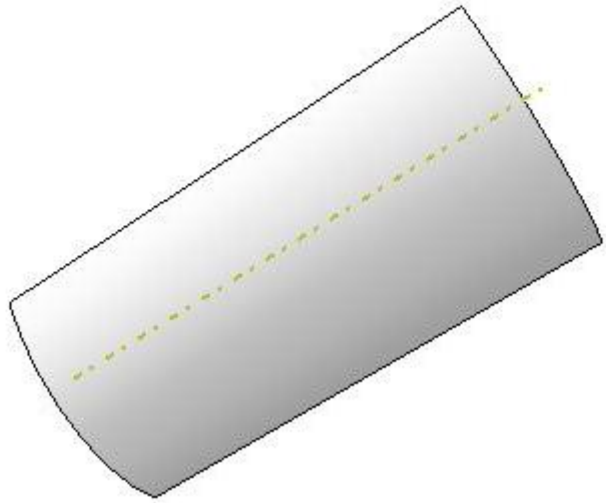

Figure 4: Finite Element Model – Geometry

The Figure 5 shows the finite element model; it consists of a shell surface with a determined mesh division over length of the thin shell. The clamped bottom edge of the cylinder is constrained against displacement in R θ and Z direction, as well as rotations. By considering the symmetric boundary condition, the two sides of the shell are also constrained against displacement in θ direction as shown in Figure 6.

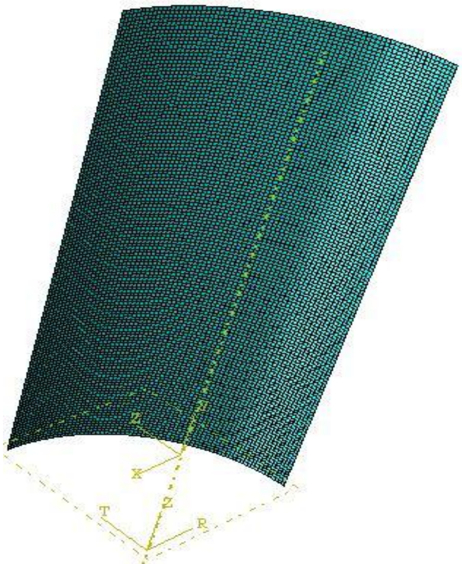

Figure 5: FE Model - Discretisation

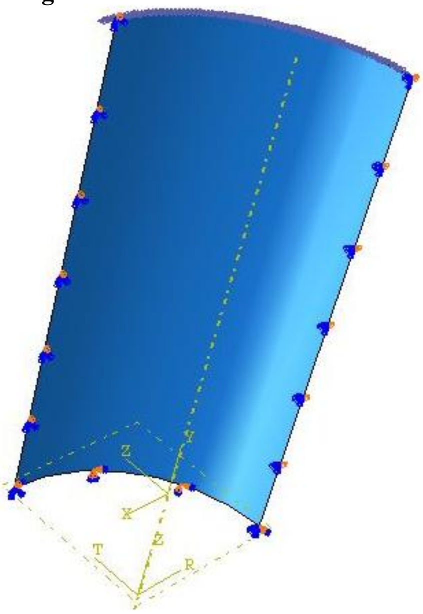

Figure 6: Loads and Boundary conditions

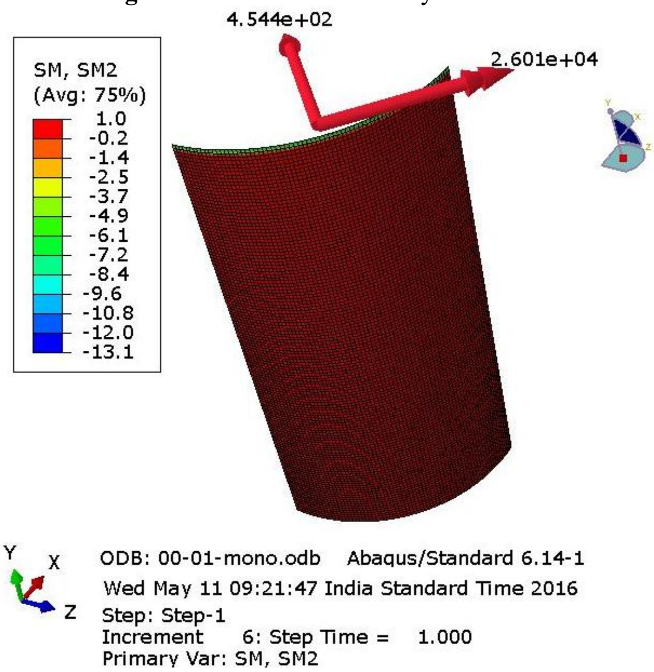

Figure 7: Finite Element Analysis Results

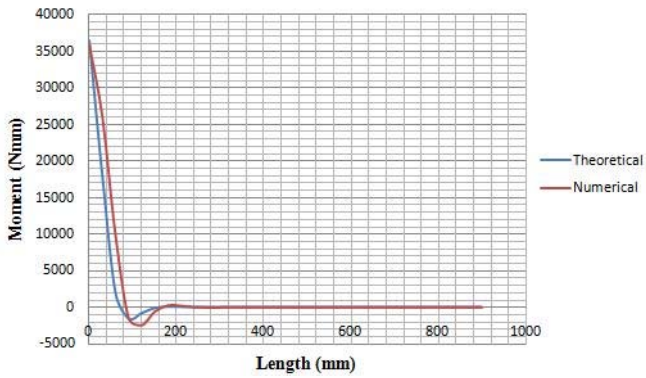

Figure 8: Numerical and Analytical Distribution of Bending Moment

The Figure 7 shows the free body diagram at a defined section of the structure along the longitudinal direction of the shell. Variation of edge moment along the length for a monocoque cylindrical shell (moment attenuating characteristics of monocoque cylindrical shell) is studied and compared as shown in Figure 8 for a typical load and boundary condition. Similar trend of moment attenuation is observed in both the cases. For theoretical and numerical analysis cases, the moment is reduced to zero within a shell length of approximately 300mm. It is understood that the moment is rapidly reduced to zero for the edge disturbances on the thin shells. In both studies, the deflection is larger at the tip of the shell which is an expected behavior for a thin shell.

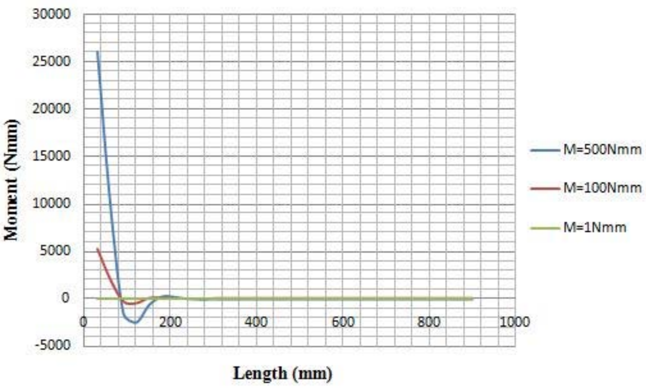

Figure 9: Variation of Moment along Length for Different Magnitude of Moment

Based on numerical values obtained for different nodal edge moment values of 1 N-mm, 100 N-mm and 500 N-mm. Results obtained as shown in Figure 9. It is found that the smaller the moment, faster the moment attenuation.

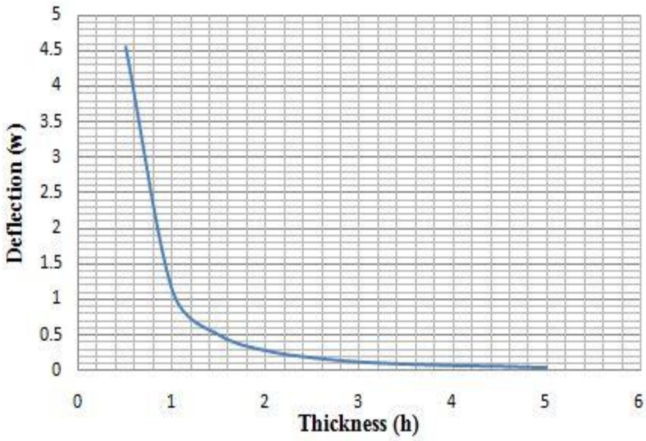

Figure 10: Maximum Deflection Studies for Various Thickness of Shell

The variation of deflection is most important characteristics in the study of shell. The deflection is reduced exponentially as the thickness of the shell increases. The edge moments are attenuated faster by local large deflections/rotations of the shell. Hence it is concluded that thinner shells deforms more and attenuate moments faster compared to thicker ones.

6. Conclusions

Variation of edge moment along the length for a monocoque cylindrical shell is derived based on the shell bending theory and the same is validated through numerical methods (Finite Element Analyses). Similar trends of moment attenuation are observed in both the cases. For theoretical and numerical analysis cases, the moment is reduced to zero within a shell length of approximately 300mm. It is understood that the moment is rapidly reduced to zero for the edge disturbances on the thin shells. Effect of thickness on the moment attenuation is studied. As the thickness increases, the moment attenuation rate is slower. In both studies, the deflection is larger at the tip of the shell which is an expected behavior for a thin shell.

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