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Finite Element Buckling Analysis of Composite Cylindrical Shell with Cutouts Subjected to Axial Compression

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Abstract

In this paper, the buckling analysis of thin walled composite cylindrical shells with and without cutouts is investigated by applying axial load on Glass Fiber Reinforced Plastic (GFRP) shell. The effect of cutout not only introduces stress concentration but also significantly reduces the buckling strength. The column is fixed at one end and load is applied at the other end. The Static and Eigenvalue buckling analysis is done on shell model. The circular, elliptical and rectangle cutouts are considered on cylindrical shell. The buckling analysis is repeated in each case. The compressive stress, buckling load factor and lateral strain of each case for cylindrical shell is obtained from ANSYS software. The buckling load decreases for shell with cutout when compared to the value of the shell without a cutout. Stress and lateral strain increases for shell with cutout when compared to the shell without a cutout. The buckling load value is maximum in circular cutout and minimum in the rectangular cutout.

Keywords: *Composite, cylindrical shell, cut-out, buckling analysis, Column*

1. Introduction

In many industrial applications, shells are equipped with openings of various shapes, sizes and locations within the lateral surface. The objective of the present paper is to understand the effect of cutouts on critical buckling load of thin composite cylindrical shells. Nowadays the usages of composite cylindrical shell are gradually increased in many engineering fields. Due to the inherent tailoring properties of these composite materials have a number of unique design features such as reduce weight, high performance, increased service life and reduced system maintenance. The composite cylindrical shells are being used widely in aerospace industries, underground pipelines, submarines, etc. During in aerospace applications, flight loads and internal cabin pressure are present in all commercial transport aircraft [1]. Some of these loads may be compressive loads and, thus, it is necessary to investigate the buckling characteristics of these structures. In addition, designers will often need to incorporate cutouts or openings in the structure to serve as doors, windows, or access ports. It has been shown by a number of authors that a cutout in a shell structure subjected to axial compression can cause a significant reduction in the buckling load of the shell [2-5].

The problem of cylindrical shell buckling subjected to axial compressive loads has been investigated by many researchers [6-10] using approximate analytical methods as well as finite element methods. Theoretically evaluated classical buckling load is generally much higher than the actual buckling load of the cylindrical shell and a knockdown factor is introduced to evaluate a better approximation based on an extensive experimental investigation [11-13]. E.R. Lancaster [14] has investigated the effect on the buckling load of imperfections in the form of local initial stress, which are probably more typical of practice than purely geometric ones. Reza Akbari Alashti [15] has presented the buckling analysis of cylindrical shells with cutouts under axial loading. The cutouts are of different types like circular, square, and rectangle subjected to internal pressure and axial compression. The responses of composite shells with cutouts are obtained using geometrically nonlinear FEM software, carried by ANSYS [16]. Mahmoud Shariati [17] presented the effect of random geometric imperfections on the limit loads of isotropic, thin-walled, cylindrical shells under deterministic axial compression analyzed. For the determination of the limit load a geometric non-linear static analysis is carried out using the general purpose code STAGS.

In the present work an attempt has been made to conduct finite element buckling analysis of composite cylindrical shell with various openings (circular, elliptical and rectangular) subjected to axial compression by using ANSYS software.

2. Finite Element Buckling Analysis of Composite Cylindrical Shell

Buckling analysis is a technique used to determine buckling loads or critical loads wherein the structure becomes unstable. The buckled mode shapes are the characteristic shape associated with a structure's buckled response.

2.1. Eigenvalue Buckling Analysis

The simplest way to get information about the critical load of a structure is to examine an appropriate linear eigenvalue problem. The system of equations, which has to be resolved, has a form: $\left| \mathbf{K}_{con} + \lambda \mathbf{K}_{\sigma} \right| \mathbf{x} = \mathbf{0}$

The $\mathbf{K}_{con}$, $\mathbf{K}_{\sigma}$, **'λ'** and **'x'** are standardized for the constitutive stiffness matrix, geometrical stiffness matrix, Eigenvalue and the corresponding eigenvector, respectively. This approach can be very attractive due to its computational efficiency; however, as a linear formulation, it is useless when the structure undergoes large deformations in the pre-buckling range.

2.2. Dimensions of Shell & Cutout

The dimensions of the composite cylindrical shell and their cutouts are outlined as follows:

2.2.1. Shell dimensions

The radius of the cylindrical shell (r) = 150 mm
Thickness of the cylindrical shell (t) = 1.25 mm
Length of the cylindrical shell (l) = 300 mm

2.2.2. Cut-out Dimensions

The same amount of Area (approximately) is removed in all cutouts.

Circular cutout:
Circle radius = 24.9 mm; Area of circle = 1947.8 mm^2

Elliptical cutout (Major axis is horizontal):
Minor axis = 46 mm; Major axis = 54 mm; Area of ellipse = 1950.9 mm^2

Rectangular cutout:
Length = 39 mm; Width = 50 mm; Area of rectangle= 1950 mm^2

2.3. Mechanical Properties of Materials

Table 1. Properties of E-Glass & Polyester

Type of material	**Young's Modulus E (GPa)**	**Poisson's ratio (ν)**	**Shear Modulus G (GPa)**	**Volume fraction in composite material (%)**
E-Glass (Fiber)	72.4	0.28	30	65
Polyester (Resin)	9	0.3	3.6	35

Table 2. Properties of Glass Fiber Reinforced Plastic Material

S.NO	**Composite material properties (E-glass/polyester)**		
	Property	**Direction**	**Value**
1	Longitudinal modulus (GPa)	$\mathbf{E_{11}} = E_f V_f + E_m V_m$	50.21
2	Transverse modulus (GPa)	$\mathbf{E_{22}} = (E_f E_m / (E_m V_f + E_f V_m))$	20.8913
3	Shear modulus (GPa)	$\mathbf{G_{12}} = G_f G_m / (G_m V_f + G_f V_m)$	7.7518
4	Poisson's ratio	$\boldsymbol{\nu_{12}} = V_m \nu_f + V_f \nu_m$	0.263
5	Density (kg/m^3)	$\boldsymbol{\rho_C} = \rho_f \nu_f + \rho_m \nu_m$	2167

2.4. Modeling and Boundary Conditions

The composite cylindrical shell with and without cutouts are modeled using CATIA software. The boundary conditions are applied on the meshed modal. The bottom end of the shell is fixed (all degrees of freedom arrested). The other end of the shell is free and compressive load of 1500 N (Top) applied on nodes.

3. Results and Discussion

The cylindrical shell is modeled for with and without cutouts. The mesh is generated and boundary conditions are applied. The loads are acting on meshed cylindrical shells. The stress, buckling load factor and deformation are obtained using ANSYS software for each case.

Buckling load = Buckling Load Factor (BLF) x Applied Load

3.1. Stress

Figure 1 shows the stress in composite cylindrical shell (a) without cutout, and with, (b) Circular cutout, (c) Elliptical cutout and (d) Rectangular cutout.

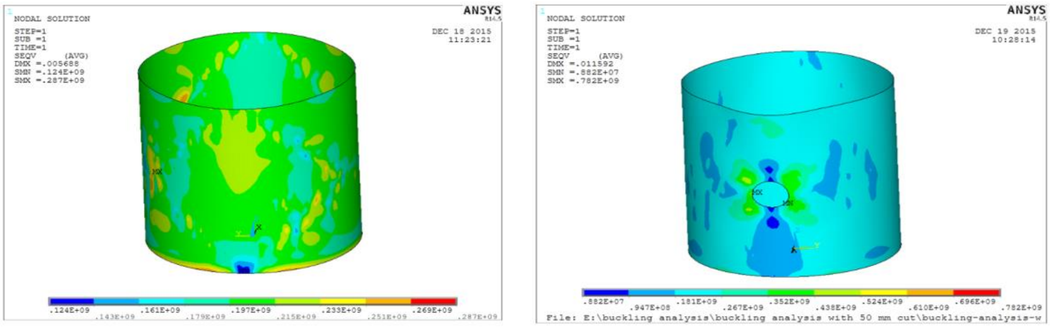

Figure 1(a). Without Cutout

Figure 1(b). Circular Cutout

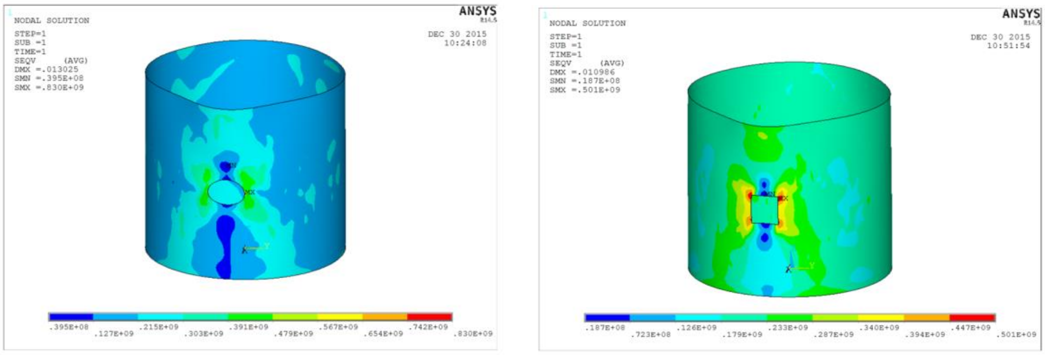

Figure 1(c). Elliptical Cutout

Figure 1(d). Rectangular Cutout

Figure 1. Stress of Composite Cylindrical Shell

3.2. Buckling Load Factor (BLF) and Deformation at Mode-1

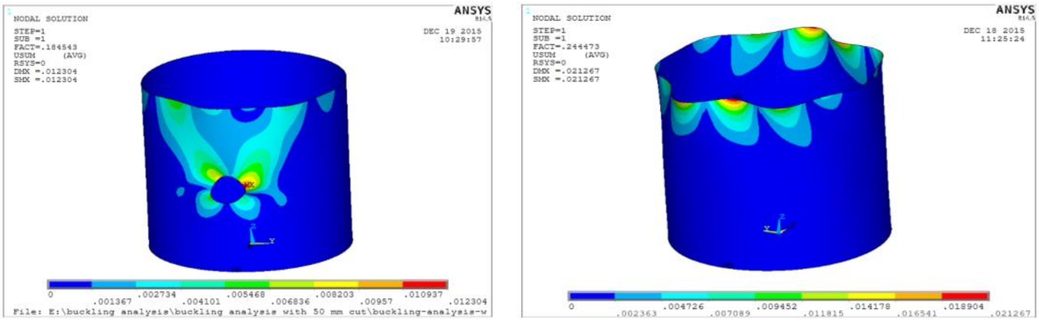

Figure 2(a). Without Cutout

Figure 2(b). Circular Cutout

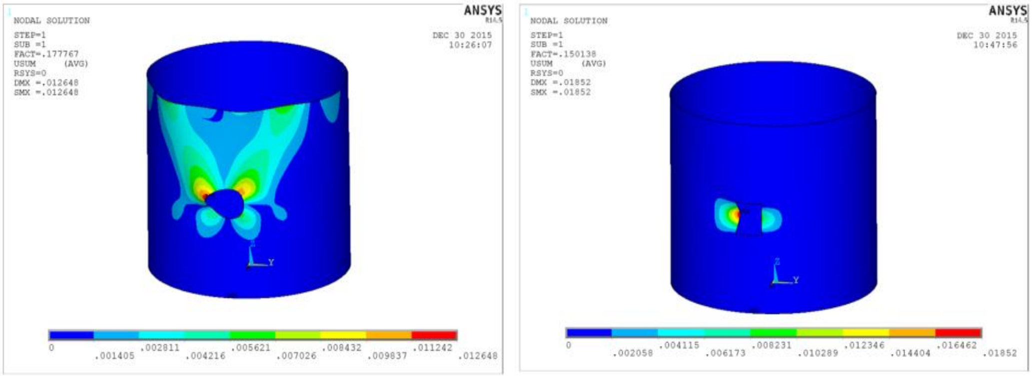

Figure 2(c). Elliptical Cutout

Figure 2(d). Rectangular Cutout

Figure 2. BLF and Deformation of Composite Cylindrical Shell

3.3. BLF and Deformation at Mode-2

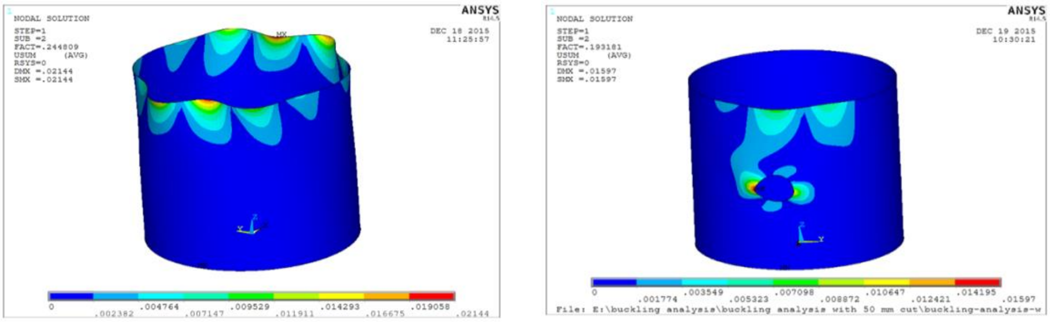

Figure 3(a). without Cutout

Figure 3(b). Circular Cutout

Figure 3(c). Elliptical Cutout

Figure 3(d). Rectangular Cutout

Figure 3. BLF and Deformation of Composite Cylindrical Shell

3.4. BLF and Deformation at Mode-3

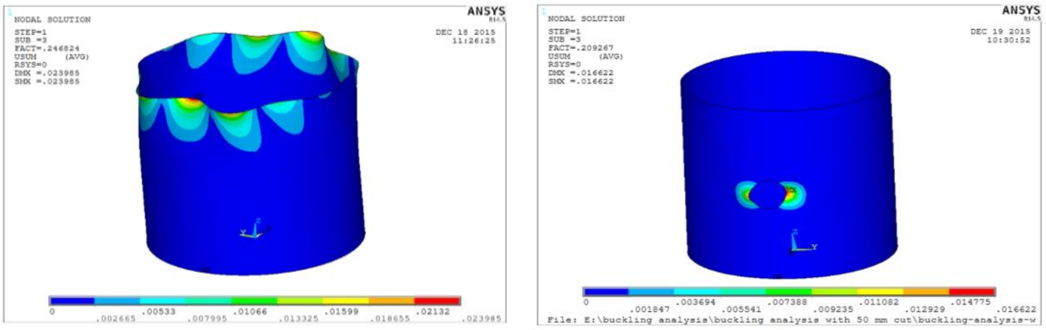

Figure 4(a). Without Cutout

Figure 4(b). Circular Cutout

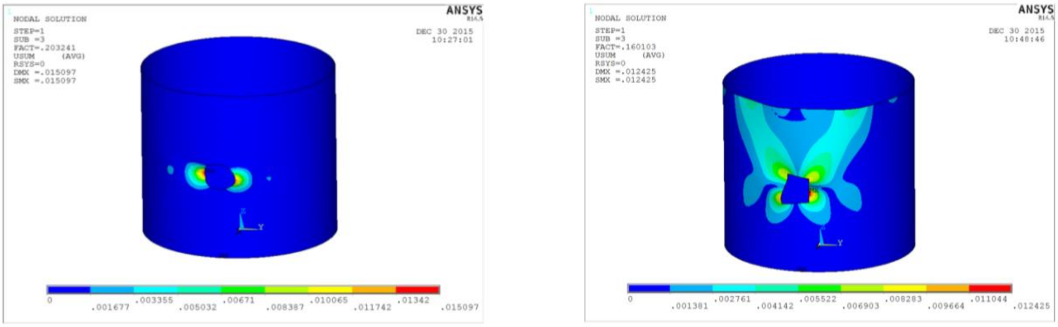

Figure 4(c). Elliptical Cutout

Figure 4(d). Rectangular Cutout

Figure 4. BLF and Deformation of Composite Cylindrical Shell

The maximum stress, BLF and lateral deformation values in each case (Figure 1 to Figure 4) are measured and presented in Table 3.

Table 3. Results of Buckling Load & Deformation at Modes

Composite thin cylindrical shell	Stress (N/mm^2)	Mode-1		Mode-2		Mode-3	
		Buckling load (N)	Deformation (mm)	Buckling load (N)	Deformation(mm)	Buckling load (N)	Deformation (mm)
Without cutout	264	366.7	0.02126	367.21	0.2144	370.23	0.02398
Circular cutout	782	276.81	0.01230	289.77	0.01597	313.90	0.01662
Elliptical cutout	830	266.65	0.12648	280.05	0.15846	304.86	0.15097
Rectangular cutout	501	225.21	0.01852	227.13	0.01906	240.15	0.01242

Figure 5 shows the response of buckling load at different modes. Figure 6 shows the response of buckling load at different deformation mode. The Euler buckling load is a function of flexural rigity and it's influenced by cutout shape.

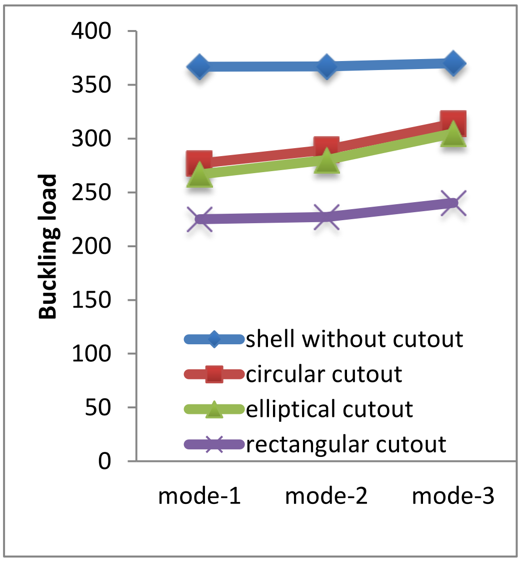

Figure 5. Buckling Loads vs Mode Shape

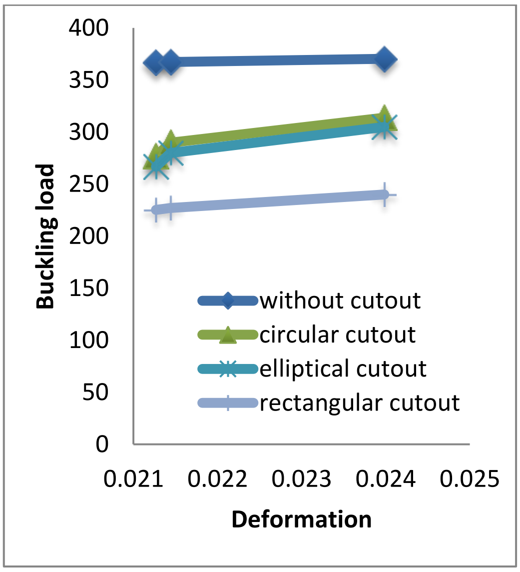

Figure 6. Deformation vs Buckling Load

4. Conclusion

The Eigenvalue buckling analysis has been carried out on composite cylindrical shell with and without cutouts using ANSYS software. The rectangular, circular and elliptical cutouts are considered. The following conclusions can be drawn:

1. The buckling load factor, compressive stress and lateral deformation are obtained using ANSYS software for each case. Buckling load is calculated using empirical formula.
2. The buckling load gets decreased for shell with cutout when compared to the shell without a cutout.
3. Regarding cutout, buckling load is maximum for shell with circular cutout and minimum for rectangular cutout.
4. Stress is maximum for shell with elliptical cutout and minimum for rectangular cutout.

5. Deformation is minimum for shell with circular cutout and maximum for rectangular cutout.

This study will help in ensuring the safety of airline passengers and factory workers.

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