

## Buckling Behavior of Clamped Laminated Composite Cylindrical Shells under External Pressure Using Finite Element Method

Behzad Abdi<sup>1,a</sup>, Hamid Mozafari<sup>2,b</sup>, Amran Ayob<sup>3,c</sup>, Roya Kohandel<sup>4,d</sup>

<sup>1,2,3</sup> Faculty of Mechanical Engineering, Universiti Teknologi Malaysia,  
81310 UTM Skudai, Johor, Malaysia

<sup>4</sup> Faculty of Civil Engineering, Universiti Teknologi Malaysia,  
81310 UTM Skudai, Johor, Malaysia

<sup>a</sup> Behzad.abdi@gmail.com, <sup>b</sup> mozafari.h@gmail.com, <sup>c</sup> amran@fkm.utm.my, <sup>d</sup> kohandel.roya@gmail.com

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**Abstract.** In this study, the elastic buckling behavior of clamped laminated composite cylindrical shells under external pressure was studied. The Finite Element Method (FEM) was used to predict the critical elastic buckling pressure behavior when composite cylindrical shells were subjected to external pressure. The edges of the cylindrical shell ends were completely constrained to simulate clamped end conditions. The influences of parameters such as wall thickness, fiber angle, number of layers and L/R ratio of laminated composite cylindrical shells on critical buckling pressure were studied. It has been found that the under external pressure, the thickness and the fiber angle of the layers have the most significant effect on the critical buckling pressure.

### Introduction

Cylindrical shells have been widely used in various industries. Structural applications of composite cylindrical shells are increasing due to high strength and stability and lightweight. However the prediction of mechanical behavior of laminated composite cylindrical shells is complicated by its dependence on the fiber angle and the thickness of the laminate layers.

Various analysts have studied the buckling of laminated composite cylindrical shell subject to various loadings [1-3]. Jones et al. [4] have presented analytical solutions for prediction of critical buckling pressures of thin composite rings and cylindrical shells. Kardomateas [5] has derived an accurate three-dimensional elasticity-based solution for determination of the buckling pressure of a thick orthotropic cylindrical shell under external pressure, and has investigated the effect of thickness on the critical pressure. The influence of filament winding pattern on the mechanical behavior of composite cylinders under external pressure was studied by Hernandez [6]. Carvelli et al. [7] worked on the buckling strength of GFRP under-water vehicles. A study on pressure vessel design, structural analysis, and pressure test of the semiautonomous underwater vehicle was investigated by Joung et al. [8].

In this study, clamped laminated composite cylindrical shells made of graphite/epoxy under external pressure are selected and analyzed by using finite element method (Fig. 1). The effect of thickness and angle of layers on critical buckling pressure of laminated composite cylindrical shell under external pressure was studied. The cylindrical shells are rigidly supported at the end edges. The dimensions of the cylinder used in this study are similar to those of Refs [9]. Also, the effect of thickness and ratio of length to the mean radius of the laminated composite cylindrical shells on critical buckling load was studied. Two cylinders with different ply orientations, ( $[0/45/90]_s$ ,  $[0/60/90]_s$ ) were studied.

### Model description

Consider a laminated composite cylindrical shell made of  $n$  orthotropic layers that the principal axis gets along with the axis ( $x$ ). The composite cylindrical shells are made of Graphite/Epoxy materials, and the mechanical properties are listed in Table 1. The dimensions of the cylinder used in this study are similar to those of Refs [9], viz, 250 mm mean radius, 2500 mm length and a total thickness of layers 5 mm. The ratio of length to radius of cylindrical shell for two type of layer orientations ( $[0/45/90]_s$ ,  $[0/60/90]_s$ ) are  $L/R = 2.5, 5, 10$ .

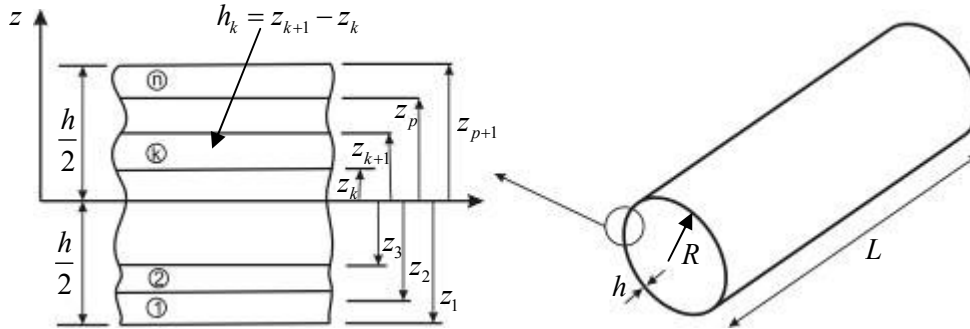


Figure 1: Laminated composite cylindrical shell

Table 1: Mechanical properties of a unidirectional lamina [10]

Property	Symbol	Unit	Graphite/Epoxy
Elastic modulus	$E_1$	$GPa$	181
	$E_2 = E_3$	$GPa$	10.30
Poisson's ratio	$\nu_{12}$	---	0.28
	$G_{12}$	$GPa$	7.17
Shear modulus	$G_{23}$	$GPa$	3.0
	$G_{13}$	$GPa$	7.0

### Finite Element Method

The elastic buckling of externally pressurized composite cylindrical shells with clamped edges was carried out by using finite element method (FEM). Three models of composite cylindrical shells were considered and studied in this paper. The effect of thickness and the angle of layer on critical buckling pressure for a composite cylindrical shell made of single and double graphite/epoxy layers were studied. Also, the effect of thickness and  $L/R$  ratio on critical buckling pressure of two composite cylindrical shells made of five layers with different orientations ( $[0/45/90]_s$ ,  $[0/60/90]_s$ ) were analyzed by finite element method. To simulate the composite layers, the ANSYS 'shell 99' element was used in this study. Figure 2 shows the orientation of a five-layer composite material ( $[0/45/90]_s$ ) that have been modeled in finite element analysis software (ANSYS).

### Results and discussion

For a clamped composite cylindrical shell made of one layer graphite/epoxy, the thickness effect and the angle of layer on the critical buckling pressure are studied and the results are shown in Fig. 3. In Fig. 4 the angle effect on the critical buckling pressure of composite cylinder made of two layers graphite/epoxy are presented. In this study, the total thickness of the layers is constant and equals to 0.005 m.

The influence of layer thickness on the critical buckling pressure of cylinders made of five graphite/epoxy layers with different orientation ( $[0/45/90]_s$ ,  $[0/60/90]_s$ ) are studied and the results are displayed in Fig. 5.

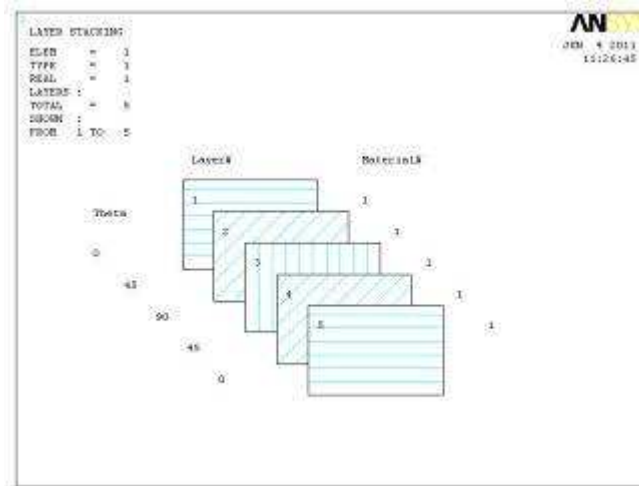


Figure 2: A five-layer composite material modeled by ANSYS

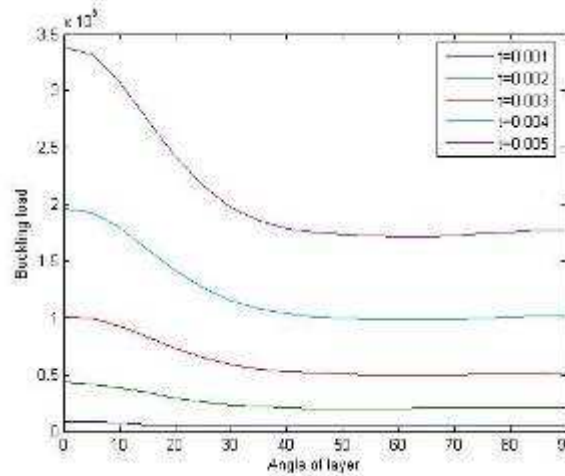


Figure 3: Effect of thickness and the angle of layer on critical buckling pressure of cylinder

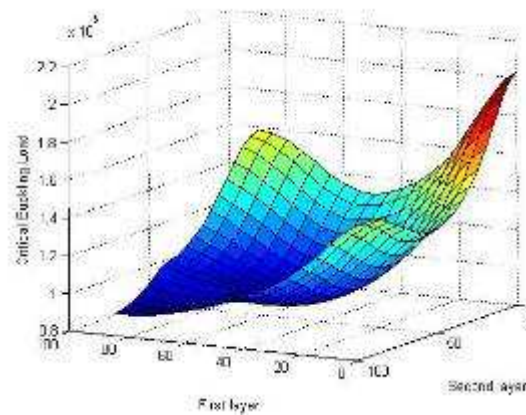


Figure 4: Effect of angle of layers on critical buckling pressure of two-ply composite cylinder

The four buckling modes of composite cylindrical shell made of five graphite/epoxy layers  $([0/45/90]_5)$  with same thickness ( $t=0.005$  m) are studied and the results are showed in Fig. 6.

From Fig. 3, for buckling of a single layer of graphite/epoxy cylindrical shell with clamped edges, it can be seen that the critical buckling pressure decreases with increasing the angle of layers and it increases by increasing the thickness of layer. For example, the critical buckling pressure for a layer with thickness of 0.003m is almost three times more than a layer with thickness of 0.001m.

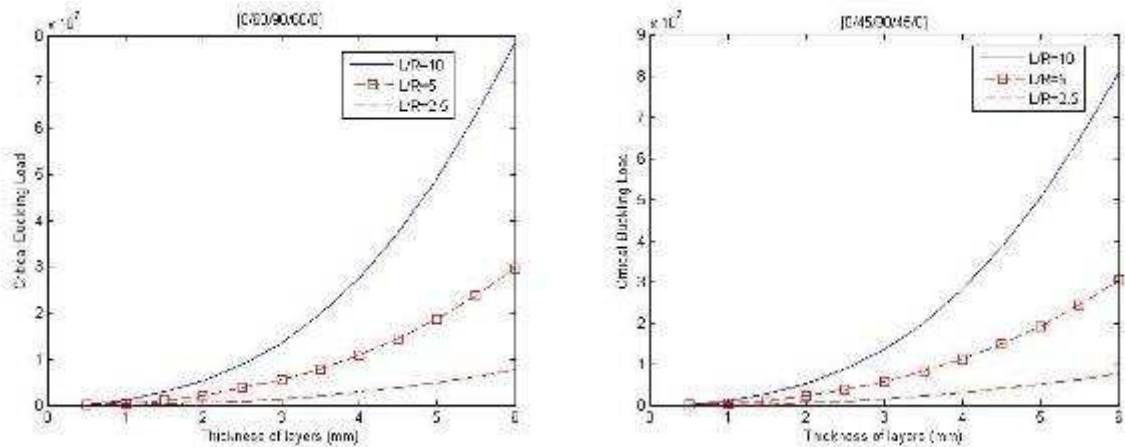


Figure 5: Effect of laminate thickness and  $L/R$  ratio on critical buckling pressure of five-ply composite cylindrical shell

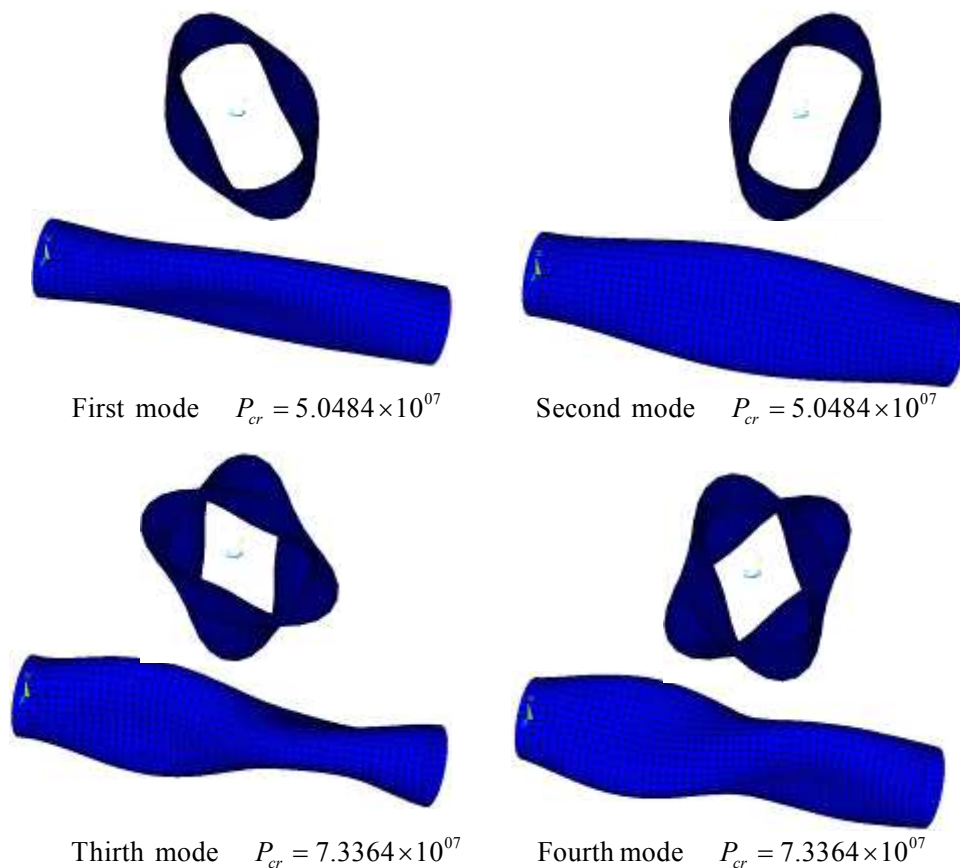


Figure 6: The four buckling modes of clamped composite cylindrical shell under external pressure

Fig.4 shows buckling of a 2-ply graphite/epoxy cylindrical shell with clamped edges. It can be seen that the critical buckling pressure behavior of cylinders strongly depends on the fiber angles of the plies. The maximum critical buckling pressure occurs when the fiber angle is  $0^\circ$  in both plies and the maximum buckling pressure occurs when the fiber angle is  $90^\circ$  in both plies.

Fig. 5 shows the effect of laminate thickness on the critical buckling behavior of five-ply graphite/epoxy cylindrical shells with different  $L/R$  ratios. Increasing the  $L/R$  ratio for both  $([0/45/90]_s, [0/60/90]_s)$ , the critical buckling pressure increases. Also, by increasing the laminate thickness, the critical buckling pressure increases exponentially. For example, in both models, the amount of critical buckling pressure for  $L/R = 2.5$  with thickness of 0.006m is almost three times the amount of buckling of cylinder with  $L/R = 5$  and almost eight times the amount of buckling

pressure of cylinder with  $L/R=10$ . It shows that by increasing the  $L/R$  ratio of composite cylindrical shells, the stability of cylinder is increased and the cylinders with small  $L/R$  ratio buckle earlier. From Fig. 5, by changing the fiber angles of second and fourth layers from  $45^\circ$  to  $60^\circ$ , the critical buckling pressure decreases by almost two percent

Fig. 6 shows the four buckling modes of a clamped composite cylindrical shell under external pressure, with laminate thickness 0.005m and  $L/R$  ratio of 10. From Fig. 6, it can be seen that the second and fourth buckling modes of cylinders are same as first and third buckling modes, respectively. Also, the amount of critical buckling pressure in third mode is almost 1.5 times the first mode and the numbers of waves in first and third modes are equals to 2 and 4 waves, respectively.

From Figs. 3, 4 and 5, increasing the number of plies have big effect on critical buckling loads on composite cylindrical shells. For example, the amount of critical buckling pressure of single ply of graphite/epoxy cylindrical shell with laminate thickness of 0.005m is six times less than a 2-ply composite cylinder and 150 times less than a 5-ply under same conditions.

## Summary

In this study, the buckling behavior of composite cylindrical shells with clamped edges under external pressure was studied by using finite element analysis software (ANSYS). It can be found there is direct relation between the elastic buckling pressure and the fiber angle, number of plies and  $L/R$  ratio of clamped composite cylindrical shells. The effects of composite material properties and the dimensions of cylinders on the buckling behavior of composite cylindrical shells are very important in designing this type of shells.

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