© May 2025| IJIRT | Volume 5 Issue 12 | ISSN: 2349-6002

Investigation on Buckling Behaviour of Orthotropic Laminated Composite Plates Including Cut-Outs by Using Finite Element Method

Annappa H Kotre
Lecturer, Department of Automobile Engineering, Government Polytechnic Bidar, Karnataka, India

Abstract: **The effects of square and rectangular cuts on the buckling behavior of a four-ply orthotropic carbon/epoxy symmetrically laminated rectangular composite plate are ascertained using a finite element approach using ANSYS software. Uniaxial compression stress was applied to the square/rectangular cuts under test. This research examines how the buckling behavior of the symmetrically laminated rectangular composite plate under uniaxial compression stress is affected by the square/rectangular cutout's size, orientation, and plate aspect ratio (a/b). For an orthotropic laminate design of [0°/45°/45°/0°], buckling loads were calculated. The findings shown that for plates with a rectangular cutout, the buckling load magnitudes decrease as the cutoff positioned angle and the c/b and d/b ratios increase. As the plate aspect ratio (a/b) increases, the buckling load magnitudes of a rectangular composite plate with square/rectangular cutout decrease. In every simulation, the aspect ratio ranged from 2 to 6. ANSYS software is used to further examine the nature of the buckling load in relation to the t/b ratio and the buckling factors at different t/b ratios, such as 1/20, 1/40, 1/60, and 1/80.**

Keywords: Buckling, Orthotropic Laminates Aspect ratio, Square/Rectangular cutout, FEM.

1. INTRODUCTION

The effects of end conditions, plate aspect ratios, and cuts on the ideal fiber orientations and corresponding optimum buckling loads of symmetrically laminated composite plates under uniaxial compression stress were examined by Hsuan-Teh Hu and Borhorng Lin [3]. The effects of end conditions, aspect ratios, cuts, and lateral loads on the ideal fiber orientations and corresponding optimum buckling loads of unsymmetrical laminated plates were examined by Hsuan-The Hu and Zhong-Zhi Chen [4]. Buckling study was performed on the rectangular composite laminates with a central circular hole by Baba and Baltaci [5, 6]. The effects of cutout, length/thickness ratio, boundary conditions, and anti-symmetric laminate structure on the buckling behavior of E-glass-epoxy composite plates were investigated numerically and experimentally. The impact of boundary conditions on the buckling and post-buckling behavior of the axially compressed quasi-isotropic laminates were examined by Dinesh, Kumar, and Singh [7] using the finite element approach. Eiblmeir and Laughlan [8, 9] investigated the impacts of cutout size with and without different kinds of reinforcing boundary conditions using the finite element technique. Guo [10, 11] assessed how reinforcements around cuts affected the buckling behavior and stress concentration of symmetrically laminated carbon/epoxy composite panels subjected to in-plane shear loads. Four different kinds of cutout reinforcements composed of different materials were assessed. Parametric investigations on several reinforcement designs were conducted in the analysis using the finite element technique and the analytical approach based on the laminate theory. Under biaxial in-plane loads, Altan and Kartal [12] conducted a buckling study of symmetrically laminated cross-ply reinforced concrete plates with a central rectangular hole. The buckling load of square composite plates with a circular cutout was examined by Husam et al. [13] in relation to the cutout size, cutout position, fiber orientation angle, and kind of loading. The impact of forms, sizes, cutout corner radii, and layer count on the critical buckling stress of the composite laminated plate was investigated by Hani Aziz Ameen [14]. The impact of boundary conditions, fiber orientations, and cutout sizes on the critical buckling load of laminated fiber-reinforced plastic square panels was assessed by Srivatsa and Murthy [15]. The impact of cuts on the buckling behavior of polymer matrix composites used to make rectangular symmetric cross ply laminates was investigated by Ghannadpour et al. [16]. To forecast how cuts will affect these plates' buckling behavior, finite element analysis was also done. Using the finite element approach, Jain and Kumar [17] conducted a post-buckling study of symmetric square laminates with a central cutout under uniaxial compression. Buckling analysis of symmetrically laminated rectangular plates was used by Shufrin et al. [18]. The impact of symmetric cross-ply and angle-ply laminate configurations on buckling load was examined numerically. A. Joshi Gowri Sankar, Ch.V. Sushama, and Dr. P. Ravinder Reddy [19] concentrated on the buckling load factor. By adding cuts and other holes, they were able to calculate the buckling load factors for various aspect ratios. They found that the buckling factor drops as the t/b ratio does. Using 2D finite element analysis, P. Ravinder Reddy, A. Joshi, V.N. Krishnareddy, and Ch.V. Sushama [20] investigated the buckling load per unit length in rectangular plates with circular cutouts under bi-axial compression. By altering the holes' locations and the length to thickness ratio, the buckling factors are assessed. The impact of altering the buckling load per unit length, a/b ratio, b/t ratio, and hole positions is examined.

2. STATEMENT OF THE PROBLEM

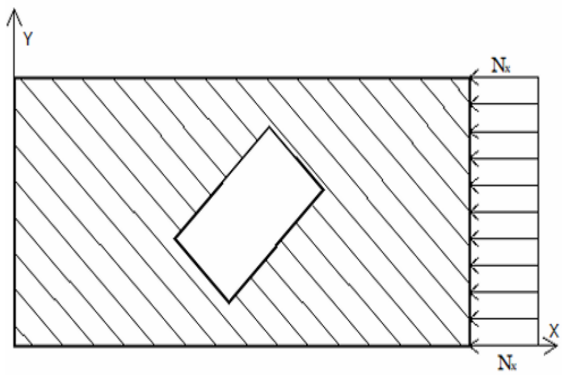
The present study uses the finite element method-based ANSYS software to look at how square and rectangular holes affect the bending behavior of orthotropic carbon/epoxy evenly bonded rectangular composite plates that are squeezed along their length. It also shows how the bending behavior of a rectangular composite plate with a square/ rectangular cutout changes when the cutout orientation angle (β), the size of the cutout, the aspect ratio (a/b) of the plate, and the ratio of the plate's width to its thickness (b/t) change. This study also looks at how the square/rectangular cutout orientation angle β, the size of the cutout, the plate aspect ratio (a/b), and the plate breadth/thickness ratio (b/t) affect the buckling response of a rectangular composite plate made of orthotropic carbon and epoxy that is symmetrically laminated and compressed in one direction. The majority of laminates used today are symmetric, which means that all bending-extension binding stiffnesses should be very close to zero. Getting rid of the connection between bending and extension has a big effect in real life. It is not likely for symmetric laminates to bend or twist when they cool down after sealing because of the natural temperature contractions that happen. As a result, equal laminates are used a lot. As a support, carbon fibers make up the lamina, and epoxy acts as a framework. Table 1 shows the features of carbon/epoxy as a material. The world x-axis lines up with the compression loads that are put on the plate.

Table 1: Material properties of carbon/epoxy

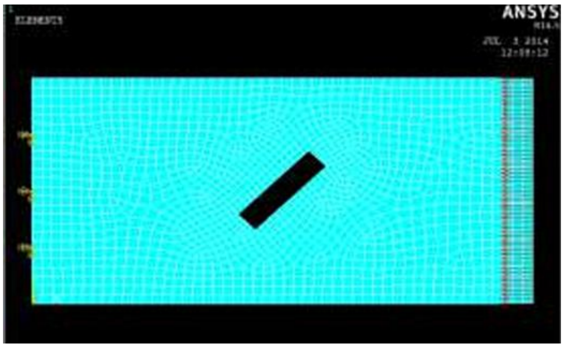
Young's modulus, GPa	Poisson's ratio	Shear modulus, GPa
E_{11} = 139	μ_{12} = 0.32	G_{12} = 4.7
E_{22} = 11	μ_{23} = 0.46	G_{23} = 3.7
E_{33} = 11	μ_{13} = 0.33	G_{13} = 4.7

3. FE MODELING OF THE PLATE

This study employs Eigen buckling analysis using ANSYS to predict the buckling load of a rectangular composite plate featuring a rectangular or square cutout. The plates are represented through the utilization of eight-node shell elements (Shell 281). The Shell 281 element type consists of eight nodes, each possessing six degrees of freedom. This includes translations in the x, y, and z directions, along with rotations about the nodal x, y, and z axes. Shell 281 is applicable for layered implementations of a structural shell model. Figure 1 illustrates the boundary conditions and the typical finite element mesh structure of the model. Two edges are constrained, while the remaining two edges remain unrestricted. The longitudinal edges at x = 0 and x = an are fixed in place, while the remaining edges at y = 0 and y = b are left unrestrained. As illustrated in Figure 1, small meshes are positioned around the cutout where significant stress concentrations are anticipated. The loading of the rectangular composite plate is illustrated in Figure 1 above. An in-plane compressive load per unit width Nx is applied at the edge X = a.



a. Geometry of the composite plate with rectangular cutout and loading



b. Meshed model with constraints and loading

Fig. 1: Geometry of the composite plate with rectangular cutout and loading

4. FINDINGS AND DISCUSSION

4.1 Effect of buckling load with various aspect ratios

Buckling factors for the plate with dimension ratios ranging from 2 to 6 and t/b ratios ranging from 1/20 to 1/80 are listed in Table 2. These buckling factors are expressed in Kilograms per Millimeter. The buckling factors are shown to diminish when the a/b ratio rises, and they fall even more when the t/b ratio fluctuates. This is seen in the table under consideration. The reason for this is because the fiber is becoming strengthened. As the aspect ratio increases, it has been shown that the buckling factor decreases. This is because to the size effect. Table 2 is an illustration of the manner in which the mode 5 buckling factor changes with regard to aspect ratio at various t/b ratios. It has been shown that the buckling factor decreases as the t/b ratio increases. During the period when the t/b ratio was reduced from 1/20 to 1/40, the buckling factor almost decreased by 7.4 points. During the period when the t/b ratio decreased from 1/40 to 1/60, the buckling factor almost decreased by a factor of 2.37. As the t/b ratio decreased from 1/60 to 1/80, the buckling factor almost decreased by a factor of 3.3 because of this change. As a consequence of this, the buckling factor decreases in tandem with the t/b ratio. In the beginning, it is very high, coming in at 7.4, but by the conclusion, it has dropped to 3.3.

Table 2: Buckling factors of various aspects ratios

Buckling factors					
t/b		1/20	1/40	1/60	1/80
a/b=2	**Mode1**	8.038	1.008	0.42	0.126
	Mode2	41.699	5.356	2.244	0.677
	Mode3	70.184	9.035	3.779	1.138
	Mode4	103.161	13.423	5.628	1.699
	Mode5	182.753	24.690	10.404	3.150
a/b=4	**Mode1**	2.004	0.250	0.104	0.031
	Mode2	17.876	2.251	0.938	0.282
	Mode3	36.844	4.722	1.978	0.597
	Mode4	48.444	6.182	2.582	0.777
	Mode5	53.628	6.868	2.874	0.866
a/b=6	**Mode1**	0.889	0.111	0.046	0.013
	Mode2	7.974	1.00042	0.416	0.125
	Mode3	21.992	2.775	1.157	0.347
	Mode4	36.058	4.617	1.934	0.583
	Mode5	42.567	5.420	2.263	0.681

4.2 Effects of the c/b and d/b ratios as well as the Cutout Orientation on the Buckling Load of a composite plate with a Rectangular Cutout:

Figures 2-5 illustrate how the c/b and d/b ratios, as well as the cutout orientation β, affect the buckling stresses of a rectangular composite plate with a rectangular cutout. It shows that the buckling loads decrease as the c/b and d/b ratios rise. Buckling loads decrease as cutout orientation β rises.

Figures 2 and 3 show that the maximum values for buckling loads are estimated when β = 0°, and the lowest values when β = 90°. Buckling loads drop slowly between 0° and 15° and 75° and 90°, but fast between 15° and 75°. The cutout orientation β has a decreasing influence on buckling strength as the rectangular cutout size decreases. Figures 4 and 5 show how c/b and d/b ratios affect buckling loads for various cutout orientations β. Figure 4 illustrates how raising the c/b ratio reduces buckling stresses. The reduction in buckling load is slower when the cutout orientation is β = 0° compared to β = 90°. As illustrated in Figure 5, buckling loads decrease as the d/b ratio increases. Buckling load decreases quicker at β = 90º compared to β = 0º. When the cutout orientation is β = 90º, the buckling load reduces fast for d/b ratios between 0 and 0.1. The plate without a hole (d/b = 0) has a larger buckling stress compared to the plate with a hole (d/b = 0.1), resulting in the quick decrease. Other d/b ratios provide a very sluggish reduction in buckling load.

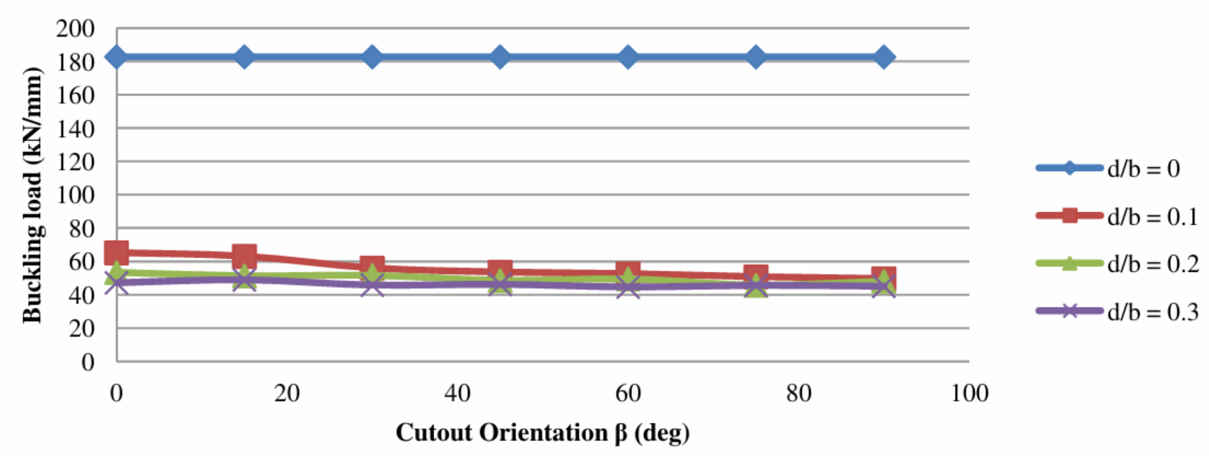


Fig. 2: Variation of buckling load with cutout orientation at c/b=0.4, a/b=2 for [0°/45°/45°/0°]

Figure 2 illustrates that the buckling stress diminishes as the cutout orientation increases from 0° to 90°. As the cutout orientation went from 0° to 90°, the buckling load for the ratio d/b=0.1 fell by about 1.32 times. As the cutout orientation grew from 0° to 90°, the buckling stress for the ratio d/b=0.2 fell by about 1.1 times. As the cutout orientation went from 0° to 90°, the buckling factor for the ratio d/b=0.3 fell by about 1.04 times.

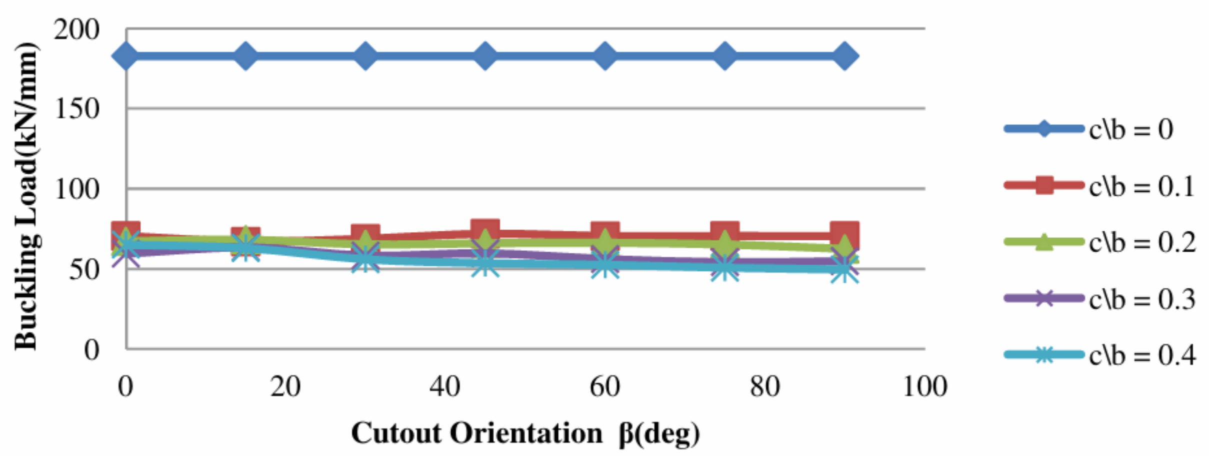


Fig. 3: Variation of buckling load with cutout orientation at d/b=0.1, a/b=2 for [0°/45°/45°/0°]

Increasing the cutout direction from 0 degrees to 90 degrees results in a reduction in the buckling load, as was seen in Figure 3. Initially, the buckling load decreases to 45 degrees when the ratio c/b is equal to 0.1, and then it increases when the cutout orientation increases from 0 degrees to 90 degrees. As the cutout orientation increased from 0 degrees to 90 degrees, the buckling force for the ratio c/b=0.2 almost decreased by a factor of around 1.07 times. The cutting direction increased from 0 degrees to 90 degrees, which resulted in the buckling factor for the ratio c/b=0.3 almost doubling. When the cutting direction was changed from 0 degrees to 90 degrees, the buckling factor for the ratio c/b=0.4 increased by roughly 1.27 times during this period.

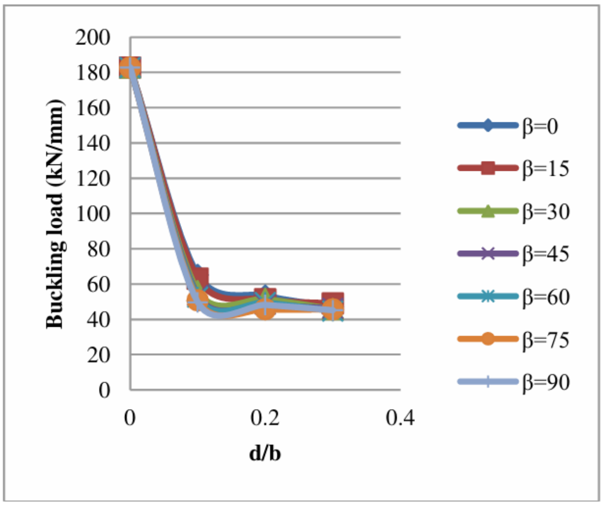


Fig. 4: Variation of buckling load with cut out orientation at c/b=0.4, a/b=2 for 0°/45°/45°/0°]

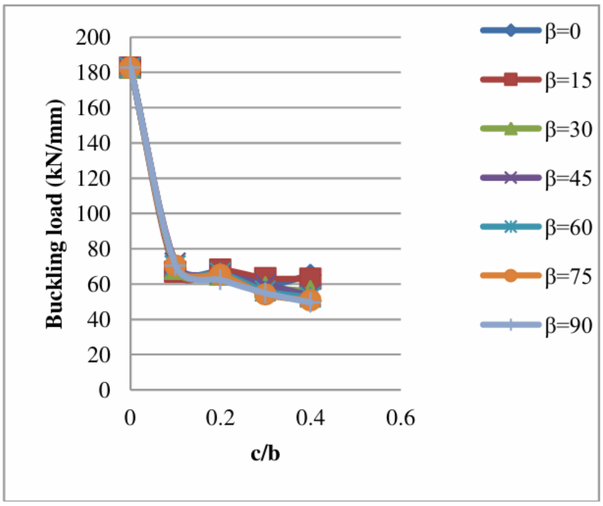


Fig. 5: Variation of buckling load with cutout orientation at d/b=0.1, a/b=2 for [0°/45°/45°/0°]

Figure4 reveals that buckling load is decreasing as the d/b ratio is increasing from d/b=0 to d/b=0.3. Figure 5 shows the buckling load is decreasing as the c/b ratio is increasing from c/b=0 to c/b=0.4.

5. CONCLUSIONS

The observation indicates that as the aspect ratio increases, the buckling factor diminishes. With a reduction in the t/b ratio, there is a corresponding decrease in the buckling factor. The buckling load diminishes as the orientation of the cutout increases. The buckling load exhibits a reduced response for square cutouts in comparison to rectangular cutouts. The buckling loads diminish as the c/b and d/b ratios increase. The buckling loads diminish as the cutout orientation β increases. The maximum buckling loads are observed at β= 0°, while the minimum buckling loads occur at β = 90°. The buckling loads show a gradual decrease when β ranges from 0° to 15° and again from 75° to 90°; however, there is a rapid decline in buckling loads when β is between 15° and 75°. The reduction in the size of the rectangular cutout leads to a diminished impact of the cutout orientation β on the buckling strength. The buckling loads diminish as the c/b ratio increases. The decrease in the buckling load at a cutout orientation of β = 0° occurs at a slower rate compared to the scenario where β = 90°. The reduction in buckling load occurs more rapidly at β = 90º compared to β = 0º. At a cutout orientation of β = 90º, there is a significant and rapid decrease in the buckling load for d/b ratios ranging from 0 to 0.1. The swift decrease is attributed to the fact that the plate lacking a hole (d/b = 0) exhibits a greater buckling load compared to the plate featuring a hole (d/b = 0.1). The reduction in buckling load occurs at a gradual pace for alternative d/b ratios. The analysis of the c/b and d/b ratios, along with the cutout orientation β, on the buckling load of a rectangular composite plate featuring a square cutout indicates that buckling loads diminish as the c/b and d/b ratios increase. The buckling loads diminish as the cutout orientation β rises from 0° to 45°, while they increase when the cutout orientation β is elevated from 45° to 90°.
The highest values of the buckling load are determined at β = 0° and 90°, which yield the same results, while the lowest values occur at β = 45°. The buckling loads exhibit a gradual decrease from 0° to 15°, followed by a rapid decline from 15° to 45°. The buckling loads exhibit a sharp increase from 45° to 75°, followed by a gradual rise from 75° to 90°. As the dimensions of the square cutout diminish, the influence of the cutout orientation β on the buckling strength becomes less significant.

REFERENCES

[1] Y. X. Zhang and C. H. Yang, Recent developments in finite element analysis for laminated composite plates, Compos Struct, 88 (2009) 147-157.
[2] U. Topal and U. Uzman, Maximization of buckling load of laminated composite plates with central circular holes using MFD method, Struct Multidisc optom, 35 (2008) 131-139.
[3] H.-T. Hu and B.-H. Lin, Buckling optimization of symmetrically laminated plates with various geometries and end conditions, Comp Scien and Technol, 55 (1995) 277-285.
[4] H.-T. Hu and Z.-Z. Chen, Buckling optimization of unsym- metrically laminated

plates under transverse loads, Structural Engg and Mechanics, 7 (1999) 19-33.
[5] B.O.Baba, Buckling behaviour of laminated composite plates, J Reinf Plast Compos, 26 (2007) 1637-55.
[6] B. O. Baba and A. Baltaci, Buckling characteristics of sym- metrically and antisymmetrically laminated composite plates with central cutout, Appl Compos Mater, 14 (2007) 265-276.
[7] K. Dinesh and S. B. Singh, Effects of boundary conditions on buckling and postbuckling responses of composite laminate with various shaped cutouts, Compos Struct, 92 (2010) 769-779.
[8] J. Eiblmeier and J. Loughlan, The buckling response of carbon fibre composite panels with reinforced cutouts, Compos Struct, 32 (1995) 97-113.
[9] J.Eiblmeier and J.Loughlan, The influence of reinforcement ring width on the buckling response of carbon fibre composite panels with circular cutouts, Compos Struct,38 (1997) 609-622
[10] S. J. Guo, Stress concentration and buckling behavior of shear loaded composite panels with reinforced cutouts, Compos Struct, 80 (2007) 1-9.
[11] Guo, Zhou and Cheung, Cutout reinforcements for shear loaded laminate and sandwich composite panels, Int J Mech Mater des, 4 (2008) 157-171.
[12] M. F. Altan and M. E. Kartal, Investigation of buckling bahaviour of laminated reinforced concrete plates with cen- tral rectangular hole using finite element method, Materials and design, 30 (2009) 2243-2249.
[13] A. Q. Husam, K. Hasan and D. Hazim, Assessment of the buckling bahaviour of square composite plates with circular cutout subjected to in-plane shear, Jordan Journal of Civil Engineering, 3 (2009) 184-195.
[14] H. A. Ameen, Buckling analysis of composite laminated plate with cutouts, Eng.& Tech. Journal, 27 (2009) 1611-1621.
[15] K. S. Srivatsa and K. Murthy, Stability of laminated composite plates with cutouts, computers & Structures, 43 (1992) 273 279.
[16] S. A. M. Ghannadpour, A. Najafi and B. Mohammadi, On the buckling bahaviour of crossply laminated composite plates due to circular/elliptical cutouts, Compos Struct, 75 (2006) 3-6.
[17] P. Jain and K. Ashwin, Post buckling response of square laminates with a central circular/elliptical cutout, Compos Struct, 65 (2004) 179-185.
[18] I. Shufrin, O. Rabinovitch and M. Eisenberger, Buckling of laminated plates with general boundary conditions under combined compression, tension and shear- A semi-analytical solution, Thin-walled Struct, 46 (2008) 925-938.
[19] Dr. P. Ravinder Reddy, A.Joshi Gowri Sankar, Ch.V.Sushma Buckling Analysis of Thin Carbon/Epoxy Plate by Using FEA Vol. 2 Issue 9, September – 2013.
[20] A.Joshi, P. Ravinder Reddy, V.N.Krishnareddy, Ch.V.Sushma buckling analysis of thin carbon/epoxy plate with circular cut-outs under biaxial compression by using FEA, eISSN: 2319-1163 pISSN: 2321-7308.