



Buckling Analysis of Orthotropic Laminated Composite Plate With Rectangular Cut-Outs By Using FEA

Dr. P. Ravinder Reddy¹, P. Surendar Reddy², P. Shashikanth Reddy³

¹Professor & Head, MED, Chaitanya Bharathi Institute of Technology, Hyderabad 75, Telangana, India

²PG Student, MED, Chaitanya Bharathi Institute of Technology, Hyderabad-75, Telangana, India

³CAE Analyst, Concurrent Analysis Pvt. Ltd, Hyderabad-28, Telangana, India

Abstract: A finite element method using ANSYS software is used to determine the effects of square and rectangular cutouts on the buckling behavior of a 4-ply orthotropic carbon/epoxy symmetrically laminated rectangular composite plate. The square/rectangular cutouts were subjected to uniaxial compression loading. This study addresses the effects of the size of the square/rectangular cutout, orientation of the square/rectangular cutout, plate aspect ratio (a/b), on the buckling behavior of the symmetrically laminated rectangular composite plate under uniaxial compression loading. Buckling loads were computed for $[0^\circ/45^\circ/45^\circ/0^\circ]$ orthotropic laminate configuration. Results showed that the magnitudes of the buckling loads decrease with increasing cutout positioned angle as well as c/b and d/b ratios for plates with a rectangular cutout. The magnitudes of the buckling loads of a rectangular composite plate with square/rectangular cutout decrease with increasing plate aspect ratio (a/b). The aspect ratio varied is from 2 to 6 in all the simulations. Further the nature of buckling load with respect to t/b ratio and the buckling factors at various t/b ratio's such as $1/20$, $1/40$, $1/60$, and $1/80$ is investigated using ANSYS software.

Keywords: Cutout orientation angle, Aspect ratio, Buckling factors, Square/Rectangular cutout, Buckling strength

I. INTRODUCTION

Hsuan-Teh Hu and Borhorng Lin [3] investigated the influence of end conditions, plate aspect ratios, and cutouts on optimal fiber orientations as well as the associated optimal buckling loads of symmetrically laminated composite plates under uni-axial compression loading. Hsuan-The Hu and Zhong-Zhi Chen [4] investigated the influence of end conditions, aspect ratios, cutouts, lateral loads on optimal fiber orientations, and associated optimal buckling loads of unsymmetrical laminated plates. Baba and Baltaci [5, 6] conducted buckling analysis on the rectangular composite laminates with a central circular hole. A numerical and experimental study was conducted to determine the effects of anti-symmetric laminate configuration, cutout and length/ thickness ratio, and boundary conditions on the buckling behavior of E-glass-epoxy composite plates. Dinesh, Kumar, and Singh [7] used the finite element method to investigate the effects of boundary conditions on the buckling and post-buckling behavior of the axially compressed quasi-isotropic laminates. Using the finite element method, Eiblmeir and Laughlan [8, 9] examined the effects of the size of cutouts with and without various types of reinforcement boundary conditions. Guo [10, 11] determined the effect of reinforcements around cutouts on the stress concentration and buckling behavior of symmetrically laminated carbon/epoxy composite panel under in-plane shear load. Four types of cutout reinforcements made from various materials were evaluated. In the analysis, the finite element method and the analytical method based on the laminate theory were employed to perform parametric studies on various reinforcement designs. Altan and Kartal [12] performed a buckling analysis of symmetrically laminated cross-ply reinforced concrete plates with a central rectangular hole under biaxial in-plane loadings. Husam et al. [13] investigated the effect of cutout size, cutout location, fiber orientation angle, and type of loading on the buckling load of square composite plates with a circular cutout. Hani Aziz Ameen [14] examined the influence of shapes, sizes, radii of the cutout corner, and number of layers on the critical buckling load of the composite laminated plate. Srivatsa and Murthy [15] evaluated the effect of boundary conditions, fiber orientations, and cutout sizes on the critical buckling load of laminated fiber-reinforced plastic square panels. Ghannadpour et al. [16] studied the influence of cutouts on the buckling behavior of rectangular symmetric cross-ply laminates made of polymer matrix composites. Finite element analysis was also performed to predict the influence of cutouts on the buckling behavior of these plates. Jain and Kumar [17] performed a post-buckling analysis of symmetric square laminates with a central cutout under uniaxial compression by using the finite element method. Shufrin et al. [18] applied buckling analysis of symmetrically laminated rectangular plates. A numerical study was conducted to investigate the influence of symmetric cross-ply and angle-ply laminate configuration on buckling load. Dr. P. Ravinder Reddy, A. Joshi Gowri Sankar, Ch.V. Sushma [19] focused on the buckling load factor. They determined Buckling load factors for different aspect ratio by introducing cutouts and multiple holes. They observed that as the t/b ratio decreases the buckling factor decreases. P. Ravinder Reddy, A. Joshi, V.N. Krishnareddy, Ch.V. Sushma [20] studied the buckling load per unit length in rectangular

plate with circular cut-outs under bi-axial compression using 2D finite element analysis. The buckling factors are evaluated by changing the position of the holes, length to thickness ratio. The effect of changing the position of holes, a/b ratio, b/t ratio and buckling load per unit length is discussed.

II. STATEMENT OF THE PROBLEM

The present study uses the ANSYS software based on finite element method to examine the effect of square and rectangular cutouts on the buckling behavior of axially compressed orthotropic carbon/epoxy symmetrically laminated rectangular composite plates. This study also reveals the influence of cutout orientation angle β , different sizes of cutout, aspect ratio (a/b) of the plate, and breadth/thickness (b/t) ratio on the buckling behavior of a rectangular composite plate with a square/rectangular cutout. This work also examines the influence of square/rectangular cutout orientation angle β , size of cutout, plate aspect ratio (a/b), and plate breadth/thickness (b/t) ratio on the buckling response of an axially compressed orthotropic carbon/epoxy symmetrically laminated rectangular composite plate with a square/rectangular cutout. Most laminates that are currently used are symmetric, suggesting that all bending-extension coupling stiffness's are expected to approach zero. Elimination of coupling between bending and extension bears an important practical implication. Symmetric laminates exhibit no tendency to bend or twist from the inevitable thermally induced contractions that occur during cooling following the curing process. Consequently, symmetric laminates are widely used. The lamina consists of carbon fibers as reinforcement material and epoxy as a matrix material. The material properties of carbon/epoxy are listed in Table 1. The compressive loads applied on the plate coincide with the global x-axis.

Table 1: Material properties of carbon/epoxy

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

III. FINITE ELEMENT MODELING OF THE PLATE

In this study, Eigen buckling analysis with ANSYS is used for predicting the buckling load of a rectangular composite plate with a rectangular/square cutout. The plates are modeled using eight-node shell elements (Shell 281). The Shell 281 element type has eight nodes with 6 degree of freedom at each node, as well as translations along the x, y, and z directions and rotations in the nodal x, y, and z axes. Shell 281 can be used for layered applications of a structural shell model. The boundary conditions and typical finite element mesh structure of the model are illustrated in Figure1. Two edges are fixed, whereas the other two edges are free. The two longitudinal edges ($x = 0$ and $x = a$) are clamped, whereas the other two edges are free ($y = 0$ and $y = b$). As seen shown in Figure1, small meshes are set in the vicinity of the cutout where large stress concentrations are expected. The loading of the rectangular composite plate is shown in above Figure1. The in-plane compressive load per unit width N_x is applied on the edge $X = a$.

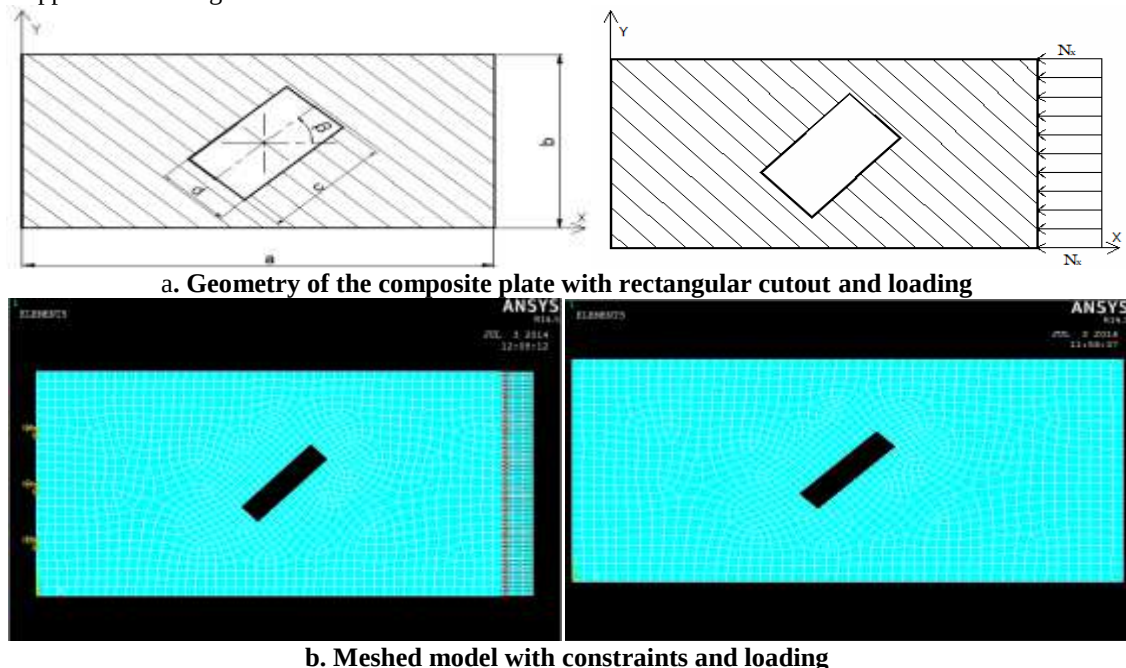


Fig. 1: Geometry of the composite plate with rectangular cutout and loading

IV. RESULTS AND DISCUSSION

A. Effect of buckling load with various aspect ratios

The buckling factors (in kN/mm) for the plate with aspect ratio varying from 2 to 6 and t/b ratio varying from 1/20 to 1/80 is listed in the table2. From the table it is observed that by increasing a/b ratio the buckling factors are reduced and also observed that by varying t/b the buckling factors further reduced it is due to the reinforcement of the fiber. It is observed that as the aspect ratio increases the buckling factor decreases because of the size effect. The table2 is showing the variation of mode 5 buckling factor at various t/b ratios by varying aspect ratio. It is observed that as the t/b ratio decreases the buckling factor decreases. As the t/b ratio decreased from 1/20 to 1/40 the buckling factor nearly decreased by 7.4 times .As the t/ b ratio decreased from 1/40 to 1/60 the buckling factor nearly decreased by 2.37 times. As the t/ b ratio decreased from 1/60 to 1/80 the buckling factor nearly decreased by 3.3 times. So the buckling factor decreases with the decrease in t/b ratio and at the initial stages it is high such as 7.4 and at the final stages it reduced 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

B. Effect of buckling loads with cutout orientation

Case(1): The variation in buckling load for various cases like for different cutout orientations (0°,15°,30°,45°,60°,75°,90°) and different d/b ratios like d/b=0, d/b=0.1, d/b=0.2, d/b=0.3 when the ratios c/b=0.4, a/b=2 are constant is as shown in table3.

Table 3: Buckling load at different cutout orientations and different d/b ratios

Cutout Orientation	d/b = 0	d/b = 0.1	d/b = 0.2	d/b = 0.3
$\beta = 0^\circ$	182.750	65.148	53.423	47.198
$\beta = 15^\circ$	182.750	63.041	51.373	49.007
$\beta = 30^\circ$	182.750	56.000	51.631	45.815
$\beta = 45^\circ$	182.750	53.584	48.583	46.264
$\beta = 60^\circ$	182.750	52.601	49.513	44.692
$\beta = 75^\circ$	182.750	50.793	45.733	45.652
$\beta = 90^\circ$	182.750	49.639	48.143	45.127

Case(2): The variation in buckling load of various cases like for different cutout orientations (0°,15°,30°,45°,60°,75°,90°) and different c/b ratios like c/b=0, c/b=0.1, c/b=0.2, c/b=0.3, c/b=0.4 when the ratios d/b=0.1, a/b=2 are taken as constant. As the d/b ratio is increasing the buckling factors are reduced and as the cut orientation is increased the buckling factors are reduced which are shown in table4.

Table 4: Buckling load at different cutout orientations and different c/b ratios

Cutout Orientation	c/b = 0	c/b = 0.1	c/b = 0.2	c/b = 0.3	c/b = 0.4
$\beta = 0^\circ$	182.750	70.480	67.188	65.486	64.148
$\beta = 15^\circ$	182.750	66.991	68.211	63.407	63.041
$\beta = 30^\circ$	182.750	68.730	65.289	58.266	56.000
$\beta = 45^\circ$	182.750	71.973	66.023	59.740	53.584
$\beta = 60^\circ$	182.750	70.446	66.340	56.132	52.601
$\beta = 75^\circ$	182.750	70.525	65.276	54.169	50.793
$\beta = 90^\circ$	182.750	70.480	62.437	54.827	49.639

Case(3): The variation in buckling load of various cases like for different cutout orientations ($0^\circ, 15^\circ, 30^\circ, 45^\circ, 60^\circ, 75^\circ, 90^\circ$) and different c/b, d/b ratios like c/b=d/b=0.2, c/b=d/b=0.3, c/b=d/b=0.4, when the ratio a/b=2 is taken as constant is shown in table5. As the c/b is increased the buckling factors are reduced and as the cutout orientation is increased the buckling factors are reducing.

Table 5: buckling load at different cutout orientations and different c/b=d/b ratios

Cutout Orientation	c/b=0.2=d/b	c/b=0.3=d/b	c/b=0.4=d/b
$\beta = 0^\circ$	58.771	47.747	43.189
$\beta = 15^\circ$	58.527	47.895	43.473
$\beta = 30^\circ$	57.631	47.458	41.409
$\beta = 45^\circ$	55.689	47.146	39.339
$\beta = 60^\circ$	56.497	47.478	41.838
$\beta = 75^\circ$	56.983	48.264	40.692
$\beta = 90^\circ$	58.771	47.747	43.189

C. 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:

The effects of the c/b and d/b ratios as well as the cutout orientation β on the buckling loads of a rectangular composite plate with a rectangular cutout are shown from Figure2 to Figure5. It reveals that the buckling loads decrease when the c/b and d/b ratios increase. The buckling loads decrease when the cutout orientation β increases. Figure 2 and 3 indicate that the highest values for the buckling loads are calculated when $\beta = 0^\circ$, whereas the lowest values for the buckling loads are calculated when $\beta = 90^\circ$. The buckling loads decrease very slowly when β is between 0° and 15° and well as between 75° and 90° ; the buckling loads rapidly decrease when β is between 15° and 75° . As the size of the rectangular cutout decreases, the effect of the cutout orientation β on the buckling strength decreases as well. The effects of the c/b and d/b ratios on the buckling loads are illustrated for different cutout orientations β in Figure 4 and 5. As shown in Figure 4, the buckling loads decrease by increasing the c/b ratio. Reduction in the buckling load when the cutout orientation is $\beta = 0^\circ$ is slower than that when $\beta = 90$. As shown in Figure5, the buckling loads decrease with the increase in the d/b ratio. The decrease in buckling load is faster when $\beta = 90^\circ$ than when $\beta = 0^\circ$. When the cutout orientation is $\beta = 90^\circ$, the buckling load decreases very rapidly for d/b ratios between 0 and 0.1. This rapid reduction occurs because the plate without a hole (d/b = 0) has a higher buckling load than the plate with a hole (d/b = 0.1). The decrease in buckling load is very slow for other d/b ratios.

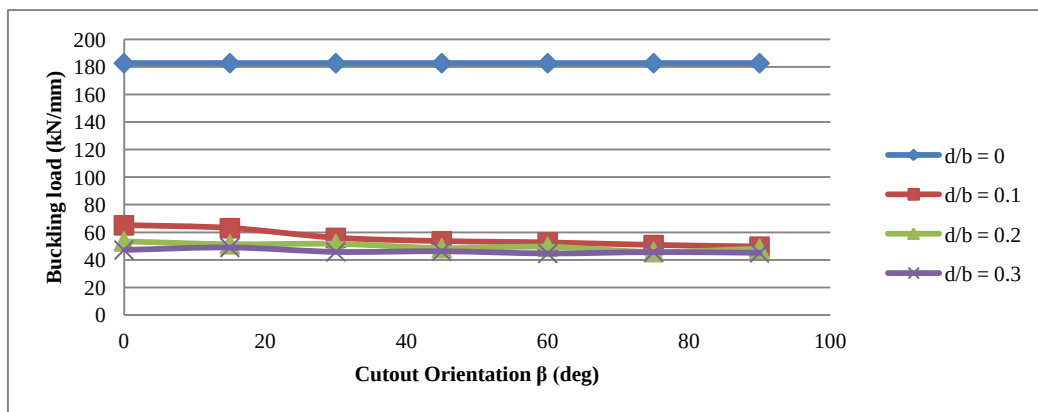


Fig. 2: Variation of buckling load with cutout orientation at c/b=0.4, a/b=2 for $[0^\circ/45^\circ/45^\circ/0^\circ]$

The above figure2 reveals that buckling load is decreasing as the cutout orientation is increasing from 0° to 90° . For the ratio $d/b=0.1$ as the cutout orientation increased from 0° to 90° the buckling load nearly decreased by 1.32 times. For the ratio $d/b=0.2$ as the cutout orientation increased from 0° to 90° the buckling load nearly decreased by 1.1 times. For the ratio $d/b=0.3$ as the cutout orientation increased from 0° to 90° the buckling factor nearly decreased by 1.04 times.

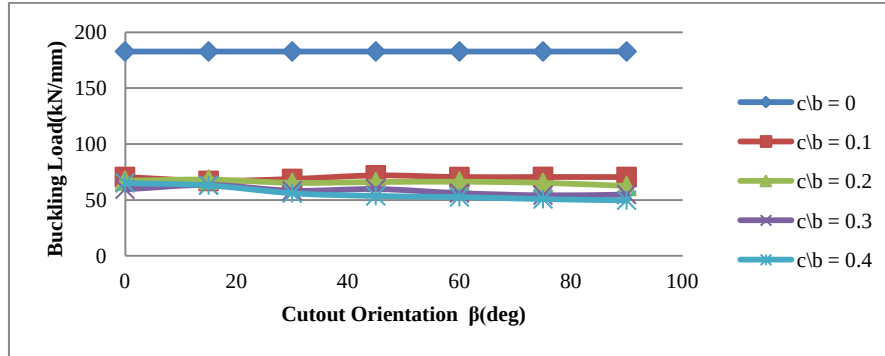


Fig. 3: Variation of buckling load with cutout orientation at $d/b=0.1$, $a/b=2$ for $[0^\circ/45^\circ/45^\circ/0^\circ]$

The figure3 reveals that buckling load is decreasing as the cutout orientation is increasing from 0° to 90° . For the ratio $c/b=0.1$ as the cutout orientation increased from 0° to 90° the buckling load first decreases up to 45° and then increases. For the ratio $c/b=0.2$ as the cutout orientation increased from 0° to 90° the buckling load nearly decreased by 1.07 times. For the ratio $c/b=0.3$ as the cutout orientation increased from 0° to 90° the buckling factor nearly decreased by 1.08 times. For the ratio $c/b=0.4$ as the cutout orientation increased from 0° to 90° the buckling factor nearly decreased by 1.27 times. Figure4 reveals that buckling load is decreasing as the d/b ratio is increasing from $d/b=0$ to $d/b=0.3$. For the orientation $\beta=0^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 3.87 times. For the orientation $\beta=15^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 3.72 times. For the orientation $\beta=30^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 3.98 times. For the orientation $\beta=45^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 3.98 times. For the orientation $\beta=60^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 4.08 times. For the orientation $\beta=75^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 4.003 times. For the orientation $\beta=90^\circ$ as the d/b ratio increased from 0.1 to 0.3 the buckling load decreases by 4.04 times. Figure 5 shows the buckling load is decreasing as the c/b ratio is increasing from $c/b=0$ to $c/b=0.4$. For the orientation $\beta=0^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 2.8 times. For the orientation $\beta=15^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 2.89 times. For the orientation $\beta=30^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 3.26 times. For the orientation $\beta=45^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 3.41 times. For the orientation $\beta=60^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 3.47 times. For the orientation $\beta=75^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 3.59 times. For the orientation $\beta=90^\circ$ as the c/b ratio increased from 0.1 to 0.4 the buckling load decreases by 3.68 times.

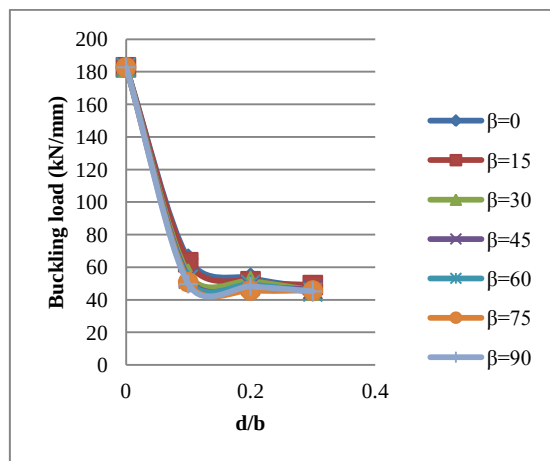


Fig. 4: Variation of buckling load with cut out orientation at $c/b=0.4$, $a/b=2$ for $[0^\circ/45^\circ/45^\circ/0^\circ]$

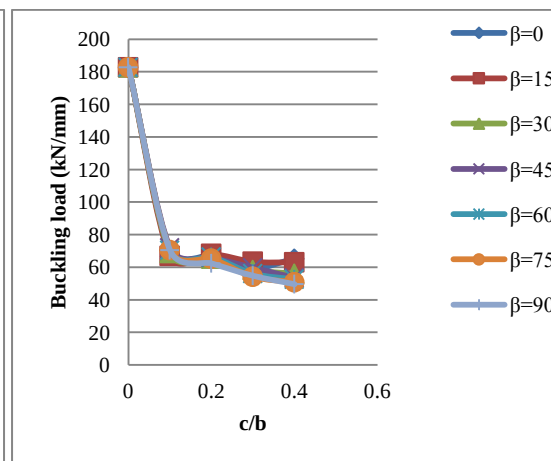


Fig. 5: Variation of buckling load with cutout orientation at $d/b=0.1$, $a/b=2$ for $[0^\circ/45^\circ/45^\circ/0^\circ]$

D. Effects of the Cutout Orientation β as well As the c/b and d/b ratios on the Buckling Load of a Rectangular Composite Plate with a Square Cutout:

The effects of the c/b and d/b ratios as well as the cutout orientation β on the buckling load of a rectangular composite plate with a square cutout are shown in Figure 6. The figure reveals that buckling loads decrease by increasing the c/b and d/b ratios. The buckling loads decrease when the cutout orientation β is increased from 0° to 45° and increase when the cutout orientation β is increased from 45° to 90° . As indicated in Figure, the maximum values of the buckling load are calculated when $\beta = 0^\circ$ and 90° , which are equal, whereas the lowest values of the buckling load are calculated when $\beta = 45^\circ$. The buckling loads decrease very slowly between 0° and 15° and rapidly between 15° and 45° . The buckling loads increase rapidly between 45° and 75° and very slowly between 75° and 90° . As the size of the square cutout decreases, the effect of the cutout orientation β on the buckling strength decreases.

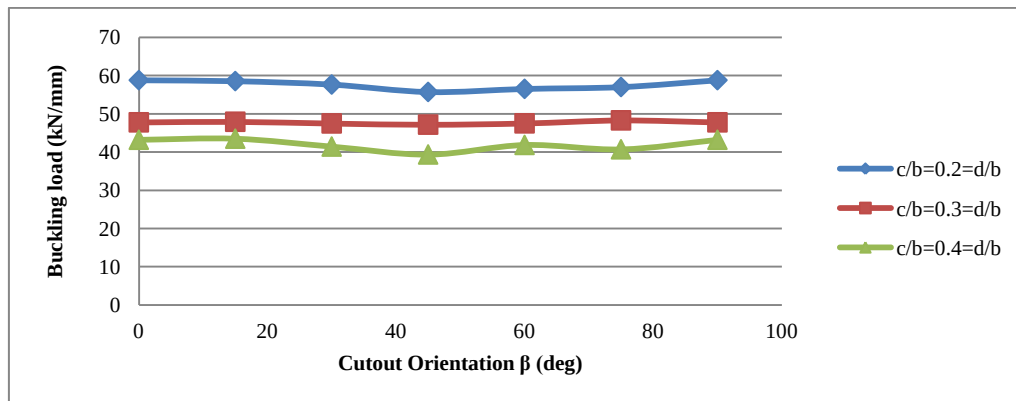


Fig. 6: Variation of Buckling Load with cutout orientation at $c/b=d/b$, $a/b=2$ for $[0^\circ/45^\circ/45^\circ/0^\circ]$

V. Conclusions

It was noted that the buckling factor decreases with increases of aspect ratio. As the t/b ratio decreases the buckling factor decreases. The buckling load decreases with increasing the cutout orientation. The buckling load has low response for square cutout as compared with rectangular cutout. The buckling loads decrease when the c/b and d/b ratios increase. The buckling loads decrease when the cutout orientation β increases. The highest values for the buckling loads are calculated when $\beta = 0^\circ$, whereas the lowest values for the buckling loads are calculated when $\beta = 90^\circ$. The buckling loads decrease very slowly when β is between 0° and 15° and well as between 75° and 90° ; the buckling loads rapidly decrease when β is between 15° and 75° . As the size of the rectangular cutout decreases, the effect of the cutout orientation β on the buckling strength decreases as well. The buckling loads decrease by increasing the c/b ratio. Reduction in the buckling load when the cutout orientation is $\beta = 0^\circ$ is slower than that when $\beta = 90^\circ$. The decrease in buckling load is faster when $\beta = 90^\circ$ than when $\beta = 0^\circ$. When the cutout orientation is $\beta = 90^\circ$, the buckling load decreases very rapidly for d/b ratios between 0 and 0.1. This rapid reduction occurs because the plate without a hole ($d/b = 0$) has a higher buckling load than the plate with a hole ($d/b = 0.1$). The decrease in buckling load is very slow for other d/b ratios. The effects of the c/b and d/b ratios as well as the cutout orientation β on the buckling load of a rectangular composite plate with a square cutout reveals that buckling loads decrease by increasing the c/b and d/b ratios. The buckling loads decrease when the cutout orientation β is increased from 0° to 45° and increase when the cutout orientation β is increased from 45° to 90° . The maximum values of the buckling load are calculated when $\beta = 0^\circ$ and 90° , which are equal, whereas the lowest values of the buckling load are calculated when $\beta = 45^\circ$. The buckling loads decrease very slowly between 0° and 15° and rapidly between 15° and 45° . The buckling loads increase rapidly between 45° and 75° and very slowly between 75° and 90° . As the size of the square cutout decreases, the effect of the cutout orientation β on the buckling strength decreases.

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 optim, 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 behaviour 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 behaviour 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 behaviour 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.