Investigating the Buckling Behavior of Cross-Ply Laminated Composite Plates Influenced by Various Cutout Geometries

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Abstract- In composite buildings, cutouts are common. These are used into building materials to facilitate air circulation and, on occasion, to reduce weight. Cutouts are essential in airplane parts (e.g., ribs, fuselage, and wings) for inspection, access, electric and fuel lines, or to lower the aircraft's total weight. The buckling behavior of rectangular plates formed of polymer matrix composites (PMC) is discussed in this work in relation to the impacts of a cutout. The focus here is on how rectangular symmetric cross-ply laminates act. We model the unloaded edges in clamped and simply supported boundary conditions so that we may analyze the influence of the loaded ones. Additionally, the impact of cuts on the buckling behavior of these plates may be foreseen using finite element analysis. The article delves into several important discoveries and traits of behavior. Among these discoveries are the consequences of various cutout dimensions, shapes, aspect ratios, and boundary constraints. One major takeaway from these investigations is that buckling loads for cutout plates are greater than those for identical plates without cuts.

Key words: Buckling load, Finite element, composite plate, Cutout geometries.

1. INTRODUCTION

Usually, subcomponents need to be cut out in order to save weight and make them more useful.

For example, holes in the wing spar and cover plates are needed to get to the hydraulic system and make the plane easier to repair. Cutouts also make the wing pieces lighter. In this case, the holes change how the membrane forces are distributed in the plates, which could make them much less stable. Over the past few years, a lot of experts have been interested in how these hollow plates buckle. Researchers like Rockey et al. [1], Azizian and Roberts [2], Shanmugam and Narayanan [3], and Sabir and Chow [4] have used FEM to look into how perforated square plates buckle when they are compressed in one direction or both directions. The results of their studies showed that the elastic buckling stress might go up as the hole size goes beyond a certain point. This is because the membrane stresses would be spread out more evenly. However, the ultimate load would be expected to go down because the plate cross section would lose a lot of its strength. In their study [5], Lin and Kuo looked into how rectangle laminates with a round hole behaved. The FEM was used to find the key loads.

Nemeth [6] looked into how symmetrical angle-ply laminates that are rectangular and have a circle hole behave when they buckle. It was looked into how graphite epoxy plates would react to both compression stress and movement. Lee and Lin [7] looked at how the degree of orthotropy affected the way square orthotropic plates with a circle hole in the middle buckled.

Shimizu and Yoshida [8] looked into how isotropic plates with a hole buckle when tension loads are applied. Srivatsa and Murti [9] did a quantitative study of how a stress-loaded composite plate with a center circle hole bends and buckles when compressed. Based on CLPT. Shanmugametal, FEM was used to get the results. [10] used FEM to come up with a design method to find out how much weight radially squeezed square plates with centrally placed holes (round or square) can hold. They came to the conclusion that the hole size and plate slenderness ratio have a big effect on the final load capacity of the square perforation plate. They also came to the conclusion that plates with circular holes can generally hold more weight than plates with square holes. This paper looks at how circular and elliptical cuts affect the bending behavior of composite plates in cross-ply laminates. This study also looks at how different plate aspect ratios and the size of the circular cuts in the plates affect how the cross-ply laminated composite plates buckle.

2. RESEARCH OBJECTIVE

In the course of this study, a comprehensive analysis of the following goals is included:

- A review of the various plate theories and approaches that are used in the process of predicting the behavior of laminated plates when they are exposed to buckling pressures will be presented.
- The construction of a theoretical model that is aimed to anticipate buckling loads in a thin laminated plate is a fresh and unrivaled approach of doing things.
- The application of the finite element approach to the investigation of rectangular laminated plates subjected to buckling stresses, as well as its development and implementation.
- It may be possible to do more study on the influence that coupling between bending and extension and/or twisting has on the behavior of laminated plates.

3. DESCRIPTION OF FE MODEL

For this study, the cross-ply laminate $[0,90]_{2s}$ rectangle plates are being looked at. Each of these eight-layer laminates is 0.15 mm thick. Table1 shows the features of the material used for the sheet. In this table, E_1, E_2, and E_3 are Young's modules, G_{12}, G_{13}, and G_{23} are shear modules that correspond to planes 1, 2, and 2–3, and v_{12}, v_{13}, and v_{23} are the appropriate Poisson ratios.

Table 1: Material properties of the lamina

Mechanical properties	Values
E_1	130.0 GPa
E_2	10.0 GPa
E_3	10.0 GPa
$G_{12} = G_{13}$	5.0 GPa
$v_{12} = v_{13}$	0.35
$v_{23} = v_{32}$	0.49

In this part, we look at how the effect of odd circle cutout size is felt. The plate is 120 mm by 120 mm. Figure 1 shows the atypical FEM model that was used in this study. The normal of the plate is in the z direction, and the size of the plate is on the xy plan. The simply supported border conditions are applied to all four edges by stopping the translational movement in the z-axis. The compression force is spread out evenly along the two opposite edges. Based on first order shear deformation theory (FSDT), these plates are connected with quadratic composite shell elements, as shown in Figure 1. In order to achieve static equilibrium, four nodes are fixed at the middle point of each edge. This means that the displacements in the y direction are fixed on the loaded edges and the displacements in the x direction are fixed on the crosswise sides.

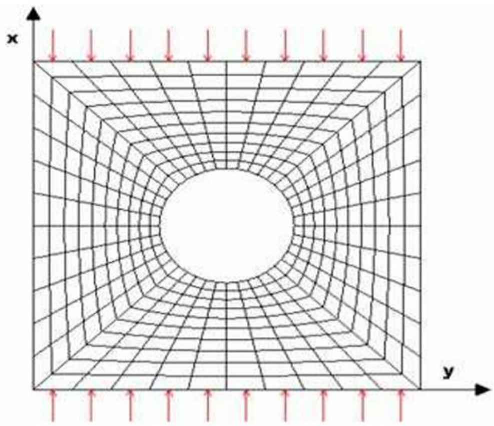

Fig.1. Typical mesh for a cross-ply square laminated plate with circular cutout.

4. RESULTS AND DISCUSSION

4.1. Effect of cutout size

Table 2 shows the non-dimensional bending loads for cross-ply laminated composite plates where the

hole diameter is different from the laminate width ratio (d/b) and ranges from 0 to 1.
0.8 are shown in Table2. The findings from Table 2 are shown in Figure 2.

By changing the hole size from 0.0 to 0.8 up to 69%, the bending load is raised. In the range of d/b=0.0 to 0.05, it's important to note that the bending load doesn't change much compared to the perfect plate.

Table 2: Cross-ply laminate with a circular cutout

d/b	Buckling load ($N_x b^2/E_2 h^3$)
0.0	13.79
0.025	13.71
0.05	13.51
0.1	12.80
0.2	10.82
0.3	8.97
0.4	7.51
0.5	6.39
0.6	5.63
0.7	4.99
0.8	4.43

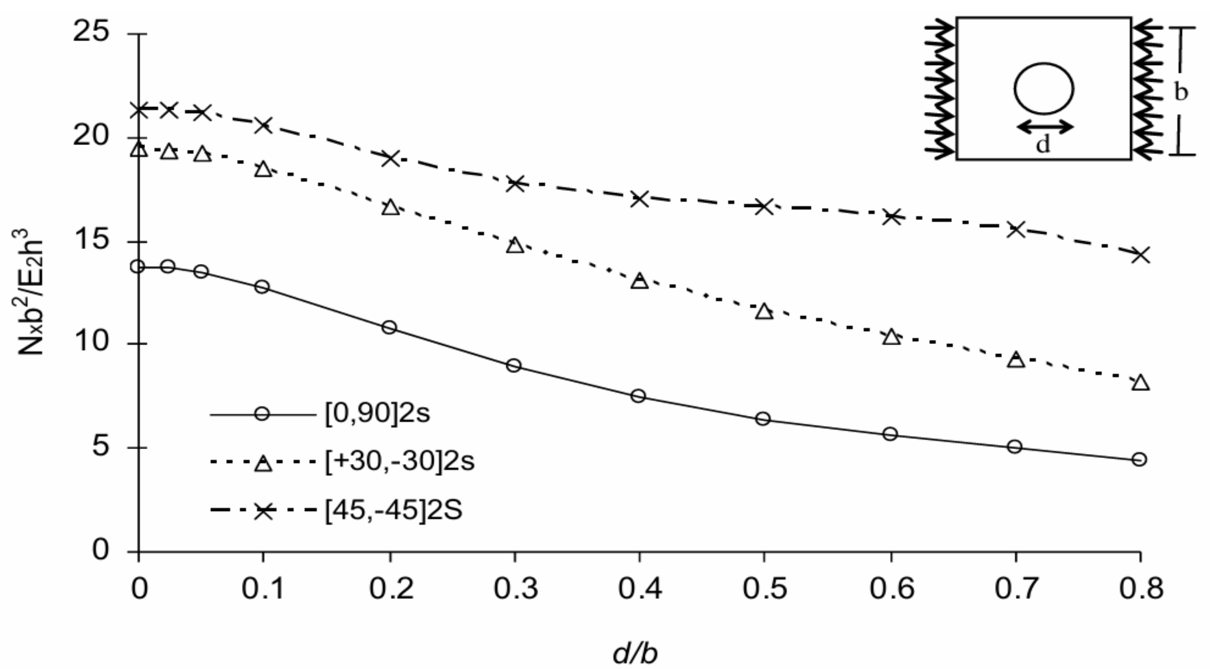

Fig.2. Variation of buckling loads with cutout dimensions.

4.2 Effect of cutout shape

Different cutout shapes may be used depending on the design needs and mindset. In this section, we look at how elliptical cuts affect things. It is thought that the cut out will be in the middle of the square plates. The direction of the loads and their limits are the same as in the last part. The ellipse's diameter that is lined in the load direction is shown by e, and the other diameter that is in the crosswise direction is shown by c. This study looks into two kinds of circular shapes. The first one looks at the oval holes whose major diameter is lined up with the load direction (x-axis), and the second one looks at the ellipse whose minor diameter is lined up with the load direction (y-axis). For the first type, e/b=0.5 stays the same, while c/b changes from 0.0 to 0.5. For the later type, c/b=0.5 is always the same, but e/b can be anywhere from 0.0 to 0.5. Table 3 shows the changes in non-dimensional bending loads in a fixed c/b and differential e/b. It is thought that the lower bending load is caused by the bigger hole area. The results of constant/band variable c/b are shown in Table4. It can be seen that the bending load also goes down as the cutout area grows. Figure 3 shows the different types of circular cutouts in both axial and transverse pressure directions. The results show that in the same cutout area, the cutout that goes across the load direction perpendicularly has a higher bending load than the cuts that go across the load direction transversely.

Table 3: Cross-ply laminate with an elliptical cutout

c/b	e/b	Buckling load $(N_x b^2/E_2 h^3)$
0.0	0.0	13.79
0.5	0.05	10.38
0.5	0.10	9.54
0.5	0.15	8.81
0.5	0.20	8.18
0.5	0.25	7.63
0.5	0.30	7.19
0.5	0.35	6.81
0.5	0.40	6.57
0.5	0.45	6.42
0.5	0.50	6.39

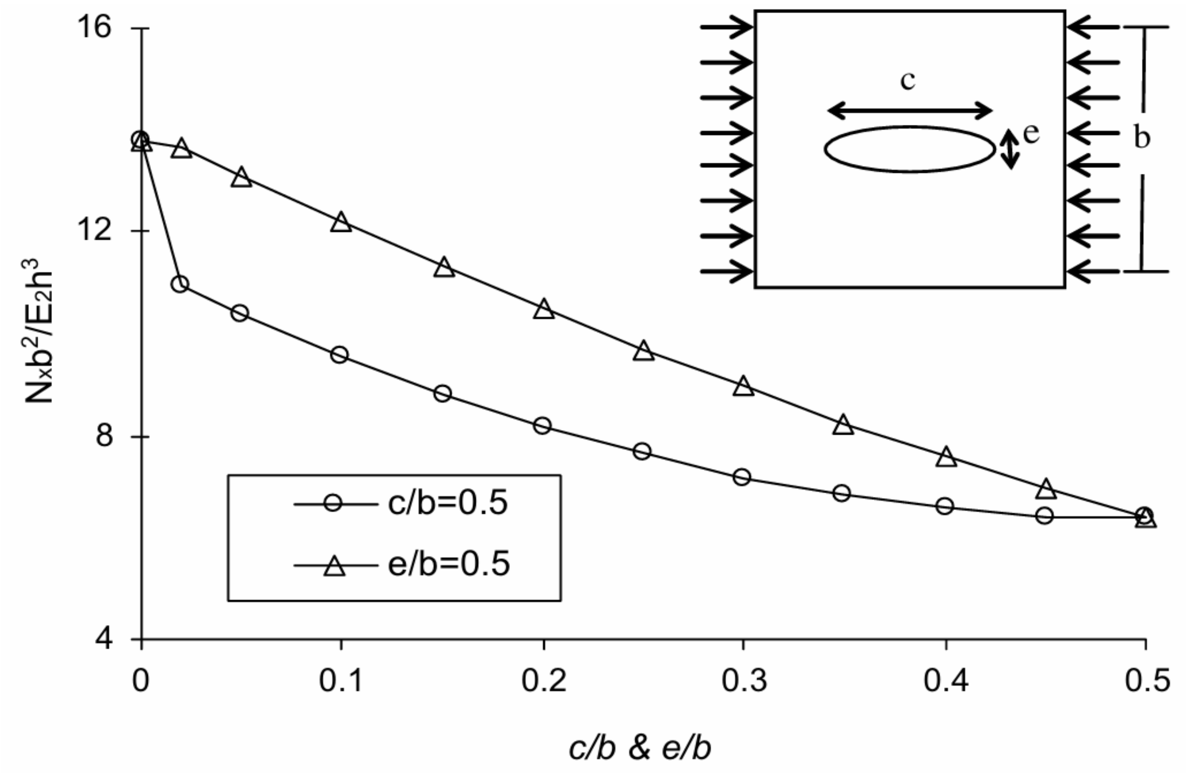

Fig.3. Variation of buckling loads with cutout dimensions.

4.3 Effect of plate aspect ratio

This part talks about how performance-rated cross-ply laminated plates buckle at different plate aspect ratios. The plate aspect ratios used in this study were chosen to have integer values, such as a/b=1,2,3. On all four edges, simply supported border conditions are used. These plates are all 120 mm wide, and all of the cuts are in the middle of the plates. The outcomes of bulk loads in various cutout sizes are shown in Figure 4. As was already said, the bending force of the square plate goes down as the hole sizes get smaller. The bending loads of plates with aspect ratios of 2 and 3 change from 0 to 0.5 when d/b changes. These numbers only have an effect on the bending load (18.7% and 4.3%). It can also be seen that the mode forms for plates with aspect ratios of 2 and 3 are two and three half waves, respectively. The results show that the bending load goes up as the hole size goes up for aspect ratios of 2 and 3, but it goes down until d/b=0.35 and up when d/b>0.35. One could say that the plate aspect ratio can make using the hole on rectangle plates better.

Table 4: Cross-ply laminate with an elliptical cutout.

e/b	c/b	Buckling load ($N_x b^2/E_2 h^3$)
0.0	0.0	13.79
0.5	0.05	13.11
0.5	0.10	12.19
0.5	0.15	11.32
0.5	0.20	10.49
0.5	0.25	9.70
0.5	0.30	8.97
0.5	0.35	8.25
0.5	0.40	7.62
0.5	0.45	6.98
0.5	0.50	6.39

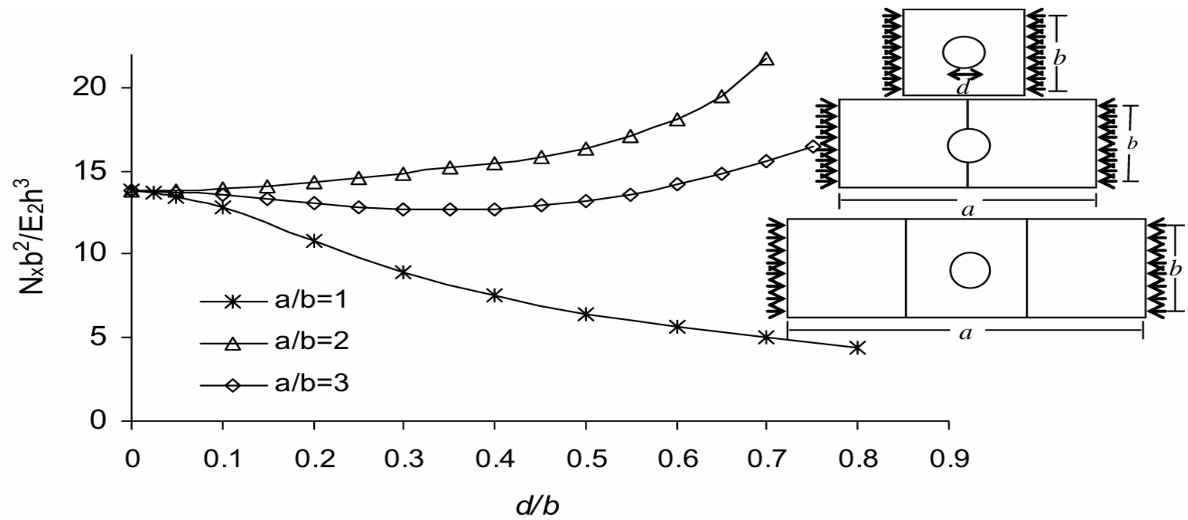

Fig. 4. Variation of buckling loads with circular cutout dimensions in different plate aspect ratios.

5. CONCLUSIONS

It is possible to draw the following conclusion on the basis of the current work, which has focused on the buckling behavior of rectangular perforated composite plates when subjected to compression load: It has been observed that the buckling load of square plates that have a circular cutout decreases as the diameter of the cutout increases.

It is possible to ignore small cuts while modelling, which may lower the amount of work required for meshing. When it comes to the elliptical cuts, the one that is aligned perpendicular to the direction of load indicates a larger buckling load than the one that is aligned in the direction it is being loaded. The buckling load is enhanced by choosing the greater value for the aspect ratio of the plate, which is accomplished by selecting the integer value for the plate aspect ratio setting. There is a significant relationship between the boundary conditions of perforated plates and the buckling load of the plates. The buckling load for the plate with clamped boundary condition on unloaded edges is two times larger than the buckling load for the plate with simply supported boundary condition. This is because the clamped boundary condition is applied to the edges of the plate.

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