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An Assessment of the Impact of Different Plate Aspect Ratios on the Buckling Analysis of Laminated Composites in Clamped Conditions

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Abstract:
The influence of plate aspect ratio on buckling behavior has been examined numerically for a sixteen-ply quasi-isotropic graphite/epoxy symmetrically laminated composite plate [0°/+45°/-45°/90°]2s, including square and rectangular cuts. The finite element method (FEM) was used to impose a spectrum of linearly varying in-plane compressive stresses on the plate. This research examines the influence of boundary conditions, the plate length-to-thickness ratio (a/t), and the dimensions of square or rectangular cuts on the buckling behavior of symmetrically laminated rectangular composite plates subjected to linearly increasing in-plane compressive pressures. The findings indicate that augmenting the ratio of a plate's aspect to its thickness and length can diminish the buckling loads of rectangular composite plates featuring rectangular or square cutouts when subjected to various linearly varying in-plane loads, regardless of the cutout's dimensions, configuration, or boundary conditions. Various linearly variable in-plane loads, length-to-thickness ratio (a/t), aspect ratio (a/b), and boundary conditions significantly influence the buckling strength of a rectangular composite plate including a square or rectangular cutout.
Keywords: *Aspect Ratio, Buckling Analysis, FEM, Laminated Composites, Clamped Conditions.*

I. INTRODUCTION

Composite laminated plates experience buckling under compressive pressures. Composites consist of two or more materials that synergistically combine to provide properties that are difficult to achieve with a single component. The weight of most of these materials is borne by their fibers. Besides providing adaptable structural performance, matrices characterized by a low modulus and high elongation protect fibers from external pressures while preserving their alignment and appropriate positioning. Due to the characteristics of the constituents, composite materials—comprising two or more components—can significantly reduce construction weight while maintaining a high strength-to-weight ratio. Fiber-reinforced composites are often used as laminas, or thin sheets, in the construction sector. The predominant kind of material macrounit is referred to as a laminate. The alignment of the fibers inside each lamina and the sequence of layer stacking may be modified to provide the necessary strength and stiffness for a specific application. The unique properties of a composite material result from a specific mix of traits influenced by the orientation, distribution, and composition of its constituent components. Cutouts are essential for several functions, including weight reduction, improved air circulation, and establishing linkages between proximate components. A composite material known as carbon-fiber reinforced plastic is produced by amalgamating several carbon fiber types with thermosetting resins. Carbon fiber reinforced plastic, or CFRP, is a lightweight, nonconductive polymer that is augmented with fibers. The chemical has a very prolonged half-life. The material's strength and stiffness may be significantly enhanced by layering several fiber sheets in various combinations. Parth Bhavsar and his colleagues investigated the buckling behavior of glass fiber reinforced polymer (GFRP) under linearly increasing loads using the finite element approach.

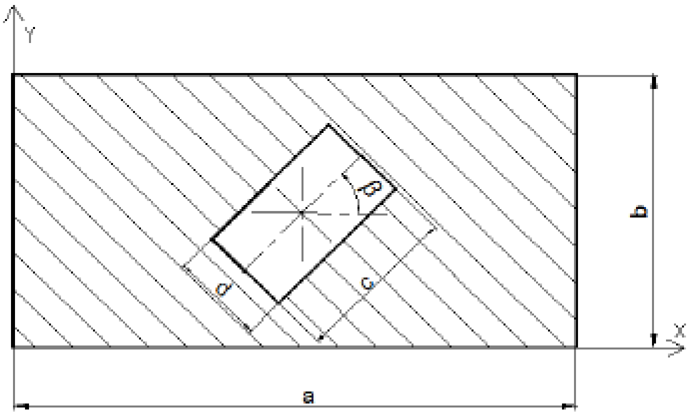

Figure 1: Geometry of the model.

For the purpose of determining the impact that various elements have on the buckling stress of rectangular plates with an aspect ratio of one, several factors have been under investigation. Using two-dimensional finite element analysis, Joshi and his colleagues were able to quantify the buckling stress per unit length of a rectangular plate that had circular incisions and was subjected to biaxial compression. Adjusting the length-to-thickness ratio and situating the holes are the two ways that may be used in order to provide an evaluation of the buckling factors. Nagendra Singh Gaira and his colleagues conducted research to explore the buckling behavior of laminated rectangular plates when subjected to clamp-free boundary conditions. The existence of cutouts is beneficial because they reduce the amount of stress that is caused by buckling. The reduction of the buckling load factor is the impact that is expected to occur as a result of increasing the aspect ratio. In order to evaluate the impact that an axial load has on the buckling load of a laminated composite cylindrical panel, Hamidreza Allahbakhsh and Ali Dadrasi conducted a buckling research study on the panel. For the purpose of the investigation, an elliptical cutout was used in a variety of sizes and placements. In the study conducted by Container Okutan Baba, the buckling stress that is created on rectangular plates is investigated in connection to various cut-out geometries, length-to-thickness ratios, and ply orientations. In order to determine how these parameters influenced the buckling behavior of E-glass/epoxy composite plates when subjected to in-plane compression stress, the researchers used both theoretical and experimental approaches. According to the findings of the finite element buckling experiment that Hsuan-Teh Hu and his colleagues conducted on composite laminate skew plates that were exposed to uniaxial compressive loads, the failure criteria and nonlinear in-plane shear had a substantial influence on the final loads that were distributed across the skew plates. The linearized buckling loads, on the other hand, have a less influence than the other loads.

II. Finite Element Model

This study employs finite element analysis to evaluate the buckling load factors of carbon fiber composite plates characterized by square or cylindrical geometries. The version of APDL is ANSYS Version 14.5. Three distinct boundary conditions—fixed, clamped, and unclamped—are evaluated in the analysis of the plate's dimensions. The first scenario consists of two levels, whereas the second scenario comprises three levels. The stacking sequences employed, specifically [0°/+45°/-45°/90°]2s, may be responsible for this outcome. The plate is required to have multiple center holes of equivalent volume to facilitate the investigation. Various configurations for the center holes are available, including square, triangular, circular, and star patterns. The characteristics of the buckling load factor are currently under investigation.

This study investigates the buckling response of quasi-isotropic graphite/epoxy composite plates featuring square or rectangular cutouts subjected to linearly increasing in-plane compressive loads. Finite Element Method (FEM) is employed to analyze the influence of plate aspect ratio (a/b), length/thickness ratio (a/t), and boundary conditions. In the lamina, epoxy functions as the matrix material, while graphite fibers act as the reinforcement. The properties of the graphite/epoxy material are presented in Table 1, sourced from the work of Hsuan*Teh Hu and Bor*Horng Lin (1995). The global X-axis is oriented in alignment with material axis 1, whereas the global Y-axis is oriented in alignment with material axis 2. The global x-axis is oriented in accordance with the compressive loads exerted on the plate. The orientation of the compressive load aligns with the 0° fiber direction.

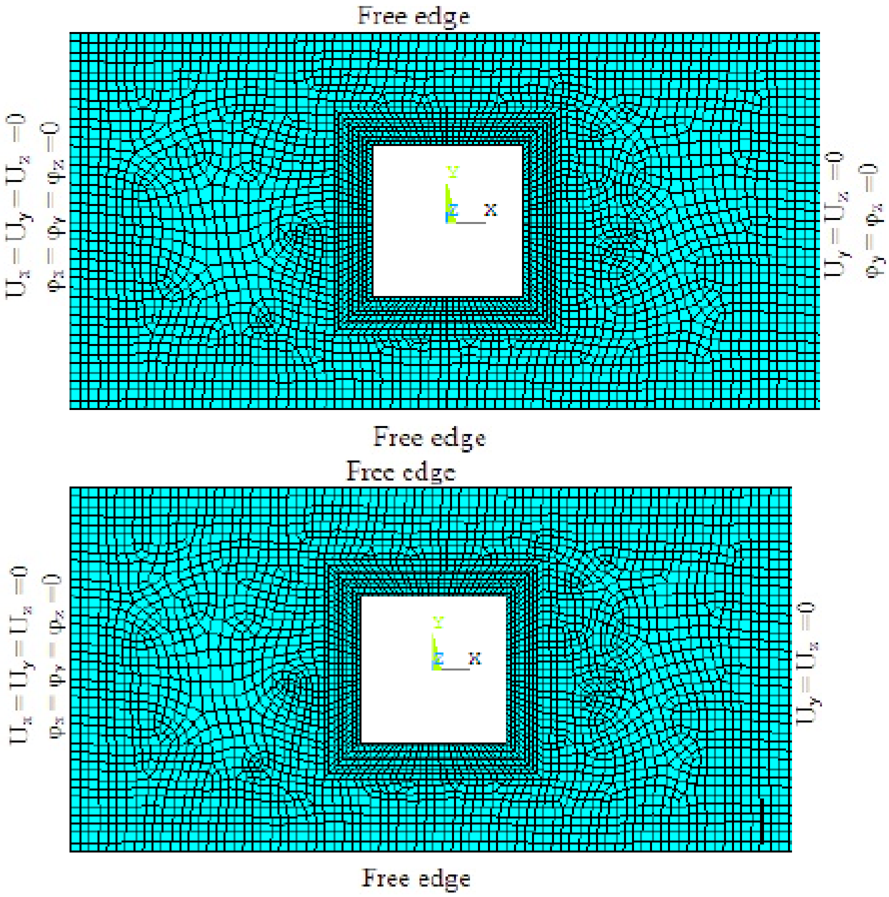

Figure 2: FE model with mesh

III. DESCRIPTION OF SHELL ELEMENT

The SHELL281 element type is utilized for this project. The analysis of very thin or moderately thick shells is facilitated by the incorporation of this shell element. This material is ideal for modeling sandwich structures and layered composite coatings due to its extensive range of applications. The optimal application of this material is most appropriate for scenarios involving significant strain nonlinearity, linearity, or rotation. The element consists of eight nodes, each possessing six degrees of freedom. The degrees of freedom facilitate translations along the x, y, and z axes contained within the element, in addition to enabling rotation about the three axes. The nonlinear element S8R5 is utilized in research involving cylindrical plates. This element is characterized by the presence of eight nodes, each possessing five degrees of freedom.

IV. GEOMETRIC MODELLING AND MATERIAL PROPERTY

The geometric features are seen in Figure 1. The length of plate 'a' is 200 mm, while the width of plate 'b' is 100 mm. Each individual layer of this sixteen-layer laminate has a thickness of 0.125 mm, where "t" represents the thickness of the plate and "β" represents the cutout orientation angle. For the sake of this investigation, a cutout orientation angle of zero degrees is assumed. Within the context of this work, a rectangular cutout that is centered on a rectangular plate is presumed. This cutout is c inches in length and d inches in width. On the condition that the ratios c and d are equal, the rectangular hole transforms into a square hole. A further investigation on the impact of square holes is carried out under the same settings. The buckling analysis takes into account both square and rectangular hollows as possibilities.

Table 1 : Property of composite material

E_{11} (GPa)	E_{22} (GPa)	v_{12}	$G_{12} = G_{13}$ (GPa)	G_{23} (GPa)
128	11	0.25	4.48	1.53

V. RESULTS AND DISCUSSION

The purpose of this section is to investigate the significance of the influence that various plate ply orientations have on the plate when subjected to certain boundary circumstances. The all of this will go place at the same time. It is being considered an example of a situation that is in place at the border permanently. The ply orientations that are used in this part are somewhat varied. 0 degrees, 45 degrees, 45 degrees, and 90 degrees are the orientations. For additional information, kindly refer to the list that is provided below. Both of them are examined, and study is carried out in order to determine the repercussions that may be caused by the circumstance. The two are investigated, along with the implications that are derived from them.The buckling loads of a rectangular composite plate with a rectangular/square cutout are shown to be affected by the plate aspect ratio (a/b), the length/thickness ratio (a/t), boundary conditions, and linearly increasing in-plane compressive stress. These factors are shown in the figures.

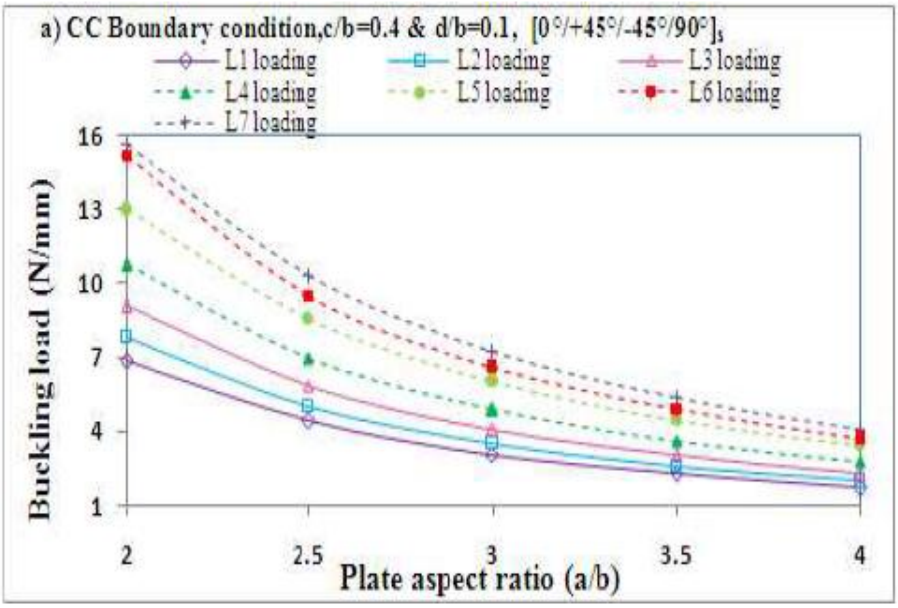

Figure 3 : Effect of plate aspect ratio with Clamped BC (S) layup Scheme

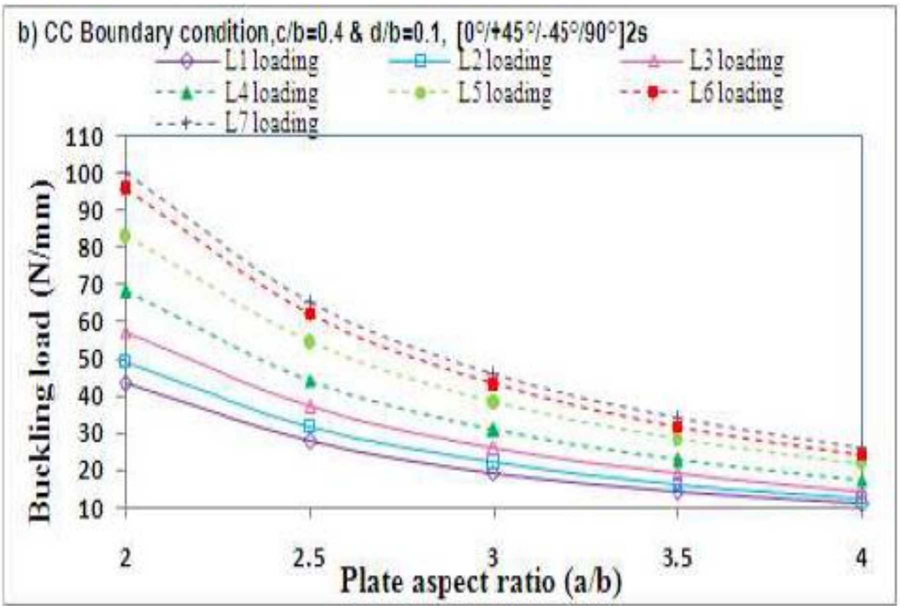

Figure 4 : Effect of plate aspect ratio with Clamped BC (2S) layup Scheme

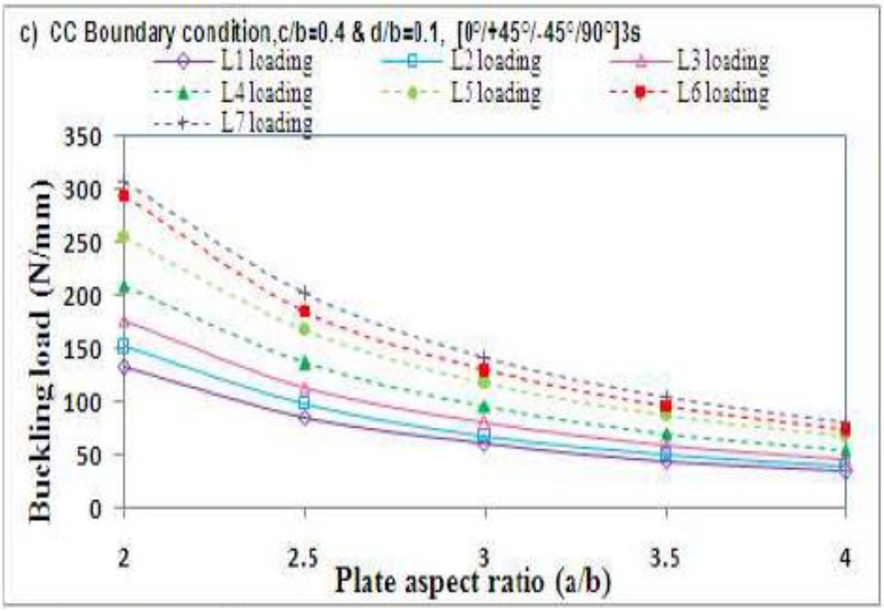

Figure 5 : Effect of plate aspect ratio with Clamped BC (3S) layup Scheme

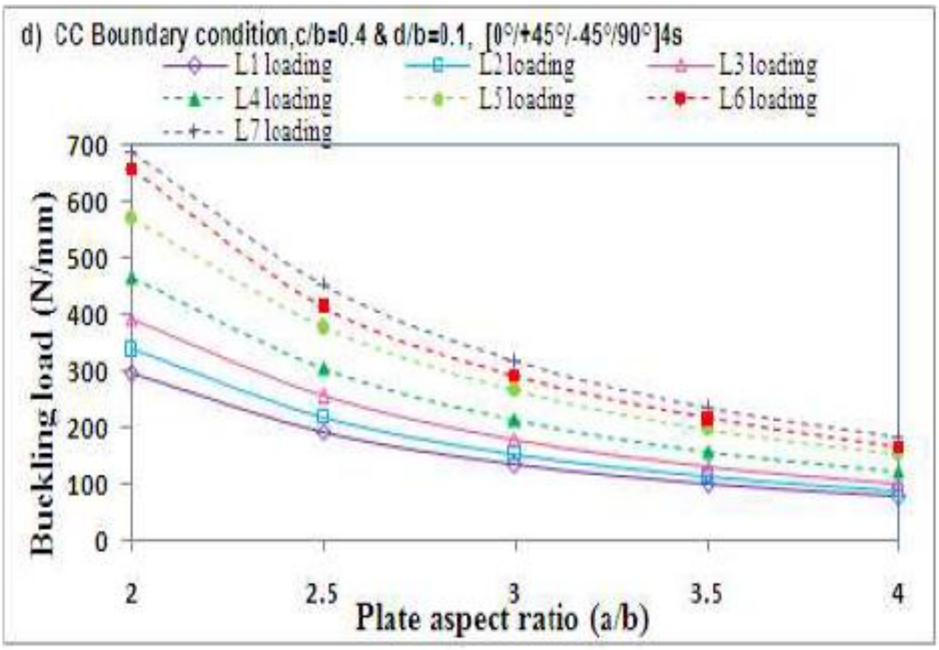

Figure 5 : Effect of plate aspect ratio with Clamped BC (4S) layup Scheme

The data illustrates the influence of the plate aspect ratio (a/b), length/thickness ratio (a/t), boundary conditions, and linearly increasing in-plane compressive stress on the buckling loads of a rectangular composite plate featuring rectangular or square cuts. Data indicates that, regardless of length/thickness ratios (a/t), boundary conditions, and linearly varying in-plane compressive loading, the buckling loads of a rectangular composite plate featuring square/rectangular cutouts vary by 35.8%, 30.4%, 26.44%, and 23.4% for a/b=2-2.5, a/b=2.5-3, a/b=3-3.5, and a/b=3.5-4, respectively. The buckling load of a rectangular composite plate with a plate aspect ratio of a/b=2 is 1.5 times, 2 times, 3 times, and 4 times greater when compared to plates with aspect ratios of 2.5, 3, 3.5, and 4, respectively. This is not influenced by boundary conditions, exhibits linear variability in in-plane compressive stress, and is related to length/thickness ratios (a/t). Independent of length/thickness ratios (a/t), boundary conditions, and linearly varying in-plane compressive loads, a rectangular composite plate featuring a square or rectangular cutout undergoes a 74% decrease in buckling load as the plate aspect ratio is elevated from 2 to 4.

VI. CONCLUSIONS

This study examines the influence of plate aspect ratio, length/thickness ratio, boundary conditions, and linearly varying in-plane compressive loading on the buckling behavior of a sixteen-ply quasi-isotropic graphite/epoxy symmetrically laminated rectangular composite plate [0°/+45°/-45°/90°]2s with square/rectangular cutouts.The rectangular composite plate with a/b=2 exhibits a greater buckling load than plates with a/b ratios of 2.5, 2.5, 3.5, and 4. This is true regardless of boundary conditions, linearly increasing in-plane compressive stresses, or length-to-thickness ratios (a/t). The buckling load of a rectangular composite plate with square or rectangular cutouts diminishes by 97% as the length-to-thickness ratio increases from 50 to 200, irrespective of plate aspect ratios (a/b) and boundary conditions, under linearly rising in-plane compressive stress.

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