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Research Paper

Buckling Mode Analysis of the Rectangular Composite Plate Featuring a Square Cutout under Different In-plane Compressive Loading Scenarios

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Abstract: *The influence of the plate aspect ratio on buckling behavior was analyzed statistically through this sixteen-ply quasi-isotropic graphite/epoxy symmetrically laminated composite plate [0°/+45°/-45°/90°]2s, incorporating both square and rectangular slices. The plate underwent a series of linearly variable in-plane compressive loads analyzed through the finite element method (FEM). This study examines the buckling behavior of symmetrically laminated rectangular composite plates, considering boundary conditions, the plate length/thickness ratio (a/t), and the dimensions of square or rectangular cuts, while subjected to linearly increasing in-plane compressive stresses. The results indicate that the buckling loads of rectangular composite plates featuring square or rectangular cutouts can be diminished by enhancing the aspect to thickness and length ratio, irrespective of the dimensions, configuration, or boundary conditions of the cutout, when these plates experience various linear in-plane loads. A rectangular composite plate featuring a square or rectangular cutout will experience a notable impact on its buckling strength due to in-plane loads that vary linearly in relation to boundary conditions, aspect ratio (a/b), and length-to-thickness ratio (a/t).*

Keywords: *Mode Shape, Rectangular Composite Plate, FEM, Square Cutout, Compressive Load.*

I. Introduction

The application of external compressive pressures leads to the buckling of composite laminated plates. The integration of the characteristics of multiple materials into a unified composite enables the attainment of outcomes that cannot be realized with any single component alone. The materials serve as fundamental components of composites. The fibers in these materials carry an unequal portion of their overall weight. A matrix characterized by low modulus and high elongation not only ensures flexible structural performance but also protects fibers from external pressures and maintains their proper positioning. Composites, made up of two or more materials, offer the ability to greatly decrease building weight while maintaining an impressive strength-to-weight ratio thanks to their unique composition. This is because composites are made up of multiple components. The construction industry frequently utilizes laminas, which are slender sheets. This application is frequently observed in fiber-reinforced composites. A common type of material macrounit found in the material is laminae. The arrangement of the layers and the alignment of the fibers within each lamina can be modified to provide the material with the necessary strength and stiffness for a particular application. The distinctive properties of a composite material arise from the unique combination of its component elements' composition, distribution, and orientation. Cutouts serve multiple important functions, including minimizing component weight, enhancing air circulation, and facilitating connections between adjacent components. Carbon-fiber reinforced plastic is a composite material created through the combination of thermosetting resins and different types of carbon fibers. A nonconductive, lightweight polymer that is enhanced with fibers composed of carbon fiber is known as carbon fiber reinforced plastic, abbreviated as CFRP. A component that exerts a significant and enduring influence. Various designs, such as stacking numerous fiber sheets, hold the potential to greatly improve the strength and stiffness of the material. This approach can yield the desired outcome. Parth Bhavsar and colleagues employed the finite element method to investigate the buckling behavior of glass fiber reinforced polymer (GFRP) under linearly increasing loads.

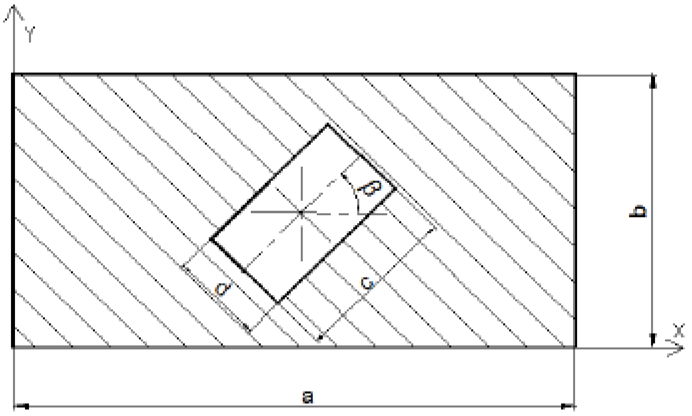
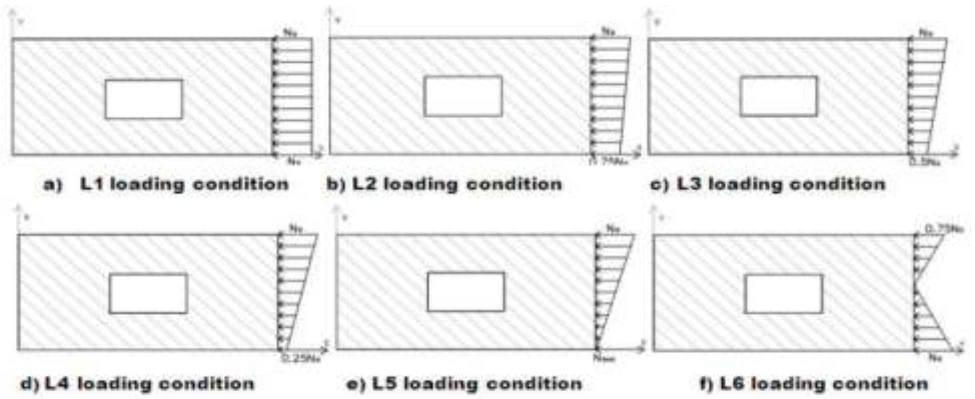


Figure 1: Geometry of the model.



a) L1 loading condition b) L2 loading condition c) L3 loading condition

d) L4 loading condition e) L5 loading condition f) L6 loading condition

Figure 2: Details various loading conditions

Investigations have been conducted on the buckling stress of one-dimensional rectangular plates by analyzing various properties to assess the impact of each on the stress. Following the application of biaxial compression to a rectangular plate featuring circular incisions, Joshi and colleagues employed two-dimensional finite element analysis to determine the buckling stress per unit length. Modifying the length-to-thickness ratio and positioning the holes are two approaches for evaluating the buckling parameters. Nagendra Singh Gaira and colleagues conducted a study on the buckling behavior of laminated rectangular plates without the presence of a border clamp. A notable observation is the reduction in the buckling load attributed to the existence of cuts. The objective is to lower the buckling load factor, which can potentially be accomplished by enhancing the aspect ratio. The impact of an axial load on the buckling load of a laminated composite cylindrical panel was the primary subject of the buckling investigation carried out by Hamidreza Allahbakhsh and Ali Dadrasi. An elliptical cutout was observed in various sizes and placements across the study. Container Okutan Baba dedicates his time to examining the influence of different cut-out shapes, length-to-thickness ratios, and ply orientations on the buckling stress experienced by rectangular plates. Following the application of in-plane compression stress to E-glass/epoxy composite plates, a combination of theoretical and experimental methods was employed to assess the influence of these parameters on the buckling behavior of the plates. In their investigation of composite laminate skew plates under uniaxial compressive loads, Hsuan-Teh Hu and colleagues discovered that the failure criteria and nonlinear in-plane shear significantly influenced the ultimate loads experienced by the plates. This represents a significant advancement when contrasted with the less impactful linearized buckling loads.

II. Finite Element Model

A simple method to adhere to the structure outlined in the research paper. This investigation seeks to determine the buckling load factors for square and cylindrical carbon fiber composite plates through the application of finite element analysis. We are utilizing ANSYS Version 14.5 along with the APDL version. The dimensions of the plate are evaluated by examining three specific border criteria. In these scenarios, we encounter both the clamped and unclamped conditions. In the second case, each scenario comprises three levels, whereas the first case includes only two. Considering the stacking sequences utilized were [0°/+45°/-45°/90°]2s, it is likely that this is the explanation. The plate must feature multiple center holes of uniform size to facilitate the study being undertaken. The arrangement of the center holes can take on various forms, such as square, triangular, circular, and star configurations. Investigation into the characteristics of the buckling load factor is currently in progress. This study investigates the buckling response of quasi-isotropic graphite/epoxy composite plates with square and rectangular cuts under linearly increasing in-plane compressive loads, utilizing the finite element method (FEM). The analysis focuses on the effects of plate aspect ratio (a/b), length/thickness ratio (a/t), and boundary conditions. The lamina is constructed with epoxy serving as the matrix material and graphite fibers utilized for reinforcement. The material characteristics of graphite/epoxy are detailed in Table 1, derived from the research conducted by Hsuan Teh Hu and Bor Horng Lin (1995). The material's x-axis and y-axis maintain perfect alignment with the global x and y axes, respectively. The pressures exerted on the plate are perpendicular to the international x-axis. The 0° fiber aligns perfectly with the direction of the compressive load.

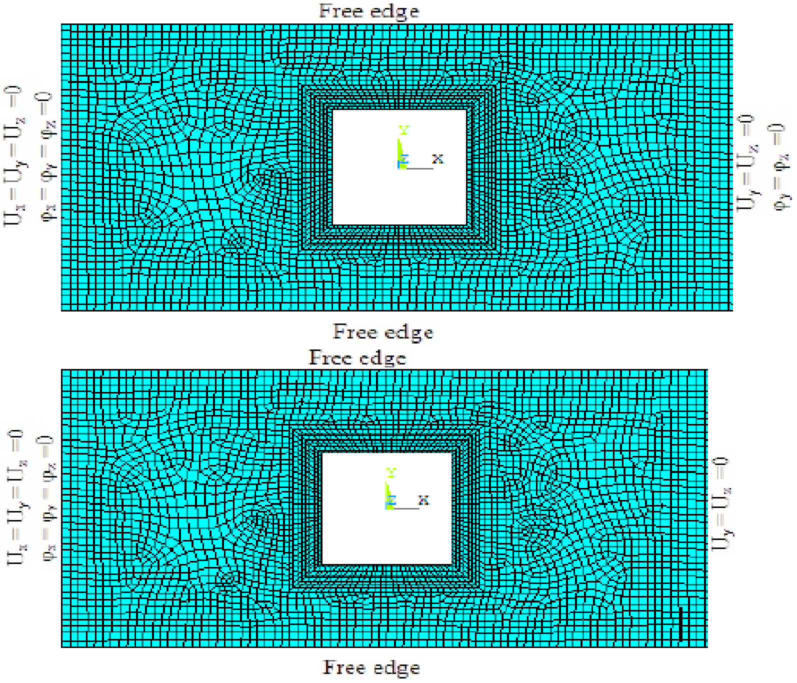


Figure 3: FE model with mesh

III. Description Of Element

This study employs the SHELL281 element type. The inclusion of this shell element facilitates the analysis of both very thin and somewhat thick shells with greater ease. The versatility of this material enhances its suitability for simulating sandwich structures and layered composite coverings. Applications that demonstrate considerable strain nonlinearity, linearity, or rotation are prime candidates for the effective utilization of this material. The element consists of eleven nodes, each possessing six degrees of freedom. With these degrees of freedom, the element can be rotated around its three axes and translated along its internal x, y, and z axes. In projects involving the use of cylindrical plates for analysis, the nonlinear element S8R5 is employed. Each of the eight nodes constituting this element can be manipulated in five distinct manners. This element's presence can serve as a means of identification.

IV. Geometric Modelling And Material Property

The geometry depicted in Figure 1 aligns precisely with the provided description. The dimensions of plate 'a' measure 200 mm in length, while plate 'b' has a width of 100 mm. The laminate consists of sixteen layers, each with a thickness of 0.125 mm. The initial "t" represents the thickness of the plate, whereas the orientation angle of the cutout is denoted by the letter "β". In this analysis, the cutout orientation angle is considered to be zero degrees. A rectangular plate featuring a central cutout acts as the base for the item. The cutout's dimensions consist of its length (c) and width (d). If the ratios of c and d are equal, a square hole will be created from the rectangular one. Additionally, under the same conditions as previously, the effect of square holes is examined. The buckling analysis takes into account both square and rectangular openings.

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

This section aims to investigate how different ply orientations impact the plate under identical boundary conditions. All of these events will occur concurrently. This situation involves a stable condition at the border, which is presently under evaluation. This section utilizes a diverse range of ply orientations. The sequence of orientations is as follows: progressing from 0 degrees to 90 degrees in the format [0°/+45°/-45°/90°]2s. If you require additional information, please refer to the list provided below. To ascertain the outcomes resulting from the situation, an examination is carried out on both subjects. An examination of both subjects is undertaken, along with an analysis of the potential consequences that may ensue. The figures presented illustrate how various factors, such as boundary conditions, linearly increasing in-plane compressive stress, rectangular or square cutouts, plate aspect ratio (a/b), and length/thickness ratio (a/t), influence the buckling loads of a rectangular composite plate.

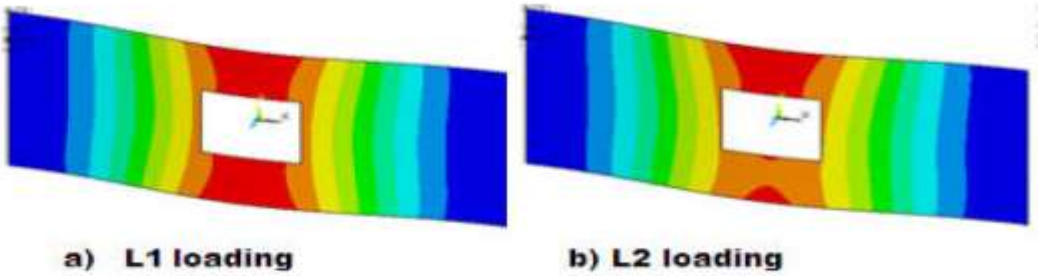

a) L1 loading
b) L2 loading

Figure 4 : First Mode shape under L1 and L2 loading conditions

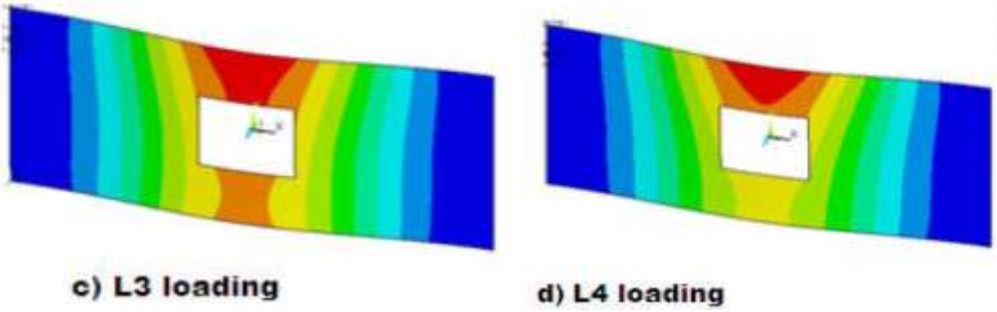

c) L3 loading
d) L4 loading

Figure 5 : First Mode shape under L3 and L4 loading conditions

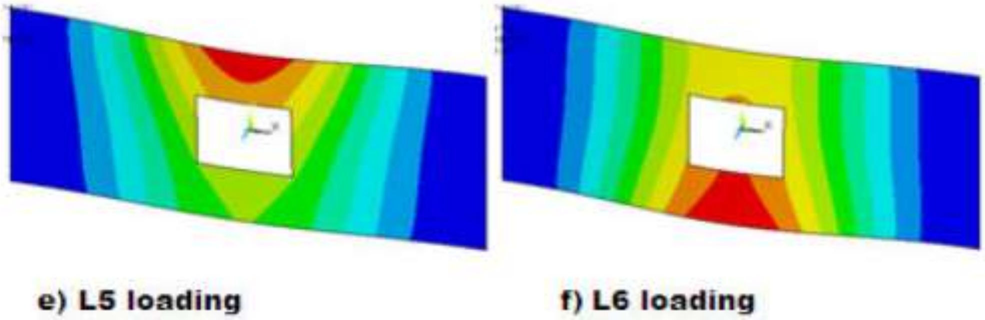

e) L5 loading
f) L6 loading

Figure 6 : First Mode shape under L6 and L7 loading conditions

The unique deformation pattern that occurs when a structure undergoes buckling or vibration at a specific mode is referred to as the mode shape. Mode shapes serve a crucial role in structural analysis by illustrating the deformation patterns of a structure when subjected to different buckling loads or natural frequencies. A structure, such as a composite plate, can experience bending and instability when subjected to increasing in-plane compressive stresses. The deformation pattern observed at the lowest critical buckling load is characterized by the initial buckling mode shape. The initial mode shape typically exhibits the most straightforward deformation pattern and is associated with the lowest buckling load. More complex mode forms display intricate deformations, characterized by additional waves or curvatures, and occur under increased loads. A square cutout modifies the mode shape and reduces the strength of the plate, frequently concentrating deformation in the vicinity of the cutout. The buckling behavior is significantly affected by the dimensions and positioning of the cutout.

Several critical factors influence the characteristics of the initial buckling mode of a rectangular composite plate featuring a square cutout when exposed to different in-plane compressive stress conditions. The term "aspect ratio" denotes the relationship between the length and breadth of a plate. The measurements of the square cutout along with its placement. The orientation of fibers and the sequence in which they are stacked are critical factors in composite layers.

Orthotropic materials exhibit distinct properties such as the elastic modulus, shear modulus, and Poisson's ratio. The buckling response is significantly influenced by the conditions of the edges, whether they are simply supported, clamped, or free. Asymmetric mode forms can indeed be introduced through the application of mixed boundary conditions. The characteristics of the first mode shape will frequently exhibit either symmetric or asymmetric deformation traits, contingent upon the dimensions of the cutout and the surrounding conditions.

Near its edges, the cutout acts as a stress concentrator, leading to localized buckling due to the tension. The critical buckling load diminishes with an increase in the cutout size, leading to a modification in the mode shape as the deformation zones shift. The orientation of fibers in reinforced composites significantly influences the deformation pattern.

VI. Conclusions

The distinct deformation pattern exhibited by a structure experiencing buckling or vibration at a specific mode is known as the mode shape. Mode shapes serve a crucial role in structural analysis by clarifying how a structure deforms when subjected to various buckling loads or natural frequencies. A structure, like a composite plate, can undergo deformation and experience instability when exposed to rising in-plane compressive pressures. The deformation pattern observed at the minimum critical buckling load is defined by the initial buckling mode shape. The primary mode shape typically displays the simplest deformation pattern and aligns with the lowest buckling load. More advanced mode forms exhibit intricate deformations, characterized by additional waves or curvatures, and manifest under heightened stresses. A square cutout alters the mode shape and affects the structural integrity of the plate, frequently leading to localized deformation around the cutout area. The dimensions and position of the cutout have a substantial impact on the buckling behavior.

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