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Vibration and Buckling Analysis of Composite Plate Using FEA

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Abstract: In order to achieve a numerical solution to the governing differential equations, the finite element technique, also known as FEM, is used. The buckling analysis of rectangular laminated plates with rectangular cross-sections is explored for a variety of boundary condition and aspect ratio combinations. Buckling loads are analysed and verified with respect to other works that may be found in the relevant body of literature in order to establish whether or not the current method is accurate. The trustworthiness of the finite element approach that was used is shown by the substantial agreement with the other data that was provided. New numerical findings have been developed for uniaxial and biaxial compression loads on symmetrically laminated composite plates. These results concentrate on the important impacts of buckling for a variety of factors, including boundary condition, aspect ratio, and modular ratio. It was discovered that the influence of boundary conditions on buckling load rises as the aspect ratio increases for both uniaxial and biaxial compression loading. This was the case regardless of whether the loading was uniaxial or biaxial. It was also discovered that, at larger values of elastic modulus ratio, the variation of buckling load with aspect ratio becomes virtually constant.
Keywords: Composite, FEA, Buckling, Vibration, laminated

I. INTRODUCTION

A. Overview

Buckling and post buckling analysis of laminated composite plates are the topics that are covered in this research. However, the critical value of load that is provided by linear buckling analysis may not adequately reflect the load-carrying capabilities of a plate. Buckling of laminated composite plates is a significant concern in the design process. Although composite laminated plates typically have a lower load-carrying capacity after buckling in comparison to their metallic counterparts, the total load that a composite laminated plate experiences during postbuckling is still several times that of the critical buckling load. This is because composite laminated plates are made up of several layers of material that are bonded together. The postbuckling behaviour has been studied to establish the sustained additional loads after buckling in order to get an idea of the practical limits of the load-carrying capability of composite laminated plates.

This was done in order to get an idea of the practical limits of the load-carrying capability of composite laminated plates. Over the course of many years, a substantial amount of work has been put into the development of computational methods for the buckling and postbuckling analyses.

Failure analysis is a topic that is covered in this research. Local failures, such as matrix cracks, fibre breakage, fibre matrix debonding, and inter-layer delamination, may develop in laminated composite structures during normal operating conditions. These failures may cause a permanent loss of integrity within the laminate, which in turn results in a loss of the material's stiffness and strength. It is vital, while evaluating the performance of composite laminated plates and constructing designs that are dependable and safe, to predict the failure process, the commencement and progression of the damages, and the maximum loads that the structures can resist before the failure occurs. In particular, the first-ply failure analysis of laminated composite plates has been actively investigated over the past few years. Additionally, the mechanical behaviour and the first-ply failure load of laminated composite plates that have been subjected to in-plane loading conditions such as tension, compression, and shear as well as out-of-plane loading conditions such as transverse loads have been investigated.

B. Vibration Analysis

Venkatesan and Kunukkasseril have looked at the free vibrational properties of stacked circular plates (1978). In order to describe the asymmetric motion, equations that take into account shear deformation and rotatory inertia have been constructed. In the case of axisymmetric motion, one may get accurate closed-form solutions. Timothy and Nayfeh (1996) developed the analysis and numerical calculations for the exact free vibration characteristics of simply supported, rectangular, thick, multilayered composite plates. They made the assumption that each layer of the composite plate is of an arbitrary thickness, is perfectly bonded to adjacent layers, possesses up to orthotropic material symmetry, and that its material crystallographic axes are oriented either parallel or perpendicular to the plate's boundaries. This allowed them to determine the exact free vibration characteristics of simply supported, rectangular, After arriving at exact formal solutions for each of the layers, which are then utilised to link the field variables at the upper and lower layer surfaces, the layers are dissected into their constituent parts. The solution is continued through by successively applying suitable interfacial continuity conditions between neighbouring lamina. This ensures that the solution is consistent throughout.

Chang and Wu (1997) used orthogonal polynomial functions and the Ritz technique to carry out the free vibration analysis of a mass-loaded rectangular composite laminates plate with mixed boundaries. They also devised the subdomain approach in order to construct the governing eigenvalue equation. During the process of finding a solution, we made use of the subdomain weighted residual in order to satisfy the compatibility at the interconnect boundaries for two adjacent subdomains and to carry out continuity matrices. After that, we made use of the Gram-Schmidt orthogonalization process in order to locate the orthogonal functions set that satisfies the simply subdomain boundary condition. In the end, the continuous matrices were used in order to build the global energy functional, and the Ritz approach was utilised in order to get the governing eigenvalue equation. The composite laminates' natural frequencies and mode shapes may be determined by first solving the equation that governs the eigenvalues, and then using those results to design new laminates. Greenberg and Stavsky conduct an investigation into the axisymmetric vibrations of orthotropic composite circular plates (1978). In this, a sixth order set of equations of motion is constructed in terms of the radial and transverse displacements for axisymmetric vibrations of circular plates laminated of polar orthotropic plies. These equations describe the motion of the plates when they vibrate in a circular pattern. The findings of previous research on heterogeneous isotropic circular plates have been included into the current theory as a special instance.Liu et al. (1999) created a finite element model for the shape control and active vibration suppression of laminated composite plates with integrated piezoelectric sensors and actuators. This model was used to simulate the behaviour of the plates. Both the traditional laminated plate theory and the notion of virtual displacements form the foundation of this model. For the purpose of modelling the laminated composite plate, four-node rectangular non-conforming plate bending components have been used. To study the vibrations of symmetrically laminated rectangular composite plates with intermediate line supports, Cheung and Zhou (2001) suggest a numerical technique that is both economical in terms of processing resources and very accurate in terms of the results it produces. The static solutions of a beam with intermediate point supports under a sequence of sinusoidal loads are used to build a collection of admissible functions. In this context, the beam may be thought of as a unit-width strip taken from the plate in a direction that is parallel to the edges of the plate. In addition to satisfying the geometric boundary conditions of the plate as well as the zero deflection conditions at the line supports, this set of static beam functions, which is distinct from the currently admissible functions, is also able to accurately describe the discontinuity of the shear forces at the line supports. As a result, more precise results can be anticipated for the dynamic analysis of laminated rectangular plates with intermediate line supports. By using the Rayleigh-Ritz method, we are able to get the equation that describes the plates' controlling eigen frequency.

C. Buckling Analysis Of Laminated Composites Considering The Effect Of Orthotropic Material

Because of their high levels of strength and stiffness, composites and laminates are increasingly being utilised in a wide variety of structural, aerospace, and mechanical engineering applications. Since these composites have the benefit of being relatively lightweight, they have become increasingly popular. Not only does an increase in stress contribute to the failure of common structures like laminates, beams, and columns, but the phenomenon of stability also plays a role. These laminates, which should ideally be utilised as thin laminates, need to have their capacity to carry buckling load evaluated before they can be used. It is necessary to conduct research into their capability for the application of a variety of loads and BCs. Composites have been receiving more attention from the design considerations recently due to the enormous stiffness and minimum weights offered by these materials. In practice, it is observed that composites are typically subjected to in-plane compressions, which leads to buckling when the load exceeds their capacity. As a result, having a firm grasp on the phenomenon of buckling in composites has emerged as a crucial component in ensuring the safety and dependability of the design of composites of this kind. In order to find a solution to the issues that are caused by the theoretical analysis for laminated composites, investigation on an experimental basis has become a priority. This is so that the stability characteristic of composite plates can be determined.

II. LITERATURE REVIEW

Atilla Yolcu, Dilek & Şencan (2020) The purpose of this research is to investigate the impact that the diameter, number of circular cutouts, and placement of those cutouts have on the free vibration response and buckling stresses of laminated composites. Using the finite element programme ANSYS, assessments of Eigen-buckling and Free Vibrations are carried out on the laminated composite plates. The numerical findings that are acquired via the use of the finite element approach are compared to the ones that are obtained through experimentation. The influence of the delamination surrounding the cutout on the buckling load as well as the natural frequency is further investigated in the numerical calculations. The values for the critical buckling load and the first natural frequency that were acquired via numerical and experimental research are included into an artificial neural network-based model for the purpose of making a forecast. As a kind of training, the Levenberg–Marquardt backpropagation algorithm is used. It has been discovered that the critical buckling load and the first natural frequency values are affected not only by the number of cutouts but also by their locations. In this presentation, numerical and experimental findings are included with the results of the ANN prediction.

Peković, Ognjen & Stupar (2015) A higher order isogeometric laminated composite plate finite element formulation is presented in this research study. [Citation needed] The isogeometric formulation relies on non-uniform rational B-splines, also known as NURBS, as its basis functions, with degrees ranging from zero to infinity. In order to prevent shear locking, plate kinematics is predicated on Reddy's third order shear deformation theory (TSDT). It is possible to acquire free vibration as well as the buckling response of laminated composite plates, and the efficiency of the procedure is taken into consideration. Numerical results with varying element orders are shown, and the resulting results are compared to analytical and conventional numerical results as well as existing isogeometric plate finite elements. Also included in this comparison are the results of existing isogeometric plate finite elements.

Narayana, Lakshmi & Rao (2014) An investigation into the effects of square and rectangular cutouts on the buckling behaviour of a sixteen-ply quasi-isotropic graphite/epoxy symmetrically laminated rectangular composite plate [0°/+45°/-45°/90°]2s that has been subjected to a variety of linearly varying in-plane compressive loads has been carried out through the use of a finite element method in a numerical study. This study has been carried out in order to In addition, this study investigates the effects of the size of the square or rectangular cutout, the orientation of the square or rectangular cutout, the plate aspect ratio (a/b), the plate length/thickness ratio (a/t), and the boundary conditions on the buckling behaviour of symmetrically laminated rectangular composite plates that have been subjected to a variety of linearly varying in-plane compressive loading. It has been found that the various in-plane loads that vary linearly and the boundary conditions have a significant impact on the buckling strength of a rectangular composite plate that has a square/rectangular cutout.

Shojaee, Saeed & Valizadeh (2012) For the purpose of analysing the natural frequencies and buckling of thin symmetrically laminated composite plates in accordance with the classical plate theory, an isogeometric finite element method that is based on non-uniform rational B-splines (NURBS) basis functions has been developed. The NURBS-based approach is used to perform the approximation of the solution space for the deflection field of the plate as well as the parameterization of the geometry. Using the Lagrange multiplier method, the essential boundary conditions are formulated independently from the discrete system equations. Additionally, an orthogonal transformation technique is applied in order to impose the essential boundary conditions on the discrete eigen-value equation. Through a series of numerical experiments of laminated composite plates with different boundary conditions, fibre orientations, lay-up numbers, eigen-modes, etc., the accuracy and efficiency of the proposed method are thus demonstrated. These experiments were carried out on a computer. After that, the obtained numerical results are compared with either the analytical solutions or other available numerical methods, and excellent agreements are found between the two sets of results.

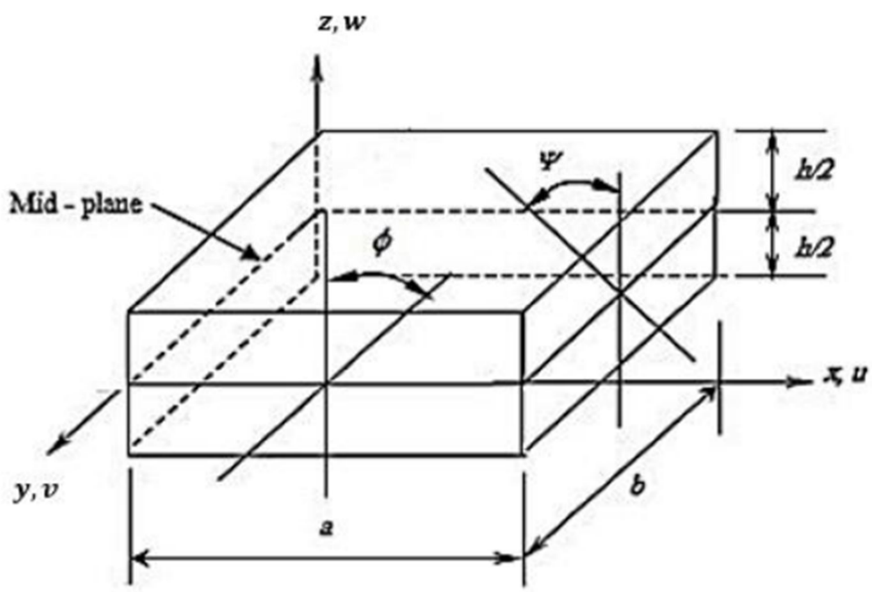
Singh, Shantanu & Chakrabarti, Anupam (2012) Buckling analysis of laminated composite plates is performed with the help of an effective C0 FE model that was developed on the basis of higher order zigzag theory. In order to solve the problem of C 1 continuity that is associated with the FE implementation of the plate theory, this model treats the first derivatives of transverse displacement as independent variables. This allows the problem to be solved. In the current FE model, the C 0 continuity is taken into account during the calculations of the stiffness matrix thanks to the use of the penalty parameter approach. The current model is shown to be very effective in predicting the buckling responses of laminated composites based on both the numerical results and the comparison with other solutions that are already in existence.

A. Mathematical Formulation

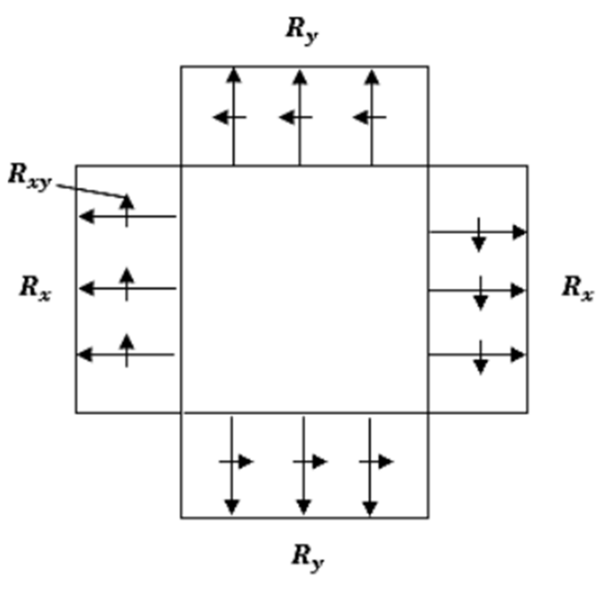
Take into consideration a thin plate with the dimensions shown in Figure 1a: length a, breadth b, and thickness h. This plate is subjected to in-plane loads shown in Figure 1b: Rx, Ry, and Rxy. As can be seen in the following diagram, the in-plane displacements u(x,y,z) and v(x,y,z), as well as the out-of-plane displacement w(x,y), can be expressed in terms of the latter.

$$u = -z\frac{\partial w}{\partial x}$$

$$v = -z\frac{\partial w}{\partial y}$$



(a)



(b)

Figure 1

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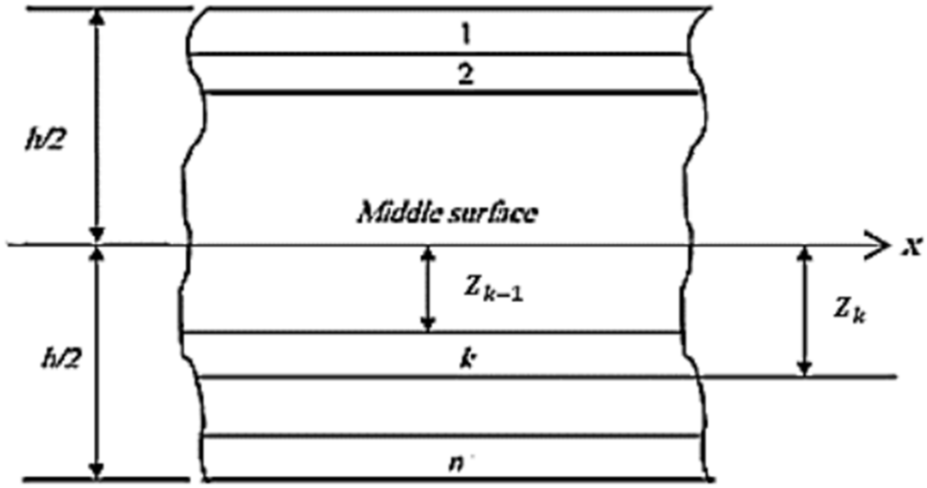

Figure 2. Geometry of an n-Layered laminate

The plate depicted in figure 1a is made up of an unspecified number of orthotropic layers that have been adhered to one another in the same manner as shown in figure 2. According to the large deformation theory, the relations between strain and displacement are as follows:

$$\epsilon_x = \frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 = -z\frac{\partial^2 w}{\partial x^2} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2$$

$$\epsilon_y = \frac{\partial v}{\partial y} + \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2 = -z\frac{\partial^2 w}{\partial y^2} + \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2$$

$$\epsilon_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} + \frac{\partial w}{\partial x}\frac{\partial w}{\partial y} = -2z\frac{\partial^2 w}{\partial x\,\partial y} + \frac{\partial w}{\partial x}\frac{\partial w}{\partial y}$$

These can be written as:

$$\epsilon = \epsilon_1 + \epsilon_2$$

Where, $\epsilon = \left[\epsilon_x \epsilon_y \epsilon_{xy}\right]^T$ and ϵ_1 and ϵ_2 represent the linear and non – linear parts of the strain, i.e.

$$\epsilon_1 = -z\left[\frac{\partial^2 w}{\partial x^2}\frac{\partial^2 w}{\partial y^2} \quad 2\frac{\partial w}{\partial x\,\partial y}\right]^T$$

$$\epsilon_2 = \frac{1}{2}\left[\left(\frac{\partial w}{\partial x}\right)^2 \left(\frac{\partial w}{\partial y}\right)^2 \quad 2\frac{\partial w}{\partial x}\frac{\partial w}{\partial y}\right]^T$$

The virtual linear strains can be written as:

$$\delta\,\epsilon_1 = -z\left[\frac{\partial^2}{\partial x^2}\frac{\partial^2}{\partial y^2} \quad 2\frac{\partial^2}{\partial x\,\partial y}\right]^T \delta\,w$$

The virtual linear strains energy

$$\delta\,U = \int_V \delta\epsilon_1^T \sigma\, dV$$

Where denotes volume The stress – strain relations,

$$\sigma = C\ \epsilon_1$$

Where C are the material properties.

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{16} \\ C_{12} & C_{22} & C_{26} \\ C_{16} & C_{26} & C_{66} \end{bmatrix}$$

Where Cij are given.

B. Static, Free Vibration And Buckling Analysis Of Composite Panels

Matrix and reinforcement make up the composite materials, which, when combined, give rise to qualities that are superior to those of the constituent parts taken separately. The reinforcement is often delivered in the form of fibres, while the matrix materials typically consist of either metals, ceramics, or polymers. The fibres are then impregnated with a matrix material, which not only transfers loads to the fibres but also provides toughness, protects the fibres from damaging environmental assault and abrasion, and maintains the fibre in the appropriate orientation. Strength and stiffness are provided by fibres, and they also carry the load that is imparted to the structure. Creating composite laminates may be accomplished by piling up layers of different composite materials and/or by orienting the fibres in a certain direction.

The weight of the designed structures has been decreased as a direct consequence of the advancements made in the area of composite materials. Composite materials have found widespread application in a variety of subfields of engineering, including but not limited to wing structures and fuselage panels of aircraft, commercial airliners or fighter jets, automotive body parts, launch vehicle upper stage cryogenic hydrogen fuel tanks, spacecraft, marine, sports, biomedical, heavy machinery, agricultural equipment and health devices, industrial machinery, carbon nanotube, and many other applications. Composite materials have several benefits over metallic alloys, especially when it comes to high strength and stiffness to weight ratios. Composite materials also have a significantly greater resistance-to-weight ratio than metal.

Composites have many benefits, including their ability to be lightweight due to their high specific strength and stiffness, resistance to fatigue and corrosion, high modulus, low specific density, long fatigue life, resistance to electrochemical corrosion, good electrical and thermal conductivity, high optimization capability, alignment of directional strength and stiffness, and good for thin-walled or generously curved construction. Composites also have the ability to maintain dimensional and orientation stability. Composites are good for thin-walled or generously curved construction. Composites are Because of the requirements for their manufacturing, the planar dimension of composite laminates is anywhere from one to two orders of magnitude bigger than their thickness. As a result, the composite laminates are considered to be components of plates. Composites of the types CFRP (carbon fibre reinforced plastic) and GFRP (glass fibre reinforced plastic) are used in a broad range of businesses and organisations. The scope of static, bucking, and free vibration analysis of composite flat panels, curved panels, and shells is the primary topic of the literature review that is presented in this research article. The following is a summary of additional design principles as well as the testing technique for evaluating the mechanical characteristics of composite laminate. The findings, which were derived from the research described above, will be helpful to designers and researchers engaged in the construction of laminated composite structures.

C. Laminated Composites

There are as many different configurations of laminated composites as there are different kinds of materials. They are a type of material that can be defined as having layers of different materials that are bonded together. These may consist of multiple layers of two or more metal materials that appear alternately or more than once in a specified order, and in as many numbers as are required for a particular reason.

These may also be stacked on top of one another. The matrix's role is to provide support and protection for the fibers, as well as to assist in load distribution among the fibres and load transmission between them. This latter function becomes particularly important in the event that the fibre breaks.

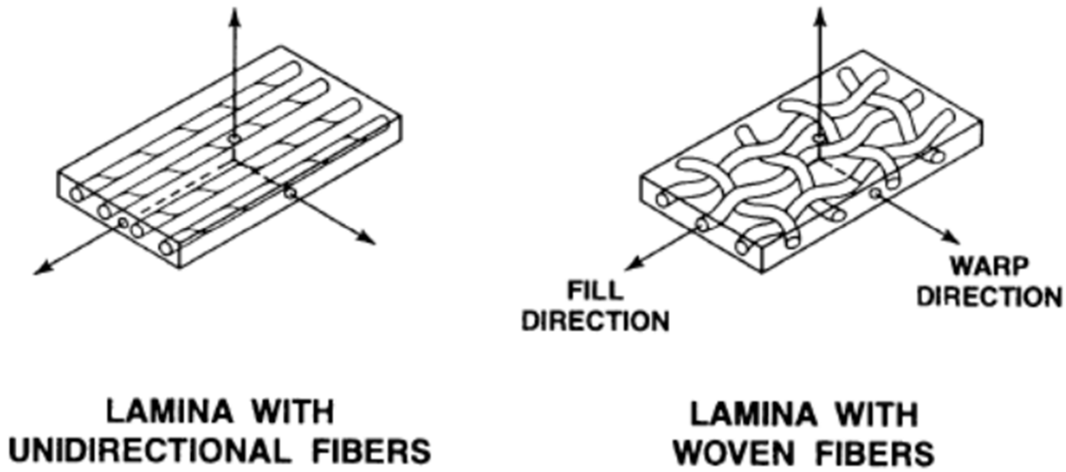

Figure 3: Two principal types of laminae

A laminate is a bonded stack of laminae, each of which has one of the various orientations of principal material shown in Fig. 1. The formation of a laminate can occur either through the addition of multiple layers of reinforcement in a matrix or through the combination of multiple layers of distinct materials. The following information is included in the definition that is printed on the laminate: (i) The orientation of each lamina with regard to the direction of the x-axis (ii) The exact geometrical form on the laminate (iii) The number of laminates that are used for each different orientation The orientation angle has a positive value when viewed in a direction that is counter-clockwise. In a numeric subscription, the number of layers that make up the ply group can be found specified. As an illustration, take the laminate with the designation of [90o, 4503, 0o]s. This laminate has a total of ten layers: one layer at an angle of 90 degrees on both the top and bottom, three layers at an angle of 45 degrees next to the 90 degree layer on both sides, and two layers at an angle of 0 degrees in the middle. The letter's' in the superscript indicates that the laminate has symmetrical properties.

D. Buckling Analysis Of Laminated Composite Plates Using An Efficient C0 Fe Model

Since laminated composite plates have a high strength to weight ratio and can be designed in a versatile manner, they are often utilised in the construction of civil infrastructure systems. Buckling is one of the primary failure modes that may occur in composite plates. Because of the orthotropic structural behaviour, the presence of various types of couplings, and the decreased thickness of the structural elements made of composites, it can be difficult to make an accurate prediction of the structural response characteristics of laminated composites. This is a challenging problem in the analysis of laminated composites. A precise buckling analysis of the laminated composite plates is, as a result, an essential component of the structural design. The approach of finite elements has seen extensive usage in recent years for the buckling analysis of laminated composite plates. Several different plate theories have been put forth in an effort to accurately estimate the buckling stress of composite plates. Only for thin laminates can the traditional laminate plate theory (CLPT), which ignores the influence of transverse shear deformation, provide results that are considered acceptable. Because the CLPT theory overestimates the buckling load of laminated composite plates, the structures that are constructed using the CLPT theory might potentially be dangerous. The first-order shear deformation theory, also known as FSDT, has been used in order to predict the dynamic response of laminated composite structures. This was done in order to take into consideration the influence of transverse shear deformation. In the first-order shear deformation theory, also known as FSDT, a shear correction factor is used in order to make up for the fact that it is assumed that the transverse shear strain fluctuations are uniform over the whole plate thickness. Many different higher-order shear deformation (HSDT) plate theories have been presented in an effort to provide a more accurate depiction of the transverse shear deformations. However, it has been observed and mentioned by a great number of researchers that increasing the number of terms in the in-plane displacement components does not improve the results, and it is required to add the effect of inter-laminar transverse shear stress continuity in a multilayered composite plate problem. This is due to the fact that increasing the number of terms in the in-plane displacement components does not improve the accuracy of the results. Di Sciuva, Murakami, Liu et al., and a few others have been responsible for a significant breakthrough in this approach.

They came up with the zigzag plate theory, in which the layer-wise theory is first utilised to describe the in-plane displacements, and piecewise linear variation is seen throughout the thickness of the material. After that, the unknowns at the various interfaces are stated in terms of those at the reference plane by ensuring that there is continuity of the transverse shear stress at the layer interfaces. The term "refined first order shear deformation theory" refers to this particular theory (RFSDT). Di Sciuva, Bhaskar et al., Cho et al., and a few other investigators contributed to a further advancement in this direction, and it is due to them. They included the condition of there being no shear stress in the transverse direction at the top and bottom of the plate in addition to the conditions of there being no shear stress at the interfaces between the layers. Higher order zigzag theory (HZT), also known as refined higher order shear deformation theory, is the name given to this theory. Nevertheless, when applied to finite elements, all of these refined theories, including the HSDT, necessitate a C1 continuity of the transverse displacement along the edges of the element. On the other hand, a C1 formulation is never recommended for use in any kind of practical application. In light of this circumstance, the development of a C0 finite element formulation that can circumvent the theory's requirement that C 1 continuity be maintained at all times is of the utmost importance.

III. CONCLUSIONS

In order to predict the buckling response of symmetric cross-ply rectangular laminates subjected to uniaxial and biaxial compression, a finite element analysis that is founded on classical laminate theory is utilized. An explanation is given for the effect that the boundary condition, aspect ratio, and elastic modulus ratio have on the buckling load. It has been discovered that the plate's resistance to buckling improves as additional constraints are applied to it. Also, the buckling load will decrease as the modulus ratio increases, and it will become almost constant as the elastic modular ratio is increased to higher values.

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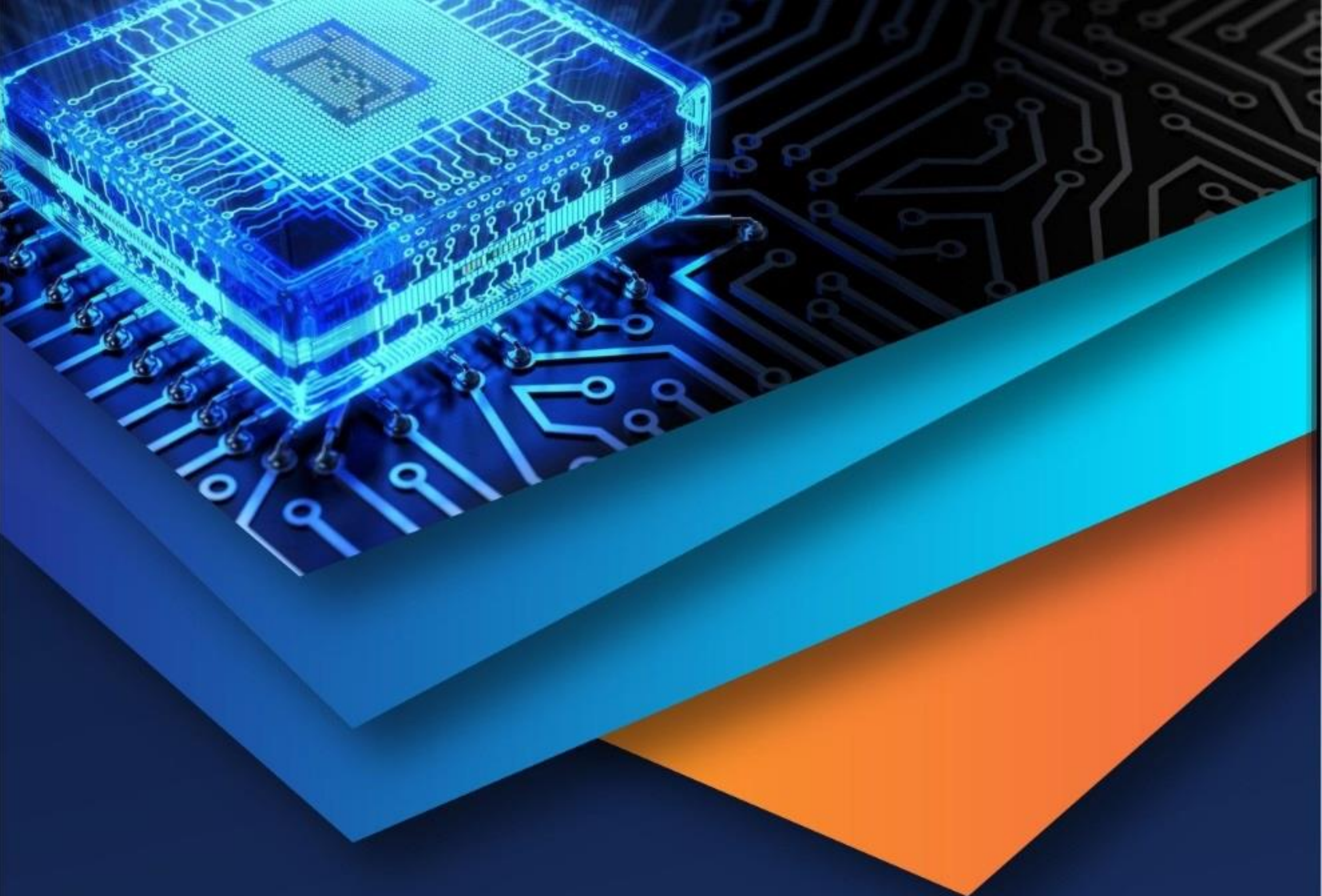

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