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Influence of A Linearly Variable In-Plane Load on the Buckling of Symmetrical Cross-Ply Composite Rectangular Plates

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***Abstract* - The purpose of this article is to present a solution in order to provide a precise solution for the buckling of simply supported symmetrical cross-ply composite rectangular plates that are exposed to a linearly varying edge stress. This article's objective is to offer a solution. During its development, the theory of shear deformation of the first order served as the basis for its application, and it was used on laminated plates that had a thickness that was quite low. The purpose of this investigation is to ascertain the buckling loads of cross-ply rectangular plates that have a variety of aspect ratios that are distinct from one another. On top of that, the effects of altering the intensity of the load as well as the arrangement of the layup on the buckling load are investigated. A piece of software known as ABAQUS is used on the computer in order to achieve the objective of ensuring that the results are accurate.**

Keywords: In-plane Load, Buckling, Cross ply, Composite Plate.

1. INTRODUCTION

The aerospace industry, the automobile industry, the marine industry, and other industries are progressively making use of laminated composite constructions. The primary reason for this is because they have high specific strength and stiffness values, and they also have the benefit of being able to have their characteristics modified to match the needs of actual applications. When designing laminated composite plates, one of the most significant design aspects to take into account is the buckling load. The buckling behavior of laminated composite plates has been the subject of substantial study conducted by a large number of researchers over the course of several years. There are a few handbooks and even literature that include information on the parametric dependency of buckling load on the layup design and fiber orientation, among other things [1–3]. In spite of this, the curves and data that are currently accessible are limited to idealized loads, namely uniaxial or biaxial homogeneous compression scenarios. On the other hand, there has been a very limited amount of knowledge about the buckling of laminated composite plates when subjected to non-uniform loads. Performing buckling analysis of laminated plates under non-uniform load may unquestionably be accomplished by the use of a variety of numerical approaches, such as the finite element method. On the other hand, owing to the intricacy of the issue, the analytical solution has been quite uncommon. The work of Lekhnitskii [4] is considered to represent the beginning of research efforts concerned with the buckling analysis of anisotropic plates when subjected to in-plane bending strain. In their study, Papazoglou and colleagues [5] looked into the buckling of asymmetric laminates when they were subjected to linearly variable biaxial in-plane stresses in conjunction with shear. Their investigation was carried out by using the Rayleigh-Ritz approach, which was founded on the principles of classical lamination theory. The optimization of laminated composite rectangular plates was investigated by Chai and Khong using the finite strip approach [6,7]. The plates were subjected to a linearly variable in-plane stress. After using the principles of classical lamination theory, we were able to determine the optimal ply angle for antisymmetric laminates in order to prevent buckling. Through the use of a shear-deformable finite element approach, Kam and Chu investigated the buckling of laminated composite plates that were exposed to non-uniform in-plane edge stresses [8]. In addition to that, they conducted experiments in order to validate their numerical findings. In order to investigate the buckling of simply supported composite rectangular plates that were exposed to a parabolically variable axial stress, Badir and Hu used the Rayleigh-Ritz technique [9]. This was done in accordance with the traditional lamination theory. According to the authors' best knowledge, there is no specific solution that can be found in the open literature for the purpose of buckling analysis of laminated composite plates when subjected to a load that is not uniform. It is important to note that significant progress has been made in this area for the purpose of buckling analysis of isotropic rectangular plates that are subjected to non-uniform loads [10–14]. On the other hand, according to Kang and Leissa [11], the research and development of precise solutions for plates that are subjected to homogenous loads is rather challenging. The challenge is in finding a solution to the highly probable bivariant in-plane forces that are included within the governing differential equations for plates that are subjected to a non-uniform load. The purpose of this study is to create an accurate buckling solution for symmetric cross-ply laminated composite plates that are angular and are subjected to a linearly variable in-plane force. In this case, it is presumed that all of the plate edges are simply supported. Due to the presence of such conditions, the plate is devoid of stress of fusion, and hence, a precise solution is made plausible.

When attempting to illustrate the displacement mode of the plate, trigonometric series are used. The current examination is challenging owing to the behavior of the composite material, despite the fact that the present solution approach is identical to that which was explored in [14], which investigated the buckling of isotropic plates that were fairly thick and subjected to linearly variable loads. Comparing the outcomes of the solution to those of the computer code ABAQUS, the findings are quite satisfactory. The buckling loads of symmetric cross-ply rectangular plates with a variety of aspect ratios are determined and visually illustrated. More than that, the effects of load intensity change and layup configuration on the buckling load are also examined.

2. ELEMENT DESCRIPTION

The SHELL281 element type is being used in this investigation. You may use this shell element to study shells that are either very thin or somewhat thick. Its layered uses also make it useful for modeling sandwich constructions and laminated composite shells. Applications involving high strain nonlinearity, linearity, or rotation are ideal for it. At each of the element's eight nodes, there are six degrees of freedom, allowing for rotation around these three axes as well as translations along the x, y, and z axes. Cylindrical plate studies make use of the eight-node nonlinear element S8R5, which has five degrees of freedom per node.

Take into consideration a symmetrical cross-ply composite rectangular plate with length a and width b (see Figure 1), with all four corners providing simple support. Cross-ply laminates of similar thickness are used to construct the plate, and the fiber angle may be either 0 or 90 degrees. A connection is made between the Cartesian coordinate system xyz and the middle plane of the plate.

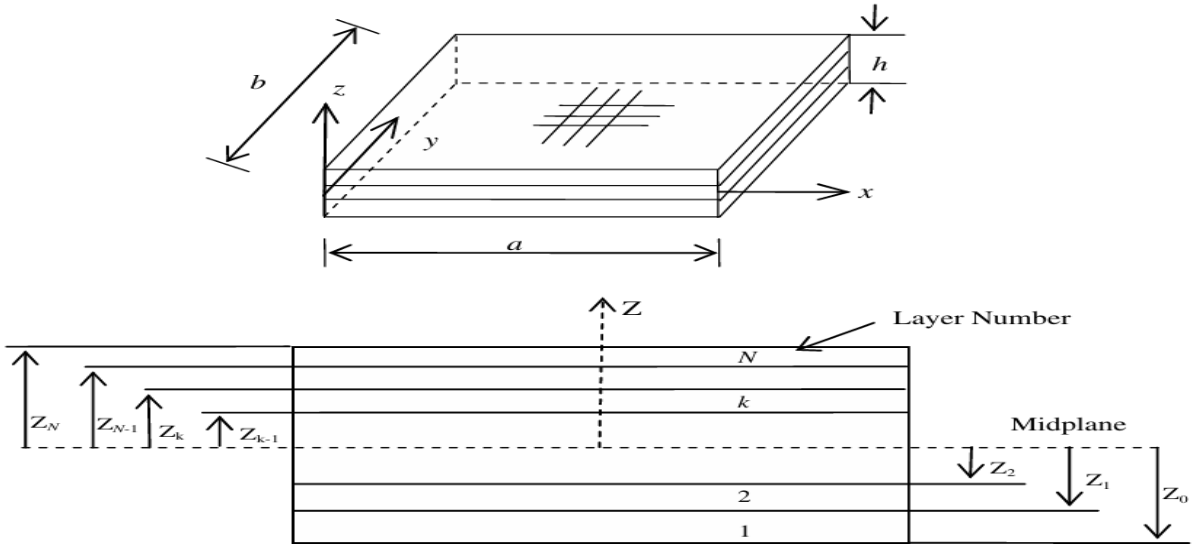

Fig.1.Geometry of a cross-ply composite plate.

3. RESULTS AND DISCUSSION

The mechanical properties assumed in the analysis are:

$$\frac{E_{\mathrm{L}}}{E_{\mathrm{T}}} = 40, \quad \frac{G_{\mathrm{LT}}}{E_{\mathrm{T}}} = \frac{G_{\mathrm{LZ}}}{E_{\mathrm{T}}} = 0.6, \quad \frac{G_{\mathrm{ZT}}}{E_{\mathrm{T}}} = 0.5, \quad \upsilon_{\mathrm{LT}} = 0.25$$

The Youngs modulus throughout the fiber, the shear modulus in planes, the transverse shear moduli, and the main Poissons ratio, respectively. When doing the calculations, the generally used shear coefficient 5/6 is taken into consideration, and a symmetrical cross-ply plate with a configuration of 0/90/0 is also taken into account. Although it is often adequate to use twenty to thirty terms, sixty terms are needed in the Fourier expansion of the linearly variable load and may be found in equation. For the purpose of ensuring the correctness and convergence of findings for any linearly variable loads and plate attributes, the Fourier expansionist makes use of a greater number of theoretical terms. For the first sixty equations, which are proven to be sufficient to gain the eigenvalue of appropriate precision, the infinite linear system is reduced to its components.

Table1 Comparison of non-dimensional buckling load factors for symmetric cross-ply square plates subjected to uni-axial uniform loads (g=0), h/b=0.1

Source	Layup configuration	$E_{\mathrm{L}}/E_{\mathrm{T}}$		
		20	30	40
Khdeir [16]	$[0°/90°/0°]$	14.985	19.027	22.315
Present		14.987	19.029	22.317
ABAQUS		14.836	18.820	22.048
Khdeir [16]	$[0°/90°/\underline{0}°]_S$	15.736	20.485	24.547
Present		15.750	20.497	24.558
ABAQUS		15.642	20.375	24.416
Khdeir [16]	$[(0°/90°)_2/\underline{0}°]_S$	16.068	21.117	25.495
Present		16.088	21.135	25.511
ABAQUS		15.997	21.050	25.427

Studying cross-ply laminate plates that have been exposed to uniaxial uniform loads (g=0) is the initial step in the process of verifying the current solution. A comparison of the buckling loads for plates that were subjected to uni-axial uniform loads (g=0) is done in Table 1. This comparison is made with the results of the computer code ABAQUS and those reported by Khdeir [16]. The fact that his findings were acquired by using a state space methodology and utilizing the identical first-order shear deformation theory is something that should be emphasized. The consensus is achieved to be good to exceptional.

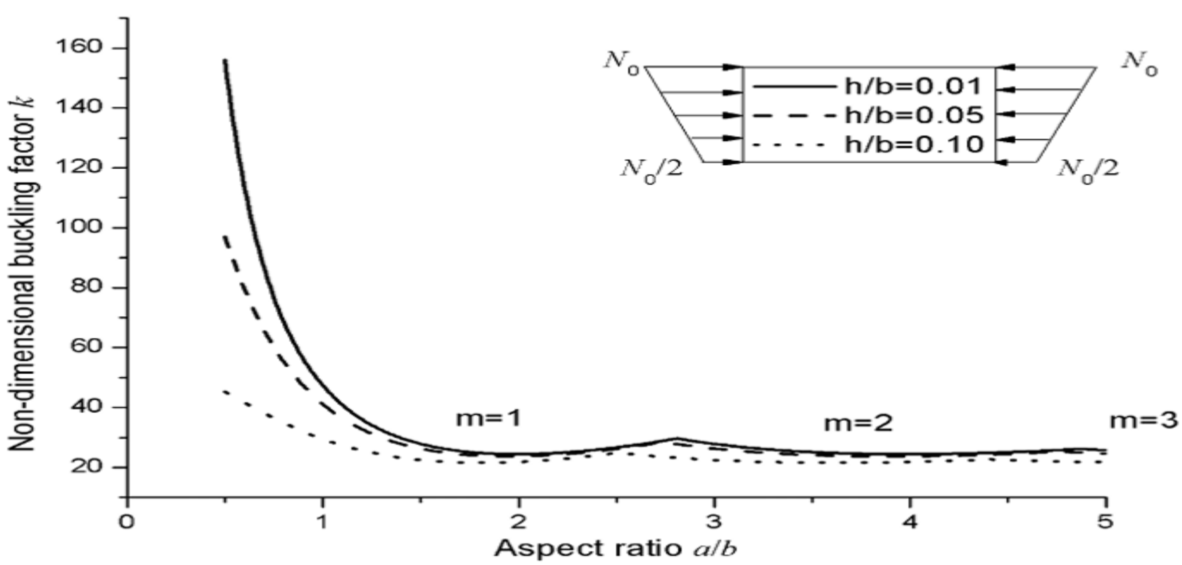

Fig. 3. Variation of the buckling factor k versus the aspect ratio a/b of [0/90/0] plates for g = 0.5.

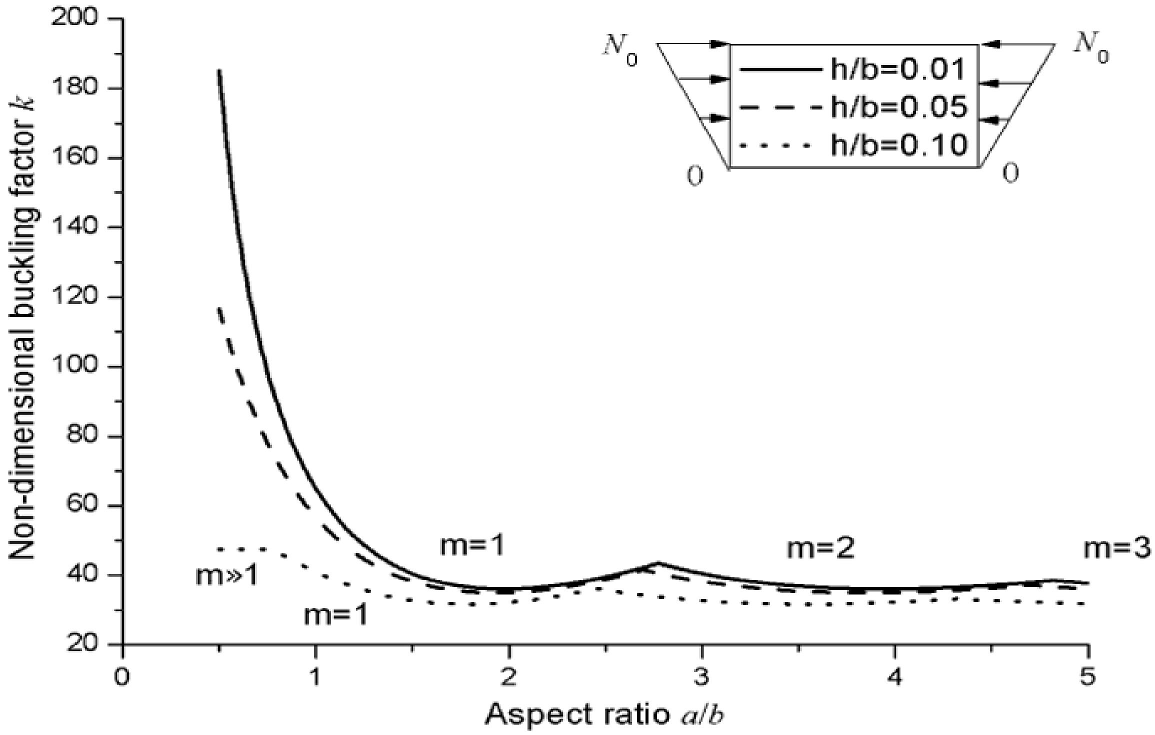

Fig. 4. Variation of the buckling factor k versus the aspect ratio a/b of [0/90/0] plates for g =1.

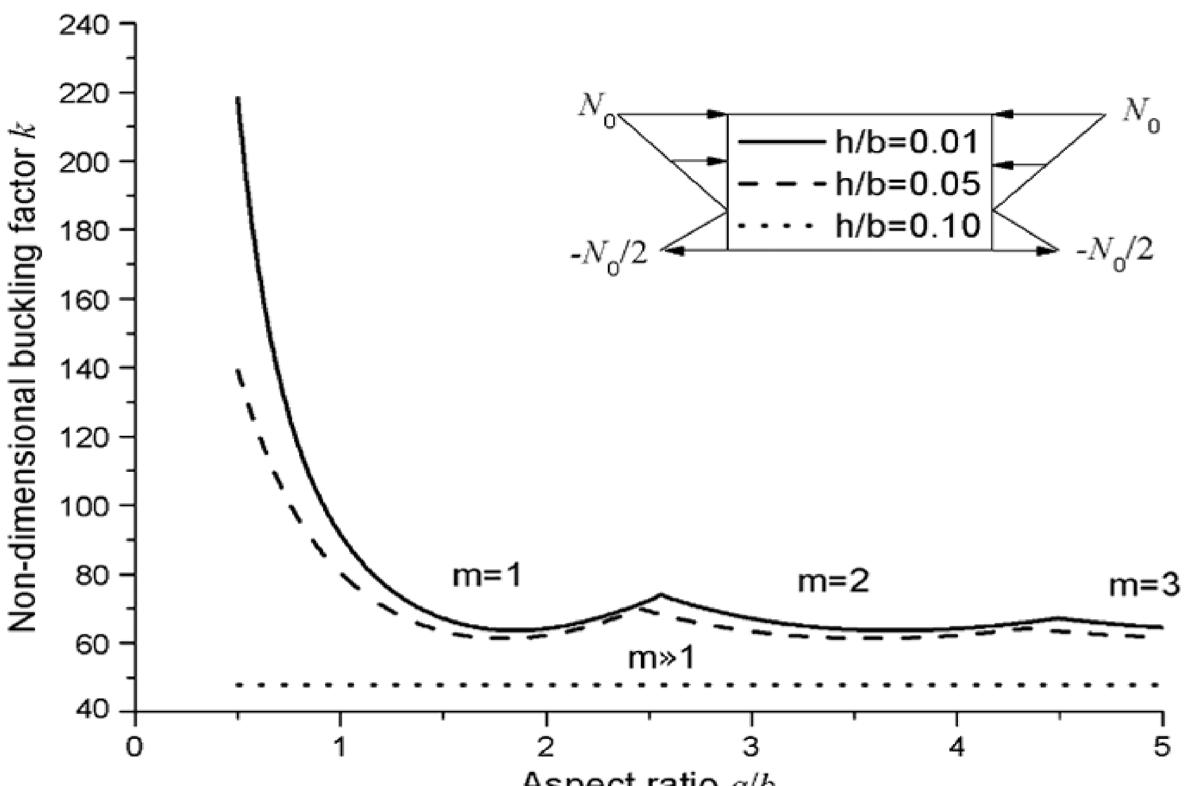

Fig. 5. Variation of the buckling factor k versus the aspect ratio a/b of [0/90/0] plates for g = 1.5.

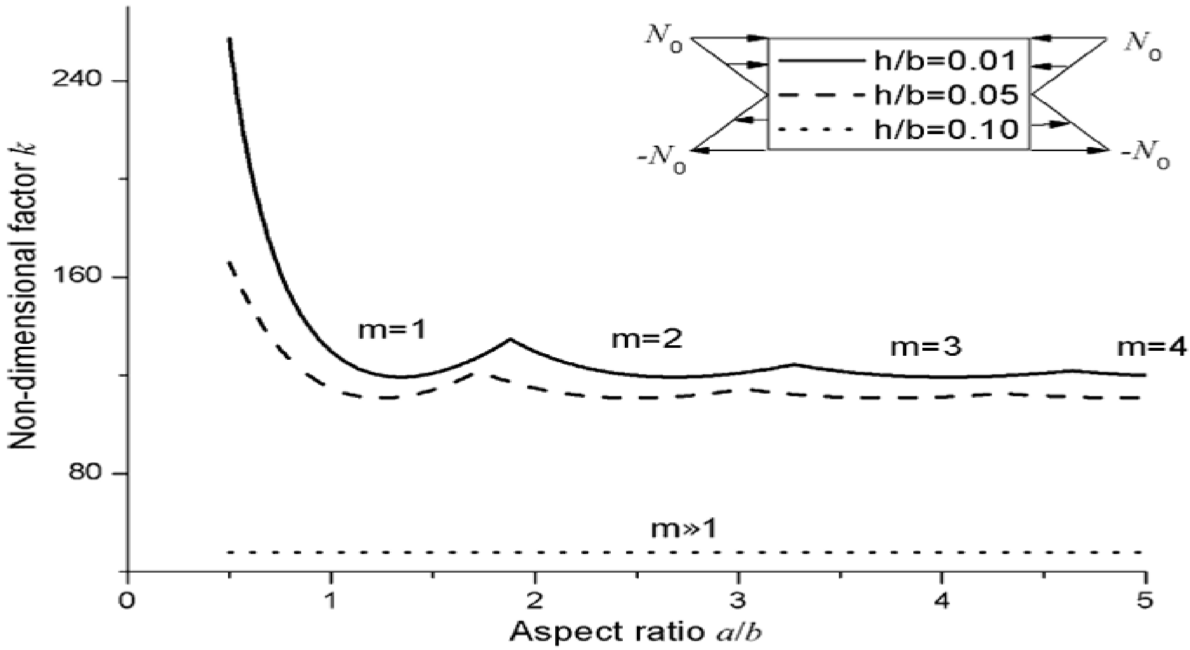

Fig. 6. Variation of the buckling factor k versus the aspect ratio a/b of [0/90/0] plates under pure in-plane bending (g = 2).

In Figures 3–6, we see the changes in the non-dimensional buckling load against the aspect ratio (a/b) of [0/90/0] plates that were subjected to linearly varying in-plane loads. These plates were subjected to loads that were linearly variable. As the aspect ratio grows, the non-dimensional buckling stress for short plates decreases. However, the impact of aspect ratio on the buckling load is minor for long plates, particularly for relatively thin plates. This is especially true for plates that are relatively thin. The plates that are relatively thin are particularly susceptible to this phenomenon. For plates that have a significant thickness-to-width ratio and are exposed to a severe unequal load (g = 1.5), it has been shown that a large m is required in the exact solution. This was determined via the process of experimentation. In addition, the effect of the aspect ratio on the non-dimensional buckling factor is negligible at best.

4. CONCLUSIONS

An accurate solution has been devised in order to explore the buckling behavior of simply supported symmetrical cross-ply rectangular plates that are exposed to linearly variable in-plane stresses in a unidirectional direction. A first-order shear deformation lamination theory was used as the foundation for the development of the current precise solution. The outcomes of the current solution are validated by the outcomes of the ABAQUS computer code. An investigation of the impacts of aspect ratio, thickness-to-width ratio, and modulus ratio on the buckling load factor is carried out via the use of a parametric analysis. The current solution provides evidence that the widely accepted conclusion that the buckling factor estimate based on uniform load is not conservative for plates that are subjected to non-uniform stress is supported by the information presented here. One of the most significant findings that emerged from this work was the realization that there is an ultimate buckling resistance capacity for moderately thick symmetric cross-ply laminated plates when subjected to a severe non-uniform in-plane load. This capacity was shown to be proportional to the rise in modulus ratio.

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