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Effect of Number of Layers on the Non-Dimensional Buckling Factor for Symmetric Cross-Ply Square Plates

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Abstract: **In order to offer a precise solution for the buckling of simply supported symmetrical cross-ply composite square plates that are subjected to a linearly variable edge stress, the objective of this article is to provide a solution that will provide a solution. The purpose of this essay is to provide a solution to the problem. During the process of its creation, the theory of shear deformation of the first order served as the foundation for its application. It was used on laminated plates that had a thickness that was relatively modest. With the help of this inquiry, we will be able to determine the buckling loads of cross-ply square plates that have a range of aspect ratios that are different from one another. Furthermore, the effects of varying the intensity of the load as well as the arrangement of the layup on the buckling load are explored. This is done in addition to the previous point. The computer is equipped with a piece of software known as ABAQUS, which is used in order to accomplish the goal of guaranteeing that the findings are correct.**

Keywords: **Number of layers, Non-dimensional Buckling, Symmetric Cross-ply, Square plate.**

1. INTRODUCTION

Laminated composite constructions are increasingly being utilized across various sectors, including aerospace, automotive, marine, and others. The main reason for this is their elevated specific strength and stiffness values, along with the advantage of being able to tailor their characteristics to align with the requirements of real-world applications. In the design of laminated composite plates, a critical aspect to consider is the buckling load. The buckling behaviour of laminated composite plates has been extensively examined through significant investigations carried out by numerous experts over the years. Several handbooks and literature sources provide insights into the parametric dependency of buckling load concerning layup design and fibre orientation, among other factors [1–3]. Despite this, the available curves and data are confined to idealized loads, specifically uniaxial or biaxial homogeneous compression scenarios. Conversely, the understanding of the buckling behaviour of laminated composite plates under non-uniform loads remains quite scarce. The buckling analysis of laminated plates subjected to non-uniform loads can certainly be conducted through various numerical methods, including the finite element method. Conversely, due to the complexity of the matter, the analytical solution has been relatively rare. The contributions of Lekhnitskii [4] are regarded as the inception of investigations focused on the buckling analysis of anisotropic plates under in-plane bending strain. In their investigation, Papazoglou and colleagues [5] examined the buckling behaviour of asymmetric laminates under the influence of linearly variable biaxial in-plane stresses alongside shear forces. Their study was conducted utilizing the Rayleigh-Ritz method, grounded in the principles of classical lamination theory. The finite strip approach was employed by Chai and Khong to examine the optimization of laminated composite square plates [6,7]. The plates experienced a linearly variable in-plane stress. Utilizing the principles of classical lamination theory, we successfully identified the optimal ply angle for antisymmetric laminates to mitigate the risk of buckling. Utilizing a shear-deformable finite element method, Kam and Chu examined the buckling behaviour of laminated composite plates subjected to non-uniform in-plane edge stresses [8]. Furthermore, experiments were carried out to confirm the numerical results obtained. To explore the buckling behaviour of simply supported composite square plates subjected to a parabolically variable axial stress, Badir and Hu employed the Rayleigh-Ritz technique [9]. This was executed following the established principles of lamination theory. Based on the authors' thorough investigation, there appears to be no dedicated solution available in the existing literature for conducting buckling analysis of laminated composite plates under non-uniform loading conditions. It is crucial to recognize that substantial advancements have been achieved in this domain concerning the buckling analysis of isotropic square plates under non-uniform loads [10–14]. Conversely, as noted by Kang and Leissa [11], developing accurate solutions for plates under homogeneous loads presents significant challenges. The task involves identifying a solution to the likely bivariant in-plane forces present in the governing differential equations for plates under non-uniform loading conditions. This study aims to develop a precise buckling solution for angular symmetric cross-ply laminated composite plates under the influence of a linearly variable in-plane force. In this scenario, it is assumed that all of the edges of the plate are simply supported. Given the existence of these conditions, the plate remains free from fusion stress, thereby making a precise solution feasible.

In the process of demonstrating the displacement mode of the plate, trigonometric series are employed. The ongoing analysis presents difficulties due to the characteristics of the composite material, even though the current methodological approach mirrors that which was previously examined in [14], which focused on the buckling of relatively thick isotropic plates under linearly variable loads. The comparison of the solution's outcomes with those generated by the computer code ABAQUS reveals highly satisfactory results. The buckling loads of symmetric cross-ply square plates across various aspect ratios are analysed and presented visually. Additionally, the investigation delves into how variations in load intensity and layup configuration influence the buckling load.

2. ELEMENT DESCRIPTION

Within the scope of this research, the SHELL281 element type is being used. Researching shells that are either very thin or relatively thick may be accomplished with the use of this shell element. Additionally, because to its layered applications, it is excellent for simulating sandwich structures as well as laminated composite coatings. Applications that involve high strain nonlinearity, linearity, or rotation are perfect for their use of this material. Six degrees of freedom are available at each of the eight nodes that make up the element. These degrees of freedom enable rotation around the three axes as well as translations along the axes of x, y, and z inside the element. Studies involving cylindrical plates make use of the nonlinear element S8R5, which consists of eight nodes and has five degrees of freedom for each node involved.

Let us take into account a symmetrical cross-ply composite square plate that has a length of a and a width of b (refer to Figure 1), with all four corners providing straightforward support. The construction of the plate is accomplished by the use of cross-ply laminates of comparable thickness, and the fibre angle may be either 0 or 90 degrees. A link is established between the centre plane of the plate and the Cartesian coordinate system, which is denoted by the letters xyz.

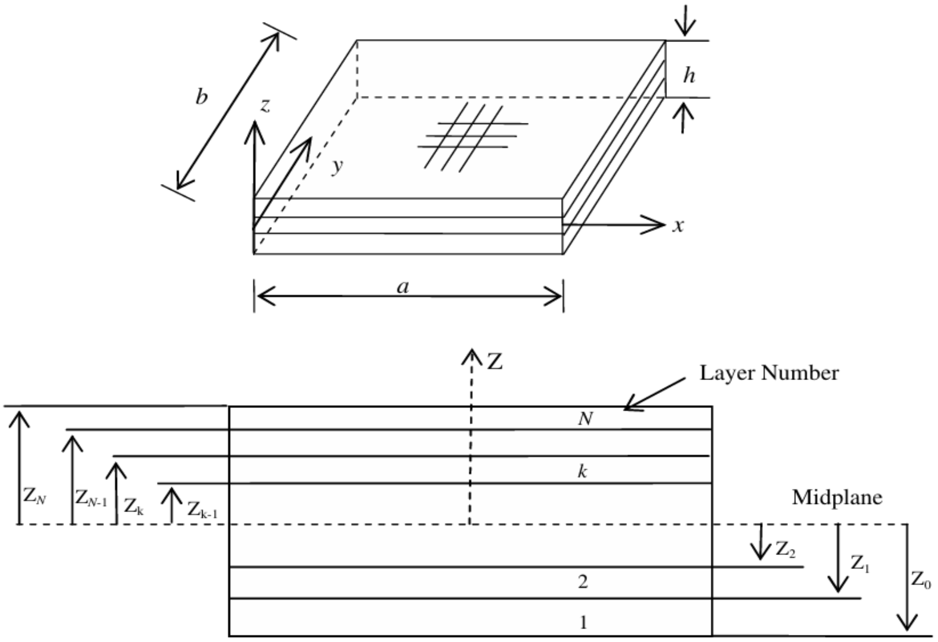

Fig.1. Geometry of a cross-ply composite plate.

3. RESULTS AND DISCUSSION

The mechanical properties assumed in the analysis are:

$$\frac{E_L}{E_T} = 40, \quad \frac{G_{LT}}{E_T} = \frac{G_{LZ}}{E_T} = 0.6, \quad \frac{G_{ZT}}{E_T} = 0.5, \quad \upsilon_{LT} = 0.25$$

The shear modulus in planes, the transverse shear moduli, the primary Poisson's ratio, and the Youngs modulus throughout the fibre are the four different types of shear moduli at the same time. In the process of doing the calculations, the shear coefficient 5/6, which is the standard value, is taken into consideration. Additionally, a symmetrical cross-ply plate with a configuration of 0/90/0 is also taken into consideration. In spite of the fact that it is often sufficient to make use of twenty to thirty terms, the Fourier expansion of the linearly variable load requires sixty terms, which may be found in the equation. An increased number of theoretical terms is used by the Fourier expansionist in order to guarantee the accuracy and convergence of results for any linearly varying loads and plate features. This is done for the goal of assuring that the findings are accurate. The components of the infinite linear system are broken down into their constituent parts for the first sixty equations, which have been shown to be enough for acquiring the eigenvalue with the required level of accuracy.

Table 1 Comparison of non-dimensional buckling load factors for symmetric cross-ply square plates [0/90/0] subjected to various linearly varying loads

η		$h/b = 0.01$	$h/b = 0.05$	$h/b = 0.1$	$h/b = 0.15$
0.5	Present	47.267	41.075	29.432	20.364
	ABAQUS	47.185	40.849	29.121	20.037
1.0	Present	64.982	56.705	40.999	21.131
	ABAQUS	64.847	56.392	40.599	21.559
1.5	Present	91.374	80.336	47.708	21.204
	ABAQUS	91.142	79.905	49.210	21.872
2.0	Present	129.785	114.837	47.872	21.277
	ABAQUS	129.450	114.296	49.955	22.214

In addition, verification is made in Table1, where the results of cross-ply plates that were exposed to linearly variable loads using the current approach are compared with the findings of ABAQUS. It is shown that they are not in agreement with each other. Largem is often necessary in order to acquire the precise buckling load form of plates that are very thick when subjected to a heavy and uneven load in the current exact solution. A very severe instance is shown in Figure 2, where the value of approaches around 10,000 before an essentially invariant buckling load for a square plate under pure bending is obtained. Within the framework of the buckling analysis, the shell element S8R5 in ABAQUS element library is applied.

There is a relationship between the load distribution parameter and the least qualified mesh density. It is sufficient to use a coarser mesh when the size is smaller. In the event of homogeneous compression (η=0), the ABAQUS analysis requires just 200 elements for plates that are either thin or moderately thick. For the moderately thick plates are subjected to a severe unequal load, say η = 1.5, and 3200 elements are used. Despite this, there are still significant disparities between the findings obtained by ABAQUS and the current solution. It is because of the intricacy of the buckling modes that this occurs.

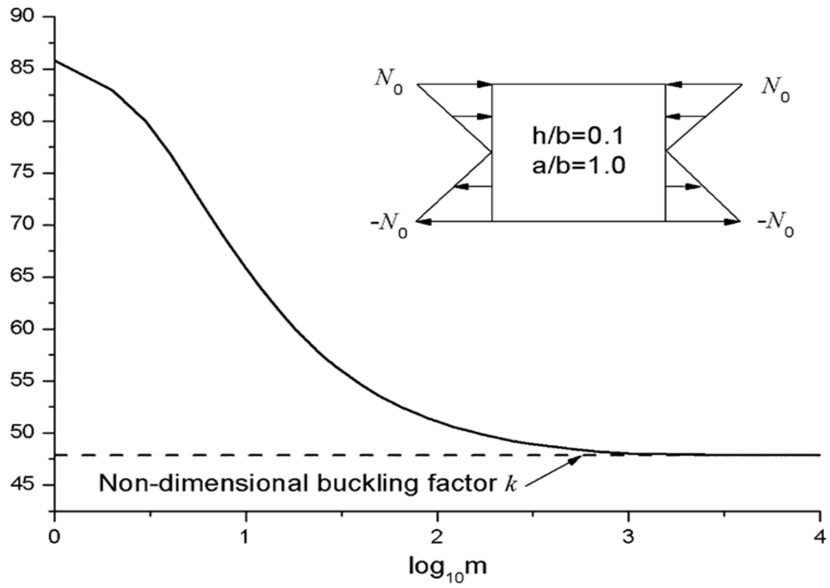

Fig. 2. Selection of number of axial half-waves in determination of buckling load.

Table 2 Effect of number of layers on the non-dimensional buckling factor for symmetric cross-ply square plates, a/b =1

Layup configuration	$\eta = 1$		$\eta = 2$	
	$h/b = 0.1$	$h/b = 0.01$	$h/b = 0.1$	$h/b = 0.01$
[0°/90°/0°]	40.999	64.982	47.872	129.785
[0°/90°/<u>0°</u>]$_S$	46.985	69.396	47.309	200.847
[0°/90°/0°/<u>90°</u>]$_S$	46.746	70.033	47.067	226.042
[(0°/90°)$_2$/<u>0°</u>]$_S$	46.613	70.295	46.933	239.171
[(0°/90°)$_3$0°/<u>90°</u>]$_S$	46.426	70.599	46.745	256.626

The impact of layup arrangement on the non-dimensional buckling factor is shown in Table 2. With the exception of thin plates under pure bending, when the buckling factor rises with the number of layers in symmetric cross-ply laminated plates, it is observed that the number of layers has less of an impact on the buckling factor. Thirteen percent of the buckling factor for three-layered plates is the biggest difference between the buckling factors for plates with three layers and plates with fifteen layers.

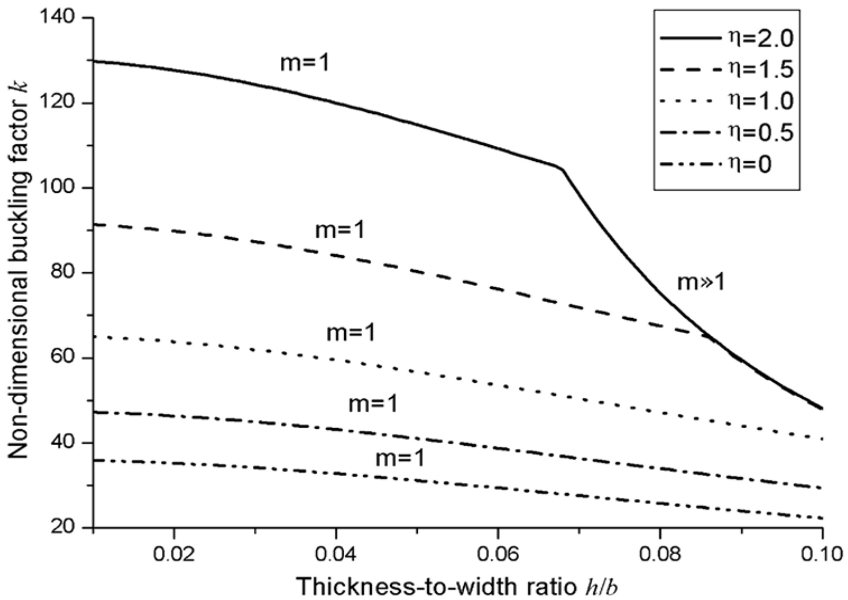

Fig. 3. Effect of thickness-to-width ratio on the buckling load of a laminated square plate.

Figure 3 illustrates how the thickness-to-width ratio affects a cross-ply laminated square plate's non-dimensional buckling factor. The non-dimensional buckling load gradually drops as the thickness-to-width ratio rises for plates with load distributions that are nearly homogeneous ($\eta < 1$). When the thickness-to-width ratio is sufficiently great, the non-dimensional buckling factor for plates subjected to severe non-uniform load distribution ($\eta > 1$) decreases more noticeably. When the thickness-to-width ratio is greater than 0.068 in the case of pure bending, buckling modes transition and there is a sharp drop. In the meanwhile, several iterations are required in the ABAQUS runs, and a big m is required to acquire the precise buckling load in the correct solution.

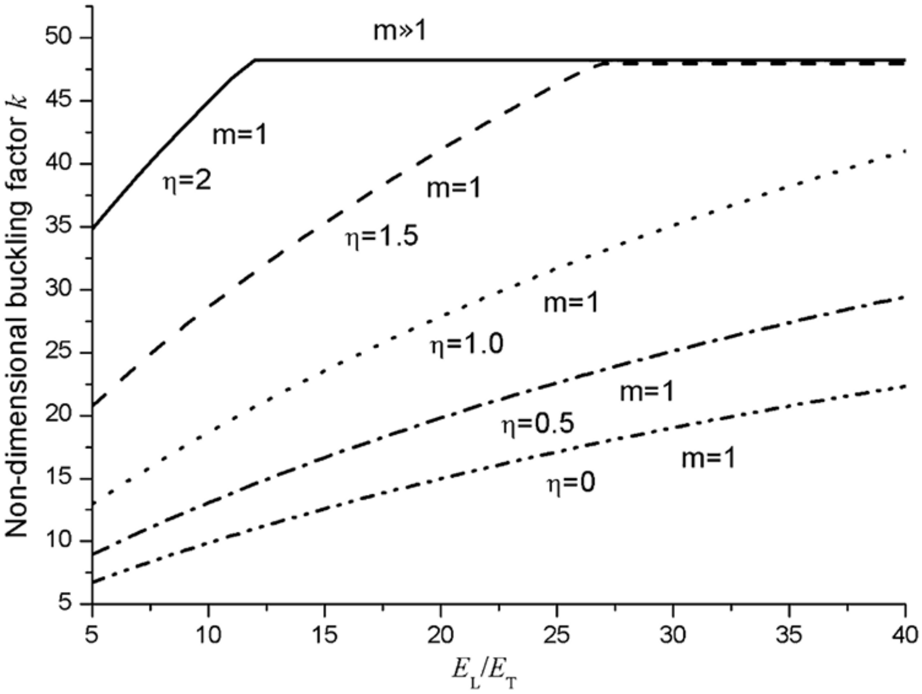

Fig. 4. Effect of modulus ratio EL/ET on the buckling load of a square plate.

Figure 4 illustrates how the ratio of Young's modulus, EL/ET, influences the non-dimensional buckling factor of a square plate with a thickness-to-width ratio of h/b = 0.1, while maintaining constant values for G_{LT}/ET, G_{LZ}/ET, and G_{TZ}/ET. The analysis indicates that the buckling factor rises with the ratio of EL to ET for plates subjected to moderately non-uniform loads ($\eta < 1.0$). A comparable situation occurs for plates subjected to significant non-uniform loading when the ratio of EL to ET is not particularly high. Nonetheless, the curves of the non-dimensional buckling factor start to stabilize for plates with high EL/ET when subjected to significant non-uniform loads. For example, the buckling load of the square plate subjected to pure bending ($\eta = 2.0$) does not vary when EL/ET exceeds 12.0. The phenomenon has been examined and validated through the results produced by the computer code ABAQUS. This unusual observation suggests that there is a definitive buckling resistance capacity for moderately thick symmetric cross-ply laminated plates when subjected to a significant non-uniform in-plane load, particularly as EL/ET increases.

4. CONCLUSIONS

The buckling behavior of simply supported symmetric cross-ply square plates subjected to linearly changing in-plane strains in a unidirectional direction has been proposed with an exact solution. The development of the present exact answer started with first-order shear deformation laminations theory. The results of the ABAQUS computer code confirm the present solution's correctness. A parametric analysis is used to investigate via aspect ratio, thickness-to-- width ratio, and modulus ratio the effects on the buckling load factor. The data reported here supports the generally recognized conclusion that the buckling factor calculation based on uniform load is not conservative for plates exposed to non-uniform stress. The observation that, under a strong non-uniform in-plane load, there is an ultimate buckling resistance capacity for rather thick symmetric cross-ply laminated plates was among the most important results of this study. This capability was proven to be commensurate with increasing modulus ratio.

REFERENCES

[1] Leissa AW. Buckling of laminated composite plates and shells panels. Air Force Wright-Patterson Aeronautical Laboratories, Final report, No. AFWAL-TR-85-3069; 1985.

[2] Herakovich CT, Tarnopolskii YM. Handbook of composites. Struc tures and design, vol. 2. Amsterdam: North-Holland; 1989.

[3] Berthelot JM. Composite materials mechanical behavior and struc tural analysis. New York: Springer; 1999.

[4] Lekhnitskii SG. Anisotropic plates. New York: Gordon and Beach Science Publishers; 1968.

[5] Papazoglou VJ, Tsouvalis NG, Kyriakopoulos GD. Buckling of unsymmetric laminates under linearly varying, biaxial in-plane loads, combined with shear. Compos Struct 1992;20:155–63.

[6] Chai GB, Khong PW. The effect of varying the support conditions on the buckling of laminated composite plates. Compos Struct 1993;24: 99–106.

[7] Chai GB, Ooi KT, Khong PW. Buckling strength optimization of laminated composite plates. Comput Struct 1993;46:77–82.

[8] KamTY,ChuKH.Bucklingof laminated composite plates subject to nonuniform in-plane edge loads. Mater Des Technol, ASME 1995;71:207–15.

[9] Badir A, Hu H. Elastic buckling of laminated plates under varying axial stresses. In: Collection of technical papers– AIAA/ASME/ ASCE/AHS/ASC structures, structural dynamics and materials conference, vol. 1. AIAA-98-1774; 1998. p. 635–40.

[10] Timoshenko SP, Gere JM. Theory of elastic stability. 2nd ed. New York: McGraw-Hill; 1961.

[11] Kang JH, Leissa AW. Vibration and buckling of SS-F-SS-F rectangular plates loaded by in-plane moments. Int J Struct Stabil Dynam 2001;1:527–43.

[12] Leissa AW, Kang JH. Exact solutions for vibration and buckling of an SS-C-SS-C rectangular plate loaded by linearly varying in-plane stresses. Int J Mech Sci 2002;44:1925–45.

[13] Bert CW, Devarakonda KK. Buckling of rectangular plates subjected to nonlinearly distributed in-plane loading. Int J Solids Struct 2003;40:4097–106.

[14] Zhong H, Gu C. Buckling of simply supported rectangular Reissner Mindlin plates subjected to linearly varying in-plane loading. J Eng Mech, ASCE 2006. May.

[15] Press WH, Flannery BP, Teukolsky SA, Vetterling WT. Numerical recipes– the art of scientific computing. Cambridge: Cambridge University Press; 1986.

[16] Khdeir AA. Free vibration and buckling of symmetric cross-ply laminated plates by an exact method. J Sound Vib 1988;126:447–61.

[17] B.O. Baba, Buckling behavior of laminated composite plates, Journal of Reinforced Plastics and Composites (2007).

[18] B.O. Baba, A. Baltaci, Buckling characteristics of symmetrically and antisymmetrically laminated composite plates with central cutout, Applied Composite Materials 14(4) (2007) 265-276.

[19] Jain,P., Ashwin,K.. Post buckling response of square laminates with a central/elliptical cutout. Compos Struct. 75, (2004).

[20] Ghannadpour, S.A.M., Najafi,A., Mohammadi,B.: Buckling of Cross-ply laminate composite plates due to circular/elliptical cutouts. Compos.Struct.27 pp. 3-6 (2006).