A Study of Buckling Load For Antisymmetric Angle-Ply Composite Plates with Different Moduli and Aspect Ratios Under Biaxial Compression

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Abstract- An investigation of the buckling stress in rectangular laminated plates that are loaded in a biaxial direction is carried out using a numerical approach. For the purpose of conducting buckling studies on thin rectangular laminated plates within the framework of classical laminated plate theory (CLPT), a Fortran program that is based on finite elements (FE) has been developed. It was done in this manner in order to accomplish the objective of carrying out the analysis. Researchers have investigated the buckling stresses for composite plates that are commonly stacked in a vertical orientation. Through the use of the energy strategy, which is characterized by a finite element model, the problem may be studied and resolved without any difficulty. The quadrilateral components are included into this method since it makes use of a model that has four nodes. The network is comprised of nodes, and each node has a distinct element that possesses three degrees of freedom. As with the degrees of freedom involved, which include rotation, lateral displacement, and rotation around the axes, similar concerns are applicable to the degrees of freedom involved. This approach is now being evaluated, and in order to confirm that it is accurate, it has been cross-referenced with the literature that is already available. By carrying out this procedure, the correctness of the approach is examined. As a result of the great degree of concordance that exists between the finite element technique and the data that is available to the general public, this demonstrates that the method is completely reliable.

Key words: FE method, Fortran program, Buckling load, Antisymmetric angle – ply, composite plate.

1. INTRODUCTION

The application of pressure in the transverse and/or in-plane directions causes two different forms of deformation in solid mechanics: flexural deformation, which occurs when cross-sections rotate, and shear deformation, which occurs when sections or layers slide past each other. Both of these types of deformation are referred to as shear deformation. There are two factors that determine the degree to which the material exhibits a change in form. These are the ratio of the width to the length, as well as the ratio of the elastic moduli to the shear moduli. When the ratio of thickness to length is low, for example, a plate is said to be thin and primarily undergoes significant form change via the process of bending. Shear, on the other hand, is the primary mechanism by which the plate undergoes a physical transformation when both the thickness-to-length ratio and the modulus ratio are increased. Furthermore, the shear displacement effects of composite laminates are exacerbated when transverse and/or in-plane forces are applied to the laminates. This is due to the fact that the ratio of in-plane modulus to transverse shear modulus is increased. To put this into perspective, here is the result that occurs when isotropic plates are loaded in the same way or in a manner that is comparable. The three-dimensional laminate theories, in which each layer is believed to be a smooth, uneven, and nonhomogeneous material (Reddy), cannot be solved. There is no method to solve them. Because of their anisotropic nature, layered composite materials often experience intricate responses when they are loaded in a variety of different ways. These mechanisms provide links between the many kinds of extension, bending, and shear deformation, which are all forms of deformation that are quite complex. There are several reasons why it is not feasible to provide a complete solution to an issue in three dimensions. These reasons include the complexity of the problem, the amount of computer power that is required, and the amount of data that is generated that is not required. In particular, this is the case for structures that are constructed out of more than one material. There are a great number of hypotheses about normal pressures and axial strain that may be found in written expression. It is possible to see this type of concept in Mindlin's work from the year 1951. It would be impossible to look at each and every one of them here. We are just going to discuss a few works and masterpieces that have been carefully selected to provide us with a fundamental understanding of what is now being discussed. As far as Phan and Reddy are concerned, these theories may be classified into two primary categories, which are determined by the domains that they describe: There are two types of theories: the first is based on stress, and the second is based. Theories that are based on displacement are founded on the concept of an imagined displacement field. The stress-based theories, on the other hand, are founded on stress fields that ought to undergo linear transformations throughout the length of the plate where they are applied. This study is discussed in the research conducted by Yang, Norris, and Stavsky, Whitney and Pagano, and Phan and Reddy, each of whom conducted their own research in their respective domains. Numerous concepts pertaining to plate analysis have been developed during the course of time. Every single one of them is founded on a distinct collection of presumptions about displacement fields. There are three primary categories that may be used for the purpose of categorizing theories. These categories are the individual layer theories (IL), the equivalent single layer theories (ESL), and the three-dimensional elasticity solution processes. It is possible to further subdivide these groupings into sub-theories to the extent that they are in agreement with certain notions. The classical laminated plate theory (CLPT), the first-order shear deformation theory (FSDT), and the higher-order shear deformation theory (HSDT) are all included in the second set of theories. Both Seloodeh and Karami Noor Omurtag (2000) and Huang and Thambiratnum (2000) discuss these concepts in their respective documents.

For the purpose of conducting this investigation, both the classical laminated plate theory (CLPT) and the Dorgruoglu method were used. However, CLPT does not take into account shear deformations that occur in a transverse direction. Based on this concept, the laminate is said to be subject to plane stress, each lamina is said to possess linear flexibility, and the layers are said to adhere to one another fully. According to the normal laminated plate theory, the line that is perpendicular to the mid-surface remains straight and parallel to the mid-surface both before and after the material deforms. This is the case regardless of whether the material is folded or not.

Taking this into consideration, this theory may be used to investigate the buckling behavior of thin laminates. For the purpose of determining whether or not the finite element solutions for biaxial bending of thin laminated rectangular plates are accurate and converge, we developed a Fortran software. The process of doing this may be accomplished in a number of ways, including comparing it to other theories and practical responses and developing fresh numerical data.

2. RESEARCH OBJECTIVE

In the course of this study, a comprehensive analysis of the following goals is included:

- A review of the various plate theories and approaches that are used in the process of predicting the behavior of laminated plates when they are exposed to buckling pressures will be presented.
- The construction of a theoretical model that is aimed to anticipate buckling loads in a thin laminated plate is a fresh and unrivalled approach of doing things.
- The application of the finite element approach to the investigation of rectangular laminated plates subjected to buckling stresses, as well as its development and implementation.
- It may be possible to do more study on the influence that coupling between bending and extension and/or twisting has on the behavior of laminated plates.

3. METHODS

This research utilizes the finite element approach to forecast the buckling loads and deformation patterns of laminated rectangular plates. This analytical method utilizes a four-node component framework. The elements of a plate including four nodes are designated as the bilinear rectangular sections. Each node has three degrees of freedom for every individual constituent. The degrees of freedom include the lateral displacement (w) and the rotations (Φ) and (Ψ) around the x and y axes, respectively. The energy approach acts as a fundamental inspiration for the finite element design methodology. The numerical technique may be concisely delineated by the following procedures:

- The element's choice and shape play a role.

- In order to create both element stiffness and differential matrices, a finite element model was made using the energy method.
- Using the rules of non-dimensionality to change the element matrices into their non-dimensional forms.
- Putting together the element stiffness and differential matrices to get the global matrices that go with them.
- Adding border conditions that are needed for the edges of the plates.
- The problem can be fixed with the right tools. In this case, FORTRAN and ANSYS were used.

This research might use three primary computational techniques: the finite difference method (FDM), dynamic relaxation in conjunction with the finite difference method (DR), and the finite element method (FEM). However, many other mathematical methods might also be used.

The finite difference approach employs a grid of discrete points, referred to as nodes. The answer domain is divided by this grid. Subsequently, a partial differential equation is formulated for each node, using finite difference approximations in lieu of the equation's derivatives when necessary. While the theoretical rationale for this point-wise approximation is straightforward, its practical application is challenging in systems characterized by irregular shapes, atypical boundary conditions, and diverse component types.

4. CONVERGENCE STUDY

When you wish to determine the bending loads with a high degree of precision, you may use a convergence analysis to determine the optimal number of plate elements in any direction. This will allow you to determine the bending loads. One method for doing this is to alter either the mesh size or the amount of discretization. When it comes to determining the appropriate quantity of finite elements, there are a number of considerations that need to be taken into account. There is a great deal of information that has to be considered, including the characteristics of the material, the dimensions of the plate, the technique of lamination, the boundary conditions, and the amount of virtual memory (RAM) that the computer possesses. It is feasible to see that the required number of finite components increases in a manner that is connected to the number of modes. This is something that may be observed. If this is the case, then it is logical to assume that the higher modes will need a greater number of components. As a consequence of it, this is the situation. Every single one of the investigations that were conducted for this thesis were carried out under the presumption that the plate was supported in ways that were either same or comparable on all four sides. A clamped–clamped edge condition (CC), a simply–simply supported edge condition (SS), and a clamped–simply supported edge condition (CS) are the three forms of edge conditions that are used in this particular scenario. Every one of these edge circumstances describes a separate edge circumstance as a whole. More information may be found in the table that is shown after this one.

Table 1: Boundary conditions.

Boundary Conditions	**Plate dimensions in y – coordinate** $\boldsymbol{x=0, x=a}$	**Plate dimensions in x – coordinate** $\boldsymbol{y=0, y=b}$
CC	$w=\phi=\psi=0$	$w=\phi=\psi=0$
SS	$w=\psi=0$	$w=\phi=0$
CS	$w=\phi=\psi=0$	$w=\phi=0$

A study was done on how the non-dimensional bending load converges on a square isotropic SS (simply supported) plate with a length to thickness ratio of twenty (a/h=20). The results can be seen below in Table 2. The plate is made of stainless steel and is only held up by something else. There are a lot of important things being thought about, some of which are below:

material 1:

$E_y/E_x = 1.0\,, G_{xy}/E_x = G_{yz}/E_x = G_{xz}/E_x = 0.4\,, v_{xy} = 0.25$

We can see from Table that the bending parameter values tend to get closer together as the mesh size decreases, which means that more parts are added to the mesh. Based on these results, putting a mesh over the plate seems like it would work for this job (the difference is less than 1.32% from the current best mesh result). For the first seven types of bending stress, we found that a mesh size of is enough to make accurate predictions. The truth is that only the first three types of bending work.

Table 2: Convergence study of non – dimensional modes of buckling of simply supported (SS) isotropic square plate with a/h=20.

Mesh Size	Mode Sequence Number						
	1	2	3	4	5	6	7
2 × 2	30.69	76.89	83.18	83.49	94.71	94.95	101.78
3 × 3	32.64	79.12	79.18	117.58	179.04	189.78	191.05
4 × 4	33.60	82.38	82.44	123.22	165.70	166.35	192.53
5 × 5	34.10	84.08	84.14	127.71	168.69	168.92	202.10
6 × 6	34.39	85.10	85.15	130.85	170.41	170.52	208.35
7 × 7	34.58	85.75	85.79	133.03	171.55	171.61	212.50
8 × 8	34.70	86.19	86.23	134.57	172.34	172.39	215.79
9 × 9	34.78	86.50	86.53	135.68	172.92	172.97	218.07
10 × 10	34.84	86.72	86.75	136.52	173.35	173.40	219.78

In order to determine whether or not the present FE method is proper, genuine, and suitable in regard to the situations that are now in place, several comparisons were carried out. When doing the final analysis and comparison, both the theoretical data and the findings of the ANSYS simulation are taken into consideration.

5. RESULTS AND DISCUSSION

In Table 3, the non-dimensional critical buckling load is shown for the purpose of comparison with the articles written by Yu and Wang Mohammadi et al. (2009) and Moktar. More specifically, the load is presented for an isotropic plate made of material 1 with varied aspect ratios. The results that are shown here are very consistent with the findings that were presented by Mohammadi et al. (2009) and Yu and Wang (2009).

Table 3: Comparison of the non – dimensional critical buckling load for an isotropic plate.

Aspect Ratio a/b	References Value	References Value	References Value	Present Study
0.5	12.33	12.3370	12.3370	12.3
1.0	19.74	19.7392	19.7392	19.7

The table that follows illustrates how the plate aspect ratio and modulus ratio influence the non-dimensional critical buckling loads of simply supported (SS) antisymmetric angle-ply rectangular laminates that are being crushed in two different directions. Utilizing the characteristics of the material was the decision that was made. It is evident from the table that the estimation of the buckling loads that was provided by the current study is more comparable to the forecasts that were generated by Osman and Elmardi (2017) and Reddy (2017).

Table 4: Buckling load for antisymmetric angle – ply $(45/-45)_4$ plate with different moduli and aspect ratios under biaxial compression (material 2)

Aspect Ratio a/b	Modular Ratio	Biaxial Compression			
	E_1/E_2	10	20	25	40
0.5	Present	19.376	36.056	44.400	69.440
	Ref.	19.480	-	44.630	-
	Ref.	18.999	35.076	43.110	67.222
1.0	Present	9.028	17.186	21.265	33.512
	Ref.	9.062	-	21.345	-
	Ref.	8.813	16.660	20.578	32.343
1.5	Present	6.144	11.596	14.322	22.013
	Ref.	6.170	-	14.383	-
	Ref.	6.001	11.251	13.877	21.743

The findings of the current research are compared to those that were simulated using the ANSYS approach, and the comparison is shown in Tables 5 through 8. When square thin laminates with a ratio of a/h equal to twenty are subjected to biaxial compression, the dimensional buckling stresses of these laminates are shown in Table 5. This table illustrates how boundary conditions influence these loads. The angle of these laminates is thirty degrees, and it is the same on both sides. Additionally, the ratio of these laminates is thirty to thirty to thirty. A decision was made to make advantage of the characteristics of the material that are listed in the table. As a consequence of the comparison between the two methods, there were a few minor variations in the outcomes of each of the techniques. In the range of less than 2% to less than 0.6%, the margin might be anything. As the mode serial number increases, it has been discovered that the difference gets more pronounced. This was discovered after careful observation. The buckling load behavior of both approaches is identical when applied to symmetrically laminated composite plates in the following order: (45/ -45/ -45/ 45), (60/ -60/ 60/ 60), and (0/ 90/ 90/ 0). Illustrations of this behavior may be found in Tables 6, 7, and 8.

Table 5: Dimensional buckling load of symmetric angle–ply (30/ -30/ -30/ 30) square thin laminates with different boundary conditions (a/h=20)

Boundary Conditions	Method	Mode Serial Number		
		1	2	3
SS	Present	109.5 N	193.4 N	322.8 N
	ANSYS	109.4 N	206.5 N	315.8 N
CS	Present	234.7 N	257.2 N	371.41 N
	ANSYS	233.21 N	255.6 N	378.7 N

Table 6: Dimensional buckling load of symmetric angle–ply (45/-45/-45/45) square thin laminates with different boundary conditions (a/h=20)

Boundary Conditions	Method	Mode Serial Number		
		1	2	3
SS	Present	115.24 N	219.5 N	305.4 N
	ANSYS	116.3 N	225.5 N	312.7 N
CS	Present	196.33 N	282.8 N	439.53 N
	ANSYS	194.7 N	287.6 N	444.51 N

Table 7: Dimensional buckling load of symmetric angle–ply (60/-60/-60/60) square thin laminates with different boundary conditions (a/h=20)

Boundary Conditions	Method	Mode Serial Number		
		1	2	3
SS	Present	109.39 N	193.213 N	322.19 N
	ANSYS	109.6 N	191.13 N	325.37 N
CS	Present	161.4 N	279.1 N	370.5 N
	ANSYS	160.6 N	280.4 N	377.7 N

Table 8: Dimensional buckling load of symmetric cross–ply (0/ 90/ 90/ 0) square thin laminates with different boundary conditions (a/h=20)

Boundary Conditions	Method	Mode Serial Number		
		1	2	3
SS	Present	93.4 N	170.4 N	329 N
	ANSYS	94.4 N	181.4 N	315 N
CS	Present	244.5 N	263.7 N	366.23 N
	ANSYS	244.4 N	265.8 N	369.6 N

6. CONCLUSION

The development of a finite element model has been done with the intention of accomplishing the objective of calculating the buckling loads of laminated plates that have a rectangular cross-section. This was something that had to be done in order to ensure that there was consistency. The buckling loads are explored and validated by the process of comparison, which involves comparing them to prior research that has been published in the relevant literature in the past. The reason that this is done is to guarantee that the approach that is currently being used produces correct results, which is the reason why this is done. There were other comparisons that were carried out, and the results that were supplied by the ANSYS software as well as the findings from the tests were compared with all of the other findings. The comparisons were carried out in more detail. With a high degree of concordance with the data that is not only available but also readily accessible, the finite element technique that was utilized demonstrates that it is dependable. This is shown by the fact that it has a high degree of alignment with the data.

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