Buckling analysis of laminate composite plate having cut-out with varying ply-orientation, aspect ratio and skewness

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Abstract : In this present study composite plates with cut-outs have been studied for their buckling strength when subjected to different shape and size of cut-out, ply orientation, aspect ratio, skewness, etc. The best suited hole-area ratio with different constraints is studied and found here. The ABAQUS software is used for the analysis. Eight-Node Shell element with five degrees of freedom (S8R5) is used throughout the analysis. Five different types of layup sequences of the laminate combined with five different types of loading are considered for the analysis. Two different types of material have also been used. Five different skew angles have been used to analyze the buckling behavior under different loading conditions. Comprehensive results have been obtained in this study which is presented accordingly.

***IndexTerms* – Laminate, Composite, Plate, Cut-out, ABAQUS, Buckling load, Skew.**

I. INTRODUCTION

Composite structures are being used widely around the world in the field of engineering as in wind turbines cutting edges, aircraft, and in specific kinds of boats, especially maritime boats. These structures comprise plates or plate-like components glued by different matrix. These auxiliary components are frequently subjected to huge powers; for example, shear stacking and in-plane compressive stacking. These show high resistance to tensile or compressive load but fails in buckling load. This is due to the nature of laminate plates to behave in an orthotropic way, the presence of couplings in load, and due to the small thickness of the structural element. Hence buckling investigation brings a significant part for sustained use of such structures. At the point when a plate which is at level condition is given load of compressive nature, it at first remains in the condition of equilibrium, but when the load is gradually increased to a limit, it ends up being unstable and gradually its arrangement progresses from level to non-level. This point of load where the plate changes from equilibrium to non-equilibrium condition and winds up unsteady is known as “Critical Buckling Load”. Many works of literature have been published for finding out the buckling load in laminates with cut-outs. Finite element method was used by many researchers like Crispino and Benson (1986) worked out on the stability of rectangular, thin, orthotropic under twist and tension. Hu and Lin (1995) found the best fiber orientation and buckling loads for the laminated plates with circular cut-out while changing aspect ratio, end condition under uniaxial load. Baba (2007) used ANSYS to validate the consequence of boundary conditions over buckling load in case of rectangular plates having changed the length to thickness ratio; different cut-out shape and various ply orientation. Zhong and Gu (2007) took thick laminate rectangular plates and analyzed it to find the exact solution using FSDT. He used ABAQUS to validate results. Qablan et al. (2009) used three different types of loading, uniaxial, biaxial, and shear having cut-out and different orientations. Aliabadi and Purbolaksono and Aliabadi (2009) did a linear elastic buckling analysis with different geometries, loading, and boundary conditions and represented it with few numerical examples. Komur et al. (2010) symmetrically arranged the cross plies having ply orientation angle as (0/90)2S, (15/75)2S, (30/60)2S, (45/45)2S in laminates and used FEM to find optimum position and shape of the elliptical cut-out. Gaira et al. (2012) used various aspect ratio and cut-out size ratios on composite laminated plates to find the buckling loads. He found that the buckling load show inverse proportionality to the to both “d/b ratio (up to 0.15) and d/D ratio (up to 0.25).” Yousef et al. (2012) concluded in his experimental study that plates that were without cut-out were having greater buckling load than those having cut-out. Alinia (2012) used the influence of in-plane bending and shear to study the inelastic buckling behavior for thick plates.

Different type of buckling analysis has been done to know the response of laminated composite plate with various types of shapes of cut-outs which influence the characteristics of plate. However, the number of literature on a combination of various cut-outs shape with different types of loading and skew angles are very limited and much research in this area is needed to be done. To bridge this gap this present literature presents a systematic study of problems related to various cut-out shape in the combination of other restraints. In the present study analysis of buckling load of the laminated composite plate with various types of cutouts using ABAQUS software to determine the best suited cut out shape and the hole-area ratio is done. In addition to that rectangular and square plates have been subject to different restraints like boundary conditions, different types of layup sequences of the laminate combined with various types of loading patterns. Two different types of materials have also been used in this work. The plates have also been given different skew angles to study the changed buckling behavior under the different types of loading conditions when the plates are skewed with cut-outs.

II. ABAQUS PROCEDURE

Here in this present study, all the models have been analyzed in ABAQUS. However, for reliability, the results of a few models have been verified by paper. The steps involved in the study of these models are:

a. Creation of model: A 3D shell element is used for the model creation. The plate is given its dimensions and material property for it is assigned.

b. Loading and Boundary Condition Definition: The desired loading and boundary conditions are given to all the edges. Here in this study uniaxial, biaxial, shear, and its combinations have been used as loading with simply supported and clamped conditions as boundary conditions.

c. Meshing of model: In this study an S8R5 i.e. an eight nodded element with five degrees of freedom has been used as an element. The mesh done is mostly sweep meshing.

d. Eigen Buckling analysis: After modal creation and meshing the post-processing work is created and executed which yields the result for buckling values in different conditions of the model taken.

III. RESULTS AND DISCUSSION

A laminated composite plate having dimensions of length (a), width (b) and thickness (t), as 500mm, 500mm and 8mm respectively is taken. The plate material properties used are E1 = 49627 MPa , E2 = 15430 MPa , E3 = 15430 MPa, ν12 = 0.272 ,ν13 = 0.272 , ν 23 = 0.607, G12 = 4800 MPa , G13 = 4800 MPa, G23 = 4800 MPa

Abbreviations and Acronyms

A.R.: Aspect Ratio.
B.C.: Boundary Condition.
a: Length of Plate.
b: Width of Plate.
c: Side of square cut-out.
d: Diameter of circular cut-out.
e: Major axis of elliptical cut-out.
m: Minor axis of elliptical cut-out.
t: Thickness of Plate.
SSSS: All sides simply supported.
CCCC: All sides clamped.

3.1 Convergence study

For convergence study a triaxial lay-up: [−45/ + 45/0/ + 45/ − 45/0]X,S with ply thicknesses t45 = t−45 = 0.143mm and t0 = 1.714mm is taken. Aspect Ratio (A.R.) (a/b) is considered as 1. It "is studied and results validated with those of Qiao Jie Yang. The convergence study is shown in Figure 1.

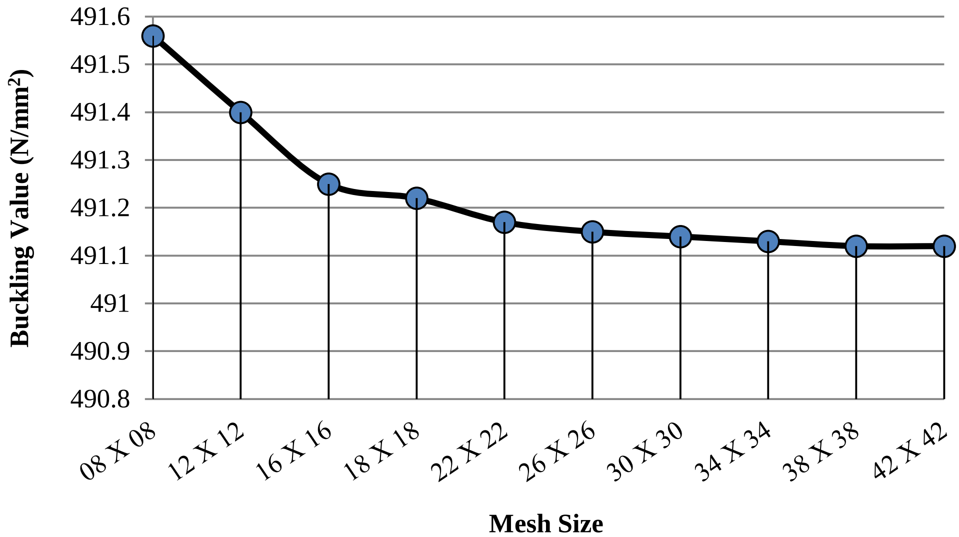

Figure 1: Convergence study graph

On conducting the convergence study we get the final mesh size of 38x38. Hence this mesh size has been taken for further analysis in this study.

3.2.1. Case – 1: Simply Supported and Clamped boundary condition (B.C.) with uniaxial loading and various cut-out shape and sizes.

Plate having triaxial Lay-up as [−45/ + 45/0/ + 45/ − 45/0]X,S, (a/b) = 1, t = 8.0 mm, b/t = 62.5, and ply thicknesses as t45 = t−45 = 0.143 mm, t0 = 1.714 mm is taken. The plate is given circular, square, elliptical (Cut parallel to the direction of the applied load.) and elliptical (Cut perpendicular to the direction of the applied load.) cut-out one by one with simply supported (SSSS) and clamped (CCCC) condition and analyzed for buckling load. The buckling values obtained are summarized in the Table 1:

Table 1 Buckling Value for SSSS and CCCC (B.C.) with uniaxial loading and various cut-out shape and sizes

Circular cut-out of diameter 'd'	d/b	d	Buckling Value (N/mm^2)
SSSS	0.0	0	172.49
	0.025	12.5	171.41
	0.05	25	169.74
	0.1	50	164.24
CCCC	0.0	0	491.12
	0.025	12.5	487.44
	0.05	25	480.67
	0.1	50	461.76
Square Cut-out of side 'c'	**c/b**	**c**	**Buckling Value (N/mm^2)**
SSSS	0.0	0	172.49
	0.025	12.5	171.25
	0.05	25	168.98
	0.1	50	161.40
CCCC	0.0	0	491.12
	0.025	12.5	486.49
	0.05	25	477.64
	0.1	50	454.89
Elliptical Cut-out of major axis 'e' and minor axis 'm'. (Cut parallel to the direction of the applied load.)	**e/b**	**m/b**	**Buckling Value (N/mm^2)**
SSSS	0.0	0	172.49
	0.3	0.025	156.02
	0.3	0.05	152.77
	0.3	0.1	146.80
CCCC	0.0	0	491.12
	0.3	0.025	439.40
	0.3	0.05	430.89
	0.3	0.1	419.28
Elliptical Cut-out of major axis 'e' and minor axis 'm'. (Cut perpendicular to the direction of the applied load.)	**m/b**	**e/b**	**Buckling Value (N/mm^2)**
SSSS	0.0	0	172.49
	0.3	0.025	164.44
	0.3	0.05	161.30
	0.3	0.1	155.01
CCCC	0.0	0	491.12
	0.3	0.025	491.11
	0.3	0.05	482.39
	0.3	0.1	466.61

3.2.2. Case – 2: Buckling load of plates with different skew angle tested with two different aspect ratio (A.R.) for different boundary conditions (B.C.) and different loading.

Plate having triaxial Lay-up as $[-45/+45/0/+45/-45/0]X,S$, t = 8.0 mm, b/t = 62.5, and ply thicknesses as t45 = t−45 = 0.143 mm, t0 = 1.714 mm is taken. In this case two different aspect ratio (A.R.) of (a/b) = 1 and (a/b) = 0.5 is taken with different skew angles given to the plate. Cut out size d/b = 0.05 is taken because at this cut-out size the buckling load do not have very significant loss. The buckling values obtained are summarized in Table 2.

Table 2: Buckling value at different skew angle tested with two different (A.R.) for different (B.C.) and different loading.

A.R.	B.C.	Loading	Skew				
			0°	15°	30°	45°	60°
a/b = 1	SSSS	Uniaxial	169.74	209.97	306.12	407.82	243.28
		Biaxial	84.872	88.042	99.501	126.64	197.22
		Shear	386.43	307.66	268.32	256.02	277.34
		Combined (Uniaxial+ Shear)	145.89	165.49	197.89	222.55	172.95
		Combined (Biaxial+ Shear)	81.176	90.501	110.66	153.34	254.03
	CCCC	Uniaxial	480.67	586.73	665.45	836.63	619.58
		Biaxial	246.11	254.18	284.76	364.52	588.41
		Shear	631.54	513.72	450.2	430.30	464.88

		Combined (Uniaxial+ Shear)	333.60	356.81	407.01	318.52	250.72
		Combined (Biaxial+ Shear)	211.44	238.25	293.82	414.24	684.17
a/b = 0.5	SSSS	Uniaxial	349.76	368.83	402.22	461.50	523.08
		Biaxial	280.5	284.22	301.88	349.69	474.02
		Shear	1186.6	970.52	846.07	785.80	769.49
		Combined (Uniaxial+ Shear)	331.65	348.79	380.25	448.52	237.07
		Combined (Biaxial+ Shear)	270.50	284.05	312.02	380.10	487.76
	CCCC	Uniaxial	1139.8	1188.1	1247.4	1115.2	567.02
		Biaxial	808.31	827.83	904.18	1021.8	630.42
		Shear	1776.6	1456.2	1263.3	1154.9	995.73
		Combined (Uniaxial+ Shear)	927.3	936.67	964.96	848.49	260.10
		Combined (Biaxial+ Shear)	663.95	735.97	847.36	973.51	497.72

3.2.3. Case – 3: Buckling load of plates with different ply angle tested on two different materials for different boundary conditions (B.C.) and different loading.

Plate having t = 8.0 mm, b/t = 62.5, (a/b) = 1, ply thicknesses as t45 = t−45 = 0.143 mm, t0 = 1.714 mm and cut-out size d/b =0.05 is taken. In this case two different materials are taken. The definition of Material-1 is E1 = 49627, E2 = 15430, E3 = 15430, ν12 = 0.272, ν13 = 0.272, ν 23 = 0.607, G12 = 4800, G13 = 4800, G23 = 4800 and definition of Material-2 is E1 = 39000, E2 = 8600, E3 = 8600, ν12 = 0.25, ν13 = 0.25, ν 23 = 0.42, G12 = 3800, G13 = 3800, G23 = 3800.Different ply angles are also taken so as to understand the best ply orientation. The buckling values obtained are summarized in Table 3.

Table 3: Buckling value with different ply angle tested on two different materials for different (B.C.) and different loading.

Material	**B.C.**	**Loading**	**Ply angle**				
			(-45/45/0/+45/0)s	**(0/45/90/-45)s**	**(0/90/0)s**	**(0/90)s**	**(0/90/90/0)s**
1	SSSS	Uniaxial	167.74	171.37	154.63	154.69	154.8
		Biaxial	84.872	85.681	77.321	77.349	77.043
		Shear	386.43	349.24	359.11	356.86	360.75
		Combined (Uniaxial + Shear)	145.89	136.93	133.02	77.345	133.21
		Combined (Biaxial + Shear)	81.176	78.438	73.927	73.937	74.011
	CCCC	Uniaxial	480.67	472.29	478.22	482.09	479.28
		Biaxial	246.11	299.38	247.19	246.04	298.05
		Shear	631.54	566.12	620.2	613.72	624.5
		Combined (Uniaxial + Shear)	333.6	302.43	327.08	328.03	325.59
		Combined (Biaxial + Shear)	211.44	196.78	210.48	209.13	211.9
2	SSSS	Uniaxial	122.39	122.79	111.29	111.22	111.36
		Biaxial	61.195	61.364	55.619	55.613	55.679
		Shear	276.89	238.36	255.41	258.1	259.78
		Combined (Uniaxial + Shear)	105.18	96.473	95.651	95.678	95.849
		Combined(Biaxial + Shear)	58.538	55.62	53.166	53.175	53.245
	CCCC	Uniaxial	349.07	341.24	350.31	347.92	344.4
		Biaxial	177.92	175.73	177.37	178.36	179.73
		Shear	452.75	395.39	439.79	447.5	452.01
		Combined (Uniaxial + Shear)	241.86	213.97	177.37	237.19	236.1
		Combined(Biaxial + Shear)	152.23	139.23	150.47	152.18	153.12

IV. CONCLUSION

From the analysis on finding the buckling strength of laminated composite plates having different cut-out, ply orientation, aspect ratio skew angle, loading conditions, and boundary conditions using ABAQUS the following conclusions are achieved:

1) The buckling strength of the plate in the clamped condition is way more than that obtained in a simply supported condition.
2) The loss of strength due to the different shapes of cut-outs is almost very small up to the c/b ratio from 0.0 to 0.05.
3) The loss of strength in elliptical cut-out (Cut perpendicular to the direction of applied load) is less than those in the circular or square cut-out.
4) The buckling load in-plane shear is much higher than any other loading condition.
5) The lowest buckling load comes for the combined loading of biaxial load and shear load.
6) The buckling load in the simply supported condition in each loading case is much lesser than its counterpart in the clamped case.
7) The buckling value in both the Material-1 and Material-2 is maximum for (-45/45/0/+45/0)s orientation
8) The strength of Material-1 is higher than Material-2
9) For different loading conditions, the skew-ness given to the plate gives a different pattern for change in buckling load.
   i. The different patterns of buckling load for aspect ratio 1 are:

(a) For Uniaxial loading, the buckling load increases up to the skew angle of 45 degrees but then decrease for 60 degrees.
(b) For Biaxial loading, the buckling load increases thoroughly with an increase in skew-ness.
(c) For Shear loading, the buckling load decreases thoroughly with an increase in skew-ness.
(d) For Combined (Uniaxial + Shear) the buckling load increases up to 30-degree skew-ness and then decreases.
(e) For Combined (Biaxial + Shear) the buckling load increases with increase skew-ness.

ii. The different patterns of buckling load for aspect ratio 0.5 are:
(a) For uniaxial loading the buckling strength increase throughout the increment of skew angle for simply supported condition but in case of the clamped condition it increases up to 30^0 and after that, it decreases with an increase in skew-ness.
(b) For biaxial loading under simply supported the buckling strength increases with an increase in skew angle but when subjected to clamped condition the buckling strength first increases up to 45^0 but after that, it decreases drastically.
(c) For shear loading in both simply supported and clamped condition the buckling strength increases gradually.
(d) For combined loading of shear and uniaxial load in both simply supported and clamped case the buckling strength increases up to 45^0 and then show a sudden decrement in strength.
(e) For biaxial and shear load combination the buckling strength in simply supported condition increases throughout but in case of the clamped condition it increases up to 45^0 and then decreases drastically.

10) For an Aspect ratio of 0.5, the buckling load increases considerably than the aspect ratio (A.R.) of 1.

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