Effect of Plate Aspect Ratio on Buckling Strength of Rectangular Composite Plate with Square/rectangular Cutout Subjected to Various Linearly Varying In-Plane Loading Using Fem

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Abstract
A numerical study has been carried out to investigate the effect of plate aspect ratio on the buckling behavior of a sixteen ply quasi-isotropic graphite/epoxy symmetrically laminated rectangular composite plate $[0°/+45°/-45°/90°]_{2s}$ with square and rectangular cutout subjected to various linearly varying in-plane compressive loads using finite element method (FEM). Further, this paper addresses the effects of size of square/ rectangular cutout, plate length/thickness ratio(a/t), boundary conditions on the buckling bahaviour of symmetrically laminated rectangular composite plates subjected to various linearly varying in-plane compressive loading. The results show that the buckling loads of rectangular composite plates with rectangular/square cutout subjected to various linearly varying in-plane loads are decreased by increasing the plate aspect ratio (a/b) and length/thickness (a/t) ratio irrespective of cutout shape, size and boundary conditions. It is observed that the various linearly varying in-plane loads, boundary conditions, aspect ratio (a/b) and length/thickness (a/t) ratio have a substantial influence on buckling strength of rectangular composite plate with square/ rectangular cutout.

Keywords: Buckling; rectangular cutout; Linearly varying in-plane load; Boundary conditions; Symmetrically laminated rectangular composite plates; Finite element analysis; Quasi-isotropic; Aspect ratio.

1. Introduction

Composite laminates have been used increasingly in aeronautical, automobile and marine industries due to their high stiffness and strength-to-weight ratios and other superior material properties of composites. A true understanding of their structural behaviour is required, such as the deflections, buckling loads and modal characteristics, the through-thickness distributions of stresses and strains, of extreme importance for obtaining strong, reliable multi-layered structures (Zhang .Y.X 2009). Studies on buckling analysis of plates under non-linear compressive loads have been very few. Plate problems are often idealizations of portions of a much larger overall stiffened or built-up structure-an aircraft wing or a ship or a multistoried building, for instance, and hence the loads that cause buckling are those exerted by the adjoining free –body on the plate; thus, uniform loading is an exception rather than the rule because the elastic forces between the free bodies depend on their relative stiffness. It is necessary to analyse plates subjected to various types of simple, assumed edge load distributions so as to understand their qualitative and quantitative influence on the buckling behavior (Jana.P 2006). In general, the analysis of composite laminated plates is more complicated due to their anisotropic and heterogeneous nature. Less attention has been paid on the buckling of rectangular composite plates with cutouts. Due to the practical requirements, cutouts are often required in structural components to produce lighter and more efficient structures. For example, cutouts in wing spars and cover panels of commercial transport wings and military fighter wings are needed to provide access for hydraulic lines, electrical lines and for damage inspection (Topal U 2008). Jana P (2006), Chai G.B et al. (1993), Hu. H et al. (2003), Nemeth (1997), Zhong.H (2007) , Kumar panda.S (2010), Leissa A.W (2002,2005) , Shufrin. I et al. (2008,2008), Singh S.B (1998) carried out buckling analysis of composite plates subjected to various linearly varying & uniformly distributed in-plane compressive loads, parabolically distributed in-plane compressive loads and pure shear loads using analytical method . The above studies in the buckling analysis of composite plates deal with plates which are continues or plates without cutout. Baba B.O (2007,2007) Husam AQ et al. (2009), Srivatsa K.S (1992) studied the buckling response of composite plate with circular cutout subjected to uniform uniaxial compression load using finite element method. Dinesh Kumar (2010), Hani

Aziz Ameen (2009), Ghannadpour S.A.M et al. (2006), Jain.P, (2004) , Aydin Komur.M et al. (2010) studied the buckling response of composite plate with circular/elliptical cutout subjected to uniform uniaxial compression load using finite element method.

Topal U (2008), Hsuan-Teh Hu (1995,1997) investigated on the critical buckling load optimization of symmetrically laminated composite plates subjected to uniform uniaxial compression load with circular cutout. The results presented in the literature indicate that the effect of plate aspect ratio(a/b), length/thickness ratio(a/t),boundary conditions and various linearly varying in-plane compressive loads on the buckling behavior of rectangular composite plates with square/rectangular cutout are needed to investigate in more detail.

In this paper the effect of plate aspect ratio(a/b), length/thickness ratio(a/t),boundary conditions on the buckling behaviour of quasi-isotropic graphite/epoxy symmetrically laminated rectangular composite plates with square/rectangular cutout subjected to various linearly varying in-plane compressive loading is studied using FEM.

2. Present study

In this study, a numerical study using FEMhas been carried out to investigate the effects of plate aspect ratio (a/b), plate length/thickness ratio (a/t) and boundary conditions on buckling response of quasi-isotropic graphite/epoxy symmetrically laminated rectangular composite plates with square/rectangular cutout subjected to various linearly varying in-plane compressive loading. The lamina consists of graphite fibers as reinforcement material and epoxy as matrix material. The material properties of graphite/epoxy are taken from reference (Hsuan-Teh Hu , Bor-Horng Lin 1995) and listed in Table 1.The material axis 1 is coincide with the global x -axis and the material axis 2 is coincide with the global y –axis. The compressive loads applied on plate coincide with global x-axis. The 0° fibre direction is aligned with the direction of the compressive load.

Table 1: Material properties of the graphite/epoxy composite material (Hsuan-Teh Hu , Bor-Horng Lin 1995)

E_{11} (GPa)	E_{22} (GPa)	ν_{12}	$G_{12} = G_{13}$ (GPa)	G_{23} (GPa)
128	11	0.25	4.48	1.53

The geometry is as shown in Fig.1.The width of the plate' b' is 100mm and the length of the plate 'a' is 200mm. The thickness of each layer of this sixteen layer laminate is 0.125mm and't' is the thickness of the plate and β is cutout orientation angle. In this study cutout orientation angle is assumed as zero degrees. In this work the cutout shape was assumed rectangular hole centered in the rectangular plate. The length and width of the cutout are c and d respectively. The parameters c and d are changed according to selected ratios, hence the rectangular hole is also positioned as square hole when c/b and d/b are equal. So, the effect of square hole is also analyzed at the same conditions. Briefly, the buckling analysis is performed for both square and rectangular holes.

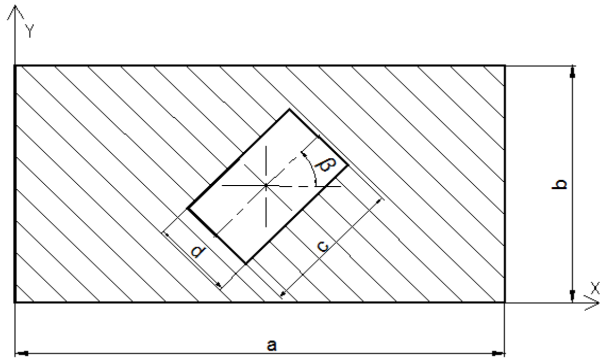
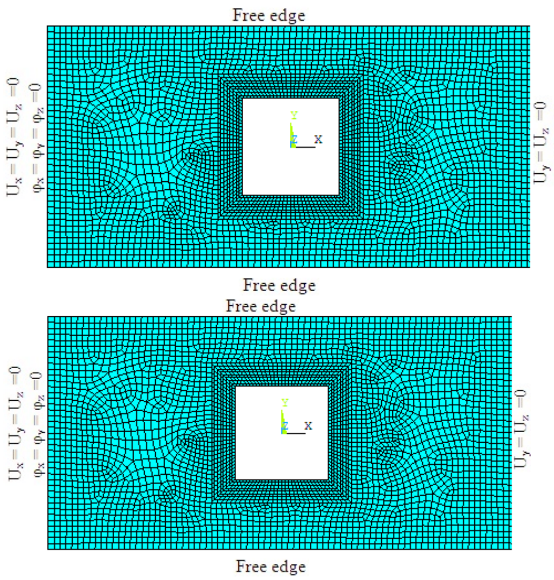


Fig.1.Geometry of the model.

3. Finite Element Modeling



a) CC type boundary condition b) CS type boundary condition

Fig.2 .Boundary conditions and finite element mesh of the laminated plate

In the present work, Eigen buckling analysis is used for predicting the buckling load of a rectangular composite plate with rectangular/square cutout through the use of finite element package named ANSYS. The plates are modeled using eight noded shell elements (SHELL 281). The “SHELL 281” structural element has been chosen from the ANSYS V.11 element library. SHELL 281 has 8 nodes with 6 degrees of freedom at each node; translations along x, y, z directions and rotations about the nodal x, y and z axes. SHELL 281 can be used for layered applications of a structural shell model. Up to 250 different layers are permitted for applications .The different models and mesh structures are made because of the different cutout dimensions and angles. A sample mesh structure is shown in Fig.2. As seen from this figure, small meshes are set in the vicinity of the cutout where large stress concentrations are expected. The boundary conditions and mesh structure of the model are illustrated in Fig 2 clearly.

4. Verification of results

The accuracy of the method is first checked by comparing buckling loads with the results available in literature. A comparison of buckling loads available in literature and the present study is shown in Table 2. For comparison purpose, the laminate dimensions, material properties and boundary conditions were the same as given in reference (Hsuan-Teh Hu , Bor-Horng Lin 1995). A good agreement has been observed between the results available in literature and the present study.

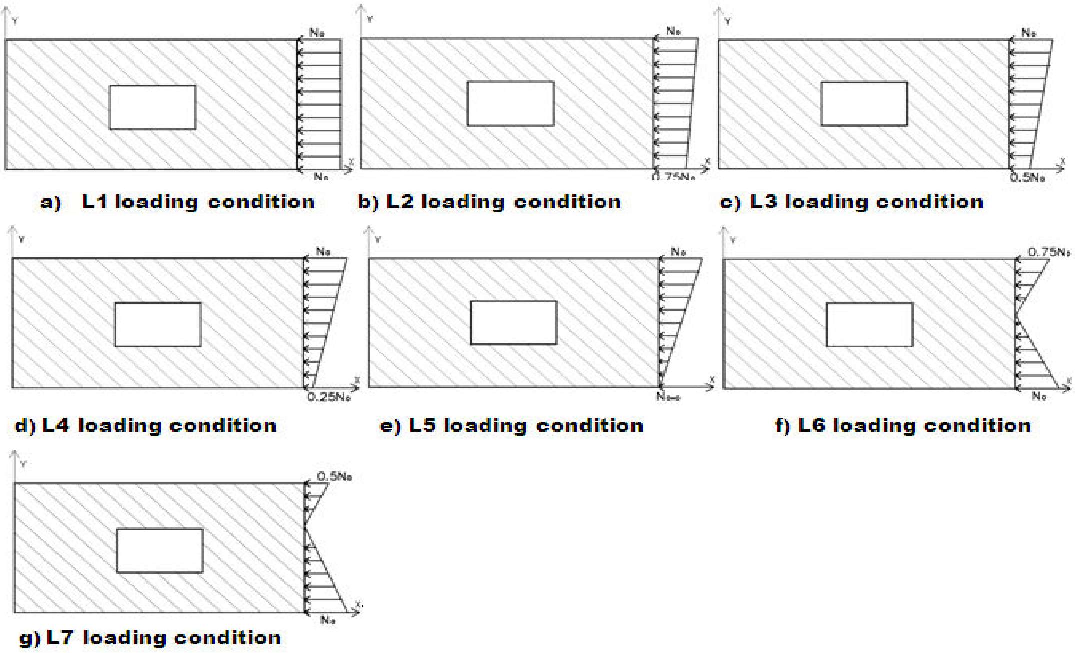


Fig.3. Details various loading conditions

Table 2: Comparison of buckling loads of composite plates under uniaxial compression load with $[40°/+40°/90°/0°]_{2s}$ laminate lay-up and with two simply supported ends and two fixed ends.

Reference	Type of plate	Buckling load (in KN/cm)	
		In reference (ABAQUS)	In present study (ANSYS)
Hsuan-Teh Hu & Bor-Horng Lin1995	Rectangular plate a/b=2	2.4	2.4
	Rectangular plate a/b=2, c/b=0.8 & d/b=0.8	3.3	3.2

5. Results and discussion

5.1. Effect of plate aspect ratio (a/b), plate length/thickness ratio (a/t), boundary conditions and various linearly varying in-plane compressive loading on buckling load of a rectangular composite plate with rectangular/square cutout.

This section deals with The effects of plate aspect ratio (a/b), plate length/thickness ratio (a/t) , boundary conditions and various linearly varying in-plane compressive loading on the buckling behavior of quasi-isotropic symmetrically laminated rectangular composite plates with rectangular/square cutout. In this section the width of the plate ‘b’ is taken as 100mm and length of the plate ‘a’ is varied between 200mm and 400mm. In this study the plate aspect ratios selected are 2, 2.5, 3, 3.5, and 4. In this study the plate length/thickness ratios (a/t) selected are 50, 66.66, 100 and 200. The thickness of the plate‘t’ taken as 1mm (8 layers), 2mm (16 layers) , 3mm (24 layers) and 4mm(32 layers). The thickness of each layer is 0.125mm.

The effects of plate aspect ratio (a/b), plate length/thickness ratio (a/t) , boundary conditions and various linearly varying in-plane compressive loading on the buckling loads of a rectangular composite plate with rectangular/square cutout are shown in Figure. 4. From figure 4 it is understood that the differences of buckling loads of a rectangular composite plate with square/rectangular cutout are approximately 35.8%, 30.4%, 26.44% and 23.4% between a/b=2-2.5, a/b=2.5-3, a/b=3-3.5 and a/b=3.5-4, respectively, irrespective of various length/thickness ratios(a/t), boundary conditions and various linearly varying inplane compressive loading. The buckling load of the rectangular composite plate with plate aspect ratio a/b=2 is approximately 1.5 times, 2 times, 3 times and 4 times higher than the buckling load of the plate with plate aspect ratio 2.5, 3, 3.5 and 4, respectively, irrespective of various length/thickness ratios (a/t), boundary conditions and various linearly varying inplane compressive loading. As the plate aspect ratio increases from 2 to 4, the decrease in the buckling load of a rectangular composite plate with square/rectangular cutout is 74%, irrespective of various length/thickness ratios (a/t), boundary conditions and various linearly varying inplane compressive loading.

The differences of buckling loads of a rectangular composite plate with square/rectangular cutout are approximately 55%, 67%, and 84% between a/t=50-66.6, a/t=66.6-100 and a/t=100-200, respectively, irrespective of various plate aspect ratios (a/b), boundary conditions and various linearly varying inplane compressive loading.

The buckling load of the rectangular composite plate with length/thickness ratio (a/t) 50 (32 layers) is approximately 2 times, 7 times and 43 times higher than the buckling load of the plate with (a/t) ratio 66.6 (24 layers), 100(16 layers) and 200 (8 layers), respectively, irrespective of various plate aspect ratios (a/b), boundary conditions and various linearly varying in-plane compressive loading conditions.

As the plate length/thickness ratio increases from 50 to 200, the decrease in the buckling load of a rectangular composite plate with square/rectangular cutout is 97%, irrespective of various plate aspect ratios ratios (a/b), boundary conditions and various linearly varying inplane compressive loading.

The magnitude of the buckling load for the composite plate under L7 type loading condition is higher than those under L1, L2, L3, L4, L5 and L6 type loading condition. The buckling load of the quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with L7,L6, L5, L4, L3 and L2 type loading condition is approximately 2.3 times, 2.2 times ,1.9 times, 1.5 times,1.3 times and 1.1 times higher than the buckling load of the composite plate with L1 type loading condition ,respectively, irrespective of various plate aspect ratios ratios (a/b), length/thickness ratios, boundary conditions and various linearly varying inplane compressive loading.

The buckling load of quasi-isotropic rectangular composite plate is highly influenced by its boundary conditions. The buckling load for the plate with CC type boundary condition is higher than the buckling load for the plate with CS type boundary condition irrespective of various plate aspect ratios ratios (a/b), length/thickness ratios & linearly varying in-plane compressive loading conditions. The buckling load of quasi-isotropic rectangular composite plate with CC type boundary condition is 2 times higher than the buckling load of the composite plate with CS type boundary condition irrespective of various plate aspect ratios ratios, length/thickness ratios & linearly varying in-plane compressive loading. As the edge support becomes rigid, buckling load of the composite plate increases irrespective of plate aspect ratios, length/thickness ratios & various linearly varying in-plane compressive loading.

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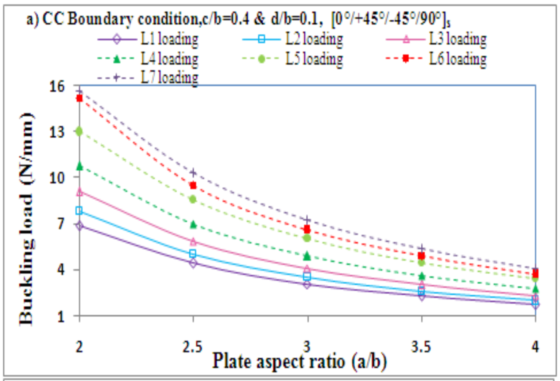

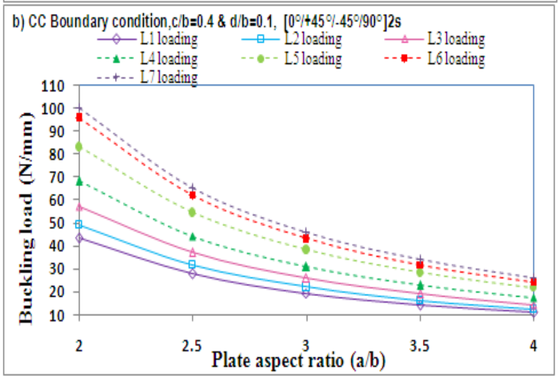

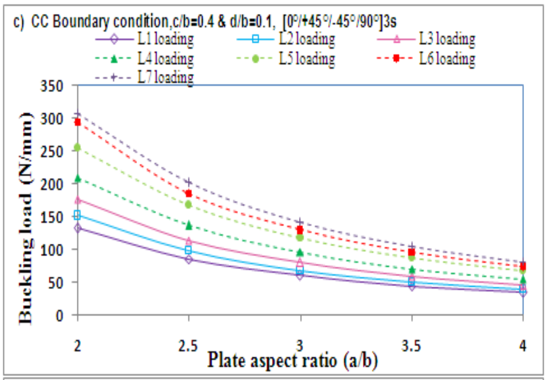

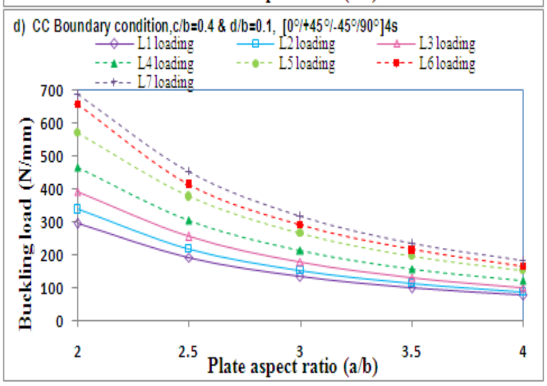

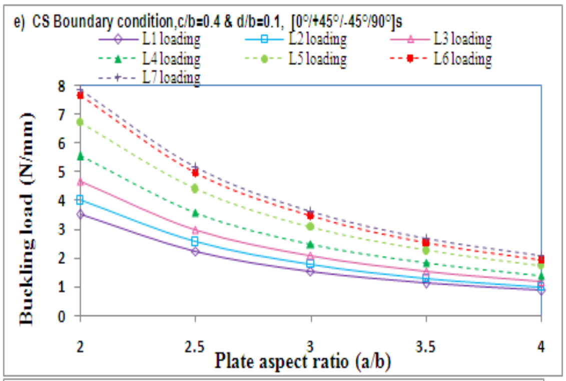

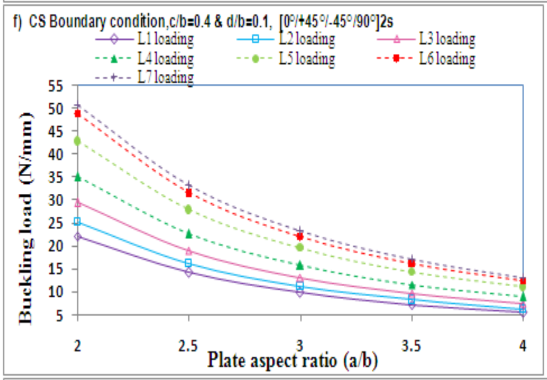

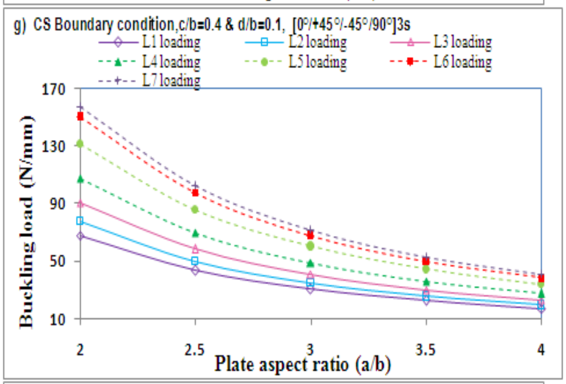

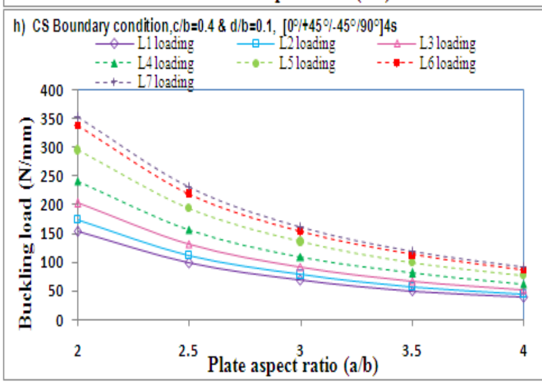

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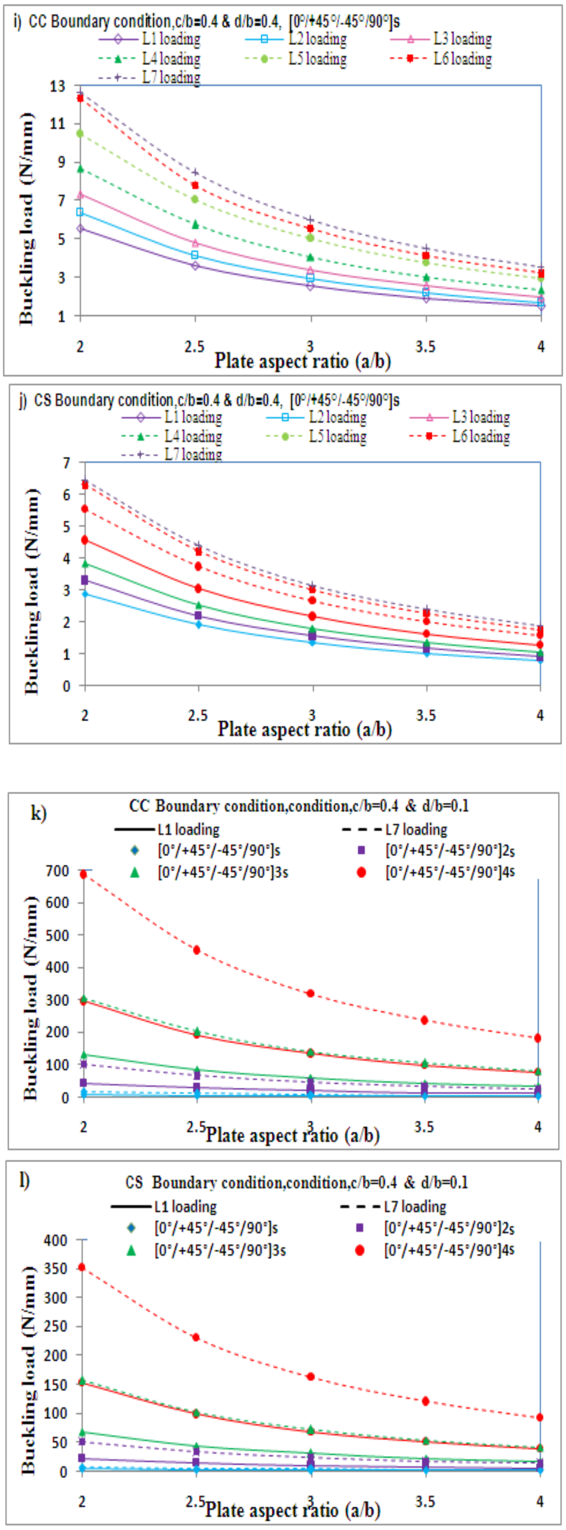

Fig.4: Effect of plate aspect ratio (a/b), plate length/thickness ratio (a/t), boundary conditions and various linearly varying in-plane compressive loading on buckling load of a rectangular composite plate with rectangular/square cutout.

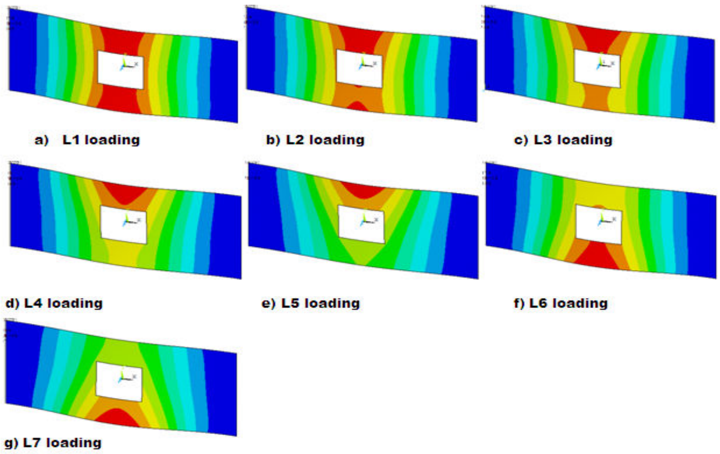

Fig.5: First buckling mode shape of the rectangular composite plate with square cutout subjected to various in-plane compressive loading conditions

Conclusions

On the basis of present study, which has dealt with the effect of plate aspect ratio ,plate length/thickness ratio, boundary conditions and various linearly varying in-plane compressive loading conditions on the buckling behaviour of a sixteen ply quasi-isotropic graphite/epoxy symmetrically laminated rectangular composite plate $[0°/+45°/-45°/90°]_{2s}$, with square/rectangular cutout, the following conclusions are drawn:

1. The buckling load of the rectangular composite plate with plate aspect ratio a/b=2 is approximately 1.5 times, 2 times, 3 times and 4 times higher than the buckling load of the plate with plate aspect ratio 2.5, 3, 3.5 and 4, respectively, irrespective of various length/thickness ratios (a/t), boundary conditions and various linearly varying inplane compressive loading.

2.As the plate length/thickness ratio increases from 50 to 200, the decrease in the buckling load of a rectangular composite plate with square/rectangular cutout is 97%, irrespective of various plate aspect ratios ratios (a/b), boundary conditions and various linearly varying inplane compressive loading.

3. The buckling load of the rectangular composite plate with length/thickness ratio (a/t) 50 (32 layers) is approximately 2 times, 7 times and 43 times higher than the buckling load of the plate with (a/t) ratio 66.6 (24 layers), 100(16 layers) and 200 (8 layers), respectively, irrespective of various plate aspect ratios (a/b), boundary conditions and various linearly varying in-plane compressive loading conditions.

4.The buckling load of the quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with L7,L6, L5, L4, L3 and L2 type loading condition is approximately

2.3 times, 2.2 times ,1.9 times, 1.5 times,1.3 times and 1.1 times higher than the buckling load of the composite plate with L1 type loading condition ,respectively, irrespective of various plate aspect ratios ratios (a/b), length/thickness ratios, boundary conditions and various linearly varying inplane compressive loading.

5. The buckling load of quasi-isotropic rectangular composite plate is highly influenced by its boundary conditions. The buckling load of the quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with CC (clamped-clamped) type boundary condition is 2 times higher than the buckling load of the composite plate with CS (clamped-simply supported) type boundary condition, irrespective of various plate aspect ratios ,plate length/thickness ratios and various linearly varying in-plane compressive loading conditions. As the edge support becomes rigid, buckling load of the composite plate increases irrespective of various plate aspect ratios and plate length/thickness ratios.

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