Effect of location of cutout and plate aspect ratio on buckling strength of rectangular composite plate with square/rectangular cutout subjected to various linearly varying in-plane loading using FEM

A. Lakshmi narayana[a], Krishnamohana Rao [b] R. Vijaya Kumar [c],

Abstract— A numerical study using finite element method (FEM) has been carried out to study the effect of plate aspect ratio and location of the cutout 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. Further, this paper addresses the effects of size of square/ rectangular cutout, location of the 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 noticed that the boundary conditions, various linearly varying in-plane loads, , 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. It is observed that the location of the square/rectangular cutout has substantial influence on buckling strength of rectangular composite plate irrespective of size and shape of cutout, orientation of cutout, plate aspect ratio (a/b), plate length/thickness ratio(a/t), boundary conditions and various linearly varying in-plane compressive loads.

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

I. 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 [23].

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 [13]. 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 [22].

Jana P[13], Chai G.B et al. [4], Hu. H et al. [10], Nemeth [17], Zhong.H [24] , Kumar panda.S [15], Leissa A.W [14] [16] , Shufrin. I et al.[18] [19], Singh S.B [20], Mohammad H.Kargarnovin, Ahmad mamandi[26] , Mohieddin Ghomshei, Oulad dameshghie[27], 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 [2] [3] Husam AQ et al. [11], Srivatsa K.S [21] studied the buckling response of composite plate with circular cutout subjected to uniform uniaxial compression load using finite element method. Dinesh Kumar [5], Hani Aziz Ameen [7], Ghannadpour S.A.M et al. [6], Jain.P [12] , Aydin Komur.M et al[1], Lakshmi narayana.A et al.[25] studied the buckling response of composite plate with circular/elliptical cutout subjected to uniform uniaxial compression load using finite element method.

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Lakshmi narayana.A et al.[26] studied the buckling response of composite plate with square/rectangular cutout subjected to various linearly varying compression loading using finite element method. Topal U [22], Hsuan-Teh Hu [8][9] 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 location of the cutout, 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 location of the cutout(fx,fy), 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.

II. PRESENT STUDY

In this study, a numerical study using FEM has 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 [8]) and listed in Table I.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 I: Material properties of the graphite/epoxy composite material (Hsuan-Teh Hu , Bor-Horng Lin [8])

E_{11} (GPa)	E_{22} (GPa)	v_{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 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. The location of the cutout is represented by fx and fy. fx is the ratio of distance from the edge of the plate to the center of the cutout (in x-direction), to the plate length (a). fy is the ratio of distance from the edge of the plate to the center of the cutout (in y-direction), to the plate width (b).

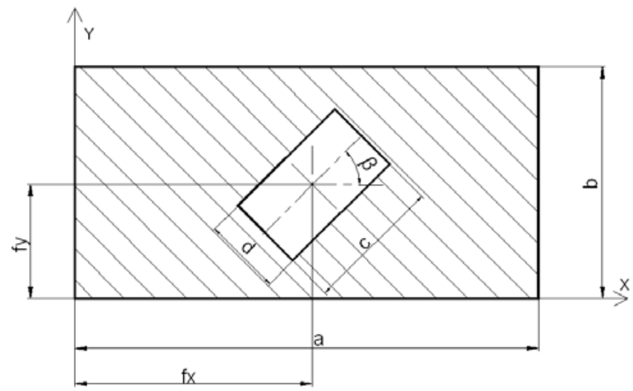
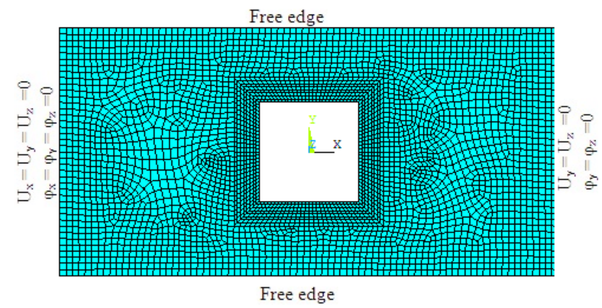
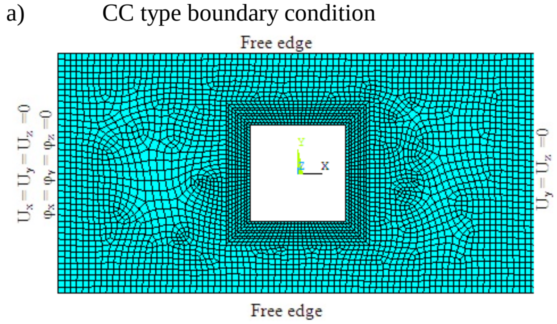


Fig.1.Geometry of the model.



a) CC type boundary condition



b) CS type boundary condition

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

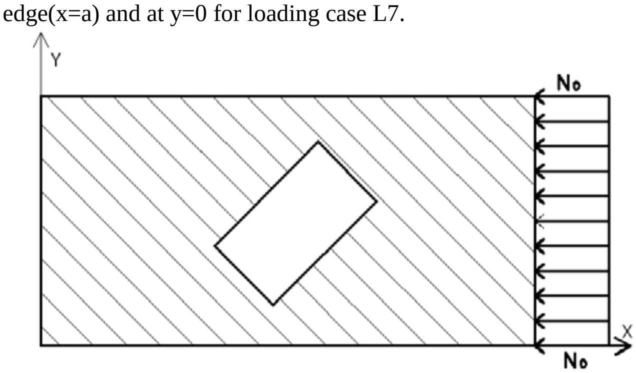
III. FINITE ELEMENT MODELLING

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.

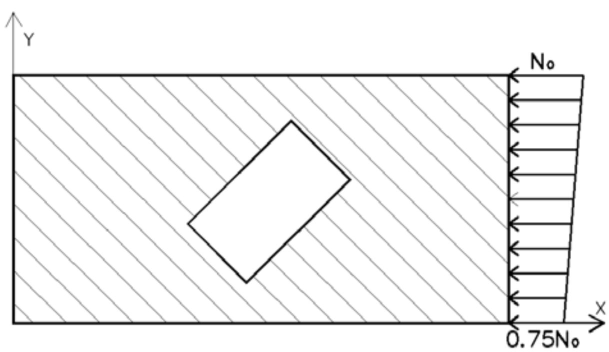
The boundary conditions have a significant influence on the buckling behavior of rectangular composite plate with rectangular/square cutout subjected to various linearly varying in-plane compressive loads. In this study the rectangular composite plate is evaluated at two different boundary conditions.

Two types of boundary conditions, namely CC and CS are considered; CC refers to a plate with two longitudinal edges (x=0 and x=a) clamped and the other two edges free (i.e y=0and y=b) and CS refers to a plate with one edge (x=0) clamped , other edge (x=a) simply supported and the other two edges free (i.e y=0 and y=b).

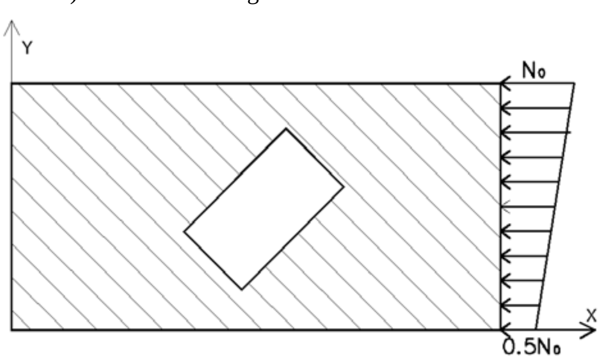
Seven types of loading conditions are considered, namely L1, L2, L3, L4, L5,L6 and L7 which are shown Fig.3. N_0 is intensity of compressive force at the plate edge(x=a) from y=0 to y=b for loading case L1; intensity of compressive force at the plate edge(x=a) and at y=b for loading case L2; intensity of compressive force at the plate edge(x=a) and at y=b for loading case L3; intensity of compressive force at the plate edge(x=a) and at y=b for loading case L4; intensity of compressive force at the plate edge(x=a) and at y=b for loading case L5; intensity of compressive force at the plate edge(x=a) and at y=0 for loading case L6; intensity of compressive force at the plate edge(x=a) and at y=0 for loading case L7.



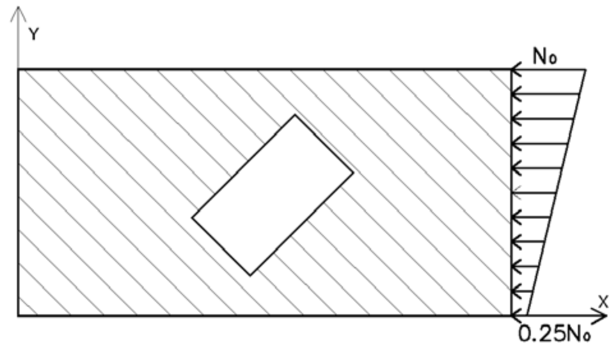
a) L1 loading condition



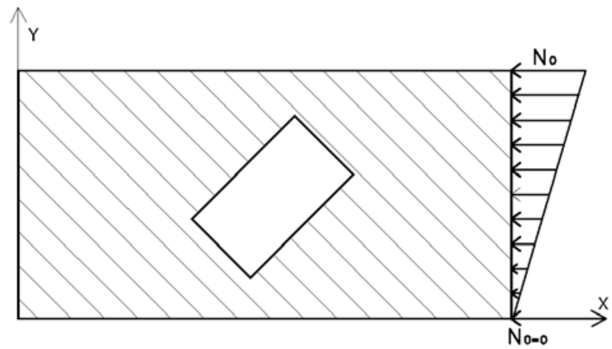
b) L2 loading condition



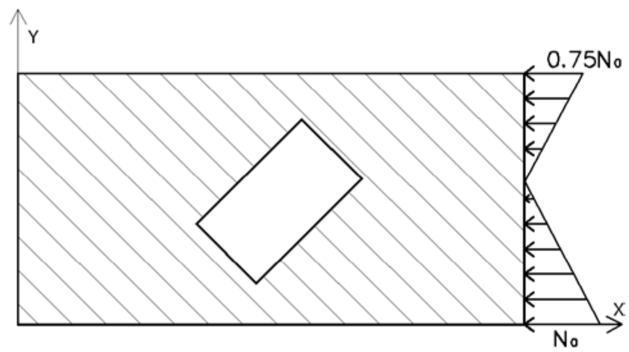
c) L3 loading condition



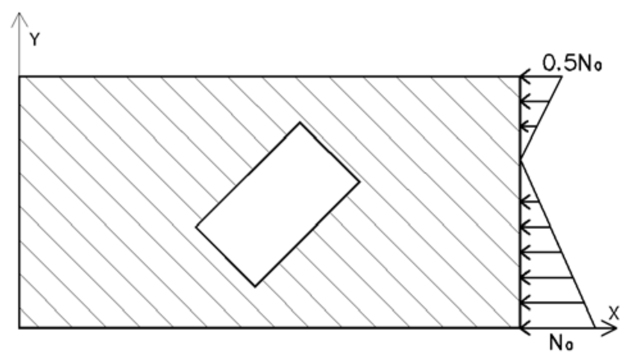
d) L4 loading condition



e) L5 loading condition



f) L6 loading condition



g) L7 loading condition

Fig.3. Details various loading conditions

IV. 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 II. 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 [8]). A good agreement has been observed between the results available in literature and the present study.

Table II: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 Lin[8]	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

V. RESULTS AND DISCUSSION

A. 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. In this study cutout orientation angle is assumed as zero degrees.

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.

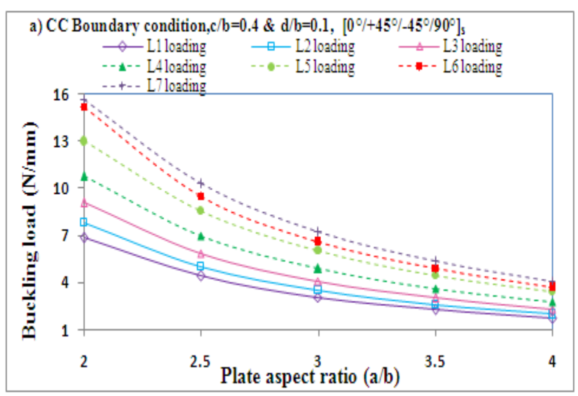
The differences of buckling loads of a rectangular composite plate with square/rectangular cutout are approximately 55%, 67%, and 84% between a/t=50-66.6, a/t=66.6-100 and a/t=100-200, respectively, irrespective of various plate aspect ratios (a/b), boundary conditions and various linearly varying inplane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

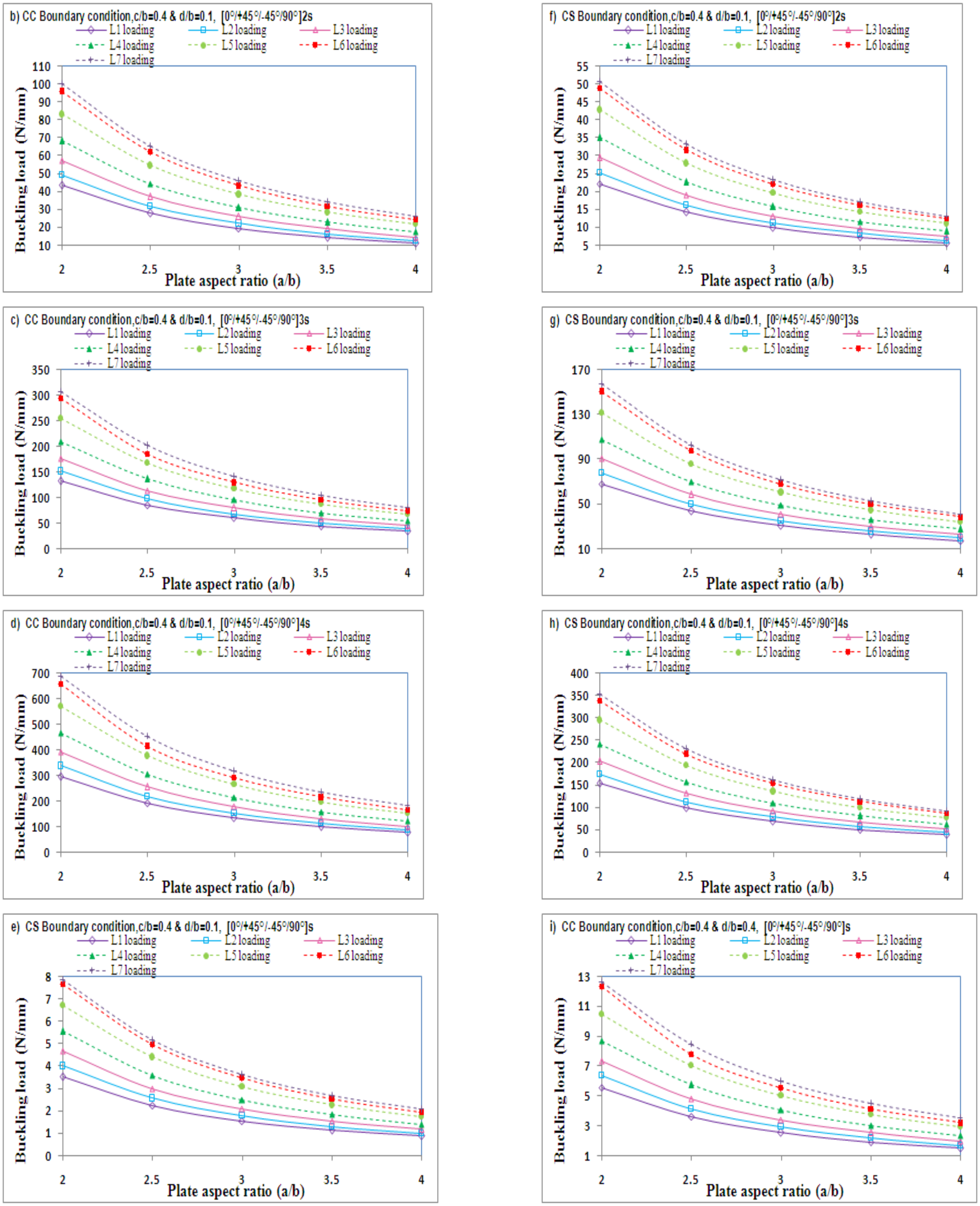
As senn from figure 4,The buckling load of the rectangular composite plate with length/thickness ratio (a/t) 50 (32 layers) is approximately 2 times, 7 times and 43 times higher than the buckling load of the plate with (a/t) ratio 66.6 (24 layers), 100(16 layers) and 200 (8 layers), respectively, irrespective 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.

As seen from figure 4,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 of 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.

As seen from figure 4, 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 of 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.




b) CC Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]2s
f) CS Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]2s
c) CC Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]3s
g) CS Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]3s
d) CC Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]4s
h) CS Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]4s
e) CS Boundary condition,c/b=0.4 & d/b=0.1, [0°/+45°/-45°/90°]s
i) CC Boundary condition,c/b=0.4 & d/b=0.4, [0°/+45°/-45°/90°]s
L1 loading
L2 loading
L3 loading
L4 loading
L5 loading
L6 loading
L7 loading
Buckling load (N/mm)
Plate aspect ratio (a/b)

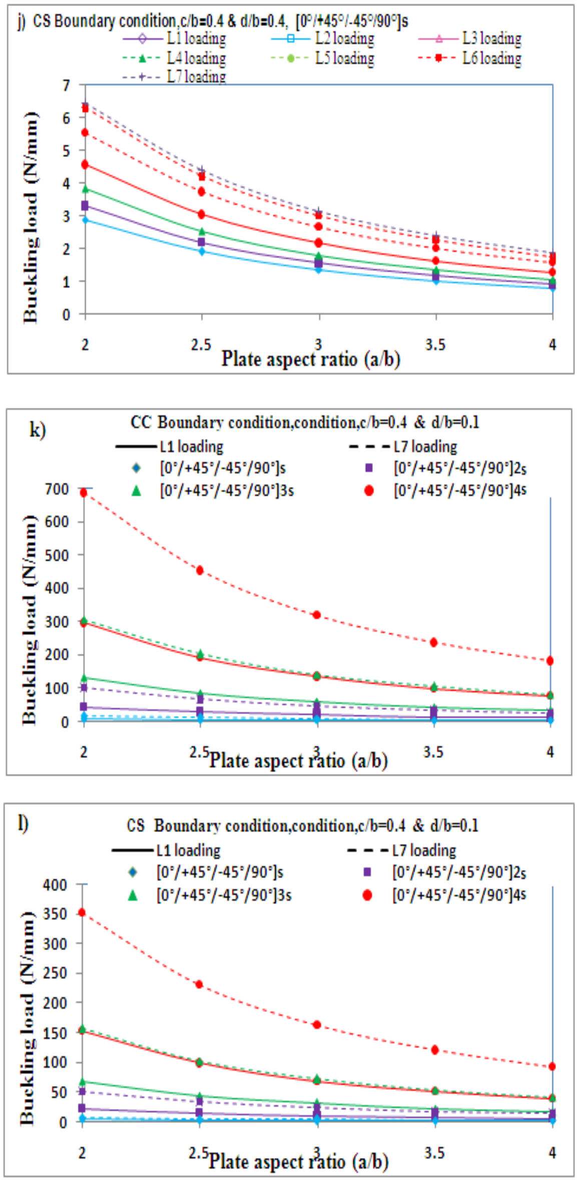


Fig.4: Effect of plate aspect ratio (a/b), plate length/thickness ratio (a/t), boundary conditions and various linearly varying in-plane compressive loading on buckling load of a rectangular composite plate with rectangular/square cutout.

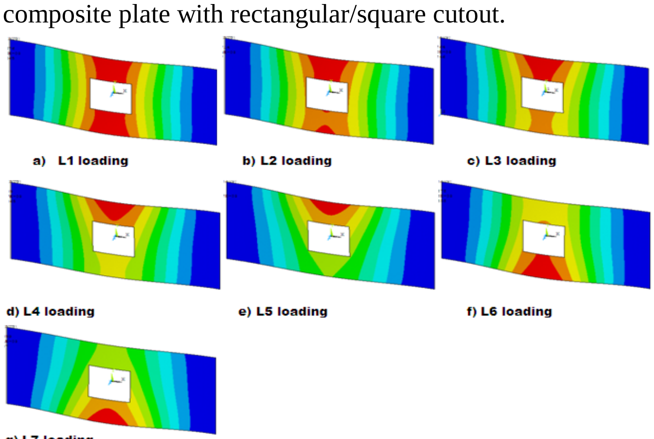


Fig.5: First buckling mode shape of the rectangular composite plate with square cutout subjected to various in-plane compressive loading conditions

B. Effect of location of cutout(fx,fy), 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 location of the cutout(fx, fy),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 ,for figures 6a to 6f,the width of the plate ‘b’ is taken as 100mm and length of the plate ‘a’ is taken as 200mm furthermore, the plate aspect ratio and length/thickness ratio (a/t) selected are2and 100,respectively. The thickness of each layer is 0.125mm and total thickness ‘t’of the plate is 2mm. in this study for figure 6g and 6h, the plate aspect ratios (a/b) selected are 2, 2.5, 3, 3.5, and 4. The width of the plate ‘b’ is taken as 100mm and length of the plate ‘a’ varied from 200mm to 400mm. In this study for figures 6i to 6j, the plate length/thickness ratios (a/t) selected are 50, 66.66, 100 and 200 and plate aspect ratio is 2.

As seen from figure 6a, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular cutout i.e c/b=0.4,d/b=0.1, subjected to L1 type loading and CC boundary condition, as the cutout orientation angle β increases from 0° to 90°, the decrease in buckling load for the cutout location fx=0.2, fx=0.4 and fx=0.5 is 2.7%, 10% and 13%,respectively.

The effect of the cutout orientation is significant when the cutout is at the centre of the plate i.e. fx=0.5. The effect of the cutout orientation is insignificant when the cutout moves towards the edge i.e. from fx=0.5 to fx=0.2.

According to figure 6b, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular cutout i.e. c/b=0.4,d/b=0.1, subjected to L1 type loading and CC boundary condition, as the cutout orientation angle β increases from 0° to 90°,the decrease in buckling load for the cutout location fy=0.3, fy=0.4 and fy=0.5 is 13.6%,13.9% and 14.2%,respectively.

The effect of the cutout orientation is same when the cutout moves in y direction i.e. from fy=0.3 to fy=0.5.In otherwords, there is no change in effect of cutout orientation when the cutout moves in y-direction.

As seen from figure 6c, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular/square cutout i.e. c/b=0.4, β=0 , subjected to L1 type loading and CC boundary condition ,as the cutout moves from the edge of the plate to center of the plate i.e.from fx=0.2 to fx=0.5 , the decrease in the buckling load by increasing the d/b ratio from 0.1,0.2, 0.3 and 0.4 is 3%, 6%, 8%, 10%,respectively.

As the size of the cutout increases the effect of the location of the cutout is significant.

As seen from figure 6d, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular/square cutout i.e. c/b=0.4, β=0, subjected to L1 type loading and CC boundary condition ,as the cutout moves from the edge of the plate to center of the plate i.e. from fy=0.3 to to fx=0.5 , the decrease in the buckling load by increasing the d/b ratio from 0.1to 0.2, 0.3 and 0.4 is 0.2%, 0.05%, 0.1%, 0.6%, respectively. The decrease in buckling load is almost negligible.

As the size of the cutout increases or decreases the effect of the location of the cutout, when the cutout moves in the Y direction is insignificant.

As seen from figure 6e, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular cutout i.e. c/b=0.4, d/b=0.1, β=0 , subjected to CC boundary condition ,as the cutout moves from the edge of the plate to center of the plate i.e.from fx=0.2

to fx=0.5 , the decrease in the buckling load is approximately 3%,irrespective of type of load.

As seen from figure 6f, for quasi-isotropic$[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular cutout i.e. c/b=0.4, d/b=0.1, β=0 , subjected CS boundary condition ,as the cutout moves from the edge of the plate to center of the plate i.e.from fx=0.2 to fx=0.5 , the decrease in the buckling load is approximately 1.5%,irrespective of type of load.

According to figure 6e and 6f, as the cutout moves from the edge of the plate to centre of the plate i.e from fx=0.2 to fx=0.5, buckling load decreases irrespective of type of loading and boundary condition. Second important point from the figure 6e and 6f is the reduction in buckling is twice when the plate is with CC boundary condition to that of plate with CS boundary condition, irrespective of various linearly varying in plane loads.

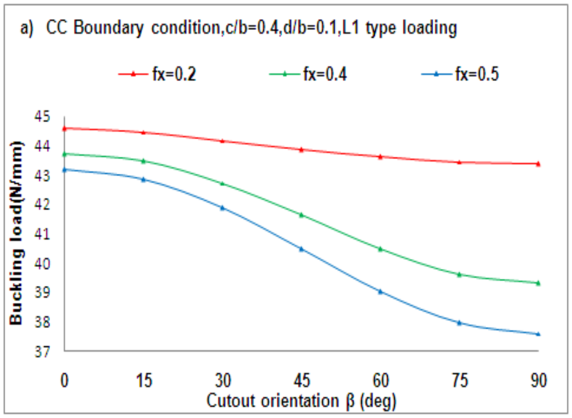
As seen from figures 6e and 6f, the magnitude of the buckling load for the composite plate under L7 type loading condition is higher than those under L1, L2, L3, L4, L5 and L6 type loading condition. The buckling load of the quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with L7,L6, 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 of the buckling load of the composite plate with L1 type loading condition ,respectively, irrespective of location of the cutout, boundary conditions .

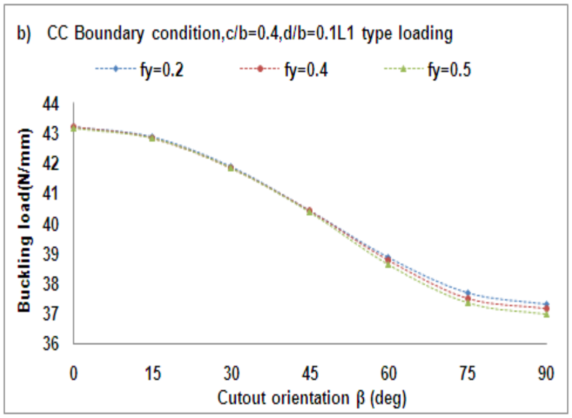
As seen from figure 6g, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular cutout cutout i.e. c/b=0.4,d/b=0.1, subjected to L1 type loading and CC boundary condition, as the cutout orientation angle β increases from 0° to 90°, the decrease in buckling load increases as the cutout location moves towards centre of the plate from the edge of the plate i.e from fx=0.2 to fx=0.5, irrespective of plate aspect ratio (a/b). As the cutout orientation angle β increases from 0° to 90°and as the plate aspect ratio increases, the decrease in the buckling load decreases as the cutout location moves towards centre of the plate from the edge of the plate i.e from fx=0.2 to fx=0.5. Second important point from figure 6g ,for the rectangular composite plate with aspect ratio a/b=2, as the cutout orientation angle β increases from 0° to 90°,the decrease in buckling load for the cutout location fx=0.2, fx=0.4 and fx=0.5 is 2.7%,10% and 13%,respectively.

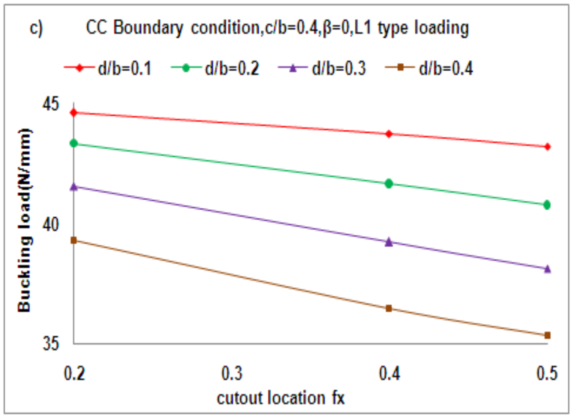
According to figure 6h, for quasi-isotropic $[0°/+45°/-45°/90°]_{2s}$ rectangular composite plate with rectangular cutout/square cutout i.e. c/b=0.4,db=0.1&d/b=0.4, β=0 , subjected to L1 type loading and CC boundary condition, the buckling load of the plate with plate aspect ratio a/b=2 is approximately 2 times and 4 times of the plate with plate aspect ratio 3 and 4 respectively, irrespective of location of the cut out i.e. fx=0.2,fx=0.4 and fx=0.5.

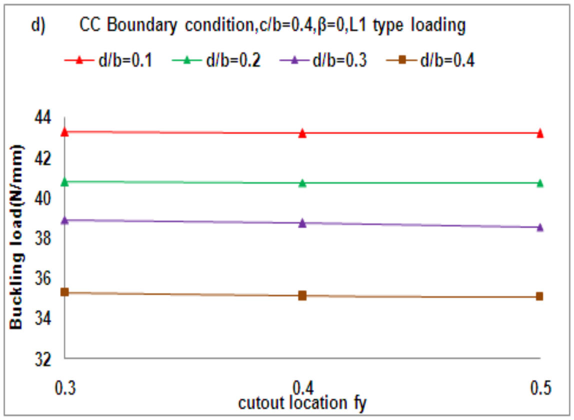
As seen from figure 6i, for quasi-isotropic rectangular composite plate with rectangular cutout cutout i.e. c/b=0.4,d/b=0.1, subjected to L1 type loading and CC boundary condition with Plate length to thickness ratio a/t=50(32 layers), as the cutout orientation angle β increases from 0° to 90°, the decrease in buckling load for the cutout location fx=0.2, fx=0.4 and fx=0.5 is 3%, 10% and 13%,respectively. Second important point from the figure 6i is, as the cutout orientation angle β increases from 0° to 90°,the decrease in buckling load increases as the cutout location moves towards centre of the plate from the edge of the plate i.e from fx=0.2 to fx=0.5,irrespective of plate length to thickness ratio (a/t). Further more, as the cutout orientation angle β increases from 0° to 90° and as the plate length to thickness ratio (a/t) increases from 50 to 200 ,the decrease in buckling load is approximately constant for a particular location of the cutout. The decrease in the buckling load is different for different location of cut but constant for a particular location of the cutout.

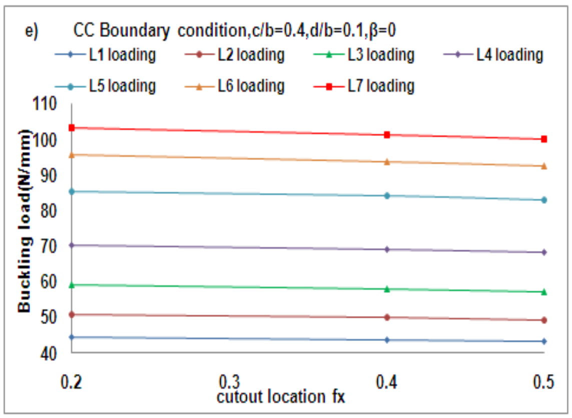
According to figure 6j, the buckling load of the rectangular composite plate with rectangular/square cutout c/b=0.4,d/b=0.1&0.4,(a/b)=2 and (a/t) ratio 50 (32 layers) is approximately 2 times,7 times and 43 times of the buckling load of the plate with (a/t) ratio 66.6 (24 layers),100(16 layers) and 200 (8 layers), respectively, irrespective of the location of the cut out i.e fx=0.2,fx=0.4 and fx=0.5.

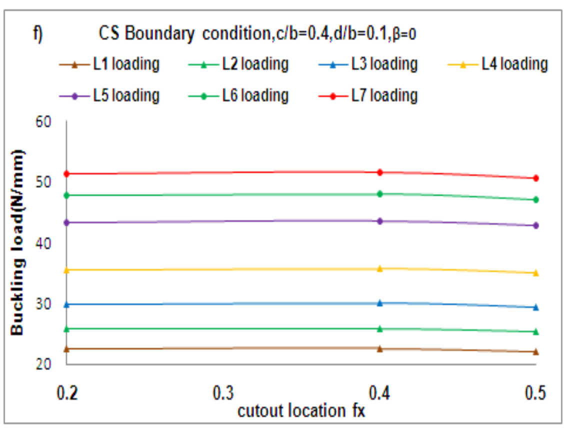


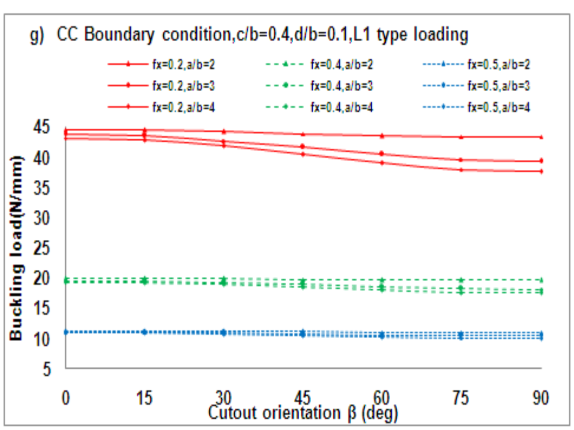


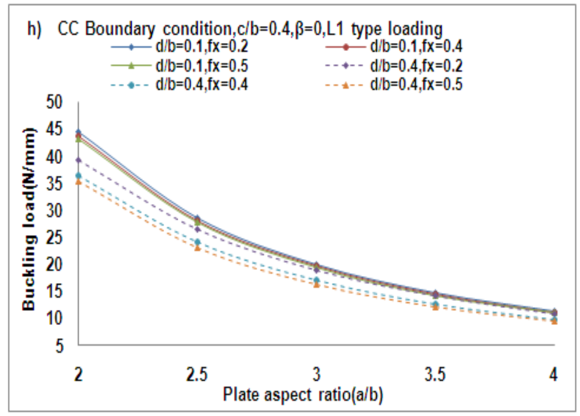


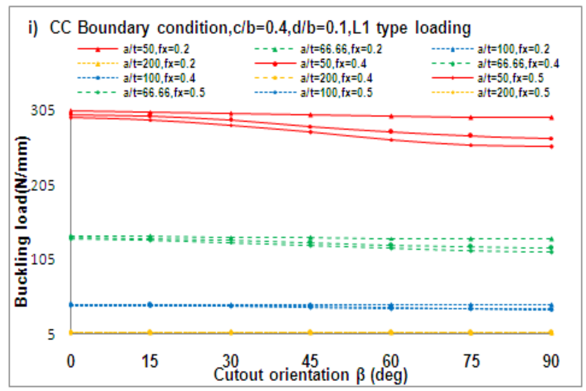












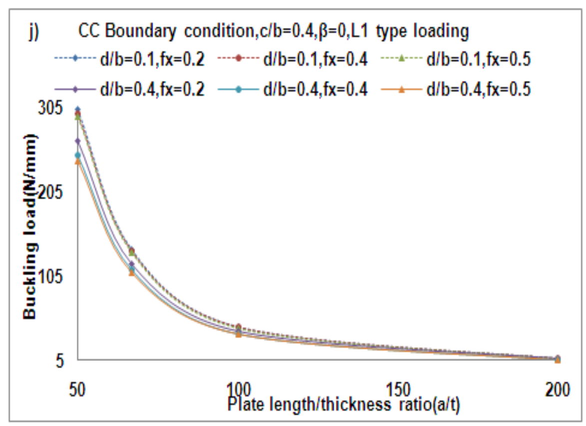


Fig.6: Effect of location of the cutout(fx,fy),cutout orientation, plate aspect ratio (a/b), plate length/thickness ratio (a/t), boundary conditions and various linearly varying in-plane compressive loading on buckling load of a rectangular composite plate with rectangular/square cutout.

VI. CONCLUSIONS

On the basis of present study, which has dealt with the effect of location of the cutout, 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 of 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.

6. The effect of the cutout orientation is significant when the cutout is at the centre of the plate i.e. fx=0.5. The effect of the cutout orientation is insignificant when the cutout moves towards the edge i.e. from fx=0.5 to fx=0.2.

7. The effect of the cutout orientation is same when the cutout moves in y direction i.e. from fy=0.3 to fy=0.5.In otherwords, there is no change in effect of cutout orientation when the cutout moves in y-direction.

8. As the size of the cutout increases the effect of the location of the cutout, when the cutout moves in the x-direction is significant i.e from fx=0.5 to fx=0.2.

9. As the size of the cutout increases or decreases the effect of the location of the cutout, when the cutout moves in the y-direction is insignificant i.e from fy=0.5 to fy=0.3.

10. As the cutout moves from the edge of the plate to centre of the plate i.e from fx=0.2 to fx=0.5, buckling load decreases irrespective of various linearly varying in plane loads and boundary condition. As the cutout moves from the edge of the plate to the center of the plate i.e from fx=0.2 to fx=0.5, the reduction in buckling is twice when the plate is with CC boundary condition to that of plate with CS boundary condition, irrespective of various linearly varying in plane loads.

11. 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 of the buckling load of the composite plate with L1 type loading condition ,respectively, irrespective of location of the cutout, boundary conditions .

12. the buckling load of the plate with plate aspect ratio a/b=2 is approximately 2 times and 4 times of the plate with plate aspect ratio 3 and 4 respectively, irrespective of location of the cut out i.e. fx=0.2,fx=0.4 and fx=0.5.

13. As the cutout orientation angle β increases from 0° to 90°, the decrease in buckling load increases as the cutout location moves towards centre of the plate from the edge of the plate i.e from fx=0.2 to fx=0.5, irrespective of plate aspect ratio (a/b). As the cutout orientation angle β increases from 0° to 90°and as the plate aspect ratio increases, the decrease in the buckling load decreases as the cutout location moves towards centre of the plate from the edge of the plate i.e from fx=0.2 to fx=0.5.

14.Buckling load of the rectangular composite plate with rectangular/square cutout, plate aspect ratio(a/b)=2 and plate length/thickness ratio (a/t) 50 (32 layers) is approximately 2 times,7 times and 43 times of the buckling load of the plate with (a/t) ratio 66.6 (24 layers),100(16 layers) and 200 (8 layers), respectively, irrespective of the location of the cut out i.e fx=0.2,fx=0.4 and fx=0.5.

15. As the cutout orientation angle β increases from 0° to 90°,the decrease in buckling load increases as the cutout location moves towards centre of the plate from the edge of the plate i.e from fx=0.2 to fx=0.5,irrespective of plate length to thickness ratio (a/t).

As the cutout orientation angle β increases from 0° to 90° and as the plate length to thickness ratio (a/t) increases from 50 to 200, the decrease in buckling load is approximately constant for a particular location of the cutout. The decrease in the buckling load is different for different location of cutout but constant for a particular location of the cutout.

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