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Buckling Analysis of Composite Laminated Plate with Cutouts

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Abstract

The determination of critical buckling load of composite plate is an important factor in determining the structural stability, which was done by ANSYS program and experimental investigation was carried out on many specimens of composite material of E-glass fiber reinforced polyester plastic materials with different no. of layers. Five cases are studied to show the effect of cutout's parameter on the structural stability in which the shape (circle, square, rectangle), size (20, 30, 50) mm, rounding corner (5, 7.5, 10)mm and orientation of cutouts (0°,30°,45°,60°) are presented . Also the effect of plate thickness (no. of layer) is studied .

In general , the results of the square clamped laminated plates with circle cutout come out in a good agreement. Which is decrease of buckling load of the plates with change the shape from circle, square and rectangle and in case of cutout size. The critical load is still constant with the radii rounding corner and increased with increasing the cutout orientation and the thickness of the plate. The effect of cutout will determine the increase or decrease of the buckling .

Keywords: Composite Materials, Buckling Analysis , Finite Element Method, ANSYS program , Eigenvalue and Eigenvector Analysis.

تحليل الانبعاج للصفائح المركبة الحاوية على ثقوب

الخلاصة

ان حساب احمال الانبعاج للصفائح المركبة عامل مهم في حساب استقرارية الهياكل ، حيث تم تنفيذ الحسابات في برنامج ANSYS و تم اجراء الدراسة عمليا على معظم العينات للصفائح المركبة من عدة طبقات المصنوعة من الياف E-glass ومادة البوليستر . خمس حالات تم دراستها لتوضيح تاثير عوامل الثقوب على استقرارية الهياكل من حيث شكل الثقوب (دائرة ، مربع ، مستطيل) ، حجمها (20 ، 30 ، 50) ملم ، تدوير حواف الثقوب (5 ، 7.5 ،10) ملم واتجاه تدويرها (0 ، 30° ، 45°،60°) وكذلك دراسة تأثير سمك الصفائح (عدد الطبقات) .
بصورة عامة، لقد بينت النتائج بان الصفيحة المركبة بطبقات مع ثقب دائري كانت الافضل. حيث ان حمل الانبعاج الحرج يقل مع تغير الشكل من دائرة الة مربع الى مستطيل وايضا بتغيير حجم الثقوب اما في حالة تدوير حواف الثقوب فان الحمل الحرج يبقى ثابتا ويزداد الحمل الحرج مع زيادة اتجاه الثقب وسمك الصفيحة . لذا فان تاثير الثقوب هو اما زيادة او نقصان الحمل الحرج .

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Introduction

Composite laminated plates when loaded in compression are subjected to a type of behavior known as buckling as long as the load on the plate is relatively small, then any increase in the load results only in an axial shortening of the plate. However once a certain critical load is reach, the plate suddenly bows out sideways. This bending gives rise to large deformations, which cause the plate collapse. The load at which buckling occurs is thus a design criterion for compression plate.

In 1964 Schlack [1] used Rayleigh- Ritz method to analyze the buckling behavior of a simple supported square plate with a circular hole. Martin [2] in 1972 studies of the buckling of square uniaxial compression loaded composite plates that have a cutout. In 1986 Marshall, Little, El-Tayeby, and Williams [3] presented results for buckling of especially orthotropic rectangular plates with longitudinally eccentric circular cutout. In 1987 Nemeth , Stein , and Johnson [4] summarized the approximate analysis and gave additional analytical results for square especially orthotropic graphite – epoxy plates that have a central circular cutout. In 1989 Lee [5] examined the buckling behavior of square plate with a central circle hole using finite element method. A buckling behavior of sequence laminated composite plate , each with a central circular cutout was presented by Lin and Kuo [6] in 1989. William [7], studied the mechanical and thermal buckling behavior of rectangular steel plates with central circular and square cutout. In 1990 Rouse [8] presented an experimental investigation of the buckling and post buckling behavior of square graphite- epoxy and graphite – thermoplastic plates loaded in shear. In 1991 Yasui [9] presented the study of buckling behavior of laminated composite plates with a central cutout that has been obtained by using the finite element method. In 2004 [10] Jameel study the elastic buckling plate behavior with circular hole .

The main purpose of the present work is to study the structural behavior of composite laminated plates (E-glass-polyester plate) with cutouts by determining the critical buckling loads. The analysis involved obtaining the eigenvalue buckling loads in which the following parameters were examined: no. of laminated layers, the cutout sizes, cutout shapes and orientation of perforated laminated plates and the radii of rounding corners of a square cutout on the compressive buckling loads of the plates. The above investigation can be achieved by using ANSYS, finite element program to analyze the critical buckling load including their eigenvalue buckling load. The experimental investigation will be carried out on many specimens of composite materials of fiber reinforced plastic materials with different no. of layers and cutouts in which the specimen is manufactured by E-glass and polyester .

Preparation of Testing Specimens:[11]

The composites plate that prepared for this study were consisted of E-glass fiber plies in a thermosetting polyester matrix. This was manufactured by hand lay-up technique. The thicknesses of the glass fabrics were approximately (2.75 mm) with an a real density of (400g/cm^2).

The resin matrix employed was a low viscosity thermosetting polyester resin commonly used for hand lay-up at room temperature. This resin is cured at 70^{o}C and designed to wet easily the reinforcement fabrics employed in hand lay-up construction. The catalyst used was methyl ethyl keton polymer (MEKP) After hand laying-up construction is done, the specimens were heated to 70^{o}C in an oven with sufficient pressure to get rid of the excess resin and entrapped air bubbles. The specimens are shown in Figure(1).

Figure(2) show the tensile test results for composite laminated plate .

The different specimens were manufactured by hand-laying as mentioned before, testing these specimens will help to study the effect of changing different cutout characteristics, as shape, size, fillet and rotation of cutouts and study the influence of each one of these characteristic on the behavior of the composite material. All these different cutouts are shown in Figure(1).

Compression device and it components

The compression testing device (Fig.(3)) was fully designed and manufactured locally [12]. The instrument was tested to verify its proper functioning during applying uniaxial or biaxial compression results. The device is consisted of:

1- Frame: The frame made from double steel channel (30 x 80 x 30 mm).
2- Die: The die is made of steel and divided into two parts:
    - The angle plate (250 x 250 x 20 mm).
    - Two plates which move freely in one direction guided with a (150 x 150 x 20 mm) steel shaft.
3- Hydraulic Jacks: two hydraulic jacks with maximum pressing force of (80000N) are used to press the two plates of the die.
4- The two 600 bars analog pressure gages to read the applied pressure by the hydraulic jacks.

This device is manufactured so that the compression force can be applied either uniaxial or biaxial

Buckling analysis by ANSYS finite element techniques [13]

Two techniques are available in the ANSYS/Mechanical, programs for predicting the buckling load of a structure: nonlinear buckling analysis and eigenvalue (or linear) buckling analysis. Since these two methods frequently yield quite different results.

Eigenvalue buckling analysis predicts the theoretical buckling strength (the bifurcation point) of an ideal linear elastic structure. This method corresponds to the approach of elastic buckling analysis: for instance, an eigenvalue buckling analysis of a column will match the classical Euler solution. However, imperfections and nonlinearities prevent most real-world structures from achieving their theoretical elastic buckling strength.

Linear buckling analysis in ANSYS finite – elements software is performed in two steps. In the first step a static solution to the structure is obtained . In this analysis the prebuckling stress of the structure is calculated. The second step involves solving the eigenvalue problem given in the form of the following equation :

$$([K]+l_i[S])\{y_i\}=\{0\}$$

Where

[K] = stiffness matrix

[S] = stress stiffness matrix

l_i = ith eigenvalue (used to multiply the loads which generated [S])

y_i = ith eigenvector of displacements

The buckling analysis is defined as the analysis type (ANTYPE, Buckle) and the analysis option (Bucopt) in which the solution methods is chosen either subspace iteration method (Subspac) which is generally recommended for eigenvalue buckling because it uses the full system matrices, and the other method is the Householder method (Reduced).

After that, the no. of eigenvalue to be extracted is chosen by activating the no. of modes to expand, the command (MXPAND).

Finite Element Analysis of the Composite Plate [13]

The composite plate is represented by the shell element; (SHELL91), this element is used for layered applications of structural shell model. This element is shown in Figure (4).

The element has six degrees of freedom (three translations (u,v and w) and three rotations (θ_x, θ_y and θ_z)). After defining the element type. The material properties must be defined, so, the material properties used are listed in Table (1) which have gained from the tensile test of the composite laminated specimens which are manufactured by E-glass and Polyster Figure (1)).

Finite Element Model [13]

Figure(5) shows the finite element model. In the present work a complete ANSYS Parametric Design Language (APDL program) is made to build the model and analyze the composite laminated plate with buckling load by ANSYS software the steps as follows:

```
/prep7
! Model Drawing
! outer rectangular
rectng,-9/100,9/100,-9/100,9/100
!  cutout ! inner circle
 cyl4,0,0,19/1000
 AsbA,1,2
! composite material three layer
ET,1,SHELL91,,1,,0,4,1,1
R,1,3  ! no. of layer = 3
RMORE
RMORE,1,0,2.25e-3/3
RMORE,1,0,2.25e-3/3
RMORE,1,0,2.25e-3/3
  MP,EX,1,2.1e9      ! Young Moduls
  MP,NUXY,1,0.32      ! possion ratio
  MP,Dens,1,1837     ! density
! meshing
ASEL, , , ,      3
AMESH,all
finish
! Solution
/solu
antype,static
pstres,on
!  Boundatry conditions
   Lsel,s,,,2,3,1
   nsll,s,1
   D,all,all
   allsel,all
! applied load
   Lsel,s,,,1
   nsll,s,1
!D,all,ux,0,,,,uz,rotx,roty,rotz
   f,all,fy,1    ! unit load
   Lsel,s,,,4
   nsll,s,1
!D,all,uy,0,,,,uz,rotx,roty,rotz
   f,all,fx,1    ! unit load
   allsel,all
Solve
Finish
/solu
antype,buckle       !buckling analysis
bucopt,subsp,2       ! 2 no. of mode shape
mxpand,2            ! 2 no. of mode shape
solve
*get,Fcr1,mode,1,freq
*get,Fcr2,mode,2,freq
*status
Finish
```

Case Studies:

All models are square in the form with their area kept the same (in case of changing the shape of cutout) and in other models are not and with different thickness of plate. In which three shapes of same area cutout were investigated (circle , rectangle and square) and also three values of cutout areas are changed and examined , and three radii of rounding corner of cutout has been examined (5,7.5,10)mm and four angles for cutout orientation were examined (0°, 30°, 45° and 60°) and the plate thickness is examined (2.75 , 3 , 3.75) mm these for three , four and five layers. The plate is clamped in two sides and subjected to uniaxial compressive loads in the (y) direction and (x) direction.

The ANSYS finite element program is used to analyze the above studies cases. The experimental investigation carried out on many specimens of composite materials to determine the critical buckling load . The results is compared with the numerical ANSYS techniques and good agreement is achieved .

Results and Discussion

Numerical ANSYS calculation values of compression loads are compared with the experimental values and an error of about (5%) was established for the following cases:

1- Effect of Cutout Shapes

Table(2) demonstrate the effect of the cutout shape. It is shown that the buckling critical load in the case of circle cutout is more that of the square and rectangle cutout.

2 - Effect of Cutout size

Table(3) demonstrate the effect of the cutout width. From these results it can be deduced that the critical buckling load deceases when the size of cutout increase.

3- Effect of radii of rounding corner cutout

Table(4) demonstrate the effect of radii of the rounding corner cutout. It is shown that the radii of rounding corner has no effect on the critical buckling load This means that the change in round radii does not make the major change in the stress concentration around each cutouts.

4- Effect of cutout orientation

Table(5) explain the effect of cutout orientation. It can be shown that thecritical buckling load increase when angle of orientation increase.

5- Effect of no. of layer (plate thickness) ***For circle cutout***

The effect of plate thickness on buckling load was investigated using ANSYS model and experiments. The first one was three layer (2.75 mm) thick and the second was four layers (3 mm) thick and the last one was five layer (3.75 mm) thick . The results of the critical buckling load is shown in Table(6).

It can be noticed that the critical buckling load increase when the no. of layer increase

Based on finite element investigation in ANSYS and employed to get analytical results which has been compared with the experimental results. It is seen that the results have the same behavior between the analytical and experimental results.

In general , the results of the square clamped plates with circle cutout come out in a good agreement. With what is expected which is decrease of buckling load of the plates with change the shape from circle, square and rectangle and in case of cutout size and is still constant with the radii rounding corner and increased with cutout orientation and the thickness of the plate. The effect of cutout will determine the increase or decrease of the buckling load that due to the stress concentration in the cutout , which cause the increase or decrease the critical buckling load.

Figure(6) demonstrate the mode shapes of the composite laminated plate with cutouts under buckling condition. From these figures it can be shown that the mode shapes are unsymmetry , that is due to the stress concentration is not uniform around the cutouts in the plate.

Conclusions

The present work deals with determination the effect of the shapes, sizes, radii of corner of cutout and no. of layers on the critical buckling load of the composite laminated plate :-

1- The effect of cutout shapes will cause decrease the critical buckling loads
2- The critical buckling load is decreased with increased the cutout sizes. Which decreases with ratio of 11% with increasing the cutout width from 20mm to 50mm.

3- The critical buckling loads do not change with changing of radii of the rounding corner of the cutouts.
4- The critical buckling loads increases with small ratio of 0.65% with the increase the angle of orientation of cutouts (from 0° to 60°)
5- The critical buckling loads is direct proportional with the plate thickness (no. of layers). Where it increase with ratio of 80% with the increase of the number of layers from 3 to 5 layers.
6- It can be concluded that the best case is when the number of layers are increased..

So, from the above conclusions, It can be recommended, that the composite laminated plate with cutouts is made with more than four layer to insure the bearing of high buckling load.

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Table (1) Mechanical Properties of the Composite laminated Plate

Property	Value
Young modulus (E)	2.1 MN/mm²
Possions ratio (υ)	0.32
Density	1,1837 kg/m

Table (2) Effect of cutout shape

Cutout Shape	ANSYS critical load (kN)	Experimental Critical load (kN)
Circle	7.6444	7.85
Square	7.5708	7.60
Rectangle	7.44013	7.78

Table(3) Effect of cutout width

Width of cutout (mm)	ANSYS critical load (kN)	Experimental critical load (kN)
20	7.9591	7.86
30	7.7185	7.2
50	7.0176	7.1

Table(4) Effect of Radii of rounding corner cutout

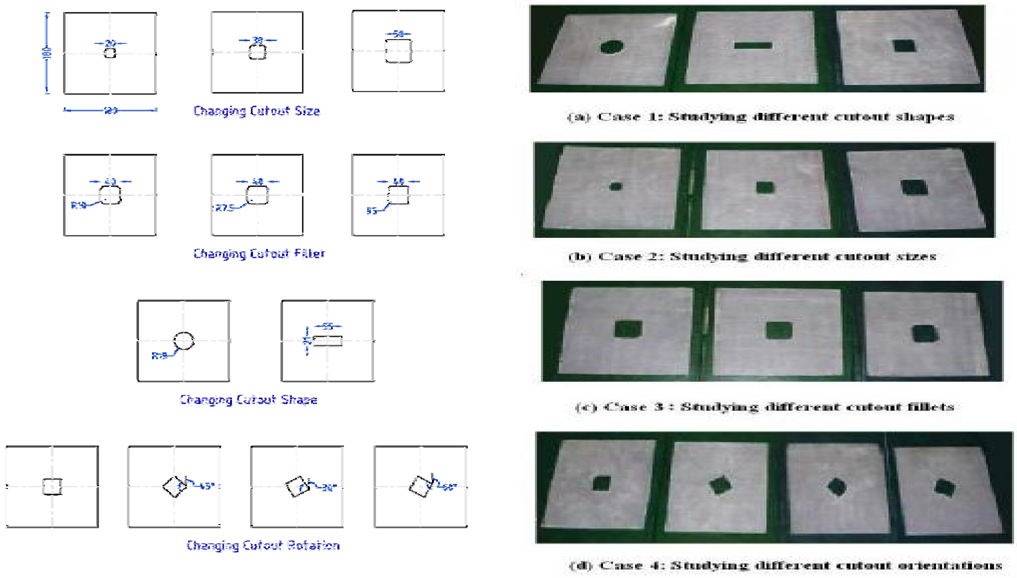
Radii of rounding corner (mm)	ANSYS critical load (kN)	Experimental critical load (kN)
R= 5	7.4265	7.40
R= 7.5	7.4265	7.40
R=10	7.4265	7.39

Table(5) Effect of cutout orientation

Cutout Orientation	ANSYS critical load (kN)	Experimental critical load (kN)
0°	7.5708	7.59
30°	7.5908	7.61
45°	7.6010	7.61
60°	7.5856	7.62

Table(6) Effect of No. of layers

No. of layers	ANSYS critical load (kN)	Experimental critical load (kN)
3	7.6444	7.61
4	18.0635	18.4
5	35.161	35.5



(a) Case 1: Studying different cutout shapes

(b) Case 2: Studying different cutout sizes

(c) Case 3 : Studying different cutout fillets

(d) Case 4: Studying different cutout orientations

Figure (1) The specimens used in the present study

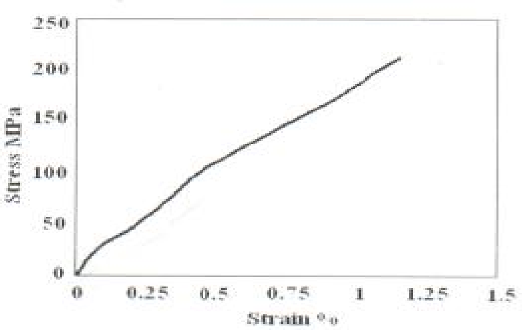


Figure (2) Tensile test results for Glass/ Polyester composite

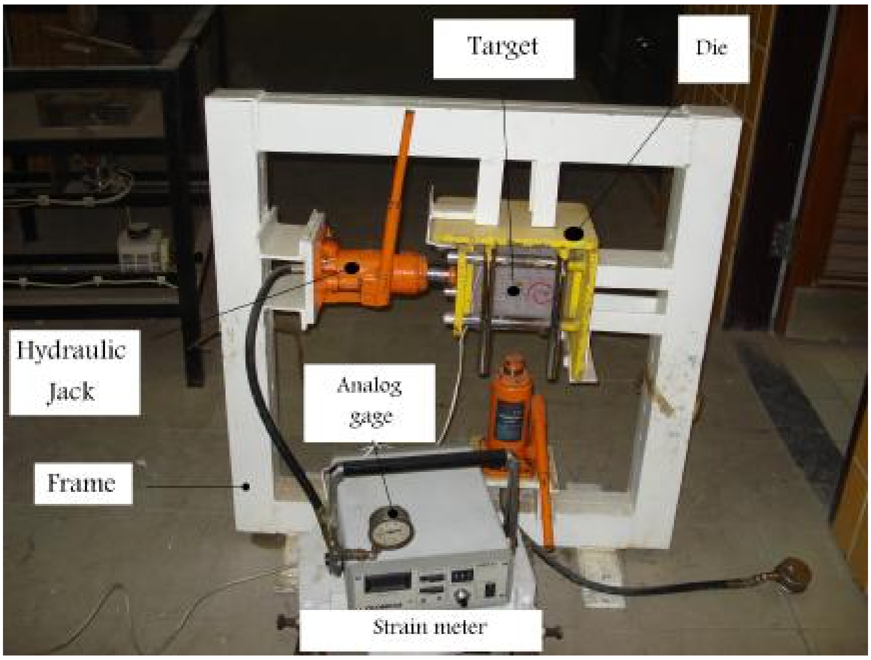


Figure (3) The compression device

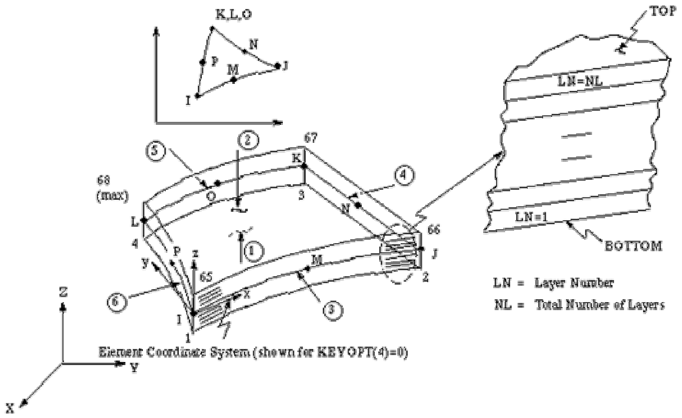


Figure (4) Shell element with 4 nodes (SHELL 91 in ANSYS)

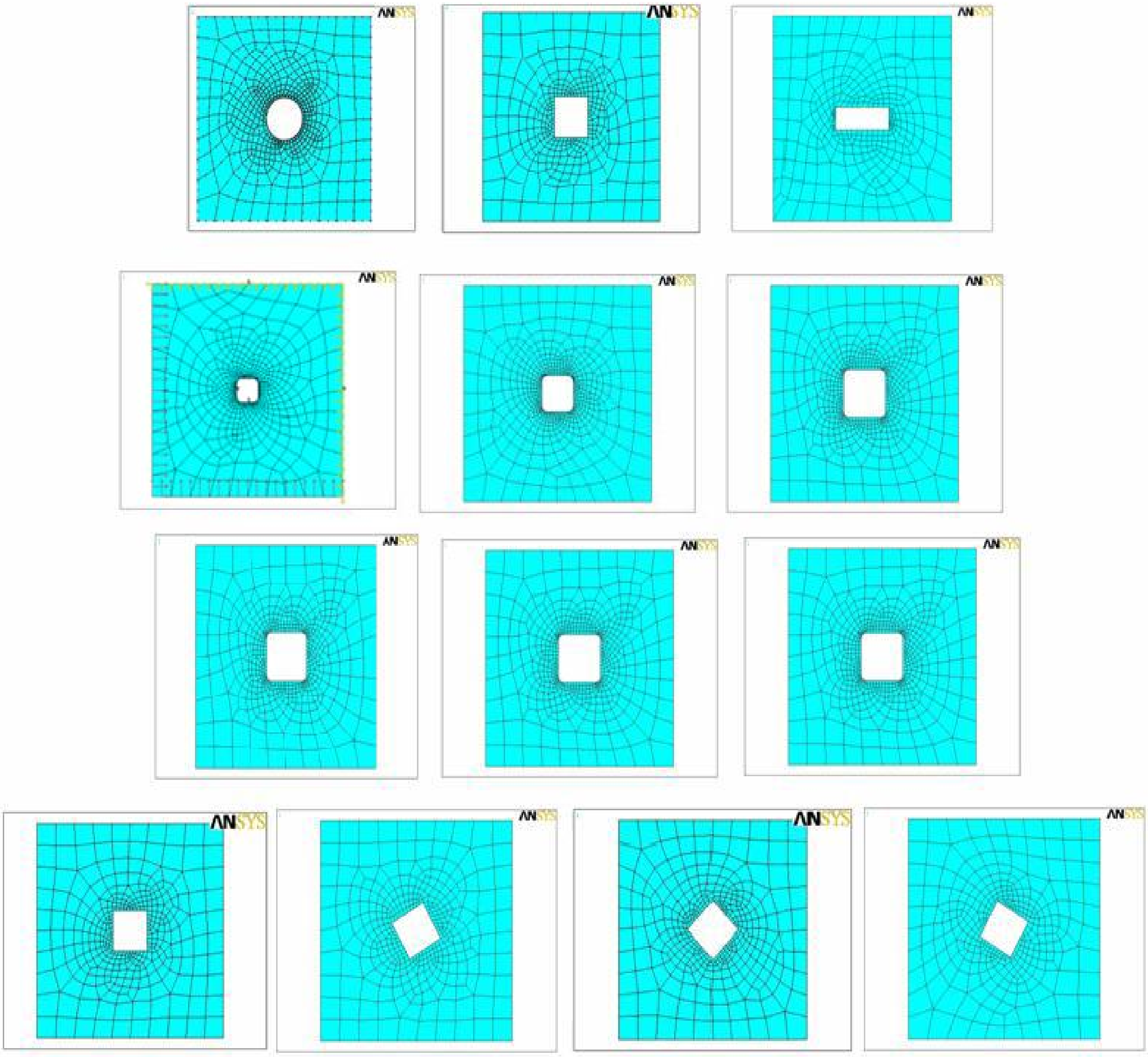
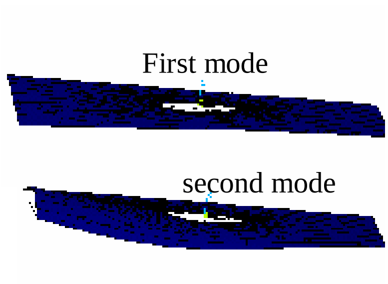
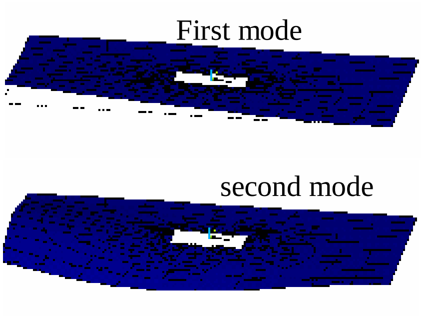


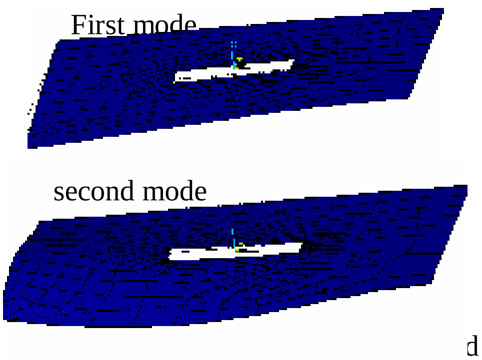
Figure (5) The Finite element model for laminated composite plate with cutouts



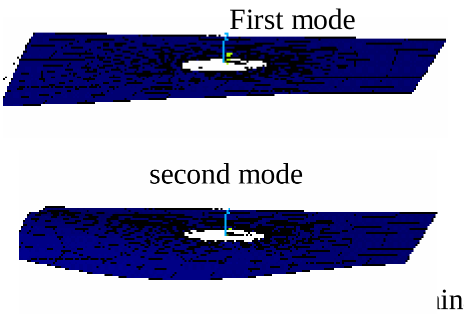
The mode shape for clamped laminated
plate with circular cutout



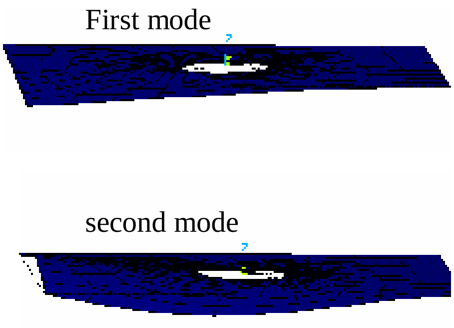
The mode shape for clamped laminated
plate with square cutout



d
plate with rectangular cutout



inated
plate with four layers , circular cutout



nated
plate with five layers , circular cutout

Figure(6) The Mode Shapes of the Clamped Composite Laminated
Plate with different cutouts