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FREE VIBRATION ANALYSIS OF COMPOSITE PLATE WITH DIFFERENT CUT OUTS, ORIENTATIONS AND BOUNDARY CONDITIONS

T Chaithanya[1], Suresh Arjula[2]
[1]PG Student, [2]Assistant Professor, Dept. of Mechanical Engineering,
JNTUH College of Engineering Jagitial, Telangana, India
*Corresponding Author: arjulasuresh@jntuh.a.cin

Abstract: Composite plates are used in wide range of applications, especially in weight sensitive structures like aircraft and spacecraft. Most of the structural components are generally subjected to dynamic loading in their working life. Very often these components may have to perform in severe dynamic environment where in the maximum damage results from the resonant vibrations. Maximum amplitude of the vibration must be in the limited for the safety of the structure. Hence vibration analysis has become very important in designing a structure to know in advance its response and to take necessary steps to control the structural vibrations and its amplitudes.

In this work, free vibration analysis of Graphite Epoxy composite plate having different cutouts and different boundary conditions is carried out. The presence of cut outs in the plates changes the stress distribution of the plates and makes the analysis complex. Hence the analysis of the modal characteristics of these plates is significant. The fundamental natural frequencies have been computed for different boundary condition, different cutouts, and different fiber orientations. The effects of these variables on the nature of vibrations have been analyzed and discussed. ANSYS APDL19.0 is used for the computation of natural frequencies.
Keywords: Vibration, Composite plate, Cutouts, Orientations, Boundary Conditions.

1. INTRODUCTION

Most structural components are generally subjected to dynamic loading in their working life. Very often these components may have to perform in severe dynamic environments where the resonant vibrations result in maximum damage. Susceptibility to material fracture owing to vibration is determined by stress and frequency. The maximum amplitude of the vibration must be restricted for the safety of the structure. Therefore, vibration analysis has become very crucial in developing a building to understand its reaction in advance and to make needed measures to regulate the concrete stresses and their amplitudes.

Nowadays, in much aviation, aviation and shipbuilding sectors, multiple synthetic sheets are used. Composite materials are increasingly being used in these days owing to their exceptional specific strength. Light weight, elevated temperature strength, stress strength, fatigue strength, excellent wear resistance, excellent hardness and so many are desired properties. Furthermore, if they are subjected to a vibrant scenario, these components offer stronger vibrant reactions than any other standard content. Weight conservation is also a significant factor for high-performance applications and for this it is essential to minimize sheets peak deflections without adding any significant weight. This can be achieved by adding stiffeners to the plates to enhance their load carrying capacity and also resists vibration due to dynamical loads [1].

Cutout is an essential component of almost all structural elements, including composite laminated plates. Cutouts are needed for component assembly, damage inspection, ports of access, electrical and fuel lines, structure opening, ventilation and weight reduction [2, 3]. These structures are subjected to unwanted vibration, additional deflection during their service life and again these cut-out plate constructions can significantly alter the response. The cutout plate reduces the complete weight which in effect impacts the reaction of the vibration. Similarly, it also decreases the complete rigidity and automatically shifts the twisting conduct.

These cut-outs can often result in error under reduced stress and sometimes also due to undesirable resonance. It is therefore essential to estimate with cut-outs the resonant frequencies of these constructions. The wide variety of practical cut-out applications in sheets needs a better understanding of the frequencies and stabilization characteristics of cut-out laminated sheets. The vibration analysis of laminated composite plates was carried out to study the effect of number of layers, thickness ratio of plate, different boundary conditions, different aspect ratio, and different angle of fiber orientation of laminated composite plate [4]. The non-dimensional fundamental frequency of vibration is found to increase with increase of angle of fiber orientation and number of layers but non-dimensional fundamental frequency decrease with increase in size ratio and thickness to width ratio. Mohsin Abdullah Al-Shammari **[**3**]** presented the effect of the void shape on direct vibration characteristics of unidirectional composite plates. This was explored for separate cutouts with the same region of distinct cutout shapes. The results of natural frequencies evaluated by laboratory work are compared with those evaluated by ANSYS. In this experiment the effect of circular cutout shape of deflection of unidirectional clamped support composite plate is more than the effect of other cutout shapes and minimal cutout shape effect on deflection of composite plate occurred when cutout is rectangular cutout shape with the same cutout area.

Syed Altaf Hussain et al. [5] carried out Vibration Analysis of Laminated Composite Plates with Holes. Free vibration analysis of four layered angle-ply symmetric GF/Epoxy laminated plates with different lamination angles (±0º to ±90°) of lamina with different hole locations was presented in this investigation. From the analysis it was inferred that the fundamental frequency of laminated composite plates decreases with increase in L/h ratio.

Mohammed Salih Hassan AL-Araj1 et al. **[**6**]** studied the vibration analysis of CF/Epoxy laminated composite plates with holes. Free vibration analysis of four layered angle-ply symmetric laminated plates of lamina with different hole locations. The plate with one hole have higher frequencies than perforated plates and the frequency decrease with increased number of holes because lower in stiffness of the laminate plates. Muhannad Al-Waily et al. **[**7**]** presented an analysis of the natural frequency of composite laminated plate with different sizes and location of de-lamination through the longitudinal and transverse directions of the composite plate in addition to the effect of de-lamination through the thickness of the plate. The composite plate studied is made of woven reinforcement glass fiber and polyester resin with eight layers with different de lamination shapes through the plate. Sridhara Raju. V.V et al. [8] focused on the evaluation of the effect of thickness ratio 'S' on the geometric nonlinear behavior of a four layered symmetric (+45°/-45°/-45°/+45°) skew bidirectional FRP laminated composite plate with a circular cut out at the geometric centre of the plate.

Udar R.S., Datta P.K. [9] studied the effects of non-uniform edge loading, centrally located circular cutout, damping, number of layers, orthotropy, the static load factor and the width-to-thickness ratio on dynamic instability behavior of simply supported laminated composite doubly curved panels were studied. It was found that under localized edge loading, combination resonance instability zones are as important as simple resonance instability zones. A central circular cutout has the destabilizing effect on the dynamic stability behavior of laminated composite doubly curved panels subjected to non-uniform edge loading.

S. B. Singh and Himanshu Chawla [10] studied dynamic characteristics of glass fiber reinforced polymer laminates with cutouts. It is an experimental investigation of the effect of cutouts on the natural frequency and damping of the plate. Conclusion drawn from this study is natural frequency decreases while damping coefficient increases with increase in the size of cutout.

From the above review of literature, it is noted that most of the work done on composite plates is based on central cut-out. The present work is to obtain the free vibration of the composite plate with different cutout shapes, different orientation and boundary conditions. The fundamental frequencies are evaluated in ANSYS using shell281element.

2. MATERIALS AND MODELLING

In this work, ANSYS 19.1 is used to model the composite plate to calculate the natural frequencies and deformed shapes of plates. The details of plate dimensions, cutout shapes, fiber orientations, boundary conditions are given below.

Dimensions of plate:
Square Plate: 0.24 m x 0.24 m
Thcickness: 0.055 m
Dimensions of cutouts:
Total Area of hole: 0.0064 m^2

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- Circular hole radius: 0.045m
- Rectangular Hole:
  Length = 0.114m, breath = 0.0564m
- Square hole: side = 0.08m

Orientation of fiber:

- 0°
- 0°/90°
- 90°/ 45°/ 0°/ 45°/ 90°

Boundary conditions:

Boundary conditions are given support to plate. Those are

- All clamped support (CCCC)
- Clamped, clamped, simple support, simple support (CCSS)
- Simple support, clamped, clamped, simple support (SCCS).

Table I Mechanical properties of a graphite/epoxy Composite

Longitudinal Modulus E1	175 GPa
Transverse modulus E2 =E3	7 GPa
Poisson's ratio ν12 = ν13 ν 23	 0.25 0.1
Shear modulus G12 = G13 G23	 35 GPa 1.4 GPa
Density	1550 Kg/m^3

The composite models have been made up with unidirectional lamina from the material: T300/5208 graphite/epoxy. The material properties of graphite/epoxy are taken from Ref.[5].

3. FINITE ELEMENT SOLUTION

The finite element analysis of composite plate with different cutout shapes, fiber orientation and boundary conditions (as mentioned in Section II) was carried out using ANSYS software for obtaining fundamental frequencies. The composite plate was meshed with SHELL281 element (Fig. 1). At each pixel, the element has eight parts with six degrees of freedom x, y, and z angle translations, and x, y, and z-axes rotations. SHELL281 is well adapted for nonlinear linear, large twist and large pressure applications.

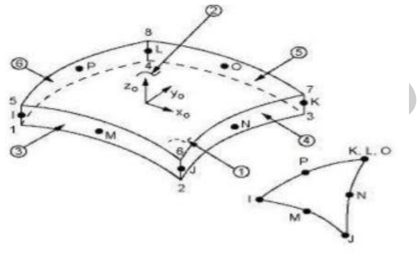

Fig. 1. Shell 288 element

4. RESULTS AND DISCUSSION

Modal analysis and calculation of natural frequency for each plate with cutout and without cutout was done using ANSYS. The results are discussed in the following sections.

4.1. Natural Frequency ff Composite Plate Under Different Conditions

The results are presented for the plate obtained for different parameters (different cutouts and orientation of fiber) of different boundary condition of plate. It is observed that, the natural frequency of composite plate maximum in clamped support with all cutouts. The natural frequencies for CCCC boundary conditions are provided in Table II. The natural frequency is more for [0°] fiber orientation composite pale for all the cutouts.

Table II Natural frequencies of plate for CCCC boundary condition

Cutouts	Fundamental Frequency (Hz)		
	0°	0°/ 90°	90°/ 45°/ 0°/ 45°/ 90°
No cutout	1165.8	1030.9	1090.7
Circular	1765.2	1334.3	1036.7
Rectangular	1646.2	1270.8	981.05
Square	1337.9	1108.8	888.21

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Table III Natural frequencies of plate for CCSS boundary condition

utouts	Fundamental Frequency (Hz)		
	0°	0°/ 90°	90°/ 45°/ 0°/ 45°/ 90°
No cutout	222.47	1165.8	233.61
Circular	182.14	1765.2	184.42
Rectangular	174.08	1646.2	183.53
Square	197.08	1337.6	190.14

The natural frequencies for CCSS boundary conditions are provided in Table III. The natural frequency is more for [0°/90°] fiber orientation composite plate for all the cutouts considered.

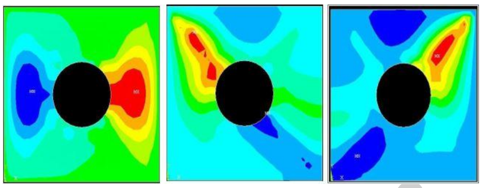
Table IV Natural frequencies for SCCS boundary condition

Cutouts	Fundamental Frequency (Hz)		
	0°	0°/ 90°	90°/ 45°/ 0°/ 45°/ 90°
No cutout	222.47	226.69	219.24
Circular	177.08	210.53	177.06
Rectangular	177.47	208.05	176.25
Square	198.3	217.97	182.7

The natural frequencies for SCSC boundary conditions are provided in Table IV. The natural frequencies for different fiber orientations and cutouts in the composite plate are closer.

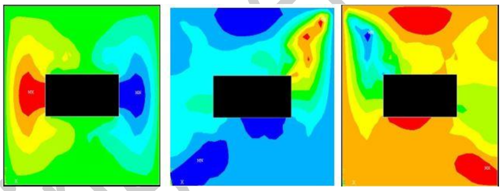
4.2 Deformed Shapes for Composite Plate [0°/90°] Fiber Orientation

The deformation of [0°/ 90°] plate for different boundary conditions with different cutout shapes is shown in Fig. 2- Fig.4. The deformation of the plate without cutout is shown in Fig. 5. The maximum deformation occurs in all clamped support condition. In CCSS clamped support deformation at corner of two clamped conditions occurs.



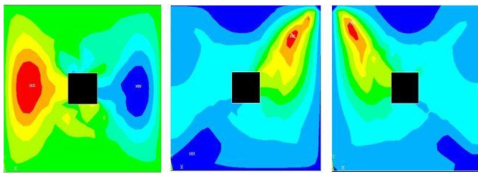
(a) (b) (c)

Fig: 2. Deformation of [0°/ 90°] plate with circular hole for a) CCCC, b) CCSS, c) SCCS boundary conditions.



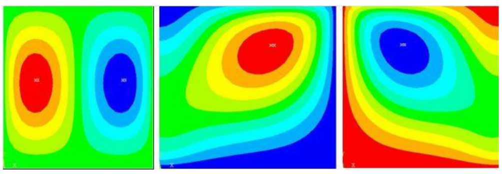
(a) (b) (c)

Fig: 3. Deformation of [0°/ 90°] plate with rectangular cutout for a) CCCC, b) CCSS, c) SCCS boundary conditions.



(a) (b) (c)

Fig. 4. Deformation of [0°/ 90°] plate with square cutout for a) CCCC, b) CCSS, c) SCCS boundary conditions



(a) (b) (c)

Fig. 5. Deformation of [0°/ 90°] plate without cutout for a) CCCC, b) CCSS, c) SCCS boundary conditions

4.3. Deformed Shapes for Composite Plate [0°] Fiber Orientation

Fig. 6-8 show the deformation of [0°] plate with different cutouts. Fig. 9 shows the deformation of

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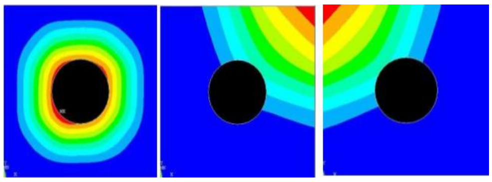
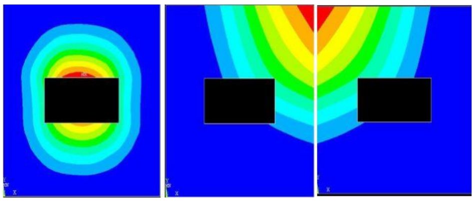
[0°] plate without cutout. It is observed that the maximum deformation occurs in all clamped support condition and it is near to the cutout. In CCSS and SCCS conditions maximum deformation at corner of two clamped conditions only.



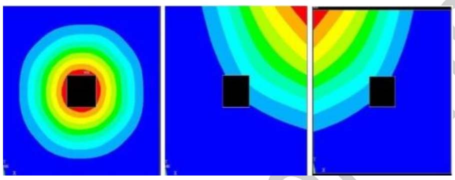
(a) (b) (c)

Fig. 6. Deformation of [0°] plate with circular hole for a) CCCC, b) CCSS, c) SCCS boundary conditions



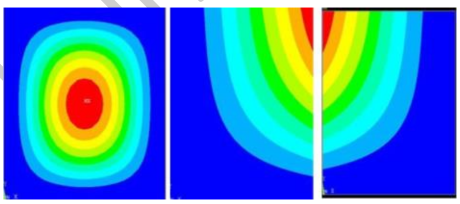
(a) (b) (c)

Fig: 7. Deformation of [0°] plate with rectangular hole with a) CCCC, b) CCSS, and c) SCCS boundary conditions



(a) (b) (c)

Fig. 8. Deformation of [0°] plate with square hole with a) CCCC b) CCSS, and c) SCCS boundary conditions

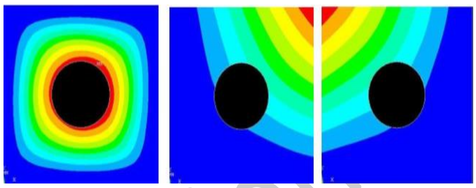


a) (b) (c)

Fig. 9. Deformation of [0°] plate without hole with a) CCCC b) CCSS, and c) SCCS boundary conditions

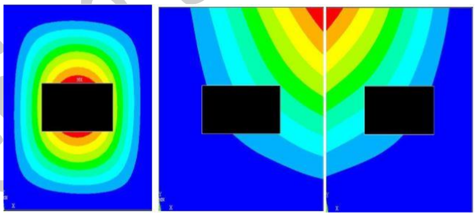
4.4. Deformed Shapes for Composite Plate [90°/ 45°/ 0°/ 45°/ 90°] Fiber Orientation

From the Fig. 10-13, it is found that the deformation shape of square cutout with [90°/ 45°/ 0°/ 45°/ 90°] fiber orientation of composite plate is maximum deformation occurs in all clamped support and near cutout. In CCSS and SCCS cases maximum deformation occur at corner of two clamped conditions.



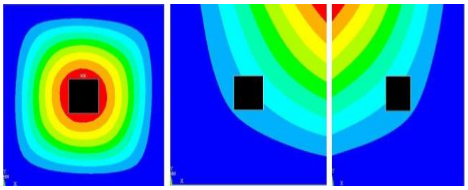
(a) (b) (c)

Fig. 10. Deformation of [90°/ 45°/ 0°/ 45°/ 90°] plate with circular hole with a) CCCC b) CCSS, and c) SCCS boundary conditions



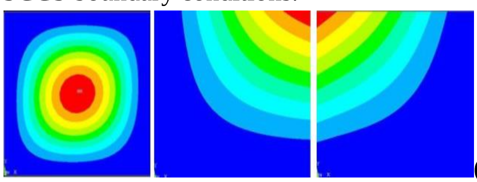
(a) (b) (c)

Fig: 11. Deformation of [90°/ 45°/ 0°/ 45°/ 90°] plate with a) CCCC, b) CCSS, and c) SCCS boundary conditions



(a) (b) (c)

Fig. 12. Deformation of [90°/ 45°/ 0°/ 45°/ 90°] plate with square hole with a) CCCC b) CCSS and c) SCCS boundary conditions.



(a)

(b) (c)

Fig. 13. Deformation of [90°/ 45°/ 0°/ 45°/ 90°] plate without hole with a) CCCC, b) CCSS, c) SCCS boundary conditions

It found that in all cases the deformation in all clamped support boundary condition maximum and in other boundary conditions the maximum

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deformation occur at edge of clamped conditions only.

5. CONCLUSIONS

The present study is related with the effect of the free vibration of graphite/Epoxy of composite plates with different cut-outs and different fiber orientation. Modal analysis of these plates was done using ANSYS APDL software. Three type of cut-out shapes Circular, Rectangular, square was selected and fiber orientations [0°], [0°/ 90°], [90°/ 45°/ 0°/ 45°/ 90°] were selected.

1) Natural frequencies for fixed plate are higher than all other boundary condition of plate for all three fiber orientations. Frequencies were maximum in clamped support only.

2) In all clamped boundary condition, natural frequency is smaller for plates having square hole. In other boundary condition that are clamped with simple support, simple support(CCSS) and simple support clamped clamped simple support (SCCS) boundary conditions, the natural frequencies were smaller for plates having rectangular cut-out.

3) Maximum Natural frequency in circular cutout with all clamped support and fiber orientation (0000). The value is 1765.2 Hz.

4) Minimum Natural frequency in rectangular cutout with (CCSS) boundary condition and [0°] fiber orientation. The value is 174.08 Hz.

From the above, it can be concluded that the vibration characteristics of plates with cut-out is affected by boundary conditions, ply orientation. The presence of cut-out may be weakening the structure under the dynamic loading and causes resonance due to reduction in natural frequency. So, cut-outs play a vital role on the vibration characteristics of the plate structure.

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