
Free Vibration of Laminated Composite Plate with Square Cut-outs: A Numerical and Experimental Analysis

Biswajit MAJHI *

*Department of Civil Engineering, Odisha University of Technology and Research,
Bhubaneswar, Odisha, India-751029, biswajitmajhi962@gmail.com*

Pradip Kumar SAHU

*Department of Mechanical Engineering, Odisha University of Technology and
Research, Bhubaneswar, Odisha, India-751029, pradipsahu2@gmail.com*

Udit Narayan BHOI

*Department of Civil Engineering, Odisha University of Technology and Research,
Bhubaneswar, Odisha, India-751029, uditnarayanbh@gmail.com*

Biswajit MOHANTY

*Department of Mechanical Engineering, Odisha University of Technology and
Research, Bhubaneswar, Odisha, India-751029, biswajitnit6@gmail.com*

*Author to whom correspondence should be addressed

Abstract: - In the current research, the hand lay-up method has been employed to produce laminated composite plates. Bidirectional glass fibers and epoxy resin have been chosen as reinforcement and matrix for the fabrication of laminated composite plates respectively. The design parameters viz. aspect ratio, position of cut out, cut out ratio, number of layers, and ply orientations in various end conditions are considered for the experimental dynamics test of the plate. The vibrational analysis of the composite plate having cut-outs has been performed numerically using ANSYS software. The changes in natural frequency concerning the considered design parameters have been analyzed and discussed for different boundary conditions. The experimental results are checked with the numerical simulation results attained through ANSYS to validate the current research.

Keywords: - Vibration analysis, cut-out, laminated composite plate, glass fiber, natural frequency.

1. INTRODUCTION

In recent days, laminated composite plates have been widely employed in several engineering applications such as helicopter blades, airplane wings, turbine blades, etc. The structures of laminated composite also find extensive application in marine, automobile, civil industries, etc. because of their exceptional strength-to-weight ratio and stiffness-to-weight ratio. The dynamic response of any structural element might vary because the structures used for various applications are often exposed to continuous dynamic loading during real-time applications.

To provide vent holes in the structure and to reduce the component weight, the concept and design of cut-outs play a significant role for any designer. Several designers, researchers, and academics have tried out different sizes and shapes of cut-outs to change the natural frequency of structural elements for safer running. Therefore, analysis of the vibrational behaviour of laminated composite plates

is a key area of investigation for researchers and design engineers. The strength of the plate decreases with the introduction of cut-outs. At the same time, it also changes the vibration response of the composite plate. Thus, it demands the prediction of dynamic vibration characteristics of the structural plate having cut-outs in the view of accuracy and cost-effectiveness of the designed structures.

2. RELATED WORK

The strength and stiffness of laminated composite plates decrease once cut-outs are fabricated in the structural element. The introduction of cut-outs in any structural composites also alters the vibration characteristics. Therefore, the shape and size of cut-outs have a major influence on the composite structural design. There have been many works and investigations related to the dynamics analysis of laminated composite plates. In the following paragraph, some of the important literatures are

depicted and critically revised considering their significance in the present work.

The characteristics of vibration of orthotropic and isotropic plates having rectangular cut-outs are investigated by Aksu and Ali [1]. Here, a finite element method has been used for the examination of vibrational behaviour. Rayleigh's method is employed by Ali and Atwal [2] to test the vibration characteristics of plates taking rectangular and square cut-outs in simple supported-type boundary situations. The Ritz technique is implemented by Laura et al. [3] to find the frequency of rectangular plates having cut-outs at the corner of the plate. The sides of the plates are presumed to be elastically constrained to any translation and rotation. The dynamic behaviour of an anisotropic rectangular composite plate is studied by Reddy [4]. Here, the effect of different design parameters like the ratio of plates side to cut-out side, side-to-thickness ratio, and aspect ratio on the natural frequency has been surveyed.

Cut-out provided at the center of the composite plate has been considered by Ramakrishna et al. [5]. The fundamental frequencies are evaluated through a program of hybrid-stress finite element method by considering various factors viz. aspect ratio, hole size, width-to-thickness ratio, and ply orientations. The vibrational behaviours of cut-outs of circular shapes on laminated composite plates have been examined both numerically and experimentally by Boay [6]. Aspect ratio and hole sizes were chosen as the design parameters for the study. The vibrational effect of different shapes of cut-outs in laminated plates in large oscillations is investigated by Sivakumar et al. [7] using the Ritz finite element method. The vibrational characteristics of the plate with cut-outs of rectangular and elliptical shapes have been examined by Chen et al. [8] using the Rayleigh-Ritz principle and Reddy's higher-order scheme. The effects of parameters on natural frequency have been depicted.

Similarly, the vibrational analysis is performed for cut-outs at the center of rectangular plates for two different boundary conditions by Liew et al [9] using Ritz discrete technique. The vibrational behaviour of composite plates with holes is examined and depicted by Hota and Padhi [10]. The analysis of the natural frequency of a plate having a circular shape cut out at the centre is discussed by Poore et al [11] and Lee and Chung [12]. The effect of cut-outs on buckling and vibration of the composite plate has been examined with two modeling methods by Ovesy and Fazilati [13]. The effect of distance between the circular cut-outs from the square cut-out at the center position of an orthotropic composite plate is studied by Kalita et al. [14]. The test data obtained from the experimentations have been analyzed with analytical

ANSYS data. The vibration analysis of a composite stiffened shallow spherical shell panel with cut-out is performed by Sahoo [15]. Here, eight noded quadratic iso-parametric elements for the shell and three noded beams for stiffened formulation have been considered for the analysis.

The influence of various design factors like aspect ratio, size of cut-out, fiber orientation, number of layers, etc. on the vibration of the composite plate having a cut-out of a triangular shape is investigated by Bhardwaj et al. [16]. To compare the analytical and experimental results, they have formulated the FEM model using ANSYS. The conclusion has been drawn that the boundary condition affects the vibration response of composite plates having cut-outs. Turkova and Karpova [17] presented a mathematical model for two-layered oval composite plates to estimate the deflection and frequency of the vibration. Vishwakarma et. al. [18] have implemented the WU-C2 RBF mesh-free method to enhance the vibration characteristic of laminated composite plates. In this paper, the authors used the transverse shear function to calculate the vibration of laminated composite. Ilangoan et. al. [19] compared the vibration characteristics of glass fiber epoxy nanocomposite plates and basalt/epoxy nanocomposite plates. They used ANSYS software to conduct simulation analysis of vibrational behaviour for different boundary conditions. Guo et al. [20] used the Walsh series to offer an effective solution for the free vibration of composite conical shells.

Jhanji et al. [21] investigated the response of glass fiber-reinforced epoxy composite with various cut-out combinations under tensile load. This investigation verified that the tensile strength of specimens having square-circle cut-outs is found to be more as compared to specimens having diamond-circle and diamond-square cut-outs. Sinha et al. [22] have considered several parameters (different fiber orientations, weight ratio of fiber to epoxy, and aspect ratio) for the analysis of free vibration characteristics of composite plates with/without cut-outs. Also, the effectiveness of experimental results has been verified with finite element analysis. Kumar et al. [23] analyzed the dynamic characteristics of functionally grade carbon nanotube-reinforced composite plates with cut-outs. The findings of the investigation show plates with carbon nanotubes showed superior properties. The free vibrational behaviour of sandwich plates with cut-outs is studied by Prusty et al. [24]. They have developed artificial neural network (ANN) models to predict the experimental and numerical findings of free vibration analysis of the plate.

It can be observed from the aforementioned survey that the cut-out has been most often chosen at

the center of the composite plate to investigate the vibrational characteristics. Earlier, bi-directional glass fiber has not been widely considered in the fabrication of laminated composite plates. However, the effect of the position of the cutout and the effect of the multiple cutouts along with the central cutout involving the natural frequency of composite plates using ANSYS are scarce in the literature. The effect of multiple cut-outs and equivalent single central cut-outs on the natural frequency of bi-directional glass fiber laminated composite plate has not been studied. Considering the aforementioned facts, the current research work emphasizes an experimental study on vibrational analysis of laminated composite plates with cut-outs at different positions (center, corner, and side of the plate). Further investigation is carried out to analyze the effect of multiple cutouts on the effective cut-out position. Different ply orientation, cut-out ratio, aspect ratio, number of layers under various support/end conditions viz. Clamped-Free-Free-Free (CFFF), Clamped-Free-Clamped-Free (CFCF), and Simple-Free-Simple-Free (SFSF) are considered as the design parameters for the analysis. To validate the present work, the analytical results obtained from the ANSYS software matched with experimental results.

3. MODELING USING ANSYS

In the present research, Finite Element Analysis (FEA) is performed using ANSYS software, an engineering simulation, and 3D design software. The software has been used to construct and design the laminated plate. The software package is further used to evaluate the natural frequencies of the composite plate and its deformed profiles. Shell 281 has been chosen for analysis which is an element-type structure of 8 nodes and each has six degrees of freedom. The laminas have been presumed to be linear, elastic, and orthotropic. Block Lanczos extraction mode has been chosen for the current work for modal analysis.

The following steps have been followed for the modal analysis of the current work.

(i) Pre-processing: In this step, the contact condition between glass fiber layers and epoxy resin is assumed as perfect bonding. The fabricated composite plate is considered as a single body for the convenience of the analysis with negligible error. The material properties and element type are defined and then sectioning, modeling, and meshing of the structure is done. As defined earlier, the element is considered to be elastic 8 noded shell 281. Figure 1(a) shows the modeled laminated composite plate. Similarly, the meshing of the plate is presented in Figure 1(b).

(ii) Solution: In this step, loads are assigned, end conditions are applied, and the modal analysis is solved. The constraints for different end conditions have been depicted in Table 1. Figure 1(c) shows the constraints for the different types of support conditions under which the vibration analysis of the plate is to be performed.

(iii) Post-processing: In this final step, the results are viewed, and mode shapes are drawn. Figure 1(d) shows the mode shape plot of a structural plate having three different cut-outs in CFFF end conditions.

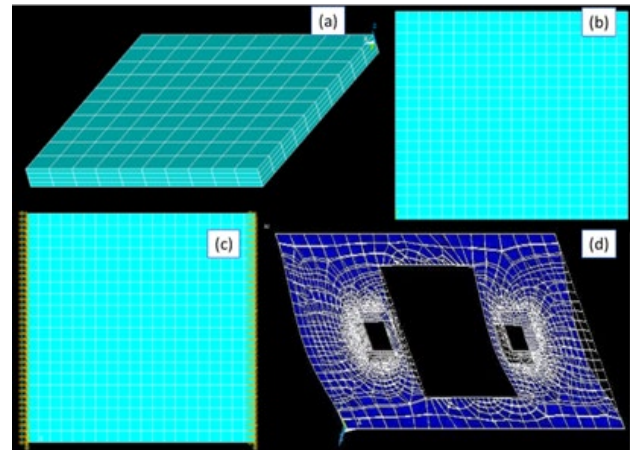


Figure 1. (a) Modelled laminated composite plate (b) Meshing of the plate (c) end conditions (d) mode shape

4. FABRICATION AND EXPERIMENTATION

4.1 Fabrication of laminated composite plate

To prepare the laminated composite plate, the required materials are Polyvinyl alcohol spray, hardener, epoxy, and woven glass fibre.

4.1.1. Procedure for fabrication

The composition is such that the fiber-to-matrix weight proportion is 50:50. In the laminated composite manufacturing process, the simple hand lay-up method has been employed. The matrix (resin/epoxy) and the reinforcement (glass fiber) are put over the finished surface of an open mould. The matrix has been made with 8% of epoxy. According to the desired shape and size of the composite plate to be made, the fibers have been cut. A plastic sheet has been placed over a flat plywood and with the help spray gun, a releasing agent has been spread over the sheet. With the help of a brush, the resin was also evenly spread on the sheet. Over that resin, the first glass fiber has been placed. A steel roller was used to do away with trapped air and then resin was laid over the first glass fibre. The same process was continued 8 times to have 8 layers of laminated composite plate.

Table 1. Constraints for various end conditions

Boundary condition	UX	UY	UZ	ROTX	ROTY	ROTZ
Simple supported	constrained	constrained	Constrained	Not constrained	Not constrained	Not constrained
Cantilever supported	constrained	constrained	Constrained	constrained	constrained	constrained
Fixed supported	constrained	constrained	Constrained	constrained	constrained	constrained

UX, UY, UZ: displacement along x,y and z direction

ROTX, ROTY, ROTZ: rotation about x,y and z axis

After that releasing agent was applied over which a plastic sheet was placed. To compress the product, a hefty flat metal board was placed over it.



Figure 2. Fabrication of laminated composite plate (a) Applying resin over the plastic sheet (b) Placing woven glass fibre over the applied resin covering (c) Removal of entrapped air with steel roller (d) Placing a heavy flat weight during the curing process

Then curing of the casting is performed at room temperature for 48 hours. After curing, the plastic sheets were detached from the mould. 250 mm x 25 mm size specimens were cut from fabricated laminated plates by a diamond cutter.

The whole process of fabrication of a bi-directional glass fiber laminated composite plate using the hand layout method has been employed. The fabrication of the laminated composite plate is shown in Figure 2(a), (b), (c), and (d) to match the ASTM D2344/D2344M (2006) specification. The average thickness of the manufactured plates was measured at 3 mm.

4.2 Evaluation of material constants

The orthotropic nature of laminated plate can be well-defined with material constants like E_{11} , E_{22} , G_{12} , and γ_{12} . The specimens are obtained through cutting using a diamond cutter as shown in Figure 3(a) and three specimens with the size of 250 mm x 25 mm x 3 mm are chosen for experimentation as presented in Figure 3(b). INSTRON 1195 UTM has been chosen for tensile testing of the sample. The experimental setup for the tensile test of the sample plate is presented in Figure 3(c). The specimens were given load in the UTM as defined in ASTM standard D3039/D3039M (2008) at a rate of 0.2mm/minute. Then, the longitudinal and lateral deformation of the laminated composite plate is noted from the extensometer, and Poisson's ratio of the material is evaluated. Figure 3 (d) shows the cracks which are formed due to tensile loading. The results of the tensile tests i.e. elastic modulus (E_{11} , E_{22}), shear modulus (G_{12}), and Poisson ratio (γ_{12}) for the materials are obtained as tabulated in Table 2. The shear modulus is determined using Equation 1.

$$G_{12} = \frac{1}{\frac{4}{E_{45}} - \frac{1}{E_{11}} - \frac{1}{E_{22}} + \frac{2\gamma_{12}}{E_{11}}} \quad (1)$$

where, E_{11} , and E_{22} are elastic modulus in the longitudinal direction and traverse direction respectively, E_{45} denotes the elastic modulus at an inclined angle of 45° , G_{12} and γ_{12} are the shear modulus, and Poisson's ratio in plane 1-2 respectively.

4.3 Laminated composite plate for vibration analysis

To construct a laminated composite plate for the vibration test, the same fabrication process as defined for the tensile test was followed as discussed in section 4.2.

Table 2. Material properties of laminated composite plate

Ply orientation [$^\circ$]	E_{11} [GPa]	E_{22} [GPa]	E_{45} [GPa]	G_{12} [GPa]	ν_{12}	Density [kg/m ³]
(0/90) ₄	12.030	12.030	7.63	2.5	0.25	1530

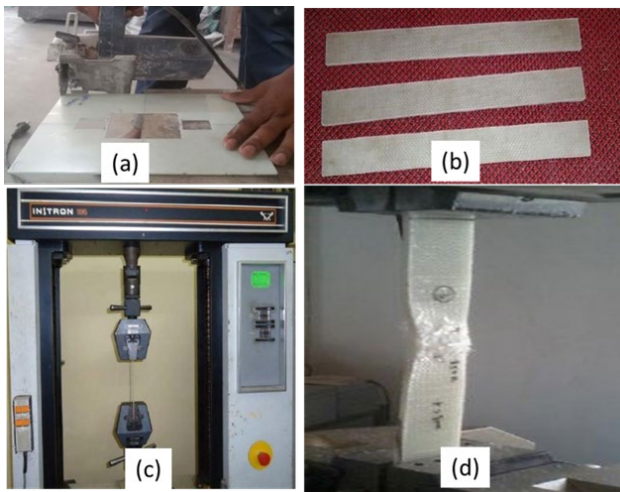


Figure 3. Evaluation of material properties (a) A diamond cutter showing the sample plate cutting. (b) Sample specimen of the laminated composite plate for tensile testing, (c) Tensile testing experimental setup (INSTRON 1195 UTM) (d) Deformation of the specimen during the tensile test.

The sample specimens are prepared with the help of a hacksaw of various cut-out ratios (d/D ratio) of 0.0, 0.1, 0.2, 0.3, and 0.4. Here, D denotes the side of the square cut-out present at the center and d denotes the side of the squares present on both sides of the central cut-out. Three samples of different sizes 235 mm x 117.5 mm, 235 mm x 156.6 mm, and 235 mm x 235 mm at a constant cut-out ratio of 0.4 have been fabricated for the proposed work. Table 3 presents the different dimensions of the plate along with their number of layers, cut-out ratio, and ply orientations which have been used for free vibration analysis of laminated composite plate. The various boundary conditions (CFFF, CFCF and SFSF) mentioned in Table 4 are depicted in Figure 4 (a), (b), and (c). The opening dimensions of the central cutout and side cutout in Figure 4 are 80 mm x 80 mm and 32 mm x 32mm respectively. Similarly, Table 5 shows the specimen dimension along with the position of cut-outs.

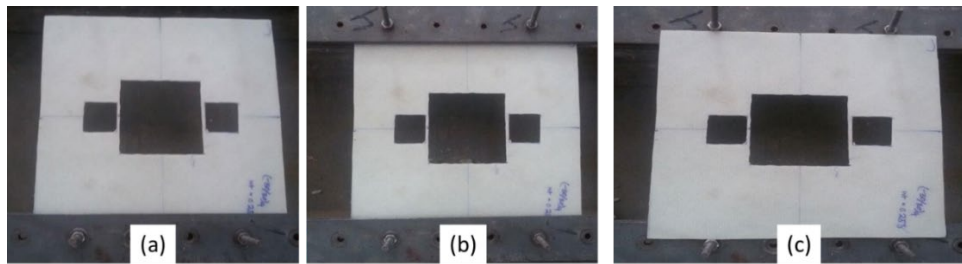


Figure 4. (a) Structure under CFFF support type (b) Structure under CFCF support type (c) Structure under SFSF end condition

Table 3. Design parameters for different dimensions of laminated plate

Size of the specimen [mm]	No of layers	d/D ratio	Ply orientation [°]	No of specimen
235x235x3	8	0	(0/90)4	1
235x235x3	8	0.1	(0/90)4	1
235x235x3	8	0.2	(0/90)4	1
235x235x3	8	0.3	(0/90)4	1
235x235x3	8	0.4	(0/90)4	1
235x235x3	8	0.4	(-30/30)4	1
235x235x3	8	0.4	(-45/45)4	1
235x235x3	4	0.4	(0/90)2	1
235x235x3	12	0.4	(0/90)6	1
235x156.6x3	8	0.4	(0/90)4	1
235x117.5x3	8	0	(0/90)4	1
235x117.5x3	8	0.1	(0/90)4	1
235x117.5x3	8	0.2	(0/90)4	1
235x117.5x3	8	0.3	(0/90)4	1
235x117.5x3	8	0.4	(0/90)4	1

Table 4. Support type and constraints description

Support type	Constraints description
CFFF	One edge is clamped and the other three are free
CFCF	Two opposite edges are clamped and other two are free
SFSF	Two opposite edges are simply supported and the others two are free

Table 5. Specimen dimensions having different cut-out position

Size of Specimen [mm]	No of layers	Size of the cut-out [mm]	Position of cut-out	Ply orientation [°]	No of Specimen
235x235x3	8	80x80	centre	(0/90)4	1
235x235x3	8	80x80	side	(0/90)4	1
235x235x3	8	80x80	corner	(0/90)4	1

4.4 Modal testing procedure

The tools and equipment employed in the present research for free-vibration experimentation are a modal accelerometer, hammer, *Fast Fourier Transform* spectrum (FFT) analyzer, and pulse software. The laminated plate is fixed according to the desired end conditions. The connection of the accelerometer, FFT analyzer, and the computer has been done. The Pulse Lab Shop window is opened on the computer. The modal hammer is stroked five times to create excitation on the plate. The accelerometer senses excitation, and the vibration signal is then fed to the analyzer. The signal is proceeded in the analyzer and a frequency spectrum is generated. The spectrum analyzer estimates the input signal versus frequency over the total frequency range and transfers the frequency response function to the computer. The analyzer interfaced with the computer produces the output frequency plot of vibration on the pulse lab shop screen. The natural frequency has been computed from the graph of the frequency response function.

5. RESULTS AND DISCUSSION

5.1 Experimental and numerical results

5.1.1 Effect of multiple cut-outs and equivalent single central cut-outs on the natural frequency of the plate

Two specimens of 235 mm x 117.5mm x 3 mm sizes are chosen to study the effect of equivalent cutting area and multiple cut-outs on the side of the cut-out present at the center. For the plates as presented in Figure 5(a), a cut-out is made at the center of the plate with a size dimension 80 mm x 80 mm, and another two cut-outs were made on both sides of the central cut-out having dimensions 32 mm x 32 mm. So, the total area of multiple cut-outs with central cut-out happens to be $80 \times 80 + 2 \times 32 \times 32 = 8448$

mm². Figure 5 (b) shows another plate which is having a single cut-out at the center of dimension 91.9 mm x 91.9 mm i.e. 8448 mm². The investigation is done by considering SFSF and CFFF as the boundary conditions. The results of the natural frequency for the two different plates have been presented in Figure 6 (a) and (b) respectively for CFFF and SFSF end conditions. In Figure 5, the symbol “a” and “b” represent the dimension of the plate.

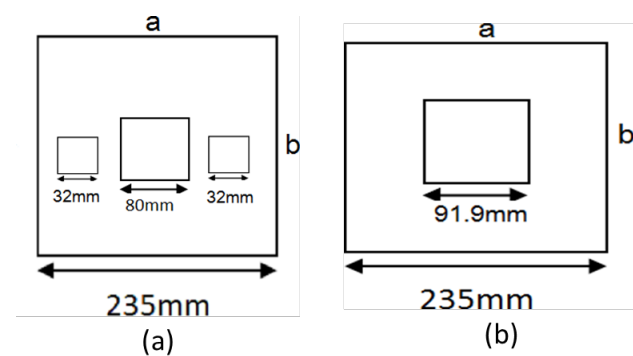


Figure 5. (a) Multiple cut-outs along with a central cut-out (b) Equivalent single central cut-out

The natural frequencies of the composite plate with multiple cutouts in case of CFFF type support condition as shown in Figure 6 (a) are decreased by around 1.5 %, 6%, 3.6 %, 5.6 %, and 5.1 % in the 1st mode, 2nd mode, 3rd mode, 4th mode and 5th mode of vibration respectively with the plate having central cut-out. Also, it can be observed from Figure 6 (b) that the natural frequency of the plate having multiple cut-outs is around 10.61% less than that of the plate with only a cut-out at the center for 1st mode vibration. The natural frequencies decrease in the same way i.e. 3.43% in the 2nd mode vibration, 17.7 % in the 3rd mode 2.05 % in the 4th mode, and 4.52 % in the 5th mode for SFSF type support condition. This is mainly happening because of the localization of stress concentration at the central hole due to the presence of multiple cutouts causing a reduction in the stiffness of the plate.

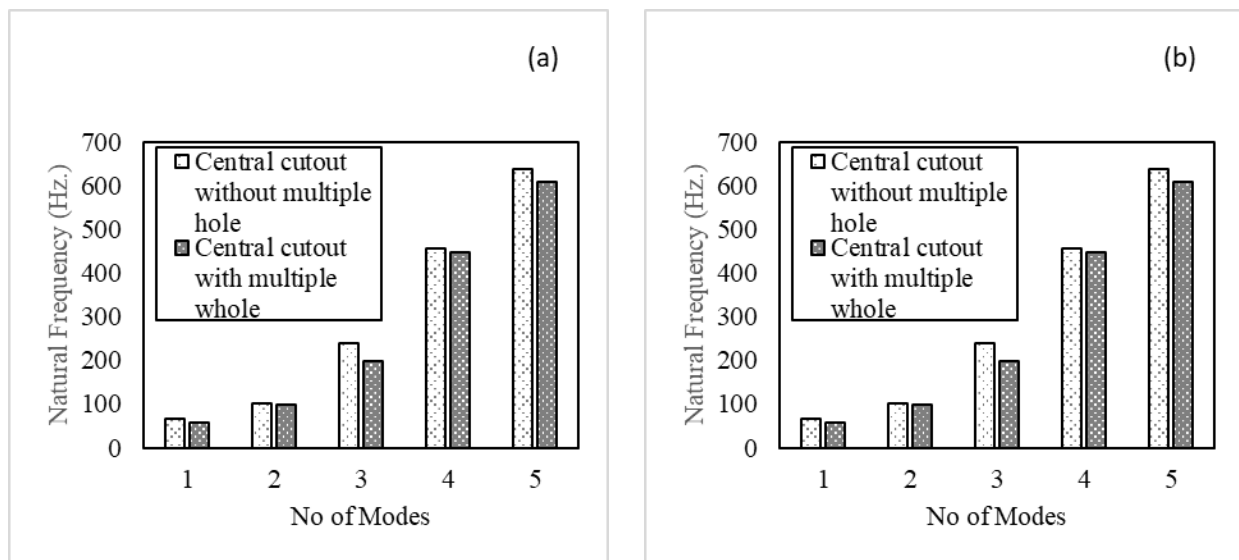


Figure 6. Frequency vs number of modes plot for central cut-out with multiple holes and a single central cut-out for the equivalent cutting area in (a) CFFF type support condition (b) SFSF type support condition

5.1.2 Frequency vs cut-out position

To investigate the influence of cutout position on the vibrational behavior of the plate, the cutouts were cut at different positions such as on the side, center, and corner of the support. The changes in natural frequencies of plates having cutouts at different positions under CFCF and SFSF end conditions are presented in Figure 7(a) and (b) respectively. The variation of results obtained from ANSYS and experiments shows that experimental results are at par with that of ANSYS results, which validates the current work. At the same time, it can be noted that the natural frequency is maximum for cut-outs/holes at the center position in both types of support. For, CFCF support type, the results of experiments show that there is a reduction in frequencies of around 16.11% from cut-out at the center to side position in the 1st mode of vibration and around 32.89% reduction from cut-out at the center to corner in the 1st mode of vibration.

There is a reduction in frequencies of around 15.60%, 7.34%, 2.58%, and 2.56% from cut-out at the center to side position in the 2nd, 3rd, 4th. and 5th modes of vibration respectively. Also, there is a reduction in frequencies of around 37.40%, 40.60%, 33.49%, and 27.40% from cut-out at the center to corner position in the 2nd, 3rd, 4th. and 5th modes of vibration respectively. So, it is concluded that the rate of reduction of natural frequency at the corner position with respect to the central cut-out is larger than at the side position. Similarly, the reduction in frequency is around 7.5% from cut-out at the center to side position and around 25% reduction from cut-out at the center to corner in the 1st mode of vibration under SFSF type support condition. There is a reduction in frequencies of around 7.5% from cut-out

at center to side position in the 2nd, 3rd, 4th. and 5th modes of vibration respectively. Also, there is a reduction in frequencies of around 25% from cut-out at center to corner position in the 2nd, 3rd, 4th. and 5th modes of vibration respectively. So, it is concluded that the rate of reduction of natural frequency with different positions of cut-out in SFSF boundary condition follows similar trends with CFCF boundary condition. The minimum reduction in stiffness of the composite plate having a central cutout for both end conditions as compared to the other two different considered positions may be due to the minimal stress region of the plate.

5.1.3 Frequency vs cut-out ratio (d/D ratio)

To study the effect of the cut-out ratio (d/D), the cut-out of the size of 80mm x 80mm is made at the center position of the plate. The cut-out ratio of 0, 0.1, 0.2, 0.3, and 0.4 has been chosen for CFCF and SFSF types of support systems. So, the side of the square cut-out on the side of the central cut-out happens to be 0mm, 8mm, 16mm, 24mm, and 32mm. Figures 8 (a) and (b) represent the effect of the cut-out ratio on the natural frequency of plate for CFCF and SFSF type of support conditions respectively. The results of presented Figures 8 (a) and 8 (b) show that the natural frequency of the plate is least at 0.4 cut-out ratio in CFCF and SFSF type support conditions. The larger cut-out ratio has considerable effects on the frequency of the plate and it decreases as the cut-out ratio increases. It has been observed that there is a 2.6%, 7.2%, 12.4%, and 16.1 % decrease in all five modes (1st, 2nd, 3rd, 4th, and 5th mode) of frequencies for 0.1, 0.2, 0.3 and 0.4 cut-out ratio respectively in CFCF boundary condition. In SFSF boundary conditions, It is observed that there is a 2.8%,

8.4%, 12.8%, and 17.6 % decrease in all five modes (1st, 2nd, 3rd, 4th, and 5th mode) of frequencies for 0.1, 0.2, 0.3 and 0.4 cut-out ratio respectively. The depicted figures confirm that the frequency decreases for cut-out ratio up to 0.4 for both end conditions

(CFCF and SFSF). This is because of a reduction in the localization of stress concentration due to multiple holes in the edges of the central cut-out. Therefore, the stiffness of the plate also reduces.

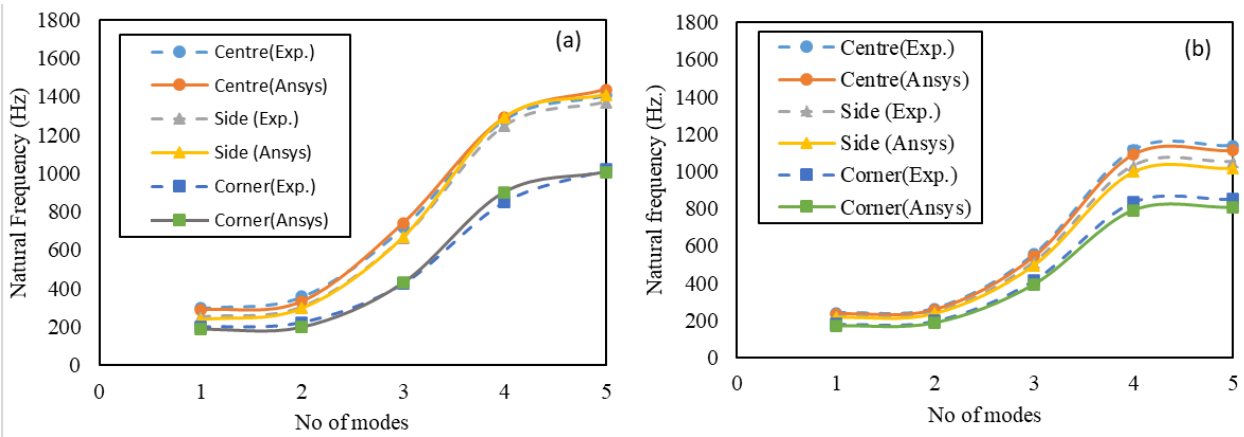


Figure 7. Natural frequency vs cut-out position in (a) CFCF support type (b) SFSF support type

Table 6. The dimension of three plate w.r.t. aspect ratio (a/b)

Aspect ratio (a/b)	Length [mm]	Width [mm]	Thickness [mm]
1	235	235	3
1.5	235	156.6	3
2	235	117.5	3

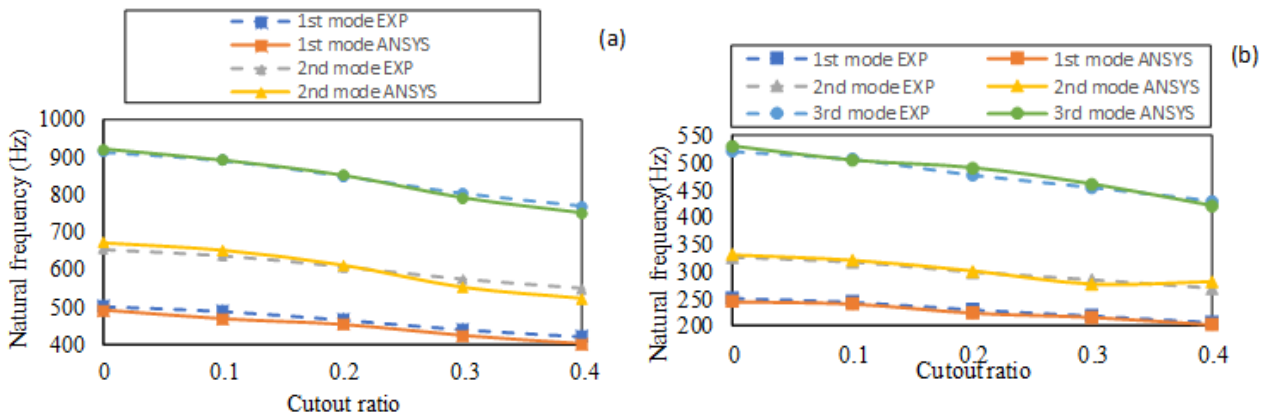


Figure 8. Natural frequency vs cut-out ratio in (a) CFCF support type (b) SFSF support type

5.1.4 Frequency vs aspect ratio (a/b)

To investigate the influence of aspect ratio on the natural frequency of the plate, a 0.4 cut-out ratio plate has been considered. The aspect ratio can be defined as the ratio of length (a) to width (b) of the plate. The aspect ratio of 1, 1.5, and 2 has been chosen for study. The dimensions of the plates are given in Table 6. The support is taken along the length of the plate. Figure 9 (a) depicts the changes in the frequency of the plate for the three-aspect ratio

of the plate (cut-out ratio 0.4) in the CFCF support type. The figure reveals that the frequency of the plate is increased by almost 58.12% and 72% for aspect ratio 1.5 and 2 respectively in all three modes (1st, 2nd, and 3rd mode) of natural frequency. Therefore, it confirms that the increase in the aspect ratio of the plate affects increasing the frequency. The increase in aspect ratio is directly related to the stiffness of the plate resulting in more natural frequency in any boundary condition.

5.1.5 Frequency vs number of layers of composite plate

To visualize the effect of the number of layers (in the laminated composite plate) on the frequency, three plates laminated with 4, 8, and 12 layers with 0.4 cut-out ratio have been examined in CFCF boundary condition. The dimensions of composite plates considered for the analysis are 235mmx235mmx1.5mm, 235mmx235mmx3mm, and 235mmx235mmx4.5mm for 4, 8, and 12 layers of laminated plate respectively.

The support is taken along the length of the laminated plates. Figure 9 (b) shows the variation of the frequency of the plate for the three different layers of fabrication. The figure depicts that the increase in the number of layers in the lamination of the plate results in an increase in the frequency of the composite plate. The level of increment in frequency can be observed as 61.5% and 74.5% for plate 8 and 12 layers respectively relative to the frequency of the plate having 4 layers in 1st mode of frequency. Similarly, the rate of increment of natural frequency for 8- and 12-layer composite plates are 64.1% and 74.10% w.r.t 4-layer composite plate respectively in 2nd mode. The variation of natural frequency with

an increase in the number of layers. In 3rd mode, the percentage increase in natural frequency for 8 and 12 layers is 62.7% and 79.6% w.r.t 4 layers composite plate. So, the increase in the number of layers in the lamination of the plate leads more stiffer plate which increases the frequency of the composite plate.

5.1.6 Frequency vs ply orientation

To study the effect of ply orientation on the frequency of the fabricated plate, various orientations such as (0/90)₄, (45/-45)₄, and (30/-60)₄ of the plate with a 0.4 cut-out ratio have been chosen for the experimentation. The plate dimensions happen to be 235mmx235mmx3mm and the Young's modulus of elasticity of the (30/-60)₄ and (45/-45)₄ ply orientation plates are 8.788 GPa and 7.574 GPa respectively. The CFCF support is chosen to study the effect of ply orientation on the frequency of the laminated composite plate. Figure 10 depicts the changes in frequency for the different ply orientations of the plates. The plot confirms that the increase in fiber angle reduces the plate frequency. This may be due to the higher Young's modulus of elasticity of the plate having fiber orientation (0/90)₄ as compared to other fiber orientations.

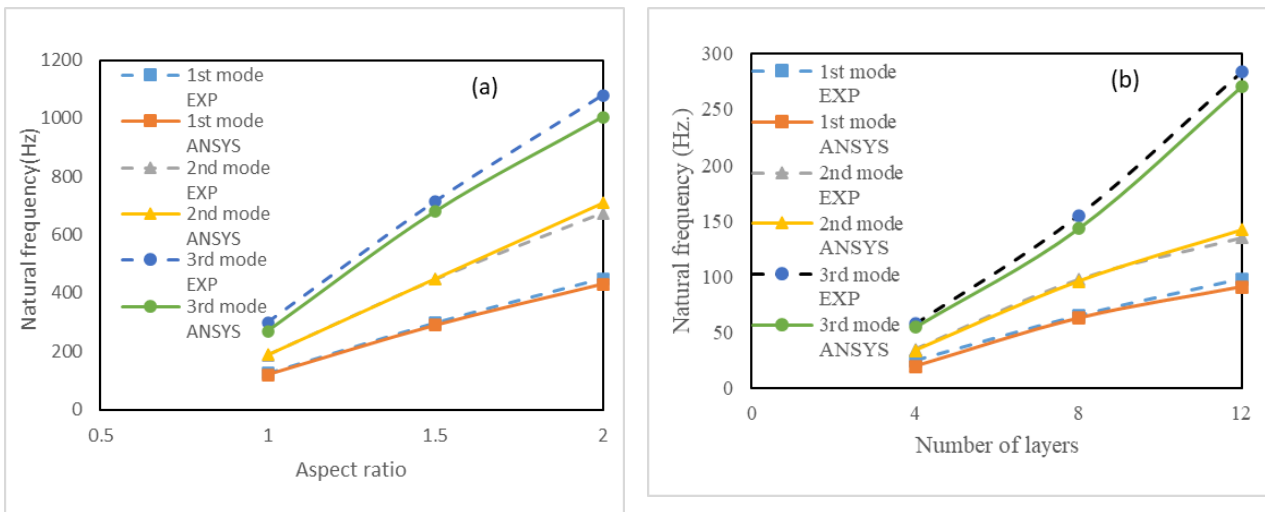


Figure 9. (a) Natural frequency vs aspect ratio in CFCF support type (b) Natural frequency vs number of layers in CFCF support type

6. CONCLUSION

The current research focused on devising the influence of multiple cut-outs on the free vibration characteristics of laminated composite plates. The numerical analysis of the vibration characteristics of the plate has been performed using ANSYS software. The experimentations of vibration analysis

are also conducted for various sets of design parameters. The effect of different design parameters like cut-out ratio, cut-out position, ply orientation, aspect ratio, and number of layers under support/end conditions on the natural frequency of the laminated plate have been presented and analyzed. The numerical results are compared with the experimental results of the tests, which validate the accuracy of the conducted work. The test confirms that the natural frequency of the plate

having cut-outs at centers and multiple cut-outs on the sides is less than that of the plate with a single cut-out of the same area at the center. With the rise in the value of the cut-out ratio, the frequency of the plate decreases in SFSF and CFCF-type support conditions. Similarly, when the aspect ratio increases, it increases the frequency of the plate. While considering the position of cut-outs as the parameters, the investigation shows that maximum frequency occurs for cut-outs at the center position and the values are minimum for corner position cut-outs regardless of the end conditions. The decrease in the number of layers during the fabrication of

glass fiber laminated composite results in the reduction of the frequency. It can also be observed that as the ply orientation (fiber angle) increases, there is a decrease in frequency value. The aforementioned facts reveal that the cut-outs might have weakened the plate in dynamic loading conditions and the decrease in frequency leads to resonance. The presented vibration analysis outcomes of the bi-directional glass fiber laminated composite will be very helpful in designing health monitoring structures and in future studies of composite structures.

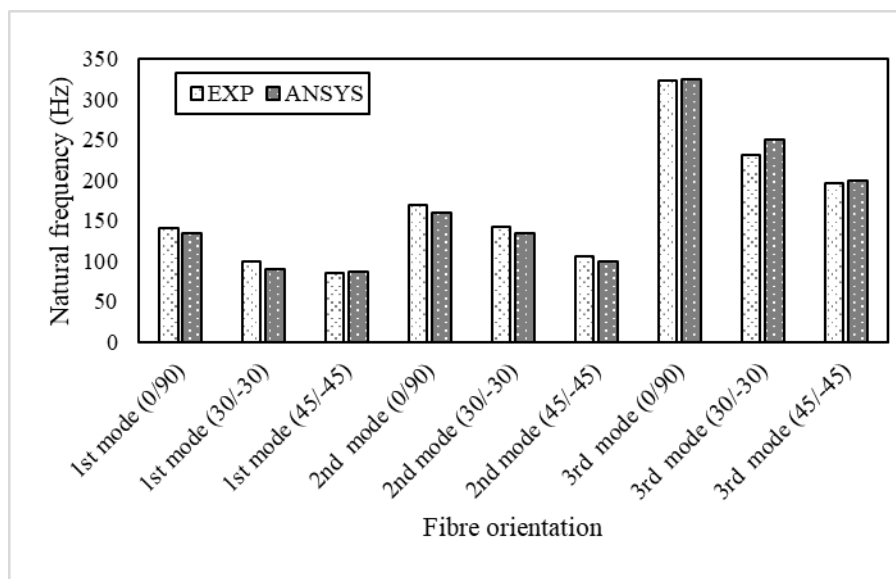


Figure 10. Natural frequency vs fiber orientation CFCF support type

REFERENCES

- [1] Aksu G., Ali R. (1976) "Determination of dynamic characteristics of rectangular plates with cut-outs using a finite difference formulation", *Journal of Sound and Vibration*, 44, 147–58.
- [2] Ali R., Atwal S.J. (1980) "Prediction of natural frequencies of vibration of rectangular plates with rectangular cut-outs", *Computer and Structure*, 12, 819–23.
- [3] ASTM D 2344/ D 2344M (2006) Standard test method for short-beam strength of polymer matrix composite materials and their laminates, Annual Book for ASTM Standards, American Society for Testing and Materials.
- [4] ASTM D 3039/D 3039 M (2008) Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.
- [5] Bhardwaj H.K., Vimal J., Sharma A.K. (2015) "Study of free vibration analysis of laminated composite plates with triangular cut-outs" *Engineering Solid Mechanics*, 3, 43-50.
- [6] Boay C.C. (1996) "Free vibration of laminated composite plates with a central circular hole", *Composite Structures*, 35, 357-368.
- [7] Chen C.C., Kitiporanchai S., Lim C.W., Liew K.M. (2000) "Free vibration of symmetrically laminated thick perforated plates", *Journal of Sound and Vibration* 230, 111–32.
- [8] Hota S.S., Padhi P. (2007) "Vibration of plates with arbitrary shapes of cutouts", *Journal of Sound and Vibration*, 302, 1030–1036.
- [9] Kalit K., Banerjee A.K., Halder S. (2013) "An analysis to mitigate induced stresses in orthotropic plates with central square cut-out." *International Journal of Engineering* 6.3, 379-386.
- [10] Laura PAA, Verniere De Irassar P, Ercoli L.(1981) "Fundamental frequency of a rectangular plate with a free, straight corner cut-out". *Journal of Sound and Vibration* 78, 489-493.
- [11] Lee S.Y., Chung D.S. (2010) "Finite element delamination model for vibrating composite spherical shell panels with central cut-outs" *Finite Elements in Analysis and Design* ,46, 247–256.
- [12] Liew K.M., Kitipornchaib S., Leungb A.Y.T., Limb C.W. (2003) "Analysis of the free vibration of rectangular plates with central cut-outs using the discrete Ritz method " *International Journal of Mechanical Sciences*, 45, 941–959.
- [13] Ovesy H.R., Fazilati J.(2012)"Buckling and free vibration finite strip analysis of composite plates with cut-out based on two different modelling approaches" *Composite Structures* , 94, 1250–1258.
- [14] Poore A.L., Barut A., Madenci E.(2008) "Free vibration of laminated cylindrical shells with a circular cutout " *Journal of Sound and Vibration*, 312, 55–73.

-
-
- [15] Ramakrishna S., Rao K. M., Rao N.S. (1992) "Free vibration analysis of laminates with circular cut-out by hybrid-stress finite element", *Composite Structures* 8, 63-81.
- [16] Reddy J.N. (1982) "Large amplitude flexural vibration of layered composites plates with cut-outs", *Journal of Sound and Vibration*, 83, 1-10.
- [17] Sahoo S. (2014) "Laminated composite stiffened shallow spherical panels with cutouts under free vibration- A finite element approach", *Engineering Science and Technology, an International Journal* ,17, 247-259.
- [18] Sharma P.K., Mishra Y, Bhatt D. (2014) "Model analysis of Centre circular laminated composite plate with circular cut-out" *International Journal of Advance Engineering and Research Development* ,vol.1,issue-10, 25-29.
- [19] Sivakumar K., Iyengar N.G.R., Deb K.(1999) "Free vibration of laminated composite plates with cut-out", *Journal of Sound and Vibration* ,221, 443-470.
- [20] Jhanji, K. P., Kumar, R. A., Das, D., & Sarkar, S. (2019, October) "Response of composite laminate with various cut-out combinations to tension load" *IOP Conference Series: Materials Science and Engineering* (Vol. 561, No. 1, p. 012109).
- [21] Sinha, L., Das, D., Nayak, A. N., & Sahu, S. K. (2021) "Experimental and numerical study on free vibration characteristics of laminated composite plate with/without cut-out" *Composite Structures*, 256, 113051.
- [22] Kumar, M., & Sarangi, S. K. (2022) "Influence of cut-out shape on the dynamic behavior of carbon nanotubes reinforced functionally graded plates" *Engineering Research Express*, 4(4), 045013.
- [23] Prusty, J. K., Papazafeiropoulos, G., & Mohanty, S. C. (2023) "Free vibration analysis of sandwich plates with cut-outs: An experimental and numerical study with artificial neural network modelling" *Composite Structures*, 321, 117328.