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Harmonic analysis of laminated skew plate with different geometrical cut-outs

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Abstract*: Skew laminated composite plates with cut-outs are used in many engineering applications like fins, wings and tails of aero planes, hulls of ships and parallelogram slabs in buildings, complex alignment problems in bridge design etc. The structure used in these applications, are often subjected to dynamic force which creates vibration. Based on the First-order Shear Deformation Theory (FSDT), this study deals with harmonic analysis of moderately thick laminated composite skew plates with cut-outs using the finite element package ANSYS. The effect of various geometries of the cut-out, on the resonance point has been investigated. An 8 node 281 shell element is adopted to mesh the plate geometry. The accuracy of the present analysis is shown in some typical cases. The results are compared with existing results based on other numerical methods and observed to be in close proximity.

***Index Terms*: Composite plate; Harmonic Response; Frequency Response Function; Skew angle; Cut-out; FEM**

I. INTRODUCTION

In skew laminated composite plates, sometimes, cut-outs are provided for the purposes of joining, reassembling and making light weight. Cut-outs can be of different geometry to gain some necessary functions such as proper ventilation, to make electrical lines as well as fuel lines etc. Geometry of cut-outs in these plates affects its harmonic behaviors. Therefore, the harmonic study of skew laminated plates with various geometrical cut-outs is important to choose the optimum geometry of cut-out. The vibration analysis of laminated composite structures has drawn attention to many researchers. Different numerical techniques are used for the vibration behavior of laminated skew plates.

The dynamic stability behaviour of laminated skew plate has been studied by Dey and Singha [1]. The finite element method was used. The free vibration behaviour of large amplitude has been studied by Singha and Daripa [2]. They used a 4-noded plate bending element and found the equation to judge the non-linear frequency.

The isotropic laminated skew plate has been studied by Das et al. [3] for the large deflection analysis. Sharma et al. [4] analyzed the free vibration behaviour of shear deformable anti-symmetric laminated plates. They used the cross-ply rectangular plate with rotational and translational edge constraints. Rao and Reddy [5] analyzed the displacements and natural frequencies of a propeller of composite material with metal using ANSYS software.

Useche et al. [6] studied the vibration and harmonic analysis of orthotropic plates having crack and having a shear deformable property. Author used a Method of Boundary Element. The experimental study on free vibration behavior of isotropic and laminated skew plates has been carried out by Srinivasa et al. [7].

Gulshan et al. [8] studied the free vibration behaviour of skew plates of FG material with temperature variation environment and found the importance of skew angle and VFI in analyzing the vibration of skew plate of functionally graded material subjected to heat load.

Vimal et al. [9] carried out the free vibration behaviour of FG skew plates using FE method and observed that the effects of the ratio of length and thickness are independent from the volume fraction on the frequency of a FG skew plate. Vivek K. Sai [10] analyzed the free vibration for laminated plates having skew angle of 15° and 30° with cut-out of circular geometry using finite element method based on FSDT. Numerical and experimental observation of laminated skew plates with and without cut-out have been studied by

Mandal et al. [11] and found that the rotary inertia observes the significant effect for thick plates. The free vibration responses of the shear deformable skew sandwich plate, have been investigated by

Katariya et al. [12] with the help of finite element method. Joseph and Mohanty [13] carried out and buckling analysis and free vibration analysis of a 3-ply skew sandwich plate.

Narwariya et al. [14] carried out a harmonic analysis of the orthotropic plate with anti symmetric laminated layers.

In this study, the effect of geometries of cut-outs on the harmonic response is determined to know the best design of skew plate.

II. MODELLING

A. Geometrical Modeling

Geometry of the laminate with different shapes of cut-outs is shown in fig. 1. The dimensions are taken as:
Skew angle (α) = 30°, Length (l) = 1m, width (w) = 1m and thickness (b) = 0.01m.
The cut-out area for all geometries is taken as same i.e. 31415.9265 mm^2.

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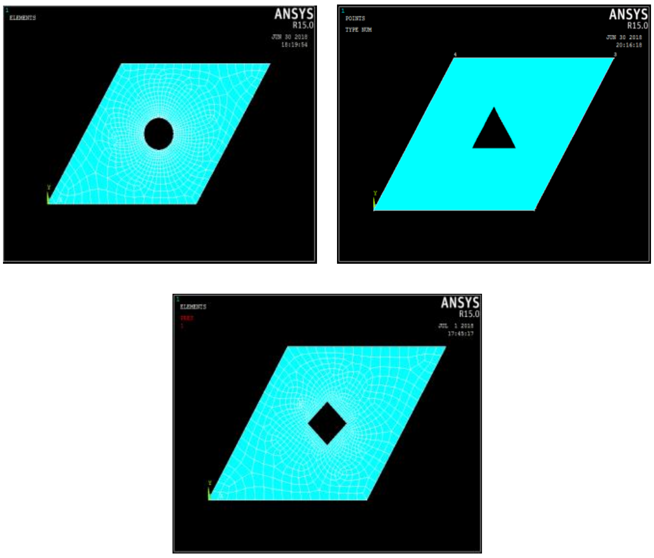

Fig. 1. Geometry of skew plate with different shapes of cut-outs

B. Boundary Condition

A skew orthotropic plate of 1m x 1m is considered in this study. Clamped boundary condition (i.e. all the edges of skew plate and cut-out are constrained to all the six degrees of freedom) is adopted to analyze the plate. A pressure of 1 Pa is applied on whole area of the plate.

C. Material Used

The Graphite/epoxy material is used for the study having the following properties.

E_1= 172720 × 106 Pa, $E_2 = E_3$ = 6909 × 106 Pa, $G_{12} = G_{13}$ = 3450 × 106 Pa, G_{23} = 1380 × 106 Pa,

μ (for all direction) = 0.25 and ρ = 1600 kg/m^3 where the subscripts 1 and 3 represent the parallel direction and 2 represents perpendicular to fiber direction in a layer.

III. RESULT AND DISCUSSION

A.Convergence Study

In this analysis, initially convergence study has been done for skew plate having symmetric and anti-symmetric laminates with CCCC boundary condition taking skew angle of 30°. Table 1 shows the convergence study for non-dimensionalized fundamental frequencies (ϖ) for clamped 4-layered symmetric i.e. (0°/90°/90°/0°) and 4-layered anti-symmetric i.e. (0°/90°/0°/90°) skew laminated composite plates for thickness to width ratio b/w = 0.01. It is clear from the results that the convergence is achieved at the mesh size of 17 × 17.

B. Comparison Study

To validate the results, a skew cross-ply laminated composite plate with cut-out of circular geometry taking 100 mm diameter, have been analyzed and compared with available publication results of Vivek k. Sai [10] using the similar shear correction factors i.e. 5/6 and frequency parameters $\left(\varpi=(\omega a^2)/(\pi^2 t)\sqrt{(\rho/E_2)}\right)$ for illustrating the precision and usefulness of the present adopted method.

Fig. 2 shows the comparison of non-dimensional fundamental frequencies $\left(\varpi=(\omega a^2)/(\pi^2 t)\sqrt{(\rho/E_2)}\right)$ for symmetric 5-layered $(90°/0°)_2/90°$ and figure 3 shows for anti-symmetric 10-layered $(90°/0°)_2/90°(90°/0°)_2/90°$ skew plates with cut-out of circular geometry under the clamped boundary condition. Skew angle (α) is taken as 30° and thickness ratio as 0.001.

It is clear from the comparison study that the results observed good agreement.

C. Harmonic Analysis

Harmonic Analysis has been done to obtain the first natural frequencies on skew composite plate with various cut-out geometries under all edges fixed boundary conditions i.e. CCCC. The plates are excited by external pressure and the response of plates is obtained on the Frequency Response Function graph. From this graph we predict its resonance amplitude. In this analysis, the three geometries of cut-outs i.e. triangular, circular and square are taken to show the effects of geometry of cut-outs on resonance amplitude.

Table 1. Convergence study for a skew 4-layered laminated plate for all edges fixed (CCCC) Boundary condition.

l/w	b/w	Skew angle	Mesh Size	$\left(\varpi=(\omega a^2)/(\pi^2 t)\sqrt{(\rho/E_2)}\right)$							
				Mode Number (M)							
				For symmetric (0°/90°/90°/0°)				For anti-symmetric (0°/90°/0°/90°)			
				M_1	M_2	M_3	M_4	M_1	M_2	M_3	M_4
1	0.01	30°	11×11	3.713	5.866	8.838	9.112	3.853	6.797	8.662	9.734
			13×13	3.713	5.864	8.835	9.103	3.853	6.794	8.659	9.726
			15×15	3.713	5.863	8.833	9.099	3.852	6.793	8.657	9.723
			17×17	3.713	5.863	8.832	9.096	3.852	6.792	8.656	9.721
			19×19	3.713	5.863	8.832	9.096	3.852	6.792	8.656	9.721
			21×21	3.713	5.862	8.832	9.096	3.852	6.792	8.656	9.721

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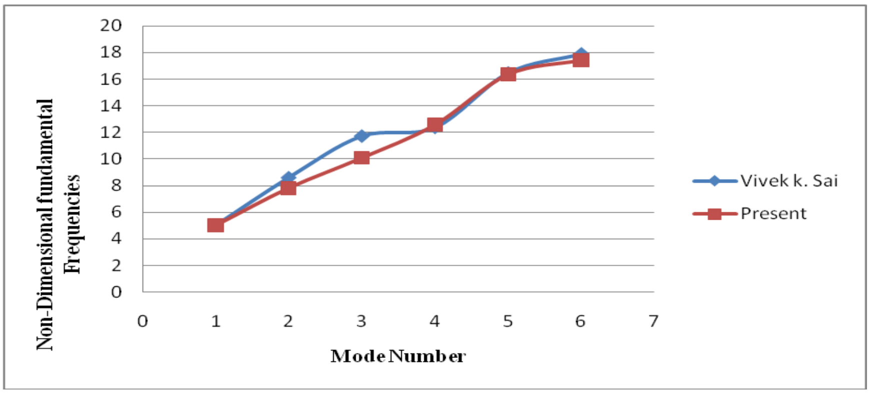

Fig. 2. Comparison of Non-dimensionalised frequencies (ϖ) for symmetric plate i.e. $(90°/0°)_2/90$

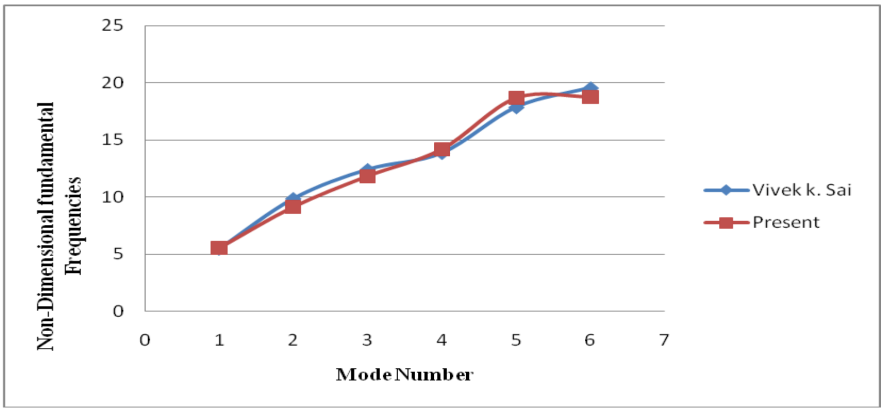

Fig. 3. Comparison of Non-dimensionalised frequencies (ϖ) for anti-symmetric plate i.e. $(90°/0°)_2/90°(90°/0°)_2/90°$

a. Triangular Cut-out.

The cross-ply skew laminated plate having triangular cut-out, with symmetric (0°/90°/90°/0°) and anti-symmetric (0°/90°/0°/90°) arrangement of layers for thickness ratio 0.01 are analyzed. The resonance amplitude 0.00195344 mm has been found at natural frequency 381.22 Hz for symmetric cross ply and resonance amplitude 0.00263434 mm found at 324.48 Hz natural frequency for anti-symmetric cross ply. Frequency response function is shown in fig. 4(a) and 4(b).

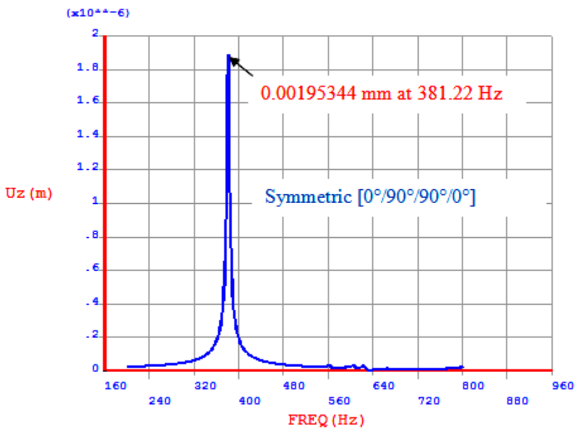

Fig. 4(a). Frequency Response Function for symmetric laminated skew plates with triangular cut-out.

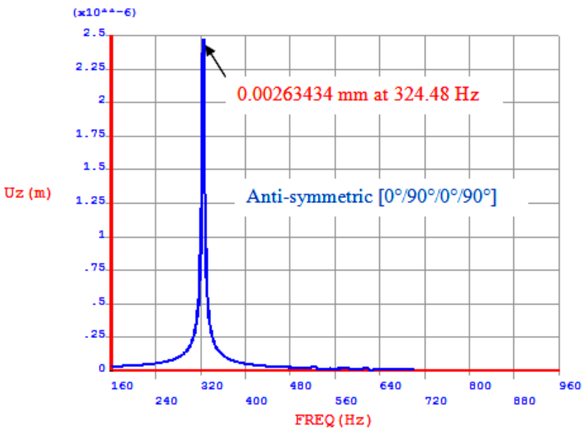

Fig. 4(b). Frequency Response Function for anti-symmetric laminated skew plates with triangular cut-out.

b. Circular Cut-out.

The resonance amplitude 0.00206252 mm has been found at natural frequency 369.91 Hz for symmetric cross ply and resonance amplitude 0.00221501 mm found at 325.38 Hz natural frequency for anti-symmetric cross ply skew plate with circular cut-out. Frequency response function is shown in fig. 5(a) and 5(b).

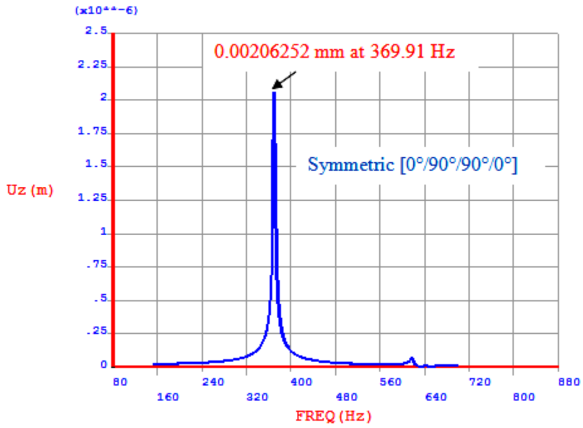

Fig. 5(a). Frequency Response Function for symmetric laminated skew plate with circular cut-out.

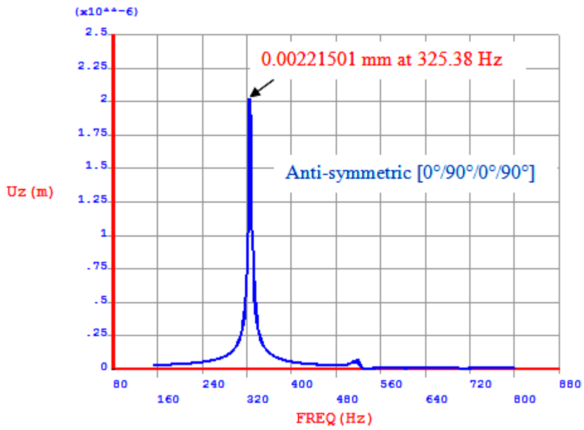

Fig. 5(c). Frequency Response Function for anti-symmetric laminated skew plate with circular cut-out.

c. Square Cut-out.

Fig. 6(a) and 6(b) show the frequency response function for symmetric and anti-symmetric 4-layered skew plate having square cut-out. It has been observed that the resonance amplitude 0.00214897 mm found at natural frequency 364.55 Hz for symmetric cross ply and resonance amplitude 0.002512719 mm found at 326.29 Hz natural frequency for anti-symmetric cross ply.

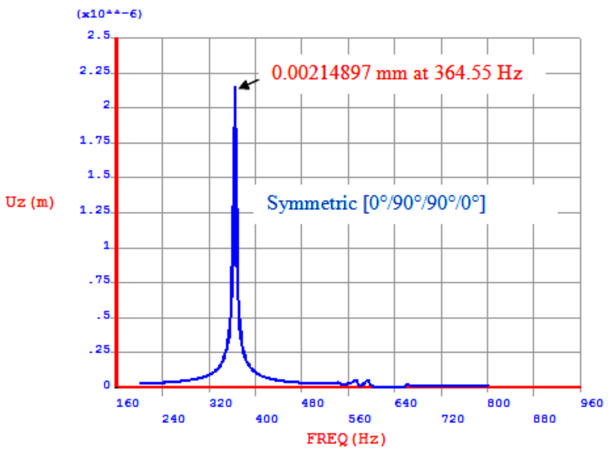

Fig. 6(a). Frequency Response Function for symmetric laminated skew plate with square cut-out.

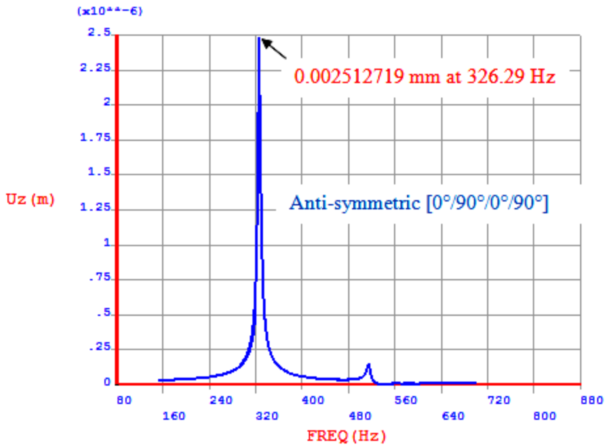

Fig. 6(b). Frequency Response Function for anti-symmetric laminated skew plate with square cut-out.

IV. Conclusion

Convergence tests and comparison studies have been carried out using the Finite Element Method. The convergence is achieved at the mesh size of 17 × 17.The obtained results have illustrated a good agreement with those available in the literature for different modulus ratios, thickness ratios and different support conditions. The present analysis deals with the harmonic analysis of skew laminated composite plate with different shapes of cut-outs. The analyses are conducted for symmetric and anti-symmetric cross ply laminates to examine the effects of different geometries of cut-out on the frequency parameter and resonance amplitude. From the analysis, it has been observed that the shape of cut-outs played the important role to design the composite structure when subjected to dynamic load. Skew plate with different geometries of cut-outs of same areas, show the different natural frequencies and resonance amplitude. From the analysis, it is found that symmetric skew plate having triangular cut-out is more suitable to design the structure due to having the minimum resonance amplitude. It can also be seen from the analysis that the lamination scheme also affects to harmonic response. The anti-symmetric skew plate with triangular cut-out shows the maximum resonance while the symmetric skew plate with same cut-out shows minimum resonance.

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