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Numerical Study of Different Parameters on Dynamic Characteristics of E-Glass Epoxy Composite Laminates

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Abstract
Free vibration analysis of E-glass composite laminates is carried out using finite element method. An 8 node shell element consisting of 48 degrees of freedom is used. Results obtained by the analysis demonstrate the efficiency of the present model. Numerical results for 4 different parameters namely- aspect ratio, thickness ratio, the number of plies and ply angles are presented. It is observed that the natural frequency parameter decreases for plate aspect ratio and thickness ratio (a/h) increases the frequency decreases. It is seen that the ply angles do not show a definite increasing or decreasing effect on natural frequency. Natural frequency increases a little when the number of plies is increased from 2 to 4 but beyond this even after increasing the number plies has minuscule effect on frequency. For mode number 1, 2 and 4 it is seen that the natural frequency increases upon increasing ply angle up to 45^{o} beyond which it starts decreasing.
*Keywords:*FEA, Composite, Dynamic analysis, frequency

1. Introduction

Using the directional properties of the fibers and arranging different layers of the laminate, the composite panel boards can be suitably designed to avoid the occurrence of resonance at low-frequency ranges, which will cause higher amplitudes of vibration, and hence reduce the damage and increase the life of the precision instruments. The parameters, which control the natural frequencies of the composite panel board are- their thickness and the number of layers in the laminate, their arrangement, the orientation of the fibers and the volume fraction of the fibers. The information available in the literature is limited to some specific shapes of composite plates and with few cutouts of regular shapes. No closed form solutions are available for the dynamic characteristics of complex shapes such as the panel board with specific boundary conditions and specified numbers, shapes and sizes of the cutouts. Hence it is worthwhile to undertake selected numerical studies to get more insight into this application area. Plate vibration problems are a subclass of the more generalized problem of mechanical vibrations. In general the third dimension of the plate is considered as very small as compared to the other two dimensions. Thus, the governing equations for motion of plates are far less complex than those of three-dimensional objects.Many researchers have thus proposed and subsequently verified that a 2D plate theory would hold good. Thus over the years a number of two-dimensional plate theories have been proposed and these theories more often than not give excellent approximation to the actual 3D motion of a plate-like object. Among the various theories developed to address the plate motion problem, the Kirchhoff-Love theory and the Mindlin-Reissner theory has been the most notable. The dynamic behavior of the plates has been successfully studied by various researchers using these two or some extensions of these theories. Both free as well as forced vibration problems have been widely studied so far. The analysis of plates first started in the 1800s. Euler (Leissa, 1973) was the first person to mathematically tackle the free vibration problem in flat plate. After him, a German scientistnamed Chladni(Whitney & Pagano, 1970)discovered the different modes of free vibrations. The elasticity theory was articulated some time later. Navier(Noor, 1973)is considered by many as the initiator of modern elasticity theory. Navier's work on plate problems has been a path breaker in the field of elasticity. In fact it was Navier who derived the exact differential equation for rectangular plates with flexural resistance. Poisson, another stalwart in the field of applied mechanics in 1829 (Noor & Burton, 1989) demonstrated the how governing equation for plate motion can be used to predict the lateral vibration of circular plates. Mindlin et al. (1955) (Majumdar, Manna, & Haldar, 2010) Investigated the effect of rotatory inertia and shear deformation on the flexural vibration of isotropic, rectangular plates. The analysis paid more attention to the higher modes and frequencies of vibration which were beyond the range of applicability of the classical theory of thin plates. Haldar and Sheikh (2005) (Haldar & Sheikh, 2005) utilized a high precision composite plate bending element was applied by to the free vibration analysis of isotropic and fiber-reinforced laminated composite folded plates. The in-plane displacements, transverse displacement, and rotations of the normal were taken as independent field variables and approximated with polynomials of different orders. Numerical examples of isotropic and composite one-, two-, and four-fold folded plates having different crank angles, fiber orientations, thickness ratios, the number of layers and boundary conditions were solved and presented using the proposed element. Kalita and Haldar (2015) (Kalita & Haldar, 2015) used a 9 node plate element in combination with FSDT theory for free vibration study of rectangular plates with centerholes. They used the FSDT to predict the plate vibration behavior for thick as well as thin plates.They reported that rotary inertia has a substantialinfluencein case of thick plates, whereas for thin plates the rotary inertia term can be disregarded. Kalita and Haldar (2016) (Kalita & Haldar, 2016)(Kalita, Ramachandran, Raichurkar, Mokal, & Haldar, 2016) (Kalita K. , Shivakoti, Ghadai, & Haldar, 2016) (Kalita K. , Shivakoti, Ghadai, & Haldar, 2016)also used the nine-node isoparametric plate element, in conjunction with first-order shear deformation theory, to free vibration analysis of rectangular plates. They found that rotary inertia significantly affects thick plates, while it can be ignored for thin plates. The numerical convergence was shown to be rapid and based on a comparison with data from the literature; it was proposed that their formulation can yield highly accurate results. Significant amount of studies has been conducted on the dynamic behaviour of composite plates. Thai and Kim (Thai & Kim, 2010) used two variable refined plate theory to calculate the natural frequencies of laminated composite plates. Thai and Choi (Thai & Choi, 2013)used a two variable refined plate theory to understand the dynamicbehaviour of rectangular plates undernumerous boundary conditions. Xiang et al. (Xiang, Shi, Wang, Ai, & Sha, 2010) presented a meshless method based on thin plate spline radial basis functions and higher-order shear deformation theory (HSDT) to analyse the free vibration of clamped laminated composite plates. Adim et al. (Adim, Daouadji, & Rabahi, 2016) recently demonstrated the utility of a simplified HSDT. Asadi et al. (Asadi, Wang, & Qatu, 2012) demonstrated the use of FSDT for composite shells. In a similar work they (Asadi & Fariborz, 2012) used general differential quadrature to solve free vibration problems of isotropic, cross-ply, angle-ply and general lay-up cylindrical shells. Higher-order shear deformation theory has been used by Asadi and co-workers to calculate natural frequencies of composite plates (Asadi & Fariborz, 2012) and shells (Yaghoubshahi, Asadi, & Fariborz, 2011). Shi et al. (Shi, Nakatani, & Kitagawa, 2004) used the Galerkin method (taking the transverse shear effects) to perform dynamic behaviour study of randomly laminated plate with all sides fixed. Therefore, the utility of the study carried out in this paper is crucial and diverse. The knowledge generated out of this thesis could be helpful for practicing engineers in domains like aerospace engineering, structural engineering, offshore and ship building industry, mechanical engineering, etc.

2. Methodology

An academic version of the popular finite element software package- ANSYS v15 is used in this study to carry out the simulations. The ANSYS parametric design language (APDL) is being used by several researchers (Deshpande, Kalita, & Ramachandran, 2014) (Dutta, Kalita, & Shinde, 2015) (Kalita, Shinde, & Haldar, 2015) (Kalita, Shinde, & Thomas, 2015) (Thirumump, Kalita, Ramachandran, & Ghadai, 2015) in the past to accurately deal with the static and dynamic analysis of composite laminates. Shell 281 elements from ANSYS APDL library is selected for building the finite element model. It is an 8 node shell element having six degrees of freedom at each node: translations in the x, y, and Z-axes, and rotations about the x, y, and Z-axes. So in total, each element has 48 degrees of freedom. It is well suited for linear, large rotation and large strain nonlinear applications. A typical 4 ply angle laminated composite plate taken in the current study is illustrated in Fig. 1. The composite plate is analyzed using finite element analysis program for fiber orientation -θ/θ/θ/-θ i.e. symmetric laminates. The material properties considered in the current study are reported in Table 1. Simply supported boundary condition is considered.

$w = U_y = \theta_x = 0$, At boundary line parallel to x-axis

$w = U_x = \theta_y = 0$, At boundary line parallel to y-axis

Table 1 Material Properties of laminate considered for the study

E_x	E_y	E_z	G_{xy}	G_{xz}	G_{yz}	μ_{xy}	μ_{xz}	μ_{yz}
(in GPa)								
34	6.53	6.53	2.433	2.433	1.698	0.217	0.217	0.366

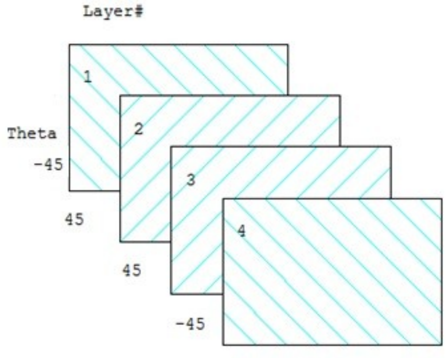


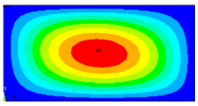
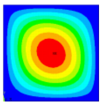
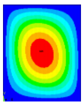
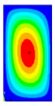
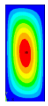
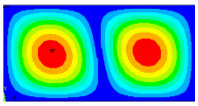
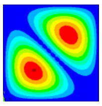
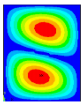
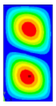
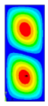
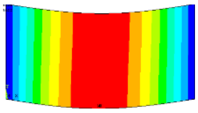
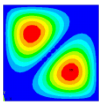
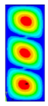
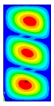
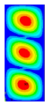
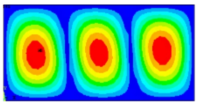
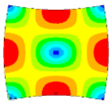
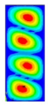
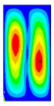
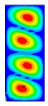
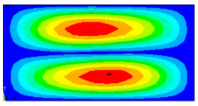
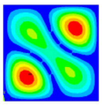
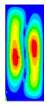
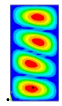
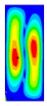
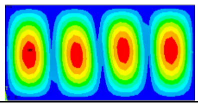
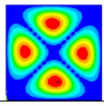
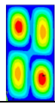
Figure 1 Layout of the composite laminate

3. Results and Discussion

3.1 Effect of aspect ratio

In this section, the effect of aspect ratio on the natural frequency of composite laminate is studied. The various aspect ratio studied are b/a=0.5, 1.0, 1.5, 2.0 and 2.5. The side parallel to the x-axis is referred here as "a" and the side parallel to the y-axis is referred here as "b". A moderately thick plate of thickness ratio, a/h=10 is considered, where "h" is the thickness of the plate. SSSS boundary condition as mentioned above is assumed. The composite laminate is a 4-ply laminate with ply orientation -45/45/45/-45. Table 2 presents the 1st six natural frequency of various rectangular E-glass composite laminate. From Fig. 2 it is realized that the natural frequency increases with decrease in the aspect ratio.

Table 2 Effect of aspect ratio (b/a)

Mode No.	b/a				
	0.5	1	1.5	2	2.5
1	465.2	217.63	158.12	134	121.92
					
2	704.28	437.64	284.36	214.84	178.37
					
3	956.16	486.04	407.92	322.57	254.69
					
4	997.01	684.12	450.74	383.7	346.14
					
5	1152.4	685.57	538.71	453.14	373.9
					
6	1325.6	779.63	637.4	463.56	382.5
					

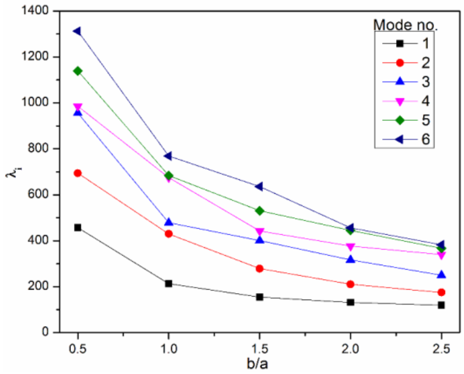
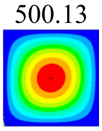
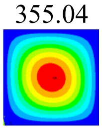
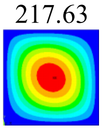
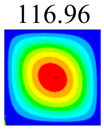
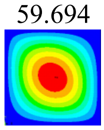


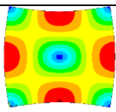
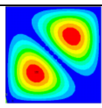
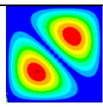
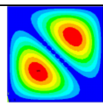
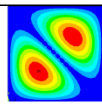
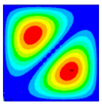
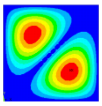
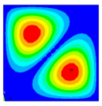
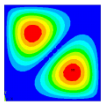
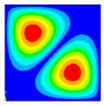
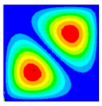
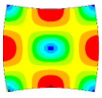
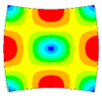
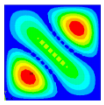
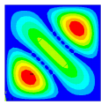
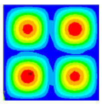
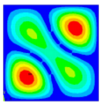
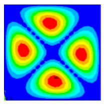
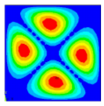
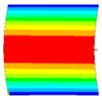
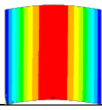
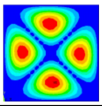
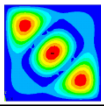
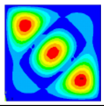
Figure 2 Comparison of 1st six natural frequencies at different aspect ratio (b/a)

3.2 Effect of thickness ratio

In this section, the effect of thickness ratio on the natural frequency of composite laminate is studied. The various thickness ratio studied are a/h= 2, 5, 10, 20 and 40. A square composite laminate with ply orientation -45/45/45/-45 and SSSS boundary condition is assumed. The consequence of thickness ratio on the first six vibrational modes is presented in Table 3 and Fig. 3. It is seen that in general as the thickness ratio (a/h) decreases the frequency increases.

Table 3 Effect of thickness ratio (a/h)

Mode No.	a/h				
	2	5	10	20	40
1	500.13	355.04	217.63	116.96	59.694
					
2	685.36	658.58	437.64	245.63	127.22

					
3	802.97	675.73	486.04	287.01	151.51
					
4	838.44	684.27	684.12	405.83	214.31
					
5	956.43	934.39	685.57	482.69	260.39
					
6	956.45	956.24	779.63	511.66	281.48
					

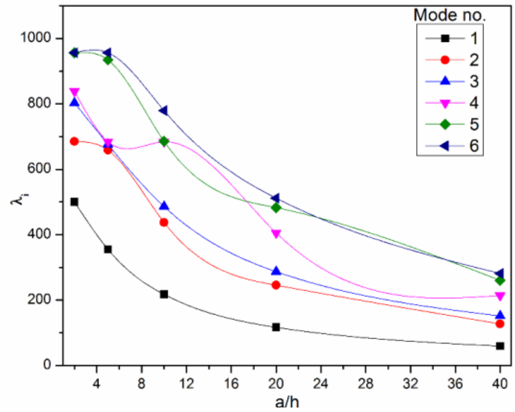
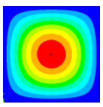
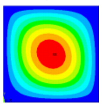
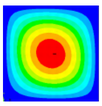
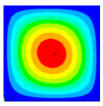
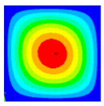
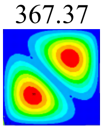
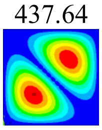
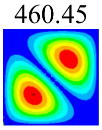
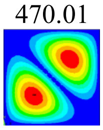
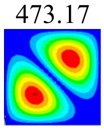


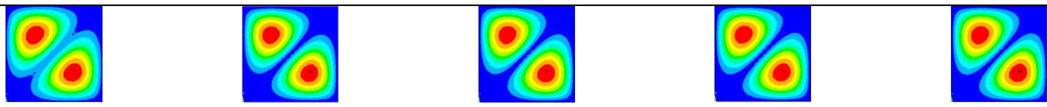
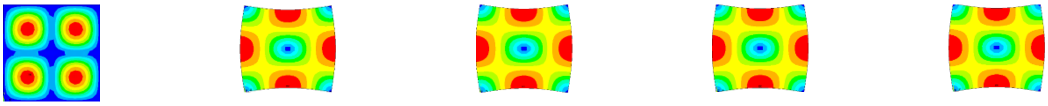
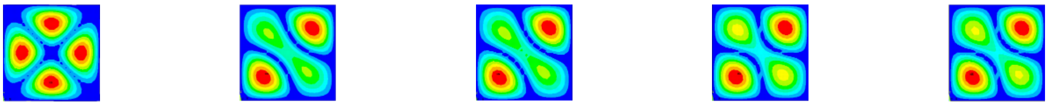
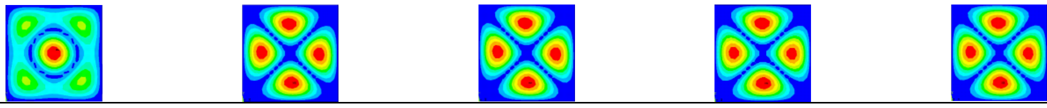
Figure 3 Comparison of 1st six natural frequencies at different thickness ratio (a/h)

3.3Effect of number of plies

In this section, the influence of number of plies on the natural frequency of composite laminate is studied. The thickness ratio (a/h) is 10 with b/a=1.0 and ply orientation -45/45/45/-45. SSSS boundary condition is assumed. The number of plies are varied as 2 (-45/45), 4 (-45/45/45/-45), 6 (-45/45/-45/-45/45/-45), 8 (45/-45/45/-45/-45/45/-45/45) and 10 (-45/45/-45/45/-45/-45 /45/-45/45/-45) i.e. each laminate thickness is considered as 0.05, 0.025, 0.0167, 0.0125 and 0.01 in the 5 cases respectively. To study the effect of number of plies, it is important that the overall thickness of the composite plate i.e. 0.1 is kept constant. The numerical value of 1st 6 natural frequencies in Hertz and the corresponding mode shape is reported in Table 4. From. Fig. 4 it is seen that the increasing number of plies has a negligible effect on the natural frequency. It increases a little when the number of plies is increased from 2 to 4 but beyond this even after increasing the number plies has very small effect on frequency.

Table 4 Effect of number of plies

Mode No.	Number of plies				
	2	4	6	8	10
1	191.75	217.63	226.14	227.61	228.98
					
2	367.37	437.64	460.45	470.01	473.17
					
3	367.44	486.04	499.73	493.84	497.04

					
4	550.84	684.12	684.12	684.12	684.12
					
5	604.18	685.57	719.06	733.22	737.17
					
6	613.16	779.63	810.55	812.11	817.81
					

3.4 Effect of ply angle

Ply angle in any designing any composite based structure is a serious concern for design engineers as practically infinite combinations of ply angles are possible. However, in this section, the study is limited to the effect of ply angles forming a symmetric laminate with only one angle present either in the clockwise or anticlockwise direction. The various combinations studies are (0/0/0/0), (-15/15/15/-15), (-30/30/30/-30), (-45/45/45/-45), (-60/60/60/-60), (-75/75/75/-75) and (-90/90/90/-90). The thickness ratio (a/h) is 10 with b/a=1.0. SSSS boundary condition is assumed. The numerical value of 1st 6 natural frequencies in Hertz and the respective mode shape is reported in Table 5. From Fig. 5 it is seen that the ply angles do not show a definite increasing or decreasing effect on natural frequency. For mode number 1, 2 and 4 it is seen that the natural frequency increases upon increasing ply angle up to 45^{o} beyond which it starts decreasing.

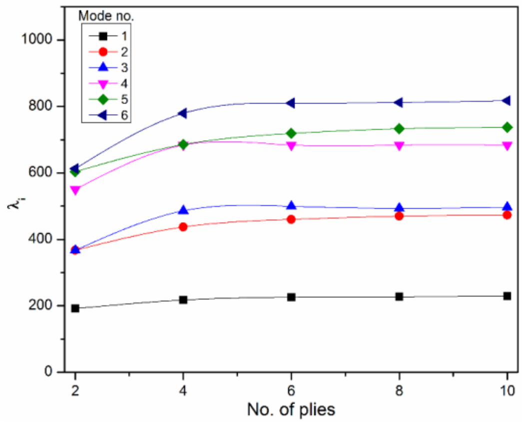
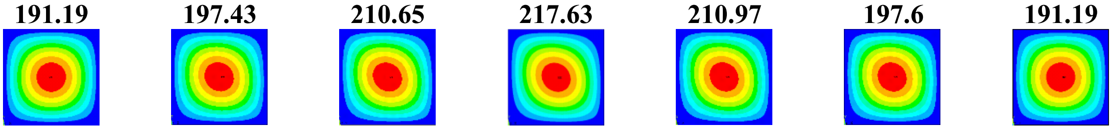
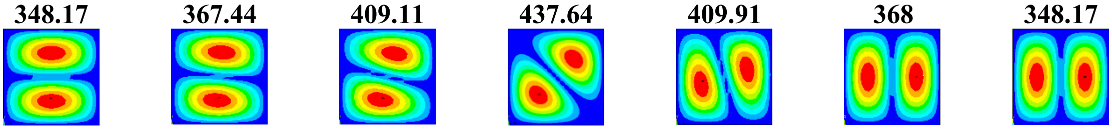
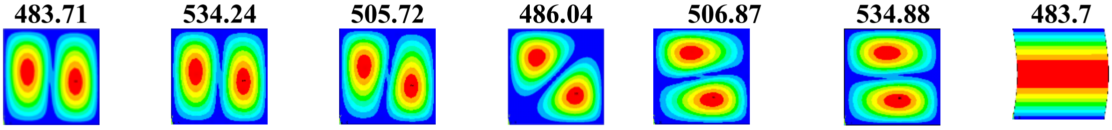
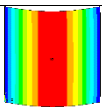
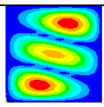
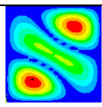
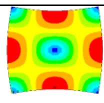
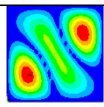
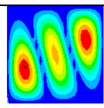
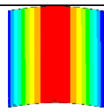
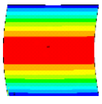
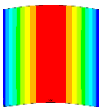
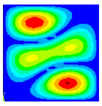
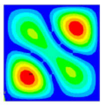
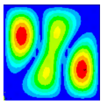
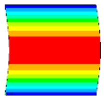
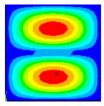
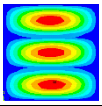
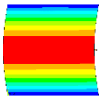
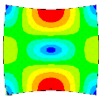
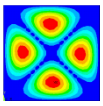
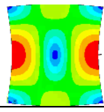
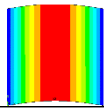
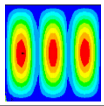


Figure 4 Comparison of 1st six natural frequencies at different number of plies

Table 5 Effect of number of ply angle

Mode No.	Ply angle						
	0	15	30	45	60	75	90
1	**191.19**	**197.43**	**210.65**	**217.63**	**210.97**	**197.6**	**191.19**
							
2	**348.17**	**367.44**	**409.11**	**437.64**	**409.91**	**368**	**348.17**
							
3	**483.71**	**534.24**	**505.72**	**486.04**	**506.87**	**534.88**	**483.7**
							
4	**483.71**	**628.81**	**666.22**	**684.12**	**665.92**	**628.49**	**483.71**

							
5	**549.31**	**635.68**	**710.16**	**685.57**	**714.28**	**635.68**	**549.31**
							
6	**611.72**	**635.68**	**810.54**	**779.63**	**810.54**	**635.68**	**611.72**
							

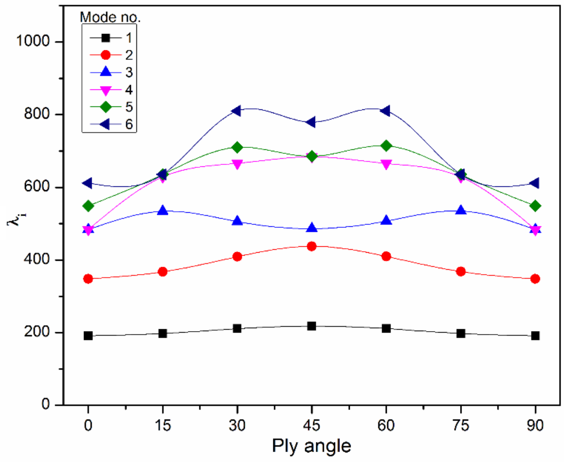


Figure 5 Comparison of 1st six natural frequencies at different ply angle

4. Conclusions

The variations of the first six natural frequencies with respect to thickness-length ratio and aspect ratio are presented under simply supported condition. The present analysis is useful for the design of composites plates for dynamic response. Based on the current study the following conclusions can be drawn. The natural frequency decreases with increase in thickness ratio. Frequency is found to be decreasing with increase aspect ratio. In general increasing number of plies would increase the natural frequency.

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