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Effect of Fiber Orientation and Position of Circular Hole on Torsional Natural Frequency of Laminated Composite Beam

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Abstract: The composite materials are well known by their excellent combination of high structural stiffness and low weight. The main feature of these anisotropic materials is their ability to be tailored for specific applications by optimizing design parameters such as stacking sequence, ply orientation and performance targets. Finding free torsional vibrations characteristics of laminated composite beams is one of the bases for designing and modeling of industrial products. With these requirements, this work considers the free torsional vibrations for laminated composite beams of doubly symmetrical cross sections. The torsional vibrations of the laminated beams are analyzed analytically based on the classical lamination theory, and accounts for the coupling of flexural and torsional modes due to fiber orientation of the laminated beams are neglected. Also, the torsional vibrations of the laminated beams analyzed by shear deformation theory in which the shear deformation effects are considered. Numerical analysis has been carried out using finite element method (FEM). The finite element software package ANSYS 13.0 is used to perform the numerical analyses using an eight-node layered shell element to describe the torsional vibration of the laminated beams. The rotary inertia and shear deformation effects of the element are taken. The influence of fiber directions and stacking sequences of laminates on torsional natural frequencies were investigated. Also, the effects of boundary conditions are demonstrated. Numerical results, obtained by the ANSYS 13.0, classical lamination theory, and shear deformation theory are presented to highlight the effects of fibers orientation and layers stacking sequence on torsional frequencies of the beams. The results obtained by ANSYS are compared against the classical lamination theory, as well as shear deformation theory.
Keyword: Composite material, shear deformation theory,ansys-13,torsional vibration

I. INTRODUCTION

A. Introduction to Composites

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components.

B. Fibers used for Reinforced Composite

The first type of fiber used in advanced composite is glass fiber. These are made by pulling molten glass through 0.8-3.0 mm diameter dies at about 1300^{0}C followed by high speed stretching to a diameter of 3-19pm. The important engineering properties of glass fibers are their high strength, high biological and chemical properties and low cost. Quartz fibers are similar to glass fibers and are obtained by high-speed stretching of quartz rods made of fused quartz crystal with sand. The same process as used for glass fibers is employed to manufacture mineral fibers, e.g., basalt fibers made of molten basalt rocks. Having relatively low strength and high density basalt fibers are not used for high performance, e.g. aerospace structures, but are promising reinforcing elements for pre-stressed reinforced concrete structures in civil engineering.

Naturally developed fiber with high and improved properties is carbon fibers. There exists fifty varieties of carbon fibers having different strengths, stiffness and cost and the advancement is still not over. Organic fibers commonly encountered in textile applications can be employed as reinforcing elements of advanced composites. Boron fibers were developed to increase the stiffness of composite materials while glass fibers were mainly used to reinforce composites of the day. There exists a special class of ceramic fibers for high-temperature applications composed of various combinations of silicon, carbon, nitrogen, aluminum, boron, and titanium. The most commonly encountered are silicon carbide (Sic) and alumina (A1203) fibers. Metal fibers (thin wires) made of steel, beryllium, titanium, tungsten, and molybdenum are used for special, e.g., low-temperature and high-temperature applications.

The orientation of the fiber in the matrix indicates that the strength of the composite and the strength is greatest along the longitudinal directional of fiber. This doesn't mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied.

Table 1.1: Mechanical properties of fibers and structural members

Sl. No.	Material	Ultimate tensile strength (MPa)	Young's modulus of Elasticity(GPa)	Specific gravity	Specific strength	Specific modulus
01	Steel(Alloys)	770-2200	180-210	7.8-7.8.5	28.8	2750
02	Aluminum(Alloys)	260-700	69-72	2.7-2.85	26.5	2670
03	Titanium	1000-1200	110	4.5	26.7	2440
04	Tungsten (20-50)	3300-4000	410	19-19.3	21.1	2160
05	Molybdenum(25-250	1800-2200	360	10.2	21.5	3500
06	EPOXY	60-90	2.4-4.2	1.2-1.3	7.5	350
07	Polyester	30-70	2.8-3.8	1.2-1.35	5.8	310
08	Phenol-formaldehyde	40-70	7.11	1.2-1.3	5.8	910

II. LITERATURE REVIEW

There is a vital need to extend successful techniques for structural healthiness monitoring, in order to enhance the safety and reliability of the structures Analysis. The prime objective of this paper is to assess the various techniques for fault detection of the composite structural element. Usages of composite materials in a variety of construction and machine elements had been substantially increased over the past few years. These materials are widely used in situations where a large strength-to-weight ratio is required. Composite materials can be tailored to meet the particular requirements of stiffness and strength by altering lay-up and fiber orientations. The ability to tailor a composite material to its job is one of the most significant advantages of a composite material over an ordinary material. So the research and development of composite materials in the design of aerospace, mechanical and civil structures has grown tremendously in the past few decades. A variety of structural components made of composite materials such as turbine blades, vehicle axles, aircraft wing, and helicopter blade can be approximated as laminated composite beams, which requires a deeper understanding of the vibration characteristics of the composite beams as mentioned by Reddy [6] has written a higher order theory for laminated composite plates and concluded the possible in some cases to disregard the effects of shear deformation and rotary inertia.

Dancila and Armanios [14] have used an analytical model, considering the bending torsion and tensile torsion couplings in a closed section, and validated the results with a finite element model. Jun and Xian ding [3] have used modal analysis to study the flexural behaviour of composite beams, determining the displacement and flexure rotation of a cantilever beam subjected to concentrated and distributed random excitations. In addition to considering the effect of bending torsion coupling to predict the dynamic response of a beam, it is necessary to include in the models the effect of shear deformation and rotary inertia. Rand [4-5] has worked on laminated composite beam and calculated its shear stresses using a complete out-of- plane shear deformation model. Hashemi and Richard [6] have investigated a dynamic finite element model for free vibration of bending-torsion coupled beams. Chandra et al. [7] calculated static displacements of a carbon/epoxy beam with a box section, comparing experimental results with those found by a finite element model and an analytical model. Lee and Kim [8] used a one dimensional finite element model applicable to open thin walled cross sections. Li et al. [9] analyzed the dynamic response of thin walled Timoshenko beams, considering concentrated and distributed dynamic loads, and bending torsion coupling. Kim et al.[10] have given a improved flexural-torsional stability analysis of thin-walled composite beam and exact stiffness matrix.

Jung et al. [11] studied the bending torsion coupling effect in closed cross section beams, analyzing their response to static loads by calculating of the bending and torsional stiffness as functions of the stacking sequence of the laminate. Banarjee and Williams [12] determined the frequencies of solid section cantilever beams manufactured from unidirectional laminate Later, Banarjee [13] completed that work by deter mining the exact expressions for frequencies and mode shapes of the same composite beam. Teh and Huang [14] evaluated the effect of the orientation of the fibres on the frequencies and mode shapes of cantilever graphite/epoxy beams, stating that the maximum coupling effect varies from 241 to 251 for the first five natural frequencies. Li et al. [15] have written stochastic formulae in bending-torsion coupled response of axially loaded slender composite thin walled beams. Yildirim and Kiral [16] have presented that the effects of inter laminar shear stress need to be taken into account in the study of laminated beams due to their low inter laminar shear modulus. Levinsion [17] has developed High order shear theories and compared with the First Order Shear Deformation Laminate Theory. Murthy [18] has given a improved model of transverse shear deformation theory for laminated anisotropic plates. Kopania[21] has concluded the First Order Shear Deformation Laminate Theory and the result is found to be similar to that of higher order theories at a lower computational cost. To analyze the behavior of laminated beams, some authors use numerical techniques such as the Finite Element Method, the Galerkin Method or the Boundary Element Method [8,22, 24], whereas others use analytical models [3,13,15,25,26]. The latter is useful in the optimization processes because they offer a simple way to evaluate the influence of the different parameters in the overall response of the structure. To solve the equations of motion of the beam by simplified methods, most researchers use Modal Analysis [3, 12 14, 27, 28]. However, if the beam has a variable bending stiffness and the boundary conditions are hyper static, the equations of motion are complex to solve by Modal Analysis. Different methods have been used in this case, such as the Boundary Integral Equation Method [5], the Transfer Matrix Method [16], the Differential Quadrature Method [29], the Green Function [30], or the Flexibility Influence Function Method (FIFM) [31]. The FIFM is a technique that does not require the calculation of the natural frequencies or vibration modes of the beam [32]. This method is especially useful for solving hyper static problems in dynamic conditions because the influence of the boundary conditions in this method is restricted to the solution of equations for static conditions. After having solved the hyperstatic problem for static conditions, the dynamic equations can be solved by a single technique, independently of the boundary conditions. The FIFM was validated in a previous work [31] by comparisons with Modal Analysis and Finite Elements Method in the calculation of the deflection and bending rotation in composite beams with a stacking sequence of 0/90. However, bending torsion coupling was not present in those beams. Most studies deal with cantilever beams, as they are representative of many structural components with bending torsion coupling effect. However, these beams are isostatic and, due to bending torsion coupling, only a torsional rotation occurs. On the contrary, in a hyperstatic beam this coupling produces both torsional rotation and torsional moment, and, at the same time, this torsional moment produces deflection and bending rotation in the beam. The present work analyses the behaviour of a bending torsional coupled laminate beam with hyperstatic boundary conditions, subjected to an impulsive load by an analytical model in which the equations were solved by FIFM. Both the deflection and torsional rotation were restricted at its ends, the bending rotation being totally free. Two analytical models were used: the first one includes the bending torsion coupling effect (FIFM) and the second one does not consider this coupling (FIFM non coupled). The deflection, bending rotation, and torsional rotation of this beam were calculated by the analytical models and compared with those determined by a FEM3D model.

In engineering practice, we often come across the analysis of structures subjected to vibratory twisting loading, such as aerodynamic or asymmetric traffic forces. Also, composite structural elements consisting of a relatively weak matrix reinforced by stronger inclusions or of different materials in contact are of increasing technological importance in engineering. Steel beams or columns totally encased in concrete are most common examples, while construction using steel beams as stiffeners of concrete plates is a quick, familiar and economical method for long bridge .In the current work the main objective is to find out the torsional vibration of laminated composite beams based on first -order shear deformation theory classical beam theory and shear deformation theory. Natural frequencies and mode shapes are obtained for the generally laminated composite beams. The natural frequencies are investigated and comparisons of the current results with the available solutions in literature are presented . also the presence of geometrical irregularity like hole on natural frequency are studied. The size and position of the hole on the torsional frequency of the beam are investigated by the help of finite element software ANSYS 13.0. Fixed- fixed and cantilever composite beam are taken for consideration

III. MIXTURE RULE

A. *Materials Characterization (Mechanical Properties by Mixture Rule)*

For the study the polyester- glass composite specimen are taken. The reinforcement or fiber used is assumed as bi-directional in nature. The mechanical properties of constituents of the test specimens, E-glass woven roving fibers and polyester matrix are listed in Table 2.1. The material elastic properties of the laminae of test specimens are determined through the simple rule-of-mixtures.

Engineering constants are generalized elastic constants i.e Young's moduli (E_x – in direction x, E_y – in direction y, E_z – in direction z), Poisson's ratios (μ_{xy}, μ_{xz}, and μ_{yz}), Inplane shear modulus (C_{xy}) and transverse shear moduli (C_{xz} and C_{yz}) as well as some other behavioral constants such as compliances or stiffness.

Micromechanical study of composite material enables determination of above properties in terms of properties of the fibers and matrix in terms of the relative volumes is termed as mixture rule.

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In functional form. These properties are $X_i = X_i(X_{if}, Uf, X_{im}, Um)$
Where
$X_i = X, Y, S$ = composite strength and $X_{if} = X_f, Y_f, S_f$ = fiber strength

$$U_f = \frac{\text{volume of fibers}}{\text{total volume of composite}}$$

$$U_v = 1 - \frac{\left(\frac{wf}{\rho f}\right) + (wc - wf)/\rho\, m}{wc/\rho\, c} \qquad (1)$$

Where w_f , w_m, and w_c are the weights of the fiber, matrix, and composite, respectively.
By using the densities of the fiber ρ_f matrix ρ_m, and composite ρ_c, respectively, the fiber volume fraction υf can be obtained by equation (2):

$\rho_c = \rho_f U_f + \rho_m U_m = \rho_f U_f + \rho_m (1 - U_f - U_v)$ (2)

Where U_f, Um, and Uv are the volume fractions of the fiber, matrix, and voids, respectively.
Using the relation of equation (2) the fiber volume fraction (U_f) is found 40 % according to the densities of fiber and matrix presented in Table 1. Then, the elastic constants of the woven fabric composite material are numerically estimated using the relations which are based on their constituent properties. The young's modulus and the Poisson's ratio of the fill and warp directions are calculated and taken as an average of the longitudinal and transverse values of the corresponding unidirectional layer.

Table 3.1 Elastic Properties of polyster -Glass fibres Composite

Material	Properties	Values
Glass fiber	Fiber longitudinal modulus in l direction Ef_l(GPa)	78
	Fiber transverse modulus in t direction Ef_tGPa	78
	Fiber shear modulus Gf_t (Gpa)	30
	Density ρ_f (kg/m3)	2650
	Fiber Poisson ratio μ_f	0.3
Epoxy resin	Elastic modulus E (Gpa)	4
	Shear modulus G (Gpa)	1.43
	Density ρ_m (kg/m3)	1250
	Poisson ratio μ_e	0.4
Orthotropic laminae	Lamina longitudinal modulus E_1(GPa)	44.7
	Lamina transverse modulus E_2 (GPa)	44.7
	Lamina transverse modulus E_3 (GPa)	8.365
	Density of composite ρ_c (kg/m3)	1893
	Lamina shear modulus in plane1–2G_{12}(GPa)	4.3
	Lamina shear modulus in plane 1–3 G_{13}(GPa)	2.86
	Lamina shear modulus in plane 2–3 G_{23}(GPa)	2.86
	Major Poisson ratio in plane1–2 υ_{12}	0.345
	Major Poisson ratio in plane1–3 υ_{13}	0.45
	Major Poisson ratio in plane2–3 υ_{23}	0.45
	Fiber volume fraction v_f	55%

IV. MATHEMATICAL MODELING

A. Beam Theory

1) *Classical Beam Theory:* The oldest and the well-known beam theory is the Euler–Bernoulli beam theory (or classical beam theory—CBT), in which the shear deformation not included. Although this theory is useful for slender beams, it does not give

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accurate solutions for thick beams. The beams to be studied are orthotropic and its cross section has two axes of symmetry y and z. The mass is also symmetrical with respect to these axes, and, accordingly, the center of mass coincides with the origin of the y-z coordinate system, so that the flexural-torsional coupling not occurs. A beam with two cross-sectional planes of symmetry may undergo flexural vibration in either of the two planes of symmetry and torsional vibration [17]. Pure torsional vibrations are focused in this study

Expressions for the torsional vibration $\omega^B_{\psi i}$ of long ($GI_t >> EI_r/L^2$) and short$GI_p << EI_r/L^2$) orthotropic beams are:

Torsional vibration of long beam is given by

$$(\omega^{B}_{\psi i})2 = \frac{\overline{GI_p}}{2\pi * I}\frac{\mu^2_{GI}}{L^2} \quad 1$$

Torsional vibrations of short beam is given by

$$(\omega^{B}_{\psi i})2 = \frac{\overline{EI_r}}{2\pi * I}\frac{\mu^4_{BI}}{L^4} \quad (1a)$$

$$I = \int_{(A)} \rho_{comp}\,(y^2 + z^2)dA \quad (1b)$$

Where$\overline{GI_p}$ is the torsional stiffness of the beam; inN.m^2$\overline{EI_r}$ is the warping stiffness of the beam; in N.m^4, I is the polar moment of mass per unit length about the shear center, ρ_{comp} is mass per unit volume, A is the area of the cross section, and μ^4_{BI} and $\mu^4_{GI}$are parameters in the calculation of natural frequencies, which are given in Table 4.1.

The torsional frequencies of a beam of arbitrary length can be approximated by

$$(\omega^{B}_{\psi i})^2 = (\omega^{B}_{\psi i})^2_S + (\omega^{B}_{\psi i})^2_L \quad (1c)$$

By using the previous two equations of torsional vibration, the torsional frequencies will be

$$(\omega^{B}_{\psi i})^2 = \frac{\overline{EI_r}}{2\pi * I}\frac{\mu^4_{BI}}{L^4} + \frac{\overline{GI_p}}{2\pi * I}\frac{\mu^2_{GI}}{L^2} \quad (1d)$$

For symmetric orthotropic laminated beam previously mentioned; the torsional stiffness of the beam $\overline{GI_p}$can be obtained by this relation,

$$\overline{GI_p} = \frac{4b}{d_{66}} \text{ in}(N.M^2) \quad (1e)$$

And warping stiffness of beam $\overline{EI_r}$ can be obtained by this relation

$$\overline{EI_r} = \frac{b^3}{a_{11}}\frac{h^3}{144} \text{in}(Nm^4) \quad (1f)$$

Where :

a_{11}:element 1-1 of the laminate extensional compliance matrix (m/N)

d_{66}: element 6–6 of the laminate bending compliance matrix (1/N. m).

Table4.1 :The Constant μ_{bi} And μ_{gi} For Different Type Of End Support

Geometry	μ_B	μ_G
Clamped free	μ_{B1}=1.875 μ_{B2}=4.694 $\mu_{Bi} \approx$ (i-0.5)	$\mu_{Gi} \approx$(I -0.5)π
Clamped- Clamped	μ_{B1}=4.730 μ_{B2}=7.853 $\mu_{Bi} \approx$ (I +0.5) π	μ_{Gi} =i π
Clamped-simply supported	μ_{B1}=3.927 μ_{B2}=7.069 $\mu_{Bi} \approx$ (i+0.25) π	μ_{Gi} = iπ
simply supported- simply supported	μ_{Bi} = iπ	$\mu_{Gi} \approx$ iπ

B. Shear Deformation Theory

The theory, based on the assumption that cross sections remain plane but not perpendicular to the axis is frequently called first-order shear theory. A beam, in which shear deformation is taken into account, is called a Timoshenko beam. In shear deformation theory the effect of the shear deformation is considered in torsional frequencies calculation as given by (La's zlo' and George, 2003). Torsional vibration with shear deformation $\omega_{\psi i}$ of short ($\overline{GI_p}\, L^2 \ll \overline{EI_r}$) and long ($\overline{GI_p}\, L^2 \gg \bar{r}$) and $\overline{S_{\omega\omega}}\, L^2 \gg \overline{EI_r}$ orthotropic beams are:

Torsional vibration of short beam is given by

$$(\omega_{\psi i})^2=[\frac{I}{\overline{EI_r}}(\frac{L}{\mu_{Bi}})^4+\frac{I}{\overline{S_{\omega\omega}}}(\frac{L}{\mu_{Si}})^2]^{-1} \quad (2)$$

Torsional vibrations of long beam is given by ,

$$(\omega_{\psi i})^2 = \frac{\overline{GI_p}}{I}\frac{\mu_{GI}^2}{L^2} \quad (3)$$

The torsional circular frequency of a beam of arbitrary length can be approximated by:

$$(\omega_{\psi i})^2=(\omega_{\psi i})^2{}_S+(\omega_{\psi i})^2{}_L \quad (4)$$

By equation (26) and (26a) then

$$(\omega_{\psi i})^2 = [\frac{I}{\overline{EI_r}}(\frac{L}{\mu_{Bi}})^4+\frac{I}{\overline{S_{\omega\omega}}}(\frac{L}{\mu_{Si}})^2]^{-1}+\frac{\overline{GI_p}}{I}\frac{\mu_{GI}^2}{L^2} \quad (5)$$

Where the torsional shear stiffness is given by

$$\overline{S_{\omega\omega}} = \frac{b}{1.2_{66}}h^2 \quad (6)$$

Where a_{66} is element 6–6 of the laminate extensional compliance matrix (m/N)

V. FINITE ELEMENT ANALYSIS

A. Element Type

The beams were discretized using (solid 8 nodded 185 element) finite element as shown in Figure 5.1 available in the commercial finite element analysis package ANSYS13.0. This element has four nodes consist of several layers that are designated by specific layer number increasing from the bottom to the top of the laminate. The last number denotes the presence of total number of layers in the laminated composite. Each and every element are designed to provide six degrees of freedom at each node i.e translational and rotational motion about x, y, and z directions. The choice of solid 8 nodded 185 element type is based on layered applications of a structural shell model, and the type of results that need to be calculated.

B. Analysis Type

Modal analysis is carried out with ANSYS 13.0 finite element software. Generally modal analysis is done to determine the vibration characteristics i.e. natural frequencies and mode shapes of a structure or machine component in the design stage. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.

C. Numerical Analysis Of Composite Beam Using Ansys

Finite element approach (FEA) is widely used numerical methods for vibration analysis of structures. ANSYS is a software tool based on FEA is used here for free vibration analysis of a composite beam under consideration. A Composite beam of dimensions 400mm×40mm×3.5mm with eight layers of Polyester Glass fibers for determinations of natural frequency and mode shapes under various end conditions with and without presence of holes were analyzed using ANSYS 13.0. The diameter of the hole is changed from 8mm to 24 mm and its effect on natural frequency is studied. Also the presences of hole of diameter 8mm at different positions are studied. In the study layered solid 8 nodded 185 elements for solid modeling is considered. A meshed beam with hole is shown in the figure5.2. Initially a model with layers representing unidirectional fiber and matrix is created. Then the model is divided in to eight layers of equal thickness by offsetting the work planes. The mechanical properties are defined as the orthotropic one. Each layer of the beam specimen is then descretized by solid 8 nodded 185 with 5mm element length and the fiber orientations of each layer are then set from 0° to 90° . The natural frequencies and mode shapes of the beams are then analyzed for each of the fiber orientations. Also the effects of stacking sequence on the natural frequency are studied. For this (0/90)2s, (45/-45)2s stacking sequence of the laminates are taken in to consideration.

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Figure 5.1 . solid 185 with 8 nodes layered element

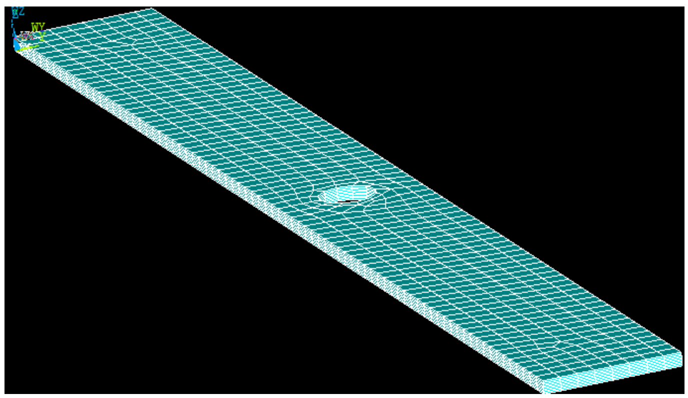


Figure 5.2 A meshed polyester-glass composite specimen with a central circular hole of 8mm diameter

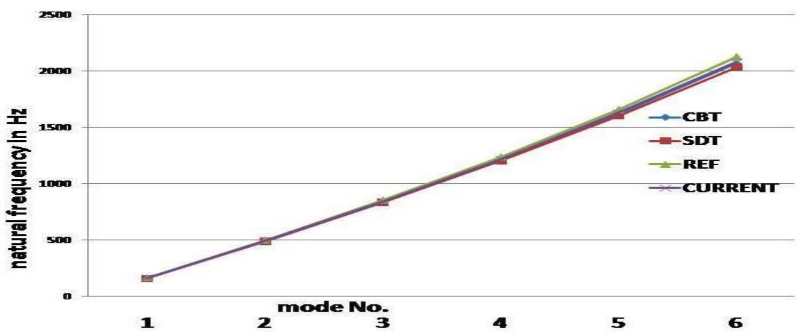
VI. VALIDATION OF THE PROCEDURE

A glass-polyester cantilever beam of length 400 mm, width 40 mm and thickness 3.5 mm is analyzed and the natural frequencies obtained are compared with the natural frequencies obtained from different beam theories like classical beam theory and shear deformation theory and with the FEA result of literature. The composite beam is assumed to be consisting of eight laminate of equal thickness. The stacking sequences of the laminates are varied according to the literature also the mechanical properties of the orthotropic composite beam as in case of literature are taken. The results obtained from the analysis are depicted in table 6.1

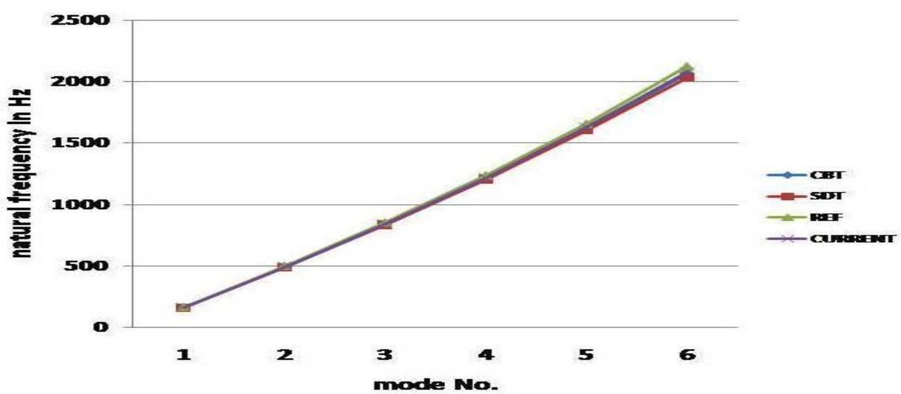
Table 6.1 comparison of results

Lamination scheme	theory	Modes					
		1	2	3	4	5	6
$(0/90)_{2s}$	CBT	161.9	490.4	836.0	1208.4	1616.3	2067.4
	SDT	161.8	490.3	835.2	1204	1602.7	2033
	FEA(REF)	164.24	499.13	852.6	1236.0	1657	2125
	FEA(CURRENT)	163.2	495.2	843.2	1216.12	1627.0	2078.9
$(45/-45)_{2s}$	CBT	250.3	752.7	1261.2	1779.4	2311	2860
	SDT	250.3	752.7	1261.1	1779.0	2310	2856.8
	FEA(REF)	246.4	741.3	1242	1754	2280	2824
	FEA(CURRENT)	249.3	746.36	1252.5	1762.1	2291	2840.1
$(45/45/0/90)_s$	CBT	242.5	720	1208	1708	2227	2767
	SDT	242.5	730	1226	1737.6	2267	2819
	FEA(REF)	239	720	1208	1709	2227	2767
	FEA(CURRENT)	240.13	725.3	1211.5	1714.28	2231.5	2785.4

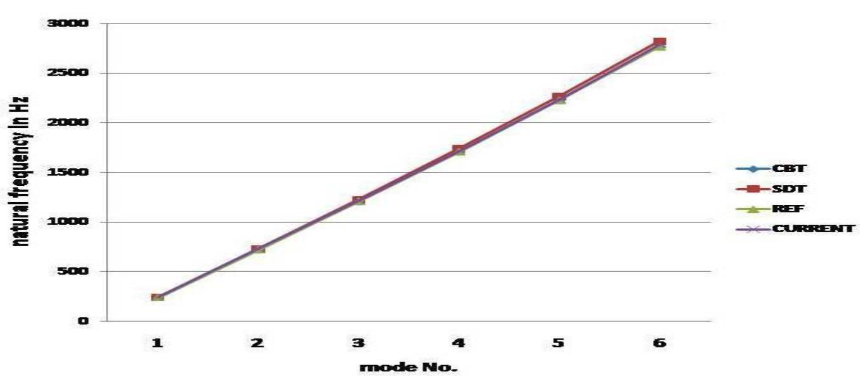
The variations of natural frequency with mode number are presented through figure 6.1 to figure 6.3. The graphs show a good agreement of the natural frequencies for torsional vibration of the beam obtained from finite element analysis (FEA) using ANSYS13.0 with the results obtained from different beam theories and from the literature. For consideration the first torsional natural frequency obtained from classical beam theory (CBT), shear deformation theory (SDT), finite element analysis(FEA) of current study and the result of reference(REF) of the beam of $(0/90)_{2s}$ stacking sequence are 161.9Hz, 161.8Hz, 162.2Hz, and 163.2 Hz respectively. The second torsional frequencies for the same stacking sequence are fond to be 490.4Hz, 491.3Hz, 499.13Hz and 495.2 Hz. Similarly the other natural frequencies have close values as presented in the table 6.1. The results have close similarity for all of the stacking sequence of laminates of the beam as depicted in table 6.1. The closeness of the results for other stacking sequence of the laminates can be observed from the curve showing the variation of natural frequency with mode number as shown in figure 6.1 to figure6.3.



6.1 Comparison of natural frequencies with mode number for the beam of $(0/90)_{2s}$ stacking sequence beam



6.2 Comparison of natural frequencies with mode number for the beam of $(45/-45)_{2s}$ stacking sequence BEAM



6.3 Comparison of natural frequencies with mode number for the beam of $(45/45/0/90)_s$ stacking sequence

VII. EFFECT OF FIBER ORIENTATIONS ON NATURAL FREQUENCIES:

To study the effect of fiber orientation on the torsional natural frequency of the beam, it is assumed that the beam comprises of eight laminates of equal thickness. During analysis the orientation of all the laminate layers are kept constant and varied from 0° to 90°. The results obtained from the analysis shows a good agreement with the result obtained from the theoretical study using shear deformation theory (SDT) as depicted in table 7.1.

Table 7.1. Variation of natural frequency with fiber orientation.

Fiber orientation in degree	Theory	Natural frequency						
		1	2	3	4	5	6	7
0	FEA	357.63	717.46	1020.1	1158.4	1634.4	2174.7	2372.1
	SDT	351.23	707.46	1001.85	1137.6	1605.2	2136.7	2330.1
10	FEA	395.95	718.86	978.07	1269	1778.9	2339.3	2350.8
	SDT	388.9	712.42	960.6	1246.3	1747.5	2297.42	2309.1
20	FEA	477.63	739.09	967.64	1483.5	2039.9	2216.5	2647.1
	SDT	369.2	729.09	950.32	1457.1	2003.8	2176.8	2600.2
30	FEA	563.63	756.23	1154.8	1744.4	2057.8	2364.7	3016.8
	SDT	354.1	746.23	1134.2	1713.2	2030.1	2322.23	2963.12
40	FEA	620.10	795.85	1247.7	1883.9	1957.9	2535.0	3205.4
	SDT	609.1	765.85	1225.36	1850.5	1923.2	2489.623	3148.1
45	FEA	628.56	801.48	1261.6	1903.6	1944.7	2559.0	3302
	SDT	617.85	789.48	1240.2	1870.56	1910.8	2513.94	3242.8
50	FEA	620.30	795.85	1247.7	1883.9	1957.9	2535.0	3205.4
	SDT	609.2	766.85	1226.3	1850.23	1923.2	2489.72	3148.23
60	FEA	562.4	797.23	1154.8	1744.4	2057.8	2364.7	3016.8
	SDT	553.54	747.13	1135.1	1714.52	2025.8	2323.23	2962.8
70	FEA	478.12	759.09	967.64	1483.5	2039.9	2216.5	2647.1
	SDT	469.09	729.39	950.41	1457.56	2007.5	2178.24	2598.5
80	FEA	396.12	722.42	978.07	1269	1778.9	2339.3	2350.8
	SDT	388.89	713.42	962.3	1246.57	1747.85	2298.53	2305.6
90	FEA	357.53	717.46	1020.1	1158.4	1634.4	2174.7	2372.1
	SDT	351.57	708.46	1002.3	1138.1	1605.8	2136.2	2331.64

The variation of first seven torsional natural frequencies of fixed-fixed composite beam with fiber orientations are depicted .Each of the graphs shows two curves that compare the variation of natural frequencies obtained from the finite element analysis using ANSYS 13.0 and shear deformation theory. From the graph it is clear that the natural frequency increases with increase in fiber orientation and becomes maximum for 45° fiber orientation. Then further increase in fiber angle after 45° leads to decrease in natural frequency. From the study the first torsional natural frequencies for 0°, 10°, 20°, 30°,40°, 45°, 50°, 60°, 70°,80° and 90° are 357.63Hz, 395.95Hz, 477.63Hz, 563.63Hz, 620.10Hz, 628.56Hz, 620.30Hz,562.4Hz, 478.12Hz,396.12Hz and 357.53Hz respectively. Also from the graph it is clear that the results obtained from FEA have close agreements with the result obtained from theoretical formulation using SDT. The natural frequencies obtained by using SDT are 351.23Hz, 388.9Hz, 369.2Hz, 554.1 Hz, 609.1 Hz, 617.85 Hz, 609.2Hz, 553.54Hz, 469.09Hz, 388.89Hz and 351.57Hz which are closer to the result of FEA. The variations of other six natural frequencies are shown through graph below.

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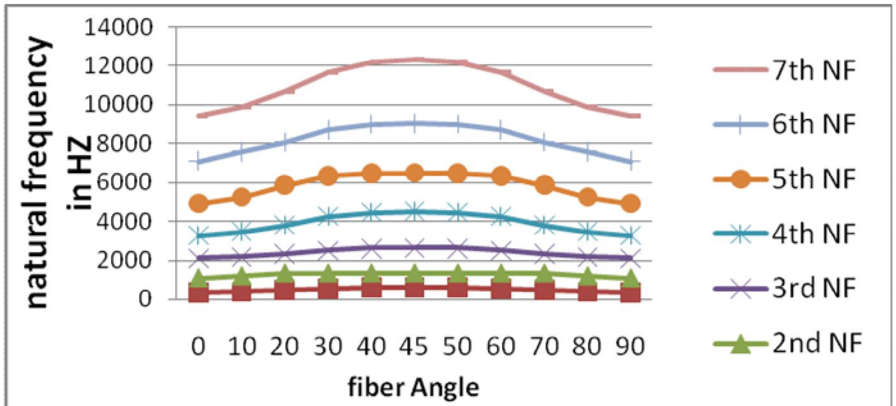

Natural frequency of different nodes

A. Effect of stacking Sequence and Size of Hole on Natural Frequency

The effects of stacking sequences of laminate on natural frequencies are studied. Also the variation of size of circular hole and its effect on natural frequencies are studied for all of the stacking sequences. For the study a hole is made at the center of the span of the beam as shown in the figure 7.9. the diameter of the hole taken for the analysis are 8mm, 16mm, 20mm and 24mm and the results obtained are compare with the result obtained for the solid beam. The results obtained from the study re presented in Table 7.2.

Table 7.2 : Effect of hole size on natural frequency

Stacking sequence in degree	Hole diameter in mm	Natural frequency						
		1	2	3	4	5	6	7
(0/90)2s	0	591.48	973.82	1020.1	1448.1	2012.2	2372.1	2663.8
	8	357.88	747.18	1021.6	1158	1651.6	2173.5	2375.6
	16	367.77	763.38	1038.2	1185.8	1680.6	2214.8	2393.4
	20	364.24	759.56	1030.4	1165.5	1668.6	2208.1	2358.9
	24	361.30	739.39	1034.7	1169.4	1627.2	2191.5	2306.9
(45/45 /0/90)s	0	446.1	738.5	1208.5	1216.5	1972.2	2059.3	2517.9
	8	430.32	717.5	1083.4	1199.3	1838.6	2145.8	2501.5
	16	428.95	718.95	1077.2	1156.6	1826.9	2377	2474.2
	20	429.38	721.03	1074.5	1128.5	1834.9	2338	2451.4
	24	361.3	739.39	1034.7	1169.4	1627.2	2191.5	2306.9
(45/-45)2s	0	428.56	729.48	1261.6	1438.5	1944.5	2530.0	2559.0
	8	398.20	665.14	1013.8	1240.7	1903.4	1944.3	2512.3
	16	399.72	670.47	1012	1189.3	1886.0	1947.1	2437.6
	20	400.34	672.23	1005.3	1155.4	1897.1	1919.2	2392.9
	24	392.99	669.87	994.22	1137.8	1888	1906.3	2379.9

Figure7.1 shows the variation of natural frequencies with size of hole obtained from finite element analysis for the fixed-fixed composite beam of $(0/90)_{2s}$ stacking sequence. From the graph it is very clear that with increase in size of the hole there is a decrease in natural frequency. Figure7.2 and figure 7.3 shows the variation of seven natural frequencies with diameter of the circular hole for (45/45/0/90) s and (45/-45)2s stacking sequence of the beam.

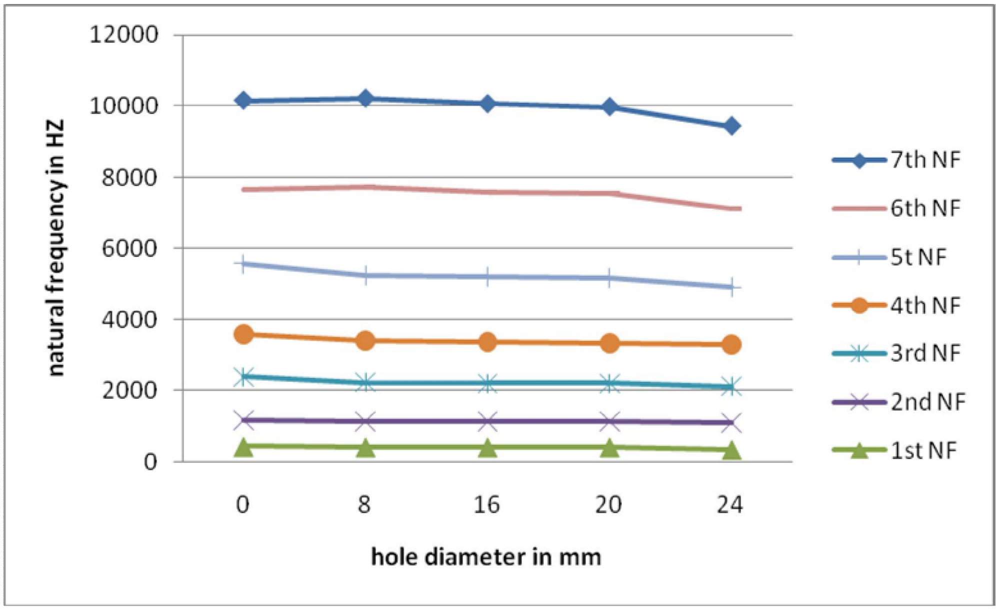

Figure7.1 Variation of NF with hole diameter for $(0/90)_{2s}$ stacking sequence beam

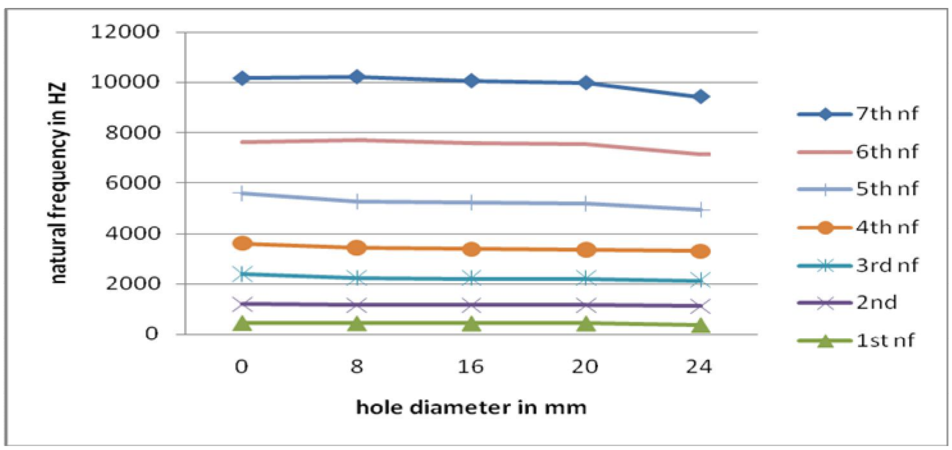

Figure7.2 Variation of NF with diameter of circular hole for(45/45/0/90)s stacking sequence of the beam

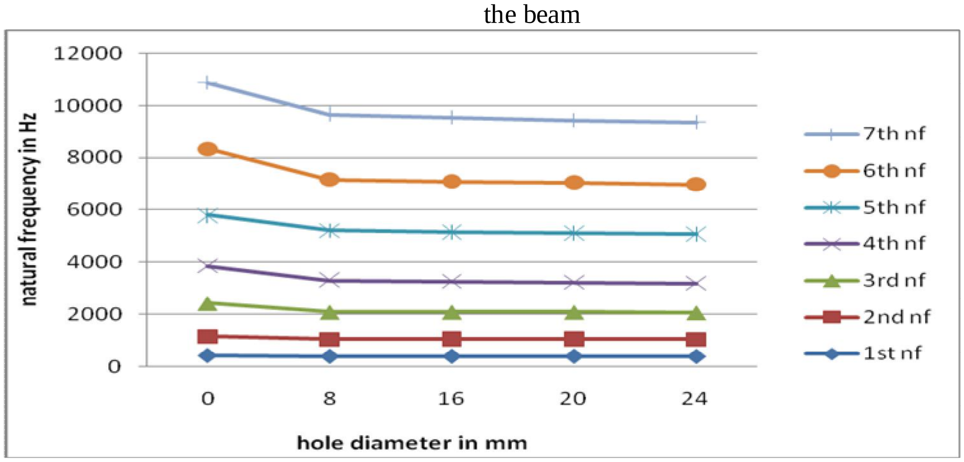

Figure7.3 Variation of NF with diameter of circular hole for(45/-45/)2s stacking sequence of the beam

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Figure 7.4 shows the variation of natural frequencies of a solid fixed-fixed specimen with mode number for different stacking sequences. From the figure it can be seen that the natural frequency increases with increase in mode number. From the figure it is also clear that the

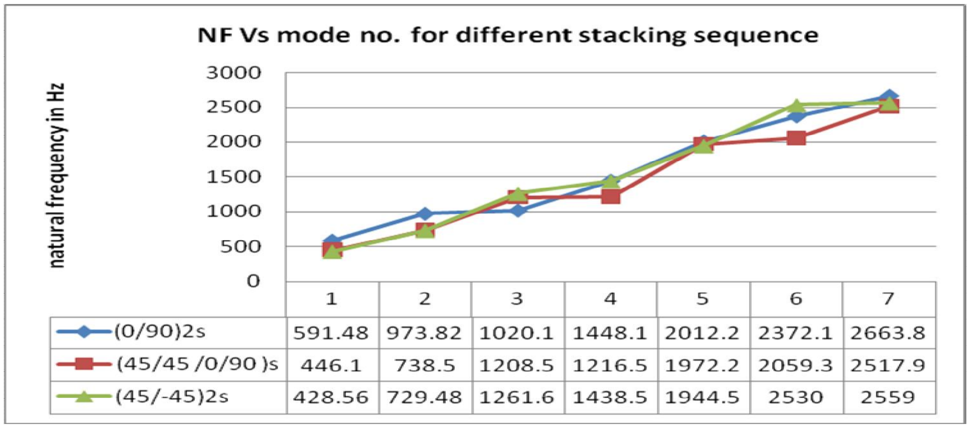

Figure7.4 Variation of NF with mode no. for solid beams

B. *Effect of position of Circular Hole on Natural Frequency*

The effect of position of hole on torsional frequencies are studied and presented through Table 7.3. For the study a fixed-fixed glass polyester beam of same dimension as before the previous study is taken in to consideration. During analysis a hole of 8mm diameter is considered and its position along the span is varied to study its effect on natural frequency. The position of the hole is kept at 70mm, 140mm, 200mm, 280mm, and 330mm from the left fixed end of the beam. (0/90)2s stacking sequence of the laminates are preferred for the study.

Table 7.3: Effect of position of circular hole on natural frequency

Stacking sequence	Natural frequency	Position of hole in mm				
		70	140	200	280	330
(0/90)2s	1	359.85	523.5	628.56	525.3	363.75
	2	740.55	839.42	729.48	843.42	741.78
	3	1022.5	1390.5	1421	1401.5	1022
	4	1159	1735.4	1938.5	1755.7	1158.7
	5	1633.4	2211.3	1944.5	2221.13	1641.5
	6	2176.8	2518.1	2575	2530	2195.8
	7	2369.7	2919.3	2995.3	2925.6	2379.8
(45/45 /0/90)s	1	430.04	433.36	437.38	433.36	430.04
	2	717.87	721.38	728.5	721.38	717.87
	3	981.65	980.79	1083.4	980.79	981.65
	4	1212.9	1196.3	1399.3	1196.3	1212.9
	5	1531.3	1538.8	1688.6	1538.8	1531.3
	6	2057.5	2086.2	2145.8	2086.2	2057.5
	7	2473.4	2474.1	2501.5	2474.1	2473.4
(45/-45)2s	1	437.38	439.5	442.38	439.5	437.8
	2	728.5	733.12	741.5	733.12	727.95
	3	1083.4	1089.5	1108.4	1088.5	1084.14
	4	1399.3	1405.2	1421.3	1405.32	1392.3
	5	1688.6	1692.8	1705.6	1692.87	1679.6
	6	2145.8	2156.3	2242.3	2156.34	2145.8
	7	2501.5	2528.9	2581.65	2528.91	2511.3

Figure7.5,7.6,7.7 shows the variation of natural frequency with the position of the circular hole of 8mm diameter. From the figure it is very clear that with increase in distance of position of hole from fixed end, natural frequency increases and becomes maximum at the middle of the beam. The first natural frequency of torsion at 70mm, 140mm, 200mm, 280mm, and 330mm from the left fixed end found to be 359.85 Hz,523.5Hz, 628.56Hz, 525.3Hz and 363.75 Hz. From this it can be observed that the natural frequency is maximum at the centre i.e. at 200mm. Similarly the second natural frequencies in torsion are found to be 740.55, 839.42, 729.48, 843.42 and 741.78 Hz showing the maximum frequency of 729.48 Hz at 200mm. Similarly the other five natural frequencies are found to be maximum at the centre of the span of the fixed-fixed beam.

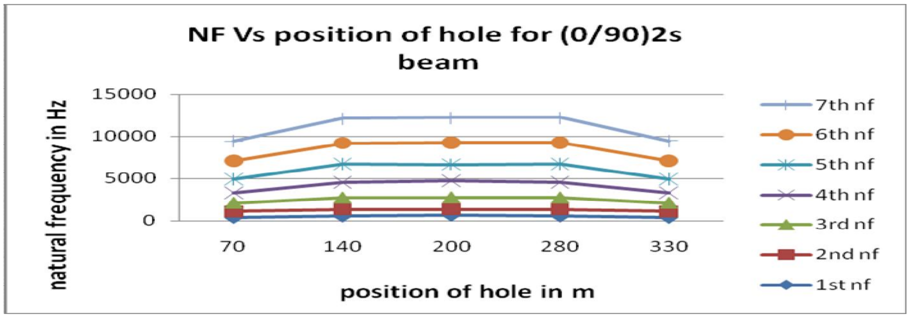

Figure 7.5 position of circular hole Vs natural frequency

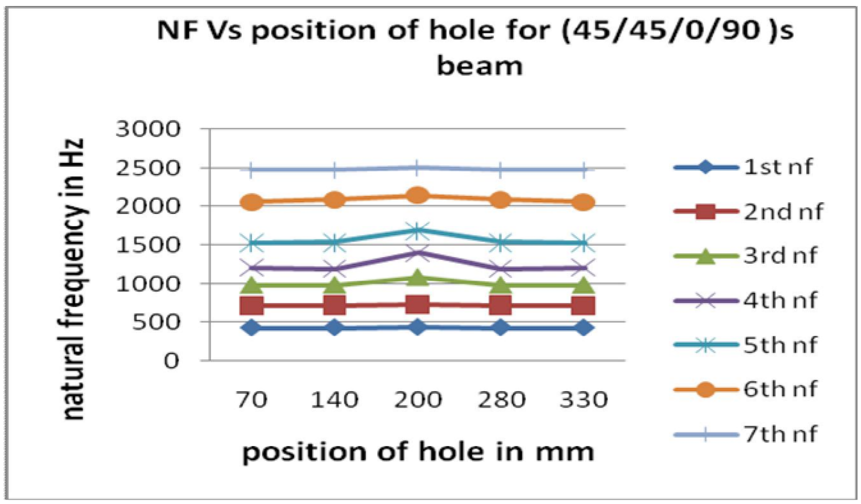

Figure 7.6 position of circular hole Vs natural frequency

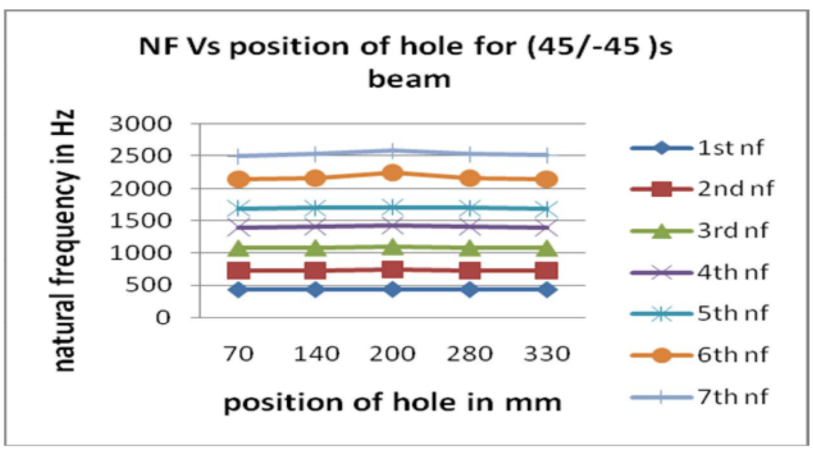

Figure 7.7 position of circular hole Vs natural frequency

VIII. CONCLUSION AND FUTURE WORK

A. *Conclusions*

The findings of the whole work can be summarized as follows

1) The natural frequency increases with increase in fiber orientation of laminates of the polyester- glass beam up to 45° and then decreases. It is assumed that the effective stiffness and young's modulus of composite beam varies with fiber orientation and is maximum for 45° of fiber orientation.
2) The results obtained from the analysis shows an good agreement with the result obtained from the theoretical study.
3) The effects of size of the circular hole on natural frequency are studied. It is found out that the increase in size of the hole leads to decrease in natural frequency. It is hence assumed that the increase in size of hole leads to decrease the effective stiffness of the beam. The conclusion drawn are found to be valid for all of the stacking sequences of the laminates of the composite beam
4) The effect of the stacking sequence of the composite laminates on natural frequencies of the beams are studied and presented. It is found out that the results obtained for the (0/90)2s stacking sequence of composite laminates of the beam is superior to the results obtained for other two types of stacking sequences of the beam.
5) Also the effect of position of the circular beam on natural frequencies of the fixed-fixed beam is studied. It is found that by increasing the distance of position of hole from fixed end the natural frequency increases and become maximum at middle of the fixed-fixed beam. It is assumed that the stiffness of the beam depends upon the continuity of the beam near the boundary of the beam. The presence of any discontinuity like a hole near the boundary decreases the stiffness of the beam. Hence increasing the distance of hole from fixed end increases the natural frequency.

B. *Future Work*

1) The study can be extended for other type of end boundary conditions.
2) The shape of the hole can be varied and its effect on the natural frequencies may be studied.

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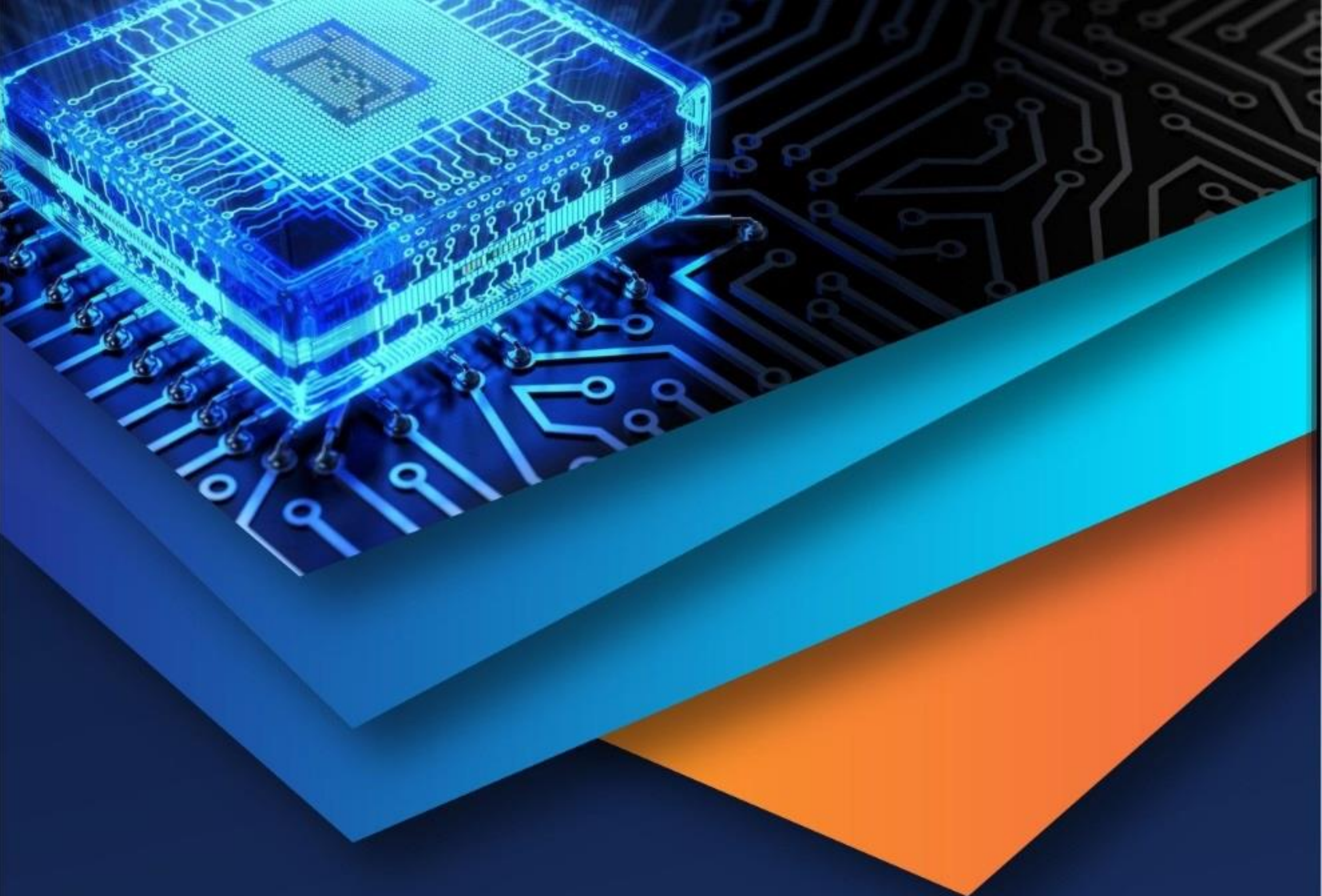

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