MODAL ANALYSIS OF COMPOSITE STRUCTURE FOR DIFFERENT FIBER ORIENTATIONS

Dissertation-II

Submitted in partial fulfilment of the requirement for the award of degree

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MECHANICAL ENGINEERING

by

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SCHOOL OF MECHANICAL ENGINEERING
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PUNJAB

2016-2017

CERTIFICATE

I, hereby certify that the work being presented in the dissertation entitled "**Modal analysis of composite structure for different fiber orientations**" in partial fulfillment of the requirement of the award of the degree of Master of Technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **Dr. Ashok Kumar** (Assistant Professor) Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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The external viva-voce examination of the student was held on successfully

Signature of Examiner

DECLARATION

I, RAHUL SAMYAL (11105708), hereby declare that this thesis report entitled "***Modal analysis of composite structure for different fiber orientations***" submitted in the partial fulfillment of the requirements for the award of degree of Master of Mechanical Engineering, in the School of Mechanical Engineering, Lovely Professional University, Phagwara, is my own work. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: Rahul Samyal

Place:

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ABSTRACT

A useful material which is manufactured by mixing of two or three different materials in homogeneous level is termed as composite material. In now day's composite materials are used in wide area such as aerospace, automobiles, satellite, bullet proof jackets, rotor blades etc. In this paper modal analysis of composite material, mixture of polyester as matrix and glass as fiber, is carried out by using ABAQUS software. The modal analysis of composite structures for different fiber orientation is carried out. In this paper by viewing the different mode shapes of the composite material, the optimal location of piezoelectric patch is carried out. In order to analysis the natural frequencies and mode shapes experimentally two sample are made having fiber orientation as 0^0 and 45^0 using Hand Lay-Up technique. For different fiber orientation behavior of natural frequencies and mode shapes is studied experimentally and results are compared with analytical results.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

A material which is formed by mixing two or more different material in homogeneous level that has quite different properties is termed as composite material. The different materials held together to give a useful composite material of unique properties, but within the composite anyone can easily tell the different materials apart because they do not dissolve or blend into each other. Properties that can be enhanced by forming composite material [1] are

- Fatigue Life
- Corrosion Resistant
- Strength
- Stiffness
- Wear Resistant
- Weight
- Thermal Insulation
- Temperature Dependent Behaviour
- Attractiveness
- Thermal Conductivity
- Acoustical Insulation

But naturally all of the above properties are not improved instantly at the same time because some properties are conflict to each other such as thermal insulation and thermal conductivity. Composite materials are mainly consists of two phases which is matrix phase and fibre phase. Both phases are having different roles such as matrix phase is used to hold the fibers exactly at the position in which they were reinforced, it also used as a binding purpose. Fibers phase is main load carrying constitute therefore fibre which is used for the composite material should have high strength as compared to the matrix material. Although matrix material does not have high strength but they are having other good parameters such as thermal insulation, thermal conductivity and many more [1]. Fibers can reinforce in different forms in composite material such as particulate, fibrous, laminated or all of three. According to the requirements of application composite materials can be manufactured as such. Industrial and commercial uses of composite materials are so advanced now a days that it is impossible to list all of them together. So some of the structural uses which includes aircrafts, aerospace, sporting goods, marine, electronics (printed circuit boards), furniture, medical industries (bone plates) and many more [2].

Now there are two main process of manufacturing composite materials which are open molding also termed as contact molding and closed molding. Both are further subdivided into different types are

- Open Molding
    - Hand Lay-Up
    - Chopped Laminate Process
    - Filament Winding
- Closed Molding
    - Compression Molding,
    - Pultrusion
    - Reinforced Reaction injection Molding
    - Resin transfer Molding
    - Vacuum Bag Molding
    - Vacuum Infusion Processing
    - Centrifugal Casting
    - Continuous Lamination.

Some of these manufacturing processes are used in Aerospace industries where high production rate is not desirable but the focus is on quality. The starting material for this is pre-pag that contains fiber in an epoxy region. The plies are joint together under the application of heat and pressure. When the whole assembly place in an autoclave, the blender is used to absorb excess resign that falls down when the plies are screwed together. The high pressure and temperature remove air other volatile material and helps in identifying the separate plies into a solid laminate.

Analytical and finite element method is used to solve the different problems under different loads and boundary conditions and comes out with approximate solution for particular problem. FEM modeling can done using numerical formulation and different software such as NISA, ANSYS, MATLAB, ABAQUS [11] etc. Modal analysis of any composite materials always results in three parameters that are natural frequencies, mode shapes and damping factor [12]. Frequency and Mode shape are two parameters to define any mode.

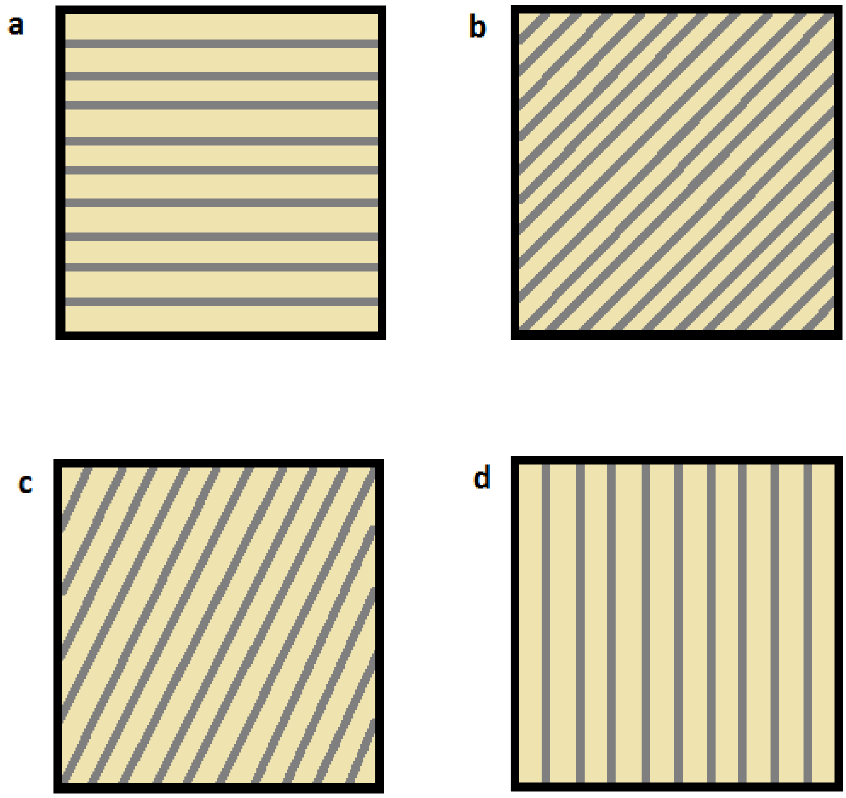


Figure 1 (a) 0° fiber orientation (b) 45° fiber orientation (c) 60° fiber orientation (d) 90° fiber orientation

Experimentally composite material is formed by using Hand-Lay-u-up technique, in which fibers are placed at an angle of 0° and 45°. As it is earlier described matrix material is polyester resin and reinforced fibers are Glass fibers, both the materials are having certain advantages and disadvantages such as

Advantages of Glass-Fiber

- High Temperature Resistant
- Non Flammable
- Corrosion Resistant
- Heat Insulation
- Acoustical Insulation
- High Tensile strength
- Easily Available

Disadvantages of Glass-Fiber

- Brittle
- Weak Abrasive Resistant

Applications of Glass Fiber

- FRP tanks and vessels
- Hockey sticks
- Paper honey comb
- Automobile bodies

Advantages of using Polyester

- Cost Effective
- Tough and Rigid
- Processed by thermoplastic operation
- UV rays resistant
- Good Finishing
- Applicability

Disadvantages of using Polyester

- Not good mechanical properties when compared to Epoxy
- Shrinkage
- Low Thermal resistant
- Poor Solvent Resistant

Applications of Polyester

- SMC (Sheet Molding Compound)
- BMC (Bulk Molding Compound)

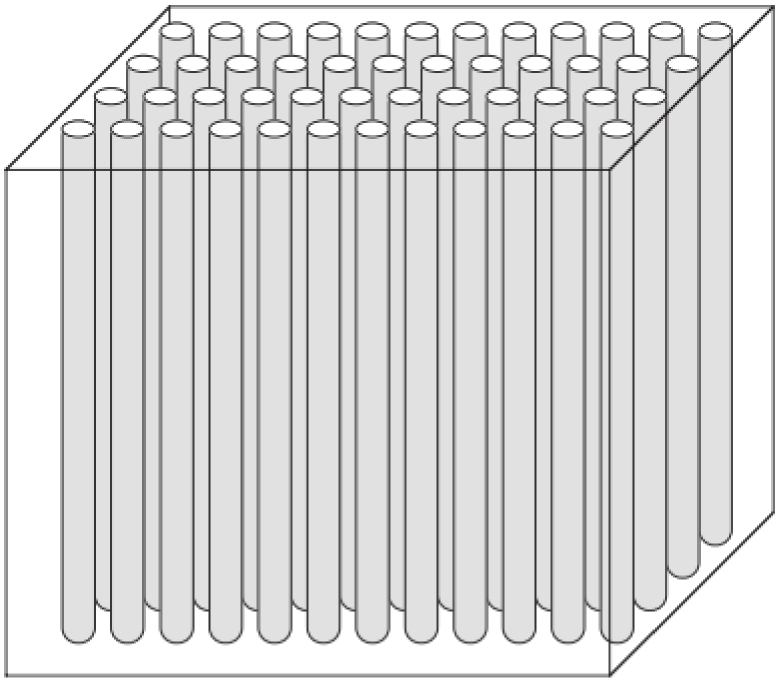


Figure 2 Unidirectional Fiber Reinforced Composite

Composite materials are also used for vibration control [5] because of having distinct properties from normal materials. Analytical and FEM of composite material with piezoelectric patch [12] is used to find out the variation in deflection, frequencies and mode shapes, and how the nodes varied after using piezoelectric patch on it. Modal analysis of composite materials for different fiber orientations is used to analysis the effect of fiber orientation on different properties. Optimal location of piezoelectric patch on composite structures is to be set on a position where it will present proper detection and should not coincide with nodes of that mode shape [12]. Modal analysis of composite beam and composite panel having polyester as matrix and glass as fiber is carried out where fibers are placed at an different angles under the boundary conditions clamped–free for beam and under the different boundary conditions for composite panel to find out the optimal location for piezoelectric patch, modal analysis of same composite beam having piezoelectric patch at different location using ABAQUS software can also be calculated. Modal analysis of composite beam is also done experimentally for 0° and 45° fiber orientation. For the validation purpose of optimal location of piezoelectric patch the FRF curve and displacement curve is drawn which describes the results perfectly.

CHAPTER 2

SCOPE OF THE STUDY

Using ABAQUS software natural frequency and mode shapes are calculated which is used to tell how these two parameters varied for composite material when compared to simple material. Study defines there is variation in natural frequencies and mode shapes with the change in fiber orientations. Piezoelectric patch is used to detect the deflection at the different locations. Behaviour of mode shape and natural frequencies varied on adding piezoelectric patch thus optimum location for piezoelectric patch is being calculated for proper detection of deflection, locations at which the node where coinciding all were rejected. FRF curve and Displacement curve describes that the elected optimal location of piezoelectric patch by viewing the different mode shapes is correct. Relation between natural frequencies and mode shapes with composite material, fiber orientation and piezoelectric patch is studied. Experiment is performed on glass-polyester beam at 0° and 45°fiber orientation to calculate the modal characteristics of it.

CHAPTER 3

OBJECTIVES OF THE STUDY

Modal characteristics for composite beam and composite panel having different fiber orientation are calculated experimentally and analytically and discussing the variation in the results when compared with each other. Calculating natural frequencies and mode shapes for a beam having piezoelectric patch at different location. After studying and viewing the different mode shapes and natural frequencies, optimum location for the piezoelectric patch is proposed. To validate the optimal location of patch FRF curve and Displacement curve is drawn at optimal location and non optimal location which clearly shows the benefits of using patch at optimal location. For experimental set up manufacturing of composite material is done by using Hand Lay-Up technique. In which Glass-Fiber are reinforced in 0° and 45°orientation. Objective of this study is to propose new method of electing optimal location of sensor, Mode shapes and natural frequencies are affected with the change in fiber orientation experimentally and analytically.

CHAPTER 4

REVIEW OF LITERATURE

Rene B. Abarcar et al. [8] (1972) in this paper they introduced experimental results for graphite epoxy and boron epoxy of natural frequencies and mode shapes. They reinforced fibers into epoxy in different orientations such as 0^0, 15^0, 30^0, and 90^0 with the axis of beam. To calculate free vibrations for graphite epoxy and boron epoxy both were set under boundary condition clamped-free and suitable relation was concluded for bending interaction.

Thomas Bailey and James E. Hubbard [23] (1985) studied analysis and design of an damper on cantilever beam analytically and experimentally, derived the distributed parameter for control Algorithm, Aluminium, Steel and PVF_2 were three materials which was used for experimentation, result contains time record for voltage, tip displacement and amplitude for tip displacement for both controlled and un-controlled beam.

Sung Kyu Ha et al. [24] (1992) described behaviour of piezoceramic sensor and actuator on composite structures using Finite Element Method, derived the formulation of static and dynamic response even for the potential energy of sensors. Results were calculated and compared for simulation, experimental and analytical formation, by using simple controlled algorithms on the integrated structures the signals were controlled actively in a closed loop.

S. Hanagud et al.[25] (1992) Studied optimal vibration control for different degree of freedoms for dynamic system, on a linear elastic beam the control technique has been applied including piezoceramic sensor and actuator, equation error approach was also used for testing the results for linear elastic beam based upon identification of structural dynamic system. Variation in weights in performance index is also included in the results.

Woo-Seok et al. [26] (1993) analysed the modal testing and finite element formulation for laminated plate along with piezoelectric patch, for quadrilateral plate elements the equation of motion and charge was distributed for 4-nodes and 12 degree of freedom, the results that the stiffness and damping properties are varied with the change of layer angel in an composite structure, active control method is used as an feed back by piezoelectric sensor, to eliminate the effect of active and passive control system both the methods were considered simultaneously.

Woo-Seok Hwang et al. [27] (1993) studied the finite element modeling for PZT(piezoelectric) sensors and actuators, the purpose of this study was to calculate the direct time response using Newmark-B method and to derive the modal damping ratio and damped frequencies for modal state analysis, the location of the piezoelectric patch is very much importantfor the control system design , by changing the assembly selection for element matrices the results are investigated.

Adams et al. [14] (1994) predicted damping factor in advanced polymer-matrix composites. Advanced FRP composites are highly being used in weight sensitive structure applications because they are having high stiffness/weight ratio. Here, they highlight another property of these materials which equally desirable in such applications, basically results are proposed for vibration damping and shows the factors affecting the damping in Fiber Reinforced Composites. It is also clear from the results that the damping property can be readily predicted.

R Hajela et al. [4] (1995) prophecies used first order deformation theory to analyze the behavior of free vibrations of simply layered composite beams. Rotary inertia and in plane are the two main parameters which were discussed in this paper. Change in natural frequency on changing boundary conditions, layups, Poisson’s effect, width effect, orientation of ply was investigated. Using symbolic computation accurate arbitrary degree was integrated from the equations of motion. They also compared the results with previously published analytical and numerical results for validation. Classical laminate theory is also used for comparison of results.

X. Q. Peng et al. [28] (1998) described element modeling by using third order theory, piezoelectric sensor and actuators are mounted on the composite beam for the purpose of position and vibration control, for the analysis of dynamic response of composite beam two methods were used which are superposition modal technique and Newmark-B method, to investigate the variation of results on changing position of piezoelectric patch and actuator both mounted on different locations.

Tita et al. [23] (2001) determined the steps to investigate the dynamic damped performance of fiber reinforced composite beam. This study describes a procedure to investigate the dynamic damped actions of fiber reinforced composite beams in flexural vibration. Experimental dynamic tests was carried out and listed to analyse the natural frequencies and mode shapes and results further gives rise to the damping factors by using a program FREQ, than these damping factors are further analysed in the form of input to damped dynamic analysis by the Finite Element Method, using Rayleigh Model. Well valid observation was proposed between analytical and experimental results, due to which results become possible to validate with the proposed procedure of evaluating dynamic damped behaviour of composite beams.

Martin et al. [24] (2003) resolved experimentation on damping of composite material that is aramid-fiber/polyester and dynamic young’s modulus. Though the kevler fiber in comparison to the glass fiber, have higher stiffness and damping also with inferior cost than graphite fiber preservation of this experimentation was to conclude the value of damping factor for Kevlar-49 fabric reinforced polyester composite. Thus the matrix of polyester resin which is inferior in price than epoxy is used with Kevlar fiber for light weight composite material.

Bothella et al. [16] (2005) prophecies the damping by using free vibration method on the continuous fiber composite materials because of low density and brilliant mechanical properties of the fiber metal laminates it gives after to replace with the current materials for aircraft structures. Non destructive Testing specially vibration testing can be done to check the mechanical properties of visco-elastic aluminium 2024 alloy, carbon, glass fiber and other composite materials. The results acquired from the experiments compared to the calculation modulus values by composite micromechanics approach. These all values when compared with the theoretical values than it gives improved results and proves the response of hybrid fiber metal laminate aluminium 2024 alloy and fiber epoxy composite can be used.

Mahmood and Najif [22] (2006) evaluated the results by done the experiments on dynamic performances of metallic plates reinforced by polymer matrix composites. The use of composite materials has become common in all the industries of different fabrications because of high strength, high stiffness and less weight. The main advantage s of using composite materials is the field of designing and manufacturing of materials. Most of the industries from aerospace are involved and researching on the composite materials to design a safe and enhanced structures, such structures can acquired by using at different layups.

Jean-Marie et al. [15] (2007) proposed research about longitudinal and transverse unidirectional fiber composites was upon the introducing some new suggestions of damping coefficient in it. It develops a new model that describes the damping of transverse unidirectional composite than the results are correlated with the experimental consequences attained for carbon, glass, kevlar fiber composites

Li Jun et al. [3] (2007), prophecies studied and introduced free vibration analysis using a dynamic finite element method for laminated composite means and formulated the influence of torsion deformation, share deformation, coupling among extensional and rotary inertia. They also evaluated the exact solutions of differential equations for free vibration of laminated composite beam. Variation of natural frequencies of composite beams under different boundary conditions, share deformations and poission’s effect is also discussed. Comparison of natural frequencies and mode shape with previous researches results for validation purpose.

A. Kumar et al. [13] (2014) studied the of problems in systems which are automobile passenger compartments, aerospace interiors and other cavities are discussed for the control of low frequency interior noise. Using active structural acoustic control approach issue related to the feedback control of interior sound was proposed. When the reference signals are not derived in an application then the feedback control strategy is useful. Through Kalman filter there was development of strategy for LQG based ASAC (Active Structural Acoustic Control) of interior sound cavity, for virtual sensing. Kalman filter was designed to estimate the status of cavity structure subjected to deflection depending upon piezoelectric patch mounted on flat plate at particular location. For the function of optimal control the Kalman filter was attached with Radiation filter to analyze the acoustic potential energy inside cavity. The optimal location for piezoelectric sensor and actuator was also proposed for effective detection of acoustic potential energy. Flexible flat plate was considered of rectangular box section cavity for numerical example. To evaluate the performance of Kalman filter noise measurement and detailed level of process was also proposed.

Shankar Ganesh [7] et al., (2016) In this paper finite element method is used for analyzing the free vibrations of delaminated composite plate by employing ESL (Equivalent Single Layer). Using two boundary conditions for analyzing free vibration in delaminate composite plate which are simply supported and clamped-free were taken. They also calculated the deflection and deformation at different positions in delaminated composite plate using analytical and computational approach. Results were evaluated with different references for validation purpose.

E.L Oliveira et al. [12] (2016) In this paper they proposed the results by using EMA (Experimental Model Analysis) to determine the natural frequencies and different mode shapes by adding piezoelectric patch on it. Composite flat plate was made up of three ply as carbon- epoxy fibers and all three ply were orientated in same direction. For EMA they manufactured five specimens having different fiber orientation as 0^0, 30^0, 45^0, 60^0 and 90^0. Polyvinlylidene Fluoride sensor and Lead Zirconate Titanate actuator was mounted on the model while performing experimental model analysis. Using Polyvinlylidene Fluoride response natural frequencies and damping factors were estimated and compared with the results of twelve measurement points. Different comparisons were made and percentage error was also calculated, results for two techniques that is single-input, single output technique and single–input, multiple-output technique was compared and shows slight difference.

CHAPTER 5

EQUIPMENTS, MATERIALS AND

EXPERIMENTATAL SETUP

5.1 Equipments

(a) Gayter Cutting Sheet

(b) 500ml Beaker

(c) C-Clampped

(d) Wooden Fixture

(e) Double Tape (2mm thickness)

(f) 3ml Dropper

(g) Stirrer

Figure 3Different equipments used during experiment (a) Gayter Cutting Sheet (b) Beaker (c) C-Clampped (d) wooden fixture (e) Double Tape (f) 3ml Dropper(g) Stirrer

5.2 Materials

(a) Polyester resin-4l

(b) Cobalt 6% - Catalyst

(c) Hardener-HY-98

(d) Glass Fiber Woven Mate

(e) Vaseline (as releasing agent)

Figure 4 shows all the materials used during experiment work (a) Polyester Resin (b) Catalyst Cobalt 6% (c)Hardener HY-98 (d) Glass-Fiber (bi directional) woven mate (e) Vaseline (as releasing agent)

5.3 Experimental Setup

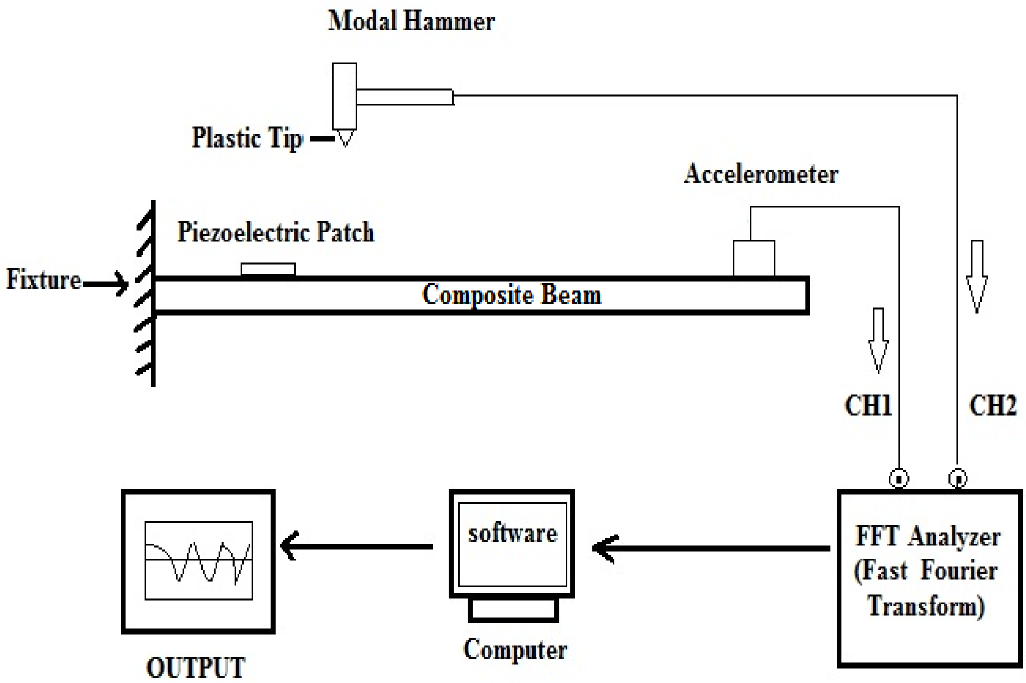
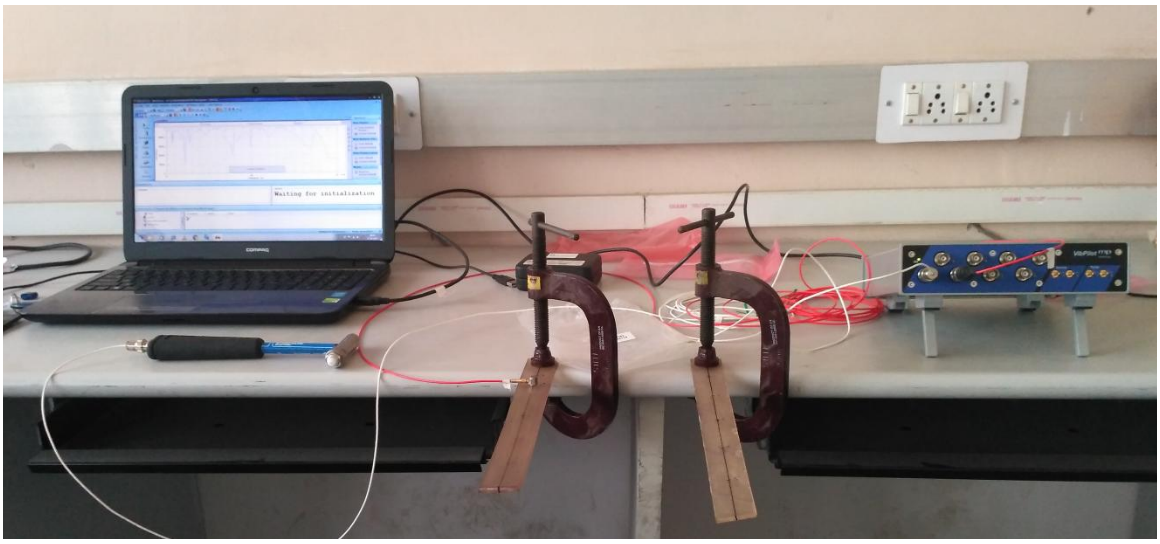
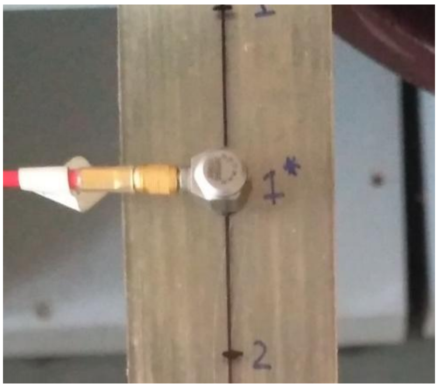


Figure 5 Shows Experimental step up which is used for calculating and analysing natural frequencies and FRF



(a) Experimental Setup

(b) Impact Hammer



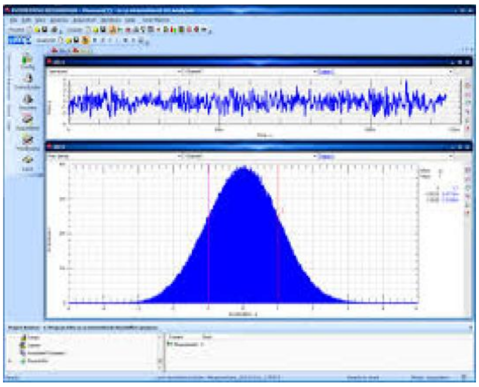
(c) Accelerometer

(d) FFT- analyser

(e) Accelerometer cable

(f) Impact Hammer Cable

(g) D-cable-PC



(h) m+p international SO analyser

Figure 6 Shows (a) Experimental Setup (b) Impact Hammer (c) Accelerometer(d) FFT analyser (e) Accelerometer cable (f) Impact Hammer Cable (g) D-Cable-PC(h) m+p SO analyser

CHAPTER 6

RESEARCH METHODOLOGY

6.1 Literature Review

From the year 1972 to 2016 literature review is studied for the modal analysis of composite structure for different fiber orientation along with the sensors attached on it, and the study defines that there is no particular work regarding this topic, in some of the earlier studies modal analysis of composite structure is done but the optimal location for the sensor is not studied [12]. This is termed as gap in this research field which is carried out in this study experimentally and analytically. Material selection and properties are based upon earlier study Li Jun [3] in 2008.

6.2 Modal Analysis using ABAQUS Software

ABAQUS software is used for the modal analysis of the composite structures, before concluding any results using this software, results are validated [29] Well satisfying results comes out from ABAQUS software.

6.3 Modal Analysis of Composite Beam and Plate

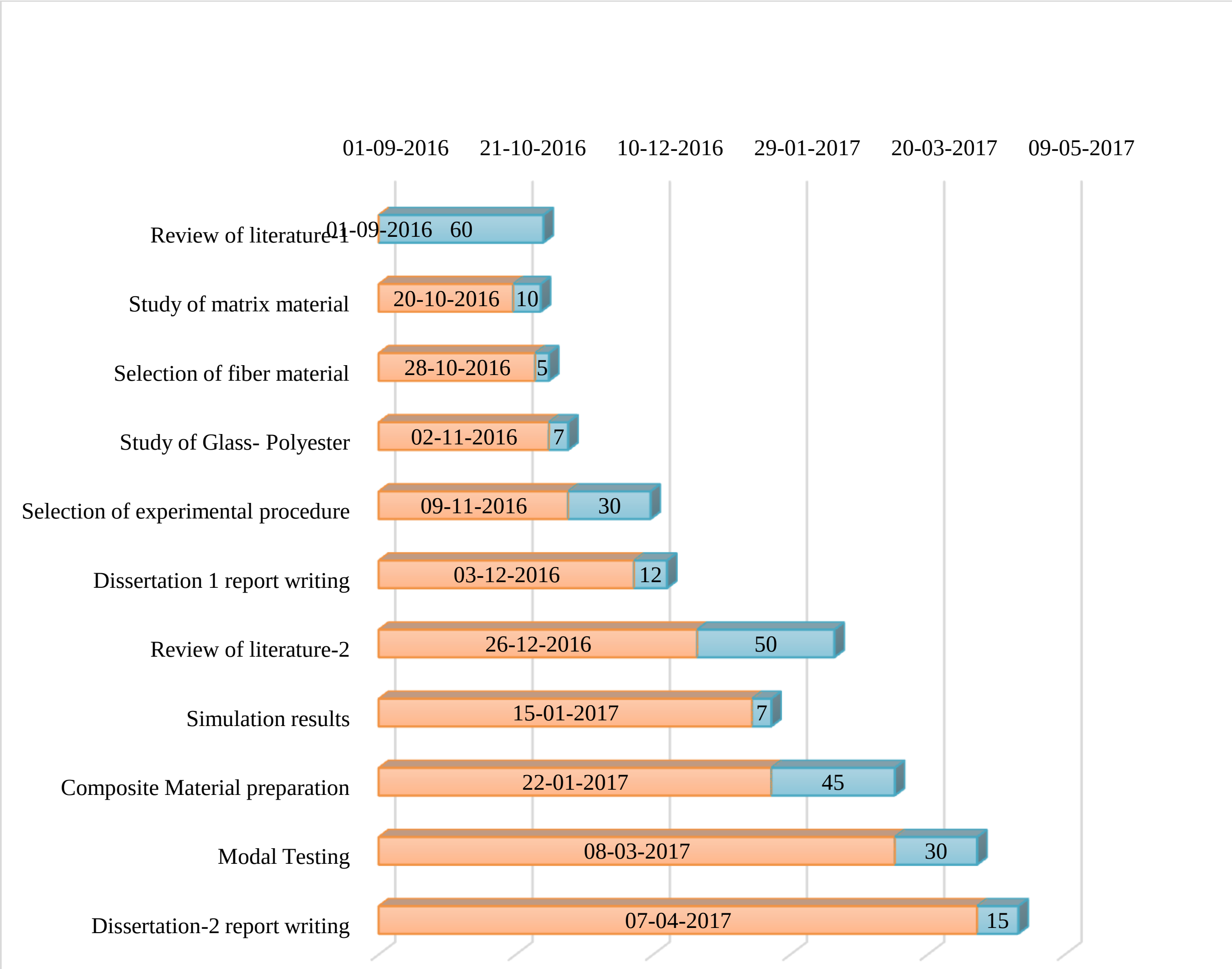
Selected composite material is Glass-Polyester composite, now modal analysis for different composite structure was carried out, by viewing different mode shapes the optimal location of sensor is identified and proposed, this method of identifying optimal location by viewing different mode shapes is new method in the research field, also the simulated results shows that mode shapes and natural frequencies are dependent to fiber orientation hence there must be different optimal location for different fiber orientation. FRF was calculated using ABAQUS which shows optimal location is correct location for sensor.

6.4 Experimental Work

Composite material was made using Hand Lay-up method for 0° and 45° fiber orientation, using experimental setup FRF and natural frequencies is determined and compared with analytical results.

CHAPTER 7

PROPOSED WORK PLAN WITH TIMLINES



CHAPTER 8

ANALYTICAL WORK

8.1 Finite Element Modeling of Composite Beam

In this section FEM modeling for composite beam is carried out having Glass as fiber and Polyester as matrix with fiber orientation 45°, Dimensions of beam as L_x=0.11179m L_y=12.7×10-3m L_z=3.38×10-3mand Lx= 0.3m Ly= 0.03m Lz= 0.004m having mesh size10×1 and number nodes are 22 for each node degree of freedom is one.

Table 1 Properties of Glass-Polyester Composite Beam [3]

E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	υ_{12}	P (Kg/m^3)
37.41	13.67	13.67	13.67	6.666	0.3	1768.9

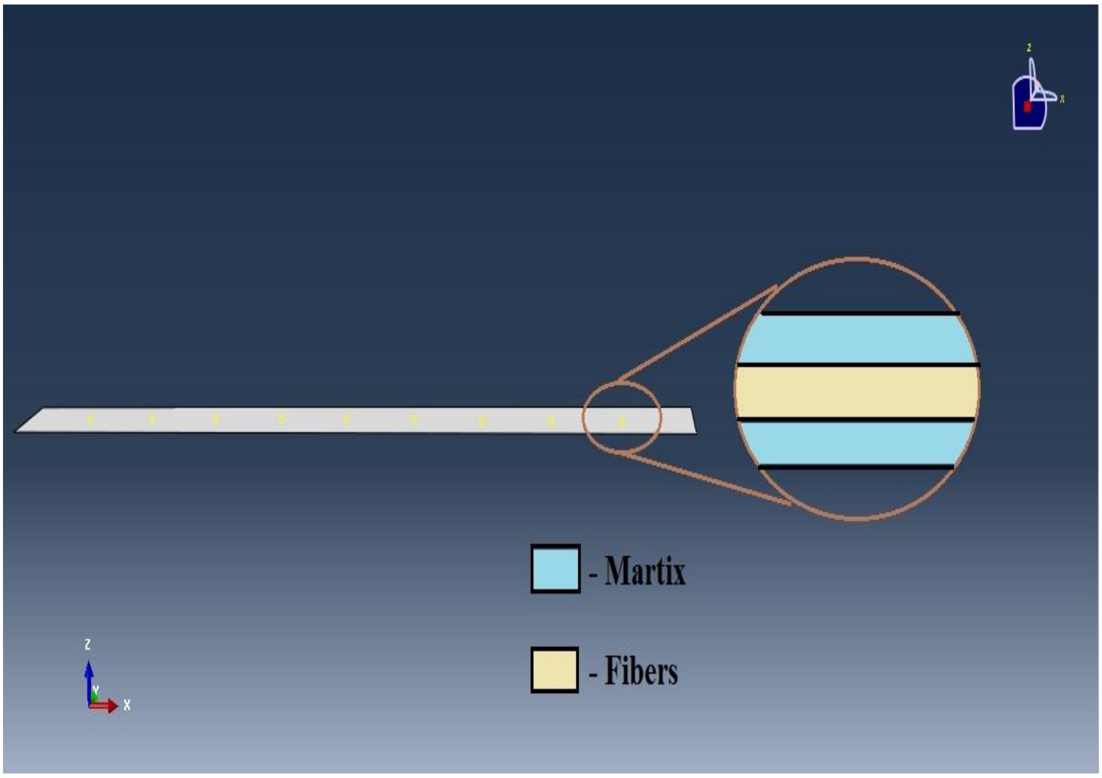


Figure 7 Shows front view of ABAQUS model of composite beam showing different layers of fiber and matrix

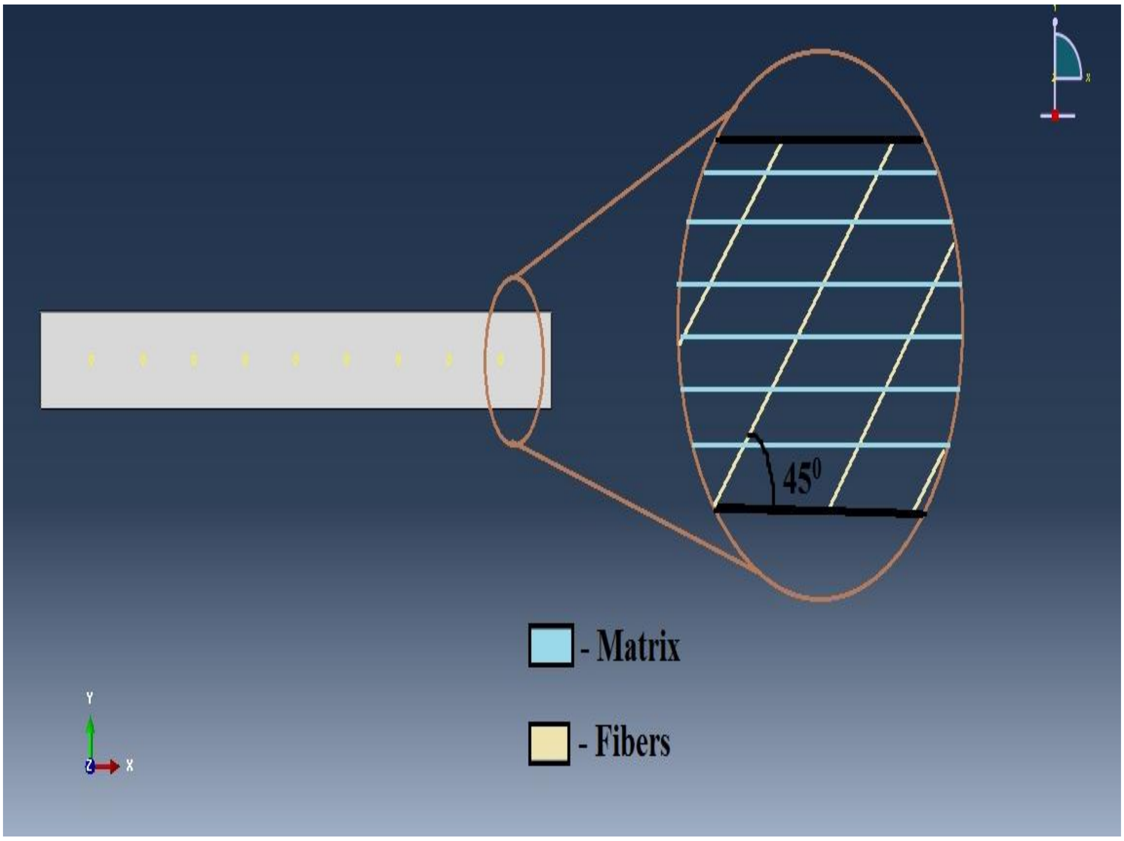


Figure 8 Shows top view of ABAQUS model of composite beam showing 450 fiber orientations

8.2 Finite Element Modeling of PZT-Piezoelectric Patch

Piezoelectric patch is a type transducer which is used to convert one form of energy into other either mechanical to electrical or electrical to mechanical energy. The dimensions of piezoelectric patch L_x=0.011179m L_y=0.0127m L_z=0.0005m with mesh size2×2. Piezoelectric patch is shifted on composite beam having 9 different locations which are represented in Fig. 8.2.1. After shifting the piezoelectric patch on beam the one optimal location is selected using viewing method, which simply by viewing the different mode shapes.

Table 2 Properties of piezoelectric patch [13]

e_{13}	e_{32}	E	P	υ	Dielectric constant
-8.9678	-8.9678	23.3GPa	7800Kg/m^3	0.34	6.6075×10^{-9}

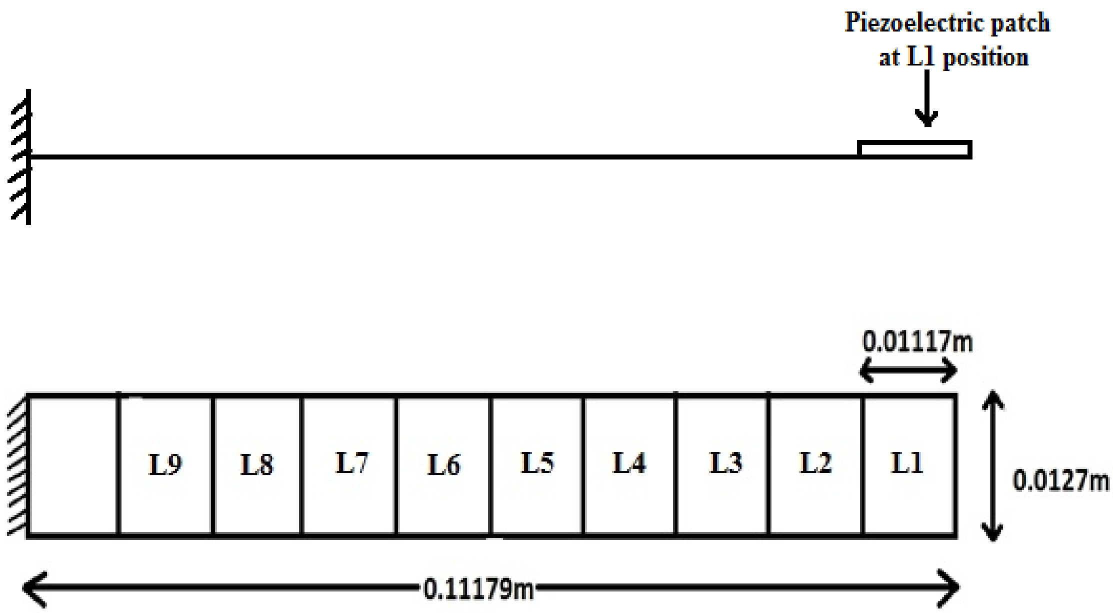


Figure 9 Shows different locations for piezoelectric patch on beam represented as L1, L2, L3, L4, L5, L6, L7, L8 and L9(Top view)

8.3 Finite Element Modeling of Simple Polyester Plate

In this section finite element modeling is carried out with polyester properties as 26MPa–Young's Modulus, 0.37-Poission's ratio and 1390 Kg/m^3–density and dimensions as Lx=0.3m Ly=0.3m Lz=0.001m and mesh size as 12×12.

8.4 Finite Element Modeling of Composite Panel

In this section finite element modelling of composite panel is done by using ABAQUS software. Glass is introduced as fiber and polyester as matrix having fiber orientations as 0°, 30°, 45°, 60° and 90°. Composite panel is divided into 169 nodes and each node is having one degree of freedom. Dimensions of composite panel are Lx=0.3m Ly=0.3m Lz=0.001m and mesh size as 12×12. There are different boundary conditions as well for different fiber orientations such as CCCC, SSSS, FFFF and CFFF to know the effect of boundary conditions on natural frequencies and mode shapes.

Table 3 Properties of Glass-Polyester Composite Beam [3]

E_1 (GPa)	E_2 (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	υ_{12}	P (Kg/m^3)
37.41	13.67	13.67	13.67	6.666	0.3	1768.9

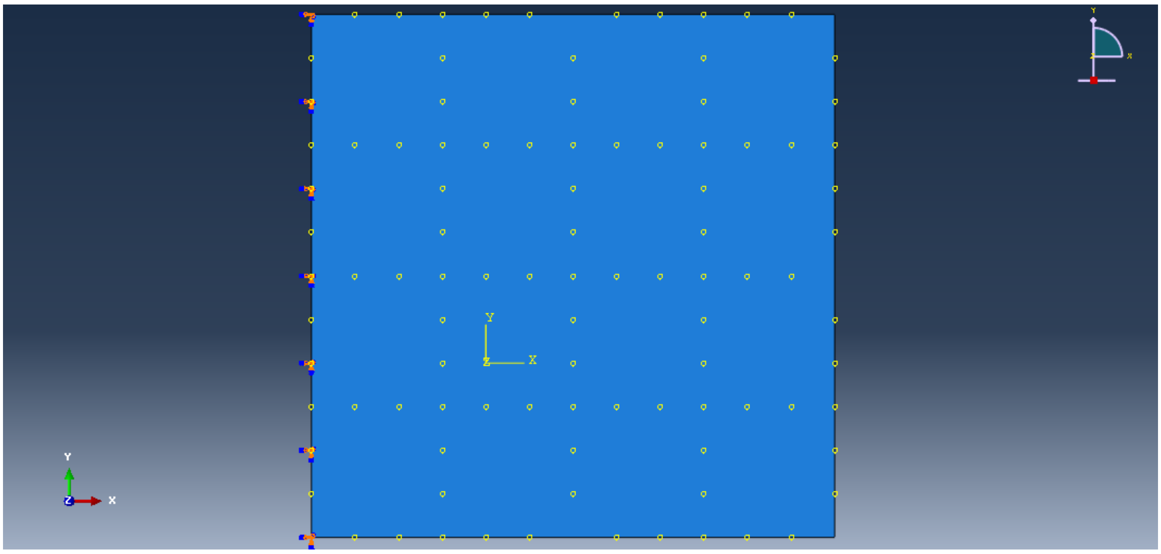


Figure 10 Shows FEM of composite plate under cantilever boundary conditions

8.5 FEM of PZT (Piezoelectric Patch) for Composite Plate.

Finite element modelling of composite material having piezoelectric patch at five different locations is carried out using ABAQUS software To make piezoelectric patch fix with the beam certain constrains were used in ABAQUS software without using those constrains piezoelectric patch dislocates from its position resulting in error and aborted file. At the one side of piezoelectric patch zero displacement boundary condition was applied. As per results torsion mode shapes and there natural frequencies were also calculated but thus were rejected because it is not required. The dimensions of piezoelectric patch L_x=0.05m L_y=0.05m L_z=0.0005m with mesh size2×2. Piezoelectric patch is shifted on composite beam having 9 different locations which are represented in Fig. 8.2.1. After shifting the piezoelectric patch on beam the one optimal location is selected using viewing method, which simply by viewing the different mode shapes.

Table 4 Properties of piezoelectric patch [13]

e_{13}	e_{32}	E	P	υ	Dielectric constant
-8.9678	-8.9678	23.3GPa	7800Kg/m^3	0.34	6.6075×10^{-9}

CHAPTER 9

EXPERIMENTAL WORK

9.1 Manufacturing of Composite Material

Now a day's there are many processes of manufacturing the composite material but most commonly used technique or method used for making composite material is Hand Lay-up. In this study Polyester resin act as matrix material and Glass Fibers as fiber and size of required specimen is 0.3m×0.03m×0.004m. There must be particular Fiber Volume Fraction before extruding the fibers on matrix material. In this study fiber volume fraction is 0.3 which is calculated from weight% of composite material. Weight of neat beam which same dimensions is 40 grams so according to 40 grams, 30% of it is 12 grams, this is the amount of fibers reinforced under the matrix material.

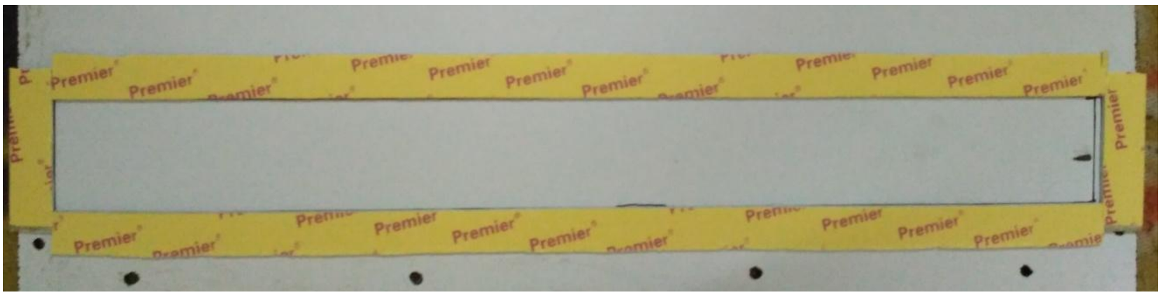
According to the instruction 2% of Polyester resin should be added as hardener and 0.75% of Polyester resin should be added as catalyst. According specimen dimension 45ml of total material should be added, 0.9ml of hardener and 0.33ml of catalyst.

9.1.1 Procedure of Making Composite

1. Place the Gayter Cutting Sheet on the grounded level and make a thin layer of Vaseline as a releasing agent.

Figure 11 Gayder cutting sheet

2. Mark the specimen dimensions on it and place the double tape on the boundary of it.



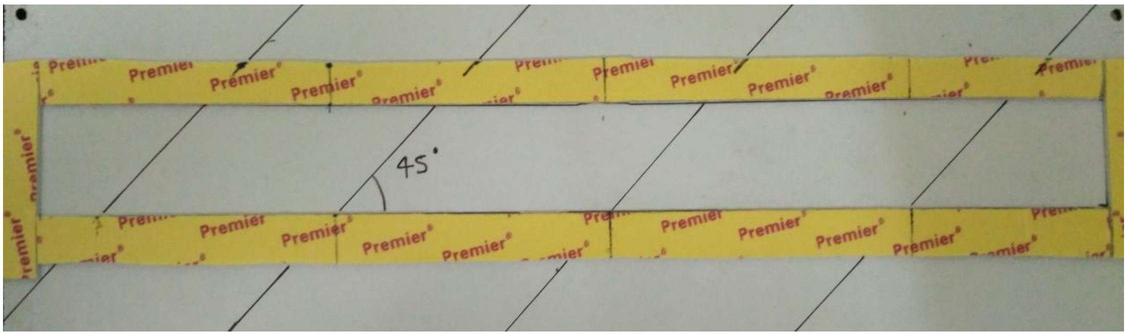


Figure 12 First layer of double tape according to dimension

3. Remove the rap of double tape and stick the Glass Fiber over it one by one.

Figure 13 Placing glass fiber

4. Now again stick the double tape on the same level

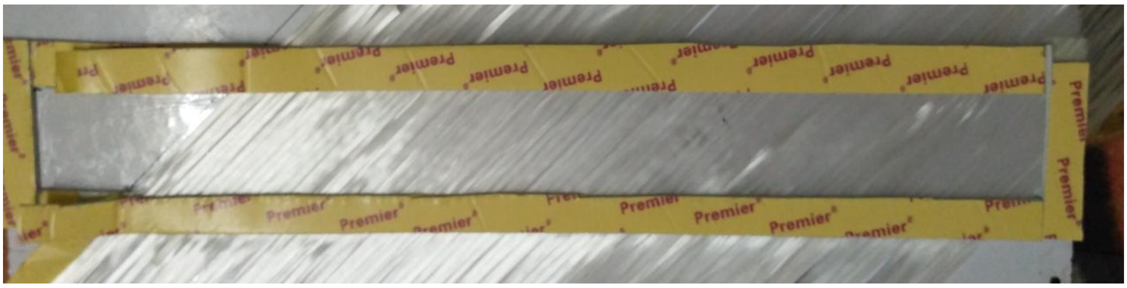


Figure 14 Placing the second layer of double tape

5. Dissolve and stir the mixture completely until it seems like mixed, once the catalyst is added remaining process should be done quickly because the catalyst cause the curing very quickly. The amount of Hardener and Catalyst should be added with different droppers otherwise it can may cause of inner layer of solidified material

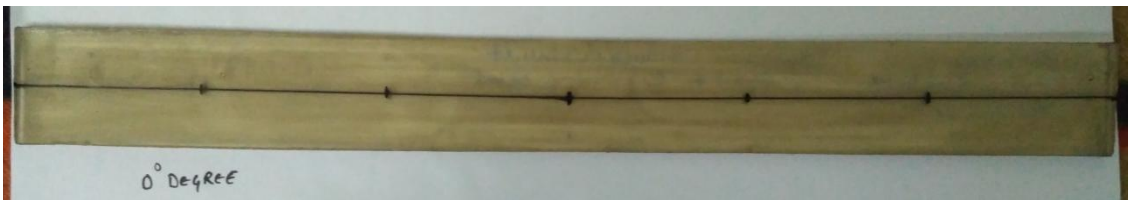
inside droppers. Also make sure that the amount of catalyst should not exceed 0.75% of polyester resin otherwise material will be full of cracks during solidifaction.

Figure 15 Beaker with solution

6. Before filling the material, checking the edges and corners, there must be no voids so that there should not be leakage. Gently pour the material in it and remove the voids or cavity by using dropper.

Figure 16 Pouring of solution

7. Let it cure for 1-2 hours, after curing remove the double tape and cut the extended fibers using cutter.



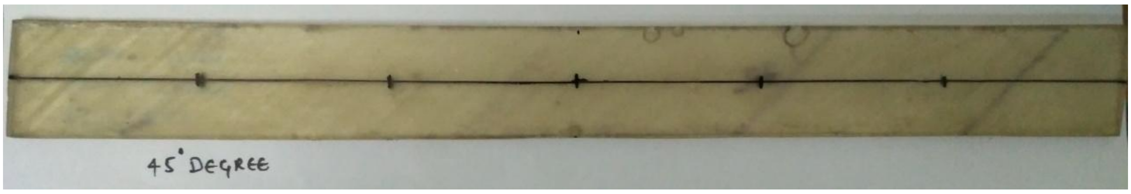


Figure 17 Specimen

9.2 Modal Testing of Composite Specimen

9.2.1 Procedure for Modal Testing

1. Installation of experimental setup and m+p international SO analyser software on PC.

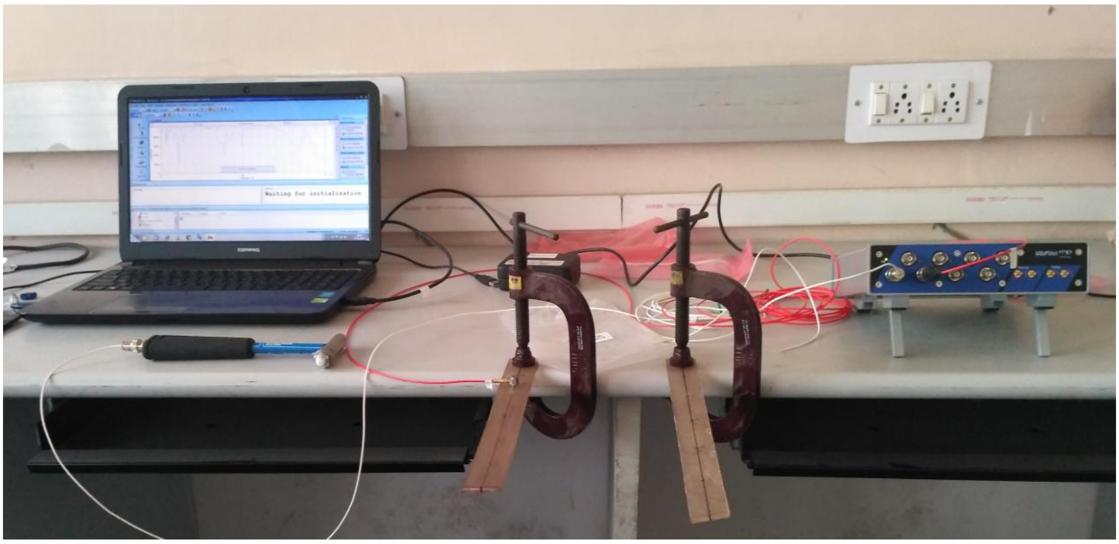


Figure 18 Experimental Setup

2. Divide the specimen into 5 sections 5 cm apart each, mark these points as 1,2,3,4 and respectively on both the specimen.

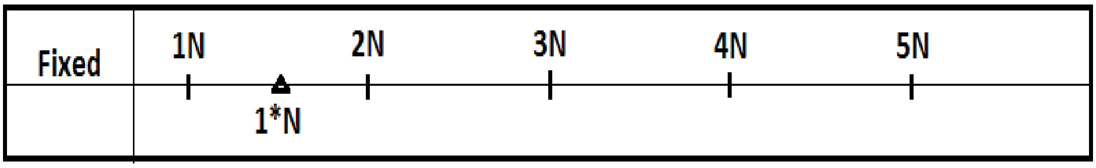


Figure 19 FEM of specimen

3. Fix the one end of specimen on table using C-Clamp.

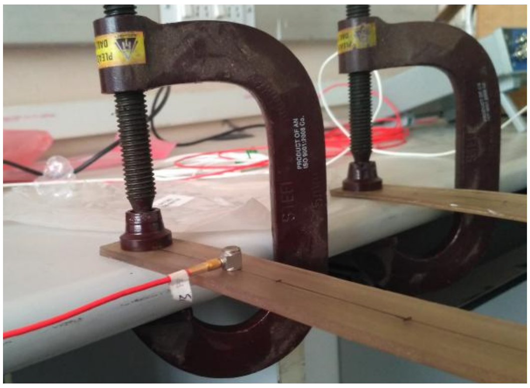


Figure 20 C - Clamp

4. Fix the Accelerometer near the boundary.

5. Attach the USB cable to PC and run software, and give 3000 Hz as maximum frequency, number of triggers as 3.

6. Gently make stroke of impact hammer on each point one by one, copy the data into clipboard and paste it on excel for both the specimen. (Sensitivity of accelerometer is 104.01 mV/g and sensitivity of impact hammer is 48.72 mV/LbF)

CHAPTER 10

RESULTS AND DISCUSSION

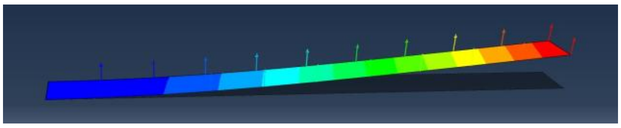
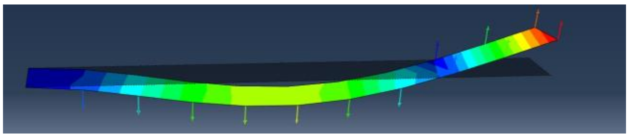
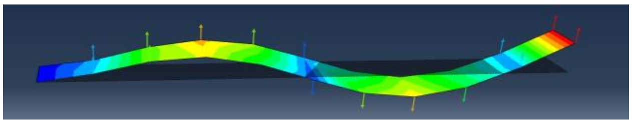
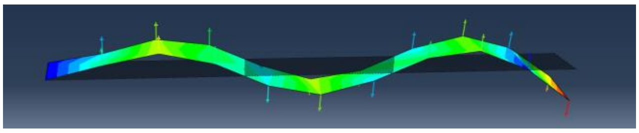
10.1 Analytical Results and Discussion

In this section results which came from ABAQUS software after modal analysis of different composite structure for different fiber orientation and under the various boundary conditions is carried out.

10.1.1 Modal Analysis of Composite Beam using ABAQUS Software

Validation is an important part for any study so before proposing any results validation is done with previously published research paper [3]. Well satisfying results comes with minimum percentage error of 0.5% maximum percentage error of 15%, as shown in Table 5. In additional mode shapes are also shown along with the natural frequencies for 1st four mode shapes. Each mode shape contains different node points at different positions except for 1st mode shape.

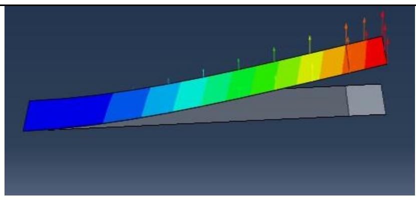
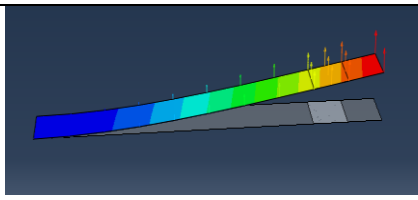
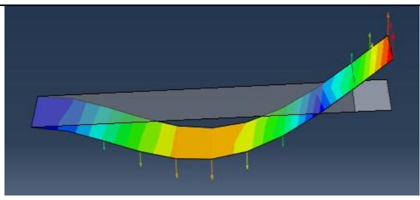
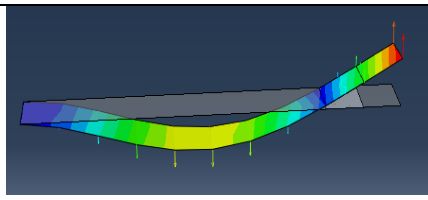
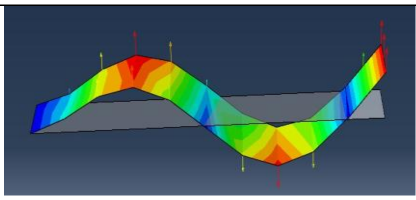
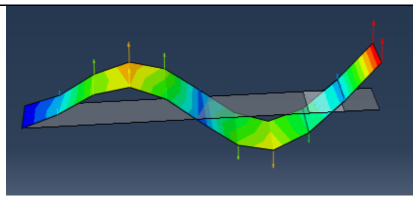
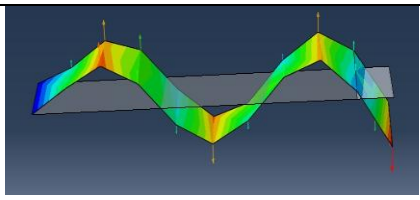
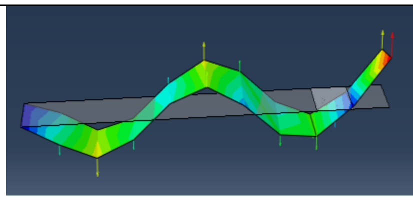
Table 5 Describes natural frequencies (in Hz) and mode shapes for Glass Polyester composite beam having fiber orientation 45^0 under the boundary conditions of clamped–free using ABAQUS software [30]

Mode No.	Present (Hz)	Reference[3] (Hz)	Mode Shapes
1.	121.11	120.5	
2.	773.35	752.4	
3.	2251.8	2092.9	
4.	4687.3	4062.2	

10.1.2 Modal Analysis of Composite Material with Piezoelectric Patch at Different Locations

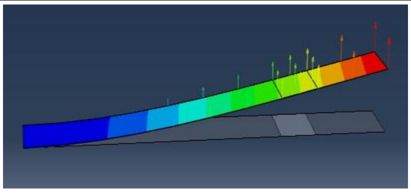
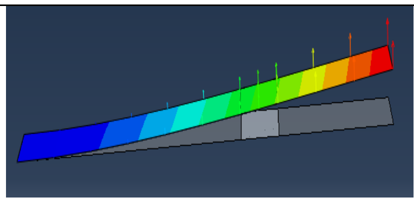
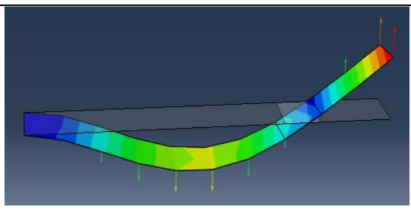
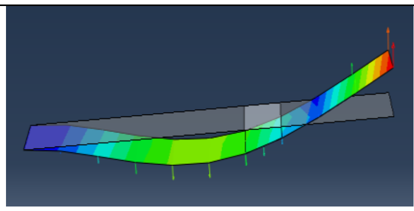
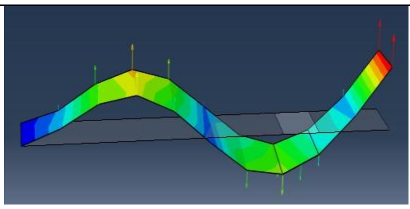
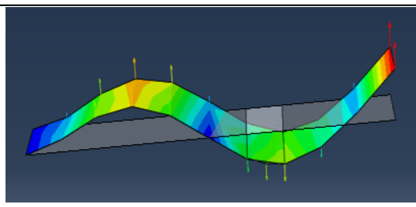
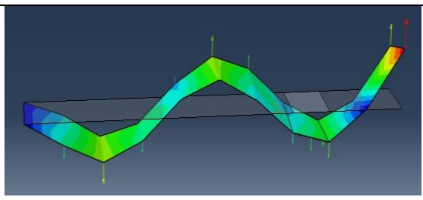
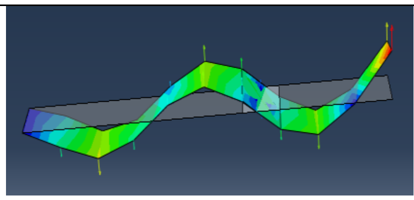
In this section the modal analysis of composite beam is carried out along with piezoelectric patch and piezoelectric patch is shifted on the beam to analyse the optimal location of PZT patch. In each table rows represents the mode shapes and column represents location number at which PZT patch is attached.

Table 6 Describes Natural frequencies (in Hz) and mode shapes for L1 and L2 locations of piezoelectric patch on composite beam having fiber orientation 45^0

Mode No.	Location No.	
	L1	L2
1.	 110.35	 113.04
2.	 731.28	 767.69
3.	 2173.7	 2277.8
4.	 4532.7	 4767.5

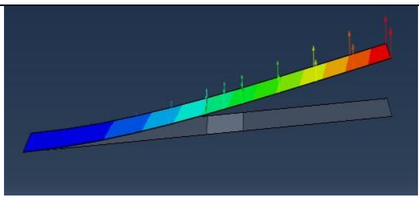
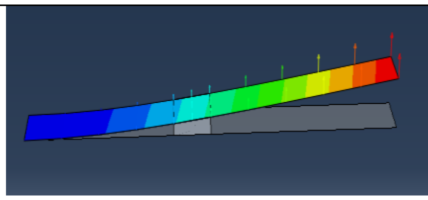
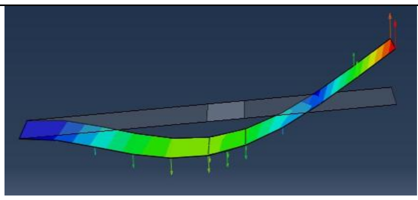
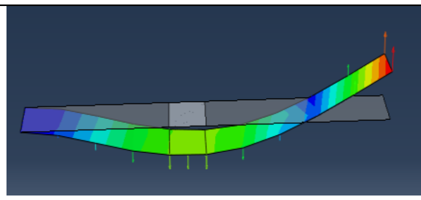
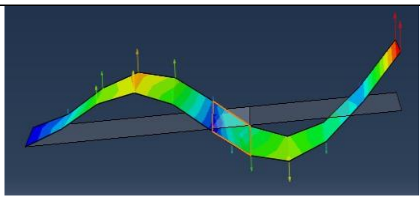
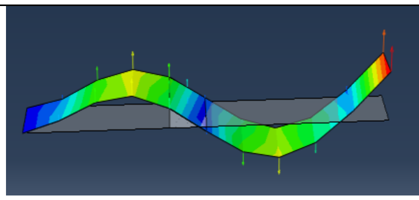
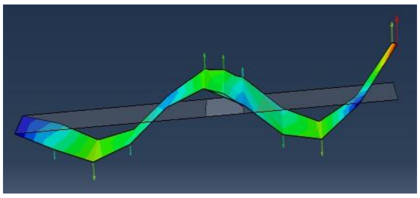
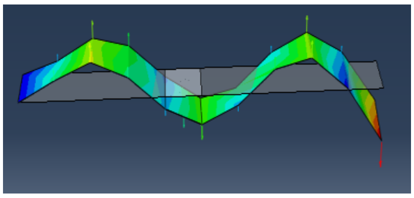
In this table by viewing mode shapes it is clear that for L1 position the location PZT patch is coinciding with node point for 3rd and 4th mode shape similarly for L2 position the location of PZT patch is coinciding with node point for 2nd, 3rd and 4th mode shape.

Table 7 Describes Natural frequencies (in Hz) and mode shapes for L3 and L4 locations of piezoelectric patch on composite beam having fiber orientation 45^0

Mode No.	Location No.	
	L3	L4
1.	 115.48	 117.36
2.	 782.31	 754.99
3.	 2284.6	 2173.8
4.	 4720.8	 4659.1

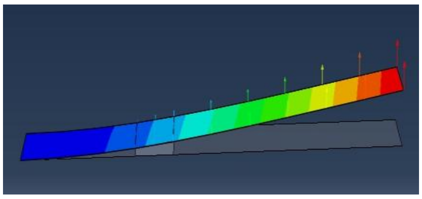
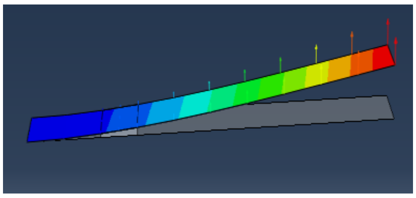
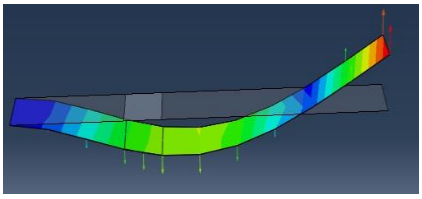
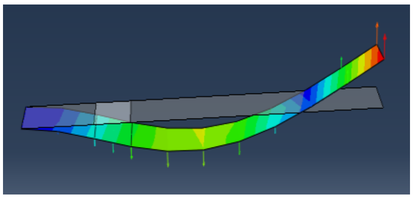
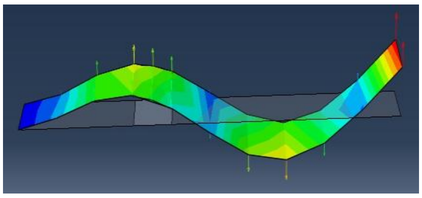
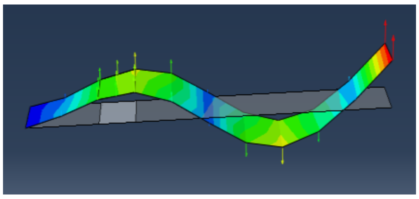
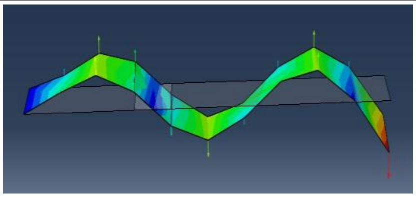
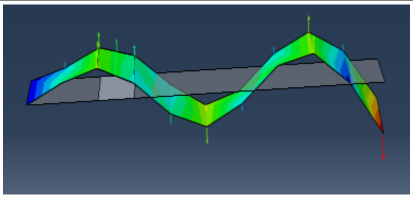
In this table by viewing mode shapes it is clear that for L3 position the location PZT patch is coinciding with node point for 2^{nd} mode shape similarly for L4 position the location of PZT patch is coinciding with node point for 4^{th} mode shape which means these respective mode shapes will not be detected by the PZT patch hence these location are not considered as optimal location. For optimal location the position of piezoelectric patch should not coincide with the node points, these are the points where there is zero displacement.

Table 8 Describes Natural frequencies (in Hz) and mode shapes for L5 and L6 locations of piezoelectric patch on composite beam having fiber orientation 45^0

<table>
<tr><td rowspan="2">Mode No.</td><td colspan="2">Location No.</td></tr>
<tr><td>L5</td><td>L6</td></tr>
<tr><td>1.</td><td>
118.90</td><td>
121.46</td></tr>
<tr><td>2.</td><td>
737.70</td><td>
763.33</td></tr>
<tr><td>3.</td><td>
2234.1</td><td>
2242.8</td></tr>
<tr><td>4.</td><td>
4527.6</td><td>
4688.5</td></tr>
</table>

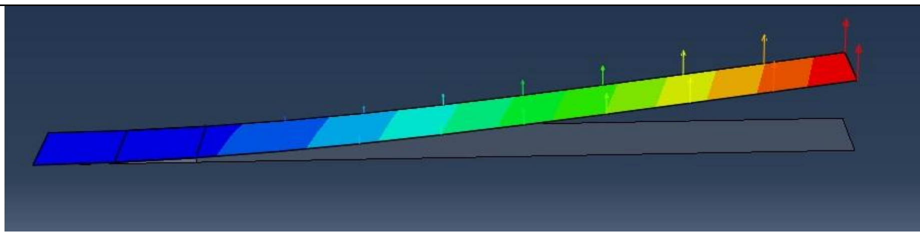
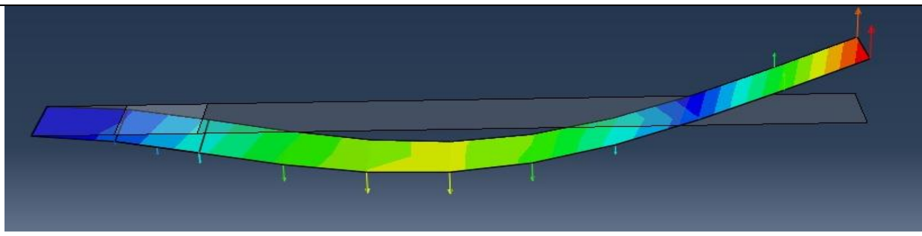
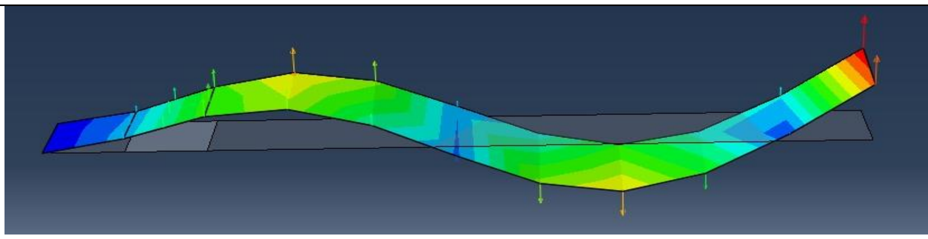
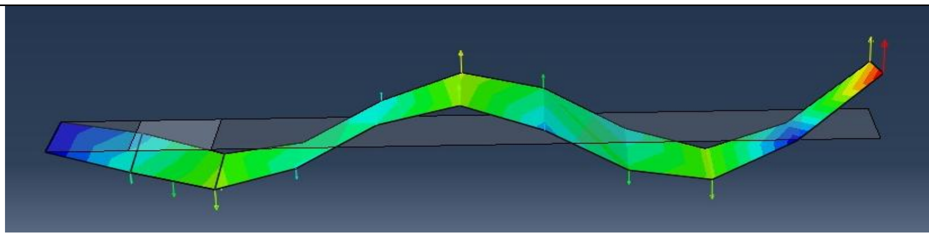
In this table by viewing mode shapes it is clear that for L5 position the location PZT patch is coinciding with node point for 3^{rd} mode shape similarly for L6 position the location of PZT patch is coinciding with node point for 3^{rd} and 4^{th} mode shape which means these respective mode shapes will not be detected by the PZT patch hence these location are not considered as optimal location. For 1^{st} mode shape there is no node point, for 2^{nd} mode shape there is only one node point similarly for 3^{rd} and 4^{th} mode shapes there are two node points.

Table 9 Describes Natural frequencies (in Hz) and mode shapes for L7 and L8 locations of piezoelectric patch on composite beam having fiber orientation 45^0

Mode No.	Location No.	
	L7	L8
1.	 120.68	 125.27
2.	 741.90	 760.11
3.	 2152.0	 2213.1
4.	 4656.4	 4688.5

In this table by viewing mode shapes it is clear that for L7 position the location PZT patch is coinciding with node point for 4^{th} mode shape similarly for L8 position the location of PZT patch is not coinciding with any node point which means this location can be elected as optimal location of PZT patch to detect all the mode shapes correctly. When 4^{th} mode shape is compared with each other for L7 location PZT location is coinciding with node point and for L8 location it is not coinciding hence this should be optimal location for PZT patch.

Table 10 describes Natural frequencies (in Hz) and mode shapes for L9 locations of piezoelectric patch on composite beam having fiber orientation 45^0

Mode No.	Location No.
	L9
1.	 129.4
2.	 781.84
3.	 2219.8
4.	 4604.8

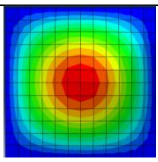
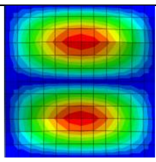
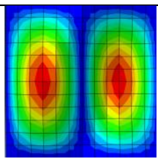
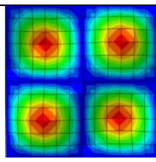
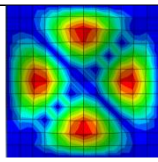
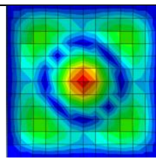
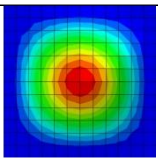
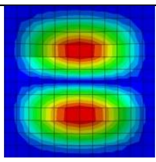
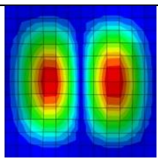
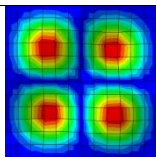
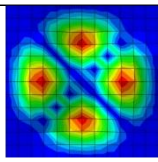
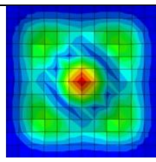
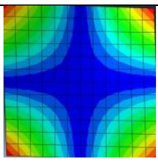
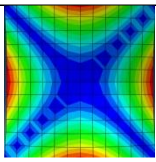
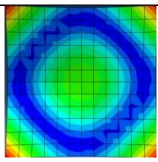
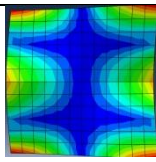
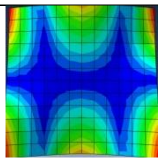
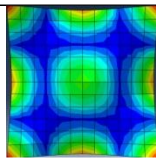
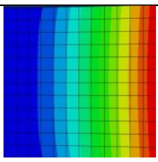
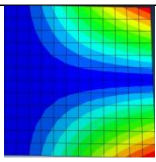
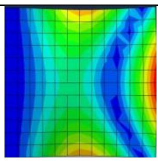
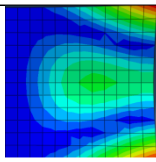
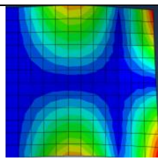
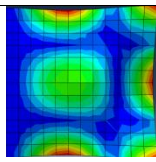
In this table by viewing the different mode shapes it is clear that the node points are not coinciding for this location of PZT patch hence this location can also be considered as optimal location. [30]

10.1.3 Optimal Location of Piezoelectric Patch using Modal Analysis

From the tables it is clear that for each position of piezoelectric patch four mode shapes were analyzed as shown in second column with particular frequencies. At L1 position for 4th mode shape there are three nodes out which 3rd node is coincide with the position of piezoelectric patch due to which the deflection won’t be detected hence this position can’t be set as optimal location. Similarly for positions L2, L3, L4, L5, L6 and L7 nodes are coinciding with piezoelectric patch for different mode shapes, so these locations are not considered as an optimal location but at L8 and L9 position by viewing all the mode shapes it is clear that there is no nodes which are coincide with this position so L8 and L9 are the two optimal location for piezoelectric patch. Although by comparing 1st mode shapes for all the locations it is analyzed that natural frequency goes on increasing with decrease in the distance of patch from fixed boundary condition. [30]

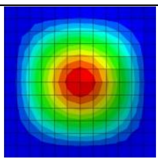
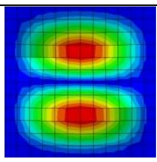
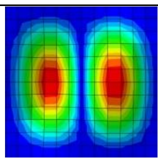
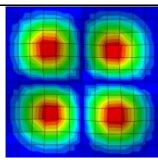
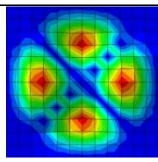
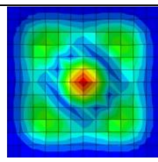
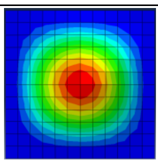
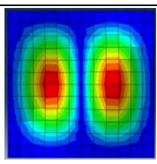
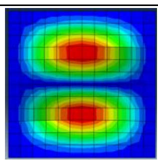
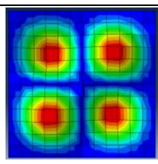
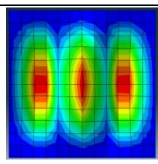
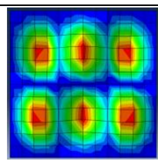
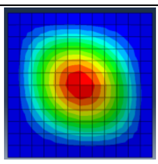
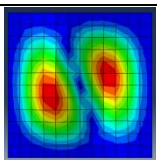
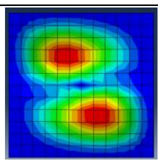
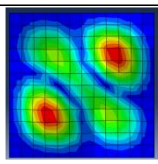
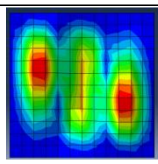
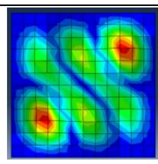
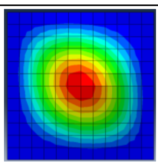
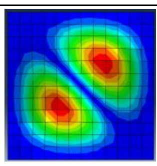
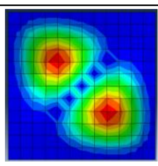
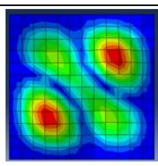
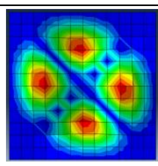
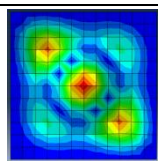
10.1.4 Modal Analysis for Simple Polyester Plate Under different Boundary Conditions

Table 11 Shows Natural Frequencies (Hz) and Mode Shapes of Simple Polyester Plate (MATRIX) under the different Boundary Conditions (B.O.)

B.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
SSSS	 1.49	 3.80	 3.80	 6.07	 7.92	 7.92
CCCC	 2.74	 5.75	 5.75	 8.44	 10.91	 10.97
FFFF	 0.96	 1.42	 1.87	 2.54	 2.54	 4.68
CFFF	 0.25	 0.61	 1.58	 2.04	 2.20	 4.00

In Table 11 number of rows represents different Boundary conditions and number of column represents different mode shapes, from the table it is clear that the mode shapes are affected by the boundary condition and natural frequency is maximum in case of simply supported and minimum for cantilever boundary condition node lines vary for different boundary condition.

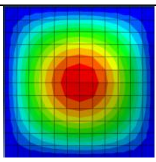
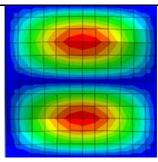
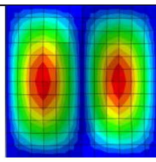
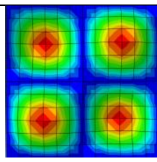
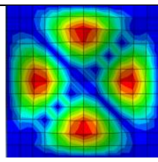
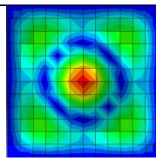
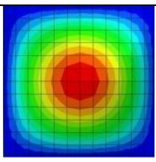
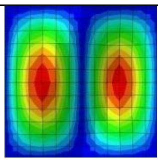
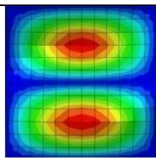
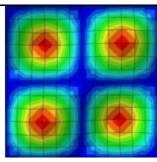
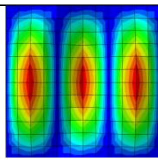
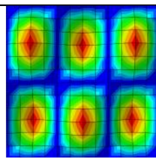
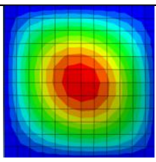
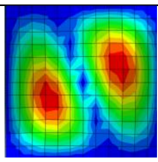
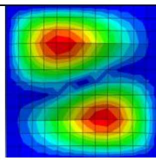
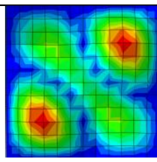
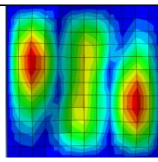
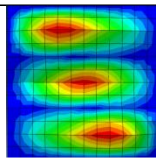
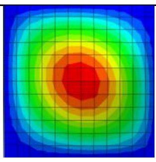
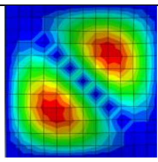
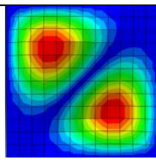
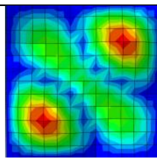
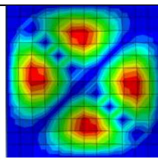
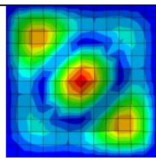
Table 12 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition all side Clamped (CCCC). [31]

F.O	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
M	 2.74	 5.75	 5.75	 8.44	 10.91	 10.97
0° And 90°	 65.003	 113.31	 157.98	 194.55	 204.33	 271.31
30° And 60°	 63.082	 118.60	 144.46	 189.39	 223.60	 277.78
45°	 62.454	 122.22	 138.07	 188.45	 242.85	 252.49

In the above Table the number rows represents the different fiber orientation and number of column represents the different mode shapes after viewing the mode shapes it is clear that mode shapes are affected by the fiber orientation, Row 1st represents mode shapes till 6th mode shape and remaining row represents different fibre orientations as 0°, 30°, 45°, 60° and 90° in Table 12 1st mode shape for all fiber orientation is almost same which contains no nodal line. In 2nd mode shape, there is one vertical nodal line but when compared at different position, the nodal line is slightly inclined at 60°and for 45°, the nodal line is inclined to greater extent. [31]
Similarly for 3rd mode shape, direction of nodal line changes from vertical to horizontal. In 4th mode shape, there are two nodal lines - one is horizontal and other

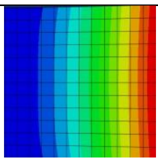
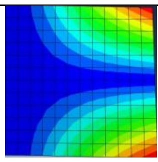
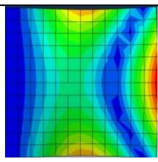
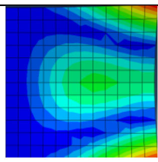
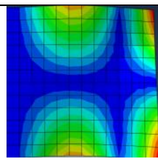
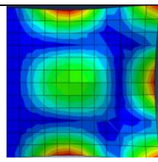
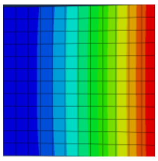
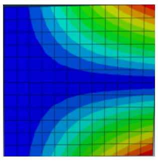
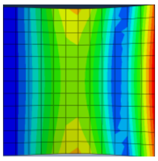
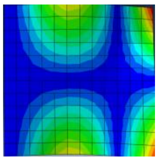
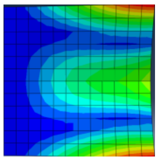
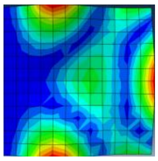
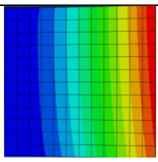
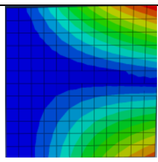
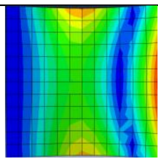
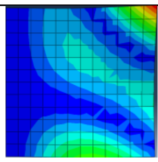
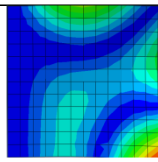
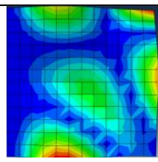
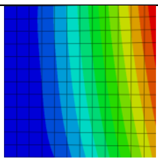
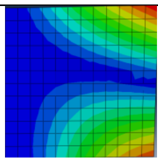
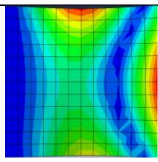
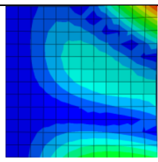
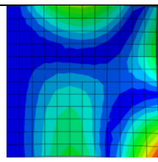
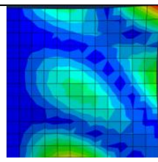
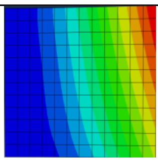
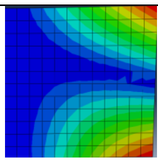
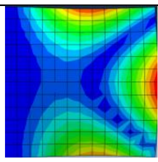
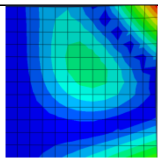
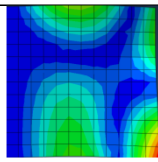
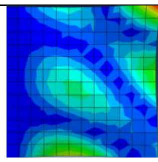
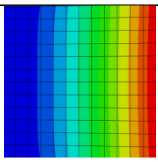
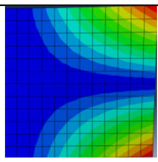
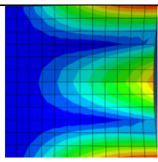
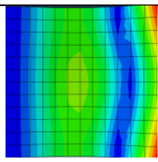
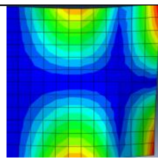
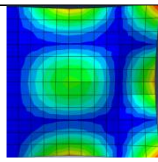
one is vertical, which shows inclination for 60° and 45° and have approximately same mode shapes. For 5th mode shape, there are two vertical nodal lines and having approximately same mode shapes for 90° and 60° but for 45° it is completely different. For 6th mode shape, there is one horizontal and two vertical nodal lines for 90° fibre orientation whereas at 60° fiber orientation there are three inclined nodal lines. At 45° orientation, there are four nodal lines which describes that the mode shapes are different for different fiber orientation. [31]

Table 13 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition all side Simply Supported. (SSSS), M-Matrix Material

F.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
M	 1.49	 3.80	 3.80	 6.07	 7.92	 7.92
0° And 90°	 32.94	 72.22	 101.46	 134.05	 146.28	 200.47
30° And 60°	 34.86	 78.56	 96.33	 136.01	 163.84	 202.18
45°	 35.53	 81.00	 94.35	 136.88	 177.67	 186.30

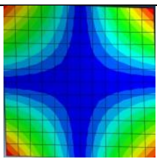
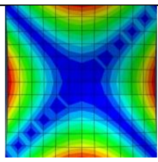
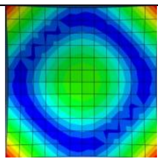
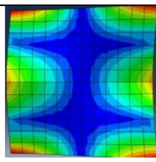
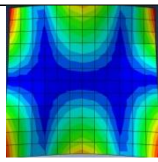
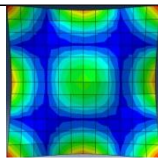
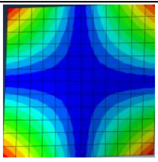
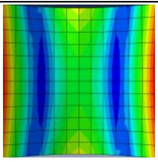
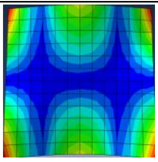
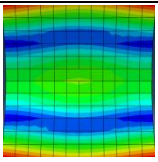
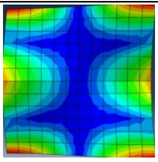
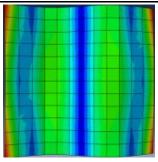
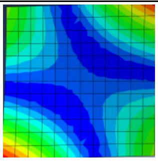
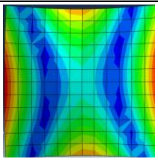
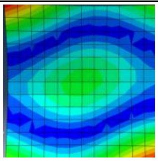
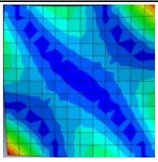
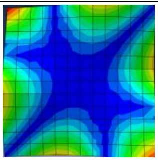
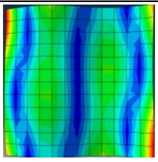
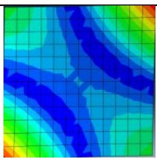
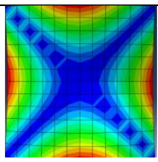
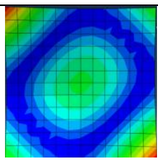
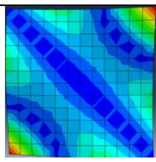
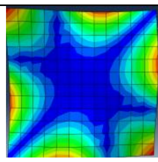
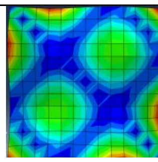
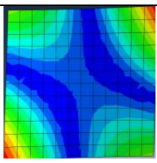
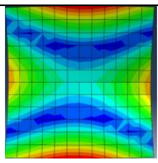
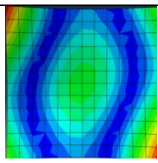
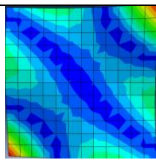
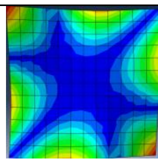
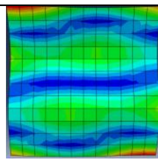
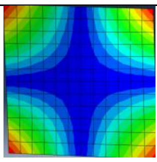
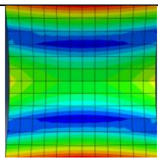
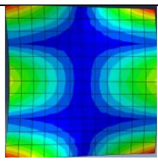
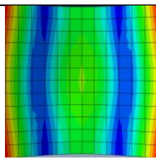
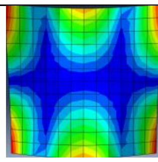
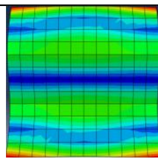
In the above Table the number rows represents the different fiber orientation and number of column represents the different mode shapes after viewing the mode shapes it is clear that mode shapes are affected by the fiber orientation, Row 1st represents mode shapes till 6th mode shape and remaining row represents different fibre orientations as 0°, 30°, 45°, 60° and 90°, The plate is under boundary condition Simply Supported from all sides.

Table 14 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition Clamped from one side and free from remaining. (CFFF), M-Matrix Material

F.O.	Mode	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
M	 0.25	 0.61	 1.58	 2.04	 2.20	 4.00
0°	 4.78	 12.14	 30.34	 44.38	 55.41	 86.57
30°	 4.97	 14.13	 31.01	 44.64	 55.79	 88.41
45°	 5.48	 15.25	 33.93	 43.97	 56.28	 90.28
60°	 6.37	 15.25	 38.620	 43.76	 57.20	 90.33
90°	 7.93	 14.13	 38.58	 50.71	 59.66	 88.49

In the above Table the number rows represents the different fiber orientation and number of column represents the different mode shapes after viewing the mode shapes it is clear that mode shapes are affected by the fiber orientation, Row 1st represents mode shapes till 6th mode shape and remaining row represents different fibre orientations as 0°, 30°, 45°, 60° and 90°, The plate is under the boundary condition Fixed from one side and remaining sides are free. The behaviour of mode shapes is affected with the change in fiber orientation which is clear from the above table.

Table 15 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition all side free. (FFFF), M-Matrix Material.

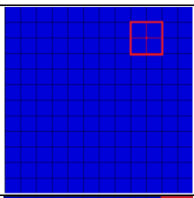
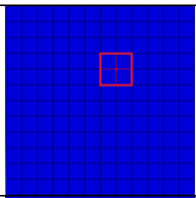
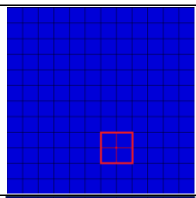
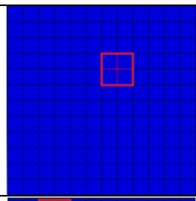
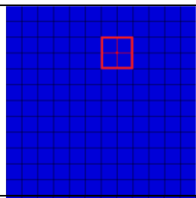
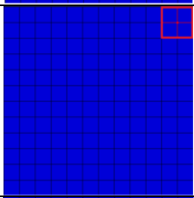
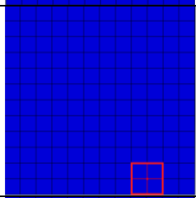
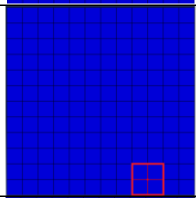
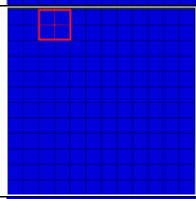
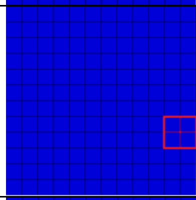
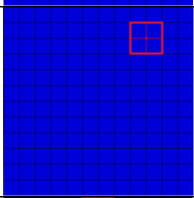
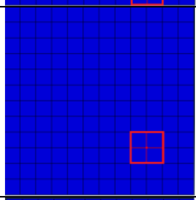
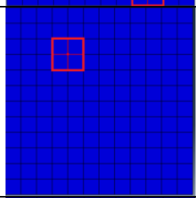
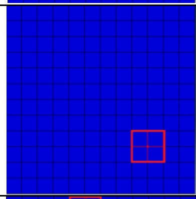
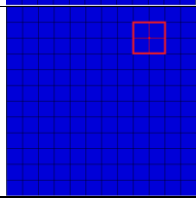
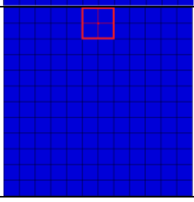
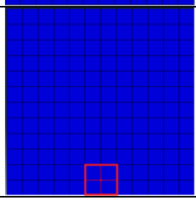
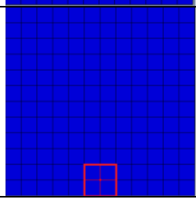
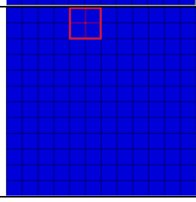
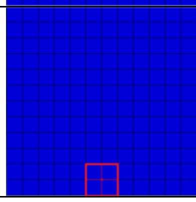
F.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
M	 0.96	 1.42	 1.87	 2.54	 2.54	 4.68
0°	 19.59	 30.35	 50.31	 51.14	 63.94	 87.69
30°	 21.97	 29.47	 45.80	 52.26	 65.14	 93.01
45°	 23.16	 28.99	 43.85	 53.34	 64.58	 101.34
60°	 21.97	 29.47	 45.80	 52.26	 65.14	 93.14
90°	 19.59	 30.35	 50.31	 51.14	 63.94	 87.69

In the above Table the number rows represents the different fiber orientation and number of column represents the different mode shapes after viewing the mode shapes it is clear that mode shapes are affected by the fiber orientation, Row 1^{st} represents mode shapes till 6^{th} mode shape and remaining row represents different fibre orientations as 0°, 30°, 45°, 60° and 90°, The plate is under the boundary condition Free from all the sides. The behaviour of mode shapes are affected with the change in fiber orientation which is clear from the above table, natural frequency for 0° and 90° remains same but mode shapes are different , similarly for 30° and 60° natural frequencies remains same but different mode shapes are obtained.

10.1.5 Optimal Location for PZT Patch on Composite Plate

In this section by viewing the different mode shapes optimal location for each boundary condition with respect to fiber orientation is proposed.

Table 16 Shows Optimal Location of Piezoelectric Patch at different fiber orientation under different Boundary Conditions.

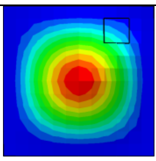
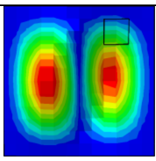
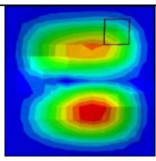
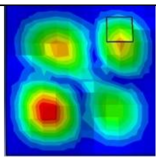
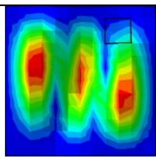
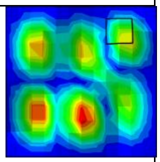
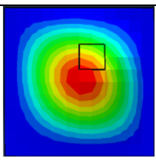
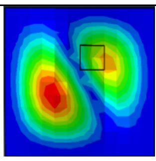
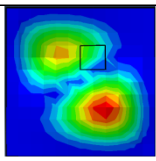
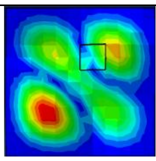
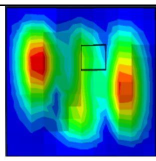
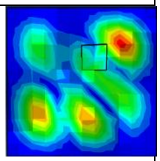
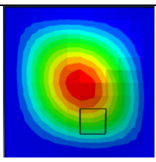
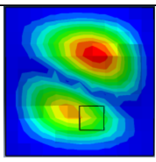
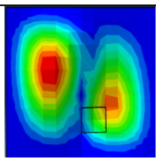
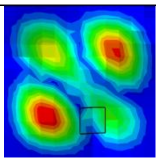
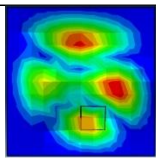
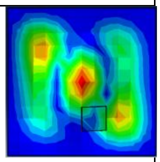
B.C.	0°	30°	45°	60°	90°
CCCC					
FFFF					
SSSS					
CFFF					

In the Above table it can be seen that the optimal location is different for each boundary condition and for each fiber orientation, now there will be proper detection when patch will added over that location. Earlier there was conventional method of attaching the piezoelectric patch, dividing the plate into four parts and mounting the patch on the 2^{nd} quadrant at 45-degree line but this method is applicable only simple materials not for composite materials because as earlier discussed the mode are totally dependent upon the fiber orientation. A new method is introduced of electing the location of sensor which is viewing method, by just viewing all the mode shapes anyone can elect the optimal location for sensor, simply that location will be optimal location for which no nodal line coincides with the sensor position for all the mode shapes, from the above table it is clear that the optimal location is not at 2^{nd} quadrant it different for different F.O.

10.1.6 Modal Analysis of Composite Plate when PZT Patch is attached over its Optimal Location

In this section Modal analysis of composite plate along with PZT patch is carried out. Below every mode shape there is Percentage sensing (%S.) of sensor when compared to more detected mode shape.

Table 17 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition all sides Clamped (CCCC), when piezoelectric patch is attached at the Optimal Location

F.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0° And 90°	 64.64	 111.46	 153.40	 184.49	 203.08	 260.05
%.S	27.54%	57.66%	79.86%	95.19%	25.31%	100%
30° And 60°	 58.27	 111.45	 138.52	 183.86	 216.51	 271.20
%.S	100%	84.24%	51.58%	34.47%	55.47%	31.83%
45°	 59.32	 117.20	 129.23	 185.59	 225.00	 248.54
%.S	79.02%	86.26%	66.91%	29.43%	100%	11.77%

In the above table the 1st column represents the different fiber orientation and remaining columns represents the different mode shapes. Below every mode shape there is percentage sensing (%S) which is with respective to maximum sensing for particular mode shapes. From the mode shapes it is clear that the no nodal line is coincides with the location of sensor, these mode shape itself proves that the sensor is attached on its optimal location, and mode shape behaviour remains the same as it was earlier when sensor was not attached, except the slightly decrease in the natural frequency that is because the plate added mass over it.

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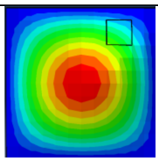
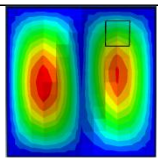
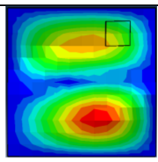
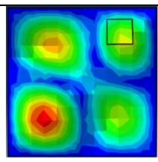
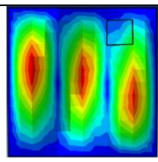
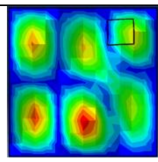
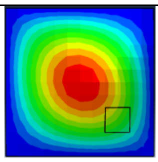
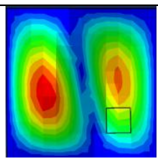
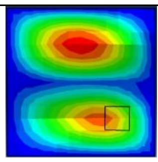
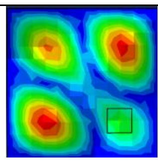
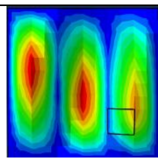
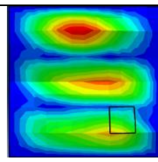
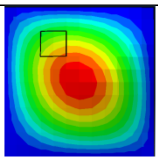
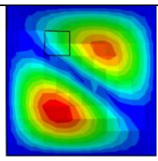
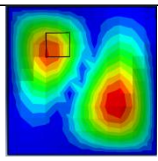
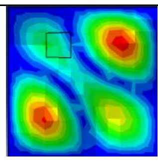
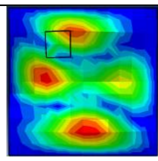
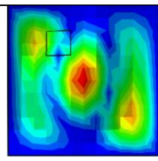
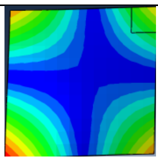
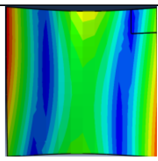
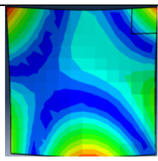
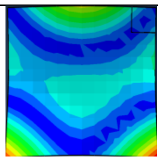
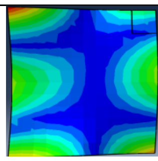
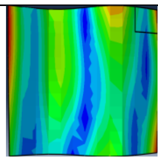
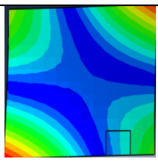
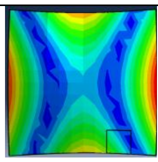
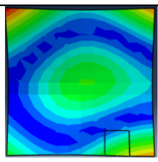
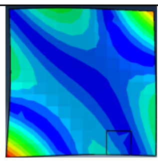
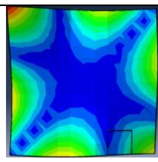
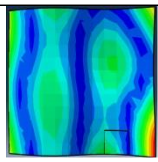
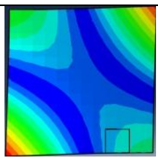
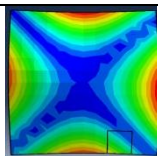
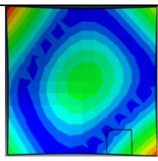
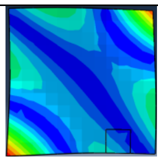
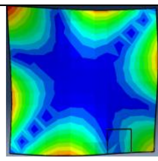
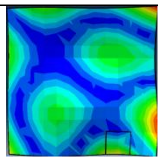
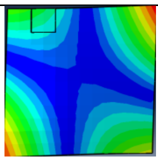
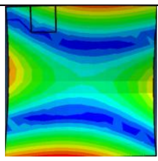
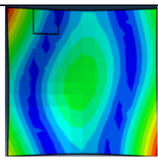
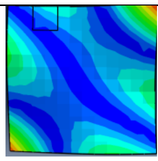
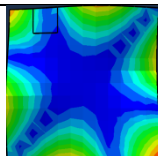
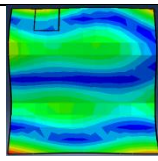
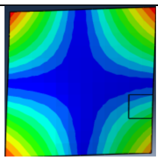
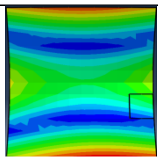
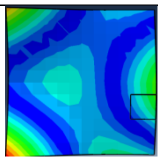
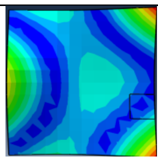
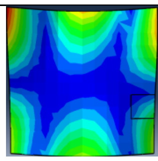
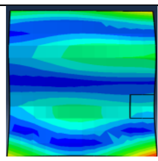
Table 18 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition all sides simply supported (SSSS), when piezoelectric patch is attached at the Optimal Location

F.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0° And 90°	 32.52	 70.37	 97.62	 126.67	 145.20	 193.69
%.S	55.60%	83.94%	95.95%	100%	28.91%	84.25%
30° And 60°	 33.85	 76.68	 89.57	 131.60	 158.05	 194.96
%.S	71.20%	72.85%	100%	65.36%	60.68%	56.22%
45°	 34.06	 80.27	 86.23	 133.57	 172.04	 180.82
%.S	78.75%.	44.05%	100%	46.87%	54.33%	30.37%

In the above table the 1st column represents the different fiber orientation and remaining columns represents the different mode shapes. Below every mode shape there is percentage sensing (%S) which is with respective to maximum sensing for particular mode shape.

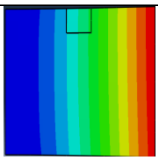
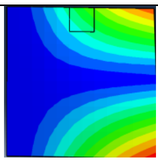
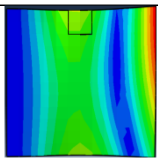
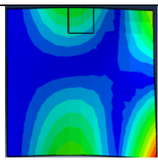
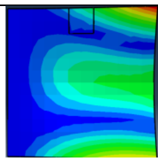
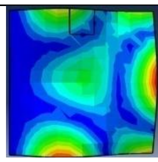
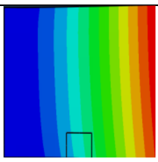
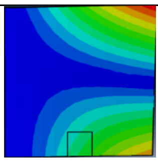
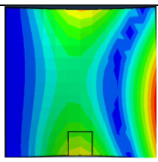
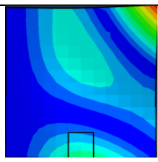
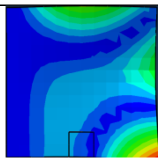
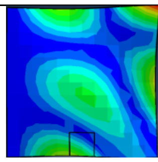
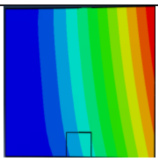
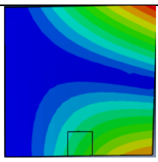
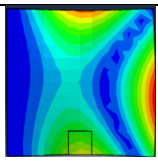
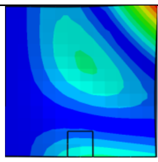
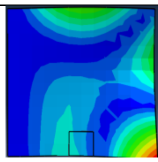
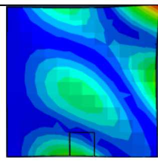
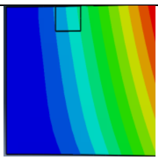
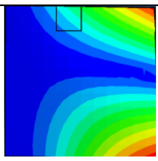
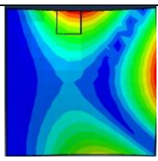
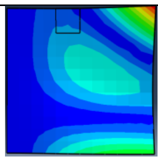
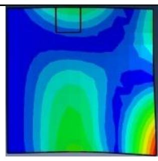
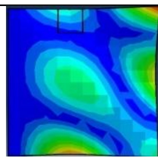
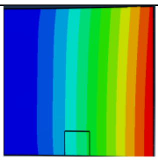
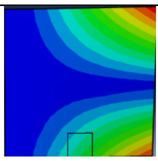
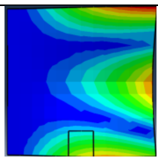
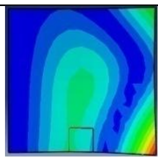
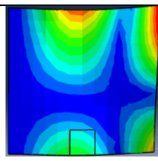
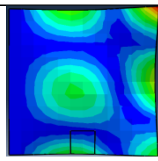
From the mode shapes it is clear that the no nodal line is coincides with the location of sensor, these mode shape itself proves that the sensor is attached on its optimal location, and mode shape behaviour remains the same as it was earlier when sensor was not attached, except the slightly decrease in the natural frequency that is because the plate added mass over it. Sometimes it becomes difficult to elect the optimal location because of many nodal line or region on a modal; in that case the location for which the more number of mode shapes are detected will be elected as optimal location. Sometimes it becomes difficult to elect the optimal location because of many nodal line or region on a modal; in that case the location for which the more number of mode shapes are detected will be elected as optimal location.

Table 19 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition all sides free (FFFF), when piezoelectric patch is attached at the Optimal Location

F.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0°	 17.95	 29.95	 46.12	 50.60	 61.68	 84.97
%.S	100%	58.11%	80.90%	6.41%	34.57%	34.94%
30°	 21.61	 29.04	 43.36	 51.50	 64.30	 91.01
%.S	60.81%	70.09%	100%	31.92%	43.52%	67.47%
45°	 22.68	 28.23	 42.45	 52.43	 63.95	 95.67
%.S	72.74%	95.19%	71.02%	41.23%	45.94%	100%
60°	 21.20	 28.62	 42.27	 51.18	 64.59	 89.61
%.S	100%	95.21%	43.73%	45.59%	35.04%	74.55%
90°	 19.25	 29.92	 48.00	 50.63	 62.81	 85.85
%.S	80.82%	100%	90.73%	7.38%	60.97%	80.74%

In the above table the 1st column represents the different fiber orientation and remaining columns represents the different mode shapes. Below every mode shape there is percentage sensing (%S) which is with respective to maximum sensing for particular mode shape. From the mode shapes it is clear that the no nodal line is coincides with the location of sensor, these mode shape itself proves that the sensor is attached on its optimal location, and mode shape behaviour remains the same as it was earlier when sensor was not attached, except the slightly decrease in the natural frequency that is because the plate added mass over it.

Table 20 Shows Natural Frequencies (Hz) and Mode Shapes of G-P Plate at different Fiber Orientations (F.O.) under the Boundary Condition one side Clamped and remaining all sides free (CFFF), when piezoelectric patch is attached at the Optimal Location

F.O.	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0°	 4.72	 11.69	 28.78	 41.46	 54.34	 83.16
%.S	55.29%	66.62%	100%	60.94%	24.57%	47.86%
30°	 4.92	 13.64	 29.16	 41.75	 55.21	 83.62
%.S	46.33%	59.91%	100%	44.08%	19.08%	41.51%
45°	 5.45	 14.63	 31.93	 42.10	 54.41	 85.17
%.S	40.21%	71.49%	100%	37.83%	36.38%	37.45%
60°	 6.31	 15.02	 32.23	 42.95	 54.44	 88.59
%.S	35.64%	36.33%	100%	20.52%	37.44%	26.08%
90°	 7.83	 13.69	 36.67	 48.49	 56.20	 84.41
%.S	71.35%	72.68%	100%	67.35%	75.78%	45.53%

In the above table the 1st column represents the different fiber orientation and remaining columns represents the different mode shapes. Below every mode shape there is percentage sensing (%S) which is with respective to maximum sensing for particular mode shape. From the mode shapes it is clear that the no nodal line is coincides with the location of sensor, these mode shape itself proves that the sensor is attached on its optimal location, and mode shape behaviour remains the same as it was earlier when sensor was not attached, except the slightly decrease in the natural frequency that is because the plate added mass over it.

10.1.7 Overlay of FRF (Frequency Response Function) at Optimal Location and Non Optimal Location for 45° Fiber Orientation under CCCC Boundary Condition

In this section the overlay for two locations is considered for 45 degree fiber orientated composite plate under CCCC Boundary conditions, from the overlay it is clear that for non optimal location 3rd and 5th mode is missed because this location coincides with the node line, but when sensor is attached over optimal location all the modes are sensed perfectly. The non optimal location used for 45° composite optimal location for 0° composite plate. This FRF curve proves that there must be different optimal location for different fiber orientation; one location should not be used for each fiber orientation if proper detection of all the mode shapes is required.

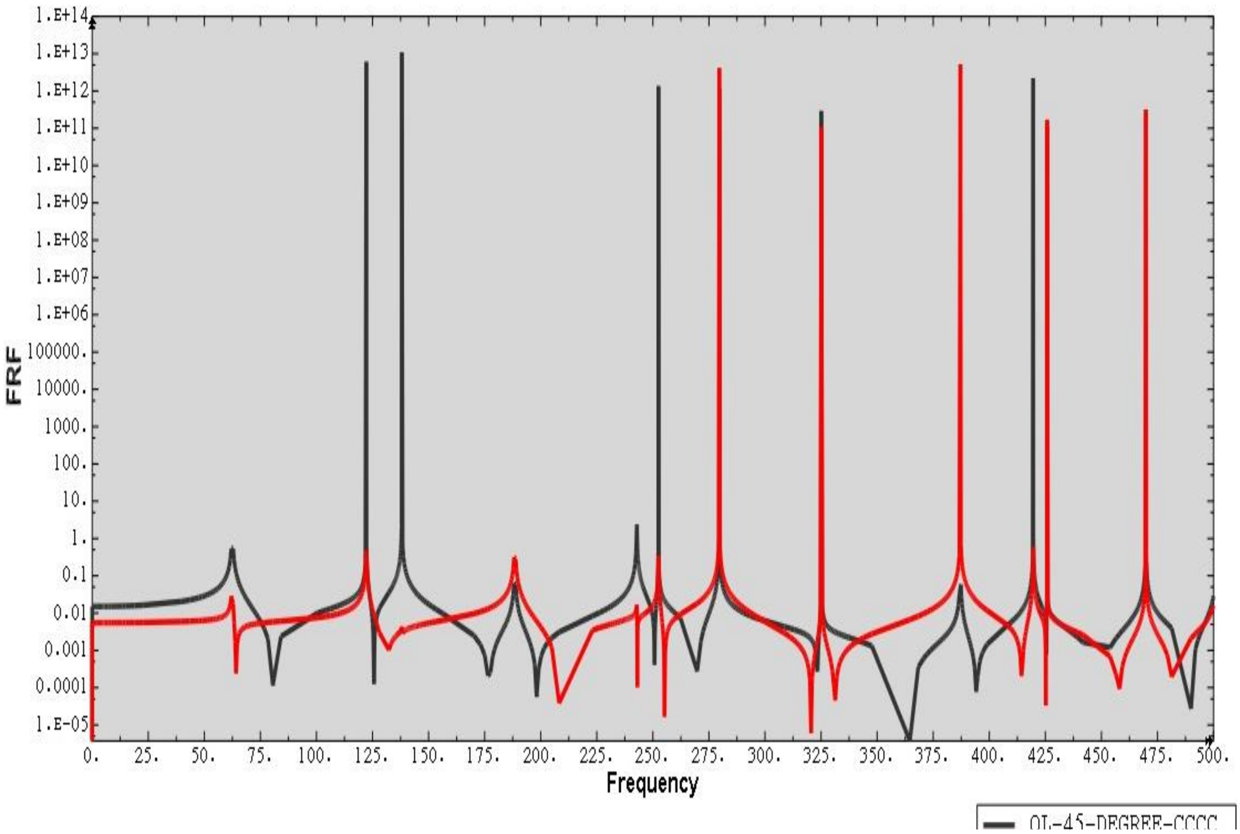


Figure 21 FRF for NOL and OL

10.1.8 Displacement Curve between Optimal Location and Non Optimal Location

The displacement curve describes location should not coincide with the nodal line where there is zero displacement. The non optimal location used for 45° composite optimal location for 0° composite plate. From curve it is clear that for non optimal location 3rd mode is not detected as this node coincide with the nodal line but for optimal location all the modes are detected.

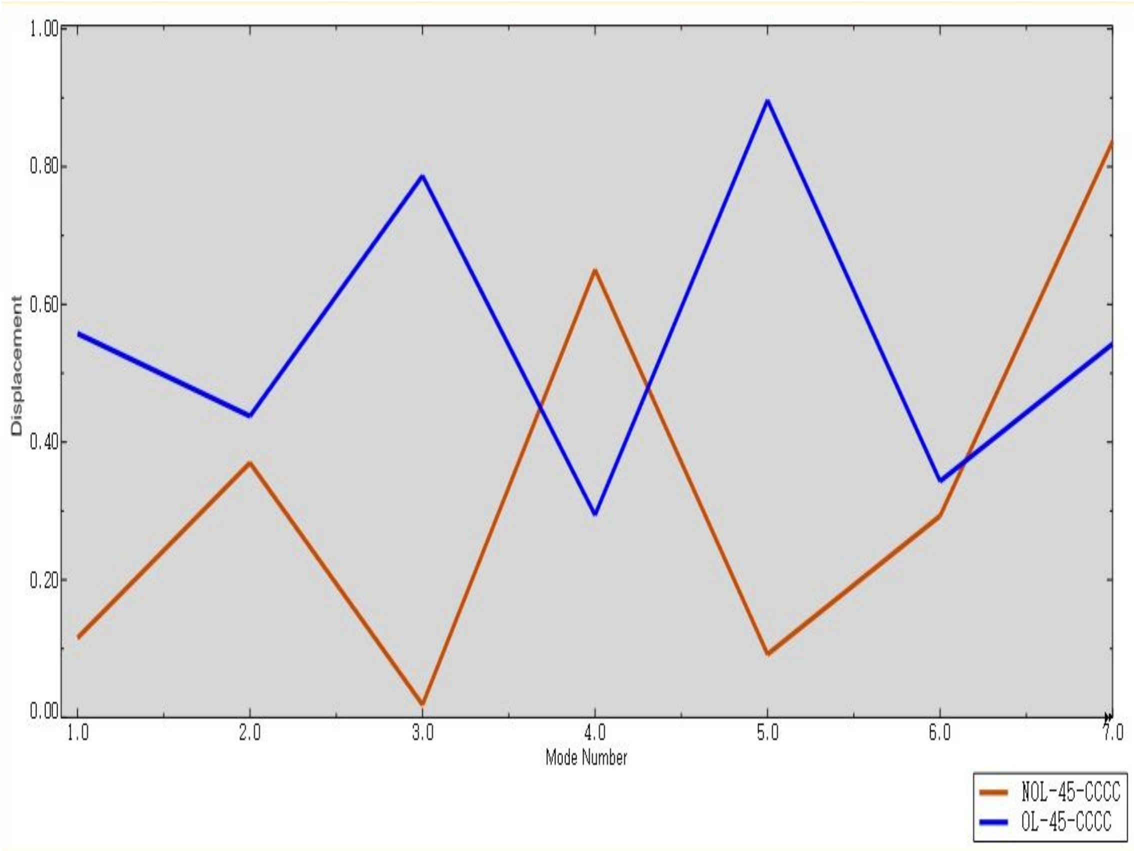


Figure 22 Displacement curve for NOL and OL

10.1.9 Modal Analysis of Composite Plate having same Dimensions as Experimental Specimen

Table 21 represents natural frequencies (Hz) for 0° and 45° glass-polyester beam

Mode No.	0°	45°
1.	33.084	27.32
2.	212.06	174.94
3.	621.15	512.66
4.	1308.1	1074.4
5.	2390.9	1955.5

10.2. Experimental Results and Discussion

As shown in the figure the beam is divided into 6 parts and 5 node points which are apart by 5cm each. 1*N is node where accelerometer was fixed which is in between the 1N and 2N.

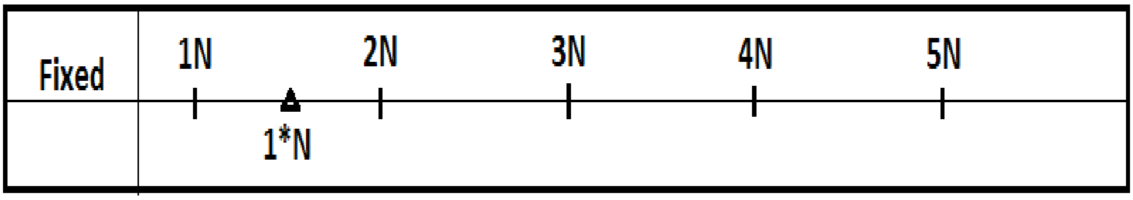


Figure 23 Top View shows different Node Points

10.2.1 FRF of 0° and 45° Composite Beam at 1st Node

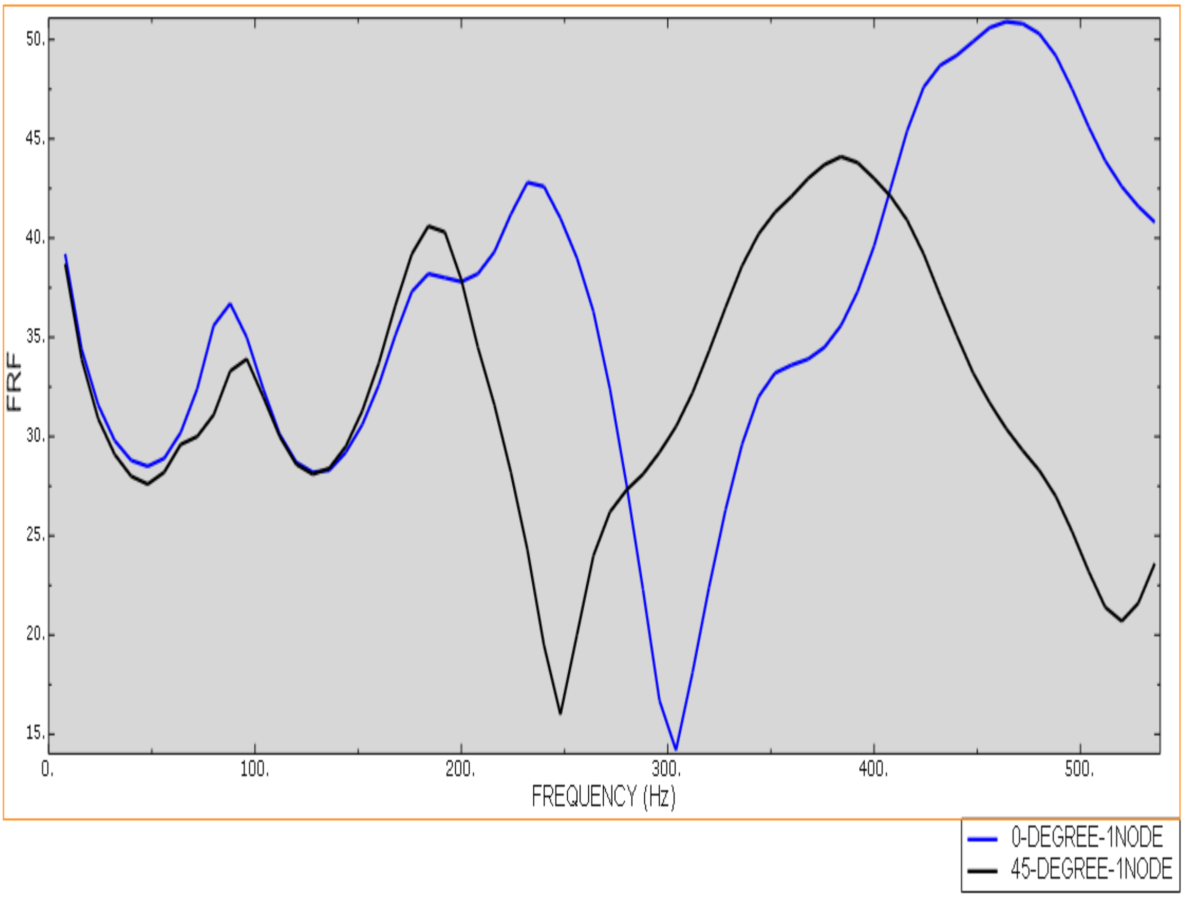


Figure 24 FRF curve for 0-Degree and 45-Degree composite beam at 1Node

10.2.2 FRF of 0° and 45° Composite Beam at 2nd Node

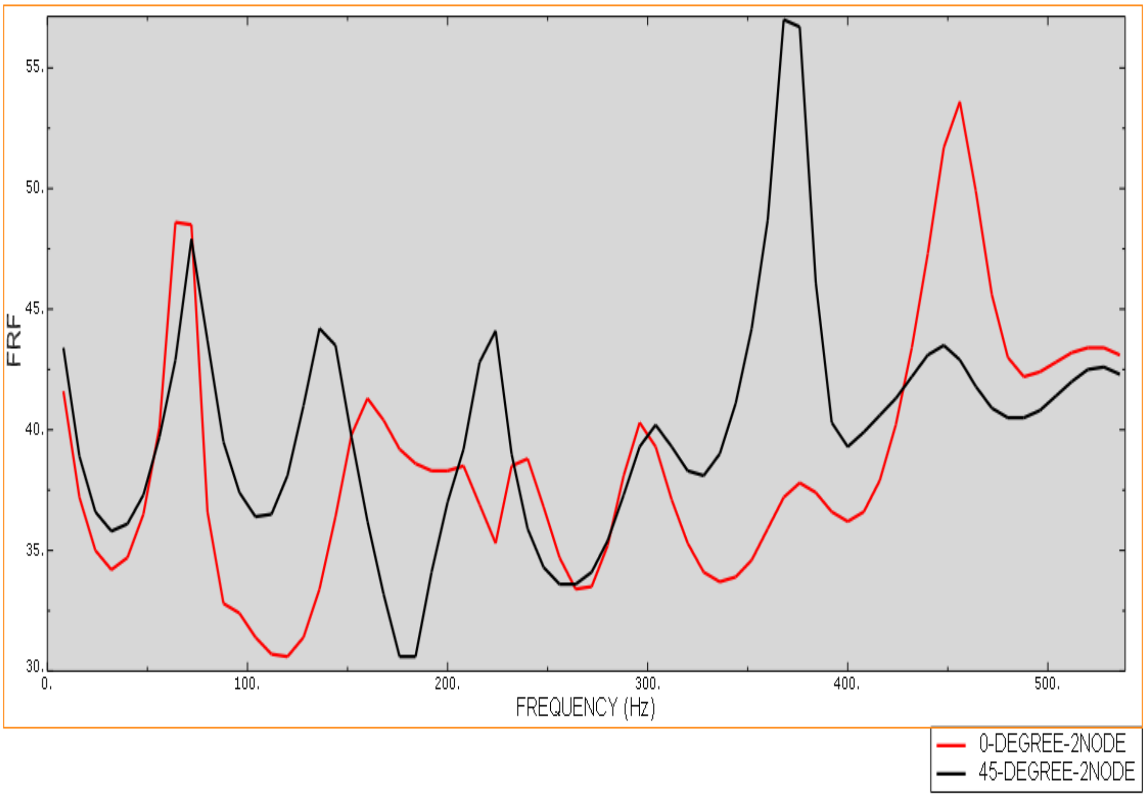


Figure 25 FRF curve for 0-Degree and 45-Degree composite beam at 2Node

10.2.3 FRF of 0° and 45° Composite Beam at 3rd Node

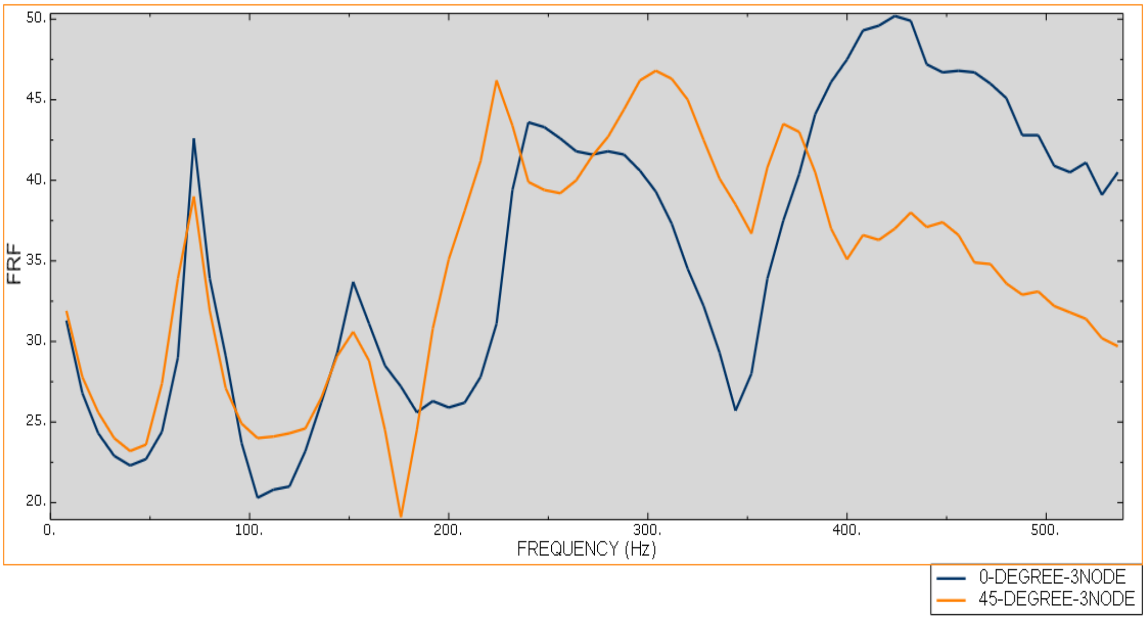


Figure 26 FRF curve for 0-Degree and 45-Degree composite beam at 3Node

10.2.4 FRF of 0° and 45° Composite Beam at 4th Node

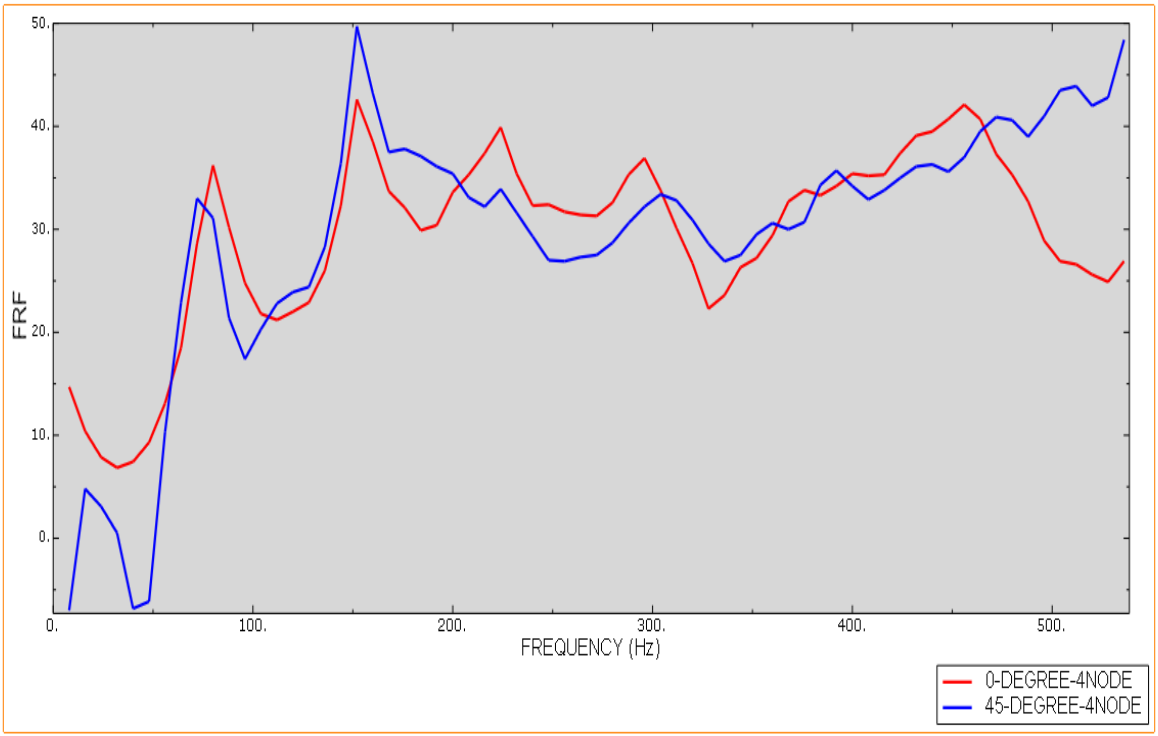


Figure 27 FRF curve for 0-Degree and 45-Degree composite beamat 4Node

10.2.5 FRF of 0° and 45° Composite Beam at 5th Node

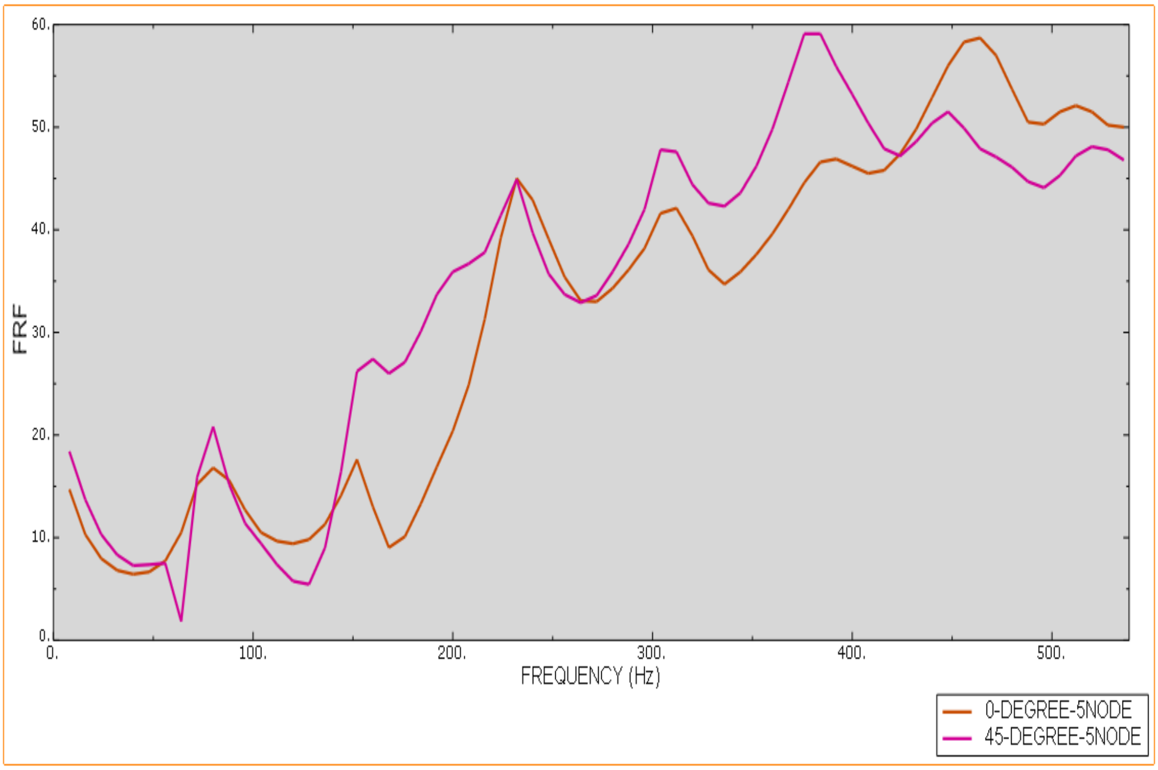


Figure 28 FRF curve for 0-Degree and 45-Degree composite beam at 5Node

10.2.6 FRF of 0° and 45° Composite Beam at 1* Node

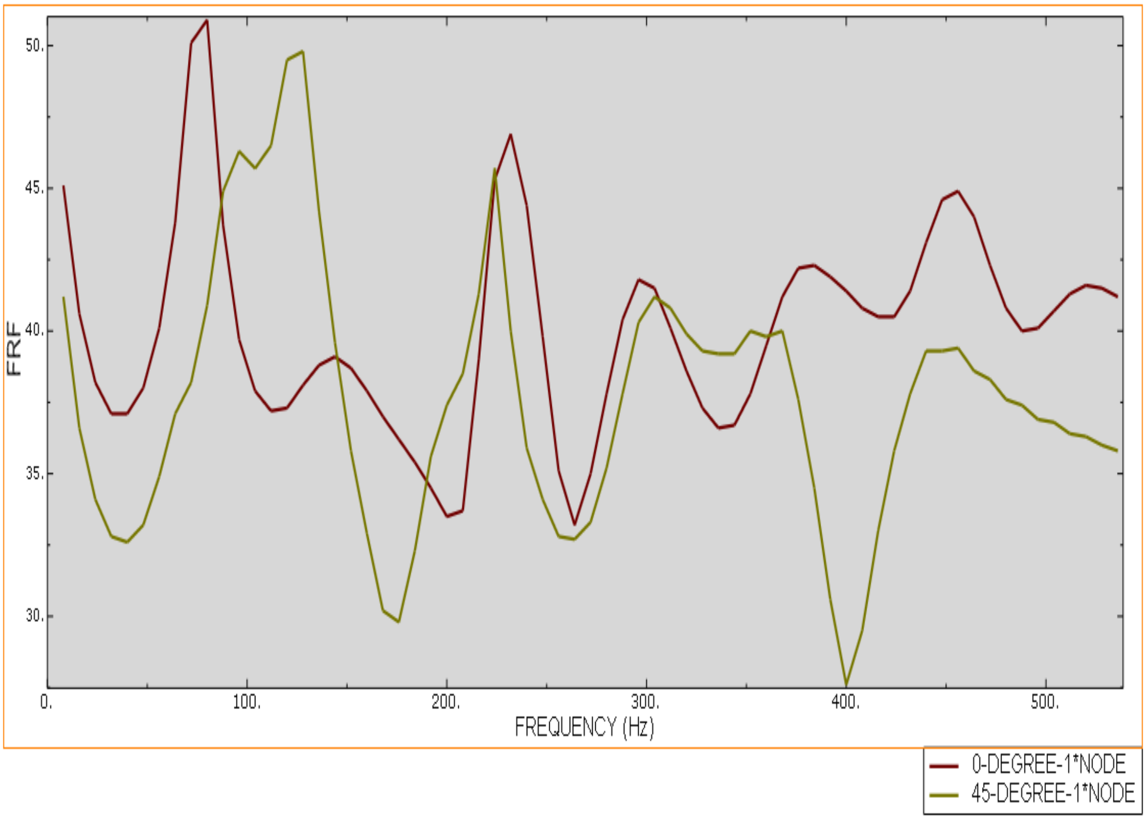


Figure 29 FRF curve for 0-Degree and 45-Degree composite beam at 1*Node

From the above FRF curve it is cleared that frequency for 0° composite beam is higher at each mode shape as compared to frequencies for 45° composite beam even the simulated results for same composite beam shows that the natural frequencies for 0° is higher when compared to 45° composite beam which were shown in Table 21. Experimental results and simulated results are following the same criteria for natural frequency, which defines results are well satisfying.

CHAPTER 11

SUMMARY AND CONCLUSIONS

- In this report, the natural frequencies and mode shapes was calculated using simulation software (ABAQUS) and compared with previous published research [3] for validation purpose.
- Well satisfying results comes out with percentage error of 0.506% when compared.
- After validation the procedure of calculating modal analysis of composite beam with piezoelectric patch in ABAQUS software was carried out.
- The choice of optimal location of piezoelectric patch on composite beam is proposed using the modal analysis.
- By viewing the different mode shapes for each location of piezoelectric patch, the optimal location of piezoelectric patch is estimated.
- The estimated location is near the boundary of the cantilever beam.
- It is seen that when the piezoelectric patch is located at the tip of the cantilever beam less strain produced in the patch. The effect is there is less change in the overall natural frequency of the system.
- When the piezoelectric patch is near the boundary of cantilever beam the natural frequency of the overall system is increased. It means the piezoelectric patch adds stiffness to the composite beam.
- Modal analysis of composite panel for different fiber orientation and under the different Boundary conditions is analysed.
- It is seen that the mode shapes and natural frequencies are affected with change in fiber orientations.
- Optimal location is proposed for each fiber orientation and under all the boundary condition by viewing the mode shapes.
- Results are validated through FRF and displacement curve.
- Manufacturing of composite material is done using Hand Lay Up method.
- Modal testing is done experimentally using experimental setup and m+p SO analyser.

- From the experimental results it clear that the natural frequency decreases when fiber orientation is changed from 0° to 45°, which is also happened in case of simulated results, hence the results are validated.

CHAPTER 12

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LIST OF PUBLICATIONS

[1] Optimal location of piezoelectric patch on composite structure using viewing method, *International Conference on Advanced Material Technologies* ***(ICAMT-2016)***, held in Visakhapatnam on 27th and 28th of December 2016.

[2] Modal Analysis of Composite Structure for different Fiber Orientation, International *Conference on Advanced Materials, Manufacturing and Applied Sciences* **(ICAMMAS-2017)**, held in Chennai on 28th and 29th March 2017.

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