Vibration Analysis of Cracked Hybrid Composite Plates using Experimental and Numerical Methods

A Thesis Submitted for Partial Fulfilment
of the Requirements for the degree of

Bachelor of Technology
in

Civil Engineering

By

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CERTIFICATE

This is to certify that project entitled "Vibration Analysis of Cracked Hybrid Composite Plates using Experimental and Numerical Methods" submitted by Sthitapragyan Nayak in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my personal supervision and guidance. To the best of my knowledge the matter embodied in this project review report has not been submitted in any college/institute for awarding degree or diploma.

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Acknowledgement

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ABSTRACT

Light weight composites have been successfully used in many engineering and aerospace applications. Nowadays, hybrid composites are replacing traditional composites because of their inherent advantages like higher strength to weight ratio, reduced cost, and improved resistance towards fatigue and impact loads, higher corrosion resistance etc. Hybrid composites are formed by the inclusion of different varieties of fibers into a specific matrix. The shortcomings of 1 fiber are balanced by the advantages of other, thus providing a perfect balance between economy and performance. Structural defects like cracks are inevitable in composite plates which reduces its strength and stiffness. Since most of the structures fail near their natural frequencies it is important to establish the vibrational behaviour of these structures accurately so as to prevent the phenomenon of resonance. The present study aims to establish above claims by using both experimental and numerical analysis for determining the natural frequencies of hybrid composite plates. The experimental values have been established by Modal Testing using FFT Analyzer. The results have been compared against the values of a Finite Element Package (ANSYS). Various parameters like length, depth, orientation, position of crack, boundary conditions as well number of layers of fibers have been varied to represent a true picture of the influence of local failures on natural frequencies. It has been observed that frequencies decrease with the increase in crack dimensions; increase in number of layers and the values are different for variable positions of crack. The attenuation of frequency is maximum when the crack is at the centre of the plate or when the angle of orientation is 90 degrees with respect to centre of plate. Comparison of experimental and numerical results have been represented in the form of bar charts to provide a better understanding about the dynamic behaviour of composites under the influence of local failures.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A composite is defined as a material formed by the combination of two or more unique materials, which retain their individual properties, to produce a new material having superior physical and mechanical properties compared to its constituents. Composite plates have wide range of applications in various fields. Aerospace engineering has extensive use of composites in mechanical parts like aircraft wings, satellites, rotor blades, spacecraft antenna etc. High strength to weight ratio, less susceptibility to brittle fractures, corrosion resistance, high impact strength, higher modulus of elasticity, dimensional stability, low thermal conductivity and absence of warping phenomenon make it a better alternative to steel and other alloys.

Hybrid composites are formed by the inclusion of different varieties of fibers into a specific matrix. The properties of these composites are the sum of the properties of its individual constituents. The main advantage of hybrid composites is that the shortcomings of one fiber are balanced by the advantages of other; as a result a proper balance between economy and performance is achieved. Some of the advantages of hybrid composites over traditional composites include higher strength to weight ratio, reduced cost, and improved resistance towards fatigue and impact loads.

1.2 Importance of Present Study

Plates in a structure are mainly subjected to transverse pressure and shear forces in the plane of the plate. Structural defects like cracks or delamination in composite plates are inevitable during the service life due to dynamic loading, corrosion effects, ageing, fluctuations in temperature, etc. The examination of dynamic properties of these cracked elements is of great interest due to its practical significance. Cracks on a plate reduce its local stiffness and therefore reduces its strength. Due to these causes, methods allowing early revelation and remedial measures for cracks are of prime importance for smooth-running and long life of machinery parts and structural elements. Most of the structures fail due to the occurrence of vibration at or near the natural frequencies. Hence it is imperative to estimate the vibrational behaviour of these structures accurately. Most of the previous studies were limited towards numerical methods for determination of natural frequencies of hybrid composite plates. Modal analysis is used in this study for analysing the dynamic behaviour of these composites. The method used is basically a non-destructive one. The results obtained from experimental work were compared with the results from numerical analysis and any alteration highlight the presence of local failure or cracks in the structure.

1.3 Outline of Present Research

The present research work is mainly concerned with the determination of natural frequencies of cracked hybrid composite plates (glass + carbon fiber). The study intends to get an accurate analysis for the vibrational characteristics of cracked plates involving a wide a range of parameters. The various parameters varied during the study were length of crack , orientation of crack with respect to centre of plate, position of crack, support conditions, thickness of plate and number of layers of the fibers. Experimental studies were conducted to determine the natural frequency under variable conditions. The results of the experiments are compared with the analytical values from FEM package ANSYS 13.0.

The thesis comprises of 5 chapters or sections. Chapter 1 highlights the topic and gives a deep insight into the significance and application of present work.

In Chapter 2, a critical discussion of the literature relevant to the works done beforehand in this area has been enlisted in detail. It also includes the aim and scope of present research work.

In Chapter 3, the mathematical equations along with the solutions of vibrational problems under external excitation have been presented in a detailed manner.

In chapter 4, the sequential steps for numerical analysis of hybrid composite plates using FEM package ANSYS has been described.

In Chapter 5, the methodology for casting of the specimen samples, tensile testing for determining the material characteristics and FFT analysis of the cracked specimens have been outlined.

In Chapter 6, the results obtained from modal analysis have been presented. The effects of variation of parameters like length, depth, orientation of crack etc have been presented in a tabulated manner. The results of ANSYS software have also been presented so as to have an idea about the variation of results from the experimental values.

In Chapter 7, the conclusions drawn from the results obtained in the previous chapter have been enlisted along with the inferences drawn.

In chapter 8, the scope for further research on this area has been pointed out.

In chapter 9, all the references used for understanding the concepts and obtaining knowledge on this topic are provided.

CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

The presence of dynamic loads on a structure justifies the reason of finding out the natural frequency of a structural element in order to avoid the possible occurrence of resonance. Local failure in a plate reduces its damping capacity, local stiffness and therefore reduces its strength. Therefore, methods allowing early revelation and remedial measures for cracks are of prime importance for smooth-running and long life of machinery parts and structural elements. FFT analysis is a powerful technique used for the analysis of stiffness of structures. Thorough inspection of the literature was done so as to obtain an in-depth knowledge about the subject matter and to throw light towards the priority of present study. Very few papers have associated experimental methods for understanding the behaviour of natural frequency of plates. Few research papers have made use of analytical softwares like ANSYS, ABACUS in their studies, thus providing scope for ample research.

2.2 Vibration of Hybrid Composite Plates

Jang *et al.* (1989) analysed the resistance under impact loads and energy dispersion under velocity impact loads. Scanning electron microscope was used to study the changes at microscopic level. Begley *et al.* (1995) analysed fatigue crack growth in metal matrix composite materials using numerical methods. They predicted growth curves concerning fiber failure for specimens of precise width. Functions for maximum fiber stresses in the bridged zone were presented here for a centre crack in tension and edge cracks in tension and bending. Lee and Kim (1995) experimented on non-linear vibrational analysis of hybrid composite plates using Langrangian equation. The influence of stacking sequences, varying aspect ratios, number of modes, number of layers and elastic properties on the nonlinear vibration behaviour was investigated. The results were compared with ABAQUS ans FEM analysis. Chen and Yang (1996) studied multilayered FEM analysis of laminated composites with lamination cracks resulting from transverse cracking. Hardayi *et al.* (1998) studied the static behaviour of composite plates with minor cracks under simply supported conditions using Ritz method. A second local analysis was used in which a small region in the proximity of the crack and covering other singular points was discretized using a finite element mesh.

Naik and Ramasimha (2001) studied the impact response and damage tolerance properties of glass carbon hybrid composite plates. Instrumented drop weight impact test apparatus was used to execute experimental analysis. Hwang *et al.* (2001) predicted the failure of delaminated interply hybrid composite plates subject to compressive load. Non-linear buckling and post-buckling analysis were conducted to anticipate the buckling load and growth load of delaminated composites. Avci and Sahin (2006) applied first order shear deformation theory for the analysis of symmetric and antisymmetric cross-ply laminated hybrid composite plates with an inclined crack subjected to thermal loading. The eight-noded Lagrangian theory was used for deriving the thermal buckling temperatures of laminated hybrid composite plates. Bambole *et al.* (2007) used a 27-node three-dimensional hexahedral hybrid-interface finite element (FE) model to study behaviour of thick laminated composite plates using the theory of minimum potential energy. Chen *et al.* (2009) analysed the stability of laminated hybrid composite plates subjected to uni-directional axial and flexural stress of periodic nature using Galerkin's method with reduced eigen functions transforms. Kar and Nutt (2011) experimented on bending and fatigue properties of hybrid composite rods. The rods were made of a combination of glass an carbon fiber. Examination was done a macroscopic level to identify failure propagation. Weibull theory was applied to evaluate the probability of damge. Hong *et al.* (2012) focussed on the damping behaviour of composite blade using principle of Rayleigh damping. The damping test was carried out to validate the hybrid method. The influence of orientation of fiber and order of stacking on the damping studies were studied. Burks and Kumosa (2012) analysed the static and dynamic behaviour of hybrid composites under thermal loading. It was concluded that temperature near the transition temperature reduced the bending strength of member. Senyer and Kazanci (2012) investigated nonlinear dynamic responses of a laminated hybrid composite plate subjected to time-dependent pulses using Galerkin's method and a MATLAB software code written to solve nonlinear coupled equations by using the Newmark Method. Cuadra *et al.* (2013) studied damage characteristics in polymer composites using a non-destructive approach. Abeysinghe *et al.* (2013) investigated the dynamic behaviour of Hybrid Composite Floor Plate System using experimental and numerical analysis (FE modelling). Investigations were conducted by applying the FE model to understand the dynamic nature of the hybrid plate system and to classify characteristics that affect acceleration of structure under service loads. Lau (2013) researched on the applications of FRP composites in structural engineering. Murugan *et al.* (2014) researched on static and dynamic behaviour of woven fabric glass/carbon hybrid composites as per ASTM regulations. The effect of stacking order of laminates on the physical properties was discussed. Samadpour (2015) analysed vibration characteristics of hybrid composite sheets using Galerkin's weighted residual method in hygrothermal conditions. Assarar *et al.* (2015) evaluated damping characteristics hybrid carbon flax composite plates. Vibrational behaviour was studied using beam test and impulse methods. A model for damping was prepared by using FEM technique to calculate dispersion energy in each layer.

2.3 Aim and Scope of Present Study

The present study is aimed to analyse the dynamic behaviour of hybrid composites (glass + carbon fiber) by introducing the finite element package ANSYS along with experimental methods. Experimental work in the Structural lab was carried out to determine the natural frequency under different variable conditions. The outcomes of these experiments were compared with the analytical values from FEM package.

The study intends to incorporate the following tests to get an accurate analysis for the vibrational characteristics of cracked plates involving a wide a range of parameters.

1) Young's Modulus and other material constants were calculated using tensile testing.

2) Modal testing using ANSYS

The factors which are varied include:

a) Length, depth, orientation, position and mode of propagation of crack

b) Support conditions

c) Thickness of plate.

FEM software ANSYS was used to observe the variation of these factors on the natural frequencies.

CHAPTER 3

MATHEMATICAL FORMULATION

3.1 Shell 281 Element

Shell 281 Element has 8 nodes with 6 degrees of freedom at each node. This element is used is linear and non-linear structural as well as acoustic analysis. The theory is influenced by shear deformation theory of first order.

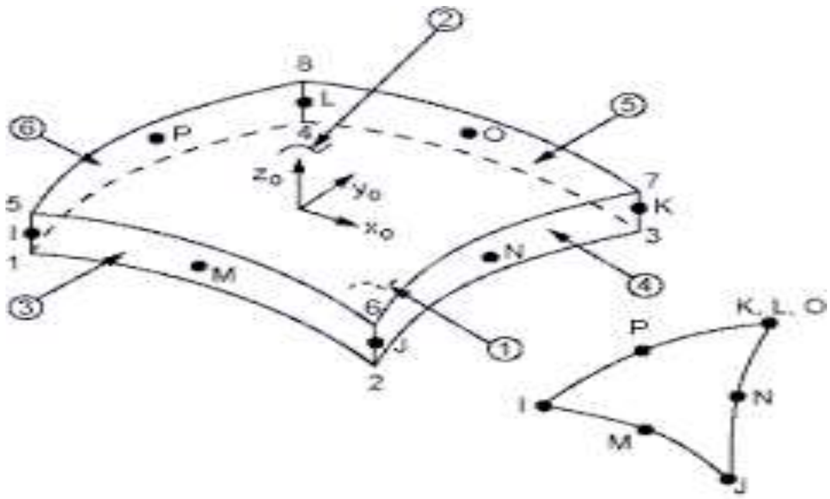


FIGURE 1: SHELL 281 ELEMENT

3.2 Governing Equations

$$A(X, Y, M) = A_0(X, Y) + M\Theta_X(X, Y)$$

$$B(X, Y, M) = B_0(X, Y) + M\Theta_X(X, Y)$$

$$C(X, Y, M) = C_0(X, Y) + M\Theta_X(X, Y)$$

The shape functions for eight-noded shell element are as stated:

$N_1 = \frac{1}{4}(1-e)(1-p)(-e-p-1)$

$N_2 = \frac{1}{4}(1+e)(1-p)(e-p-1)$

$N_3 = \frac{1}{4}(1+e)(1+p)(e+p-1)$

$N_4 = \frac{1}{4}(1-e)(1+p)(-e+p-1)$

$N_5 = \frac{1}{2}(1-e^2)(1-p)$

$N_6 = \frac{1}{2}(1+e)(1-p^2)$

$N_7 = \frac{1}{2}(1-e^2)(1+p)$

$N_8 = \frac{1}{2}(1-e)(1-p^2)$

The strain vector in terms of displacement vector is as follows:

$\{e\} = [B]\{\partial\}$,

CHAPTER 4

EXPERIMENTAL PROGRAMME

The experimental programme inculcates the procedural steps for fabrication of composite specimens, tensile testing of specimen and vibration te4sting using FFT analyzer.

4.1 MATERIALS REQUIRED FOR FABRICATION

1. Carbon and Glass fiber (reinforcement)
2. Epoxy (resin) (matrix)
3. Hardener (generally 8-10% x quantity of epoxy) (matrix)
4. Polyvinyl Alcohol (PVA) (releasing spray)

4.2 FABRICATION PROCEDURE

The composite specimens were casted using Hand-Layup method. Matrix element epoxy was applied along with carbon and glass fiber. The ratio of fiber and matrix was taken in the ratio of 1:1 by weight where matrix constituents comprised of resin and hardener. The fabrication of plates was done as per ASTM-D5678M-07. The calculation of the quantities of epoxy and hardener is shown in the following table. After placing each layer, matrix was applied uniformly above each layer. Any air which may be present in the voids was removed using steel rollers. After the completion of the process, plastic sheet was provide on the top and bottom layers by applying PVA as releasing agent. Finally two wooden boards were provided on the top and bottom. A heavy weight was kept on the top board and the specimens were kept at room temperature for a minimum period of 48 hours. After that they were cut to the exact dimensions of 235x235mm and taken for tensile testing.

4.3 CALCULATION OF QUANTITIES OF MATRIX CONSTITUENTS

Weight of glass fibers + carbon fibers (4 layers each): 193 g

Wt. of matrix (epoxy + hardener) = 193 g

Wt. of hardener = 8% x quantity of epoxy

Let E= wt. of epoxy, H= wt. of hardener.

H =0.08 x E

- E + H = 193

$\Rightarrow$ E + 0.08 x E = 193

$\Rightarrow$ E = 193/1.08

$\Rightarrow$ E = 178.7 g H = 193-178.7 = 14.3 g

Wt. of Epoxy =178.7 g

Wt. of hardener=14.3 g

Figure 2: Hand Lay-Up Technique

4.4 DETERMINATION OF ELASTIC CONSTANTS

The material properties of the specimen were determined using tensile testing. First of all, a hybrid plate of dimensions 30cmx30cm was casted using hand lay-up process. It was then cut into standard dimensions of 25cmx5cm for testing using diamond cutter. The guidelines for the testing procedure are given in ASTM-D3039 M-08.The sample specimen were tested using INSTON 1195 UTM machine. The rate of loading/extension was kept constant at 2mm/min. Specimens were first fixed in the top jaw and later in the bottom jaw. The gauge length was kept 50mm. Load cell and extensometer were respectively used for measuring the load and extension.

Table 1: Material properties of the fabricated sample plate

Sl. No.	**No. of layers of fibers**	**Length of plate (m)**	**Width of plate (m)**	**Thickness of plate (m)**	**Mass of plate (in gram)**	**Density of plate (kg/m^3)**
1	8	0.235	0.235	0.003	193	1291.69

4.4.1 Machine specifications

Sample rate (in pts. / Sec) – 4.55

Speed of cross head (in mm/min) – 1

Full Scale Range of Load (kN) – 50

Type of sample –ASTM

Humidity– 50%

Temperature (ºC)-27

Figure 3: Instron 1195

Figure 4: Control and Display Unit **Figure 5: Tensile Testing**

RESULTS

E1=E2=11200 MPa

The value of Poisson's ratio is taken as 0.25

4.4.2 Calculation of quantities of epoxy and hardener for tensile testing

SIZE OF SPECIMEN= 250X25X3mm

Weight of glass fibers + carbon fibers (4 layers each): 152 g

Wt. of matrix (epoxy + hardener): 152 g

Wt. of hardener = 8% x quantity of epoxy

Let wt. of Epoxy = E, wt. of hardener = H.

H = 0.08 x E

- E + H = 152

⇒ E + 0.08E = 152

⇒ E = 152/1.08

⇒ E = 141 g H = 152-141 = 11 g

Wt. of Epoxy used = 141 g

Wt. of Hardener used = 11 g

4.5 EQUIPMENTS REQUIRED FOR VIBRATION TESTING

- Modal hammer
- Accelerometer
- FFT Analyser
- Pulse software

❖ **Modal Hammer:** The initation of Modal testing was done by exciting the specimen with the help of a modal hammer (Model No. - 2302-5). As a consequence of this, the Plate vibrated at its ‘natural frequency’.

❖ **Accelerometer :**(B&K Type 4507) Accelerometer is the equipment connected to sensor i.e. it senses the frequency of vibration of the plate and conveys it to FFT analyser.

❖ **FFT Analyzer:** FFT analyser receives the signal from Accelerometer and is the primary device of this vibration setup. The signal is transferred to the computer which displays the Frequency Response Function (FRF) through the pulse software.

FIGURE 6: Vibration Testing Apparatus

4.5.1 Experimental Set-up and Test Procedure for Vibration Testing

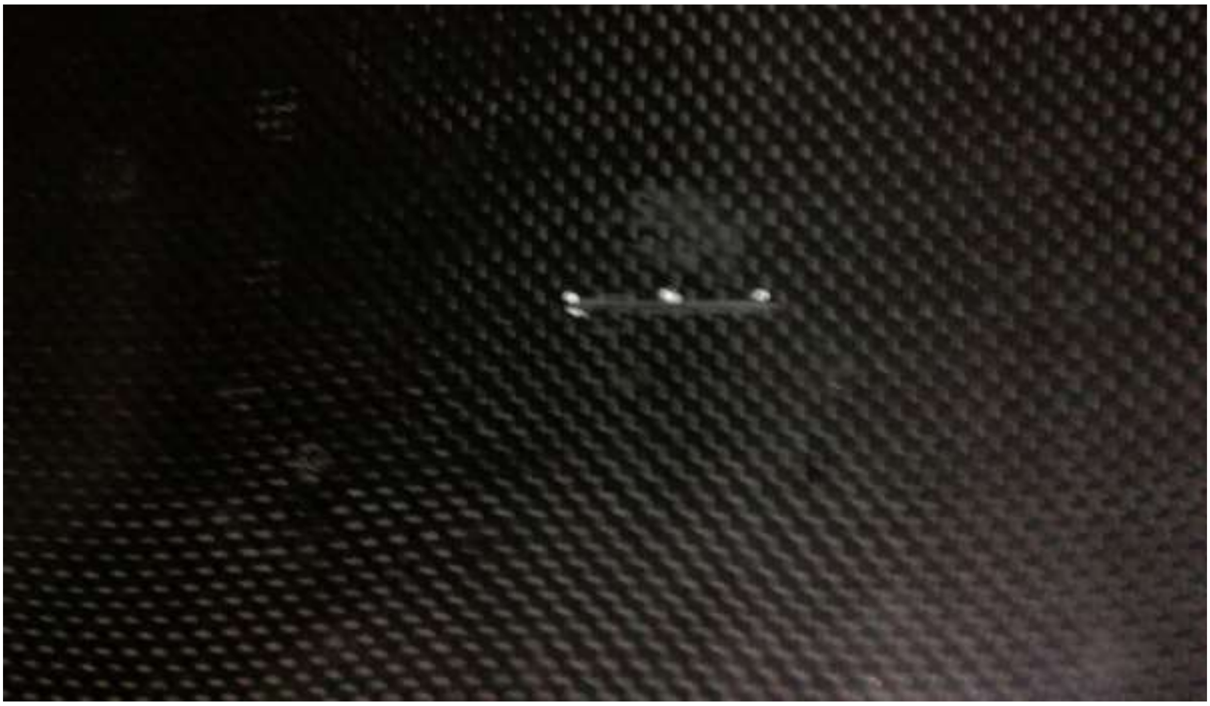
The connections of FFT analyzer, transducers, modal hammer and cables to the system were done as per specifications. The pulse software key was inserted to the port of laptop. At 2 or 3 points the modal hammer was hit five number of times and the average output of the Frequency Response Function was displayed on the laptop screen through the PULSE software. The hammer was struck perpendicular to the plates and care was taken not to hit the plate too hard. The plates were placed as per requisite end conditions. The different boundary conditions used in the analysis were:

1) All four sides free (FFFF)
2) Two opposite sides simply supported, remaining two sides free (SFSF)
3) One side clamped and other 3 sides free (CFFF)
4) Two opposite sides clamped, other two sides free (CFCF)

FIGURE 7: CFFF CONDITION

FIGURE 8: SFSF CONDITION

FIGURE 9: CFCF CONDITION



l= 0.1L= 23.5mm, d=1mm

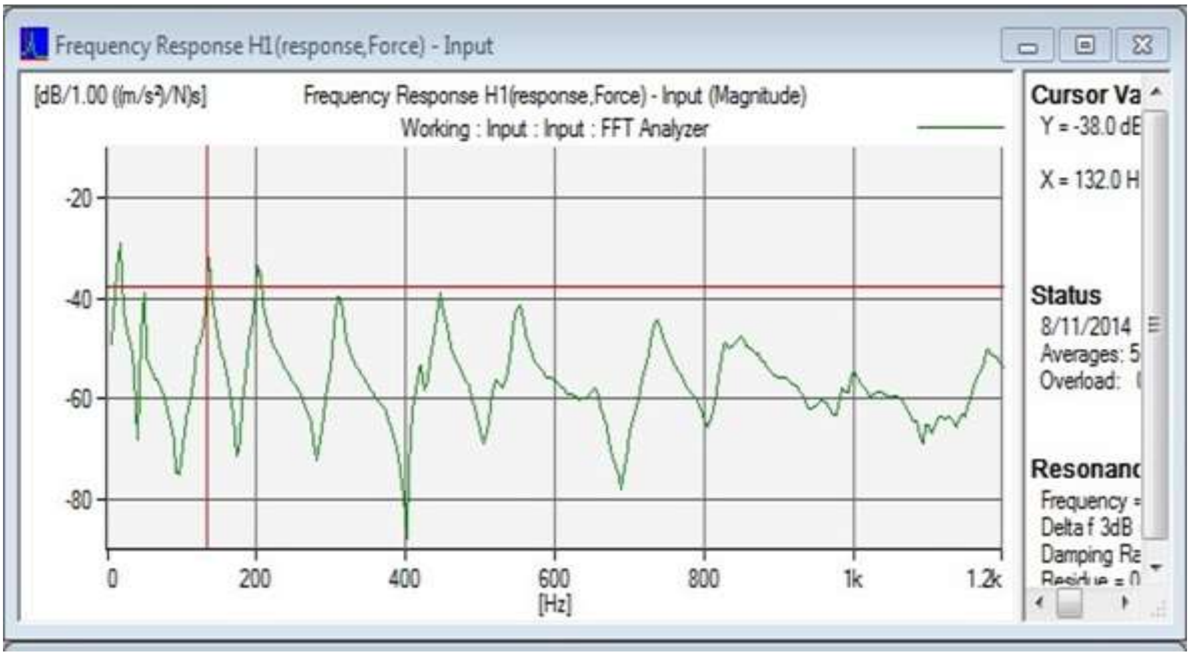


FIGURE 10: LOCATION OF CRACK AND FREQUENCY RESPONSE FUNCTION

CHAPTER 5

MODELLING USING ANSYS 15.0

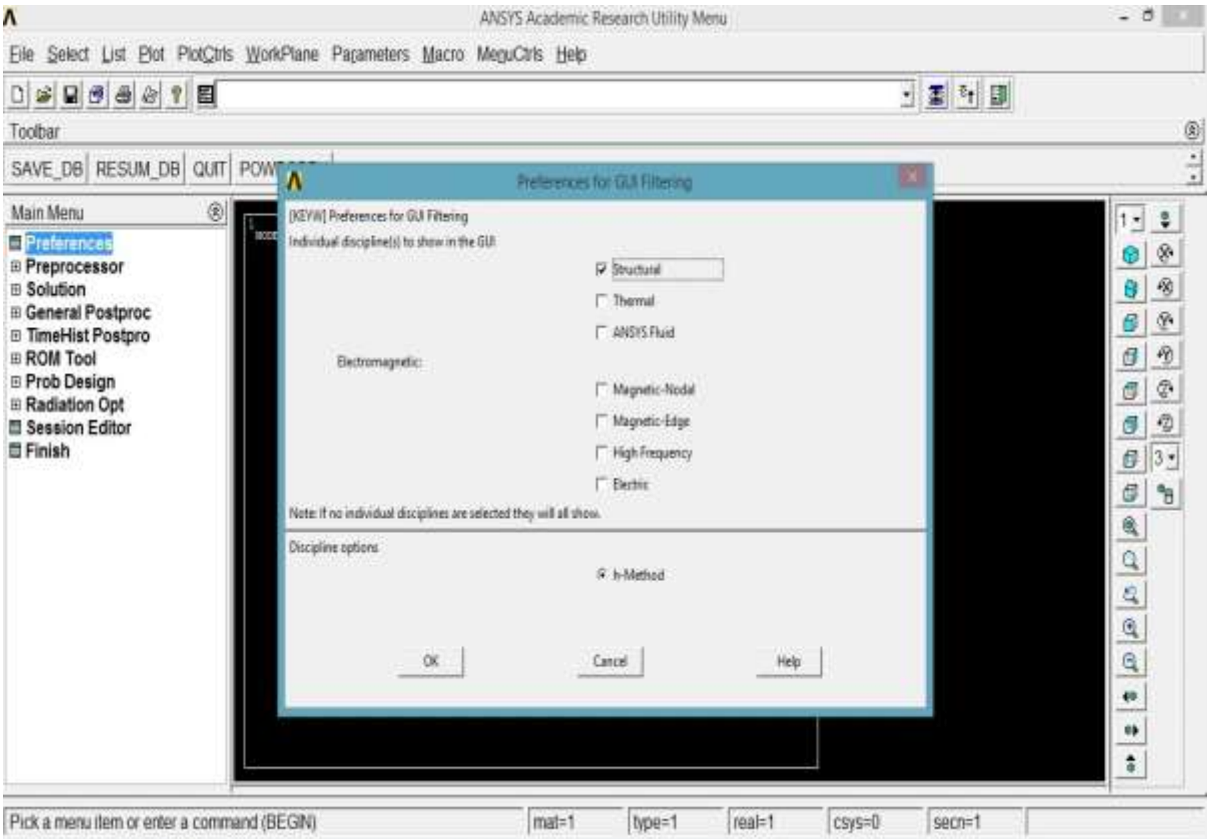
5.1 ANSYS MODEL

ANSYS software is a Finite Element Package which can be used to study static/dynamic structure analysis, electromagnetic problems and heat transfer and fluid analysis.

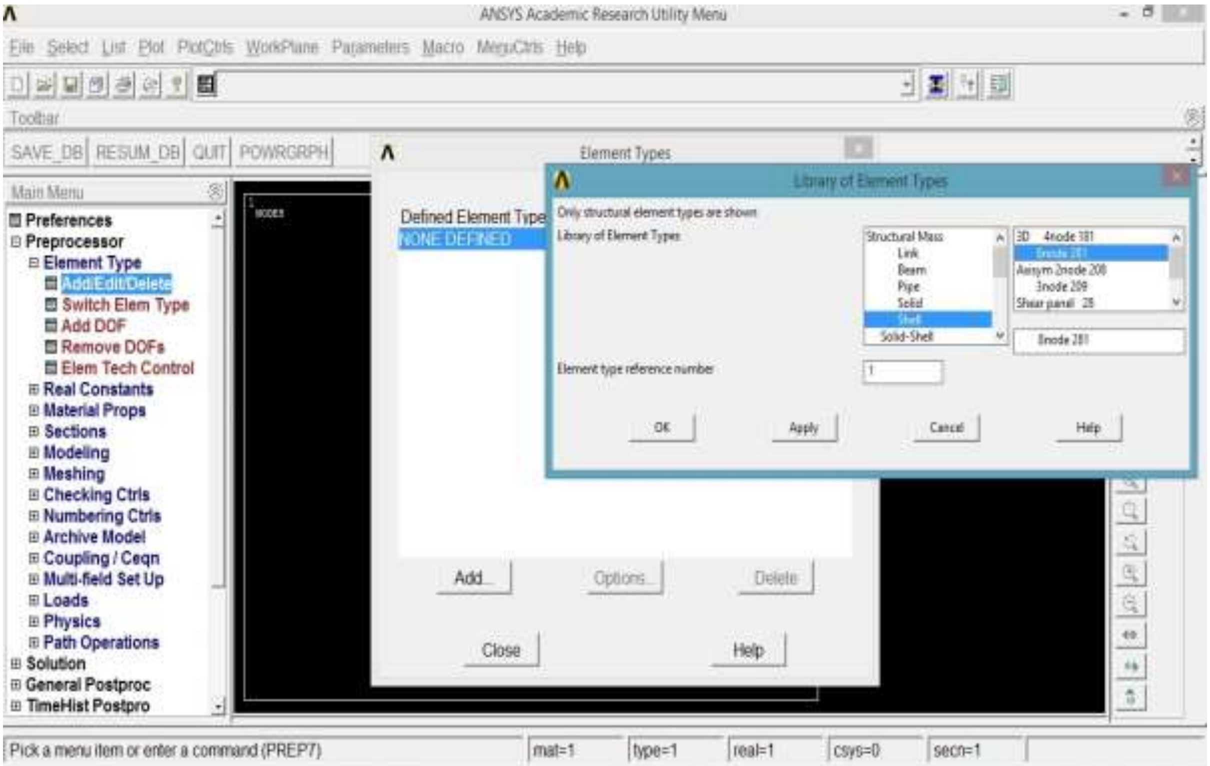
The type of element used is SHELL 281 which is an 8 noded shell element. The element has 8 nodes with 6 degrees of freedom at each node. Meshing was done by dividing the whole domain is divided into 8x8 meshes. The boundary conditions of CCCC, CSCS, SSSS and CFFF were introduced by appropriate end conditions. FFFF condition was simulated by limiting displacement of the plate in vertical direction along the plane of plate. This is because the plate was hung vertically by strings of negligible stiffness.

5.2 Steps of ANSYS Modelling

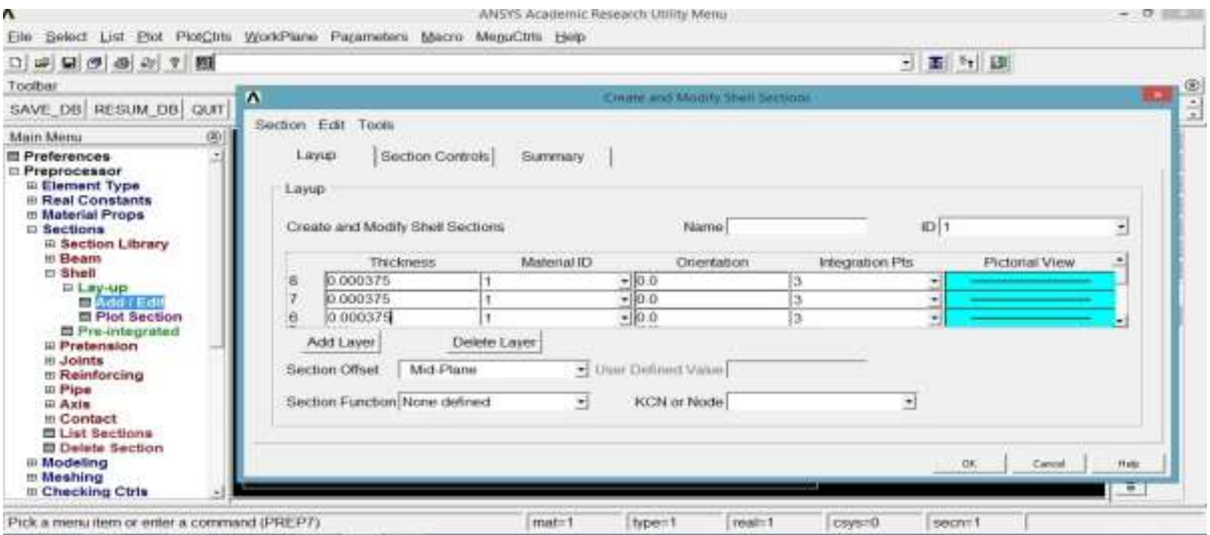
- Go to Preferences ->Then Structural ->Click on Ok



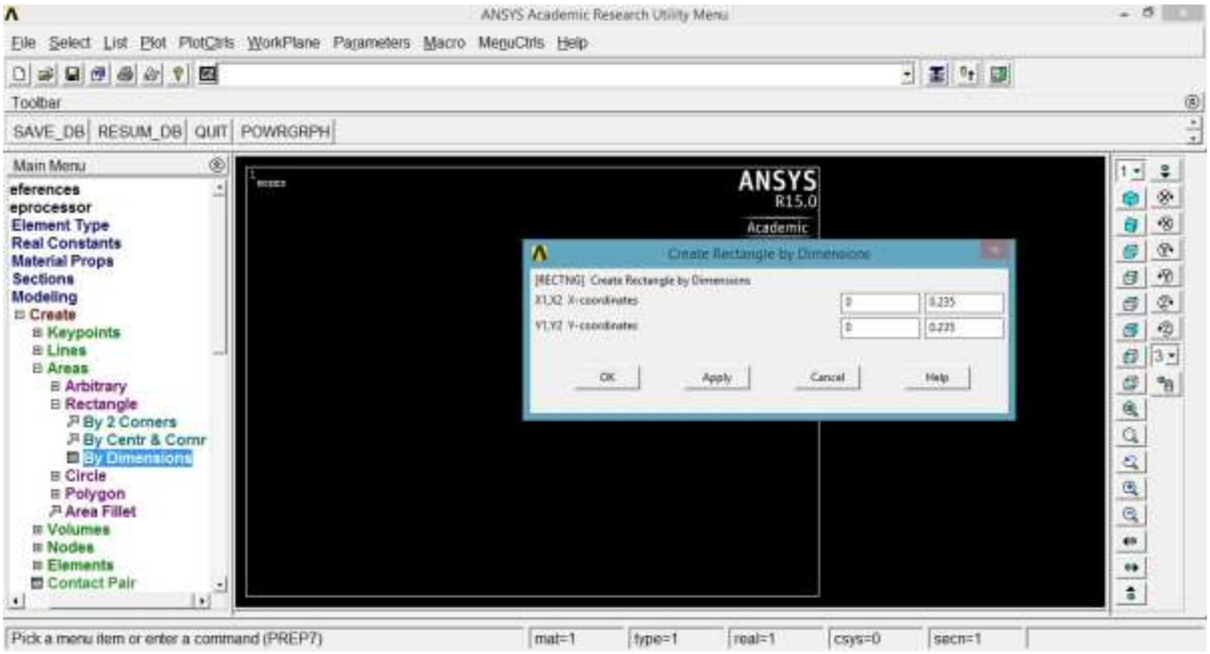
- In the next step go to Preprocessor -> Select Element Type -> Select Add/Edit/Delete -> Choose Add option ->Select Structural Mass ->next option is Shell ->Take 8node 281 ->Choose Ok



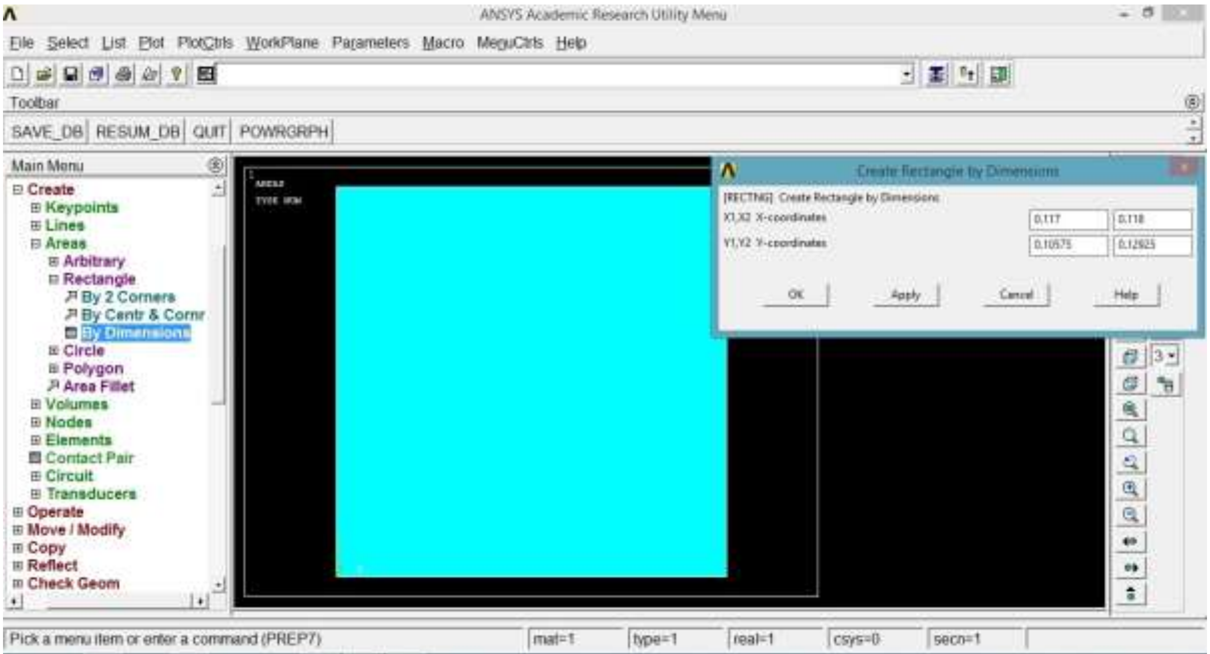
- Next step is Preprocessor ->Click on Material Props ->Choose Material Models ->Click on Structural ->Select Linear ->Then Elastic ->Then Isotropic ->For the material taken enter material properties ->Click on Ok
- The next step that follows is Preprocessor ->Take the option Sections ->Then Shell ->Click on Lay-up ->Choose the option Add/Edit ->Give no. of layers as 8 and thickness of each layer as 0.000375m ->Next prefer Ok



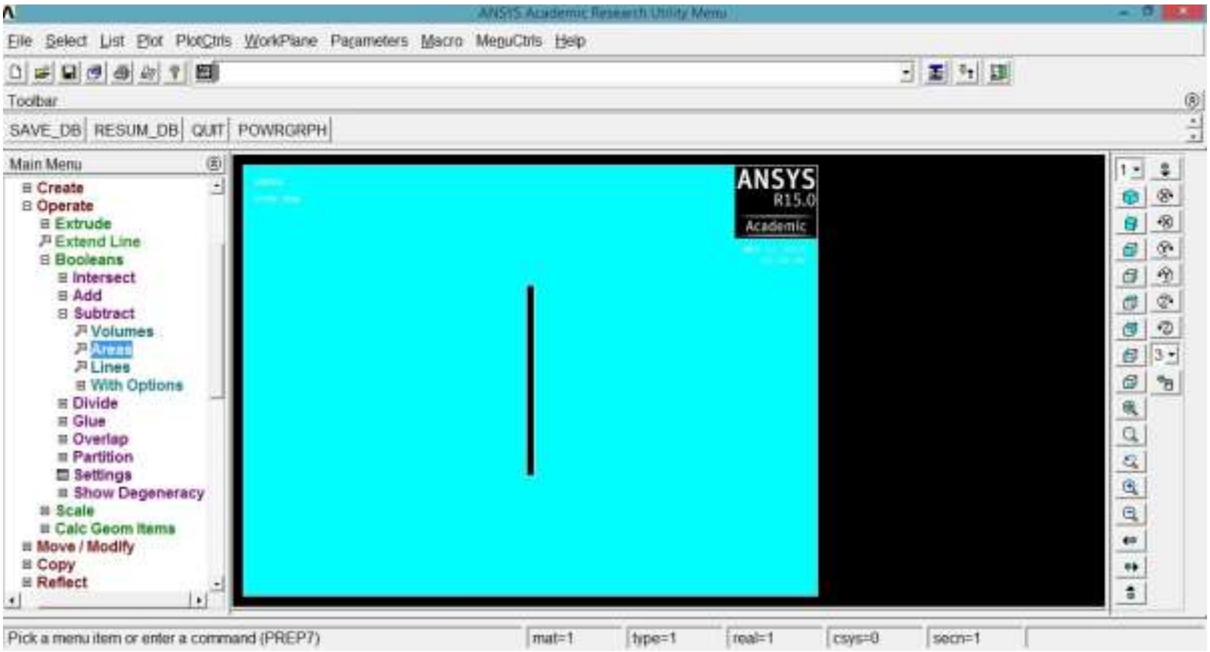
- The subsequent step is to select Preprocessor -> Select Modelling ->Choose Create option ->Click on Areas ->Since plate is rectangular take the option Rectangle -> Take 'by dimensions' option ->Input the Size of the composite specimen ->Choose ok



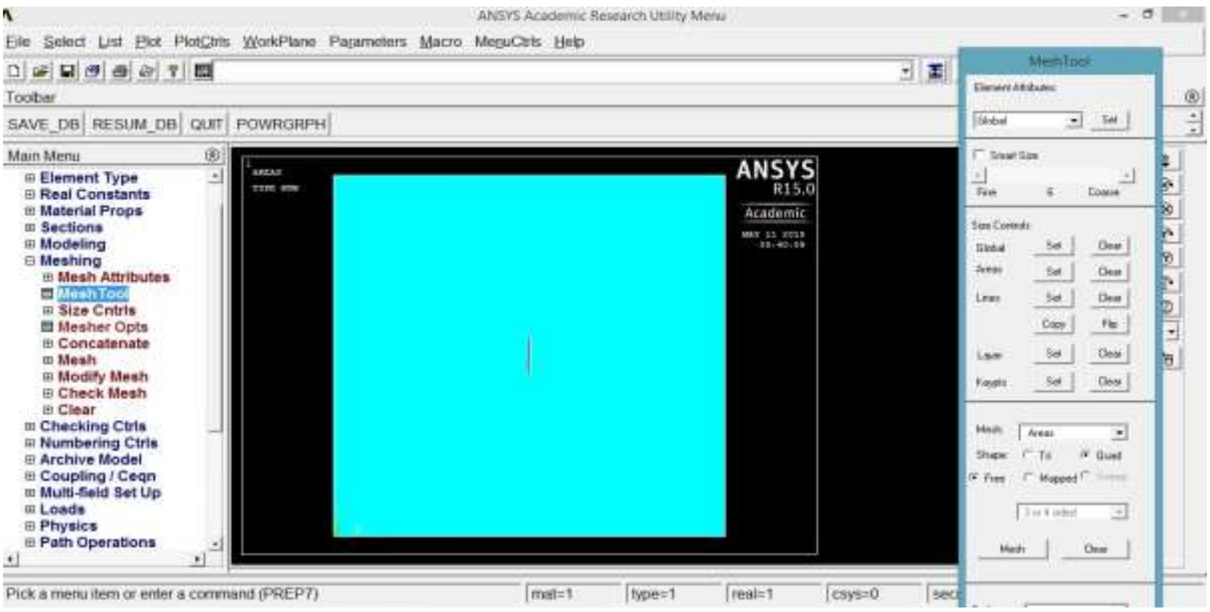
- Form a crack of required dimensions at the central location of the specimen



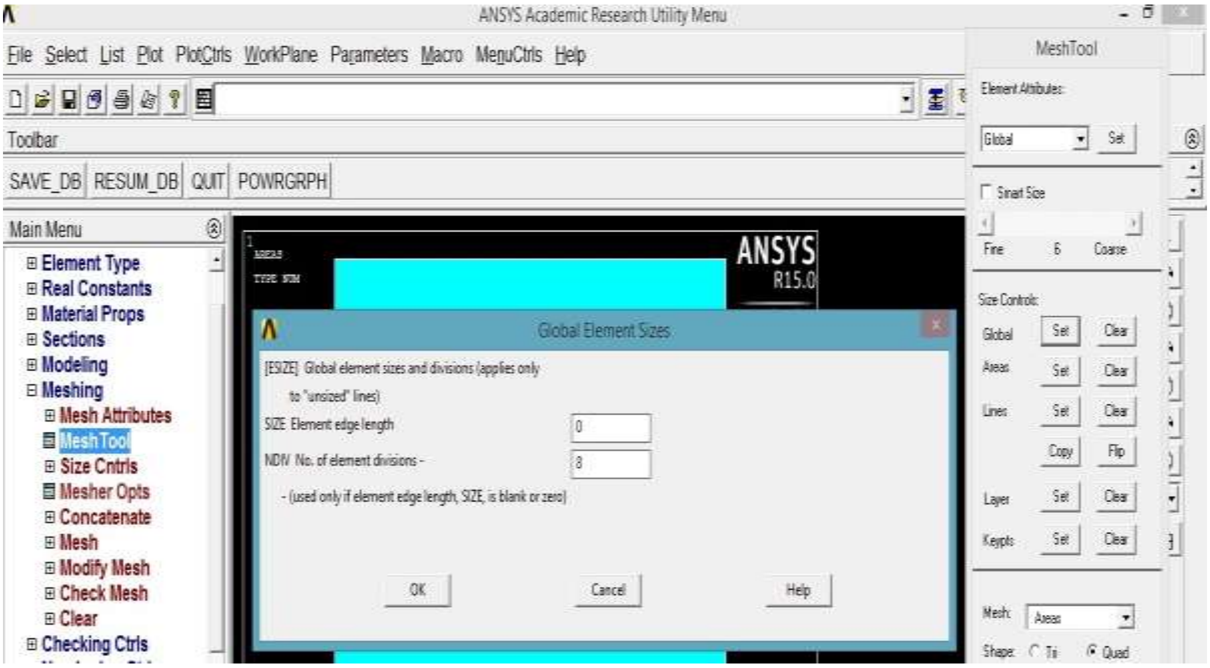
- The next step is to select Preprocessor ->Go to Modelling ->Choose Operate ->Select Boolean Operation ->Select Subtract -> Click on the Areas option -> Input 1 ->Select Ok -> Input 2 -> Prefer Ok



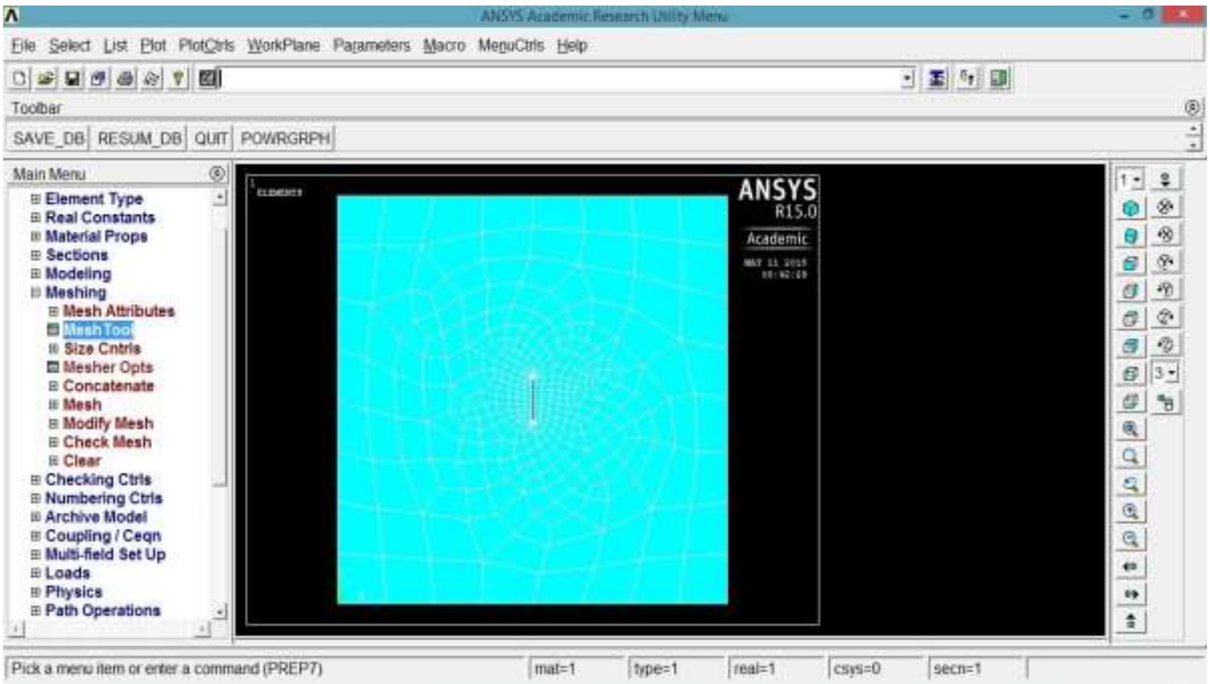
- For ,Meshing operation go to Preprocessor ->click on the Meshing button ->Perform meshing operation by clicking on Mesh Tool



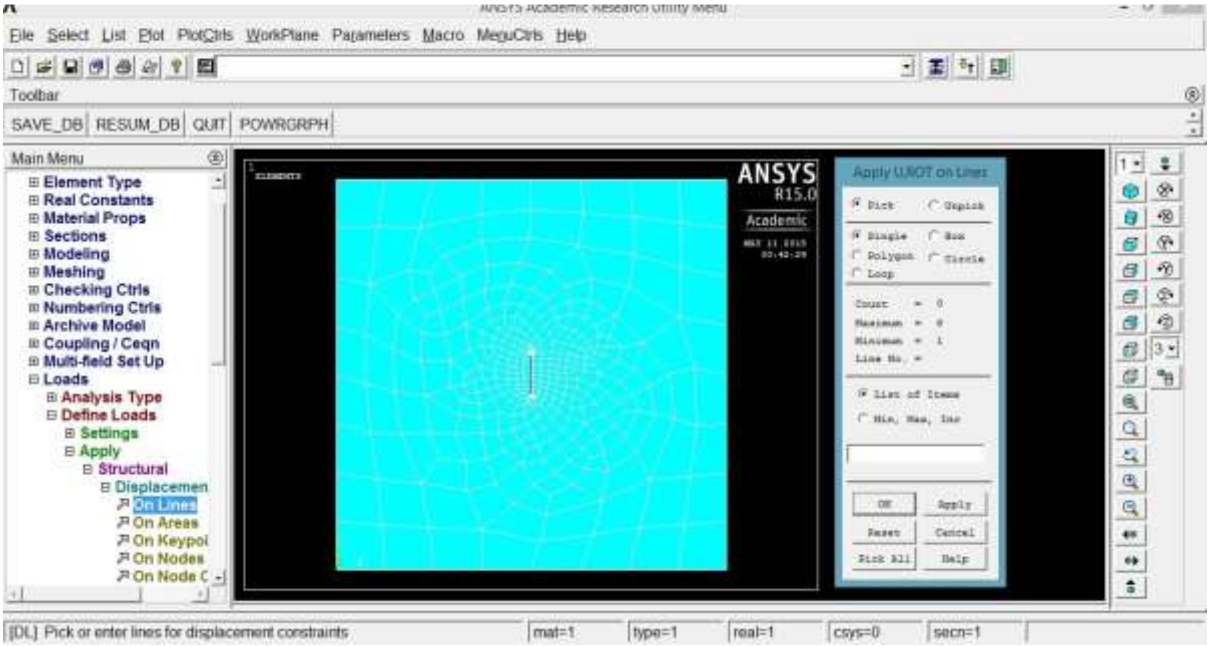
- Go to Mesh Tool ->Give the meshing type to be Global in Size Controls -> Now go to the option ‘Global’ and then ‘Set’-> Input the no. of times in which the element is to be divided as 8 -> choose the Ok button



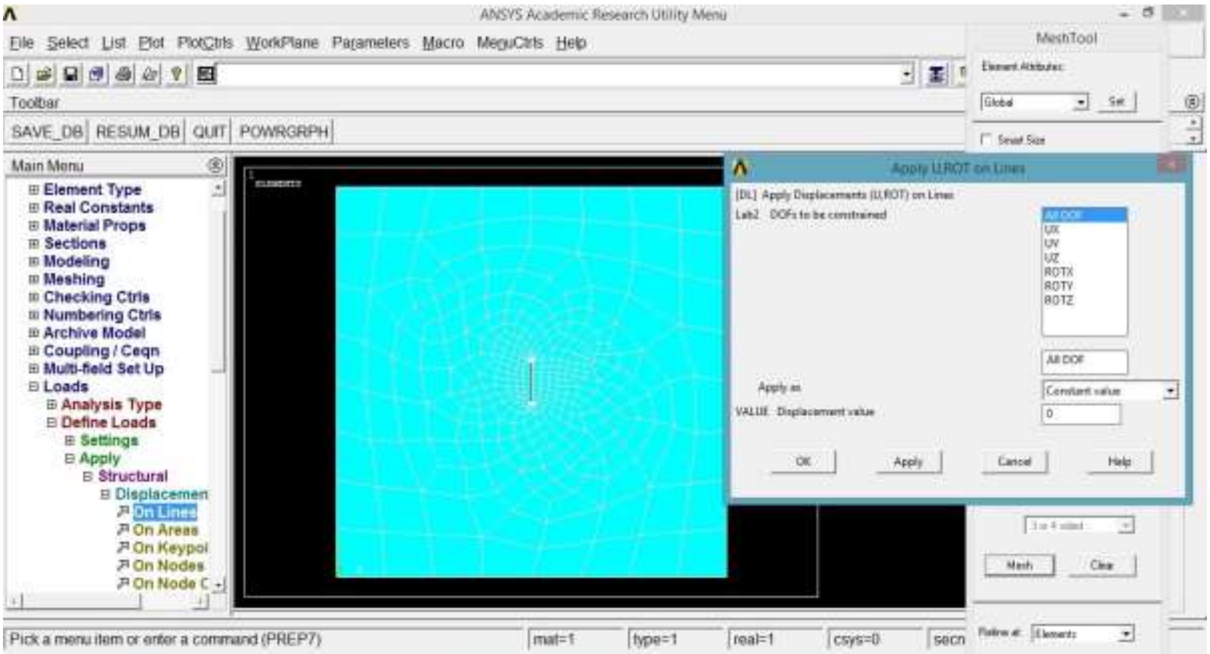
- After the meshing operation the element looks like this



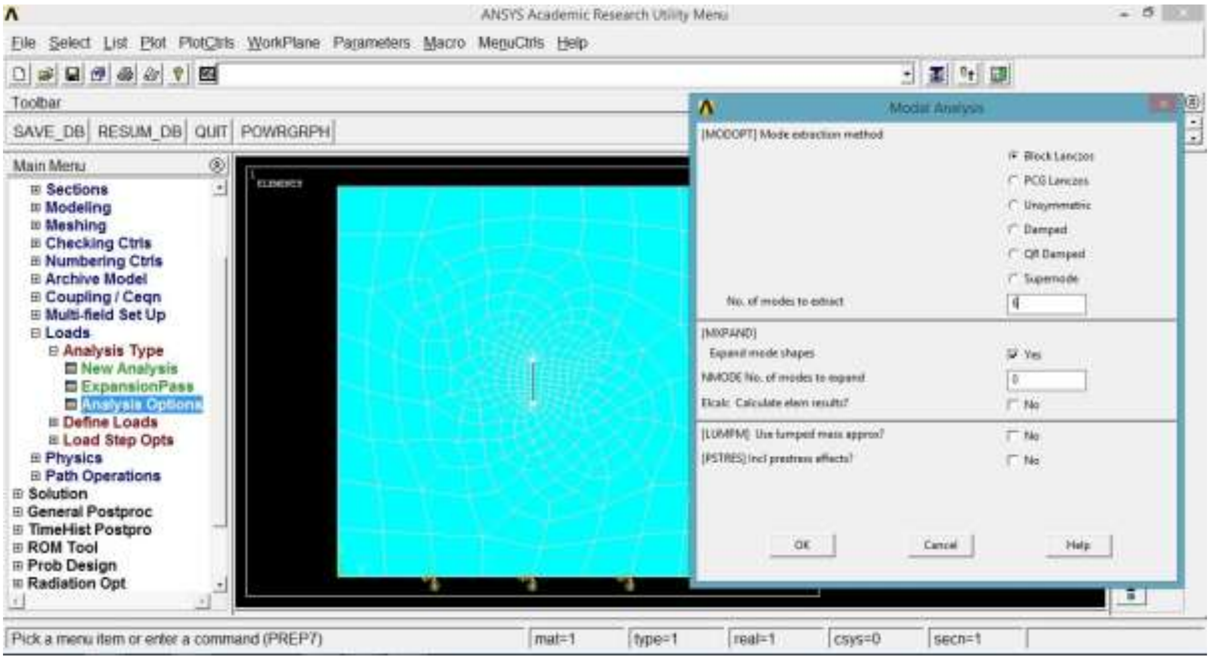
- For applying B.C go to Preprocessor ->click on Loads ->Prefer the option Define Loads ->Click on Apply ->Since it is a structural analysis click on Structural -> Go to the displacement option-> Apply proper B.C on the edges-> According to the B.C restrain the degree of freedom -> Finally select ok



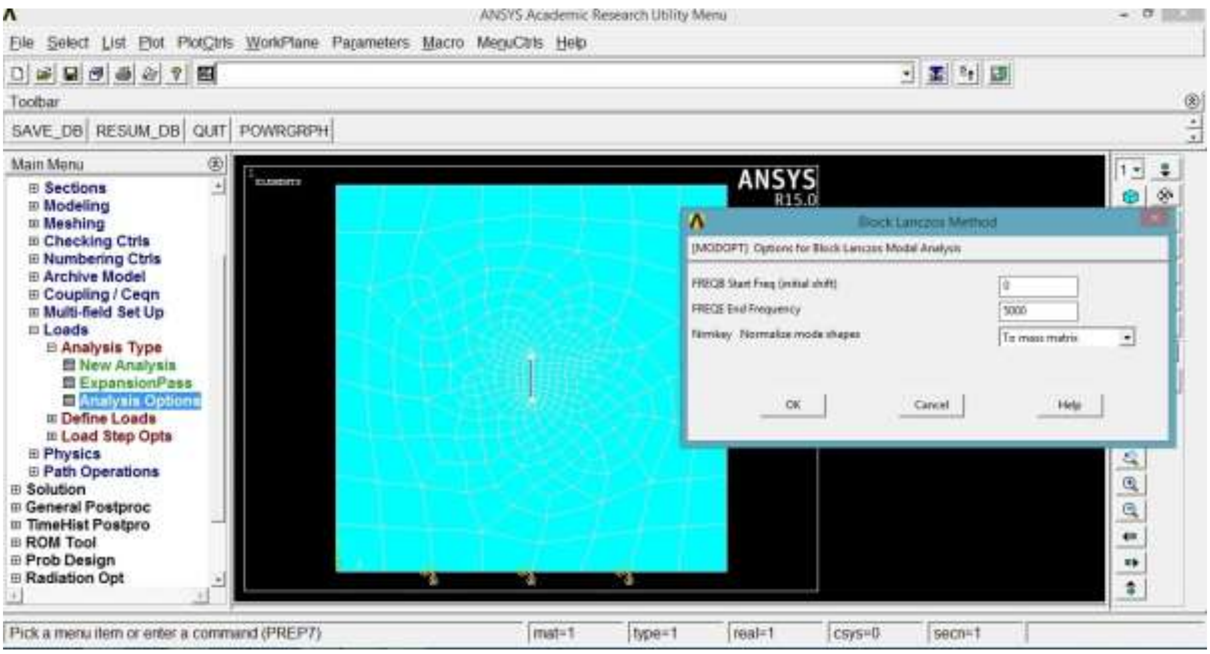
- Then go to Preprocessor ->Prefer the option Loads ->Choose the type of analysis -> -> Since it is a dynamic analysis select ->Click on the ok button



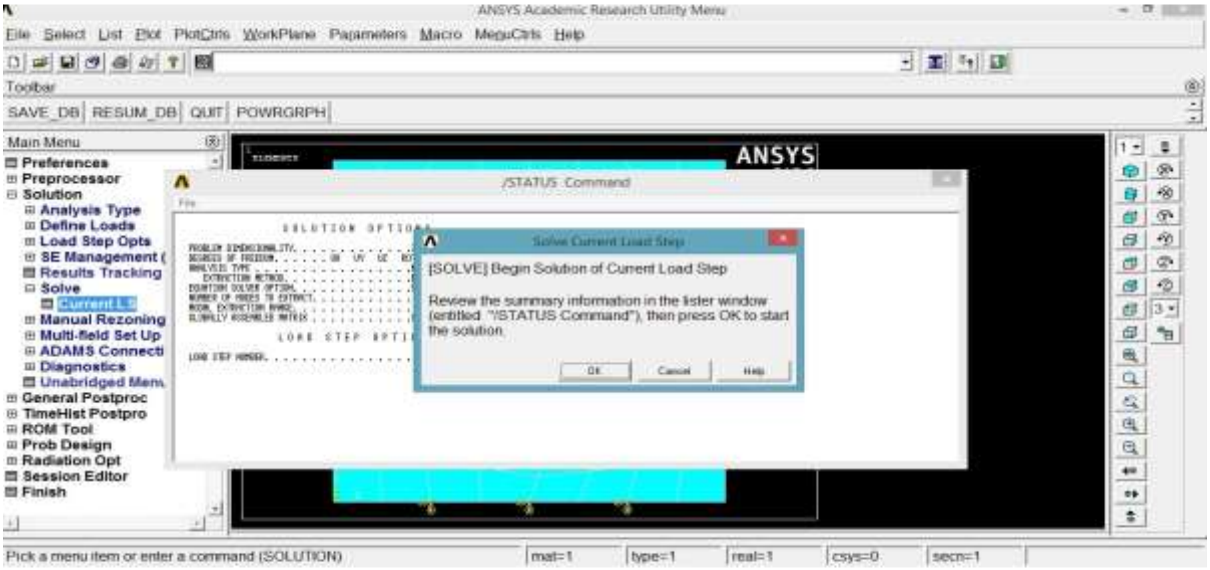
- Next go to Preprocessor ->Go to Loads ->go to the Analysis Type option ->Choose the button Analysis Options -> We require first 3 modes but give the no. of modes as 6-> Finally click on ok



- Then the sequence that follows is to select Block Lanczos analysis -> Input the limits of frequency -> Select ok



- To obtain the solution of the problem click Solution ->Go to solve button -> prefer the option Current LS -> Choose ok in the next window that comes up -> Select Ok



- The ultimate step is to see the results by hovering to General Postprocessing button ->Clicking on Results Summary gives us our solution

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Results of Modal Analysis of Uncracked Glass-Carbon Hybrid Composite Plates

Table 2 Variation of Natural Frequencies for Cracked and Uncracked Plate in FFFF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz	Ansys Results (uncracked) in Hz	Ansys Results (cracked) in Hz
1	376	364	412.31	411.38
2	508	492	564.57	561.19
3	596	584	624.86	621.71

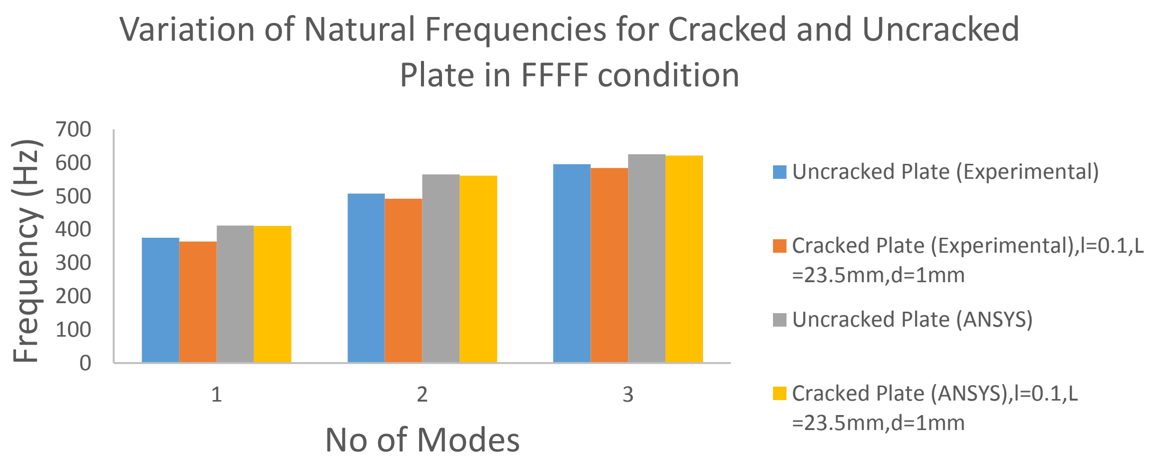


FIGURE 11

<u>Table 3 Variation of Natural Frequencies for Cracked and Uncracked Plate in CFFF condition</u>

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz	Ansys Results (uncracked) in Hz	Ansys Results (cracked) in Hz
1	160	152	164.76	163.68
2	196	184	209.29	207.36
3	224	216	240.51	237.57

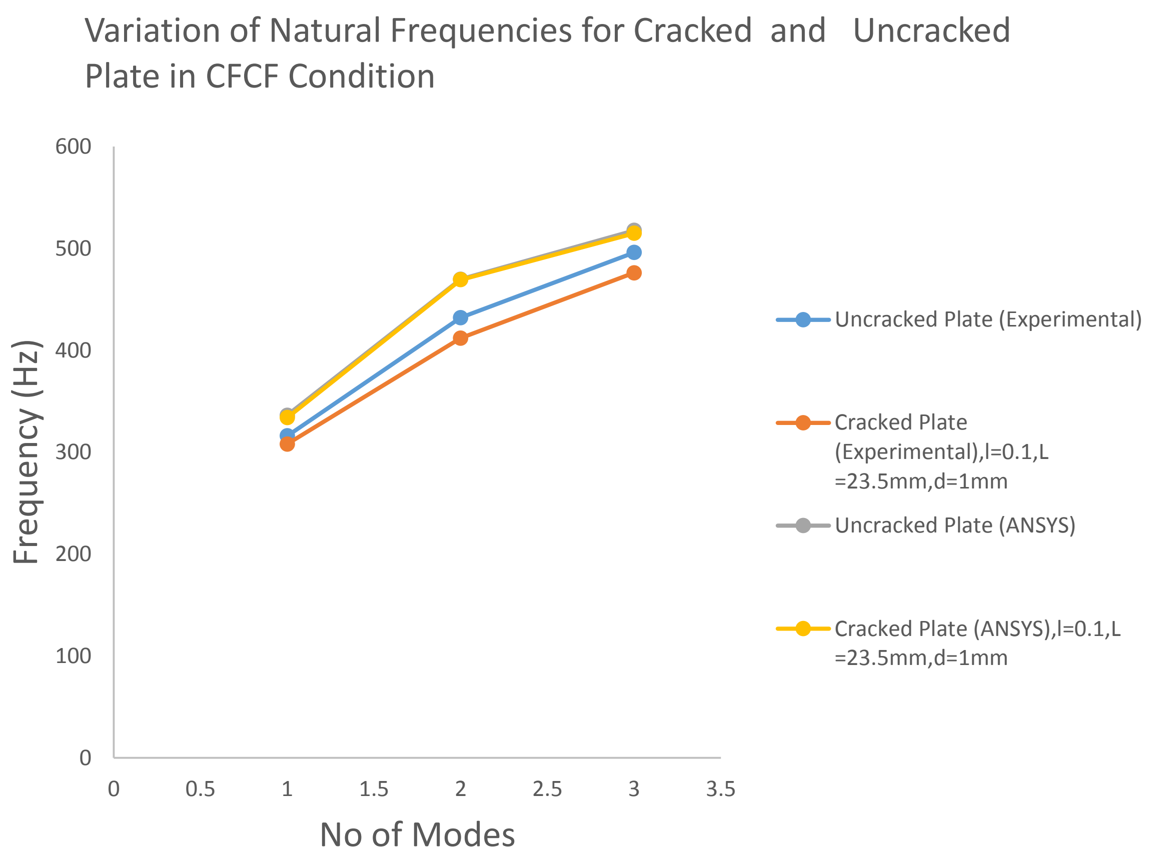


FIGURE 12

Table 4 Variation of Natural Frequencies for Cracked and Uncracked Plate in SFSF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz	Ansys Results (uncracked) in Hz	Ansys Results (cracked) in Hz
1	252	248	283.49	281.17
2	296	276	299.52	297.78
3	312	304	361.46	356.88

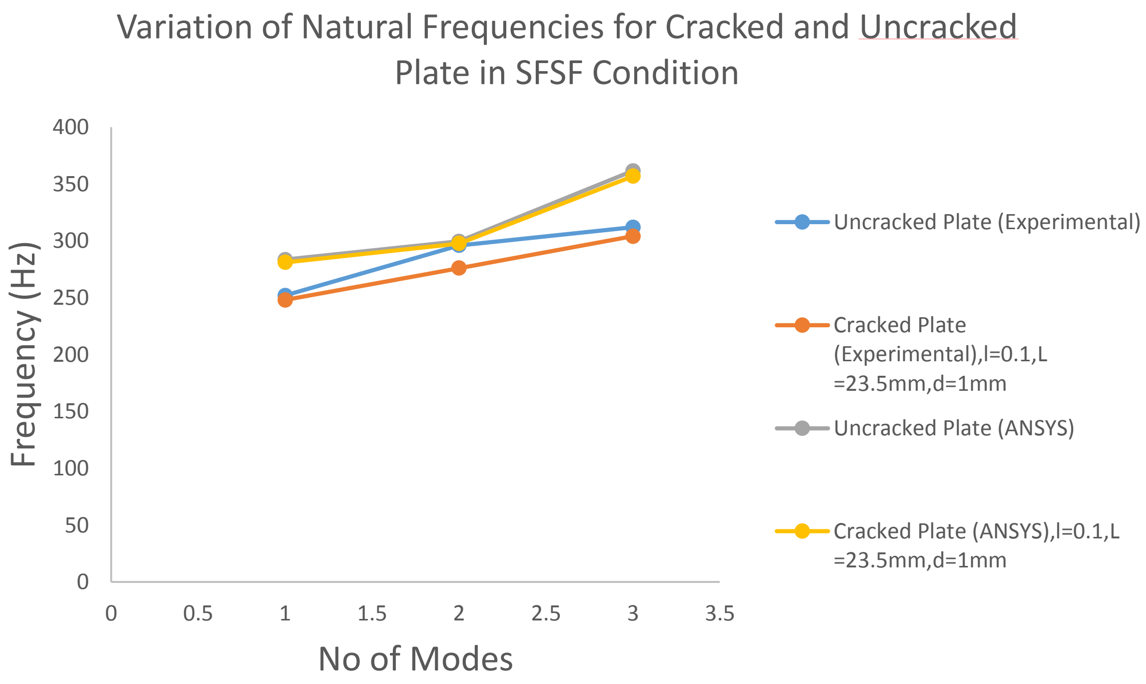


FIGURE 13

Table 5 Variation of Natural Frequencies for Cracked and Uncracked Plate in CFCF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz	Ansys Results (uncracked) in Hz	Ansys Results (cracked) in Hz
1	316	308	336.18	333.85
2	432	412	469.78	469.22
3	496	476	517.63	514.76

6.2 Effect of varying the depth of the crack

Table 6 Variation of Natural Frequencies for Cracked and Uncracked Plate in FFFF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz l=23.5mm, d=2mm	Ansys Results (uncracked) in Hz l=23.5mm, d=1mm	Ansys Results (cracked) in Hz l=23.5mm, d=1mm Hz
1	364	364	411.38	409.69
2	492	488	561.19	560.32
3	584	576	621.71	619.19

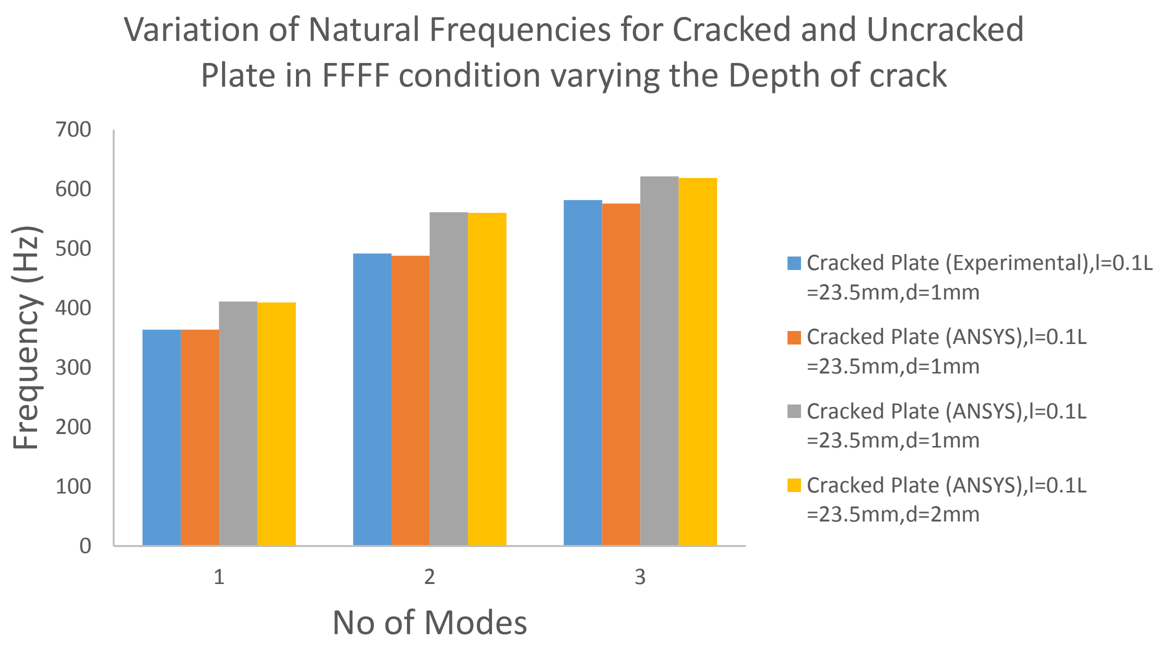


FIGURE 14

Table 7 Variation of Natural Frequencies for Cracked and Uncracked Plate in CFFF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz l=23.5mm, d=2mm	Ansys Results (uncracked) in Hz l=23.5mm, d=1mm	Ansys Results (cracked) in Hz l=23.5mm, d=1mm Hz
1	152	136	163.68	163.52
2	184	180	207.36	207.33
3	216	204	237.57	235.51

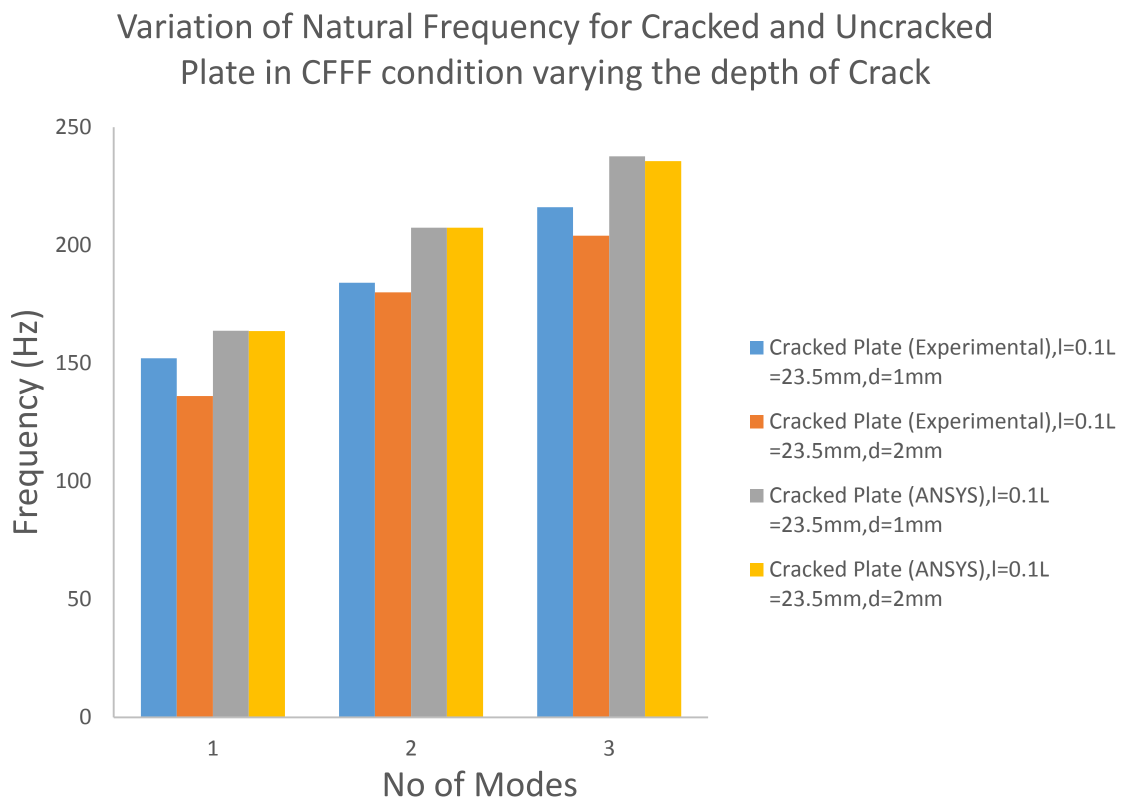


FIGURE 15

Table 8 Variation of Natural Frequencies for Cracked and Uncracked Plate in SFSF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz l=23.5mm, d=2mm	Ansys Results (uncracked) in Hz l=23.5mm, d=1mm	Ansys Results (cracked) in Hz l=23.5mm, d=1mm
1	248	228	281.17	281.09
2	276	272	297.78	297.71
3	304	300	256.88	356.23

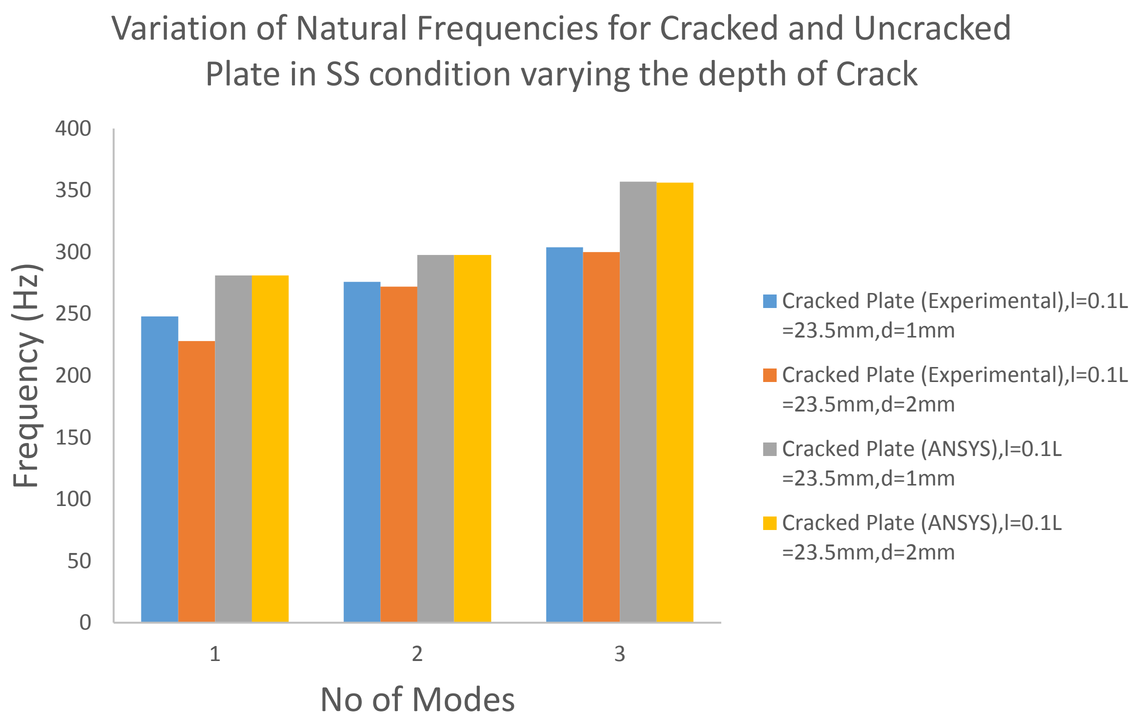


FIGURE 16

Table 9 Variation of Natural Frequencies for Cracked and Uncracked Plate in CFCF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm	Experimental Results (cracked) in Hz l=23.5mm, d=2mm	Ansys Results (uncracked) in Hz l=23.5mm, d=1mm	Ansys Results (cracked) in Hz l=23.5mm, d=1mm
1	308	304	333.85	332.96
2	412	400	469.22	468.27
3	476	460	514.76	512.71

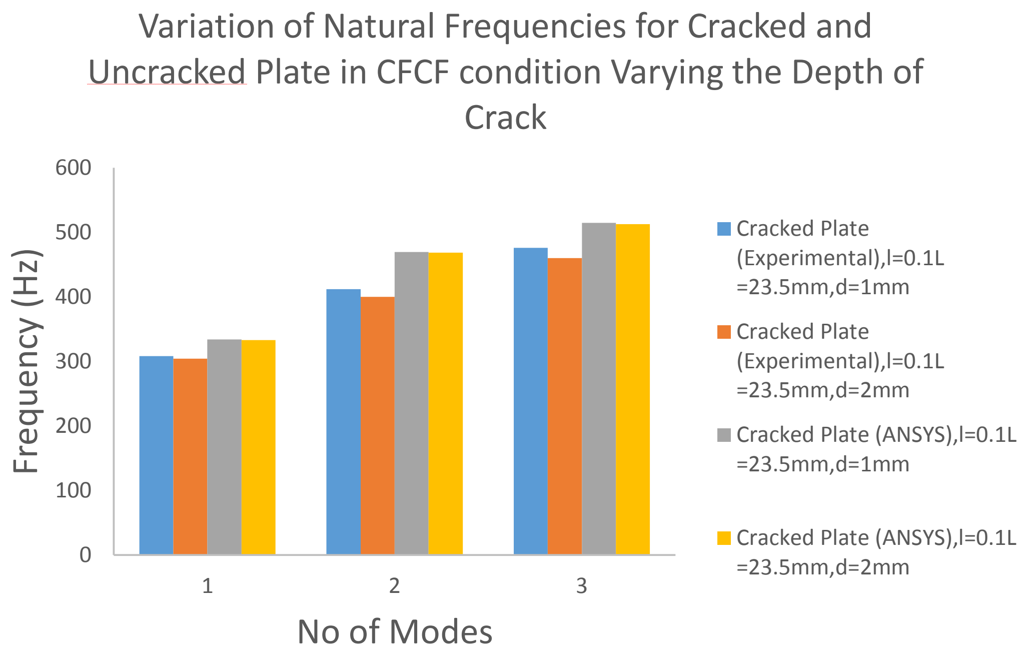


FIGURE 17

6.3 Effect of varying the Length of the crack

Table 10 Variation of Natural Frequencies for Cracked and Uncracked Plate in FFFF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.2L=47mm, d=1mm	Experimental Results (cracked) in Hz l=141mm, d=1mm	Ansys Results (uncracked) in Hz l=47mm, d=1mm	Ansys Results (cracked) in Hz l=141mm, d=1mm
1	360	336	410.88	406.18
2	488	476	560.74	558.85
3	578	554	621.11	612.55

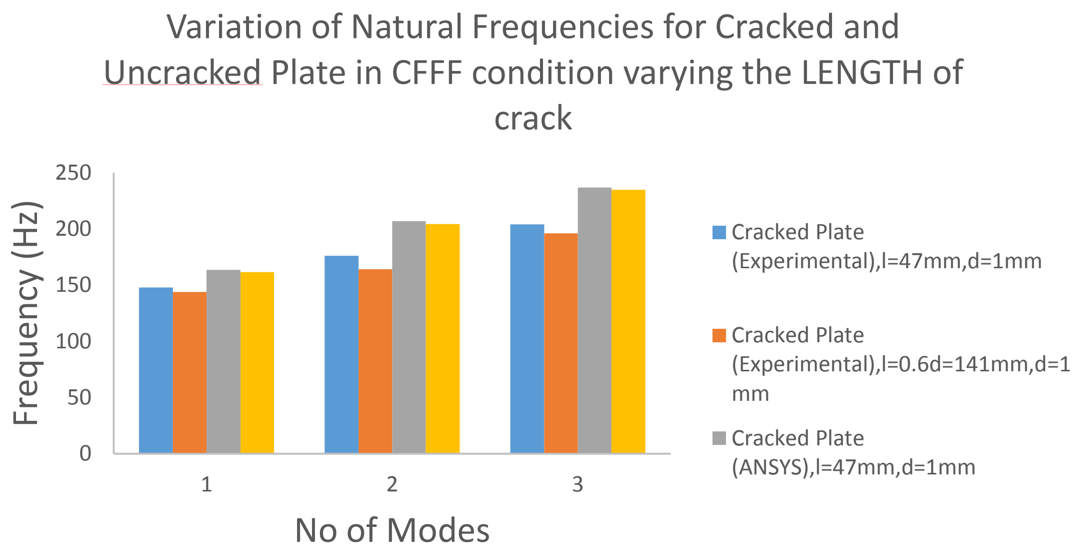


FIGURE 18

6.4 Effect of varying the number of layers

Table 11 Variation of Natural Frequencies for Cracked and Uncracked Plate in FFFF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm, 8 layers	Experimental Results (cracked) in Hz l=23.5mm, d=1mm, 4 layers	Ansys Results (uncracked)in Hz, l=23.5mm, d=1mm,8 layers	Ansys Results (cracked) in Hz l=23.5mm, d=1mm, 4 layers
1	364	186	411.38	206.155
2	492	226	561.19	282.38
3	584	286	621.71	312.63

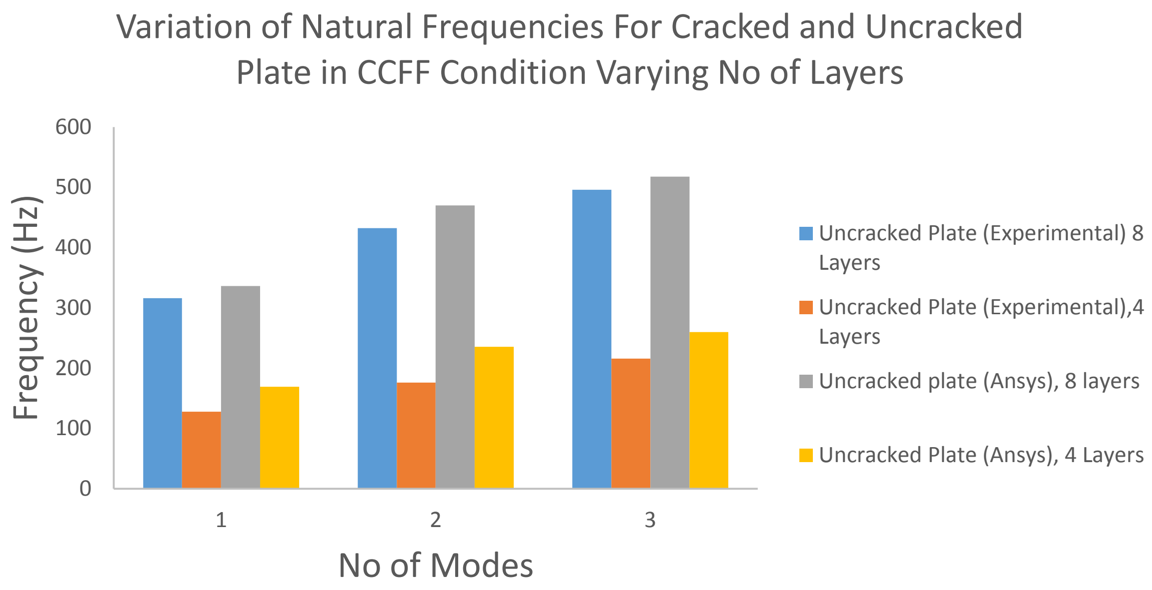


FIGURE 19

6.5 Effect of varying the angle of orientation of crack w.r.t centre of plate

Table 12 Variation of Natural Frequencies for Cracked and Uncracked Plate in FFFF condition

l= length of crack, d= depth of crack, L=length of Plate=235mm

Mode	Experimental Results (uncracked) in Hz l=0.1L=23.5mm, d=1mm, 45 degree	Experimental Results (cracked) in Hz l=23.5mm, d=1mm, 30 degree	Ansys Results (uncracked)in Hz, l=23.5mm, d=1mm, 45 degree	Ansys Results (cracked) in Hz l=23.5mm, d=1mm, 30 degree
1	368	368	411.93	411.18
2	492	472	564.52	562.375
3	584	580	623.19	621.523

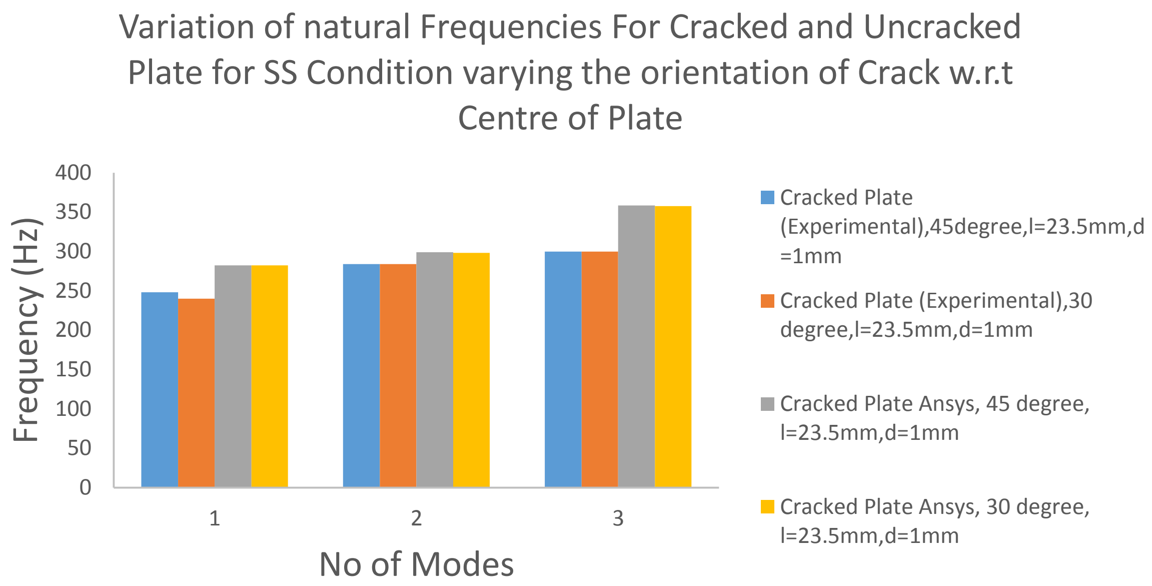


FIGURE 20

6.6 Effect of varying the position crack w.r.t centre of plate

l= length of crack, d= depth of crack, L=length of Plate=235mm

Crack location-0.2d from centre

<u>Table 13 Variation of Natural Frequencies for Cracked Plate in all 4 boundary conditions</u>

Mode	Experimental Results (cracked) in Hz, CCFF l=23.5mm, d=1mm,	Experimental Results (cracked) in Hz, SFSF l=23.5mm, d=1mm,	Ansys Results (uncracked)in Hz, CCFF l=23.5mm, d=1mm,	Ansys Results (cracked) in Hz, FFFF, l=23.5mm, d=1mm
1	308	364	163.82	412.78
2	412	492	208.06	561.85
3	476	584	237.92	622.86

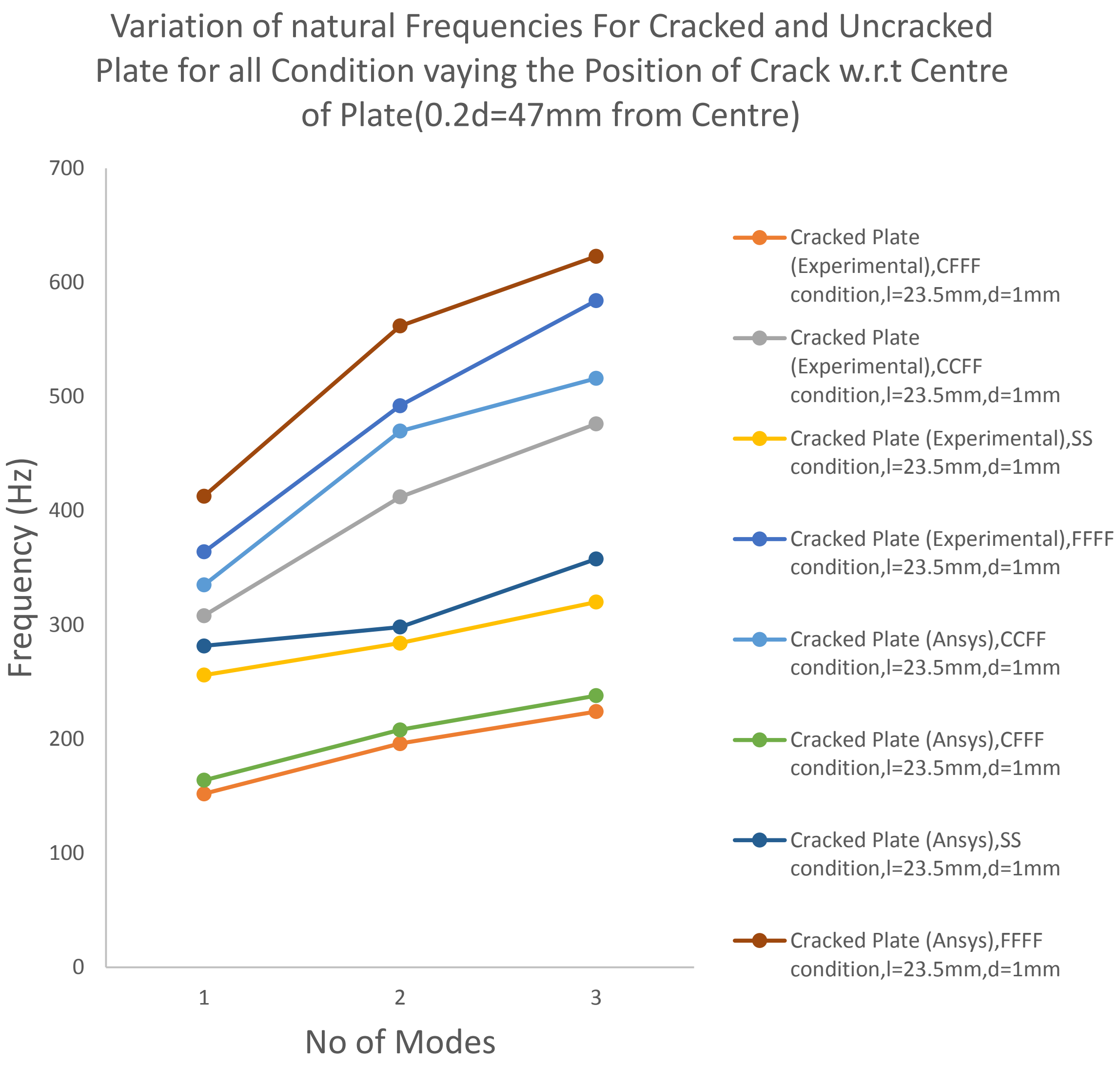

Variation of natural Frequencies For Cracked and Uncracked Plate for all Condition vaying the Position of Crack w.r.t Centre of Plate(0.2d=47mm from Centre)
700
600
500
400
300
200
100
0
Frequency (Hz)
1
2
3
No of Modes
Cracked Plate (Experimental),CFFF condition,l=23.5mm,d=1mm
Cracked Plate (Experimental),CCFF condition,l=23.5mm,d=1mm
Cracked Plate (Experimental),SS condition,l=23.5mm,d=1mm
Cracked Plate (Experimental),FFFF condition,l=23.5mm,d=1mm
Cracked Plate (Ansys),CCFF condition,l=23.5mm,d=1mm
Cracked Plate (Ansys),CFFF condition,l=23.5mm,d=1mm
Cracked Plate (Ansys),SS condition,l=23.5mm,d=1mm
Cracked Plate (Ansys),FFFF condition,l=23.5mm,d=1mm

FIGURE 21

CHAPTER 7

CONCLUSION

The present study deals with the vibrational behaviour of glass-carbon hybrid composite plates of size 235x235mm using FFT analyser. Frequency Response Function (FRF) of composite plates was examined using FFT analyser through PULSE software. The variation of parameters like length, depth, orientation of crack had substantial effect on the natural frequency of these composites. The results so obtained are compared with the values from Finite Element Package software ANSYS.

The important conclusions drawn from this research work are:

1. With increase in depth of crack, natural frequency decreases both in experimental as well as ANSYS results.
2. With increase in length of the crack the experimental and ANSYS values both decrease. However the decrease is less compared to the previous case.
3. The natural frequencies follow the order below.
   FFFF>CCFF>SS>CFFF
   This relation holds good for all the cases
4. When angle of orientation of crack is 90 degrees or 0 degrees, there is maximum reduction in natural frequency. Similarly when angle of orientation of crack is 45 degrees, there is decrease in natural frequency but this reduction is less than when the orientation is 90 or 30 degrees.
5. By varying the position of crack, natural frequency decreases too. The decrease is maximum when the crack is at the centre if the plate.
6. The values of natural frequencies obtained from ANSYS analysis are usually higher compared to experimental results. This is because experimental work involves practical conditions and environmental disturbances (damping factor) which reduce the value of frequencies. The efficiency of apparatus used and degree of accuracy of the user are important parameters which affect the experimental results.

CHAPTER 8

SCOPE FOR FUTURE WORK

The present research work can be extended to the following areas:

- ✓ Vibrational behaviour of cracked hybrid composite plates under hygrothermal effects.
- ✓ Buckling behaviour of cracked hybrid composite plate under different loading conditions.
- ✓ Influence of joints on the vibrational studies of hybrid composites.
- ✓ Study of natural frequencies of delaminated hybrid composites.
- ✓ FFT analysis of curved hybrid composite shells.
- ✓ Develop a computer code for the efficient design of hybrid composite specimens based on the information obtained from research.

CHAPTER 9

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