Vibration Analysis of Cracked Composite Plate

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

Bachelor of Technology
in

Civil Engineering

By

Regal Mohanty

Roll: 111CE0043

Department Of Civil Engineering
National Institute Of Technology Rourkela
Rourkela-769008
Orissa, India

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008

CERTIFICATE

This is to certify that project entitled "Vibration Analysis of Cracked Composite Plate" submitted by Regal Mohanty in partial fulfillment 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.

Prof. S.K.Sahu
Department of civil engineering
National Institute of Technology
Rourkela - 769008

Acknowledgement

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Last but not the least I would like to thank all the staff members of Department of Civil Engineering who have been very cooperative with me.

Submitted By:

Regal Mohanty

Department of Civil Engineering

National Institute of Technology

Rourkela

CONTENTS

Abstract

Composite materials are widely used in different arenas such as aircraft, naval and automobiles. Main motive behind that is the distinctive property of weight reduction, which is important for greater speeds, improved payloads and efficient fuel consumption. Various damages like cracks or delamination are inevitable during service period. They may be due to impact load, chemical decay or change in temperature or pressure conditions. It has been experimentally proved that confined damage in a structure causes the reduction in local structural stiffness, resulting in deviations in dynamic performance of the structure. Additional resonance or crack proliferation induce large displacements resulting in the failure of the structure. In this study, efforts have been made to determine the natural frequency of vibration of composite plate in different boundary conditions and the multiple parameters of crack have been varied and the results have been established. The tests on composite plate is done experimentally to find natural frequency using FFT analyser and the results are validated using ANSYS. The work is done with varying crack parameters like depth, length and orientation. The frequency decreases with increase in crack dimensions and decreases with increasing orientations. For different boundary conditions, frequency increases with decreasing degrees of freedom. This will help in designing structures resistant to earthquakes and other disasters, given that the resonance frequency is known earlier. It will help in building a safe structure and will prolong its life for many years.

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CHAPTER 1

INTRODUCTION

1.1 Composites

An engineered material system comprising of two or more phases on a macroscopic level is termed as a structural composite. The mechanical performance and properties of composite are superior to the properties of the independent constituents. The stiffer and stronger phase is called reinforcement, whereas the delicate phase is called matrix. Reinforcement, the mainstay of composite, defines its strength and stringency. The matrix protects and supports subtle fibres and results in transmission of stress from one fibre to another. Fibre-reinforced Polymer (FRP) is one such where glass fibres or carbon fibres are implemented as reinforcements.

Composite materials are widely used in different arenas such as aircraft, naval and automobiles. Main motive behind that is the distinctive property of weight reduction, which is important for greater speeds, improved payloads and efficient fuel consumption. Roofing and flooring are its usage in structural analysis and design. Composites have distinctive characteristics such as excellent resilience, high resistance to corrosion, low coefficient of heat expansion, greater specific strength and many more. These properties make it a better material than other alloys and steel. Hence, its enhanced utilisation in modern days is of no surprise and highlights the birth of a new construction material in the field of structures.

1.2 Significance of Present Study

Various damages like cracks or delamination are inevitable during service period. They may be due to impact load, chemical decay or change in temperature or pressure conditions. It has been experimentally proved that confined damage in a structure causes the reduction in local structural stiffness, resulting in deviations in dynamic performance of the structure. Additional resonance or crack proliferation induce large displacements resulting in the failure of the structure. Due to their practical significance and widespread usage, the dynamic criteria of these cracked elements is to be investigated with a great interest. Modal analysis, a non-destructive technique, is utilised to determine the stiffness of structures. Earlier, mostly numerical methods were taken into consideration while evaluating the natural frequency of composite plates. Using modal analysis, experimental results are to be compared with results of numerical method and any differences point towards local failure or cracks in the plate. The main objective of estimation of fundamental frequency is to prevent the failure of large structures due to the phenomenon of resonance.

1.3 Outline of the Present Study

The present study deals with the vibration characteristics of composite plates with cracks. It includes method of fabrication of composite plates followed by characterization by tensile testing and vibration testing. Results were obtained for composite plates comprising of glass fibre and epoxy. The work was mainly to study the effects of crack parameters on composite plates, which can be enlisted as depth of crack, length of crack (aspect ratio), orientation of crack with direction of fibre and different support conditions on edges. Tests were carried out on composite plate, varying the above parameters, to determine the natural frequency of vibration; both experimentally and using the finite-element package ANSYS 15.0.

This thesis consists of six major chapters. The Chapter 1 is a brief introduction into the base material of the research and its widespread applications around the world. It also describes the significance and usage of the current study.

Chapter 2 includes the critical review of literature related to the research based on the works done earlier on this arena. It was primarily done to achieve a better level of understanding of the concepts, problem statement and troubles during the experiments. The aim and scope of the study is also presented here.

Chapter 3 deals with the mathematical formulation of the problem to get the solution of vibration analysis theoretically. It also describes the formula used when modelling in ANSYS.

Chapter 4 completely describes the procedures followed for the experiment starting from the fabrication of specimen to the vibration testing. The procedures for introduction of crack in the plate and tensile testing are also discussed in details.

Chapter 5 includes a complete stepwise description of the procedure of modelling the glass fibre composite plate using the finite element package ANSYS 15.0.

Chapter 6 tabulates all the results obtained from the current study and also the results obtained using ANSYS 15.0 and discusses the variation of natural frequency of vibration of a cracked composite plate with different parameters such as crack depth, crack length and crack orientation.

Chapter 7 presents the conclusions extracted from the observations and they are discussed in details. Also the future scope of the present study is stated here.

Chapter 8 (the last) enlists all the references which were referred during the making of this research project.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

Fibre reinforced composite plates have widespread sphere of usage in various arenas, which has paved the way for a large number of research projects related to composite plates. It is of high importance that the vibration characteristics is to be known to study the behaviour of structures under dynamic loading. Any deviation or dissimilarity in results gives an indication of presence of cracks or defects in the plate. Such analysis helps in early diagnosis of damage severity in aircrafts or machinery and instant repairs at the spot. The literature was thus critically reviewed to have a good level of understanding of the problem and to execute plans of current study so as to overcome the lacunae in the previous works. Most of the previous studies are based on theoretical approach and less parameters have been taken into account. A brief insight to the previous works done, to determine the natural frequency and to carefully examine the effects of crack parameters on vibration, is rendered in the subsequent paragraphs.

Cawley and Adams (1978) studied the natural modes for square composite plates for free-free boundary conditions. Crawley (1979) practically determined vibration frequencies of composite plates for various aspect ratios and compared with FEM. Palardy and Palazotto (1990) studied frequency response of laminated cross ply using Levy approach based on shear deformation. Lee and Lim (1993) used numerical method based on the Rayleigh method for predicting the natural frequencies of a rectangular composite plate with a centrally located crack. Sinha and Maiti (1996) used the FSDT theory to develop methodology for vibration response of thick composite plates. Chakraborty *et al.* (2000) studied GFRP plates for vibration properties and used NISA to validate the results. Hwang and Chang (2000) utilized impulse technique for frequency testing of composite plates. Guan-Yuan Wu and Yan-Shin Shih (2005) studied the dynamic uncertainty of rectangular composite plate having a crack at one side.

Qu *et al.* (2006) established dynamic model for piezoelectric composite plate and analysed effect of cracks on mode shapes. Bachene *et al.* (2009) experimented on cracked composite plates to determine natural frequency of vibrations using the extended finite element method. The conclusion induced from the paper is that cracked plate vibration frequency decreases with increase in length. But they did not consider the other crack parameters. Zhang and Yang (2009) discovered new methods and focused on contemporary developments in finite element analysis for layered composite plates. They referred to vibration analysis of laminated composite plates using computational models based on first-order shear deformation theory. Lei *et al.* (2010) studied effects of different woven structures on frequency properties of composite plates. Natarajan *et al.* (2011) studied linear free flexural vibration of graded composite plates with cracks in thermal environment. The vibrations of functionally graded material plates with a through centre crack were studied using an 8-noded shear elastic element. Temperature dependence was one of the important material properties and it was graded in the thickness direction. Jweeg, Hammood and Al-Waily (2012) experimented on different composite plates to study the effect of crack orientation on natural frequency of vibration. They conducted the study firstly by using time-varied load in experimental program and validated the result with ANSYS 14.0. They also observed that frequency of vibration varies with stiffness and dimensions of the plate. El-Raouf and El-Hamid Hamada (2014) emphasised on effect of crack length and depth on cracked composite plates and they did vibration analysis experimentally and validated results using numerical methods which uses finite element techniques. They have taken damping factor into consideration in experimental method which resulted in near equal values between experimental and numerical values.

2.2 Aim and Scope of the Study

The primary aim of this research is to study the vibration characteristics of a glass fibre composite plate with cracks. The values obtained experimentally are compared with that obtained using ANSYS 15.0.

The effects of different crack parameters like depth of the crack, length of crack, and orientation of crack on natural frequency of composite plate are studied and conclusions have been made to describe its property.

CHAPTER 3

MATHEMATICAL FORMULATION

3.1 Shell 281 Model

It is a linear element having a total number of eight-nodes with degrees of freedom equal to six at each node. Those degrees of freedom include translation in x- , y-, z- axes and also rotation in x-, y-, z- axes. The element is mostly used for analysis for linear and rotations of larger scale. The analysis is governed by use of First order Shear Deformation Theory.

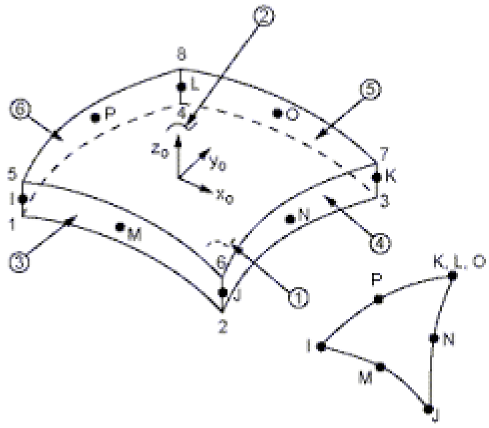


Figure 1: Shell 281 Geometry

3.2 Governing Equations

The mathematical modelling in ANSYS is generally based on the concept of the FSDT and it is demonstrated as follows:

$$U'(X',Y',Z') = U_0'(X',Y') + Z'\Theta_{X'}(X',Y')$$

$$V'(X',Y',Z') = V_0'(X',Y') + Z'\Theta_{X'}(X',Y')$$

$$W'(X',Y',Z') = W_0'(X',Y') + Z'\Theta_{X'}(X',Y')$$

The displacements are presented and derived in terms of Shape Functions (N_i).

$\delta = \sum N_i \delta_i$, i varies from 1 to j

where $\delta_i = [U'_{0i}\ V'_{0i}\ W'_{0i}\ \phi_{X'i}\ \phi_{Y'i}\ \phi_{Z'i}]^T$

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

$N_1 = \frac{1}{4}\ (1-\varepsilon)(1-n)(-\varepsilon-n-1)$

$N_2 = \frac{1}{4}\ (1+\varepsilon)(1-n)(\varepsilon-n-1)$

$N_3 = \frac{1}{4}\ (1+\varepsilon)(1+n)(\varepsilon+n-1)$

$N_4 = \frac{1}{4}\ (1-\varepsilon)(1+n)(-\varepsilon+n-1)$

$N_5 = \frac{1}{2}\ (1-\varepsilon^2)(1-n)$

$N_6 = \frac{1}{2}\ (1+\varepsilon)(1-n^2)$

$N_7 = \frac{1}{2}\ (1-\varepsilon^2)(1+n)$

$N_8 = \frac{1}{2}\ (1-\varepsilon)(1-n^2)$

The above equations are based on natural coordinates and U', V', W' represent the displacement of any point along X', Y', Z' coordinate axes.

Strains along different axes are determined by derivation of displacements along respective directions.

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

$\{ \varepsilon \} = [B] \{ \delta \}$,

where

[B] is the strain displacement matrix comprising of interpolation functions and their derivatives

$\{ \delta \}$ is the nodal displacement vector

CHAPTER 4

EXPERIMENTAL PROGRAMME

The experimental procedure chapter includes a complete description of the methods involved during casting of woven glass fibre composite plates for characterisation through tensile testing, procedure for tensile testing, fabrication of plates for vibration analysis and vibration testing.

4.1 Fabrication Methodology

Hand Layup technique was used to cast composite plates. In hand layup technique glass fibre is placed along with liquid epoxy against an open mould. The two materials are combined to overcome each other's lacunae in properties and to get a material with much improved characteristics. The epoxy is very strong in compression and comparatively weaker in tension whereas glass fibre has high tensile strength. Thus this combination provides a unique solution to resist both tension and compression. The composition of fibre and matrix is taken as 50:50 by weight where matrix includes the epoxy and hardener as per ASTM-D5678M-07. Epoxy and hardener are distributed as 42% and 8%. The hardener generally used for this method is Hardener HY591. To prepare the specimen the matrix is uniformly applied over the glass fibre after each layer. To expel out any air which might be present between the fibre layers, hand-held steel rollers are used. Thin plastic sheets are provided both at topmost layer and the bottommost layer of the composite plate to give it a smooth finish and also protect it from any kind of damage. During provision of the plastic sheet, a spray of polyvinyl alcohol is applied which acts as a releasing agent. The plates are cured for about 48 hours after which they are cut into required dimensions for vibration testing. Crack is made on it with the help of a saw.

A few calculations involved before casting of plates are presented below:

CALCULATION (FOR PLATE FOR VIBRATION TESTING):

Weight of glass fibres (8 layers): 271 g

Weight of matrix (epoxy + hardener): 271 g

Weight of hardener to be taken= 8% of epoxy by weight

Let weight of epoxy be E and weight of hardener be H.

H = 8% of E = 0.08E

$E + H = 271$

$\Rightarrow E + 0.08E = 271$

$\Rightarrow E = 271/1.08$

$\Rightarrow E = 251 \qquad H = 271-251 = 20$

Weight of epoxy used: 251 g

Weight of hardener used: 20 g

<u>CALCULATION (FOR PLATE FOR TENSILE TESTING)</u>:

Weight of glass fibres (8 layers): 173 g

Weight of matrix (epoxy + hardener): 173 g

Weight of hardener to be taken= 8% of epoxy by weight

Let weight of epoxy be E and weight of hardener be H.

H = 8% of E = 0.08E

$E + H = 173$

$\Rightarrow E + 0.08E = 173$

$\Rightarrow E = 173/1.08$

$\Rightarrow E = 160 \qquad H = 173-160 = 13$

Weight of epoxy used: 160 g

Weight of hardener used: 13 g

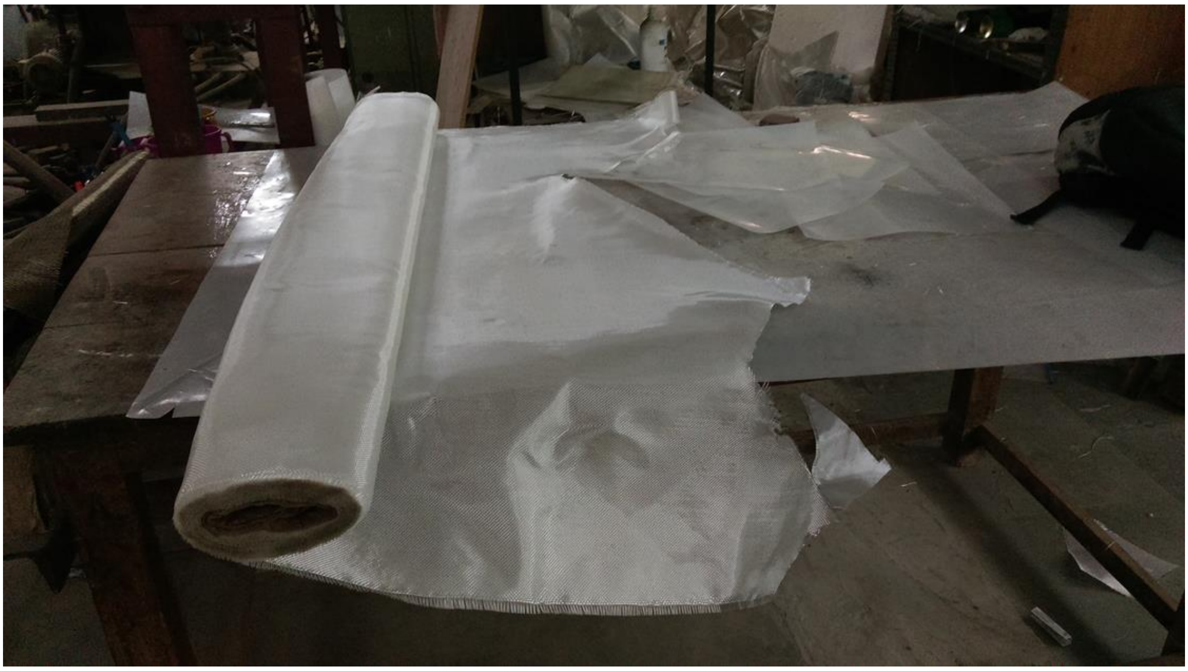


Figure 2: Woven Glass Fibre

Figure 3: Curing of composite plate

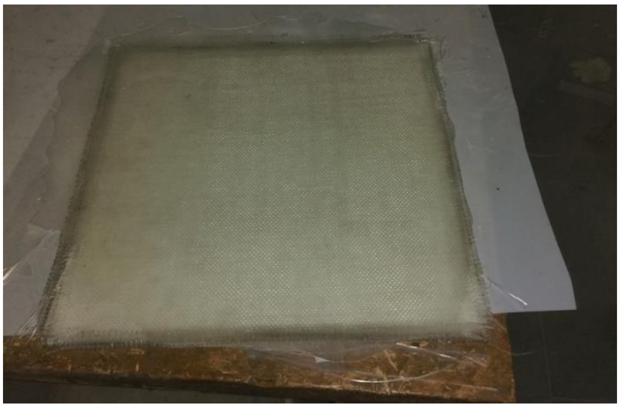


Figure 4: Fabricated Composite Plate

4.2 Determination of Physical Properties

The physical properties of fabricated composite plates, e.g., thickness and density were measured accurately. The Vernier callipers, having a least count of 0.1 mm, was used to measure the thickness of the casted composite plate. The weight of the plate is measured in weighing balance. Weight is required to calculate the density of the plate.

Table 1: Physical properties of the fabricated specimen

Sl. No.	**No. of layers**	**Length (in m)**	**Width (in m)**	**Thickness (in m)**	**Mass (in g)**	**Density (in Kg/m^3)**
1	8	0.235	0.235	0.003	271	1630

4.3 Tensile Test of the Specimens

Tensile test was carried out to determine the Young's modulus of elasticity. The test was unidirectional. Three specimens were cut longitudinally as per specified in ASTM-D3039M-08. Strips cut down from the casted plate for tensile testing were of the dimensions 250 mm long x 25 mm width. Each specimen was loaded in the machine until sudden failure occurs, which denotes the brittle nature of the glass fibre composite. The effective length of the specimen is taken as 150 mm and the gripping length is taken as 50 mm on each side. The INSTRON 1195 machine is used for the tensile testing and it is shown in the figure 5.

Figure 5: INSTRON 1195 machine

Figure 6: Control and display parts

Figure 7: Tensile testing of a specimen

4.3.1 Input parameters for the tensile test machine

Sample Rate (in pts per sec) = 4.562

Speed (mm/min) = 2

Load Range (kN) = 50

Sample Type = ASTM

4.3.2 Observations of tensile test

Table 2: Determination of Young's Modulus from tensile test

Specimen Number	Displacement at peak (mm)	% Strain at peak (%)	Load at peak (kN)	Stress at peak (MPa)	Young's Modulus (MPa)
1	6.271	4.181	22.32	297.6	10360
2	6.691	4.461	23.77	317.0	9843
3	6.027	4.018	20.53	273.7	9848
Average	6.330	4.220	22.21	296.1	10020

From the test, the Young's modulus of elasticity $E_1 = E_2 = 10.02$ GPa. The ratio of lateral strain to longitudinal strain is called the Poisson's ratio. Here, the Poisson's ratio is taken as 0.25.

4.4 Apparatus Setup and Procedure of Vibration Test

4.4.1 Equipment used in vibration test

- Modal Hammer
- FFT Analyzer
- Accelerometer
- Pulse Software

- **Modal Hammer:** The plate is impacted upon by means of a modal hammer (Model 2302-5). As it excites the specimen, the composite plate vibrates with its natural frequency which can be further noted by the accelerometer.
- **Accelerometer:** Accelerometer is the device connected to sensor. It senses the vibration produced by means of Impact hammer and delivers it to FFT Analyzer. It is mounted on the specimen by means of bees wax. The model used is B&K Type 4507.
- **FFT Analyzer:** FFT analyzer processes the signals received from accelerometer. It further transfers the signals to the computer which shows the output in the form of FRF (Frequency Response Function).

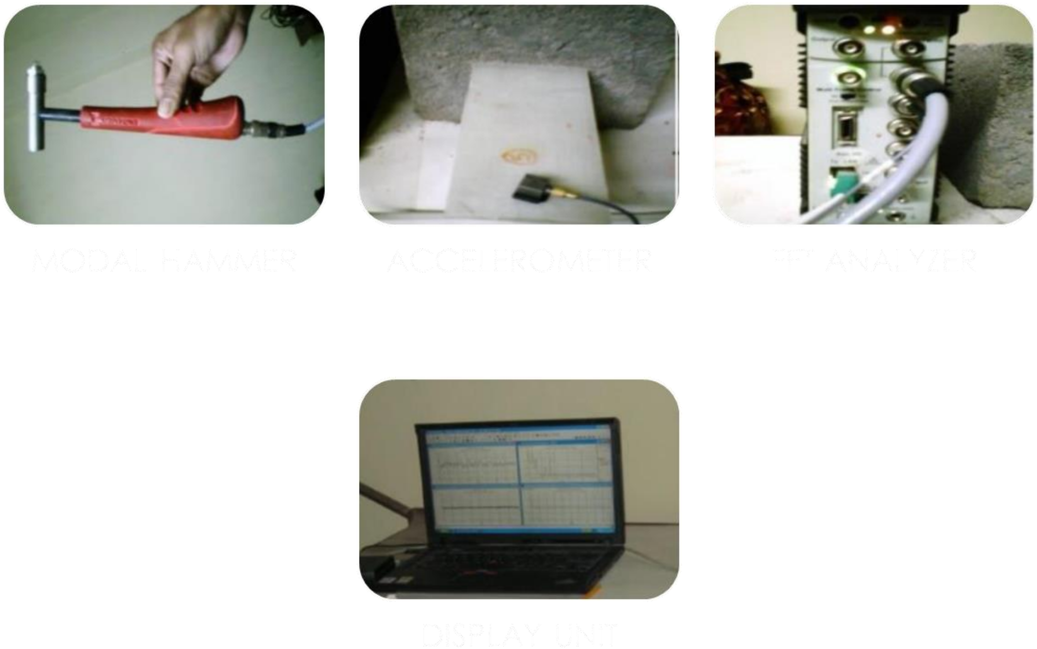


Figure 8: Equipment for vibration test

4.4.2 Vibration Test Procedure

The FFT analyzer, laptop, transducers, modal hammer and cables were connected to the computer as per the guidance manual. The pulse lab shop software key was inserted to the port of laptop. Modal hammer was used to excite the plate by striking it in a specified location on the plate.

The resulting vibrations of the specimens on the selected point were measured by the accelerometer mounted on the specimen by means of bees wax. The plates were adjusted as per the required boundary conditions. The various boundary conditions under study are as follows:

1. Free on all sides (FFFF)

2. Simply supported on two opposite sides and free on other two sides (SFSF)

3. Clamped on one side and free on the other three sides (CFFF)

4. Clamped on two opposite sides and free on the other two sides (CFCF)

CFFF SFSF CFCF

Figure 9: Different Boundary Conditions used in Vibration Test

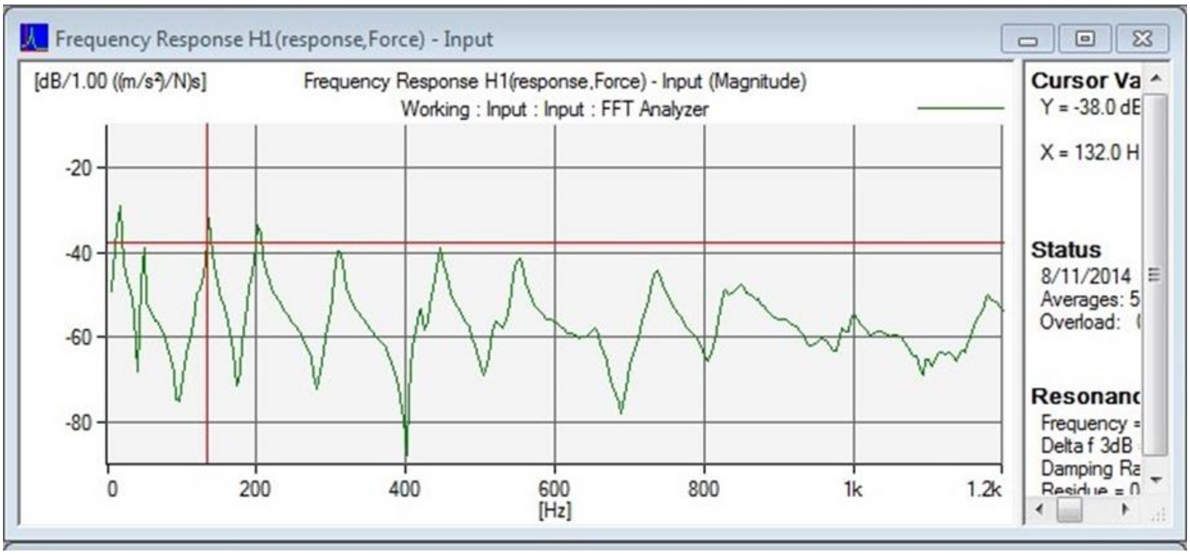


Figure 10: A sample of display of frequency in Pulse software

CHAPTER 5

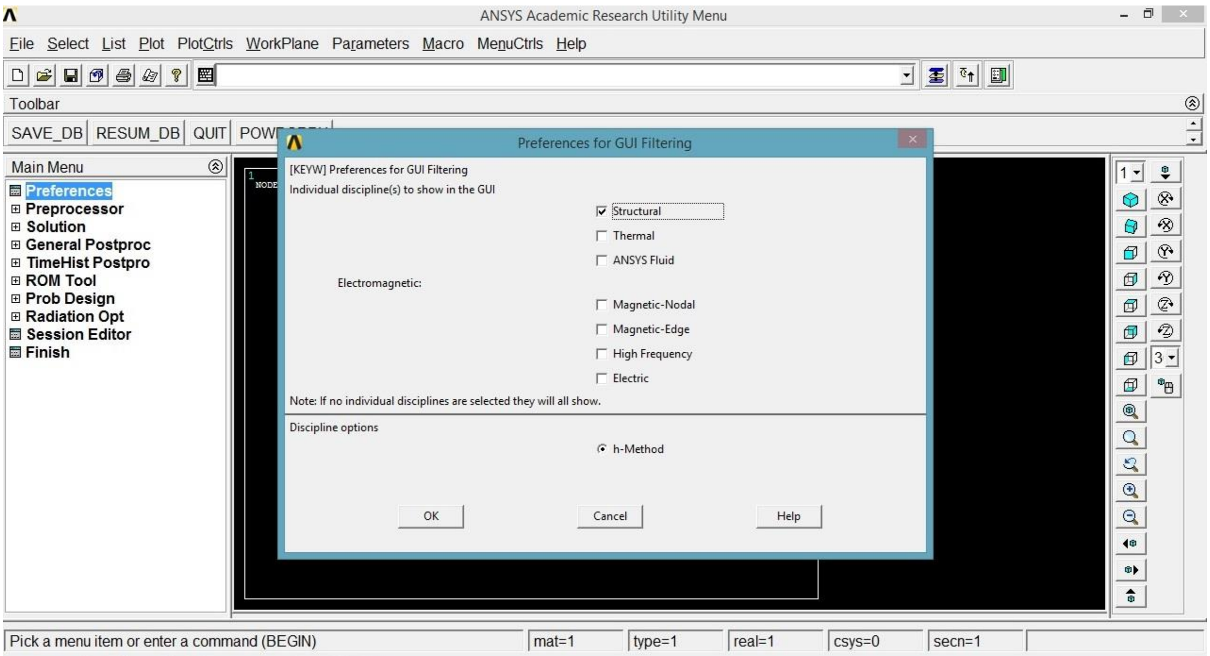
MODELLING IN ANSYS 15.0

5.1 Pre-requisites

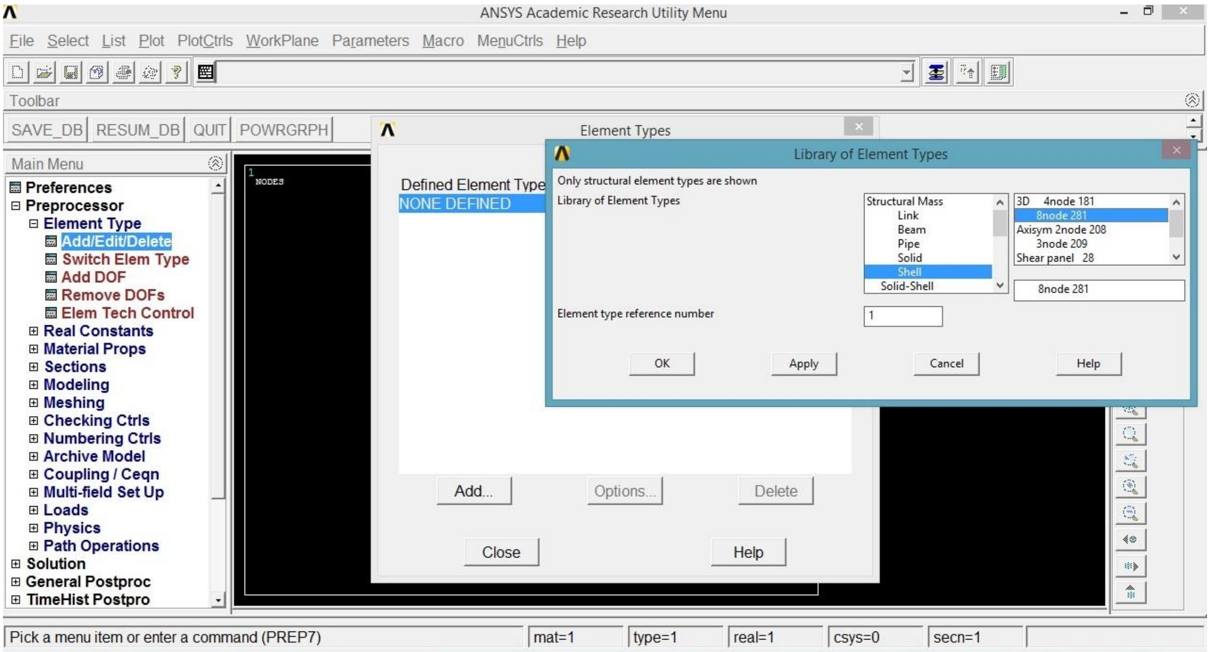
The experimental results for the vibration of the composite plate were validated with a finite element package ANSYS 15.0. The element used for modal analysis in ANSYS is SHELL 281. It is a 8-noded element. The whole field was divided into 8 x 8 meshes for all the boundary conditions. The boundary conditions for testing such as CFFF, CFCF and SFSF were applied in ANSYS by restraining motion and reducing DOF at each node.

5.2 Procedure for modelling in ANSYS

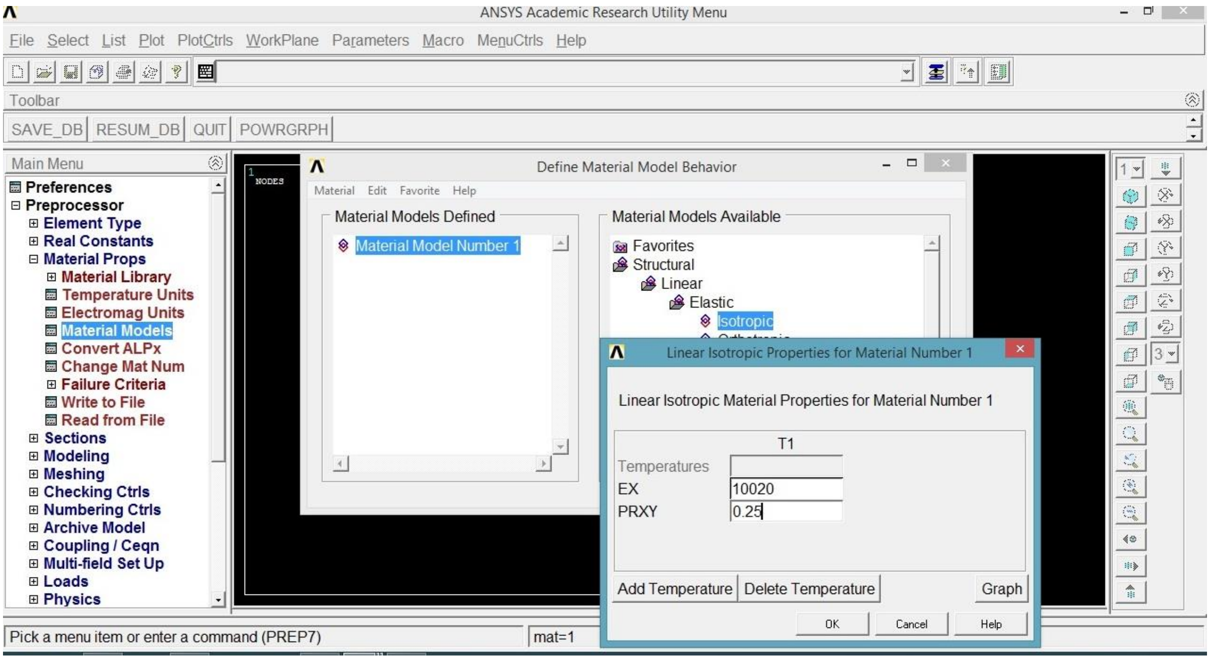
A. Click Preferences -> Go to Structural -> Click Ok



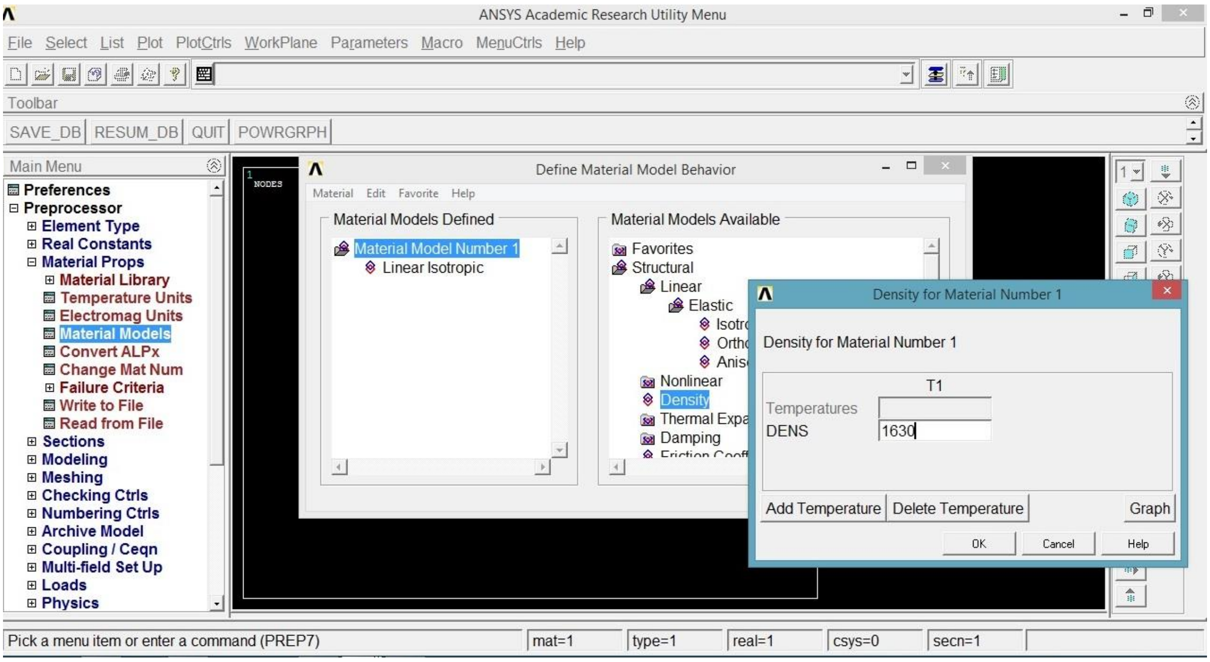
B. Click Preprocessor -> Choose Element Type -> Add/Edit/Delete -> Add -> Structural Mass -> Select Shell -> Select 8node 281 -> Click Ok



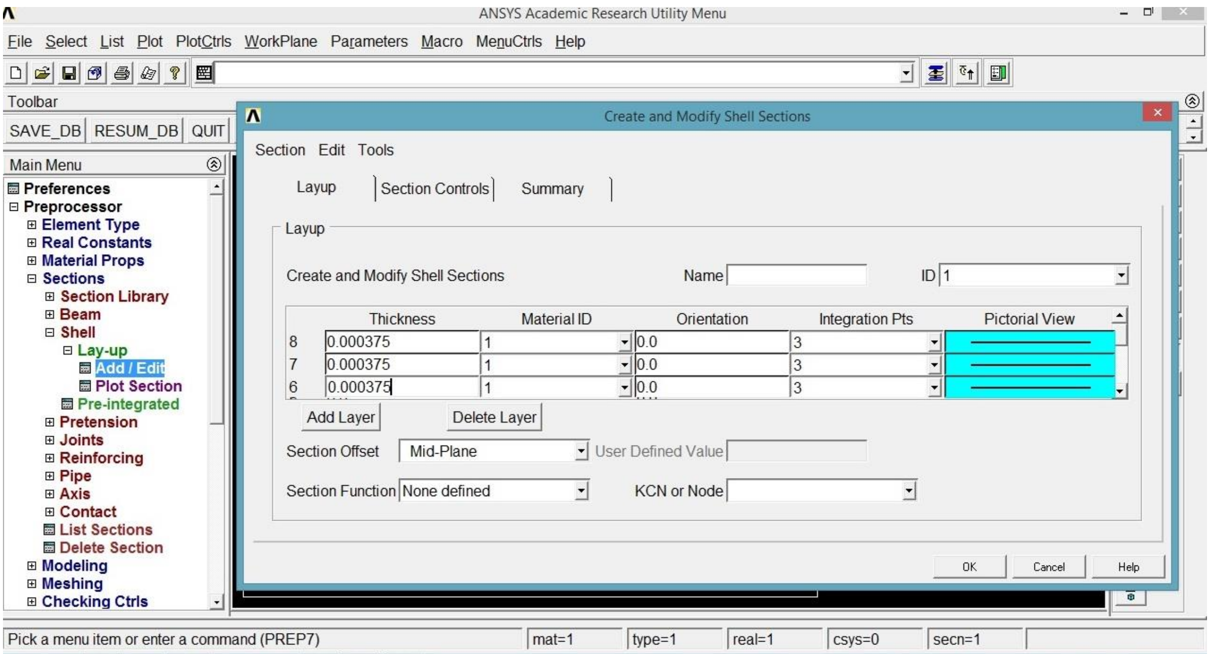
C. Click Preprocessor -> Material Props -> Choose Material Models -> Structural -> Linear -> Elastic -> Isotropic -> Enter material properties -> Click Ok



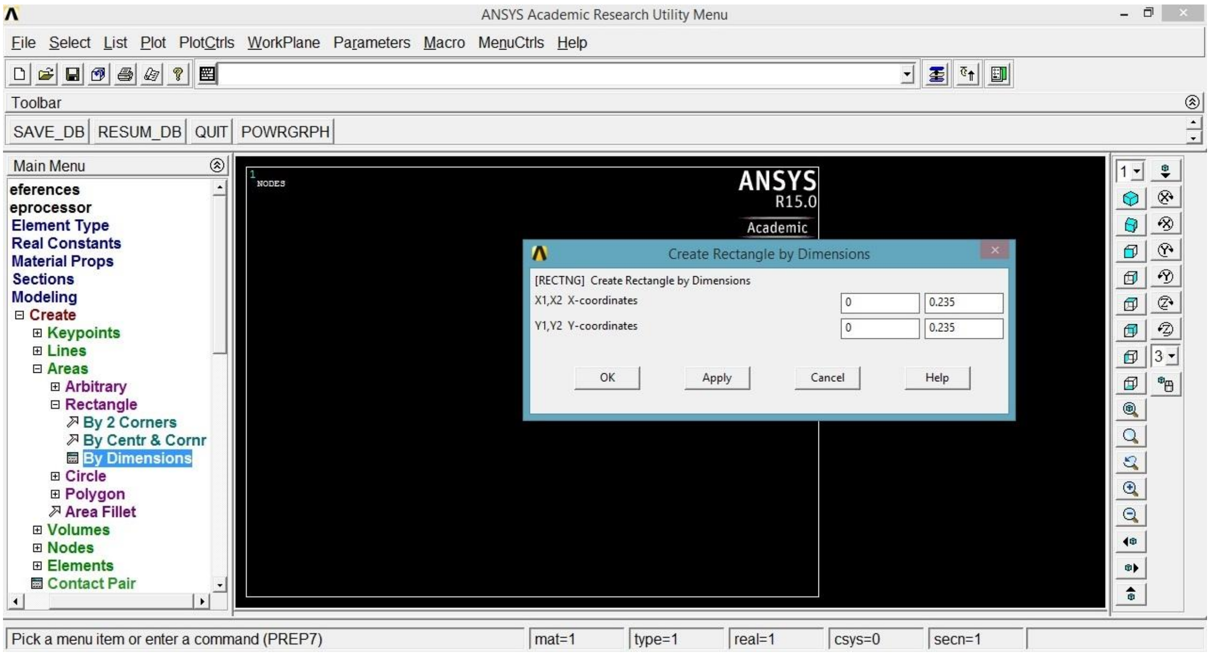
D. Enter the density of composite plate -> Click Ok



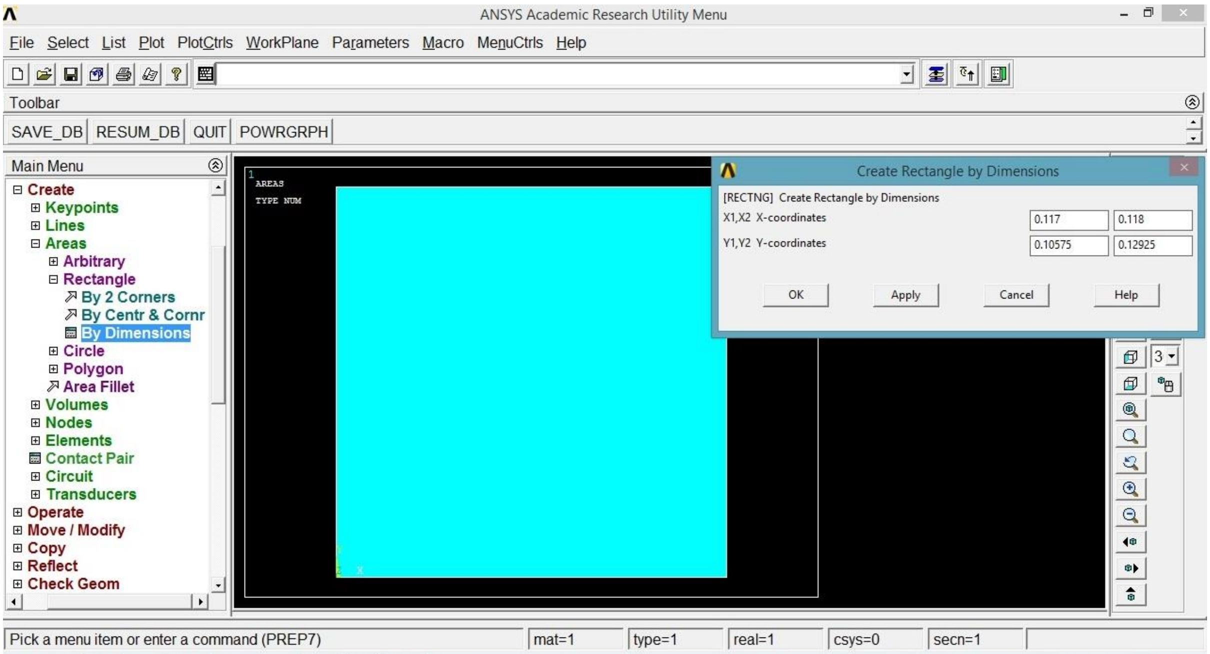
E. Click Preprocessor -> Sections -> Choose Shell -> Click Lay-up -> Add/Edit -> Add 8 layers and give the thickness of each individual layer -> Click Ok



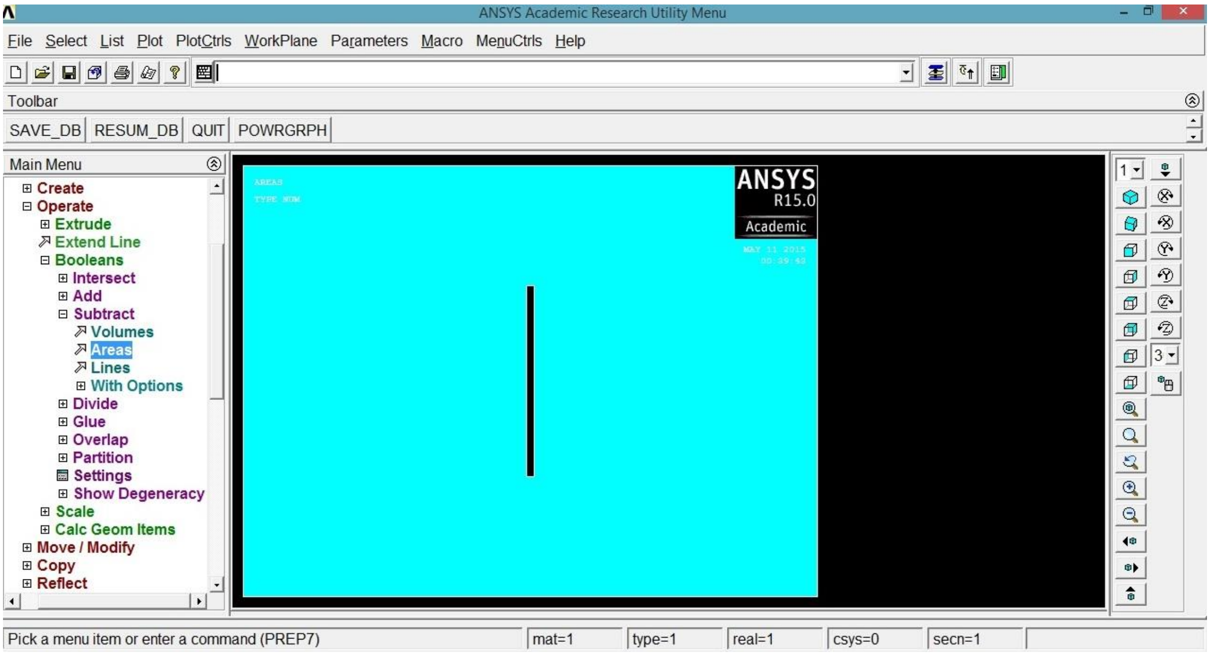
F. Click Preprocessor -> Choose Modelling -> Create -> Areas -> Rectangle -> By Dimensions -> Enter the dimensions of the required plate -> Click Ok



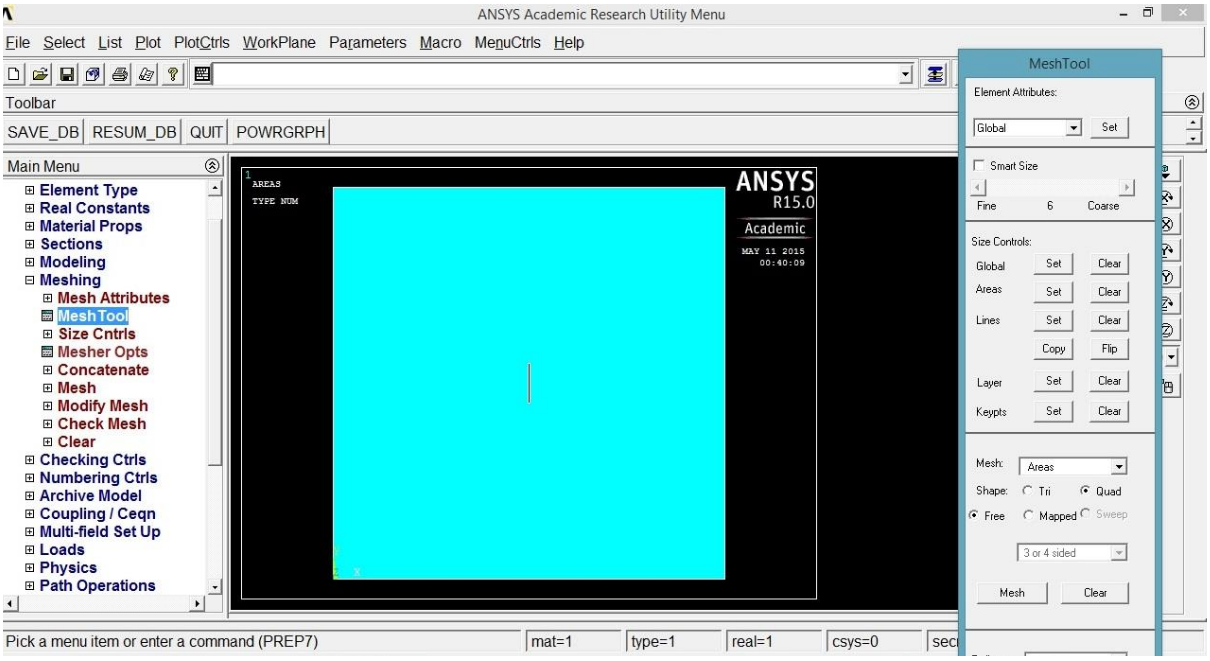
G. Create another rectangle over the existing one having the coordinates of vertices of rectangular crack



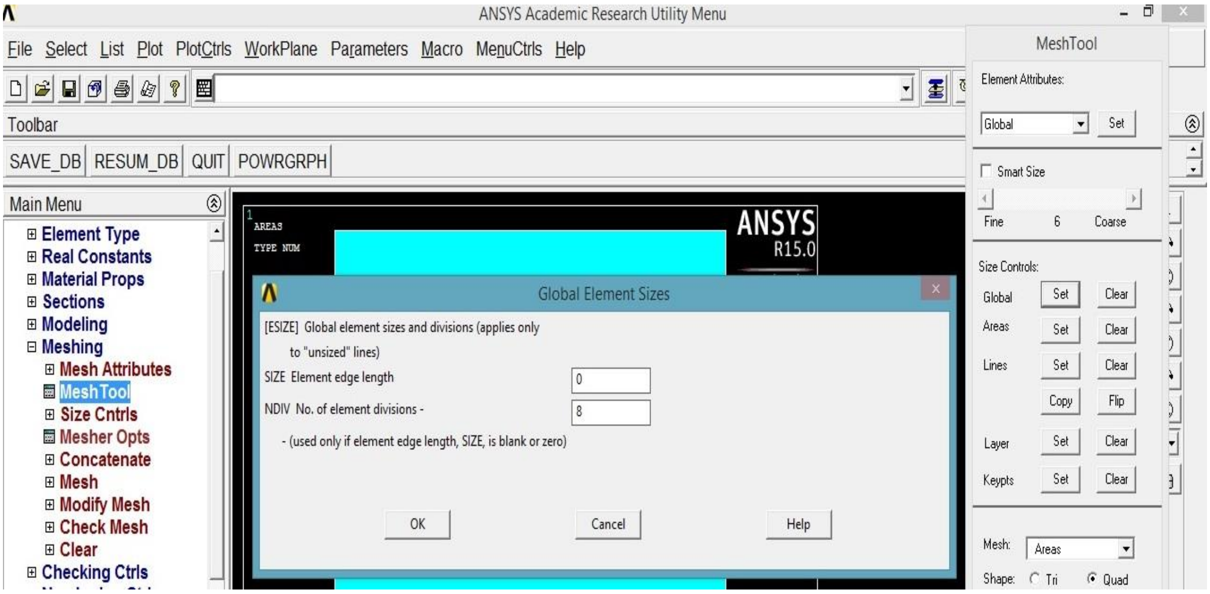
H. Click Preprocessor -> Click Modelling -> Operate -> Booleans -> Subtract -> Areas -> Enter 1 -> Click Ok -> Enter 2 -> Click Ok



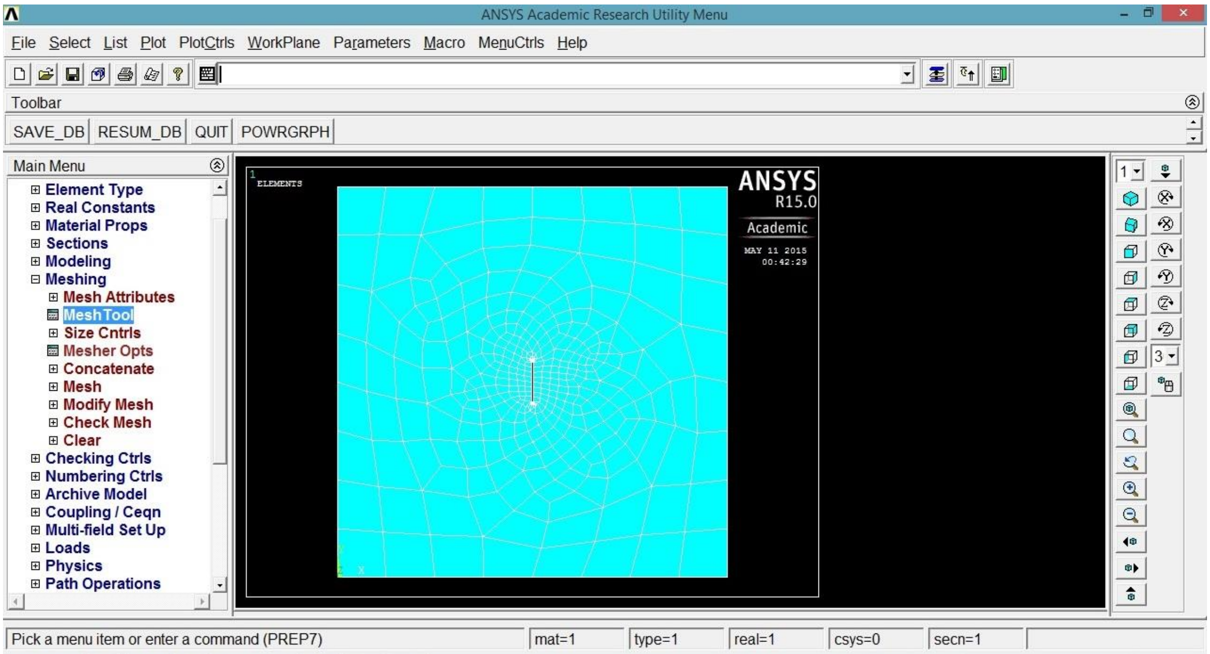
I. Click Preprocessor -> Click Meshing -> Click Mesh Tool



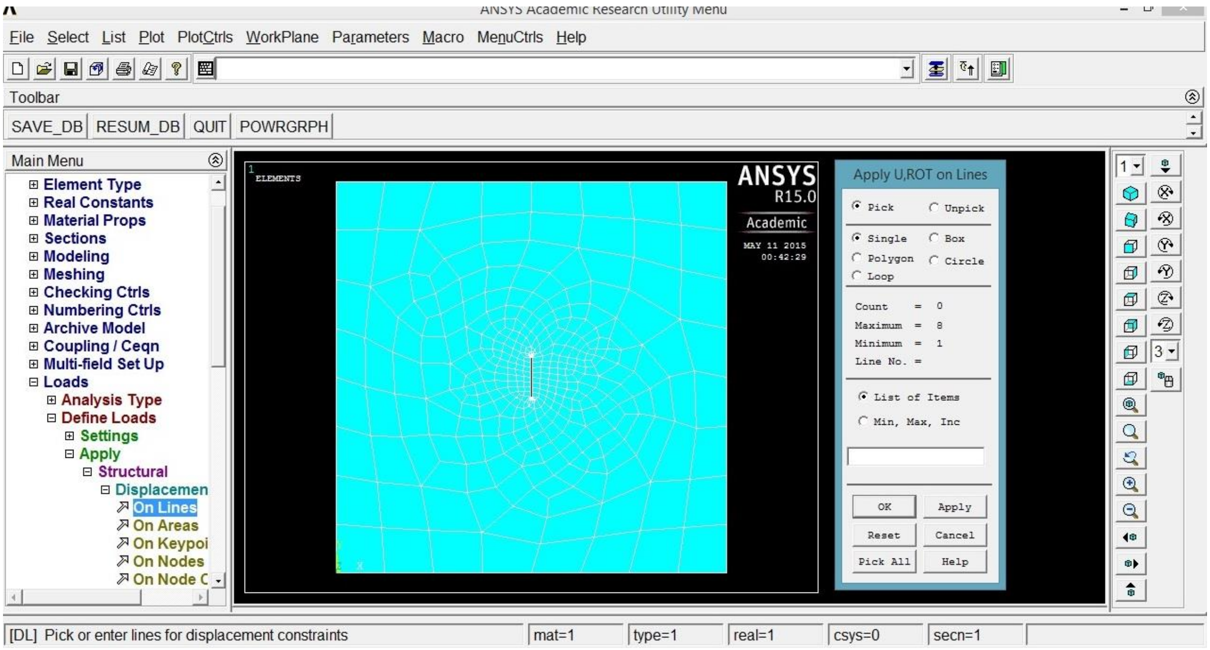
J. Mesh Tool -> Size Controls: Global -> Set -> Enter number of element divisions -> Click Ok

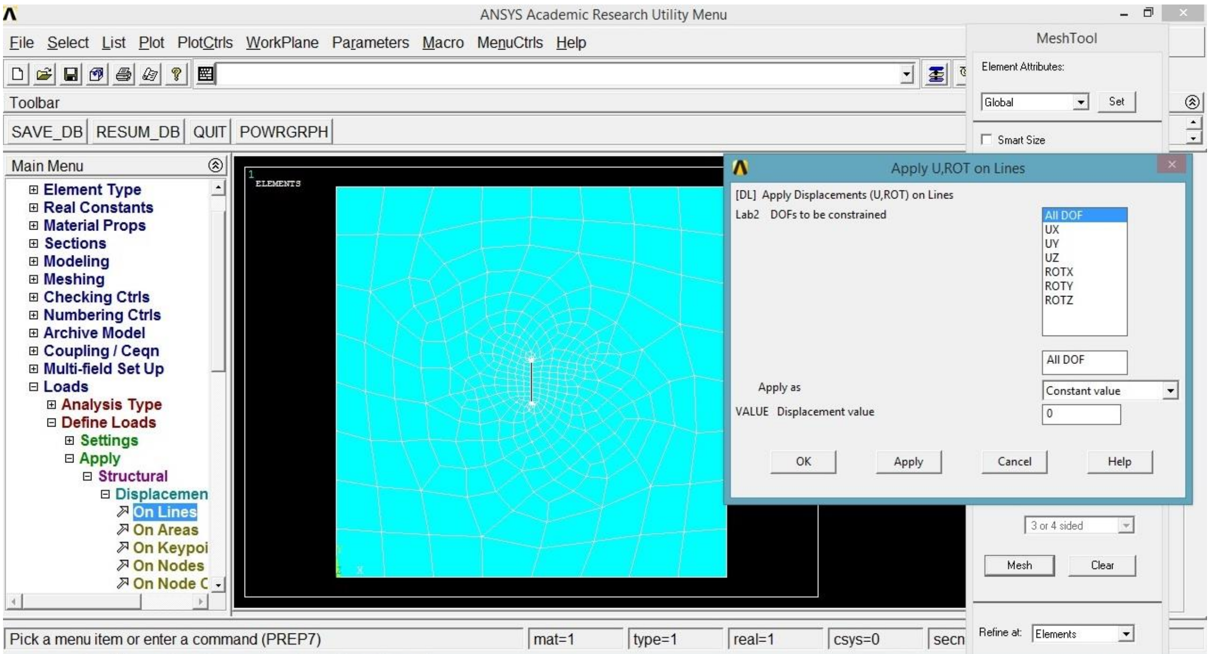


K. The meshing should look like this

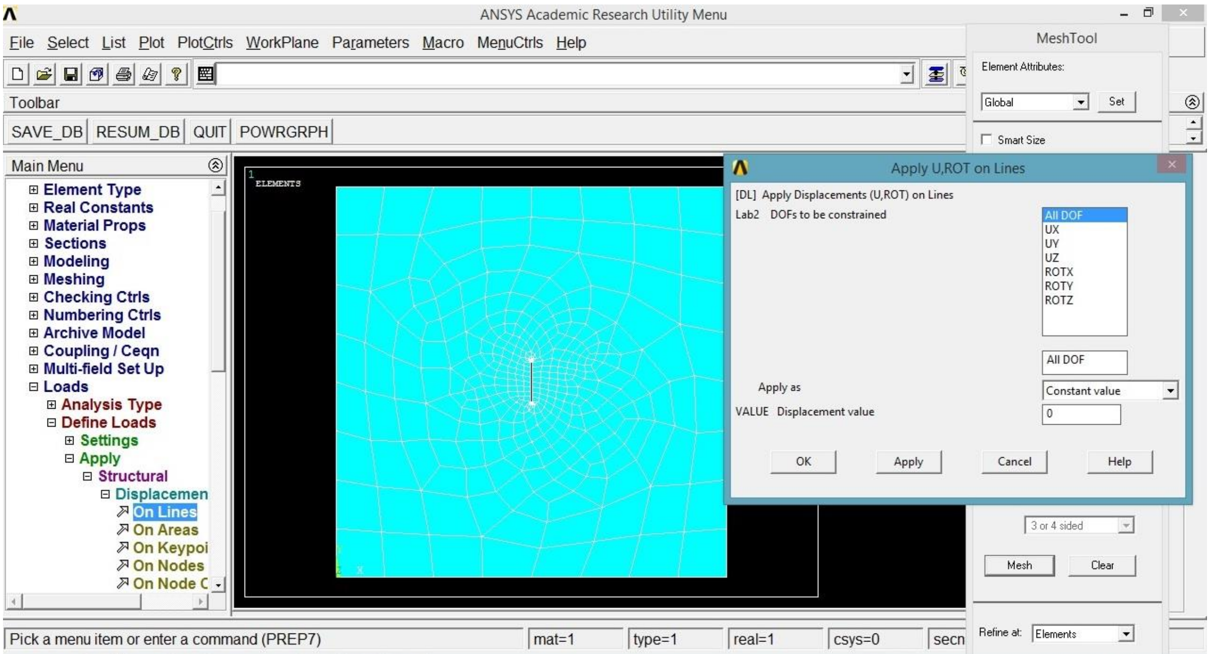


L. Click Preprocessor -> Loads -> Define Loads -> Apply -> Structural -> Displacement -> On lines -> Click on the edge on which the load is to be applied -> Choose the number of DOF to be restrained as per the boundary condition used -> Click Ok

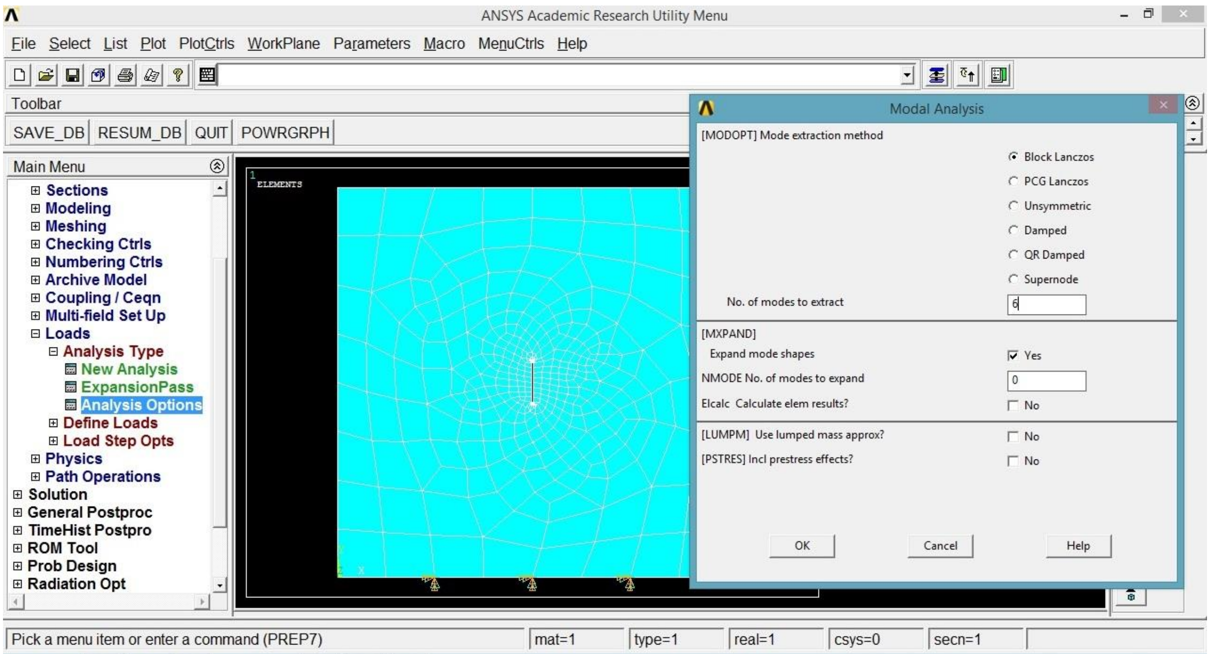




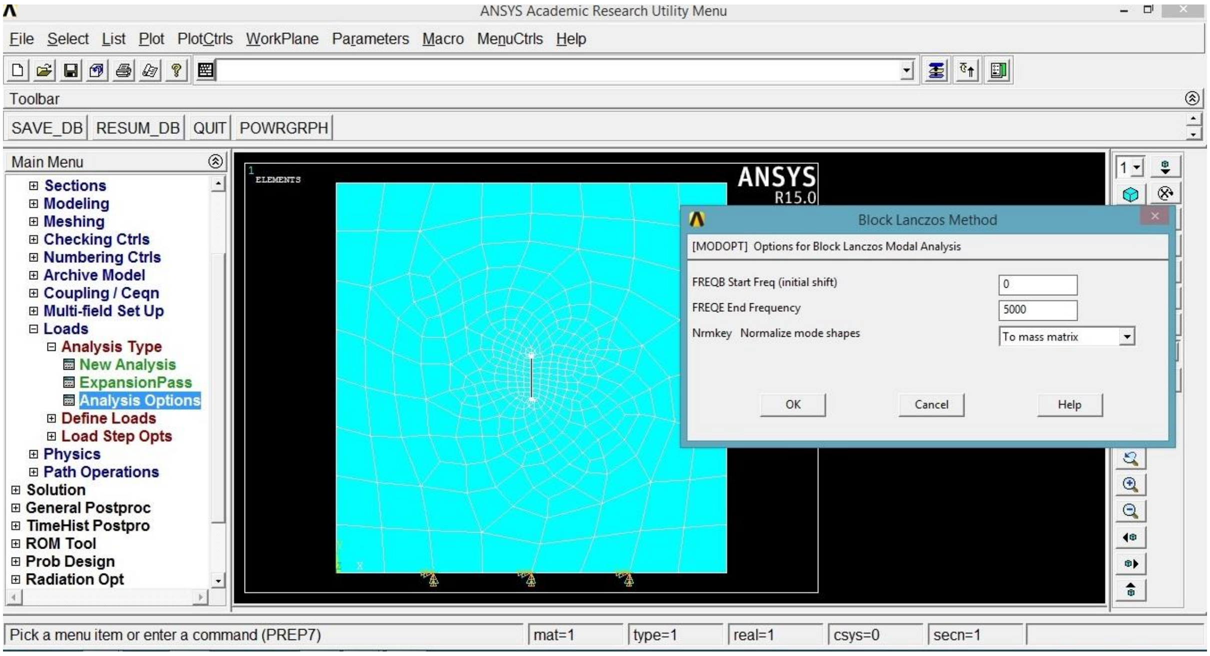
M. Click Preprocessor -> Click Loads -> Choose Analysis Type -> Click New Analysis -> Choose Type of Analysis = Modal -> Click Ok



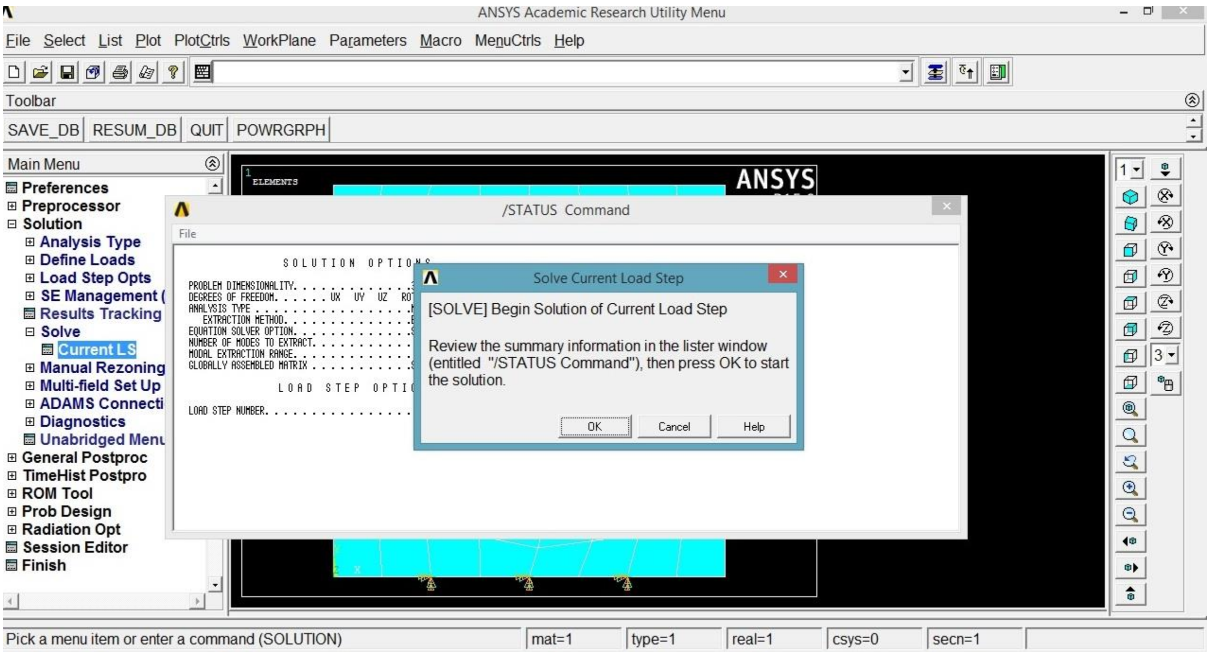
N. Click Preprocessor -> Click Loads -> Choose Analysis Type -> Analysis Options -> No. of modes to be extracted = 6 -> Click Ok



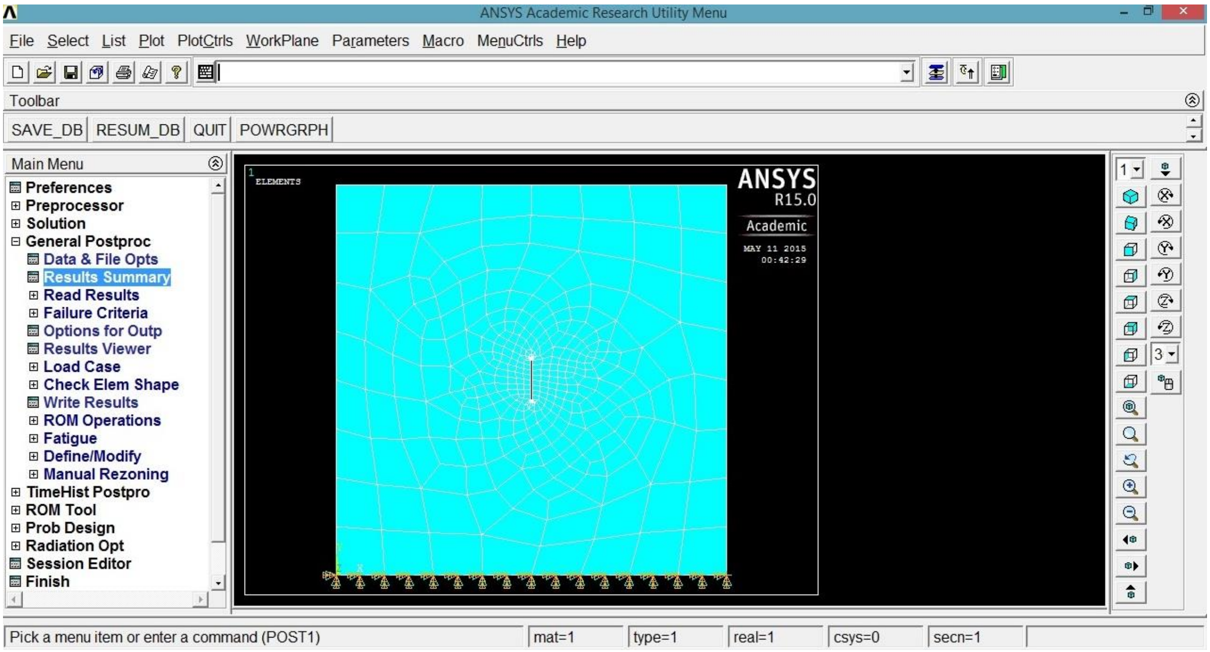
O. Block Lanczos Modal Analysis Options -> Give Start and End Frequency -> Click Ok



P. Click Solution -> Click Solve -> Choose Current LS -> Solve Current Load Step window pops up -> Click Ok



Q. For viewing results, Go to General Postprocessing -> Click Results Summary



CHAPTER 6

RESULTS AND DISCUSSIONS

The following results were obtained from the experiment on cracked composite plate and these vibration frequencies are compared with that obtained using ANSYS 15.0.

6.1 Vibration Testing Results of Glass Fibre Composite Plate

6.1.1 Effect of introduction of crack into the plate for different boundary conditions

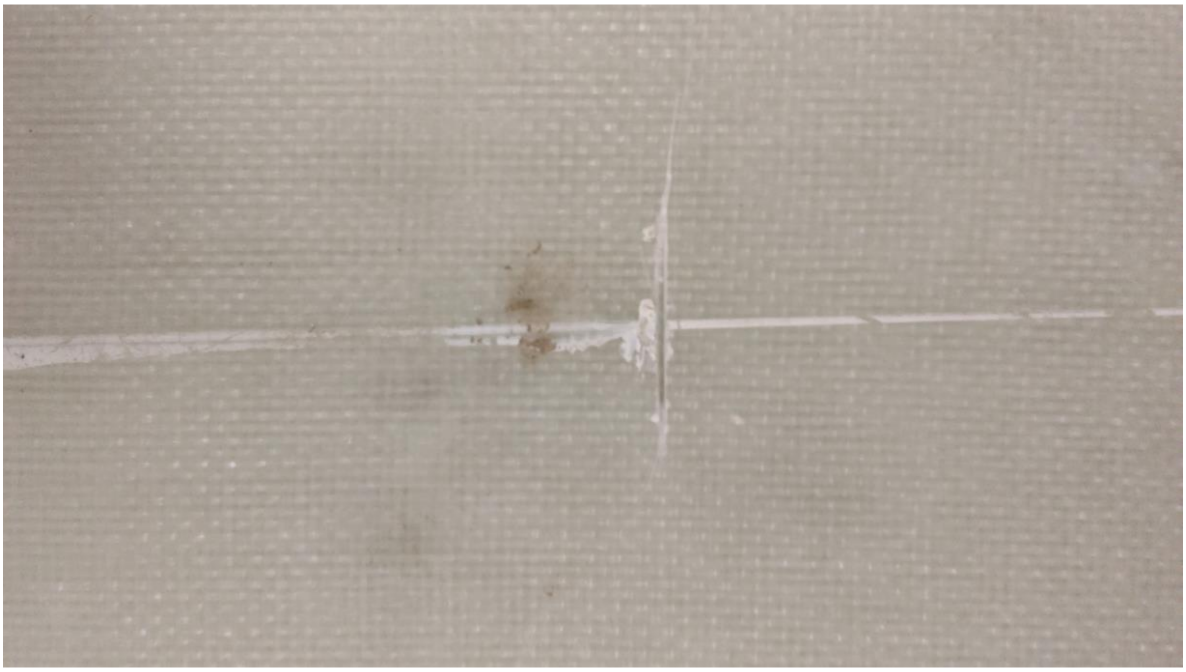


Figure 11: Crack in the Composite Plate

The frequencies for the first 3 modes in case of both cracked and uncracked composite plate are shown in table. The frequencies are shown in different boundary conditions and compared for both experimental and with ANSYS.

Using Crack dimension: Length (a) = 0.1L = 23.5 mm, Depth (d) = 0.5 mm

Table 3: Natural Frequencies (in Hz) of both cracked and uncracked composite plate in different boundary conditions

Boundary conditions	**Frequency modes**	**Plate without crack (Exp.)**	**Plate without crack (ANSYS)**	**Cracked plate (Exp.)**	**Cracked plate (ANSYS)**
FFFF	Mode 1	276	284.46	200	200.26
	Mode 2	404	432.81	356	372.42
	Mode 3	492	512.72	452	476
CFFF	Mode 1	184	192.15	172	174.67
	Mode 2	212	248.37	196	202.72
	Mode 3	360	387.24	344	350.60
CFCF	Mode 1	204	237.51	188	190.32
	Mode 2	292	312.14	256	280.57
	Mode 3	408	457.13	360	392.97
SFSF	Mode 1	196	212.67	180	178.24
	Mode 2	276	308.29	228	234.59
	Mode 3	384	426.32	352	358.57

It can be seen from the observations of the table that the natural frequency for all different boundary conditions decrease with the introduction of a crack. The crack is centrally located. It is due to reduction in the stiffness of the plate as the crack is introduced. The values of vibration frequency obtained with ANSYS are greater than experimental ones because the damping factor is not applied to the experimental values.

It is simply observed that the vibration frequency is greatest for FFFF condition and then follows the sequence CFCF > SFSF > CFFF. As the restrain at the support conditions increases, frequency also increases.

The variation of modal frequency for different boundary conditions are compared through the following figures:

Figure 12: Variation of natural frequency (in Hz) for cracked and uncracked plates in different boundary conditions

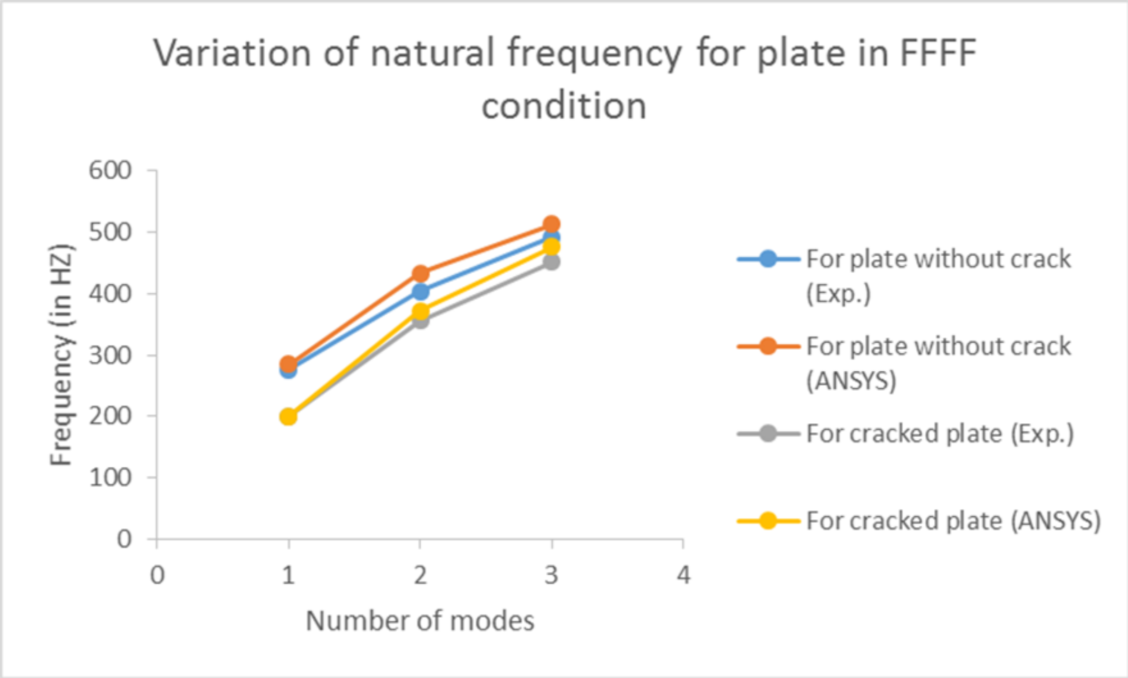


Figure 12(a): Variation of natural frequency for plate in FFFF condition

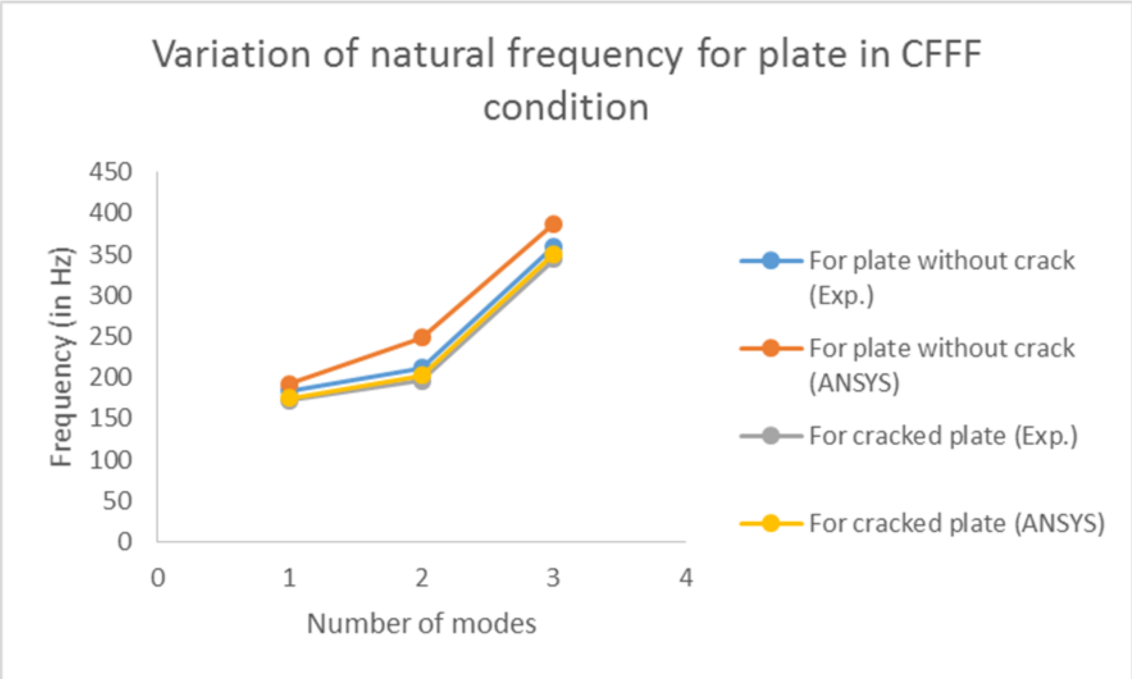


Figure 12(b): Variation of natural frequency for plate in CFFF condition

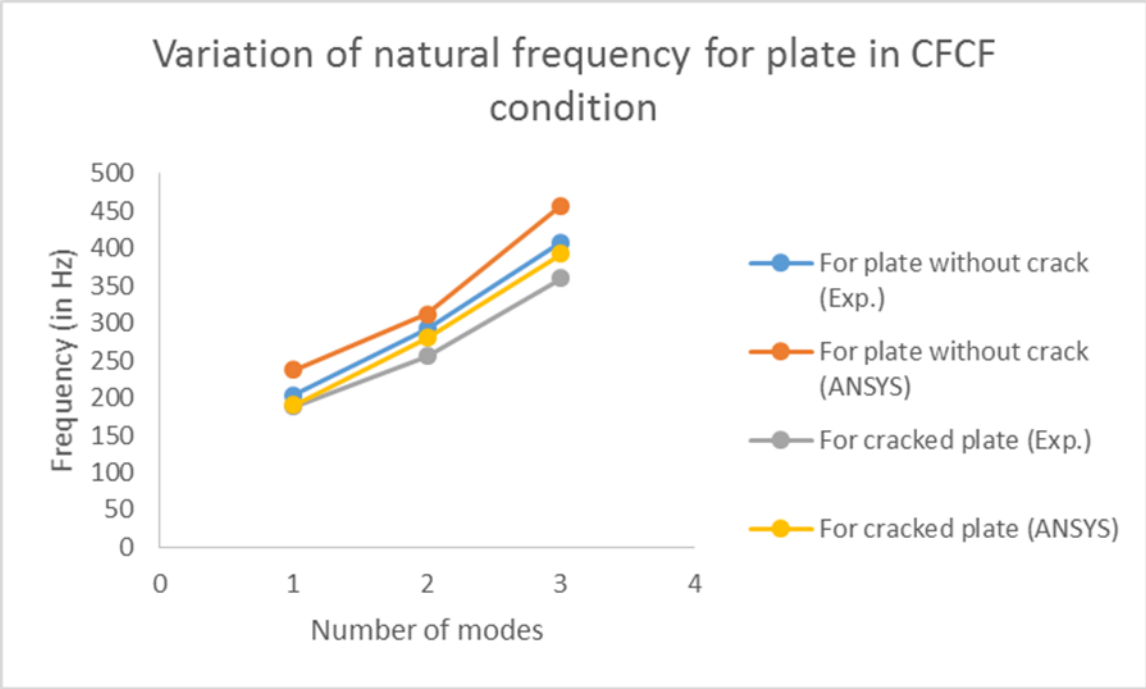


Figure 12(c): Variation of natural frequency for plate in CFCF condition

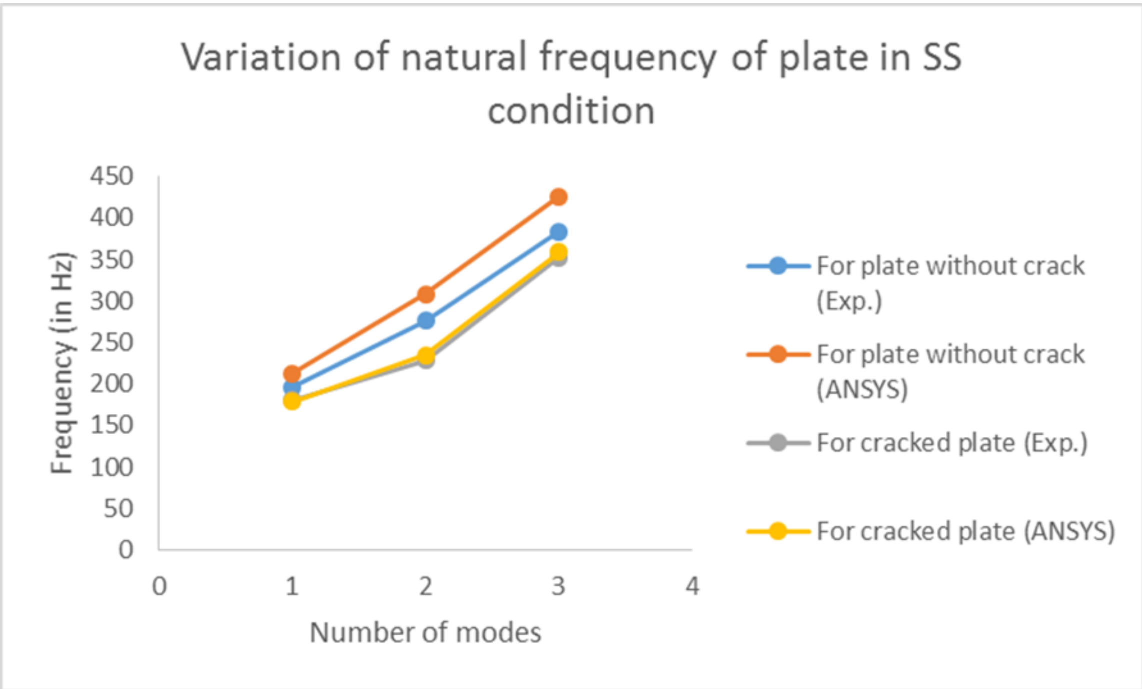


Figure 12(d): Variation of natural frequency of plate in SFSF condition

6.1.2 Effect of crack depth on natural frequency for different boundary conditions

The depth of the crack was varied as 0.5 mm, 1 mm and 2 mm. The total thickness of the composite was 3 mm. The crack length was same for all cases (a = 23.5 mm). The frequency obtained from experiment was validated using ANSYS and the values are shown in the table

A. Crack Length (a) = 23.5 mm, crack depth (d) = 0.5 mm

Table 4: Natural frequency (in Hz) of cracked plate for depth d = 0.5 mm

Boundary conditions	**Frequency modes**	**Cracked Plate (Exp.)**	**Cracked Plate (ANSYS)**
CFFF	Mode 1	172	174.67
	Mode 2	196	202.72
	Mode 3	344	350.60
CFCF	Mode 1	188	190.32
	Mode 2	256	280.57
	Mode 3	360	392.97
SFSF	Mode 1	180	178.24
	Mode 2	228	234.59
	Mode 3	352	358.57

B. Crack Length (a) = 23.5 mm, crack depth (d) = 1 mm

Table 5: Natural frequency (in Hz) of cracked plate for depth d = 1 mm

Boundary conditions	**Frequency modes**	**Cracked plate (Exp.)**	**Cracked Plate (ANSYS)**
CFFF	Mode 1	168	173.76
	Mode 2	184	201
	Mode 3	336	349.94
CFCF	Mode 1	180	188.35
	Mode 2	244	278.78
	Mode 3	348	392.40
SFSF	Mode 1	172	177.63
	Mode 2	216	230.38
	Mode 3	344	356.97

C. Crack Length (a) = 23.5 mm, crack depth (d) = 2 mm

Table 6: Natural frequency (in Hz) of cracked plate for depth d = 2 mm

Boundary conditions	**Frequency modes**	**Cracked Plate (Exp.)**	**Cracked Plate (ANSYS)**
CFFF	Mode 1	162	168.53
	Mode 2	176	198.26
	Mode 3	324	347.65
CFCF	Mode 1	172	187.45
	Mode 2	236	274.82
	Mode 3	344	390.42
SFSF	Mode 1	166	175.28
	Mode 2	208	228.95
	Mode 3	332	352.47

It can be concluded from the observations that the natural frequency of vibration of the composite plate decreases with increase in depth of the crack. The similar trend is observed for all the three boundary conditions used for testing. The variations of natural frequency with different crack depths for different boundary conditions are shown in the following figures:

Figure 13: Variation of frequency (in Hz) for different crack depths in different boundary conditions

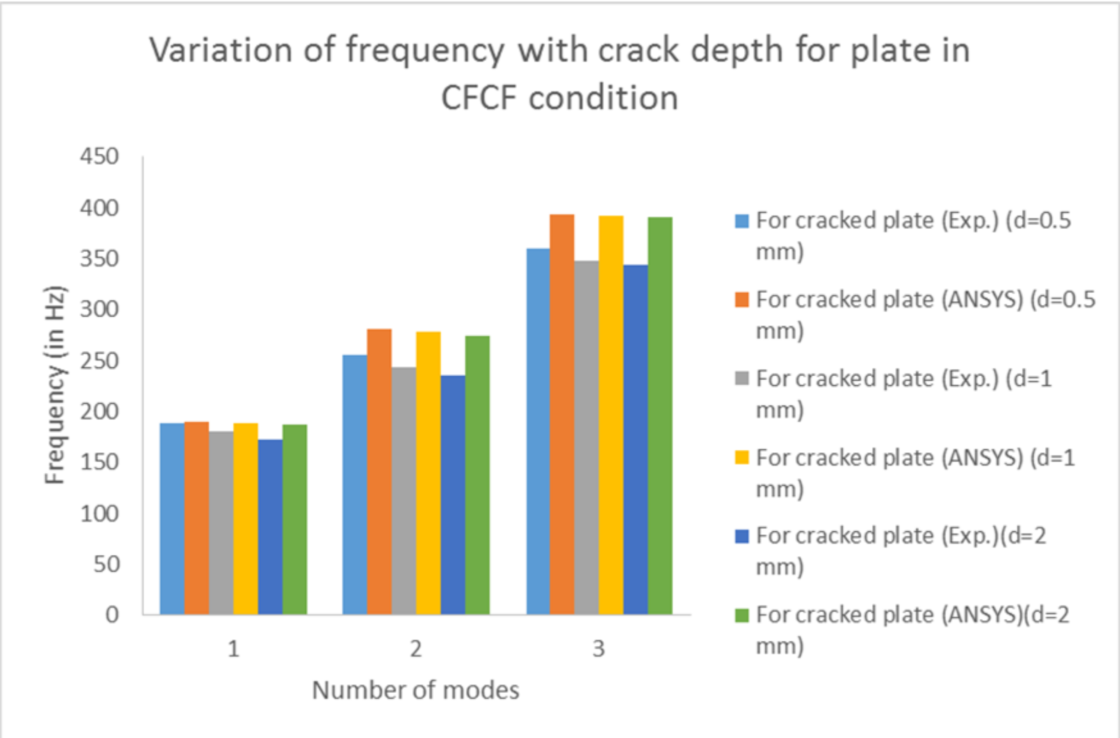


Figure 13(a): Variation of frequency with crack depth for plate in CFCF condition

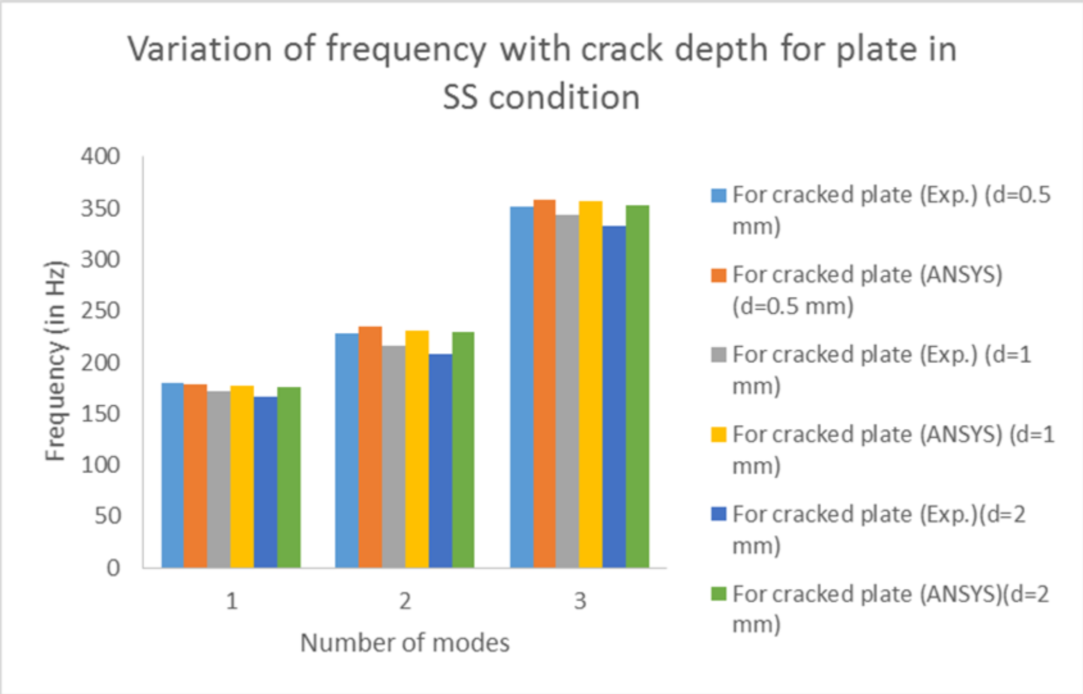


Figure 13(b): Variation of frequency with crack depth for plate in SFSF condition

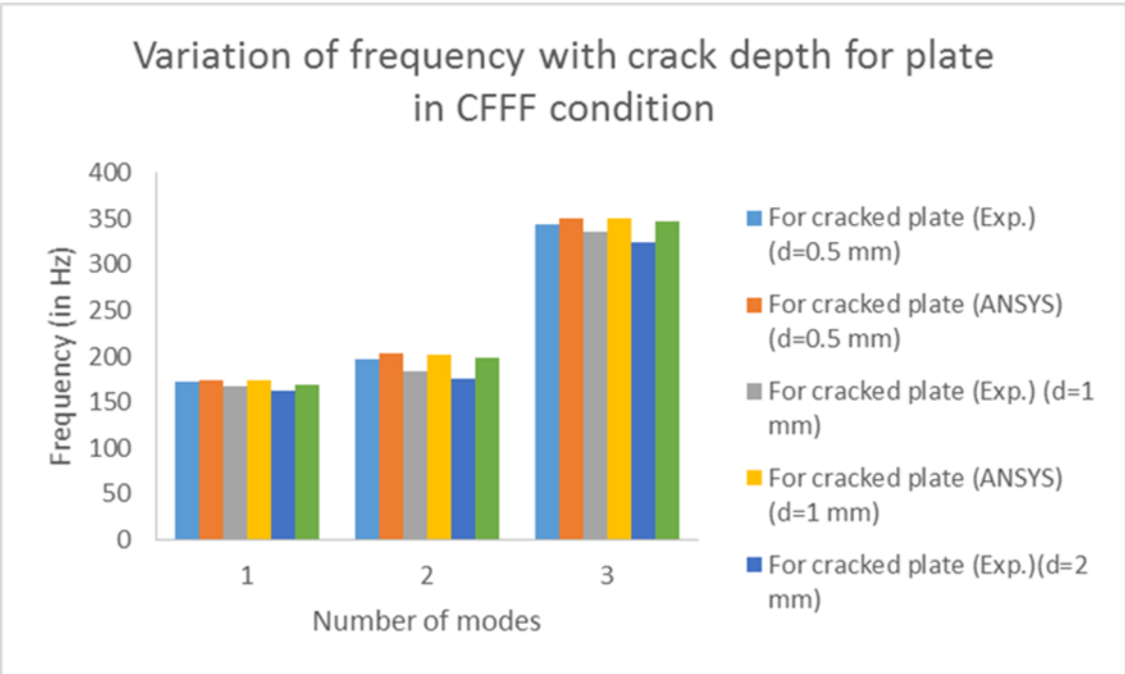


Figure 13(c): Variation of frequency with crack depth for plate in CFFF condition

6.1.3 Effect of crack length on natural frequency for different boundary conditions

This is the most effective parameter among all the crack parameters considered for the vibration testing of the composite plate. The length of the crack was varied as different aspect ratios (a/L) were taken. The aspect ratios for which it was tested were 0.1, 0.2 and 0.5. The length of the crack were calculated as 23.5 mm, 47 mm and 117.5 mm respectively. The depth of the crack was however kept constant, i.e., d = 1 mm. The results have been shown in the following tables.

A. Crack length(a) = 0.1L = 23.5 mm, crack depth (d) = 1 mm

Table 7: Natural frequency (in Hz) for crack length a = 23.5 mm

Boundary conditions	**Frequency modes**	**Cracked plate (Exp.)**	**Cracked Plate (ANSYS)**
CFFF	Mode 1	168	173.76
	Mode 2	184	201
	Mode 3	336	349.94
CFCF	Mode 1	180	188.35
	Mode 2	244	278.78
	Mode 3	348	392.40
SFSF	Mode 1	172	177.63
	Mode 2	216	230.38
	Mode 3	344	356.97

B. Crack length(a) = 0.2L = 47 mm, crack depth (d) = 1 mm

Table 8: Natural Frequency (in Hz) for crack length a = 47 mm

Boundary conditions	**Frequency modes**	**Cracked plate (Exp.)**	**Cracked Plate (ANSYS)**
CFFF	Mode 1	156	170.81
	Mode 2	180	200.95
	Mode 3	316	345.82
CFCF	Mode 1	172	185.53
	Mode 2	236	272.30
	Mode 3	340	392.40
SFSF	Mode 1	164	175.22
	Mode 2	212	228.88
	Mode 3	328	353.82

C. Crack length(a) = 0.5L = 117.5 mm, crack depth (d) = 1 mm

Table 9: Natural Frequency (in Hz) for crack length a = 117.5 mm

Boundary conditions	Frequency modes	Cracked plate (Exp.)	Cracked Plate (ANSYS)
CFFF	Mode 1	144	154.92
	Mode 2	176	194.59
	Mode 3	308	332.82
CFCF	Mode 1	164	166.01
	Mode 2	232	247.77
	Mode 3	332	382.28
SFSF	Mode 1	160	162.63
	Mode 2	196	203.35
	Mode 3	300	301.26

From the above results, we can conclude that the vibration natural frequency of the plate decreases with increase in length of the crack. This indicates that frequency varies with stiffness of the plate and it decreases when stiffness does too. The comparison between the effects of different crack lengths is shown in the following figures.

Figure 14: Variation of natural frequency (in Hz) with length of crack in different boundary conditions

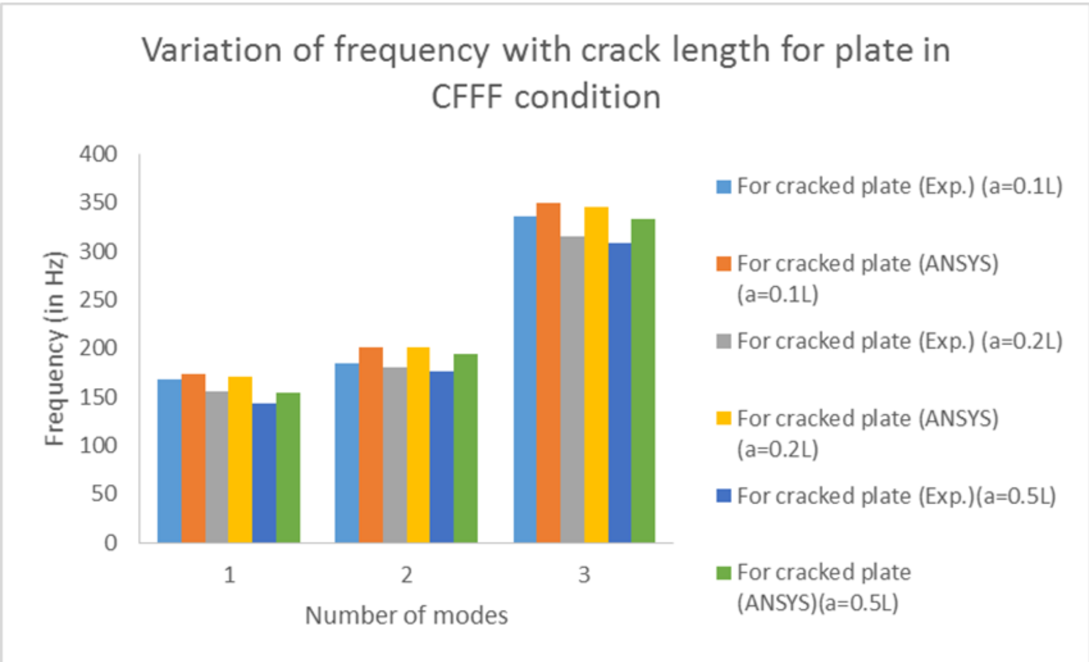


Figure 14(a): Variation of frequency with crack length for plate in CFFF condition

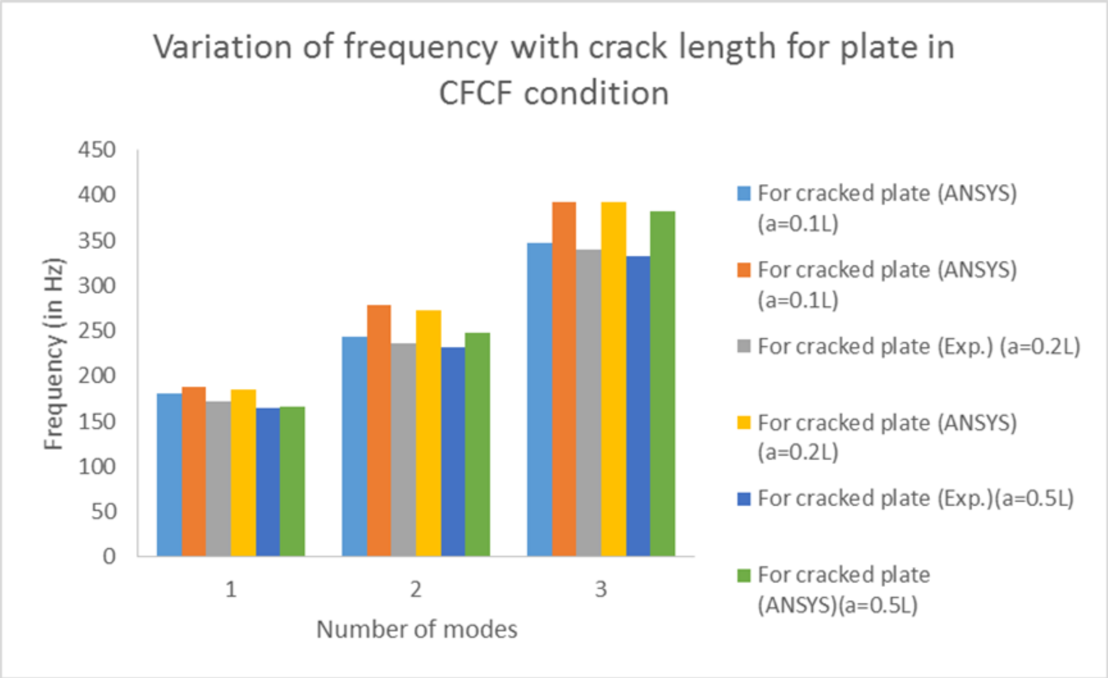


Figure 14(b): Variation of frequency with crack length for plate in CFCF condition

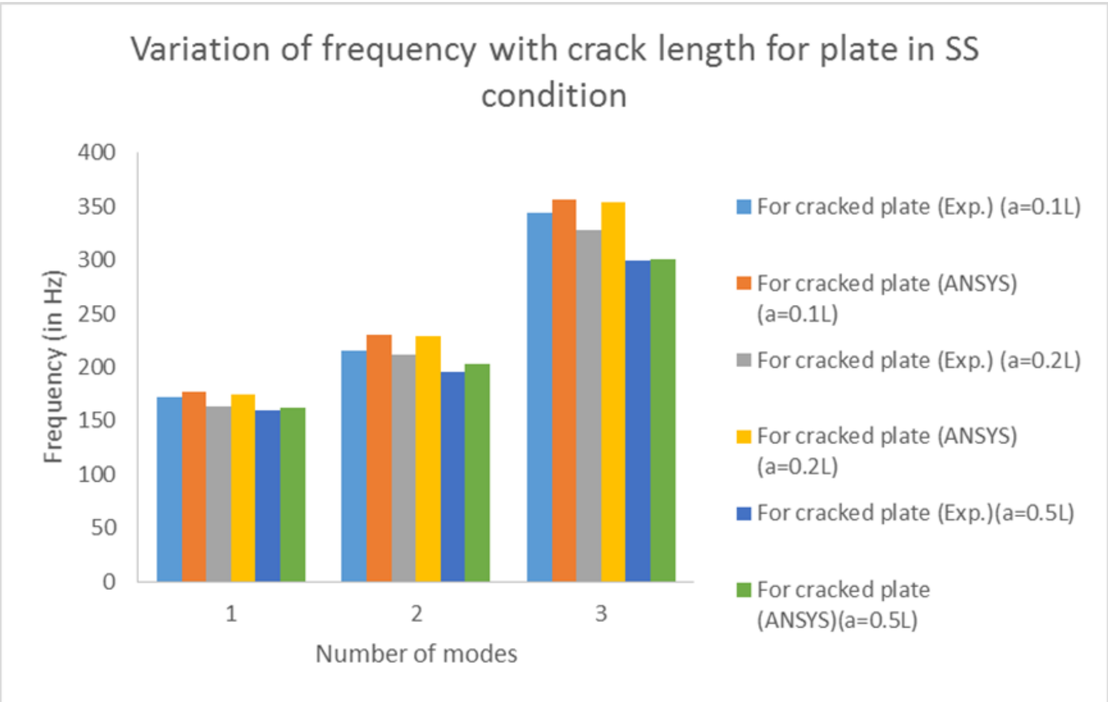


Figure 14(c): Variation of frequency with crack length for plate in SFSF condition

6.1.4 Effect of crack orientation on natural frequency for different boundary conditions

The orientation of crack was initially 90 degrees. Then it was changed to 45 degrees. The orientation was measured with respect to the horizontal glass fibres of the composite plate. However, the length and depth of the crack were kept constants (a = 23.5 mm, d = 1 mm). The results of the experiment and that obtained from ANSYS have been tabulated below.

For crack length (a) = 23.5 mm, depth (d) = 1 mm

Table 10: Natural Frequency (in Hz) for plate in 90 and 45 degrees orientations

Boundary conditions	**Frequency mode**	**90 degree (exp.)**	**90 degree (ANSYS)**	**45 degree (exp.)**	**45 degree (ANSYS)**
CFFF	Mode 1	168	173.76	200	211.41
	Mode 2	184	201	228	234.26
	Mode 3	336	349.94	356	358.94
CFCF	Mode 1	180	188.35	188	191.25
	Mode 2	244	278.78	248	280.45
	Mode 3	348	392.40	372	408.36
SFSF	Mode 1	172	177.63	192	196.28
	Mode 2	216	230.38	244	247.71
	Mode 3	348	356.97	368	371.18

From the above results, it can be induced that frequency decreases by lesser amount when a crack is introduced at an angle rather than perpendicular to the direction of fibres. And also the trend is similar for complementary angles. The variation of natural frequency with orientation of crack in different boundary conditions is expressed in figures below.

Figure 15: Variation of natural frequency (in Hz) with different crack orientations in different boundary conditions

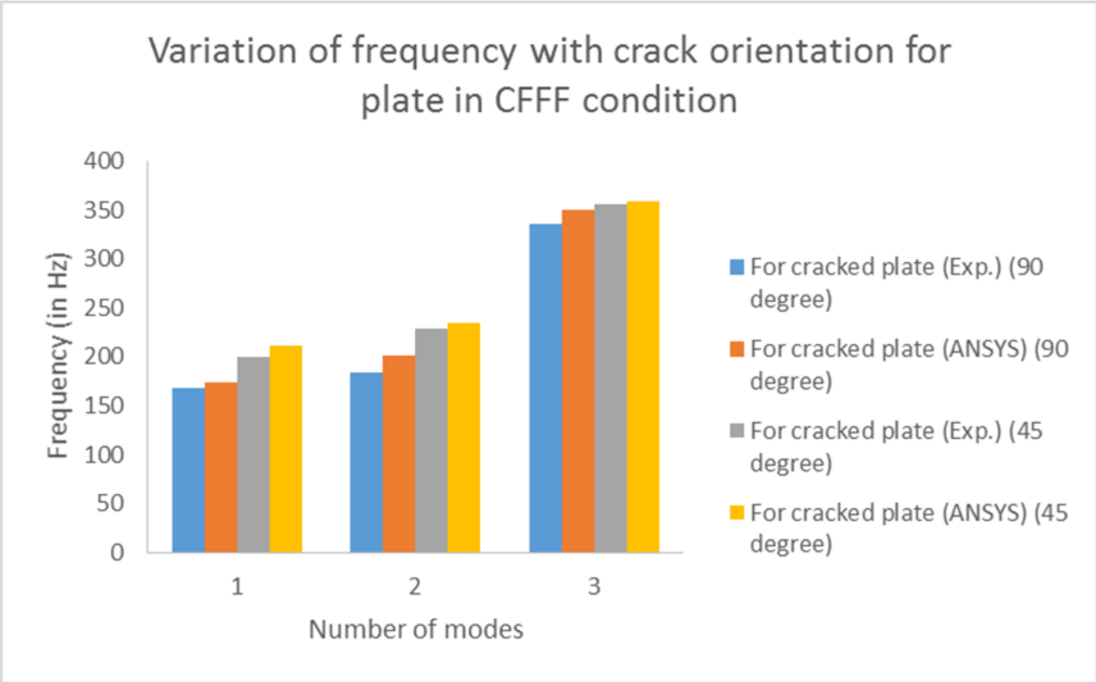


Figure 15(a): Variation of frequency with crack orientation for plate in CFFF condition

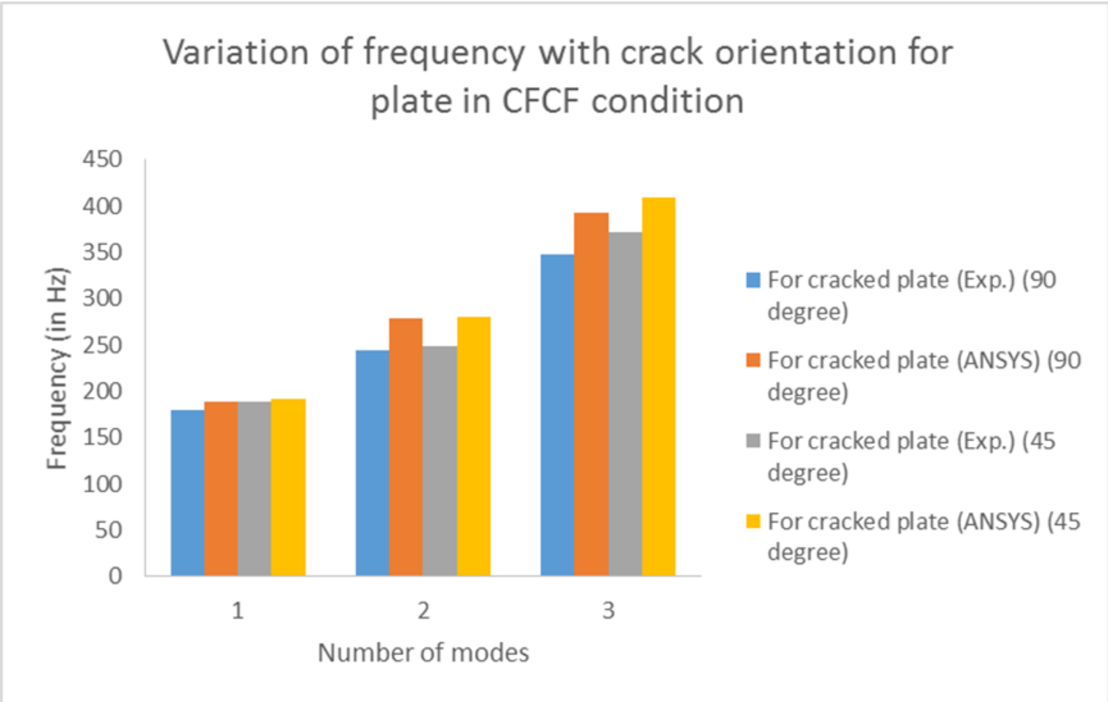


Figure 15(b): Variation of frequency with crack orientation for plate in CFCF condition

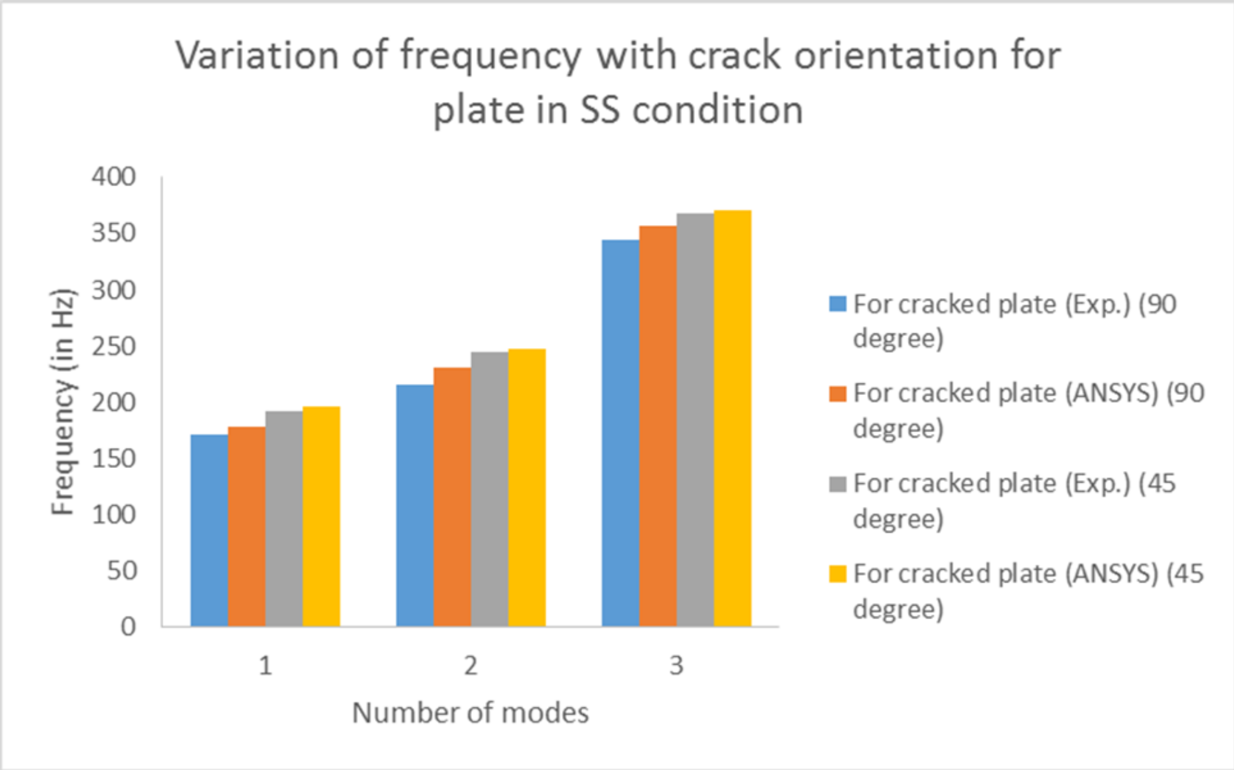


Figure 15(c): Variation of frequency with crack orientation for plate in SFSF condition

CHAPTER 7

CONCLUSION

7.1 Conclusion

The whole study deals with vibration testing of the fabricated composite plates to determine the natural frequency of vibration so as to prevent damages in structures due to the phenomenon of resonance. In the initial stages, composite plates were fabricated using the simple hand layup technique. Then the plates were cut into specimens of size 235 mm x 235 mm for vibration testing using FFT analyser and pulse software. A crack was introduced centrally in the plate to study the effects of varying parameters. The natural frequencies for first three modes were determined from the Frequency Response Function obtained in the Pulse Lab Software. The tests were conducted varying different crack parameters like depth of crack, length of crack and orientation of crack. The results obtained from the experiments were thus compared with those obtained by using the finite element package ANSYS 15.0.

The various conclusions obtained from this study are:

- The composite plates can be casted easily using the Hand Layup technique.
- The natural frequency at which the plate vibrates decreases with the introduction of a crack.
- The natural frequency is highest for the FFFF boundary condition and then follows the sequence CFCF > SFSF > CFFF.
- If the depth of the crack increases, then the frequency of vibration of the plate decreases.
- Natural frequency of vibration also decreases with the increase in length of the crack.
- The frequency varies with the orientation of crack, so it increases if the orientation is changed from 90 degrees to 45 degrees. It is maximum at 45 degrees.
- The values obtained by using ANSYS software are greater than the experimental values.

7.2 Scope for future work

The current study of vibration analysis of cracked glass fibre composite plates can be expanded to the following arenas:

- Study of Hygrothermal effects on the natural vibration frequency of cracked composite plates.
- Study of buckling characteristics of composite plate with crack and study of Hygrothermal effects on the buckling characteristics of the plate.
- Study of vibrational characteristics on delaminated specimens of glass fibre composite plate with crack.
- Study of vibration characteristics of cracked composite plates made of carbon fibres and also cracked hybrid composite plates.
- Study of vibration characteristics of cracked composite plate in many more boundary conditions and other different crack parameters.

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