MODAL ANALYSIS OF NOTCHED BEAM

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MODAL ANALYSIS OF NOTCHED BEAM

NAEEM BIN ZULKIFLE

Report submitted in partial fulfillment of the requirements
For the award of the degree of
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Faculty of Mechanical Engineering
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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled *"Modal Analysis of Notched Beam"* is written by *Naeem Bin Zulkifle.* I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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I hereby declare that I have checked this project and in my opinion this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT’S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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I humbly dedicate this thesis to

my lovely mom and dad, Ziayah Md Idris and Zulkifle Mohammad
my elder brother, Haneef
my dearest sister, Syahidah Nadhirah
my dearest brother, Abdullah Zaid, Mohd Ridhuan, Umayr,
Ahmad Faheem, Mohd Akram

who always trust me, love me and had been a great source of support and motivation.

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ABSTRACT

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. The purpose of this study is to determine the dynamic behavior of notched beam for various distances and notch size and their effect on natural frequency. In this project, six beams are used to perform in simulation and experimental hammer test. Finite Element Analysis (FEA) comprise of a computer model of a material that is stressed and analyzed for specific results. ALGOR Fempro is used to analyze the model that build in SOLIDWORK. After modeling the beam with dimension as desired in Solidwork software, CAE Analysis or ALGOR Fempro used to simulate the beam to obtain natural frequency. The finite element model of the components was analyzed using the Natural Frequency (modal) approaches. Finally, the natural frequency obtain from the result of analysis are known as simulation result. In the experimental hammer test, natural frequencies are obtained from Frequency Response Function (FRF) graph using PULSE Labshop Software. Relationship between results of experimental and simulation showed the effect of notch on beam with both distance and depth. It is shown that the natural frequency is decreasing with the increasing of distance of notch and depth of notch on beams.

ABSTRAK

Analisis Modal adalah kajian tentang sifat-sifat dinamik dari struktur di bawah eksitasi getaran. Tujuan dari penelitian ini adalah untuk menentukan perilaku dinamik dari angka berlekuk untuk jarak dan saiz lekukan dan kesannya pada frekuensi semulajadi. Dalam projek ini, enam model digunakan untuk digunakan di simulasi dan eksperimen uji palu. Analisis Elemen Infiniti (FEA) terdiri daripada sebuah model komputer dari suatu material yang stres dan dianalisis untuk mendapatkan hasil tertentu. ALGOR Fempro digunakan untuk menganalisis model yang dimodelkan di Solidwork. Setelah pemodelan angka dengan dimensi yang dikehendaki dalam perisian solidwork, CAE Analisis atau ALGOR Fempro digunakan untuk mensimulasikan sinar untuk mendapatkan frekuensi semulajadi. Model elemen Infiniti model dianalisis menggunakan Frekuensi Semulajadi (modal) pendekatan. Akhirnya, frekuensi semulajadi diperolehi daripada hasil analisis dikenali sebagai hasil simulasi. Dalam uji eksperimental palu, frekuensi semulajadi diperolehi daripada Fungsi Respon Frekuensi (FRF) grafik menggunakan PULSE Labshop Software. Hubungan antara kesan eksperimen dan simulasi menunjukkan kesan takuk pada model melalui jarak dan kedalaman. Ini menunjukkan frekuensi semulajadi menurun dengan peningkatan jarak lekukan dan kedalaman lekukan di model.

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LIST OF SYMBOLS

f	Frequency
f_n	Natural frequency

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
CAD	Computer Aided Design
CAE	Computer Aided Engineering
DOF	Degree Of Freedom
EDM	Electric Discharge Machining
ESR	Electron Spin Resonance
FEA	Finite Element Analysis
FFT	Fast Fourier Transform
FKM	Fakulti Kejuruteraan Mekanikal
FRF	Frequency Response Function
FYP	Final Year Project
NMR	Nuclear Magnetic Resonance
PC	Personal Computer

CHAPTER 1

INTRODUCTION

1.1 PROJECT OVERVIEW

Modal analysis is the process of determining the inherent dynamics characteristics of a system in forms of natural frequencies. The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. Commonly, the finite element method (FEM) is used to perform this analysis because, like other calculations using the FEM, the object that being analyzed can have arbitrary shape and the results of the calculations are acceptable. The types of equations which arise from modal analysis are those seen in eigensystems.

The connection between the natural frequency and resonance of the beam that had been notched at a variety place and as desired in experiment is to be figure out. Natural frequency is the frequency or frequencies at which an object tends to vibrate with when hit, struck, plucked, strummed or somehow disturbed.

$$\text{Frequency} = \text{speed}/\text{wavelength} \tag{1.1}$$

Resonance is the tendency of a system (usually a linear system) to oscillate at larger amplitude at some frequencies than at others. Also known as resonant frequencies and at these frequencies, even small periodic driving forces can produce large amplitude oscillations. This project will studied more on mechanical resonance.

Resonances occur when a system is able to store and easily transfer energy between two or more different storage modes (such as kinetic energy and potential energy in the case of a pendulum). However, there are some losses from cycle to cycle, called damping. When damping is small, the resonant frequency is approximately equal to a natural frequency of the system, which is a frequency of unforced vibrations. Some systems have multiple, distinct, resonant frequencies.

Resonance phenomena occur with all types of vibrations or waves: there is mechanical resonance, acoustic resonance, electromagnetic resonance, nuclear magnetic resonance (NMR), electron spin resonance (ESR) and resonance of quantum wave functions. Resonant systems can be used to generate vibrations of a specific frequency (e.g. musical instruments), or pick out specific frequencies from a complex vibration containing many frequencies.

Mechanical resonance is the tendency of a mechanical system to absorb more energy when the frequency of its oscillations matches the system's natural frequency of vibration than it does at other frequencies. It may cause violent swaying motions and even catastrophic failure in improperly constructed structures including bridges, buildings, and airplanes. Engineers when designing objects must ensure that the mechanical resonant frequencies of the component parts do not match driving vibrational frequencies of the motors or other oscillating parts a phenomenon known as resonance disaster.

This project is using beam as material to test for it’s vibration, frequency occurance and resonance that may be used for benefical in engineering sector. Modal testing is to be used for this notched beam to determining its natural frequencies in it system. Hammer test will be used, a fixed response location is used while alternatively moving force excitation points.

1.2 PROBLEM STATEMENT

Nowadays, there are a lot of building and structures are to build as development of new era of globalization and the theory of resonance, frequency and others must be considered and put it in the test. Some of the problems that been recognized are:

i. If the frequency that occurred in system such as bridge is same as natural frequency of the bridge, it will then facing failure and costly a lot.
ii. There are a lot of factors that may disturb and influence building and structures that may cause unwanted resonance and frequency.

1.3 PROJECT OBJECTIVES

To determine the dynamic behavior of notched beam for various distance and notch size and their effect on natural frequency.

1.4 PROJECT SCOPES

The main project scopes are:

1) Selection of beam that need to be used in simulation and experiments.
2) Study and identify the mechanical properties of the material e.g. Density, modulus Young etc.
3) Undergo machining process to form notch on beam as desired dimension.
4) Modeling in CAD or Solidwork and do analysis (identify mode shape and natural frequency,f_n for first 6 models).
5) Carry out model analysis using available equipment called impact hammer test equipment.
6) Comparison between simulation and experiments.

1.5 THESIS ORGANIZATION

This thesis consists of 4 chapters. Chapter 1 will discuss about the Introduction to the Project. These first chapters briefly explain about the objective of the project, problem statement and project scopes. Chapter 2 is about the literature review. Chapter 3 will discuss the methods will be used, elaborating the sources from the research, and deciding the best tools that will be used to build and analyze the project. Chapter 4 is the conclusion and overall summary of the system, data, and methodology.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In the past two decade, many developments in areas such as engineering, science and technology have been using application of modal analysis. The practical applications of modal analysis are going to be a significant in the future and largely related to the advances in experimental technology. It was reported that the majority of practical application cases were came from aeronautical engineering, mechanical engineering and automotive engineering. This is not the cause that the application of modal analysis is can't be becoming more strongly widely used in others area.

Enormous applications of structural dynamics will succeed by depending on accurate mathematical model for using dynamic structure such as a model can be derived from the finite element modeling.

In 1943, R. Courant become the first person developed FEA when he was managed to utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. FEA was limited use by early 70's to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Later, FEA has been developed to an incredible precision since the rapid decline in the cost of computers and the phenomenal increase in computing power. Supercomputer nowadays seems to calculate and produce accurate data for all parameters.

2.2 MODAL ANALYSIS

Modal analysis is to determine the frequencies at a system that are apparently occur analytically. In addition, modal shapes which the system assumes are the properties of the system are also to be analyzed. Vibration modes is a crucial part or component in such a design that to be analyzed. Structural elements such as complex steel floor systems can be specifically liable to noticeable vibration, irritating building occupants or interrupting sensitive equipment.

Intrinsic or inherent vibrations modes in many of structural components or mechanical systems are so depending on research on how to avoid them from shorten equipment life where unpredicted failure occurs. Moreover it will result in risky situations. To estimate the possible for failure or damage resulting from rapid stress cycles of vibration, detailed fatigue analysis is required. To understand the natural vibration modes of a system whereby the massive amount of energy acting on a system during seismic activity varies with frequency, detailed seismic qualification are needed. Detailed modal analysis discovers the basic of vibration mode shapes and equivalent frequencies. These are simply simple for basic components of a simple system. For complex device or complicated structure exposed to periodic wind loading, it is extremely complicated to qualifying it. Hence, using techniques such as Finite Element Analysis (FEA) is one of most successful method to obtained accurate determination of natural frequencies and mode shapes.

In other word, modal analysis studied the dynamic properties of mechanical structure under dynamic excitation which are resonant frequency, mode shapes and damping. For more simple approach, in Figure 2.1, a plate will be taken as a theoretical example and a force that varies in a sinusoidal fashion on one corner. Then, the rate of oscillation (frequency rate) of the sinusoidal force will be change but the peak force remains unchanged. After that, the response of the excitation with an accelerometer attached to the other corner of the plate will be compute.

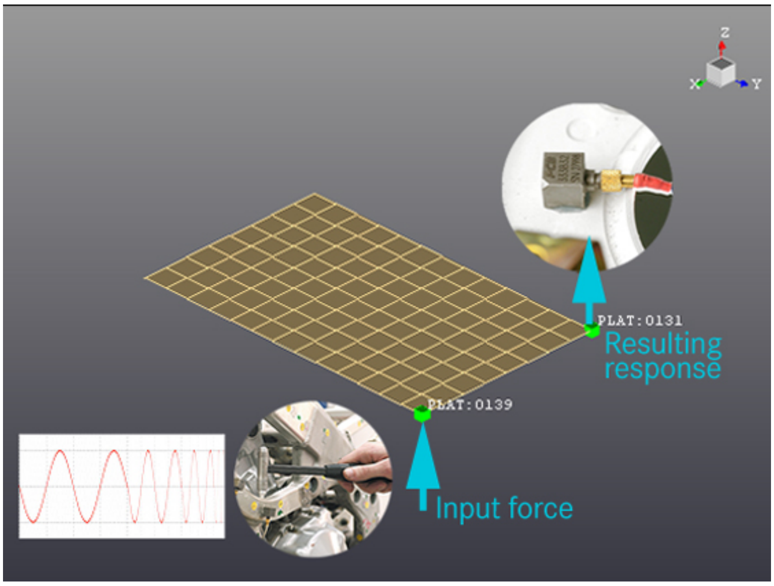


Figure 2.1: Hammer test

[Source http://www.lmsintl.com/modal-analysis]

The measured amplitude can be diverse according on the frequency rate of the input force. The response amplifies as a force with a frequency rate that gets closer and closer to the system's resonant or natural frequencies. From the time data that was taken, the functional peaks that take place at the resonant frequencies of the system can be observed after transform it to the frequency domain using a Fast Fourier Transform algorithm to compute something called the "frequency response function".

Figure 2.2 shows the deformation patterns of simple plate (bending, twisting, torsioning and etc) at these resonant frequencies take on a variety shapes depending on the excitation force frequency. These deformation patterns are referred to as the structure's mode shapes.

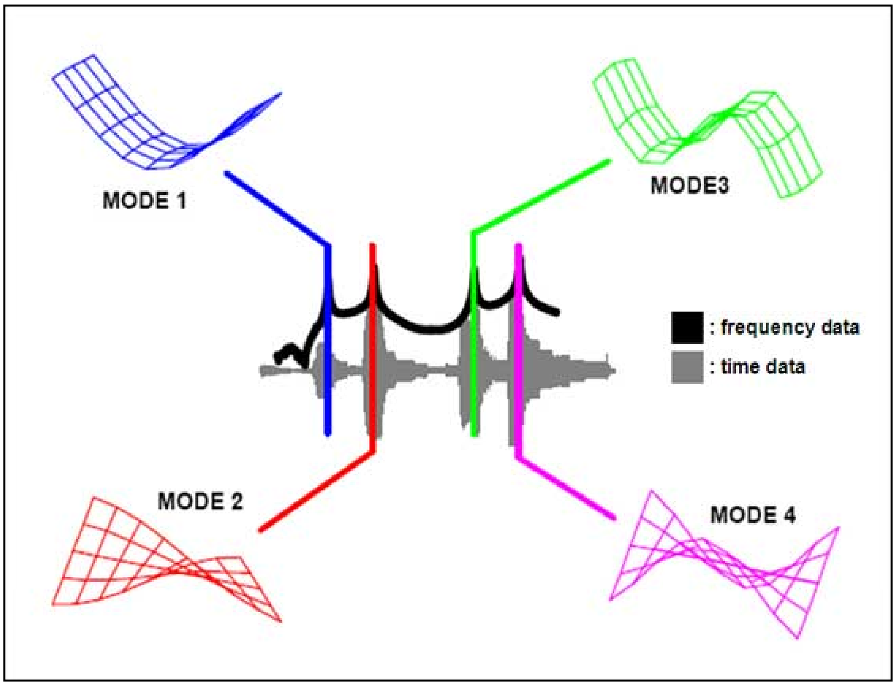


Figure 2.2: Simple plate sine dwell responses

Structural damping provides information about how quickly the structure dissipates vibration energy and returns to rest when the excitation force is removed. Damping graph of excitation force is shown in Figure 2.3.

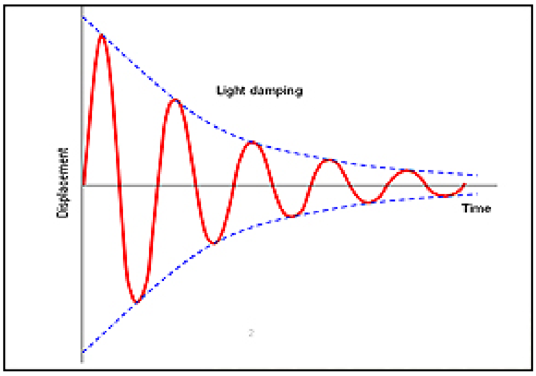


Figure 2.3: Damping graph

Figure 2.4: Tacoma Bridge

Both an acquisition phase and an analysis phase are considered by modal analysis. In experimental modal analysis, an impact hammer or shaker is used to give external force to excite the structure. Modal testing systems consist of transducers (typically accelerometers and force cells), an analog to digital converter or front-end to digitize the analog instrumentation signals and a host PC to review and analyze the data.

In order to test cars, airplanes, wind turbines and any other applications that are difficult or even impossible to excite by external force, owing to boundary conditions or sheer physical size, experimental modal analysis is used where it only measures the response of test structures under actual operating conditions. Tacoma Bridge in Figure 2.4 is one example of application that complicated to excite by external force. Modal testing results can also be used to correlate simulation analysis and create a ‘real-life’ simulation model.

To ensure that the simulation provide high fidelity data acquired, dependable simulation results that requires component, subsystem and full-system models to be compared with experimental data, or alternatively validated models of similar structures must be definitely stated and ensure. It is essential to obey strict accuracy standard. By build structure from the beginning may avoid accumulating inaccuracies.

2.3 FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) comprise of a computer model of a material that is stressed and analyzed for specific results. It is widely used in new design and existing product refinement. Moreover, client of a company can decide the desired specifications prior to manufacturing and construction from the company proposal on some design that has been verified. In such case like failure, FEA can be used to help the design modifications to meet the new condition.

In general, two types of analysis used in industry: 2-D modeling, and 3-D modeling. 2-D modeling gives less accurate results when it just conserves simplicity and allows the analysis to be run on a relatively normal computer. Compared to 3-D modeling, it produced more accurate and specific results while sacrificing the ability to run on all but the fastest computers effectively.

For finding approximate solutions of partial differential equations (PDE) as well as of integral equations, finite element method (FEM) is used where its practical application called FEA. This solution use standard techniques such as Euler's method, Runge-Kutta, etc. for numerically integrated due it based either on eliminating the differential equation completely (steady-state problems) or rendering the PDE into an approximating system of ordinary differential equations.

In origin of finite-element method was started to solving complex elasticity and structural analysis problems in civil and aeronautical engineering. It was developed by Alexander Hrennikoff (1941) and Richard Courant (1942). Instead of different approaches used, mesh discretization was then observed and shared by these two pioneers. It is a continuous domain into a set of discrete sub-domains, commonly known as elements.

2.4 MODAL ANALYSIS AND SHAPE OPTIMIZATION OF ROTATING CANTILEVER BEAM

Hong Hee Yoo, a research on had been done by him entitled “Modal Analysis and shape optimization of rotating cantilever beam”. This paperwork discuss on how to optimize the rotating beam from it variety shape desired. But the material property and geometric shape must be given. Then, continued by mode shape analysis or finite element analysis for more accurate of modal characteristics. Calculate natural frequencies of design or structures are necessary to avoid undesired problems such as resonance phenomena.

In 1920s, Southwell and Gough pioneered to investigate the modal characteristics of rotating beams. All their monumental work was followed by many theoretical and numerical studies. After that, more advanced methods were developed and the more complicated effects were considered to analyze the modal characteristics of rotating structures. Therefore, with geometric shape and material property was given, the modal characteristics of the structure can be effectively analyze. Unfortunately, in many practical design situations, the geometric shape need to be found instead of being given and the modal characteristics are specified as design requirements (to avoid undesirable vibration problems).

The purpose of this paperwork prepared by Hong Hee Yoo is to find the optimal shapes of rotating cantiveler beams that provide some specific modal characteristics. Maximal or minimal increasing rate of a natural frequency versus the angular speed could be one of the specific modal characteristics. In his study, the cross section area of the rotating beam is assumed rectangular and the length of the beam is divided into multiple segments. The thickness and the width at every segment assumed to be cubic splines functions. In this study also, a linear dynamic modeling that employs hybrid deformation variables is utilized to derive the equations of motion for rotating cantilever beams.

Firstly, some assumptions have to be made to simplify the modeling procedure and to focus on major interest to study. First, the beam is homogeneous and isotropic material properties. Secondly, the beam has slender shape so that the shear and rotary inertia effects are ignored. Lastly, he just considered the stretching and the out-of-plane bending deformations. Therefore, the optimal shape of rotating beams that satisfy certain requirements of modal characteristics can be found.

In this present study, certain modal characteristics requirements such as maximum and minimum slope natural frequency loci are specified and the geometric shapes that satisfy the requirements are obtained through this optimization procedure. Figure 2.5 to 2.7 shows the beam thickness variations of three cases of test problem.

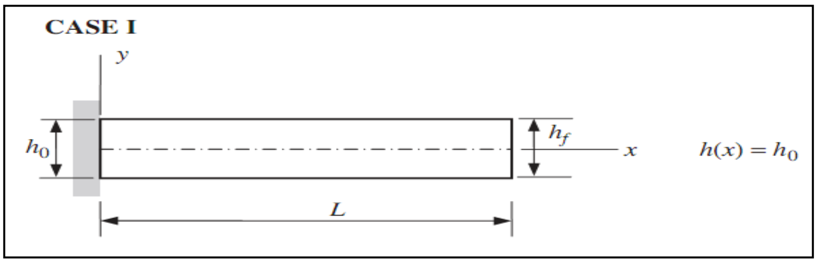


Figure 2.5: Beam thickness variation of first case of test problem

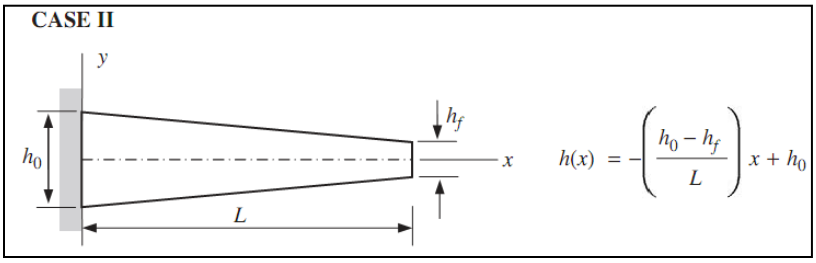


Figure 2.6: Beam thickness variation of second case of test problem

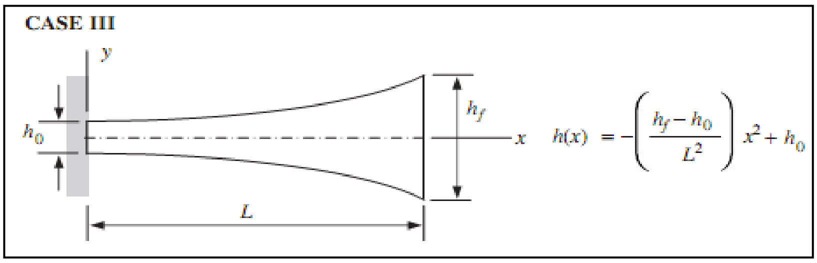


Figure 2.7: Beam thickness variation of third case of test problem

In this study, an optimization method is employed to find the cross section shape variations of rotating beams that satisfy some specific modal characteristics. The beam is divided into multiple segments and the thickness and the width are assumed as cubic splines functions at the segments. The stage values of thickness and width are employed as design variables and optimization problems to find the design are formulated. Numerical results show that there exist specific cross section shape variations that satisfy certain modal characteristic requirements. It is also found that the angular speed and size of hub radius a little bit influence the optimal shapes of rotating beam.

2.5 MODAL ANALYSIS ON CRACKED, UNIDIRECTIONAL COMPOSITE BEAM

According to M. Krawczuk, et al, a model and an algorithm for creation of the characteristic matrices of a composite beam with a single transverse fatigue crack.

The use of composite material in diverse construction element has increased considerably over the past few years. This material specifically widely used in circumstances where a large strength to weight ratio required. Composite materials are also facing similar problem to various types of damage, mostly crack and delaminations. Delamination is a mode failure for composite material.

Mode failure also is known as failure mechanisms. These damage then changes the stiffness of material such in material and plus, their dynamic characteristics are altered. Figure 2.8 shows the examples of numerical calculations of the influence of crack parameters (depth and position) and on the changes of natural bending vibrations.

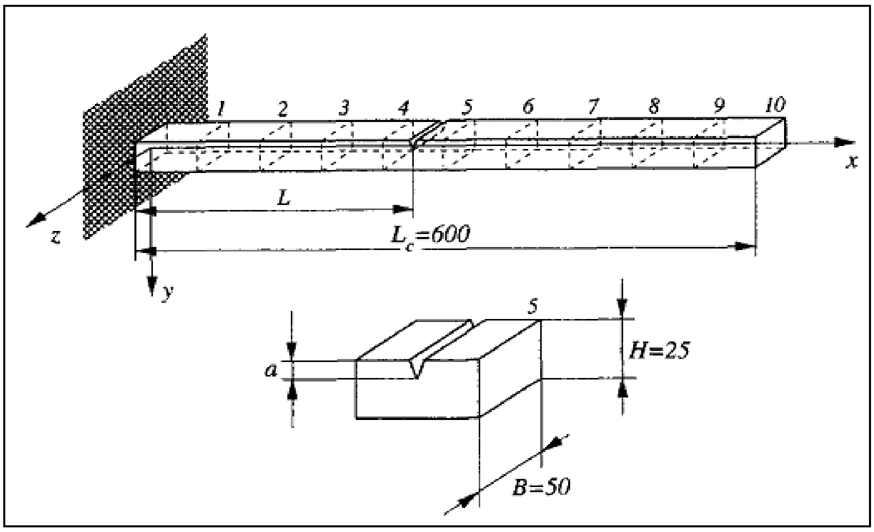


Figure 2.8: Numerical calculations of the influence of crack parameters (depth and position) and on the changes of natural bending vibrations

Figure 2.9 – 2.12 shows the increase of crack depth causes a decrease in the calculated natural bending frequency of the beam. In this vibration of cantilever beam case, it is clearly explained that maximum torque appears in the nodes, while in the loops of vibrations torque is assumed to be zero. The decrease of stiffness in the crack corresponds (through the values of stress) to the value of torque.

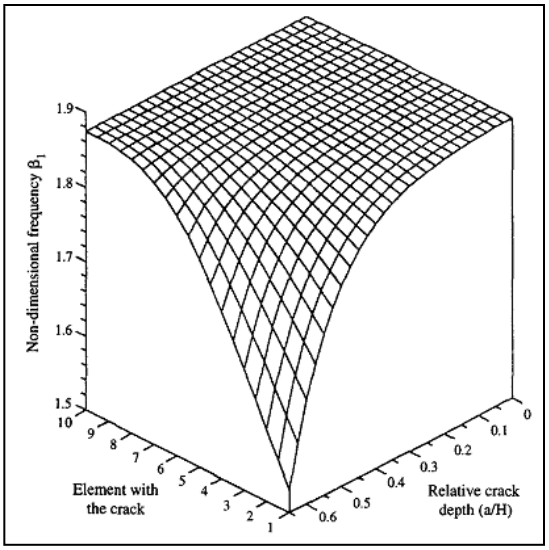


Figure 2.9: Influence of the position and depth of the crack on the changes in first natural bending frequency

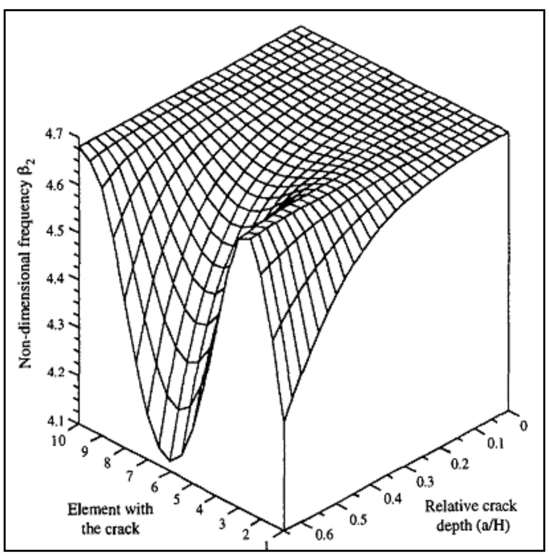


Figure 2.10: Influence of the position and depth of the crack on the changes in second natural bending frequency

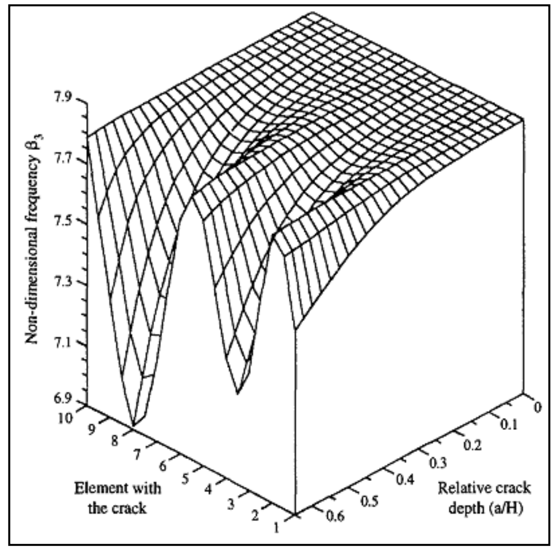


Figure 2.11: Influence of the position and depth of the crack on the changes in third natural bending frequency

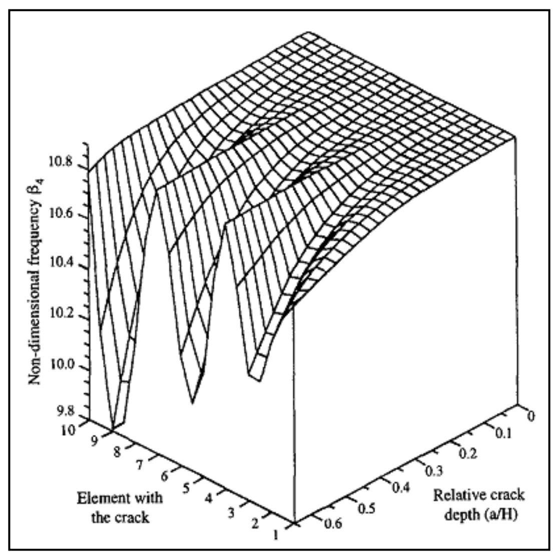


Figure 2.12: Influence of the position and depth of the crack on the changes in fourth natural bending frequency

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discuss on steps to work on in order to achieve project objectives. In this project, there are 6 model shapes to be analyzed by modeling and simulation using software. Data then are obtained.

This part consists 4 parts which are project flow description, modeling using Solidwork, Finite Element Analysis (Algor software) and experimental method (hammer test).

It is very crucial to arrange and plan project flow chart in Figure 3.1 or research management activities very well to ensure the progress of this study going smoothly. Completing each step is vital in order to avoid any errors in next step. Methodology or procedure conducted by analyzing using simulation and experimental method. All data that will be use for analyzing comes from resources and revision of theories, technically, figures, equation, graphs and others.

3.2 PROJECT FLOW CHART

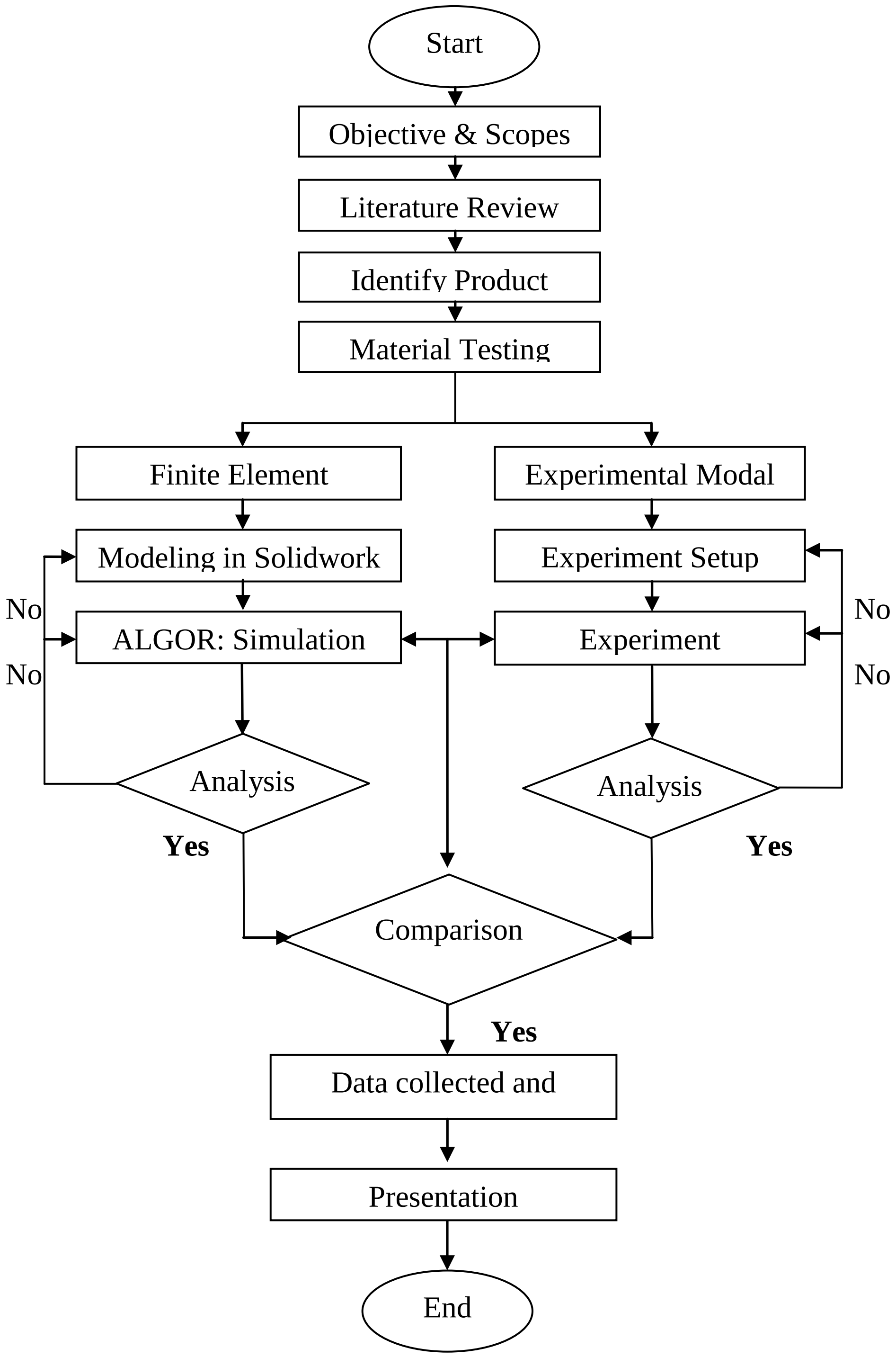


Figure 3.1: Project Flow Chart

3.3 MATERIAL TESTING

The reason of material testing is to identify the composition of element inside the material. Spectrometer (arc spark type) in Figure 3.2 and surface grinder are use to conduct this experiment. There are several steps to conduct the testing. Before the material tested by spectrometer, the surface of the material is need to be flattening using surface grinder. The flat surface of material were put in bottom side to let the arc spark reached it. In order to get the accurate results and avoid errors, five tests on different spot of the surface were repeated.

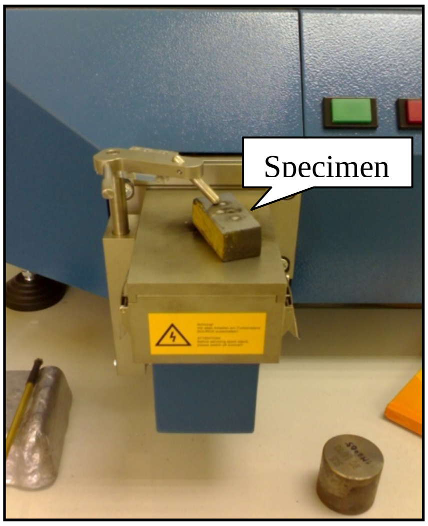


Figure 3.2: Mass Spectrometer

3.3.1 Composition of Element Material

From Table 3.1, the composition of element with the high average percentage will consider the material of this specimen. The high average percentage of this element is Iron, Fe with 98.4 percent followed by Manganese, Mn and Copper, Cu with each of them are, 0.593 and 0.264. With these three main elements in the material, steel was selected as the suitable material. The element specification of this steel shows in Table 3.2.

Table 3.1: Composition element of the beam

No.	Component Element	Test (%)					Average (%)
		1	2	3	4	5	
1	Iron, Fe	98.500	98.500	98.500	98.400	98.400	98.400
2	Carbon, C	0.1290	0.1600	0.1620	0.1830	0.2020	0.1670
3	Silicon, Si	0.2320	0.2070	0.2040	0.1930	0.2120	0.2100
4	Manganese, Mn	0.5960	0.5950	0.5820	0.5980	0.5930	0.5930
5	Phosphorous, P	0.0600	0.0663	0.0673	0.0698	0.0714	0.0670
6	Sulfur, S	0.0366	0.0359	0.0412	0.0396	0.0402	0.0387
7	Chromium, Cr	0.0665	0.0620	0.0601	0.0630	0.0640	0.0631
8	Molybdenum, Mo	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
9	Nickel, Ni	0.0955	0.0923	0.0732	0.0859	0.1040	0.00902
10	Aluminum, Al	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
11	Cobalt, Co	0.0110	0.0105	0.0103	0.0108	0.0108	0.0107
12	Copper, Cu	0.2670	0.2600	0.2640	0.2570	0.2700	0.2640
13	Niobium, Nb	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
14	Titanium, Ti	0.0019	0.0010	0.0010	0.0014	0.0015	0.0012
15	Vanadium, V	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
16	Tungsten, W	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250
17	Lead, Pb	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050

Table 3.2: Element Specification of Steel

No.	Element	Value	Unit
1	Mass density	7850	kg/m^3
2	Modulus of Elasticity	202,361,112,660	N/m^2
3	Poisson’s Ratio	0.29	-
4	Thermal Coefficient of Expansion	0.0000461	$1/^oC$
5	Shear Modulus of Elasticity	79,979,184,600	N/m^2

3.4 MODELING PROCESS OF BEAM

Solidwork software is chosen to develop beam in various types of desired shapes before obtaining result by analyzing it in simulation software. Solidwork is one of the computer aided design (CAD) software use to draw 2-D and 3-D of modeling structure. Simplification is constantly used in modeling where it reduces the number of vertices for mesh features, or reduces the number of points for point cloud features, resulting in a simpler, smaller file size. It is often crucial when the point cloud size is very large, in which case the size should be simplified to efficiently form a mesh. But for this type of beam with notch each, there no need to use simplification due to simple model.

The dimension of the beam as shown in Table 3.3 was taken from the real part to ensure there are no errors between simulation and experimental data. Figures from 3.3 to 3.9 are show modeling in Solidwork with the desired length and depth of notch.

Table 3.3: Parameters of each beam

Dimension	Parameter (m)
Length	0.700
Height	0.050
Width	0.019

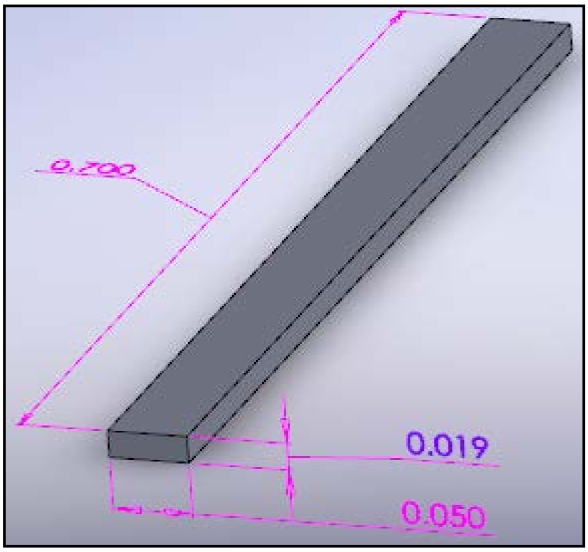


Figure 3.3: Control beam

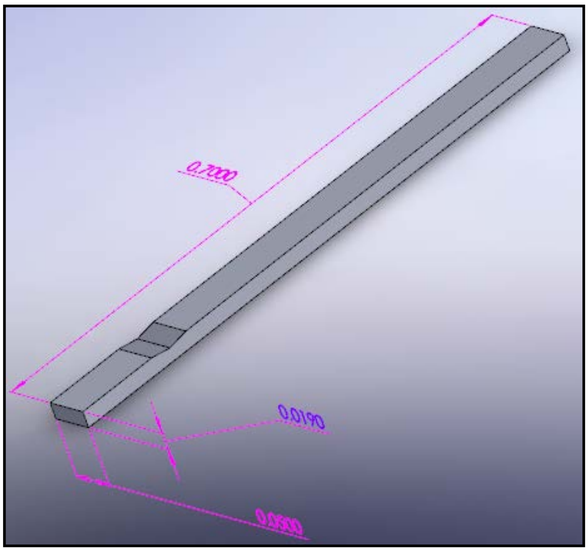


Figure 3.4: 1st model of beam, 100 mm of distance

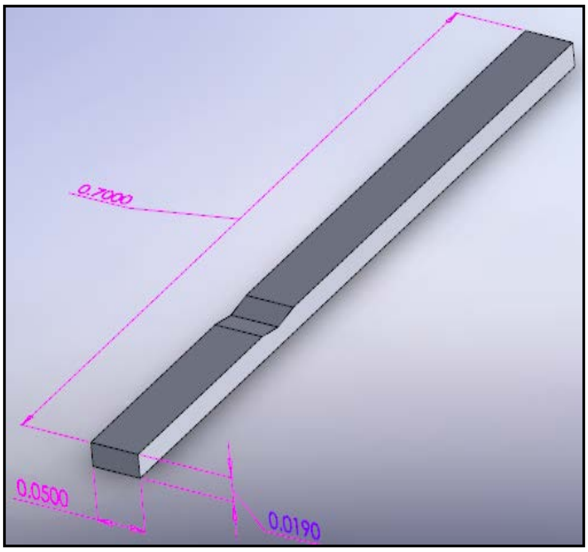


Figure 3.5: 2nd model of beam, 200 mm of distance

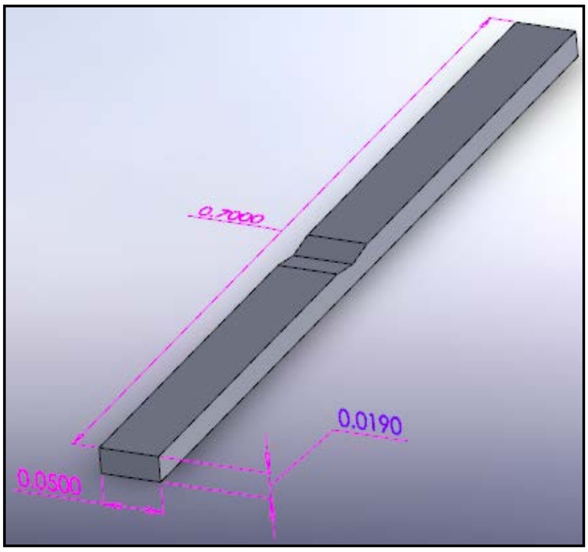


Figure 3.6: 3rd model of beam, 300 mm of distance

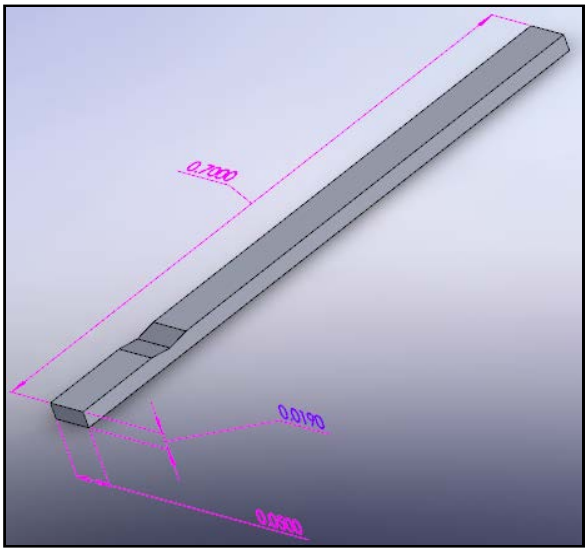


Figure 3.7: 4th model of beam, 4mm depth of notch

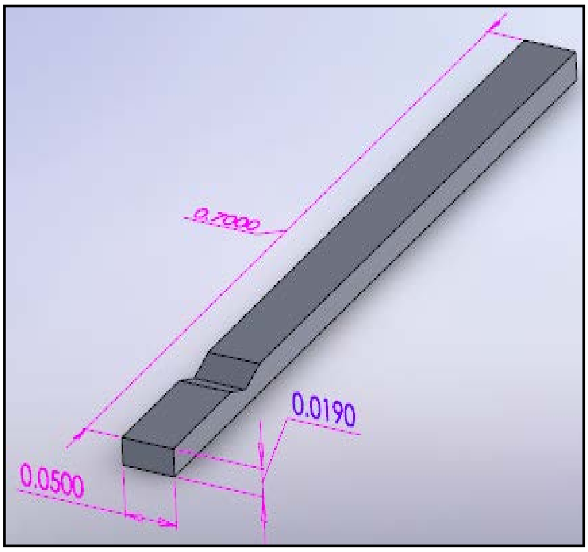


Figure 3.8: 5th model of beam, 8mm depth of notch

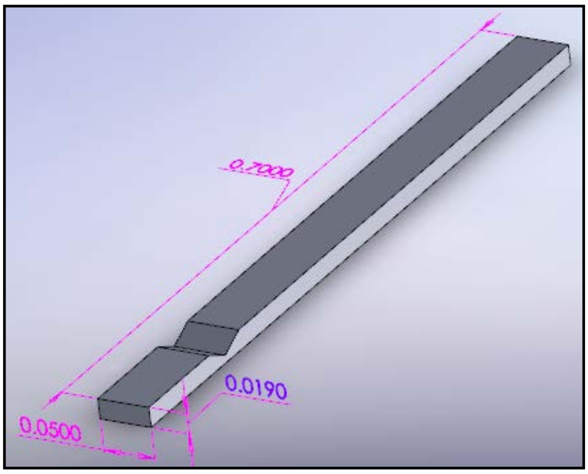


Figure 3.9: 6th model of beam, 12mm depth of notch

3.5 FINITE ELEMENT ANALYSIS

Finite element analysis is used after modeling 6 models of beam in the solidwork 2008 software in order to analyze the model which frequency and mode shapes can be obtained. In this project, ALGOR 23.1 version 2009 is preferred. The advantage of using this software is the capability to create surface and solid meshes with control over mesh size parameters. It can be done quickly that because it is a technology that has made the integration of CAD and FEA practically effortless compared to manually building the mesh. InCAD's meshing tools automatically create high-quality meshes, but still provide full control over the mesh size when desired (Ted Fryberger, P.E. DeepSoft Inc.)

First, all solidwork model required to be save in 'IGES' type of file or format. The file of 'IGES' type as save in Solidwork software is opened in ALGOR software. Mesh size are required to set as desired value which are 100%, 90%, 80%, 70%, 60%,50% and 40%. After creating mesh, the next step is to set Element type as Tetrahedron. Tetrahedron is providing triangle meshing. Then, modified properties is set by using the data acquired from experimental of material testing to fill up requirement data such as Mass density, Modulus elasticity, Poisson's Ratio, Thermal coefficient of expansion and shear modulus.

Tetrahedron was selected because linear tetrahedral elements are either constant stress elements with four nodes or linear stress elements with 10 nodes. These elements are formulated in three-dimensional space with three degrees of freedom per node; these are the translational degrees of freedom in the X, Y and Z directions, respectively. The ten-node element is an isoperimetric element and stresses are calculated at the nodes.

Natural frequency (modal) was selected to calculate the natural frequencies and mode shapes of the modal due to entirely geometric and material properties. Differ to natural frequency with Nonlinear Material Modes where the change in frequency due to displacements and changing in material properties is not included. The final meshing model in Algor is shown in Figure 3.10.

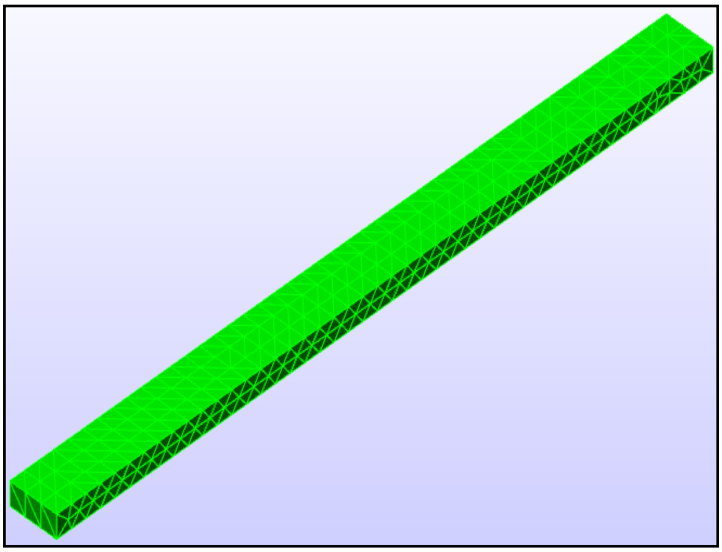


Figure 3.10: Finished meshing model

3.6 EXPERIMENTAL MODAL ANALYSIS

A typical measurement set-up in a laboratory environment should have three constituent parts. The first part is responsible for generating the excitation force and applying it to the test structure. This will handle by modal hammer. The second part is to measure and acquire the response data. The third part provides signal processing capacity to derive FRF data from the measured force and response data.

3.6.1 List of Apparatus

Table 3.4 shows the lists of the apparatus used for this experimental method. Figures from 3.11 to 3.12 are some example of apparatus used in the experimental test.

Table 3.4: List of Apparatus

No	Apparatus	Function
1	Modal Hammer Model: Endevco Type: 2302-10	i. Impact all the DOF's point on the beam.
2	8 Channel FFT Analyzer	i. Collect time data and convert it to FRF measurement. ii. Response will displayed in PC

3	Computer with PULSE-Lite software version 10.2, ME's Scope version 4.0, Solidwork 2008 and Algor FEMPRO V23	i. PULSE-Lite – display the collected data ii. Solidwork – create CAD modeled iii. Algor – simulation for modal analysis

Figure 3.11: Modal hammer

Model: 2302-10, Endevco

Figure 3.12: Data Acquisition System

3.6.2 Experimental Procedure

Figure 3.13 shows 5 points are labeled as point 1,2,3,4 and 5 as a guide to use hammer test. The distance between each point is 140 mm. These are several steps to conduct hammer test: Software PULSE Labshop Version 11.1 is used to run this experiment. This type of study requires free boundary condition. To imitate perfect boundary condition is impossible but still can be stimulated by supporting the structure with soft materials such as springs or elastic bands. For this case, sponge was used. After measurement setup, hammer test was run. Precaution need to be taken on how to handle the experiment, it needs to hit the specimen carefully to avoid overloading error. For this experiment, line needs to be set to 1600 and 3.2kHz for span. Repeatability of the measurement is crucial due to ensure the structure's dynamic behavior and the whole measurement setup is time invariant. From there, measurement errors can be reduced. After the specimen was hit twice, the Frequency Response Function (FRF) and coherence graph was obtained. Results were recorded and continued with 5 others specimen.

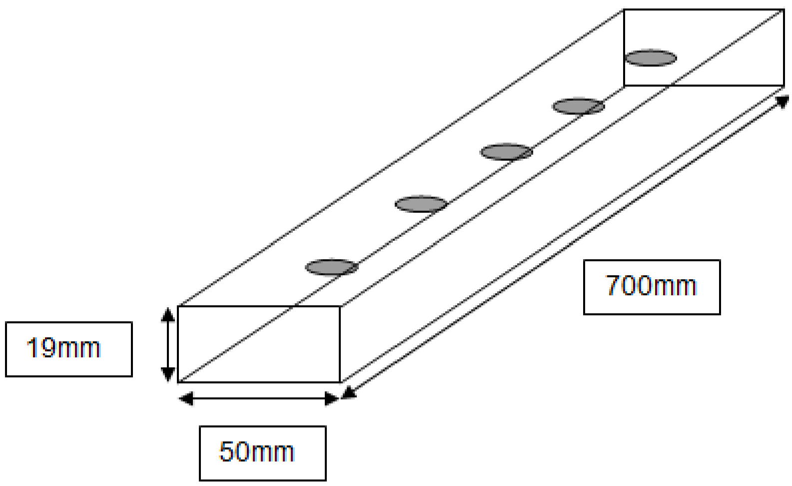


Figure 3.13: 5 points to be hit on each beam

3.7 CONCLUSION

The conclusion for this chapter is steel is selected as material for this beam. The element specification which gathered for this type of material is used in FEMPRO Algor software to run simulation. The result obtained from both methods will compare in the next chapter.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows the simulation of finite element analysis by using ALGOR FEMPRO software and frequency obtained each mode shapes obtained. The data of hammer test experiment were obtained and graphs plotted each beam. In Section 4.2 to 4.8, it concludes the result of Algor software and experimental test. The comparison of frequencies from the each beam result will be discussed in Section 4.9.

4.2 CONTROL BEAM (CONTROL CONDITION)

Control condition is an experiment in which the variable factors are controlled so as to make it possible to observe the results of varying one factor at a time. Table 4.1 shows the result of frequency in control beam obtained from Algor software.

Table 4.1: Result of frequency in control beam

Mesh (%)/ Frequency	**Mode 1**	**Mode 2**	**Mode 3**	**Mode 4**	**Mode 5**
100	456.83	709.37	1237.50	1865.04	2395.45
90	433.05	691.38	1186.49	1838.37	2260.13
80	407.99	676.31	1114.93	1801.77	2135.35
70	319.58	594.37	882.55	1583.24	1736.77
60	263.25	597.18	710.68	1380.37	1583.51
50	257.51	569.42	718.04	1389.88	1521.90

4.2.1 Simulation in Algor: Mode Shapes

Figure 4.1 shows 5 mode shapes of control beam obtained from Algor software.

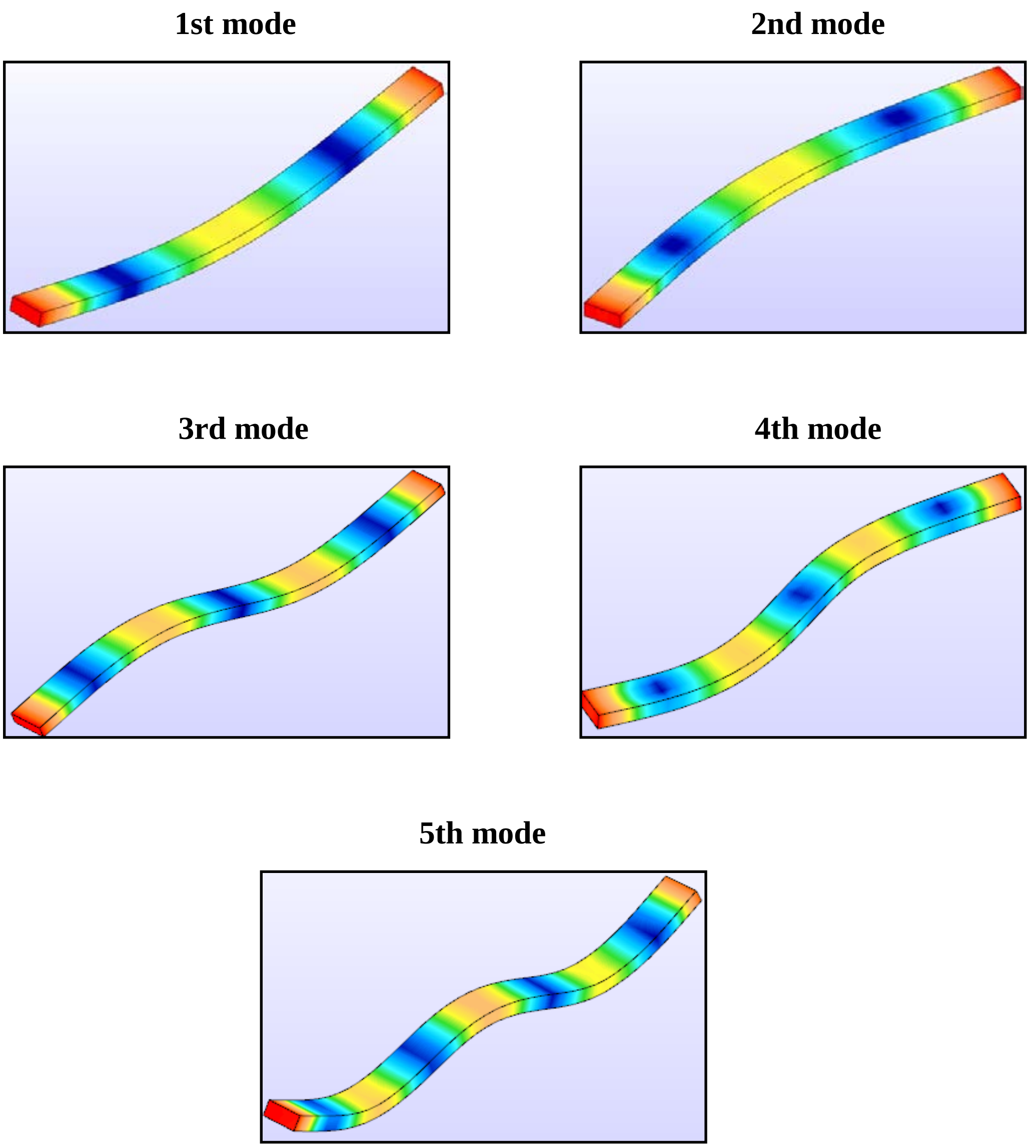


Figure 4.1: Five mode shapes of control beam

4.2.2 Experiment Result

Figure 4.2 and 4.3 show FRF and coherence graph for control beam obtained from experimental test.

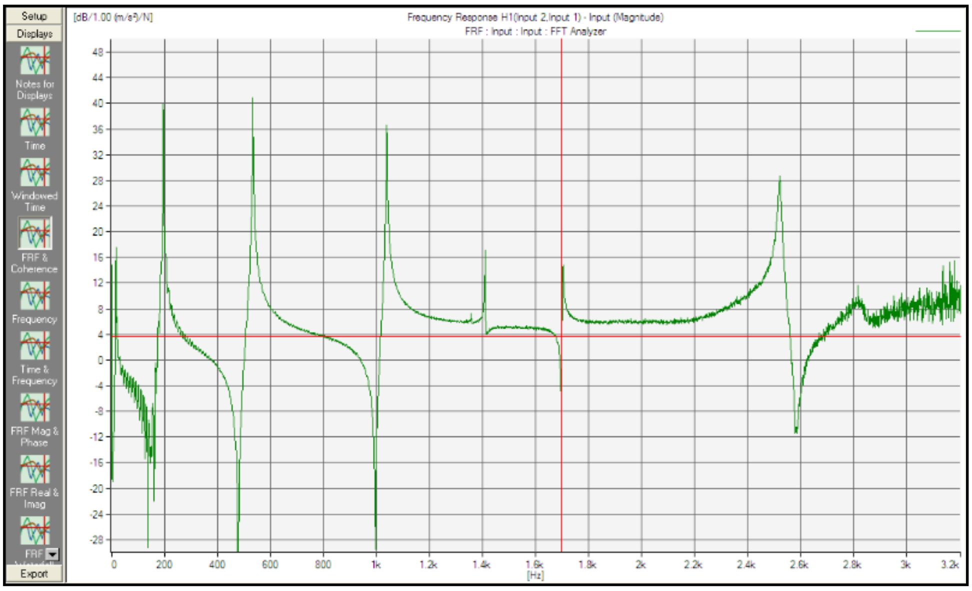


Figure 4.2: FRF graph of control beam

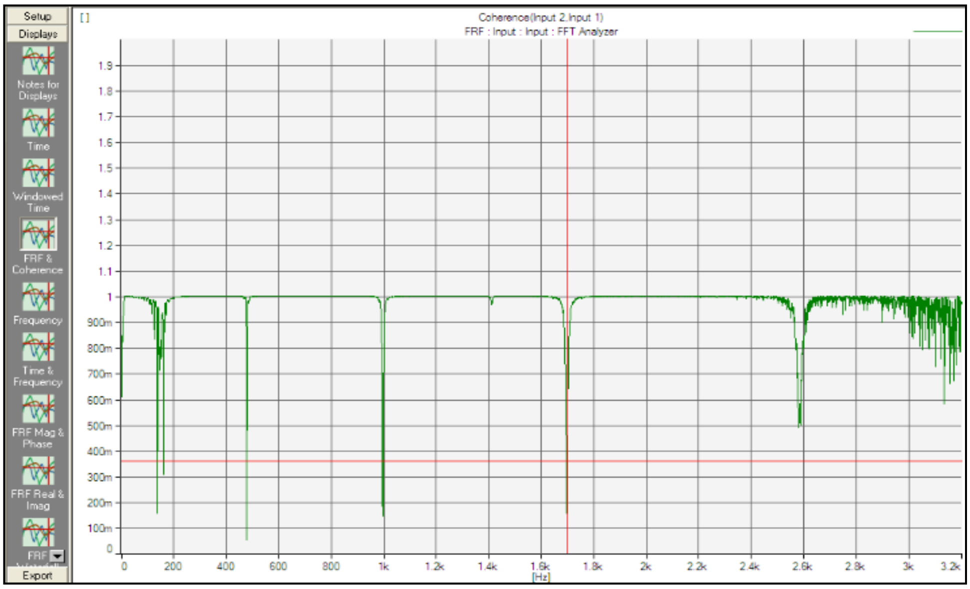


Figure 4.3: Coherence graph of control beam

Table 4.2 shows frequencies obtained for experimental test for control beam. Point hit 1 is selected due to slightly changes in number between points hit.

Table 4.2: Experiment Hammer Test of control beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Control	1	194	532	1037	1702	2520
	2	194	532	1037	1702	2520
	3	195	532	1037	1701	2520
	4	194	532	1037	1702	2520
	5	194	532	1037	1702	2519

From the graph in Figure 4.4, it shows that experiment data is almost directly proportional to all simulation data. To select the most correct mesh for this beam, the frequencies of a beam must be a lot frequency closer to experimental test frequency. For this data, mesh 80 is the most influence and closer pattern identical to experimental. Frequencies at mode 2, 3 and 4 (676.31, 1114.93, 1801.77) Hz for this mesh are closer to experimental (532, 1037, 1702) Hz.

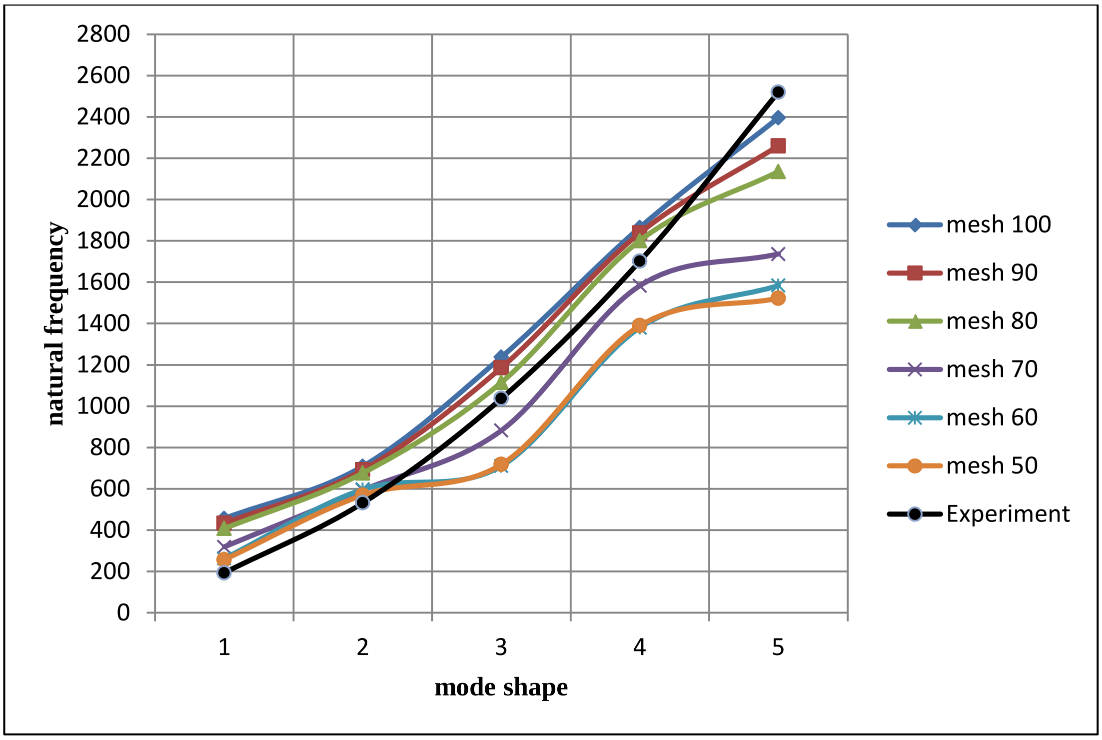


Figure 4.4: Combination of simulation and experiment data of control beam

4.3 FIRST NOTCHED BEAM

Table 4.3 shows the result of frequency in first beam obtained from Algor software.

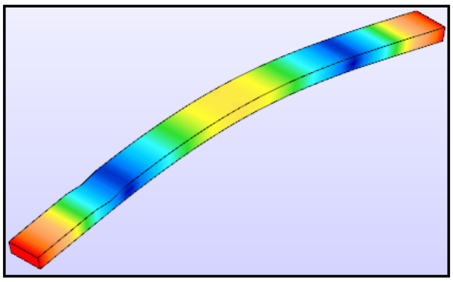
Table 4.3: Result of frequency in 1st notched beam

Mesh (%)/ Frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
100	361.54	609.37	984.24	1618.74	1856.40
90	290.42	605.33	782.87	1518.07	1597.49
80	257.17	572.16	699.21	1334.11	1517.37
70	267.31	573.66	723.17	1391.44	1518.75
60	261.60	552.82	709.40	1361.42	1468.76
50	249.96	541.57	676.95	1302.11	1440.57

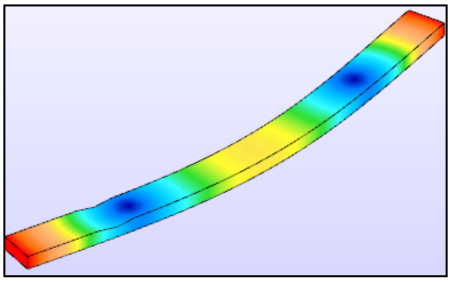
4.3.1 Simulation Algor: Mode Shapes

Figure 4.5 shows 5 mode shapes of first beam obtained from Algor software.

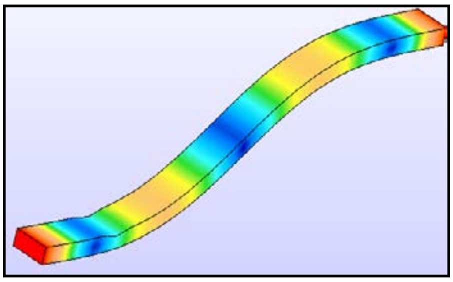
1st mode



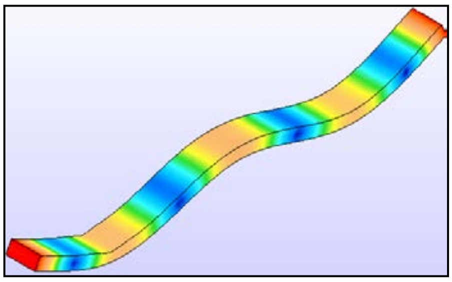
2nd mode



3rd mode



4th mode



5th mode

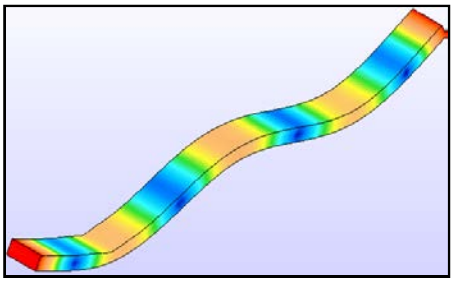


Figure 4.5: Five mode shapes of first beam

4.3.2 Experimental result

Figure 4.6 and 4.7 show FRF and coherence graph for first beam obtained from experimental test.

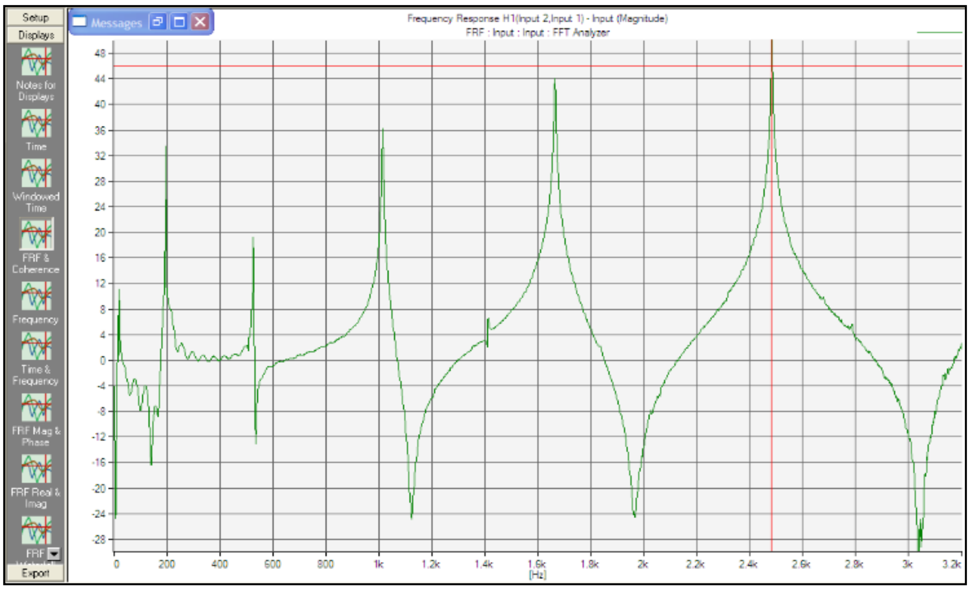


Figure 4.6: FRF graph of first beam

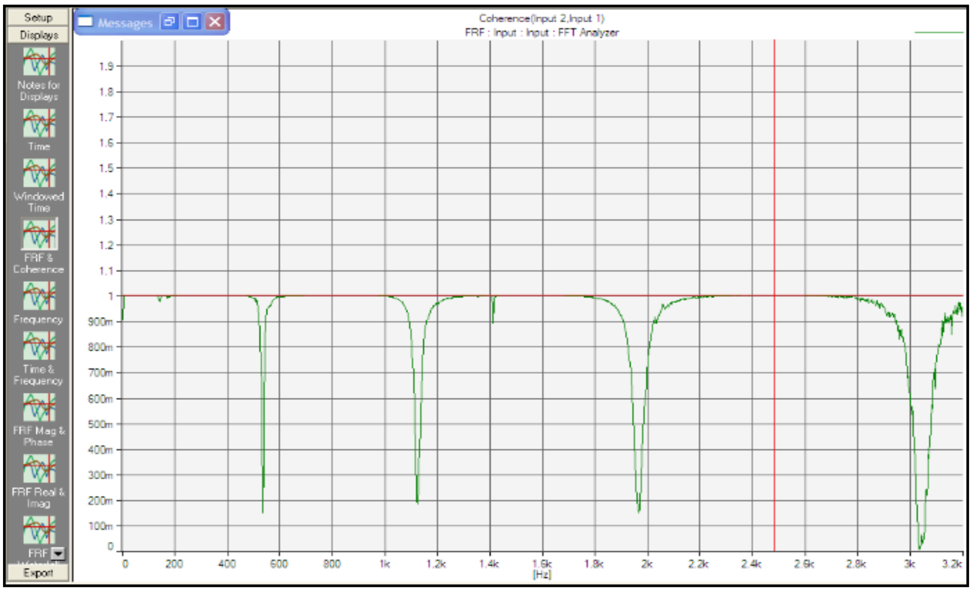


Figure 4.7: Coherence graph of first beam

Table 4.4 shows frequencies obtained for experimental test for first beam. Point hit 2 is selected due to slightly changes in number between points hit.

Table 4.4: Experiment Hammer Test of first beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
1	1	190	518	1032	1690	2470
	2	190	517	1032	1688	2472
	3	190	517	1032	1688	2473
	4	190	517	1032	1689	2471
	5	190	517	1017	1688	2472

From the graph in Figure 4.8, mesh 100 is selected due to it frequencies and graph are closer to the experimental. Frequencies at mode 2, 3 and 4 (609.37, 984.24, 1618.74) Hz for this mesh are closer to experimental (517, 1032, 1688) Hz.

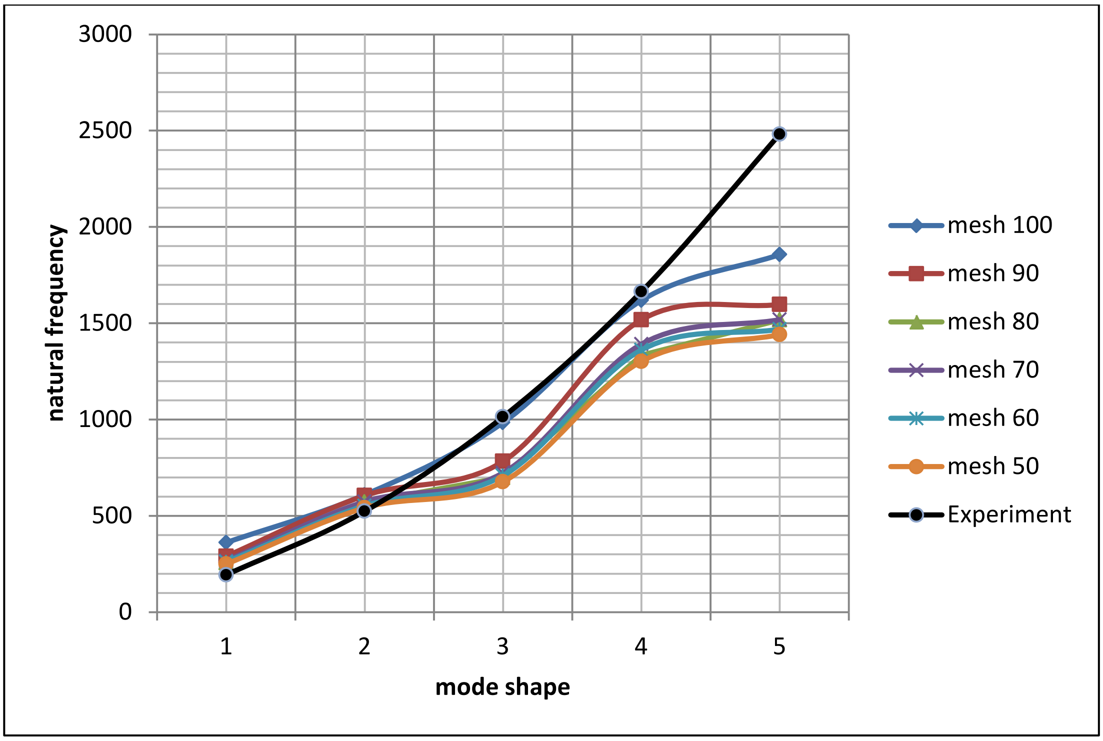


Figure 4.8: Combination of simulation and experiment data of first beam

4.4 SECOND NOTCHED BEAM

Table 4.5 shows the result of frequency in second beam obtained from Algor software.

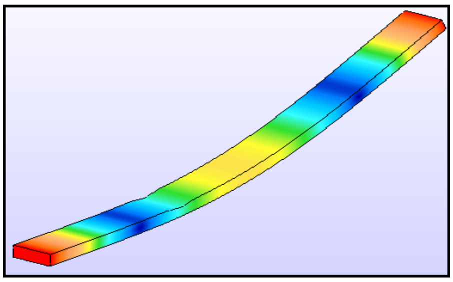
Table 4.5: Result of frequency in 2^{nd} notched beam

Mesh (%)/ Frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
100	364.44	605.58	973.83	1602.29	1901.35
90	328.36	606.15	853.25	1604.53	1653.21
80	277.54	578.19	744.22	1453.52	1529.67
70	258.06	562.90	710.17	1387.38	1503.21
60	258.29	549.22	705.06	1397.06	1466.84
50	244.42	538.72	670.91	1320.76	1440.44

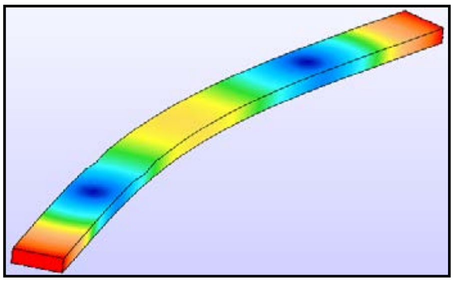
4.4.1 Simulation Algor: Mode Shapes

Figure 4.9 shows 5 mode shapes of second beam obtained from Algor software.

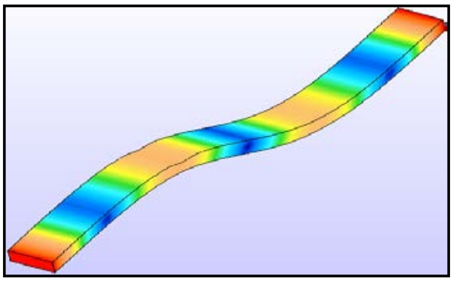
1^{st} mode



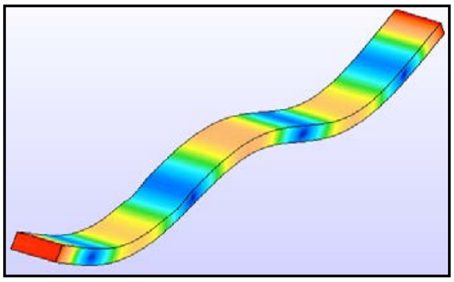
2^{nd} mode



3^{rd} mode



4^{th} mode



5th mode

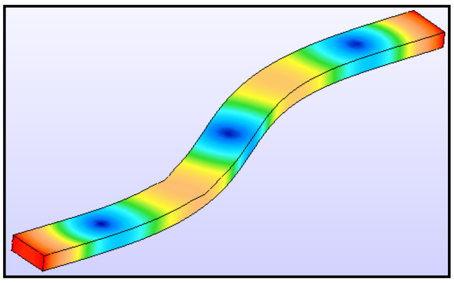


Figure 4.9: Five mode shapes of second beam

4.4.2 Experimental Result

Figure 4.10 and 4.11 show FRF and coherence graph for second beam obtained from experimental test.

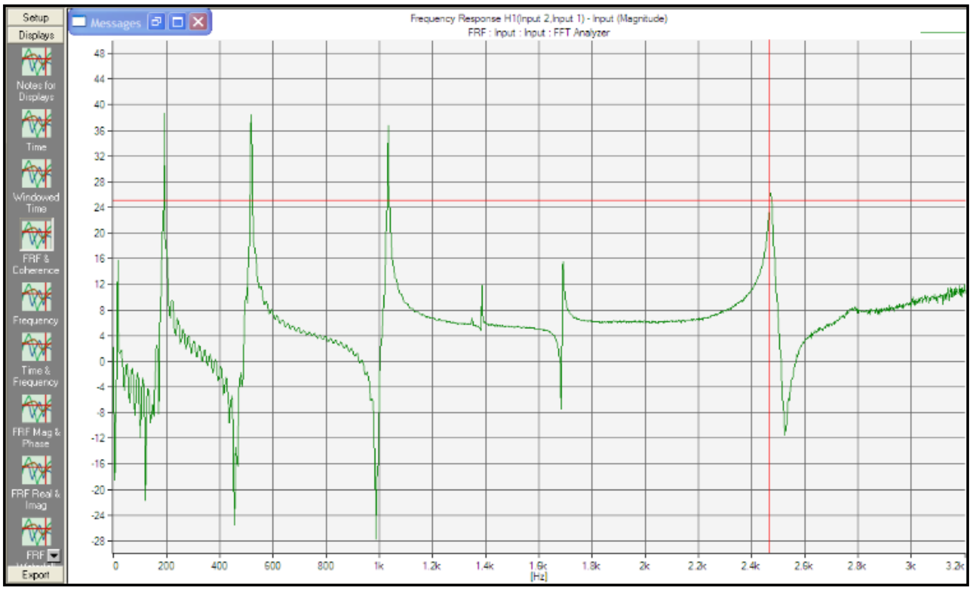


Figure 4.10: FRF graph of second beam

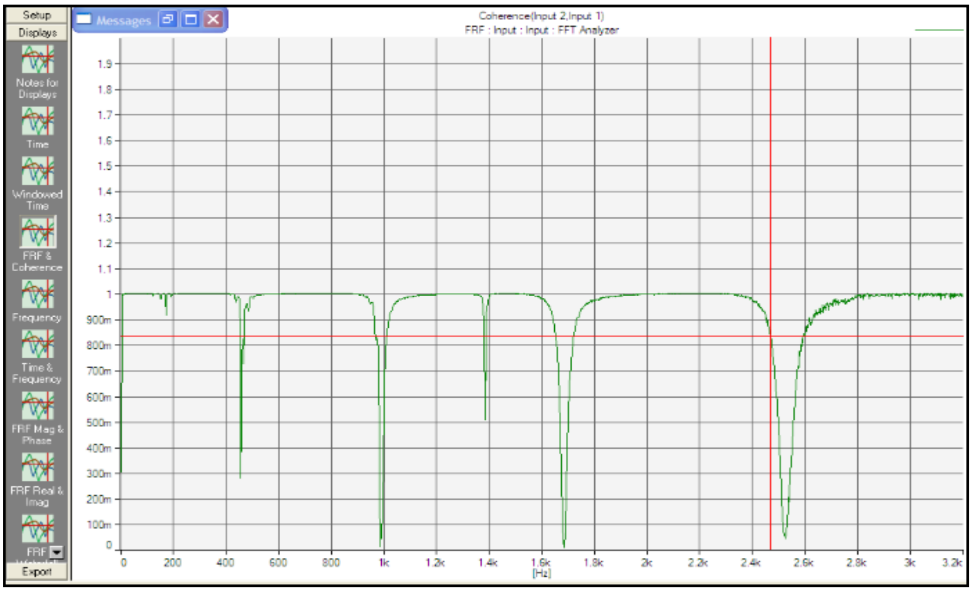


Figure 4.11: Coherence graph of second beam

Table 4.6 shows frequencies obtained for experimental test for second beam. Point hit 2 is selected due to slightly changes in number between points hit.

Table 4.6: Experiment Hammer Test of second beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
2	1	198	524	1014	1664	2482
	2	194	524	1014	1664	2482
	3	194	524	1012	1664	2484
	4	194	524	1012	1664	2482
	5	194	524	1012	1664	2482

From the graph in Figure 4.12, mesh 100 is selected. Frequencies at mode 2, 3 and 4 (605.58, 973.83, 1602.29) Hz for this mesh are closer to experimental (524, 1014, 1664) Hz.

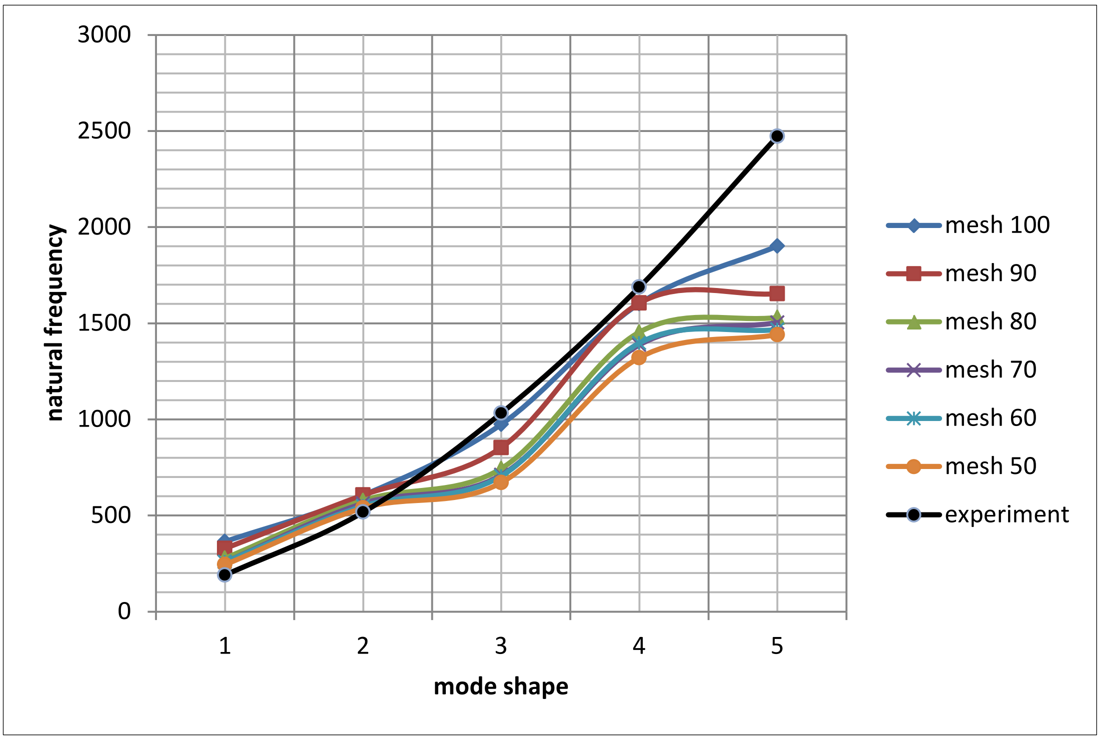


Figure 4.12: Combination of simulation and experiment data of second beam

4.5 THIRD NOTCHED BEAM

Table 4.7 shows the result of frequency in third beam obtained from Algor software.

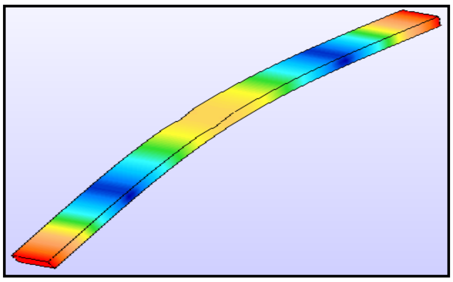
Table 4.7: Result of frequency in 3^{rd} notched beam

Mesh (%)/ Frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
100	342.62	597.61	935.61	1583.19	1745.37
90	325.25	599.12	866.91	1593.62	1634.83
80	265.58	573.50	736.67	1415.17	1529.51
70	264.98	568.53	734.94	1407.75	1522.28
60	256.06	548.78	719.02	1381.35	1471.17
50	240.77	538.05	673.21	1296.09	1444.34

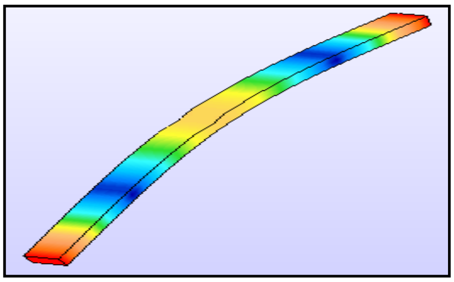
4.5.1 Simulation Algor: Mode Shapes

Figure 4.13 shows 5 mode shapes of third beam obtained from Algor software.

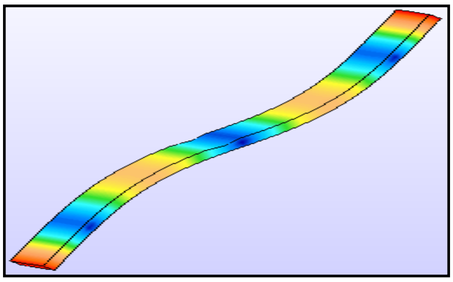
1^{st} mode



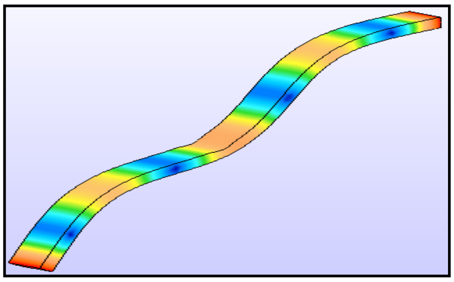
2^{nd} mode



3^{rd} mode



4^{th} mode



5th mode

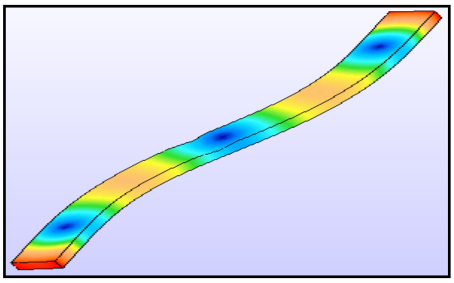


Figure 4.13: Five mode shapes of third beam

4.5.2 Experimental Result

Figure 4.14 and 4.15 show FRF and coherence graph for third beam obtained from experimental test.

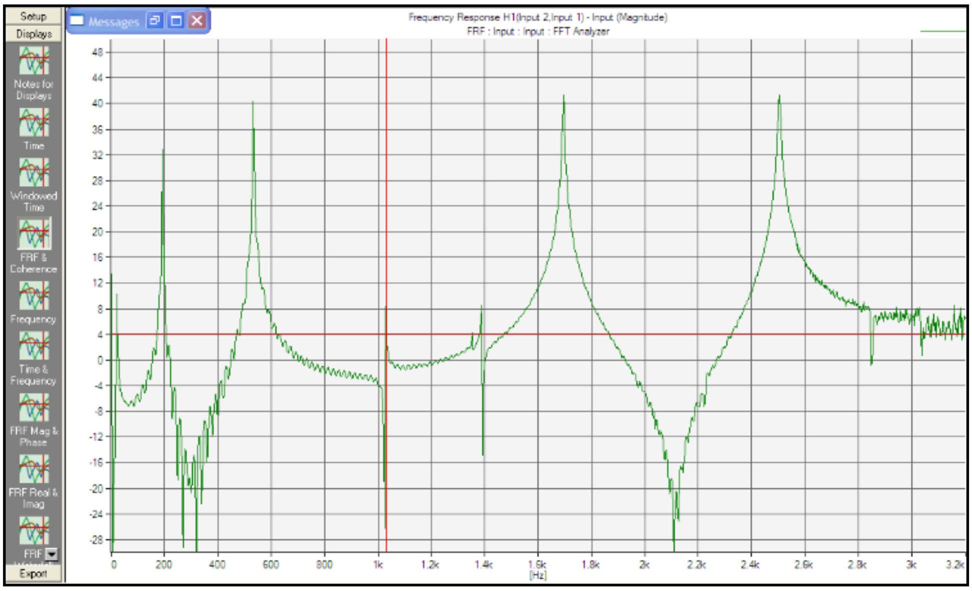


Figure 4.14: FRF graph of third beam

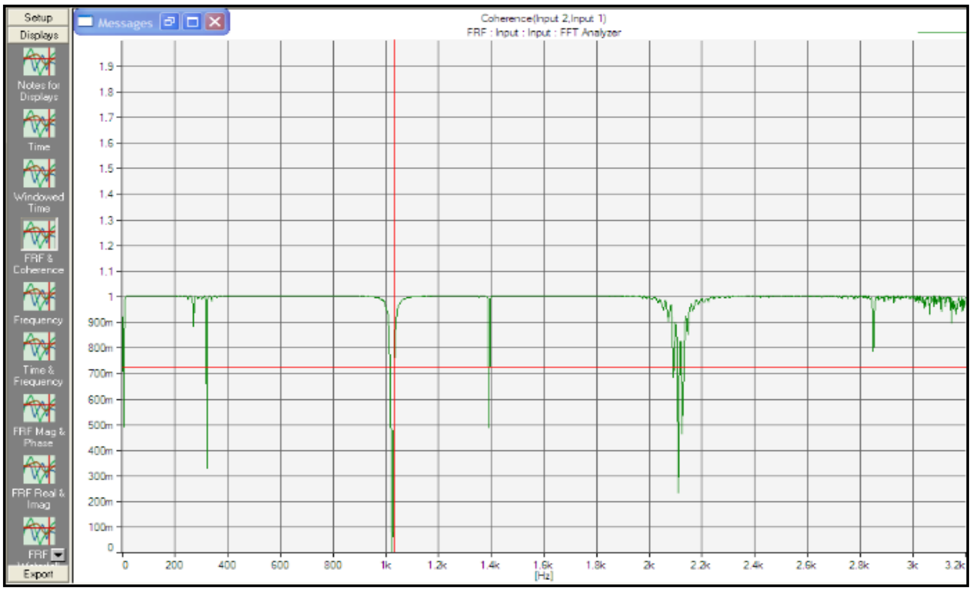


Figure 4.15: Coherence graph of third beam

Table 4.8 shows frequencies obtained for experimental test for third beam. Point hit 1 is selected due to slightly changes in number between points hit.

Table 4.8: Experiment Hammer Test of third beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
3	1	190	532	1026	1684	2502
	2	190	530	1026	1684	2502
	3	190	532	1026	1684	2502
	4	190	532	1026	1684	2502
	5	190	532	1026	1684	2502

From the graph in Figure 4.16, mesh 100 is selected. Frequencies at mode 2, 3 and 4 (597.61, 935.61, 1583.19) Hz for this mesh are closer to experimental (532, 1026, 1684) Hz.

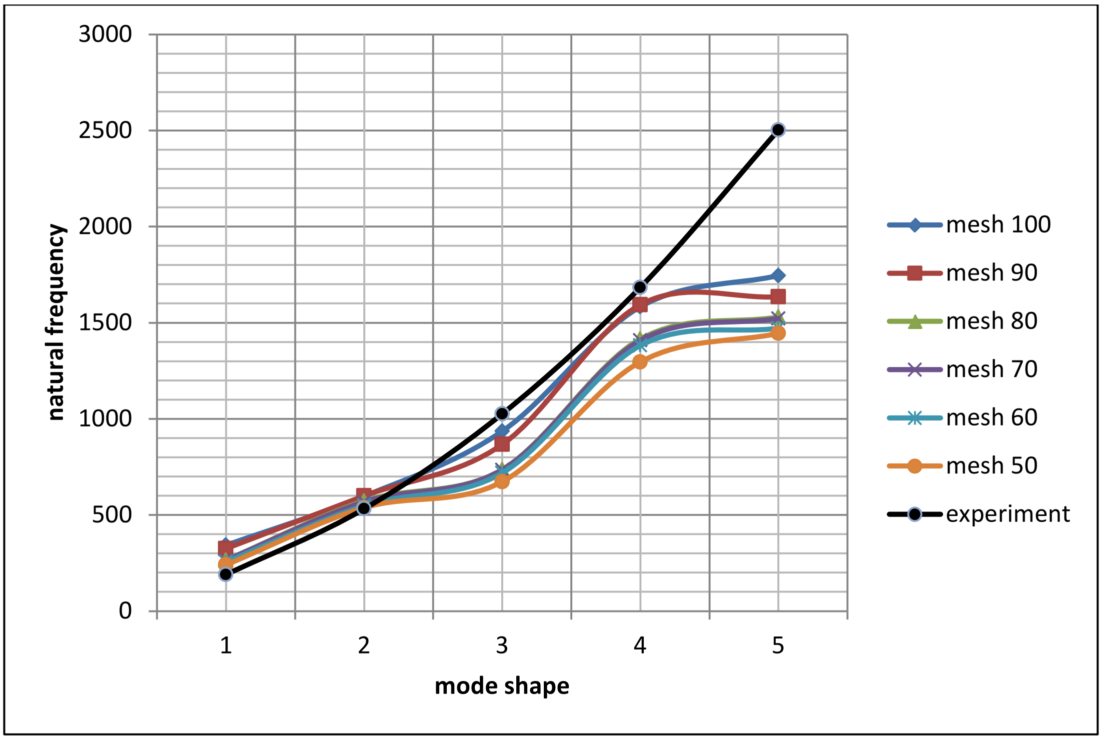


Figure 4.16: Combination of simulation and experiment data of third beam

4.6 FOURTH NOTCHED BEAM (DEPTH OF 4 MM)

Table 4.9 shows the result of frequency in fourth beam obtained from Algor software.

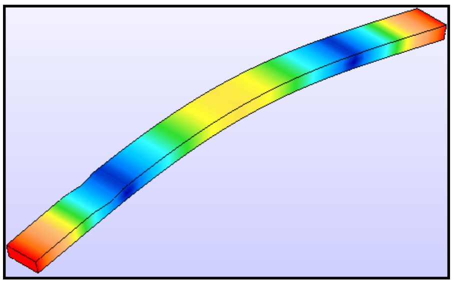
Table 4.9: Result of frequency in 4th notched beam

Mesh (%)/ Frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
100	361.54	609.37	984.24	1618.74	1856.40
90	290.42	605.33	782.82	1518.07	1597.49
80	257.17	572.16	699.21	1334.11	1517.37
70	267.31	573.66	723.17	1391.44	1518.75
60	261.60	552.82	709.40	1361.42	1468.76
50	249.96	541.57	676.95	1302.11	1440.57

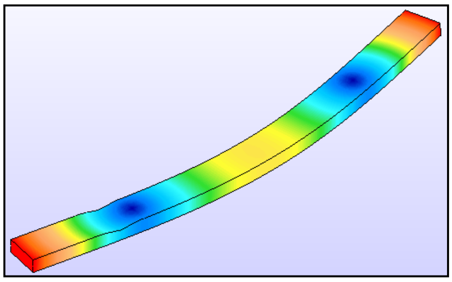
4.6.1 Simulation Algor: Mode Shapes

Figure 4.17 shows 5 mode shapes of fourth beam obtained from Algor software.

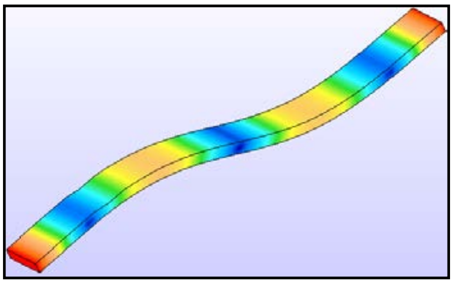
1st mode



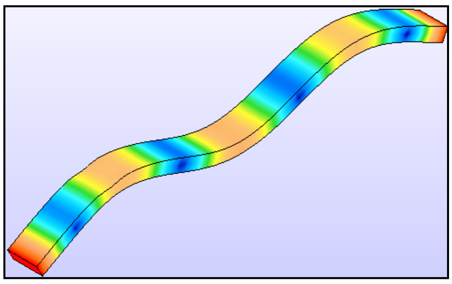
2nd mode



3rd mode



4th mode



5th mode

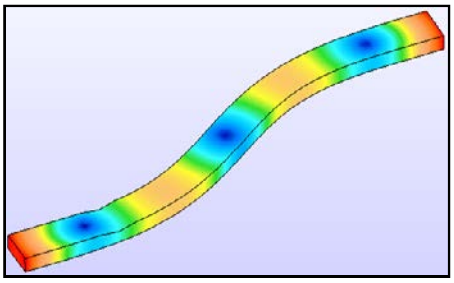


Figure 4.17: Five mode shapes of fourth beam

4.6.2 Experimental Result

Figure 4.18 and 4.19 show FRF and coherence graph for fourth beam obtained from experimental test.

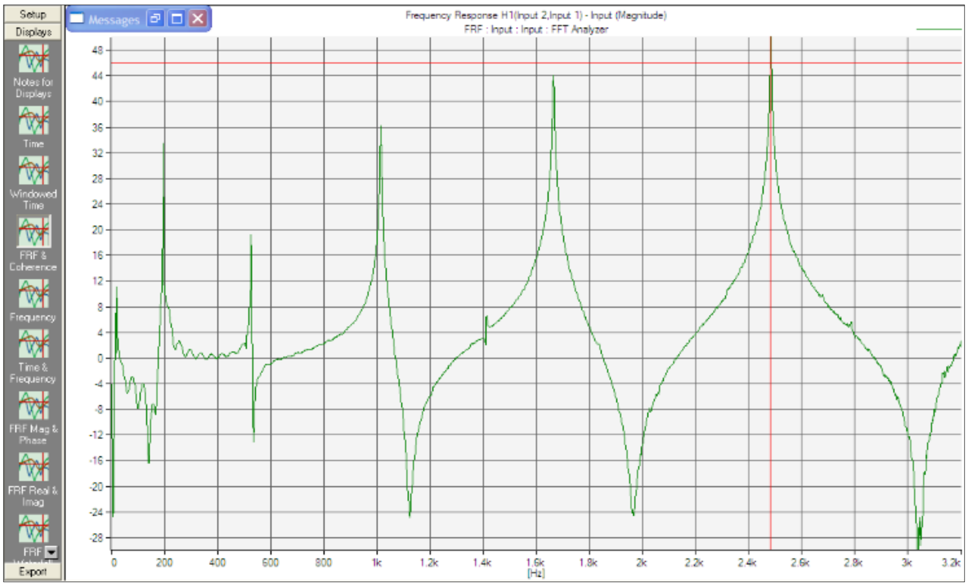


Figure 4.18: FRF graph of fourth beam

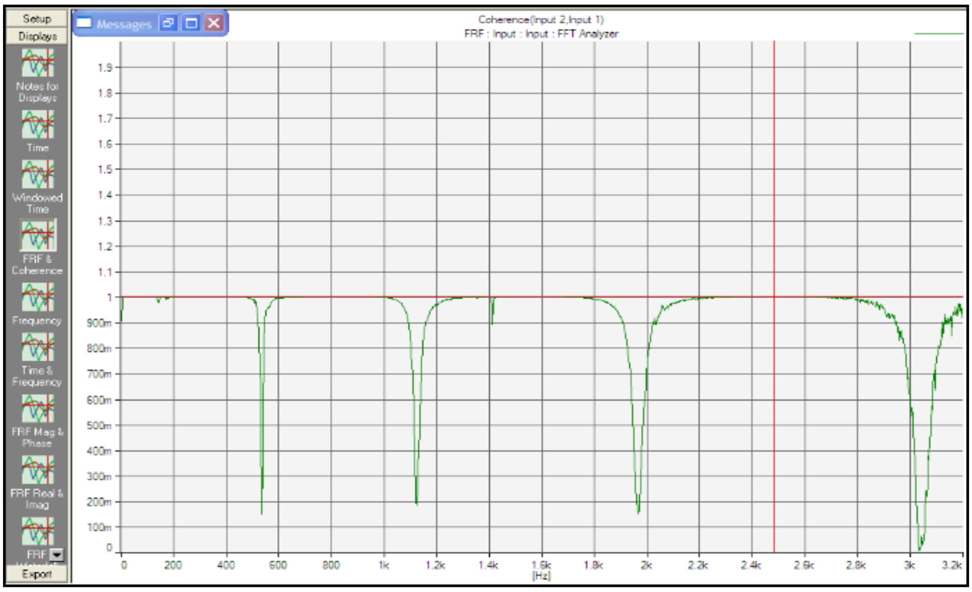


Figure 4.19: Coherence graph of fourth beam

Table 4.10 shows frequencies obtained for experimental test for fourth beam. Point hit 1 is selected due to slightly changes in number between points hit.

Table 4.10: Experiment Hammer Test of fourth beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
4	190	518	1032	1690	2470	190
	190	517	1032	1688	2472	190
	190	517	1032	1688	2473	190
	190	517	1032	1689	2471	190
	190	517	1017	1688	2472	190

The graph in Figure 4.20 shows that mesh 80 is the most influence and closer pattern alike to experimental. Frequencies at mode 2, 3 and 4 (676.31, 1114.93, 1801.77) Hz for this mesh are closer to experimental (532, 1037, 1702) Hz.

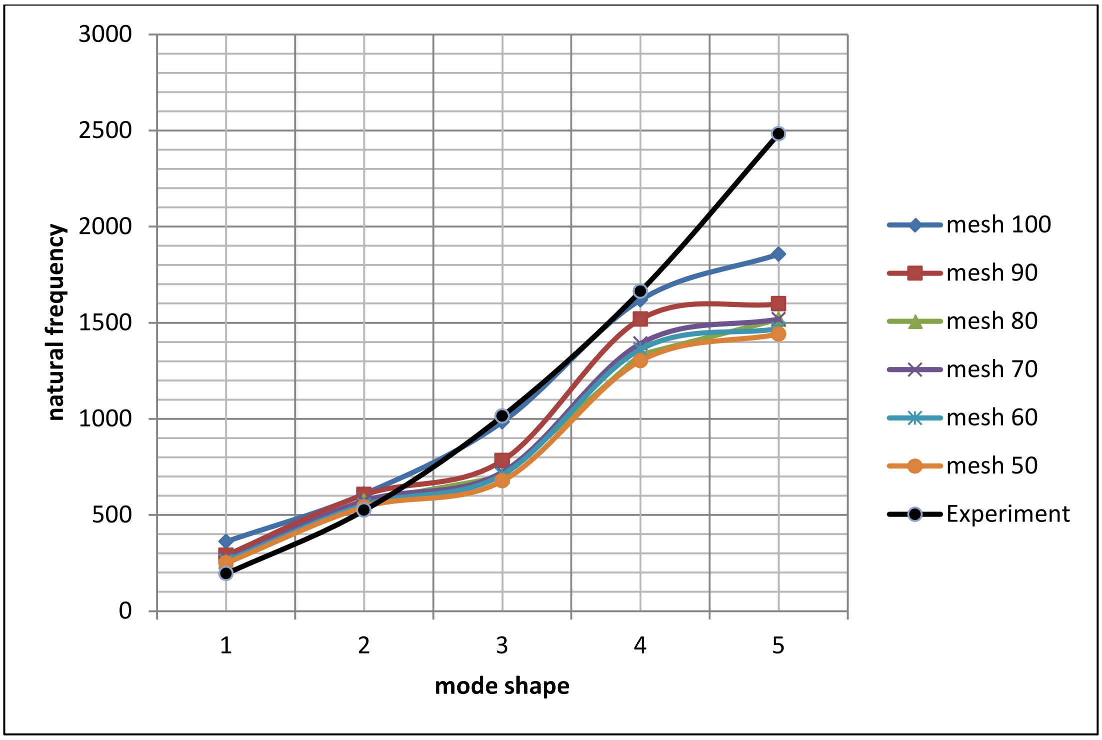


Figure 4.20: Combination of simulation and experiment data of fourth beam

4.7 FIFTH NOTCHED BEAM (DEPTH OF 8 MM)

Table 4.11 shows the result of frequency in fifth beam obtained from Algor software.

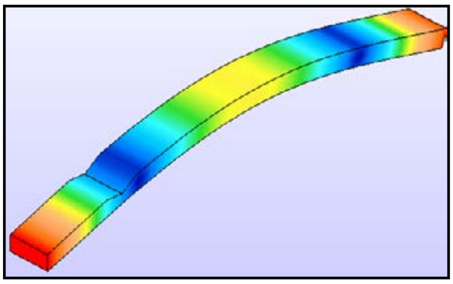
Table 4.11: Result of frequency in 5th notched beam

Mesh (%)/ Frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
100	358.81	608.78	955.06	1611.81	1788.48
90	289.30	605.21	766.11	1474.39	1591.78
80	259.40	569.99	702.40	1348.06	1505.69
70	269.41	567.91	724.65	1390.34	1497.89
60	261.84	550.26	690.07	1321.67	1451.12
50	246.55	540.52	657.92	1255.68	1429.62

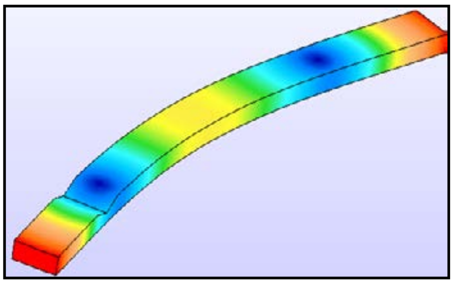
4.7.1 Simulation Algor: Mode Shapes

Figure 4.21 shows 5 mode shapes of fifth beam obtained from Algor software.

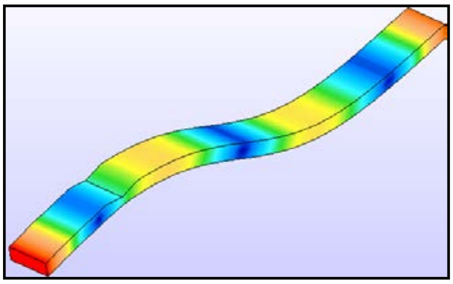
1st mode



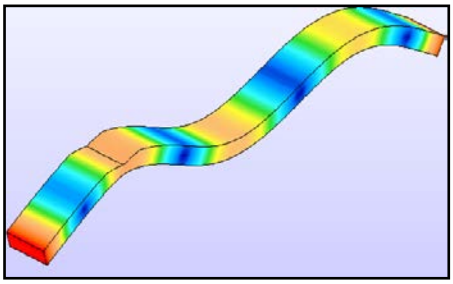
2nd mode



3rd mode



4th mode



5th mode

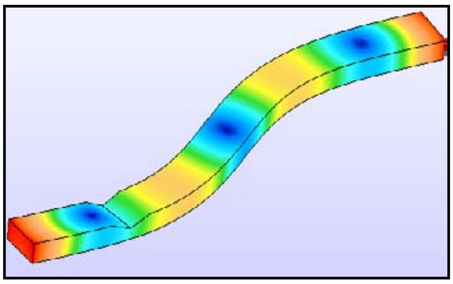


Figure 4.21: Five mode shapes of fifth beam

4.7.2 Experimental Result

Figure 4.22 and 4.23 show FRF and coherence graph for fifth beam obtained from experimental test.

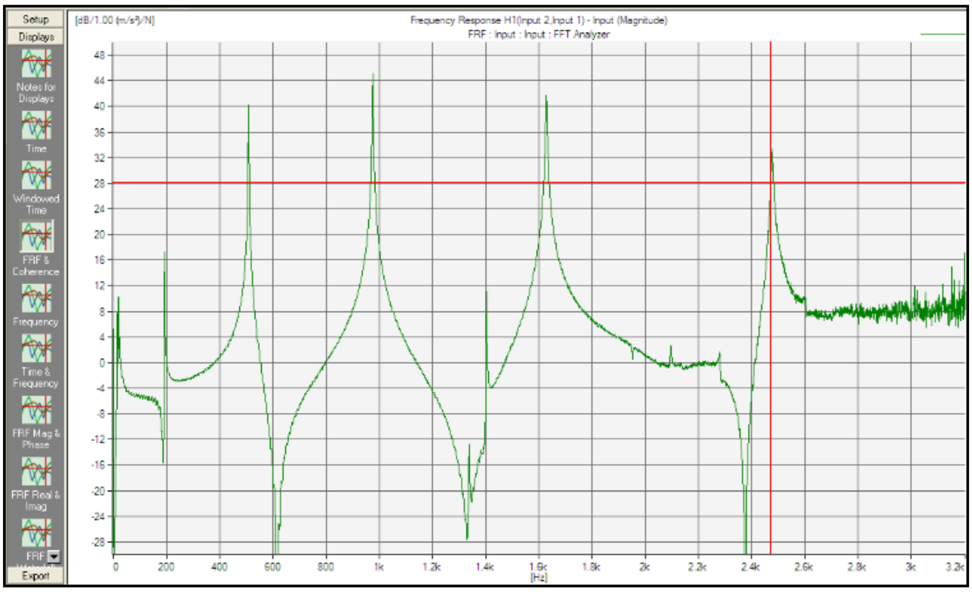


Figure 4.22: FRF graph of fifth beam

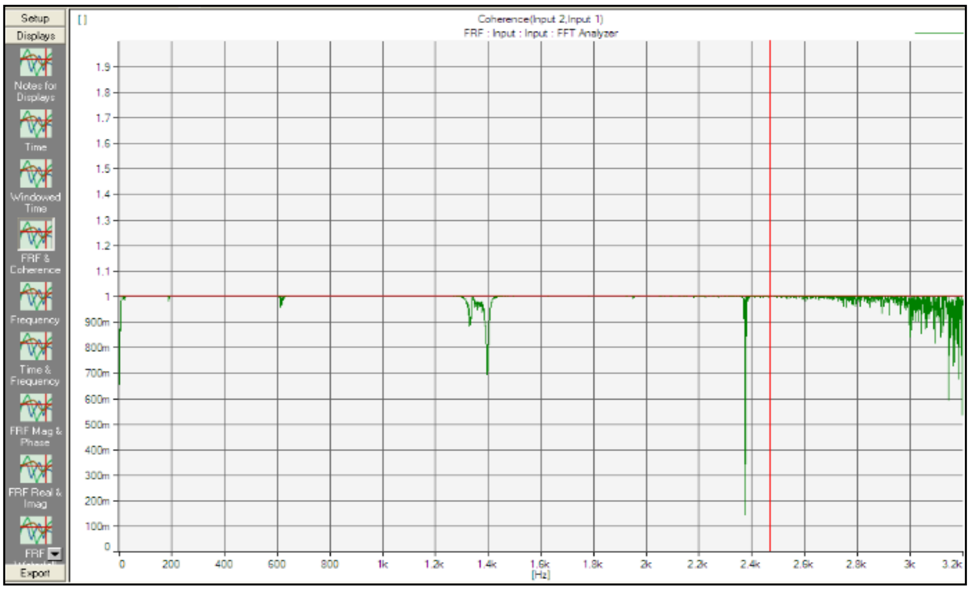


Figure 4.23: Coherence graph of fifth beam

Table 4.12 shows frequencies obtained for experimental test for fifth beam. Point hit 1 is selected due to slightly changes in number between points hit.

Table 4.12: Experiment Hammer Test of fifth beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
5	1	192	508	974	1627	2474
	2	192	504	974	1626	2474
	3	192	508	974	1627	2475
	4	192	508	974	1627	2475
	5	192	508	974	1627	2474

The graph in Figure 4.24 shows that mesh 100 is the most influence and closer pattern alike to experimental. Frequencies at mode 2, 3 and 4 (608.78, 955.06, 1611.81) Hz for this mesh are closer to experimental (508, 974, 1627) Hz.

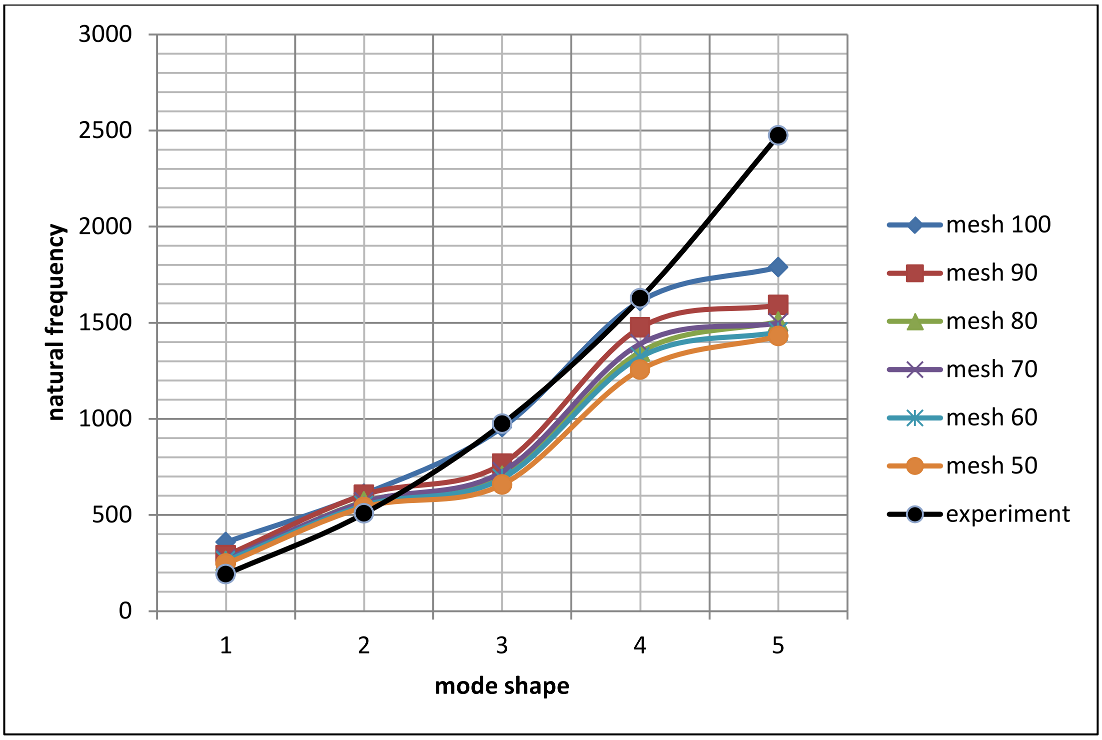


Figure 4.24: Combination of simulation and experiment data of fifth beam

4.8 SIXTH NOTCHED BEAM (DEPTH OF 12 MM)

Table 4.13 shows the result of frequency in sisth beam obtained from Algor software.

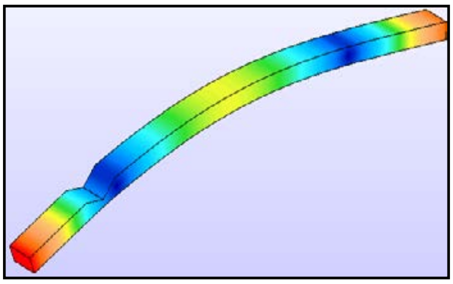
Table 4.13: Result of frequency in 6th notched beam

Mesh (%)/ Frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
100	361.67	604.91	887.29	1577.62	1686.67
90	289.37	602.46	725.97	1389.39	1567.50
80	254.24	569.10	670.59	1276.47	1496.58
70	263.67	564.94	676.13	1278.44	1487.02
60	255.78	547.19	654.48	1240.05	1434.62
50	243.27	538.92	621.87	1175.32	1410.10

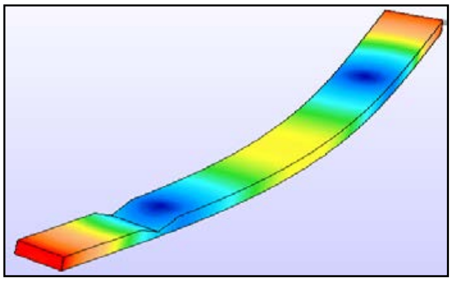
4.8.1 Simulation Algor: Mode Shapes

Figure 4.25 shows 5 mode shapes of sixth beam obtained from Algor software.

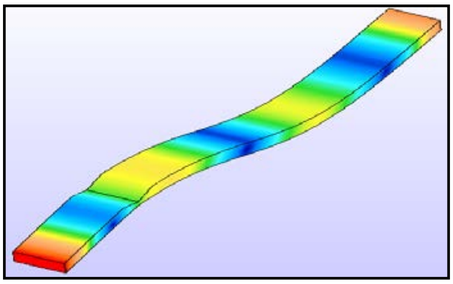
1st mode



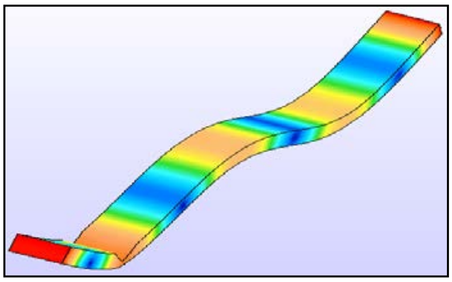
2nd mode



3rd mode



4th mode



5th mode

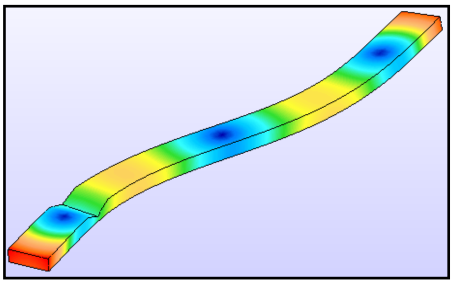


Figure 4.25: Five mode shapes of sixth beam

4.8.2 Experimental Result

Figure 4.26 and 4.27 show FRF and coherence graph for sixth beam obtained from experimental test.

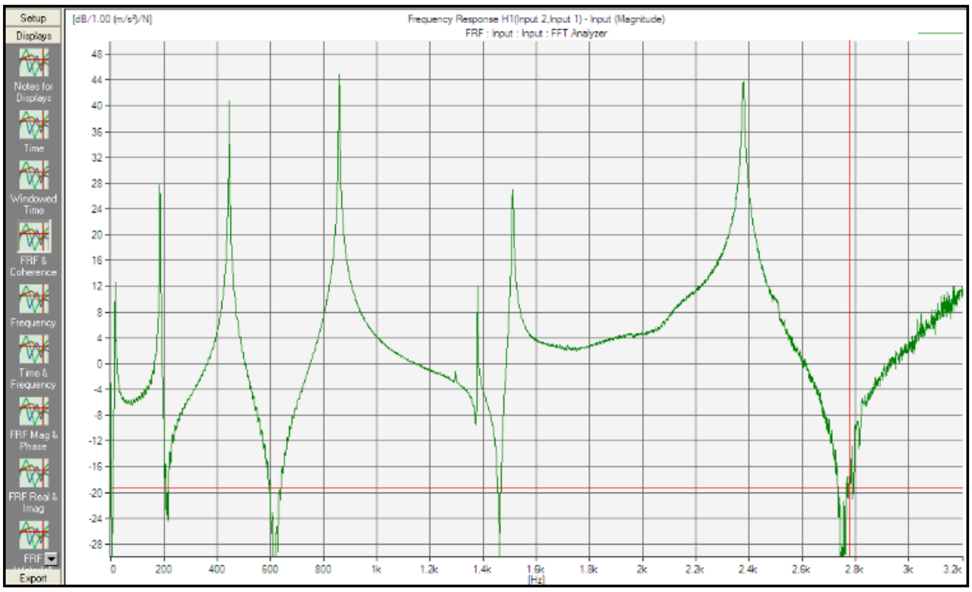


Figure 4.26: FRF graph of sixth beam

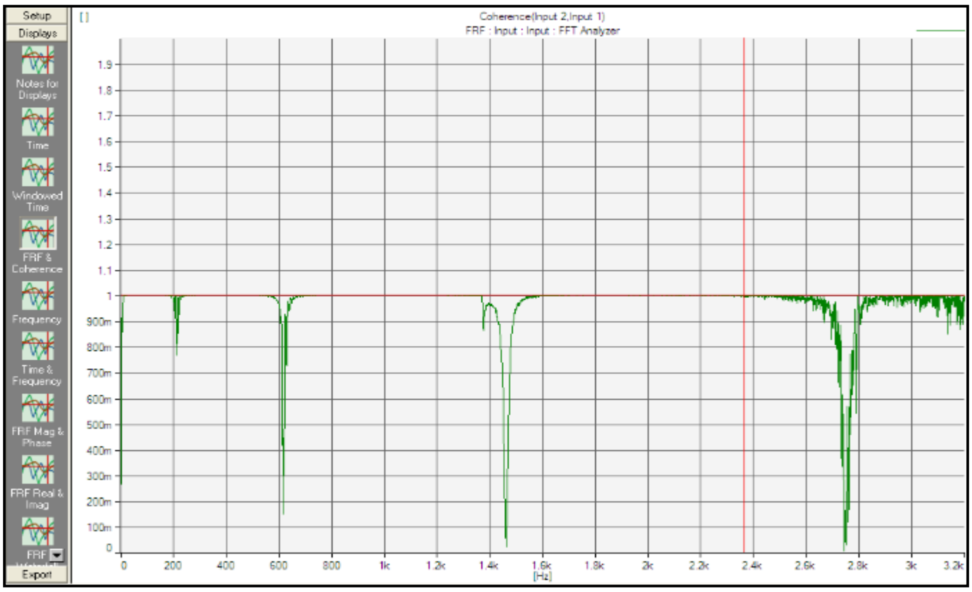


Figure 4.27: Coherence graph of sixth beam

Table 4.14 shows frequencies obtained for experimental test for sixth beam. Point hit 1 is selected due to slightly changes in number between points hit.

Table 4.14: Experiment Hammer Test of sixth beam

Model	Point Hit	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
6	1	184	444	858	1510	2376
	2	167	437	858	1509	2376
	3	168	444	858	1509	2376
	4	184	444	858	1509	2376
	5	184	444	858	1509	2375

The graph in Figure 4.28 shows that mesh 100 is the most influence and closer pattern alike to experimental. Frequencies at mode 2, 3 and 4 (604.91, 887.29, 1577.62) Hz for this mesh are closer to experimental (444, 858, 1510) Hz.

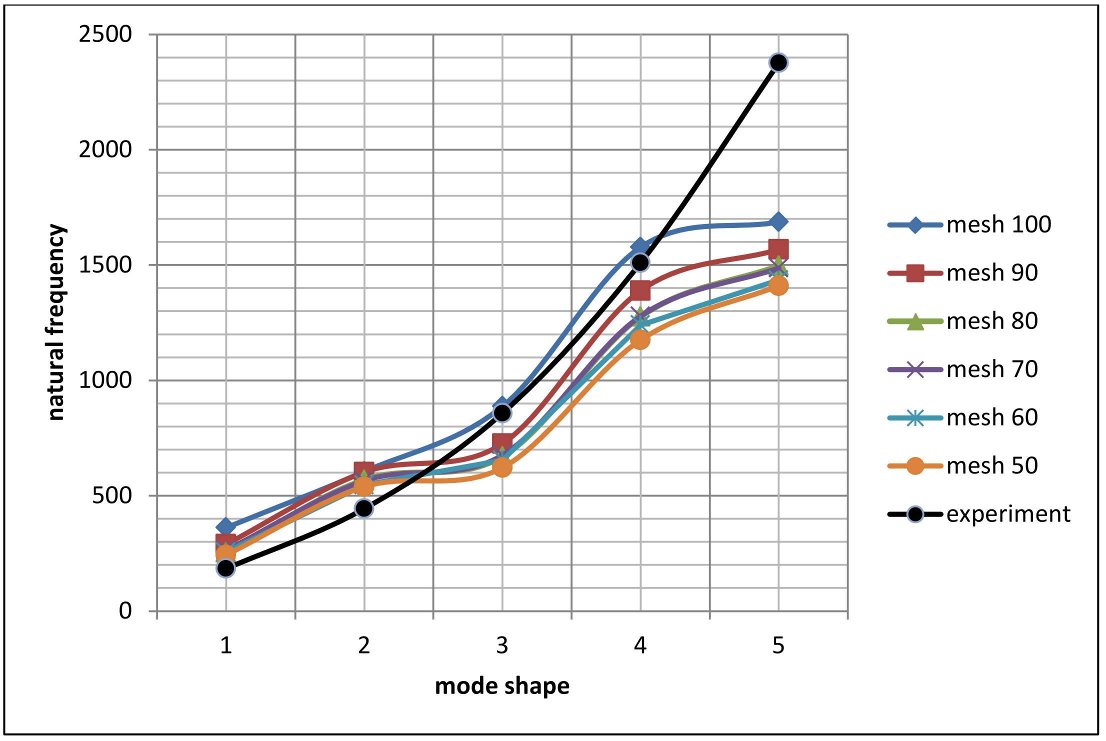


Figure 4.28: Combination of simulation and experiment data of sixth beam

4.9 DISCUSSION

4.9.1 Mode shape

First of all, each mode shape contains both bending component and twisting component (Jen San Chen). In the first mode (Fig. 4.29 (a)) the trailing edge near the tip and nothed has larger deformation compared to other parts. This specifies that the fundamental bending deformation dominates the first mode. In the second mode (Fig. 4.29 (b)) two node fixed and it bending on it left.

In the third mode (Figure 4.29 (c)) it shown that obvious twisting deformation near the tip by observing that the two points between the tip, one on the leading edge and the other on the trailing edge, are moving in opposite directions. The fourth mode (Figure 5(d)) reveals even higher order of bending deformation as observed of two obvious nodal points on the trailing edge.

There are 4 fixed node and the vibration looks like a wave propagation phenomenon. In the four modes represented in Figure 4.29, modes 1, 2, and 3 are close to real modes, while mode 4 is apparently a complex mode (Jen San Chen). The 4^{th} mode is torsion likely to mode 3 but in the different axis, which moving in X axis.

In the previous Figures with mode shapes from control beam until 6^{th} beam of notched are not quite different between their shapes. It differs a little on the notch part. The main point is the different of frequencies obtained between beams in each mode shapes.

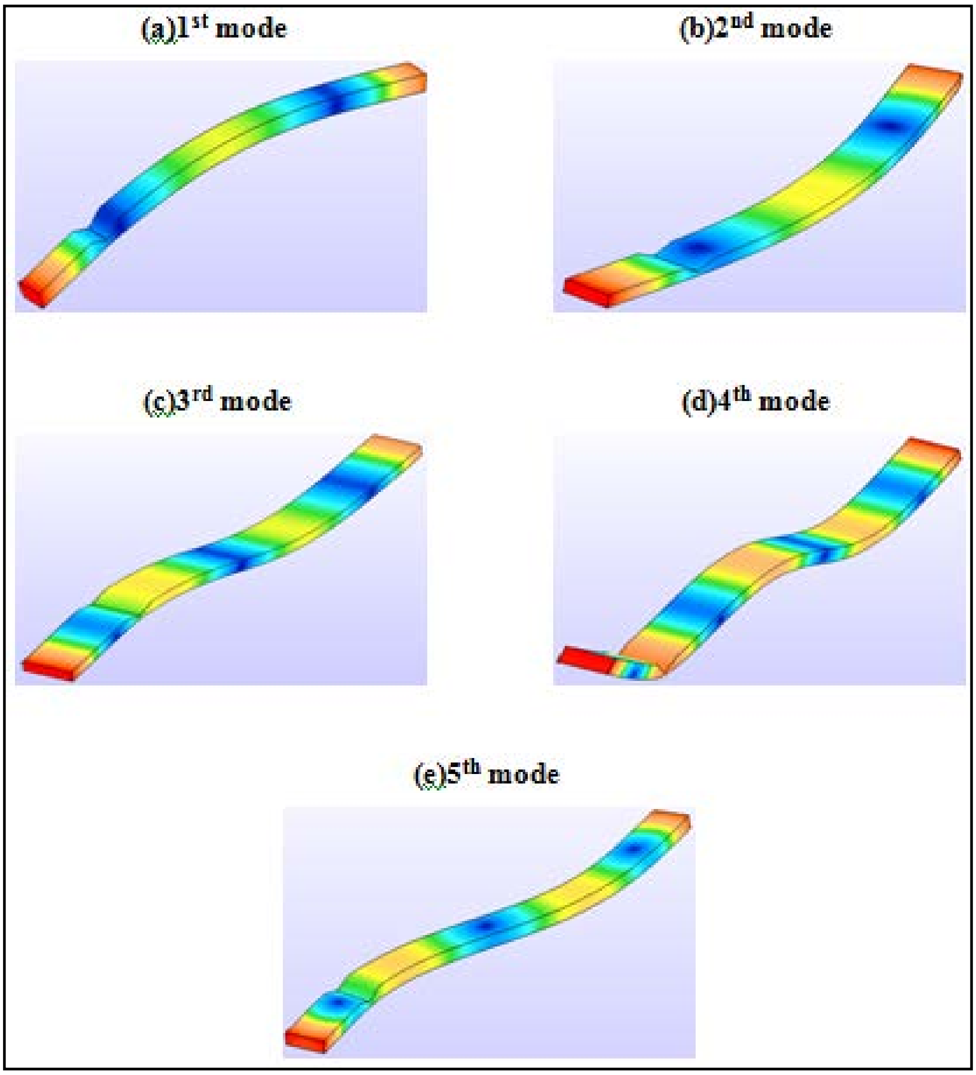


Figure 4.29: (a) - (e) Mode shapes corresponding to the 6th notched beam

4.9.2 Frequency Response Function and Coherence Graph

Frequency Response Function (FRF) is computed from two signals. The FRF is also often referred to as by the term “transfer function”. The FRF describes the level of one signal relative to another signal verses frequency. In modal analysis, it measures the vibration response of the structure relative to the force input of the impact hammer or shaker. An FRF is a complex signal with both magnitude and phase information. Each peak in the FRF represents one of the vibrational modes of the beam. In this graph, second peak (200 and above) Hz and so on were taken to compare them with simulation result due to setting cut off frequency in software is 50Hz. Figure 4.30 shows an example of FRF graph of one of the notched beams.

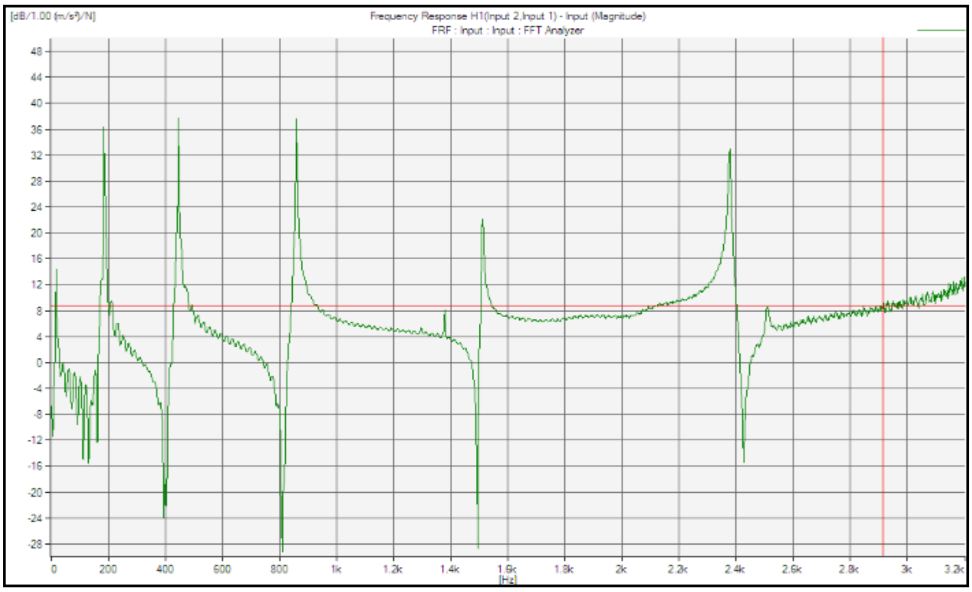


Figure 4.30: Example: FRF graph of 6th notched beam (12mm depth)

Coherence as for example in Figure 4.31 is related to the FRF and it indicates what part of one signal is correlated with a second signal. It varies from zero to one and is a function of frequency. In modal analysis, it is used to evaluate the quality of a measurement where a good impact produces a vibration response that is completely correlated with the impact, designate by a coherence graph that is near one over the entire frequency range. Graph in Figure 4.31 shows the good impact data provided almost straight line for example at 400 Hz. But still did not match the FRF graph in Figure 4.30 at the same spot. It is due to some other source of vibration, or noise or the hammer is not exciting the entire frequency range, that distracts the exact data needed.

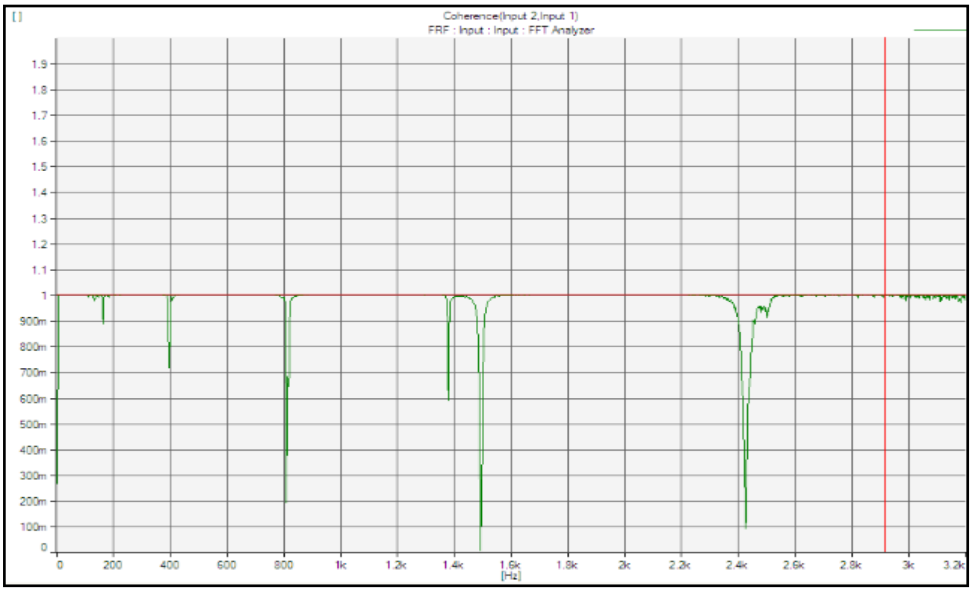


Figure 4.31: Example: Coherence graph of 6th notched beam (12mm depth)

4.9.3 Notched with Various Distance

After correlate the data between simulation and experiment natural frequency for notched beam with various distances, the mesh selected are shown in Table 4.15.

Table 4.15: Notched Beam with Various Distances

No of model	Mesh frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Control	80	407.99	676.31	1114.93	1801.77	2135.35
1	100	361.54	609.37	984.24	1618.74	1856.40
2	100	364.44	605.58	973.83	1602.29	1901.35
3	100	342.62	597.61	935.61	1583.19	1745.37

From the graph in Figure 4.32, it showed that the distance of notched do affect the natural frequency. The notched at 100 mm has greater frequency than 200 mm and 300 mm from most of its mode's frequencies. Compare to notch at 300 mm, the value showed the lowest frequency with all of its mode's frequencies.

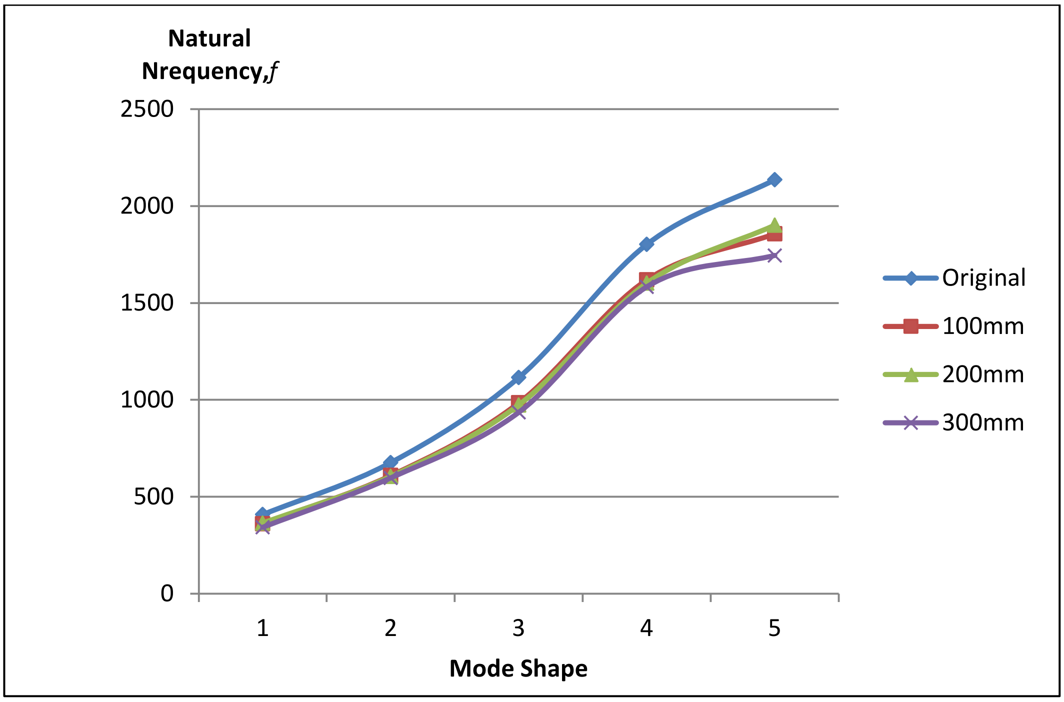


Figure 4.32: Graph of Notched Beam with Various Distances

4.9.4 Notched with Various Depth

The data from simulation and experimental of notched with depth give suitable mesh in simulation to be selected. The data required completed in Table 4.16.

Table 4.16: Notched Beam with Various Depth

No of model	Mesh frequency	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Control	80	407.99	676.31	1114.93	1801.77	2135.35
4	100	361.54	609.37	984.24	1618.74	1856.40
5	100	358.81	608.78	955.06	1611.81	1788.48
6	100	361.67	604.91	887.29	1577.62	1686.67

From the graph in Figure 4.33, the notched beam with depth of 4 mm showed the highest frequencies whereas the notch of 12 mm is the lowest frequency. It can conclude that the more depth of the notched, the more frequency to be reduced from the original beam with no notched applied to it.

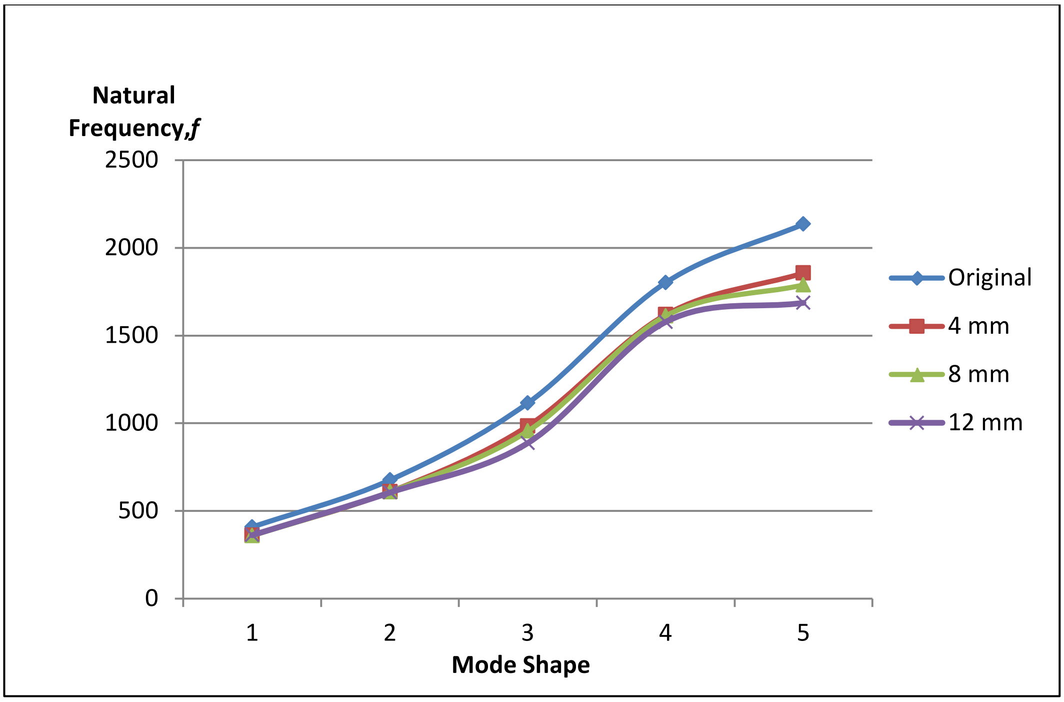


Figure 4.33: Graph of Notched Beam with Various Depths

4.9.5 The Comparison between Simulation and Experimental Result

From the results in Table 4.17 and 4.18, percentage error for distance case is around 19-23 % and for depth case is around 20-25 %. This small percentage accounted by some factors. The main error is using too high force until it stated overload.

Other factors are not hitting the beam at the accelerometer position, not hit the same point for each the two taps and not ensuring the beam has stopped vibrating before second tap. By avoiding these all factors, better results can be obtains and reduce the percentage of error.

Table 4.17: Comparison result and percentage error for distance

Mode	1st (100 mm)		%	2nd (200 mm)		%	3rd (300 mm)		%
	Notch With Various Distance								
	Sim.	**Exp**	**Error**	**Sim.**	**Exp**	**Error**	**Sim.**	**Exp**	**Error**
1	361.537	190	47.45	364.444	194	46.77	342.619	190	44.54
2	609.368	517	15.16	605.583	524	13.47	597.614	532	10.98
3	984.238	1032	4.85	973.827	1014	4.13	935.611	1026	9.66
4	1618.74	1688	4.28	1602.29	1664	3.85	1583.19	1684	6.36
5	1856.40	2472	33.16	1901.35	2482	30.54	1745.37	2502	43.35
Average Percentage Frequency difference (%)			20.98			19.75			22.98

Table 4.18: Comparison result and percentage error for depth

Mode	4th (4 mm)		%	5th (8 mm)		%	6th (12 mm)		%
	Notch With Various Depth								
	Sim.	**Exp**	**Error**	**Sim.**	**Exp**	**Error**	**Sim.**	**Exp**	**Error**
1	361.537	190	47.45	358.814	192	46.50	361.671	184	49.13
2	609.368	517	15.16	608.777	508	16.55	604.914	444	26.60
3	984.238	1032	4.85	955.062	974	1.98	887.294	858	3.30
4	1618.74	1688	4.28	1611.81	1627	0.94	1577.62	1510	4.28
5	1856.40	2472	33.16	1788.48	2474	38.33	1686.67	2376	40.87
Average Percentage Frequency difference (%)			20.98			20.86			24.84

4.10 CONCLUSION

The conclusion for this chapter is the experiment handled in good condition and the results were obtained. From comparison made between experiment and simulation, the natural frequency from experimental test is closer to simulation. Furthermore, the notch of each beam does affect their natural frequency. Detailed conclusion will be made in the next chapter.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

The effects of notched beam with various distance and depth are investigated at a uniform of boundary condition. Three notch distances of 100, 200 and 300 mm and three notch depths of 4, 8 and 12 mm are considered. Natural frequency of this six type of notched are determined from simulation, which using FEA Algor software and experimental modal analysis, which by using hammer test. Important observations from the simulation and experimental data are noted and summarized.

The mode shapes of all six beam show the dynamic behavior of the beam do not change but do affect the natural frequency each beam in each mode. From all data of frequency between simulation and experimental, mesh 100 is the best mesh for all six beam. Except for original beam, mesh 80 is selected as the best mesh. The simulation data must correlate to experimental data, hence graph of combination in Figure 4.32 and 4.33. Plus, the percentage errors between them are just approximately 19-23 % for distance and 20-25 % for depth, which mean there are some minor disturbance occurred.

In this study, the natural frequency of beam is decreasing with the notch distance from the tip of beam is increasing toward the middle of the beam. From the depth of notch study, the natural frequency decreasing with the deeper the notched build on the beam.

5.2 RECOMMENDATIONS

5.2.1 Suggestions

This research still has to be carry forward to get the more accurate frequency for the notched beam. During the experimental analysis several factos are not considered in the scope analysis and for the further work strongly recommended. The first one is, simulates the material by using different material, mesh, and other parameters to be change. Secondly, the beam has to be more various of notch place and size which mean a lot of beam needed. Furthermore, shape of notch can also considered like U shape. During experiment, there are many disturbance, therefore, a lot of sensors required to maximize the ablility to obtain the accurate results. In making variety of experiment type, force can be applied during testing, and fixing both tip of beam also will be one of the choices. Another futher study can be made is by using MEScope.

5.2.2 Problem of the Research

In this project, there are some problems that have been encountered from the beginning until at the end of the research. So there are some suggestions to improve this research. During work progress, the need of suitable machine to conduct machining process to form notch is crucial which the right miling machine is not available. The progress was lagging due to using the EDM wire cut machine, which the machine using wire to cut piece of work and that take time to finish the job. The other problem occured was boundary condition can not 100 percent be imitated due to some lack of device. Thus, there are disturbance from other form of energy like sound during the hammer test.

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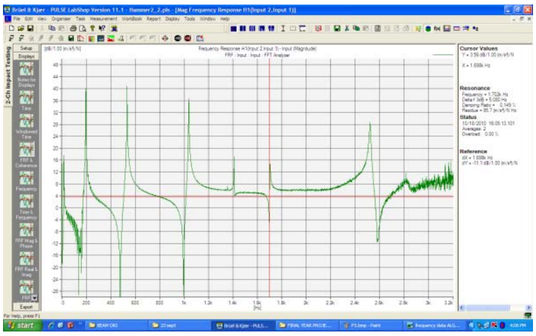
Shun-zhang Chen and Lu-ping LI. 3D Modeling and Finite Element analysis of Dynamic Characteristics for Blades of Wind Turbine

APPENDIX A

FIGURE OF EXPERIMENT

Point 1



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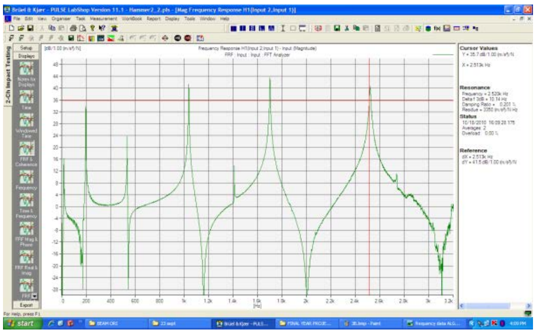

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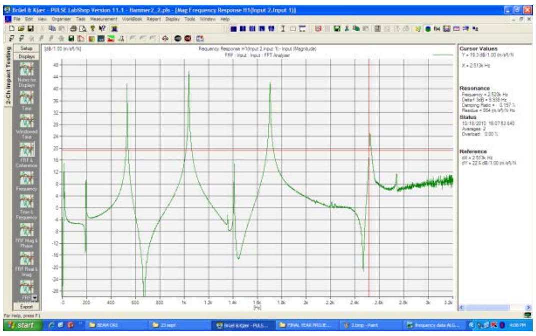

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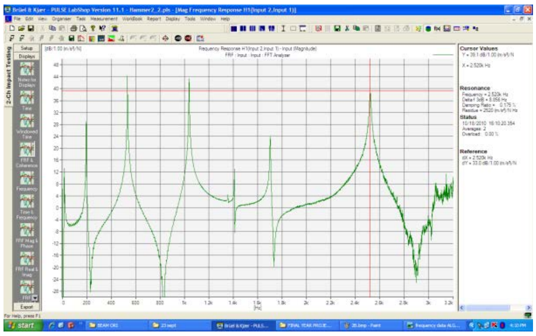

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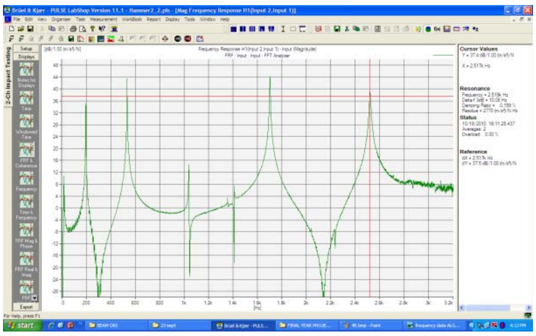
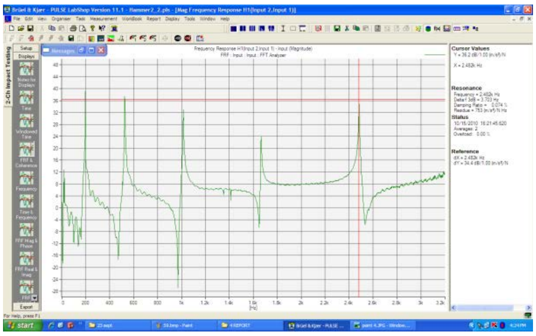


Figure 6.1: 5 Points on Original Beam

Point 1



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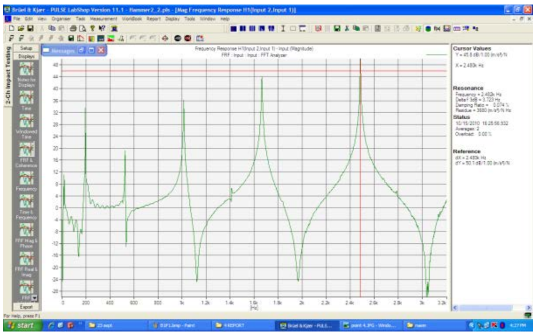

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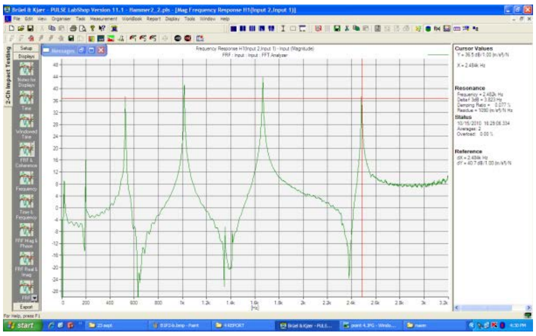

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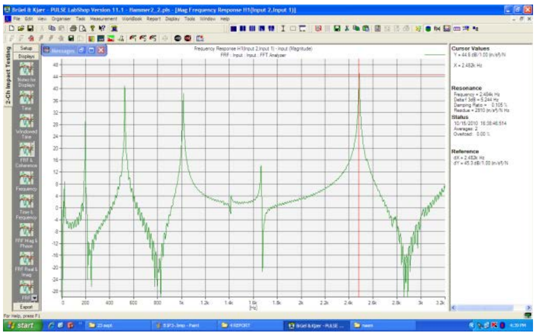

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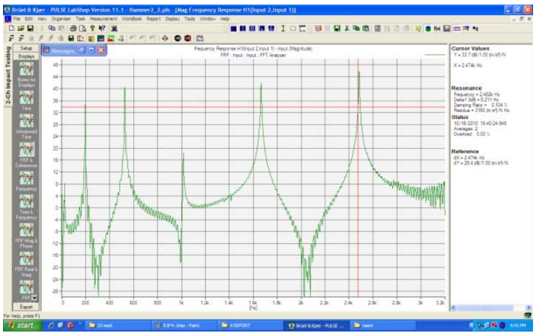
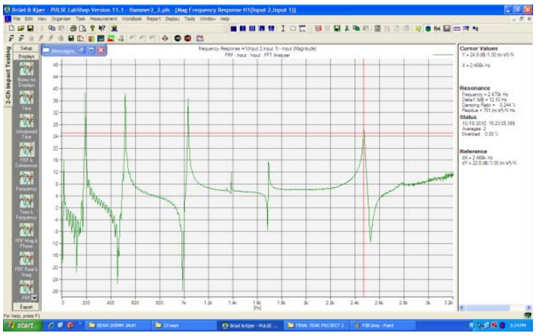


Figure 6.2: 5 Points on First Beam

Point 1



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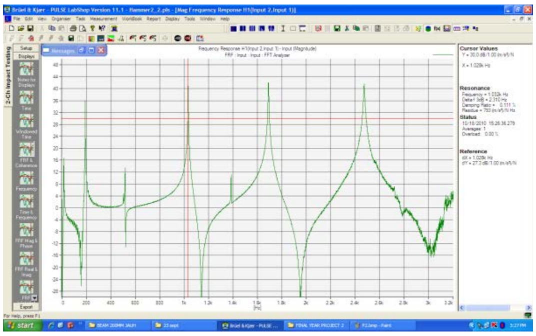

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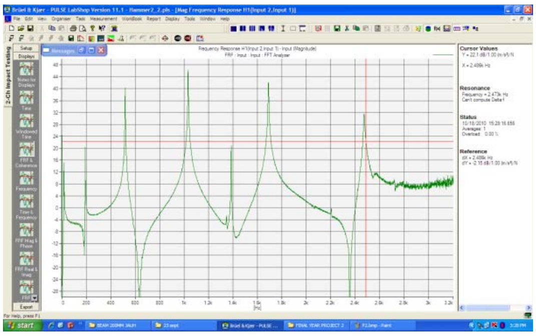

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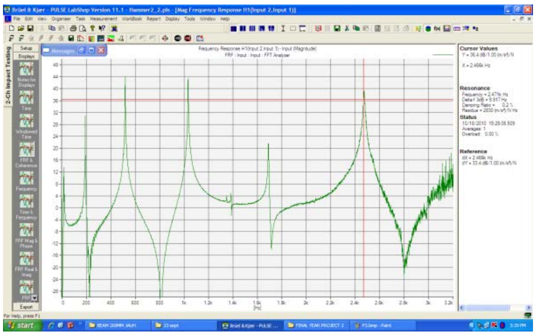

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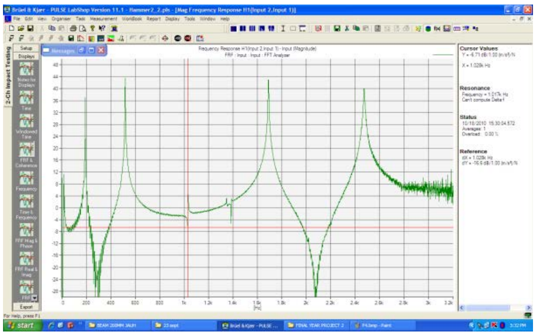
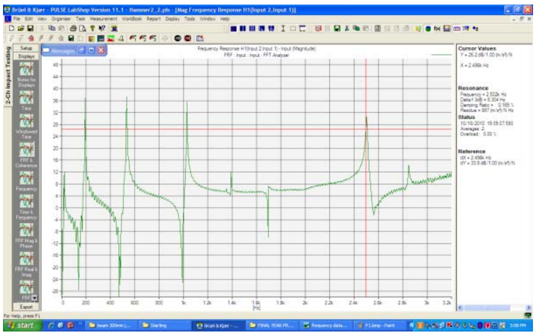


Figure 6.3: 5 Points on Second Beam

Point 1



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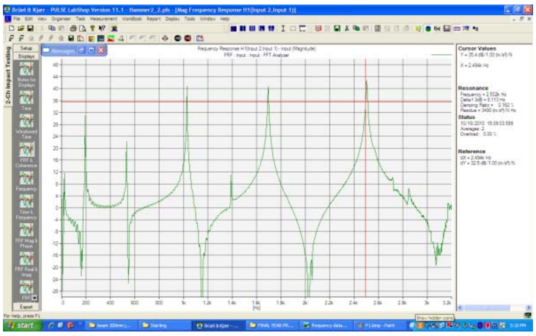

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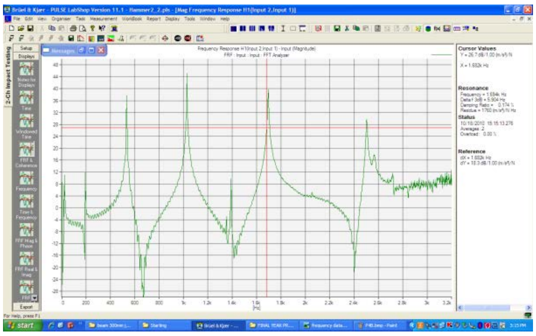

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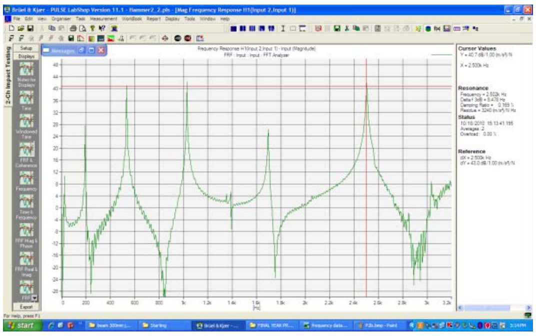

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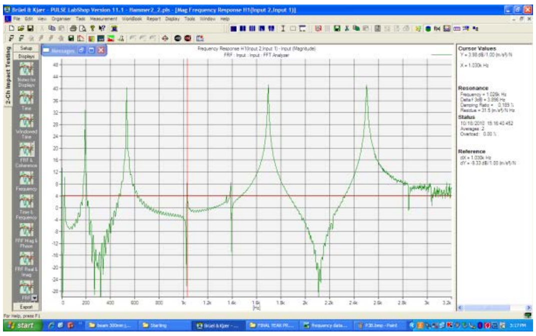
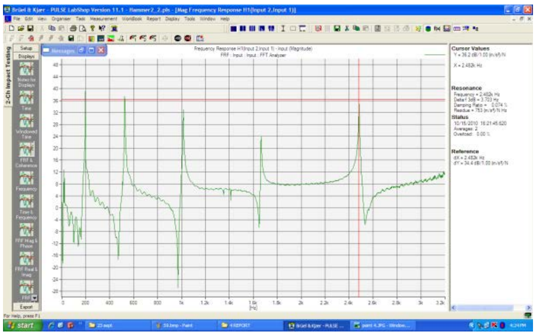


Figure 6.4: 5 Points of Third beam

Point 1



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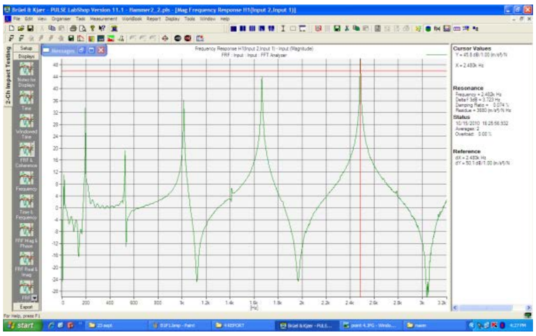

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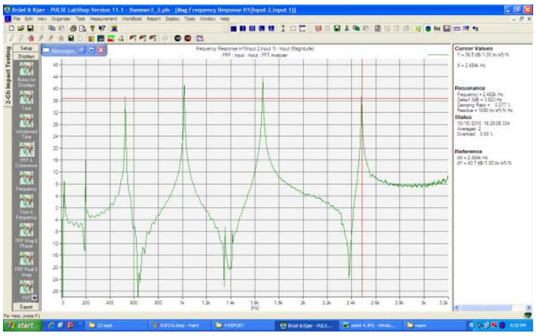

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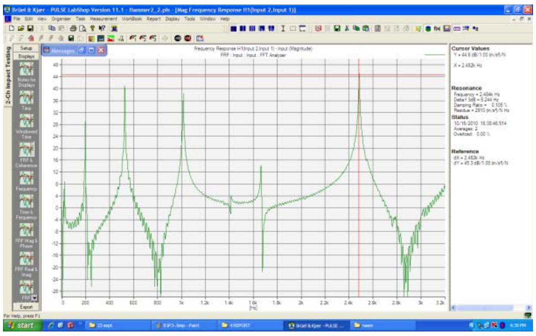

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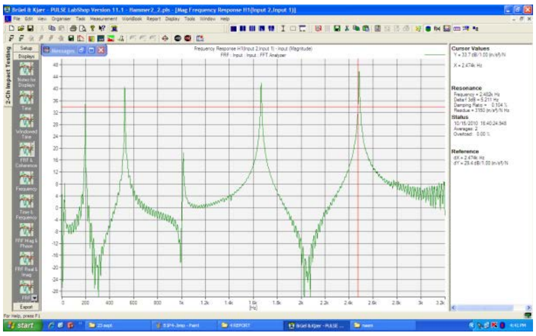
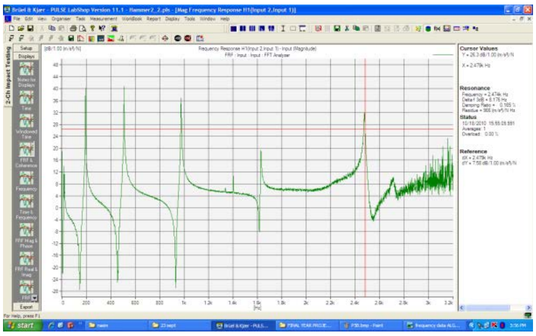


Figure 6.5: 5 Points on fourth Beam

Point 1



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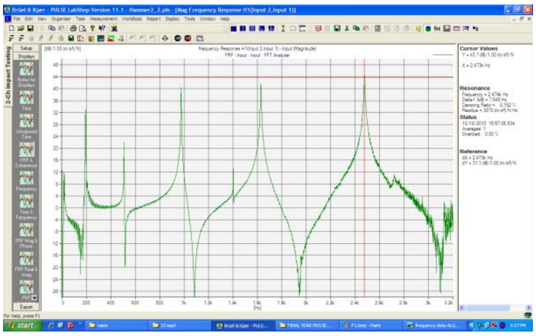

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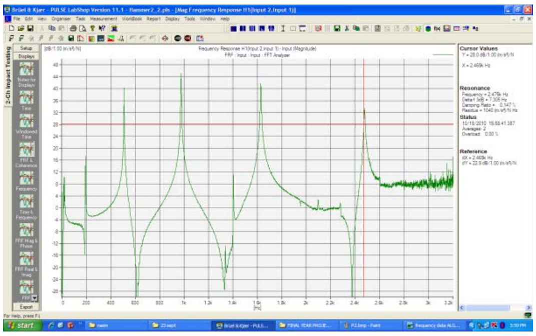

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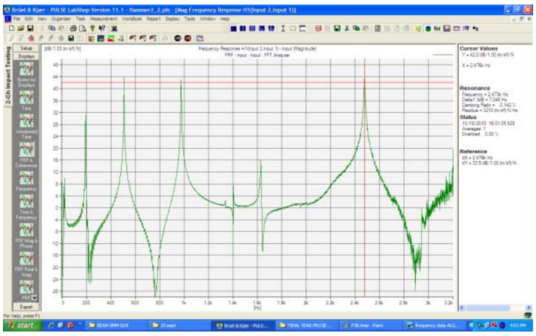

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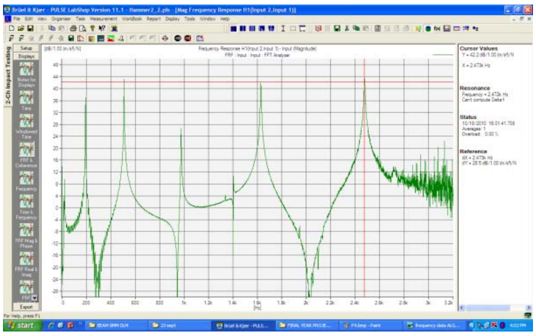
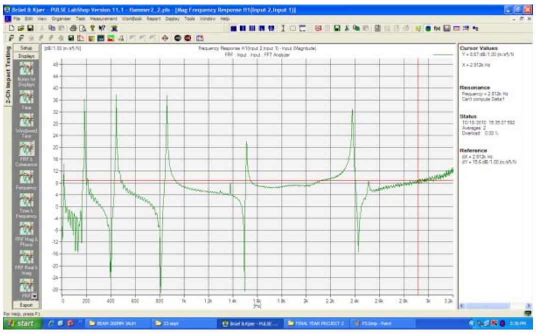


Figure 6.6: 5 Points On Fifth Beam

Point 1



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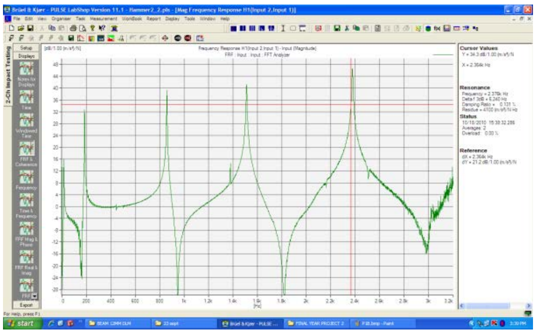

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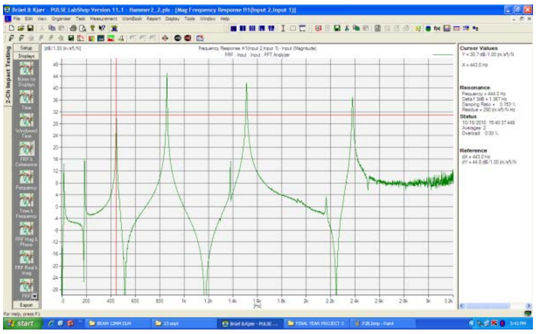

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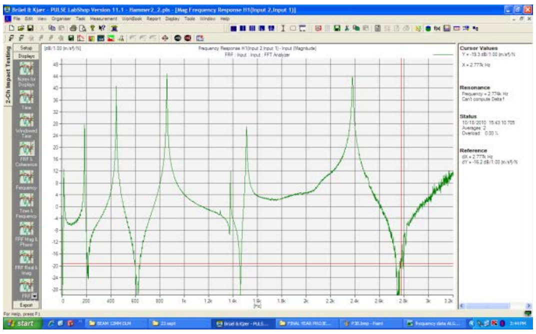

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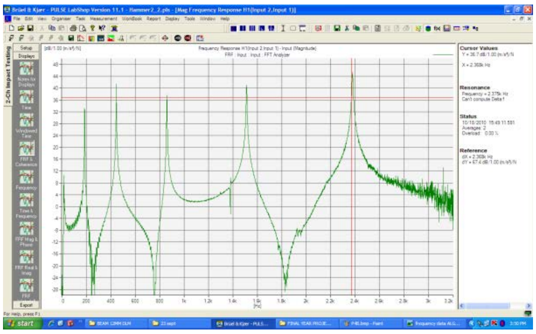

Figure 6.7: 5 Points On Sixth Beam

APPENDIX B1

GANTT CHART FYP1

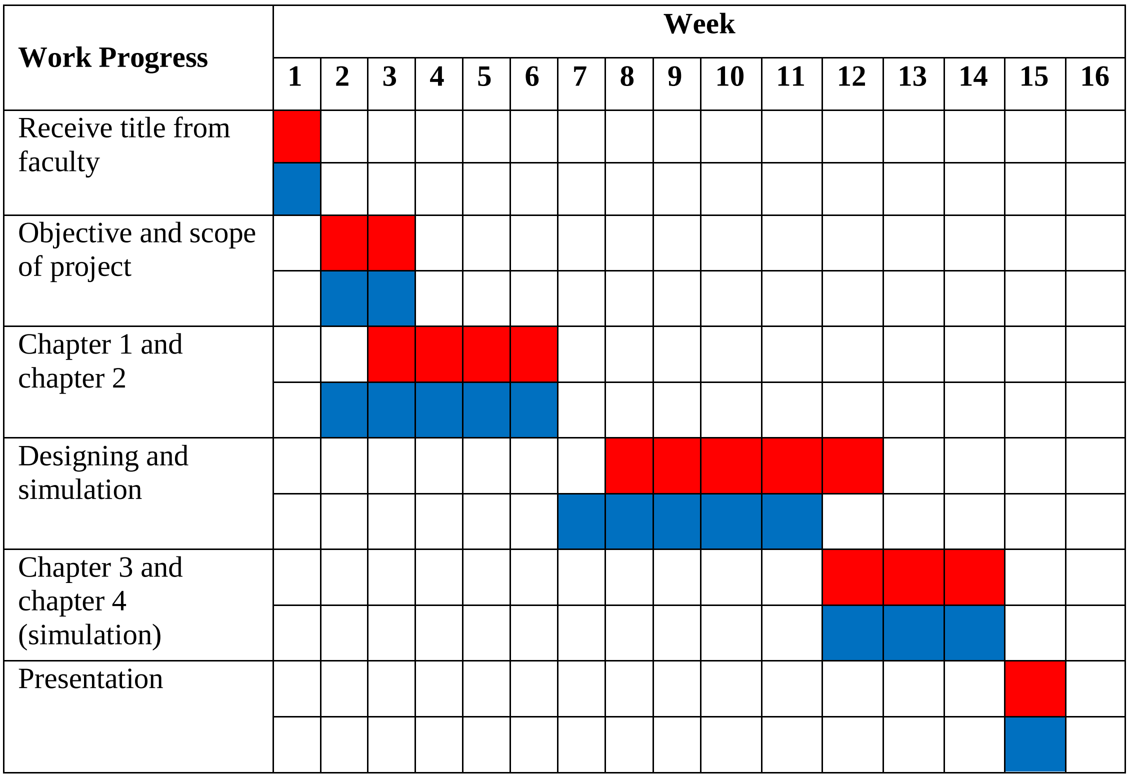

Figure 6.8: Gantt Chart FYP 1

Actual

Planning

APPENDIX B2

GANTT CHART FYP II

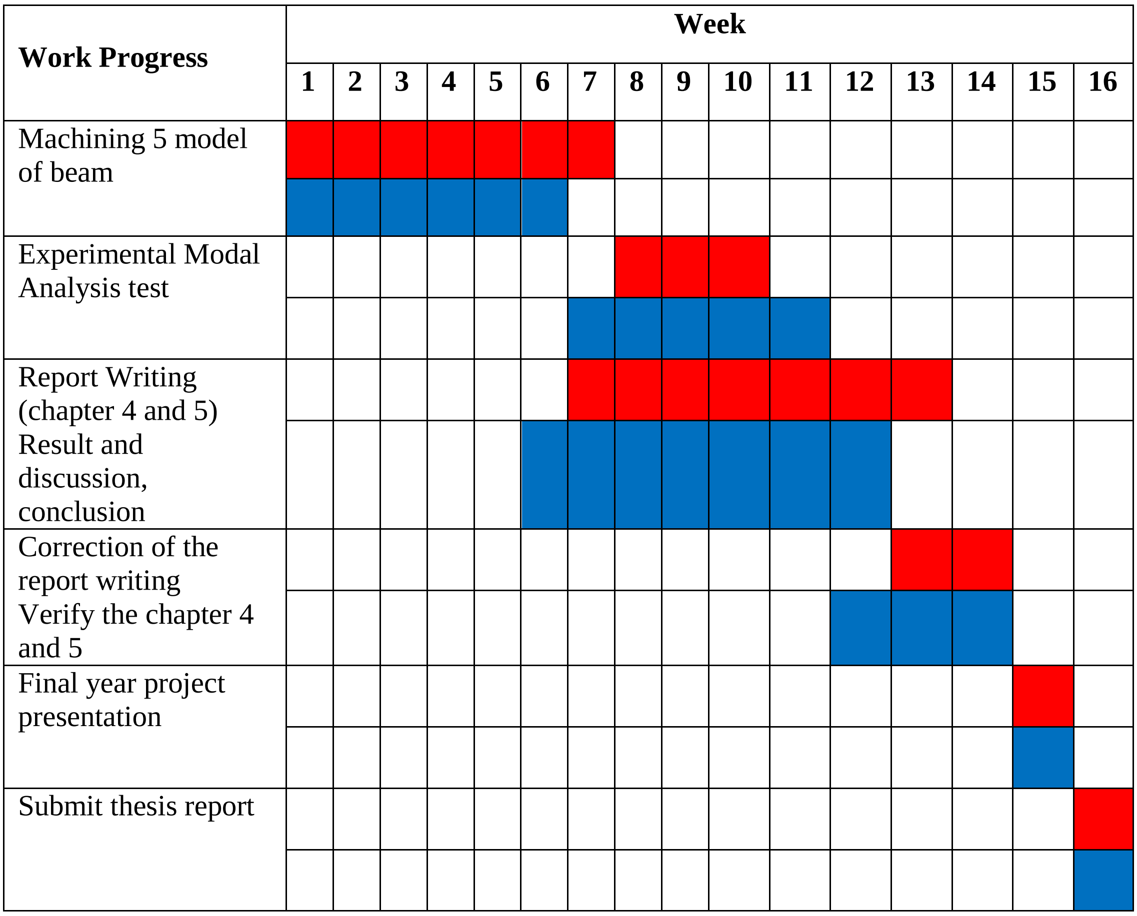

Figure 6.9: Gantt Chart FYP II