A WAVELET ANALYSIS FOR CRACK LOCATION DETECTION ON CANTILEVER BEAM

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A WAVELET ANALYSIS FOR CRACK LOCATION DETECTION ON CANTILEVER BEAM

MUHAMMAD ‘AFIF BIN MOHAMED AZMI

A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelors of Mechanical Engineering

Faculty of Mechanical Engineering
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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*A Wavelet Analysis for Crack Location Detection on Cantilever Beam*" is written by *Muhammad 'Afif Bin Mohamed Azmi*. 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 degree of Bachelor Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor Mechanical Engineering.

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

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Specially dedicated to my beloved mother, father

Mrs. Ros Lindawati binti Md Nadzir

Mr. Mohamed Azmi bin Ramli

and my brothers & sisters

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ABSTRACT

Over the last few decades, the damage identification methods of civil and mechanical structures have been drawing much interest from various fields. Wavelet analysis, a relatively new mathematical and signal processing tool, is one of such methods that have been studied recently. It is a time–frequency analysis that provides more detailed information about non-stationary signals which traditional Fourier analysis miss. This rather new method has been applied to various fields including civil, mechanical and aerospace engineering, especially for damage detection. The purpose of this paper is to provide the review of the research that has been conducted on damage detection by wavelet analysis. First, the theory of wavelet analysis is presented including continuous wavelet transform followed by its application. This paper proposes damage detection in beam-like structures with small cracks, whose crack ratio [r = Hc/H] in between 10% to 20%, without baseline modal parameters. The approach is based on the difference of the continuous wavelet transforms (CWTs) of two sets of mode shape data which correspond to the uncrack cantilever beam with the crack cantilever beam. The mode shape data of a cracked beam are apparently smooth curves, but actually exhibit local peaks or discontinuities in the region of damage because they include additional response due to the cracks. The modal responses of the crack cantilever beams used are computed using the modal testing method. The results demonstrate whether the crack can be detect on the cantilever beam using the CWT, and they provide a better crack indicator than the result of the CWT of the original mode shape data. The effects of crack location and sampling interval are examined. The experimental and the analysis results show that the proposed method has great potential in crack detection of beam-like structures as it does not require the modal parameter of an uncrack beam as a baseline for crack detection. It can be recommended for real applications.

ABSTRAK

Sejak beberapa dekad yang lalu, kaedah mengenal pasti kerosakan struktur awam dan mekanikal telah menarik minat dari pelbagai bidang. Analisis mengunakan wavelet yang juga merupakan satu kaedah baru dalam memproses isyarat. Analisis ini dapat menyediakan maklumat yang lebih terperinci jika di bandingkan dengan analisis Fourier yang sudah ketinggalan. Tujuan utama laporan ini disediakan adalah untuk mengesan kerosakan pada struktur bahan mengunakan wavelet analisis. Pertama sekali kita perlu memahami teori wavelet analisis sebelum menjalankan kajian terhadap struktur bahan tersebut bagi mengesan kerosakan. Laporan ini mencadangkan dalam mengesan kerosakan struktur dengan mengkaji kerosakan kecil seperti retakan pada struktur bahan tersebut. Nisbah yang dikaji adalah 10% dan 20% retakan yang di bina pada struktur bahan tersebut tanpa ade modal parameter. Pendekatan ini adalah berdasarkan perbezaan dari penjelmaan isyarat perkali yang dikeluarkan oleh struktur yang tiada retakan dan struktur bahan yang mempunyai retakan. Laporan ini menunjukkan perubahan pada isyarat mod yang dipilih antara struktur yang tiada retakkan dan struktur yang ade retakkan. Pada lokasi yang mempunyai retakan yang sebenar dimana pada lokasi 180mm telah mempamirakan puncak yang tertinggi pada perkali wavelet oleh kerana tindak balas tambahan kerana retakkan.Perkali wavelet berkait rapat dengan perubahan amplitude di mana kesan retakan telah menyebabkan perubahan pada tindak balas dinamik pada struktur tersebut di mana kekukuhan bahan tersebut berubah akibat retakan itu. Eksperimen dan keputusan analisis menunjukkan bahawa kaedah yang dicadangkan mempunyai potensi yang besar dalam pengesanan kerosakkan pada. Ia boleh disyorkan untuk aplikasi sebenar.

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LIST OF SYMBOLS

$\hat{f}(\omega)$	Fourier Transform
$\omega(t)$	Window Function
$\psi^{a,b}(t)$	Wavelet Transform
$\psi^{a,b}$	Wavelet
ψ	Mother Wavelet
R_C	Ratio of crack
N	Total number of sampling point
*	Complex Conjugate
H	Height of beam

LIST OF ABBREVIATIONS

CWT	Coefficient Wavelet Transform
FRF	Frequency Response Function
FFT	Fast Fourier Transform
WC	Wavelet Coefficient
NF	Natural Frequency
STFT	Short Time Fourier Transform
TD	Time Domain
FD	Frequency Domain
TFD	Time-Frequency Domain
MS	Mode Shape

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain about the introduction of this project task. The introduction is general information regarding to the topic that will be discuss in this project. This topic will consist of background of proposed study, problem statement, objectives and scope of project. That information is important before further discuss to the analysis and study case later.

1.2 BACKGROUND OF PROPOSED STUDY

The interest in the ability to monitor a structure and to detect damage at the earliest possible stage is pervasive throughout the civil, mechanical and aerospace engineering communities. During the past two decades, a variety of analytical, numerical and experimental investigations have been carried out on cracked structures with a view to developing robust crack location detection methods. Any crack in a structure reduces the stiffness and increases the damping in the structure. Reduction in stiffness is associated with decreases in the natural frequencies and modification of the mode shape of the structure. Several researchers have used mode shape measurements to detect damage. Pandey et al. (1991) showed that absolute changes in the curvature mode shapes are localized in the region of damage and hence can be used to detect damage in a structure. The change in the curvature mode shapes increases with increasing size of damage. This information can be used to obtain the amount of damage in the structure. Ratcliffe (1996) found that the mode shapes associated with higher natural frequencies can be used to verify the location of damage, but they are not as sensitive as the lower modes. Modal curvatures seem to be locally much more sensitive to damage than modal displacements. In fact, Shuncong Zhong. (2005) have shown that higher derivatives give a more sensitive detection. Abdel Wahab and De Roeck (1999) investigated the application of the change in modal curvatures to detect damage in a pre-stressed concrete bridge. They introduced a damage indicator called 'curvature damage factor'.

A crack in a structure introduces a local flexibility that can change the dynamic behaviour of the structure. Some damage index methods require the baseline data set of the intact structure for comparison to inspect the change in modal parameters due to damage. Typically, the baseline is obtained from measurements of the undamaged structure. As an example, Pandey et al. (1991) compared the curvatures of the modes shapes between the undamaged and damaged structures. Sampaio et al. (1999) directly subtracted the values of the mode shape curvature of the damaged structure from that of the undamaged structure.

In recent years, the use of wavelet analysis in damage detection has become an area of research activity in structural and machine health monitoring. The main advantage gained by using wavelets is the ability to perform local analysis of a signal which is capable of revealing some hidden aspects of the data that other signal analysis techniques fail to detect. This property is particularly important for damage detection applications. A review is provided by Peng and Chu (1996) of available wavelet transformation methods and their application to machine condition monitoring. Deng and Wang (1998) applied directly discrete wavelets transform to structural response signals to locate a crack along the length of a beam. Tian et al. (1999) provided a method of crack detection in beams by wavelet analysis of transient flexural wave. Wang and Deng (1998) discussed a structural damage detection technique based on wavelet analysis of spatially distributed response measurements. The premise of the technique is that damage in a structure will cause structural response perturbations at damage sites. Such local perturbations, although they may not be apparent from the measured total response data, are often discernible from component wavelets. Liew and Wang (2002) found that the presence of cracks can be detected by the change of some wavelet coefficients along the length of a structural component.

1.3 INTRODUCTION OF THE PROJECT

Cracks or defect are defining as some material that break or cause to break without a complete separation of the parts. It is the nature of many construction materials to crack as they age and as they expand and contract, particularly with exposure to moisture as they get wet and dry out. The more common of these include concrete, asphalt, stucco, stone, brick, mortar, concrete block, plaster, and drywall (also called sheetrock or Gypsum). Besides that, composite structure material is also to crack as they ages and they expand. Example for steels structure material is Mild Steel. It have received a great deal of attention among many engineering societies worldwide. Many engineers consider Mild Steel as one of the most innovative materials that may overcome the inherited deficiency of reinforcing concrete structures by steel rebars in harsh environments due to corrosion. It is virtually impossible to determine whether cracks are caused by structural failure or by some other cause, or, if caused by structural failure, whether the cause is active and on-going. However, continued cracking could result in failure in those structures and, depending on the proximity damage to the structure.

Almost by definition, structure will crack simply because the material cracks as it dries, cures, and ages. Common cracks can appear at any time in the life of a structure. However, all cracks need to be monitored regularly to determine if they are expanding or lengthening, at which point other problems might be present. Crack present a serious threat to the performance of structures since most of the structural failures are due to material fatigue. For this reason, methods allowing early detection and localization of cracks have been the subject of intensive investigation the last two decades. As a result, a variety of analytical, numerical and experimental investigations now exist such as a wavelet analysis for crack detection.

1.4 PROBLEM STATEMENT

It is impossible to determine whether cracks are caused by structural failure or by some other cause, or, if caused by structural failure, whether the cause is active and on-going. However, continued cracking could result in failure in those structures and, depending on the proximity damage to the structure.

For this reason, methods allowing early detection and localization of cracks have been the subject of intensive investigation the last two decades. As a result, a variety of analytical, numerical and experimental investigations now exist such as a wavelet analysis for damage detection.

1.5 OBJECTIVE

The main objective on this research is to improve a better understanding on crack identification using wavelet analysis. The work has been carried out to meet the following specific objective:

i. To obtain the signal response (frequency response function) on each specimens.
ii. To determine the mode shapes that give significant changes to the crack.
iii. To extract the selected mode using continuous wavelet transform.
iv. To determine the location of the crack using wavelet transform.

1.6 SCOPE OF PROJECT

This study was focus on detection of the crack location on cantilever beam. The step consists of:

i. The type of material to be used is mild steel.
ii. Experimental Modal Analysis will be carried out which is using Modal testing (impact hammering).
iii. ME Scope analysis will be applied to get mode shape that give obvious significant change to the crack.

iv. Wavelet Analysis will be applied on the selected mode shape to get the location of the damages by using Continuous Wavelet Transform.

v. Study was only focus on the location detection of crack for cantilever be

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about the literature review of crack identification in structure, modal testing, signal analysis and introduction to wavelet. The sources are taking from the journals, and articles and books. Literature review is helping in order to provide important information regarding previous research which related to this project. Those information are important to know before can proceed further to analysis and study later.

2.2 INTRODUCTION IN CRACK DETECTION

Cracks found in structural elements have various causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may be also due to mechanical defects, as in the case of turbine blades of jet turbine engines. In these engines the cracks are caused by sand and small stones sucked from the surface of runway. Another group involves cracks which are inside the material. They are created as a result of manufacturing processes. The presence of vibrations on structures and machine components leads to cyclic stresses resulting in material fatigue and failure. Most of the failures of present equipment are due to material fatigue. It is very essential to detect the crack in structures& machine members from very early stage. A crack in a structure induces local flexibility and it results in reduction in natural frequencies and change in mode shapes. Dimarogonus(1976) carried out lot of work on this.

A review of the state of the art of vibration based methods for testing cracked structures has been published by Dimarogonas (1996). A crack in a structure induces a local flexibility which affects the dynamic behaviour of the whole structure to a considerable degree. It results in reduction of natural frequencies and changes in mode shapes of vibration. An analysis of these changes makes it possible to identify cracks. Dimarogonas (1976) and Paipetis and Dimarogonas (1986) the crack was modelled as a local flexibility and the equivalent stiffness was computed using fracture mechanics methods. In that vein, Chondros and Dimarogonas (1980) developed methods to identify cracks in various structures relating the crack depth to the change in natural frequencies for known crack position. Adams and Cawley (1979) developed an experimental technique to estimate the location and depth of a crack from changes in natural frequencies Gudmunson (1982) used a perturbation method to predict changes in natural frequencies of structures resulting from cracks, notches and other geometrical changes. Further work on crack identification via natural frequency changes was done by Anifantis et al. (1985). Using a similar approach Masoud et al. (1998) investigated the vibrational characteristics of a prestressed fixed–fixed beam with a symmetric crack and the coupling effect between crack depth and axial load. Narkis (1993) developed a closed form solution for the problem of a cracked beam, which he applied to study the inverse problem of localization of cracks on the basis of natural frequency measurements. The main reason for the popularity of natural frequencies as damage indicators is that natural frequencies are rather easy to determine with a high degree of accuracy. A sensor placed on a structure and connected to a frequency analyzer gives estimates of several natural frequencies.

The idea of using mode shapes as crack identification tool is the fact that the presence of a crack causes changes in the modal characteristics. Rizos et al. (1990) suggested a method for using measured amplitudes of two points of a cantilever beam vibrating at one of its natural modes to identify crack location and depth. Recently, an interesting comparison between a frequency—based and mode shape—based method for damage identification in beam like structures has been published by Kim et al. (2003). The advantage of using mode shapes is that changes in mode shapes are much more sensitive compared to changes in natural frequencies. Using mode shapes, however, has some drawbacks. The presence of damage may not significantly influence mode shapes of the lower modes usually measured. Furthermore, environmental noise and choice of sensors used can considerably affect the accuracy of the damage detection procedure. To overcome these difficulties, modal testing using scanning laser vibrometers have been developed (Stanbridge and Ewing, 1999). The laser vibrometer, used as a vibration transducer, has the advantage of being non-contacting and measures at a controlled position with high accuracy. In the last few years, wavelet analysis has become a promising damage detection tool due to the fact that it is very accurate to detect localized abnormalities in a mode shape caused by the presence of a crack. It has useful localization characteristics and does not require the numerical differentiation of the measured data (Newland, 1994a,b). Wavelet transform can be implemented as fast as the Fourier transform and its main advantage is the fact that the local features in a signal can be identified with a desired resolution. Deng and Wang (1998) applied the discrete wavelet transform to locate a crack along the length of a beam. Wang and Deng (1999) extended the analysis to a plate with a through-thickness crack. In the last study, the Haar wavelet were used with success. However, a method for estimating the crack extend has not been proposed. Haar wavelets were also used in the study of Quek et al. (2001). The authors were able to accurately detect relatively small cracks under both simply-supported and fixed-ended conditions. Here again, the estimation of the size of the crack is not discussed. Hong et al. (2002) used the Lipschitz exponent for the detection of singularities in beam modal data. The Mexican hat wavelet was used throughout the study and the crack size has been related to different values of the exponent. In the present work, a method for crack identification in beam structures based on wavelet analysis is presented. The fundamental vibration mode of a cracked beam is wavelet transformed and both the location and size of the crack are estimated. For this purpose, a ‘‘symmetrical 4’’ wavelet having two vanishing moments is utilized. The position of the crack is located by the variation of the spatial signal at the site of the crack due to the high resolution property of the wavelet transform. To estimate the size of the crack, an intensity factor is defined which relates the size of the crack to the coefficients of the wavelet.

2.3 EXPERIMENTAL MODAL ANALYSIS

Modal analysis is a method to describe a structure in terms of its natural characteristics which are the frequency, damping and mode shapes. Modal analysis involves process of determining the modal parameters of a structure to construct a modal model of the response. The modal parameters maybe determined by analytical means, such as finite element analysis, and one of the common reasons for experimental modal analysis is the verification or correction of the results of the analytical approach (model updating). Predominately, experimental modal analysis is used to explain a dynamics problem, vibration or acoustic that is not obvious from intuition, analytical models, or previous similar experience. Theoretical [Finite Element Analysis (FEA)] and Experimental Modal Analysis (EMA) have been very separate engineering activities aimed at solving above mentioned common problem. Now the two technologies are converging and powerful new tools for solving noise and vibration problems are emerging as a result.

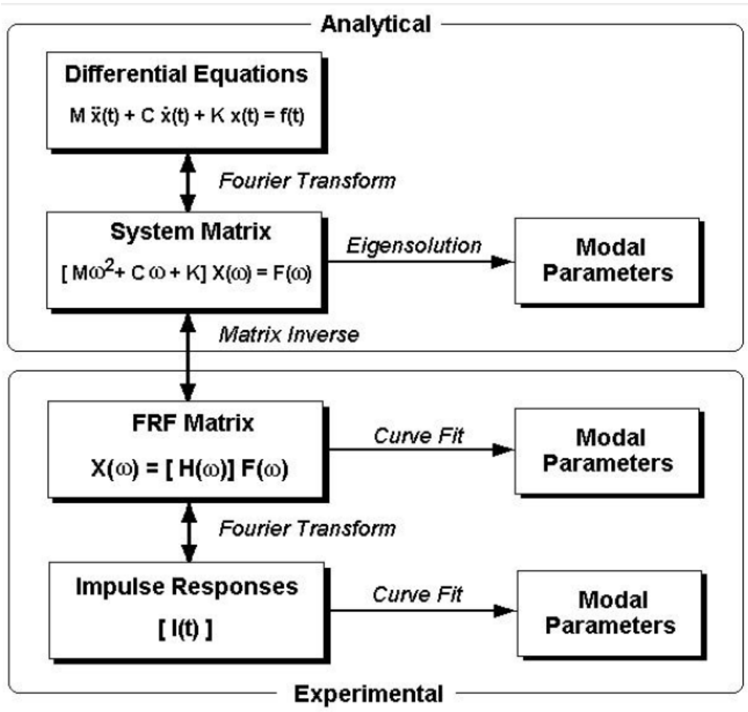

Figure 2.1: Equation of analytical and experimental.

Source: B& K Application Note.

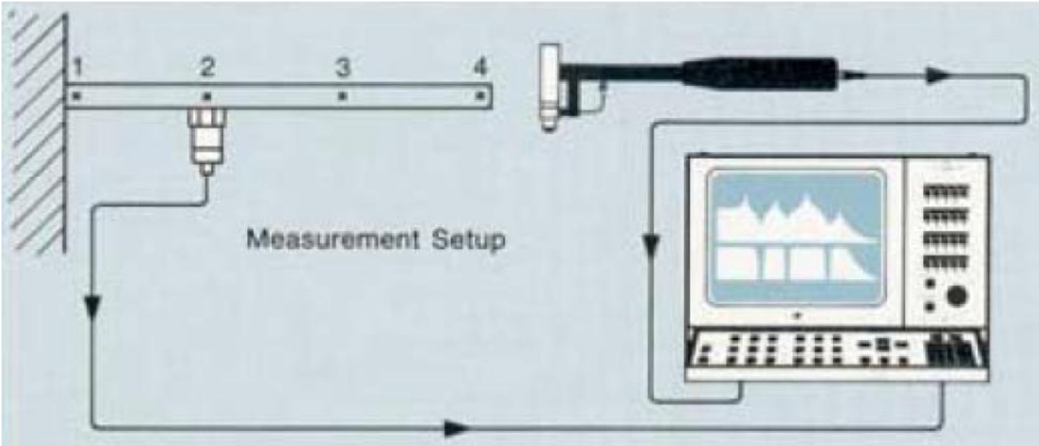

Figure 2.2: Modal Testing Impact hammering.

Source: B& K Application Note.

Modal testing is one of famous method in vibration. Modal testing can be achieved by introducing a forcing function into a certain structure, usually with some type of shaker and familiar ways that are usually be used is like a impact testing or some shaker that used in the lab. In other words, a structure that want to be tested is attached to the table of contain shaker, like a surface containing a few spring that can be shake during handling an experiment. Instantly, for a relatively low frequency forcing, an electronic devices called as a servo hydraulic are used and for higher frequency an electrodynamics shakers are used. In my project, excitation forces is prefer to come from an impact hammer as it is not complicated and easily can be used. For this crack identification which used a modal testing as an experiment, the prefer way to give force to the beam is by the impact hammer. When we use this impact hammer, it gives a perfect impulse which has an infinitely small duration causing constant amplitude in the frequency domain, resulting in all modes of vibration being excited with equal energy.

2.4 SIGNAL ANALYSIS

Signal analysis is an area of systems engineering and applied mathematics that deals with operations on or in other words we call it as signal processing. Signal analysis can be including sound, images and sensor of data like control systems signal, transmissions signals and many others. There are several categories in signal analysis which is signal acquisition, quality improvement and also feature extraction. Based on the research done and journal, suitable categories will be signal acquisition as it involves measuring a physical signal, storing it and possibly later rebuilding the original signal. In this experiment signal analysis can be get by the DasyLab software and also Ansys software.

2.4.1 Time Domain Analysis

Time domain is the analysis of mathematical function, physical signals or time series of economic or environmental data, with respect to time. In the time domain, the signal or function value is known for all real number, for the case of continuous time, or at various separate instants in the case of discrete time. An oscilloscope is a tool used to visualize real world signal in the time domain. A time domain graph shows how a signal changes with time.

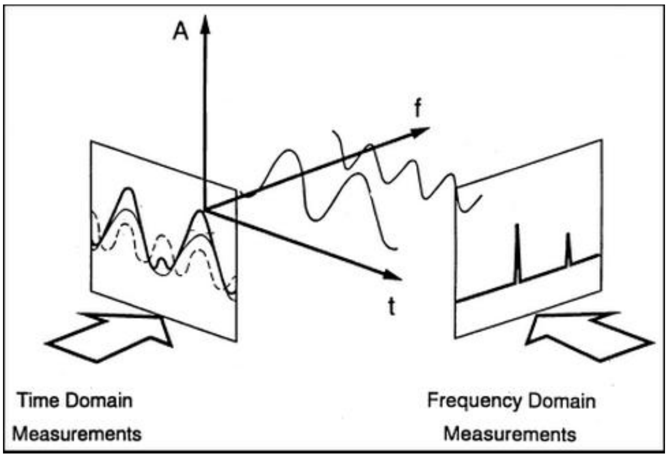

Figure 2.3: Time Domain and Frequency Domain Graph.

Source: B& K Application Note.

Example of time domain analysis in crack detecting to determine if it is feasible to detect and size cracks with the time-domain wave propagation techniques and to recommend the best field-test configuration to be used. A finite element program was used to model a cracked medium. Several parameters were considered the location of source and receivers relative to the crack, the depth of the crack, the width of the crack, and the duration of the source impulse. Major parameters that significantly affect the waveforms were identified by performing a sensitivity analysis on each parameter. The most significant feature that can be used to predict the crack is the existence of standing wave energy detected in the waveforms from receivers located relatively close to the downstream end of the crack. The best test setup is obtained when the source and one receiver are located close to the crack on one side of a crack and a second receiver located on the opposite side of the crack at a distance from the crack. Imran, I., Nazarian, S., and Picornell, M. (1995).

2.4.2 Frequency Domain Analysis

Frequency domain is a method used to analyze data. This refers to analyzing a mathematical function or a signal with respect to the frequency. Frequency domain analysis is widely used in fields such as control systems engineering, electronics and statistics. Frequency domain analysis is mostly used to signals or functions that are periodic over time. This does not mean that frequency domain analysis cannot be used in signals that are not periodic. The most important concept in the frequency domain analysis is the transformation. Transformation is used to convert a time domain function to a frequency domain function and vice versa. The most common transformation used in the frequency domain is the Fourier transformations. Fourier transformation is used to convert a signal of any shape into a sum of infinite number of sinusoidal waves. Since analyzing sinusoidal functions is easier than analyzing general shaped functions, this method is very useful and widely used.

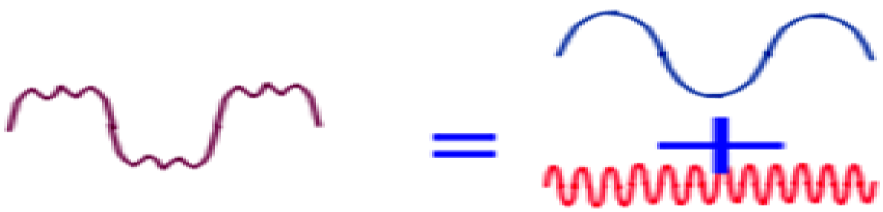

Figure 2.4: Frequency domain.

Source: B& K Application Note.

The frequency domain using a two-dimensional Fourier Transform for inspection of stress cracks. Investigations were also conducted to define suitable conditions and optimum image resolution for viewing stress cracks in corn kernels using a computer vision system. A pre-processing procedure included contrast enhancement, edge enhancement, and kernel edge elimination to improve stress crack recognition. A Fast Fourier Transform algorithm was applied to the pre-processed images, and the transformation results were condensed into 33 feature signatures representing position or orientation invariant morphological features. A multivariate discriminant analysis and multiple regression analysis were used to develop classification criteria for stress crack inspection. Both methods were able to detect stress cracks satisfactorily with an average success ratio above 96%. Keywords. Machine visions, Image analysis, Fourier transform, Corn and rice quality. Y. J. Han, Y. Feng, C. L. Weller (1996).

Time domain and frequency domain are two modes used to analyze data. Both time domain analysis and frequency domain analysis are widely used in fields such as electronics, acoustics, telecommunications, and many other fields.

i. Frequency domain analysis is used in conditions where processes such as filtering, amplifying and mixing are required.
ii. Time domain analysis gives the behaviour of the signal over time. This allows predictions and regression models for the signal.
iii. Frequency domain analysis is very useful in creating desired wave patterns such as binary bit patterns of a computer.
iv. Time domain analysis is used to understand data sent in such bit patterns over time

2.4.3 Time-Frequency Domain Analysis

A time–frequency representation (TFR) is a view of a signal (taken to be a function of time) represented over both time and frequency. Time–frequency analysis means analysis into the time–frequency domain provided by a TFR. This is achieved by using a formulation often called "Time–Frequency Distribution", abbreviated as TFD. TFRs are often complex-valued fields over time and frequency, where the modulus of the field represents either amplitude or "energy density" (the concentration of the root mean square over time and frequency), and the argument of the field represents phase. Consist of Short Time Fourier Transform and Wavelet. The short-time Fourier transform (STFT), or alternatively short-term Fourier transform, is a Fourier-related transform used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time.

2.5 FUNDAMENTALS OF WAVELET ANALYSIS

The starting point is the Fourier transform and the windowed Fourier transform. Following the reflections on these methods, which are extensively utilised for analysing signals in the frequency and time-frequency domain, respectively, wavelet analysis is introduced. First the continuous wavelet transform is described before passing on to the discrete wavelet transform. The multi-scale analysis, that the fast wavelet transformation algorithms are based on, is explained.

2.5.1 The Fourier Transform and the Windowed Fourier Transform

As in other engineering disciplines, an important part of structural dynamics is the identification of certain properties of time-variable processes. In this context measured signals that can be interpreted as functions with respect to time are often transferred into another domain. The most commonly used transformation method in signal analysis is the Fourier transformation. The basic idea of the Fourier analysis is to describe a signal by means of an infinite series of harmonic functions. The Fourier transform of a function $f(t)$ is defined as:

$$f\hat{}(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} f(t) e^{-i\omega t}\, dt \qquad (2.1)$$

Its inverse is given by:

$$f(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} f\hat{}(\omega) e^{-i\omega t}\, d\omega \qquad (2.2)$$

The Fourier transform is defined for real functions that are square-integrable. A function $f(t)$ belongs to the space $L^2(R), R := (-\infty; +\infty)$ if

$$\int_R \; f^2(t)dt \; < \; \infty \tag{2.3}$$

If the condition in equation 2.3 is satisfied and with the normalisation used in equations (2.1) and (2.2) one has

$$||f\hat{}(\omega)||_{L^2} = ||f||_{L^2} \tag{2.4}$$

With

$$||f||_{L^2} = [\int |f(t)|^2]^{\frac{1}{2}} \tag{2.5}$$

The application of the Fourier analysis has become very popular since the introduction of the Fast Fourier Transform method (FFT). Usually the Fourier analysis is applied to finite time series assuming that the signals are periodically about how the frequency contents of a signal behave with respect to time. Therefore the Fourier analysis is not particularly appropriate for the investigation of non-linear and non-stationary problems. The first important step in the analysis of signals in the time-frequency domain was the introduction of the windowed Fourier transform. Basically, with the windowed Fourier transform the frequency contents of a signal within a time window are analysed. The window is of constant length and is translated along the time axis. That means, the Fourier analysis is only applied to a section of the entire signal. Within each of these sections the signal is assumed to be stationary. Such a section is called windowed signal:

$$f_\omega(t) = \omega(t)f(t) \tag{2.6}$$

The window function $\omega(t)$ must be square-integrable and the product $f(t)\,w(t)$ has to be an element of $L2\,(R)$ as well. By moving the window along the time axis, the complete time domain is covered. Consequently the windowed signal $f_\omega(t)$ depends both on the time t and the windows position:

$$f_{\omega}(t,\tau) = \omega(t-\tau)f(t) \tag{2.7}$$

By applying the Fourier transformation on such a windowed signal, one obtains the windowed Fourier transform as a function of the frequency ω and the window's position:

$$f\hat{}_{\omega}(\omega,\tau) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} \omega(t-\tau)\, f(t)\, e^{-i\omega t}\, dt \tag{2.8}$$

If the Fourier transform of the window function $\omega(t)$ is also a window function ($\omega\hat{}(\omega) \in L^2(R), \omega\omega\hat{}(\omega) \in L^2(R)$) then equation (2.8) is called the short time Fourier transform. The resolutions in the frequency and time domains are generally different. They are governed by the length and the frequency band width of the utilised window function. For an "optimal" localisation in the time-frequency domain, the application of a function proportional to the Gaussian function is recommended

$$\omega = g_{\propto}\frac{1}{2\sqrt{\pi\propto}}e^{-\frac{t^2}{4\propto}} \tag{2.9}$$

Where, α > 0 is a constant. The respective windowed Fourier transform is also called the Gabor transform. Fourier analysis decomposes a signal by means of elementary harmonic functions. For the windowed Fourier transformation the decomposition is carried out partially. The basic functions usually are decaying harmonic functions of constant duration. The number of oscillations within a window varies.

2.5.2 Introduction to Wavelet Analysis

Similar to the windowed Fourier transformation, the one-dimensional wavelet transformation projects a signal into a two-dimensional space. Analogous to equation (2.8) the wavelet transforms of a signal $f(t)$ is defined as:

$$W_{\omega}^{f}(a,b) = |a|^{-\frac{1}{2}}\int_{-\infty}^{+\infty} f(t)\psi * \left(\frac{t-b}{a}\right) dt \tag{2.10}$$

Where $\psi * (.)$ denotes the complex conjugate of $\psi(.)$. It is assumed that the mean value of the function ψ vanishes

$$\int_{-\infty}^{+\infty} \psi(t)\, dt = 0 \tag{2.11}$$

Both in the windowed Fourier transformation and in the wavelet transformation the signal $f(t)$ is multiplied by a function of two variables. In the case of the windowed Fourier transform this is the function

$$\omega^{\omega,\tau}(t) = \frac{1}{2\sqrt{\pi}} \mathrm{w}(t-\tau)e^{-i\omega t} \tag{2.12}$$

The respective function for the wavelet transformation is

$$\psi^{a,b}(t) = |a|^{-\frac{1}{2}}\, \psi * \left(\frac{t-b}{a}\right) \tag{2.13}$$

The functions $\psi^{a,b}$ are called wavelets. They are dilated and translated versions of the mother wavelet ψ. As the basic functions of the windowed Fourier transformation, wavelets are usually oscillating, rapidly decaying functions. However, in contrast to the functions $\omega^{\omega,\tau}(t)$, the number of oscillations of the functions $\psi^{a,b}(t)$ remains constant with the changing width of the window. This means a wavelet is “stretched” or “squeezed” (dilated) along the time axis. For the windowed Fourier transformation the size of the window remains constant while the number of oscillations changes. This principle is illustrated in figure 2.1.

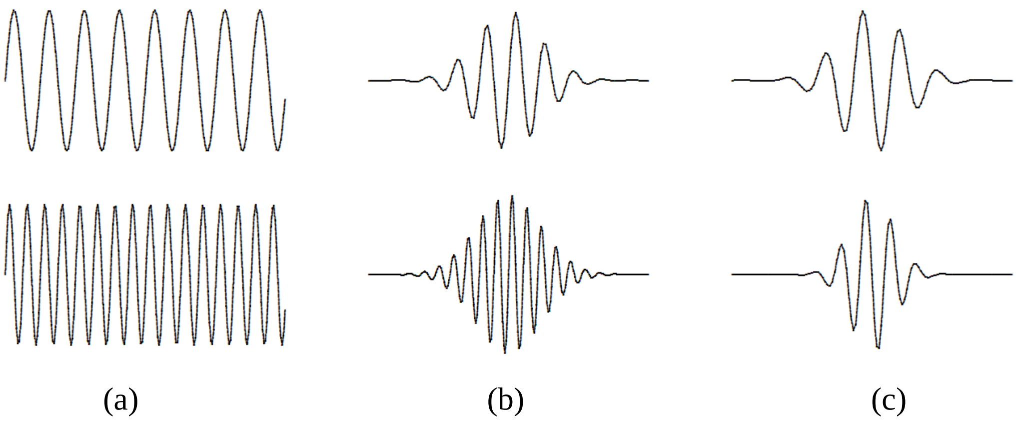

Figure 2.5: Illustration of the basic functions for the Fourier transformation (a), the windowed Fourier transformation (b) and the wavelet transformation (c).

Source: C. L. Weller (1996).

A typical example for a wavelet is the so-called "Mexican hat":

$$\psi(t) = (1 - t^2)e^{-\frac{t^2}{2}} \tag{2.14}$$

The second derivative of the Gaussian functions. The condition of equation (2.11) is satisfied for the "Mexican hat". Large values of the scaling parameter a correspond with small frequencies. A change of the parameter b results in a translation of the localisation point. Each $\psi\hat{}(a\omega)$ is located at $t = b$. The wavelet transform of a function $f(t)$ can be calculated by means of the Fourier transforms of this function, $f\hat{}(\omega)$ and of the dilated wavelet, $\psi^{a,b}(t)$. Equation (2.10) becomes then:

$$W_\psi^f(a,b) = \frac{\sqrt{a}}{2\pi}\int^{+\infty} f\hat{}(\omega)\psi\hat{} * (a\omega)e^{i\omega b}d\omega \tag{2.15}$$

Generally two types of the wavelet transformation can be distinguished:

i. The continuous wavelet transformation and
ii. The discrete wavelet transformation.

2.5.3 Continuous wavelet transform

This section presents a brief background on continuous wavelet transform utilized in this paper. More facts on continuous wavelet transform can be found in the study of Daubechies (21). A mother wavelet $\psi(x)$ can be defined as a function with zero average value,

$$\int_{-\infty}^{+\infty} \psi(t)dx = 0 \quad (2.16)$$

$\psi(t)$ is normalise:

$$\int_{-\infty}^{+\infty} |\psi(t)|^2 dx = 1 \quad (2.17)$$

From mother wavelet $\psi(t)$, the analysing wavelets can be obtained by dilation parameter s and translation parameter b:

$$\psi_{b,s}(x) = \frac{1}{\sqrt{s}} e(\frac{x-b}{s}) \quad (2.18)$$

where both s and b are real numbers, and s must be positive. The continuous wavelet transform of a signal $f(x) \in L^2(R)$ depending on time or space is defined by

$$(Wf)(s,b) = \int_{-\infty}^{+\infty} f(x) \frac{1}{\sqrt{s}} \psi * (\frac{x-b}{s}) dx \quad (2.19)$$

where $(*)$ denotes the complex conjugate, the mother wavelet should satisfy an admissibility condition to ensure existence of the inverse wavelet transform, such as

$$C_\psi = \int_{-\infty}^{+\infty} \frac{|F_\psi(\omega)|^2}{|\omega|} d\omega < \infty \quad (2.20)$$

Where $F_\psi(\omega)$ denotes the Fourier transform of $\psi(x)$ defined as

$$F_\psi(\omega) = \int_{-\infty}^{+\infty} \psi(x) e^{-i\omega x} dx, x \in R \quad (2.21)$$

The signal $f(x)$ may be recovered or reconstructed by an inverse wavelet transform of $Wf(s,b)$ defined as

$$f(x) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}(Wf)(s,b)\psi(\frac{x-b}{s})\frac{dsdb}{s^2} \tag{2.22}$$

Also, the CWT may as well be performed in Fourier space

$$(Wf)(s,b) = \frac{1}{2\pi}\int_{-\infty}^{+\infty}F_f\ (\omega)e^{ib\omega}F *_{\psi}\ (s\omega)d\omega \tag{2.23}$$

where $F_f(\omega)$ is the Fourier transform of $f(x)$ defined as

$$F_f(\omega) = \int_{-\infty}^{+\infty}f(x)e^{-i\omega x}dx, x \in R \tag{2.24}$$

The local resolution of the CWT in time or space and in frequency depends on the dilation parameter s and is determined, respectively, by the duration Δx_{ψ} and bandwidth $\Delta\omega_{\psi}$ of the mother wavelet

$$\Delta x = s\Delta x_{\psi}, \Delta\omega = \frac{\Delta\omega_{\psi}}{s} \tag{2.25}$$

Here, Δx_{ψ} and $\Delta\omega_{\psi}$ are defined as

$$\Delta x_{\psi} = \frac{1}{||\psi(x)||_2}\sqrt{\int_{-\infty}^{+\infty}(x - x_{\psi})^2|\psi(x)|^2dx} \tag{2.26}$$

$$\Delta\omega_{\psi} = \frac{1}{||F_{\psi}(\omega)||_2}\sqrt{\int_{-\infty}^{+\infty}(\omega - \omega_{\psi})^2|F_{\psi}(x)|^2d\omega} \tag{2.27}$$

where x_{ψ} and ω_{ψ} are the centre of $\psi(x)$ and $F_{\psi}(\omega)$, respectively,

$$x_{\psi} = \int_{-\infty}^{+\infty}x\frac{|\psi(x)|^2}{||\psi(x)||_2^2}dx \tag{2.28}$$

$$\omega_{\psi} = \int_{-\infty}^{+\infty} \omega \frac{|F_{\psi}(\omega)|^2}{||F_{\psi}(\omega)||_2^2} d\omega \tag{2.29}$$

$||\,.\,||^2$ denotes the classical norm in the space of square integrable functions. It is well known that the number of vanishing moments is one of the most important factors for the success of wavelets in various applications. In the present work, a symlet wavelet 'symmetrical 4' having four vanishing moments has been selected and used as the analysing wavelet. The scaling function and wavelet function of 'symmetrical 4' wavelet are shown in figure 2.6 (a) and (b).

2.5.4 Continuous wavelet transforms of reconstructed mode shape data

This method uses the difference of the CWTs of two reconstructed sets of data or signal series obtained from the original mode shape of a cracked beam. Firstly, the original mode shape signal is divided and reconstructed into two signal series as follows. If the original mode shape 'signal' is made up of d_1, d_2…., d_N data points, where N is the total number of sampling points, the first segment (s'_1) of the signal is the first half of the original mode shape 'signal', that is, d_1, d_2,…., $d_{N/2+1}$. The second segment (s'_2) of the signal is the second half of the original mode shape 'signal', that is, $d_{N/2+1}$, $d_{N/2+2}$,…, d_N. This process of dividing and reconstituting the signals is illustrated in figure 2.7 (a-1) and (a-2) for modes 1 and 2, respectively, of the beam. There are two cases, namely symmetric and antisymmetric cases. For symmetric cases, the mode shape is symmetrical about the centre of the beam, as illustrated in figure 2.7 (a-1) for the first mode. In this case, the modal data is cut into left and right segments s'_1 and (s'_2), respectively. The right modal data segment is rotated about a vertical axis to produce a modified dataset s_2 which is similar to the left modal data segment s_1. The two new signal series s_1 and s_2 are obtained as d_1, d_2,…., $d_{N/2+1}$ (the signal series s_1) and d_N, d_{N-1},…., $d_{N/2+1}$ (the signal series s_2), as shown in figure 2.7 (b-1). For antisymmetric cases, the mode shape is antisymmetrical about the centre of the beam as illustrated in figure 2.7 (a-2) for the second mode. In this case, the right data segment is rotated twice: firstly about the vertical axis and secondly about the horizontal axis to produce a modified dataset s_2. Thus, the two signal series will be d_1, d_2,…., $d_{N/2+1}$ (the signal series s_1) and $-d_N$, $-d_{N-1}$,…., $-d_{N/2+1}$ (the signal series s_2), as shown in figure 2.7 (b-2). Then the wavelet coefficients, the difference of CWT of s_1 and s_2, will be obtained after CWTs of s_1 and s_2 are performed. For the case of a beam with small cracks, CWT of s_1 or s_2 includes some crack information. However, due to the smallness of the crack, the distortion of the transformed data caused by the crack is not very significant and, therefore, cannot provide clear crack detection. Finally, the difference of the CWT of s_1 and s_2 is determined to give a better crack indication than the CWT of the original mode shape. However, it is noted that the proposed method is only suitable for the simply-supported beams with symmetric and antisymmetric mode shapes.

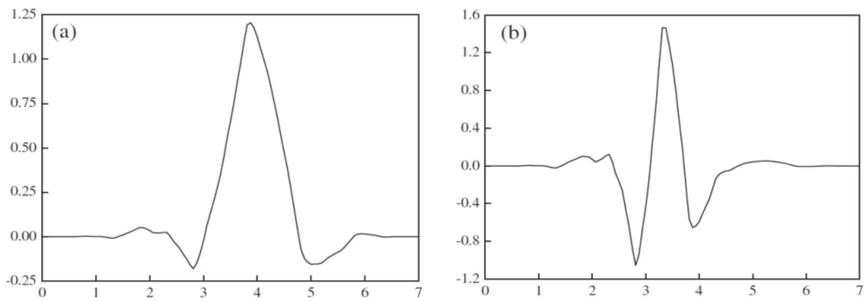

Figure 2.6: Symmetrical 4' wavelet: (a) scaling function and (b) wavelet function.

Source: C. L. Weller (1996).

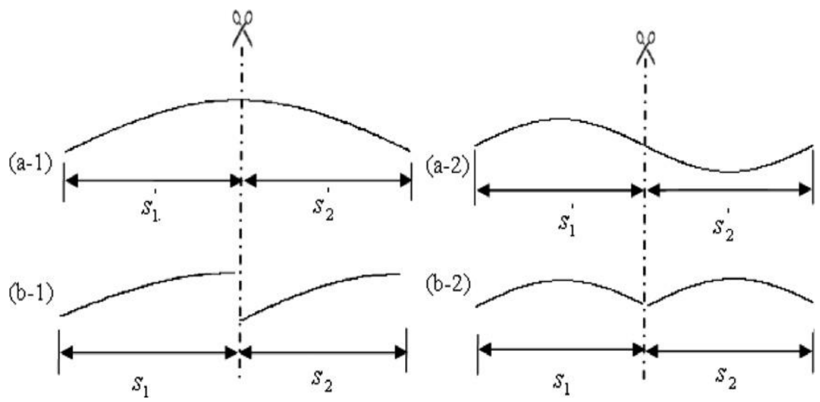

Figure 2.7: Two series signals divided and reconstructed from the original mode shape data.

Source: C. L. Weller (1996).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will described about the procedures analysis on a wavelet analysis for crack detection. Research methodology is a set of procedures or methods used to conduct research. Methodology is needed for a guideline in order to ensure the result is accurate based on objective. Type research that will be used in determining the crack on beam is quantitative methodologies. There are several steps need to be followed to ensure the objective of the research can be achieve starting from finding literatures until submitting the final report.

3.2 FLOW CHART OF METHODOLOGY

Flowchart is represents a process by showing the steps as box of various kinds, and their order by connecting with arrows. Flowchart is important in doing research by helping viewer to understand a process flow and help to visualize what is going on. Flow chart methodologies were constructed related to the scope of product as a guided principal to formulate this research successfully, in order to achieve the objectives of the project research.

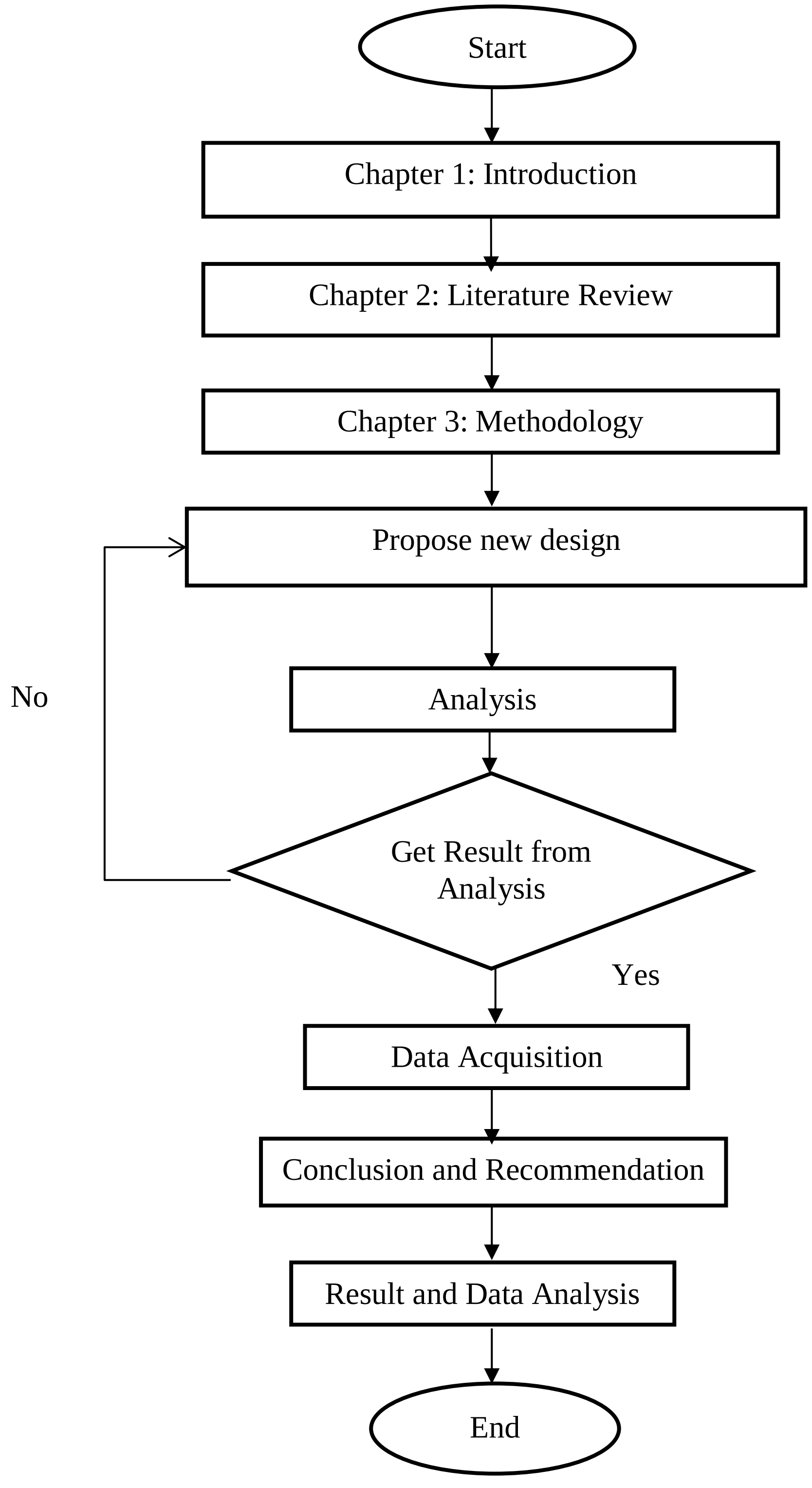

Figure 3.1: Overall Research Flowchart.

3.2.1 Process Flow

The complete procedure to obtain crack location on cantilever beam is shown as in Figure 3.2. It consists of modelling design until analysis of the result.

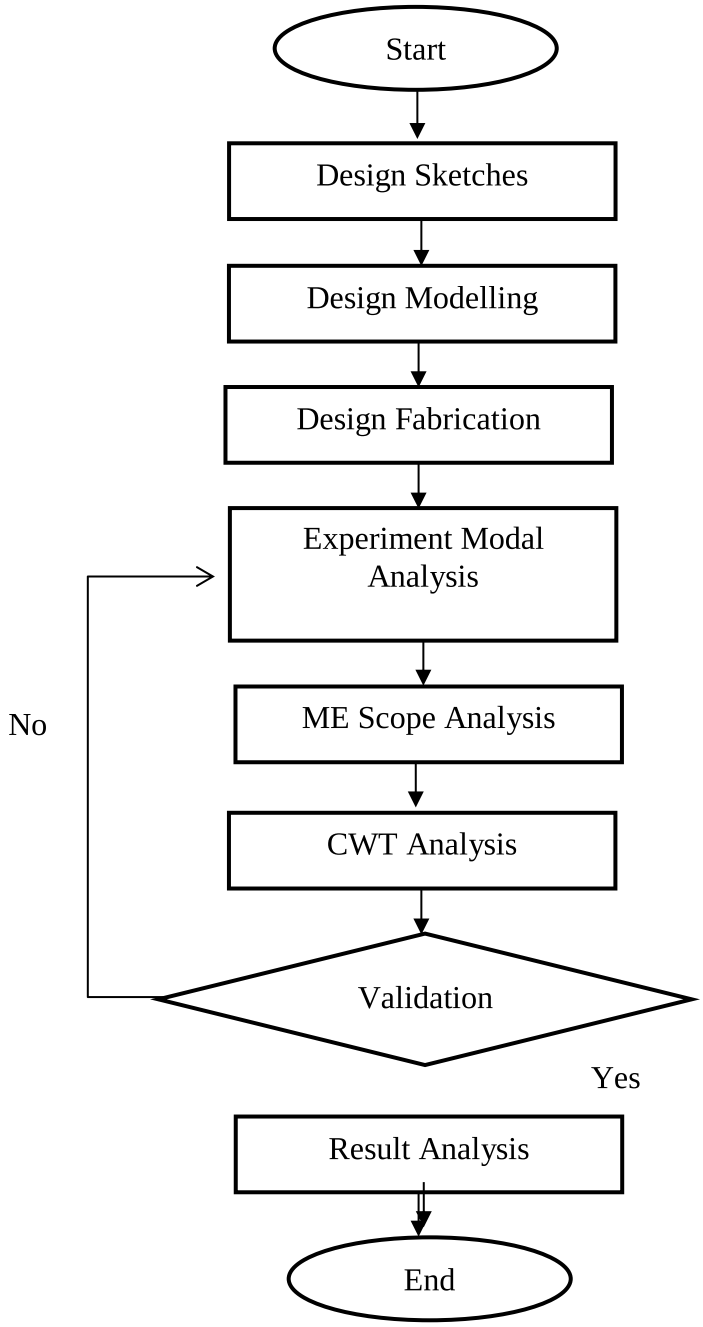

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Figure 3.2: Methodology Flowchart

3.3 DESIGN SKETCH

Figure 3.3 show the sketch of cantilever beam. Modal testing will be done using impact hammer to obtain their dynamic responses which are natural frequency and mode shape.

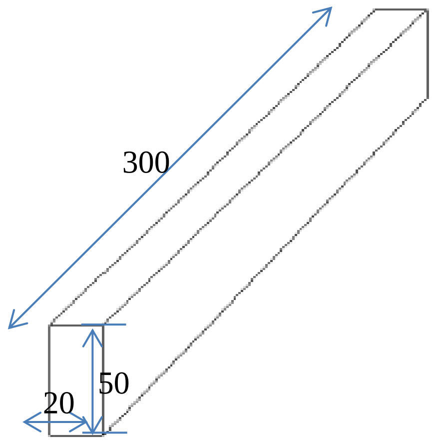


Figure 3.3: Cantilever Beam

3.4 DESIGN MODELLING

Figure 3.4 shows the cantilever beam that was draw using solidwork software with cross-section 20 x 50 mm^2 and length 300mm.

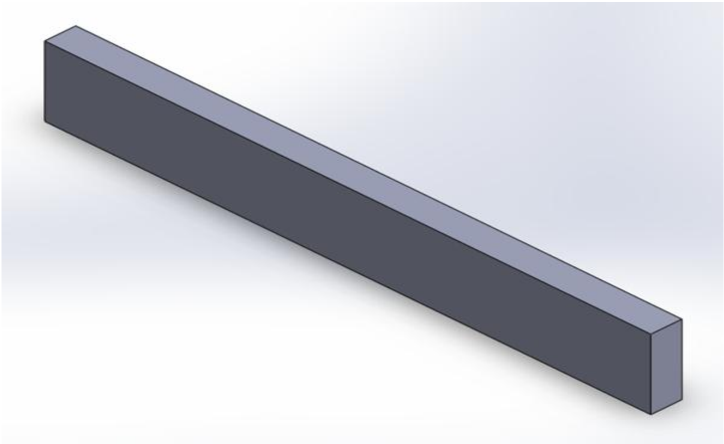


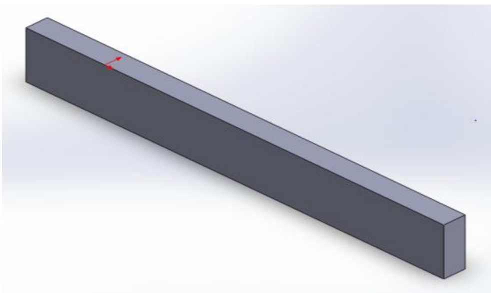
Figure 3.4: Cantilever Beam in SolidWork software.

3.4.1 Design consideration of cantilever beam.

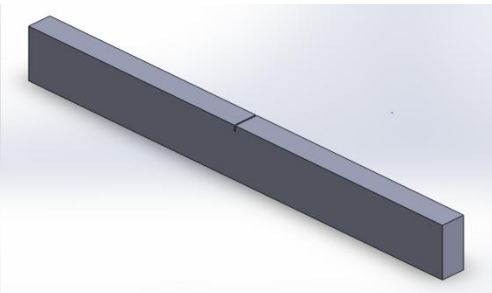
In this project, the design consideration play an important role in the modal testing because it totally affect the results obtained at the last of experiment that be held. So, design that will be chose as primarily tested is steel beam about 300mm in length and cross section area 20mm x 50mm^2. Then the specimen will be divided into three specimens which is uncrack beam, 10% crack depth beam and 20% crack depth beam. The dimension is the same.

3.4.2 Specification of the specimen

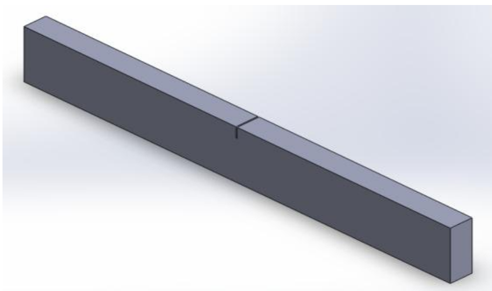
The specifications for the specimen is it will be divided into 3 specimens please refer table 3.1. It will be draw using solid work software. The entire three specimens will be marked into 30 measuring point each in order to get the accurate and precise results. The location of depth same with others and will be in at 180mm for each specimen since the location of the depth is constant.



(a)



(b)



(c)

Figure 3.5: The specimens of cantilever beams; (a) uncrack beam; (b) 10% crack depth beam; (c) 20% crack depth beam.

3.5 DESIGN FABRICATION

There are procedures and some method to fabricate the specimens for modal testing experiment. The procedures are stated below;

i. The beam dimensions have cross-section area of 20 x $50mm^2$ and length of 300mm.
ii. The specimen will be divided into three specimens as the dimension still the same but differ in depth of crack.
iii. There are 3 process involve in fabricating the cantilever beam firstly bands saw process to cut the beam length.
iv. Next by milling process so that the beam is precisely in according dimension.
v. Lastly wire cut process for accurate and precise crack on each specimens by create the crack depth at the 180mm measuring point location.

3.6 EXPERIMENTAL MODAL ANALYSIS

3.6.1 Experiment Modal Description

Three specimens of steel cantilever beams were used for this experimental investigation. The objective to conduct the EMA is to determine the Frequency Response Function which is signal response on the cantilever beam. By using the impact hammering method the EMA can be conducted to find the output response of the experiment.

3.6.2 Experiment Setup

Figure 3.6 shows the experiment setup for EMA that consist of impact hammer as the input force the accelerometer as a sensor that measure the response and the PC that analyse the output.

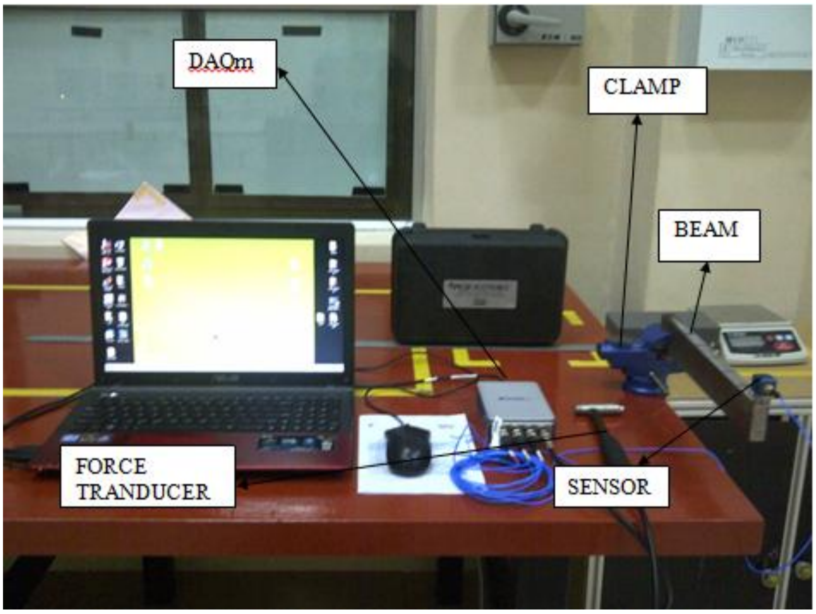


Figure 3.6: Experiment Setup

3.6.3 Software Setup

The software that we use on EMA is DASYLab software. By referring the figure 3.7 shows the block diagram setup for DASYLab software. The parameter used for block size is 8192 and the sampling rate is 8192. The input is force transducer which is impact hammer that will give the force in the cantilever beam, the accelerometer as a sensor will measure the response and the output is the dynamic responses consist of natural frequency, mode shape and damping.

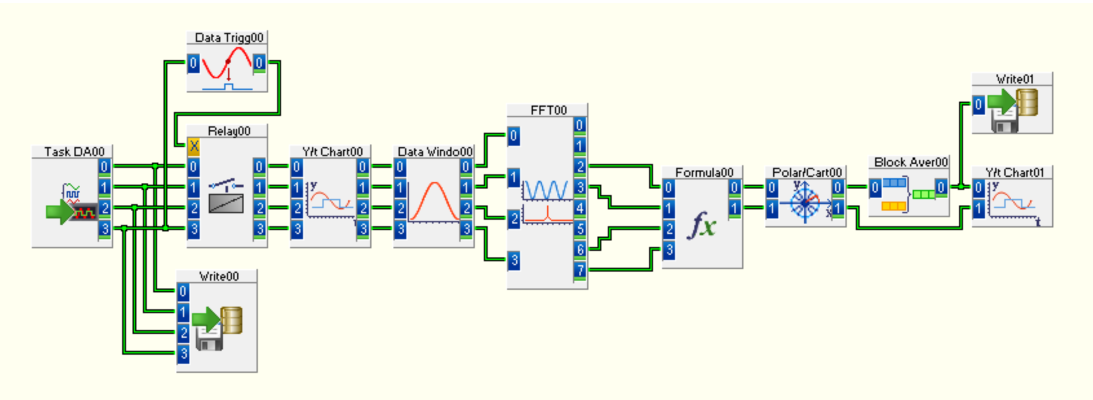


Figure 3.7: Block diagram setup of the DASYLab software.

3.6.4 Experiment Procedure

There are procedures and method in conducting experiment for EMA. The procedures are stated below.

i. The entire specimen will be divided into 30 measuring points.
ii. The specimen will be clamp onto the table provided in the lab and accelerometer will be attached on it refer figure 3.6.
iii. The accelerometer will be connected to the DAQ tools as it captures the vibration signal and will transmit it into the DASY lab software.
iv. The block diagram will be arranged based on objective of the project on the DASY lab software so that the result will be obtained and the data will be tabulate automatically onto table.
v. Mark the 30 measuring point start 10mm until 300mm that have increment 10mm.
vi. The impact hammer will give an excitation forces at the same spot which is at the end of the beam near the first measuring point.
vii. The accelerometer will start at first measuring point until 30 measuring point
viii. The natural frequency and the mode shape will be observed and the data will be captured.
ix. Step above will be repeated to another two specimen which having a crack on it, but differ on depth.
x. The data will be collected for the three specimens and the analysis will be conducted.

3.7 ME SCOPE ANALYSIS

The objective by conducting the ME Scope analysis is to determine the mode shape that will give most significant change to the crack. To obtain that the me scope analysis must be conducted.

3.7.1 Me Scope Procedure

There are procedures and method in conducting Me scope software for Me Scope Analysis. The procedures are stated below.

i. Firstly the FRF data must be import into the Me Scope software refer figure 3.8.
ii. Next the data now will be overlay traces to see every mode shapes that occur refer figure 3.9
iii. From overlay traces of the FRF data find each mode parameter.
iv. Draw the structure of the beam with their measuring point from one until 30 measuring point.
v. Collect the dynamic response data each mode.
vi. Animate the FRF data to obtain the mode shapes.
vii. Step above will be repeated with difference specimens.

Figure 3.8 shows the data FRF that were imported to create the block data for me scope analysis.

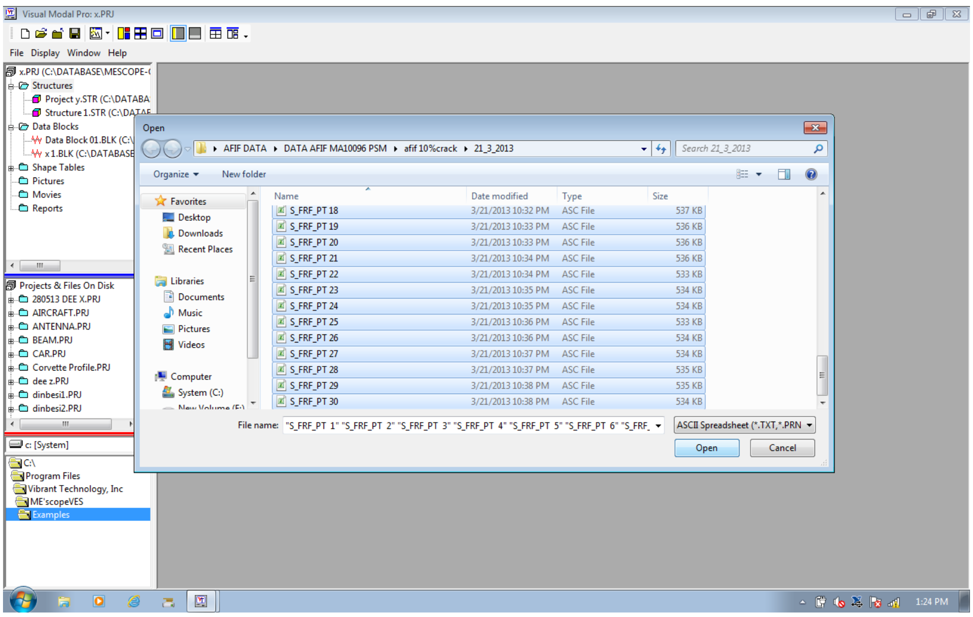


Figure 3.8: Block Data Import in Me Scope

Figure 3.9 shows the example of 10% crack depth cantilever beam overlay traces of modes in FRF data

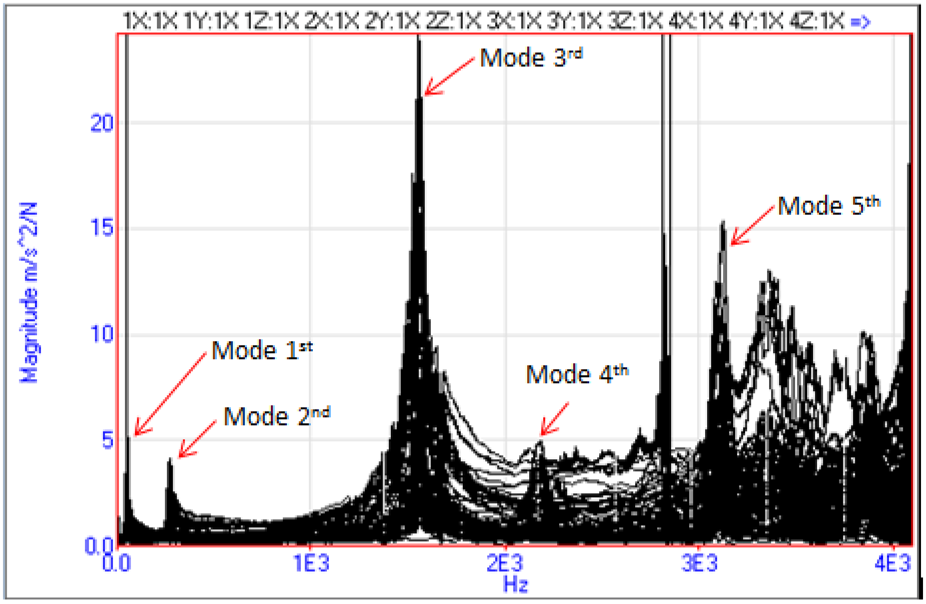


Figure 3.9: Overlay traces of FRF data.

3.8 CONTINUOUS WAVELET TRANSFORM ANALYSIS

The objective to conduct the CWT analysis on the cantilever beam for each specimen is to make the analysis simpler by extracting the bending mode that had been selected. Means by that only the area selected must be study. Example there are 5 modes that are active on the beam and the third mode had been selected because it give the most significant change to the crack. We only need to study one mode only in detecting crack whether others mode because it had been proven by Pandey 20

3.8.1 CWT analysis Procedure

There are procedures and method in conducting CWT analysis. The analysis is conducting using MATHLab software and all the calculation and analysis is using coding that already formulated in the MATHLab software. This analysis is one by one analysis which is analysis at one measuring point location only but will be conduct until the end of measuring point location. The procedures are stated below.

i. Import raw data from the EMA into MATHLab software.
ii. From the time domain data, the data now will be transforming into frequency domain data and into time-frequency domain data.
iii. The time domain will be plotted and time-frequency domain called scalogram continuous wavelet transform will be show. Inside the scalogram CWT consist of wavelet coefficient refer figure 3.10.
iv. Extract the wavelet coefficient from the scalogram CWT according to the frequency range of the selected mode refer figure 3.11.
v. Sum the coefficient using coding and will get the total coefficient value for one measuring point.
vi. Do iteration until 30 measuring point.
vii. Collect the data and plot the data on each specimen.

Figure 3.10 shows the plotted graph of time domain data and the scalogram continuous wavelet transform and inside the scalogram consist of coefficient at every frequency range and time.

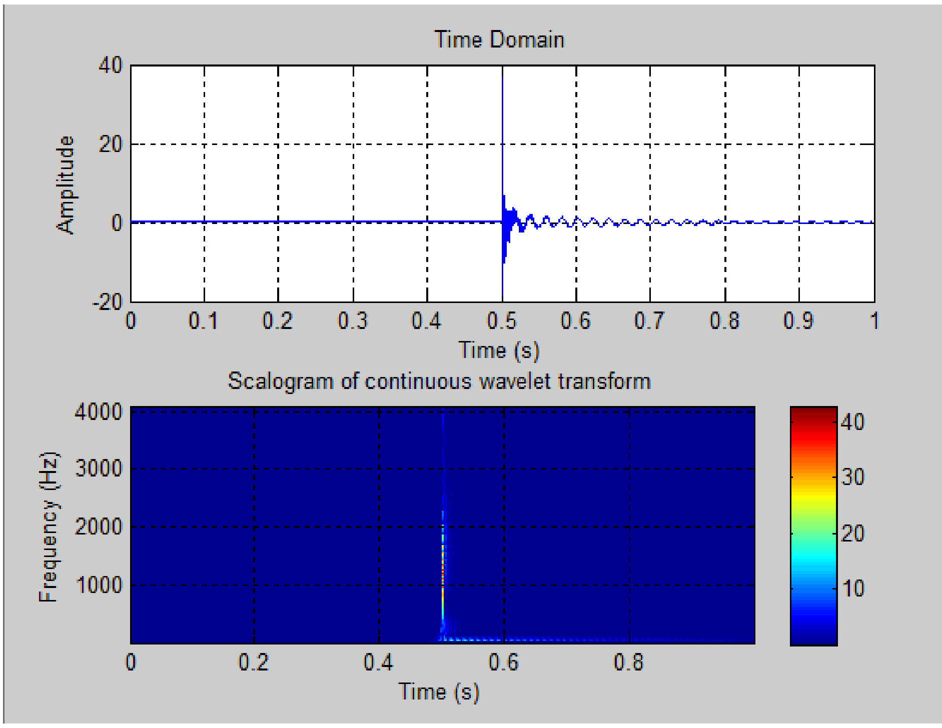


Figure 3.10: Plotted graph of time domain data and Scalogram Continuous Wavelet Transform

Figure 3.11 shows the scalogram CWT and the red circle is the range of the frequency range for selected mode. It is consist of wavelet coefficient that will be extracted and will be sum to obtain the total coefficient value. The total coefficient value each measuring point of crack beam will be will be compared with the total coefficient value of uncrack beam. Crack location detection will be present at the comparison graph.

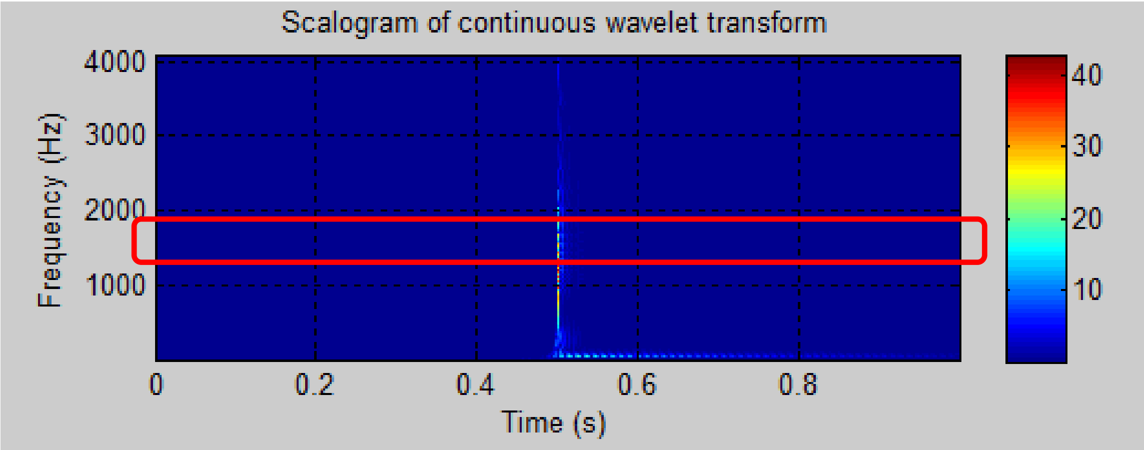


Figure 3.11: Frequency range area for selected mode on scalogram CWT

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

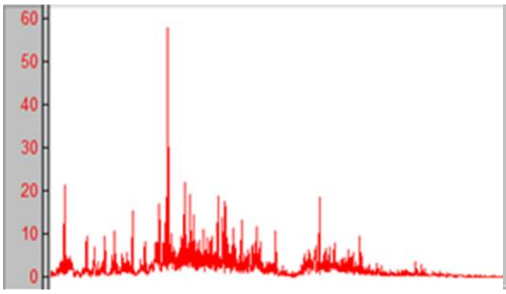
The purpose of this investigation was to detect the crack location on cantilever beam using a wavelet analysis. There are three process in detecting crack location in cantilever beam using wavelet analysis but before analyze using wavelet two process had been conducted which is Modal testing experiment and Me scope analysis. The processes in detecting the crack in cantilever beam are by conducting the Modal testing experiment on the specimens to obtain the Frequency Response Function (FRF). Next is conducting the Analysis using Me Scope software to obtain their Mode shapes and Natural frequency. Lastly Advance analysis will be conducted on the selected mode using Continuous Wavelet Transform (CWT). The results of the present investigation are organized under the following headings:

a) Experiment Modal Analysis.
b) Analysis using Me Scope.
c) Advance analysis using CWT.

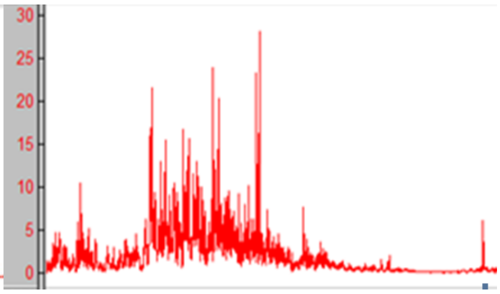
4.2 EXPERIMENT MODAL ANALYSIS

Modal testing experiment has been carried out to get all the dynamic response on each specimen for each point. The objective of this investigation was to collect the frequency response function data for further analysis. The crack detection methods are validated using a comprehensive data provided by Silva and Gomes. Those researchers performed an extensive set of modal analysis experiments on Clamp end cantilever beams with the goal of providing objective data to validate proposed techniques for damage detection. The results for this investigation are shown below.

Figure 4.1 until figure 4.3 shows the FRF obtain on each specimen at point the crack location. According the figure it shows that with the change of the crack depth it will affected the mode shape due to the change of the specimen geometry. The frequency response data are collected will bring to the next process which is me scope analysis.



(a)



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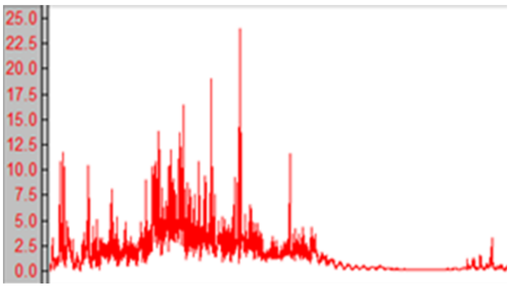


(c)

Figure 4.1: FRF signal at crack point; (a) uncrack beam; (b) 10% crack depth; (c) 20% crack depth.

4.3 ANALYSIS USING ME SCOPE

Me scope analysis is the next process step in detecting crack location. The objectives of me scope analysis to determine the mode shape that give the most significant change to the crack location and their frequency range for further analysis in advance analysis. The important of me scope analysis in getting crack location detection and it will give every detail mode shapes that exist on the cantilever beam. The results for this investigation are shown below.

The FRF obtain were curve fitted using the Me Scope software package. The experiment data from the curve fitted result were tabulated (refer figure 4.2). The figure shows the modes that occur at the cantilever beam.

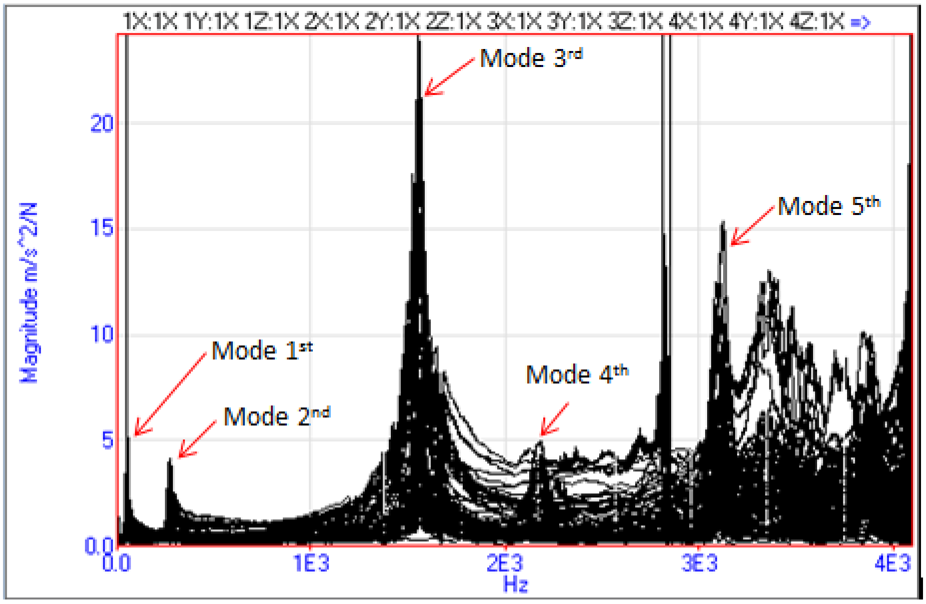


Figure 4.2: FRF using Me Scope Software.

Table 4.1 showed the data taken from the mode analysis by me scope software. From the result obtain, it is observed that when the crack depth increase the natural frequency is decreased. Figure 4.3 and 4.4 shows the mode shape animation of 10% and 20% crack depth cantilever beam. From the animation obtain, it is observed that when the crack location at 180mm the first and second mode (refer figure 4.3 (a) and (b) and 4.4 (a) and (b)), was comparatively much less affected than the third, fourth and fifth mode are for a crack located at the 180mm (refer figure 4.3 (c), (d) and (e) and 4.4 (c), (d) and (e)). The third bending mode were choose because the bending mode are obviously happen at the crack location and it give the most significant change for a crack located at the 180mm. It is also shows the highest stress on the crack location. Since the crack location and the crack depth influence the changes in the natural frequencies of a cracked beam, a particular frequency can correspond to different crack locations and crack depth. The development of a crack, at a certain location, corresponds to a sudden reduction of the bending stiffness of the beam, and furthermore leads to a shift of the natural frequency.

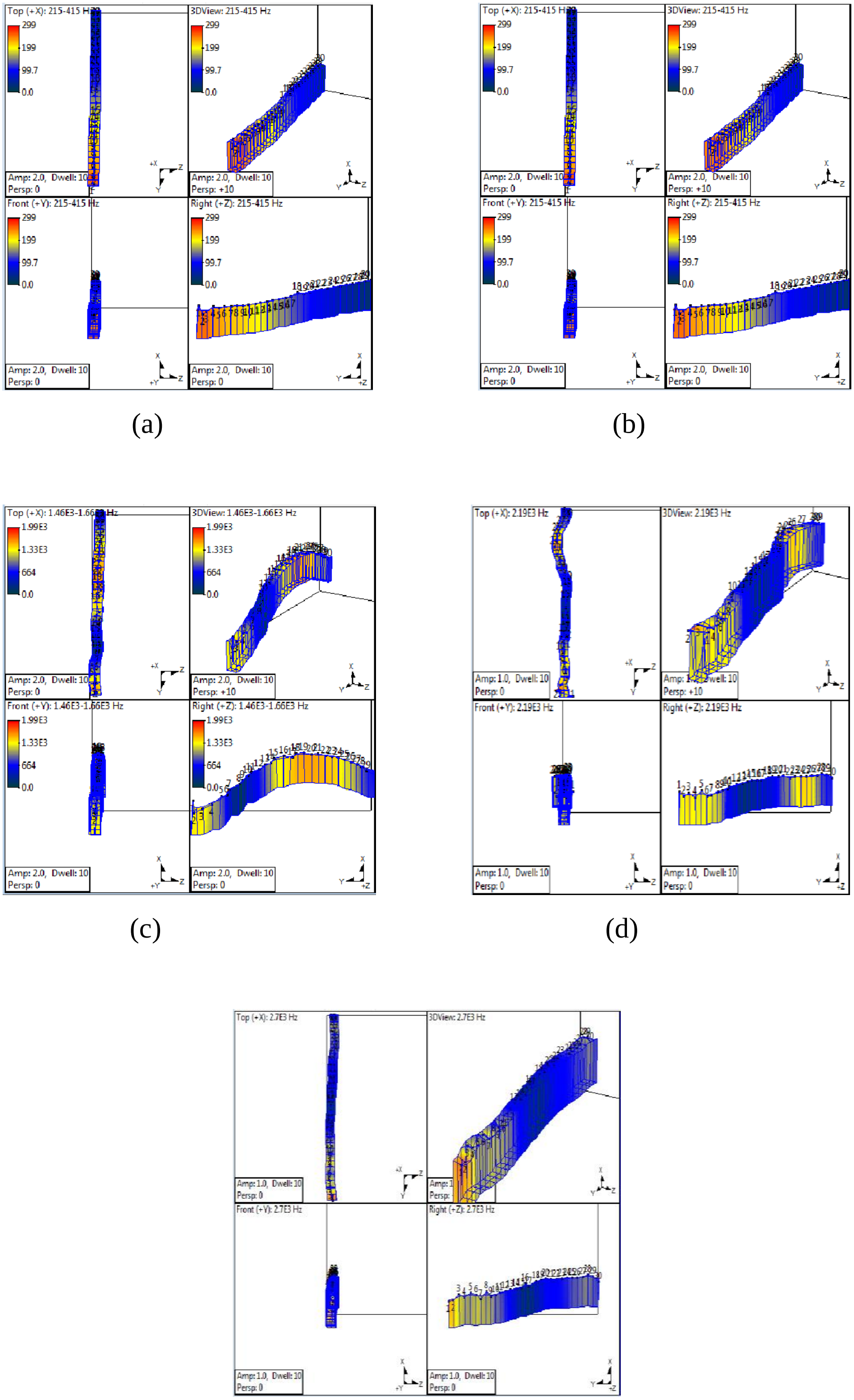
Table 4.1: Damage scenarios and resonance frequencies (Hz) of cantilever beams.

Mode	Crack location (mm)	Natural Frequency (Hz) Uncrack	10% Crack	20% Crack
1	180	48.5	47.3	45.6
2	180	273	261	255
3	180	1770	1550	1310
4	180	2430	2370	2220
5	180	3540	3360	2970

Table 4.2 shows the frequency range of selected mode which is bending mode 3 that we choose to further analysis and will be used in CWT analysis. The objective of Me scope analysis that were conducted just to determine The CWT analysis will be analyse using mathlab software and all the calculation n formular are using coding that already have in mathlab. The frequency range will be inserted in the coding further detail explanation will be carried out in CWT analysis.

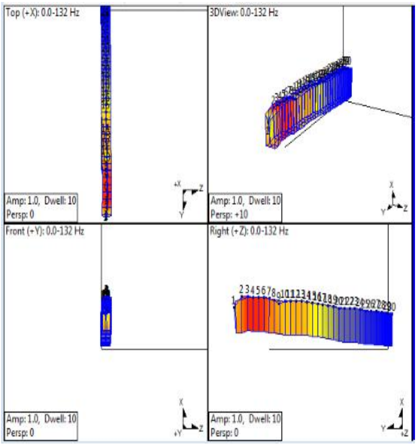
Table 4.2: Frequency range for crack beam.

Mode	Crack Location (mm)	Frequency Range (Hz) 10% Crack	20% Crack
3	180	1530-1570	1500-1520

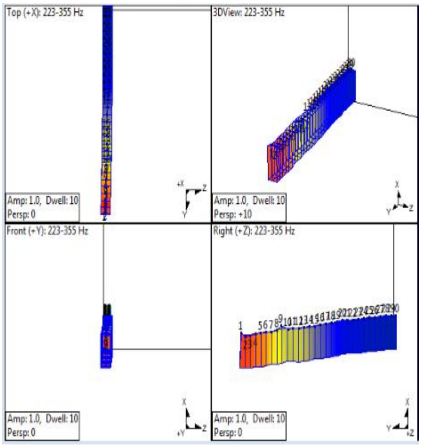


(a) (b) (c) (d) (e)

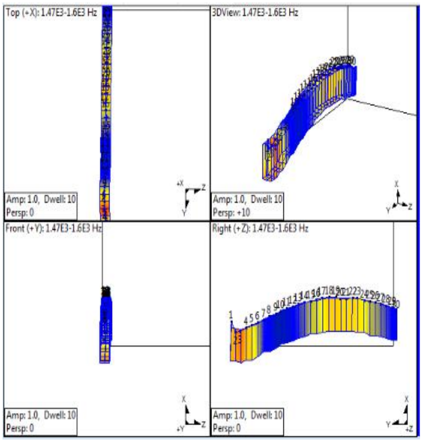
Figure 4.3: The mode shape for 10% crack depth beam; (a) mode 1; (b) mode 2; (c) mode 3; (d) mode 4 and (e) mode 5



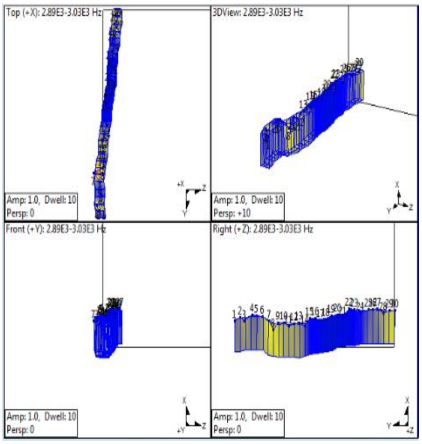
(a)



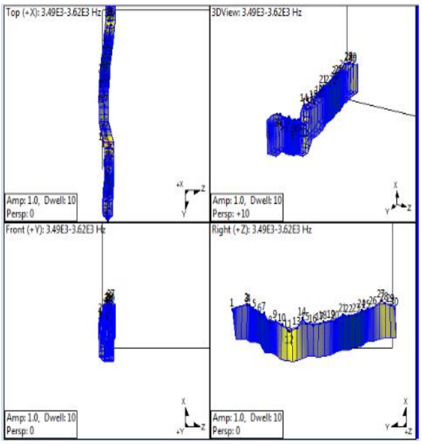
(b)



(c)



(d)



(e)

Figure 4.4: The mode shape for 20% crack depth beam; (a) mode 1; (b) mode 2; (c) mode 3; (d) mode 4 and (e) mode 5

4.4 ADVANCE ANALYSIS USING CWT

4.4.1 Total Wavelet Coefficient Value of Each Specimen.

Table 4.3 and 4.4 shows the data from the wavelet analysis using continuous wavelet transform to obtain the wavelet coefficient at each measuring point. The maximum wavelet coefficient value were found at crack location on each crack beam.

Table 4.3: Total Wavelet coefficient value data for 10% crack depth on cantilever beam

Location (mm)	Total wavelet coefficient
10	45536.01
20	45483.36
30	44292.25
40	45512.36
50	43897.74
60	32269.48
70	23258.66
80	13612.88
90	12047.26
100	22363.89
110	20039.19
120	42104.61
130	52693.42
140	61865.98
150	64911.96
160	69085.04
170	63487.11
180	119235.63
190	78148.27
200	81719.57
210	63236.01
220	70214.24
230	75664.11
240	78712.06
250	61436.21
260	58498.19
270	47915.91

280	49075.27
290	38075.27
300	29426.85

Table 4.4: Total Wavelet coefficient value data for 20% crack depth on cantilever beam

Location (mm)	**Total wavelet coefficient**
10	24095.60
20	24046.93
30	23088.07
40	24295.59
50	22609.21
60	17772.34
70	12805.25
80	7456.29
90	6391.10
100	11908.29
110	11081.66
120	21529.20
130	29007.34
140	32645.59
150	35589.51
160	36449.61
170	34224.77
180	69402.89
190	40138.76
200	42059.94
210	32457.65
220	36763.73
230	40023.97
240	41116.85
250	32482.30
260	30101.27
270	25288.73
280	27310.50
290	21202.65
300	15219.68

The graph at figure 4.5 and 4.6 shows the bending mode shape of the 10% and 20% crack depth cantilever beam and the maximum wavelet coefficient value were located at 180mm measuring point which is at the crack location but the value is difference between the crack depth.

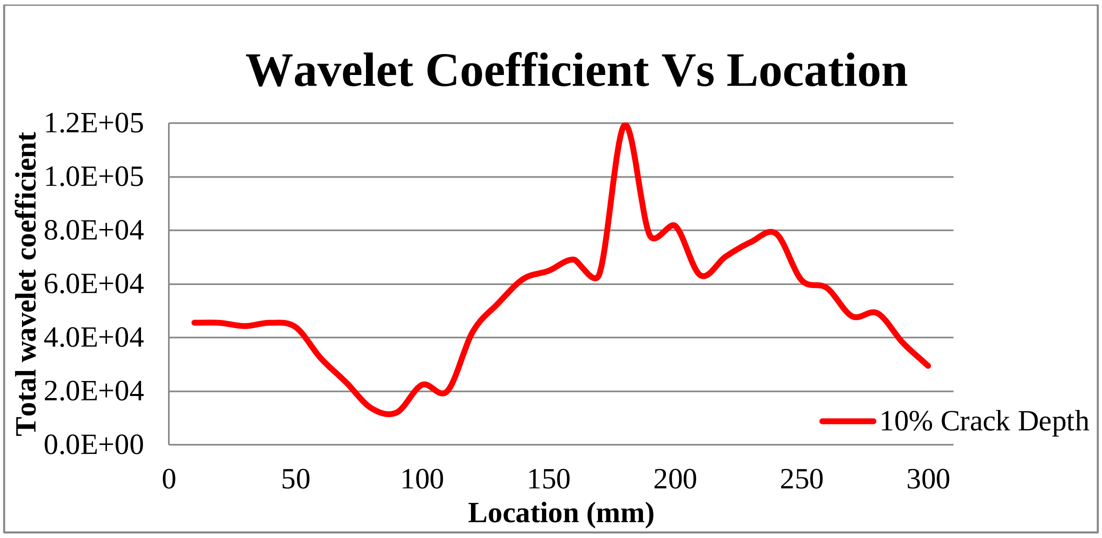


Figure 4.5: Plot graph on the Total wavelet coefficient vs Location (mm) for 10% crack depth cantilever beam.

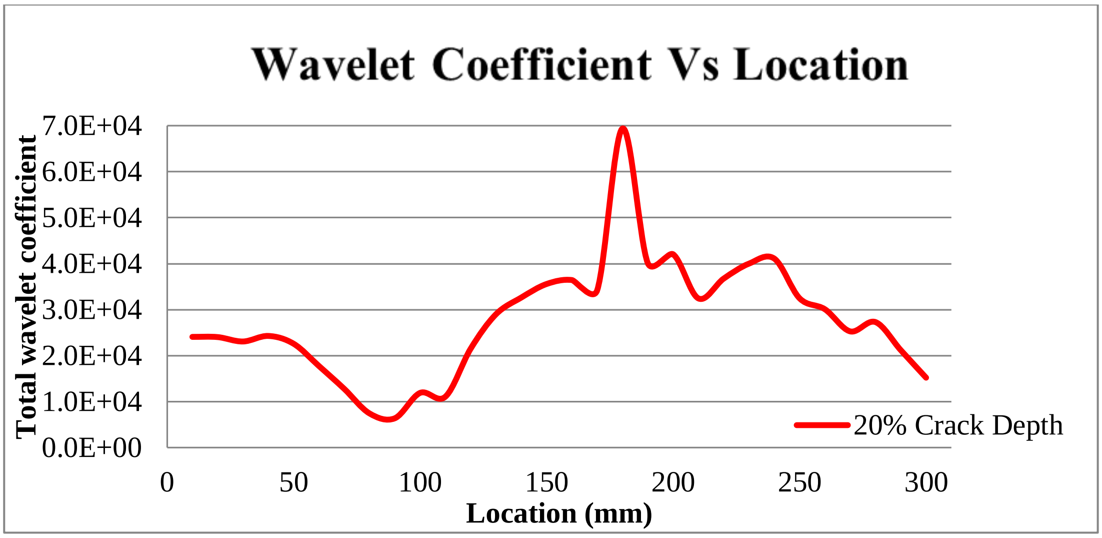


Figure 4.6: Plot graph on the Total wavelet coefficient vs Location (mm) for 20% crack depth cantilever beam.

4.4.2 Comparison of Total Wavelet Coefficient Value.

Table 4.5 and 4.6 shows comparison of the wavelet coefficient data between uncrack and crack cantilever beam.

Table 4.5: Total wavelet coefficient value data for uncrack and 10% crack depth on cantilever beam.

Location (mm)	Total wavelet coefficient	
	Uncrack	**10% Crack Depth**
10	42519.84	45536.01
20	42519.84	45483.36
30	41546.52	44292.25
40	42928.79	45512.36
50	41307.46	43897.74
60	30777.63	32269.48
70	21607.10	23258.66
80	11198.05	13612.88
90	11029.52	12047.26
100	19276.44	22363.89
110	17931.39	20039.19
120	39069.50	42104.61
130	50385.01	52693.42
140	57851.11	61865.98
150	62631.41	64911.96
160	65013.87	69085.04
170	58919.13	63487.11
180	71187.52	119235.63
190	72378.29	78148.27
200	75651.71	81719.57
210	57017.76	63236.01
220	66573.06	70214.24
230	71661.20	75664.11
240	74440.38	78712.06
250	55863.67	61436.21
260	52684.44	58498.19
270	45738.92	47915.91
280	45833.16	49075.27
290	35579.15	38075.27
300	26883.07	29426.85

Table 4.6: Total wavelet coefficient value data for uncrack and 20% crack depth on cantilever beam.

Location (mm)	Total wavelet coefficient	
	Uncrack	20% Crack Depth
10	22110.33	24095.60
20	22110.33	24046.93
30	21612.82	23088.07
40	22361.07	24295.59
50	21124.62	22609.21
60	16751.82	17772.34
70	12003.60	12805.25
80	6099.11	7456.29
90	6085.73	6391.10
100	10532.23	11908.29
110	9876.96	11081.66
120	20519.29	21529.20
130	26274.01	29007.34
140	29747.66	32645.59
150	32615.04	35589.51
160	33930.71	36449.61
170	30792.67	34224.77
180	37394.27	69402.89
190	37479.98	40138.76
200	39382.18	42059.94
210	29265.24	32457.65
220	35115.94	36763.73
230	37238.57	40023.97
240	38769.56	41116.85
250	29453.77	32482.30
260	27053.08	30101.27
270	23573.73	25288.73
280	24067.48	27310.50
290	19053.92	21202.65
300	13916.16	15219.68

Figure 4.7 and 4.8 shows the comparison of the third bending mode between uncracked cantilever beam and crack cantilever beam. From the figures of the third mode shape that had been chosen to study the mode shape of the crack and uncrack cantilever beam is in the same pattern.

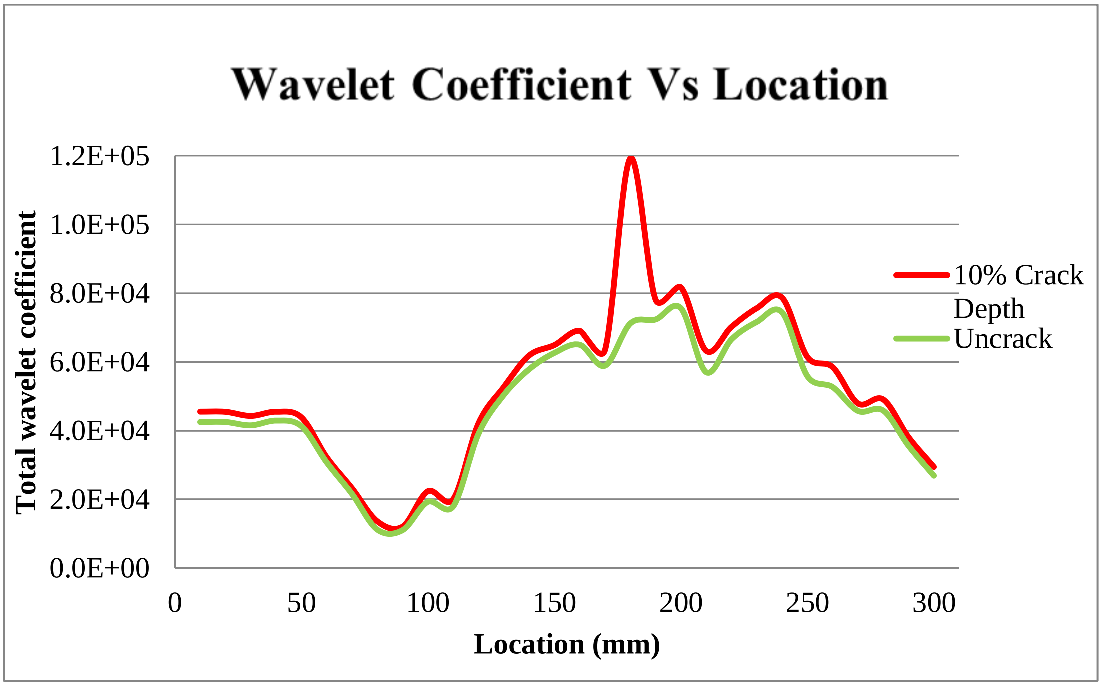


Figure 4.7: Plot graph on the Total wavelet coefficient vs Location (mm) for 10% crack depth cantilever beam and uncrack cantilever beam.

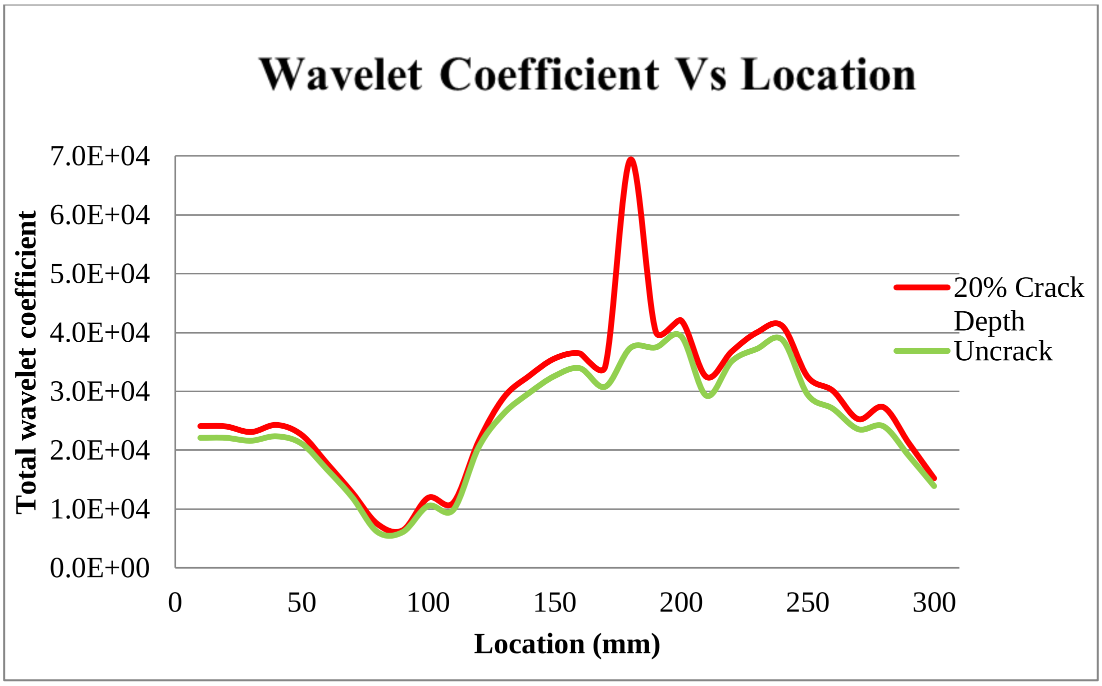


Figure 4.8: Plot graph on the Total wavelet coefficient vs Location (mm) for 20% crack depth cantilever beam and uncrack cantilever beam.

Figure 4.9 and 4.10 show the graph of the comparison between uncrack cantilever beam with crack cantilever beam. This graph is the same data from previous figure but just more smoother the mode shape using polynomial.

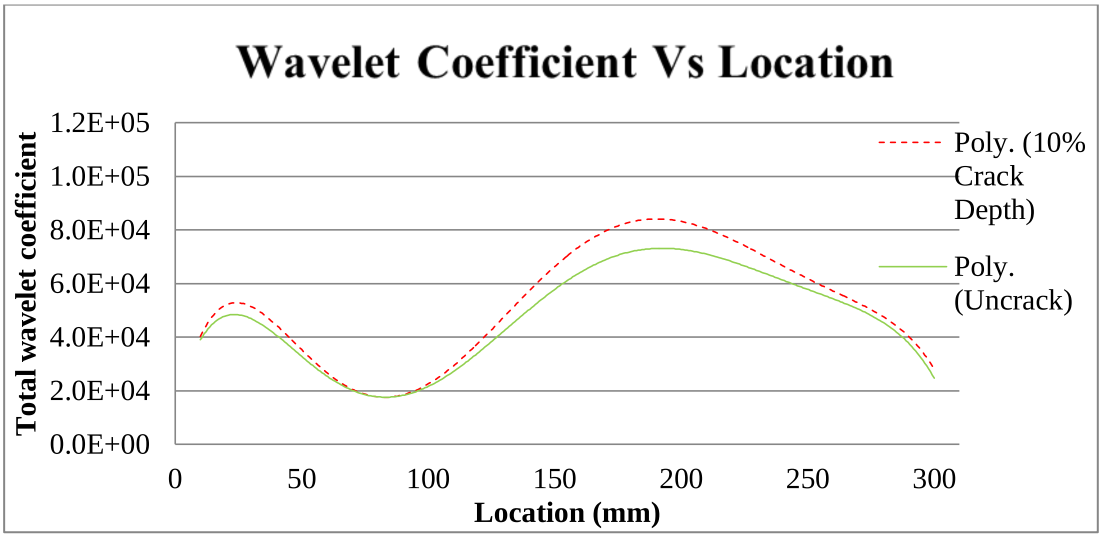


Figure 4.9: Graph of deflection response between uncrack cantilever beam with 10% crack depth cantilever beam after smoother using polynomial.

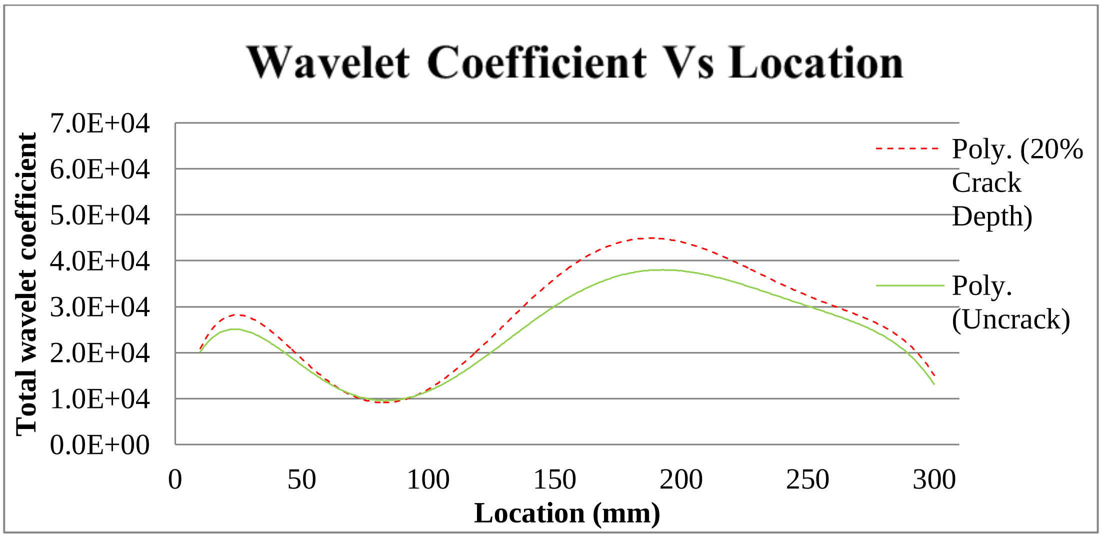


Figure 4.10: Graph of deflection response between uncrack cantilever beam with 20% crack depth cantilever beam after smoother using polynomial.

4.4.3 Comparison of total wavelet coefficient ratio.

Table 4.7 and 4.8 shows the ratio data between crack cantilever beam and uncrack cantilever beam

Table 4.7: Total wavelet coefficient value data for uncrack and 10% crack depth on cantilever beam with the ratio.

Location (mm)	Total wavelet coefficient		
	Uncrack	10% Crack Depth	Ratio
10	42519.84	45536.01	1.07
20	42519.84	45483.36	1.07
30	41546.52	44292.25	1.07
40	42928.79	45512.36	1.06
50	41307.46	43897.74	1.06
60	30777.63	32269.48	1.05
70	21607.10	23258.66	1.08
80	11198.05	13612.88	1.22
90	11029.52	12047.26	1.09
100	19276.44	22363.89	1.16
110	17931.39	20039.19	1.12
120	39069.50	42104.61	1.08
130	50385.01	52693.42	1.05
140	57851.11	61865.98	1.07
150	62631.41	64911.96	1.04
160	65013.87	69085.04	1.06
170	58919.13	63487.11	1.08
180	71187.52	119235.63	1.67
190	72378.29	78148.27	1.08
200	75651.71	81719.57	1.08
210	57017.76	63236.01	1.11
220	66573.06	70214.24	1.05
230	71661.20	75664.11	1.06
240	74440.38	78712.06	1.06
250	55863.67	61436.21	1.10
260	52684.44	58498.19	1.11
270	45738.92	47915.91	1.05
280	45833.16	49075.27	1.07
290	35579.15	38075.27	1.07
300	26883.07	29426.85	1.09

Table 4.8: Total wavelet coefficient value data for uncrack and 20% crack depth on cantilever beam with the ratio.

Location (mm)	**Total wavelet coefficient**		
	Uncrack	**20% Crack Depth**	**Ratio**
10	22110.33	24095.60	1.09
20	22110.33	24046.93	1.09
30	21612.82	23088.07	1.07
40	22361.07	24295.59	1.09
50	21124.62	22609.21	1.07
60	16751.82	17772.34	1.06
70	12003.60	12805.25	1.07
80	6099.11	7456.29	1.22
90	6085.73	6391.10	1.05
100	10532.23	11908.29	1.13
110	9876.96	11081.66	1.12
120	20519.29	21529.20	1.05
130	26274.01	29007.34	1.10
140	29747.66	32645.59	1.10
150	32615.04	35589.51	1.09
160	33930.71	36449.61	1.07
170	30792.67	34224.77	1.11
180	37394.27	69402.89	1.86
190	37479.98	40138.76	1.07
200	39382.18	42059.94	1.07
210	29265.24	32457.65	1.11
220	35115.94	36763.73	1.05
230	37238.57	40023.97	1.07
240	38769.56	41116.85	1.06
250	29453.77	32482.30	1.10
260	27053.08	30101.27	1.11
270	23573.73	25288.73	1.07
280	24067.48	27310.50	1.13
290	19053.92	21202.65	1.11
300	13916.16	15219.68	1.09

The figure at 4.11 and 4.12 shows the graph ratio of the wavelet coefficient value between uncrack cantilever beam and crack cantilever beam.

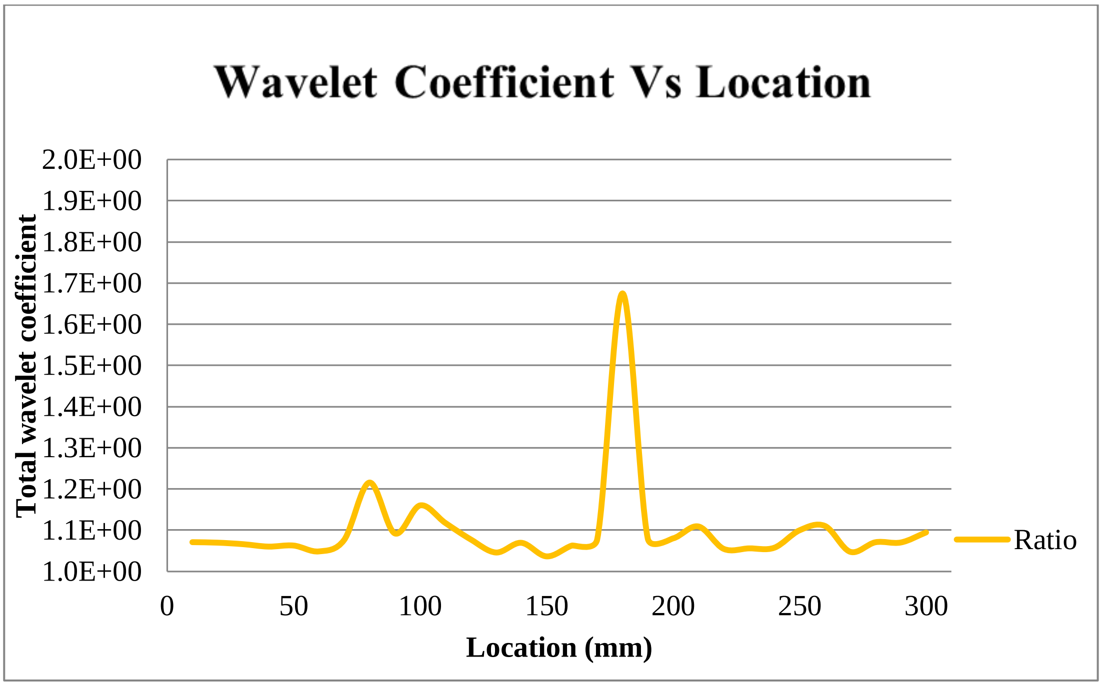


Figure 4.11: Plot graph on the ratio between uncrack cantilever beam and 10% crack depth cantilever beam.

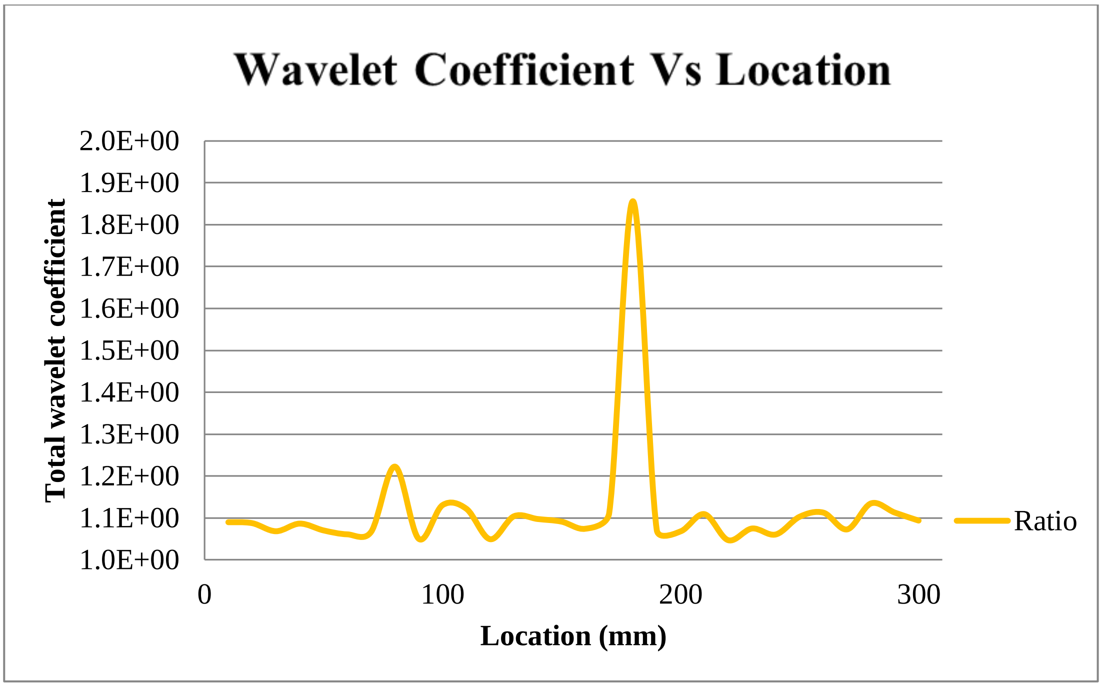


Figure 4.12: Plot graph on the ratio between uncrack cantilever beam and 20% crack depth cantilever beam.

4.4.4 Conclusion of Crack Identification

Theoretical analysis of crack beam were carried out by Pandey et. al. (1991). In this paper, an continuous wavelet transform method was develop to investigate the influence of cracks on the structural dynamic characteristics during the vibration of the cantilever beam. Upon the determination of wavelet coefficient value in crack beam and uncrack beam the coefficient was being plotted. It could be observe that, the crack location can be seen by looking at certain characteristics peak associated to the curvarture mode shape changes between uncrack and crack cantilever beam. Figure 4.7 and 4.8 shows the significant change of peak in third bending mode at crack location 180mm. It is due to the maximum wavelet coefficent because wavelet coefficient is relatively to the amplitude value. When the crack is applied on the cantilever beam their geometry of the structure will be change. The changest of the geometry of the structure will effected to the dynamic stiffness. Consequently its also effected their characteristics, such as natural frequencies and mode shape would change due to the reducing resistance. It has been proven by the Pandey et. al. (1991). Figure 4.11 and 4.12 shows the graph of coefficient value ratio between uncrack and crack cantilver beam and the highest peak was at crack location 180mm. It also showed another smaller peak occur at measuring point 80mm and 100mm this occur due to the higher force impaction to the cantilever beam at that time when modal testing experiment were conducted. To improve the results further, the number of spatial measurements should be increased substantially. It was not possible to carry out more measurements in the present work. In order to reduce the experimental noise effect, finding the differences of the CWT coefficient of the two signal uncrack signal and crack signal that are obtained from the third mode shape. Figure 4.13 and 4.14 show the ratio of the averange of differences of the CWT coefficient. The figures show very clear evidences of crack existence at 180 mm at the centre of cantilever beam. All the process in CWT are easily made automatic using Matlab wavelet and signal processing toolboxes, so the proposed method can be recommended for real monitoring applications.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter discuss the conclusion from the result and analysis and it also discuss the recommendation for future work about the project.

5.2 CONCLUSION

Considering the objective and the scope of this study the following conclusions were drawn from the investigation:

As a conclusion, this paper proposes a new approach based on the difference of the CWT coefficients of the two reconstructed signal series to provide a method without baseline modal parameters for damage detection in beam-like structures with small cracks, whose crack ratio (r = Hc/H) in between 10% to 20%. The two signal series are obtained and reconstructed from the original third mode shape 'signal' of a cracked beam. For a beam containing a single crack, one of these 'signals', which is apparently a smooth curve, actually exhibits a local peak or discontinuity in the region of damage because it includes additional response due to the crack. This can be obtained by comparing with the signal from uncrack beam that reconstructed from the original third mode shape.

The initial crack damage in cantilever beam can be efficiently detected using the wavelet coefficient variation signal of the structural vibration response decomposed by wavelet analysis as proposed in this paper. The adopted piezoelectric smart structure technology is also helpful to the active and online detection of structural damage. Structural damage detection based on structural vibration responses only requires limited hardware together with piezoelectric actuators and sensors integrated with the structure. The local physical behaviour of the structure can be determined using the global structural dynamic characteristics.

The objective and the scope of this project are achieve by obtained results show that a crack in a cantilever beam with has cross section area 20mm x $50mm^2$ and the length 300mm may be detected using the proposed technique. Therefore, the method proposed in this study is effective for detecting extremely small local crack damage in cantilever beam structures without using external excitation equipment. Such early detection helps in keeping close watch on the crack growth to avoid breakdowns. The methodology developed can be extended for online monitoring system for structures for early identification of crack location with sensors coupled in proximity with crack location. This will help itself to provide useful information of crack growth and severity of damage.

5.3 RECOMMENDATION FOR FUTURE RESEARCH

Based on the findings of the present investigation, the following recommendations are made for further research:

Experimental results verify that the present method can be utilized to detect crack location. It should be noted that the use of this method based on CWT requires fairly accurate estimates of the mode shapes. This is the difficulty for application to real structures. Generally, to get accurate estimates of the mode shapes, however, one needs detailed measurements of the mode shapes. This fact increases considerably the duration of the investigation and this is the main disadvantage of using mode shapes for crack identification. However, with the availability of fast measurement techniques, such as scanning laser vibrometer, this limitation is not a serious issue. On the other hand, it has been shown that less-detailed measurement can still be used provided a spline interpolation is used to improve the accuracy of the crack detection. The procedure for detection of crack is simple and general. It is believed that this procedure can be easily extended to complex structures, such as rotor, blade, etc. with multiple cracks. Such early detection helps in keeping close watch on the crack growth to avoid breakdowns. The methodology developed can be extended for online monitoring system for structures for early identification of crack location with sensors coupled in proximity with crack location. This will help itself to provide useful information of crack growth and severity of damage.

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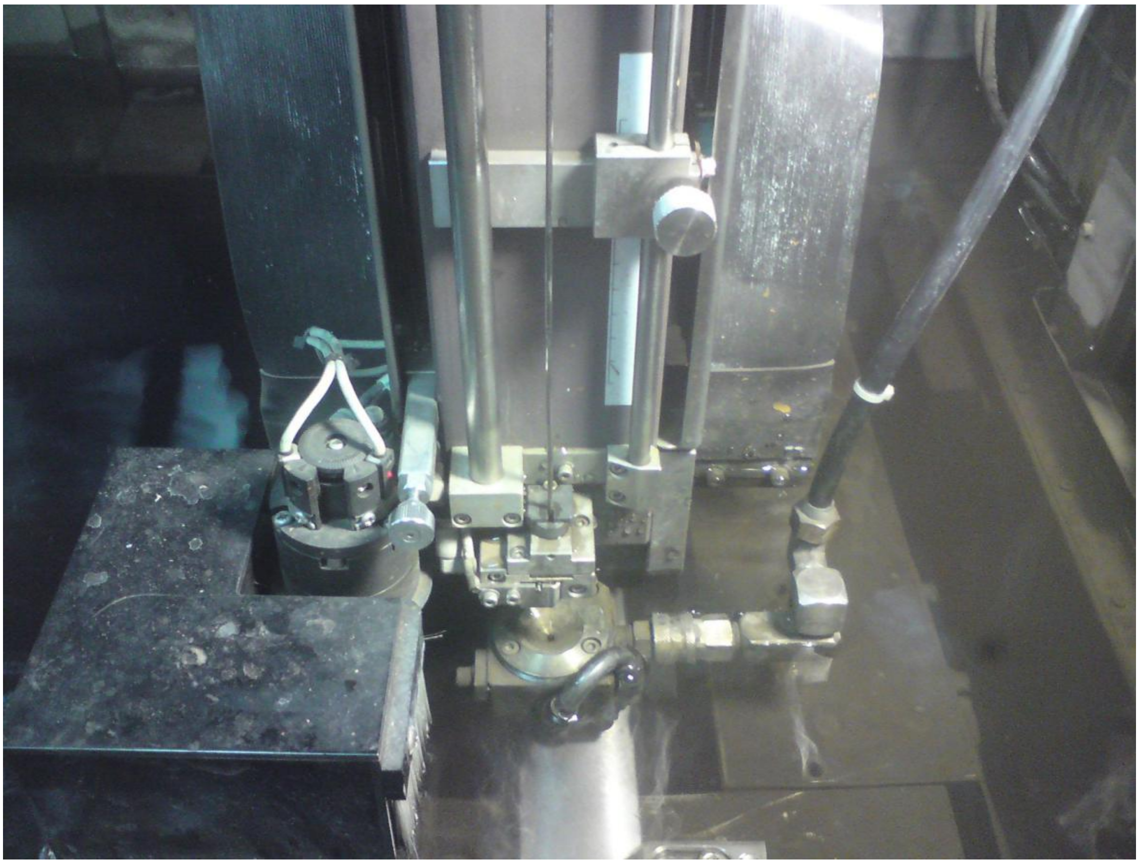
APPENDICES

APPENDIX A

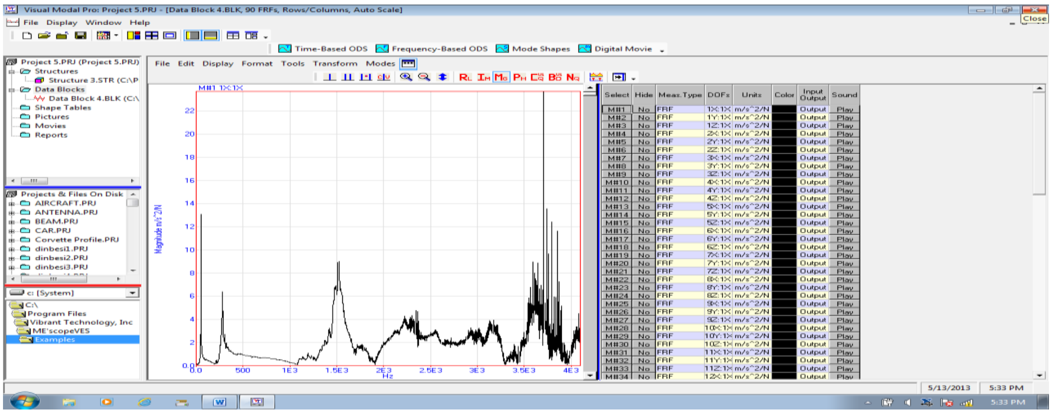
Milling process in fabrication of cantilever beam

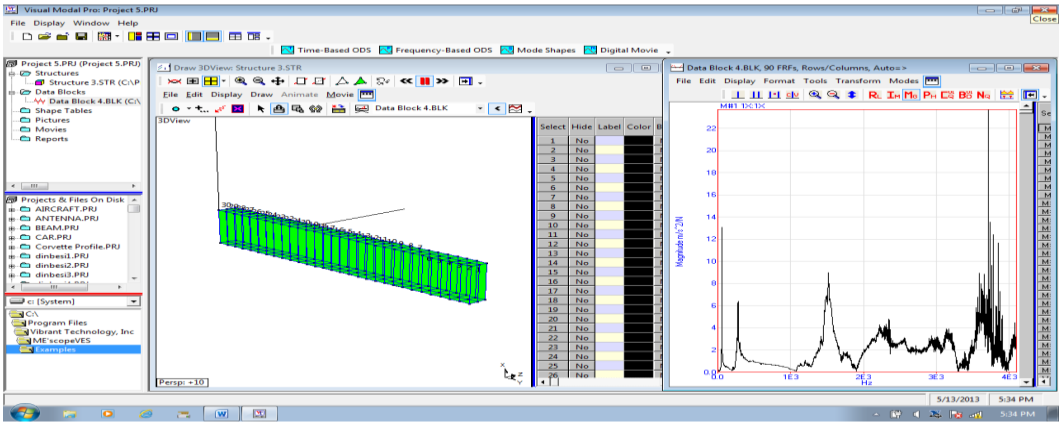
APPENDIX B

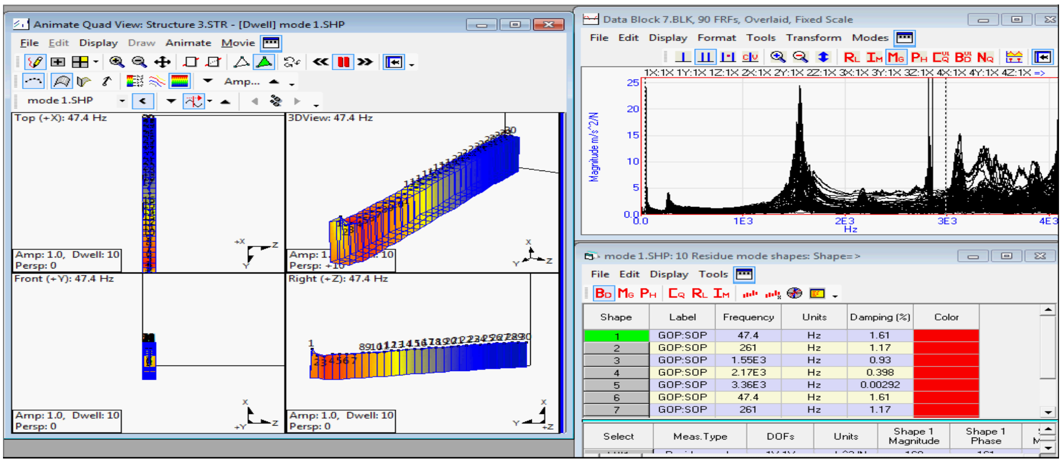


Wire cutting process in making precise crack on the cantilever beam.

APPENDIX C







Me Scope analysis from FRF data

APPENDIX D1

Bil.	**Task**		**Week**													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Choose Supervisor discuss topic	Plan														
		Actual														
2	Register Title and Prepare Journal	Plan														
		Actual														
3	Literature Review (overall flow chart)	Plan														
		Actual														
4	Literature Review (research past experiment)	Plan														
		Actual														
5	Prepare for project proposal	Plan														
		Actual														
6	Submit proposal and Slide presentation	Plan														
		Actual														
7	Prepare for Progress Presentation PSM 1	Plan														
		Actual														
8	Progress Presentation PSM 1	Plan														
		Actual														
9	Methodology (design experiment setup)	Plan														
		Actual														
11	Methodology (design experiment setup)	Plan														
		Actual														
12	Methodology (Testing)	Plan														
		Actual														
13	Methodology (expected outcomes)	Plan														
		Actual														
14	Report for PSM 1 and log book	Plan														
		Actual														

Gantt Chart Psm 1

APPENDIX D2

Bil.	Task		Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Meet supervisor to discuss about PSM 2	Plan														
		Actual														
2	Literature Review (finalize study)	Plan														
		Actual														
3	Progress Presentation	Plan														
		Actual														
4	Methodology (Testing)	Plan														
		Actual														
5	Prepare for project proposal	Plan														
		Actual														
6	Methodology (design experiment setup)	Plan														
		Actual														
7	Methodology (Modal Testing Experiment)	Plan														
		Actual														
8	Result and Discussions	Plan														
		Actual														
9	Prepare for Progress Presentation 2	Plan														
		Actual														
11	Progress Presentation 2	Plan														
		Actual														
12	Prepare for Final Presentation PSM 2	Plan														
		Actual														
13	Final Presentation PSM 2	Plan														
		Actual														
14	Report for PSM 2 and log book	Plan														
		Actual														

Gantt Chart Psm 2