COMPARATIVE STUDY OF THE STRAIN SIGNAL AND THE EDITED STRAIN SIGNAL

MUHAMAD FAIZAL BIN ABD GHANI

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS◆

JUDUL: **COMPARATIVE STUDY OF THE STRAIN SIGNAL AND THE EDITED STRAIN SIGNAL**

SESI PENGAJIAN: 2011/2012

Saya, **MUHAMAD FAIZAL BIN ABD GHANI (891022-07-5081)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
√	**TIDAK TERHAD**	

Disahkan oleh:

_________________________ _________________________
(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:

NO. 675 LRG ANGSANA 9/2,
TMN ANGSANA, 09000 KULIM,
KEDAH DARUL AMAN

NURAZIMA ISMAIL
(NAMA PENYELIA)

Tarikh: **08 JUNE 2012** Tarikh: **08 JUNE 2012**

CATATAN: * Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

◆ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi
bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Comparative Study of the Strain Signal and the Edited Strain Signal" is written by Muhamad Faizal Bin Abd Ghani. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We were here with recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

(MR. LEE GIOK CHUI)

EXAMINER SIGNATURE

COMPARATIVE STUDY OF THE STRAIN SIGNAL AND THE EDITED STRAIN SIGNAL

MUHAMAD FAIZAL BIN ABD GHANI

Report submitted in fulfilment of
The requirements for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

SUPERVISOR'S DECLARATION

We hereby declare that 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.

Signature	:	
Name of Supervisor	:	NURAZIMA ISMAIL
Position	:	LECTURER OF MECHANICAL ENGINEERING
Date	:	

STUDENT'S DECLARATION

I hereby declare that the work in this project 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.

Signature :

Name : MUHAMAD FAIZAL BIN ABD GHANI

ID Number : MA08089

Date :

Dedicated to my father, Mr. Abd Ghani Bin Bahari, my beloved mother, Mrs. Asmah Bt Saad, my brothers Muhamad Ridzuan Bin Abd Ghani and Muhamad Firdaus Bin Abd Ghani, my sister Nurain Bt. AbdGhani and last but not list to all my beloved fellow friends…

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Ms. Nurazima Bt Ismail for her germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. She has always impressed me with her outstanding professional conduct, her strong conviction for science, and her belief that a bachelor program is only a start of a life-long learning experience. I appreciate her consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for her progressive vision about my training in science, her tolerance of my naive mistakes, and her commitment to my future career

My sincere thanks go to all my lab mates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This study presents the comparative study between the original strain signal and its edited strain signal. In this study, the data of fatigue strain loading on an automobile coil spring was used and the purpose to this component is because it been identified as one of the critical component in an automobile. The strain signal editing process was performed by removing low amplitude cycles were eliminated based on the cut-off level of the signal energy distribution in the time representation. Thus, the new edited signal was obtained which has retained almost 100% of the original fatigue damage and has equivalent signal statistic. The original and edited strain signals were analysed for predicting the fatigue damage of the coil spring. A comparison study of the fatigue damage and the highest damage zone obtained from the original strain signal and the edited strain signal carried out. From the result obtained, the prediction of the fatigue damage and the highest damage zone for both strain signals original and edited is equivalents. Hence, for the laboratory fatigue testing the shortened signals that was produced from damage editing process can be used as a tool to accelerate the fatigue testing.

ABSTRAK

Kajian ini membentangkan kajian perbandingan di antara isyarat terikan yang asal dan isyarat terikan yang telah disunting. Dalam kajian ini, data beban terikan lesu pada pegas gegelung kereta telah digunakan dan ini adalah kerana komponen ini telah dikenal pasti sebagai salah satu komponen penting dalam automobil. Proses penyuntingan isyarat terikan dilakukan dengan mengeluarkan kitaran amplitude rendah telah dihapuskan berdasarkan peringkat potong taburan tenaga isyarat dalam perwakilan masa. Oleh itu, isyarat baru yang telah disunting diperolehi mengekalkan hampir 100% kerosakan lesu yang asal dan mempunyai statisti isyarat yang setara. Isyarat terikan asal dan yang telah disunting itu dianalisa untuk meramalkan kerosakan lesu lingkaran spring. Satu kajian perbandingan kerosakan lesu dan zon kerosakan tertinggi yang diperoleh daripada isyarat terikan asal dan isyarat terikan disunting dijalankan. Berdasarkan keputusan yang diperolehi, ramalan kerosakan lesu dan zon kerosakan tertinggi bagi kedua-dua isyarat terikan asaldan isyarat terikan yang telah disunting adalah setara.Oleh itu, untuk kajian makmal, isyarat yang dipendekkan yang terhasil daripada proses penyuntingan kerosakan boleh digunakan sebagai alat untuk mempercepatkan ujian lesu.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ε_e	Elastic Component Cyclic Strain
σ_a	Cyclic Stress Amplitude
σ_f'	Fatigue Strength Coefficient
N_f	Number Cycle Failure
b	Fatigue Strength Coefficient
ε_p	Plastic Component Cyclic Strain Amplitude
ε_f'	Fatigue Ductility Coefficient
c	Fatigue Ductility Coefficient
$2N_t$	Transition Life
E	Elongation
σ_0	Mean Stress
σ_{max}	Maximum Stress
D	Damage
X	Damage Criterion
N_i	Fatigue Life At Constant Stress Level S_i
n_i	Number Applied Load Cycles At Constant Stress LevelS_i
S_1	Stress 1
S_2	Stress 2
r	Radius
K	Stiffness
w	Translating Window
τ	Time
t	Time
f	Frequency
exp	Exponent
∞	Infinity
π	22/7

LIST OF ABBREVIATIONS

STFT	Short Time Fourier Transform
SAE	Society Of Automotive Engineer
ASTM	American Society For Testing And Material
LEFM	Linear Elastic Fracture Mechanics
NDT	Non-Destructive Testing
FFT	Fast Fourier Transform
3D	3-Dimensional
FEM	Finite Element Method
FEA	Finite Element Analysis
CAD	Computer Aided Design
S-N	Stress Life
E-N	Strain Life

CHAPTER 1

INTRODUCTION

1.1 Introduction

Suspension is the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. This is important for absorbing bumps in rough terrain, gracefully landing jumps, and getting the right amount of body lean and weight transfer in turns. Both end of this component are fixed to the wheel and the chassis. Suspension components, along with wheel rims and brake components are un-sprung masses, which make weight reduction important for ride quality and response as well as for reducing the total vehicle weight. Each of the automotive suspension system has two goals, that is passenger comfort and vehicle control. Comfort is provided by isolating the passengers vehicle's from road disturbances like bumps or potholes. Control is achieved by keeping the car body from rolling and pitching excessively, and maintaining good contact between the tire and the road.

The most of the failure observed in the real structure and mechanical component are due to the fatigue. Fatigue can be analysed using either three method that is Stress-Life (S-N), Strain-Life (ε-N) and Crack-Growth Method. In the design of the real system subjected to the environment loadings, both the fatigue strength and dynamic properties of the external loads are important.

Chromium steels are a family of special grade of iron-based alloys that contain at least 10% of chromium in their composition of steels. Chromium steels have remarkable resistance to corrosion. Due to its characteristic chromium steel is use to make the suspension spring coil that can withstand corrosion and able to withstand large load applied to the coil.

1.2 Project Background

This is project about comparative study of strain signal and edited strain signal. This project will use a few method that need to be taken into consideration to successfully accomplish this project. The methods that are going to use is strain-life method. There are three models in strain life method that is coffin Manson, Morrow and Smith Watson Topper. Fatigue is the most important failure mode to be considered in a mechanical design. Under the action of oscillatory tensile stresses of sufficient magnitude, a small crack will initiate at a point of the stress concentration. Once the crack is initiated, it will tend to grow in a direction orthogonal to the direction of the oscillatory tensile loads.

Fatigue analysis is an analysis to determine fatigue failure of a certain products or certain material. Usually fatigue analysis is done using fatigue software. In fatigue analysis nCode software packages is usually used to run the analysis. There are two kind of software, which is GlyphWorks® software packages and also design life software packages. This two software provide different display of result of fatigue analysis. For this project fatigue damage editing was done using GlyphWorks® software packages, and for the determining the value of fatigue damage using design life software packages. Validation process is used in this project to verify whether the result of fatigue damage of original strain signal and edited strain signal is the same or not. Theoretically, the result of the fatigue damage of original and edited strain signal should be the same.

1.3 Problem Statement

The current strain signal consist noise that did not contribute to the fatigue damage value. In order to remove the noise Short Time Fourier Transform (STFT) method is use to remove low cycle amplitude from strain signal, based on gate value. Gate value is minimum amplitude of the strain signal that will contribute to the fatigue damage. After the damage editing process the length of strain signal in second is shorten to a certain value. So, this process is used to accelerate the fatigue analysis. By using the original strain signal, the fatigue analysis takes longer time to finish compared to edited strain signal.

1.4 Objectives

The Objective of the project is:

1) Comparative study between the original strain signal and edited strain signal should give the same value of the fatigue damage. To show that the noise that been removed did not contribute to the fatigue damage value.

2) Comparison study of fatigue damage for different road profile using strain life approach. Different road profile shows that different stress applied to the suspension spring coil which is highway road, university road and public road.

1.5 Hypothesis

The value of fatigue damage for original and edited strain signal should be the same after damage editing process of the strain signal. The signal that been removed did not contribute to the fatigue damage value. after damage editing process of the original strain signal, the signal shorten and when running the analysis the edited signal will finish analysis much faster compared to the original strain signal.

Different road profile show different damage value. the public road should show the highest damage value followed by university road and highway road show the lowest damage value due to its surface of road that are smooth well-made compared to the public road.

1.6 Scope of Research

The first element that needs to be considered that is to perform finite element analysis using Patran Nastran MSC fatigue software. MSC Fatigue is a Finite element based durability and damage tolerance solver that enables users to perform comprehensive durability analysis. Finite element analysis programs can tell you where stress “hot spots” exist, but on their own can’t tell you whether those hot spots are critical areas for fatigue failure, or when fatigue might become a problem. MSC Fatigue enables the engineers to quickly predict how long products will last under certain loading conditions.

The second element is to perform fatigue damage analysis using nCode DesignLife® Software packages. By importing the result of static loading from the MSC fatigue, it will be used to run analysis in DesignLife® Software. The result will be show in a form of finite element display. It also shows the result of fatigue damage with colour contour for the finite element display.

The third element is to run the fatigue damage editing process. This process will be running using software nCode GlyphWorks® software packages. nCode GlyphWorks® is a powerful data processing system for engineering test data analysis with specific application for fatigue analysis. Users can simply create an analysis workflow by ‘drag and dropping’ analysis building blocks. In addition to general signal processing, GlyphWorks® provides leading fatigue analysis capabilities for measured data. The signal noise will be removed from the original strain signal.

The last element is validation process. This process will show the comparison between fatigue damage values of original with edited strain signal. At the end of the project we will see which road profile will give the highest and lowest fatigue damage value.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews about literature review of some recent project or existing experiment. In this project, this chapter will reviews about the fatigue, methods in fatigue prediction, comparison of methods in fatigue and last but not least is strain signal damage editing.

2.2 Fatigue

Fatigue is the process of progressive localized permanent structural change occurring in a material subjected to conditions that produce fluctuating stresses and strains at some point or points and that may culminate in cracks or complete fracture after a sufficient number of fluctuations. If the maximum stress in the specimen does not exceed the elastic limit of the material, the specimen returns to its initial condition when the load is removed. A given loading may be repeated many times, provided that the stresses remain in the elastic range. Such a conclusion is correct for loadings repeated even a few hundred times. However, it is not correct when loadings are repeated thousands or millions of times. In such cases, crack will occur at a stress much lower than static breaking strength. This phenomenon is known as fatigue. (Ariduru 2004)

To be effective in averting failure, the designer should have a good working knowledge of analytical and empirical techniques of predicting failure so that during the prescribed design, failure may be prevented. That is why in the failure analysis prevention is of critical importance to the designer to achieve a success.

2.3 Stress-Life Based Approach (*S-N* Method)

For the fatigue design and components, several methods are available. All require similar types of information. These are the identification of candidate locations for fatigue failure, the load spectrum for the structure or component, the stresses or strains at the candidate locations resulting from the loads, the temperature, the corrosive environment, the material behaviour, and a methodology that combines all these effects to give a life prediction. Prediction procedures are provided for estimating life using stress life (Stress vs. Number of cycle's curves), hot-spot stresses, strain life, and fracture mechanics. With the exception of hot-spot stress method, Figure 2.1 shows all these procedures have been used for the design of aluminium structures (Rise et al. 1988).

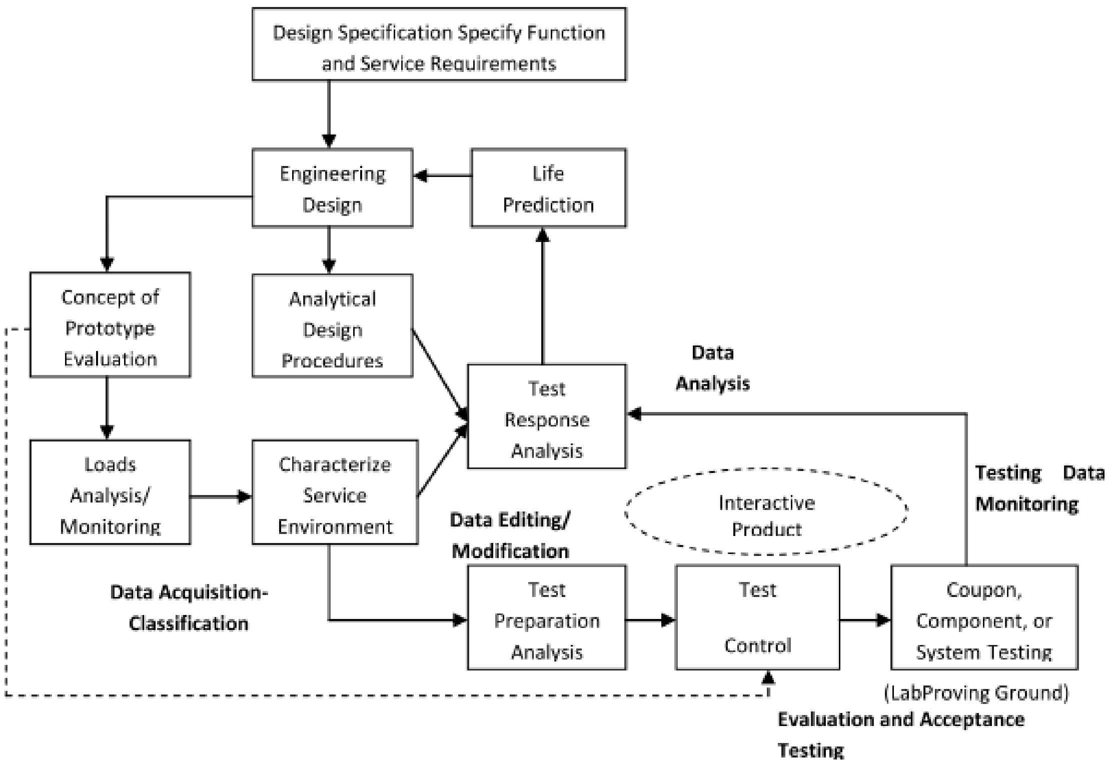


Figure 2.1: Functional diagram of engineering design and analysis

Sources: Rise et al. (1988)

Since the well-known work of Wohler in Germany starting in the 1850's, engineers have employed curves of stress versus cycles to fatigue failure, which are often called *S-N* curves (stress-number of cycles) or Wohler's curve (Lalanne et al.1999). Since the well-known work of Wohler in Germany starting in the 1850's, engineers have employed curves of stress versus cycles to fatigue failure, which are often called *S-N* curves (stress-number of cycles) or Wohler's curve.

The basis of the stress-life method is the Wohler *S-N* curve, that is a plot of alternating stress, *S*, versus cycles to failure, *N*. The data which results from these tests can be plotted on a curve of stress versus number of cycles to failure. This curve shows the scatter of the data taken for this simplest of fatigue tests. A typical *S-N* material data can be seen in Figure 2.2. The arrows imply that the specimen had not failed in 10^7 cycles (Lalanne et al. 1999).

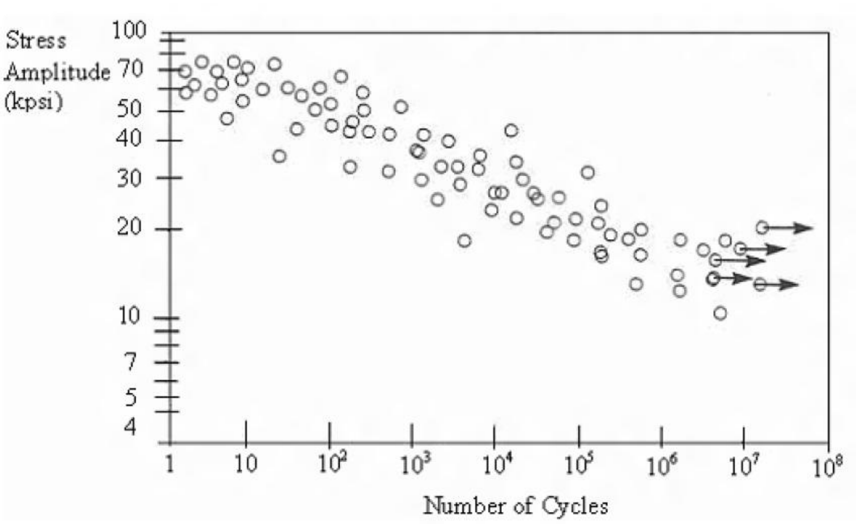


Figure 2.2: A typical *S-N* material data

Sources: Ariduru (2004)

2.4 Strain-Life Based Approach (ε-N Method)

The Strain-Life method is based on the observation that in many components the response of the material in critical locations such as notches is strain or deformation dependent. In the Strain-Life approach the plastic strain or deformation is directly measured and quantified. The Stress-Life approach does not account for plastic strain. (J. A. Bannantine 1990)

Although most engineering structures and components are designed such that the nominal loads remain elastic, stress concentrations often cause plastic strains to develop in the vicinity of notches. Due to the constraint imposed by the elastically-stressed material surrounding the plastic zone, deformation at the notch root is considered strain-controlled.

Crack growth is not explicitly accounted for in the Strain-Life method. Because of this, Strain-Life methods are often considered crack initiation life estimates. For some applications, the existence of a crack is an overly conservative criterion for failure. In these situations, fracture mechanics methods may be employed to determine crack propagation life from an assumed initial crack size to a final crack length. Total lives are then reported as the sum of the initiation and propagation segments.

The local Strain-Life approach has gained acceptance as a useful method of evaluating the fatigue life of a notched component. Both the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE) have recommended procedures and practices for conducting strain-controlled tests and using these data to predict fatigue lives. (J. A. Bannantine 1990)

2.4.1 Strain-Life Behaviour

In 1910, Basquin observed that Stress-Life data could be modelled using a power relationship, which results in a straight line on a log-log plot. This observation corresponds to elastic material behaviour in the Strain-Life approach. The Basquin equation can be expressed in terms of true elastic strain amplitude as:

$$\varepsilon_e = \frac{\sigma_a}{E} = \frac{\sigma_f'}{E}\left(2N_f\right)^b \tag{2.1}$$

Where: ε_e is the elastic component of the cyclic strain amplitude

σ_a is the cyclic stress amplitude

$\sigma' f$ is the regression intercept called the fatigue strength coefficient

N_f is the number of cycles to failure

b is the regression slope called the fatigue strength exponent

In the 1950's Coffin and Manson independently found that plastic Strain-Life data could also be modelled using a power relationship:

$$\varepsilon_p = \varepsilon_f'\left(2N_f\right)^c \tag{2.2}$$

Where: ε_p is the plastic component of the cyclic strain amplitude

ε_f' is the regression intercept called the fatigue ductility coefficient

N_f is the number of cycles to failure

c is the regression slope called the fatigue ductility exponent

The Strain-Life Curve can be formed by summing the elastic and plastic components:

$$\varepsilon_t = \varepsilon_e + \varepsilon_p \tag{2.3}$$

$$\varepsilon_t = \frac{\sigma_f'}{E}\left(2N_f\right)^b + \varepsilon_f'\left(2N_f\right)^c \tag{2.4}$$

The influence of the elastic and plastic components on the strain-life curve is shown in Figure 2.3.

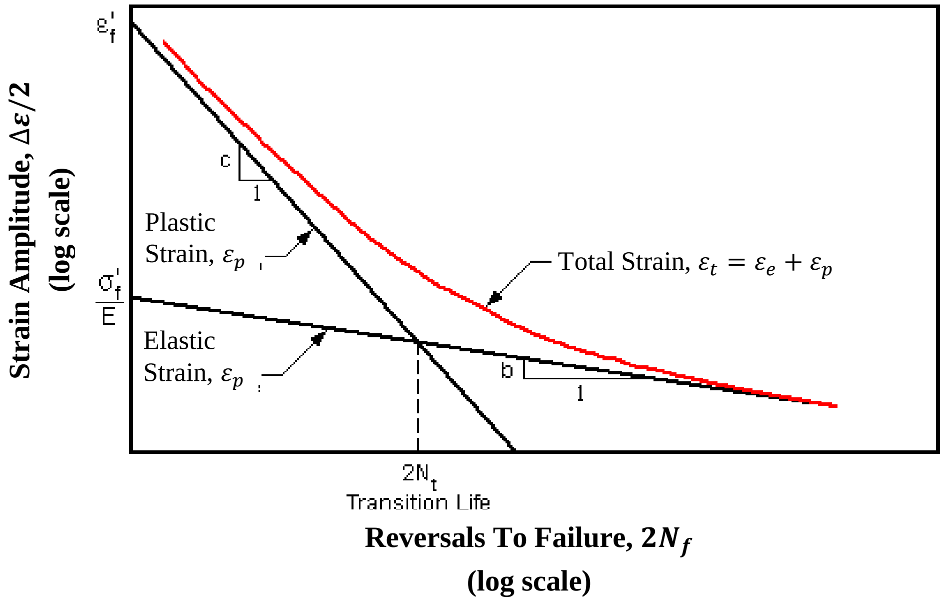


Figure 2.3: Typical strain-life curve

Sources: J. A. Bannantine (1990)

The transition life $2N_t$ represents the life at which the elastic and plastic strain ranges are equivalent. It can be expressed by the following:

$$2N_t = \left(\frac{\varepsilon_f' E}{\sigma_f'}\right)^{\frac{1}{b-c}} \tag{2.5}$$

As shown in Figure 2.3, elastic strains have a greater influence on fatigue lives above the transition life. Plastic strains have a greater influence below the transition life. Thus the transition life provides a convenient delineation between low-cycle and high-cycle fatigue regimes.

Note that at long fatigue lives the fatigue strength $\left(\frac{\sigma_{f'}}{E}\right)$ controls the fatigue performance and the Strain-Life and Stress-Life approaches give essentially the same results. For short fatigue lives, plastic strain is dominant and fatigue ductility $(\sigma_{f'})$ controls the fatigue performance. The optimum material is therefore one that has both high ductility and high strength. Unfortunately, there is usually a trade-off between these two properties and a compromise must be made for the expected load or strain conditions being considered.

2.4.2 Mean Stress Effects

Most basic *S-N* fatigue data collected in the laboratory is generated using a fully-reversed stress cycle. However, actual loading applications usually involve a mean stress on which the oscillatory stress is superimposed. For details on the parameters used to define a stress cycle with both alternating and mean stress, see the Stress-Analysis module.

The effect of mean stress on the strain-life curve is shown schematically in Figure 2.4. Mean stress primarily affects component life in the high-cycle regime, with compressive means extending life and tensile means reducing it. In the plastic regime, large cyclic plastic strains caused mean stress relaxation, and any mean stress tends towards zero.

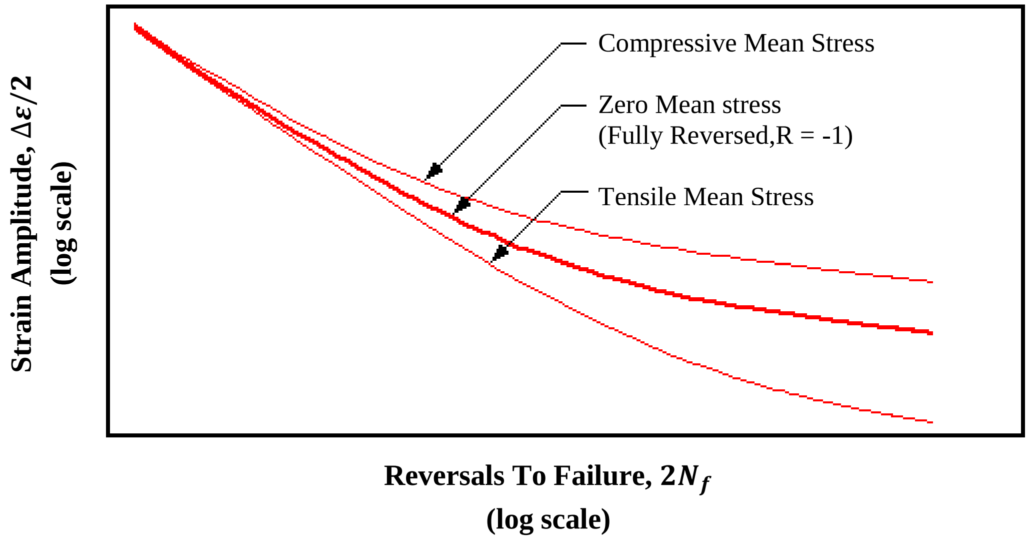


Figure 2.4: Effect of mean stress on Strain-Life curve

Sources: J. A. Bannantine (1990)

Morrow was the first to propose a modification to the baseline strain-life curve to account for the effect of mean stress. His approach was to alter the value of the fatigue strength coefficient in the elastic component of the stress-strain relationship:

$$\sigma_a = (\sigma_f' - \sigma_0)(2N_f)^b \tag{2.6}$$

where σ_0 Is the mean stress.

In this equation, tensile mean stresses are positive $(\sigma_0 > 0)$, and compressive means are negative $(\sigma_0 < 0)$.

In terms of the strain-life relationship, the Morrow Mean Stress Correction can be expressed by:

$$\varepsilon_t = \frac{\Delta\varepsilon}{2} = \frac{\sigma_f' - \sigma_0}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c \tag{2.6}$$

Where the mean stress σ_0 is positive for tensile stress and negative for compressive stress. Figure 2.5 illustrates the effect of a tensile mean stress in modifying the strain-life curve using the Morrow equation.

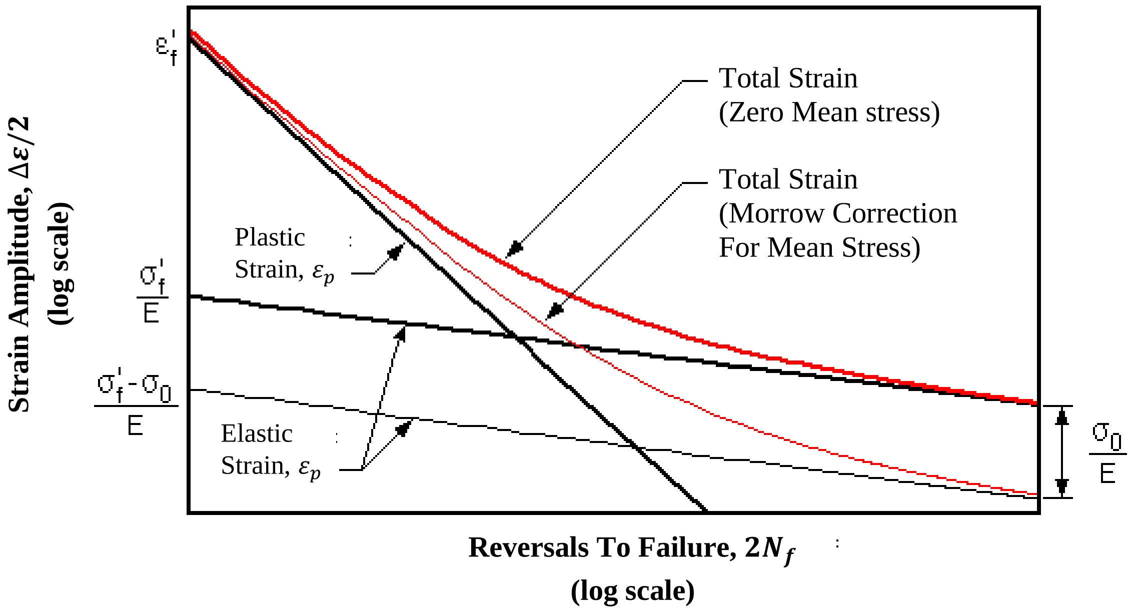


Figure 2.5: Effect of mean stress on strain-life curve (Morrow Correction)

Sources: J. A. Bannantine (1990)

A different method for modifying the strain-life curve to account for mean stress was proposed by Smith, Watson, and Topper. Their approach uses the Basquin relation relating the maximum stress σ_{max} of a fully-reversed cycle to fatigue life:

$$\sigma_{max} = \sigma_f'(2N_f)^b \tag{2.7}$$

Multiplying the strain-life equation by this term gives the Smith-Watson-Topper (SWT) Mean Stress Correction:

$$\sigma_{max}\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E}(2N_f)^{2b} + \sigma_f'\varepsilon_f'(2N_f)^{b+c} \tag{2.8}$$

The SWT equation predicts that no fatigue damage occurs when the maximum stress is zero or negative, which is not always true. Therefore the Morrow correction should be used for loading sequences that are predominantly compressive. In cases of predominantly tensile loading, the SWT approach is more conservative than the Morrow approach and is thus recommended.

2.4.3 Linear Damage Rule (Miner's Rule)

The Linear Damage Rule was first proposed by Palmgren in 1924 and was further developed by Miner in 1945. Today the method is commonly known as Miner's Rule.

The Linear Damage Rule is based on the concept of fatigue damage. A damage fraction, *D*, is defined as the fraction of life used up by an event or a series of events. Failure is predicted to occur when:

$$\sum_{i=1}^{I} D_i = X \tag{2.9}$$

Where:

i - Index of each set of applied load cycles at constant stress level S_i

D_i - Damage fraction accumulated during the load cycles of interval i at constant stress level S_i

X - Damage criterion (a constant).

The Linear Damage Rule states that the damage fraction at a given constant stress level $\boldsymbol{S_i}$ is equal to the number of applied cycle's *n* at stress level $\boldsymbol{S_i}$ divided by the fatigue life *N* at stress level $\boldsymbol{S_i}$. That is:

$$D_i = \frac{n_i}{N_i} \tag{2.10}$$

Where:

D_i - Damage fraction accumulated during the load cycles of interval *i* at constant stress level S_i

n_i - Number of applied load cycles at constant stress level S_i

N_i - Fatigue life at constant stress level S_i, obtained from the *S*-*N* curve.

For Miner's Rule, the damage criterion X is assumed to be equal to 1.0, and failure is predicted to occur when:

$$\sum_{i=1}^{I} \frac{n_i}{N_i} \geq 1 \tag{2.11}$$

Considerable test data has been generated in an attempt to verify Miner's Rule. Most test cases use a two-step load history. This involves testing at an initial stress level S_i for a certain number of cycles, and then the stress level is changed to a second level S_i until failure occurs. If, $S_1 > S_2$, it is called a high-low test, and if, $S_1 < S_2$, a low-high test. The results of Miner's original tests showed that the damage criterion X corresponding to failure ranged from 0.61 to 1.45. Other researchers have shown variations as large as 0.18 to 23.0, with most results tending to fall between 0.5 and 2.0. In most cases, the average value is close to Miner's proposed value of 1.0.

One problem with two-level step tests is that they do not accurately represent many service load histories. Most load histories do not follow any step arrangement and instead are made up of a random distribution of loads of various magnitudes. However, tests using random histories with several stress levels show good correlation with Miner's rule. Even so, for conservative estimates of the life of a structure an X value of less than 1.0 is usually used.

The Linear Damage Rule has two main shortcomings when it comes to describing observed material behaviour:

1. Load sequence effects are ignored. The theory predicts that the damage caused by a stress cycle is independent of where it occurs in the load history.

An example of this discrepancy was discussed earlier regarding high-low and low-high tests.

2. The rate of damage accumulation is independent of the stress level. This trend does not correspond to observed behaviour. At high strain amplitudes cracks will initiate in a few cycles, whereas at low strain amplitudes almost all the life is spent initiating a crack.

3. Despite these limitations, the Linear Damage Rule is still widely used. This is due both to its simplicity and the fact that more sophisticated methods do not always result in better predictions.

2.5 Linear Elastic Fracture Mechanics

The fatigue life of a component is made up of initiation and propagation stages. This is illustrated schematically in Figure 2.6. The size of the crack at the transition from initiation to propagation is usually unknown and often depends on the point of view of the analyst and the size of the component being analysed. For example, for a researcher equipped with microscopic equipment it may be on the order of a crystal imperfection, dislocation, or a 0.1 mm-crack, while to the inspector in the field it may be the smallest crack that is readily detectable with non-destructive inspection equipment. Nevertheless, the distinction between the initiation life and propagation life is important. At low strain amplitudes up to 90% of the life may be taken up with initiation, while at high amplitudes the majority of the fatigue life may be spent propagating a crack. Fracture mechanics approaches are used to estimate the propagation life. (J. A. Bannantine 1990)

Fracture mechanics approaches require that an initial crack size be known or assumed. For components with imperfections or defects an initial crack size may be known. Alternatively, for an estimate of the total fatigue life of a defect-free material, fracture mechanics approaches can be used to determine propagation. Strain-life approaches may then be used to determine initiation life, with the total life being the sum of these two estimates.

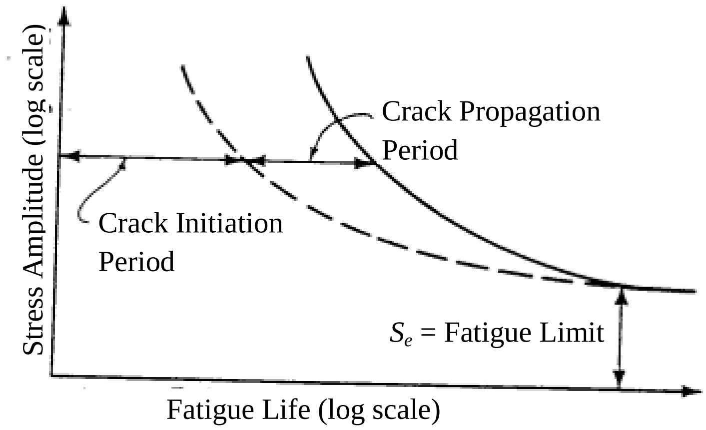


Figure 2.6: Initiation and propagation portions of fatigue life

Sources: J. A. Bannantine (1990)

Linear elastic fracture mechanics (LEFM) principles are used to relate the stress magnitude and distribution near the crack tip to:

• Remote stresses applied to the cracked component

• The crack size and shape

• The material properties of the cracked component

2.5.1 Historical Overview

In the 1920s, Griffith formulated the concept that a crack in a component will propagate if the total energy of the system is lowered with crack propagation. That is, if the change in elastic strain energy due to crack extension is larger than the energy required creating new crack surfaces, crack propagation will occur.

Griffith's theory was developed for brittle materials. In the 1940s, Irwin extended the theory for ductile materials. He postulated that the energy due to plastic deformation must be added to the surface energy associated with the creation of new crack surfaces. He recognized that for ductile materials, the surface energy term is often negligible compared to the energy associated with plastic deformation. Further, he defined a quantity, *G*, the strain energy release rate or "crack driving force," which is the total energy absorbed during cracking per unit increase in crack length and per unit thickness. (J. A. Bannantine 1990)

2.5.2 LEFM Assumptions

Linear elastic fracture mechanics (LEFM) is based on the application of the theory of elasticity to bodies containing cracks or defects. The assumptions used in elasticity are also inherent in the theory of LEFM: namely, small displacements and general linearity between stresses and strains. The general form of the LEFM equations is given in Equation below. As seen, a singularity exists such that as r, the distance from the crack tip, tends toward zero, the stresses go to infinity. Since materials plastically deform as the yield stress is exceeded, a plastic zone will form near the crack tip. The basis of LEFM remains valid, though, if this region of plasticity remains small in relation to the overall dimensions of the crack and cracked body.

$$\sigma_{ij} = \frac{K}{\sqrt{2\pi r}} f_{ij}(\theta) + \cdots \qquad (2.12)$$

2.6 Comparison of Method

In the previous topics, three different methods of fatigue analysis have been discussed. The purpose of this comparison method is to show each method have their own relative strengths and limitations

2.6.1 Stress-Life (*S*-*N*) Approach

The Strength for stress-life (*S*-*N*) approach method are:

1. The analysis and estimation of material constants necessary for this method for calculations to get a reasonable estimate of life.

2. This method works well for designs involving long life, constant amplitude histories.

The weaknesses for stress-life (*S*-*N*) approach method are:

1. The plastic strains, which are critical at short lives, are ignored. This limits the *S*-*N* approach to long life applications.

2. Since the true stress-strain relationship of the material at the root of notches is ignored, there is no way to model the mean residual stresses resulting from sequential loading effects. This means that the *S*-*N* approach has problems dealing with load histories that are not close to constant amplitude.

3. The *S*-*N* approach does not distinguish between initiation and propagation. Historically, this phenomenon was taken care of in one of the many empirical constants. This gives limited insights into the concept of damage.

The Typical Applications for stress-life (*S*-*N*) approach method is:

1. The *S*-*N* method can be used in almost any situation to get a rough estimate of life. This method works very well in situations involving constant amplitude loading and long fatigue lives. The best examples of application of this method are in the design of various machine elements, such as power transmission shafts, valve springs, and gears. The *S*-*N* approach may be used more intelligently when used in conjunction with the insights offered by the other methods.

2.6.2 Strain-Life (ε-*N*) Approach

The Strength for strain-life approach (ε-*N*) method are:

1. Plastic strain, the mechanism that leads to crack initiation, is accurately modelled. This method can be used in high strain or low cycle situations.

2. This method can model the residual mean stresses resulting from the sequence effect in load histories. This allows for more accurate accounting of cumulative damage under variable amplitude loading.

3. This method can be used in high temperature applications where fatigue-creep interaction is critical.

The weaknesses for strain-life approach (ε-N) method are:

1. This method involves a more complicated level of analysis. Some technique must be used to determine notch root strains, such as a Neuber analysis, a finite element analysis, or strain gage measurements. The life calculation involves numerical iterations which are best handled with computers.

2. The ε-N method only accounts for initiation life and cannot be used to predict propagation life.

The Typical Applications for strain-life approach (ε-N) method are:

1. Applications where plastic strains are significant. This may involve situations where load or stress levels are high. It may also involve materials with very low yield points, such as low strength steels and some stainless steels.

2. High temperature applications, such as gas turbine engine components, where fatigue-creep interaction is important.

3. Applications involving variable amplitude load histories, where the load sequence effect on residual mean stress is important.

4. Smaller components, where initiation life is the primary concern.

2.6.3 Fracture Mechanics LEFM Approach

The strength for fracture mechanics LEFM approach method are:

1. The LEFM approach is the only method that deals directly with the propagation of fatigue cracks. It also provides a method to characterize final failure due to fracture of the remaining cracked section.

2. Since crack length gives a physical measure of damage, crack growth rates can be incorporated with non-destructive inspection techniques to find the "safe life" of cracked components.

3. This method gives better insights into the actual mechanisms of fatigue that are important in research. It provides a method to deal with no propagating cracks and crack arrest behaviour due to overloads.

The weaknesses for fracture mechanics LEFM approach method are:

1. This method has problems when used to deal with crack initiation. It is very difficult to estimate the initial crack size in situations where there is no obvious crack like defect. In most cases the estimate of initial crack size has a major influence on the predicted fatigue life.

2. In certain situations the assumptions of linear elastic fracture mechanics are not valid and elastic-plastic fracture mechanics concepts must be used. This makes the analysis much more difficult. These situations include small crack growth in the plastic field near notches and crack growth at high loads.

3. This method requires an estimate of stress intensity factors which may be difficult to determine for complicated geometries.

Typical application of fracture mechanics LEFM approach method can be used:

1. To measure the crack growth from an assumed initial existing flaw. This analysis is used in conjunction with periodic in-service non-destructive testing (NDT) techniques to determine the safe life of damage-tolerant structures. In effect, the structure is designed to tolerate crack growth during a specified service period. This approach is used on large structures where propagation dominates fatigue life.

2.6.4 Conclusion for Comparison of Method

There is no general fatigue analysis method that is best for all design situations. Each technique has its own advantages and limitations and a selection must be based on material, load history, service environment, component and geometry, and consequences of component failure

2.6 Strain Signal Damage Editing

Fourier analysis is a method to analyse random data of frequency domain analysis. The STFT is performed by dividing the signal into small sequential or overlapping data frames. Then, Fast Fourier Transform (FFT) has been applied to each data frame. The output of successive STFT can provide a time–frequency representation of the signal. In order to accomplish this, the signal is truncated into short data frames by multiplying it by a window so that the modified signal is zero outside the data frame. In order to analyse the whole signal, the window is then translated into a time and reapplied to the signal. (Abdullah et al. 2009)

For the resolution, the length of the window used in this method is fixed on every time and frequency axis. Window size used will determine the obtained resolution, where small windows present good time resolution, and longer windows represent good frequency representations.

The STFT is composed by the local spectra of segments of the primary function, as viewed through a translating window of fixed shape. The local spectra at all points on the primary time axis constitute the STFT. Generally, the STFT is expressed as:

$$STFT(t,f) = \int_{-\infty}^{\infty} h(t)w(t-\tau)exp(-2\pi if\tau)d\tau \qquad (2.13)$$

Where h is the primary function, τ is the time, and f is the frequency. The position of the translating window w is determined by t, which has the same units as τ. If w is replaced with the value of 1, the STFT reduces to H, i.e. the Fourier transform of h. The modulus of the STFT is also known as the spectrogram. (Abdullah et al. 2009)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is discussed the ideas about the method how to implement this research. In this study, there are a few categories in this methodology process. The categories are material used, design of suspension coil spring, finite element analysis, fatigue assessment and validation analysis.

Selected chromium steel will be used as the main material of the static loading analysis and fatigue analysis. The design of the suspension coil spring will be modelled using SolidWorks® Software. MSC Patran Nastran Software was used to run the finite element analysis. It is called static loading finite element analysis to analyse the stress applied to the suspension coil spring due the weight of the car and passenger. There two type of fatigue assessment that is fatigue damage analysis using Design Life software. Another fatigue damage assessment is strain signal damage editing using GlyphWorks® software. Both software packages are from the same provider that is nCode Company. The validation analysis is analysis to compare between edited and original strain signal shows the same fatigue damage value or not and to verify which road profile has higher and lower fatigue damage value. Figure 3.1 is an overview about the overall steps during the research.

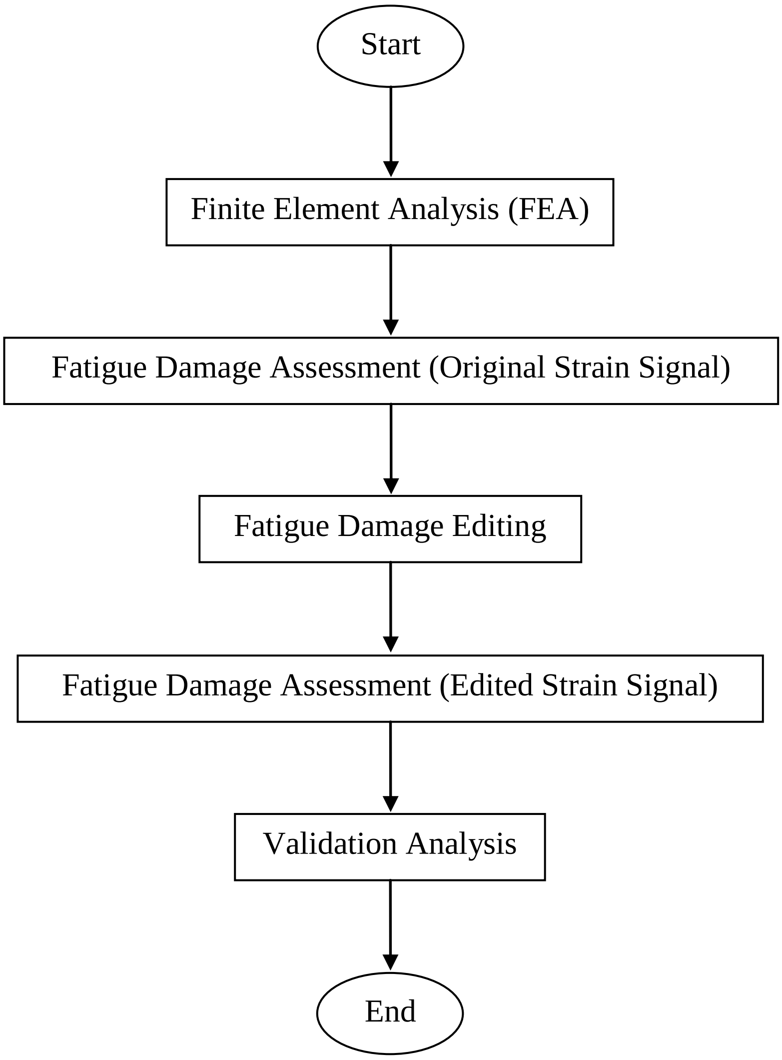


Figure 3.1: Flowchart of Research Methodology

3.2 Material

The main material for this project is chromium steel or we called it stainless steel. Stainless Steels are iron-base alloys that contain Chromium composite. Stainless steels usually contain less than 30% Cr and more than 50% Fe. Some other alloying elements added to improve specific characteristics of the alloy include nickel, molybdenum, copper, titanium, aluminium, silicon, niobium, and nitrogen. Carbon is usually present in amounts ranging from less than 0.03% to over 1.0% in certain martensitic grades. Corrosion resistance and mechanical properties are commonly the principal factors in selecting a grade of stainless steel for a given application. There are five groups of stainless steel that is martensitic, ferritic, austenitic, duplex and lastly precipitation-hardening stainless steel.

Table 3.1: Type of Stainless steel

Type	**Chromium (%)**	**Characteristics**
Martensitic	<18	Less resistant Corrosion
Ferritic	<30	Good ductility and formability
Austenitic	16-26	high temperature
Duplex	Dependent on heat treatment	Greater tensile and yield strength but poor toughness
Precipitation-hardening	Austenitic or martensitic	High strength by precipitation hardening of the martensitic structure.

3.3 Design Stage

In this study, the specimen was modelled using SolidWorks®. SolidWorks® Software is one of the latest software that can help produce engineering drawing in 3 dimensional (3D). SolidWorks® is a 3-D modelling tool. Unlike other 3-D modelling tools, SolidWorks® is not fully three dimensional. Other programs allow the user to easily draw in three dimensional spaces. In SolidWorks®, one draws in a plane and then extrudes solids from the plane. Planes are used to obtain position in three dimensional spaces. It is possible to draw in three dimensional space using SolidWorks®, but is very difficult. Therefore the best method of creating three dimensional objects is using planes. In real, industries, SolidWorks® is not widely use. Usually industries always use software use such as Catia® and also AutoCAD®. Table 3.2 show the dimension of the suspension coil spring and Figure 3.2 shows the flowchart of modelling the suspension coil spring using SolidWorks® Software.

Table 3.2: Dimension of suspension coil spring

Dimension	
Length	29 cm
Suspension Diameter	11 cm
Coil Diameter	1.1 cm
No. of turn	7

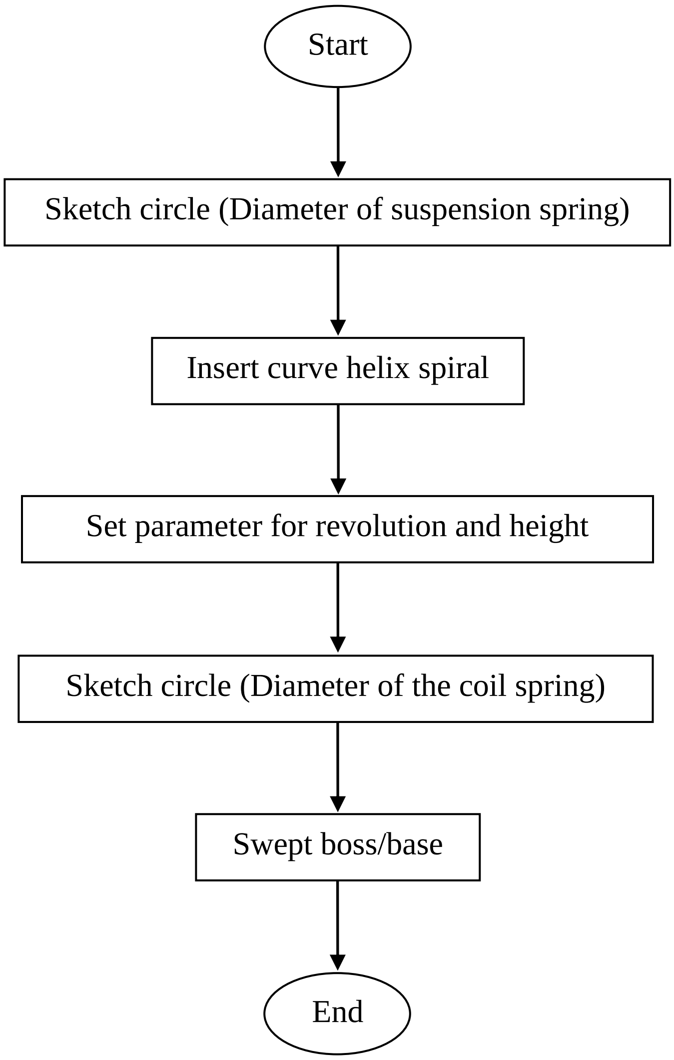


Figure 3.2: Flowchart of modelling the suspension coil spring

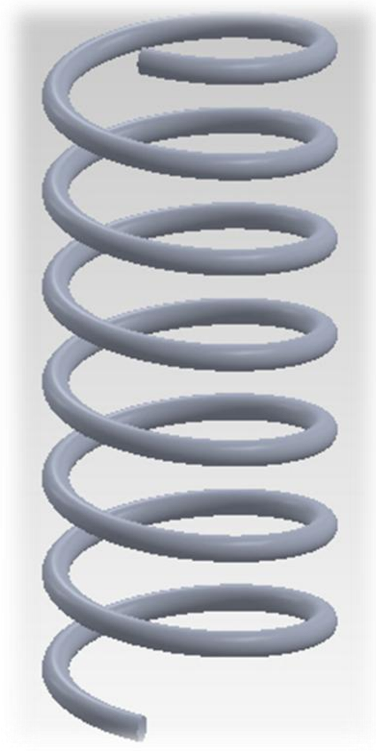


Figure 3.3: Model of coil spring

Figure 3.3 below show the model of suspension coil spring model by using SolidWorks® software. SolidWorks® software can provide hybrid model for industry which is combined with feature modelling and geometric modelling. Besides that, this software is capable to provide complex form such as aerofoil and manifold which is an industrial product and this software also can be used design for installation, component, sketch, sample, jig, equipment, sheet-iron and others.

3.4 Finite Element Analysis (Static Loading Analysis)

Finite element method has become a powerful tool to solve a lot of engineering problems such as fatigue. With the advances in computer technology and CAD system, complex problem can be modelled easily using software. It is very useful, more in prototyping stage. It helps a lot in reducing cost and saving times. FEM is a method for numerical solution of field problems. It divides structure in few elements. Then all the elements were dividing into nodes.

Some of the advantages of FEM is it can readily handle very complex geometry. In the real case of scenario, most of the structures are dealing with complex loading and when come to this kind problem, FEM is the best choices to solve the problem. Load can be applied as nodal loads that represent the point load or element load like pressure or inertial forces.

But when come to the process comparing result from the FEM with result from experimental the result not exactly the same but generally closed. It is because in FEM, it did not consider environmental situation. Figure 3.4 shows the common process flow of FEA using commercial software.

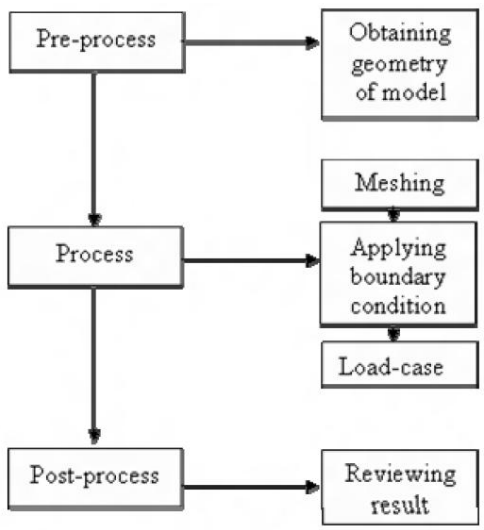


Figure 3.4: Typical FEA procedures by commercial software

Source: F. N. Ahmad Refengah et. Al (2009)

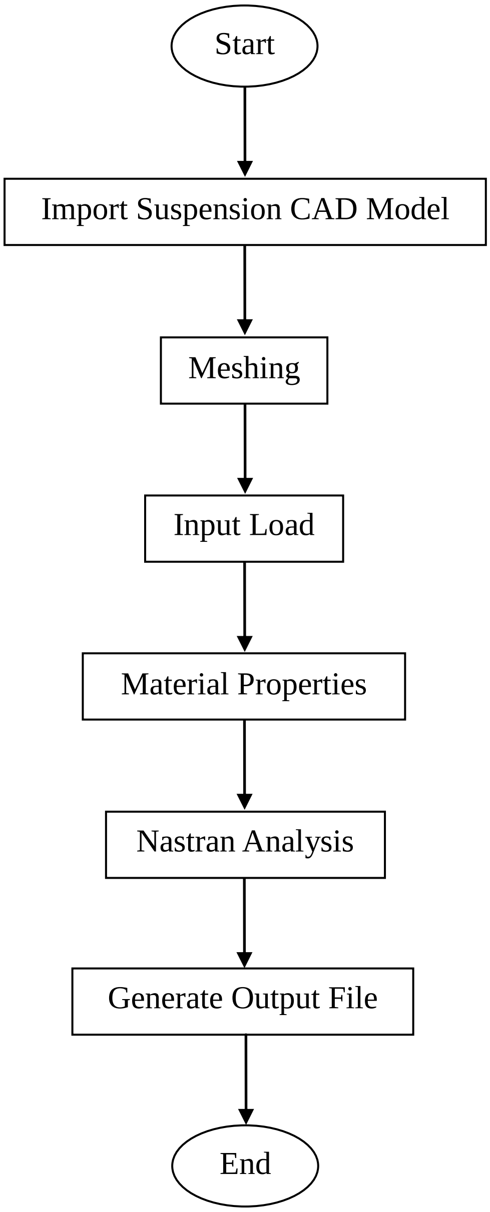


Figure 3.5: Flowchart of Finite Element Analysis

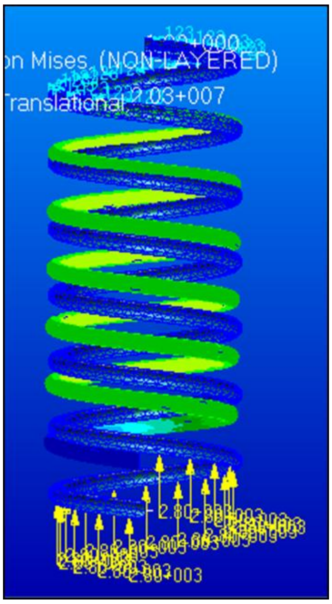


Figure 3.6: Result of FEA

Figure 3.5 shows the flowchart of finite element process for this project. The meshing for the finite element had been done using 0.5 global edge length, lower global edge length give more accuracy but take a lot of time to finish meshing the model. The static loading applied is 2800N. The load was applied at the lower side of suspension spring. The calculation for static loading is in APPENDIX C.

Table 3.3: Material properties input for FEA

SAE 5160	
Modulus Elasticity	270GPa
Density	7.8 g/cm^3
Poison ratio	0.28

The upper side of the suspension spring is fixed that means zero displacement. The material properties are manually input as in Table 3.3. After all process has been done, the post processing started by reviewing the result and also generate op2 type file for fatigue assessment.

3.5 Fatigue Assessment

Fatigue assessment is an analysis to determine the fatigue damage value. For this analysis nCode software had been used to run the analysis. There are two nCode software used that is DesignLife® and GlyphWorks®. Design life will display the fatigue damage value and also finite element display with colour contour.

Element model or op2 type file from finite element analysis was imported to the design life software with the variable amplitude loading or strain signal to simulate the actual road loading condition. The strain signal was captured from differences road profile that is highway road, university road and lastly public road.

Each road profile have differences strain signal due to differences stress applied to suspension coil spring, so it will display difference damage value and differences finite element display. The fatigue analysis also has another variable that is strain life model. As we know there are three strain life models that are Coffin Manson, Morrow and Smith Watson Topper. The *ε-N* analysis windows on DesignLife® will be set based on these three models.

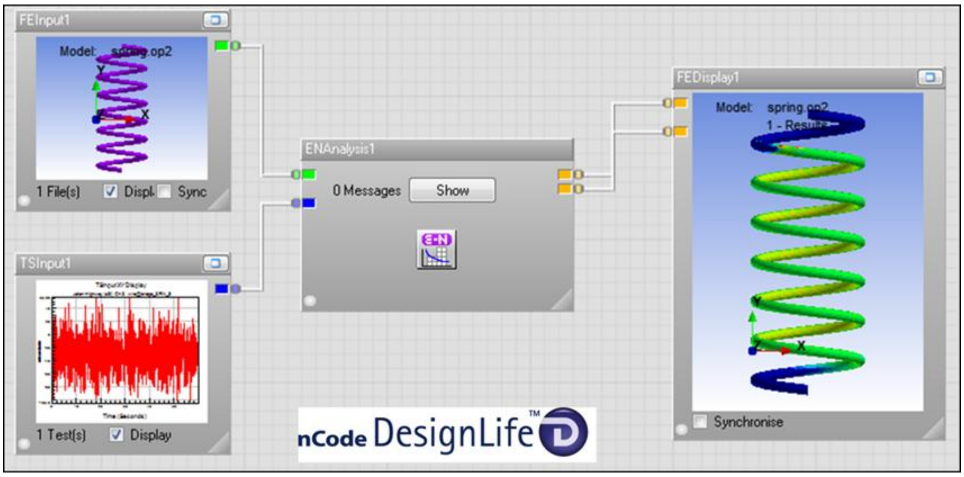


Figure 3.7: Fatigue damage assessment using DesignLife® software

Another fatigue damage assessment is fatigue damage editing, fatigue damage editing is process to remove noise that did not contribute to the fatigue damage, the strain signal damage editing will use GlyphWorks® software. This original strain signal will be edited using Short Time Fourier Transform (STFT) method. The reason behind this method is to remove cycles with low energy content. The cycles remain are higher energy content for further analysis. This cycle will concatenate together to produce new edit signal but shorter time length. The low energy cycle were removing from time domain signal based on low energy cycle location in time history. Cut off energy (COE) is the minimum energy values that will be remain in the time domain of the original signal. Energy that below COE will be removes from the time domain of the strain signal. Figure 3.8 shows the strain damage editing interface.

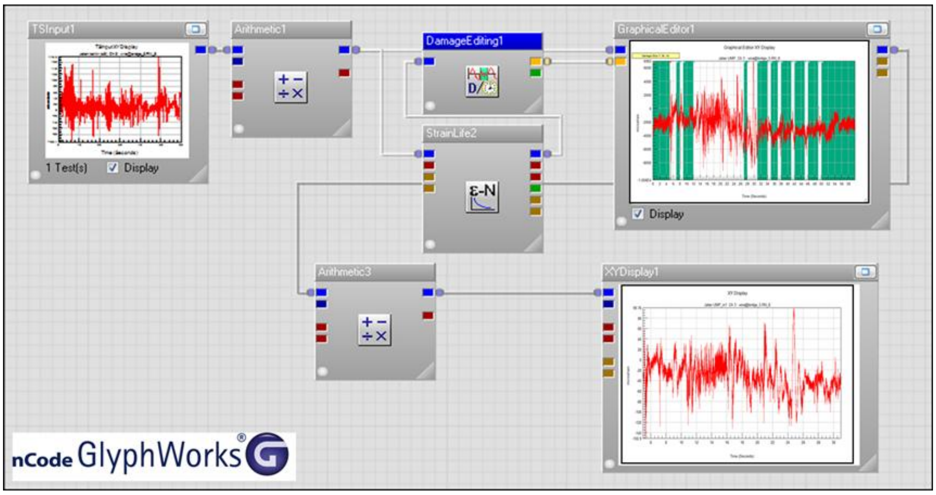


Figure 3.8: Fatigue damage editing using GlyphWorks®

The edited signal was imported as an input of time series for the fatigue damage assessment. The analysis between original and edited will be performed after obtained the result of fatigue damage.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will show the result that has been obtained through this project that is strain signal of the suspension and also the fatigue finite element analysis of the suspension spring. The data that have been obtained was analyzed base on finite element analysis using software DesignLife® and GlyphWorks®. The strain signal also will be analysis and edited using the Short-time Fourier Transform method. The signal that did not contribute to the fatigue life analysis will be removed. The main objective of the project is to study the fatigue signal obtain with the finite element of suspension spring and obtain the fatigue life by combine the fatigue signal with the finite element of the suspension spring. This will show how much cycle that the suspension spring can withstand.

4.2 Strain signal

Figure 4.1 show the original and edited strain signals and also strain signal that that been removed from for the highway road strain signal, respectively. Then Figure 4.2 show the original and edited strain signals and also strain signal that that been removed for university road strain signal, respectively. The last but not least Figure 4.3 show the original and edited strain signals and also strain signal that that been removed for the public road strain signal, respectively. Figure 4.1, 4.2 and 4.3 only shows the strain signal for Coffin Manson Method. So, for Morrow and SWT method are at the APPENDIX D, E and F. Short-time Fourier Transform (STFT) is a method use in damage editing process. The time domain fatigue signal was then edited for shortening the signal length with the removal of low amplitude cycles. These cycles were removed based on time domain analysis. The module for fatigue damage editing in the GlyphWorks® software package was applied to perform the time signal shortening. In this process all the strain range less than the gate value were removed, for which the gate value was calculated based on strain-life relationship.

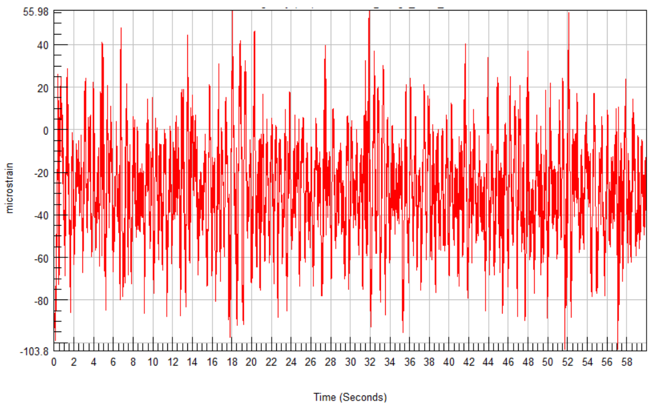
Table 4.1: Damage editing process result

Road	Total Length in Time, s			
	Original Signal	Coffin Manson	Morrow	SWT
Highway Road	60	54	52	45
University Road	60	31	29	27
Public Road	60	33	32	32

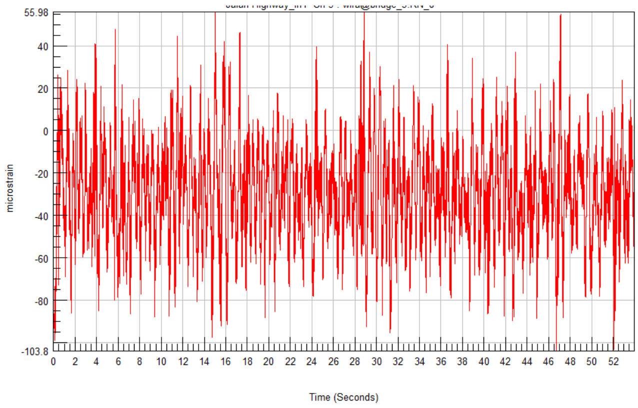
After damage editing process, there are changes to the total length in time. The total length in time for the highway road decrease from 60 seconds to 54 seconds for Coffin Manson model, 52 seconds for Morrow model and 45 seconds for SWT. This means the about 6 to 15 second of the original length in time is remove because it did not contribute to the fatigue damage result. The other hand, for the University Road, the total time length is decrease by 29 to 33 seconds from 60 second to 31 second for Coffin Manson, 29 seconds for Morrow and 27 seconds for SWT. For Public road, the time domain graph signal decrease from 60 seconds to 33 seconds for Coffin Manson, 32 seconds for Morrow and SWT. Its near 50 % of the signal is remove that did not change the value of fatigue damage, doesn't contribute for the fatigue damage result.

Table 4.1 shows the result from fatigue damage assessment processes. Based on the result, it shows that strain signal for public's road and university road have the higher amplitude of strain consist higher amplitude cycles compare to highway road that have low strain signal and low amplitude cycle. Higher amplitude strain signal means higher stress to the suspension spring. This will lead to damage of the suspension spring. The value of fatigue damage for suspension spring decrease when strain value increase. This is due to the university road has a lot of speed stopper, and the public's road such in road in village it is not well made, and it is also have hole on the roads. It will make the suspension displacement from maximum to minimum that will cause the suspension undergo high stress that will also lead to high strain. On the other hand, highway road is smooth. So, the signal that we got also smoother due to the displacement of suspension coil is small compared to public's road and university road.

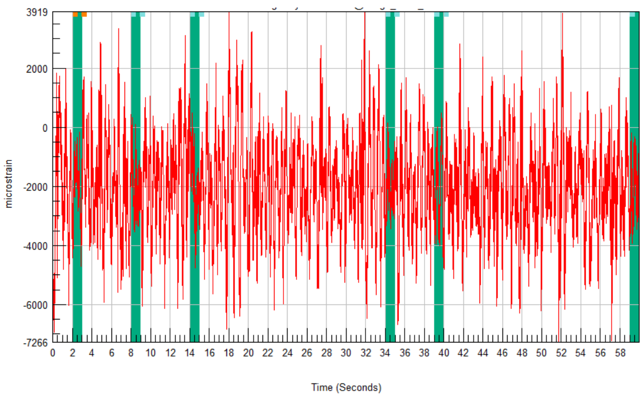
For further analysis, the value of edited strain signal will be used to calculate the fatigue life of the suspension spring. It shows that total fatigue damage of the edited strain signal for this three kind of road is the same as total fatigue damage of the original strain signal even though the total length of time shorten. The equivalence of the edited strain fatigue damage and the original fatigue damage prove that when remove low strain cycles amplitude, no damage losses and do not bring any effect to the fatigue life analysis of the suspension spring. From the result, removing the low cycle amplitude is more effective and still give the same value as the original signal and at the same time it reduce the fatigue test time.



(a)

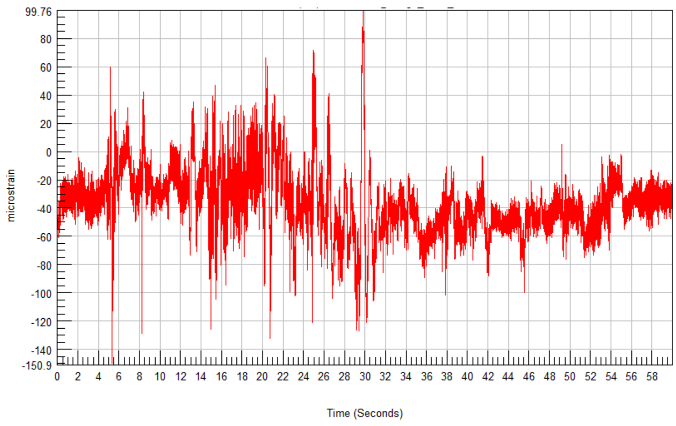


(b)

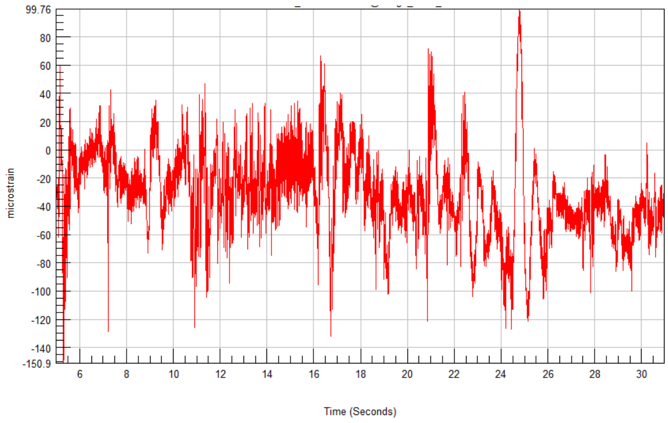


(c)

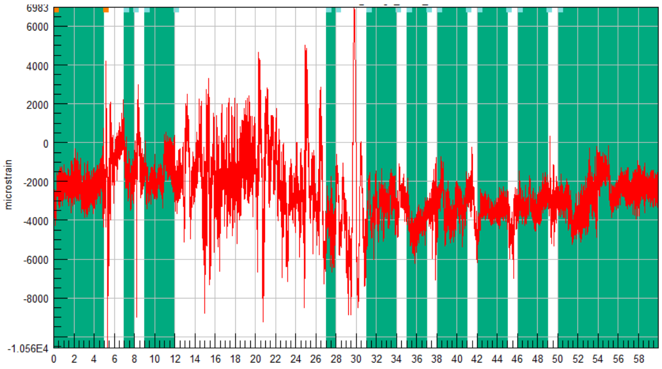
Figure 4.1: Strain signal of highway road using Coffin Manson: (a) Original strain signal, (b) Edited strain signal, (c) Signal remove



(a)

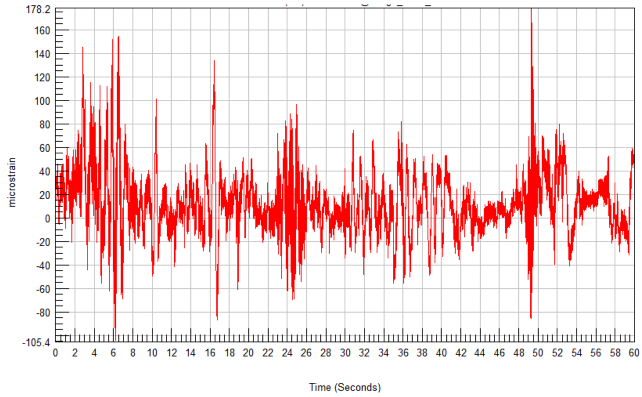


(b)

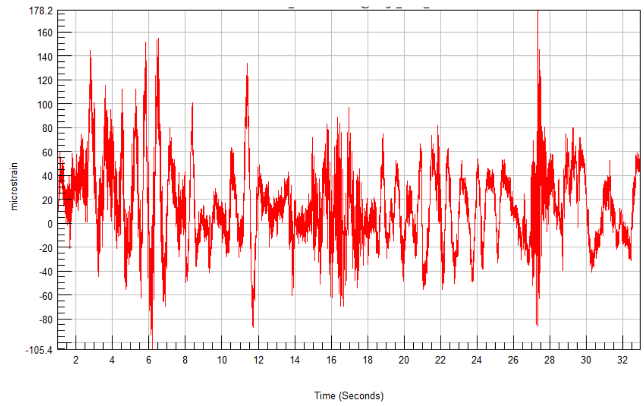


(c)

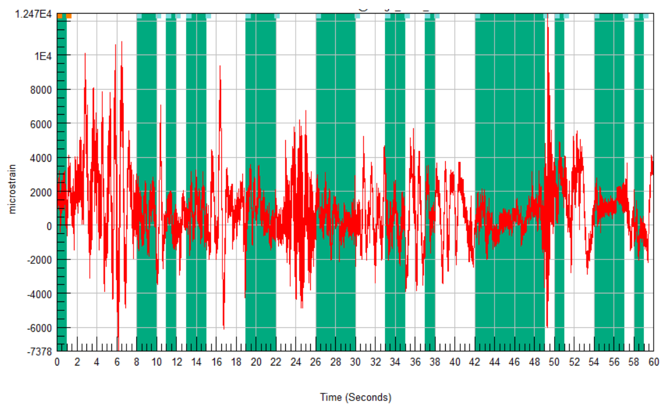
Figure 4.2: Strain signal of University Road using Coffin Manson: (a) Original strain signal, (b) Edited strain signal, (c) Signal remove



(a)



(b)



(c)

Figure 4.3: Strain signal of Public Road using Coffin Manson: (a) Original strain signal, (b) Edited strain signal, (c) Signal remove

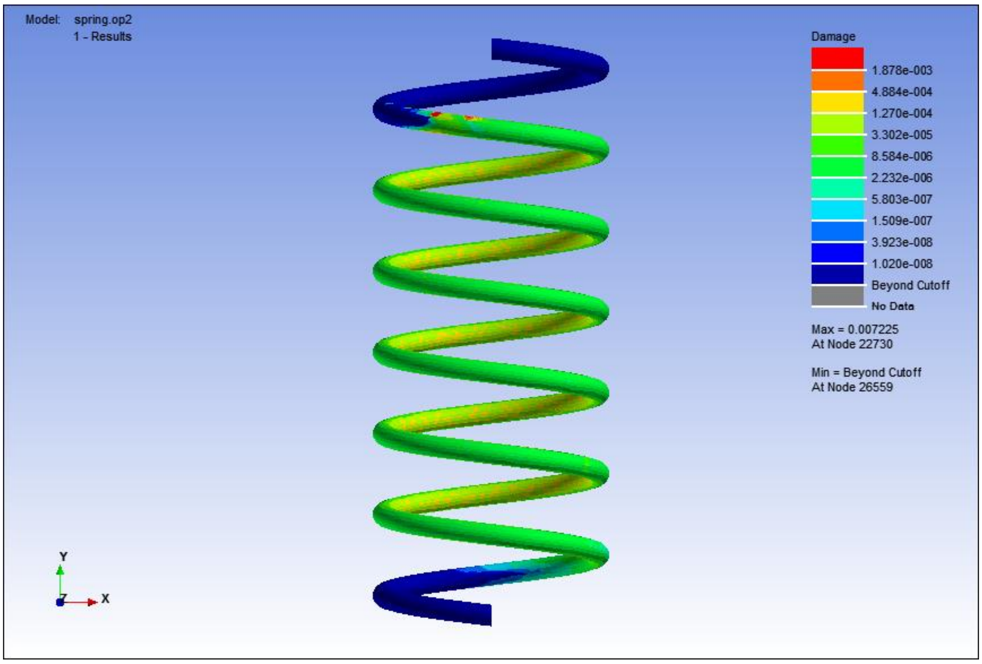
4.3 Finite Element Analysis (FEA)

For this project, finite element method is use to show the total fatigue damage result of the suspension spring. This method will be used to verify whether the total fatigue damage result of the original and edited strain signal is the same or not. The result is presented in form of colour contour. Different colour contour illustrates the different total fatigue damage value. The red colour contour illustrates the maximum fatigue damage value, and the grey colour contour illustrates the minimum fatigue damage value. Figure 4.4 shows the FEA results of the highway surface road. The lowest value of fatigue damage was found at range 0.00436 to 0.007225 by the highway surface road. Figure 4.5 shows the FEA results of the UMP surface road. The fatigue damage value at range 0.0118 to 0.01309 was found by the UMP surface road. Figure 4.6 shows the FEA results of the damage surface road. The highest value of fatigue damage was found at range 0.02581 to 0.2811 by the damage road surface. Table 4.2 shows the value of fatigue damage using original and edited strain signal for difference road profile. Figure 4.4, 4.5 and 4.6 only shows the result for Coffin Manson Method. So, for Morrow and SWT method are at the APPENDIX G, H and I.

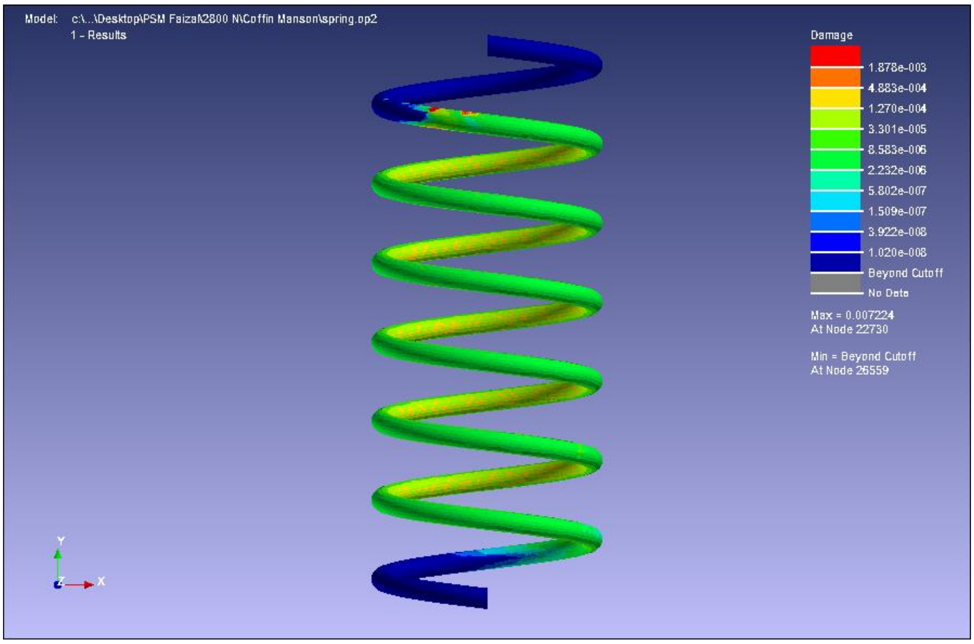
Table 4.2: Fatigue damage value

Road Profile	**Strain Signal**	**Fatigue Damage**		
		Coffin Manson	**Morrow**	**SWT**
Highway	Original	0.007225	0.005555	0.00436
	Edited	0.007224	0.005554	0.004359
University	Original	0.01309	0.00125	0.00118
	Edited	0.01308	0.00125	0.001179
Public	Original	0.02581	0.0266	0.02811
	Edited	0.02581	0.0266	0.0281

The strain signal of the highway, UMP and damage surface road were analyses using FEA to verify the total damage value between original strain signal and edited strain signal. By using the original and edited strain signal, as an input for the FEA analysis, the value of fatigue damage of original and edited strain signal should show the same results of fatigue damage. After FEA analysis, fatigue damage value for the highway surface road, UMP surface road and also damage surface road is equivalent between original strain signal and edited strain signal. Thus, the value obtained from the FEA analysis of the suspension spring agrees with the result of the fatigue life analysis.

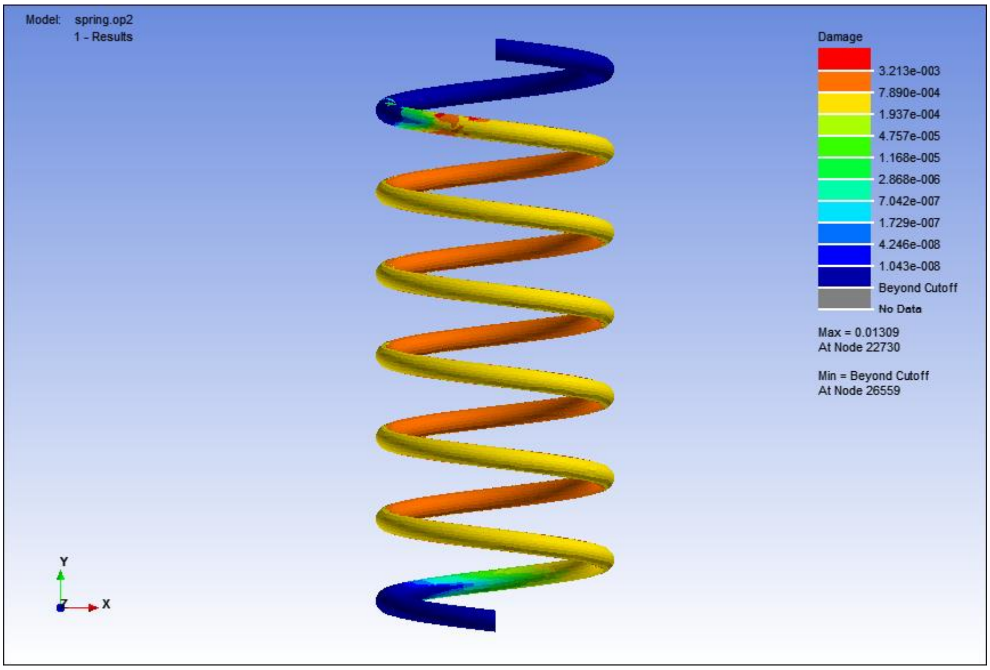


(a)

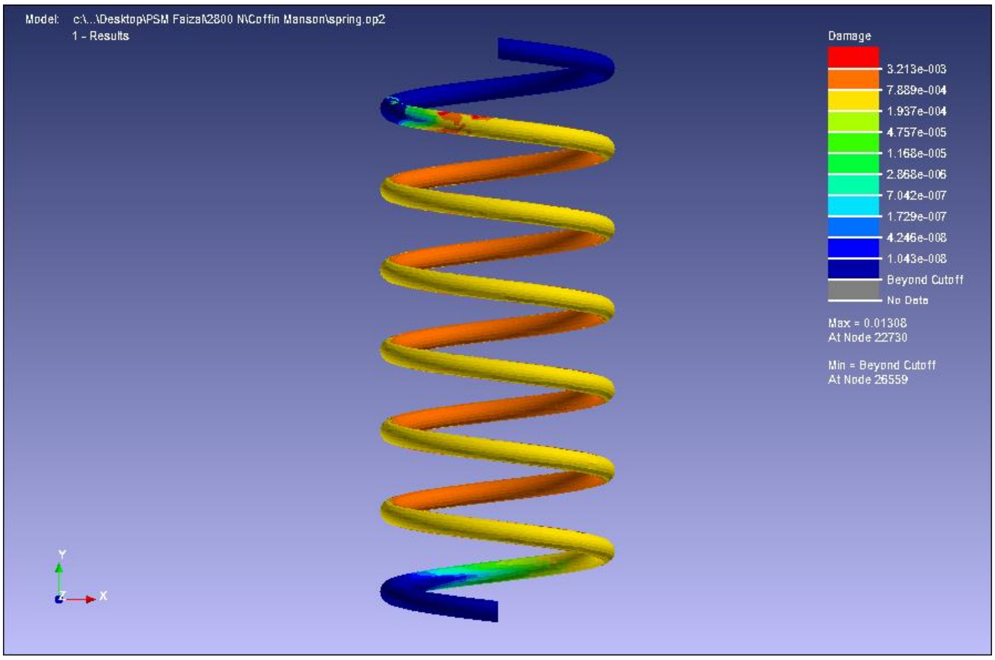


(b)

Figure 4.4: The colour contour for the fatigue tests using Coffin Manson method for highway road: (a) using original data as strain signal input, (b) using edited data as strain signal input

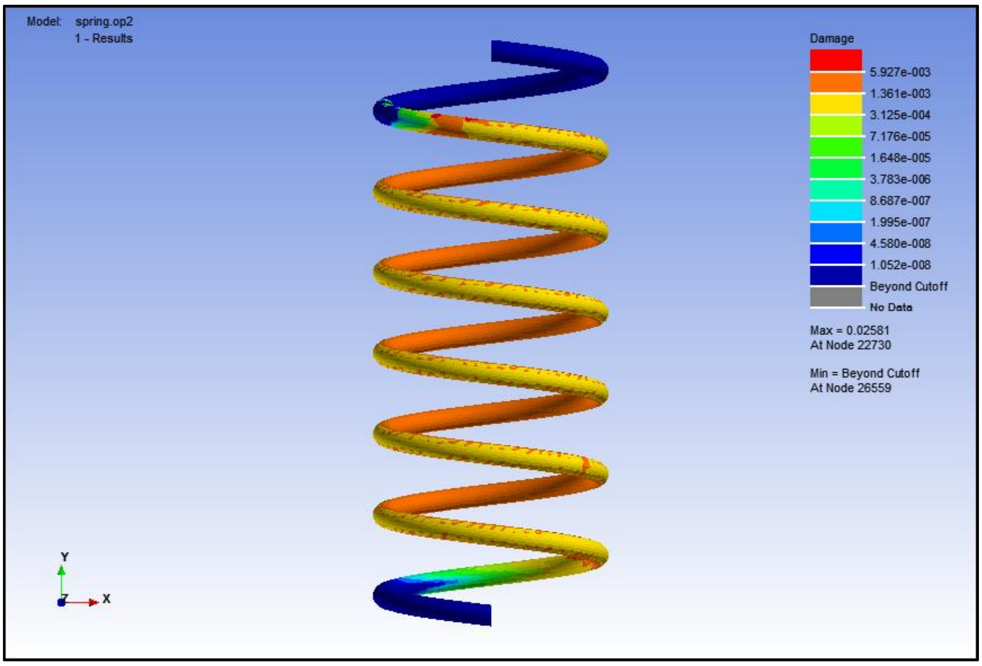


(a)

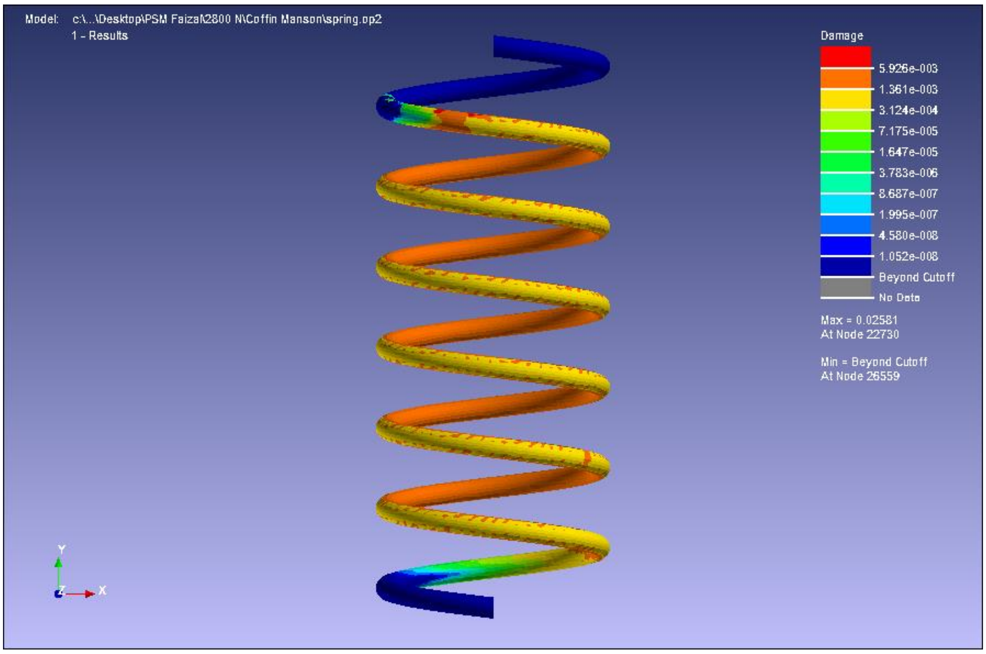


(b)

Figure 4.5: The colour contour for the fatigue tests using Coffin Manson method for university road: (a) using original data as strain signal input, (b) using edited data as strain signal input



(a)



(b)

Figure 4.6: The colour contour for the fatigue tests using Coffin Manson method for public road: (a) using original data as strain signal input, (b) using edited data as strain signal input

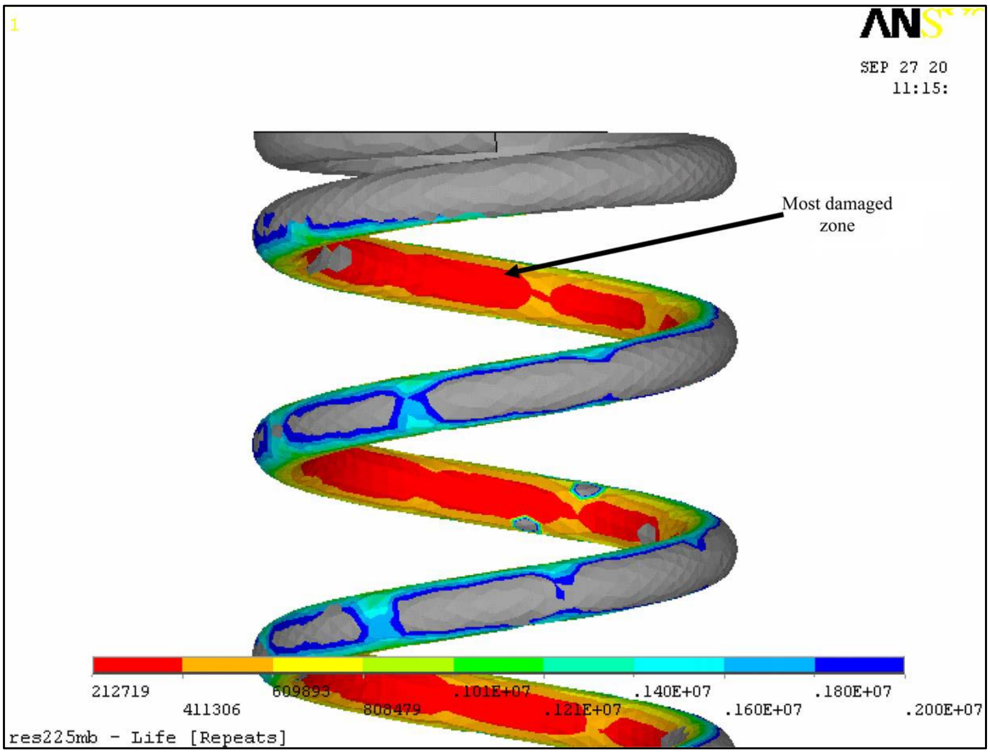


Figure 4.7: Fatigue numerical prediction using nCode and ANSYS of the fatigue crack initiation life.

Source: Vizcaya et al. (2006)

From the strain analysis results obtained, the inner of the suspension spring coil undergo high strain compared to the outer of the coil undergo lower strain. From Vizcaya et al. (2006) research in figure 4.7 shows the inner area of the spring coil undergo high strain because, because this area is the starting area for the crack growth to the outer side of spring coil. It is show by the red colour contour, it means at the area undergo the highest strain that will lead to fatigue failure. Since stress occur due to strain, so high value of strain lead to high value of stress. So the inner side of the coil will also undergo high stress.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study discussed the comparative study between the original strain signal and edited strain signal. The data obtained from the coil spring which was driven over three kind of road profile that were Highway Road, University Road and Public Road were used as the subject of this study. The edited signal obtained using the Short-Time Fourier series (STFT) method. The editing process was performed based on the Cut-Off Level (COL) parameter which remove the cycle that contain power spectrum lower than COL value. The strain signal analysed for both signals were performed using fatigue analysis software that is nCode GlyphWorks® and nCode DesignLife®. The finite element analysis is done by MSC fatigue software.

From the Finite Element Analysis (FEA), the edited strain signal show the same result as the original strain signal. The validation of the effectiveness of damage editing process was done by carried out the FEA. From the analysis, it was found and proved that using the edited signal do not affected the value of fatigue damage even the strain signal is shorter than original. There is no fatigue damage losses occur in this study. So, first objective of comparative study between original and edited is achieved. From the result also shows that public road profile has larger fatigue damage value followed by university road and highway road. So, the second objectives which are comparative study between different road profiles achieve. This shortened signal normally suitable approach to be used in laboratory scale fatigue test. Such test is very important in the fatigue design criteria for the purposes of accelerated fatigue testing. In Addition, it can also be used at the design stage of suspension system for approaching an optimised system right from the start. Finally, this method is suggested as an alternative in fatigue durability study, especially for the automotive engineering field.

5.2 Recommendation

During this study there is some problem when importing the CAD design of suspension spring into the MSC Patran Nastran software, real suspension system have variable diameter and pitch. When import the suspension coil spring design that have variable diameter and pitch, there is error on the design model view in Patran Nastran software. Figure 5.1 shows the problem that occurs by importing the design that consists of variable diameter and variable pitch.

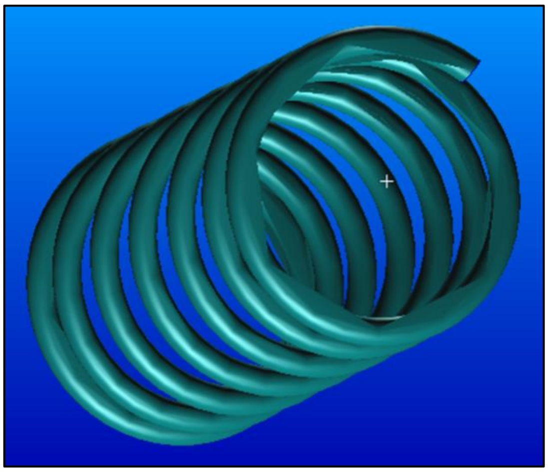


Figure 5.1: Problem when importing variable diameter and pitch CAD model into MSC Patran Nastran.

For the study, it was recommended to use other software such as Ansys®, Ansys® is from the same company that make GlyphWorks® and DesignLife®. Since it from the same company, it uses the same method that is drag and drop. So it's more user friendly compared MSC Patran Nastran. And also synchronization between fatigue software and Finite Element software is better to give better result. For the next study it is recommended to analysis the suspension spring with the cap of the suspension spring that will cover the top and bottom of the suspension spring. So, for the load can just applied one node at the centre of the cap it will be much easier. Compare to this study need to use node by node loading it takes a lot of time. In real cases, the suspension is applied with existence of cap that covers on top and bottom. The result of will be more accurate.

REFERENCES

This thesis is prepared based on the following references:

Christian Lalanne.(1999). Mechanical *Vibration & Shock*, *Fatigue Damage*, Volume IV, Taylor and Francis Books, Inc.

F. N. Ahmad Refngah, S. Abdullah, A Jalar, L. B., Chua. (2009). *Life Assessment of a Parabolic Spring Under Cyclic Strain Loading.*

Griffith A.A.(1921).*The phenomena Of Rupture And Flow In Solids.*

Irwin G.(1957). *Analysis of Stresses and Strain Near the End Of A Crack transversing A Plate.*

Julie A. Bannantine, Jess J. Comer, James L. Handrock. (1990).*Fundamentals Metal Fatigue Analysis*, Prentice Hall, pp. 40-70.

L. Del Llano-Vizcaya, C. Rubio-Gonza´lez, G. Mesmacque ,T. Cervantes-Herna´ndez. (2006). *Multiaxial fatigue and failure analysis of helical compression springs.*

Marcos Giovani Dropa de Bortoli, Raul Bosco Jr, Rinaldo Puff.(2010). *Fatigue Analysis of Helical Suspension Springs for Reciprocating Compressors*.

Miner, M.A.(1945).*Cumulative Damage In Fatigue.*

O.H. Basquin (1910), The *Exponential Law Of Endurance Test.*

Palmgrem, A.(1924). *Durability Of Ball Bearing.*

Richard C.Rise, Brian N.Leis, Drew V.Nelson, Henry D.Berns, Dan Lingenfelser, M.R. Mitchell.(1988). *Fatigue Design Handbook*, Society of Automotive Engineers, Inc.

S. Abdullah and J.C. Choi.(2006). *Using A Fatigue Data Editing Approach For Analysing Cycle Sequence Effects In Variable Amplitude Road Loadings.*

S. Abdullah, C.K.E. Nizwan and M.Z. Nuawi. (2009). *A Study of Fatigue Data Editing using the Short-Time Fourier Transform (STFT).*

S. Abdullah, N. Ismail, M.Z. Nuawi, C.K.E. Nizwan and M.F. Abdullah.(2011). *Comparative Study Of The Strain Signal And The Edited Strain Signal.*

S. Abdullah, T. E. Putra, M. Z. Nuawi, Z. M. Nopiah, A. Arifin And L. Abdullah.(2009).*Time-Frequency Localisation Analysis for Extracting Fatigue Damaging Events.*

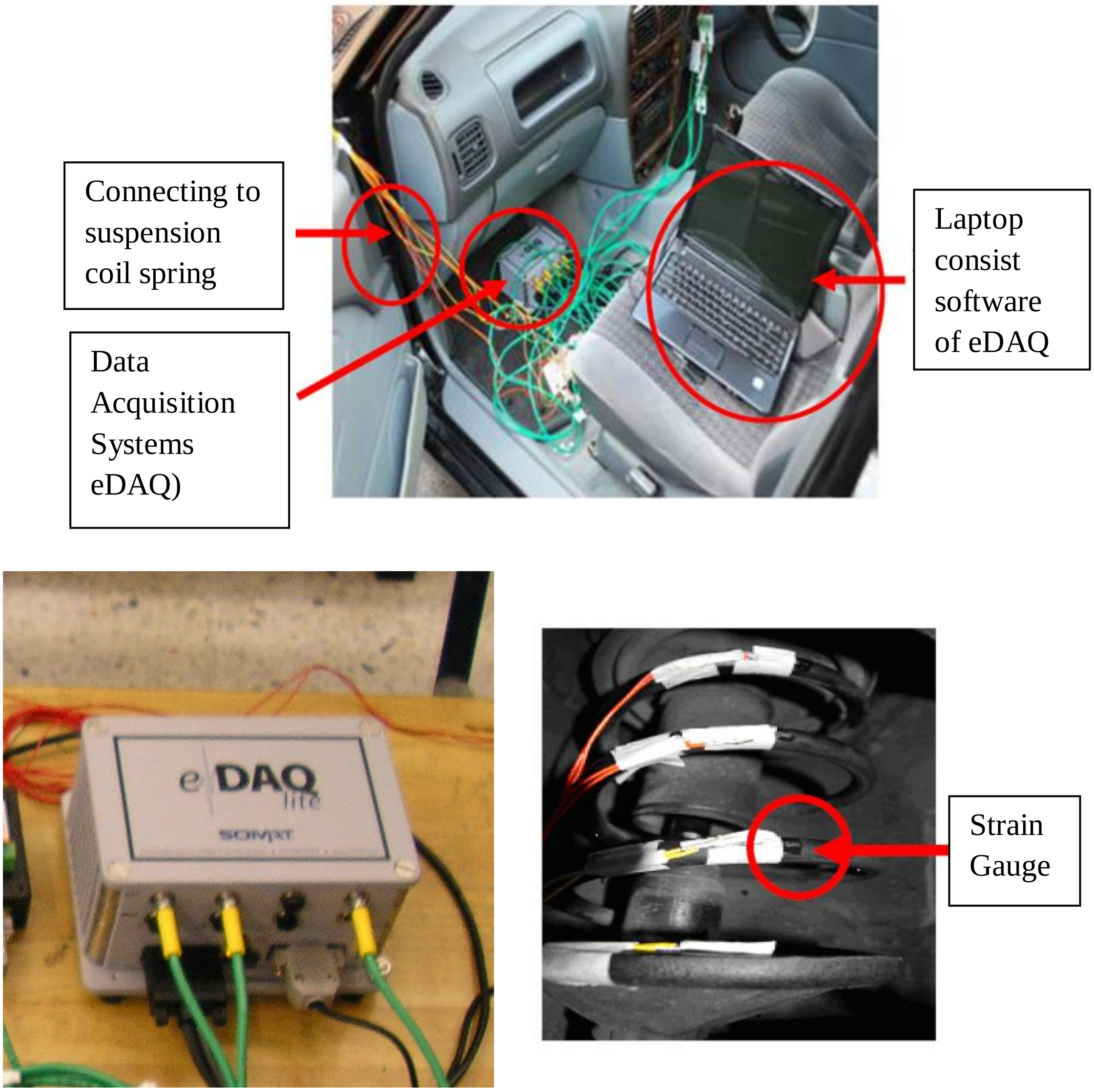
S. Abdullah, T. E. Putra, M. Z. Nuawi, Z. M. Nopiah, A. Arifin And L. Abdullah. (2010). *Extracting Fatigue Damage Features Using STFT and CWT.*

Seçil Ariduru.(2004). *Fatigue Life Calculation By Rainflow Cycle Counting Method.*

Z. Husin, M.M. Rahman, K. Kadirgama, M.M. Noor and Rosli A. Bakar.(2010). *Prediction Of Fatigue Life On Lower Suspension ArmSubjected To Variable Amplitude Loading*

APPENDIX A

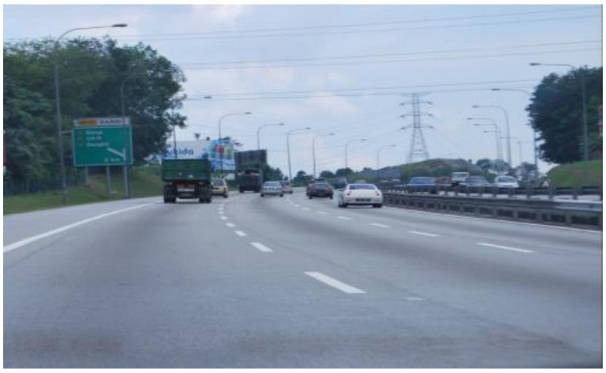
Figure 6.1 : Experiment Setup to capture strain signal from suspension Coil spring



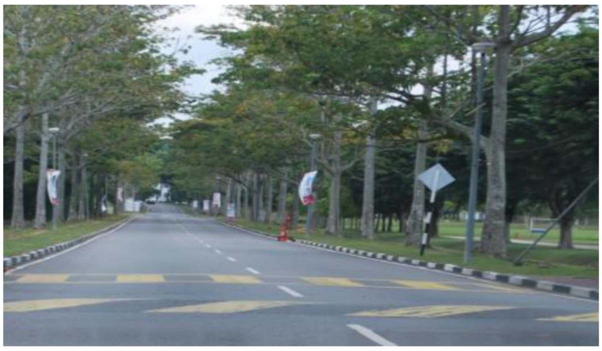
Data acquisition system as in SoMat eDAQ is a system used to observe the fatigue strain data which is captured by strain gauges. The system operates in conjunction with a laptop computer that the captured fatigue strain data will be displayed in the laptop computer in the time domain graph. Figure 6.1 shows the arrangement of the road system during the test.

APPENDIX B

Figure 6.2 : The Road profile with speed of the test car



(a)



(b)

(c)

APPENDIX C

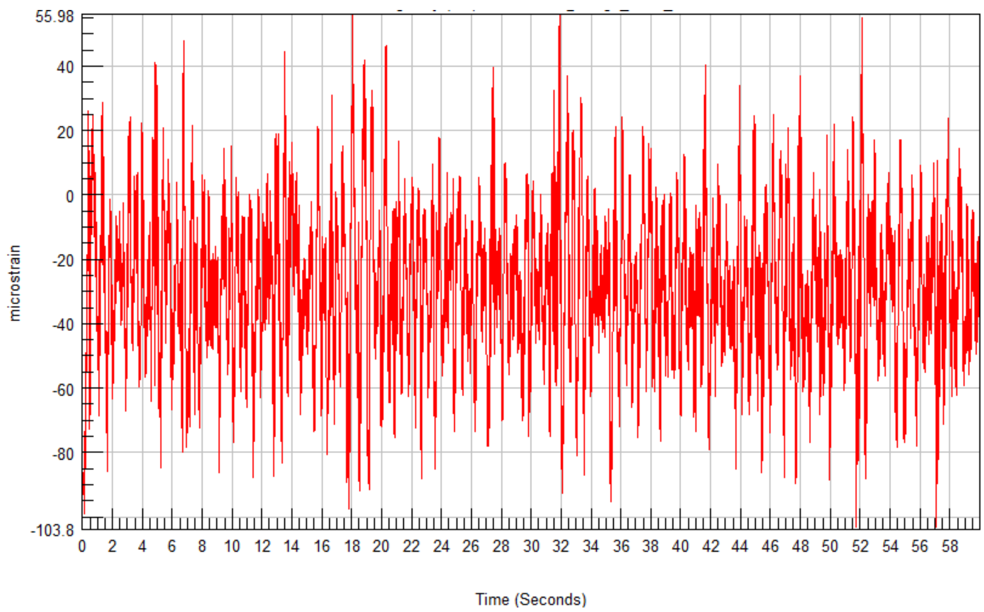
Table 6.1: Static loading calculation

Parameter	Value
Weight of car	980 *kg*
Weight of passenger	162 *kg*
Number Of Spring	4

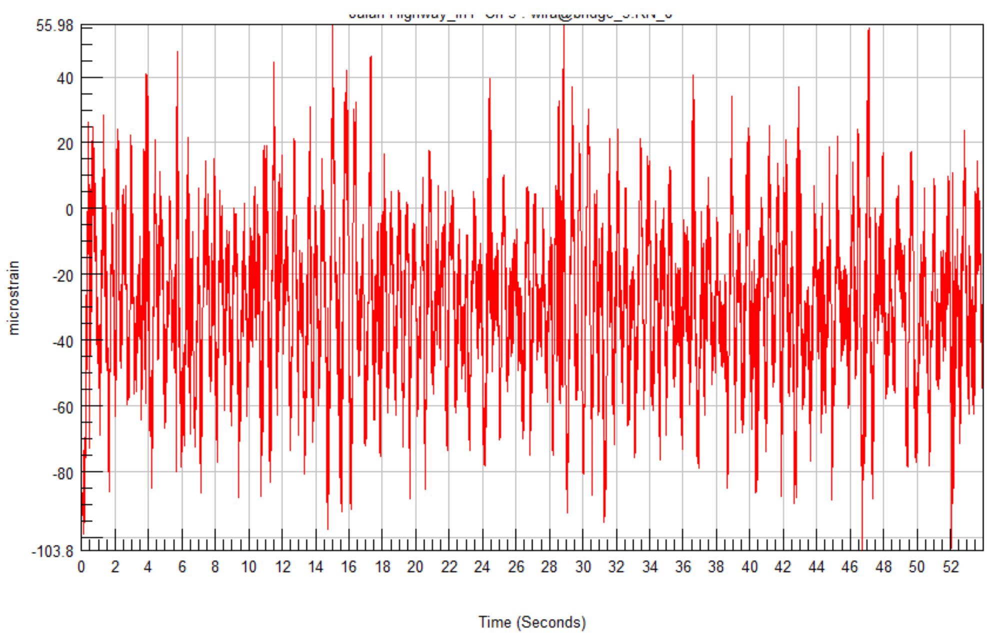
$$\frac{980kg + 162kg}{4\ spring} \times 9.81\frac{N}{kg} = \mathbf{2800N/spring}$$

APPENDIX D

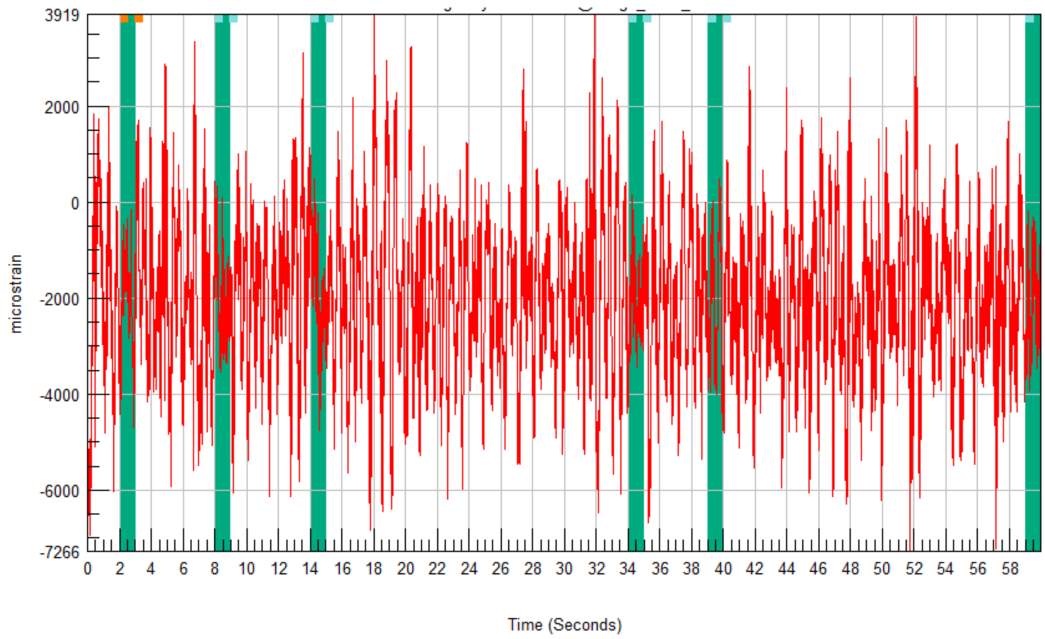
Figure 6.3: Strain signal of Highway Road using Coffin Manson:
(a) Original strain signal, (b) Edited strain signal, (c) Signal remove



(a)



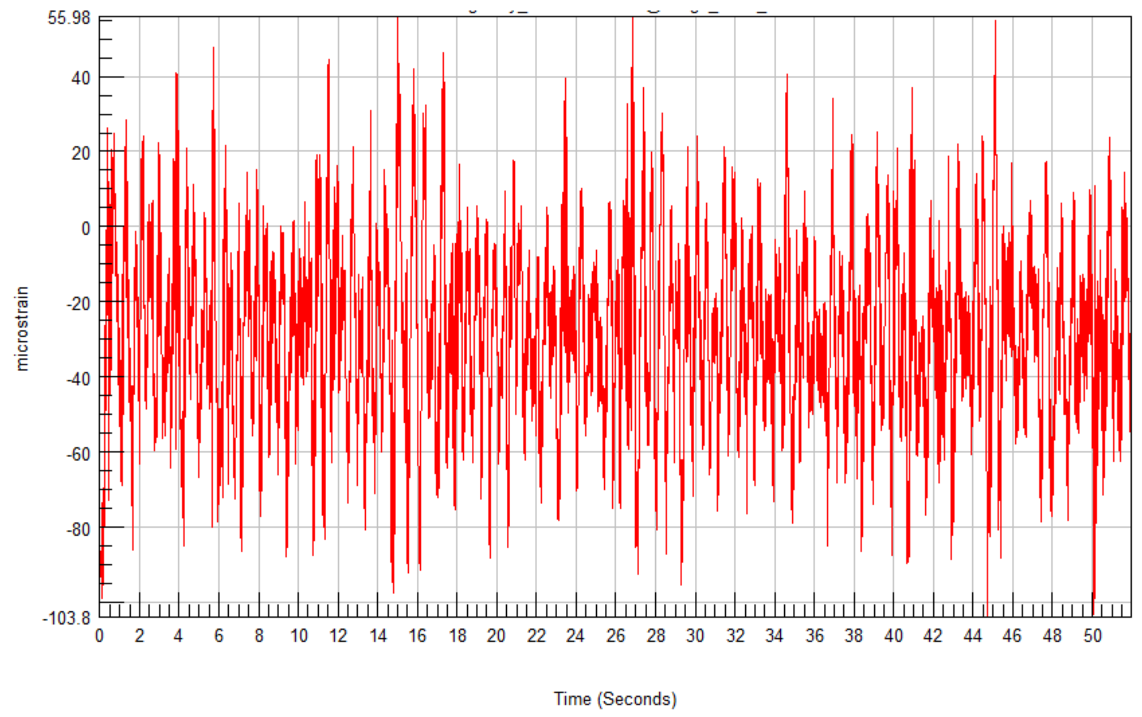
(b)



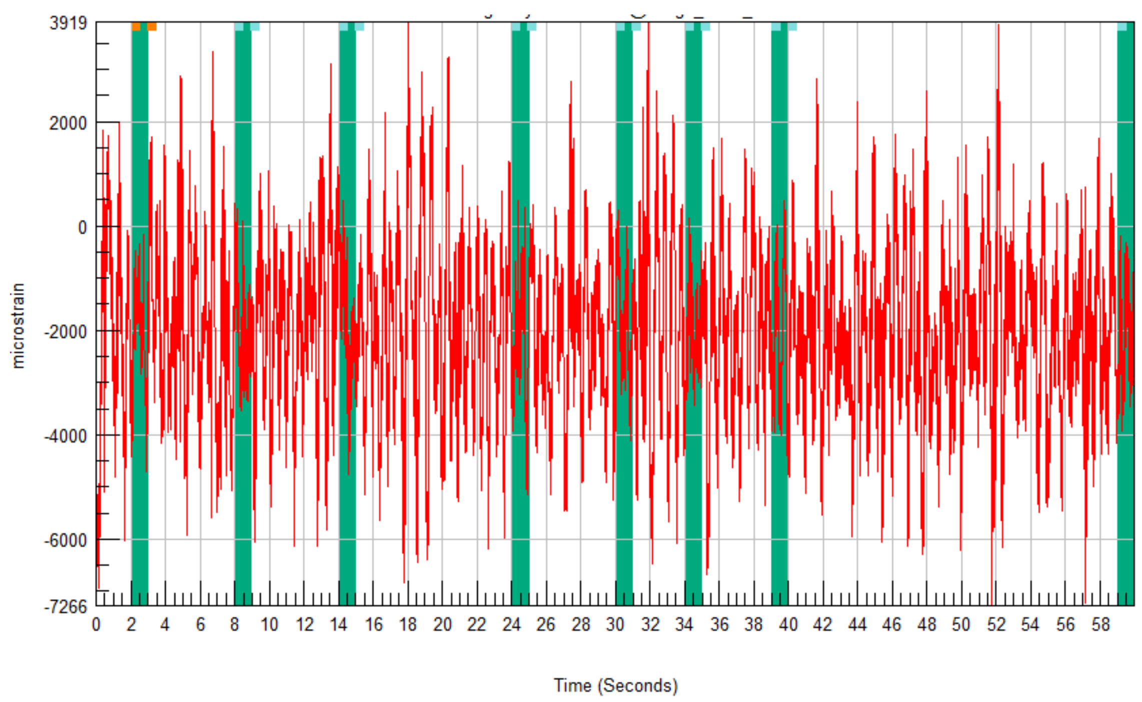
3919
2000
0
-2000
-4000
-6000
-7266
microstrain
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58
Time (Seconds)

(c)

Figure 6.4: Strain signal of Highway Road using Morrow:
(a) Edited strain signal and (b) Signal remove

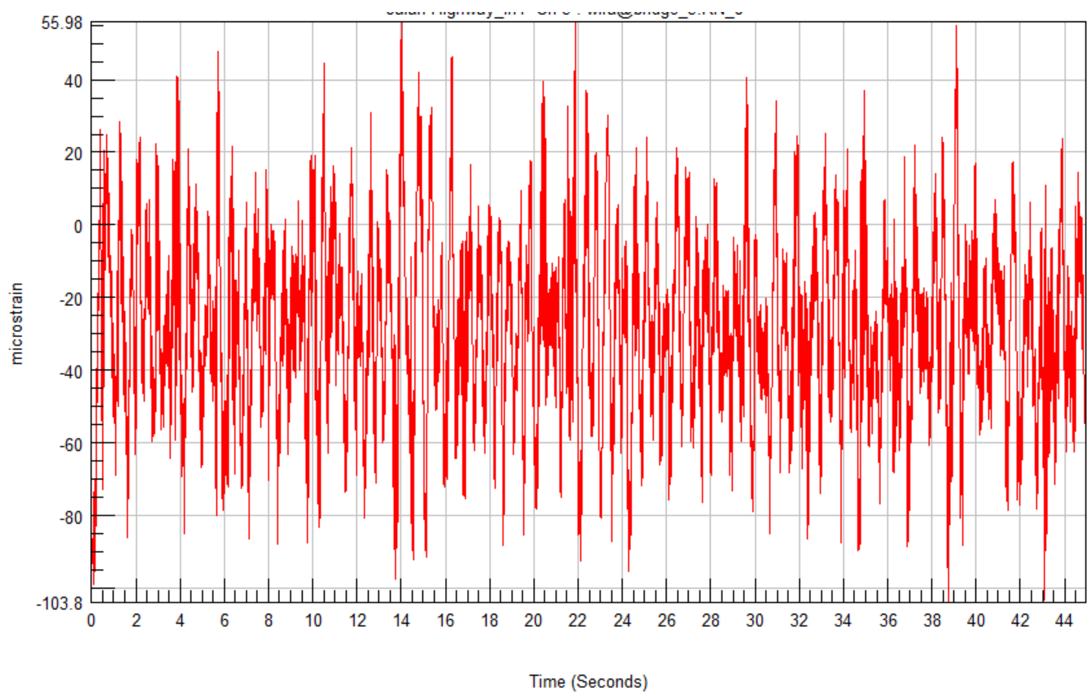


(a)

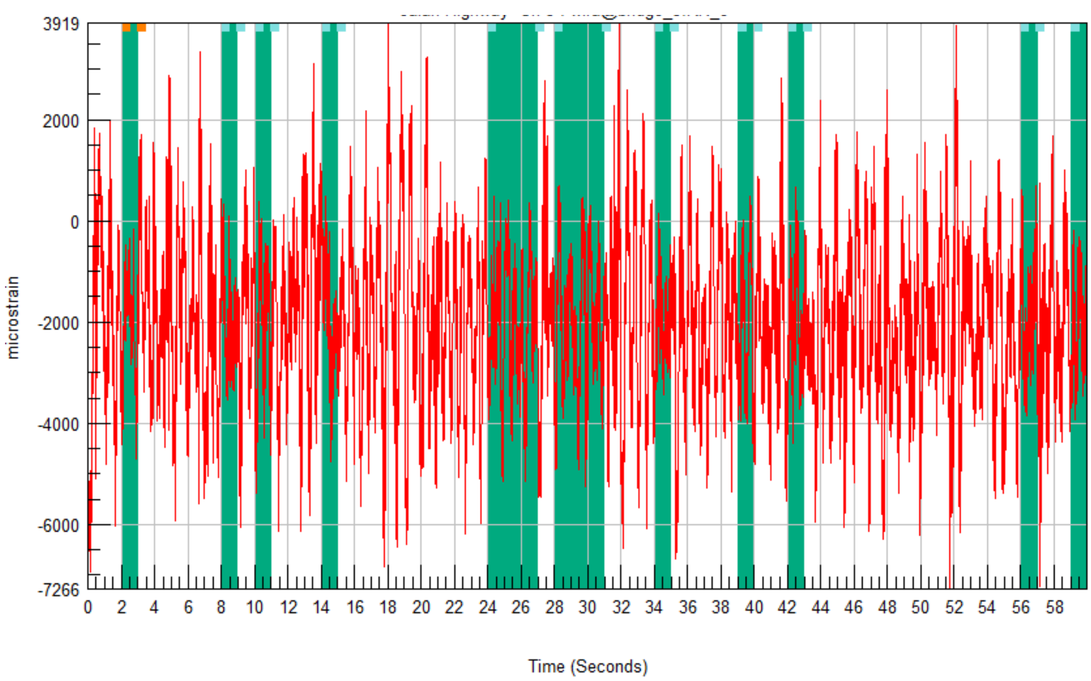


(b)

Figure 6.5: Strain signal of Highway Road using SWT:
(a) Edited strain signal and (b) Signal remove



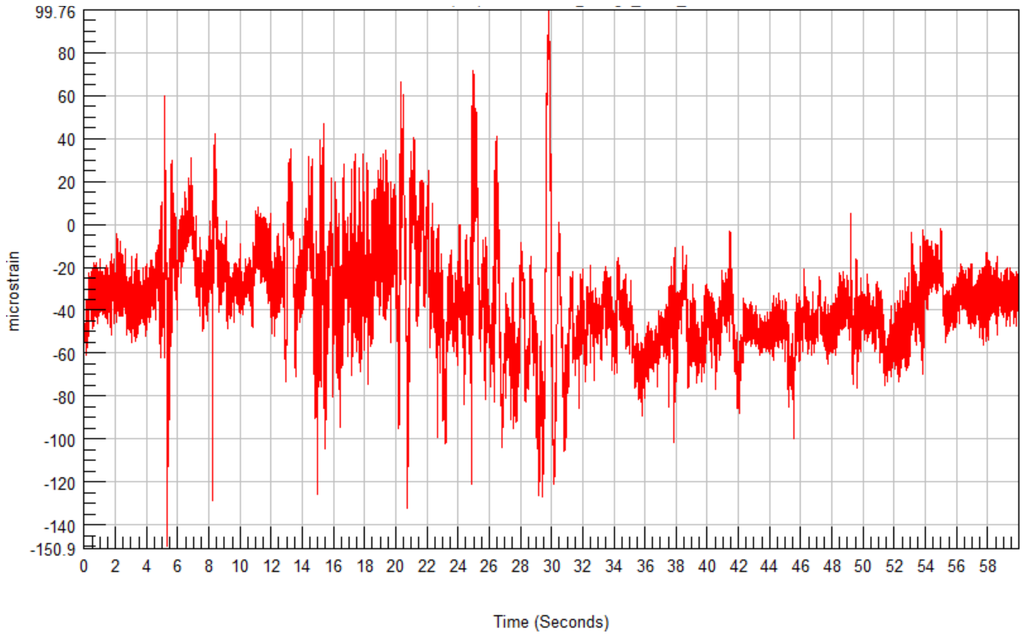
(a)



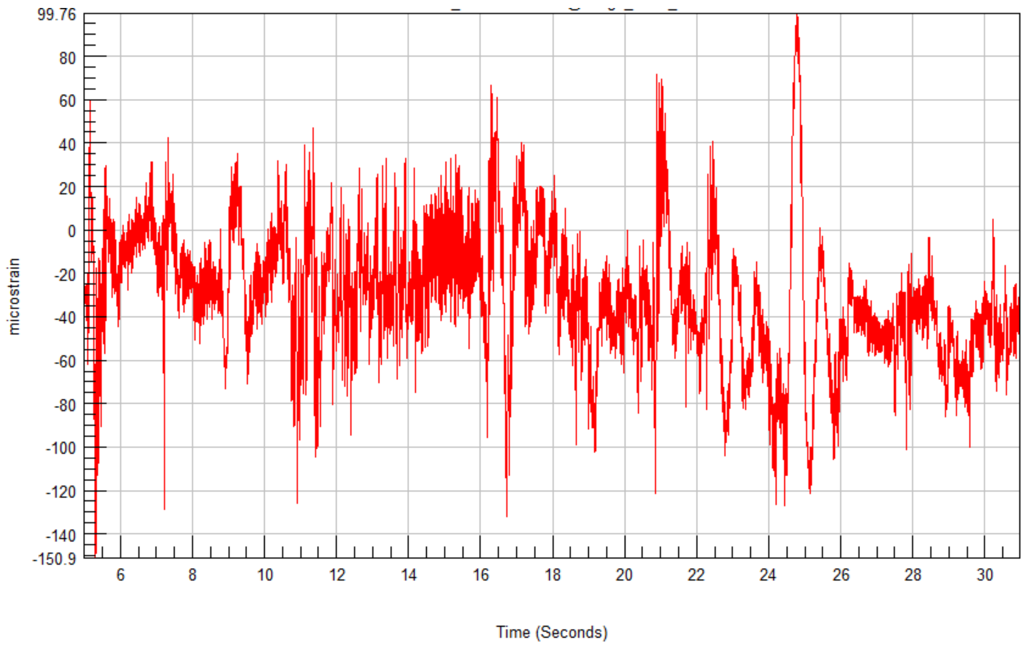
(b)

APPENDIX E

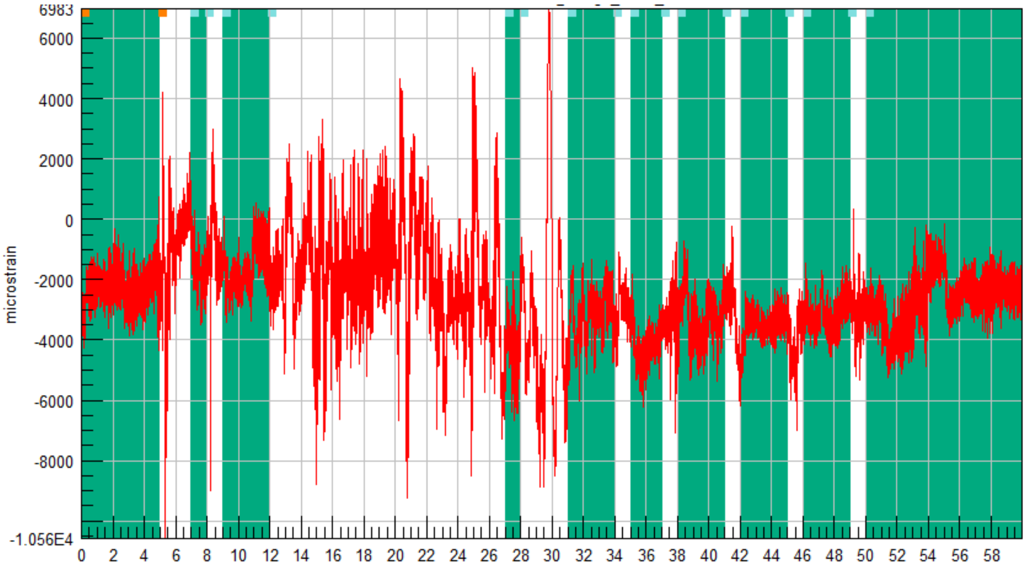
Figure 6.6: Strain signal of University Road using Coffin Manson: (a) Original strain signal, (b) Edited strain signal, (c) Signal remove



(a)

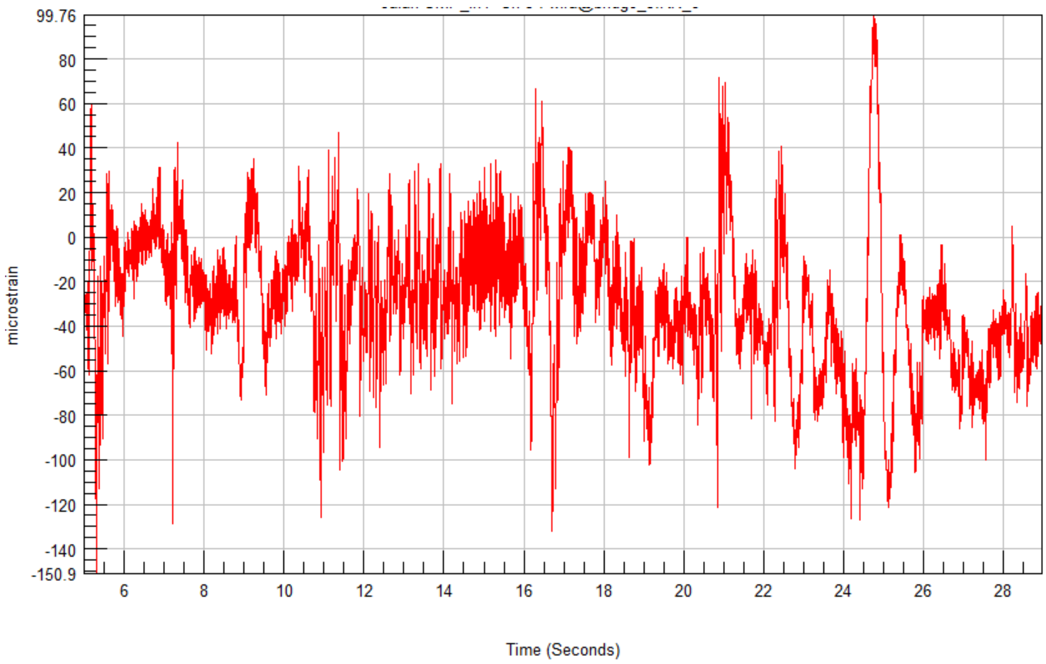


(b)

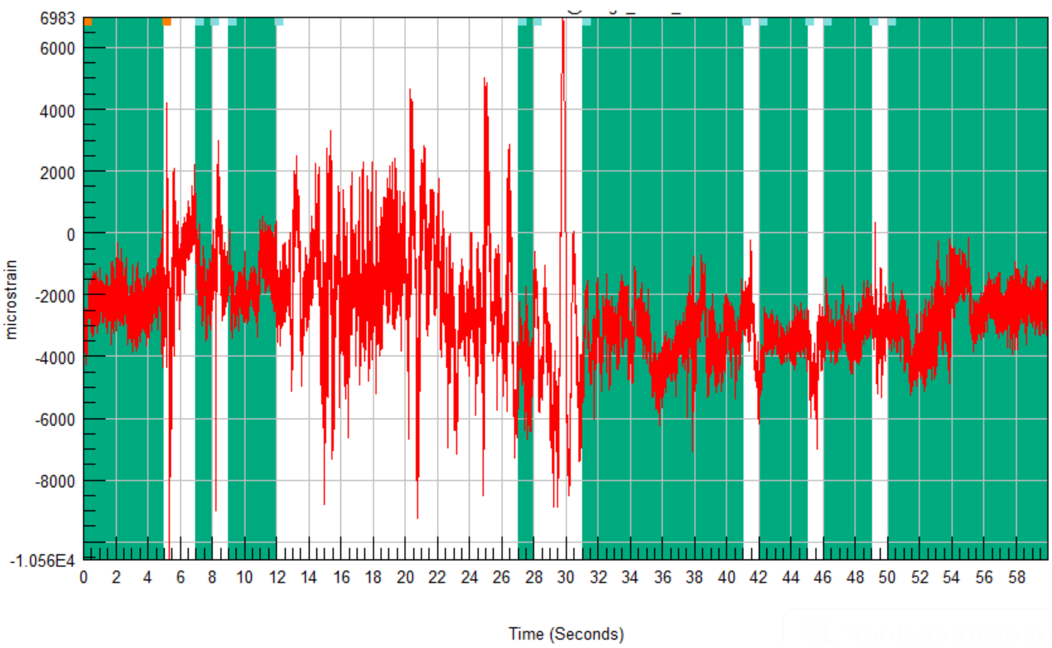

6983
6000
4000
2000
0
-2000
-4000
-6000
-8000
-1.056E4
microstrain
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58

(c)

Figure 6.7: Strain signal of University Road using Morrow:
(a) Edited strain signal and (b) Signal remove

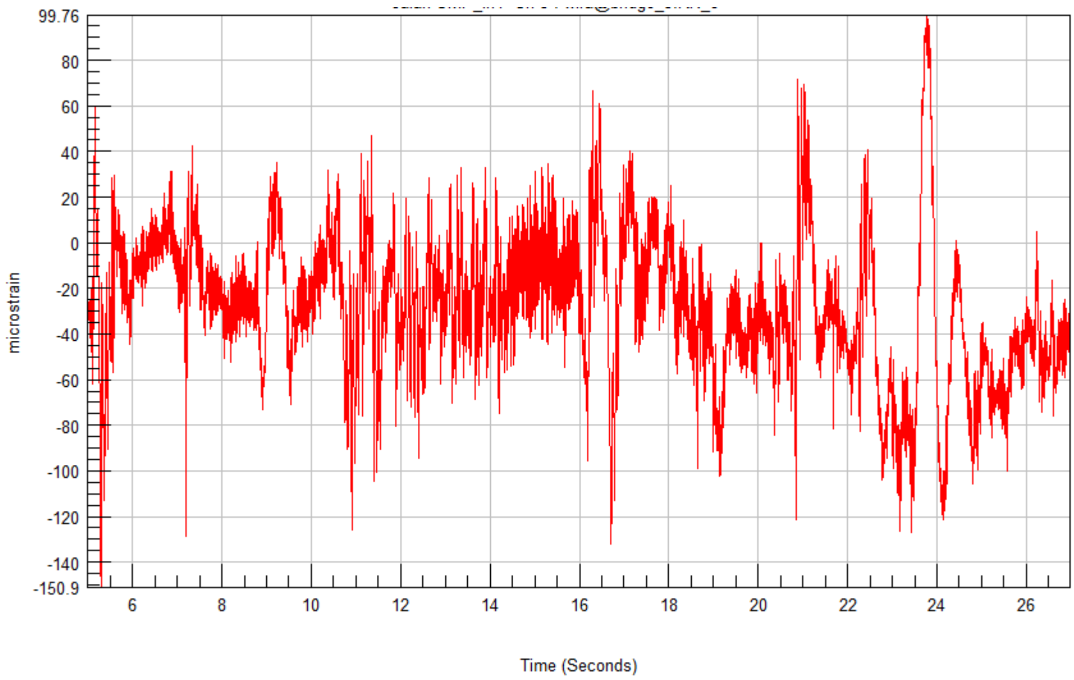


(a)

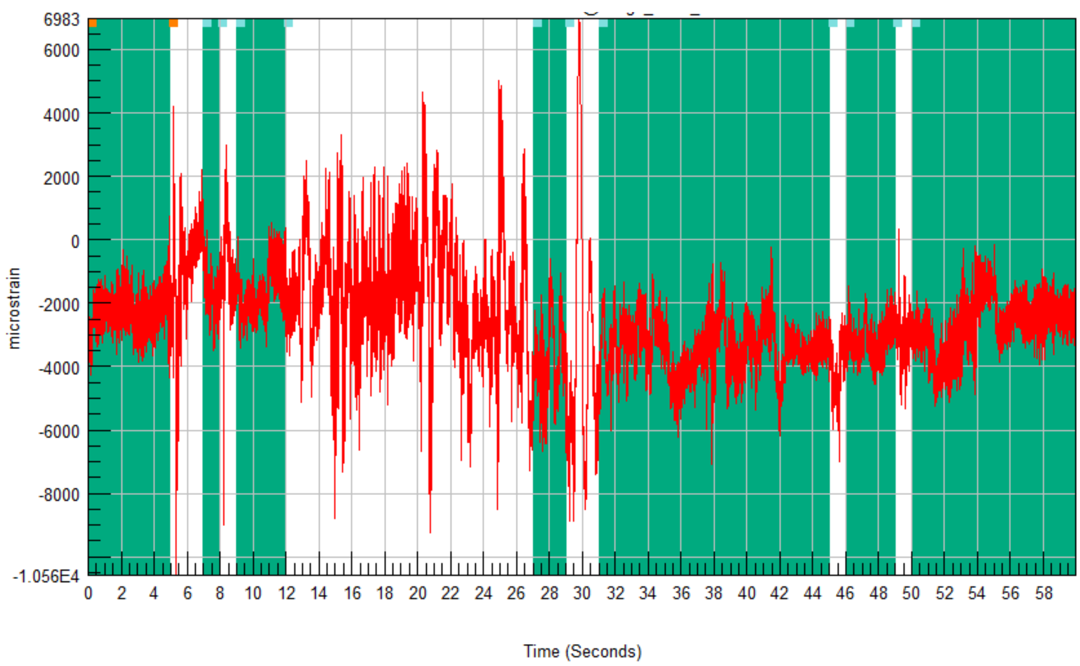


(b)

Figure 6.8: Strain signal of University Road using:
(a) Edited strain signal and (b) Signal remove



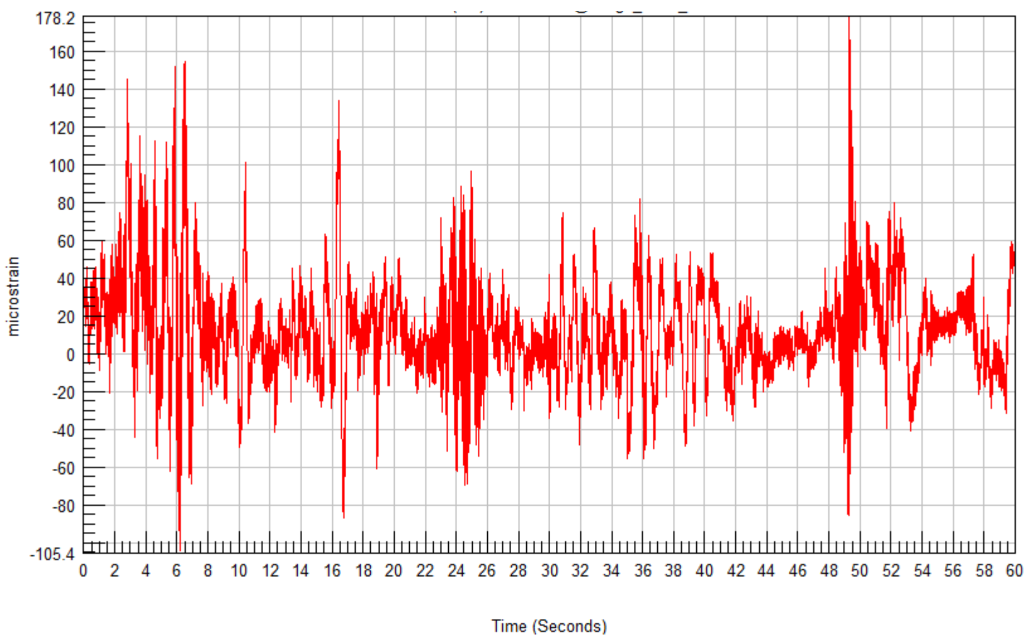
(a)



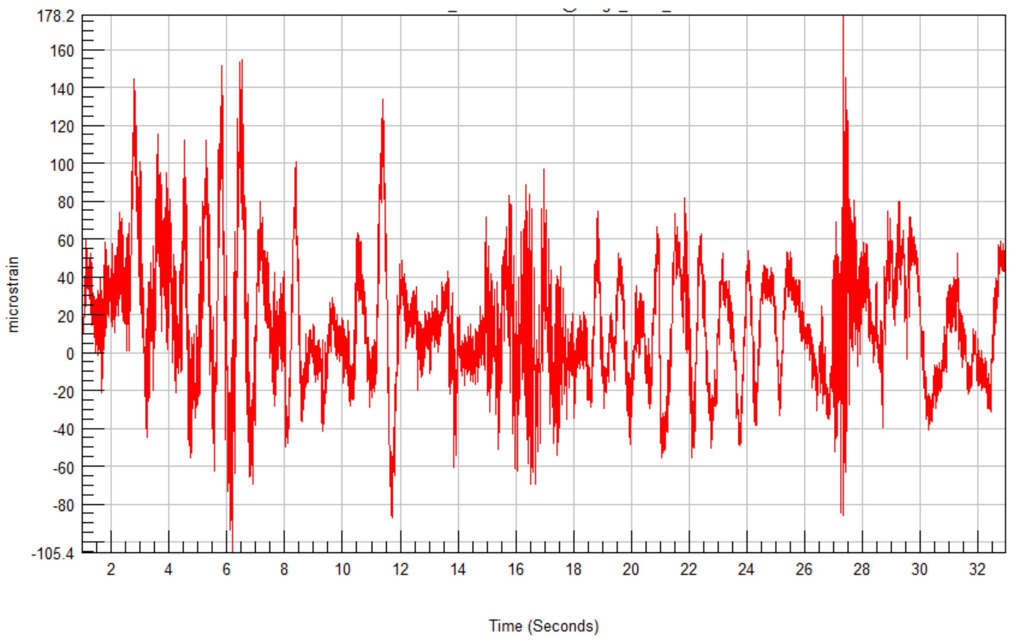
(b)

APPENDIX F

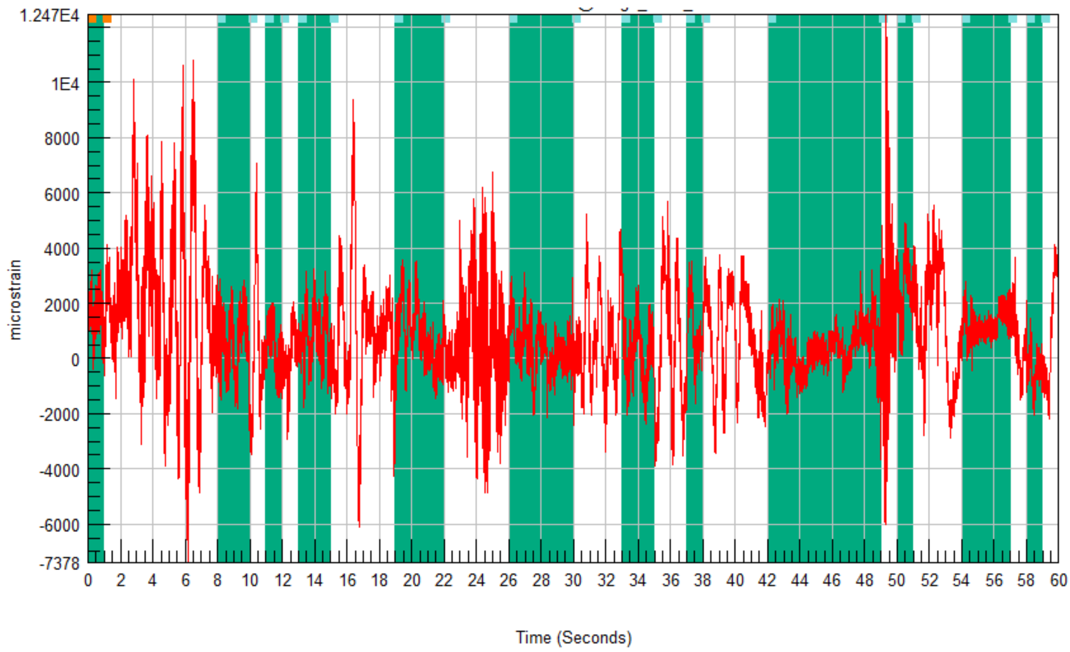
Figure 6.9: Strain signal of Public Road using Coffin Manson:
(a) Original strain signal, (b) Edited strain signal, (c) Signal remove



(a)

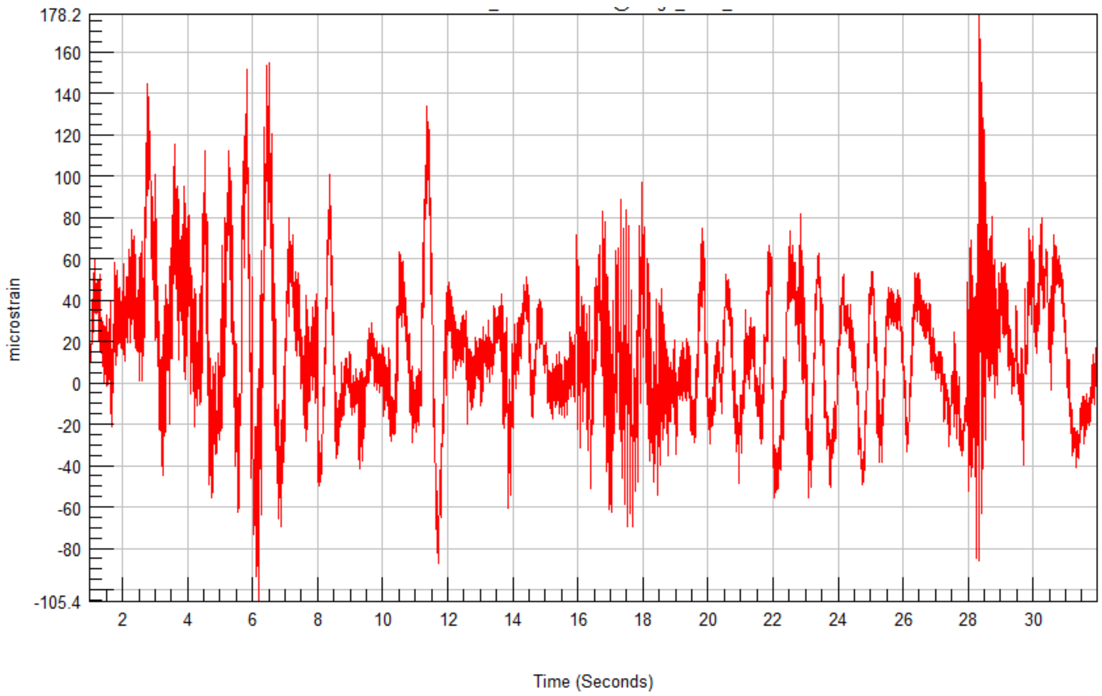


(b)

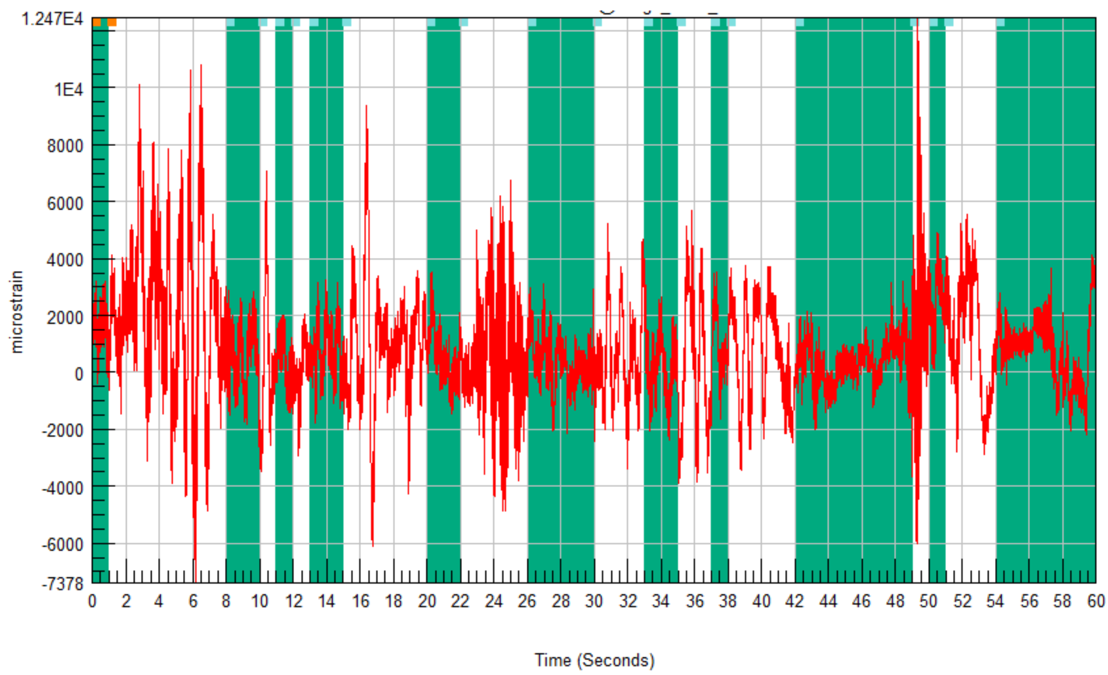

1.247E4
1E4
8000
6000
4000
2000
0
-2000
-4000
-6000
-7378
microstrain
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Time (Seconds)

(c)

Figure 6.10: Strain signal of Public Road using Morrow:
(a) Edited strain signal and (b) Signal remove

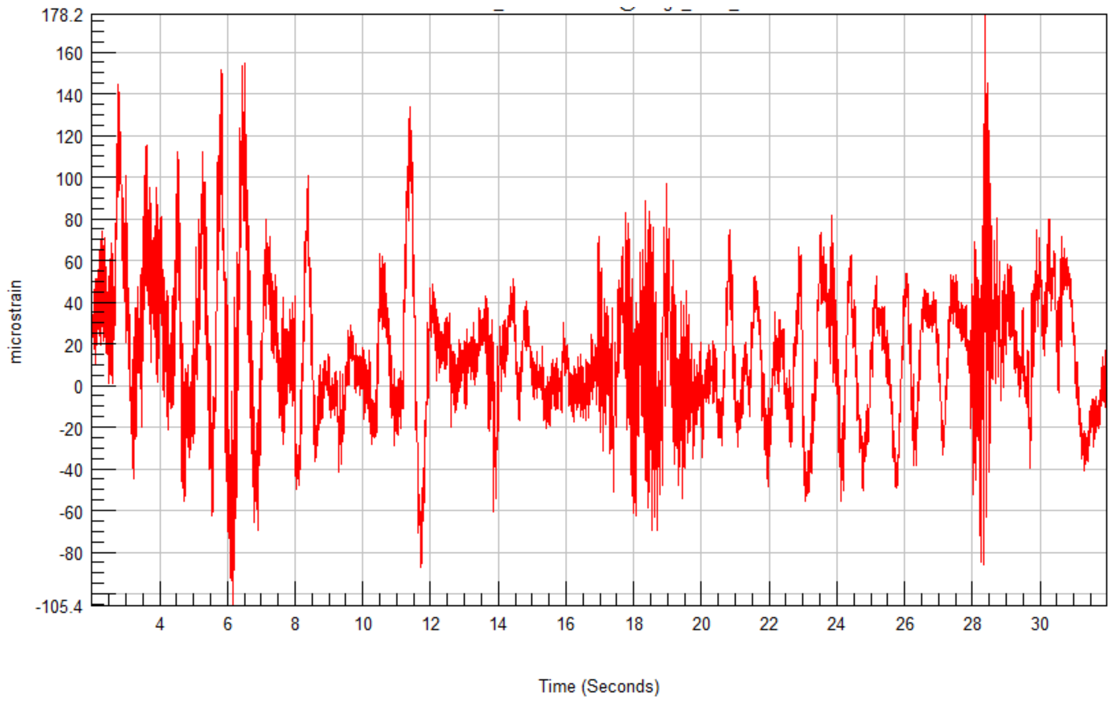


(a)

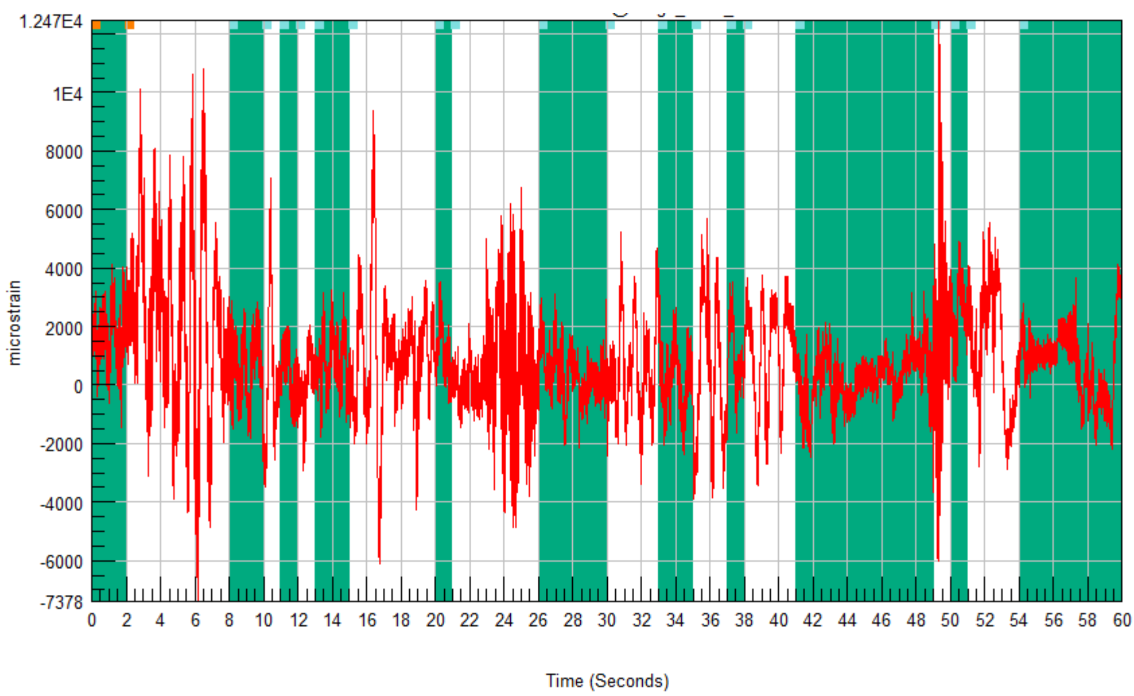


(b)

Figure 6.11: Strain signal of Public Road using SWT:
(a) Edited strain signal and (b) Signal remove



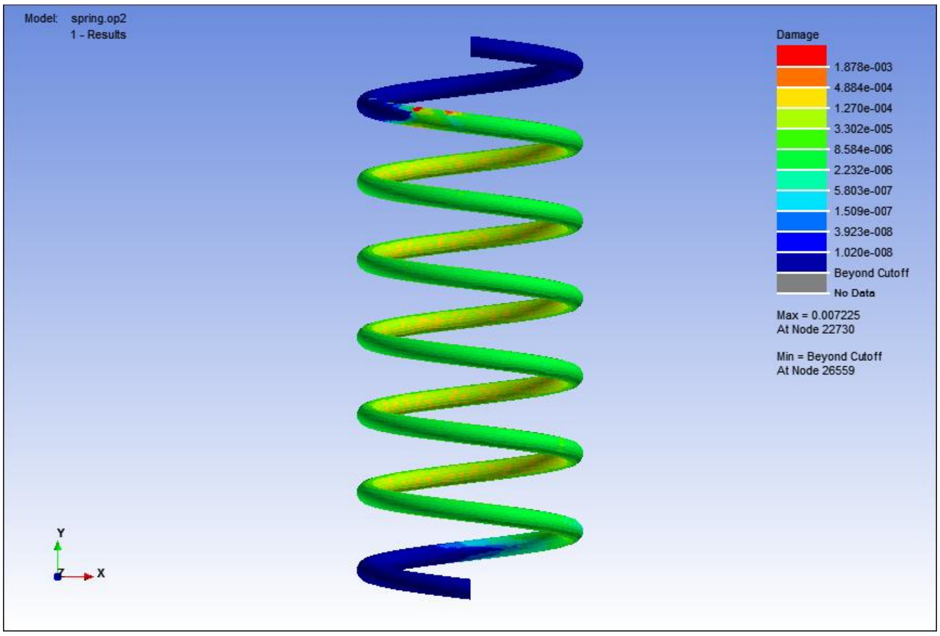
(a)



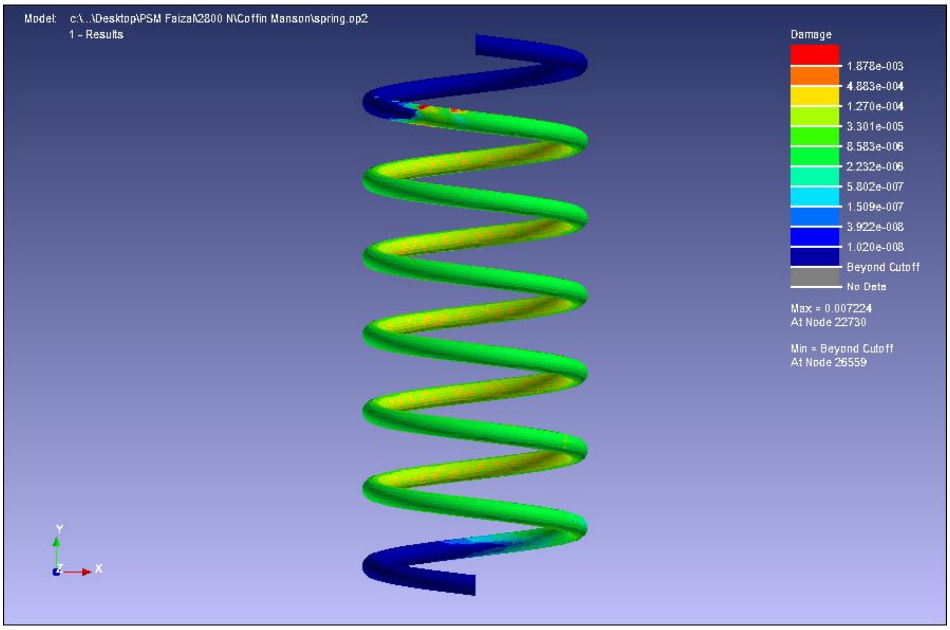
(b)

APPENDIX G

Figure 6.12: Fatigue damage result for Highway Road using Coffin Manson method: (a) Original data as strain signal input, (b) edited data as strain signal input

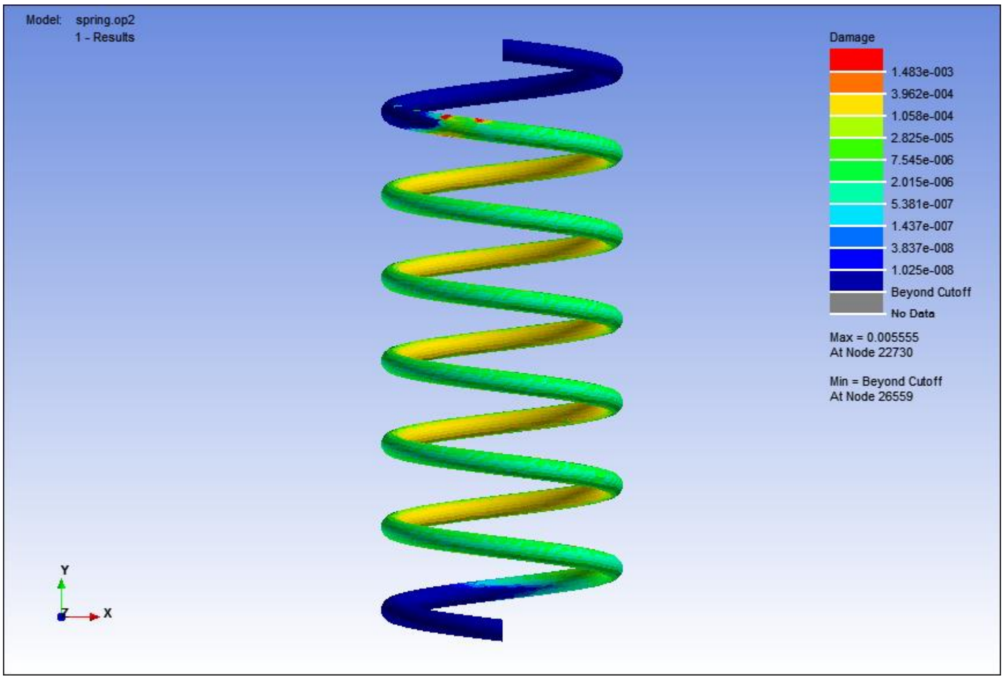


(a)

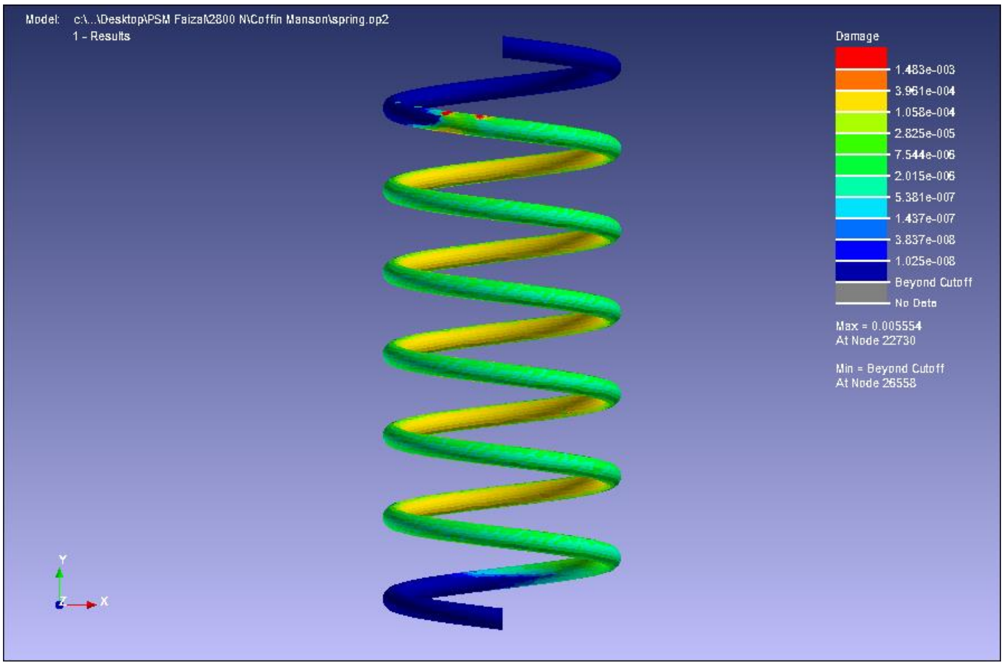


(b)

Figure 6.13: Fatigue damage result for Highway Road using Morrow method: (a) Original data as strain signal input, (b) edited data as strain signal input

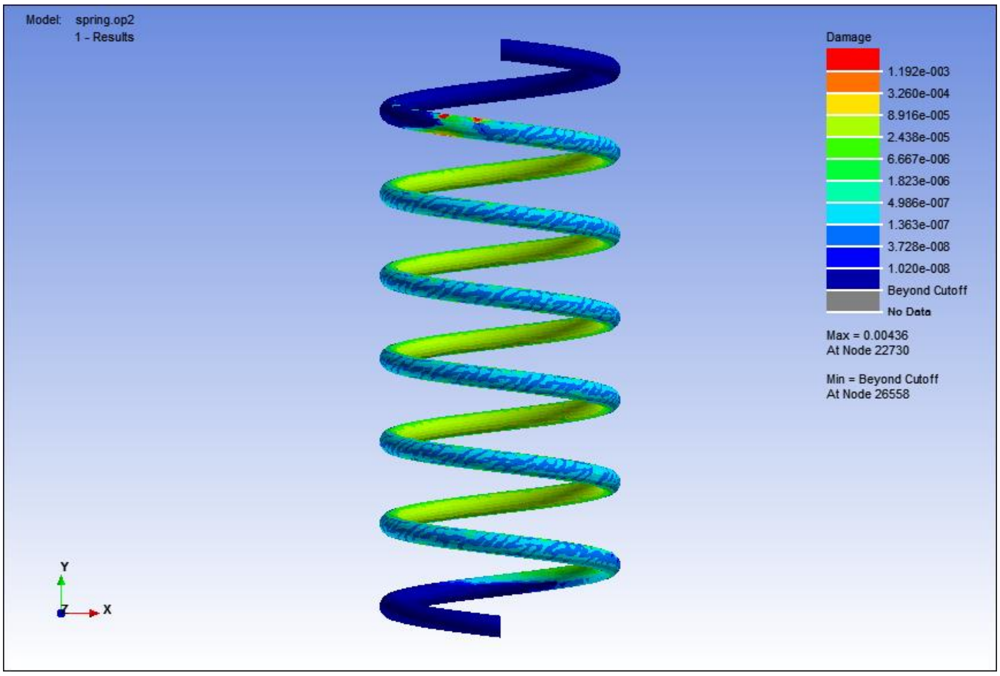


(a)

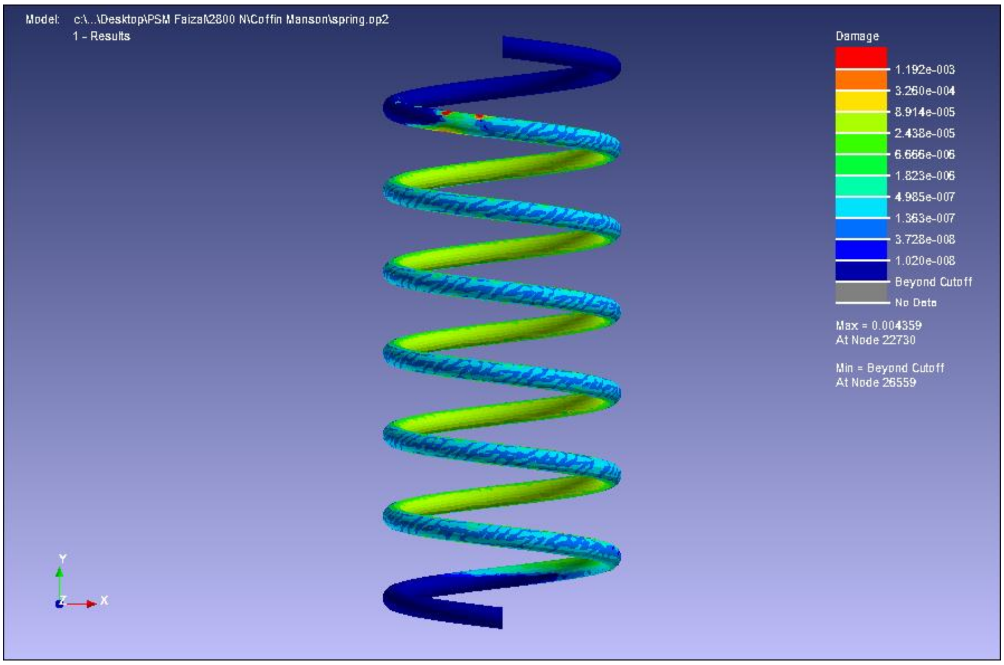


(b)

Figure 6.14: Fatigue damage result for Highway Road using SWT method: (a) Original data as strain signal input, (b) edited data as strain signal input



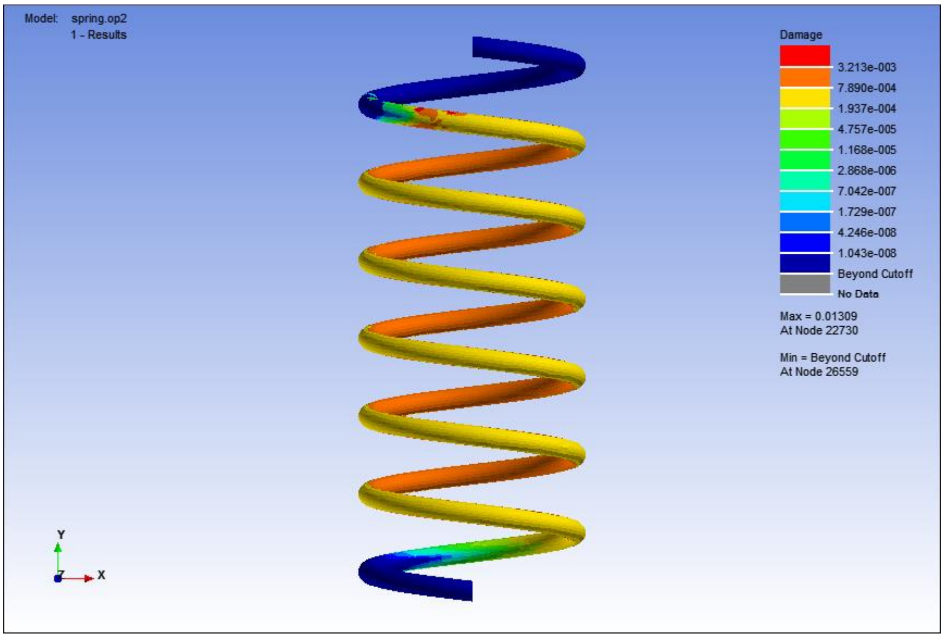
(a)



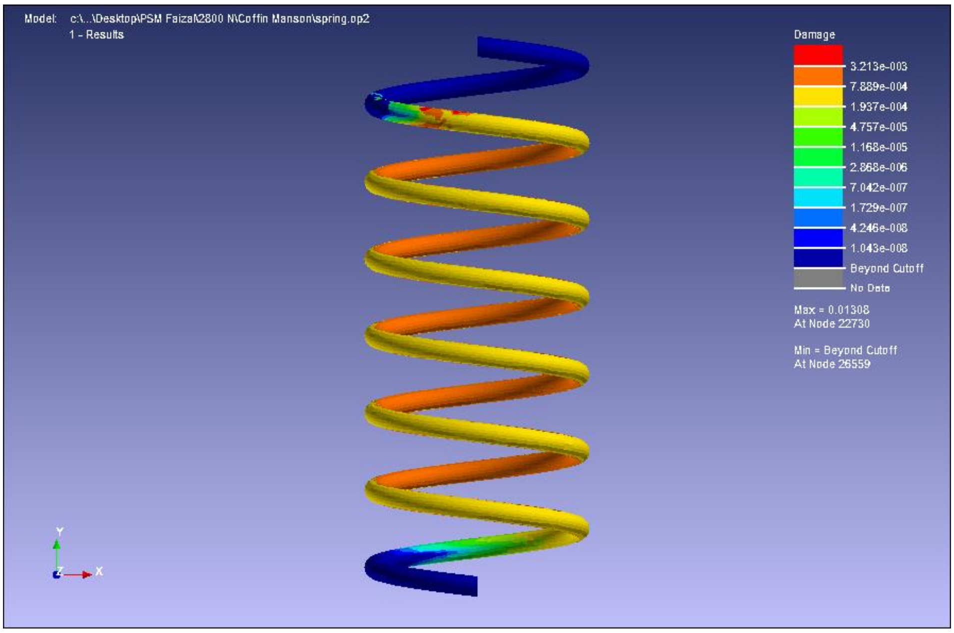
(b)

APPENDIX H

Figure 6.15: Fatigue damage result for University Road using Coffin Manson method: (a) original data as strain signal input, (b) edited data as strain signal input

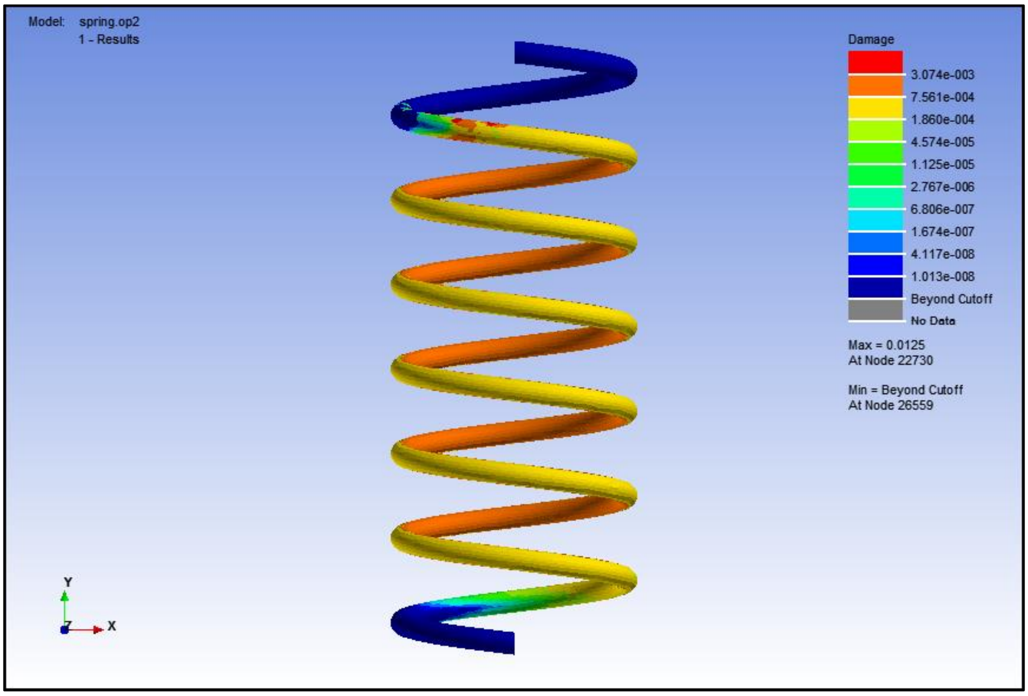


(a)

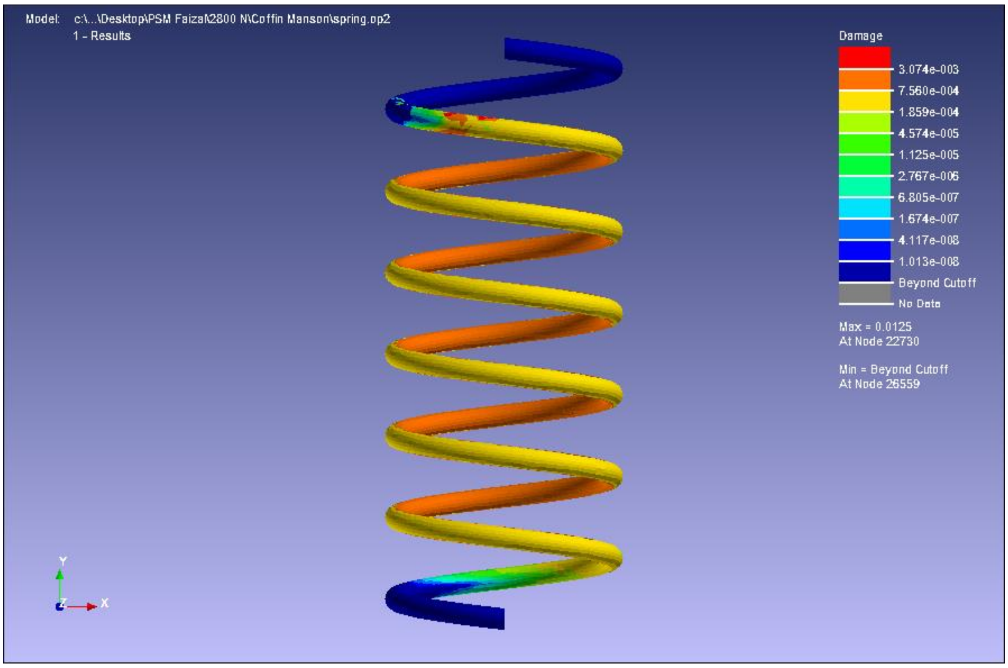


(b)

Figure 6.16: The Fatigue damage result for University Road using Morrow method: (a) Original data as strain signal input, (b) edited data as strain signal input

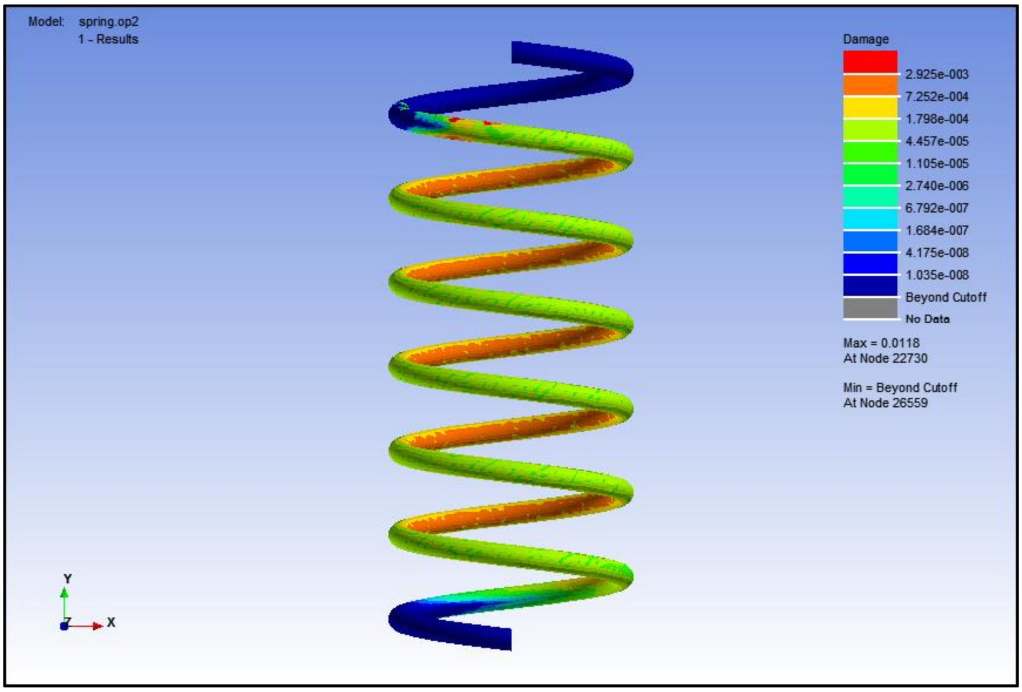


(a)

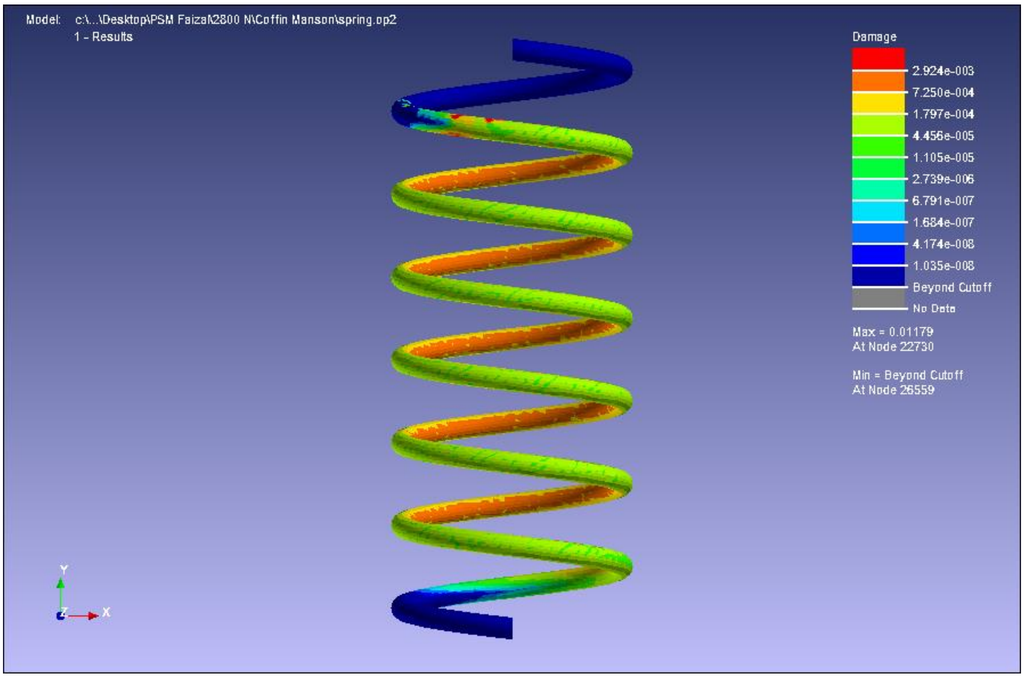


(b)

Figure 6.17: The Fatigue damage result for University Road using SWT method: (a) Original data as strain signal input, (b) edited data as strain signal input



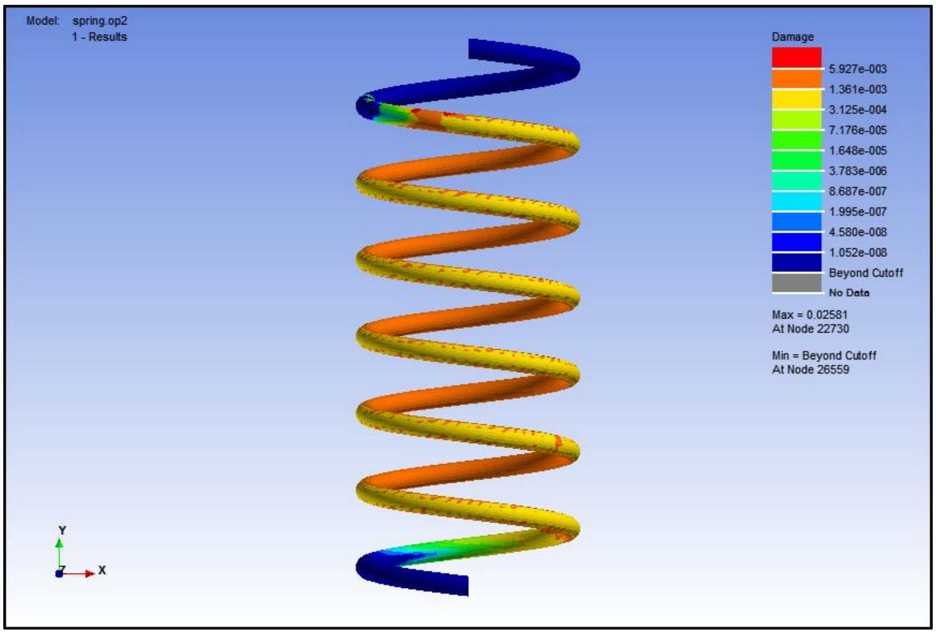
(a)



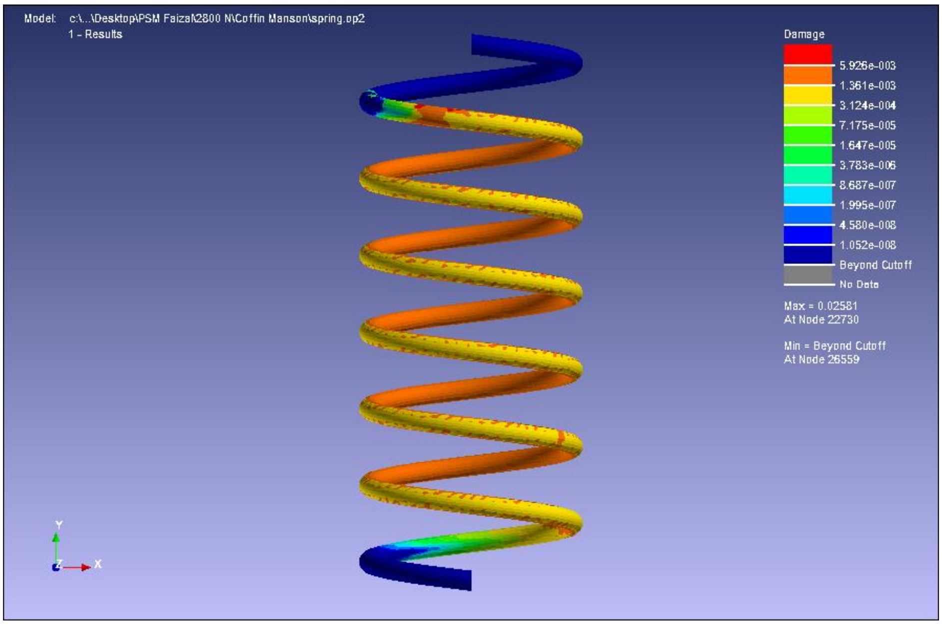
(b)

APPENDIX I

Figure 6.18: The Fatigue damage result for Public Road using Coffin Manson method: (a) original data as strain signal input, (b) edited data as strain signal input

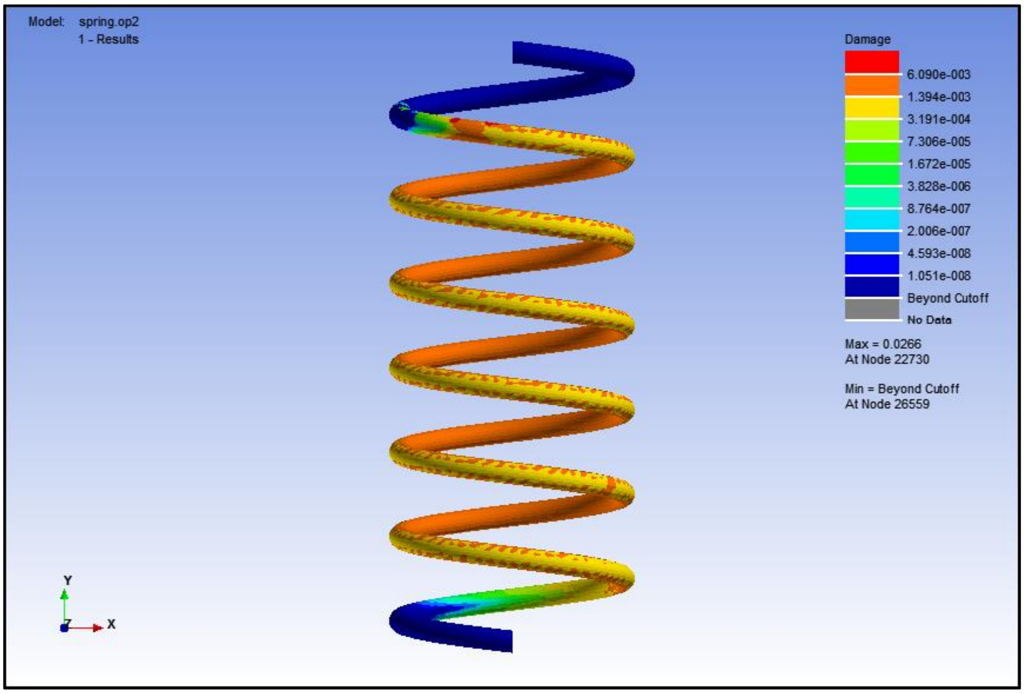


(a)

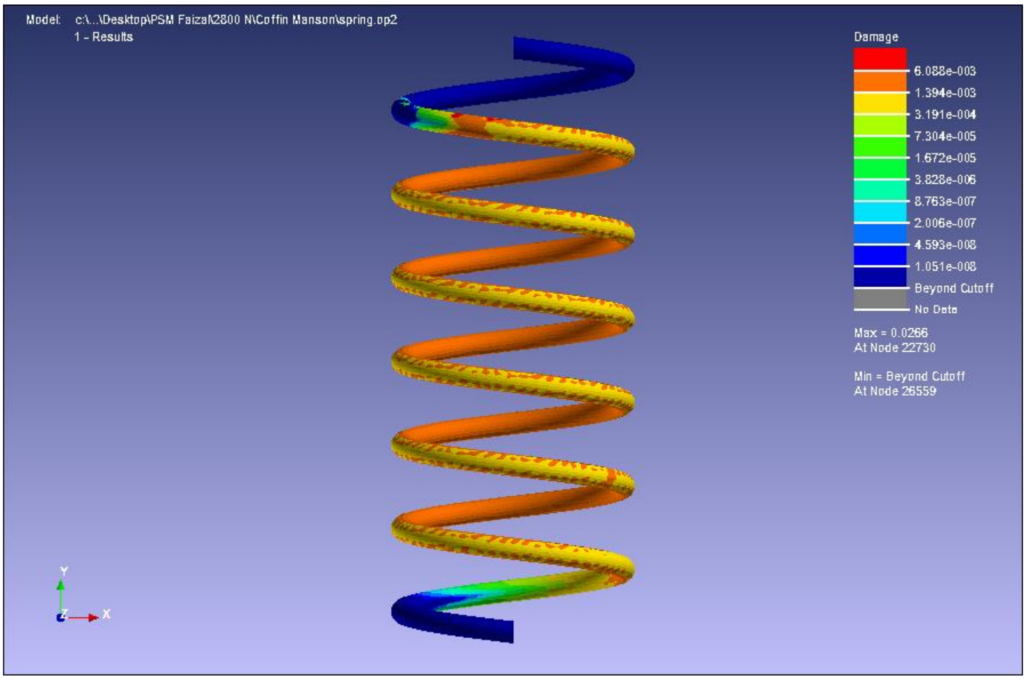


(b)

Figure 6.19: The Fatigue damage result for Public Road using Morrow method: (a) Original data as strain signal input, (b) edited data as strain signal input

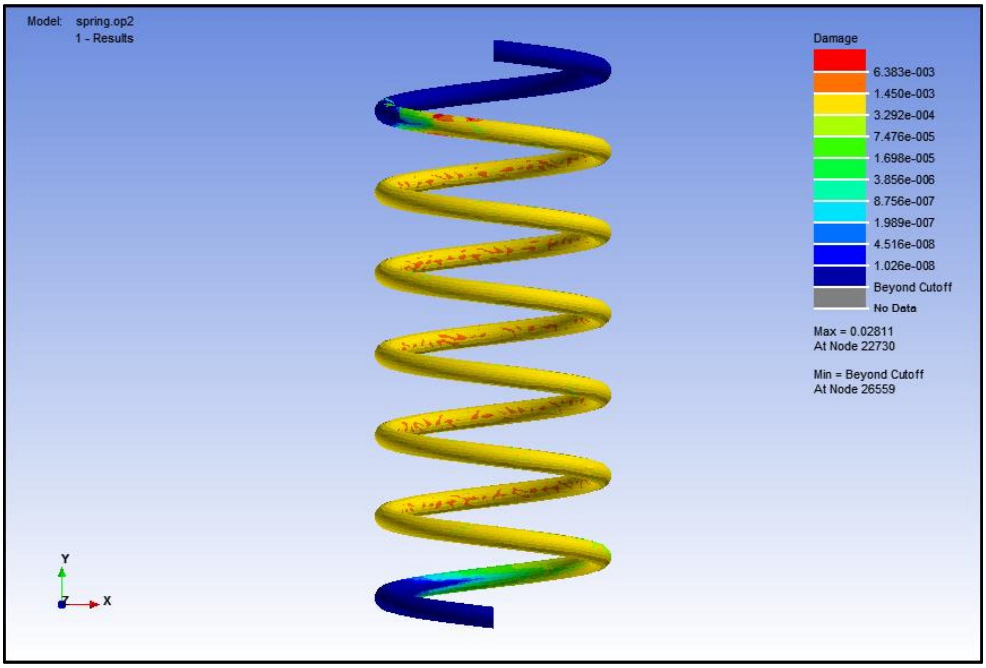


(a)

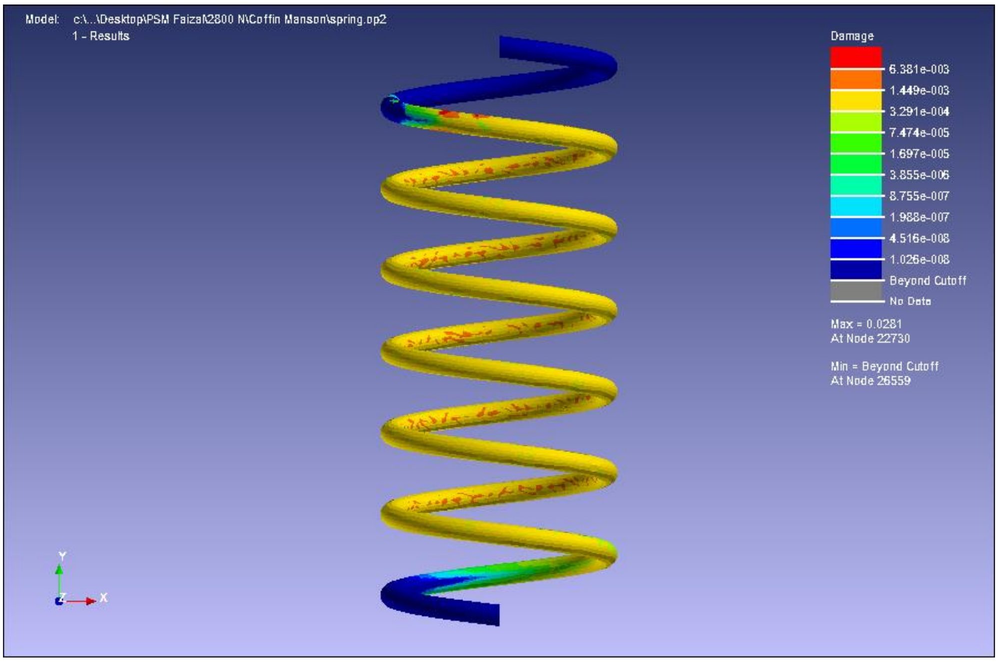


(b)

Figure 6.20: The Fatigue damage result for Public Road using SWT method: (a) Original data as strain signal input, (b) edited data as strain signal input

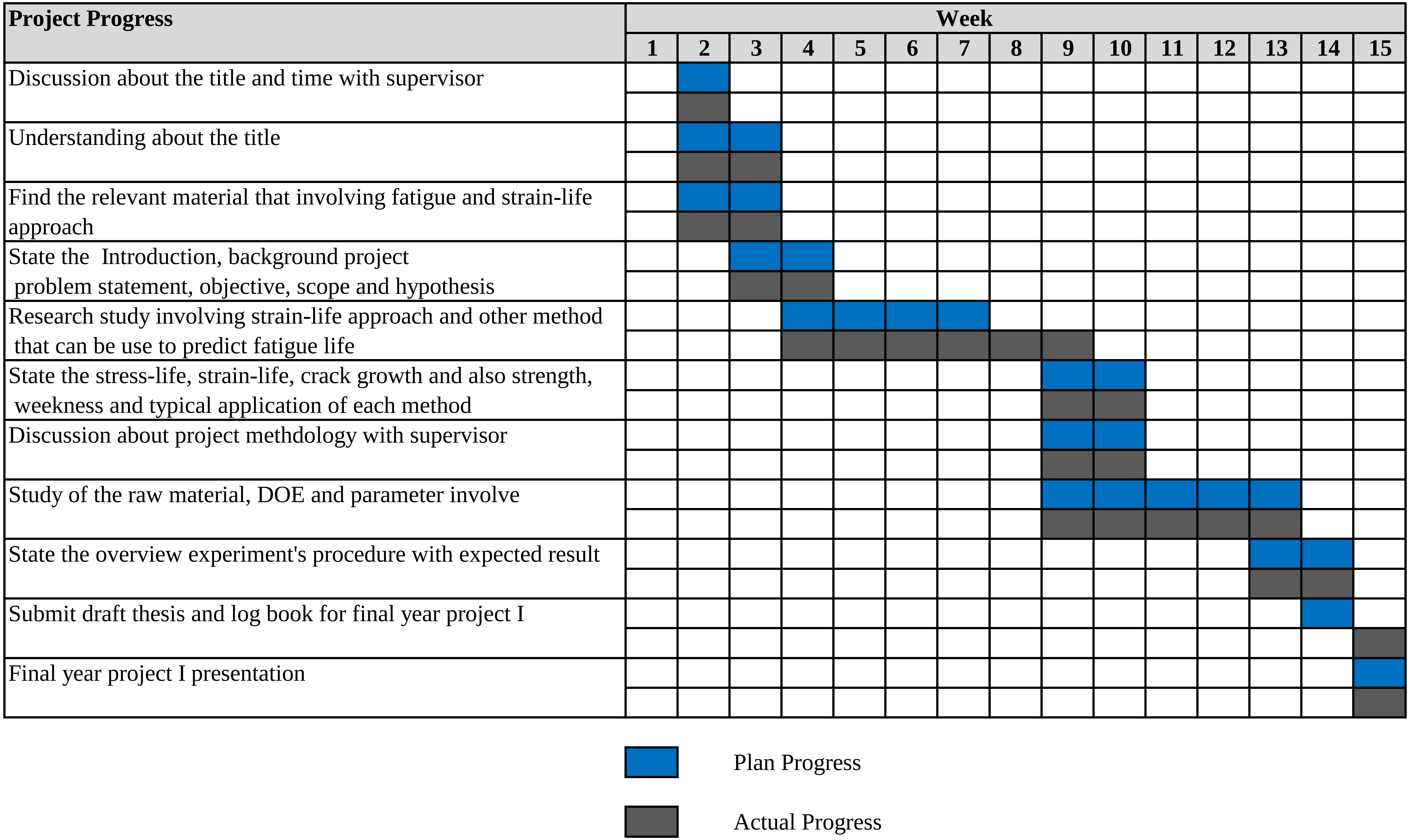


(a)



(b)

GANTT CHART FOR FINAL YEAR PROJECT I



GANTT CHART FOR FINAL YEAR PROJECT 2

Project Progress	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discussion about the methodology to proceed for PSM 2														
Proceed methodology stage														
Decide capability to finish the project														
Change the title due to capability finishing in 1 semester.														
Deciding introduction, background, problem statement, scopes, and hypothesis														
Proceed for finding materials for literature review														
Proceed methodolgy for modeling spring coil learning using patran nastran, fatigue software.														
Run the analysis using fatigue software														
Got the result and done the discussion, and conclusion of the project study														
Final Year Project 2 presentation														

Plan Progress

Actual Progress