

**ANALYSIS OF PROPERTIES OF FATIGUE LOADED  
BACKBONE DISCS**

By

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FINAL REPORT

Submitted to the Electrical & Electronics Engineering Program

in Partial Fulfillment of the Requirements

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by

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**CERTIFICATION OF APPROVAL**

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Electrical & Electronics Engineering Programme  
Universiti Teknologi PETRONAS  
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Approved:

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TRONOH, PERAK

Dec 2010

## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Fara Rozana bt Salikin

## **ABSTRACT**

This study aims to find the effects of fatigue loading and rest on dynamic properties of healthy vertebra discs. The author's objective is to use signal processing methods to analyze vertebra disc data and produce meaningful results of that analysis. Vital to a healthy back are the midsection of the body, good posture, weight control, spinal alignment, rest and stress management. There are many underlying causes of upper or lower backbone pain, such as arthritis, osteoporosis, infection and fever, tumors, weak stomach muscles and emotional tension or stress, muscle strain results from excessive or improper physical exertion, incorrect posture, sleeping on soft beds or incorrect lifting. The spine (vertebra or backbone) is a very complex structure which is never still. The slightest movement, including breathing, involves the spine and spinal discs which is located in between of vertebra.

## **ACKNOWLEDGEMENT**

First and foremost, praise to Allah the Almighty for giving me strength and enthusiasm to work on Final Year Project, FYP entitled 'Analysis of Properties of Fatigue Loaded Backbone Discs'. Without Him, I am sure I would not have made it this far. Special acknowledgements are owed to my beloved family and friends for giving me the support and inspiration.

In particular, I would like to offer special thanks to my supervisor Dr Aamir Saeed Malik who have taught me many things, kind enough to give me invaluable support and advice as well as feedbacks on my project. The thanks too, go to other EE lecturers and EE Technicians who have willingly shared their knowledge.

Last but not least, warm thank you is highlighted to my fellow colleagues in making my FYP a great success. Additionally, to those whom their names are not mentioned here that have helped me directly or indirectly, thank you so much. It is not easy to erase all these sweet memories in Universiti Teknologi PETRONAS.

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## **LIST OF ABBREVIATIONS**

**LVDT** Linear Voltage Displacement Transducer

**PCA** Principal Component Analysis

**SVD** Singular Value Decomposition

# CHAPTER 1

## INTRODUCTION

### 1.1 Background of Study

Backbone is very important for us. It supports human body. In our backbone, there are discs between the bones. When we carry weight, the discs are pressed. When we remove the weight, the discs will come back to the normal position. However, over long time and under repetitive loads, the discs do not fully come back to the original position. These may cause fractures and low back pain. To ease the pain, we can do either prophylactic augmentation or cement augmentation. The prophylactic itself means preventive measure before the pain happen while cement augmentation is preventive measure after the pain happen. Both preventions are to enhance failure strength of backbone and maintain the stiffness of non-fractured vertebra. For cement augmentation, researchers perform experiments to test the strength of the backbone that have been penetrated by cement. Based on one of the experiments done by a group of researchers in Taiwan, there were three parameters that had been measured from three types of sensors which are Load Cell, Accelerometer and Linear Voltage Displacement Transducer (LDVT).

We collaborate with the researchers in Taiwan and they have provided us data so that author can analyze the data by using signal processing methods. Initially, author used SVD and PCA techniques to check the relationship between various dimensions of data and later to predict the damage done to vertebra.

## **1.2 Problem Statement**

Because of fatigue loading, vertebral (backbone) discs might get damaged. So, we need to identify and analyze the various parameters for assessing the effects of fatigue loading.

The parameters stated are ‘Acceleration 1’ taken from upper vertebra, ‘Acceleration 2’ taken from lower vertebra, ‘Force’ and ‘Displacement’. These four parameters are acquired for 2 seconds after every 10 minutes over 1 hour.

## **1.3 Objectives and Project Scope**

### *1.3.1 Objectives*

- 1) Analysis of various factors affecting the fatigue-loaded vertebral (backbone) disc
- 2) Finding correlation between those factors and the effects of fatigue loading

### 1.3.2 Project Methodology

- 1) Fatigue Loaded Backbone Disc data acquired with following parameters
  - Acceleration 1 (upper vertebra)
  - Acceleration 2 (lower vertebra)
  - Force
  - Displacement
  
- 2) Using filters for minimizing noise
  - Median filter
  - Average filter
  
- 3) Using statistical techniques to interpret data
  - Principal Component Analysis, PCA
  - Singular Value Decomposition, SVD
  
- 4) Discrete Time Signals and Systems
  - Correlation
  
- 5) MATLAB programming

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Case Study

The spinal disc commonly known as backbone is the most vital parts of the human anatomy. It is a bony structure which covers and protects spinal cord. In our backbone, there are discs in between the bones. The spinal discs lie between two vertebrae to act as ligaments and allow slight movement of vertebra. Body weight, loading, movements and impacts on spinal column are distributed by the spinal discs uniformly among the vertebra. Otherwise, it will result in an overload of the vertebra and lead to vertebral breaks. In long term loads, core fluid of the vertebral discs is compressed through the firm fiber ring into the blood and lymphatic system, therefore the spinal disc reduces its fluid content and becomes narrower. That is especially the case during hour long sitting or while carrying heavy loads. When we carry the weight, the discs are pressed. When we remove the weight, the discs come back to the original position. These processes are measured to investigate the effects of fatigue loading.



Figure 1 Spinal discs deformity [1]



The fatigue loading is a risk factor for low back pain. The disc dynamic properties describe the shock attenuation capability of disc. Knowledge of effect of fatigue loading and rest on the disc dynamic properties can be beneficial for the study of fatigue loading induced spinal disorder. The first percutaneous vertebroplasty was performed in Europe in 1984 and the first vertebroplasty in America was performed in 1993. Percutaneous vertebroplasty is preventive measure based on surgical method to prevent the pain in vertebra. There are now more than 253 published reports focused on vertebroplasty [2]. Since the time these previous studies were published, there were a lot of procedural techniques that had been modified. By studying other methods, there are approximately 530 treatment levels to report important lesson from these studies [2].

Some researches also had used the khypholasty (hunch back) methods for the treatment of osteoporotic vertebral fractures under repetitive loading conditions. Khypholasty was derived from vertebroplasty [3]. Balloon kyphoplasty utilizes orthopedic balloons to create a void in a fractured vertebra, restore vertebral body height and correct angular deformity. The void allows a viscous cement to be positioned in a controlled manner stabilizing the fracture. In vertebroplasty, no balloon is used to restore vertebral body height and no cavity is created. Cement is injected into the fractured vertebra stabilizing it in its current state [4].

Based on the research, height of vertebra was restored with khypholasty but the vertebral bodies showed significant height loss during cyclic loading. While looking for vertebroplasty method, specimens had higher compression stiffness and smaller height reduction. Vertebroplasty has become a common treatment for painful osteoporotic vertebral fractures, but there is limited evidence to support its use. They found no beneficial effect of vertebroplasty as compared with a sham procedure in patients with painful osteoporotic vertebral fractures [5]. However in the other research done in America, they recommend that both procedures be available in the treatment [6]. Both procedures showed the complications. Regardless of which procedure is chosen, safety depends upon operator experience, excellent imaging equipment, and adequate cement pacification.

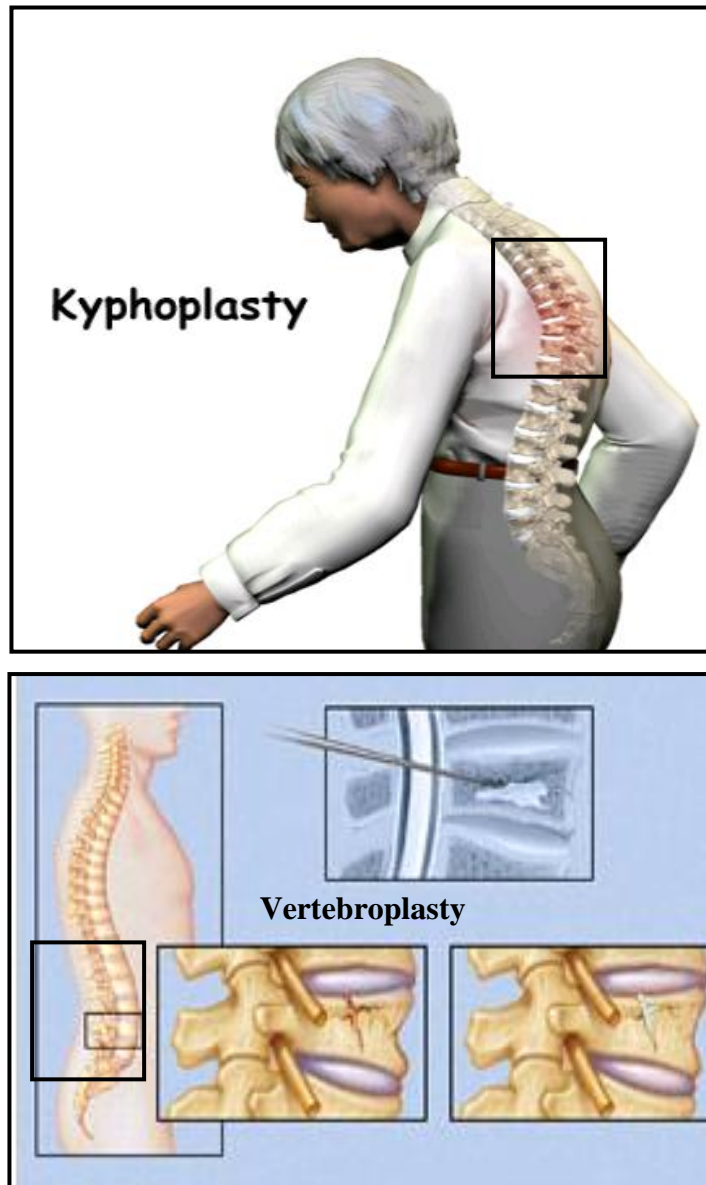


Figure 2 Khyphoplasty vs Vertebroplasty [9] [10]

The researchers assumed that vertebroplasty and khypholasty give same result to encounter fatigue loading conditions. We have collaborated with National Health Research Institute in Taiwan in research of vertebroplasty augmentation studies. The data has been taken from the research of in vitro biomechanical study using human spines specimens [7] [8]. Several methods are attempted to analyze the effects of fatigue loading to vertebral discs. For the author's project, signal processing techniques will be applied to analyze the effects of fatigue loading to vertebral discs. In the end of the project, she might come out with an algorithm to predict the damage of vertebral discs based on the various factors which are accelerations, force and displacement.

## 2.2 Filter

To understand the data better, author use filter to minimize noise. In her FYP1, she used two types of filters:

- Average Filter
- Median Filter

### 2.2.1 *Average Filter*

Average filter is generated by adding all signals and dividing by the number of population. This filter minimizes noise but also distort signals.

### 2.2.2 *Median Filter*

Median filter is generated by arranging signals increasingly and taking the middle value of the distributed data. This filter makes the data smoother by removing the noise.

## 2.3 Statistics

The entire subject of statistics is based around the idea the author have big set of data, and she wanted to analyze that set in terms of the relationships between the individual points in that data set. She was going to look at a few of the measures that can be done on a set of data, and what they told her about the data itself. In her project, author focused on

- Principal Component Analysis, PCA [11] [12]
- Singular Value Decomposition, SVD [13]

### 2.3.1 PCA Theory

It is a way of identifying patterns in data and expressing the data to highlight their similarities and differences. For high dimensions of data, the graphical representation is not available; PCA then is a powerful tool for analyzing data. The other main advantage of PCA is that author found by compressing the data; the number of dimensions was reduced without much loss of information. The assumption of PCA can be made on the statistical significance of mean and covariance [15]. The steps are:

Step 1: Getting some data

The desired result basically is to find any relationship between various dimensions data. For example is to find the relationship between two matrices or more.

Step 2: Subtracting the mean

For PCA to work properly, the author has to subtract the mean from each of the data dimensions. The mean subtracted is the average across each dimension. So, all the values have (the mean of the values of all the data points) subtracted, and all the values are subtracted from them.

$$X_{\text{mean}} = \frac{\sum_{i=1}^n \bar{X}_i}{n} \dots\dots\dots(1)$$

$$X_{\text{adjusted}} = X - X_{\text{mean}} \dots\dots\dots(2)$$

For example;

Table 1 Initial data and Adjusted data

Initial Data		Adjusted Data	
X	Y	X <sub>mean</sub>	Y <sub>mean</sub>
2.3	2.4	0.38	0.44
0.6	0.9	-1.32	-1.06
2.2	2.7	0.28	0.74
1.9	2.3	0.88	0.34
3.1	3.2	1.18	1.24
2.3	2.7	0.38	0.74
2.1	1.6	0.18	-0.36
1.2	1.4	-0.72	-0.56
1.5	1.6	-0.42	-0.36
1.1	0.8	-0.82	-1.16

Step 3: Computing the covariance matrix

Covariance is always measured between 2 dimensions or more. The formula for variance and covariance are written like this:

$$\text{var X} = \frac{\sum_{i=1}^n (X_i - \bar{X})(X_i - \bar{X})}{(n - 1)} \dots\dots\dots(3)$$

$$\text{cov (X,Y)} = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{(n - 1)} \dots\dots\dots(4)$$

For the above example, since the data has two dimensions, so the covariance matrix is 2 by 2. If the non-diagonal elements in this covariance matrix are positive, the author should expect that both variables increase together.

$$\text{cov (X,Y)} = \begin{pmatrix} 0.6307 & 0.5842 \\ 0.5842 & 0.6649 \end{pmatrix}$$

The important for covariance is its sign. If the value is positive it indicates the both dimensions increase together. If the value is negative, then as one dimension increases, the other decreases. In the last case if the covariance is zero. It indicates the two dimensions are independent each other.

#### Step 4: Computing the eigenvectors and eigenvalues of the covariance matrix

Since the covariance matrix is square, the author can calculate the eigenvectors and eigenvalues for this matrix. They tell her useful information about the data. It is important to notice that these eigenvectors are both unit eigenvectors i.e. their lengths are both 1. This is very important for PCA.

From the covariance matrix, it is seen that the two variables do indeed increase together. As stated in the eigenvector section, they are perpendicular to each other. But, more importantly, they provide her with information about the patterns in the data.

$$\text{Eigenvalues} = \begin{pmatrix} 1.2323 \\ 0.0633 \end{pmatrix}$$

$$\text{Eigenvectors} = \begin{pmatrix} 0.6967 & -0.7174 \\ 0.7174 & 0.6964 \end{pmatrix}$$

An eigenvectors of an  $n \times n$  matrix  $A$  is nonzero such  $A\mathbf{x}=\lambda\mathbf{x}$  for some scalar  $\lambda$ . A scalar  $\lambda$  is called an eigenvalue of  $A$ ; such an  $x$  is called an eigenvector corresponding to  $\lambda$ .

Once the eigenvectors are found from the covariance matrix, the next step is to arrange the eigenvalue decreasingly. The author does lose some information, but if the eigenvalues are small that do not lose much. The final data set will have fewer dimensions than the original.

### 2.3.2 SVD Theory

Singular Value Decomposition is an important factorization of a rectangular real or complex matrix, with many applications in signal processing and statics. SVD provides qualitative information about the structure of linear equations. This is accomplished by decomposing the original data with each succeeding nonzero singular value. Furthermore, a fewer singular values is good enough to reduce the storage size. The steps are:

#### Step 1: Computing $A^T A$

Singular value decomposition of  $[m \times n]$  matrix  $A$  is given by  $A = U \Sigma V^T$  where  $U$  is an  $[m \times m]$  orthogonal matrix;  $V$  an  $[n \times n]$  orthogonal matrix, and  $\Sigma$  an  $[m \times n]$  matrix containing the singular values of  $A$   $\sigma_1 \geq \sigma_2 \geq \dots \geq \sigma_n \geq 0$  along its main diagonal. Working with symmetric matrix  $A^T A$  then two conditions must be true:

1. The eigenvalues of  $A^T A$  will be real and nonnegative
2. The eigenvectors will be orthogonal

The original formula is :  $A = U_{m \times m} \cdot \Sigma_{m \times n} \cdot V^T_{n \times m}$  .....(5)

#### Step 2: Computing matrix $\Sigma$

From the equation in Step 1,  $\Sigma^2$  contains the eigenvalues of  $A^T A$ . By letting denote  $\Sigma$  as square matrix containing the nonzero singular values  $[\sigma_1, \sigma_2, \dots, \sigma_r]$  of  $A$  along its main diagonal. Therefore matrix  $\Sigma$  may be represented by

$$\Sigma = \begin{pmatrix} \sigma_1 & 0 \\ 0 & 0 \end{pmatrix}$$

Where the singular values along the diagonal are arranged in decreasing magnitude, and the zero singular values are placed at the end of the diagonal. The singular value of  $A$  is also defined as the square root of the corresponding eigenvalues of the matrix  $A^T A$  such as:

$$\sigma_j = \sqrt{\lambda_j}, \text{ where } j = 1, 2, \dots, n \text{ .....(6)}$$





Therefore  $Av_j = \sigma_j u_j$  ; where  $j=1,2,\dots,n$ . This equation shows  $\sigma_j$  is scalar,  $v_j$  and  $u_j$  are column vectors and matrix vector multiplication results in another vector. In other words,  $Av_j$  is a vector lying in the direction of the unit vector  $u_j$  with absolute length  $\sigma_j$ . Then unit vector of  $u_j$  is a result of

$$u_j = \frac{Av_j}{\sigma_j} \dots\dots\dots(11)$$

## 2.4 Correlation

Correlation [14] is a measure of similarity between a pair of sequences,  $x[n]$  and  $y[n]$  is given by cross-correlation sequence  $r_{xy}[k]$  defined by:

$$r_{xy}[n] = x(n) \text{ } \text{O} \text{ } y(n) = \sum_{n=(-\infty)}^{\infty} x(k) y(-n+k) \dots\dots\dots(12)$$

if we compare above expression with convolution  $x(n)$  and  $h(n)$

$$y(n) = x(n) * h(n) = \sum_{n=(-\infty)}^{\infty} x(k) h(n-k) \dots\dots\dots(13)$$

We see the difference, in the case correlation,  $y(k)$  is shifted by  $(-n)$  without the time reversal whereas in convolution,  $h(k)$  is time reversed to give  $h(-k)$  prior to shifting by  $(n)$ . Therefore correlation can be performed using the convolution operation.

$$r_{xy}[n] = x(n) \text{ } \text{O} \text{ } y(n) = x(n) * y(-n) \dots\dots\dots(14)$$

Correlation can be normalized for convenience in comparing and displaying. Normalized forms of correlation given by:

$$P_{xx} [l] = r_{xx} [l] / r_{xx}[0] \dots\dots\dots(15)$$

$$P_{xy} [l] = r_{xy} [l] / \sqrt{r_{xx}[0] r_{yy}[0]} \dots\dots\dots(16)$$

These two equations (8) and (9) are often used. After normalized, the result is in the range of  $[-1 \ 1]$ . Correlation equals to 1 means the pair of sequence have strong relationship while correlation equals to -1 means the pair of sequence have weak relationship.

## CHAPTER 3

### METHODOLOGY

#### 3.1 Procedure Identification

Analysis of properties of fatigue loaded backbone has 5 steps. The set of protocol in order to predict damages in backbone was prepared by researchers of Institute of Biomedical Engineering and Department of Medical Imaging, National Taiwan University Taipei, Taiwan.

Below is the flow of project:

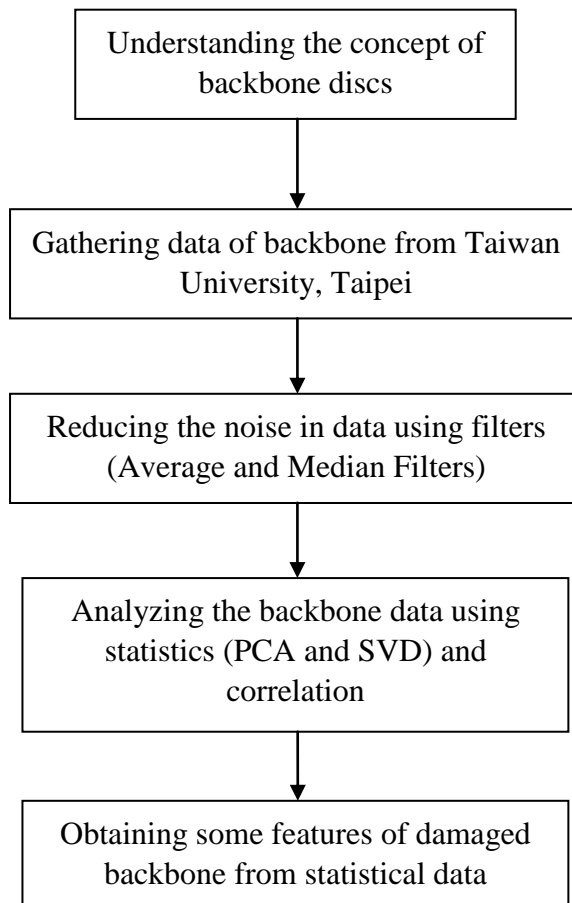


Figure 3 Flow of Project

### 3.1.1 Data Acquisition

The experiment done in Taiwan was using the fatigue and impulse loading apparatus.

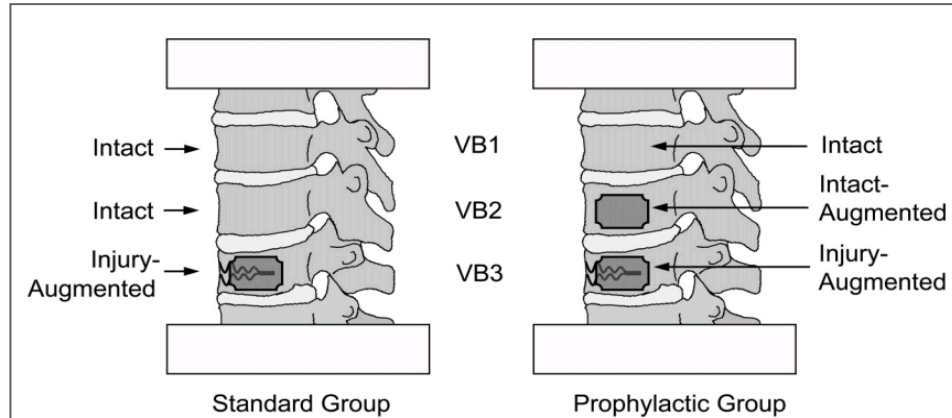


Figure 4 Division for vertebra level [7]

- 1) As shown in Figure 4 we could see two sets of vertebra labeled as standard group and prophylactic group. The major difference is the standard group was not penetrated with cement while the prophylactic group had vertebra which intact-augmented.
- 2) Below is the experiment setup

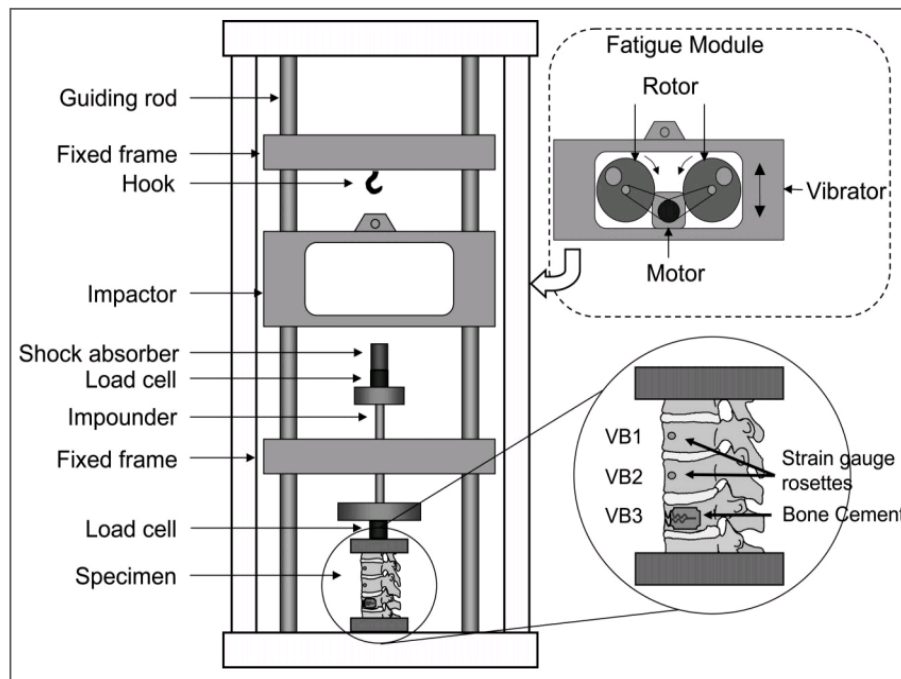


Figure 5 Experiment setup [7]

- 3) Figure 5 shows the experiment setup to test vertebra. The most important part is impactor. It would create impulse energy by free fall and was transmitted to the specimen through impounder. The function of shock absorber is to control the impulse contact period. The contact period is the time interval that impactor compresses the impounder before it bounces back.
- 4) The result which is resultant force had been measured due to the resulting force cause by impulse energy. A linear potentiometer would measure the displacement.
- 5) The experiment has been conducted by using three types of sensors that collect values for three parameters; which are Load Cell to collect force measured from backbone, Accelerometer to record the acceleration of the backbone vertically and LDVT to check the displacement of the backbone.

### 3.1.2 Experiment Protocol

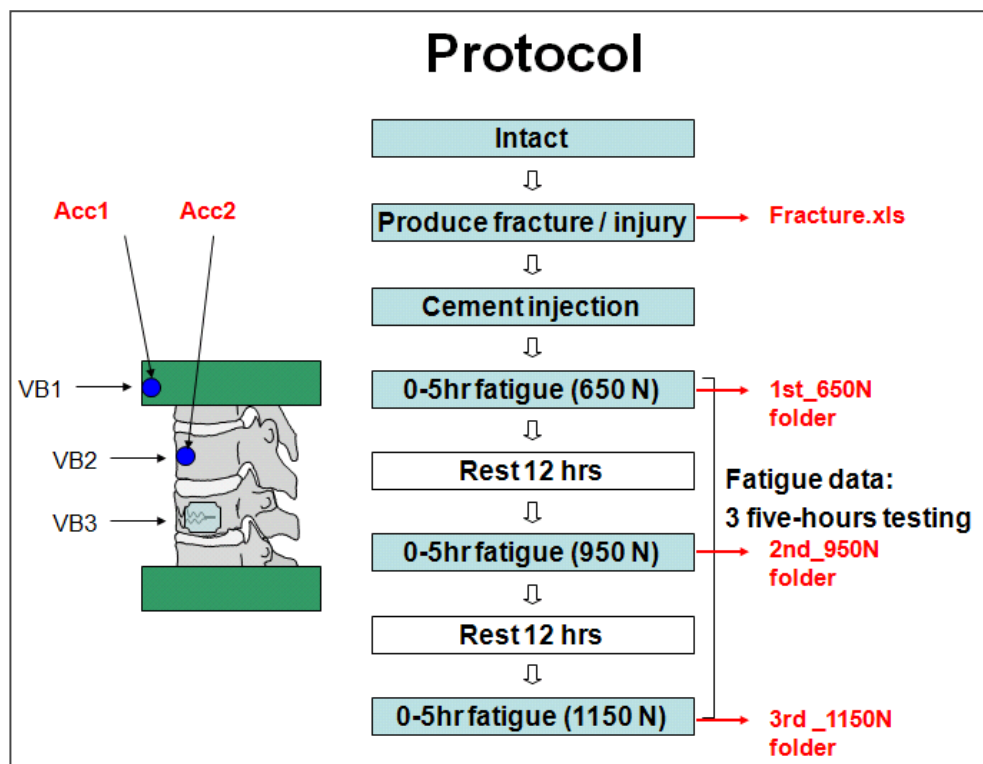


Figure 6 Experiment Protocol [19]

- 1) First stage was labeling vertebra level. VB3 was the vertebra that would be the location of cement injection. VB2 was the intact vertebra due to fracture –to-be of VB3.
- 2) Second stage was to produce fracture or injury. This one was by applying impulse energy to the tested vertebra.
- 3) Third stage was when cement injection done in the VB3, where the fracture occurred.
- 4) Fourth stage was when we applying 650N force within 0-5 hours fatigue.
- 5) Fifth stage was when the tested vertebra rest for about 12 hours. It was important to ensure the spinal disc would back to the original form. The fourth and fifth stages were repeated by applying 950N and 1150N respectively.

Parameters of data investigation based on this experiment are:

- Acceleration 1 (taken from upper vertebra, VB1)
- Acceleration 2 (taken from lower vertebra, VB2)
- Force
- Displacement (taken when any displacement experienced by vertebra)

## **3.2 Tool and Equipment**

### *3.2.1 Software*

MATLAB is numerical computing environment and programming language. Created by The MathWorks, Matlab allows easy matrix manipulation, plotting the functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. The Matlab code used for the project is attached in Appendix B.

## **3.3 Data Analysis using Filter**

The author used data from *Fracture.xls*. The data contains information of ‘Acceleration 1’, ‘Acceleration 2’ and ‘Displacement’ respectively. First of all, the author plotted the original data. Then, she analyzed the data by using average and median filters. X-axis of the graph shows the time of data taken which is 2 seconds

for total of 10000 samples while y-axis shows the duration in order from 0min in the bottom to 60min in the top. 0min in the bottom was considered as the reference value.

Both showed the data became smoother and noise removed. Figure 7, 8 and 9 shows the distribution of data based on the duration respectively. For average filter, she used sliding window of 5. The higher the size of the window, the smoother data she got. For median filter, she used the order of 5. The higher the order number, the smoother data she got. From the graphs, she managed to differentiate that median filter is better than average filter. It is because of median filter considers the outliers, so the result would be taken in the middle value and do not interrupt other values. As a simple analysis from these result was the more the load was put on the back bone, the more it got fractured.

### **3.4 Data Analysis using Signal Processing Approaches**

Data is analyzed using the Statistics. PCA and SVD are useful techniques that have found application in fields such as face recognition and image compression, and are common techniques for finding the patterns in data of high dimension. Both of the data analysis mainly have objective to find the features that provide information on:

- Duration of load when VB1 and VB2 start to slip and accelerate
- Relationship between all parameters

#### *3.4.1 PCA*

PCA involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. PCA is the simplest of true eigenvector based multivariate analysis. It supplies us with lower dimensional data space from most informative viewpoint [15].

### 3.4.1.1 Input Data

The input was taken from median filtered data. Once performing PCA to the median filtered data, author obtained the eigenvalues from the covariance matrix. This is important to measure the percentage differences and similarity factors between two dimensions data. The data of producing fracture later were denoted in 7 time frames which were 0min, 10min, 20min, 30min, 40min, 50min and 60min. Then PCA relationship is easier to be determined.

### 3.4.1.2 Feature Extraction

Each denoted data consist of 4 parameters which are ‘Acceleration1’, ‘Acceleration2’, ‘Force’ and ‘Displacement’. The author computed PCA to these four parameters to find the covariance matrix, eigenvalues matrix and eigenvectors matrix.

After that she calculated the percentage of similarity factors and differences based on its diagonal matrices of eigenvalues of covariance matrix. The percentage differences between dimension was obtained by defining first the reference value. Let say 0min as reference. Therefore, she calculated the percentage difference between this reference value with other time frames. As the percentage difference become larger, the more differ the value with the reference value.

The similarity factors between dimension was obtained by using the cosine product of eigenvectors for such matrix X and Y. She used equations below to calculate the energy of matrices.

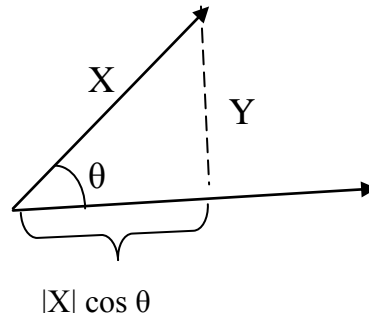
$$E [X] = \| X \|_F^2 = \sum_{i=1}^m \sum_{j=1}^n (x_{ij})^2$$

$$E [Y] = \| Y \|_F^2 = \sum_{i=1}^m \sum_{j=1}^n (y_{ij})^2$$

The length of the arrows represents the magnitudes of the vectors and the angle described by the vectors represents their orientation in the two-dimensional space. As the angle between the vectors shortens, the cosine angle approaches 1, meaning that the two vectors are getting closer. Therefore the similarity of both

vectors increases. In the other words is just to estimate the closeness between vectors. The dot product is normalized by dividing the magnitudes to compute a cosine angle. This is also known as cosine normalization which allows one to compare the angle between the weighted vectors [16] [17].

$ X  = \sqrt{x^2};  Y  = \sqrt{y^2}$ $X \cdot Y =  X   Y  \cos \theta$ $\cos \theta = (X \cdot Y) / ( x   y )$
--



### 3.4.2 SVD

The purpose of SVD is to decompose a dataset containing a large number of values to a dataset containing significantly fewer values, but which still contains a large fraction of the variability present in the original data. Often in the atmospheric and geophysical sciences, data will exhibit large spatial correlations. SVD analysis results in a more compact representation of these correlations, especially with multivariate datasets and can provide insight into spatial and temporal variations exhibited in the fields of data being analyzed [18].

#### 3.4.2.1 Input Data

The input data is taken from median filtered data. SVD can be used to investigate the relationship between two dimensions or more. The connections between various parameters are shown in the eigenvalues and eigenvector of input matrix. The data of producing fracture later were denoted in 7 time frames which were 0min, 10min, 20min, 30min, 40min, 50min and 60min. Whereas the data after cement injection were denoted in time frames of 1hour, 2hour, 3hour, until 35hour so that SVD analysis will be much easier.



### *3.4.2.2 Feature Extraction*

Each denoted data consist of 4 parameters which are ‘Acceleration1’, ‘Acceleration2’, ‘Force’ and ‘Displacement’. The author calculated the relation between these four parameters based on the singular matrix. After that she calculated the percentage differences and similarity factors also the energy based on its diagonal matrices of singular matrix of SVD. The details is repetition in Section 3.4.1.2.

## CHAPTER 4

### RESULT AND DISCUSSION

#### 4.1 Result

Section 4.1.1 touches on result of reduction noise for the Fracture.xls file which is the producing fracture data. Section 4.1.2 touches on measurement of percentage different of the producing fracture data based on PCA and SVD features. Next, section 4.1.3 discusses on measurement of similarity factor of the producing fracture data based on PCA and SVD features. Then, section 4.1.4 discusses on percentage difference of cement injection data based on SVD feature.

Based on the Fracture.xls which recorded the producing fracture had 4 parameters; ‘Acceleration1’, ‘Acceleration2’, ‘Displacement’ and ‘Force’. The data was measured for 2 seconds and this measurement repeated every 10 minutes for total period of 1 hour. Therefore the time frames would be 0min, 10min, 20min, 30min, 40min, 50min and 60min. In the other hand, cement injection data was measured for total period of 5 hours. Then, the time frames would be 0min, 10min, 20min until 300min.

For PCA, first step was to get zero-mean data. Then the covariance of matrix was calculated using all parameters. Second, the eigenvectors or principal component matrix and eigenvalues of covariance matrix were calculated.

For SVD, as previous description;

$$\mathbf{A} = \mathbf{U}_{m \times m} \cdot \mathbf{\Sigma}_{m \times n} \cdot \mathbf{V}_{n \times n}^T$$

$$\mathbf{A} = \mathbf{U}_{10000 \times 10000} \cdot \mathbf{\Sigma}_{10000 \times 4} \cdot \mathbf{V}_{4 \times 4}^T$$

Matrix  $\mathbf{\Sigma}$  contains singular values for matrix A. Actual size of matrix  $\mathbf{\Sigma}$  was 10000x4 dimensions which was arranged in descending order and 4x1 dimensions, because the rest are close to 0. Column of matrix V are eigenvectors for  $\mathbf{A}^* \mathbf{A}$ . Column of matrix U are eigenvectors for  $\mathbf{A} \mathbf{A}^*$ . Since matrix U has large dimension of

10000x10000, the author only consider the values that contribute most to this calculation. Details are attached in Appendix A.

The author expressed 4 important parameters that need to be analyzed which were 'Acceleration1', 'Acceleration2', 'Displacement' and 'Force'. After filtered by median filter, these parameters were computed using PCA and SVD. Author defined 5 cases to determine the relationship among all parameters. The parameters were arranged in column respectively. The cases were:

- 1) 4 parameters [Displacement Force Acceleration1 Acceleration2]
- 2) 3 parameters [Displacement Acceleration1 Acceleration2]
- 3) 2 parameters [Displacement Acceleration1]
- 4) 2 parameters [Displacement Acceleration2]
- 5) 2 parameters [Acceleration1 Acceleration2]

#### **4.1.1 Noise Reduction**

The author is just showing the Displacement versus duration as an example of before and after filtering. The rest are attached in Appendix A.

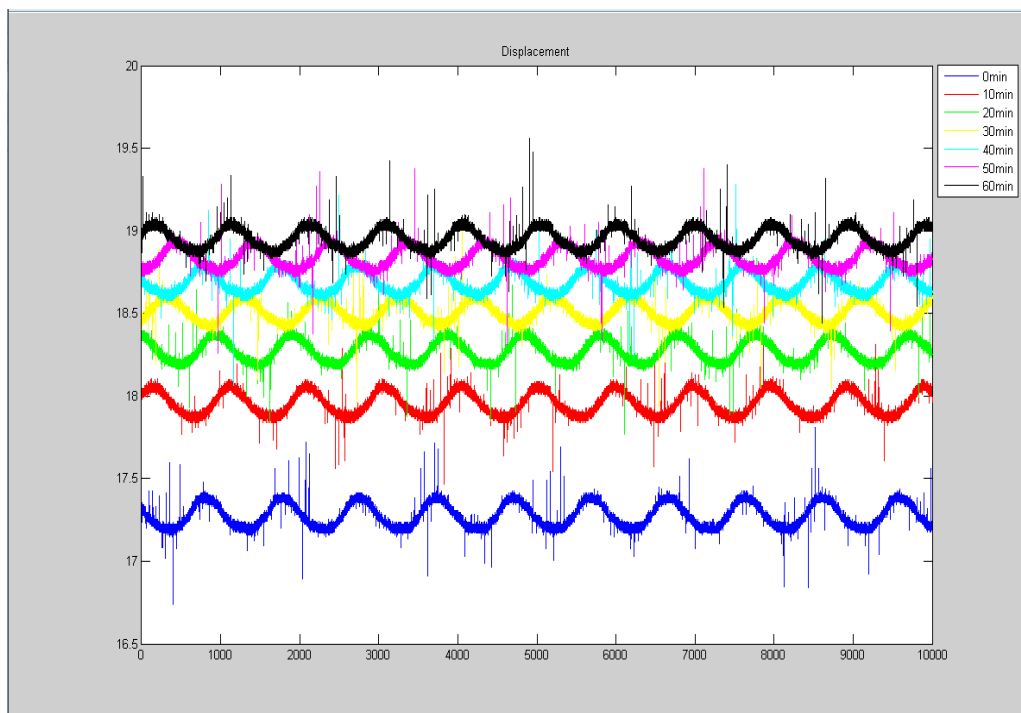


Figure 7 Before filtering Displacement data

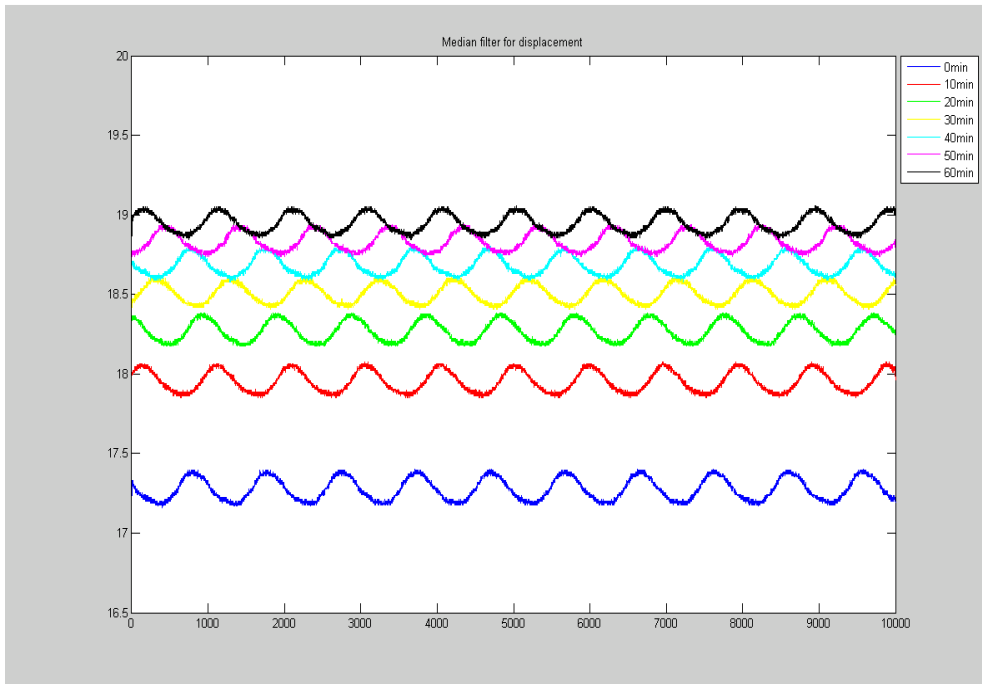


Figure 8 After filtering the Displacement data using Median Filter

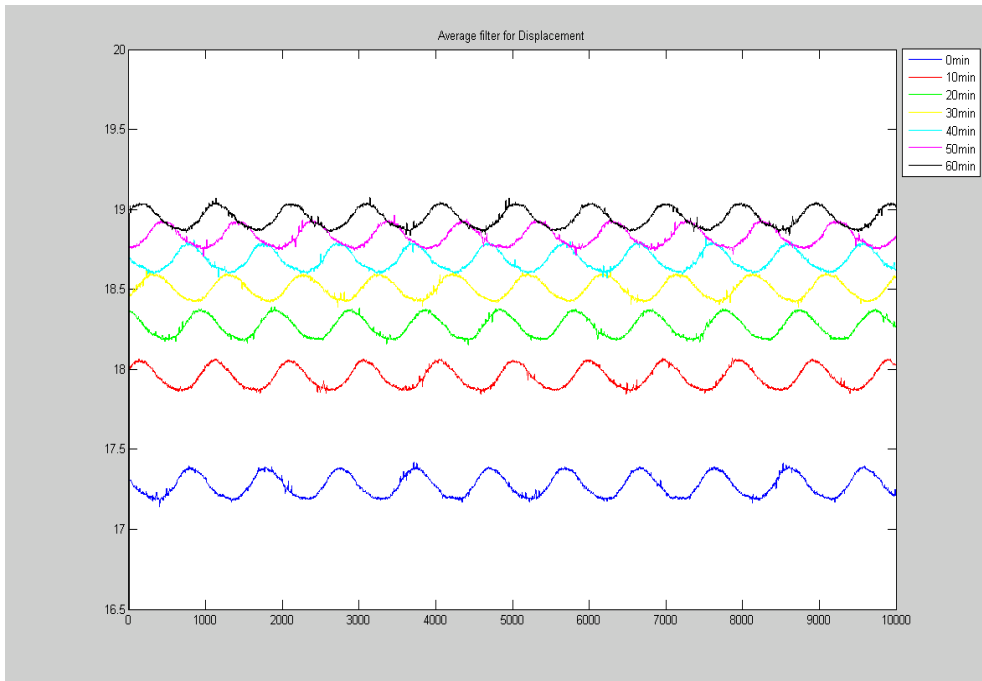


Figure 9 After filtering the Displacement data using Average Filter

The result she obtained by filtering data *Fracture.xls* which is data of producing fracture and data after cement injection using median filter was later used to be the input for all analysis in this project

#### 4.1.2 Measurement of Percentage Differences

During the short-term fatigue loading when the process of producing fracture took place. The vertebra was loaded with 0.5kN and the measurement was taken for each 2 seconds and was repeated every 10 minutes for total period of 1 hour. To calculate percentage difference for PCA analysis, the source data was first value of eigenvalues matrix whereas to calculate percentage difference for SVD analysis, the source data was first value of singular matrix. Author used the first value because it contains the most information.

The plot in graph starts from zero. First, takes 0min PCA or SVD value as a reference to all other time frames. Similarly plot in graph by taking 10min SVD as reference to all time frames and do same for the rest.

##### 4.1.2.1 Analysis using PCA

PCA method was used to predict and analyze various parameters on mechanical discs. After computing PCA to Case1, author obtained eigenvalues matrix and eigenvectors. Let denote X as the first value of eigenvalues matrix of 0min value a reference. Let Y denote as the first eigenvalues matrix of 10min. For example:

$$X = 0.2554; Y = 0.3059$$

$$\text{Percentage difference} = \frac{|0.2554 - 0.3059|}{0.2554} \times 100 = 19.77\%$$

She did the same way for all cases. Figure 10 shows the percentage difference for first value of eigenvalues matrix for Case 1. Result in tabular forms for Case 1 and the others are attached in Appendix B. x-axis is the time frame of 0min, 10min until 60min with 10 minutes different for total period of 1 hour. y-axis is the percentage difference among the time frames. Recall that, 0min value was when vertebra started to put some load which there was no fracture occur yet. Therefore, she only considered calculation of 0min as reference as the most valid information for all cases and the others were neglected.

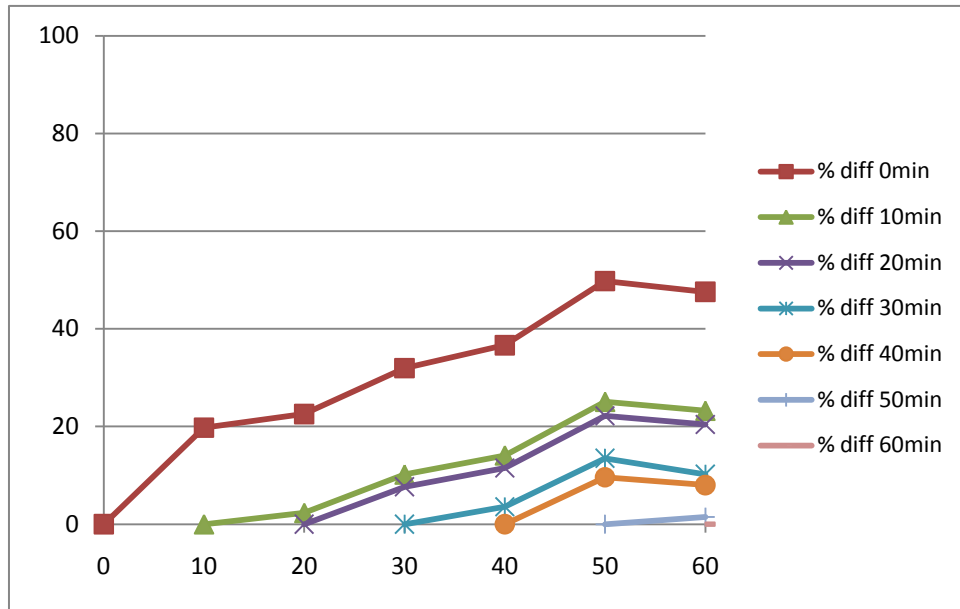


Figure 10 Percentage difference using PCA for Case 1

Figure 10 shows the first value of eigenvalues matrix for Case 1 which used Displacement, Force, Acceleration1 and Acceleration2 as parameters. We can see percentages different increased from 0min to 50min about 13 to 20%. When it arrived at 50min, the percentage different decreased about 2%.

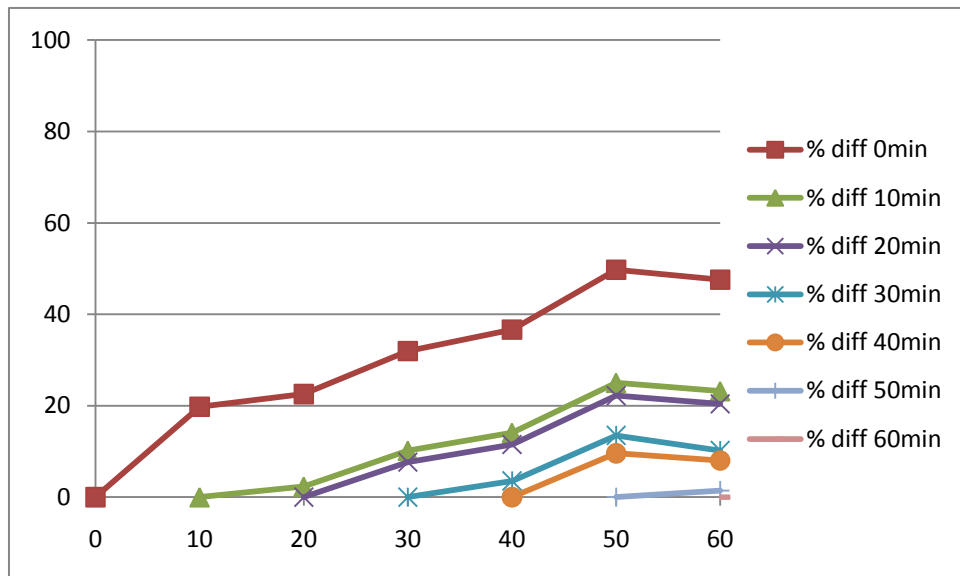


Figure 11 Percentage difference using PCA for Case 2

Figure 11 showed graph for Case 2. We can see the pattern was similar to Case 1. Difference parameters were used but obtained the same graph. Therefore author conclude that Force parameter is constant parameter and did not effect to the vertebra and vertebral disc changes.

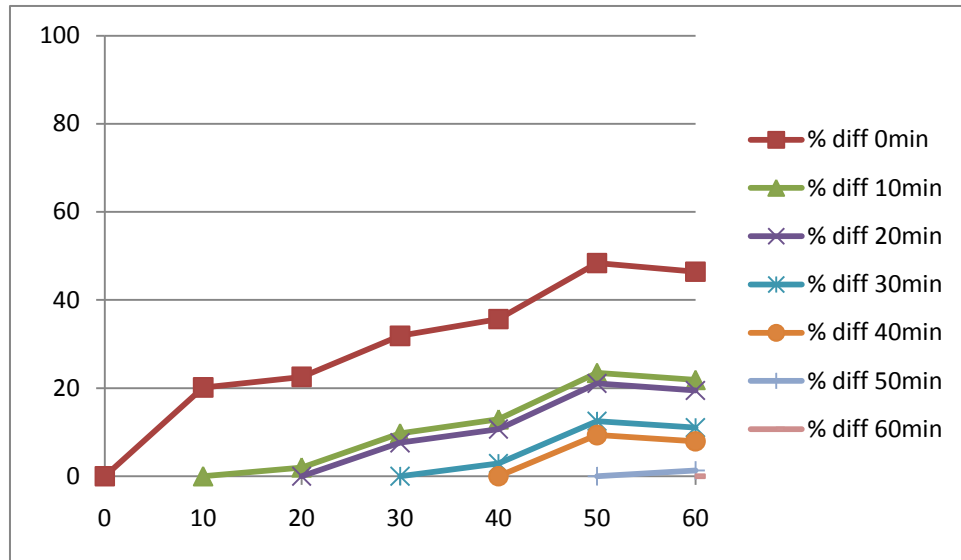


Figure 12 Percentage difference using PCA for Case 3

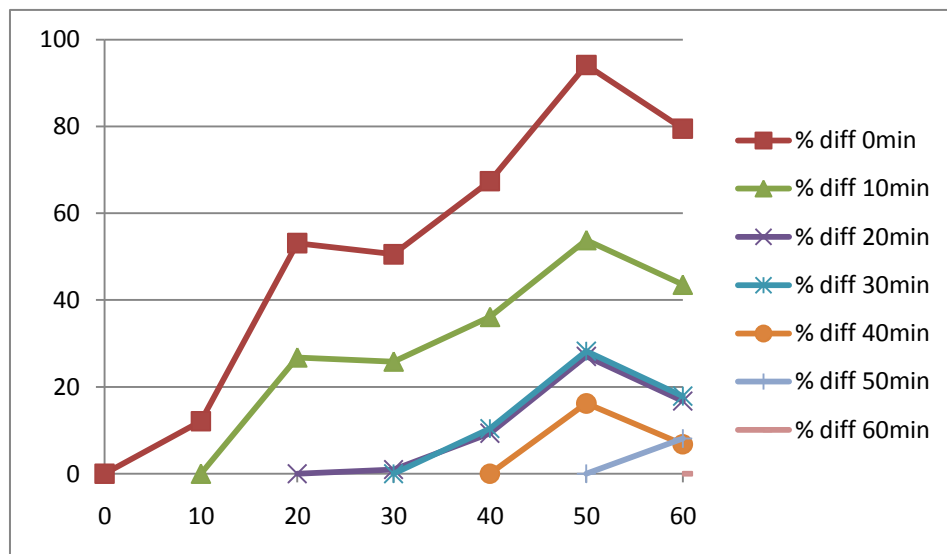


Figure 13 Percentage difference using PCA Case 4

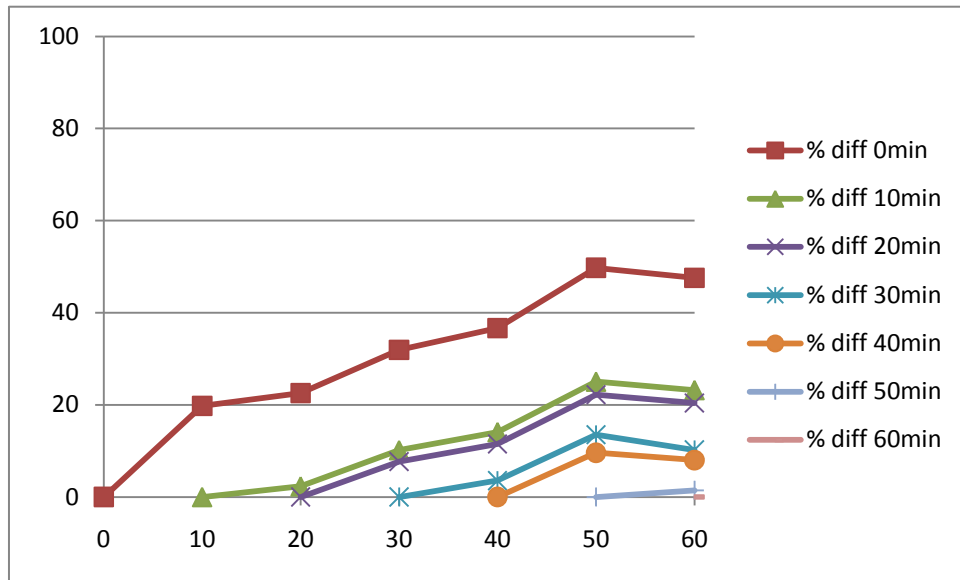


Figure 14 Percentage difference using PCA for Case 5

Figure 12 to 14 showed the graph of Case 3, Case 4 and Case 5 respectively. She obtained Case 3 and Case 5 similar to Case 1. These showed strong relation the increased of eigenvalues with time until minute of 50. There were slightly decreasing value of percentage different. For Case 4, there are some difference in value of increment and decrement but still showing the same pattern with others.

#### 4.1.2.2 Measurement using SVD

SVD method was also used to predict and analyze various parameters on mechanical discs. She used median filtered data as a source of SVD for Case 1 and computed singular matrix, right singular matrix and left singular matrix. Let denote X as singular matrix of 0min value; let denote Y as singular matrix of 10min. Later she computed the consecutive difference between X and Y, X and Z until time frame of 60min. For example:

$$X = 1728.9 ; Y = 1796.5$$

$$\text{Percentage difference} = \frac{|1728.9 - 1796.5|}{1728.9} \times 100 = 19.77\%$$



She did the same way for all cases. Figure 15 shows the percentage difference for first value of singular matrix for Case 1. Result in tabular forms for Case 1 and the others are attached in Appendix B. x-axis is the time frame of 0min, 10min until 60min with 10 minutes different for total period of 1 hour. y-axis is the percentage difference among all the time frames. Recall that, 0min value was when vertebra started to put some load which there was no fracture occur yet. Therefore, she only considered calculation of 0min as reference as the most valid information for all cases and the others were neglected.

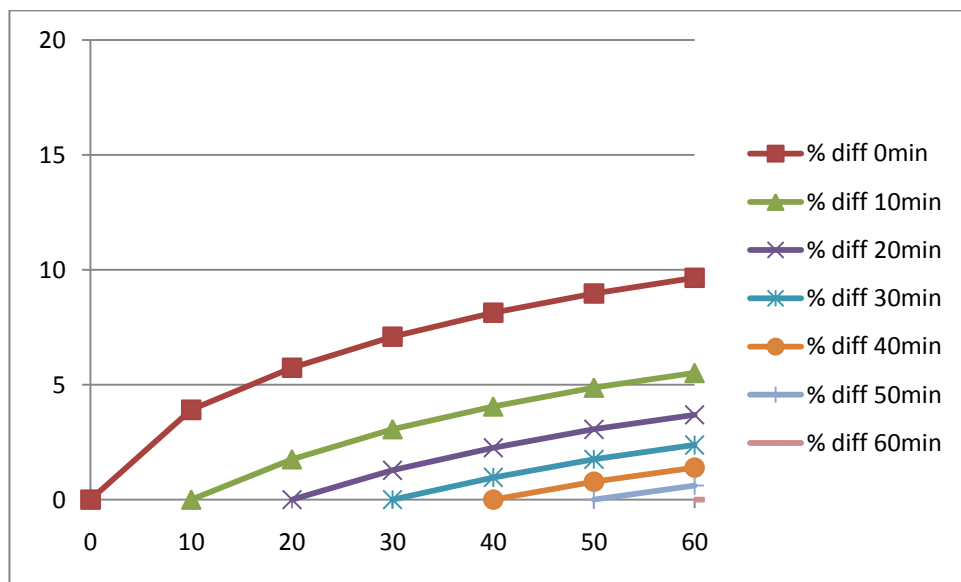


Figure 15 Percentage difference using SVD Case 1

Based on Figure 15, the highest increment was during 0min and 10min which was 3.9%. Then, it experienced increment about 1.83% at 0min and 20min and increment of 2.39% at 0min and 30min. After minute of 30, there were small increments which were below 1%. It can be considered as steady state which might show the vertebra started to fracture.

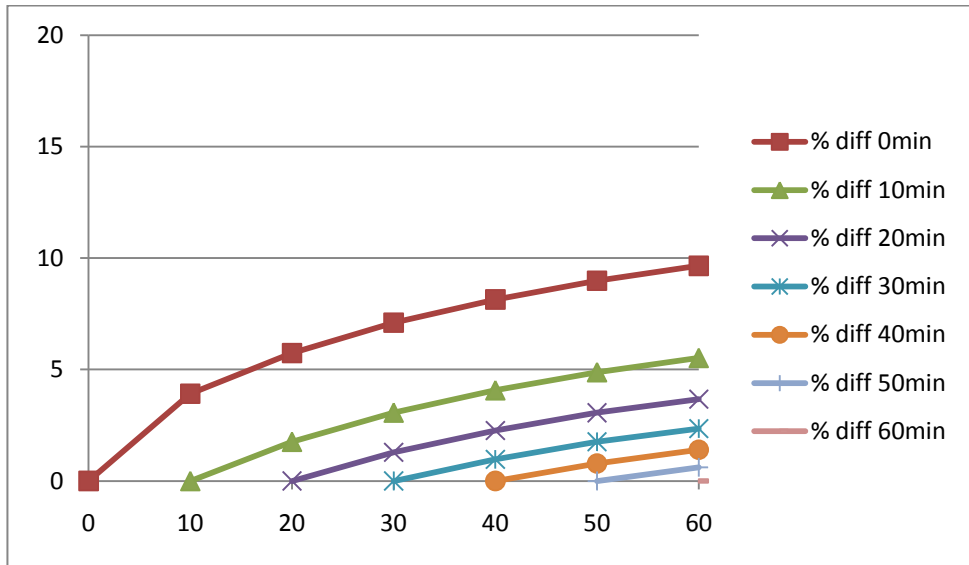


Figure 16 Percentage difference using SVD for Case 2

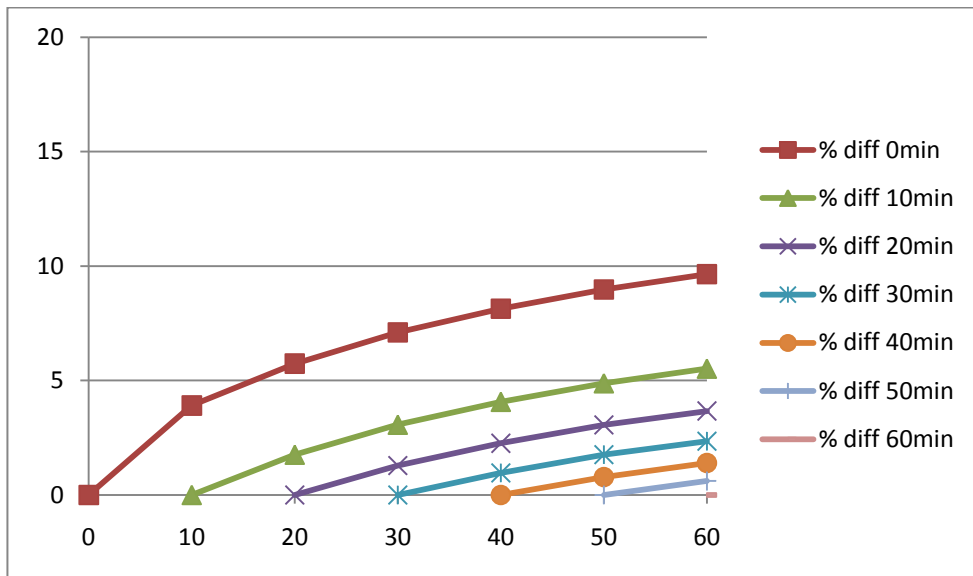


Figure 17 Percentage difference using SVD for Case 3

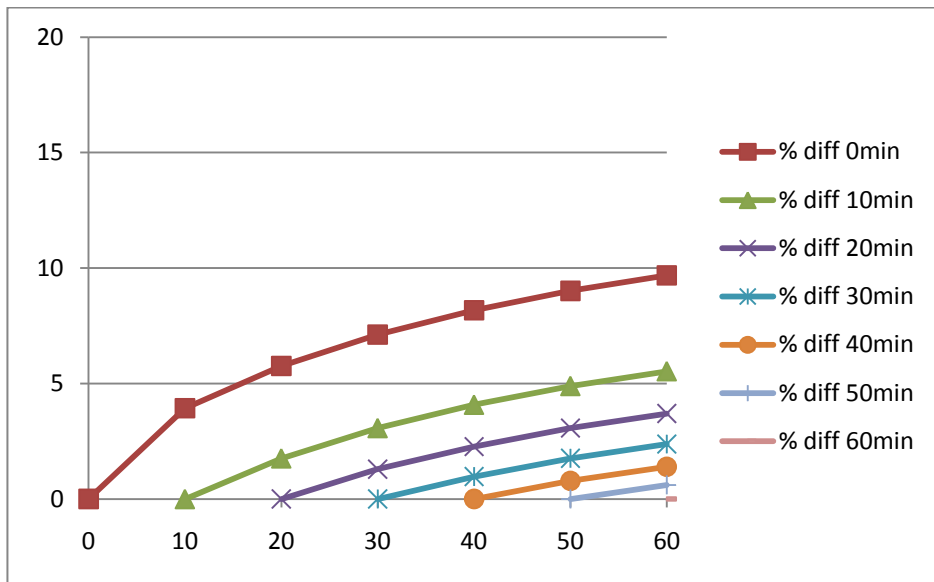


Figure 18 Percentage difference using SVD for Case 4

Figure 16 to 18 showed Case 2, Case 3 and Case 4 respectively. By computing SVD method on data, author obtained values of singular matrix which have similar result with Case 1. Then, it increased about 3.9% between 0min and 10min. Then increment about 2% between 0min and 10min. Increment 0min and 20min also about 2%. After minute of 30, the increments were only about 1%. Early prediction, Case 1, Case 2, Case 3 and Case 4 showed percentage differences after 30min can be considered as steady state which suggested the vertebra started to fracture.

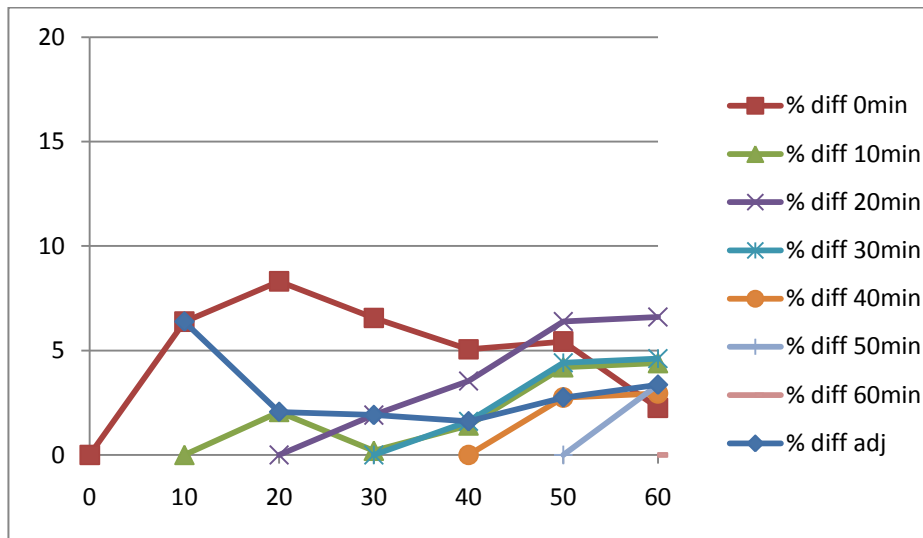


Figure 19 Percentage difference using SVD for Case 5

By computing SVD method on data, author obtained values of singular matrix for Case 5 was totally different with others refer Figure 19. The values were increasing and decreasing without sequences. Therefore author concluded that Case 5 can be ignored when computed stages after Cement Injection.

Figure 15 to 18 showed the significant percentage difference for first value of singular matrix of SVD respectively based on cases announced by author in the early analysis. These tables showed singular matrix of SVD and percentage difference between consecutive values increased as the time increased. 0min was considered as reference value because there was no load condition. During frequent bending and lifting, it might cause mechanism of fatigue failure and lead to the process of low back disorders. That was why values keep increasing. As we put some loads within some periods, the percentage different increased until 30min. After minute of 30, increment of percentage differences were only 1%. She presumed data already reached in the steady state. For early prediction, she has priori knowledge that the fracture occurs around 30min to 50min. If no rest, the disc cannot restore the fluid content in normal position because it might take a long time to be healed.

### 4.1.3 Measurement of Similarity Factor

During the short-term fatigue loading when the process of producing fracture took place. The vertebra was loaded with 0.5kN and the measurement was taken for each 2 seconds and was repeated every 10 minutes for total period of 1 hour. To calculate similarity factor for PCA analysis, the source data was eigenvectors matrix whereas to calculate percentage difference for SVD analysis, the source data was right singular matrix. The plot in graph starts from zero. First takes 0min and 10min PCA or SVD and calculate the similarity percentage. Similarly, plot in graph by taking 0min and 20min PCA or SVD and calculate the similarity percentage. She repeated the step for the rest.

#### 4.1.3.1 Analysis using PCA

In the initial stage, PCA was examined on prediction of backbone get damaged. The result obtained that 30 to 50min is the optimum time that backbone discs get damaged since there were recorded to had least change in eigenvalues matrix values. She used result of median filtered and applied to PCA. Later she obtained the eigenvectors which became the source to compute the similarity factors between all time frames. To calculate similarity factors, let denote A as eigenvectors matrix of 0min and B as eigenvectors matrix for 10min.

$$\begin{aligned}\text{Similarity factor} &= (|A \cdot B|) / \sqrt{(A^2 \cdot B^2)} \times 100 \\ &= 99.8862\%.\end{aligned}$$

Figure 20 shows the similarity factors for first value of principal component matrix for Case 1. Result in tabular forms for Case 1 and the others are attached in Appendix B. x-axis is the time frame of 0min, 10min until 60min with 10 minutes different for total period of 1 hour. y-axis is the percentage difference among all the time frames.

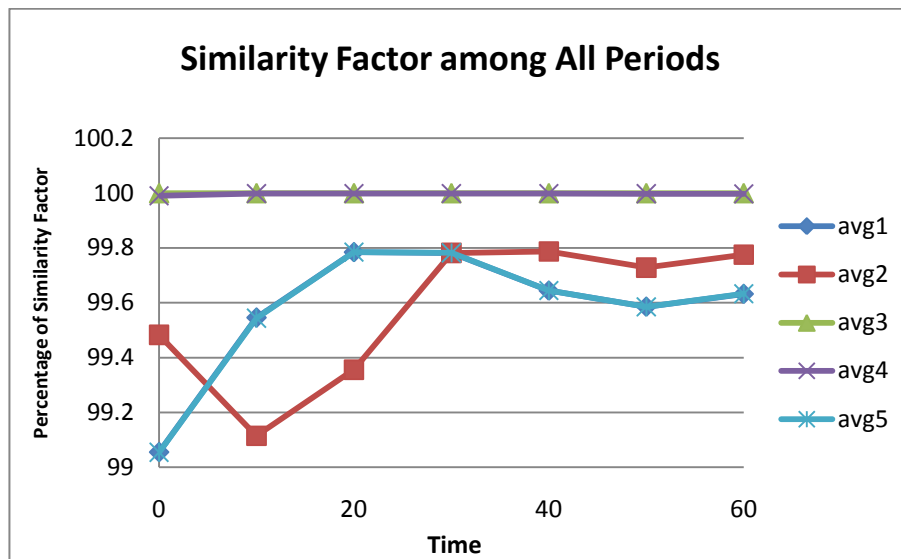


Figure 20 Similarity factor using PCA for all cases

Author computed the similarity factor among 0min and all time frames, later 10min and all time frames, 20min with all time frames and so on. As the other values than 0min were used as a reference, the patterns were almost the same. It increased from 0min to 20min, then constant at 30min. Later it decreased after 30min. For better understanding Figure 20 plotted only average of similarity factors between all time frames.

She obtained similarity factors of Case 1 between 0min and all periods were increasing. There was 0.5% increment from 0min to 10min. Later it increased about 0.23%. For 20min and 30min experienced only 0.003% increment. However, when arrived at minute of 40 the percentage decreased about 0.14%. At 50min also decreased again about 0.06%. Next at 60min, it increased 0.047%. Result of Case 1 was similar to Case 5. Recall that Case 5 is combination Acceleration1 and Acceleration2 parameters.

Red colored line explains the relationship between three parameters. At time between 0min and 10min, it decreased about 0.37%. Then after 20min, similar factors increased about 0.24% and appeared to be constant after time at 30min. Author concluded these three parameters increased as the time increased and suggested Force parameter still has some effect to the backbone in early fatigue loading. Line green and purple showed the two parameters in Case 3 and Case 4 respectively. The

similarity factors almost reached 100% for all time frames. It means, as the time increased, these parameters also increased. Or the more precise, as the Displacement parameter increased with time, Acceleration1 and Acceleration2 parameters also increased.

The five figures explained much about mechanical discs condition before and after removing the weight. In Figure 20 alone explained as time at 0min to 10min, there were almost constant for Case 3 and Case 4 between all time frames. This show that the function of compressive and tensile might start to change the physical of vertebra discs. As displacement increased, acceleration also increased. This guess may prove by formula of acceleration equals to velocity divided by time. Note that velocity is in term of displacement. It is true because of the vertebra transverse long arc at some velocity. This Acceleration clearly computed the rate of vertebra accelerated in small amount of displacement relative to the adjacent vertebra. For Case 1 and Case 5 appeared to be same pattern but the similarity factor were low. It might be caused of all parameters increment did not proportional to each other. For Case 4, even though Displacement parameter strongly correlated with Acceleration1 and Acceleration2 parameters, author suggested Acceleration1 and Acceleration2 did not proportional to each other since Acceleration2 is the most affected due to it is nearer to the fractured vertebra. When the discs were squeezed, logically the most proximal vertebra would experience more displacement to complete the movement of vertebra. However, she needs to analyze further to validate this conclusion.

#### *4.1.3.2 Analysis using SVD*

In the initial stage, SVD was examined on prediction of backbone get damaged. The result obtained that 30min is the optimum time that backbone discs get damaged since there were recorded to had least change in singular matrix values. Next was to find similarity factors for all the time frames. She used median filtered data and applied SVD. Then she calculated the similarity between those periods, let denote A as right singular matrix for 0min and B as right singular matrix for 10min. The cosine of two genuine singular vectors A and B was calculated as

$$\cos (Y) = (|A.B|) / \sqrt{(A^2.B^2)} \times 100$$

$$= 99.9957\%.$$

The rest used the same way. Result in tabular forms for all cases is attached in Appendix B. x-axis is the time frame of 0min, 10min until 60min with 10 minutes different for total period of 1 hour. y-axis is the percentage of similarity factors between parameters based on each time frame.

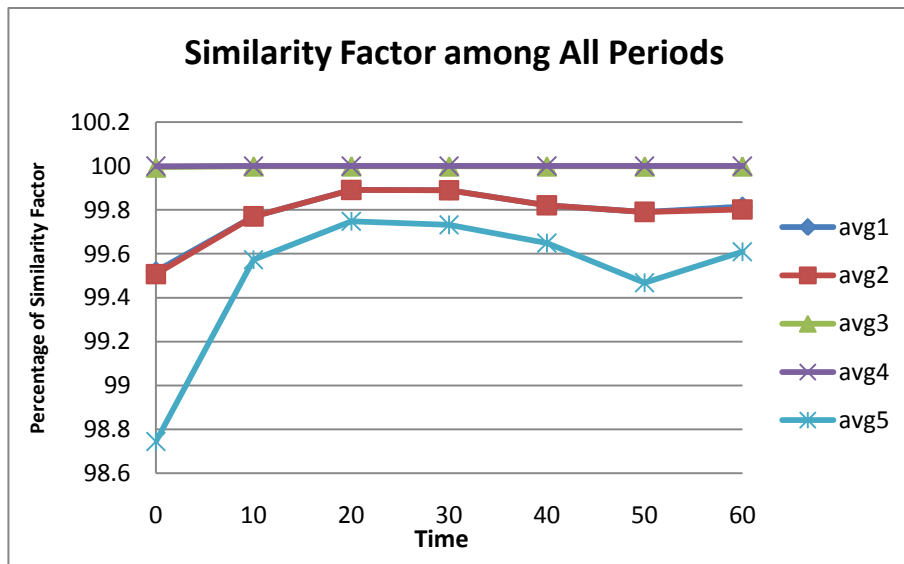


Figure 21 Similarity factor using SVD method for all cases

Author computed such that 0min as a reference; she calculated similarity factors between 0min and all time frames, later it repeated 10min and all time frames, 20min with all time frames and so on. For better understanding Figure 21 plotted only average of similarity factor among all cases.

For Case 1 and Case 2, they appeared to be similar. Author obtained similar factors among 0min and all period were increasing. There was 0.25% increment from 0min to 10min. Later it increased to about 0.11%. After minute of 20 it increased and decreased about 0.001% increment which almost constant. Next she examined the similarity factor for Case 3 recall that two parameters which were Displacement and Acceleration1 were involved. As we can see, the pattern of graph for Case 4 which involved Displacement and Acceleration2 was similar to Case 3. The similar factors were increasing and decreasing in the range of 99.99% plus to make these two lines



constant value. It showed when vertebrae get fractured, as the time increased, Displacement and Acceleration would increase. Case 5 which involved Acceleration1 and Acceleration2 showed percentage similarity was lower than others. Therefore, author suggested that the increment in Acceleration1 did not proportional to the value of Acceleration2 and vice versa.

It can be seen all cases except Case 2 in PCA and SVD have similar patterns. Author suggested that both have same progression and explanation. The five figures explained much about mechanical discs condition before and after removing the weight. In Figure 21 alone explained as time at 0min to 10min, there were almost constant for Case 3 and Case 4 between all time frames. This show that the function of compressive and tensile might start to change the physical of vertebra discs. As displacement increased, acceleration also increased. This guess may prove by formula of acceleration equals to velocity divided by time. Note that velocity is in term of displacement. It is true because of the vertebra transverse long arc at some velocity. This Acceleration clearly computed the rate of vertebra accelerated in small amount of displacement relative to the adjacent vertebra. For Case 1 and Case 2 appeared to be same pattern suggested that Force did not convey much information. For Case 5 it might be caused of all parameters increment did not proportional to each other. Even though Displacement parameter strongly correlated with Acceleration1 and Acceleration2 parameters, author suggested Acceleration1 and Acceleration2 did not proportional to each other since Acceleration2 is the most affected due to it is nearer to the fractured vertebra. Author suggests when discs were squeezed; the most proximal vertebra of cause would experience more displacement to complete the movement of vertebra.

#### 4.1.4 Analyzing Data after Cement Injection

Recall that analysis in section 4.1.2 and 4.1.3 were referring to produce fracture or injury stage. The load applied was 0.5kN. We can refer to Protocol Experiment in Figure 6. The stage after that was Cement Injection. The measurement was taken each 2 seconds and was repeated every 10 minutes for total of 5 hours. Therefore, the time samples were 0min, 10min, until 300min. Three different loads were applied e.g. 0.65kN, 0.95kN and 1.15kN. Each load was alternated by 12 hours rest. This is vital to ensure the vertebra disc come back to the normal position and prevent from low back pain.

However, author did not intend to analyze the data using all methods. For completeness she chose to compute data using percentage difference of singular matrix because it can show directly the changes of different loads applied. The result was shown in Figure 22.

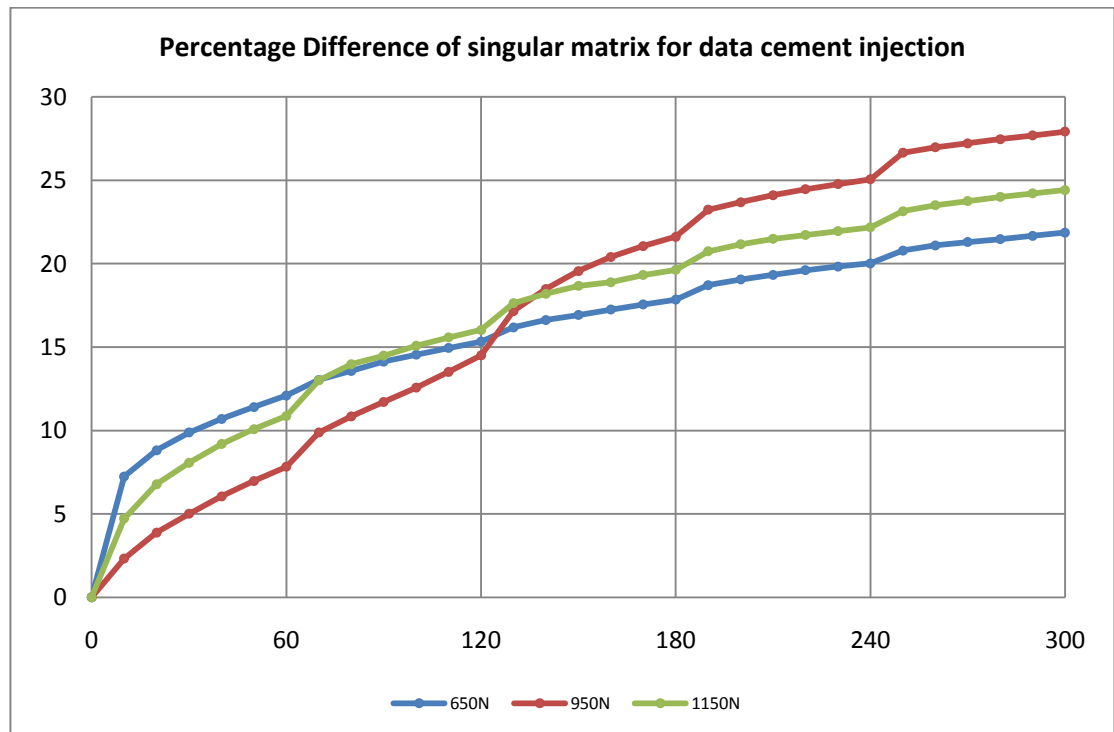


Figure 22 Percentage difference using SVD for data cement injection

From Figure 22 we can see the percentage difference increased as the time increased. All values were calculated the same way in section 4.1.2. But this time, she fixed the value of 0hour in each load as the reference value. Author analyzed line by

line, starting with blue line, 0.65kN load. From author's observation, it can be seen the percentage difference 0min with 10min was the highest compared to 0.95kN and 1.15kN which is about 7%. The different was showing big progression might be due to penetration cement filled the cleft first. After 40min it increased with small increment about 0.17% to 1.58% for rest hours. It showed that cement already fully penetrated and enhanced the strength of backbone discs.

After 12 hour rest, 0.95kN load was applied which shown in red line. At first 0min and 10min had small different about 2%. It showed rest and cement injection can prevent from progression until one limit. From this graph, 120min might be the maximum percentage different since recorded increment was 2.14%. Then it became constant or in the other words, the vertebra got fracture.

After 12 hour rest, load of 1.15kN was applied to vertebra, shown in green line. 0min and 10min recorded about 4% percentage different. It was slightly higher than when applying 0.95kN because vertebra already got fracture. However, she need to do more experiments to validate this result.

#### 4.1.5 Correlation result

In this project, author used correlation to measure the similarity between parameters while time was increasing. The result should she get was in the range -1 to 1. Correlation equals to 1 subject to strong relation between both parameters. If correlation equals to 0, it means there are no relation between both parameters. In the other hand, correlation equals to -1 means weak relation between both parameters. She decided to compute correlation between all parameters; Acceleration1, Acceleration2, Force and Displacement.

First she down sampled the *Fracture.xls* data. She took the value of every 50th (E.g. 51, 101, 151 etc). Total data is 200. Without filtering the data, she computed correlation between all parameters. Denote A as 0min data of Displacement and B as 0min data of Acceleration1. Later, she computed correlation between A and B. This computation continued until Acceleration equals to 60min. After that, plot in the same graph to compare the relationship between parameters as the time increasing. The stronger the relationship between parameters, the higher amplitude obtained. Same step used to compute the correlation between parameters stated earlier.

Result in Figure 23 is correlation between parameters which author labeled with number 1 to 6. The description for each:

- 1) Force and Displacement
- 2) Acceleration1 and Acceleration2
- 3) Acceleration1 and Displacement
- 4) Acceleration2 and Displacement
- 5) Acceleration1 and Force
- 6) Acceleration2 and Force

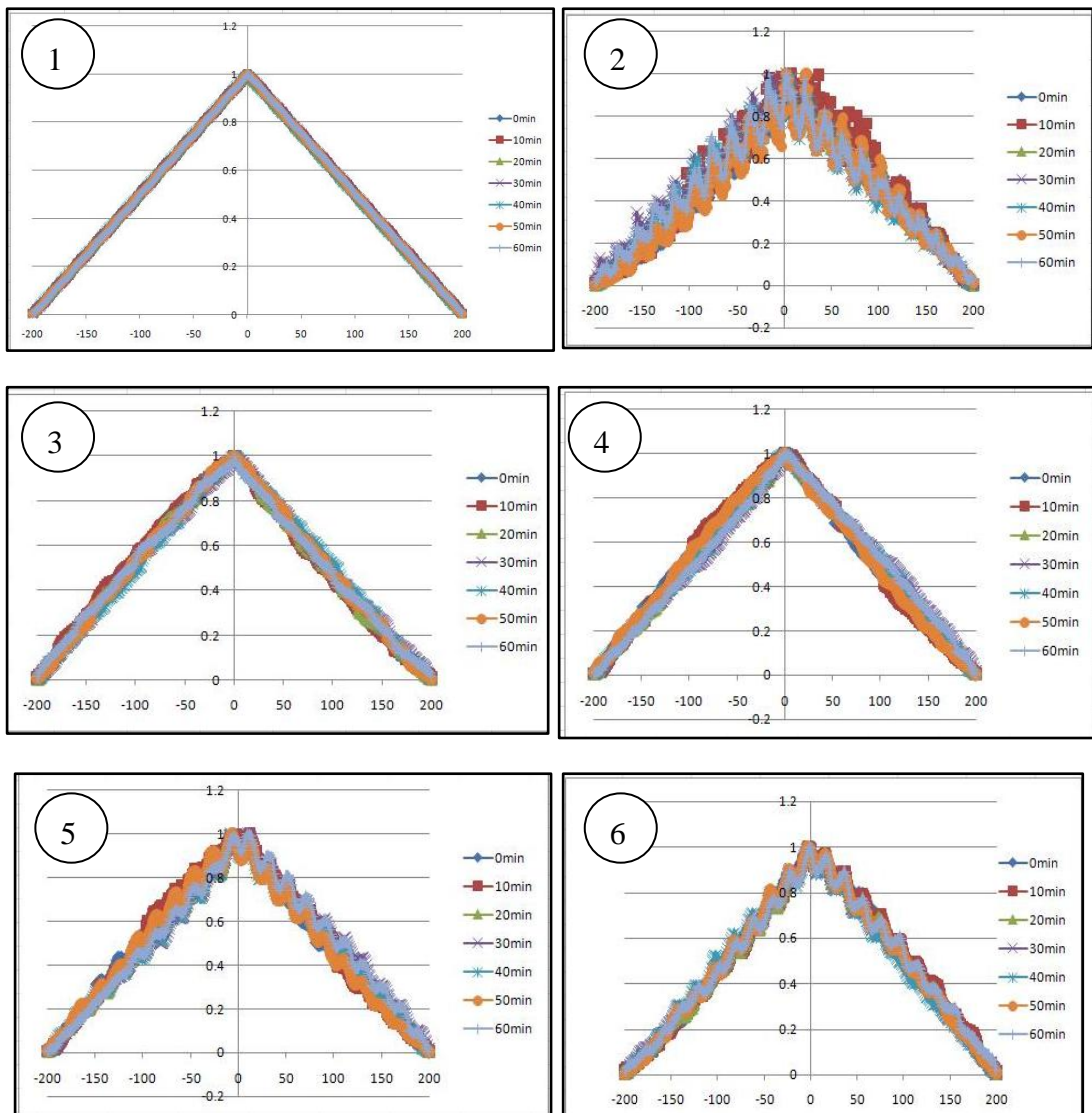


Figure 23 Result of correlation

Figure 23 shows the correlation between all parameters. We can see clearly, graph labeled 1 which is Force-Displacement has strongest relationship. It means, as the time increased, when force increased, displacement also increased. Looking for label 3, correlation between Acceleration1-Displacement; and label 4, Acceleration2-Displacement, there were similar. The argument is still the same. Acceleration is a rate of vertebra keeps moving to complete its angular displacement which author can say that the displacement increased, acceleration also increased. Therefore analysis using SVD and PCA were proved by this relationship. Correlation between Acceleration1-Force and Acceleration2-Force, refer label 5 and 6 were also similar to each other. Since Force had strong correlation with Displacement, automatically it would effect acceleration. The heavier the load vertebra has to hold, acceleration would also increase. Lastly is the correlation between Acceleration1 and Acceleration2, refer label 2. There had the weakest relation among others. The progression of Acceleration1 and Acceleration2 were not proportional to each other. Since there were inspected in different angle of vertebra. Author concluded that all correlation result satisfied SVD and PCA analysis.

## 4.2 Discussion

First finding touches the analysis of data produce injury. Based on PCA result, all graphs showed maximum percentage difference when time at 50min. It concluded that if people put load at maximum 50min, vertebral discs won't come back to normal position. This study has provided new information on kinematic behavior of the spine in 60 minutes. By combining the result of Acceleration, Displacement and Force that affecting spine movement, author was able to suggest some information throughout the movement of the cycle. Note that the more proximal vertebra of a two vertebra motion segment moves with higher velocity than the more distal vertebra of that segment. Acceleration1 is subjected to a distal vertebra while Acceleration2 is subjected to a proximal vertebra. The discs then may experience more mechanical deformation. For simple subject, acceleration refers to the rate at which each vertebra body accelerated relative to the adjacent vertebra body as the spine moved from extension to flexion. Or it can be proved by simple equation; acceleration equals to velocity divided by time. Note that velocity is a factor of displacement. In addition as time increased, each vertebra had larger angular displacement. The acceleration in vertebra also increased. Therefore it is expected that more proximal vertebra transverse a longer arc and have to move in higher velocity to complete this movement. Compared to the more distal vertebra, it accelerated slower.

Still analyzing the data of produce injury, author suggests vertebral acceleration and displacement is dependant on the force applied in the spine. Second main finding is vertebra can support load as much as 0.5kN limited to 30 to 50 minutes. Vertebra then shows the symptom of occurring fracture especially in vertebral discs. It cannot fully come back to the normal position. From PCA analysis, we can see the abrupt changes in similarity factor, shows that force was acting as a load. The tendency of vertebra discs to come back to normal position is almost zero percent due to joint degeneration because vertebra experienced wedging and compressing. Author was unable to conclude what is the real reason of deformity of vertebra discs based on its internal structure because it is not shown in this study.

All result obtained explaining much about mechanical discs condition before and after removing the weight. As we know, as the period increased, the more discs got damaged. The function such as compressive and tensile might restore its normal position after taking some rest. Researchers from University of Taipei provided the

data after cement injection. This was when vertebra got fracture then cement was penetrated to strengthen the bone so it can reduce the effect of fatigue loading.

Third main finding touches about analysis of data after cement injection. The result should give some valuable information. To get faster prediction, author considered only percentage difference method to analyze the data. Recall that, the last three stages were applying 0.65kN load to vertebra, 0.95kN load and 1.15kN load respectively. These stages were alternated with 12 hours rest. The rest was to ensure the vertebra and vertebral discs had enough strength to hold load without fracture. The percentage difference between 0min and 10min was highest when 0.65kN load was applied to vertebra. This was anticipated since the vertebra was just undergoing cement injection which reduced the progression of deformity during fatigue loading. This guess maybe proved by the less magnitude of height loss in vertebra. However, the percentage difference between 0hour and 1hour for 0.95kN was smallest since rest and cement injection have recovered the backbone disc deformity. For 1.15kN load recorded slightly higher percentage different compared to 0.95kN because the vertebra was already experiencing abnormalities. In the other hand, author obtained the three stages drew same pattern. Author predicted the 12 hour rest and cement injection can only support up to 120 minutes when putting load in backbone before get fractured again. If people want to put load for longer duration, he has to make sure to get enough rest.

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 Conclusion**

As early conclusion, the more proximal vertebra to the fractured vertebra may transverse the longer arc to move at higher velocity to complete this movement. The arc is recorded as displacement parameter. Then, when movement at higher velocity is recorded, it at the same time experience acceleration which is the rate of vertebral body accelerated to the adjacent vertebra. In addition, if people set load at range of 30 to 50 minutes, vertebra discs cannot fully come back to the normal position anymore depending on total load. It implies that fracture may occur. Rest is vey important in order to prevent the deformity and abnormalities of backbone discs. Based on author's computation using data given, people could only support loads up to 120 minutes even after rest and cement injection. After that, the performance of vertebra is lower.

#### **5.2 Recommendation**

As the objective of this project is to analyze properties of fatigue loaded backbone discs has completed, author would like to recommend the followings:

- 1) Analyzing the data using Region of Convergence or Power Spectral Density Method to get better features of parameters involved
- 2) Comparison between male and female progression of fatigue loaded backbone discs



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## **APPENDICES**

# APPENDIX A

## RESULT

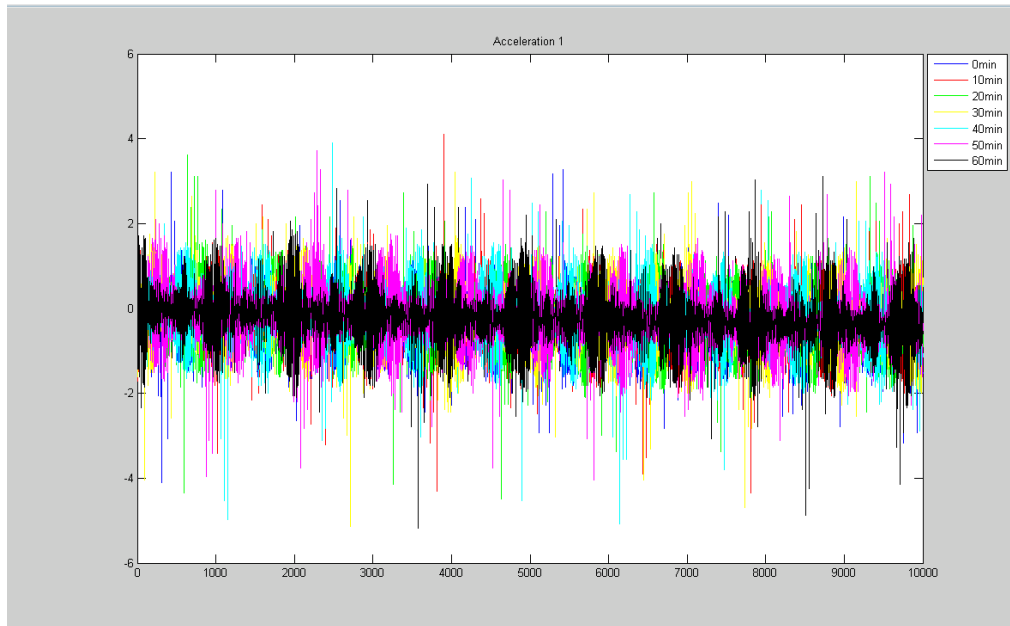


Figure 1 Acceleration1 before filtering

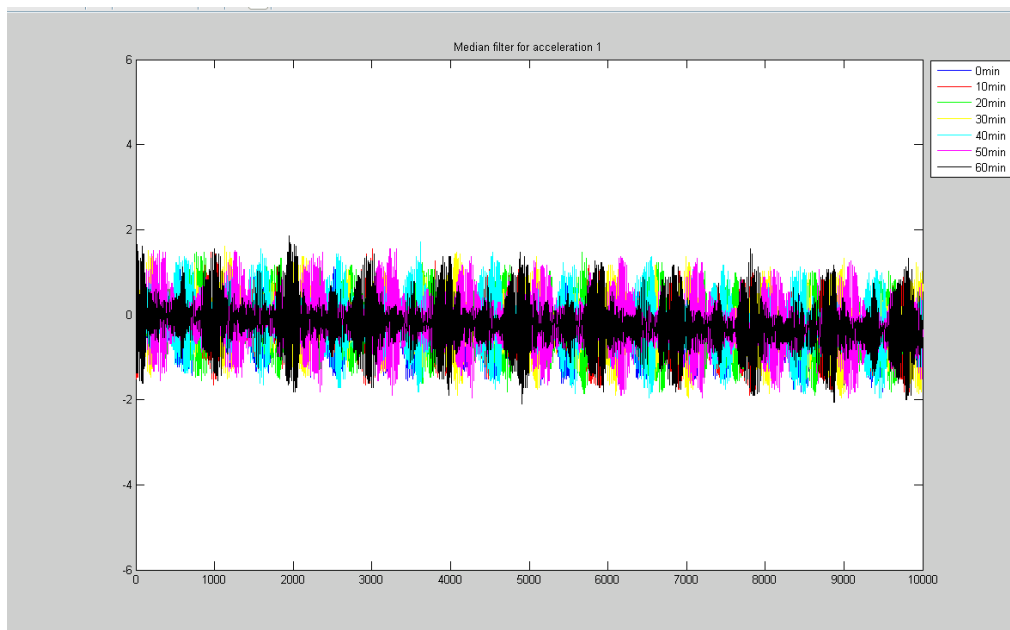


Figure 2 Acceleration1 after filtering with Median Filter

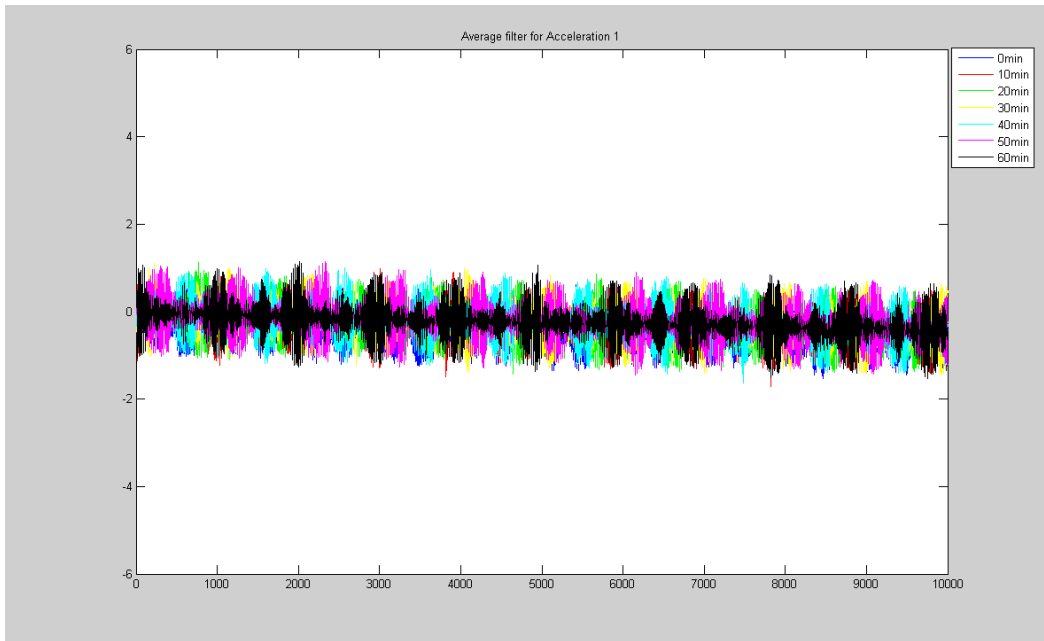


Figure 3 Acceleration1 after filtering with Average Filter

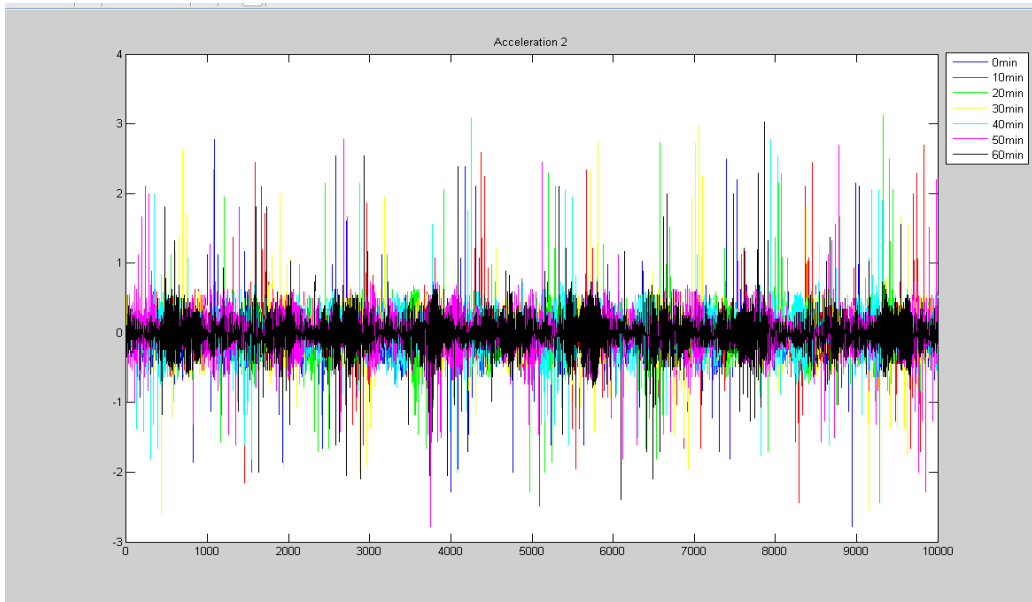


Figure 4 Acceleration2 before filtering

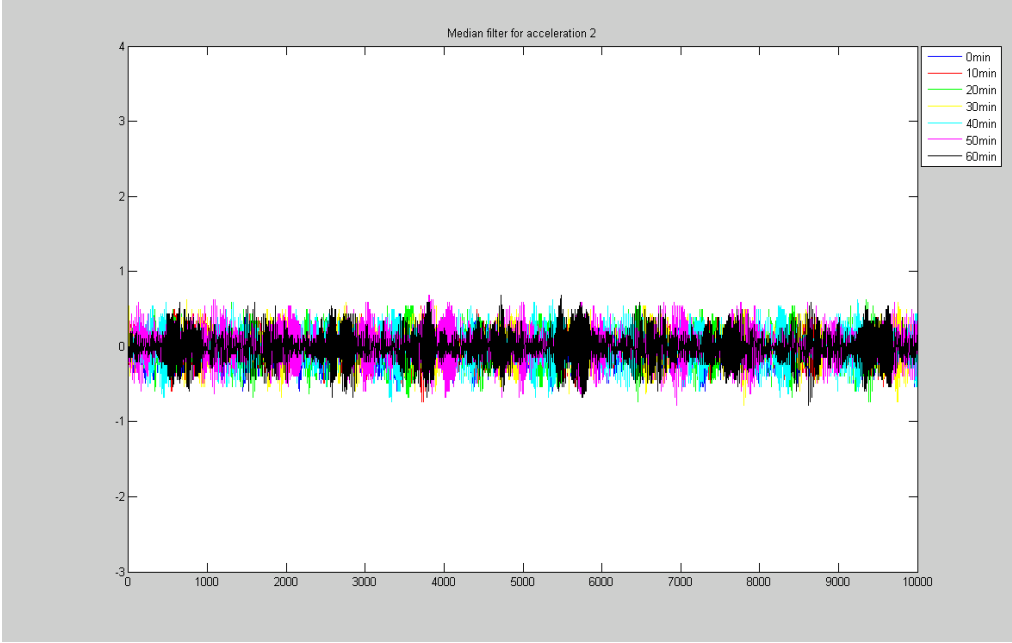


Figure 5 Acceleration2 after filtering with Median Filter

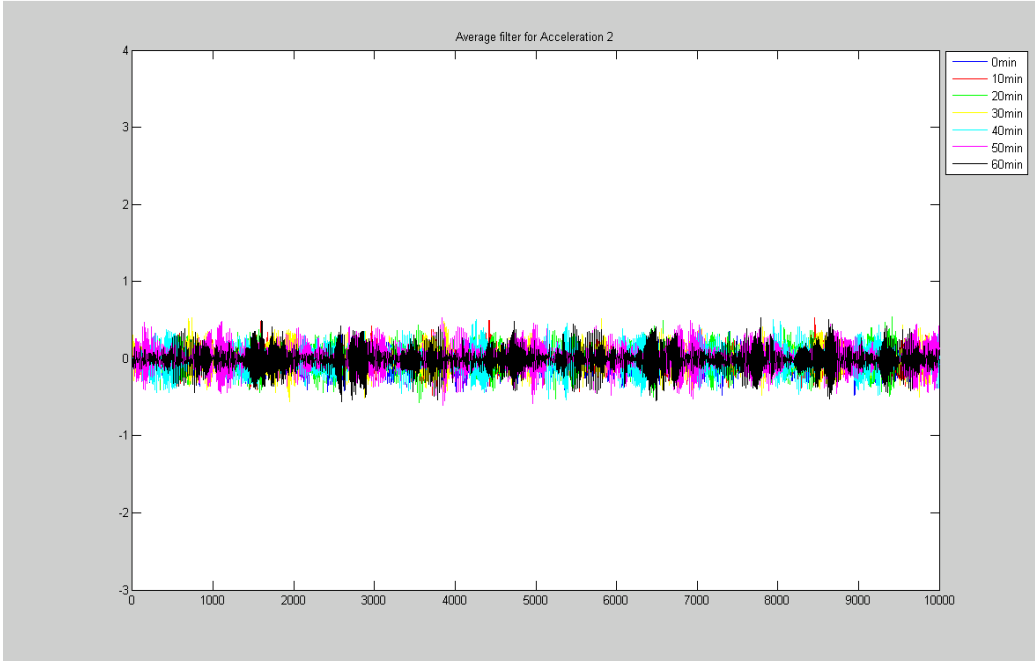


Figure 6 Acceleration2 after filtering with Average Filter

## APPENDIX B

### MATLAB CODE

#### 1) Matlab Code for PCA

```
data1= xlsread('recon_acc1.xls','G1:G10000');
data2= xlsread('recon_acc2.xls','G1:G10000');
data3= xlsread('recon_disp.xls','G1:G10000');
data4= xlsread('recon_force.xls','G1:G10000');
data = [data1 data2 data3 data4];

%%to get result from princomp function
[COEFF1, SCORE1, latent] = princomp(data, 'econ');

%%to get adjusted mean; adjusted mean = mean-adjust data set
inputsize=size(data);
numcols=inputsize(2);
means=mean(data)
tmpmeanadjusted=data(:,1)-means(:,1);
for var=2:numcols
    tmpmeanadjusted(:,var)=data(:,var)-means(:,var);
end
meanadjusted=tmpmeanadjusted;

%% to find covariance of matrix
sizex=size(data);
meanx = mean (data);
for var = 1:sizex(2)
    x1=data(:,var);
    mx1=meanx(var);
    for ct = var:sizex(2)
        x2=data(:,ct);
        mx2=meanx(ct);
        v=( (x1-mx1)'*(x2-mx2))/(sizex(1)-1);
        cv(var,ct)=v;
        cv(ct,var)=v;
    end
end
covariance=cv;

%%to find eigenvalues and eigenvectors
[eigenvec,eigenval]=eigs(covariance)

%%to get result from pcacov function
[COEFF2, latent, explained]=pcacov(covariance);
LatentPcacov=latent
ExplainedLatentPcacov=explained

%%to find final projected data after reducing dimension
prefinaldata=-(eigenvec'*meanadjusted');
finaldata=prefinaldata';
```

## 2) Matlab Code for SVD

```
num1=xlsread('recon_acc1.xls','A1:A10000');
num2=xlsread('recon_acc2.xls','A1:A10000');
num3=xlsread('recon_disp.xls','A1:A10000');
num4=xlsread('recon_force.xls','A1:A10000');

data1=[num1 num2 num3 num4];
[a1,a2,a3]=svd(data1, 'econ');
```

## 3) Matlab Code for Median Filter

```
num=xlsread('displacement');
A=num(:,1);

%%the higher the window size, the smoother data we get
windowSize=5
y0=filter(ones(1,windowSize)/windowSize,1,A);

plot (y0)
title('Average filter for Displacement')
```

## 4) Matlab Code for Average Filter

```
num=xlsread('displacement');
A=num(:,1);

%%the higher number of order the smoother result we get
y0=medfilt1(A,5);
plot (y0)

title('Median filter for displacement')
legend('0min','10min','20min','30min','40min','50min','60min',1)
```

## 5) Similarity Factor of PCA

```
%%similarity factor between 40min and 50min
num1=xlsread('recon_acc1.xls','E1:E10000');
num2=xlsread('recon_acc2.xls','E1:E10000');
num3=xlsread('recon_disp.xls','E1:E10000');
num4=xlsread('recon_force.xls','E1:E10000');
data1=[num1 num2 num3 num4];

den1=xlsread('recon_acc1.xls','F1:F10000');
den2=xlsread('recon_acc2.xls','F1:F10000');
den3=xlsread('recon_disp.xls','F1:F10000');
den4=xlsread('recon_force.xls','F1:F10000');
data2=[den1 den2 den3 den4];

[COEFF1,SCORE1,latent1]=princomp(data1,'econ');
clear latent1
clear SCORE1
[COEFF2,SCORE2,latent2]=princomp(data2,'econ');
clear latent2
clear SCORE2
```



```

s=3;
U1=COEFF1;
U2=COEFF2;

for u=1:s
    d=U1(:,u).'*U2(:,u);
    D1=sqrt(sum(U1(:,u).^2));
    D2=sqrt(sum(U2(:,u).^2));
    dis(u)=d/(D1*D2);
end

x=mean(abs(dis))*100

```

## 6) Similarity Factor SVD

```

% % %similarity factor between 40min and 50min
num1=xlsread('recon_acc1.xls','E1:E10000');
num2=xlsread('recon_acc2.xls','E1:E10000');
num3=xlsread('recon_disp.xls','E1:E10000');
num4=xlsread('recon_force.xls','E1:E10000');
data1=[num1 num2 num3 num4];

den1=xlsread('recon_acc1.xls','F1:F10000');
den2=xlsread('recon_acc2.xls','F1:F10000');
den3=xlsread('recon_disp.xls','F1:F10000');
den4=xlsread('recon_force.xls','F1:F10000');
data2 = [den1 den2 den3 den4];

[a1,a2,a3]=svd(data1,'econ');
[b1,b2,b3]=svd(data2,'econ');

s=3;
U1=a3;
U2=b3;

for u=1:s
    d=U1(:,u).'*U2(:,u);
    D1=sqrt(sum(U1(:,u).^2))
    D2=sqrt(sum(U2(:,u).^2))
    dis(u)=d/(D1*D2);
end

x=mean(abs(dis))*100

```

## 7) Cross Correlation

```

A = xlsread ('sample_a1');
B = xlsread ('sample_disp');
C =xcorr(A,B);
C1=abs(max(C));
D=C/C1
axis ([0,20000,-1500,1500]);
plot(C1)

```

**APPENDIX C**  
**GANTT CHART**

No	Details / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	
1	Continuing FYP progress								M								
2	Preparing Progress Report 1								I								
3	Submit Progress report: 20/8/2010								D								
4	Preparing Progress Report 2								S								
5	Submit Progress report: 24/9/2010								E								
6	Preparing poster. Submit date and Poster Presentation: 13/10/2010								M								
7	Preparing Draft Report								B								
8	Submit Draft report: 20/10/2010								R								
9	Preparing Final Report and Technical Paper								E								
10	Submit Final Report (soft cover - 3 copies) and Technical Paper (2 copies) 4/11/2010								A								
11	Ready for Oral Presentation: a week after Examination week (6-12/12/2010)								K								