EARTHQUAKE RESISTANCE AND STRUCTURAL PERFORMANCE OF STEEL WAREHOUSE UNDER ACHEH AND EL CENTRO EXCITATION

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EARTHQUAKE RESISTANCE AND STRUCTURAL PERFORMANCE OF STEEL WAREHOUSE UNDER ACHEH AND EL CENTRO EXCITATION

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Thesis submitted in fulfillment of the requirements
for the award of the
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Dedicated to my family,

Nourishing me with affection and love,

Their dedicated partnership for success in my life.

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ABSTRACT

Malaysia started to experience earthquake especially in Sabah and Sarawak compared to Peninsular Malaysia. Structures in Malaysia was designed without considering the seismic code of practice. Therefore, a study of earthquake resistance and performance was conducted for steel warehouse when subjected to Acheh and El Centro excitation. SAP2000 software was used to analyze the structure for linear and non-linear analysis. Modal analysis was done to determine the vulnerability of steel warehouse. 12 mode shapes were produced with different frequency and time period. The lower the frequency, the longer its time period to make a complete cycle. Steel warehouse under Acheh and El Centro excitation were compared for their strength and resistance. El Centro excitation is much stronger compared to Acheh, since it produce large acceleration on structural member joint. Based on time history analysis, the structures are analyzed with only the loading of earthquake obtained from Malaysia Meteorological Department. Response spectrum analysis was based on Eurocode 8 which produced much accurate value of acceleration and displacement for structure design purposes. Therefore, the dynamic characteristics of steel warehouse could be studied through these analysis. The vulnerability of structure also defined based on the critical member of steel warehouse.

ABSTRAK

Malaysia mula mengalami gempa bumi terutama sekali di Sabah dan Sarawak berbanding dengan Semenanjung Malaysia. Bangunan di Malaysia telah direka bentuk tanpa mengambil kira factor-faktor seismik. Oleh itu, satu kajian telah dijalankan ke atas gudang keluli untuk rintangan gempa bumi dan prestasi apabila dikenakan beban gempa dari Acheh dan El Centro. Perisian SAP2000 digunakan bagi menganalisis struktur ini bagi analisis linear dan bukan linear. Analisis modal telah dilakukan untuk menentukan kelemahan gudang keluli. 12 bentuk mod dihasilkan dengan frekuensi dan tempoh masa yang berbeza. Lebih rendah frekuensi, lebih lama tempoh masa yang diambil untuk melakukan satu putaran lengkap. Stuktur yang dikenakan beban gempa dari Acheh dan El Centro dibandingkan untuk kekuatan dan ketahanan. Gempa dari El Centro lebih kuat berbanding Acheh kerana ia menghasilkan kadar pergerakan yang tinggi pada struktur keluli. Berdasarkan analisis sejarah masa, struktur dianalisis dengan hanya beban gempa bumi yang diperoleh dari Jabatan Meteorologi Malaysia. Manakala, analisis spektrum gerak balas adalah berdasarkan Eurocode 8 yang menghasilkan nilai lebih tepat bagi pecutan dan ajakan strucktur bagi tujuan reka bentuk bangunan. Oleh itu, ciri-ciri dinamik gudang keluli boleh dikaji melalui analisis-analisis ini. Kelemahan struktur juga dapat dikesan berdasarkan tahap kritikal gudang keluli tersebut.

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LIST OF SYMBOLS

γ_{M0}	Partial factor for building
A	Cross sectional area
f_y	Yield strength
b	Overall breadth
h	Overall depth
h_w	Depth of web
t_f	Flange thickness
t_w	Web thickness
η	Member verification

LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
DL	Dead load
LL	Live load
RSA	Response Spectrum Analysis
SAP	Stuctural Analysis & Design Program
WL	Wind load

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Earthquake happens in an instant without any early signs. Seismic waves are created from the energy released from the earthquake. Steel structure buildings may be affected and suffered great damage due to the seismic waves. The structures may defect in term of deflection and cracking that may reduce the aesthetic value of the building.

In Malaysia, nowadays most of the buildings are steel structures especially warehouse and factories. Steel structures are made up of members, such as beam, column, girder, or braced. They are widely used because of their light weight which provides lighter dead load to the structures. The structural steel is fabricated off-site which minimized the construction time on site. It also saves time for erection since concreting work is not required. Moreover, it is the most economical construction material. Number of labors, machineries and equipment required are also reduced hence reducing the construction cost.

Construction materials for the structure are from high strength steel. The great strength of steel provides advantages to the building. Steel also provides flexibility to the building where it can bend without causing any cracks. Besides that, steel allows the structure to bends slowly due to its plasticity characteristic. However, the strength of steel may be weakened when in contact with fire or very high temperature. Due to that, the steel is coated with a fire protection material as for protection. Therefore, these advantages allow the steel to perform better than other materials especially when the steel structures are subjected to earthquake.

Structural steel comes with various shape that satisfy the strength requirement according to their mechanical and chemical properties. The shapes available are T-bar, L-angle, hollow structural steel (HSS), wide flanged, I-beam, channel and etc. Figure 1.1 presents an illustration of the steel shapes.

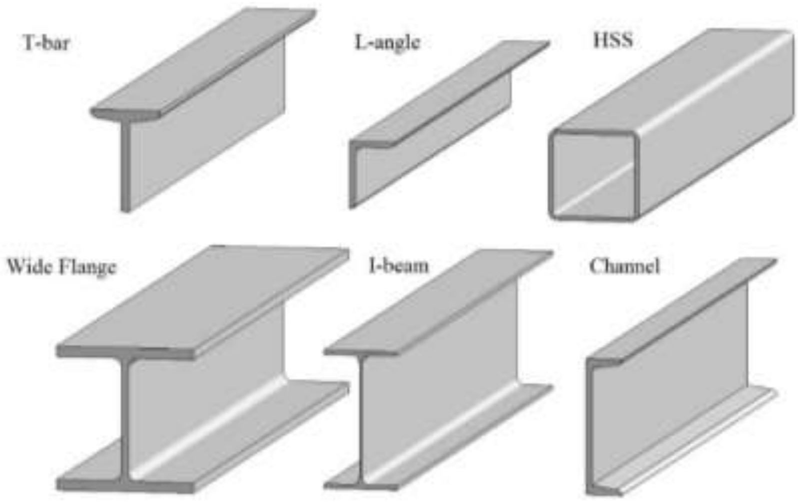

Figure 1.1: Various shapes of structural steel

Source: Autoworkshop. Image by unknown

1.2 PROBLEM STATEMENT

Malaysia can be said to be free from earthquake and categorized in low seismicity group, but yet can feel the tremors at certain places. Sabah and Sarawak experiencing the earthquake more than the peninsular Malaysia. A 4.0 magnitude earthquake hit the Mount Kinabalu area, some 16km west of Ranau at about 9.39am Friday, according to the Malaysian Meteorological Department website (Anon 2016). The seismic crisis affected buildings and infrastructures with a total damage besides of fatality. Most of the buildings are designed by only considering wind effect rather than seismic effect. Therefore, seismic effect need be considered since the minor disaster had already occurred.

Distant ground motions have been recorded by the Malaysian network of seismic stations, from two most active plate tectonic margins in the world i.e. the Sumatran subduction zone, and the 1650 km long Sumatran fault; and the Philippines plate alike (Sooria et al. 2012). As the last large earthquake on the southern San Andreas occurred in 1857, that section of the fault is considered a likely location for an earthquake within the next few decades. The San Francisco Bay area has a slightly lower potential for a great earthquake, as less than 100 years have passed since the great 1906 earthquake; however, moderate-sized, potentially damaging earthquakes could occur in this area at any time (Sandra S. et al. 2016). Location of Sumatran fault and San Andreas fault are illustrated as shown in Figure 1.4 and Figure 1.5.

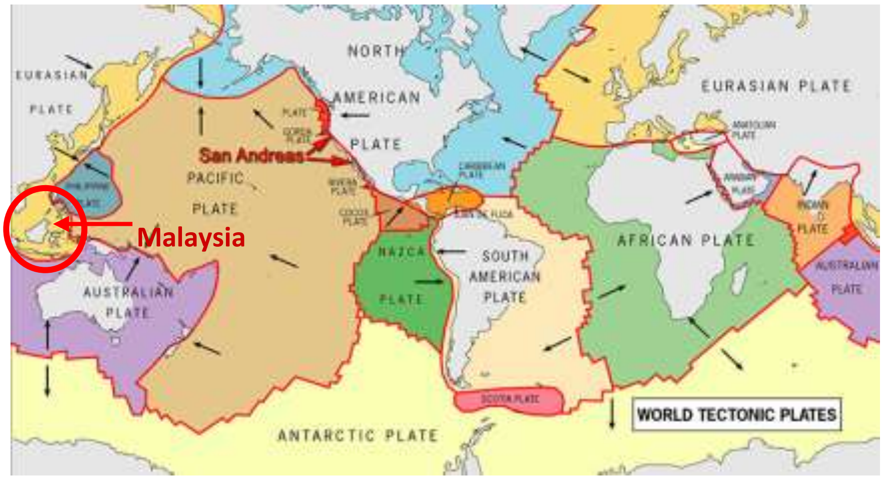

Figure 1.3: Major tectonic plates surround Malaysia.

Source: UWEC. Image by unknown

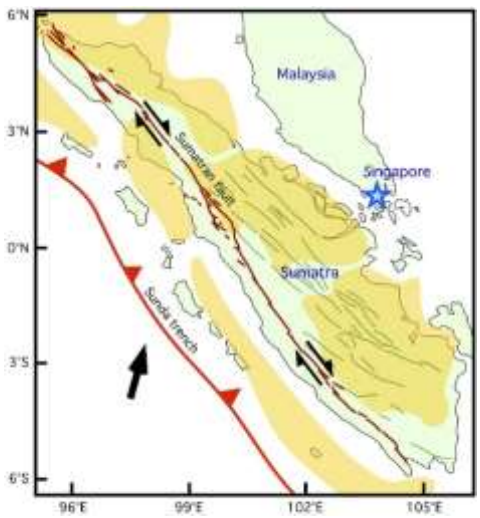

Figure 1.4: Location of Sumatran fault

Source: Sieh K et al. (2000)

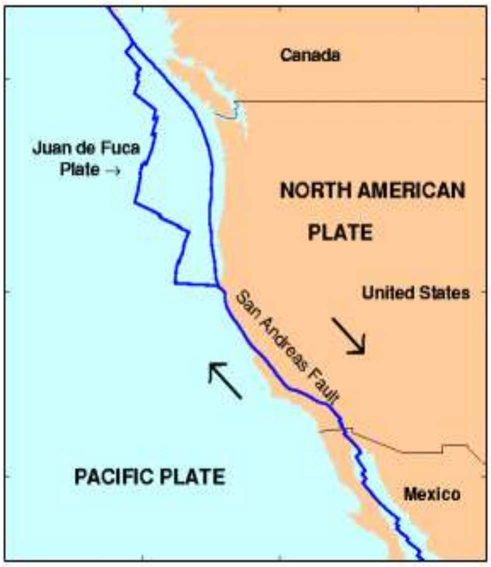

Figure 1.5: Location of San Andreas fault

Source: Robert M et al. (2009)

1.3 RESEARCH OBJECTIVES

The main objectives for this research are:

i. To determine the vulnerability of steel warehouse in Malaysia.

ii. To compare the capability and resistance of steel warehouse under Acheh and El Centro excitation.

iii. To study dynamic characteristic of steel warehouse under different types of loading.

1.4 SCOPE OF STUDY

In this research, the earthquake resistance and performances of steel structure will be investigated. The scope of this study are:

i. Type of structure will be used is steel structure.

ii. Case of study is earthquake effect to steel structure in Malaysia region due to Acheh and El Centro earthquake excitation.

iii. Analyze earthquake data provided from Malaysia Meteorology Department (MMD).
iv. Software to be used for steel structure modelling analysis is SAP 2000.

1.5 SIGNIFICANCE OF STUDY

Throughout this research study, the vulnerability of existing critical steel structure in Malaysia region could be determined. Due to earthquake effect from Acheh and El Centro, the characteristics of the steel structure could be determined when earthquake occurred. These characteristics might be helpful in designing the steel structures by considering the seismic effect on structures in Malaysia. Considerations regarding seismic effect could save many lives. Besides that, the steel structures can be prevented from any damaged.

CHAPTER 2

LITERATURE REVIEW

2.1 EARTHQUAKE

Surfaces of Earth or ‘crust’ is like a jigsaw puzzle which is not in a piece of land. The Earth is covered with 20 pieces of puzzle that are constantly moving in a slow motion. These piece of puzzles are known as ‘tectonic plate’. Earthquake happens when the plates hitting, bumping or sliding past another plate. The surfaces where it happens is called as ‘fault’ or ‘fault plane’. Mostly the ground shaking occurs along the fault line.

The sudden movement is caused when rocks in the Earth’s crust that are located along the weak region are reaching their strength limitation. Strain energy is stored in the rocks for a very long time ago since the deformation that occur in due to gigantic tectonic plates (C.V.R Murty 2002). The released stored energy is causing the earthquake. The location where the earthquake starts is beneath the earth’s surface which is known as hypocenter. In addition, epicenter is located just above the hypocenter which is on the earth’s surface. Figure 2.1 illustrate the cross section of fault plane.

An earthquake can causes another natural disaster such as tsunami, landslides and flooding. The earthquake could not be predicted when it will attack. Based on the seismic monitoring alone, the earthquake still could not be predicted. As for sure, it could be a guideline for us to be more careful and aware about this earthquake.

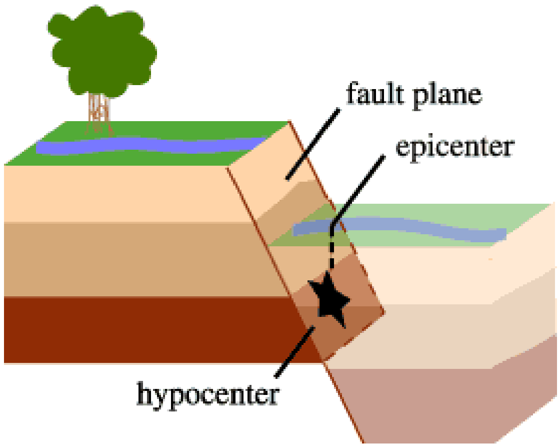

Figure 2.1: Cross-section of fault plane occurrence

Source: USGS. Image by unknown

2.2 CAUSES OF EARTHQUAKE

Earth is made up from four layers; the inner core (radius ~1250km), the outer core (thickness ~2200km), the mantle (thickness ~2900km) and the crust (thickness ~5 to 100km) (USGS 1999). Figure 2.2 illustrate the cross section of the Earth. Crust and mantle are made up from pieces of tectonic plates that formed the Earth's surfaces. These moving tectonic plates cause the earthquake to happen. Even though the plates are slowly moving, but they are sliding past and keep bumping with each other. The plate boundaries; the edges of each tectonic plates are made up from many faults. Mostly, the earthquake would takes place along the faults when the plates are moving far apart from the faults.

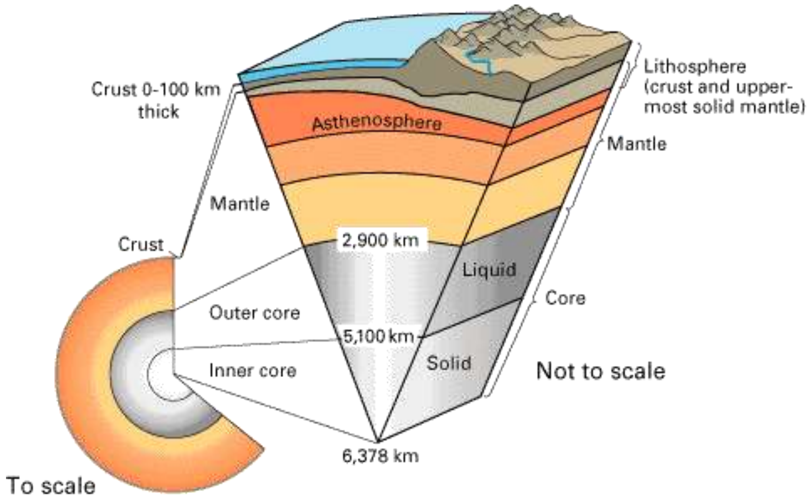

Figure 2.2: Cross-section that shows the internal structure of Earth

Source: USGS. Image by unknown

2.2.1 Types of Earthquakes

Earthquakes occurred along the boundaries where two plates meet each other. There are also two events of earthquakes that happened on Earth such as inter-plate and intra-plate earthquakes.

The event occurred along the plate boundaries called as inter-plate boundary. It occurred when the plates trying to return into the original position. The strain energy that stored at the plate boundaries become stronger and caused them to move. Due to this occurrence, a natural disaster is formed which is tsunami that will cause damage and destruction over the affected area. Meanwhile, intra-plate earthquake occurrence takes place in the interior of lithospheric plates. Lithospheric plate is also called as tectonic plate.

2.2.2 Earthquake Plate Tectonics

Pieces of crust that covered the Earth's are tectonic plates. The Earth's surfaces consisting of seven major tectonic plates and numerous minor or smaller tectonic plates. The major tectonic plates on the Earth's surface are as in Figure 1.3. These plates are moving in various direction with different speeds. In result, mountain and rift are formed.

Through the plate movements, there are three different types of inter-plate boundaries as shown in Figure 2.3. The first type is transform boundary. This boundary occurred when lithospheric plates sliding past each other along the transform faults. The second type is divergent boundary. This boundary occurred when two plates moving apart from each other. Lastly, the third type is convergent boundary. This boundary occurred when two plates sliding towards each other to form subduction zone or continental collision and sometimes the colliding plates want to sink. Along these fault a very strong earthquake can happened.

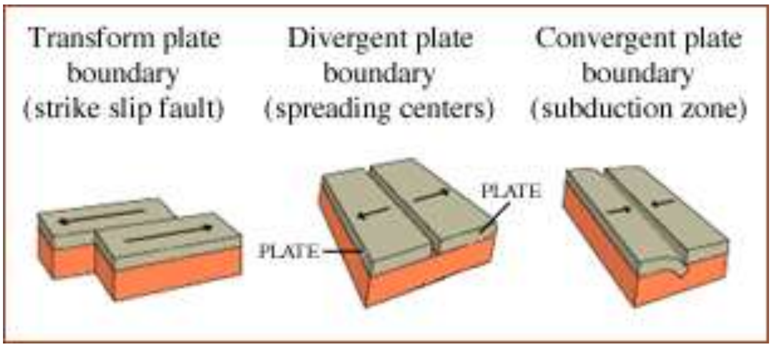

Figure 2.3: Types of inter-plate boundaries

Source: Volcano Discovery. Image by unknown

2.2.3 Faults

During the earthquake two type of faults are generated from both types of earthquakes. The types of faults are dip slip and strike slip. Both faults are all with different directions. Slip motion referring to the motion of rock on each side of the faults.

Dip slip occurred parallel with the faults in vertical direction. The dip slip is divided into two types which are normal and reverse faults. Normal fault occur when one mass of rock slides downward and pulling away from another mass of rock. The formation occurs when the plates are slowly moving apart from each other. The other fault is reverse fault. This fault occur when plates are being pushed together. The plates colliding with each other and caused them to move and buckle upwards.

Strike slip occurred when two plates are sliding past each other. The Earth's surface is moving in the sideway. This most famous fault is found in California, which is the San Andreas fault. It caused a very powerful earthquakes. Figure 2.5 illustrate the different types of fault.

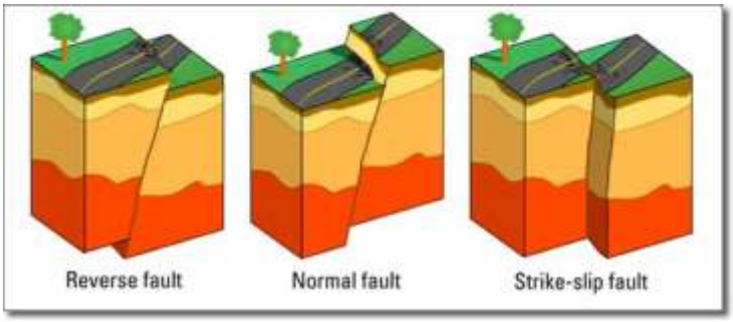

Figure 2.4: Types of faults

Source: Tsunami Warning. Image by unknown

2.3 Seismic Wave

Waves of energy caused by the sudden breaking of rock within the earth or an explosion is called seismic wave. A series of seismic waves penetrate on Earth's layers are generated when an earthquake occurred. The waves travels in all direction through the Earth's layers. Seismic waves arriving on Earth is illustrated in Figure 2.6. The waves are divided into two types which are body waves and surface waves. Body waves are waves that travel through the interior of Earth, meanwhile surface wave only travel at the interface between two different layer in between Earth and atmosphere.

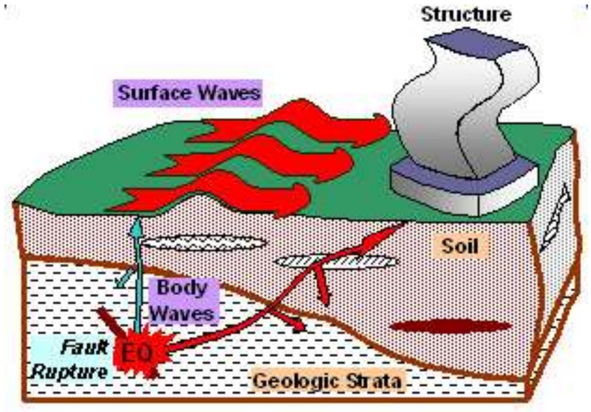

Figure 2.5: Arrival of seismic waves on Earth

Source: Old Website. Image by unknown

2.3.1 Body Waves

Waves that arrived first on Earth from the earthquake is body waves which are the fastest wave. Body waves consist of another type of waves such as Primary Waves (P-waves) and Secondary Waves (S-waves). Both types of body waves are illustrated in Figure 2.7

P-wave can move through solid rocks and fluids. The waves pushes and pulls the rock as they went through that medium. Due to this characteristic the waves are known as compression waves. This waves will shakes the ground when it traveled inside the Earth's surface. The movement of wave's direction are the same as the direction travelled by the energy. It also called as 'direction of wave propagation'.

S-wave can only move through solid rock and not through fluid medium so it arrive much slower compared to P-wave. As the waves passing through the medium, they moves the solid rock particles up and down or side by side which are perpendicular to the direction of wave propagation.

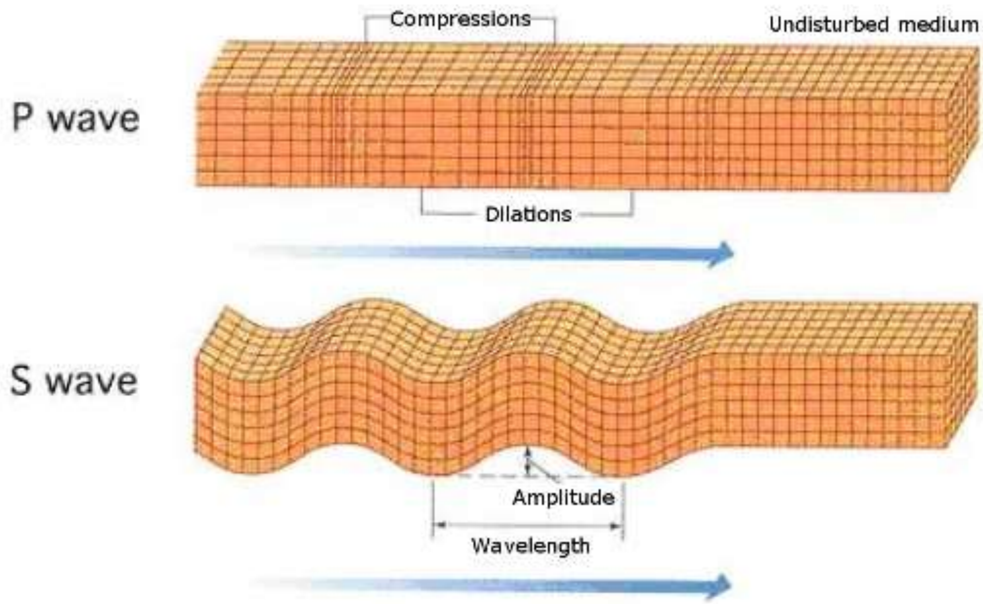

Figure 2.6: Types and illustration of body waves

Source: Seismic Warning. Image by unknown

2.3.2 Surface Waves

Surface waves are travelling through the Earth's crust which its frequency is much lower compared to body waves. As a result on seismogram, this waves can also be easily differentiate. This waves that causes damages and destruction occurred during the earthquake. Surface waves have two different type of waves which are Love waves and Rayleigh waves as illustrated in Figure 2.8.

Love waves movement are similar with S-waves but with no vertical movement. This waves causes the most damage to structures due to their side by side movement; where the ground surface was twisted from side to side.

Meanwhile, Rayleigh wave's movement are rolling, up and down motion, and side by side with the same direction of waves. They moves along the ground surfaces which looks like ocean waves. This waves are larger compared to other waves and it causes shaking produced from the earthquake.

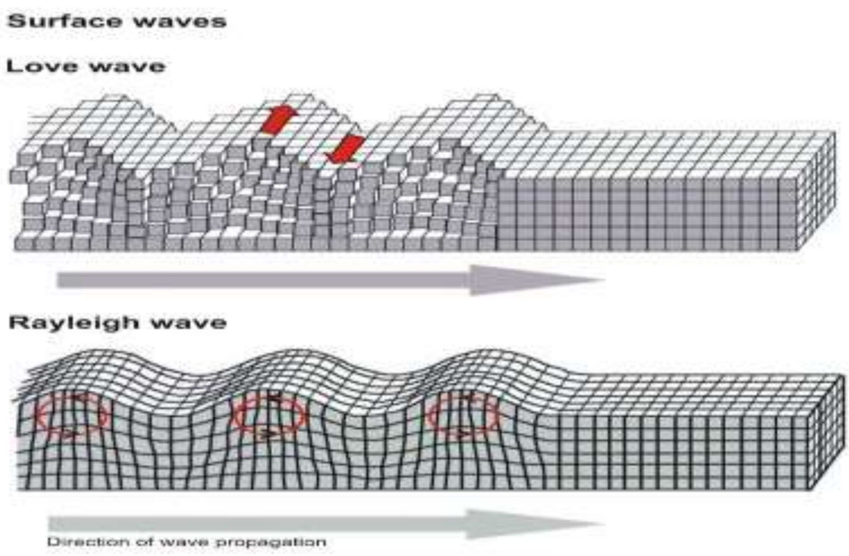

Figure 2.7: Types and illustration of surface waves

Sources: LAMIT. Image by unknown

2.4 Measurement of Earthquake

Seismic waves lose lot of energy in traveling over great distances. A sensitive detector (seismometers) can records these waves that vibrations and intensity emitted by a very small earthquakes. After connecting the seismometer with a system that produced a permanent recording, it is called as seismograph (Earthquake Information Bulletin 1970).

2.4.1 Seismographs

Seismographs using the principle of inertia where an inertial mass remains at rest unless it is applied with a force. Apparatus used for seismograph is a simple pendulum. During vibrations, the ground will shakes and moved the base and frame together. However, the pendulum bob remain static in place as the inertia keeps it stationary. It moves with respect to vibrating ground. The changes over time was recorded by the displacement of pendulum as illustrated in Figure 2.9. The process of tracing out the record is called as seismogram. Figure 2.10 shows a seismogram of time versus ground displacement.

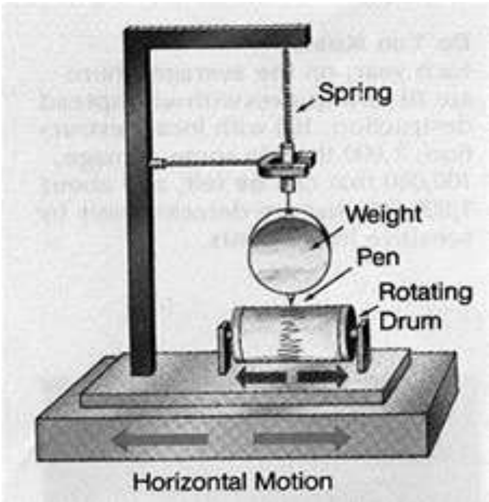

Figure 2.8: A seismograph

Source: USGS. Image by unknown

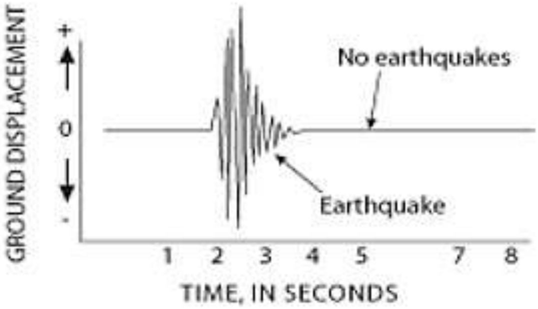

Figure 2.9: A seismogram

Source: IRIS. Image by unknown

2.4.2 Magnitude

The severity of an earthquake can vary and not detectable by the devices, which causes a very bad damages such as tsunami and volcanic activity. This severity is called as magnitude and it is used to measure the intensity of seismic waves. In 1930's, the earthquake magnitude and Richter scale was developed by Charles F. Richter. Large earthquake are less frequent compared to small earthquakes. Table 2.1 shows the frequency of earthquake's occurrence with the description of each magnitude.

Table 2.1: Frequency of earthquake's occurrence based on observations since 1990

Descriptor	Magnitude	Average annually
Very great	> 9.0	1 at 20 years
Great	8.0 or more	1
Major	7.0 – 7.9	18
Strong	6.0 – 6.9	120
Moderate	5.0 – 5.9	800
Light	4.0 – 4.9	6,200
Minor	3.0 – 3.9	49,000
Very minor	2.0 – 2.9	About 1000 per day
	1.0 – 1.9	About 8000 per day

Source: Mazzolani (2002)

2.4.3 Intensity

Intensity is degree of surface shaking for each unit increase of magnitude of a shallow crustal earthquake is unknown. It is based on the acceleration of an earthquake and the longevity of it persistence. The intensity is determined from effects on people, structures and environment. Figure 2.11 shows the Ritcher scale with descriptions for earthquake happened during year 2004-2010.

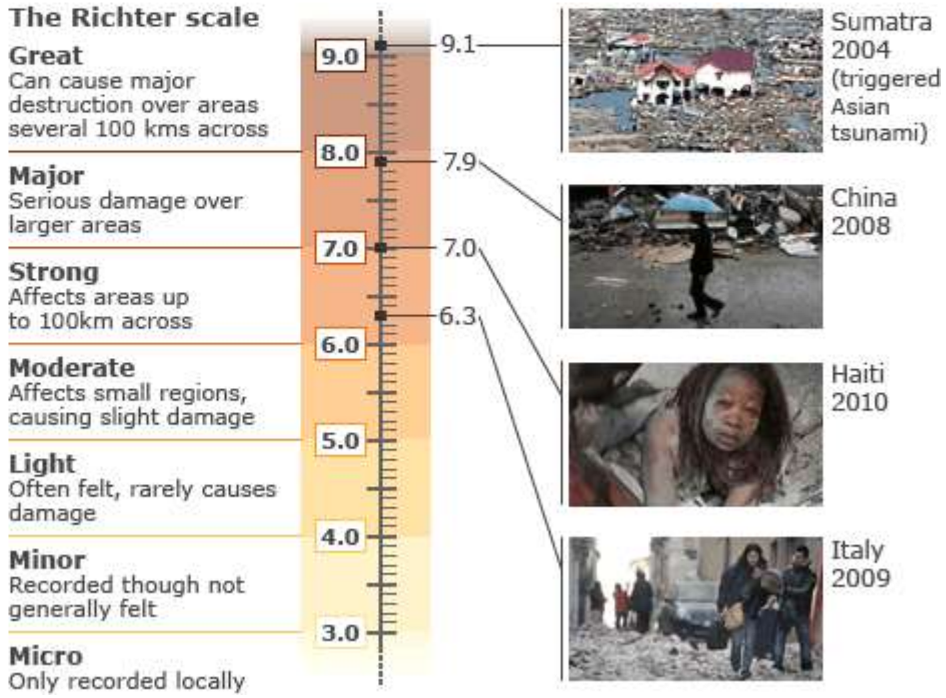

Figure 2.10: Richter magnitude scale with the occurred effects

Source: BBC News. Image by unknown

2.5 STEEL STRUCTURE

In 1994, due to earthquake happened at Northridge, California the severity of the ground shaking and the large number of steel structures existing in the affected area was considered. Steel structures were damaged but there is no sign of collapsed have occurred. Observations had been made in many high rise building and focused more on fractures in moment resisting frames. Meanwhile, the behavior of the braced frame structures is not focused (Krawinkler H 1995).

Even though steel structure does not collapse after the earthquake tremors, the effect and performance on the structures should be considered. The ductility and flexibility of steel allowing them to withstand the pressure from earthquake. In future, the designing of steel structure must consider the effect of seismic to increase the life span and services of the structures.

2.6 LITERATURE REVIEW

Journal and articles are the resources used to obtain information. Table 2.2 shows the references used for this research.

Table 2.2: Literature review on journal chosen for this research

NO	YEAR	TITLE	AUTHOR	DESCRIPTIONS
1	1995	Earthquake Design and Performance of Steel Structures	H. Krawinkler	Fractures had been frequently observed on welded beam-to-column connections. The failure had raised design and research issues towards the improvement of steel structures performance in future earthquake.
2	1998	Engineering Structure: Performances and Damages to Steel Structures During the 1995 Hyokogen-Nanbu Earthquake	E. Watanabe, K. Sugiura, K. Nagata and Y. Kitane	Key concept for the earthquake-resistant design of bridges, several recommendations are made for the improvement of pier design.
3	2001	Earthquake Monitoring in Malaysia	Mohd Rosaidi bin Che Abas	The maximum observed intensity was VI on the Modified Mercalli (MM) scale.

4	2005	Earthquake Tips: Learning Earthquake Design and Construction	C.V.R Murty	Basic introduction to earthquakes and terminology such as magnitude and intensity.
5	2007	Documentation for The Southeast Asia Seismic Hazard Maps	Mark Peterson, Stephen Harmsen, Charles Mueller	Future structural damage and societal losses from large earthquakes can be mitigated by providing an advance warning of tsunamis and introducing seismic hazard provisions in building codes that allow buildings and structures to withstand strong ground shaking associated with anticipated earthquakes.
6	2012	Performance of Steel Structures During the February 27, 2010, Chile Earthquake	R. Herrera and J.F. Beltran	Performance of steel structures is related to the over strength of structures rather than large ductility capacity. Due to this condition of performance, it is a consequences of the application of the current seismic design codes.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Research methodology is a process of collecting information and data for the purpose of making the decisions. The methods may varies such as research techniques, journal, interview and surveys.

This chapter will review the process of this research collection of data and analyzing the data. The data from Acheh's and El Centro's earthquake is used for seismic analysis on the structure, where the data was obtained from the Malaysian Meteorological Department. SAP 2000 software is used in this research to analyses the seismic waves.

The type of structure that being analyzed is warehouse steel structure. Steel structure is designed to be more flexible and ductile; and allowing them to perform better when subjected to earthquake. Through this methodology, the vulnerability of these type of structures in Malaysia can be determined. Capability and resistance of steel structures can be compared when subjected under Acheh and El Centro excitation. Besides that, the dynamic characteristics of the structures can be studied when subjected under different type of loadings.

As to ensure the research smoothness and successful, the following planning and scheduling are arranged.

3.1.1 Research Planning

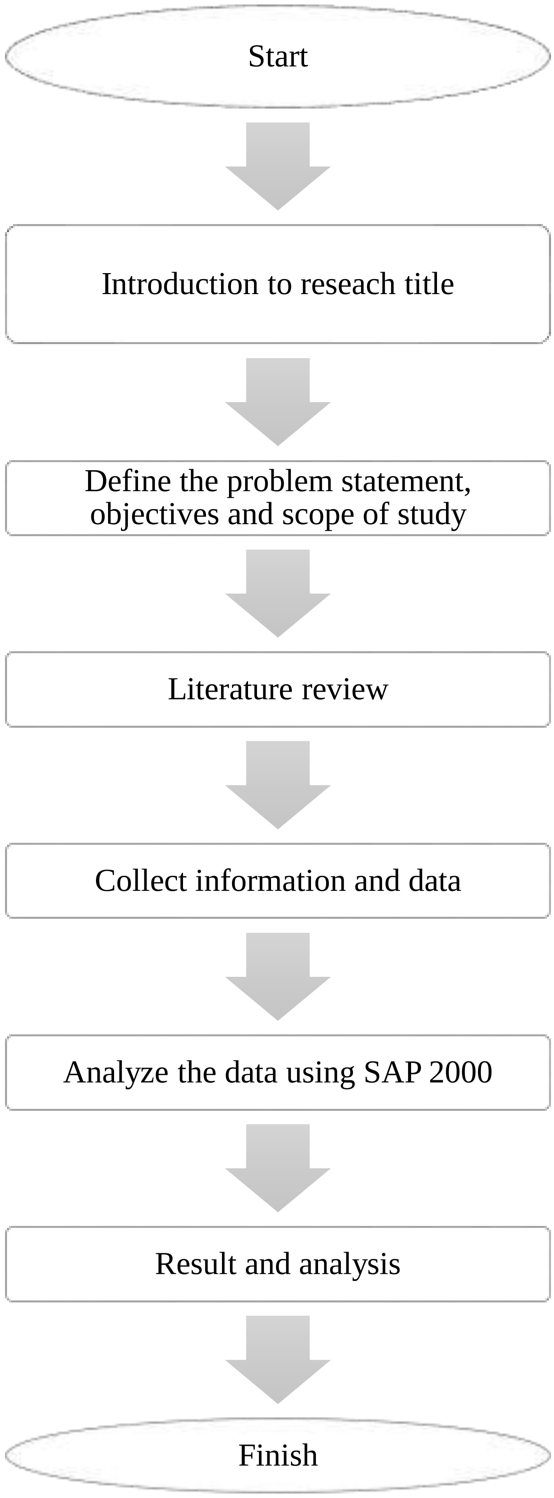

Figure 3.1: Flowchart of research planning

3.2 LITERATURE REVIEW

Literature review is important to demonstrate the understanding about this research. The sources of obtaining the literature review is info from article, journal and a research paper or thesis. This process used to prove the research by providing evidence to the statement in the research.

Data collections for this research are earthquake, causes of earthquake, seismic wave, measurement of earthquake and SAP 2000 software program. The main articles and journals used to complete this research is “Performances of Steel Structures during the February 27, 2010, Chile Earthquake” by R. Herrera and J.F. Beltran.

In this phase, all the data, studies, facts and information that related to this research are being collected. The collecting data process is concentrate on the main topics of this project as follows:

1. Earthquake Magnitude
2. Steel Structure Drawing
3. SAP2000 Program

3.3 INFORMATION AND DATA COLLECTION

In this stage, in ensuring the research is run smoothly, the further data and information for the analysis and modelling work need to be carry out. The data and information that required are as below:

1. Drawing of steel structure
2. Material and types of the structure
3. Loading carried by the structure
4. Data of the earthquake from Malaysia Meteorological Department (MMD)

3.4 SAP2000 PROGRAM

SAP2000 is a software use for analysis and design of the structural and earthquake engineering. This software feature are very sophisticated, versatile and advance for user with the interface operated by the design tools which is very fast and perfect construction models for engineer to solve the most complex projects.

Complex Models can be produced and coincided with effective layouts of implicit. Coordinated configuration code components can consequently create wave, span, wind and burdens of seismic with extensive programmed steel and solid outline code checks per Canadian, US and global configuration norms.

3.4.1 Modelling

SAP2000 software was used in modelling a warehouse steel structure. These are the steps in modelling the structures:

1. Determine the type of the model of structure to be used
2. Know the material used
3. Detailed the section frame properties
4. Determine the load pattern
5. Define the response of the spectrum function
6. Define the load case and load combination
7. Draw the building based on the properties
8. Define the joint restraint
9. Run the analysis of the load case
10. Analyses the result from the graph and table attained

3.4.2 SAP2000 Software Flowchart

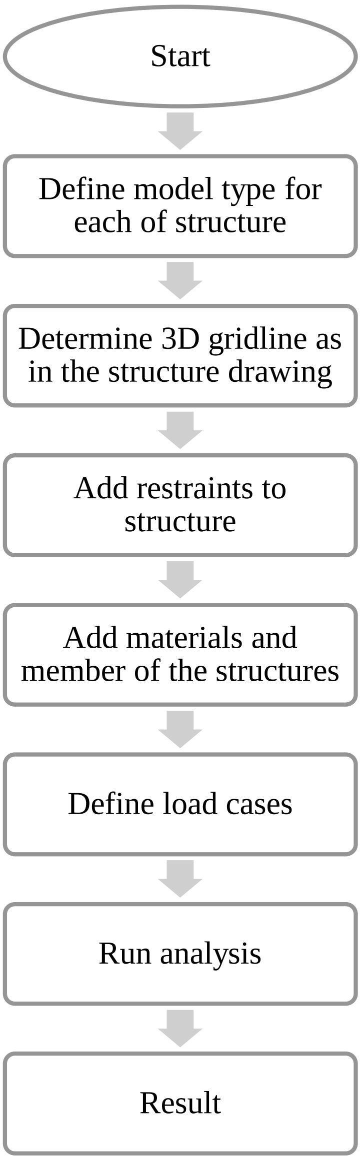

Figure 3.2: Flowchart of SAP2000 Software

3.4.3 Steps in SAP2000 Software

Step 1: Define model type

Structure model type is chosen based on the template provided which is suitable for the structures. The selected template will then be used to create a warehouse steel structure.

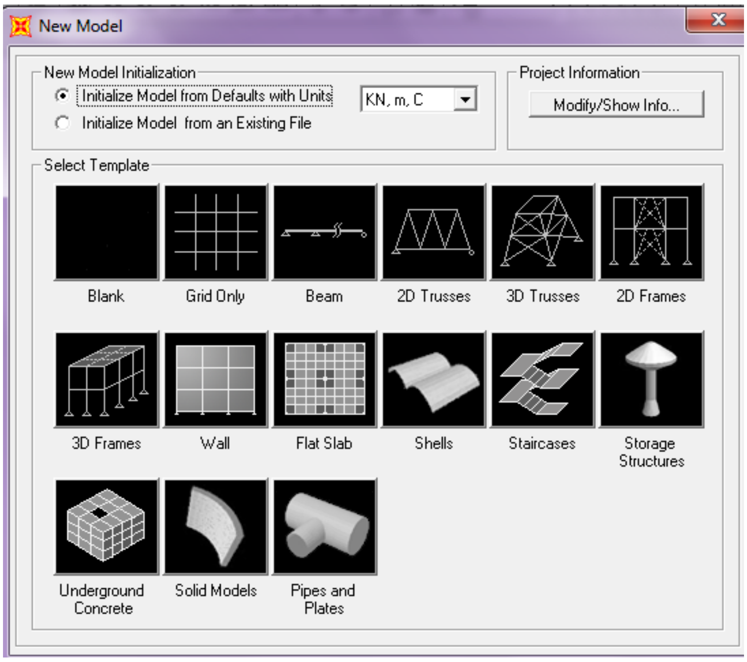

Figure 3.3: Select structure model type

Step 2: Determine the 3D gridline or workspace

All the grid data is filled with dimension according to the structure drawing as to assign the frame element.

Figure 3.4: Define grid system data

Step 3: Add restraint

Select all joints and add joint restraints.

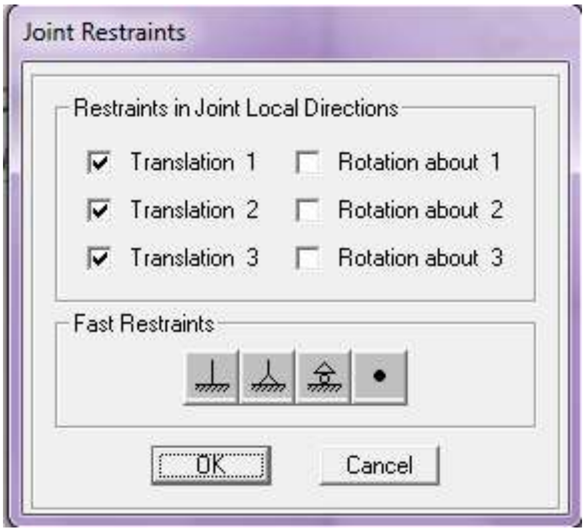

Figure 3.5: Add restraints at the base condition

Step 4: Add material and member of structure

New material for frame section is added to the structure such as angle and flange steel section.

Steel Structure

A warehouse with trusses roof was chosen as steel structure building for this research as illustrated in Figure 3.6.

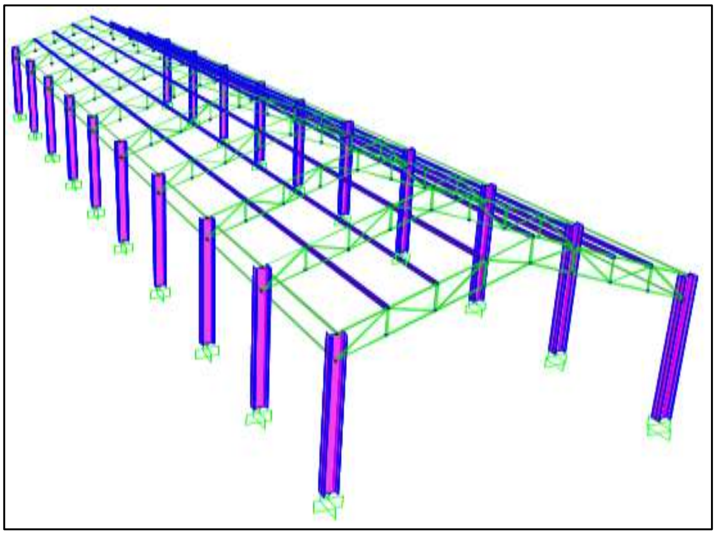

Figure 3.6: Model structure of warehouse with trusses roof in SAP2000 (3D)

Step 5: Define load cases

Various types of load cases being considered to analyses the structures. The load cases are as stated in Figure 3.7 which are:

i. Dead load
ii. Live load
iii. Wind load
iv. Earthquake data – El Centro
v. Earthquake data – Acheh

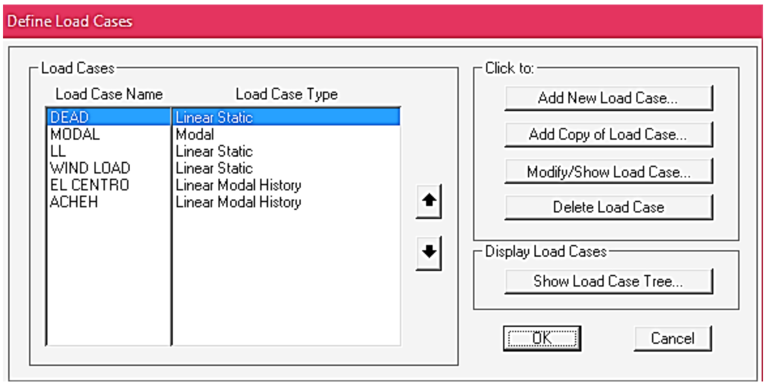

Figure 3.7: Load cases data

As for earthquake data, Acheh and El Centro earthquake data are used to analyze the structures.

Step 6: Define load combination

Load combination were made based on the considered load cases. The combination of load are shown in Figure 3.8 which are:

i. Dead load
ii. Dead load + Live load
iii. Dead load + Live load + Wind load + El Centro
iv. Dead Load + Live load + Wind load + Acheh

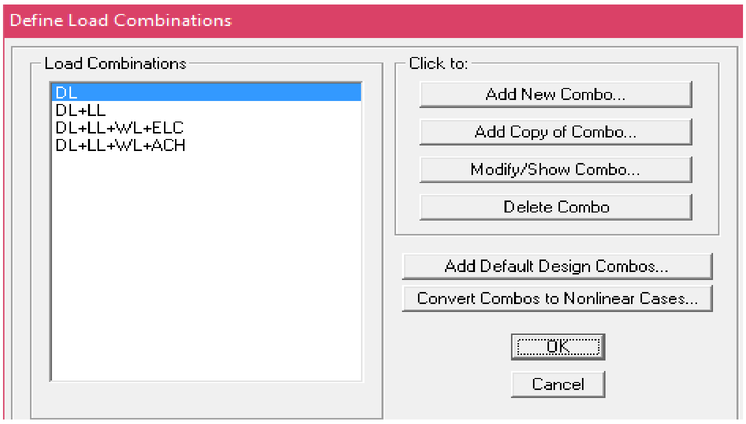

Figure 3.8: Load combination data

Step 7: Run the analysis

The analysis is run for free vibration analysis. Modal load case will be selected and run the analysis to the structures. Next, other load cases were run simultaneously as shown in Figure 3.9.

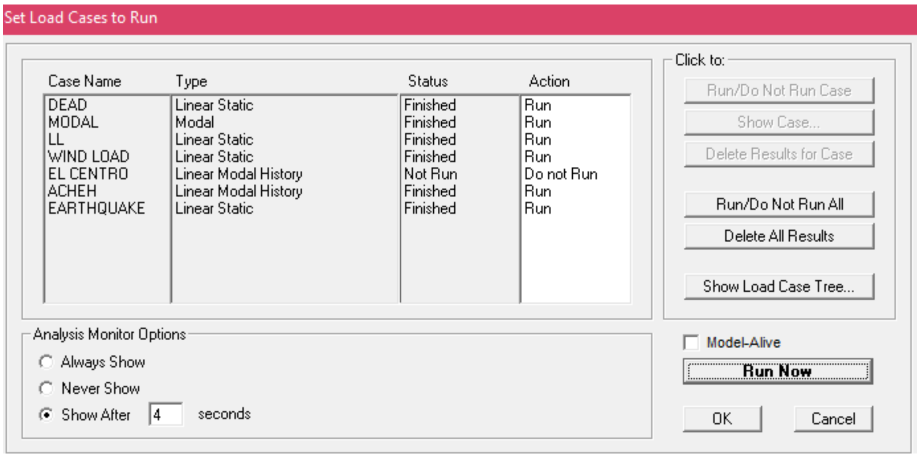

Figure 3.9: List of load cases run for the analysis

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter represent the assessment of seismic performance of steel structure which under the earthquake loading in Malaysia region. The results for steel structure analysis using SAP2000 software are presented in graph and table forms. The result displayed 12 mode shapes in model analysis when the structure is free from any vibration. Based on these mode shapes, a table showing the frequency derived from the time period. Furthermore, the maximum shear and moment of critical structure member are displayed in a graph form.

4.2 STEEL STRUCTURE MODELLING

Nowadays, steel structures are widely used in Malaysia with various kind of purposes. There are many types of steel structures, for this research a warehouse is chosen to observe its performances due to earthquake loading. SAP2000 software is used to design the steel structures based on its structural drawing. Then, they are being investigated to define their geometric definitions and understanding the performances.

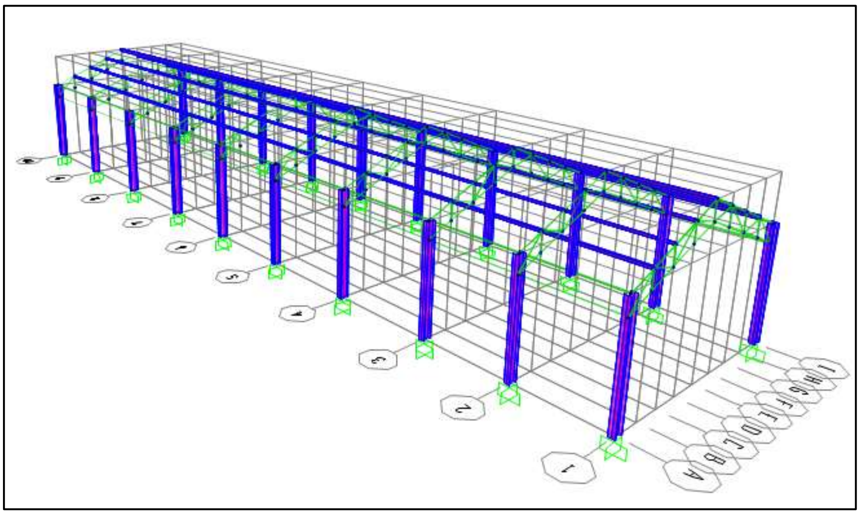

Figure 4.1: Steel structure warehouse model

4.3 STEEL STRUCTURE ANALYSIS

The warehouse steel structure has been modelled and analyzed by using SAP2000 software. There are four types of loads considered for this structure which includes dead load, live load, wind load and seismic load.

Load combination is combination of variety load cases to ensure the safety of steel structure under different maximum loading conditions. Several combinations of load cases were applied in this analysis, these consist of:

i. Free vibration analysis (Modal Analysis)
ii. Dead Load + Live Load
iii. Dead Load + Live Load + Wind Load + Earthquake (Acheh)
iv. Dead Load + Live Load + Wind Load + Earthquake (El Centro)

4.3.1 Modal Analysis

Free vibration analysis or modal analysis is the condition of structure with the motion without any external forces or support motion. Warehouse steel structure will be moved away from its equilibrium state because of the modal analysis.

Any physical system like structure can vibrating at any time. Naturally the vibration occurs due to frequency. It is showing that earthquake bring frequency to the earth and causing vibration to the ground. The modal shapes which are vibrating which have been assumed are properties of the system. Besides, it can be decisive empirically by using Modal Analysis.

Based on the free vibration analysis, these following data are obtained such as natural period, 12 modes shape of steel structure, natural frequency, joint and displacement. Each mode shape have different natural period and natural frequency.

12 modes shape of warehouse steel structure are illustrate in Figure 4.2 – Figure 4.13.

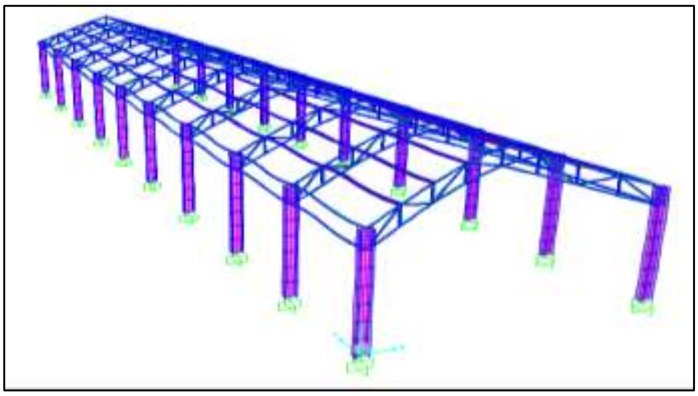

Figure 4.2: Mode shape 1 with period of 0.52809 and frequency of 1.89361

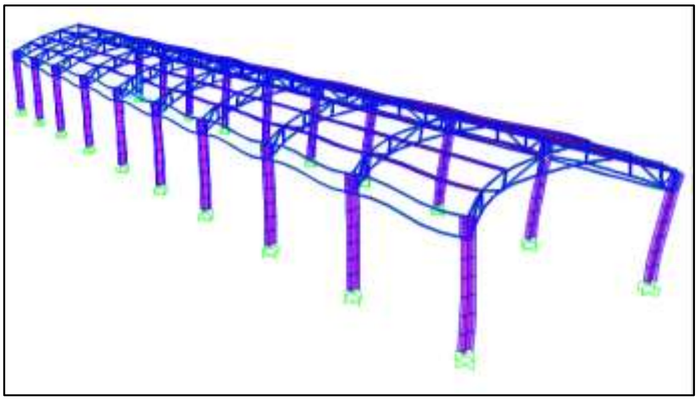

Figure 4.3: Mode shape 2 with period of 0.26025 and frequency of 3.84249

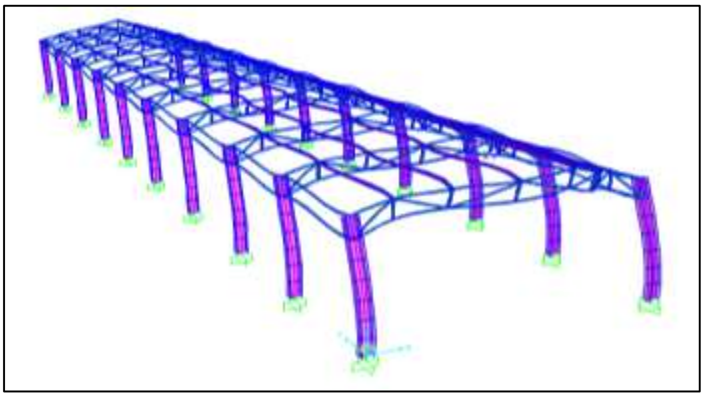

Figure 4.4: Mode shape 3 with period of 0.19324 and frequency of 5.17490

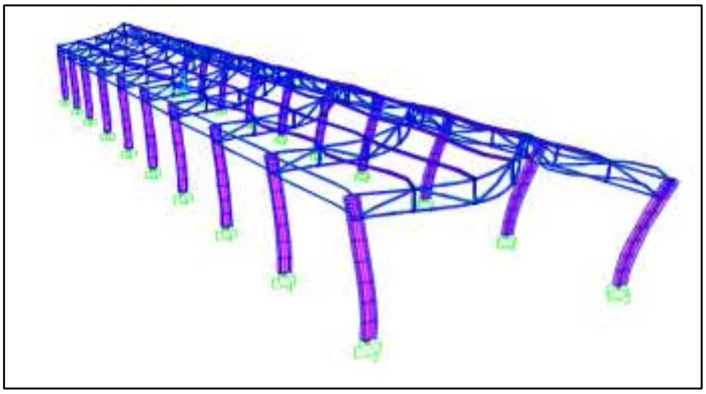

Figure 4.5: Mode shape 4 with period of 0.16924 and frequency of 5.90894

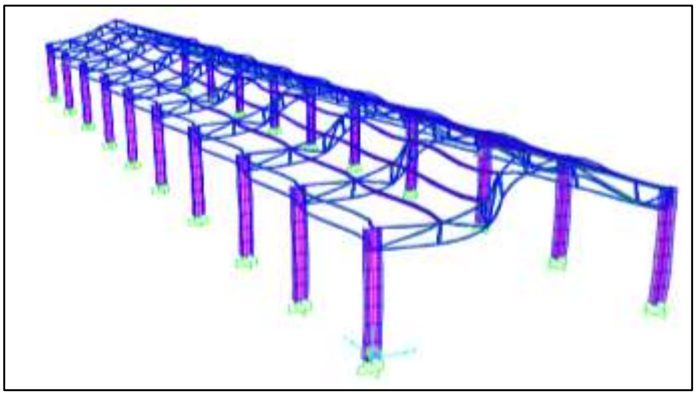

Figure 4.6: Mode shape 5 with period of 0.13425 and frequency of 7.44867

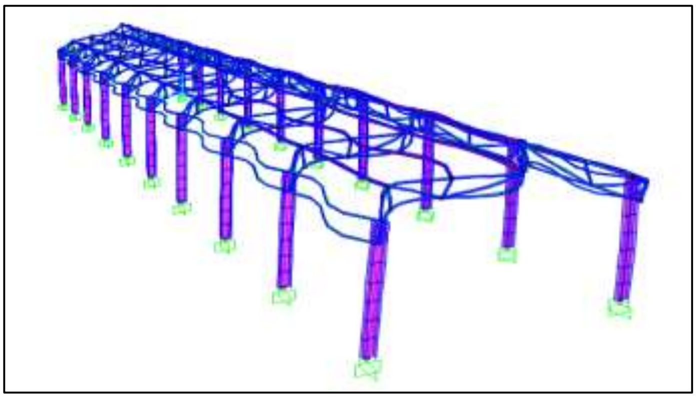

Figure 4.7: Mode shape 6 with period of 0.09865 and frequency of 10.13643

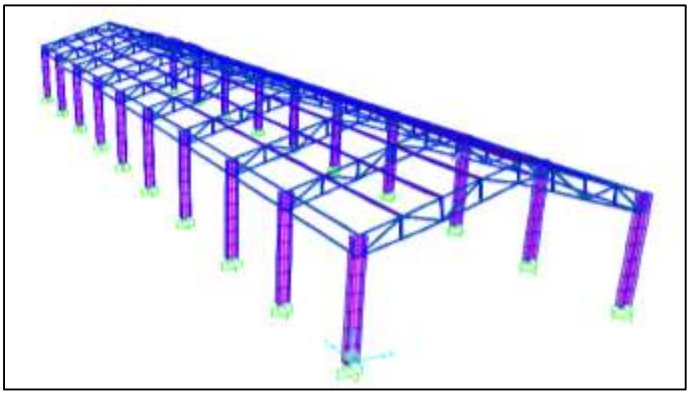

Figure 4.8: Mode shape 7 with period of 0.08535 and frequency of 11.71614

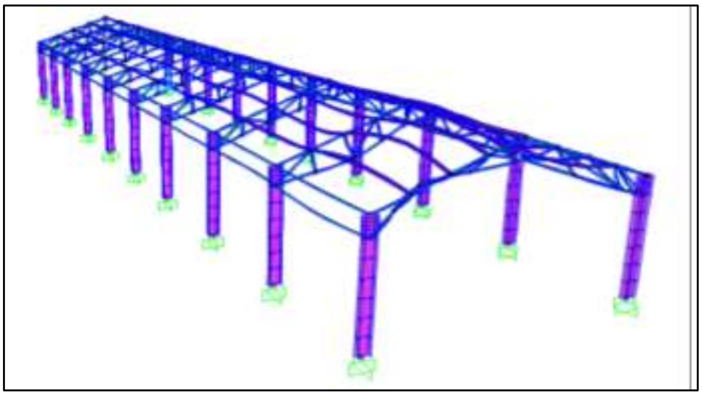

Figure 4.9: Mode shape 8 with period of 0.08364 and frequency of 11.95581

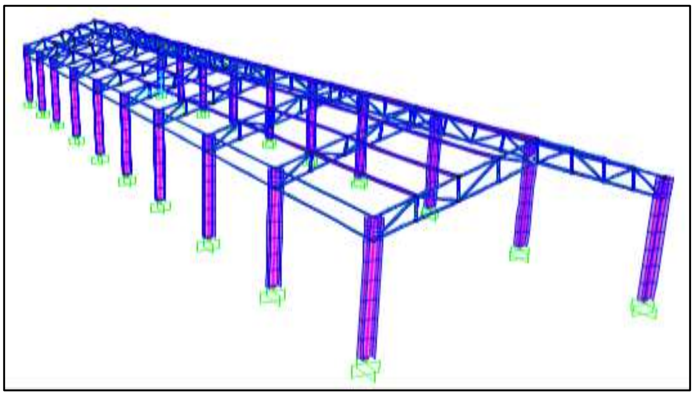

Figure 4.10: Mode shape 9 with period of 0.08226 and frequency of 12.15587

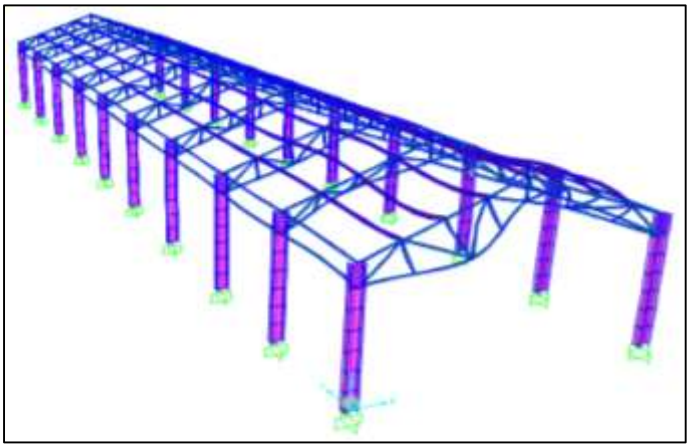

Figure 4.11: Mode shape 10 with period of 0.08087 and frequency of 12.36511

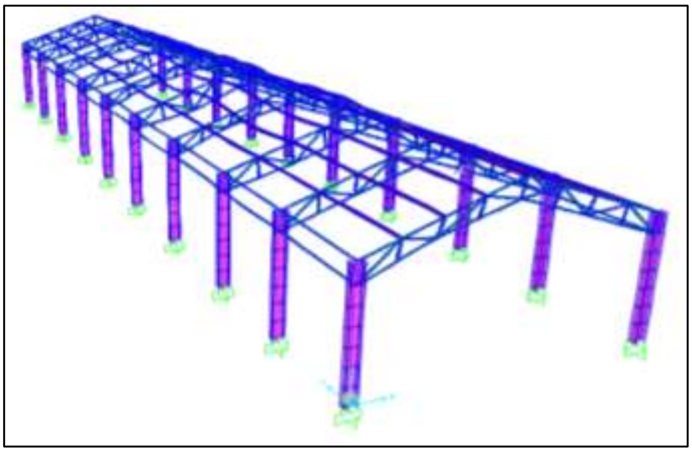

Figure 4.12: Mode shape 11 with period of 0.07957 and frequency of 12.56702

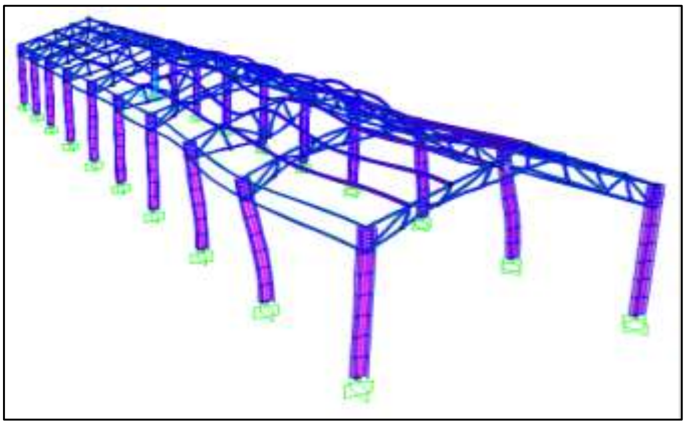

Figure 4.13: Mode shape 12 with period of 0.07875 and frequency of 12.69874

After run the modal analysis, all time period and frequency of each mode are shown as in Table 4.1.

Table 4.1: Period and frequencies of each mode

Mode	Period (Sec)	Frequency (Cyc/sec)
1	0.528093	1.8936
2	0.260248	3.8426
3	0.193241	5.1749
4	0.169235	5.9089
5	0.134252	7.4487
6	0.098654	10.136
7	0.085352	11.716
8	0.083641	11.956
9	0.082265	12.156
10	0.080873	12.365
11	0.079573	12.567
12	0.078748	12.699

Based on the modal analysis, Mode shape 1 have the highest time period which is 0.528093 sec and the natural of frequency is 1.8936/sec. The second highest time period is Mode 2 which is 0.260248 and the natural of frequency is 3.8425/sec. Last but not least the third highest time period is Mode 3 which is 0.193241 and the natural of frequency is 5.1749/sec. These results show that the top three mode is the best mode shape among of 12 modes shape because of their highest time period and lowest natural of frequency. Frequency also can be calculated by using Eq. (4.1).

$$\text{Frequency} = \frac{1}{\text{Period}} \tag{4.1}$$

Mode shape 1 produce a time period of 1.528093 sec. The frequency can be calculated using the formula above:

$$\text{Frequency} = \frac{1}{0.528093}$$

$$\text{Frequency} = 1.8936/\text{sec}$$

4.3.2 Dead Load + Live Load

Dead load is a permanent load that is not moving on a structure. The roof of steel structure warehouse is considered as dead load. Live load or imposed load is a moving load. Load combination of dead and live is one of the combination to obtain the maximum loading situations and maximum required strength of steel structure warehouse. The dead load and live load factor is 1.2 times the weight of the structures. A critical members of steel structure warehouse are chosen to illustrate the structures shear, moment, axial load, torsion and deflection. A column at gridline 9/I was chosen as shown in Figure 4.14.

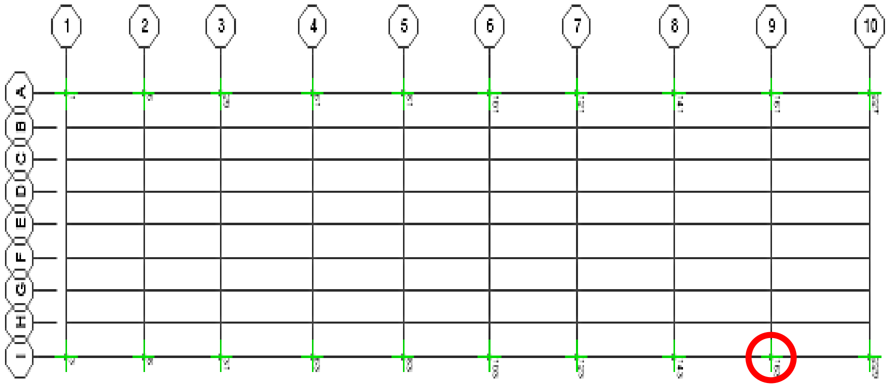

Figure 4.14: Gridline of chosen critical column of steel structure warehouse

Under dead load and live load combination, column at gridline 9/I have the greatest shear and moment among other column. Figure 4.15 illustrated the result of forces obtained from SAP2000 analysis in steel warehouse frame. The maximum shear force is 468.149 kN and the maximum moment is 426.3165 kNm. Maximum axial force is 382.249 kN and maximum torsion is 0.4778 kNm as illustrated in Figure 4.16. Figure 4.17 illustrate the maximum deflection and stress occur at column. The maximum deflection is 0.006335 m and the maximum stress is 313203.96 kN/m^2.

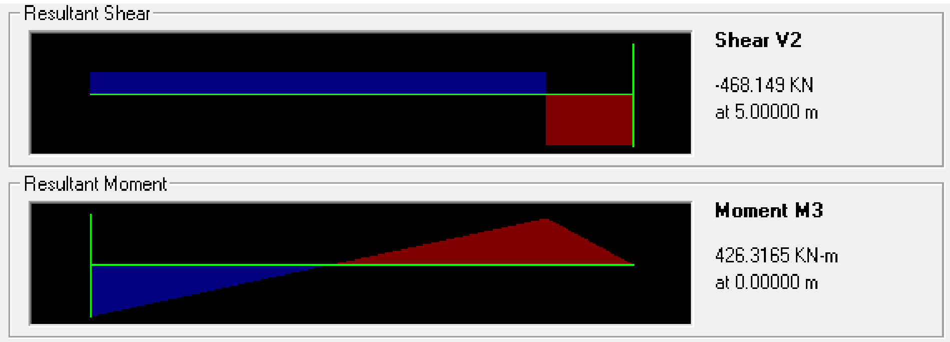

Figure 4.15: Result of maximum shear and moment for column at gridline 9/I

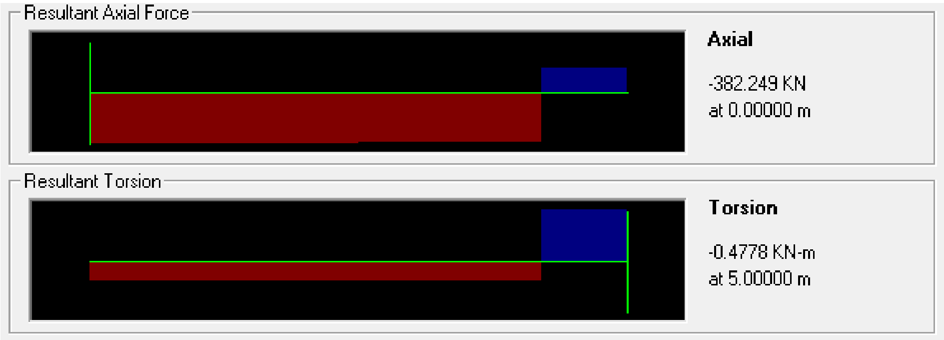

Figure 4.16: Result of maximum axial force and torsion for column at gridline 9/I

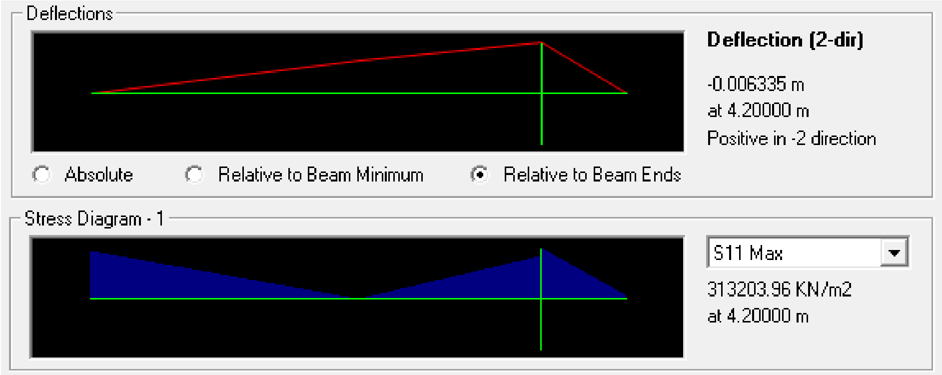

Figure 4.17: Result of maximum deflection and stress for column at gridline 9/I

4.3.3 Dead Load + Live Load + Wind Load + Earthquake (Acheh)

Combination of dead load, live load, wind load and earthquake is the maximum combination with 1.2 factored load. Under Acheh earthquake loading, the following results are obtained from SAP2000 software for column at gridline 9/I.

Figure 4.18 illustrated the result of forces obtained for steel warehouse frame analysis. The maximum shear force is 471.762 kN and the maximum moment is 428.6929 kNm. Maximum axial force is 392.255 kN and maximum torsion is 0.4818 kNm as illustrated in Figure 4.19. Figure 4.20 illustrate the maximum stress occur at column. The maximum stress is 315657.10 kN/m^2.

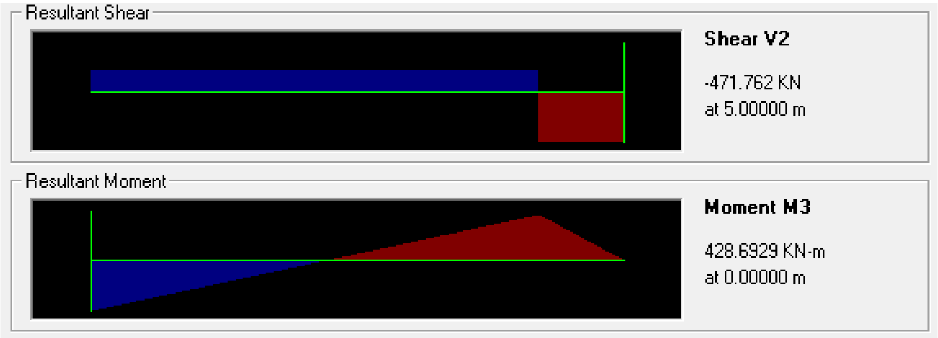

Figure 4.18: Result of maximum shear and moment for column at gridline 9/I under Acheh earthquake loading

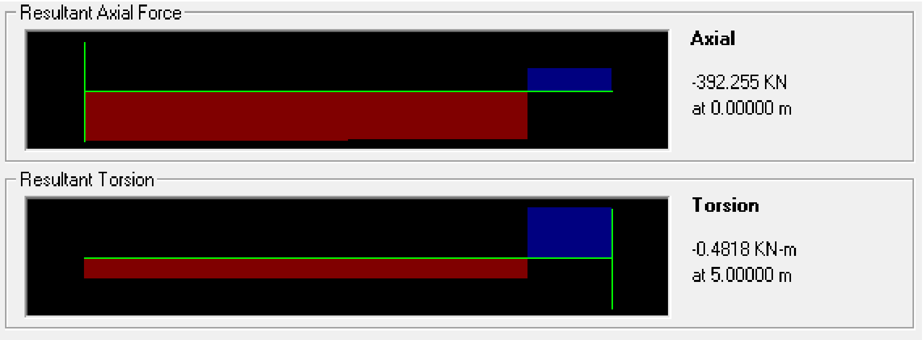

Figure 4.19: Result of maximum axial force and torsion for column at gridline 9/I under Acheh earthquake loading

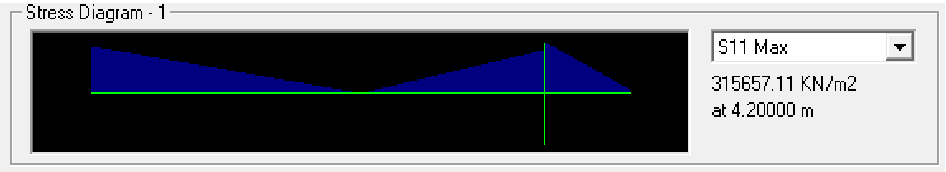

Figure 4.20: Result of maximum stress for column at gridline 9/I under Acheh earthquake loading

4.3.4 Dead Load + Live Load + Wind Load + Earthquake (El Centro)

Under El Centro earthquake loading, the following results are obtained from SAP2000 software for column at gridline 9/I. Figure 4.21 illustrated the result of forces obtained for steel warehouse frame analysis. The maximum shear force is 295.166 kN and the maximum moment is 428.6929 kNm. Maximum axial force is 344.341 kN and maximum torsion is 3.3906 kNm as illustrated in Figure 4.22. Figure 4.23 illustrate the maximum stress occur at column. The maximum stress is 2381623.38 kN/m^2.

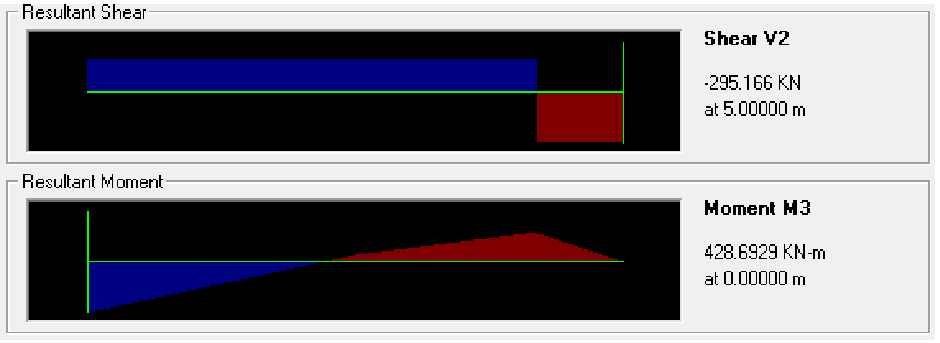

Figure 4.21: Result of maximum shear and moment for column at gridline 9/I under El Centro earthquake loading

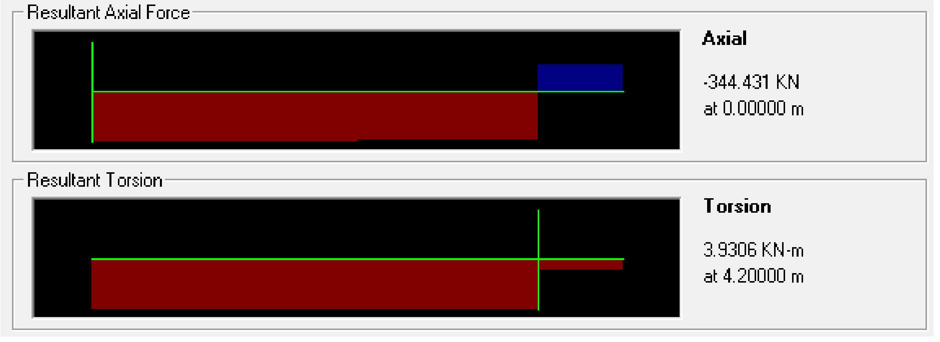

Figure 4.22: Result of maximum axial force and torsion for column at gridline 9/I under El Centro earthquake loading

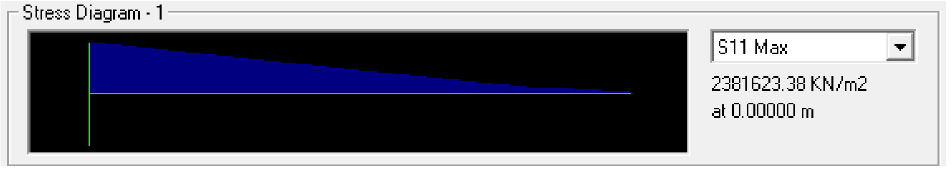

Figure 4.23: Result of maximum stress for column at gridline 9/I under El Centro earthquake loading

4.3.5 Comparison of Steel Capacity and Resistance

Steel capacity must not greater than the steel resistance to ensure the building is safe to be used. In steel, the design resistance is also known as plastic resistance. A comparison was made for shear and moment resistance capacity. Ratio of the comparison must not be greater than 1 to indicate the durability of a building. Shear and moment resistance can be calculated by referring to Eurocode 3: Part 1 which is used for steel structure. Moment resistance can be calculated by using Eq. (4.2) and Eq. (4.3) while shear resistance can be calculated using Eq. (4.4) and Eq. (4.5). The result of moment comparison was tabulated in Table 4.2 and Table 4.3 for shear comparison. Refer Appendix A1 for calculation of moment resistance and Appendix A2 for shear resistance.

Clause 6.2.5: Moment

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1.0 \tag{4.2}$$

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma M_0} \text{ for class 1 or 2 cross section} \tag{4.3}$$

Clause 6.2.6: Shear

$$\frac{V_{Ed}}{V_{c,Rd}} \leq 1.0 \tag{4.4}$$

Where, $V_{c,Rd}$ is the design plastic shear resistance $V_{pl.Rd.}$

$$V_{pl,Rd} = \frac{A_v\left(\frac{f_y}{\sqrt{3}}\right)}{\gamma M_0} \tag{4.5}$$

Where, A_v is shear area.

The shear area A_v may be taken as follow:

- Welded I, H and box sections, load parallel to web: $\eta \Sigma(h_w t_w)$

Table 4.2: Comparison of steel moment capacity and resistance

Load Combinations	M_{Ed} (kN)	$M_{pl,Rd}$ (kN)	$\frac{M_{Ed}}{M_{pl,Rd}}$
DL + LL	426.3165	514.25	0.83
DL + LL + WL + ACHEH	428.6929	514.25	0.84
DL + LL + WL + EL CENTRO	428.6929	514.25	0.84

Table 4.3: Comparison of steel shear capacity and resistance

Load Combinations	V_{Ed} (kN)	$V_{pl,Rd}$ (kN)	$\frac{V_{Ed}}{V_{pl,Rd}}$
DL + LL	468.149	479.90	0.98
DL + LL + WL + ACHEH	471.762	479.90	0.98
DL + LL + WL + EL CENTRO	295.166	479.90	0.62

4.4 VIRTUAL WORK DIAGRAMS

Principle of virtual work states that a body is in equilibrium if, and only if, the virtual work of all forces acting on the body is zero (C. Colin, 2007). Virtual work is defined in two ways which are virtual forces and virtual displacement.

Virtual work diagram can be used to determine which elements should be stiffened based on its virtual color. It is to achieve the most efficient control over the lateral displacement as in SAP2000 software. The virtual work diagrams for warehouse structure are illustrated in Figure 4.24 – Figure 4.29.

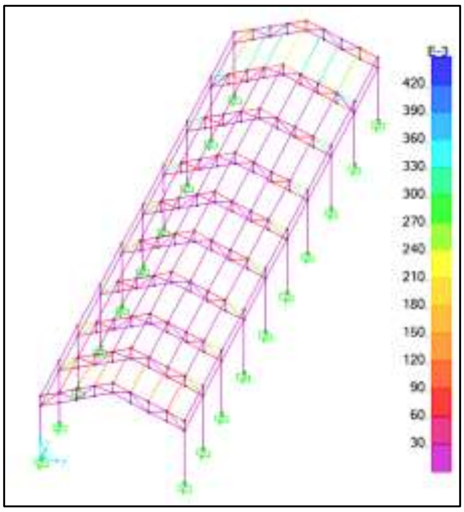

Figure 4.24: Forces: Dead,
Displacement: Dead

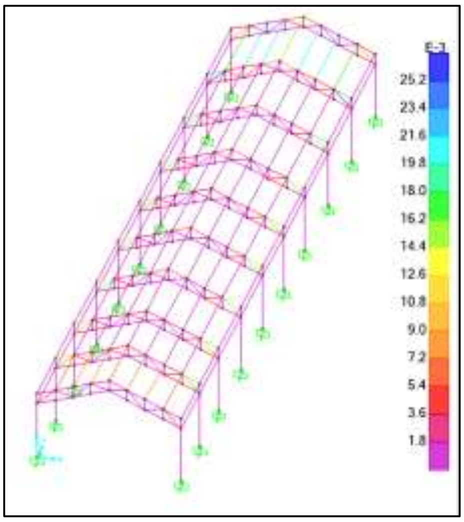

Figure 4.25: Forces: Dead,
Displacement: Live

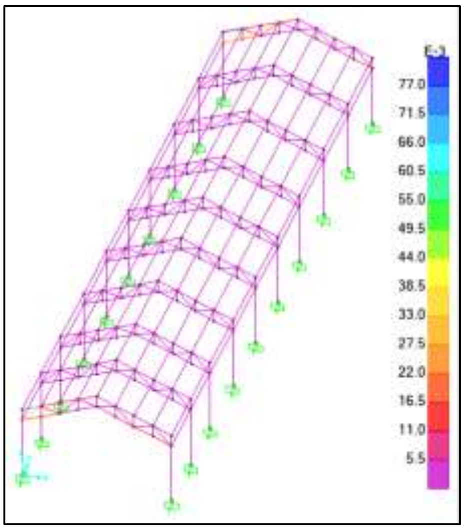

Figure 4.26: Forces: Dead,
Displacement: Wind

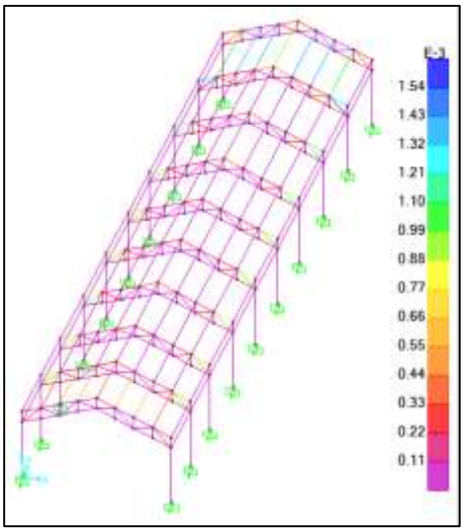

Figure 4.27: Forces: Live,
Displacement: Live

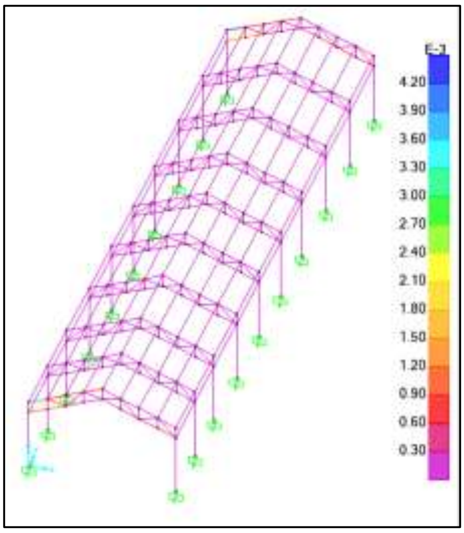

Figure 4.28: Forces: Live,
Displacement: Wind

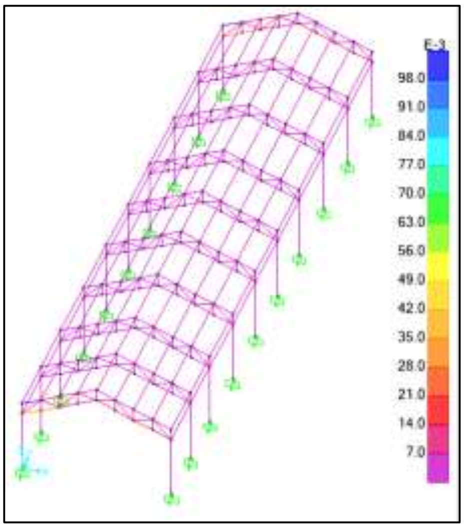

Figure 4.29: Forces: Wind,
Displacement: Wind

4.5 TIME HISTORY ANALYSIS

Time history analysis gives a result of nonlinear assessment of dynamic response under different earthquake loading. Time history analysis is used to determine the seismic response of a structure under dynamic loading of representative earthquake (Wilkinson and Hiley, 2006).

Time history analysis on joint is based on combination cases of Acheh and El Centro earthquake. The combination is the maximum strength required for structure. The maximum joint displacement for both earthquake in x and y direction are illustrated in Figure 4.30 and Figure 4.31 respectively. The maximum joint acceleration for both earthquake in x and y direction are illustrated in Figure 4.32 and Figure 4.33 respectively.

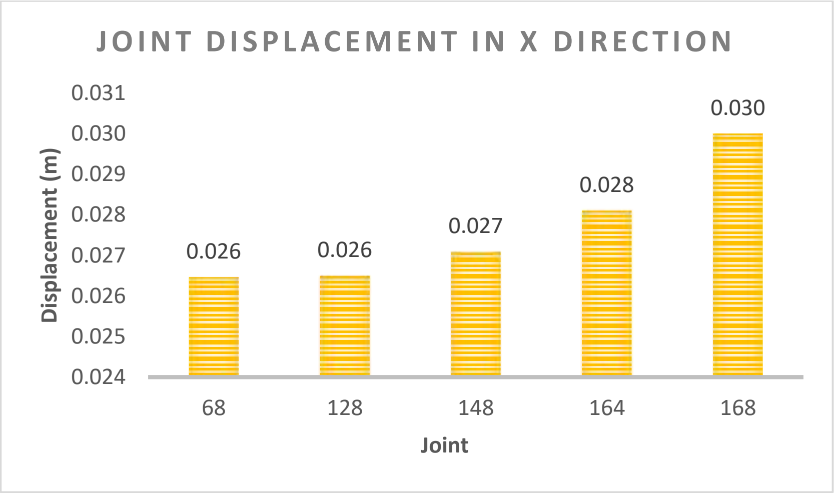

Figure 4.30: Maximum joint displacement in x direction

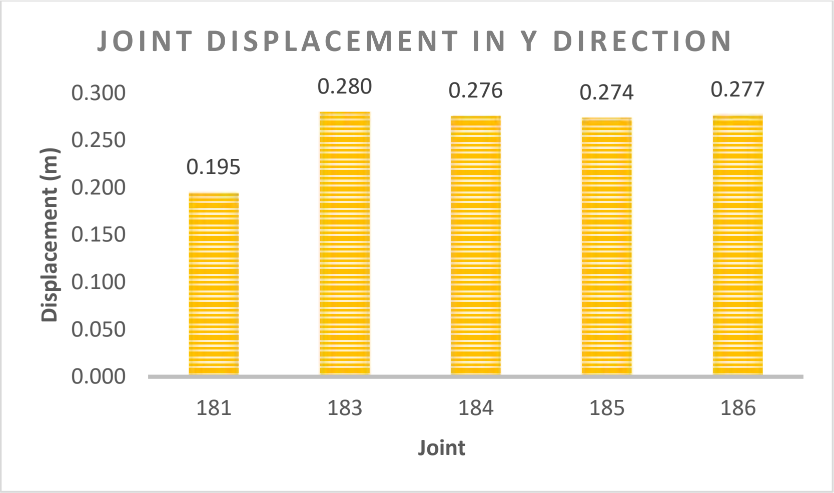

Figure 4.31: Maximum joint displacement in y direction

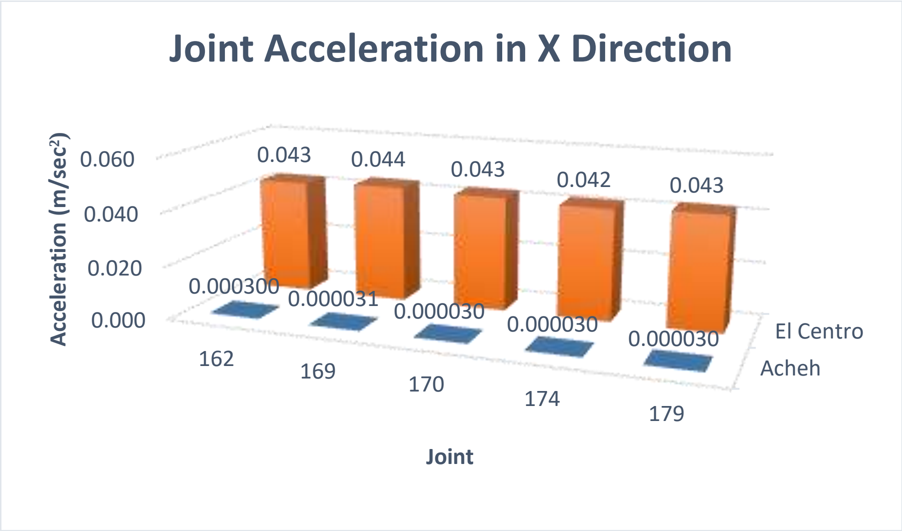

Figure 4.32: Maximum joint acceleration in x direction

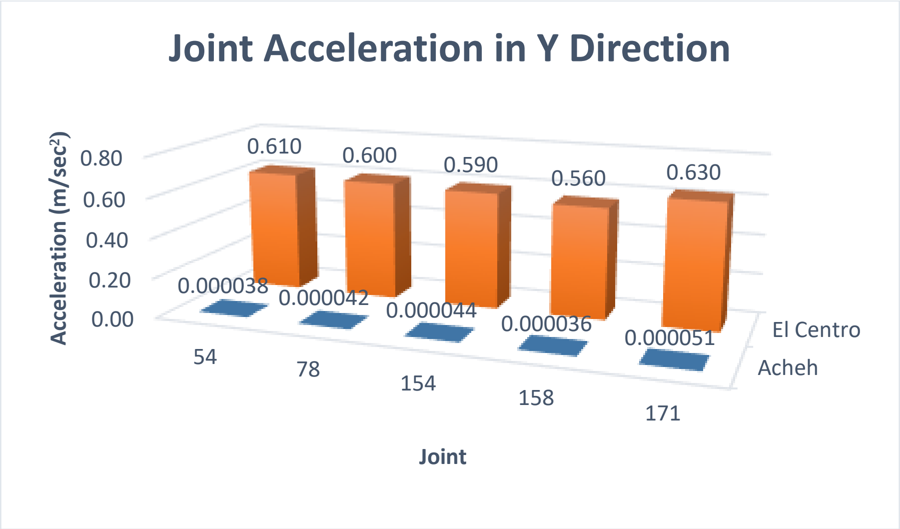

Figure 4.33: Maximum joint acceleration in y direction

The result shows that the maximum joint displacement for both earthquake are 0.030 m in direction of x at joint 168 and 0.280 m in direction of y at joint 183. Under Acheh excitation, the maximum joint acceleration are 0.000031 m/sec^2 and 0.000051 m/sec^2 in x direction at joint 169 and y direction at joint 171 respectively. Under El Centro excitation, the maximum joint acceleration are 0.044 m/sec^2 and 0.63 m/sec^2 in x direction at joint 169 and y direction at joint 158 respectively.

4.6 RESPONSE SPECTRUM ANALYSIS (RSA)

Response spectrum analysis is a linear dynamic analysis method which is quite accurate for structural design applications. Peak response of the structure is obtained directly from the earthquake response (Duggal, 2010). RSA is method that measures the contribution from each mode of vibration to determine the maximum seismic response of elastic structure.

The analysis include two terms; time period and frequency in x and y directions. RSA have 5 specifications for both terms, which are:

i. Spectral Displacement
ii. Spectral Velocities
iii. Pseudo Spectral Velocities
iv. Spectral Accelerations
v. Pseudo Spectral Acceleration

4.6.1 Time Period

Joint 169 is chosen to run this analysis for time period. Figure 4.34 – Figure 4.43 illustrate the peak response of structure in both direction which are subjected to Acheh earthquake loading. The response was selected for damping 0%, 10% and 50%. Table 4.4 and 4.5 shows the maximum peak of RSA for x and y direction respectively.

X Direction

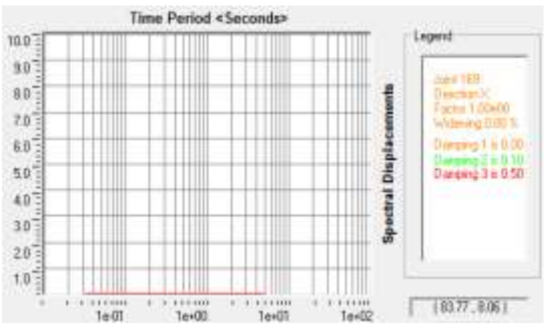

Figure 4.34: Spectral displacement in x direction

Y Direction

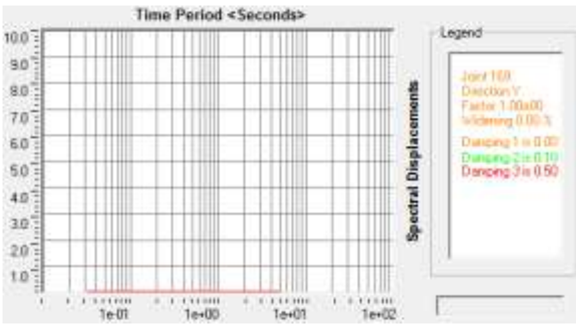

Figure 4.35: Spectral displacement in y direction

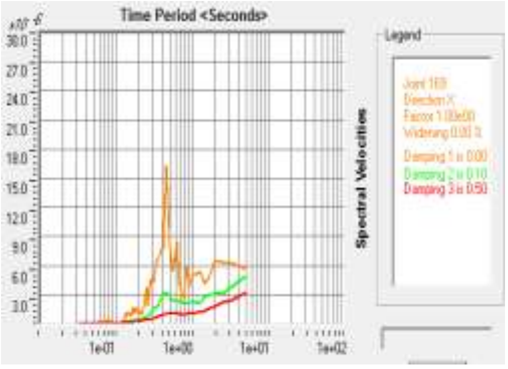

Figure 4.36: Spectral velocities in x direction

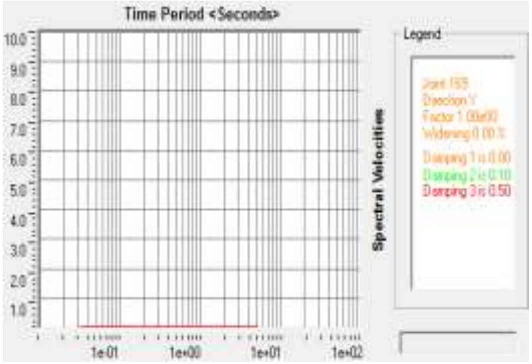

Figure 4.37: Spectral velocities in y direction

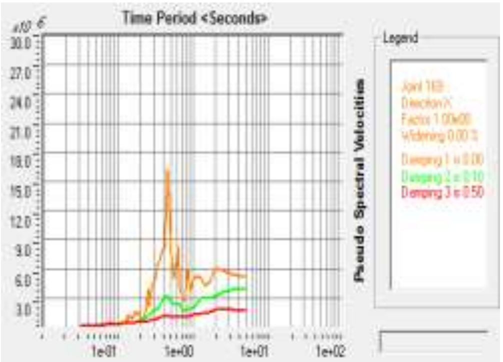

Figure 4.38: Pseudo spectral velocities in x direction

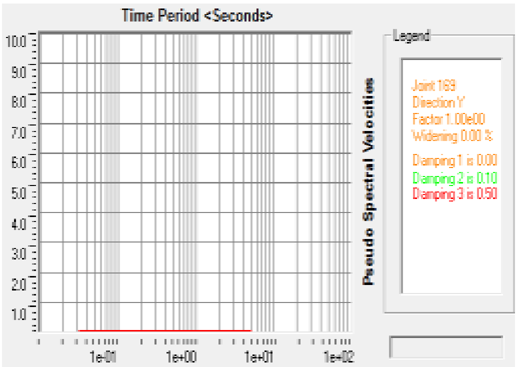

Figure 4.39: Pseudo spectral velocities in y direction

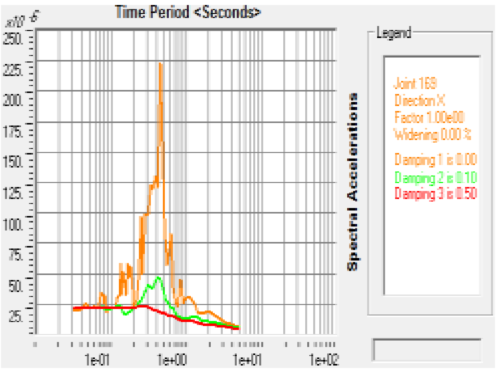

Figure 4.40: Spectral acceleration in x direction

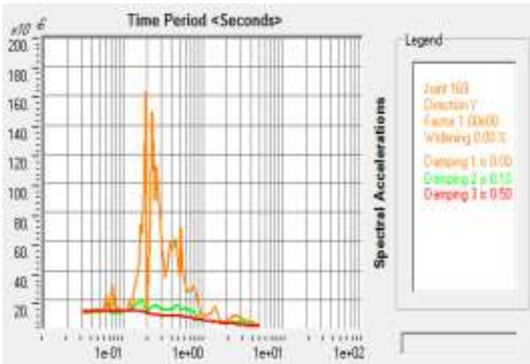

Figure 4.41: Spectral acceleration in y direction

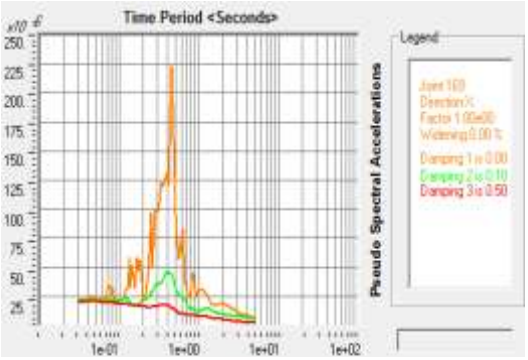

Figure 4.42: Pseudo spectral acceleration in x direction

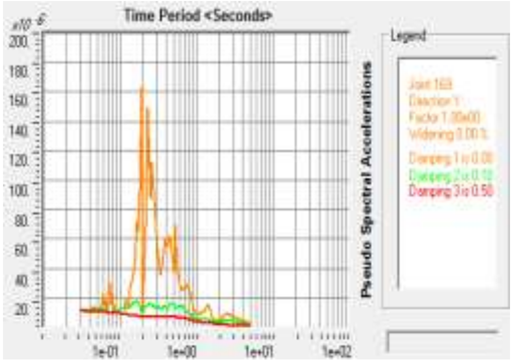

Figure 4.43: Pseudo spectral acceleration in y direction

Table 4.4: Peak response spectrum for Acheh excitation in x direction (Time Period)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	$4.12\text{x}10^{-6}$	$3.15\text{x}10^{-6}$	$1.37\text{x}10^{-6}$
SV (m/s)	$8.45\text{x}10^{-6}$	$4.89\text{x}10^{-6}$	$3.17\text{x}10^{-6}$
PSV (m/s)	$8.30\text{x}10^{-6}$	$3.20\text{x}10^{-6}$	$1.40\text{x}10^{-6}$
SA (m/s^2)	$4.12\text{x}10^{-4}$	$4.12\text{x}10^{-5}$	$4.12\text{x}10^{-5}$
PSA (m/s^2)	$4.12\text{x}10^{-4}$	$4.12\text{x}10^{-5}$	$4.12\text{x}10^{-5}$

Table 4.5: Peak response spectrum for Acheh excitation in y direction (Time Period)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	$1.78\text{x}10^{-6}$	$9.30\text{x}10^{-7}$	$5.47\text{x}10^{-7}$
SV (m/s)	$6.39\text{x}10^{-6}$	$2.50\text{x}10^{-6}$	$1.30\text{x}10^{-6}$
PSV (m/s)	$5.88\text{x}10^{-6}$	$1.75\text{x}10^{-6}$	$6.60\text{x}10^{-7}$
SA (m/s^2)	$1.62\text{x}10^{-4}$	$2.00\text{x}10^{-5}$	$1.24\text{x}10^{-5}$
PSA (m/s^2)	$1.63\text{x}10^{-4}$	$1.63\text{x}10^{-5}$	$1.06\text{x}10^{-5}$

Under El Centro earthquake loading, the peak response of structure are illustrated in Figure 4.44 – Figure 4.53. Joint 169 is chosen to run this analysis for time period. The response was selected for damping 0%, 10% and 50%. Table 4.6 and 4.7 shows the maximum peak of RSA for x and y direction respectively.

<u>X Direction</u>

<u>Y Direction</u>

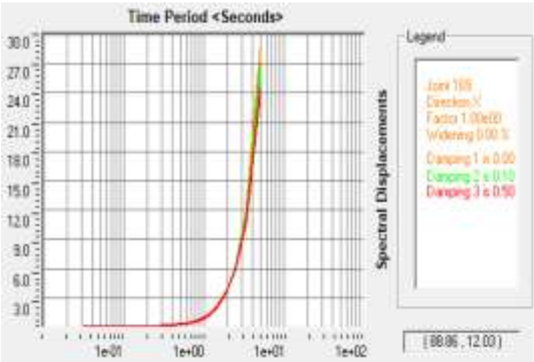

Figure 4.44: Spectral displacement in x direction

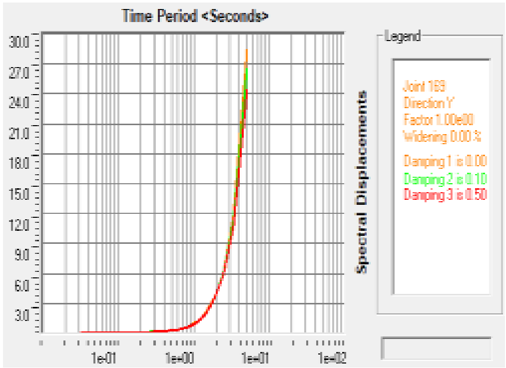

Figure 4.45: Spectral displacement in y direction

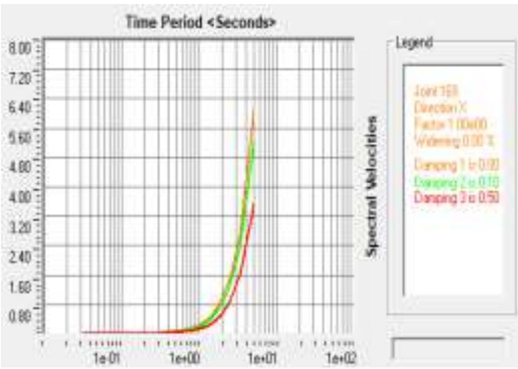

Figure 4.46: Spectral velocities in x direction

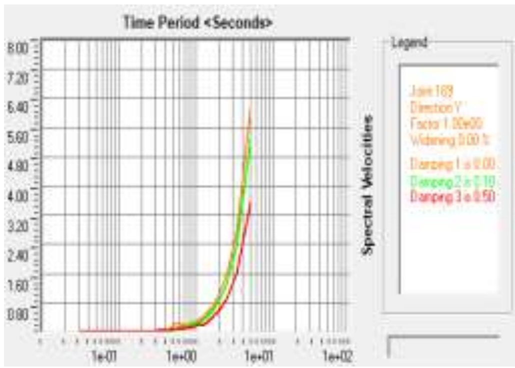

Figure 4.47: Spectral velocities in y direction

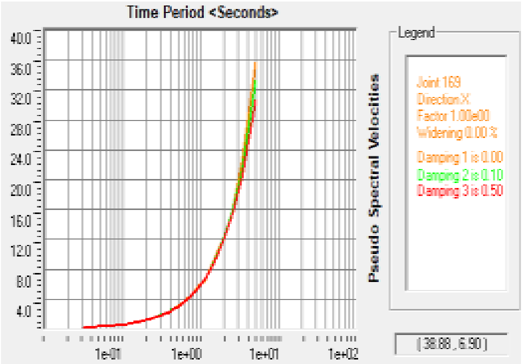

Figure 4.48: Pseudo spectral velocities in x direction

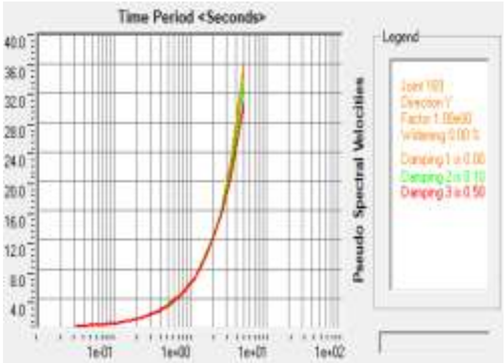

Figure 4.49: Pseudo spectral velocities in y direction

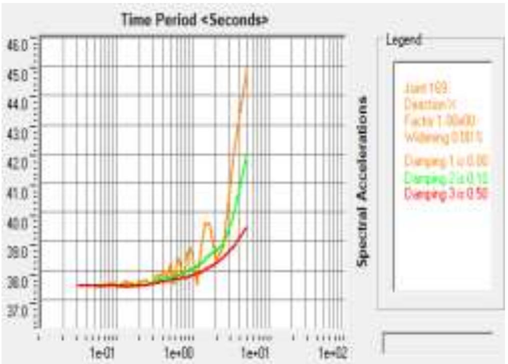

Figure 4.50: Spectral acceleration in x direction

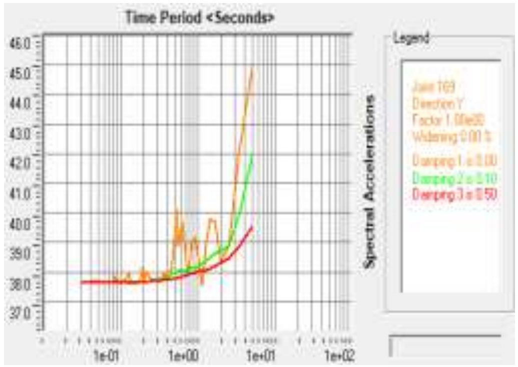

Figure 4.51: Spectral acceleration in y direction

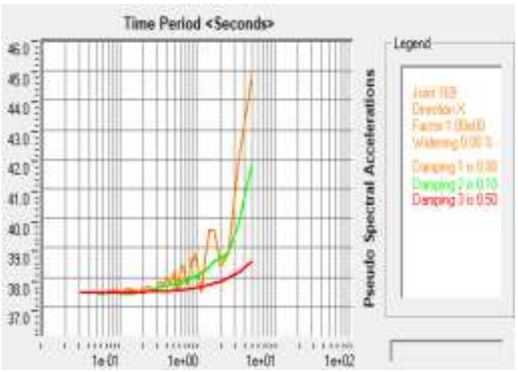

Figure 4.52: Pseudo spectral acceleration in x direction

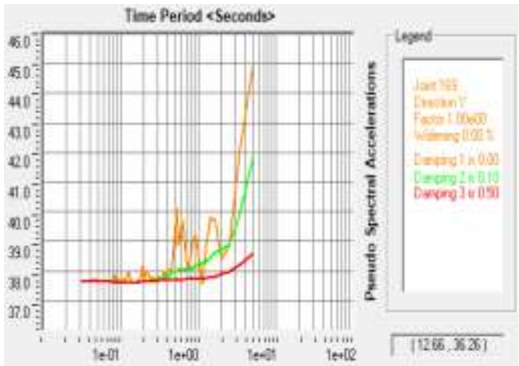

Figure 4.53: Pseudo spectral acceleration in y direction

Table 4.6: Peak response spectrum for El Centro excitation in x direction (Time Period)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	28.45	26.50	24.42
SV (m/s)	6.08	5.25	3.54
PSV (m/s)	35.76	33.30	30.68
SA (m/s^2)	44.93	41.95	39.50
PSA (m/s^2)	44.93	41.85	38.56

Table 4.7: Peak response spectrum for El Centro excitation in y direction (Time Period)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	28.48	26.52	24.42
SV (m/s)	6.10	5.27	3.54
PSV (m/s)	35.79	33.32	30.69
SA (m/s^2)	44.97	41.97	39.52
PSA (m/s^2)	44.97	41.88	38.57

4.6.2 Frequency

Joint 169 is chosen to run this analysis for frequency. Figure 4.54 – Figure 4.63 illustrate the peak response of structure in both direction which are subjected to Acheh earthquake loading. The response was selected for damping 0%, 10% and 50%. Table 4.8 and 4.9 shows the maximum peak of RSA for x and y direction respectively.

X Direction

Y Direction

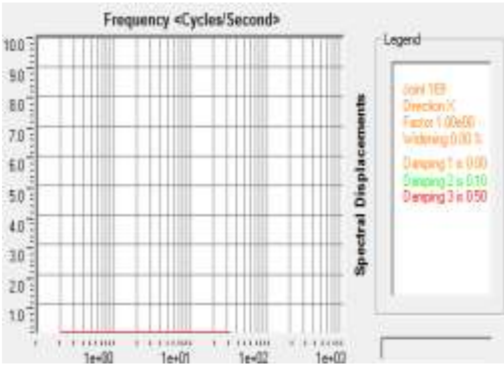

Figure 4.54: Spectral displacement in x direction

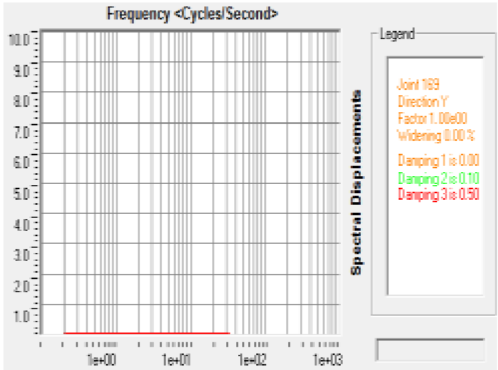

Figure 4.55: Spectral displacement in y direction

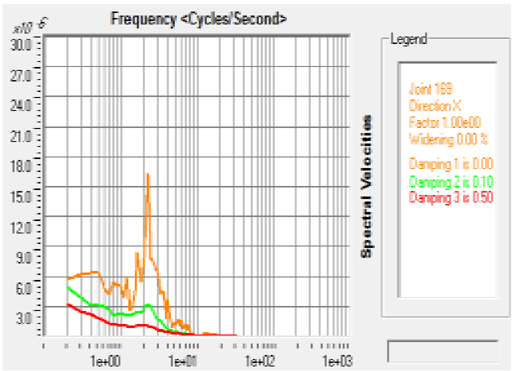

Figure 4.56: Spectral velocities in x direction

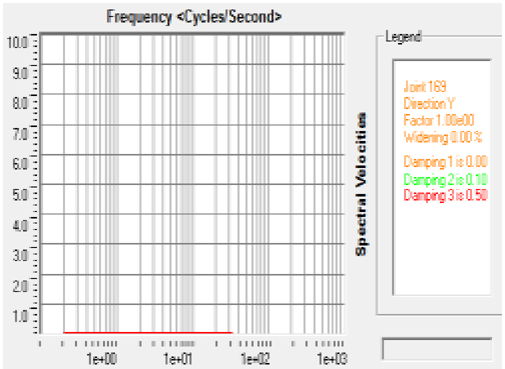

Figure 4.57: Spectral velocities in y direction

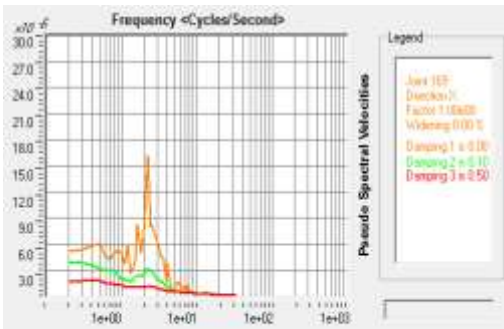

Figure 4.58: Pseudo spectral velocities in x direction

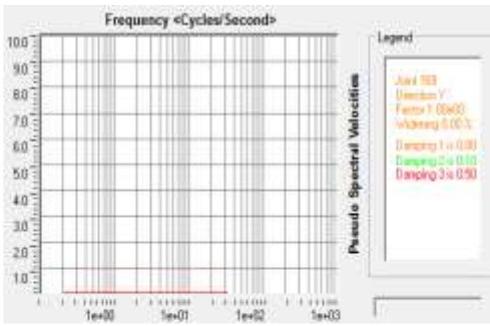

Figure 4.59: Pseudo spectral velocities in y direction

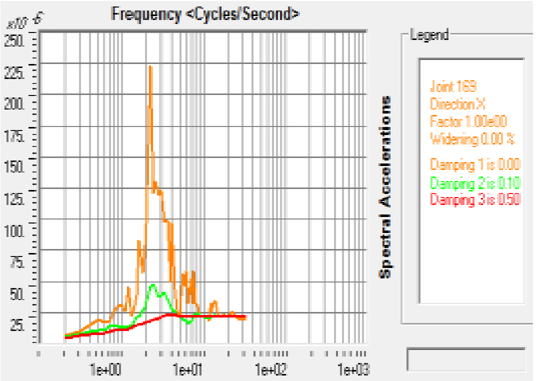

Figure 4.60: Spectral acceleration in x direction

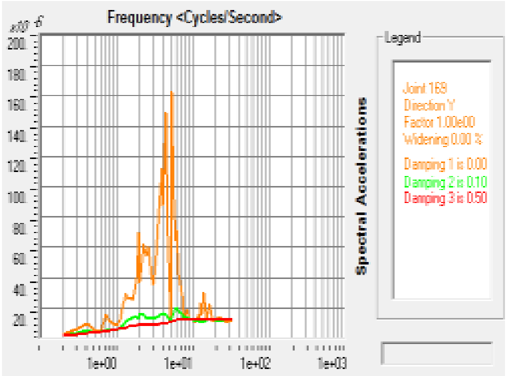

Figure 4.61: Spectral acceleration in y direction

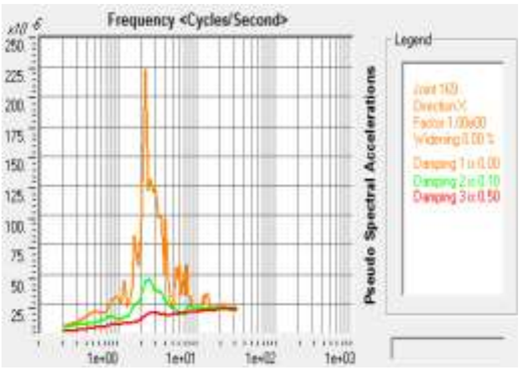

Figure 4.62: Pseudo spectral acceleration in x direction

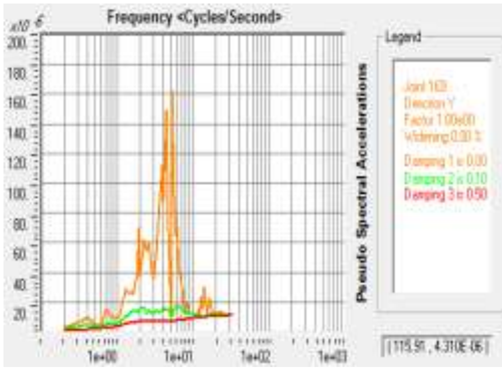

Figure 4.63: Pseudo spectral acceleration in y direction

Table 4.8: Peak response spectrum for Acheh excitation in x direction (Frequency)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	$4.12\text{x}10^{-6}$	$3.15\text{x}10^{-6}$	$1.37\text{x}10^{-6}$
SV (m/s)	$8.45\text{x}10^{-6}$	$4.89\text{x}10^{-6}$	$3.17\text{x}10^{-6}$
PSV (m/s)	$8.30\text{x}10^{-6}$	$3.95\text{x}10^{-6}$	$1.86\text{x}10^{-6}$
SA (m/s^2)	$2.23\text{x}10^{-4}$	$4.74\text{x}10^{-6}$	$2.30\text{x}10^{-6}$
PSA (m/s^2)	$2.23\text{x}10^{-4}$	$4.61\text{x}10^{-6}$	$2.07\text{x}10^{-6}$

Table 4.9: Peak response spectrum for Acheh excitation in y direction (Frequency)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	$1.78x10^{-6}$	$9.30x10^{-7}$	$5.47x10^{-7}$
SV (m/s)	$6.39x10^{-6}$	$2.50x10^{-6}$	$1.30x10^{-6}$
PSV (m/s)	$5.88x10^{-6}$	$1.90x10^{-6}$	$6.89x10^{-7}$
SA (m/s²)	$1.63x10^{-4}$	$2.00x10^{-6}$	$1.24x10^{-6}$
PSA (m/s²)	$1.49x10^{-5}$	$1.80x10^{-5}$	$1.10x10^{-5}$

Under El Centro earthquake loading, the peak response of structure are illustrated in Figure 4.64 – Figure 4.73. Joint 169 is chosen to run this analysis for frequency. The response was selected for damping 0%, 10% and 50%. Table 4.10 and 4.11 shows the maximum peak of RSA for x and y direction respectively.

X Direction

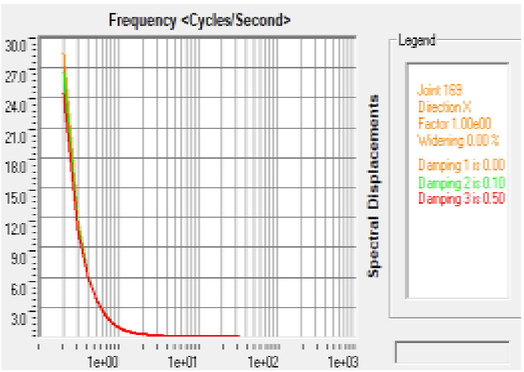

Figure 4.64: Spectral displacement in x direction

Y Direction

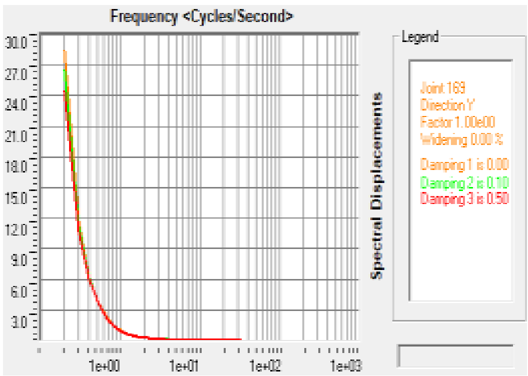

Figure 4.65: Spectral displacement in y direction

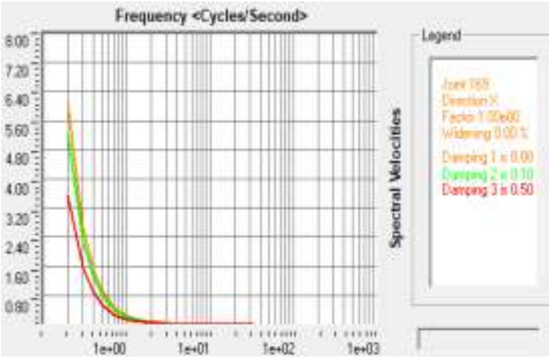

Figure 4.66: Spectral velocities in x direction

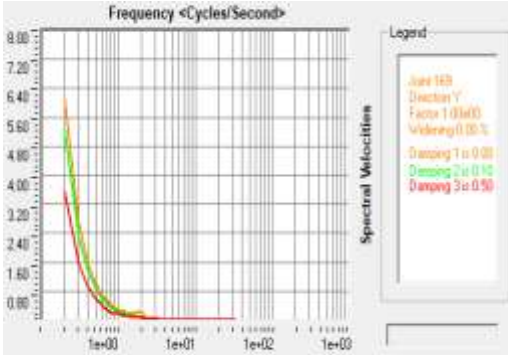

Figure 4.67: Spectral velocities in y direction

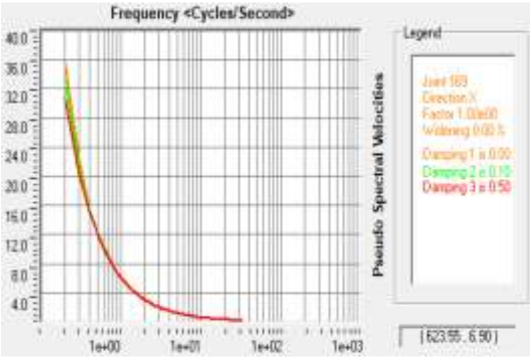

Figure 4.68: Pseudo spectral velocities in x direction

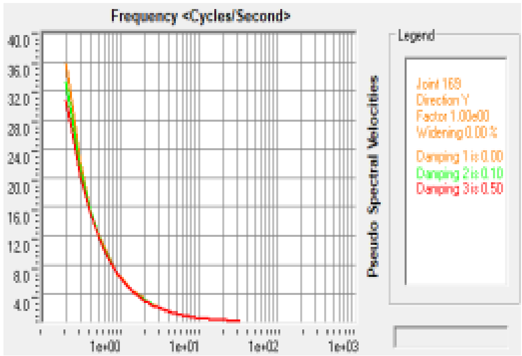

Figure 4.69: Pseudo spectral velocities in y direction

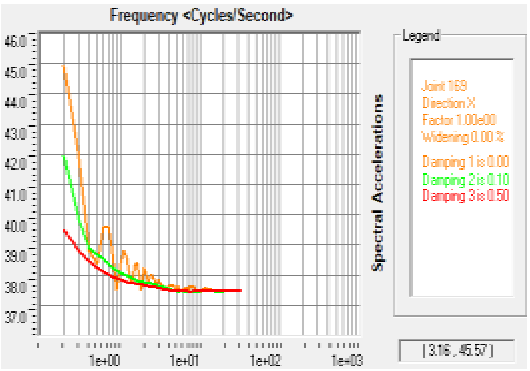

Figure 4.70: Spectral acceleration in x direction

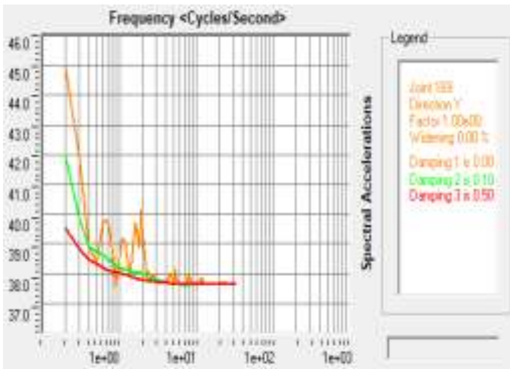

Figure 4.71: Spectral acceleration in y direction

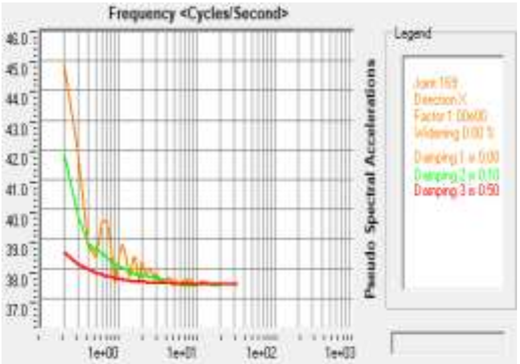

Figure 4.72: Pseudo spectral acceleration in x direction

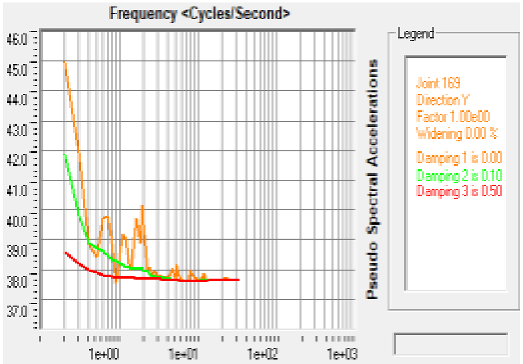

Figure 4.73: Pseudo spectral acceleration in y direction

Table 4.10: Peak response spectrum for El Centro excitation in x direction (Frequency)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	8.72×10^{-4}	8.72×10^{-4}	8.71×10^{-4}
SV (m/s)	2.12×10^{-4}	1.25×10^{-4}	1.23×10^{-4}
PSV (m/s)	1.81×10^{-1}	1.81×10^{-1}	1.81×10^{-1}
SA (m/s^2)	37.49	37.46	37.45
PSA (m/s^2)	37.49	37.46	37.45

Table 4.11: Peak response spectrum for El Centro excitation in y direction (Frequency)

	Peak response		
RSA/Damping	**0**	**0.1**	**0.5**
SD (m)	8.76×10^{-4}	8.76×10^{-4}	8.75×10^{-4}
SV (m/s)	2.09×10^{-4}	1.83×10^{-4}	1.81×10^{-4}
PSV (m/s)	1.82×10^{-1}	1.82×10^{-1}	1.81×10^{-1}
SA (m/s^2)	37.65	37.64	37.64
PSA (m/s^2)	37.65	37.64	37.63

4.7 SUMMARY OF ANALYSIS

Different types of structures materials can impact to the existing structures. Usage of steel structures can impact the existing building, due to seismic forces distribution that is most certainly not considered in the design. Besides, type of steel material and element could also influence the existing building.

Different properties of steel have different strength, which could give different impact to the structures. The properties of steel which is flexible, is the advantage compared to other structure materials. The building tends to bend without causing any cracks to the building.

4.7.1 Time Period and Frequency

Vibratory motion in the building are developed when the structure is subjected to a dynamic action. The motion is caused from the structure elastic mass and properties. Vibration of building consists of a fundamental mode of vibration and additional contribution of various modes, which vibrates at the highest frequencies. Building with high frequency and short time period, tend to experience high acceleration with small displacement.

On the basis of time period, the building may be classified as rigid ($T < 0.3$ sec), semi-rigid (0.3 sec $< T < 1$ sec) and flexible structure ($T > 1$). Fundamental period of vibration for steel structure can be determined by using Eq. (4.1). Table 4.12 shows the summary of modal period and frequency with the structure classification. Based on the result, steel structure warehouse is considered as semi-rigid building. As the frequency increase, the time period to complete one cycle will decrease.

Table 4.12: Steel warehouse classification based on time period and frequency

Mode Shape	Frequency (Cyc/sec)	Time Period (sec)	Structure classification
1	1.8936	0.528093	Semi-rigid
2	3.8425	0.260248	Rigid
3	5.1749	0.193241	Rigid
4	5.9089	0.169235	Rigid
5	7.4487	0.134252	Rigid
6	10.136	0.098654	Rigid
7	11.716	0.085352	Rigid
8	11.956	0.083641	Rigid
9	12.156	0.082265	Rigid
10	12.365	0.080873	Rigid
11	12.567	0.079573	Rigid
12	12.699	0.078748	Rigid

4.7.2 Maximum Result of Load Combination

A critical structure member was chosen for load combination analysis. Table 4.13 shows the result of maximum shear, moment, axial forces, torsion, deflection and stress of critical column at gridline 9/I under different load combination.

Table 4.13: Maximum result of column subjected under different load combination

Load Combination	**DL + LL**	**DL + LL + WL + ACHEH**	**DL + LL + WL + EL CENTRO**
Shear (kN)	468.149	471.762	295.166
Moment (kNm)	426.3165	428.6929	428.6929
Axial Force (kN)	382.249	392.255	344.341
Torsion (kNm)	0.4778	0.4818	3.3906
Deflection (m)	0.006335	0.013896	0.062950
Stress (kN/m^2)	313203.96	31567.10	2381623.38
$V_{Ed}/V_{pl,Rd}$	0.98	0.98	0.62
$M_{Ed}/M_{pl,Rd}$	0.83	0.84	0.84

4.7.3 Time History

Table 4.14 shows the maximum displacement and acceleration occurred on critical joint when subjected to different earthquake excitation. Based on the result, El Centro earthquake excitation produce larger acceleration compared to Acheh earthquake excitation at the same displacement.

Table 4.14: Maximum displacement and acceleration under different earthquake excitation

Earthquake Excitation	**Acheh**		**El Centro**	
Direction	**U1**	**U2**	**U1**	**U2**
Displacement (m)	0.03	0.28	0.03	0.28
Acceleration (m/sec^2)	0.000031	0.000051	0.044	0.63

4.7.4 RSA

Table 4.15 shows the maximum displacement and acceleration of 0% damping occurred on critical joint when subjected to different earthquake excitation. Based on the result, El Centro earthquake excitation produce larger displacement and acceleration compared to Acheh earthquake excitation.

Table 4.15: Maximum displacement and acceleration of 0% damping under different excitation

	Acheh		**El Centro**	
	Period	**Frequency**	**Period**	**Frequency**
SD (m)	$4.12\text{x}10^{-6}$	$4.12\text{x}10^{-6}$	28.48	$8.76\text{x}10^{-4}$
SA (m/s^2)	$4.12\text{x}10^{-4}$	$2.23\text{x}10^{-4}$	44.97	37.65
PSA (m/s^2)	$4.12\text{x}10^{-4}$	$2.23\text{x}10^{-4}$	44.97	37.65

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Malaysia region some earthquake excitation from Acheh and El Centro. Sabah and Sarawak often experienced the tremors from the earthquake. Nowadays, Peninsular Malaysia started to experience that. Based on this research, analysis was made for earthquake resistance and performance of steel warehouse under Acheh and El Centro excitation.

5.1.1 Vulnerability of Steel Warehouse

Based on the analysis of SAP2000, the vulnerable and critical member of steel warehouse was defined. Column at gridline 9/I was determined as the most critical member based on its maximum shear and moment. Besides, 12 mode shapes from Modal Analysis show the possible movement of steel warehouse when subjected to no loading.

5.1.2 Capability and Resistance of Structure under Acheh and El Centro Excitation

Under Acheh earthquake loading, the maximum shear is 471.762 kN and the maximum moment is 428.6929 kNm. While under El Centro earthquake loading, the maximum shear is 295.166 kN and the maximum moment is 428.6929 kNm. The ratio of shear and moment design with its resistance are below than 1.0. The value are relatively near to 1.0 which could risk the steel warehouse.

5.1.3 Dynamic Characteristic of Structure under Different Types of Loading

Displacement and acceleration was the dynamic characteristics studied for this research. Under different types of loading, displacement and acceleration produced are different. Based on the analysis, when steel warehouse was subjected under El Centro excitation the displacement and acceleration produced are larger compared with Acheh excitation. Table 5.1 show the maximum dynamic characteristics of steel warehouse under different type of loading.

Table 5.1: Maximum dynamic characteristics of steel warehouse

	Acheh		**El Centro**	
	Time History	**RSA**	**Time History**	**RSA**
Displacement (m)	0.28	0.00000412	0.28	28.48
Acceleration (m/sec^2)	0.000051	0.000223	0.63	44.97

5.2 RECOMMENDATIONS

For the future study, engineer need to design the steel structure building in Malaysia by considering the earthquake. Nowadays, Malaysia experienced small scale earthquake in Sabah because Malaysia is near to major tectonic plates on Earth surface. Even it is in small scale, it still can make building collapse especially when the structure is not design with considering seismic effects. In future, steel structure building in Malaysia need to consider earthquake loading when designing.

RSA is important in designing a structure because it produce the most accurate result for displacement and acceleration. The percentage of damping used for the design will be based on real time test. The test is conducted on the structure to obtain the damping percentage that will be used for the analysis.

REFERENCES

This research is prepared based on the following references;

Abas, M. (2001). Earthquake Monitoring in Malaysia, Seismic Risk Seminar, Malaysia, September, 2001.

Agarwal, P. and Shrikande, M. 2006. *Earthquake Resistance Design of Structures.* New Delhi: Prentice-Hall.

C.V.R Murty. (2005) *Earthquake Tips: Learning Earthquake Design and Construction*

Duggal, S.K. 2010. *Earthquake Resistance Design of Structure*. New Delhi: Oxford University Press.

Goincu, V. and Mazzolani F.M. 2011. Advances in Seismic Design Methodologies. *Earthquake Engineering for Structural Design,* **Vol. 1** p.p: 386-446.

Herrera, R. and Beltran, J.F. 2012. Performance of Steel Structures during the February 27, 2010, Chile Earthquake. 15th WCEE, LISBOA 2012.

Krawinkler, H. 1995. Earthquake Design and Performance of Steel Structures. *Bulletin of the New Zealand National Society for Earthquake Engineering.* **Vol. 29**, No. 4, p.p: 229-241.

Midorikawa, M. and Okazaki, T. 2012. Earthquake and tsunami Damage to Steel Structures. Structure Congress, ASCE 2012.

Takeda, T., Sozen, M.A. and Nielsen, N.N. Reinforced Concrete Response to Stimulated Earthquakes.

Watanabe, E., Sugiura, K., Nagata, K. and Kitane, Y. 1997. Performances and Damages to Steel Structures during the 1995 Hyokugen-Nanbu Earthquake. *Engineering Structures*, **Vol. 20**, Nos 4-6, p.p: 282-290.

Wilkinson, S. and Hiley, R. 2006. A Non-Linear Response History Model for the Seismic Analysis of High-Rise Framed Buildings. *Computers and Structures*. **Vol. 84.**

Patil, A.S, and Kumbhar, P.D. 2013. Time History Analysis of Multistoried RCC Building for Different Seismic Intensities. *International Journal of Structural and Civil Engineering Research.* **Vol. 2,** No.3, p.p: 194-201.

APPENDIX A1

MOMENT RESISTANCE OF STEEL

Properties of steel warehouse column:

Grade = S275

t_f = 12.7 mm A = 9161.27 mm^2

t_w = 8.50 mm f_y = 275 N/mm^2

h = 380 mm γ_{M0} = 1.0

b = 255 mm $W_{pl,Rd}$ = 1870 cm^3

Moment Resistance

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1.0 \qquad (4.2)$$

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma M_0} \text{ for class 1 or 2 cross section} \qquad (4.3)$$

$$M_{pl,Rd} = \frac{1870 \text{ x } 275}{1.0} \text{ x } 10^{-6} = 514.25 \text{ kNm}$$

1. DL + LL

   $\frac{426.3165}{514.25} \leq 1.0$

   0.83 ≤ 1.0 Cross section is satisfied.

2. DL + LL + WL + ACHEH

   $\frac{428.6929}{514.25} \leq 1.0$

   0.84 ≤ 1.0 Cross section is satisfied.

3. DL + LL + WL + EL CENTRO

   $\frac{428.6929}{514.25} \leq 1.0$

   0.84 ≤ 1.0 Cross section is satisfied.

APPENDIX A2

SHEAR RESISTANCE OF STEEL

Shear Resistance

$$\frac{V_{Ed}}{V_{c,Rd}} \leq 1.0 \qquad (4.4)$$

$$V_{pl,Rd} = \frac{A_v(\frac{f_y}{\sqrt{3}})}{\gamma M_0} \qquad (4.5)$$

The shear area A_v may be taken as follow:

- Welded I, H and box sections, load parallel to web: $\eta\Sigma(h_w t_w)$

A_v $= 1.0\ [\ (h - 2t_f)\ (t_w)\ ]$

$= 1.0\ [\ (380 - 2(12.7))\ (8.50)]$

$= 3022.6\ mm^2$

$$V_{pl,Rd} = \frac{3022.6(\frac{275}{\sqrt{3}})}{1.0} \times 10^{-3} = 479.90\ kN$$

1. DL + LL

   $\frac{468.149}{479.90} \leq 1.0$

   $0.98 \leq 1.0$ Cross section is satisfied.

2. DL + LL + WL + ACHEH

   $\frac{471.762}{479.90} \leq 1.0$

   $0.98 \leq 1.0$ Cross section is satisfied.

3. DL + LL + WL + EL CENTRO

   $\frac{295.166}{479.90} \leq 1.0$

   $0.62 \leq 1.0$ Cross section is satisfied.