SEISMIC PERFORMANCE OF FLAT SLAB UNDER THE DIFFERENT EARTHQUAKE LOADING

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This thesis is proudly dedicated to:

All my beloved family (my mother, my father, my brother and all my friends)

Thanks for your endless love, sacrifices, prayers, supports and advices

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ABSTRACT

Malaysia is the country region that free from red zones which is earthquake zones. But nowadays we heard news about earthquake that suddenly happen in Malaysia. So a study of earthquake was carrying out for structural which is flat slab structure. Flat Slab Structure is the structure that will damage cause by the seismic effect and also an important structure. Most structure of Flat Slab in Malaysia does not take account the seismic loading. Therefore, by using SAP 2000 software a modal analysis was created and the purpose of this research is to study the performance of the flat slab structure. The performance characteristic includes displacement, acceleration and velocity of the flat slab structure. The performance for each member of the structure can be determined through the displacement and the acceleration value. The earthquake data is from Acheh and Bukit Tinggi earthquake that get from the Malaysia Meteorological Department. After the analyse the 12 mode shape had been shown. Each mode shape produces the different number of frequency and also natural time period. According to 12 mode shape produced, three mode shapes with the highest frequency will be selected as the best mode shape. Other than that the rigidity of shape of each mode shape also can be determined according to the classification of time period the building. The classification are Rigid ($T < 0.3$ sec), Semi-Rigid (0.3 sec $< T < 1$ sec), and Flexible Structure ($T > 1$).

ABSTRAK

Malaysia adalah rantau negara yang bebas daripada zon merah yang merupakan zon gempa bumi. Tetapi pada masa sekarang, kita mendengar berita mengenai gempa bumi yang tiba-tiba berlaku di Malaysia. Oleh itu, satu kajian mengenai gempa bumi telah dilakukan untuk struktur struktur leper yang rata. Struktur Lembaran Rata adalah struktur yang akan merosakkan sebab oleh kesan seismik dan juga struktur penting. Kebanyakan struktur Flat Slab di Malaysia tidak mengambil kira pemuatan seismik. Oleh itu, dengan menggunakan perisian SAP 2000, analisis modal dibuat dan tujuan kajian ini adalah untuk mengkaji prestasi struktur papak rata. Ciri prestasi termasuk anjakan, pecutan dan halaju struktur papak rata. Prestasi bagi setiap anggota struktur boleh ditentukan melalui anjakan dan nilai pecutan. Data gempa bumi adalah dari gempa Acheh dan Bukit Tinggi yang mendapat dari Jabatan Meteorologi Malaysia. Selepas analisis 12 bentuk mod telah ditunjukkan. Setiap bentuk mod menghasilkan bilangan kekerapan yang berbeza dan juga tempoh masa semulajadi. Menurut 12 bentuk mod yang dihasilkan, tiga bentuk mod dengan frekuensi tertinggi akan dipilih sebagai bentuk mod terbaik. Selain daripada itu ketegaran bentuk setiap bentuk mod juga boleh ditentukan mengikut klasifikasi tempoh masa bangunan tersebut. Pengelasan adalah Tegar (T <0.3 saat), Semi-Tegar (0.3 sec <T <1 saat), dan Struktur Fleksibel (T> 1).

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

An earthquake is a shaking of the ground caused by the sudden breaking and movement of large sections (tectonic plates) of the earth's rocky outermost crust. The edges of the tectonic plates are marked by faults (or fractures). Most earthquakes occur along the fault lines when the plates slide past each other or collide against each other. Earthquake also can created seismic waves from the energy released. Building structure usually 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.

Nowadays flat slab are commonly used for construction industry especially in Malaysia. Flat slab is the reinforcement concrete slab which supported directly by concrete slab and concrete column without using the beams. They are widely used because of the procedure of the installation is easy and saving on construction time. The structure also can increase the shear capacity and the stiffness of the floor system under vertical loads. Moreover, it is the most economical construction material. The number of labors, machineries and equipment required are also reduced hence reducing the construction cost.

Construction of the flat slab can deeply reduce floor to floor height of building. This can prove gainful in case of lower building height, decreased cladding expense and pre-fabricated services. The great strength of the flat slab can provides advantage for the building structures. However, the critical middle strip deflection can occur when overloading the structures. It strength depends on the traverse reinforcement by punching shear. Therefore, these advantages allow it to perform better especially when the structures are subjected to earthquake.

Flat Slab comes with various types that satisfy the strength requirement according to their design and it function. The types available are Simple Flat Slab, Mushroom Slab with column capitals, Mushroom slab with drop panel, wide flanged, I-beam, channel and etc.

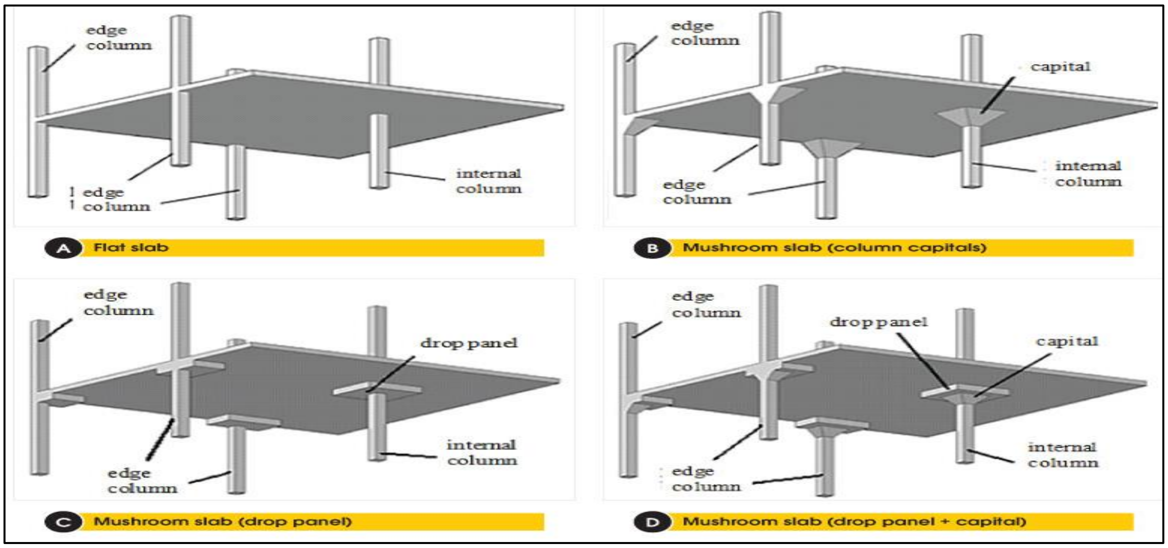

Figure 1.1 *: Types of Flat Slab Structure 2*

Source: www.scielo.br.com [Online image]. (2016).

Figure 1.2 : *Flat Slab in construction building*

Source: www.nexus.globalquakemodel.org [Online image]. (2016).

1.2 PROBLEM STATEMENT

Malaysia is the country which free from red zones of seismicity activity, but can feel the tremors at certain places. However, in East of Malaysia was 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, 28 June 2016 on Friday in Sabah, according to the Malaysian Meteorological Department website (The Star Online, 2016). The seismic crisis affected buildings and infrastructures with a total damage besides of fatality. Moreover the designation of buildings are only considering wind effect rather than seismic effect. Therefore, seismic effect need to be considered since the minor disaster had already occurred.

Malaysia is situated in between 3 major tectonic plates which are Eurasian-Sunda plate, Indian-Australian plate and Philippines-Pacific plate as shown in Figure 1.3. 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, Sawada, & Goto, 2012).

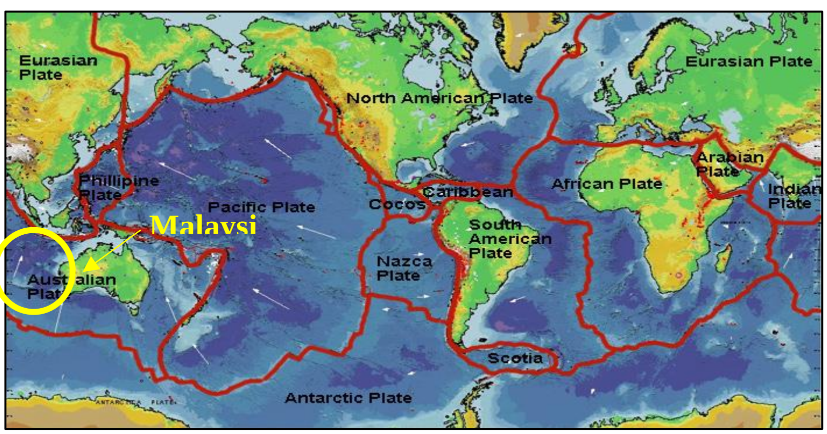

Figure 1.3*: Major tectonic plates surround Malaysia.*

Source: classified-blog.com [Online image]. (2016).

1.3 RESEARCH OBJECTIVES

The main objectives for this research are:

i. To determine the vulnerability of flat slab structures in Malaysia.

ii. To determine characteristics of flat slab structures when earthquake occur based on recent earthquake.

iv. To determine the performance of flat slab under different earthquake 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 flat slab will be used is building structure.

ii. Case of study is earthquake effect to flat slab structure in Malaysia region due to earthquake.

iii. Analyze data provided from Malaysia Meteorology Department (MMD).

iv. Software to be used for flat slab structure modelling analysis is SAP 2000.

1.5 SIGNIFICANCE OF STUDY

Throughout this research study, the seismic performance of flat slab structure in Malaysia region could be determined. Due to earthquake in Acheh, the characteristics of the flat slab 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. These consideration regarding seismic effect could save many lives. Besides that, the flab slab structures can be prevented from any damaged.

CHAPTER 2

LITERATURE REVIEW

2.1 EARTHQUAKE

2.1.1 WHAT IS EARTHQUAKE?

An earthquake also synonyms as a quake, shock, aftershock, foreshock, convulsion, seismic activity, tremor or temblor. It resulting from the sudden release of energy in the Earth's lithosphere that creates seismic waves. Earthquakes can range in size from those that are so weak that they cannot be felt to those violent enough to toss people around and destroy whole cities. The seismicity or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time.

Earthquakes are the vibrations caused by rocks breaking under stress. The underground surface along which the rock breaks and moves is called a fault plane. This phenomenon also define as shaking of the ground caused by the sudden breaking and movement of large sections called tectonic plates of the earth's rocky outermost crust. The edges of the tectonic plates are marked by faults or fractures. Most earthquakes occur along the fault lines when the plates slide past each other or collide against each other.

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.

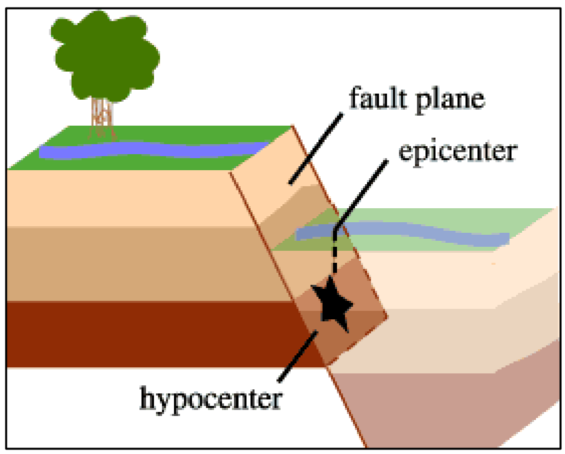

Figure 2.1: *Cross-section of fault plane occurrence.*

Source: earthquake.usgs.gov [Online image]. (2016).

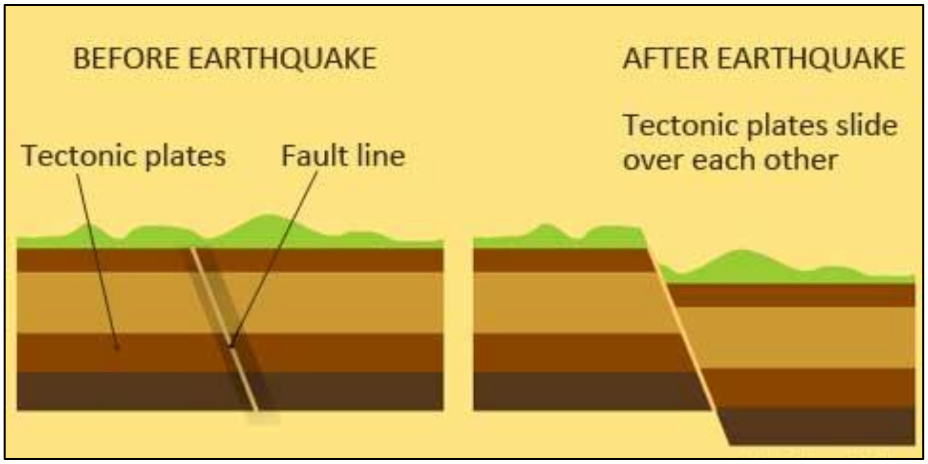

Figure 2.2: *Cross-section of fault plane of earth.*

Source: eschooltoday [Online image]. (2016).

2.1.2 TYPES OF EARTHQUAKE

The phenomenon of the earthquake can be form by three condition depending on plate movement that happens beneath the earth surface. They could be Convergent Boundary, Divergent Boundary and Transform fault.

i) Convergent Boundary.

Destructive plate boundary which actively deforming region where two or more tectonic plates lithosphere move toward one another and collided. One plate is forced over another plate during movement creating a thrust fault.

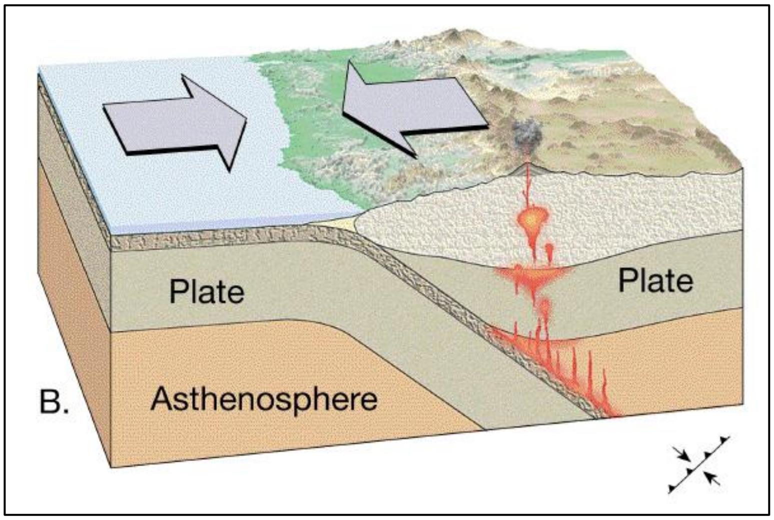

Figure 2.3: *Cross-section of Convergent Boundary.*

Source: geography.unt.edu [Online image]. (2016

ii) Divergent Boundary

The plates forced apart each other, usually forming a Rift Zone. This kind is common in ocean floors where new floors are created. There is a straight fracture that exists between two tectonic plates that are moving away from each other. Most active divergent plate boundaries occur between oceanic plates and exist as mid-oceanic ridges. Divergent boundaries also form volcanic islands which occur when the plates move apart to produce gaps which molten lava rises to fill.

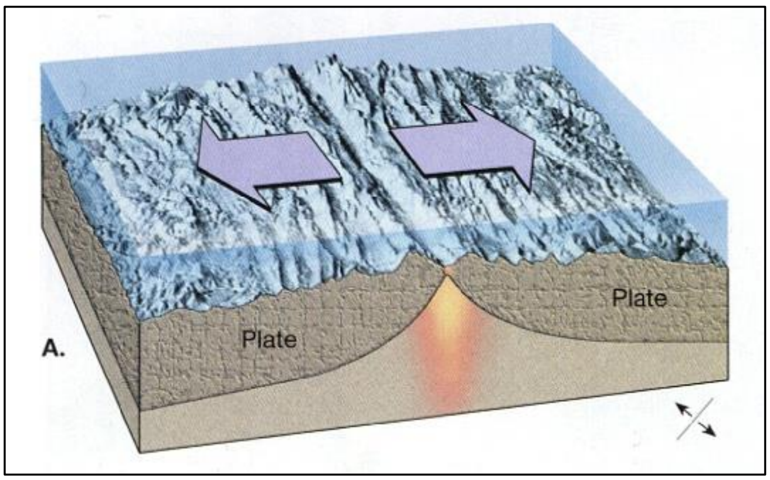

Figure 2.4: *Cross-section of Divergent Boundary.*

Source: tectonictrip [Online image]. (2016). Retrieved from Mei 2, 2017 from http://tectonictrip.blogspot.my/2012/04/divergent-boundary.html.

iii) Transform Boundary.

A transform fault also known as conservative plate boundary since these faults neither create nor destroy lithosphere, is a type of fault whose relative motion is predominantly horizontal in either sinistral or dextral direction. The plates here slip by each other (Strike-Slip).

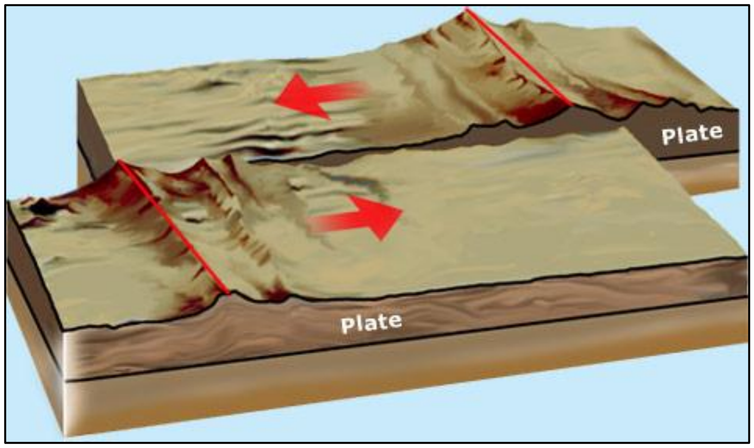

Figure 2.5: *Cross-section of Transform Boundary.*

Source: khsappliedgeography.weebly [Online image

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. These plates are moving in various direction with different speeds. In result, mountain and rift are formed.

2.2 SEISMIC WAVE

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) meanwhile surface waves consists Love waves and Rayliegh waves.

i) P-waves (Primary waves)

Longitudinal waves and underneath the ground, it shakes them back and forth in the same direction. It is moving as fast as lightning with 5 to 7 km/sec of velocity.

ii) S-waves (Secondary waves)

Shear waves and shakes the ground in perpendicularly from the direction.S-waves is slower than the P-waves with 3-4 km/sec and cannot go through the liquids.

iii) Love Waves

Move side to side which similar to S-wave but not in vertical component. It is moving with velocity 2-4.4 km/sec.

iv) Rayleigh waves

Move up-down and side-side which are from the combination of P-waves and S-waves movement. The velocity is same with Loves waves. Generally. It will arrive at the same time with L-waves.

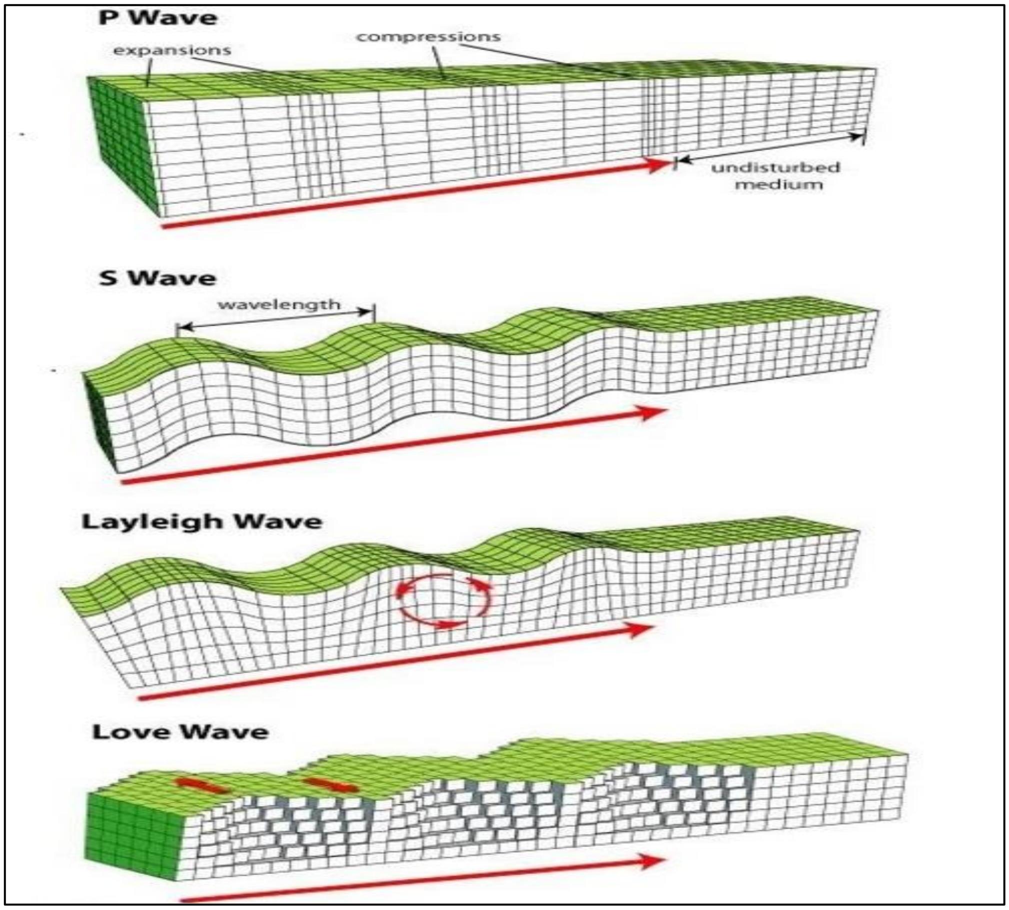

Figure 2.6: *Illustration type of seismic wave.*

Source: sciencelearn.org.nz[Online image]. (2017).

2.3 EARTHQUAKE MEASUREMENT

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).

i) Seismographs

Seismographs using the principle of inertia where an inertial mass remains at rest unless it is applied with a force. The 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. The process of tracing out the record is called as seismogram.

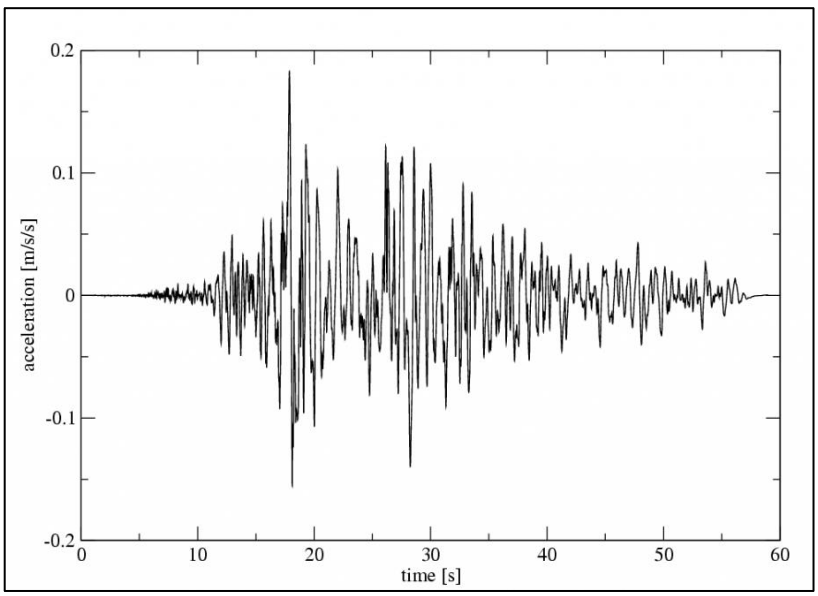

Figure 2.7*: A seismogram.*

Source: eqhazard [Online image]. (2017).

2.4 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. It determined by the strain energy that has been released while faults ruptured which can recorded by seismograph. Earthquake magnitudes are most commonly measured using Ritcher Scale (Båth, 1981). In 1930's, the earthquake magnitude and Richter scale was developed by Charles F. Richter (Spence, A. Sipkin, & L. Choy, 1989). Large earthquake are less frequent compared to small earthquakes. The table shows the frequency of magnitude with the description of each earthquakes.

Modified Mercalli Intensity Scale Compared to Richter Magnitude

MERCALLI INTENSITY	RICHTER MAGNITUDE	DESCRIPTION
I-II	< 2	Not felt by most people
III	3	Felt by some people indoors, especially on high floors
IV-V	4	Noticed by most people. Hanging objects swing, dishes rattle.
VI-VII	5	All people feel. Some building damage (esp. to masonry), waves on ponds.
VII-VIII	6	Difficult to stand, people scared or panicked. Difficult to steer cars. Moderate damage to buildings.
IX-X	7	Major damage, general panic of public. Most masonry and frame structures destroyed. Underground pipes broken. Large landslides.
XI-XII	8 and higher	Near total destruction

***Figure 2.8**: Modified Mercalli Intensity Scale compared to Ritcher Magnitude.*

Source: EARTHQUAKES : Plates Tectonics and Earthquake Hazards, T. Kusky 2008.

2.5 INTENSITY

Intensity is degree of surface shaking for each unit increase of magnitude of a shallow crustal earthquake is unknown (Spence, A. Sipkin, & L. Choy, 1989). 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. The intensity may be based on the vibration feeling from the people and animals, damage of the buildings and the natural surroundings changes.

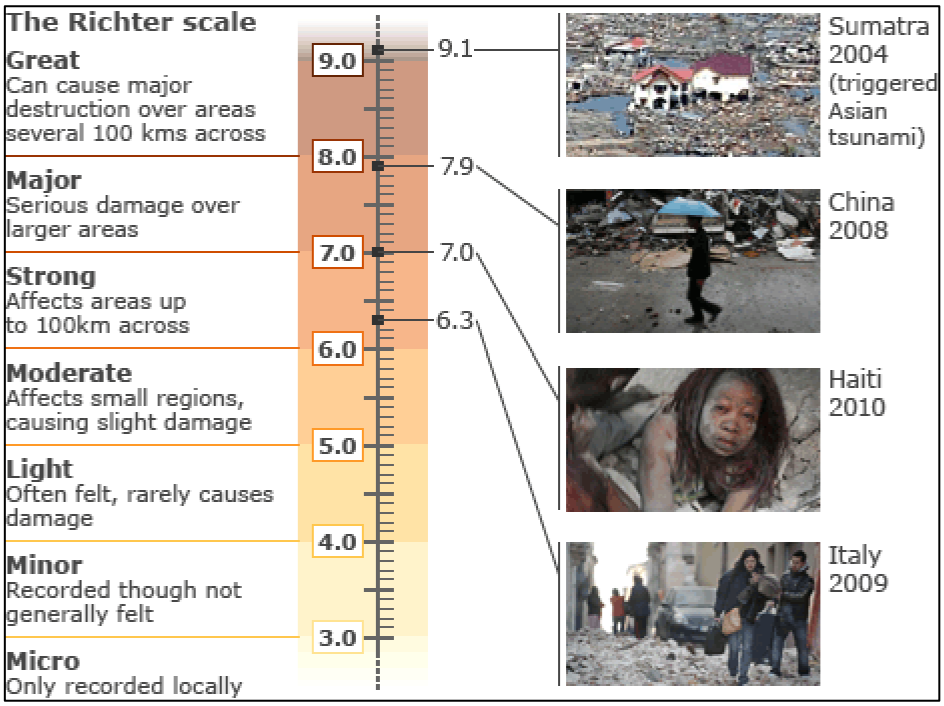

***Figure 2.9**: Richter magnitude scale with the effects occurred.*

Source: grenfiledgeography.wikispaces.com [Online image]. (2016).

2.6 EARTHQUAKE IN WEST MALAYSIA

West Malaysia is occasionally affected by tremors originating from large earthquakes in the Sumatran plate margin. The maximum observed intensity so far was VI on the Modified Mercalli (MM) scale. East Malaysia has experienced earthquakes of local origin which some of them resulted in some damage on properties and even human injuries. Beside of the local earthquakes, East Malaysia also affected by large earthquakes located over Southern Philippines and in the Straits of Macassar, Sulu Sea and Celebes Sea. The maximum observed intensity so far was VII on MM scale. The Malaysian Meteorological Service (MMS) is a Government institution, which is responsible for monitoring earthquake activities of the country. To do so, MMS is operating twelve seismic stations, while the MMS Head Quarter in Petaling Jaya, Selangor operates as a national seismic center (Abas, 2001).

In 2015, West Malaysia earthquake struck Ranau, Sabah, Malaysia with a moment magnitude of 6.0 on 5 June, which lasted for 30 seconds (Borneo Post Online 2015). The earthquake was the strongest to affect Malaysia since 1976. In the past century, Sabah has experienced only three earthquakes greater than Friday's magnitude 6.0. In 1923 and 1976, magnitude 6.3 and 6.2 earthquakes occurred about 100km to the southeast. In 1951, a magnitude 6.1 earthquake occurred about 50km to the north. (Nanyang Technological University Singapore, 2015).

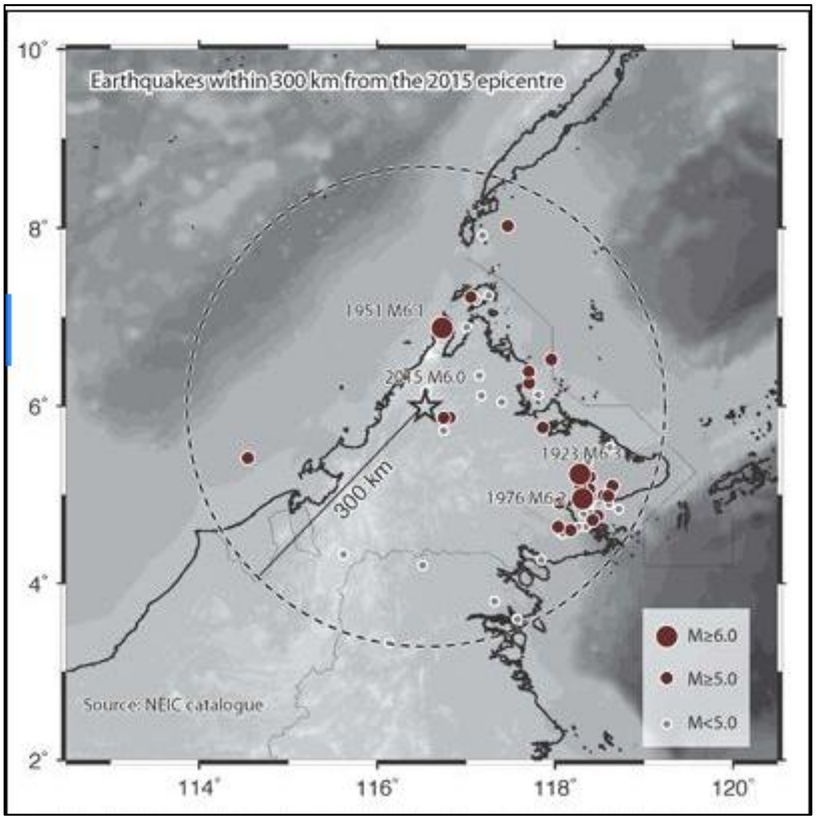

Figure 2.10*: Map of earthquake epicentres in Sabah over the past century.*

Source: USGS [Online image]. (2016).

A quick initial exploration of the records of past earthquakes by EOS scientists indicates that within a 300-km radius of the recent epicentre, there have been just four earthquakes equal to or greater than magnitude 6 in the past century, and none larger than 6.3. In comparison, Indonesia's Sumatra has experienced in the past 15 years over a hundred earthquakes with magnitudes greater than or equal to 6, with 14 of these having magnitudes between 7 and 9.2.

Seismological recordings indicate that last week's earthquake was caused by sudden slippage along a fault about 10km in size and centered a little over 10km beneath the Earth's surface, south of Mount Kinabalu.

2.7 FLAT SLAB

The flat slab system has been adopted in many buildings constructed recently due to the advantage of reduced floor heights to meet the economical and architectural demands (Kim & Lee, 2005). Flat slab is a reinforced concrete slab which is supported directly by concrete columns without the use of beams. Flat slab is defined as one sided or two-sided support system with sheer load of the slab being concentrated on the supporting columns and a square slab called 'drop panels'.

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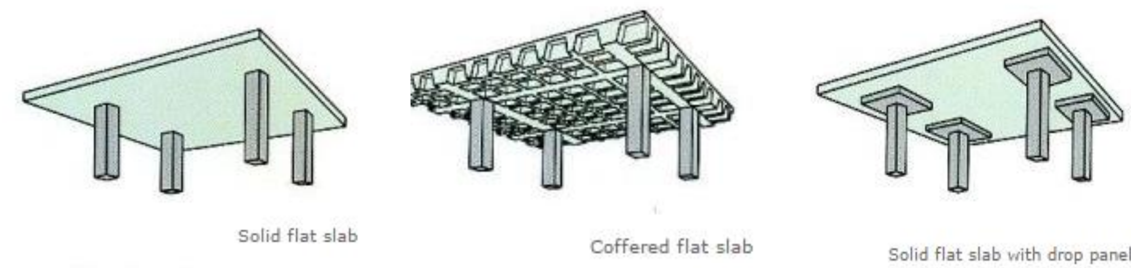


Figure 2.11*: Ilustration of solid flat slab.*

Source: The Concrete Society [Online image]. (2016

Reinforced concrete flat slabs are commonly used in construction as they provide a number of benefits to the designer including The thin sections allowing for greater roof heights and lighter floors. The reinforcement concrete flat slab can be exposed as ceilings. The column are flexible in arrangement and more difficult to achieve for beam-column design. The structure of flat slab can made using simple formwork as well as it is fast and cheap construction.

However, flat slabs have a lower stiffness in comparison to a beam-column floor plan which can lead to relatively large deflections. In addition to this, the shear capacity can also be reduced in particular around the column head where large shear forces can develop.

There are two main failure modes of flat slabs :-

i) Flexural Failure

The failure mode is ductile therefore giving relatively large deflections under excessive loading, also cracks will appear on the bottom surface before failure occurs. These signs allow the problem to be addressed before failure occurs.

ii) Punching Shear Failure

Punching shear failure by comparison is a brittle failure mode when shear reinforcement is not added, meaning failure will occur before significant deflections take place, in addition to this any cracks that will develop before failure will propagate from the top surface. Since this surface is typically covered, it is unlikely that there will be sufficient warning available before failure occurs.

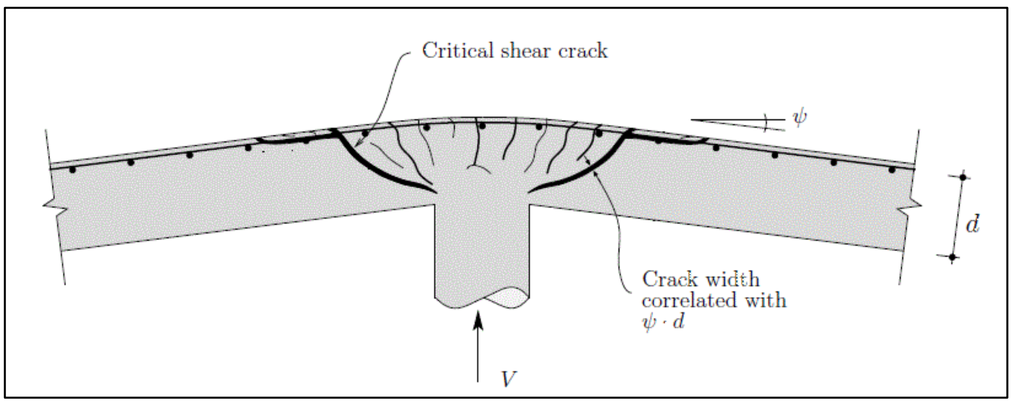


Figure 2.12*: Punching Shear Failure in flat slab..*

Source: modellingflatslabsinfire [Online image]. (2016

2.8 ISSUES ON EARTHQUAKE EFFECT

Earthquake can vigorously damage the structure whether totally collapsed or severely damage. The reinforcement concrete flat slab is a structure that important in high risk building which can easier to construct. The are several examples places the earthquake effects on the structure had happen before.

1.1 February 2011; Christchurch, New Zealand

The pancake collapse of the Smiths City Dundas St. car park due to punching shear failure of the slab column connections.

Figure 2.13: *Punching Shear Failure in flat slab.*

Source: Setia S, Kalyani S. Seismic Behavior of Connections Subjected to Punching Shear in Flat-Slab Systems. J Eng Technol [serial online]

2.1 January 17, 1994; Northridge, Los Angeles, California.

Major earthquake to occur directly in residential area in Southern California. The columns of this structure punched through the concrete slab floor systems, dropping the floors and roof and completely collapsing the interior of the building.

***Figure 2.14**: Building collapse due to punching of the flat slab.*

Source: Setia S, Kalyani S. Seismic Behavior of Connections Subjected to Punching Shear in Flat-Slab Systems. J Eng Technol [serial online]

2.9 INTRODUCTION TO SAP 2000 SOFWARE

The software is Structural Analysis program that used to analyze and design any structural system. The software provided 2D to 3D model of structure. The programming including to analyze the loading such as seismic, wind and waves which can be generated to structure. It also can obtain the outputs such as model response, displacement, bending moment and shear. Furthermore, in this research study it very strongly useable which needed to do the analysis related to time history and seismic load.

CHAPTER 3

RESEARCH 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.

In this chapter we will discuss the process to analysis research study. The SAP 2000 software being used to analyze the elevated flat slab building structure. This software specialized by analyzing a structure in term seismic performance. All the step involve in this research is listed in this chapter. The analysis will include the performance of the structure, time history and spectrum analysis. The time history is the data of Acheh earthquake obtained from Malaysia Meteorological Department. The result of the analysis is obtained and discuss in detail in the next chapter.

Flat Slab structures are designed to be more flexible and ductile; and allowing them to perform better when subjected to earthquake. Through this methodology, the performance of flat slab structures in Malaysia can be determined. Besides that, the characteristics and dynamic characteristics of that structures can be studied when subjected under different earthquake loadings.

Hence, to ensure the research successful, the following planning and scheduling are arranged to ease the research that be rum in SAP 2000 software.

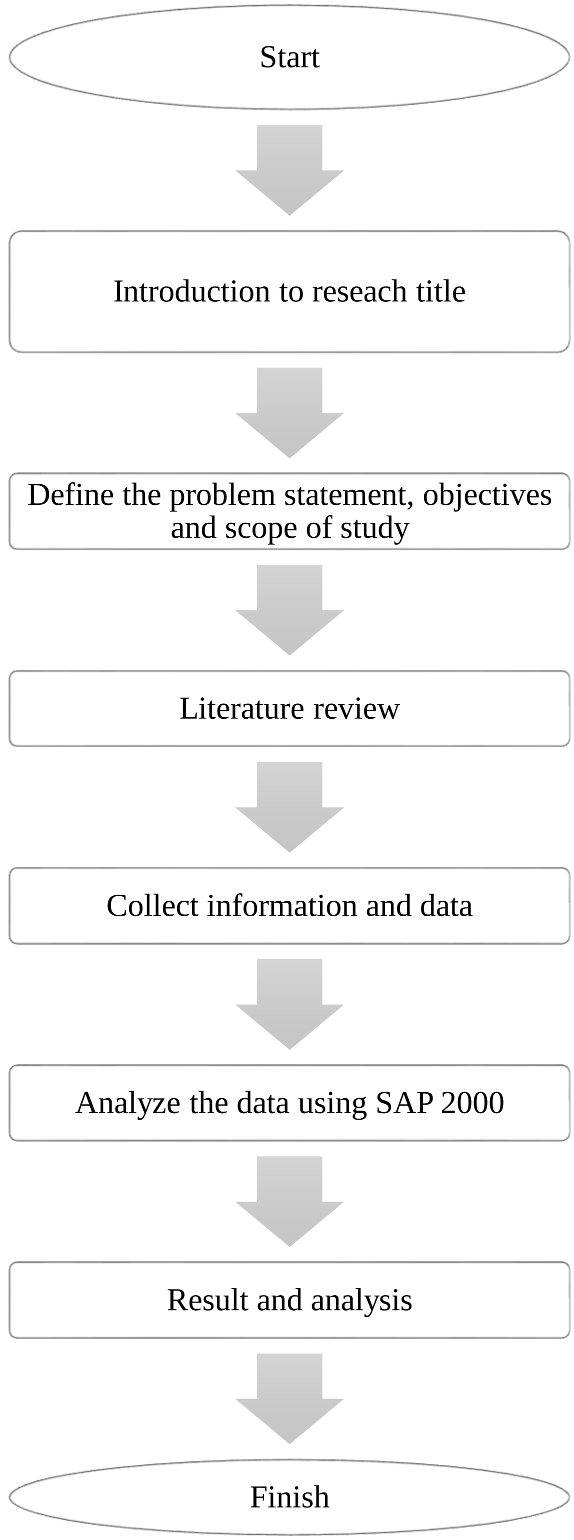


***Figure 2.15** : Step of Research Methodology.*

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 are "Seismic Behaviour of Flat Slab Systems" by Lande, Pradip S Raut, Aniket B, "Structural performance assessment of reinforced concrete flat slab-edge" by Albuquerque, N.G.B Melo, G.S.S; and "Behaviour Of Reinforced Concrete Buildings Under Vrancea Earthquake" by Musat, Sorin, Dutescu, Ovidiu Mestesug, Maria Cismelaru, Adelin Coordinator, Scientific Prof, Assoc.

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
2. Seismic wave
3. Measuring Earthquake
4. Earthquake Magnitude
5. Reinforced Concrete Structure Drawing
6. 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 the reinforced concrete of Flat slab 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.

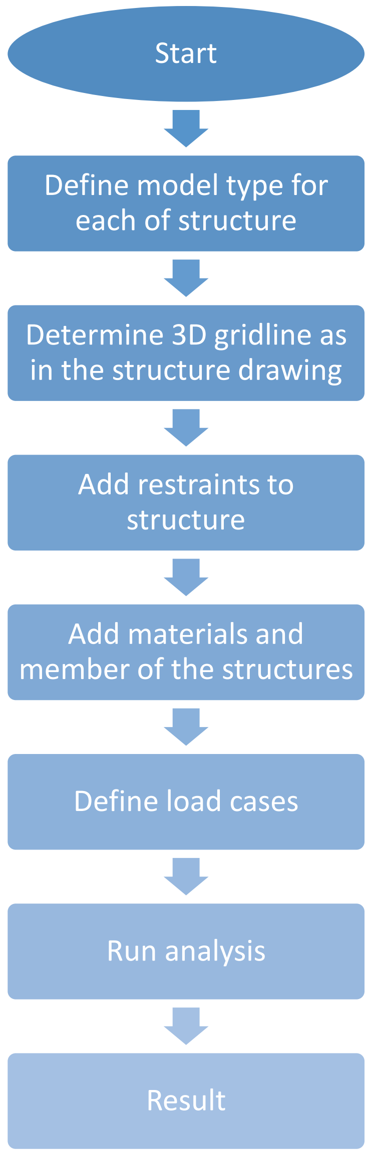
Complex Models can be produced and coincided with effective layouts of implicit. Coordinated configuration code components can consequently create wave, span, wind and burdens of seismic with extensive programmed steel and solid outline code checks per Canadian, US and global configuration norms.

3.4.1 Modelling

SAP2000 is used in modelling a typical double storey RC building, truss bridge and steel structure. These are the step in modelling the structures:

1. Determine the type of the model of structure to be use
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



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 use to create a four storey RC building, truss bridge and warehouse steel structure.

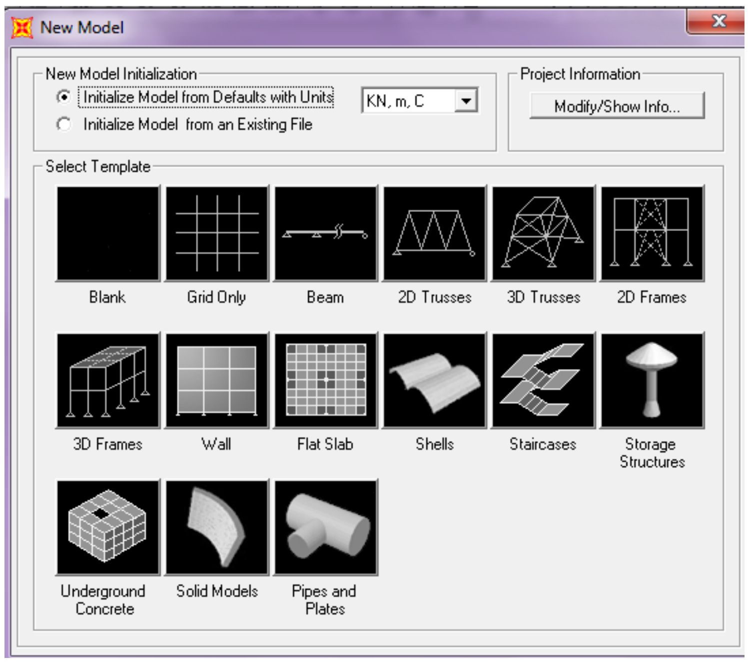


Figure 3.1: *Select structure model type*

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.

- Height of the structure = 36 meter
- Height of each storey = 6 meter

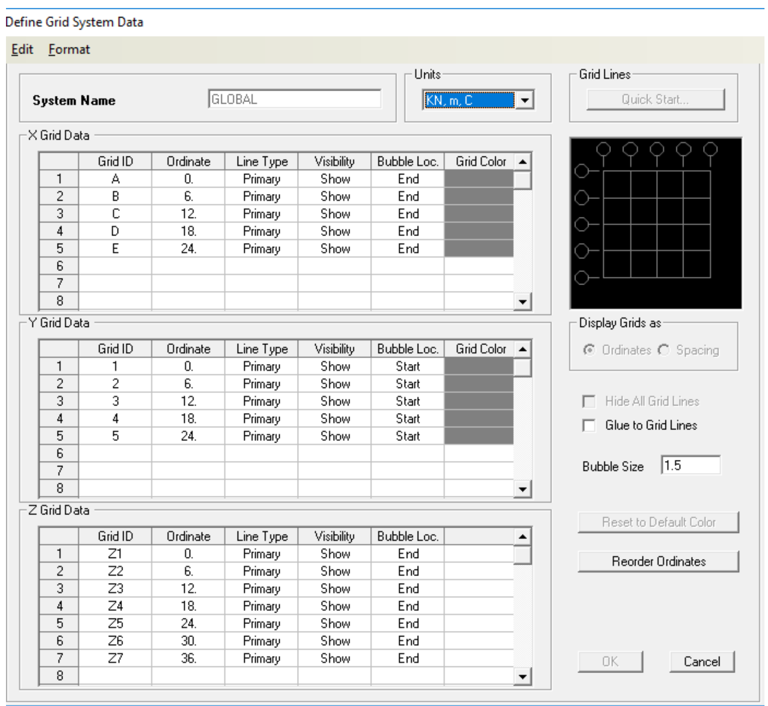


Figure 3.2: *Define grid system data*

Step 3: Add restraint

Select all joints and add joint restraints.

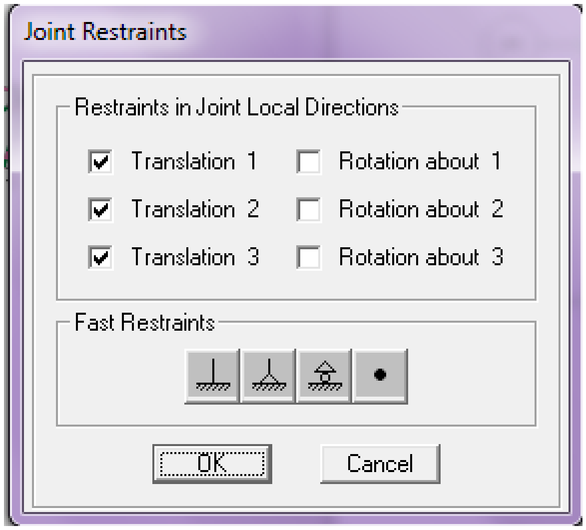


Figure 3.3: *Add restraints at the base condition*

Step 4: Add material and member of structure

New material is added to the structure such as rebar, concrete and steel. The properties of each material is chosen according to its suitability which is provided in the software. Beam, column, slab and trusses are added to the structures. Trusses is applied for bridge and steel structures while concrete is applied to RC building and bridge.

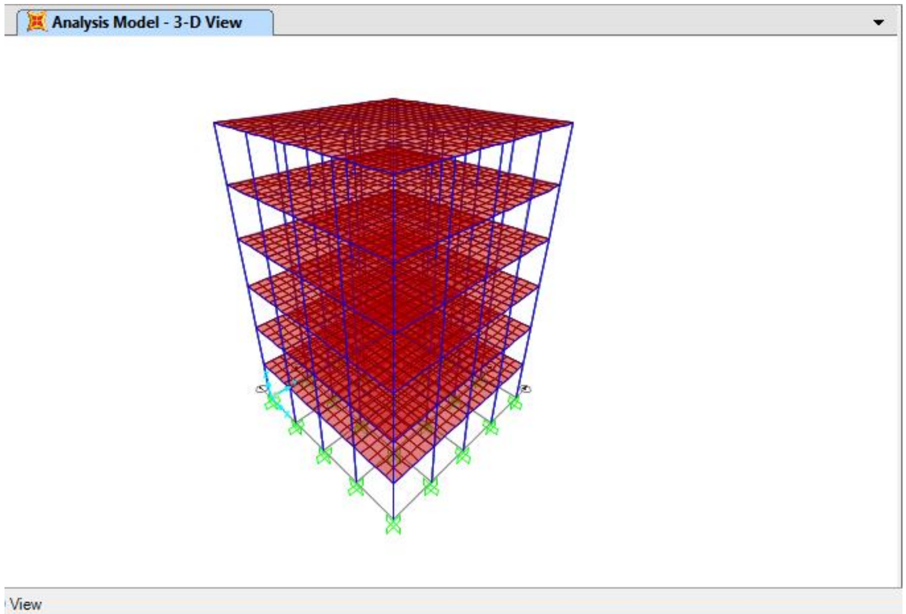


Figure 3.4: *3D view of the structure elevated flat slab.*

Step 5: Define load cases

Two types of cases being considered to analyses the structures. The load cases are as follow:

i. Dead and live load
ii. Dead and live load and earthquake

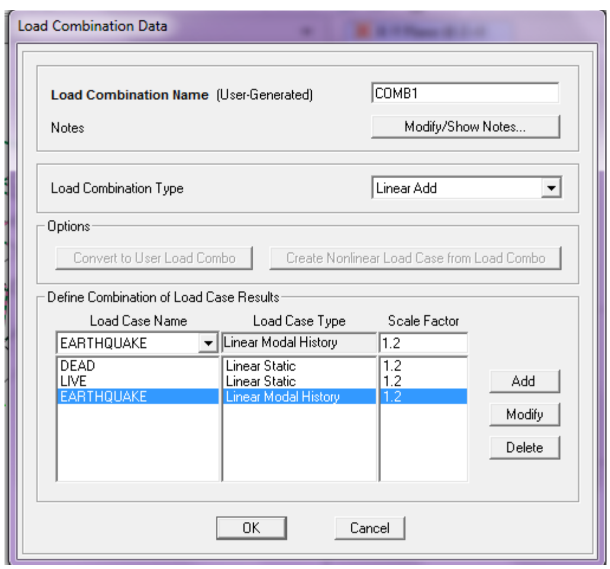


Figure 3.5: *Load combination data*

As for earthquake data, Acheh earthquake data is used to analyse the structures.

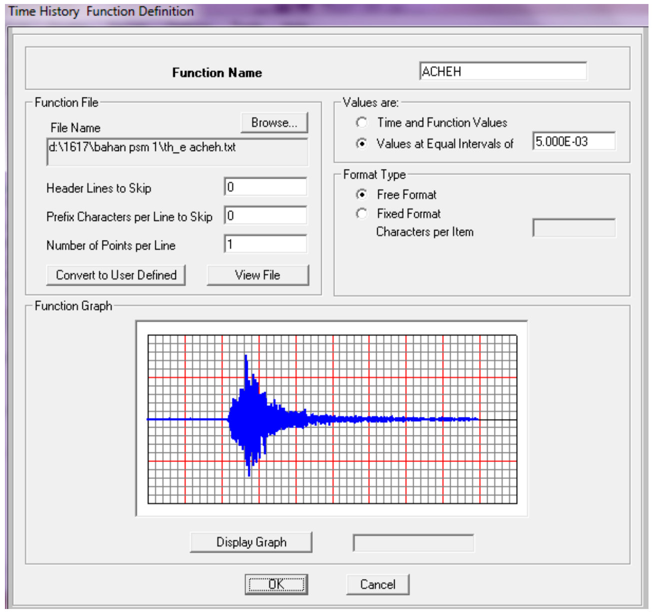


Figure 3.6: *Time history function using Acheh earthquake data*

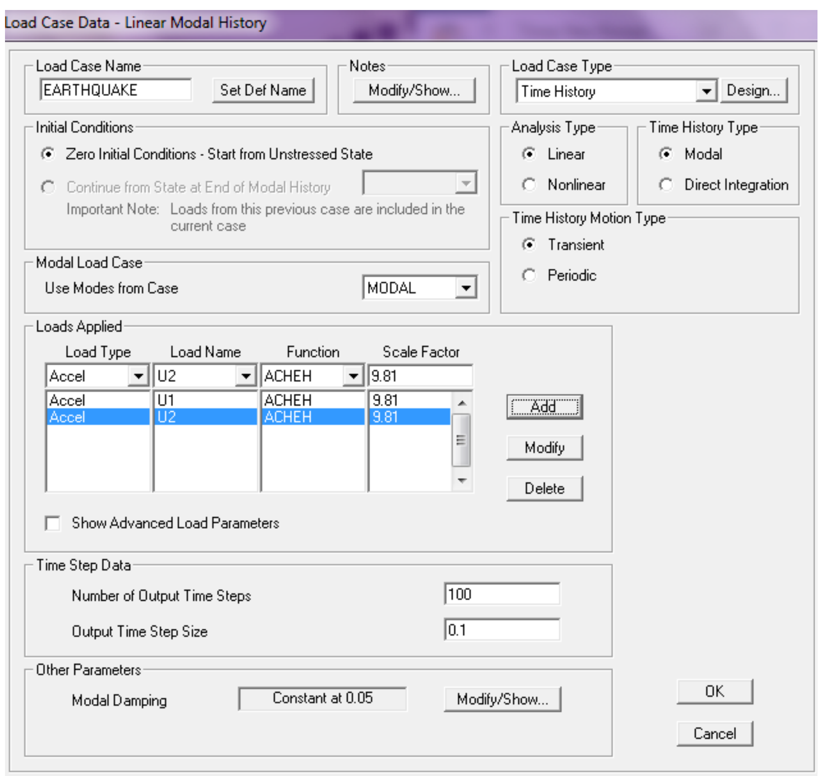


Figure 3.7: *Time history load cases data*

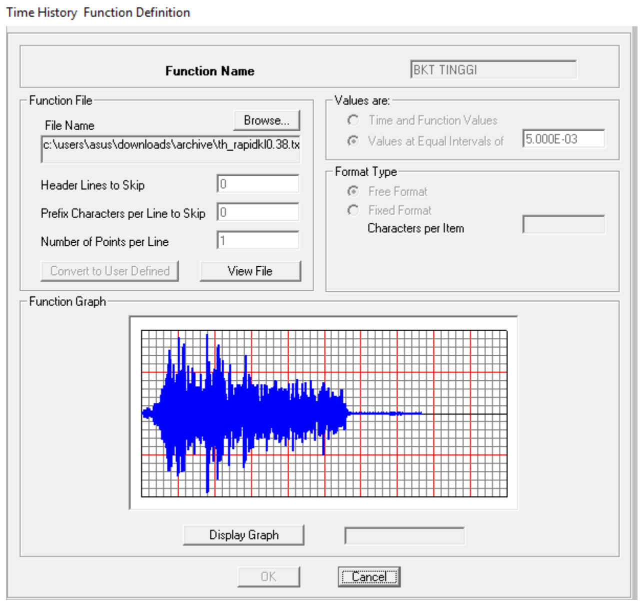


Figure 3.8: *Time history function using Bukit Tinggi earthquake data*

Step 6: Run the analysis

The analysis is run for free vibration analysis. Modal load case will be selected and run the analysis to the structures.

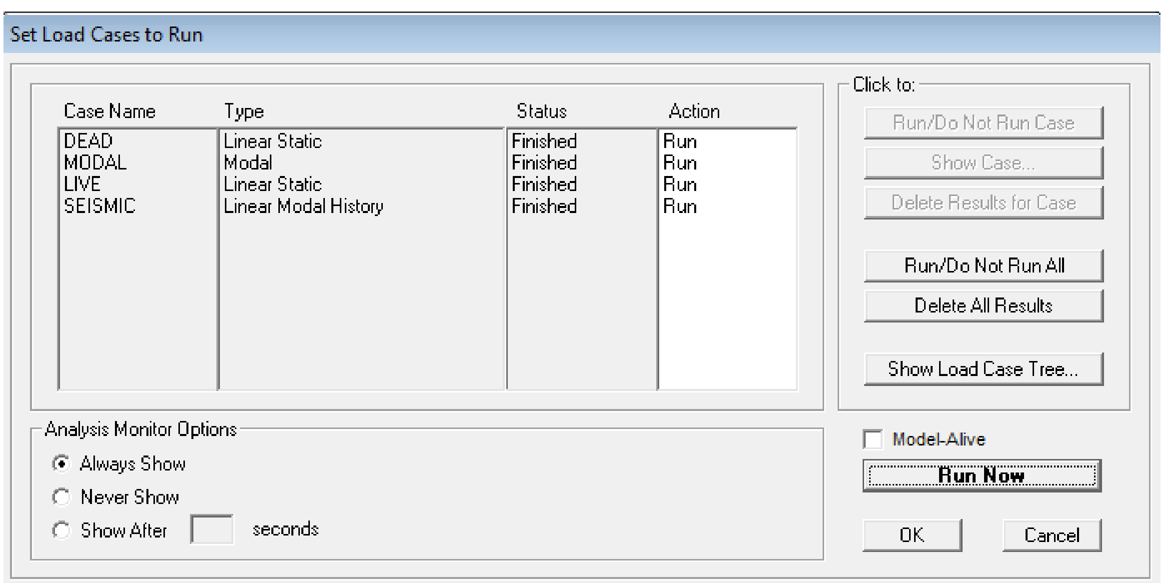


Figure 3.9: *Run the modal case (SAP 2000)*

3.5 SUMMARY

Hence, this chapter explained the step in this research which using the software, SAP2000. Before the analysis conducted, the model of the structure of elevated concrete flat slab is constructed. The design of the elevated flat slab is in Malaysia which is the earthquake data of Acheh earthquake that used to analyze the structure is applied on the structure. After the analysis is run, all objectives of the research can be determined.

CHAPTER 4

RESULT AND ANALYSIS

4.1 INTRODUCTION

This chapter will explain the analysis and result of flat slab structure under the different earthquake loading which is data from Acheh and Bukit Tinggi by using SAP2000 software. There is the comparison result of the structure from both earthquake loading.

4.2 CHARACTERISTIC OF STRUCTURE

The type of structure use is concrete flat slab which has 6 storey of the structure. The height of the structure is 36 m. Other section and dimension are as below:

1. Column size : 450 x 450 mm.
2. Beam size : 230 x 400 mm.
3. Thickness of flat slab : 150 mm.

4.3 ANALYSIS OF CONCRETE FLAT SLAB STRUCTURE USING SAP2000 SOFTWARE

There considered three types of load for the concrete flat slab structure which are dead load, live load and earthquake load. All the load are being analyse by three sets of load cases combination :-

i) Modal analysis
ii) Dead Load (DL) + Live Load (LL)
iii) Dead Load (DL) + Live Load (LL) + Earthquake Load

4.3.1 Modal Analysis

The modal analysis will show the deformed shape natural frequency for each mode. The shape of each mode would be different from each other. The movement of the structure also called as free vibration mode. The vibration modes are horizontal, vertical and torsional. In seismic design, we only consider the horizontal movement as the time history or earthquake ground motion moves in horizontal. The total of mode display is 12. . Each of the mode shape produces different natural period, natural frequency, circ frequency and also eigenvalue.

Deformed shape : Mode 1

Period, T : 4.10949

Frequency, f : 0.24334 Hz

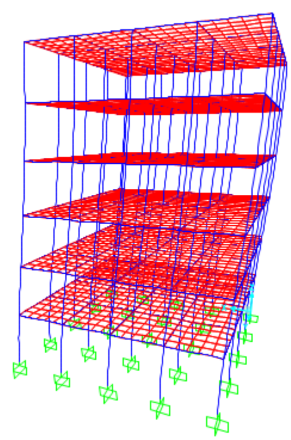


Figure 4.1 *: Mode Shape 1*

Deformed shape : Mode 2

Period, T : 3.72933

Frequency, f : 0.26814 Hz

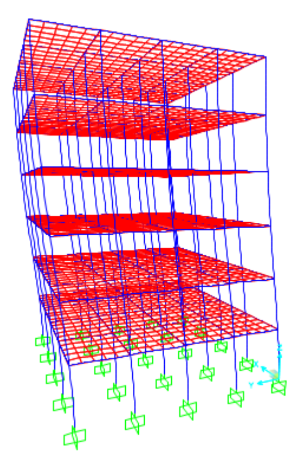


Figure 4.2 *: Mode Shape 2*

Deformed shape : Mode 3

Period, T : 3.30303

Frequency, f : 0.30275 Hz

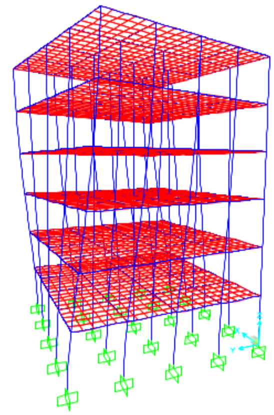


Figure 4.3 *: Mode Shape 3*

Deformed shape : Mode 4

Period, T : 1.24943

Frequency, f : 0.80036 Hz

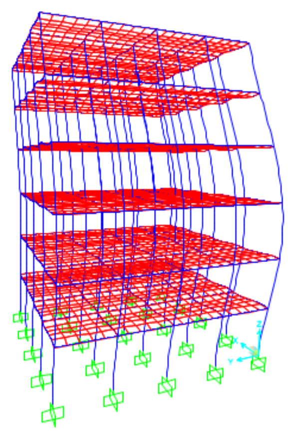


Figure 4.4 *: Mode Shape 4*

Deformed shape : Mode 5

Period, T : 1.15159

Frequency, f : 0.86836 Hz

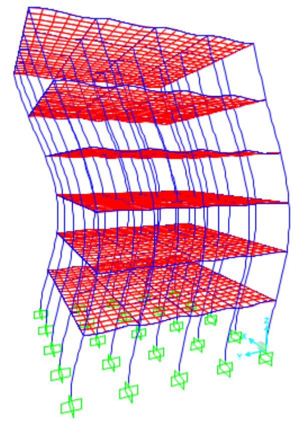


Figure 4.5 *: Mode Shape 5*

Deformed shape : Mode 6

Period, T : 1.02002

Frequency, f : 0.98037 Hz

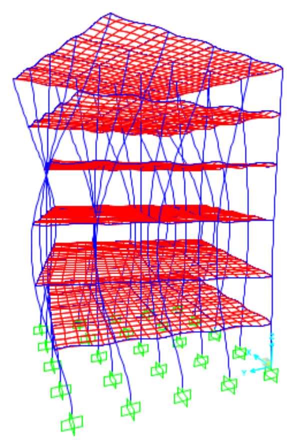


Figure 4.6 : *Mode Shape 6*

Deformed shape : Mode 7

Period, T : 0.64863

Frequency, f : 1.54171 Hz

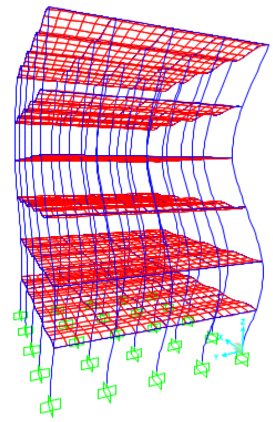


Figure 4.7 *: Mode Shape 7*

Deformed shape : Mode 8

Period, T : 0.61187

Frequency, f : 1.63433 Hz

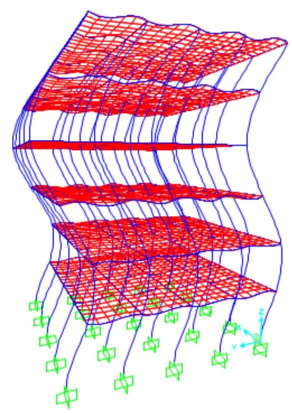


Figure 4.8 *: Mode Shape 8*

Deformed shape : Mode 9

Period, T : 0.54151

Frequency, f : 1.84668 Hz

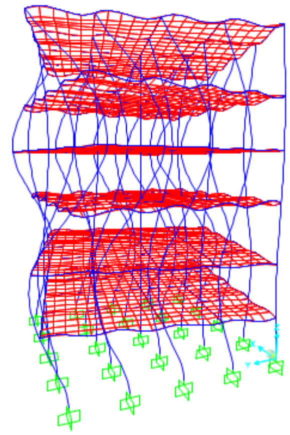


***Figure 4.9** : Mode Shape 9*

Deformed shape : Mode 10

Period, T : 0.40006

Frequency, f : 2.49960 Hz

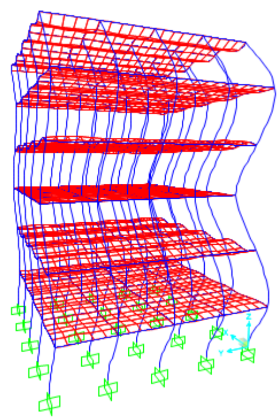


***Figure 4.10** : Mode Shape 10*

Deformed shape : Mode 11

Period, T : 0.38587

Frequency, f : 2.59158 Hz

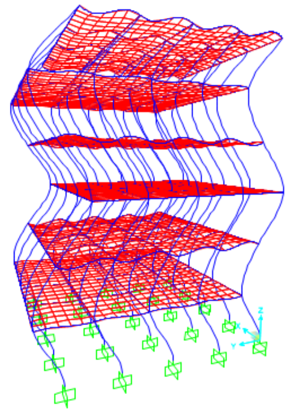


Figure 4.11 *: Mode Shape 11*

Deformed shape : Mode 12

Period, T : 0.34034

Frequency, f : 2.93821 Hz

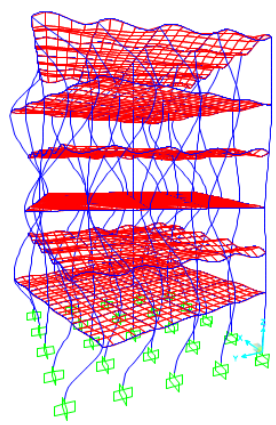
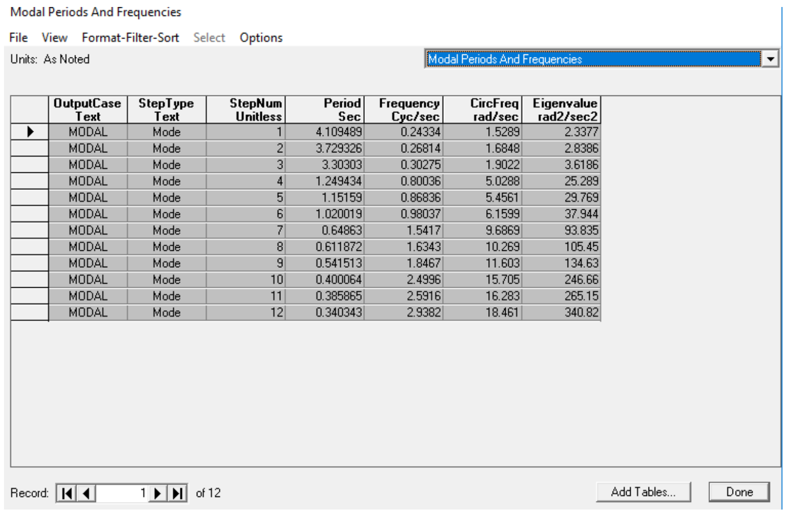


Figure 4.12 *: Mode Shape 12*

After run modal analysis, all the modal periods and frequency has been shown below:


Modal Periods And Frequencies

File View Format-Filter-Sort Select Options

Units: As Noted — Modal Periods And Frequencies

OutputCase Text	StepType Text	StepNum Unitless	Period Sec	Frequency Cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
MODAL	Mode	1	4.109489	0.24334	1.5289	2.3377
MODAL	Mode	2	3.729326	0.26814	1.6848	2.8386
MODAL	Mode	3	3.30303	0.30275	1.9022	3.6186
MODAL	Mode	4	1.249434	0.80036	5.0288	25.289
MODAL	Mode	5	1.15159	0.86836	5.4561	29.769
MODAL	Mode	6	1.020019	0.98037	6.1599	37.944
MODAL	Mode	7	0.64863	1.5417	9.6869	93.835
MODAL	Mode	8	0.611872	1.6343	10.269	105.45
MODAL	Mode	9	0.541513	1.8467	11.603	134.63
MODAL	Mode	10	0.400064	2.4996	15.705	246.66
MODAL	Mode	11	0.385865	2.5916	16.283	265.15
MODAL	Mode	12	0.340343	2.9382	18.461	340.82

Record: 1 of 12 — Add Tables... — Done

Figure 4.13: *Modal period and frequency*

From the modal analysis, it shows that Mode shape 1 have the highest time period which is 4.10949 sec and the natural frequency is 0.24334/sec while Mode shapes 2 produce 3.72933 sec of period and 0.26814/sec of natural frequency. Thus Mode shape 2 was in the second place of the highest period. Mode shape 3 also produces highest time period among 12 Mode shapes which is 3.30303 sec with the natural frequency of 0.30275 /sec. This shows that the first three of the mode shape is the best mode shape between twelve other. This is because they produce highest time period with lowest frequency. Frequency also can be calculated by using formula of:

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

Example calculation:

Mode shape 1 produced period of 4.10949 sec. Frequency can be calculated by:

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

$$\text{Frequency} = \frac{1}{4.10949\ sec}$$

Frequency = 0.24334/sec

4.3.2 Dead Load (DL) + Live Load (LL)

The dead load and live load of structure is being analyze in SAP2000. The self-weight of the slab is considered as dead load. The live load of the elevated flat slab is factored by 1.0. The Figure 4,5 shows the deformed shape of dead load and live load. The analysis showed that the deformed shape for dead load is more critical than the live load.

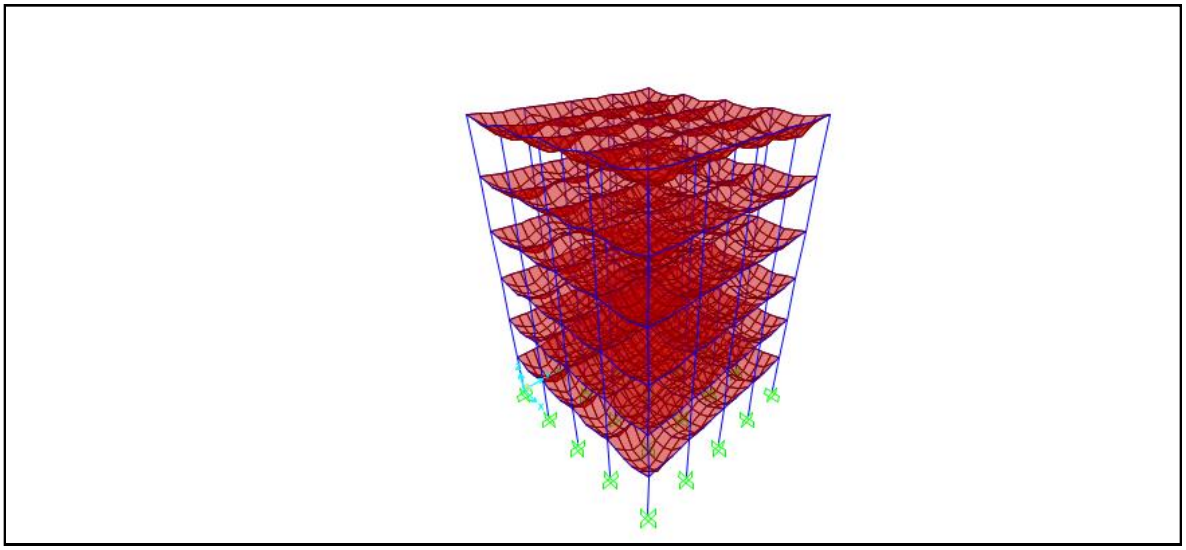


Figure 4.14: *Deformed shape from the analysis of dead load and live load.*

4.3.3 Dead Load (DL) + Live Load (LL) + Earthquake Load.

The load combination analysis showed the behavior of the elevated water tank structure when the earthquake loading occurred. In the analysis, the movement of ground motion earthquake will have the effect on the displacement and acceleration on the structure. Random joints in the structure are selected to show the result of the spectral displacement and acceleration of the joint.

4.3.4 TIME HISTORY ANALYSIS

Time history analysis will study the relationship between joint of displacement and acceleration of flat slab structure for U1 (x-axis) and U2 (y-axis).Time History Analysis is based on the earthquake loading Acheh and Bukit Tinggi. Base on this analysis, the highest displacement and acceleration of each joint of member can be determined. Other than that, it can show the comparison value of displacement and acceleration for different types of earthquake loading.

The figure below shows the displacement of the random joint of the elevated flat slab. There are three displacement which are displacement on x-axis and displacement on y-axis.

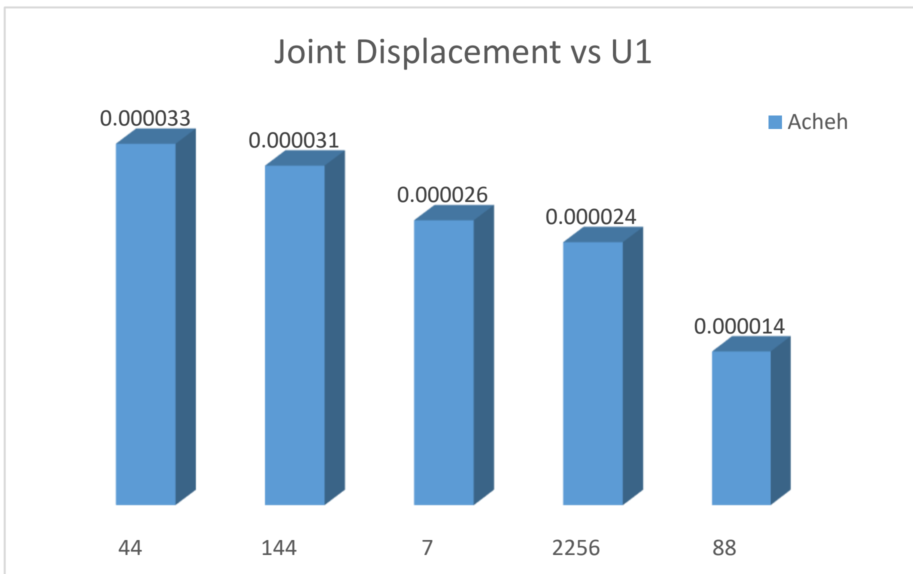


Figure 4.15: *Bar graph of joint versus displacement at x-axis for Acheh Earthquake Loading*

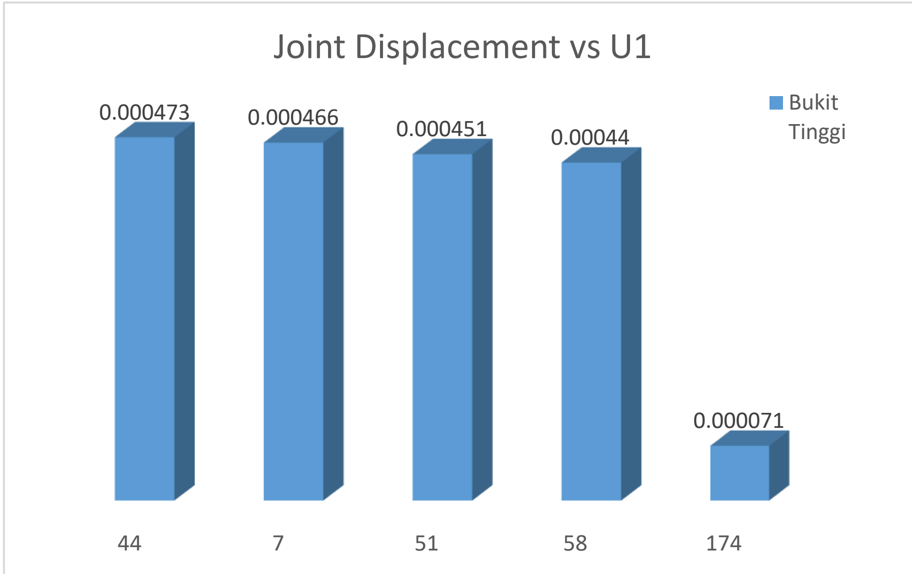


Figure 4.16: *Bar graph of joint versus displacement at x-axis for Bukit Tinggi Earthquake Loading*

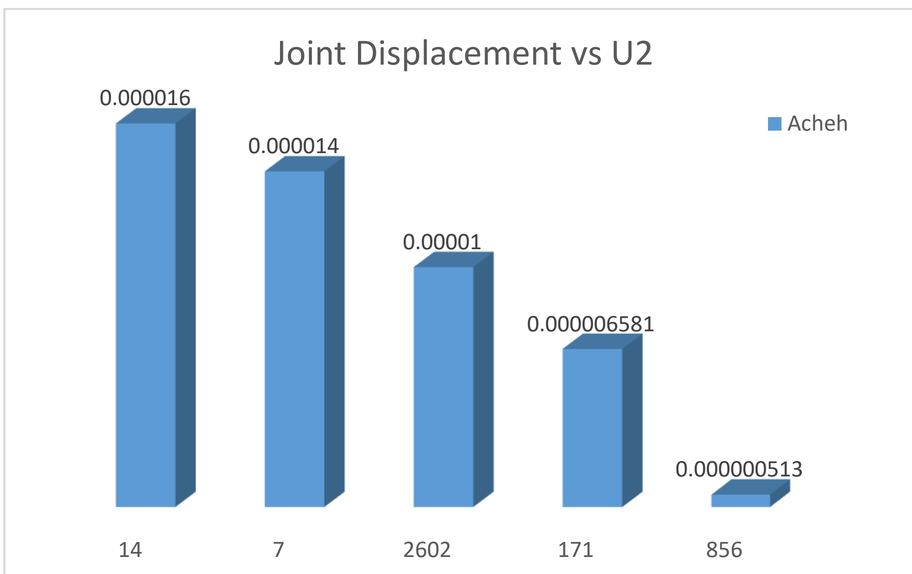


Figure 4.17: *Bar graph of joint versus displacement at y-axis for for Acheh Earthquake Loading*

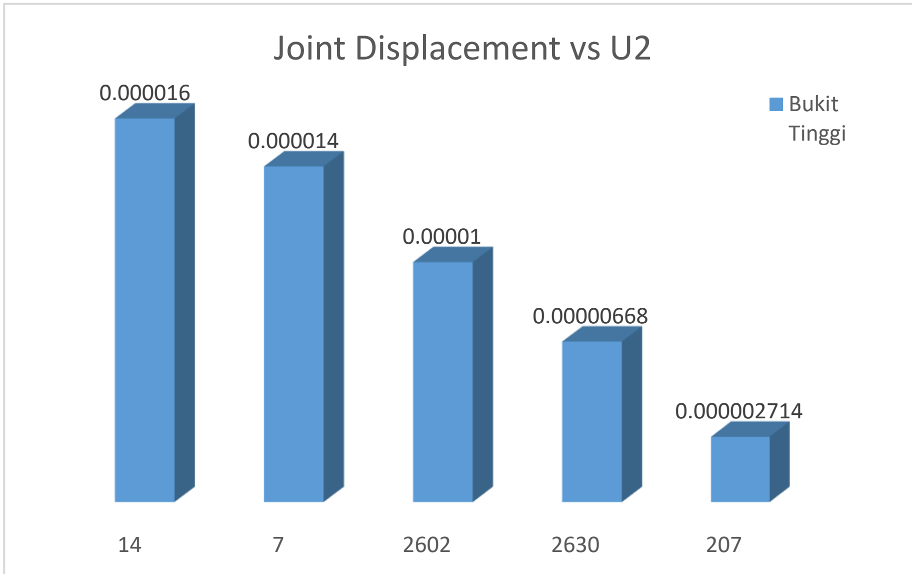


Figure 4.18: *Bar graph of joint versus displacement at y-axis for for Bukit Tinggi Earthquake Loading*

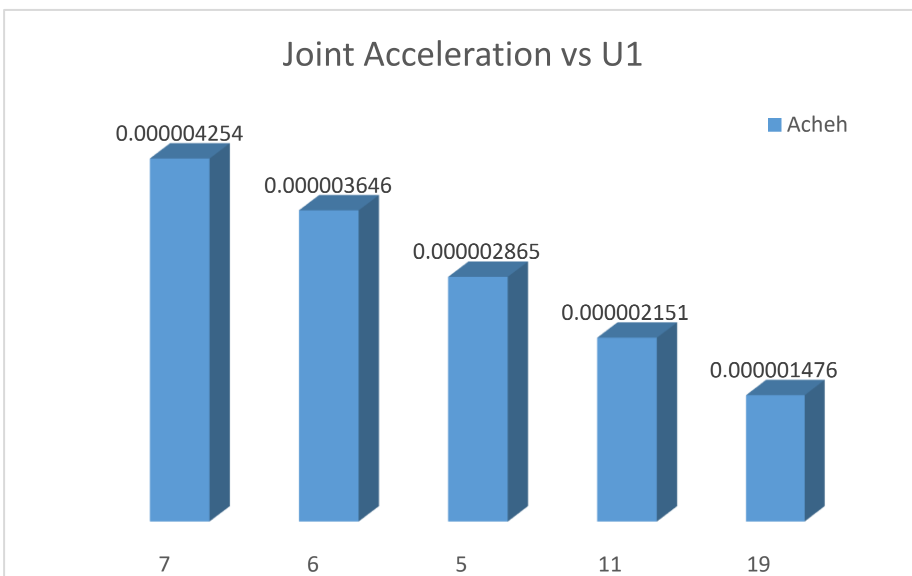


Figure 4.19: *Bar graph of joint versus displacement at x-axis for for Acheh Earthquake Loading*

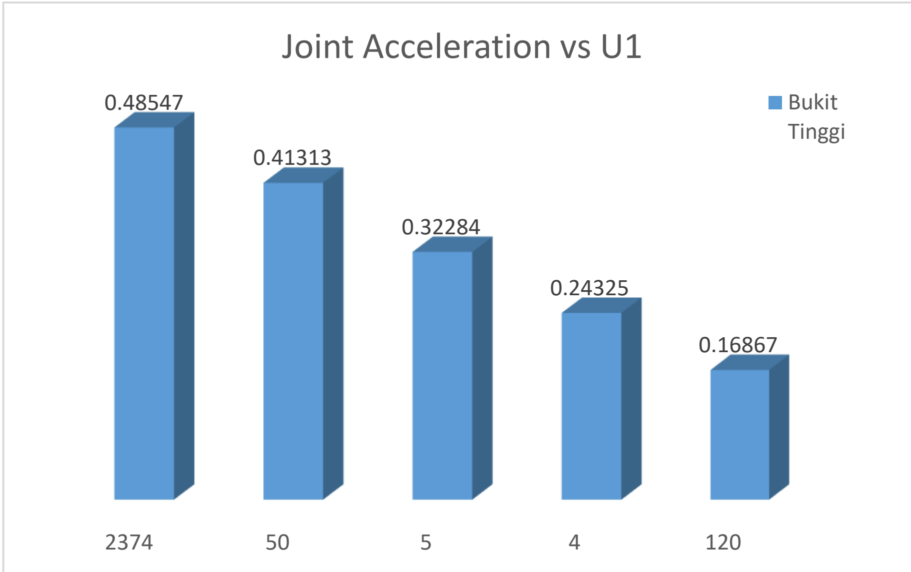


Figure 4.20: *Bar graph of joint versus displacement at x-axis for for Bukit Tinggi Earthquake Loading*

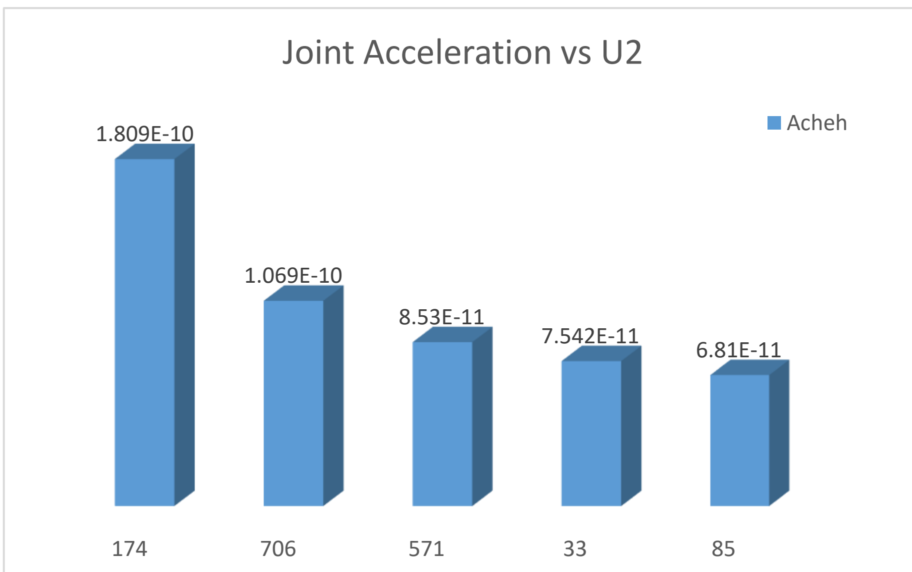


Figure 4.21: *Bar graph of joint versus displacement at y-axis for for Acheh Earthquake Loading*

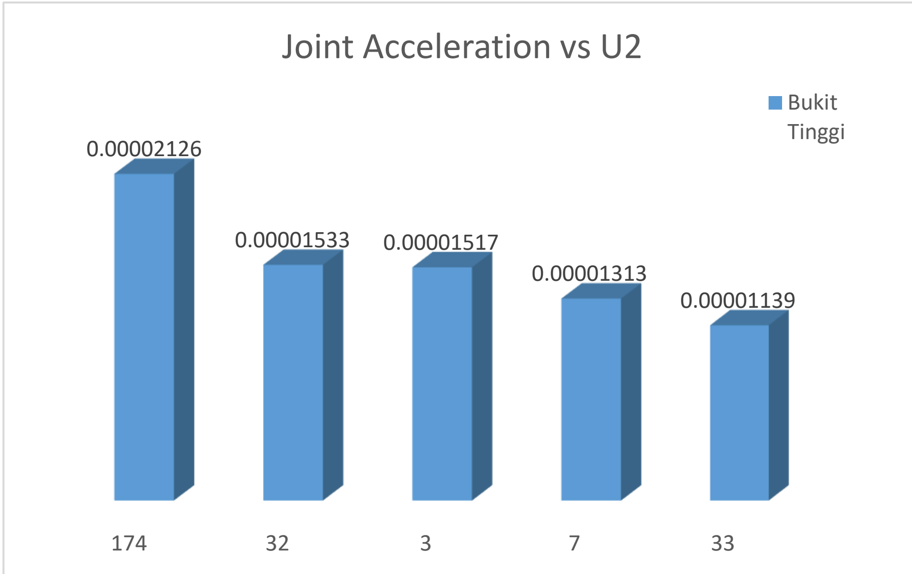


Figure 4.22: *Bar graph of joint versus displacement at y-axis for for Bukit Tinggi Earthquake Loading*

From the bar chart it shows that both joint displacement and joint acceleration is highest for Bukit Tinggi earthquake loading. Bukit Tinggi produces the highest value of displacement in x direction at joint 44 which is 0.000473 m while Acheh produce the highest displacement at joint 17 with 0.000033 m. In y-direction, the highest value of displacement is Bukit Tinggi with 0.000016 m at joint 14. Meanwhile, for the acceleration bar chart its shows that, at joint 7 Bukit Tinggi produce the highest acceleration with 0.48544 m/s^2 in x direction. Below is a summary table for the maximum value at joint for displacement and acceleration for both Acheh and Bukit Tinggi earthquake.

***Table 4.1**: Maximum Joint Displacement vs. U1*

Acheh		Bukit Tinggi	
Joint	Displacement (m)	Joint	Displacement (m)
44	0.000033	44	0.000473

***Table 4.2**: Maximum Joint Displacement vs. U2*

Acheh		Bukit Tinggi	
Joint	Displacement (m)	Joint	Displacement (m)
14	0.000016	14	0.000016

***Table 4.3**: Maximum Joint Acceleration vs. U1*

Acheh		Bukit Tinggi	
Joint	Acceleration (m/s^2)	Joint	Acceleration (m/s^2)
174	1.809×10^{-10}	174	0.00002126

***Table 4.4**: Maximum Joint Acceleration vs. U2*

Acheh		Bukit Tinggi	
Joint	Acceleration (m/s^2)	Joint	Acceleration (m/s^2)
7	0.000004254	2374	0.48547

4.4 VIRTUAL WORK DIAGRAM

Virtual work diagram can be used to determine which element should be stiffened based on its virtual colour. It is to achieve the most efficient control over the lateral displacement as in SAP 2000

Based on different load cases and displacement the virtual work diagrams are as follow:

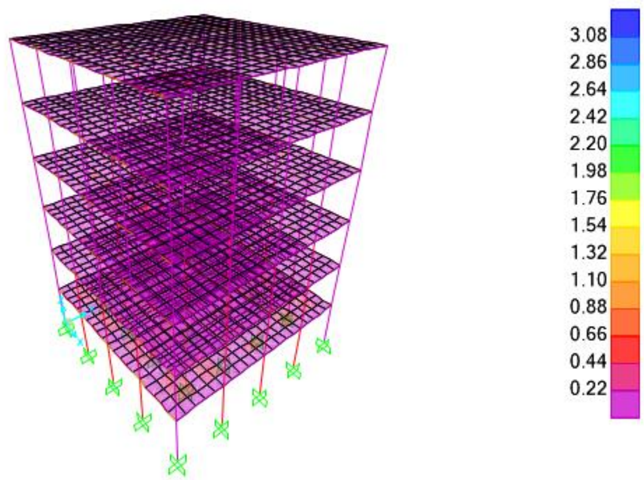


Figure 4.23: *Forces: Dead, Displacement: Dead*

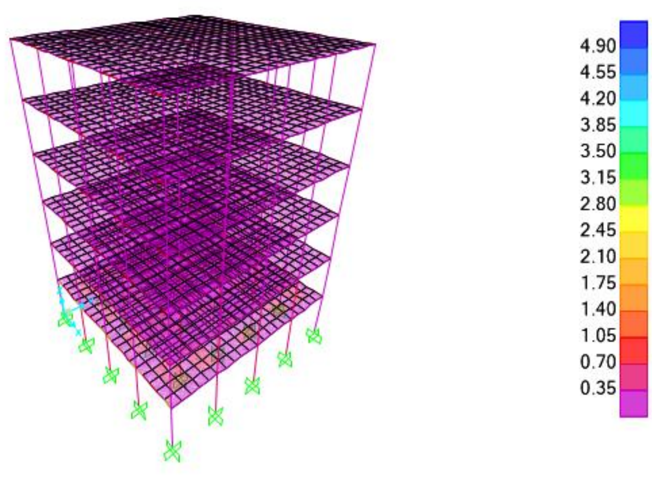


Figure 4.24: *Forces: Dead, Displacement: Live*

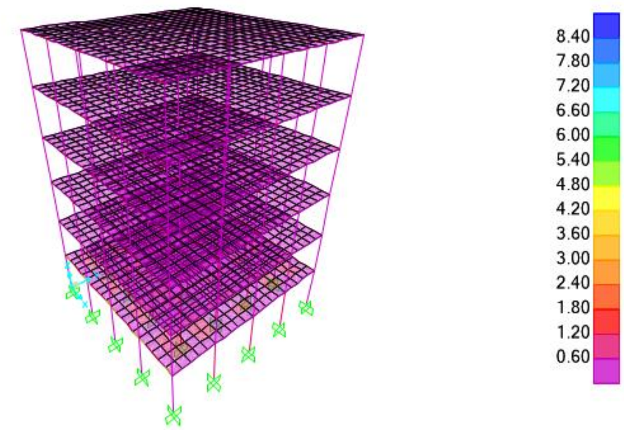


Figure 4.25: *Forces: Live, Displacement: Live*

The blue colour scale shows that it is critical value of displacement of truss bridge while the purple colour is shows the least value of motion of bridge from its main position.

4.5 RESPONSE SPECTRUM ANALYSIS (RSA)

Response-spectrum analysis (RSA) can be said as a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration as to indicate the likely maximum seismic response of an essentially elastic structure. Besides, RSA is simply a plot of the peak or steady-state response in the terms of displacement, velocity or acceleration of a series of oscillators of varying natural frequency which are forced into motion by the same vibration in the function of structural period for a given time history and level of damping.

Below are the graph of the RSA for Acheh and Bukit Tinggi earthquake in term of frequency and time period in both x and y axis. The joint with the maximum acceleration was chosen. For x direction joint 7 was chosen while for y direction joint 2374 was chosen with the damping of 0%, 2% and 5%. RSA contain five types of graph which are as below:

1. Spectral Displacements
2. Spectral Velocities
3. Pseudo Spectral Velocities
4. Spectral Accelerations
5. Pseudo Spectral Acceleration

4.5.1 Acheh Earthquake loading

<u>Frequency</u>

x-direction **y-direction**

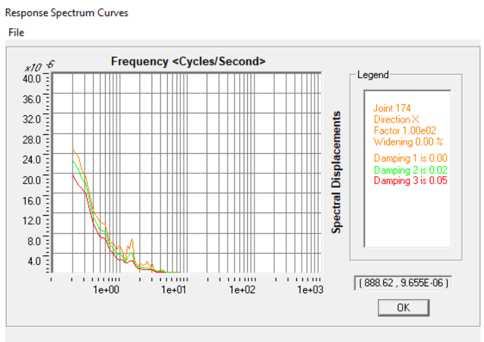


__Figure 4.26:__ Spectra Displacement in X direction

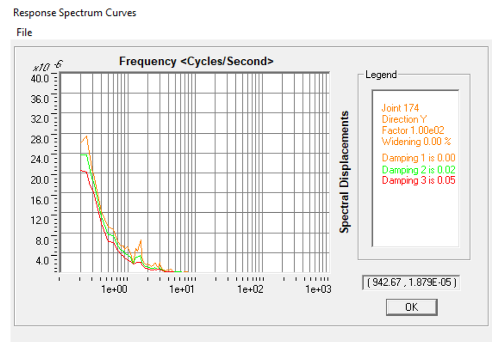


__Figure 4.27:__ Spectra Displacement in Y direction

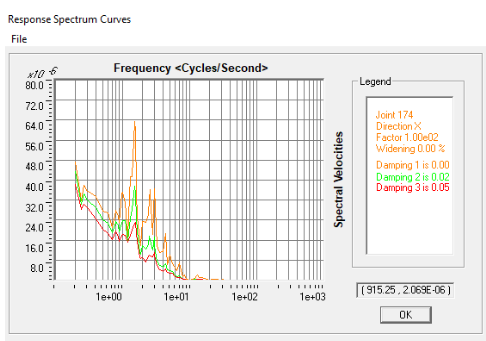


__Figure 4.28:__ Spectra Velocities in X direction

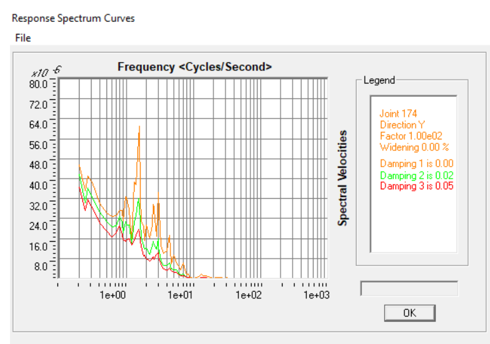


__Figure 4.29:__ Spectra Velocities in y direction.

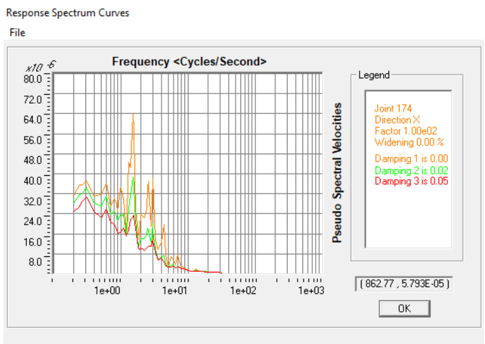


Figure 4.30: *Pseudo Spectra Velocities in X direction*

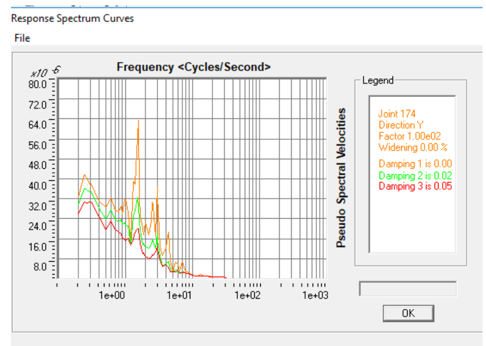


Figure 4.31: *Pseudo Spectra Velocities in y direction.*

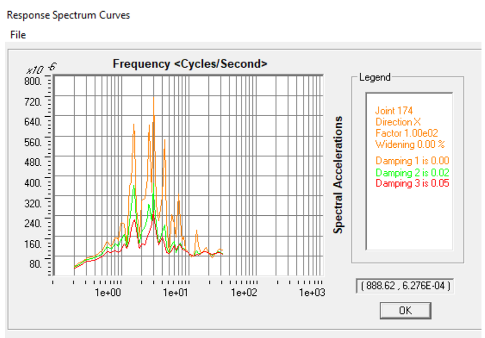


Figure 4.32: *Spectra Acceleration in X direction*

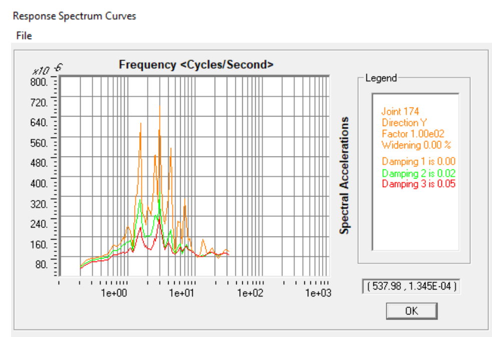


Figure 4.33: *Spectra Acceleration in y direction.*

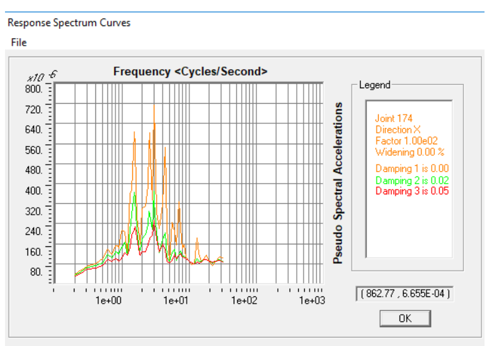


Figure 4.34: *Pseudo Spectra Acceleration in x-direction*

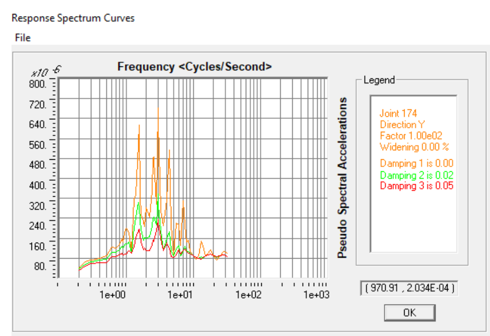


Figure 4.35: *Pseudo Spectra Acceleration in y direction.*

Table 4.5: *Peak Respon Spectrum for Acheh Earhquake in x direction (Frequency)*

Peak Response			
Damping	**0**	**0.02**	**0.05**
SD(m)	$2.031x10^{-6}$	$1.972x10^{-6}$	$1.914x10^{-6}$
SV (m/s)	$6.345x10^{-5}$	$2.092x10^{-5}$	$1.970x10^{-5}$
PSV (m/s)	$6.379x10^{-5}$	$3.793x10^{-5}$	$3.070x10^{-5}$
SA (m/s^2)	$7.207x10^{-4}$	$3.828x10^{-4}$	$2.379x10^{-4}$
PSA (m/s^2)	$7.207x10^{-4}$	$3.862x10^{-4}$	$2.517x10^{-4}$

Table 4.6: *Peak Respon Spectrum for Acheh Earhquake in y direction (Frequency)*

Peak Response			
Damping	**0**	**0.02**	**0.05**
SD(m)	$2.420x10^{-6}$	$2.345x10^{-6}$	$2.031x10^{-6}$
SV (m/s)	$6.069x10^{-5}$	$1.972x10^{-5}$	$1.859x10^{-5}$
PSV (m/s)	$6.379x10^{-5}$	$2.572x10^{-5}$	$2.354x10^{-5}$
SA (m/s^2)	$6.862x10^{-4}$	$3.517x10^{-4}$	$2.345x10^{-4}$
PSA (m/s^2)	$6.724x10^{-4}$	$3.966x10^{-4}$	$2.379x10^{-4}$

Period

x-direction **y-direction**

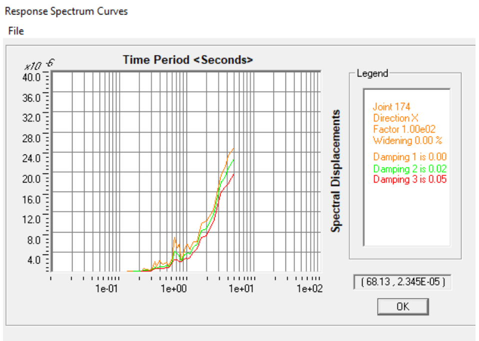


Figure 4.36: *Spectra Displacement in X direction*

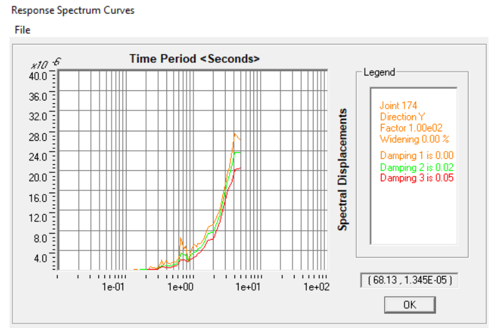


Figure 4.37: *Spectra Displacement in Y direction*

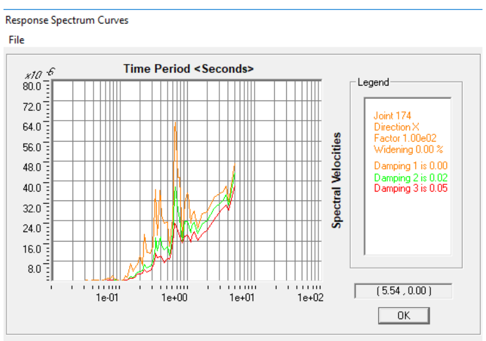


Figure 4.38: *Spectra Velocities in X direction*

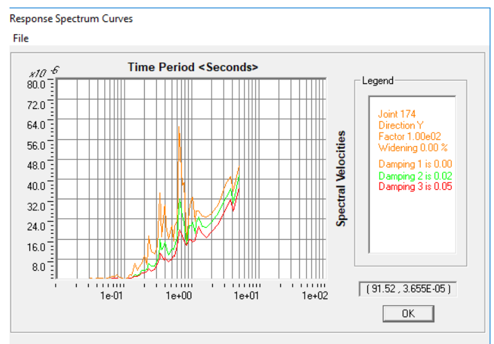


Figure 4.39: *Spectra Velocities in y direction.*

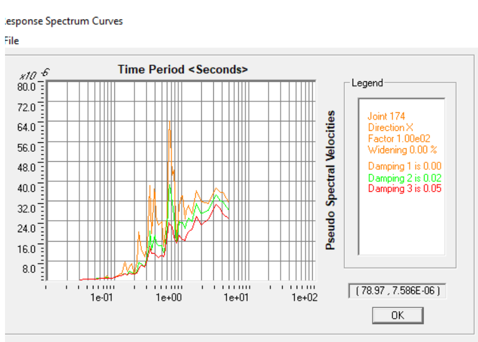


Figure 4.40: *Pseudo Spectra Velocities in X direction*

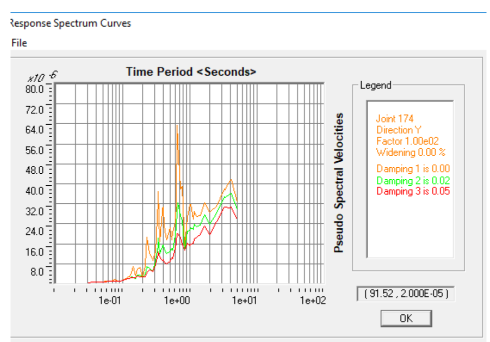


Figure 4.41: *Pseudo Spectra Velocities in y direction.*

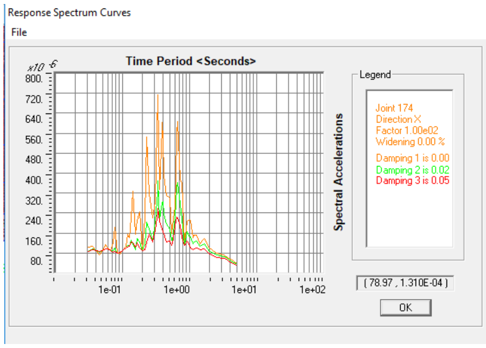


Figure 4.42: *Spectra Acceleration in X direction*

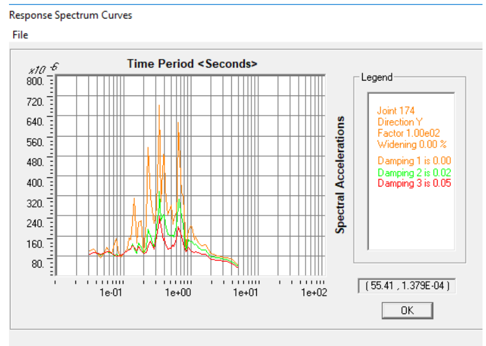


Figure 4.43: *Spectra Acceleration in y direction.*

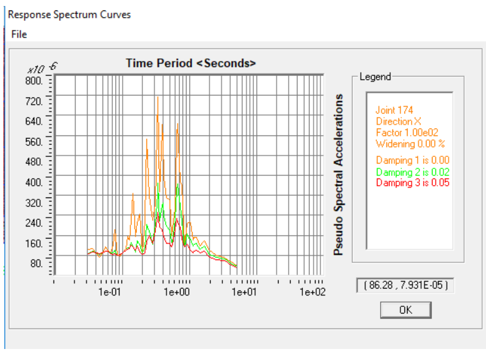


Figure 4.44: *Pseudo Spectra Acceleration in x-direction*

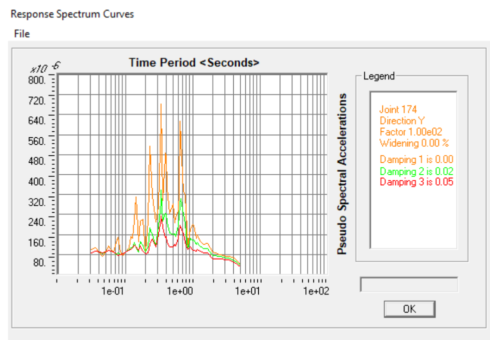


Figure 4.45: *Pseudo Spectra Acceleration in y direction.*

Table 4.7: *Peak Response Spectrum for Acheh Earhquake in x direction (Period)*

Peak Response			
Damping	**0**	**0.02**	**0.05**
SD(m)	$2.500x10^{-5}$	$2.276x10^{-5}$	$1.983x10^{-5}$
SV (m/s)	$6.615x10^{-5}$	$4.379x10^{-5}$	$3.828x10^{-5}$
PSV (m/s)	$6.813x10^{-5}$	$6.615x10^{-5}$	$3.103x10^{-5}$
SA (m/s^2)	$3.335x10^{-5}$	$3.257x10^{-5}$	$3.162x10^{-5}$
PSA (m/s^2)	$3.559x10^{-5}$	$6.615x10^{-5}$	$3.257x10^{-5}$

Table 4.8: *Peak Respon Spectrum for Acheh Earhquake in y direction (Frequency)*

Peak Response			
Damping	**0**	**0.02**	**0.05**
SD(m)	2.7.41x10^{-5}	2.517x10^{-6}	2.069x10^{-6}
SV (m/s)	4.615x10^{-5}	4.207x10^{-5}	3.621x10^{-5}
PSV (m/s)	6.615x10^{-5}	3.552x10^{-5}	3.069x10^{-5}
SA (m/s^2)	3.355x10^{-4}	3.257x10^{-4}	3.455x10^{-4}
PSA (m/s^2)	3.355x10^{-4}	3.455x10^{-4}	3.455x10^{-4}

4.5.2 *Bukit Tinggi Earthquake loading*

Frequency

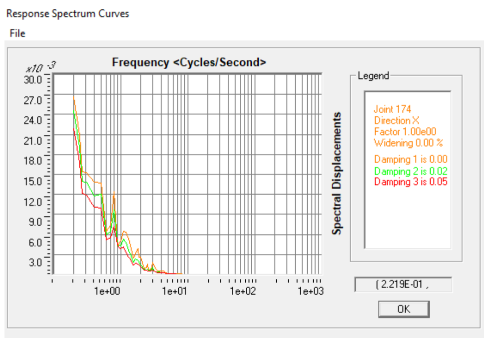


Figure 4.46: *Spectra Displacement in X direction*

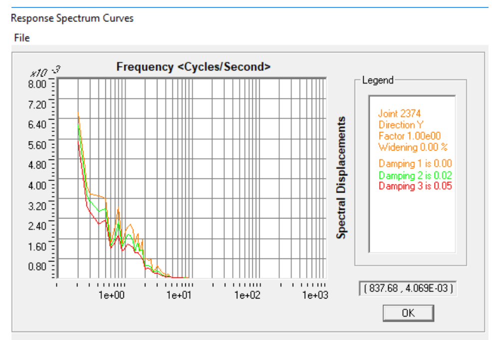


Figure 4.47: *Spectra Displacement in Y direction*

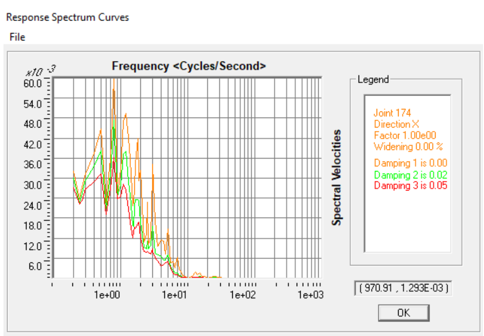


Figure 4.48: *Spectra Velocities in X direction*

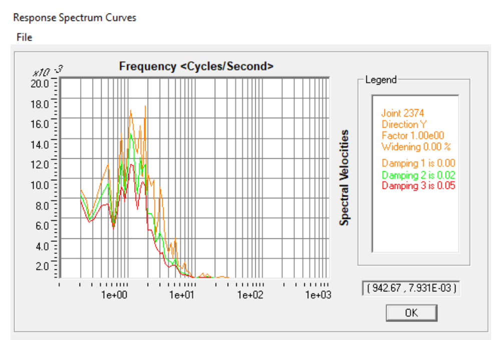


Figure 4.49: *Spectra Velocities in y direction.*

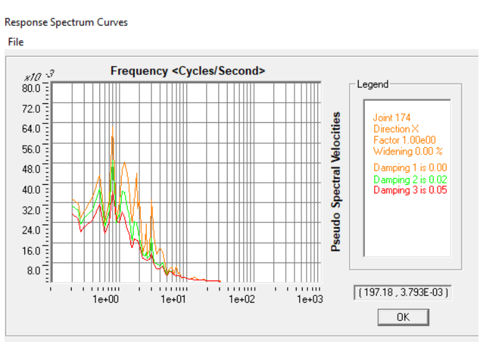


Figure 4.50: *Pseudo Spectra Velocities in X direction*

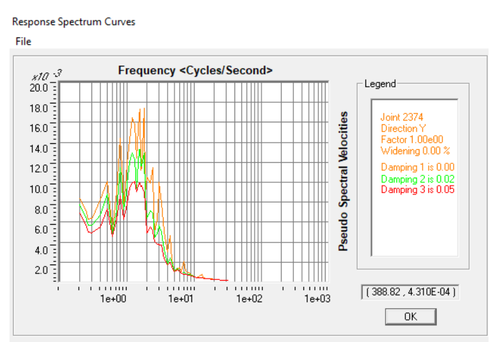
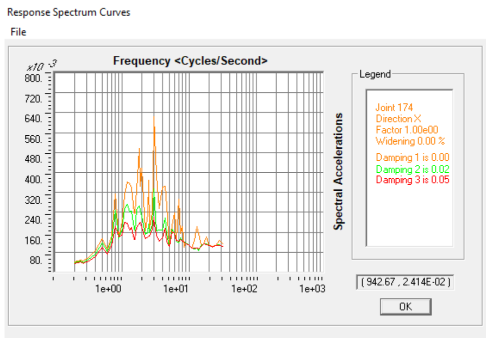


Figure 4.51: *Pseudo Spectra Velocities in y direction*



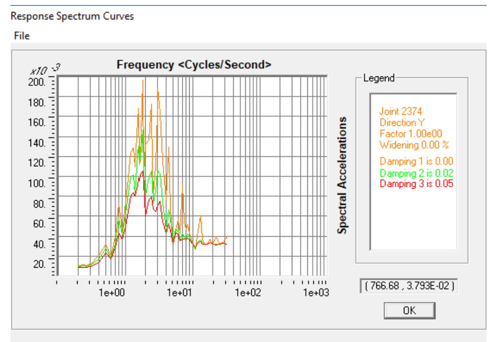
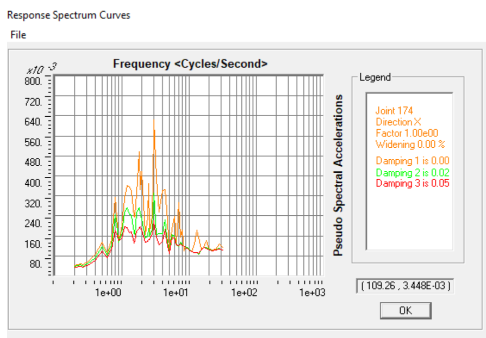


Figure 4.52: *Spectra Acceleration in X direction*

Figure 4.53: *Spectra Acceleration in y direction*



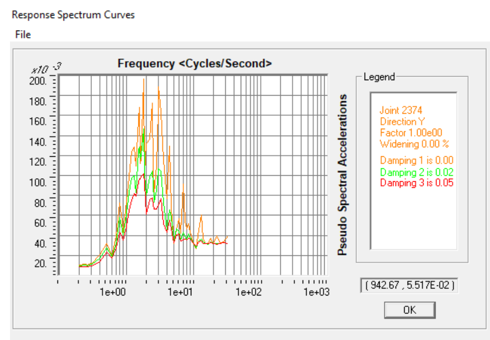


Figure 4.54: *Pseudo Spectra Acceleration in x-direction*

Figure 4.55: *Pseudo Spectra Acceleration in y direction.*

Period

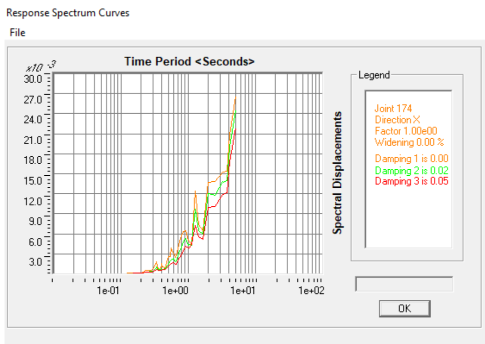


Figure 4.56: *Spectra Displacement in X direction*

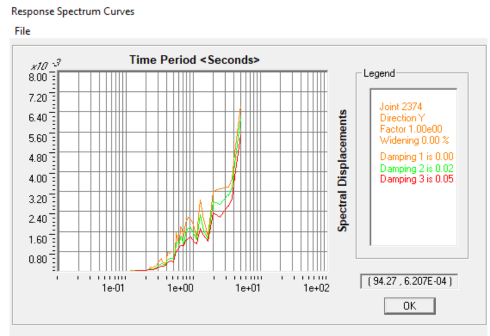


Figure 4.57: *Spectra Displacement in Y direction*

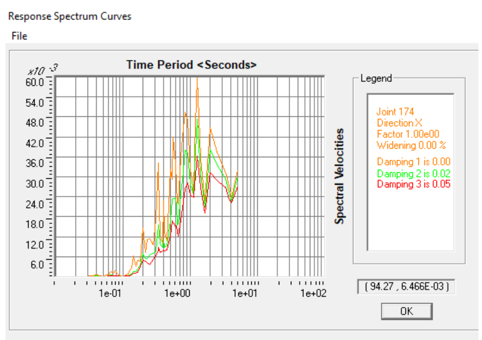


Figure 4.58: *Spectra Velocities in X direction*

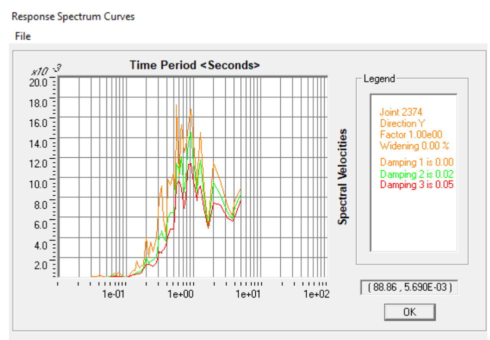


Figure 4.59: *Spectra Velocities in y direction*

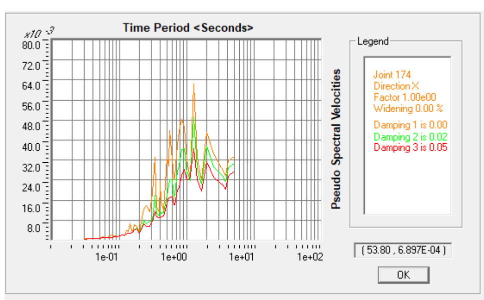


Figure 4.60: *Pseudo Spectra Velocities in X direction*

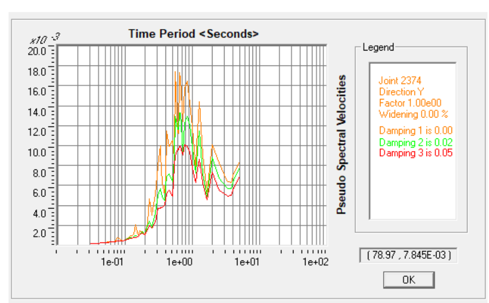


Figure 4.61: *Pseudo Spectra Velocities in y direction.*

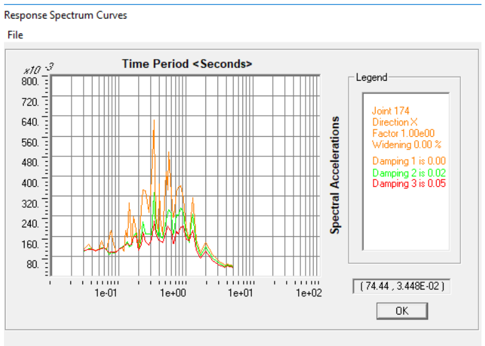


Figure 4.62: *Spectra Acceleration in X direction*

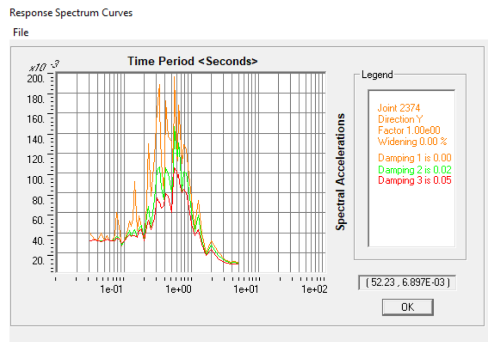


Figure 4.63: *Spectra Acceleration in y direction.*

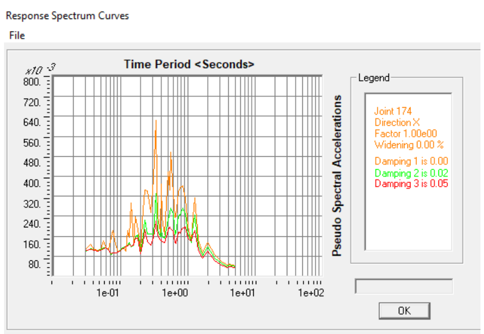


Figure 4.64: *Pseudo Spectra Acceleration in x-direction*

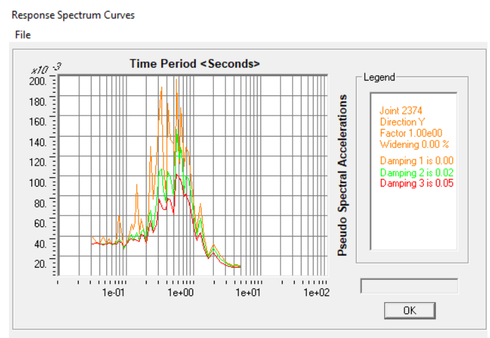


Figure 4.65: *Pseudo Spectra Acceleration in y direction.*

Table 4.9: *Peak Respon Spectrum for Acheh Earhquake in x direction (Period)*

Peak Response			
Damping	**0**	**0.02**	**0.05**
SD(m)	$2.301x10^{-3}$	$1.972x10^{-3}$	$1.859x10^{-3}$
SV (m/s)	$7.897x10^{-3}$	$8.133x10^{-3}$	$6.150x10^{-3}$
PSV (m/s)	$7.067x10^{-3}$	$8.377x10^{-3}$	$8.86x10^{-3}$
SA (m/s^2)	$6.483x10^{-3}$	$3.310x10^{-3}$	$2.241x10^{-3}$
PSA (m/s^2)	$6.310x10^{-3}$	$3.207x10^{-3}$	$2.207x10^{-3}$

Table 4.10: Peak Respon Spectrum for Acheh Earhquake in y direction (Period)

Peak Response			
Damping	**0**	**0.02**	**0.05**
SD(m)	$2.7.41x10^{-5}$	$2.517x10^{-6}$	$2.069x10^{-6}$
SV (m/s)	$4.615x10^{-5}$	$4.207x10^{-5}$	$3.621x10^{-5}$
PSV (m/s)	$6.615x10^{-5}$	$3.552x10^{-5}$	$3.069x10^{-5}$
SA (m/s^2)	$3.355x10^{-4}$	$3.257x10^{-4}$	$3.455x10^{-4}$
PSA (m/s^2)	$3.355x10^{-4}$	$3.455x10^{-4}$	$3.455x10^{-4}$

4.6 SUMMARY OF THE ANALYSIS

Flat Slabs are considered suitable for most of the construction and for asymmetrical column layouts like floors with curved shapes and ramps etc. The advantages of applying flat slabs are many like depth solution, flat soffit and flexibility in design layout.. Thus flat slab structure is one of the importance structures for building. Without considering the earthquakes loading the flat slab structure may collapses due to the certain frequency. Base on the analysis, earthquake loading gives a huge impact towards the flat slab structure.

4.6.1 Time Period and Frequency

The time of an object takes to vibrate back and forth one complete cycle is known as its period of vibration. Period of vibration is one of the important factors for determining how a structure will respond to ground shake. For an earthquake 15 sec long, the structure will go through this shaking approximately 30 times. On the basis of time period the building or other structure 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 can be determined by the empirical formula as shown before.

Table 4.11: *Rigidity of shape according to their time period*

MODE SHAPE	FREQUENCY (Hz)	TIME PERIOD (sec)	RIGIDITY OF SHAPE
1	0.24334	4.10949	FLEXIBLE
2	0.26814	3.72933	FLEXIBLE
3	0.30275	3.30303	FLEXIBLE
4	0.80036	1.24943	FLEXIBLE
5	0.86836	1.15159	FLEXIBLE
6	1.02002	0.98037	SEMI-RIGID
7	0.64863	1.54171	FLEXIBLE
8	0.61187	1.63433	FLEXIBLE
9	0.54151	1.84668	FLEXIBLE
10	2.49960	0.40006	SEMI-RIGID
11	0.38587	0.184443	RIGID
12	0.34034	2.93821	FLEXIBLE

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the research, the conclusion that can be made are :

i. Modal analysis from SAP2000 can produced 12 mode shape with their natural period and frequency
ii. From modal analysis, the highest natural period is mode shape 1 which is 4.10949.
iii. SAP 2000 can consider the earthquake loading
iv. The mode shape of flat slab structure is different when the earthquake occurred as the structure move based on upon the ground motion.
v. The value of response spectral Analysis can be determined when earthquake occur.
vi. Based on the analysis, the critical joint is joint 44 where it have highest displacement value 0.000033 m.
vii. The building structure in Malaysia shall be design with considering the earthquake loading.

5.2 RECOMMENDATION

For the future study, flat slab structure in Malaysia should be design considering the earthquake loads. This is because, nowadays Malaysia also experiencing aftershock from the earthquake just in a small scale. Even the scale is small but the effect is huge and also can collapse the flat slab structure if the earthquake loadings were not considered. The small scale of the earthquake happened in Malaysia is not the reason for the engineer to ignore the earthquake loadings in design the bridge structure. By doing the analysis, the structural engineer can design the structure with recommendation material strength based on the result and analysis that have achieved in the research.

The recent earthquake in Ranau, Sabah has open many eyes on the structure affected by earthquake. The time history in Ranau, Sabah can be used to analyse the structure in Malaysia. Even though it is average magnitude value, it can be the reference in the future to enhance the safeguard of the population. As conclusion, Malaysia did not apply any earthquake regulations in designing structure of building. The design of building structure on Malaysia should consider the seismic or earthquake loading regulations. The seismic regulation must adaptable with the specific condition of the country, the land management, disaster prevention and environment protection.

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