SEISMIC PERFORMANCE OF ELEVATED WATER TANK UNDER EARTHQUAKE LOADING

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NURUL ATIKHA BINTI KHARIUL ABIDIN

Thesis submitted in fulfillment of the requirements for the award of the degree of the Bachelor (Hons.) of Civil Engineering

Faculty of Civil Engineering and Earth Resource

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SUPERVISOR'S DECLARATION

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I dedicated this thesis to my sweet and loving parents,

Mr. Khariul Abidin Bin Mohlas and Mrs. Juhati Binti Ngadi,

who taught me the best kind of knowledge to have is that which is learned for its own sake and

even the largest task can be accomplished if it is done one step a time.

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ABSTRACT

The elevated water tank is very important structure and it consist various type. Water tank is designed to store quantity of liquid such as liquid petroleum and water to supply to the public or residential area. The design also must resist earthquake loading since Malaysia have been experienced a few earthquake event due to the earthquake loading that occurred in the neighboring countries. Back in 2015, the earthquake has occurred in Ranau, Sabah which affected the building structure and geological changes. However, most of the structure designed in Malaysia did not consider the earthquake loading. So, this study will focused on the seismic performance on reinforced concrete of elevated water tank under earthquake loading. The main objective of this research is to study the seismic behavior of elevated water tank structure in Malaysia region under far field earthquake loading. The structure will be design and simulate by using computer software, SAP2000.

ABSTRAK

Tangki air bertingkat adalah struktur yang sangat penting dan ia terdiri daripada pelbagai jenis. Tangki air direka untuk menyimpan bahan cecair seperti petroleum dan air untuk dibekalkan kepada kawasan kediaman atau awam. Reka bentuk struktur tersebut mestilah dapat menahan gegaran gempa bumi. Malaysia telah mengalamibeberapa peristiwa gegaran gempa bumi yang disebabkan oleh gegaran gempa bumi yang berlaku di negara jiran. Pada tahun 2015, gempa bumi telah berlaku di Ranau, Sabah yang memberi kesan kepada struktur bangunan dan perubahan geologi. Walau bagaimanapun, kebanyakan struktur bangunan yang direka di Malaysia tidak mengutamakan gegaran gempa bumi. Justeru, kajian ini akan memberi tumpuan kepada prestasi seismik pada konkrit bertetulang tangki air bertingkat apabila berlakunya gegaran gempa bumi. Objektif utama kajian ini adalah untuk mengkaji tingkah laku seismik struktur tangki air bertimgkat di rantau Malaysia apabila berlakunya gegaran gempa bumi di lapangan. Struktur tangki air bertingkat akan direka bentuk berdasarkan struktur yang terdapat di Malaysia dan simulasi akan dilakukan menggunakan perisian komputer, SAP2000.

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LIST OF SYMBOLS

m	meter
m/sec^2	meter per second square
m^3	cubic meter
s	second
Hz	Hertz
g	gal

LIST OF ABBREVIATIONS

2D	Two dimension
3D	Three dimension
UITM	Universiti Teknologi Mara
RC	Reinforced concrete
FEMA	Federal Emergency Management Agency
USGS	United State Geological Survey
NYSED	New York State Education Department
PEER	Pacific Earthquake Engineering Research Centre
DL	Dead Load
LL	Live Load

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Elevated storage tank is commonly used to store water for domestic activities. Water is human basic in daily life either in residential or commercial service. Water is supplied to citizen depends on the design of water tank in certain area. Elevated water tank is design and constructed to hold the water that will be supplied to the citizen. Usually the elevated water tank is constructed and be placed at the highest point for distribution system by pressurize the water.

The used of the elevated water storage tank in various forms are existed since ancient times. The used of elevated water tank which distributed the water to public is started in the middle of 19^{th} century. The elevated water tank is widely used in recent years worldwide including Malaysia.

It has been proven that the earthquake cause the most bad phenomenon that can happen in human life with a lot damages. An earthquake happened when two tectonic plates moved or slipped and produced a large strain energy which released to the earth's surface. The energy then transform to the seismic waves or vibration of the ground motion.

Based on the seismothecnic map, Malaysia is located near Sunda trench and surrounded with Indian plates, Australian plates and Eurasian plates. In other words, Malaysia is located outside of the active earthquake zone. However, Malaysia still experiences the side effect of the earthquake vibration that occurred in the country nearby especially from Indonesia and Philippines.

In 5th June 2015, Malaysia has experienced earthquake phenomenon in Ranau, Sabah with Magnitude of 5.9. It caused a few damages to the residential buildings and infrastructure, landslides and geological changes. Therefore, Malaysia shall not be considered as the country that totally free from the earthquake vibration. From the earthquake track retrieved from 4th December 2016, there was a few earthquake event occurred at neighboring countries about a year ago as in 2016 there was no earthquake magnitude detected. Southern Sabah have most earthquake event which between 4.0 until 6.1 magnitude. The structure design in Malaysia should include the seismic loading and effect including the structure of elevated water tank. Therefore, this paper is written to study and analyze the side effect of seismic loading on the elevated water tank.

Figure 1.1 : Screen capped from Earthquake Track website

Sources: http://earthquaketrack.com/p/malaysia/recent

1.2 PROBLEM STATEMENT

The design of water tank in Malaysia is known to have a lower intensity of seismic effect. Furthermore, the seismic loading also did not include in the calculation design of water tank. Therefore, this study is carried to recognize the effect and the performance of the water tank to endure the earthquake loading.

1.3 RESEARCH OBJECTIVE

The main objectives of this study are:

i. To study the behavior of water tank under far field earthquake loading

ii. To determine the displacement and acceleration of elevated water tank

iii. To study the dynamic characteristic of the elevated water tank

1.4 SCOPE OF STUDY

a) Limited to only one design of elevated water tank

b) The case of study will be related to Aceh earthquake that affected the elevated water tank in Malaysia region.

c) The effect of earthquake loading to the elevated water tank structure

d) The elevated water tank structure modeling and analysis software used is SAP2000

1.5 SIGNIFICANCE OF STUDY

Throughout this research, we could determine the behavior of the elevated water tank structure under the earthquake loading from Aceh earthquake in Malaysia region. The result determine from the study may be used to develop and determine a seismic design criteria of elevated water tank structure in Malaysia. By considering the earthquake resistance, we could save more live. As we know if the elevated water tank structure is collapsed or failed, it will give a worst damage to the whole of residential area.

In addition, these study able to inform the public on earthquake so that they are aware of the hazards by the earthquake. It could reduce the loss of life, injuries and extensive property damage.

1.6 SUMMARY

The thesis will focus on the research of the seismic performance of the elevated water tank under far field earthquake loading, which is the earthquake loading data from Acheh earthquake. Through this thesis, the results will come out with the behavior of elevated water tank under far field earthquake loading, the displacement, acceleration and the dynamic characteristics of elevated water tank. Based on the research, it will show the effort of the researcher in determine the possible damage on the structure when earthquake occurred in neighborhood country that will affect Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 EARTHQUAKE

2.1.1 FUNDAMENTAL OF EARTHQUAKE

Earthquake is one of a natural disaster that approached the earth every single day. This would not kill the humans but the building and structure failure will. Earthquake occurred when a sudden movement takes place in the Earth's crust where the rocky material have reached their strength limit and fractured. A sudden slips happened and the large elastic strain energy was released at the interfere.

The strain energy released from the underneath of earth is called as tectonic plates. Tectonic plates are divided by minor and major plates which are 38 and 14 respectively. The movement of edges plates between each other causes earthquake and they move in different directions and velocities. Plates may have three types of boundaries which are divergent, convergent and transform. Divergent boundaries occurred when the two plates move away from each other and create a void which will fill with the molten lava later.

Convergent boundaries occurred when the two plates move toward each other which will cause a collision. The transform boundaries is when the two plates pass each other with different velocity and direction.

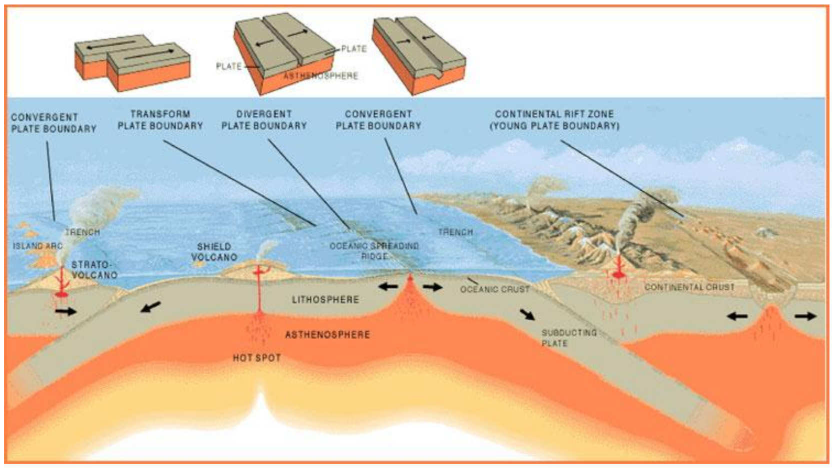

Figure 2.1 : Types of plate boundary

Source: United State Geological Survey (USGS)

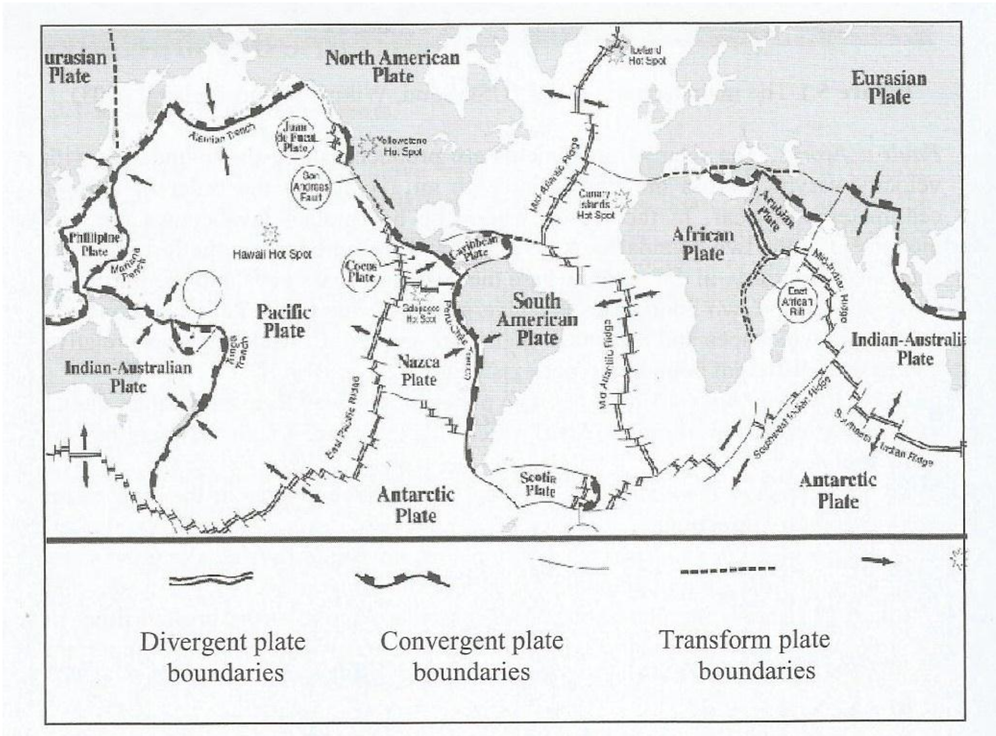

Figure 2.2 : World plate boundaries (modified after NYSED, 2001)

There are two types of earthquake which are inter-plate earthquake and intra-plate earthquake. The inter-plate earthquake is the most common earthquake occurred in the world which it is occur along the plate boundaries. Meanwhile, the intra-plate earthquake occurs further from the boundaries.

2.1.2 TYPES OF SEISMIC WAVES

The seismic waves will travel in all directions through the Earth's layer during an earthquake. There are 2 types of seismic waves which are body waves and surface waves. Body waves consist of P-waves and S-waves meanwhile surface waves consist of Love waves and Rayleigh's waves.

i) P-Waves

P-waves also called as Primary waves. P-waves is a longitudinal waves and underneath the ground, it shakes them back and forth in the same direction. It is moving as fast as lightning with a velocity of 5 to 7km/sec.

ii) S-Waves

It is called Secondary waves. S-waves is a shear waves and shake the ground in perpendicularly from the direction. Furthermore, S-waves is slower than the P-waves with a velocity of 3 to 4km/sec and it cannot go through the liquids.

iii) Love Waves

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

iv) Rayleigh Waves

The wave is moving up and down and side to side which are from the combination of P-waves and S-waves movement. The velocity of Rayleigh waves is same with Love waves. Generally, it will arrive at the site at the same time with L-waves.

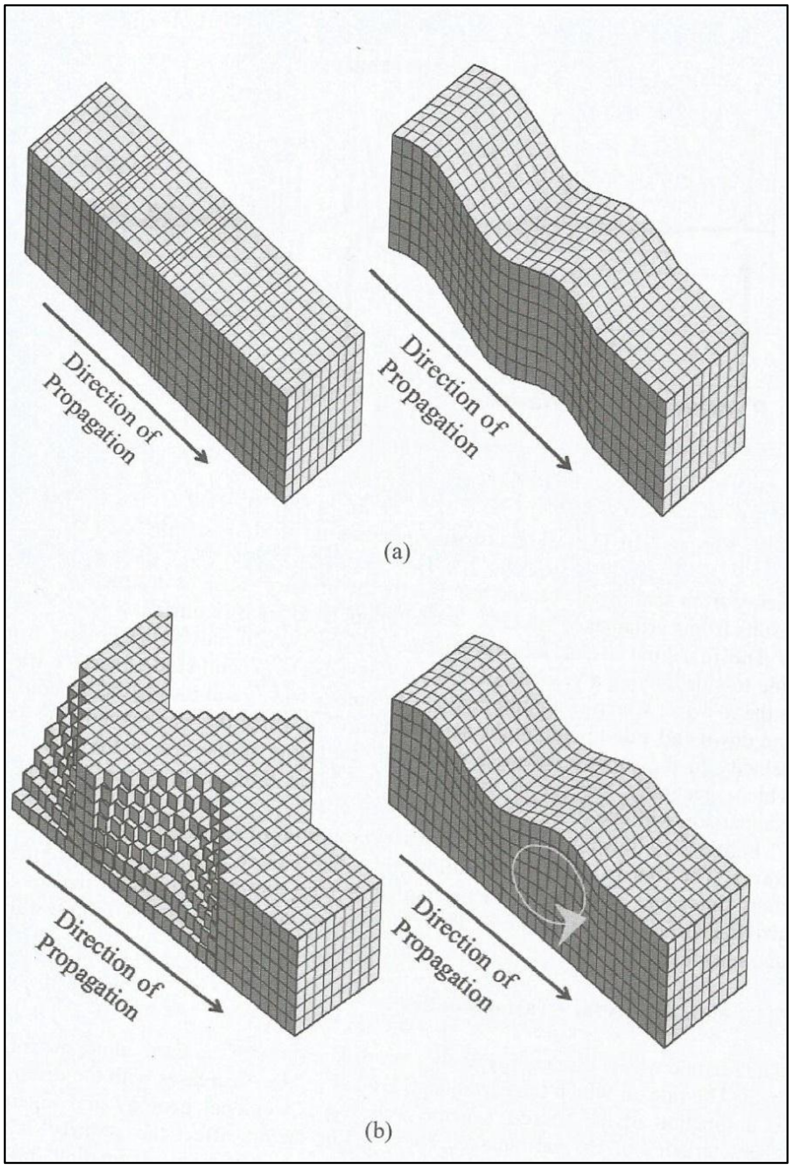

Figure 2.3 : Seismic wave types: (a) Body waves; (b) Surface waves

Source: FEMA, Session 5, 2005

2.1.3 MAGNITUDE

Magnitude is the measurable of the definite size of the earthquake. It determined by the strain energy that has been released while the faults ruptured which can be recorded by seismograph. Earthquake magnitudes are most commonly measured using the Richter Scale (Kusky,2008). In 1935, Charles F. Richter , a California seismologist has introduced the magnitude Richter scale. The magnitude scales are calculated using the zigzag trace on the seismograph.

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 2.4 : Modified Mercalli Intensity Scale compared to Richter Magnitude

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

2.1.4 INTENSITY

Intensity is the measurable of the definite shaking at a location during an earthquake. The intensity may be based on three aspects which are the vibration feeling from the people and animals, damage of the buildings and the natural surrounding changes. The people near the epicenter of the earthquake can feel the higher vibration whereas the people further from the epicenter face the smaller vibration. The commonly used for measuring the intensity of earthquake is the Modified Mercalli Intensity Scale.

2.2 THE ACEH EARTHQUAKE, INDONESIA

Malaysia is known to be safe from the earthquake event as Malaysia is not located at the active earthquake zone. Earthquake hazard from long-distance earthquakes in Peninsular Malaysia originates from two sources, namely the Sumatra subduction zone and the great Sumatra fault. (A.B.Nabilah & T.Balendra, 2012). The Sumatra subduction zone is the most active plate tectonic in the world. Therefore, in this research paper, the elevated water tank structure is going to be analyzing with the Aceh earthquake data.

Magnitude	9.1
Date-Time	**Sunday, December 26, 2004 at 00:58:53 UTC** Sunday, December 26, 2004 at 07:58:53 AM at epicenter Time of Earthquake in other Time Zones
Location	3.316°N, 95.854°E
Depth	30 km (18.6 miles) set by location program
Region	OFF THE WEST COAST OF NORTHERN SUMATRA
Distances	250 km (155 miles) SSE of **Banda Aceh, Sumatra, Indonesia** 300 km (185 miles) W of **Medan, Sumatra, Indonesia** 1260 km (780 miles) SSW of **BANGKOK, Thailand** 1590 km (990 miles) NW of **JAKARTA, Java, Indonesia**
Location Uncertainty	horizontal +/- 5.6 km (3.5 miles); depth fixed by location program
Parameters	NST=276, Nph=276, Dmin=654.9 km, Rmss=1.04 sec, Gp= 29°, M-type=teleseismic moment magnitude (Mw), Version=U
Source	USGS NEIC (WDCS-D)
Event ID	us2004slav

Figure 2.5 : The earthquake data in Aceh, Indonesia

Sources: Earthquake.usgs.gov [Online image]. (2012). Retrieved 12 May, 2016 from http://earthquake.usgs.gov/earthquakes/eqinthenews/2004/us2004slav/#details

The Aceh earthquake in 2004 is the third largest earthquake that has been recorded after the Alaska earthquake and Chile earthquake which with magnitude of 9.1. The large magnitude of earthquake occurred in Indonesia will effect Malaysia as well. Luckily, the earthquake in 2004 is not damaging any buildings in Malaysia.

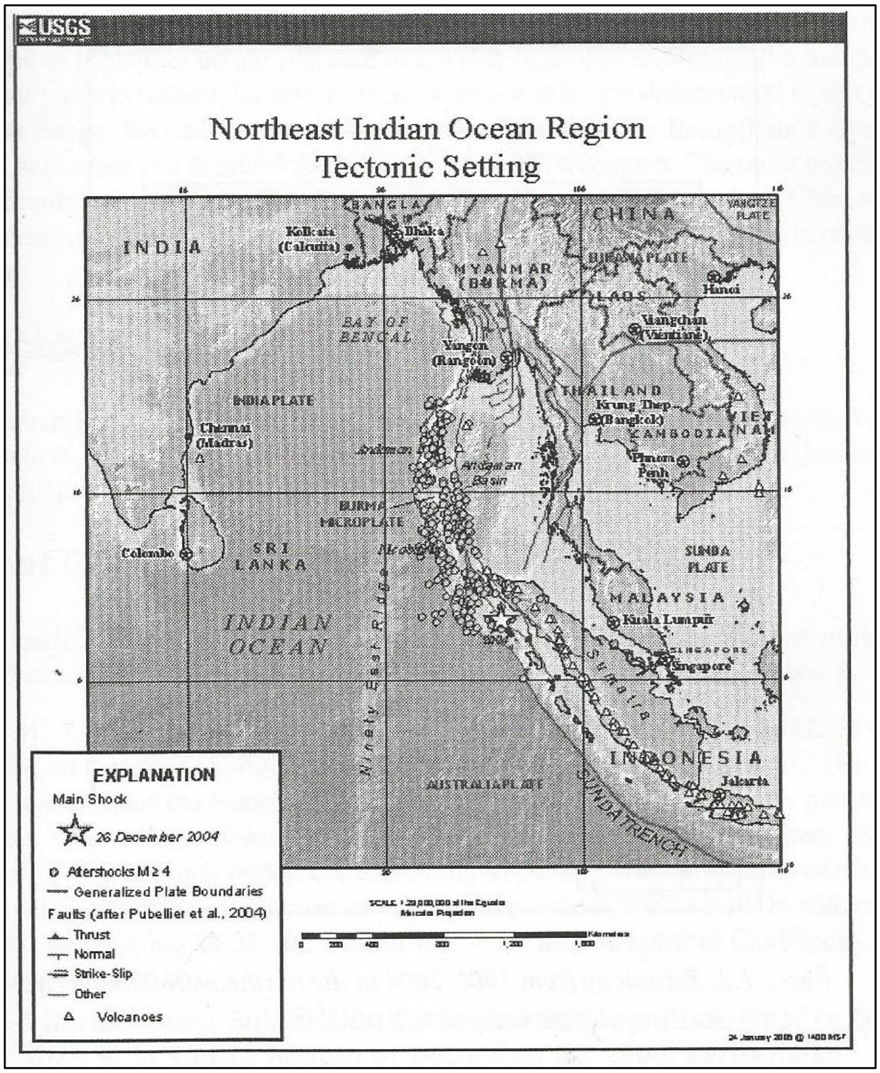

Figure 2.6 : Tectonic Setting of the main shock and aftershock of the M9.1 Sumatra-Andaman Islands earthquake of December 26, 2004.

Source: Courtesy of United State Geological Survey (USGS)

Country	Intensity	Location
Indonesia	IX	Banda Aceh
	VIII	Meulaboh
	IV	Medan and Sampali
	III	Bukittinggi, Parapat, and Payakumbuh
	Felt	Jakarta
India	VII	Port Blair, Andaman Islands
	IV	Madras
	III	Bengaluru, and Vishakhapatnam
	Felt	Bangalore, Bhubaneshwar, Clcutta, and Kochi
Malaysia	V	Gelugor Estate
	IV	Sugai Ara
	III	Alor Setar, George Town, Kampong Tanjong Bunga, Kuala Lumpur, and Kulim
Thailand	V	Hat Yai
	IV	Bangkok
	III	Chiang Mei and Phuket
Myanmar	IV	Mandalay
	III	Rangoon
Singapore	II	Singapore
Bangladesh	III	Dhaka
	Felt	Chittagong
Sri Lanka	II	Kandy and in other parts of Sri Lanka
Maldives	IV	Male (nearly 2,500 km from the epicenter)
Guam	Felt	In a high rise building at Hagatna (more than 5,400 km from the epicenter)

Figure 2.7 : The cities effected by the earthquake

Source: Carl and John, 2007

2.3 INTRODUCTION TO STORAGE TANK

Storage tank is a container that had been design to hold liquids or compressed gases. It can be found in various shapes usually in cylindrical shape. It also can be design either on the ground or overhead. This paper is focus on the elevated water tank. The water tank design under the ground usually stores a large amount of water. Meanwhile, the elevated water tank store an amount of water that will directly distribute to the citizen by the gravity or pump system.

2.3.1 TYPE OF WATER TANK

As we know water tank is design to distribute water to citizen. There are three types of water tank which are resting on ground, underground and elevated. The water tank can be design in various shapes:

i) Cylindrical tanks
ii) Rectangular tanks
iii) Circular tanks with conical bottom

I) Cylindrical Tank

The cylindrical tank usually designs to restrain large capacity of the pressure from the water. There are two types of cylindrical tank engineer used to design which are a cylindrical tank on braced column and a cylindrical tank on shaft. For cylindrical tank on shaft sometimes it will design with separated column based on the condition and location of tank's building. The shaft and braced column structure is design to support the load from the cylindrical tank.

Figure 2.8 : Cylindrical water tank on braced column in Bandar Bestari, Selangor. Sources: perinagasetia.com [Online image]. (2016). Retrieved December 04, 2016 from http://perinagasetia.com/galleries/1177626-project-bandar-bestari-water-tank

Figure 2.9 : Cylindrical tank on shaft with separated column in Puchong Hartamas, Selangor.

Sources: perinagasetia.com [Online image]. (2016). Retrieved December 04, 2016 from http://perinagasetia.com/galleries/672939-completed-project?page=2

II) Rectangular Tank

Rectangular water tank is used when the capacity of the water is small. The rectangular water tank must be in square on plan view.

Figure 2.10 : Rectangular water tank in Ampang Saujana, Selangor.
Sources: perinagasetia.com [Online image]. (2016). Retrieved December 04, 2016 from http://perinagasetia.com/galleries?page=7

III) Circular Tank with Conical Bottom

The circular tank with conical bottom is quite used design in construction as the tank have advantages in emptying the tank as the flow of the water is greater than the normal circular tank. Furthermore, the high of the tank structure can be design with lower height for the same containing volume of cylindrical shape.

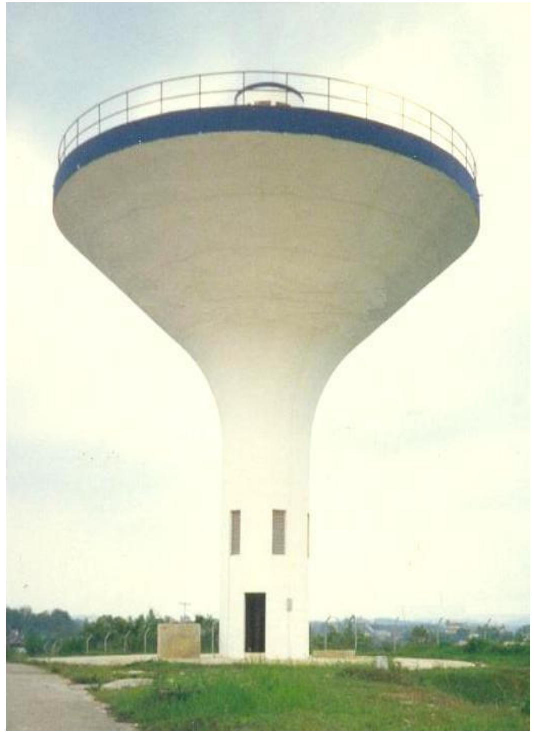

Figure 2.11 : Circular tank with conical bottom.
Sources: perinagasetia.com [Online image]. (2016). Retrieved December 04, 2016 from http://perinagasetia.com/galleries?page=7

2.3.1 ISSUES ON EARTHQUAKE EFFECTS

Earthquake can vigorously damage the structure whether totally collapsed or severely damage. The elevated water tank is a structure that important in town cities where the citizen would receive water supply from that. Their safety performance is a critical concern during strong earthquake. (Soroushina et al., 2011). There are several examples of the earthquake effects on the structure had happened before:

i. Shear failure modes in beams

It were happened in Chile, South America in May 1960 and Bhuj, India in January 2001 with a magnitude of M= 8.5 and M= 7.7 respectively. This type of failure occurred due to the high shear force at the end of the beams.

Figure 2.12 : Elevated water tank, 1960, Chile Earthquake

Sources: Pacific Earthquake Engineering Research Center (PEER)

Figure 2.13 (a) - Collapsed slender and weak framed staging of water tanks in Manfera Village; **Figure 2.13(b)** - Severe damage occurred to elevated water tanks in Bhachau

Source: C Rai, 2003

ii. Bending shear failure in beams

This type of failure occurred when middle section of beam failed and cracked.

Figure 2.14 : Elevated water tank in Chile earthquake, 1960

Source: Pacific Earthquake Engineering Research Center (PEER)

iii. Axial failure in columns

This type of failure occurred at the column element where a vertical crack happened due to compressive large force.

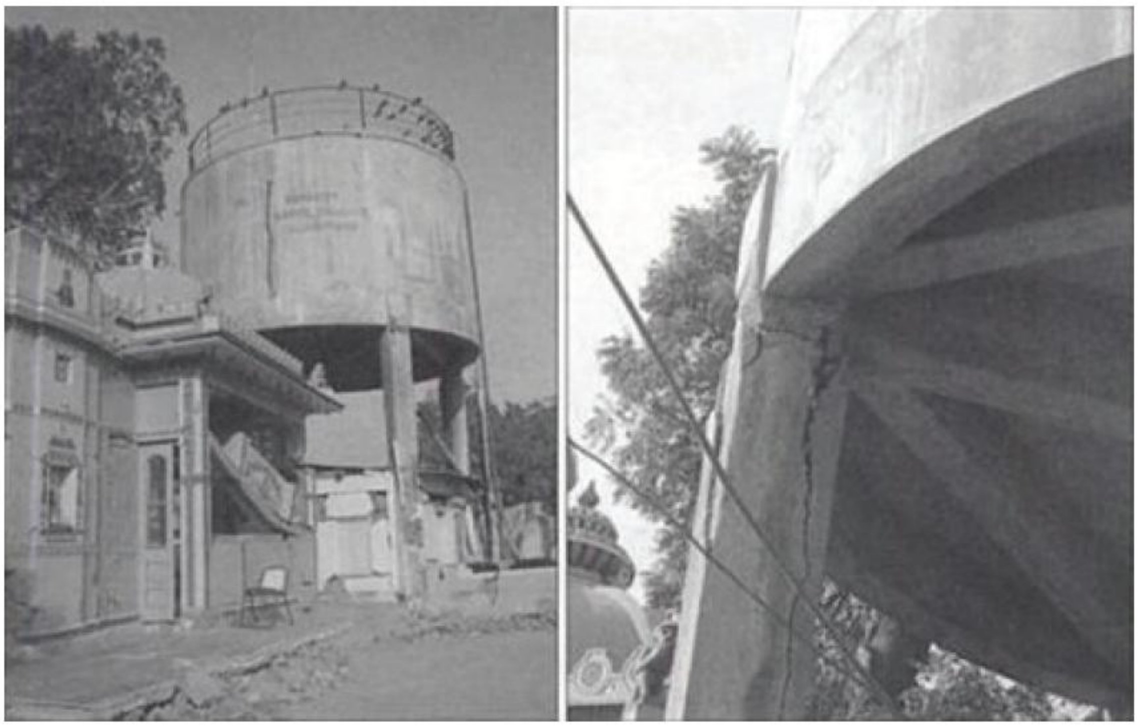

Figure 2.15 : Elevated water tank in Gujarat, India

Source: Eidinger, 2001

2.4 INTRODUCTION TO SAP2000 SOFTWARE

SAP2000 software is a Structural Analysis Program that used to analyze and design any structural system. The software provided 2D to 3D model of structure. The programs in SAP2000 software is including the analysis in loading such as seismic, wind, vehicle and waves which can be generated to structure. Besides, SAP2000 is the first finite element program created where we can obtain the outputs such as model response, displacement, bending moment and shear. Moreover, it strongly useable in this research study which we need to do the analysis related to time history and seismic load.

2.5 SUMMARY

Earthquake event occurred when the tectonic plates released from underneath of earth. It caused by the sudden slips that happened in the Earth’s crust. When the earthquake happened, the seismic waves move in all directions and there were two types of the seismic waves which are body waves and surface waves. The strength or size of earthquake can be determined by the magnitude scale where the largest magnitude is 9 meanwhile the smallest magnitude is 1. In this research, the structure that will be analyzed is storage tank which is elevated water tank. The elevated water tank usually used to store water that later will be distributed to the citizen. It will be analyze with the Acheh earthquake data. The analysis of the model will be conducted by using computer software which is SAP2000.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter, we will discuss the process to analysis research study. Method that will be used to analyze the elevated water tank structure is by using software SAP2000. SAP2000 has been known with specialty in analysing a structure in term seismic performance. All the steps involve in this research is listed in this chapter. The analysis will include the behavior of the structure, time history and spectrum analysis. The time history is the data of Acheh Earthquake obtained from the Malaysian Meteorological Department. The results of the analysis is obtained and discussed in detail in the next chapter. The **Figure 3.1** behind showed the flow chart on how the analysis is going to be run by using software, SAP2000.

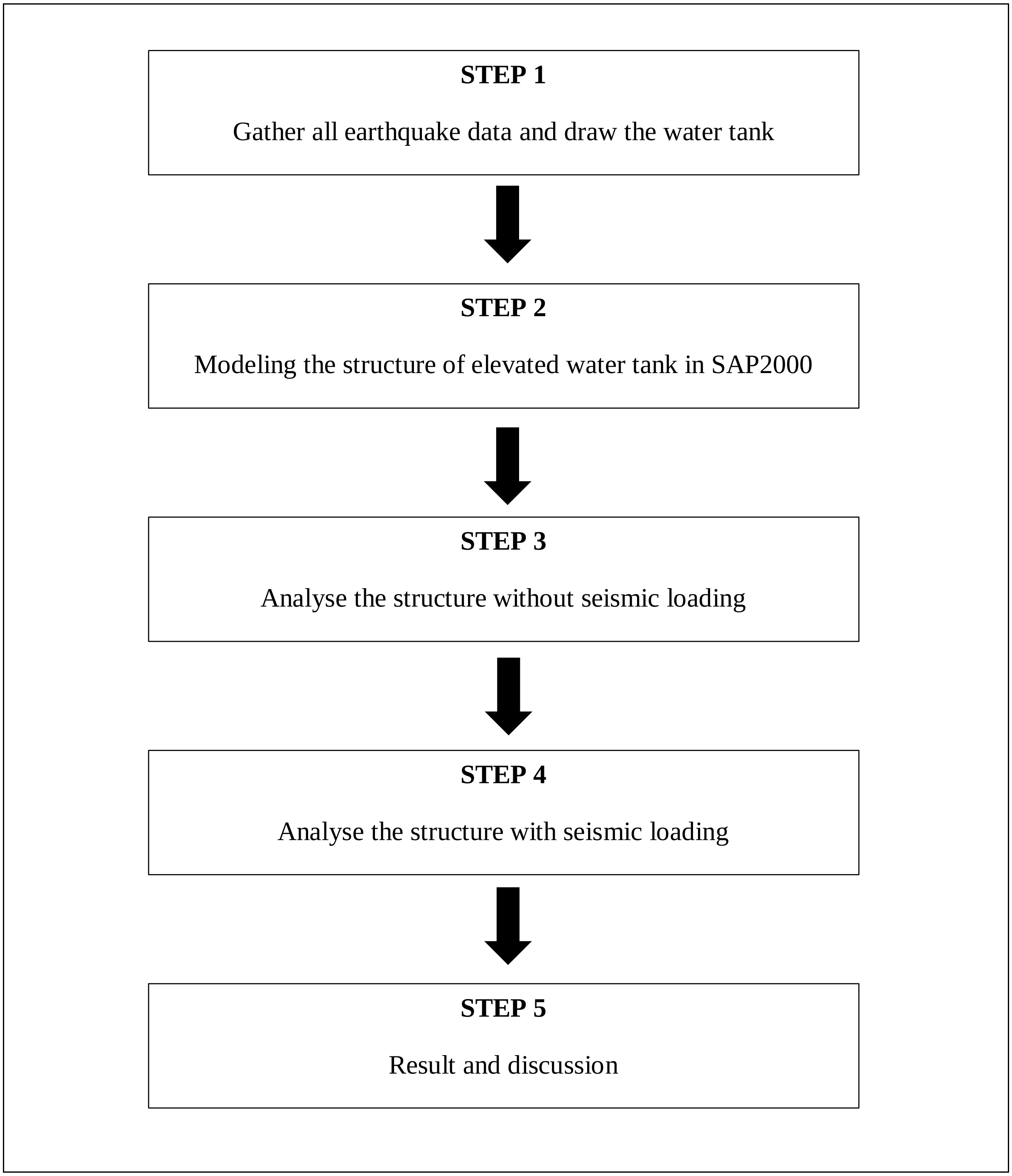

Figure 3.1 : Flow chart of methodology

3.2 GATHERING INFORMATION AND DATA

During this phase, the important information and data for modeling and analyzing the structure need to be obtained so that the research study will go smoothly. The information and data needed are as follow:

i. Location of the case study of the elevated water tank. The design used for the analysis is one of elevated water tank design from UITM campus.

ii. Drawing of the elevated water tank. The drawing contained the details of the design such as the height of the elevated water tank, the diameter of water tank and the capacity of the water tank.

iii. Material used for the structure of elevated water tank. For this analysis, the materials used for the structure is reinforced concrete (RC).

iv. Earthquake data for seismic analysis. The earthquake data used in this research is from the Acheh Earthquake that occurred in 2004. The data is acquired from the Malaysian Meteorological Department.

3.3 STEP ANALYSIS IN SAP2000 PROGRAM

Step 1: Define the model type

The storage structures model type is selected as the elevated water tank is one of the storage structure types.

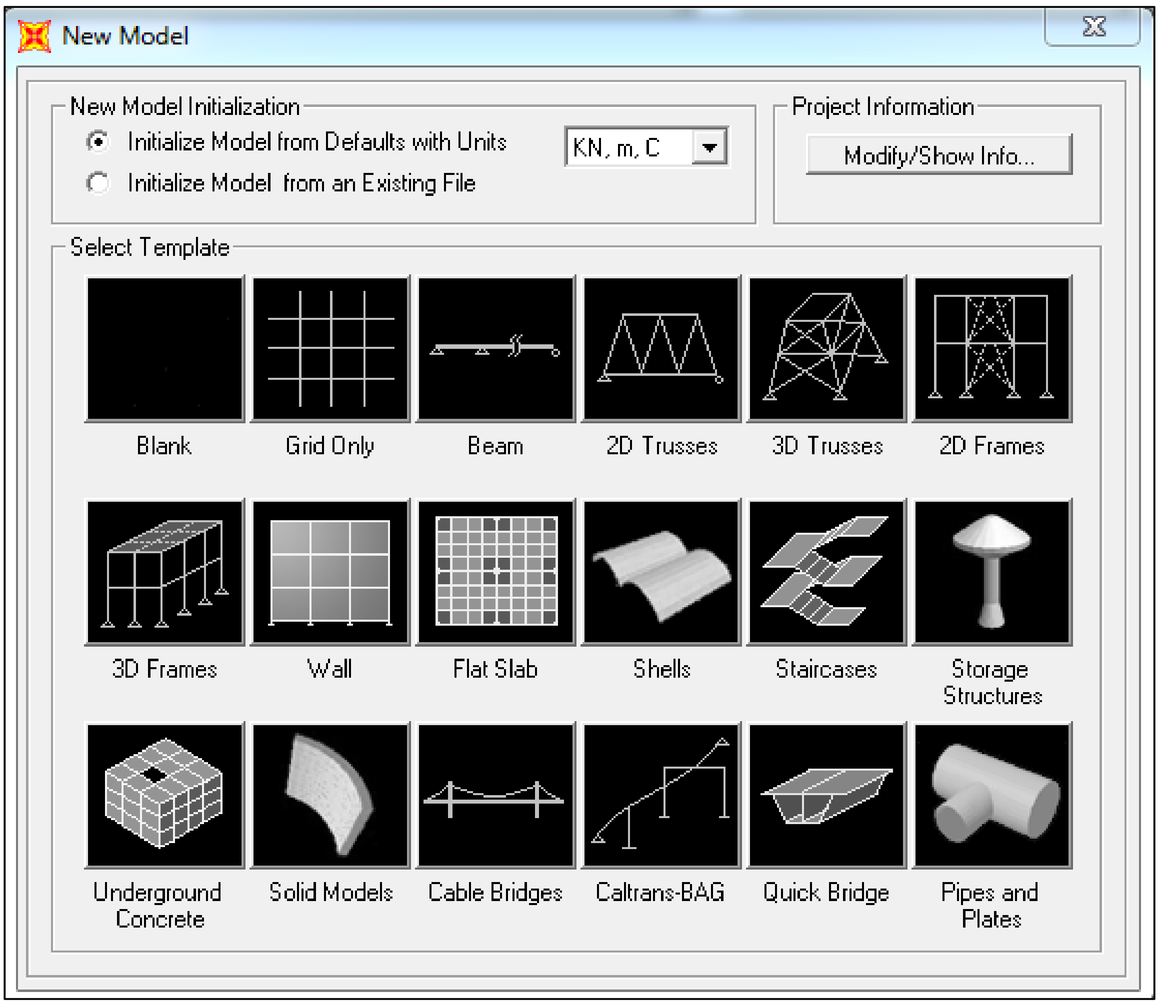

Figure 3.2 : Select the structure model type

Step 2: Determine the 3D on the workspace

Insert all the grids to allocate the frame element accordingly to the drawing. The design of the elevated water tank is from one of elevated water tank of UITM campus. The details of the design of the elevated water tank are as below:

- Height of the elevated water tank = 30m
- Diameter of the water tank = 16m
- Height of the water tank = 9m

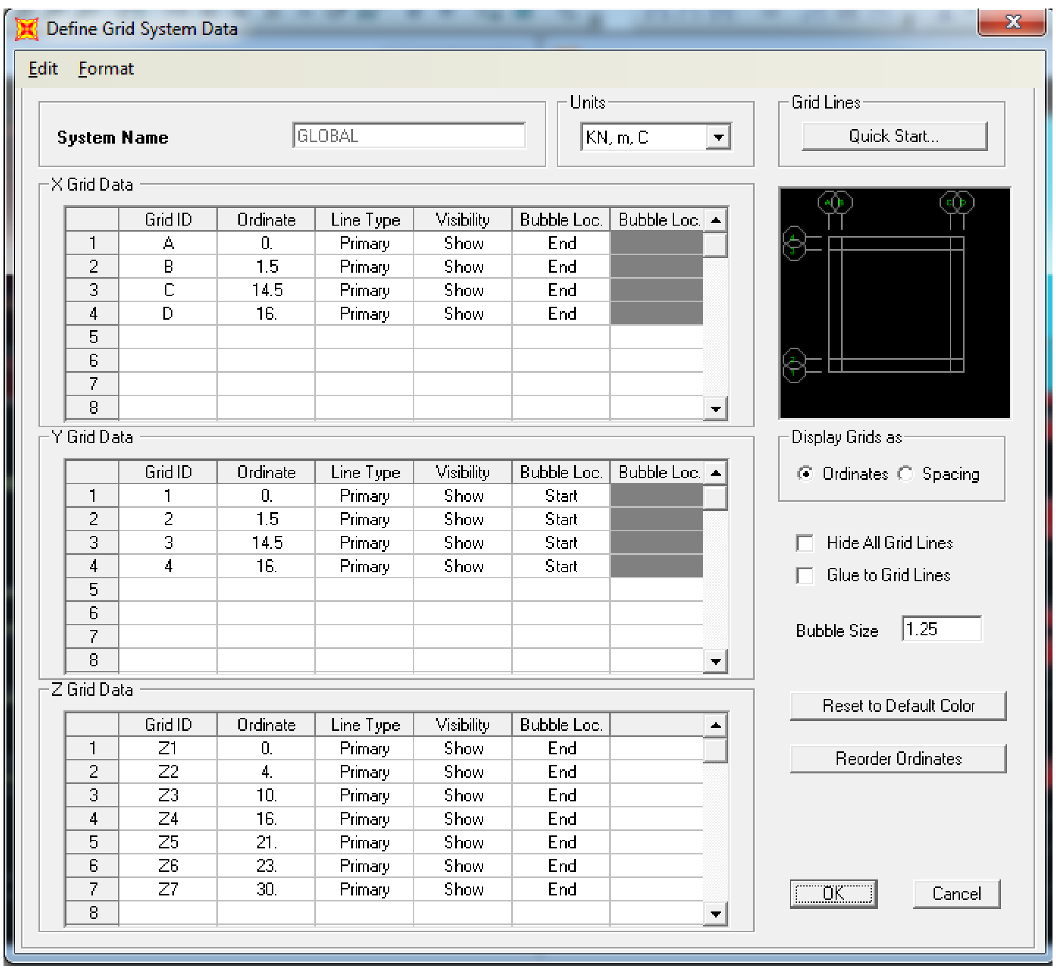

Figure 3.3: Define grid system data

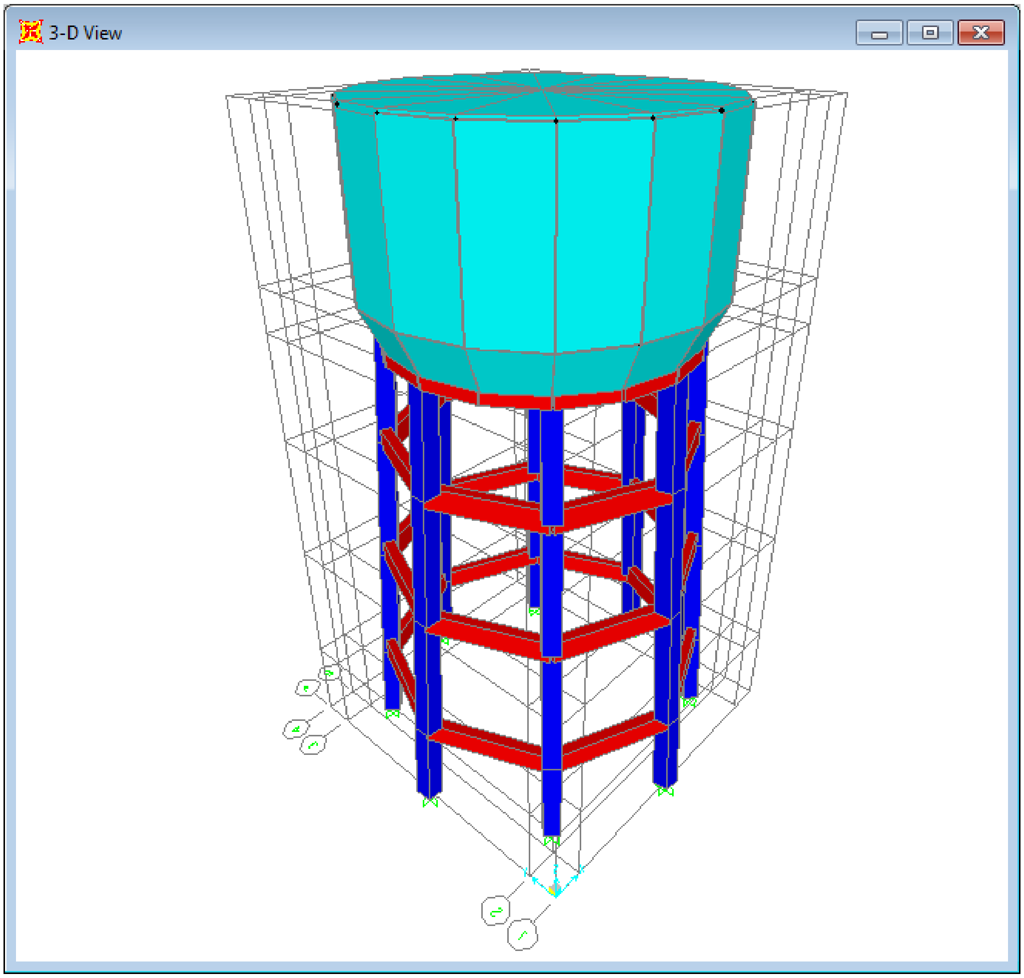

Figure 3.4: 3D view of the structure elevated water tank

Step 3: Add Restrain

Select all joint and add joint restraint.

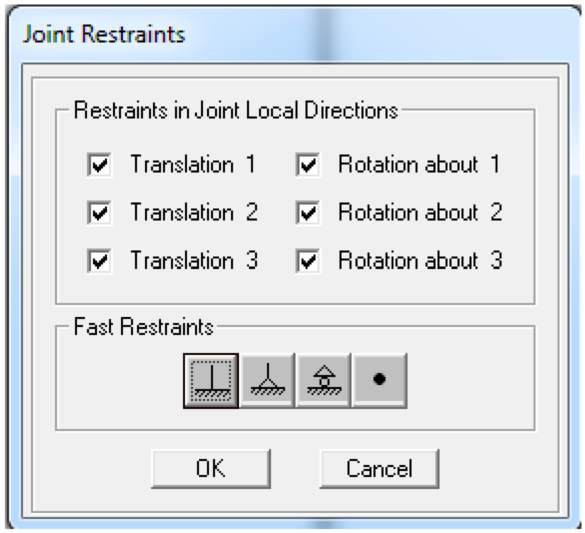

Figure 3.5: Add joint restraints

Step 4: Define the load cases

The load cases included in the analysis are dead load, live load, and earthquake load.

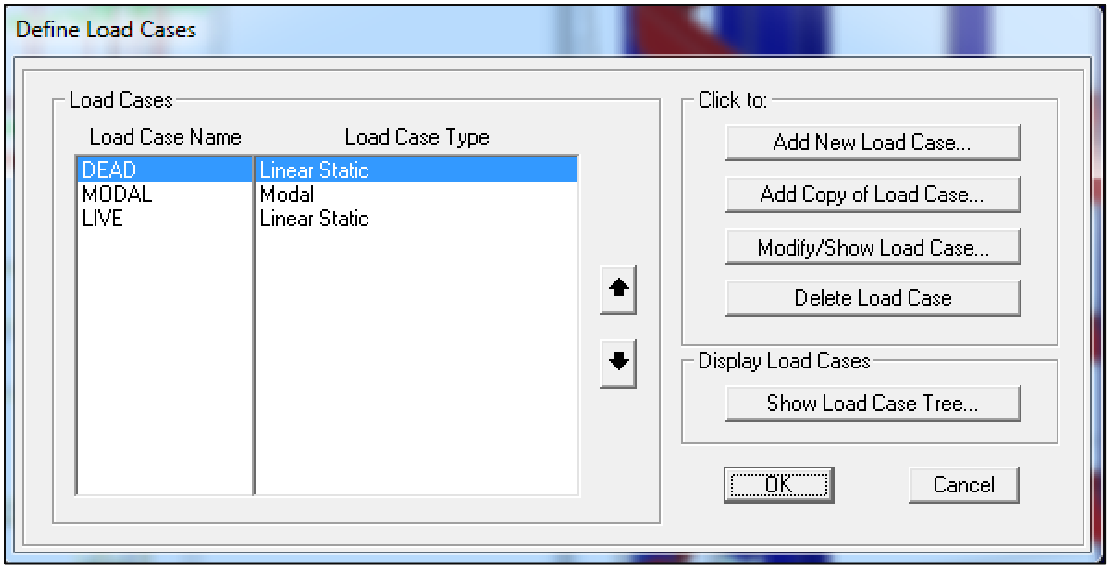

Figure 3.6 : Define load cases

STEP 5 : Define the time history

The earthquake data used in this research is from Acheh earthquake which occurred in 2004. The earthquake data is earned from the Malaysian Meteorological Department.

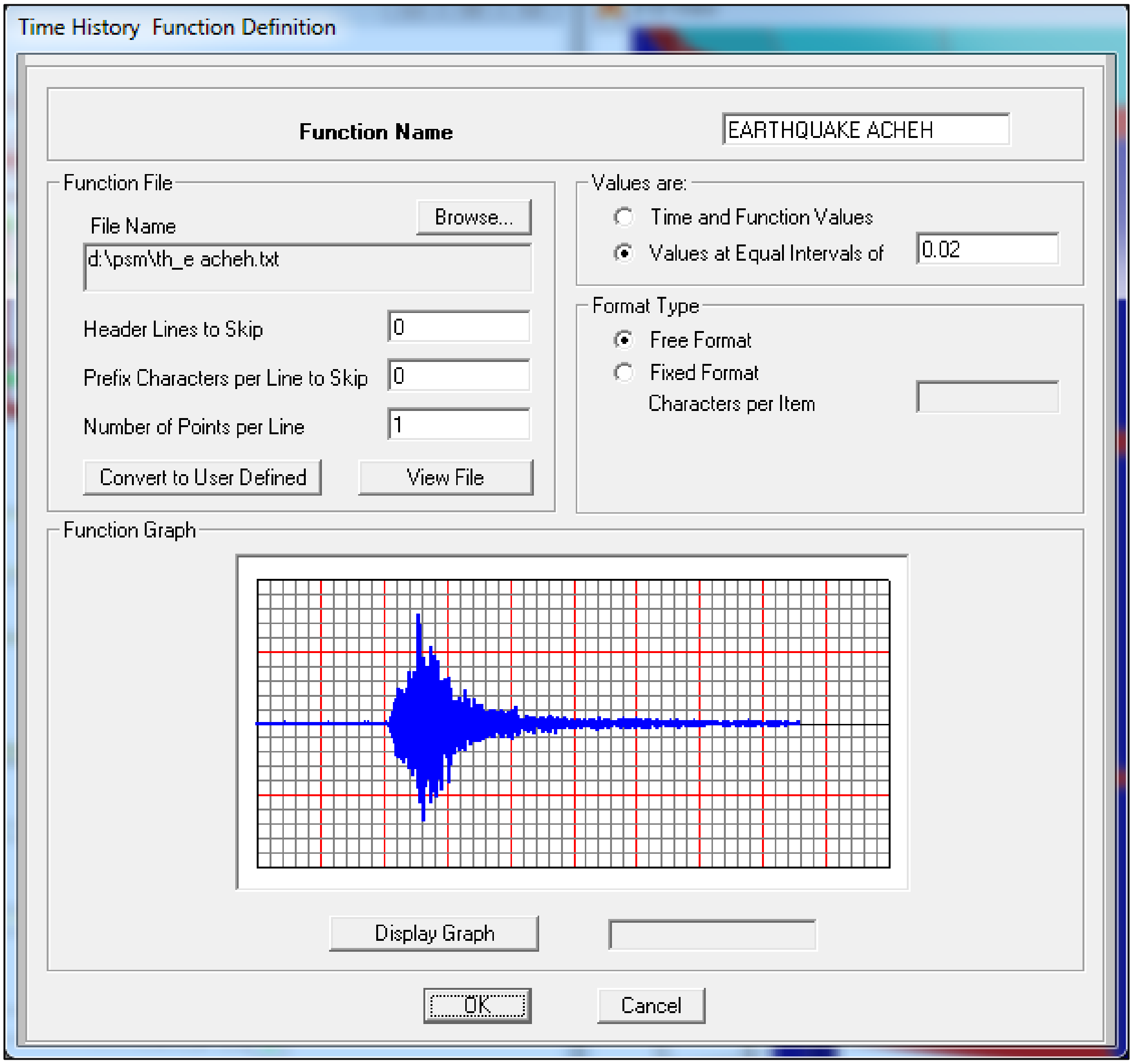

Figure 3.7 : Time history function (SAP2000)

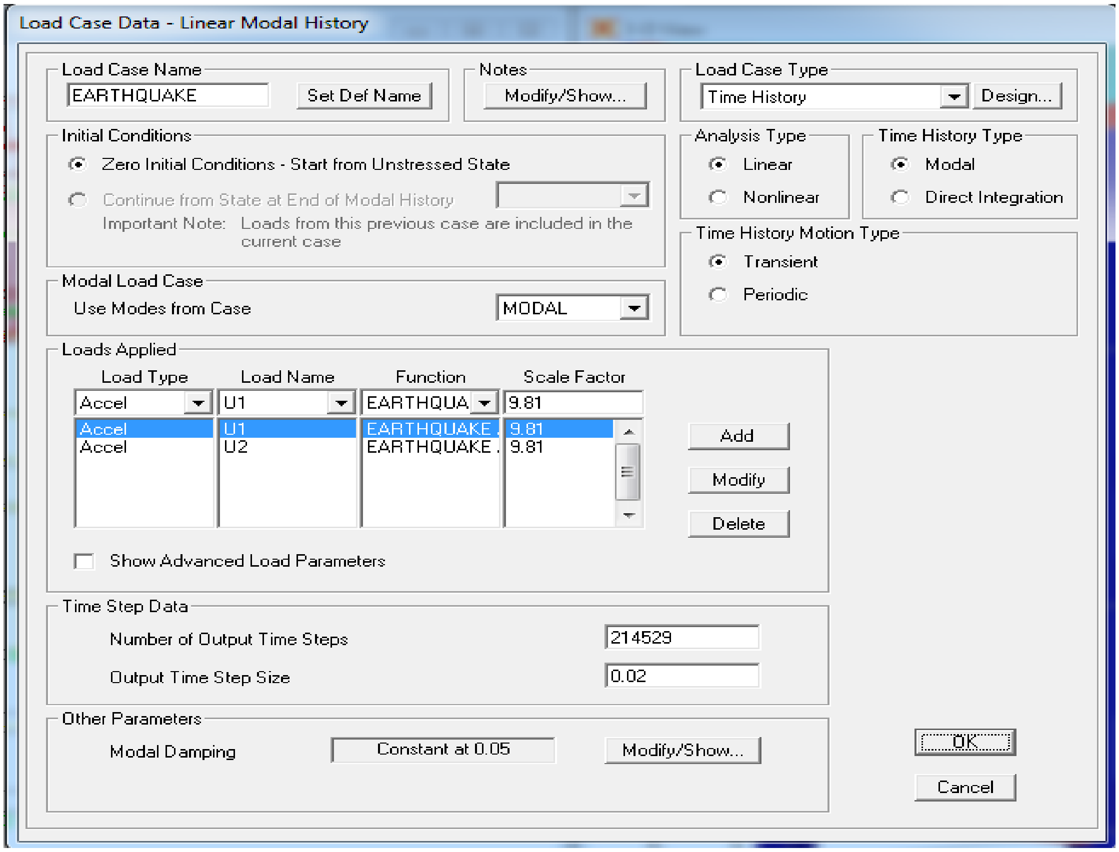

Figure 3.8 : Define load case data for modal time history

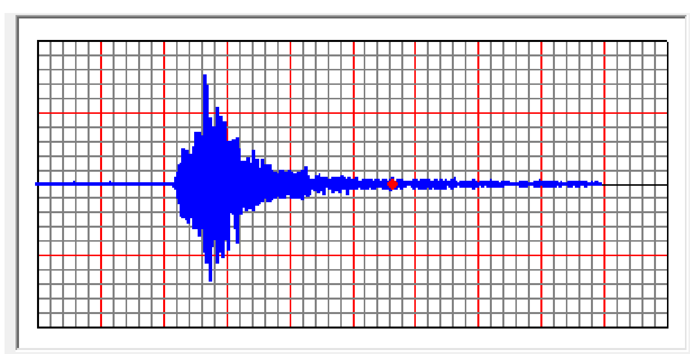

Figure 3.9 : The time history from Acheh earthquake. (SAP2000)

STEP 6 : Run the analysis

There are three load cases combination for this concrete elevated water tank.

i) Modal analysis

Select the modal case and run the analysis.

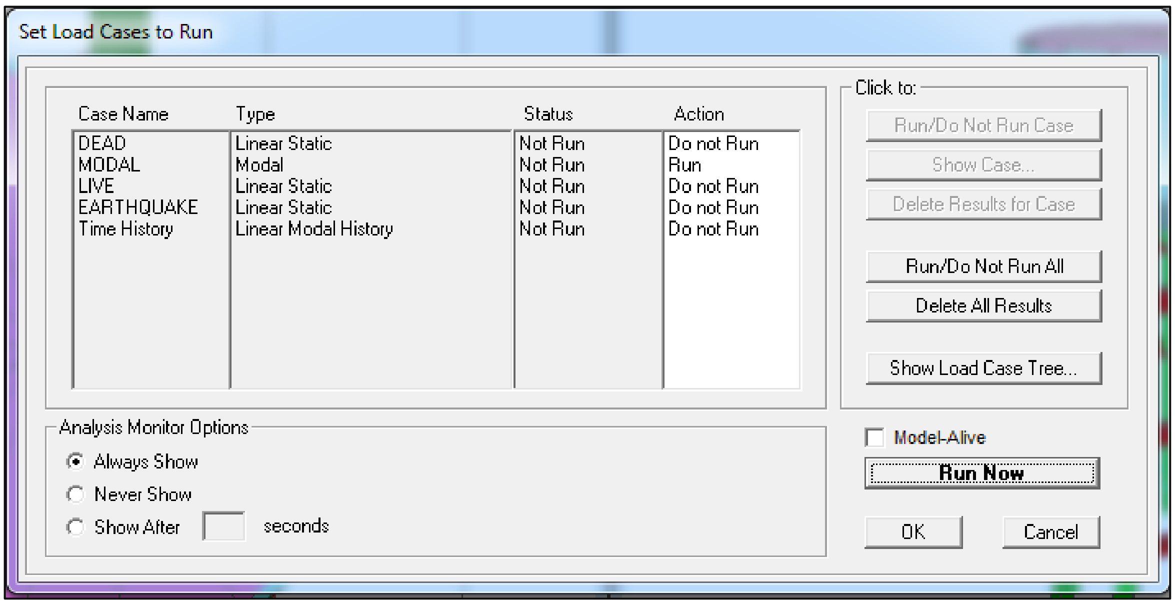

Figure 3.10 : Run the modal case (SAP2000)

ii) Dead Load + Live Load analysis

Select the dead case and live case modal to run as a set of load cases combination.

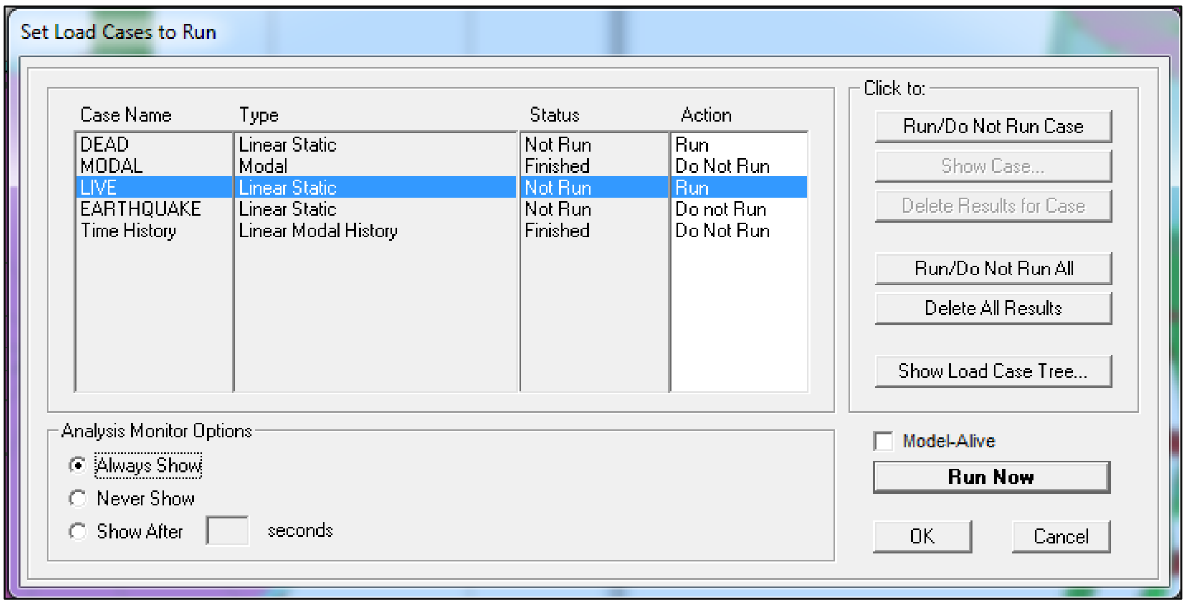

Figure 3.11 : Analyse the dead and live cases (SAP2000)

iii) Dead Load, Live Load and Earthquake Load

Select the dead case, live case and earthquake loading case to run as the set of load cases combination.

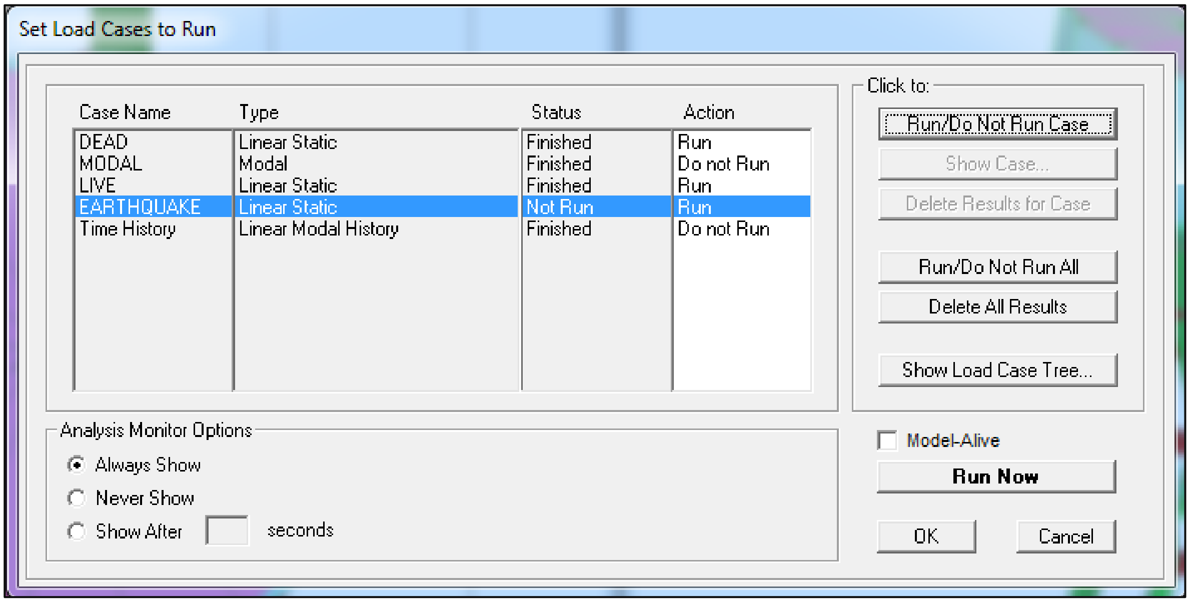

Figure 3.12 : Analyse the dead load, live load and earthquake loading. (SAP2000)

3.4 SUMMARY

In a nutshell, this chapter explained the step used in this research which using the computer software, SAP2000. Before the analysis is conducted, the model of the structure of the elevated water tank is constructed. The design of the elevated water tank is from one of elevated water tank in UITM campus. Later, the earthquake data that used to analyze the structure is applied on the structure. After the analysis is run, all the objectives of the research can be determined.

CHAPTER 4

RESULT AND ANALYSIS

4.1 INTRODUCTION

This chapter will explain the analysis and result of elevated water tank under earthquake loading by using SAP2000 software.

4.2 ANALYSIS OF CONCRETE ELEVATED WATER TANK USING SAP2000 SOFTWARE

There are three types of load for the concrete elevated water tank which are dead load, live load and earthquake load. All the loads 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

4.2.1 Modal Analysis

The modal analysis will show the deformed shape, natural period and 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. But in majority cases, the first three modes are the most important for the structural analysis (Gioncu and Mazzolani, 2011).

The figures shown as follow containing the data and mode shape for the 12 mode of concrete elevated water tank:

Deformed shape: Mode 1

Period, T = 0.67189 s

Frequency, f = 1.48834 Hz

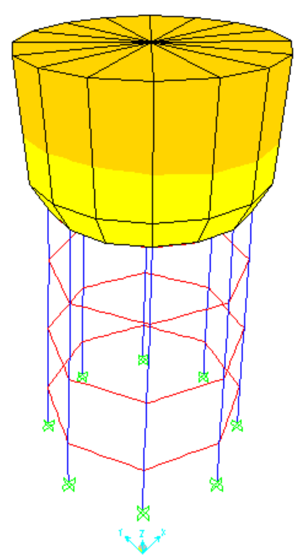

Figure 4.1: Mode shape 1

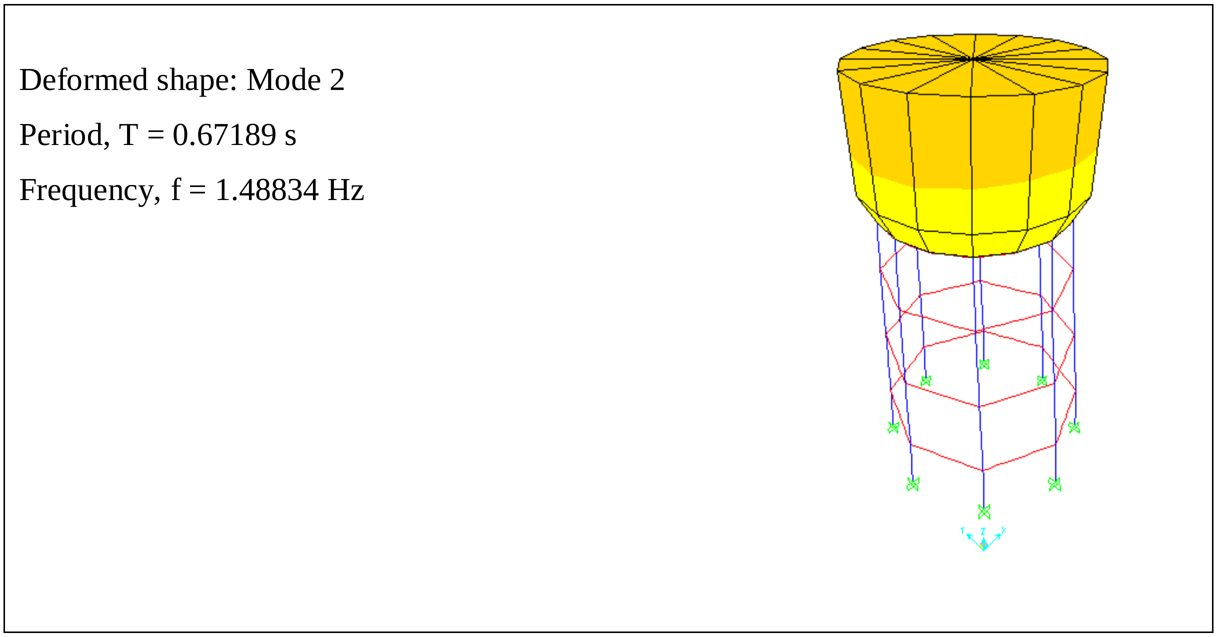

Figure 4.2: Mode shape 2

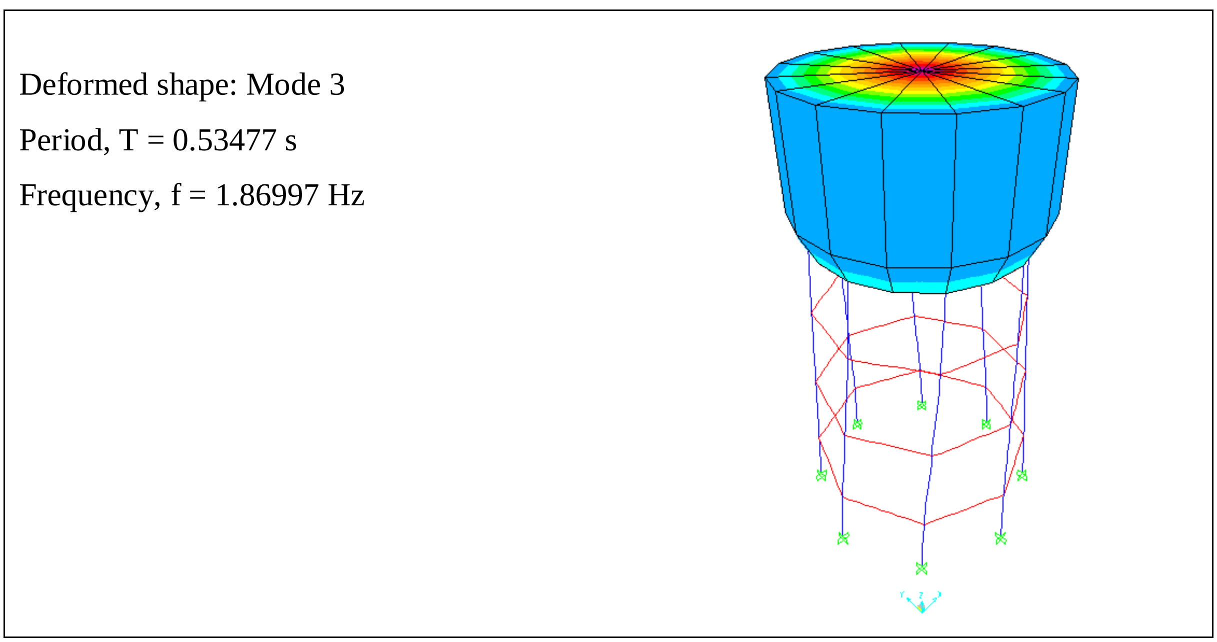

Figure 4.3: Mode shape 3

Deformed shape: Mode 4

Period, T = 0.50168 s

Frequency, f = 1.9330 Hz

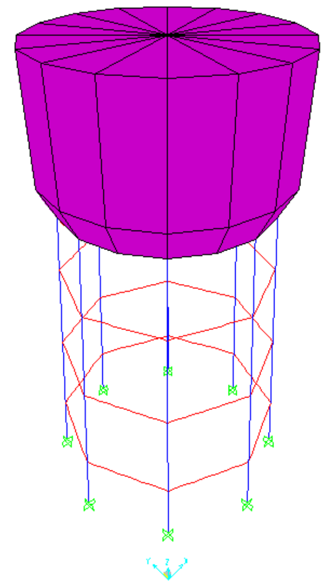

Figure 4.4: Modal shape 4

Deformed shape: Mode 5

Period, T = 0.50168 s

Frequency, f = 1.99330Hz

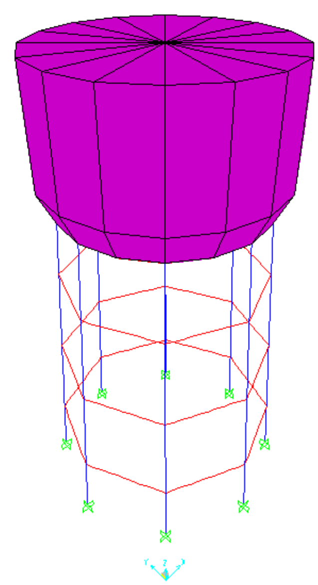

Figure 4.5: Mode shape 5

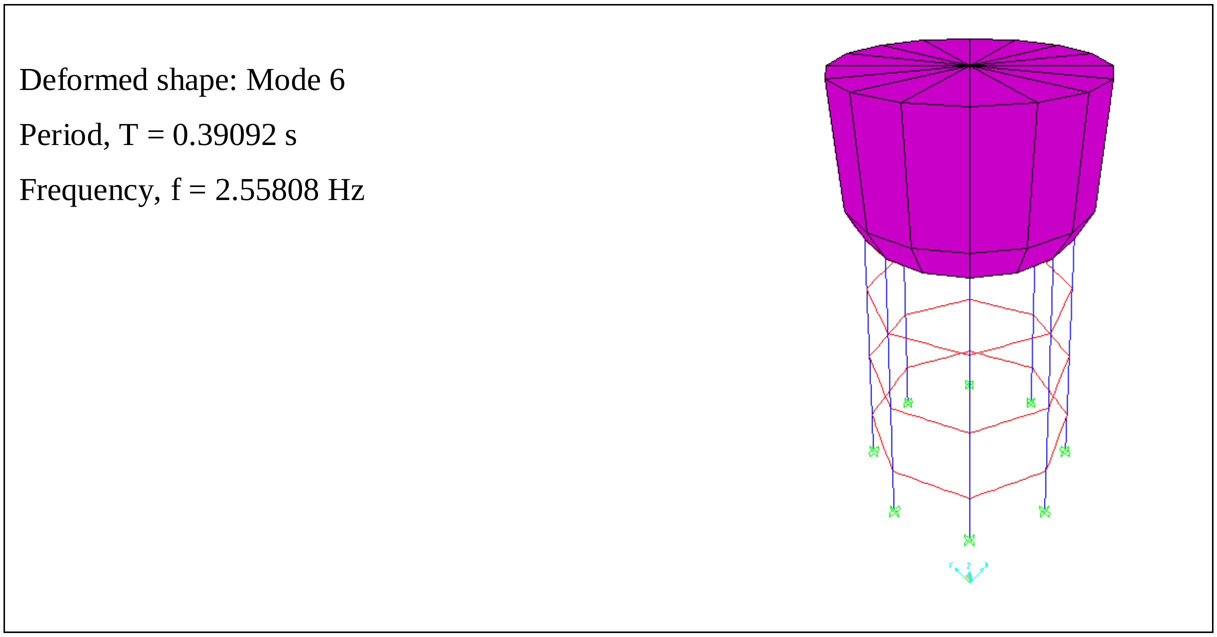

Figure 4.6: Mode shape 6

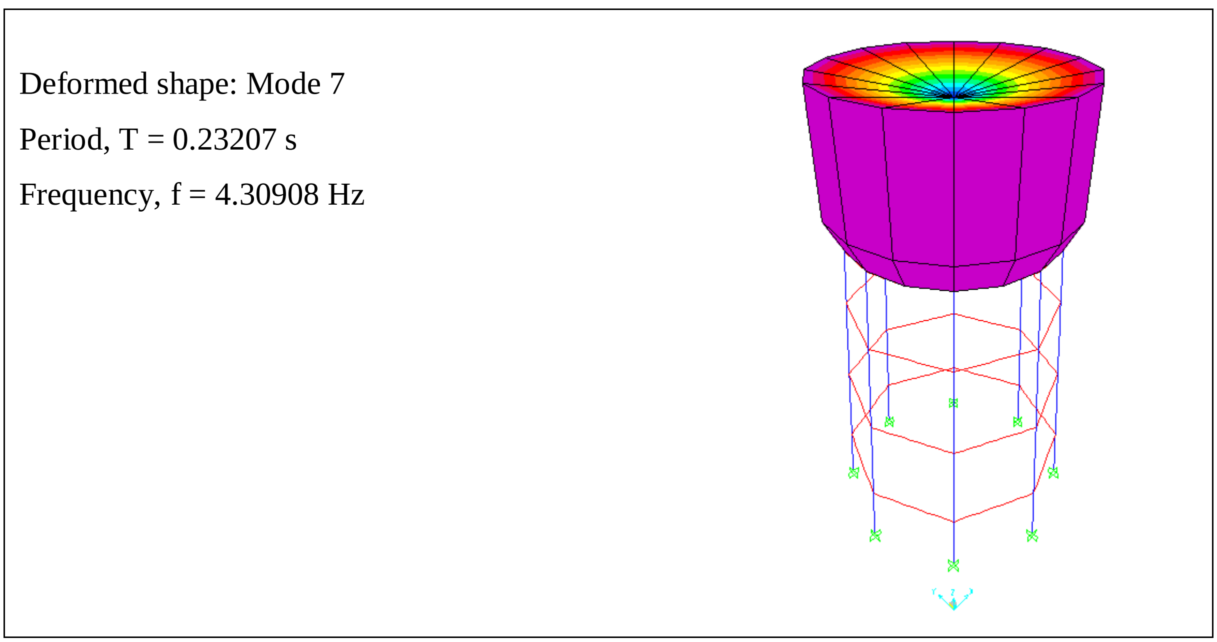

Figure 4.7: Mode shape 7

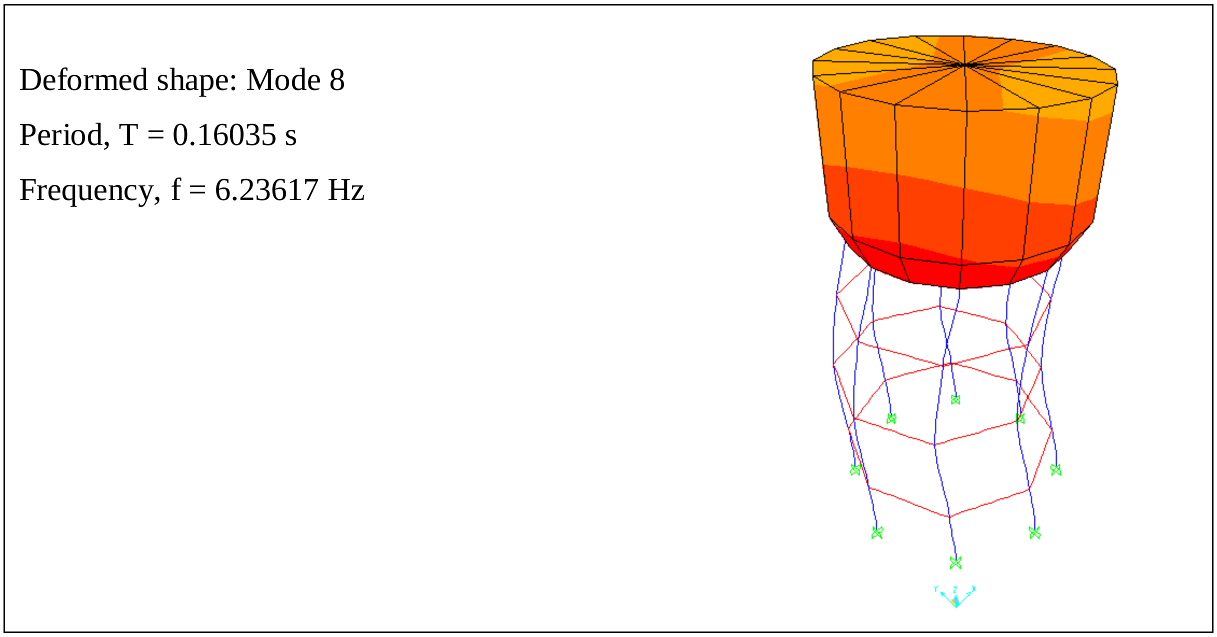

Figure 4.8: Mode shape 8

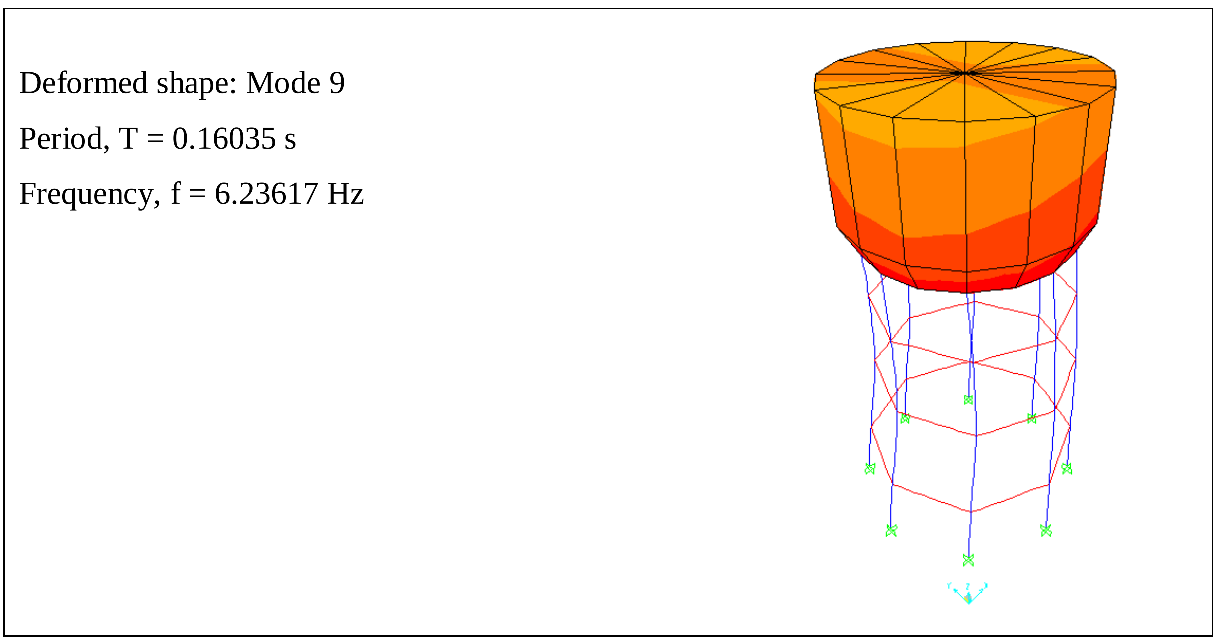

Figure 4.9: Mode shape 9

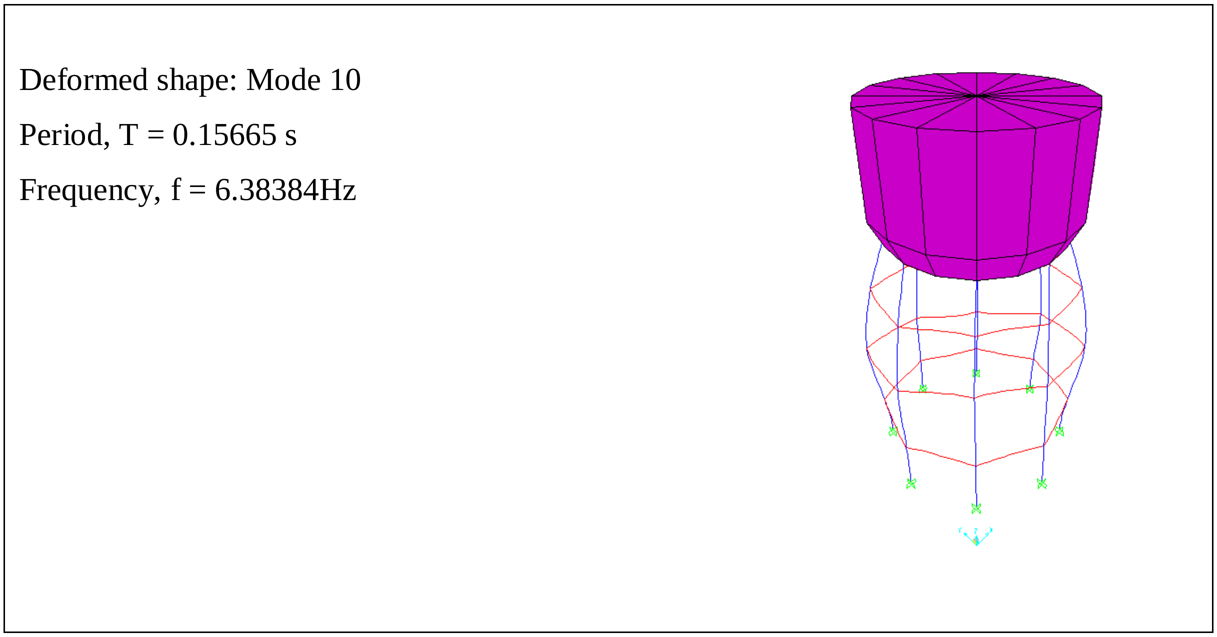

Figure 4.10: Mode shape 10

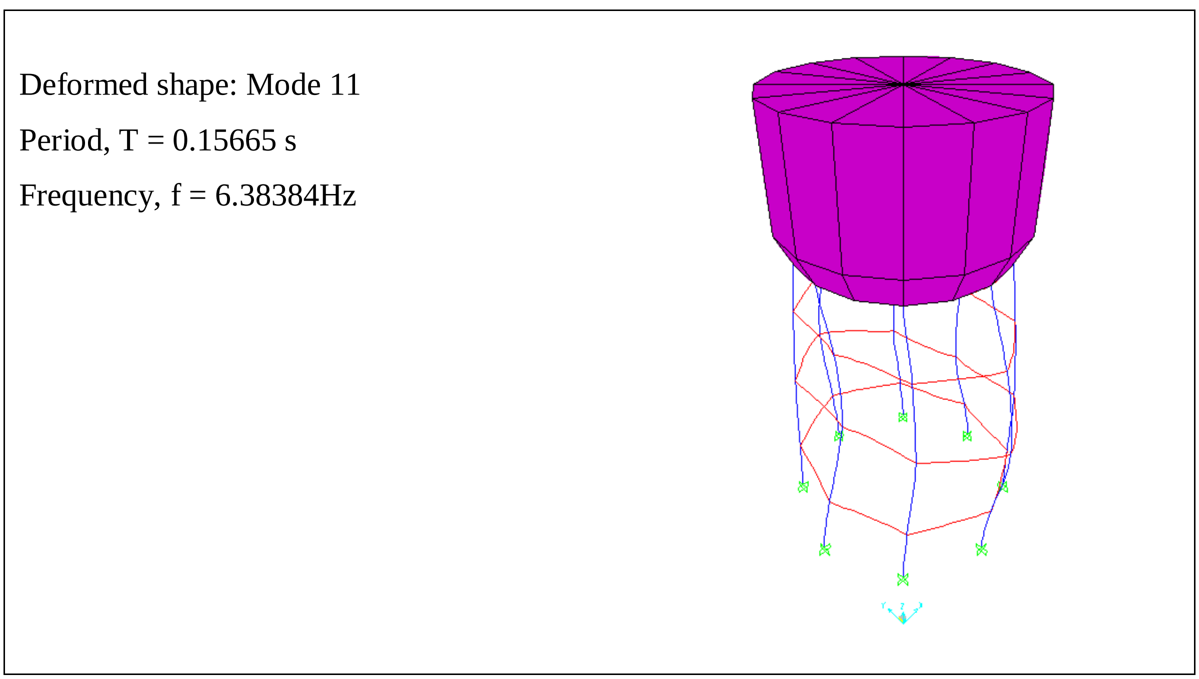

Figure 4.11: Mode shape 11

Deformed shape: Mode 12

Period, T = 0.12846 s

Frequency, f = 7.78428 Hz

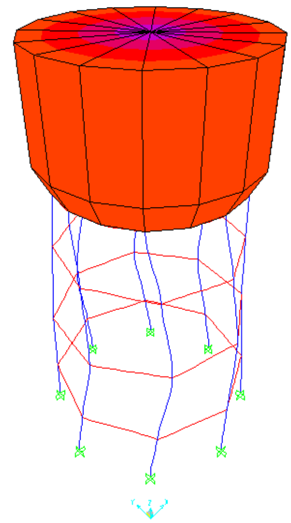

Figure 4.12: Mode shape 12

From the modal analysis, Modal Shape 1 have the lowest frequency and higher value of time period which are 1.488339 and 0.671890. Apparently, Modal Shape 2 have the same value of frequency and time period with modal shape 1. The modal shape 3 have the third highest frequency and time period which are 1.869966 and 0.534769.

The **Figure 4.13** as follow showed the modal case analysis data after the analysis on the structure is run.

```
CASE: MODAL

USING STIFFNESS AT ZERO (UNSTRESSED) INITIAL CONDITIONS

NUMBER OF STIFFNESS DEGREES OF FREEDOM    =          630
NUMBER OF MASS DEGREES OF FREEDOM         =          315
MAXIMUM NUMBER OF EIGEN MODES SOUGHT      =           12
MINIMUM NUMBER OF EIGEN MODES SOUGHT      =            1
NUMBER OF RESIDUAL-MASS MODES SOUGHT      =            0
NUMBER OF SUBSPACE VECTORS USED           =           24
RELATIVE CONVERGENCE TOLERANCE            =     1.00E-09

FREQUENCY SHIFT  (CENTER) (CYC/TIME)      =      .000000
FREQUENCY CUTOFF (RADIUS) (CYC/TIME)      =   -INFINITY-
ALLOW AUTOMATIC FREQUENCY SHIFTING        =          YES


Original stiffness at shift : EV= 0.0000000E+00, f=      .000000, T=  -INFINITY-
Number of eigenvalues below shift =       0
Found mode       1 of      12:  EV= 8.7450769E+01, f=     1.488339, T=     0.671890
Found mode       2 of      12:  EV= 8.7450769E+01, f=     1.488339, T=     0.671890
Found mode       3 of      12:  EV= 1.3804703E+02, f=     1.869966, T=     0.534769
Found mode       4 of      12:  EV= 1.5685769E+02, f=     1.993302, T=     0.501680
Found mode       5 of      12:  EV= 1.5685769E+02, f=     1.993302, T=     0.501680
Found mode       6 of      12:  EV= 2.5833834E+02, f=     2.558083, T=     0.390918
Found mode       7 of      12:  EV= 7.3304042E+02, f=     4.309075, T=     0.232068
Found mode       8 of      12:  EV= 1.5353065E+03, f=     6.236166, T=     0.160355
Found mode       9 of      12:  EV= 1.5353065E+03, f=     6.236166, T=     0.160355
Found mode      10 of      12:  EV= 1.6088797E+03, f=     6.383839, T=     0.156646
Found mode      11 of      12:  EV= 1.6088797E+03, f=     6.383839, T=     0.156646
Found mode      12 of      12:  EV= 2.3921979E+03, f=     7.784284, T=     0.128464

NUMBER OF EIGEN MODES FOUND               =           12
NUMBER OF ITERATIONS PERFORMED            =            8
NUMBER OF STIFFNESS SHIFTS                =            0
```

Figure 4.13 : Modal case analysis

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

The dead load and live load of the structure is being analyse in SAP2000. The dead load of the elevated water tank and water pressure from the tank is considered as dead load. The dead load of the elevated water tank is 3082.33 m^3 where the water tank contain 800 000 gallon. The live load of the elevated water tan is factored by 1.0.

The **Figure 4.14** as follow 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.

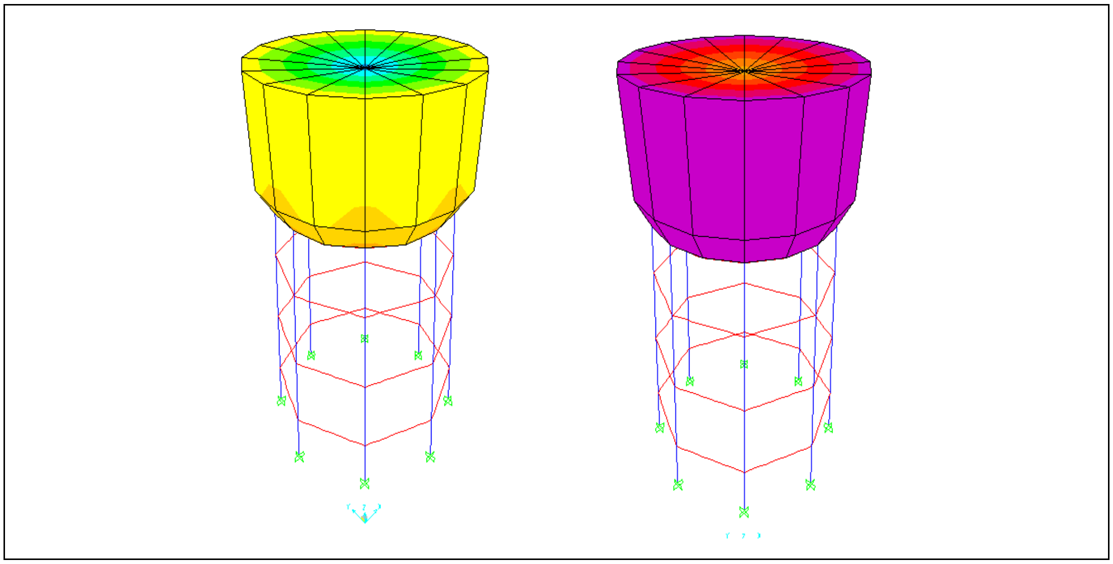

Figure 4.14: Deformed shape from the analysis of Dead Load and Live Load.

4.2.3 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 this analysis, the movement of ground motion earthquake will have the effect on the displacement and acceleration on the structure. Random joints on the structure are selected to show the result of the spectral displacement and acceleration of the joint.

The **Figure 4.15** below show the random joints selected on the elevated water tank.

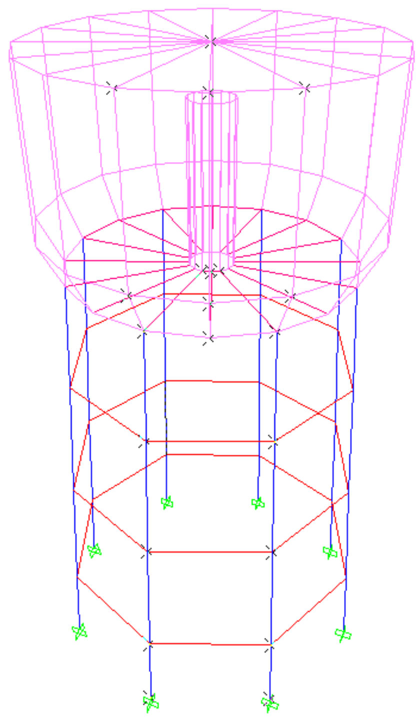

Figure 4.15: Screen capped of the joint selected on the elevated water tank. (SAP2000)

The figure below shows the displacement of the random joint of the elevated water tank. There are three displacement which are displacement on x-axis, displacement on y-axis and displacement on z-axis.

The **Figure 4.16** as follow shows the bar graph of the joint against the displacement occurred on the x-axis. The analysis show the greatest displacement on x-axis is at joint 30 which is 0.39057 m meanwhile the smallest displacement on x-axis is at joint 119 which is 0.018667 m.

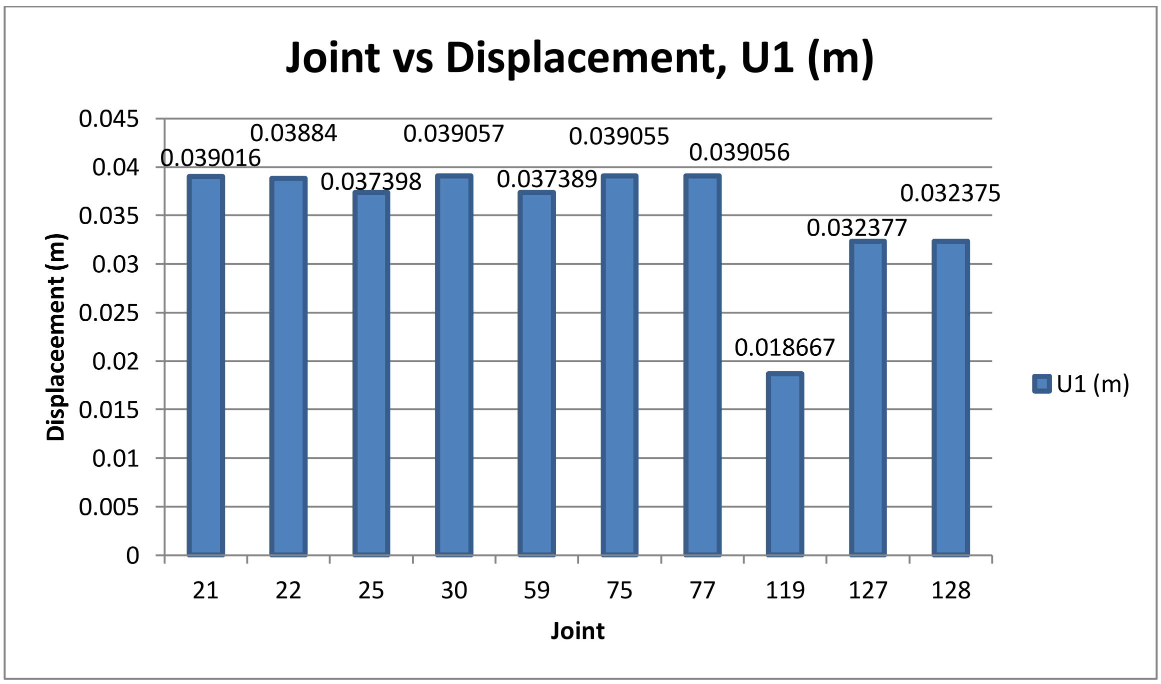

Figure 4.16: Bar graph of joint versus displacement at x-axis, U1(m)

The **Figure 4.17** below shows the bar graph of the joint against the displacement occurred on the y-axis. The analysis show the greatest displacement on y-axis is at joint 21 which is 0.004125 m meanwhile the smallest displacement on y-axis is at joint 119 which is 0.00197 m.

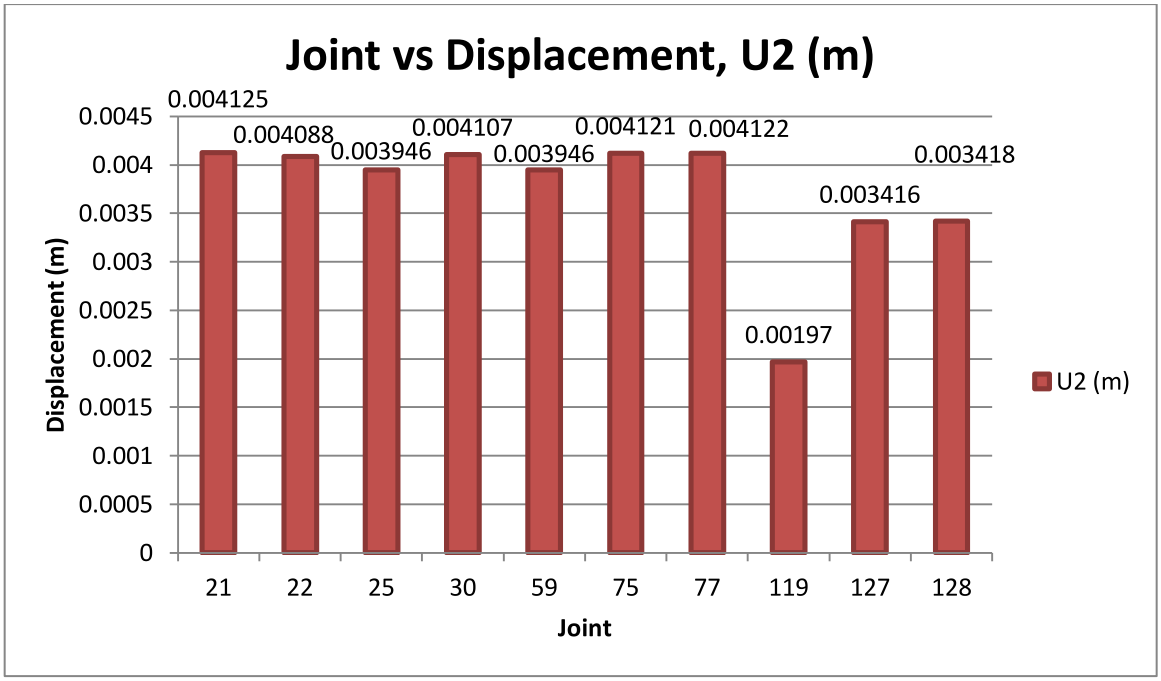

Figure 4.17: Bar graph of joint versus displacement at y-axis, U2(m)

The **Figure 4.18** below shows the bar graph of the joint against the displacement occurred on the z-axis. The analysis show the greatest displacement on z-axis is at joint 75 which is 0.005781 m meanwhile the smallest displacement on z-axis is at joint 25 which is 1.54×10^{-12} m.

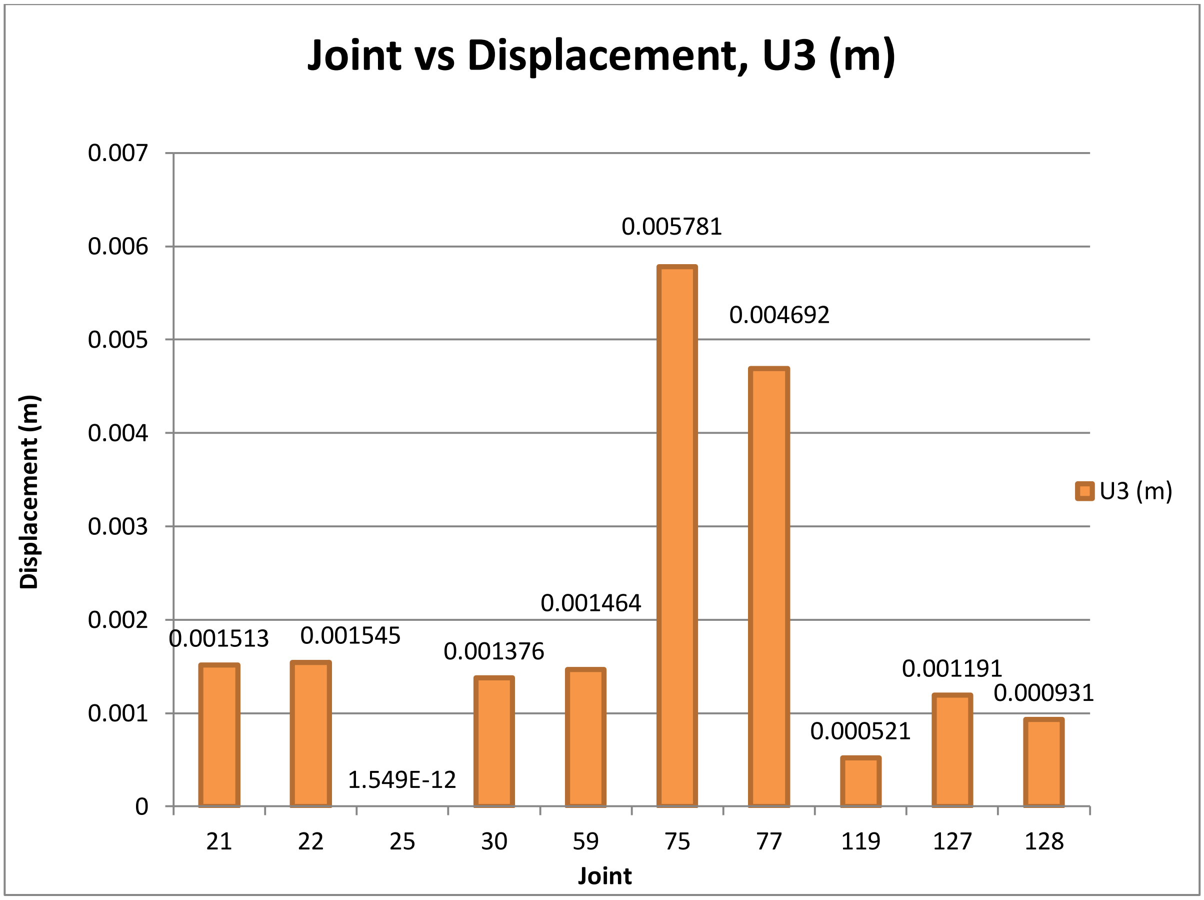

Figure 4.18: Bar graph of joint versus displacement at z-axis, U3(m)

The figure below shows the acceleration of the random joint of the elevated water tank. There are three acceleration which are acceleration on x-axis, acceleration y-axis and acceleration on z-axis.

The **Figure 4.19** below shows the bar graph of the joint against the acceleration occurred on the x-axis. The analysis show the greatest acceleration on x-axis is at joint 119 which is 94.21668 m/sec^2 meanwhile the smallest acceleration on x-axis is at joint 21 which is 13.49249 m/sec^2.

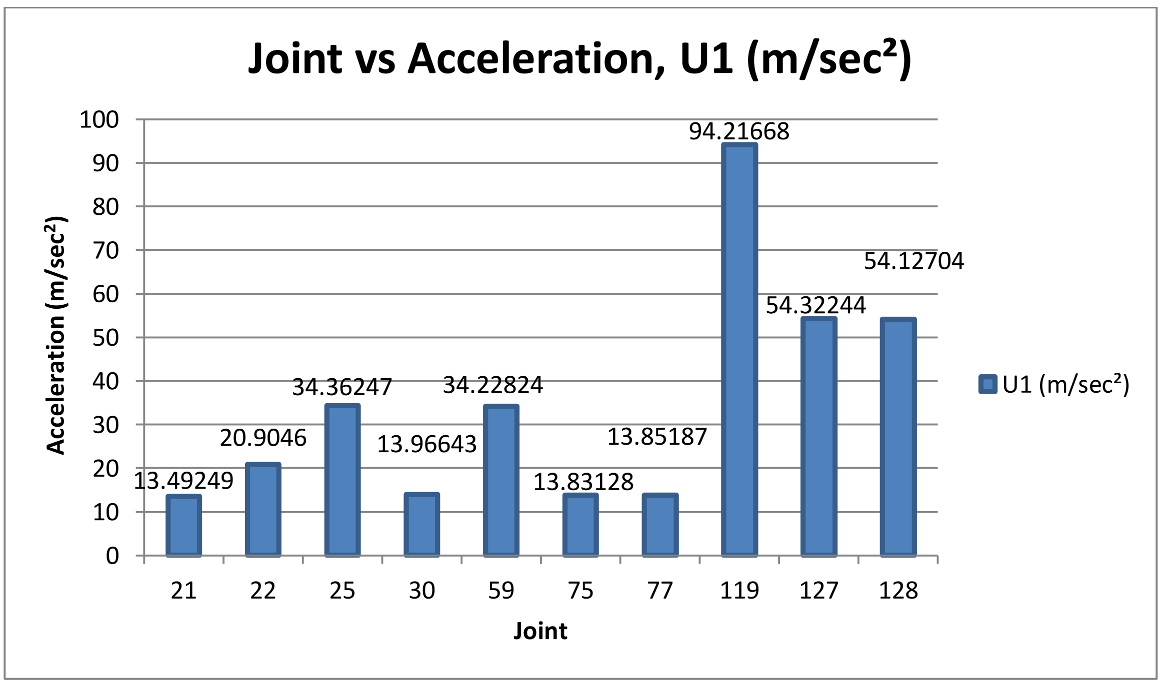

Figure 4.19: Bar graph of joint versus acceleration at x-axis, U1(m/sec^2)

The **Figure 4.20** below shows the bar graph of the joint against the acceleration occurred on the y-axis. The analysis show the greatest acceleration on y-axis is at joint 119 which is 41.64834 m/sec^2 meanwhile the smallest acceleration on y-axis is at joint 75 which is 6.155 m/sec^2.

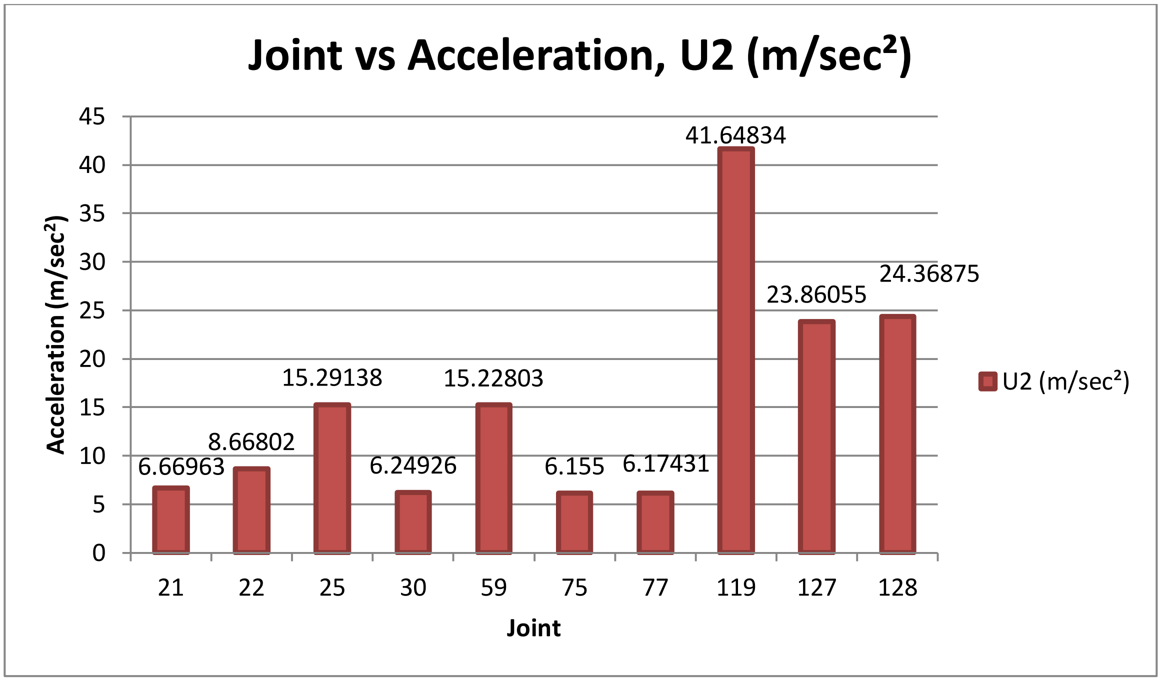

Figure 4.20: Bar graph of joint versus acceleration at y-axis, U2(m/sec^2)

The **Figure 4.21** below shows the bar graph of the joint against the acceleration occurred on the z-axis. The analysis show the greatest acceleration on z-axis is at joint 119 which is 15.95548 m/sec^2 meanwhile the smallest acceleration on z-axis is at joint 25 which is 6.362 x 10^{-7} m/sec^2.

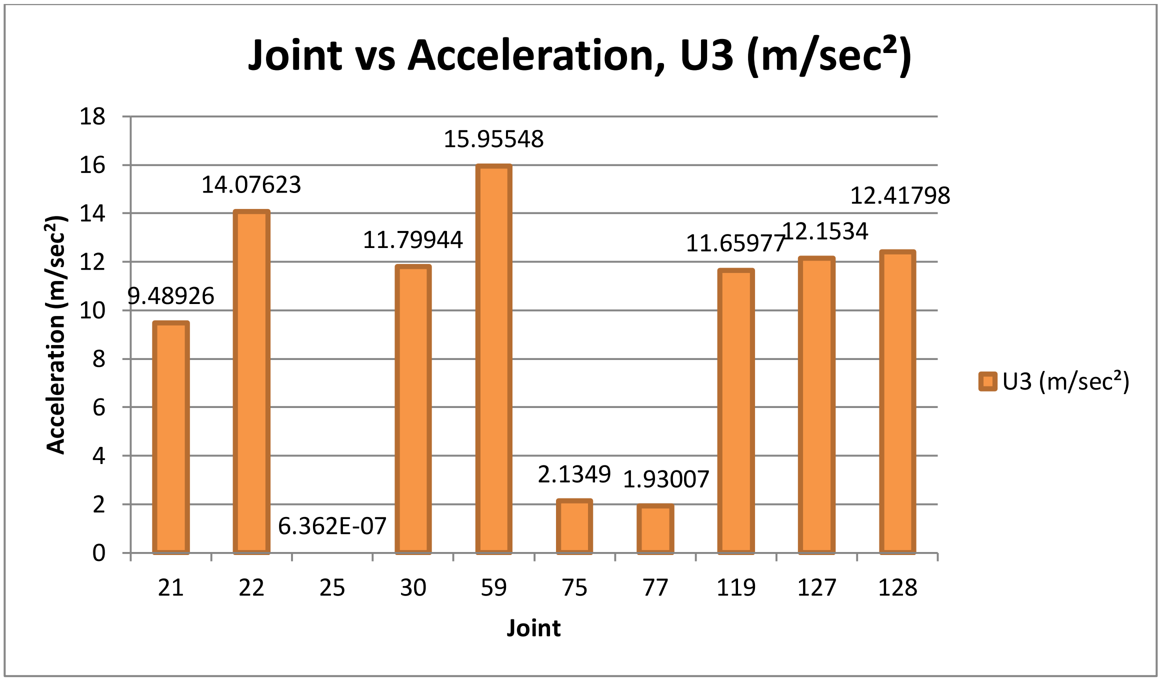

Figure 4.21: Bar graph of joint versus acceleration at z-axis, U3(m/sec^2)

Response spectrum illustrates the natural period and damping of the building on response to earthquake loading. The maximum value of spectral acceleration, velocity and displacement can be obtained based on the response spectrum plot. One joint have been selected as the average value of the displacement of the joint is the highest value. Recently, however, displacement-based design has attracted growing interest among engineers, because it is recognized that displacements describe in a more explicit way the structural response under seismic actions, compared to forces (Priestley, 1997, Tolis and Facciolo, 1991).

Table 4.1 showed the value of displacement of each joint. The highlighted text is the highest displacement among the joints. The joint selected to present the response spectrum curve is joint 75.

Table 4.1: Result of joint displacement for x, y and z axis in m.

Joint	U1	U2	U3	Average
21	0.039016	0.004125	0.001513	0.0148847
22	0.03884	0.004088	0.001545	0.0148243
25	0.037398	0.003946	1.549E-12	0.0137813
30	0.039057	0.004107	0.001376	0.0148467
59	0.037389	0.003946	0.001464	0.0142663
75	0.039055	0.004121	0.005781	0.016319
77	0.039056	0.004122	0.004692	0.0159567
119	0.018667	0.00197	0.000521	0.0070527
127	0.032377	0.003416	0.001191	0.012328
128	0.032375	0.003418	0.000931	0.0122413

Figure 4.22 showed the response spectrum of spectral acceleration in meanwhile **Figure 4.23** showed the response spectrum of spectral displacement. Damping curve show in the response spectrum depends on the materials used for the building. Damping occurred when there is motion in the internal friction within the building. Damping absorbs the earthquake energy and reduces resonance or the build-up of earthquake inertia forces so it is very beneficial (Gioncu and Mazzolani, 2011). Most building codes using damping of 5% which is damping 0.05, the critical damping. The value of spectral acceleration and the spectral displacement of joint 75 on the elevated water tank is 0.12 g and 16.0 g.

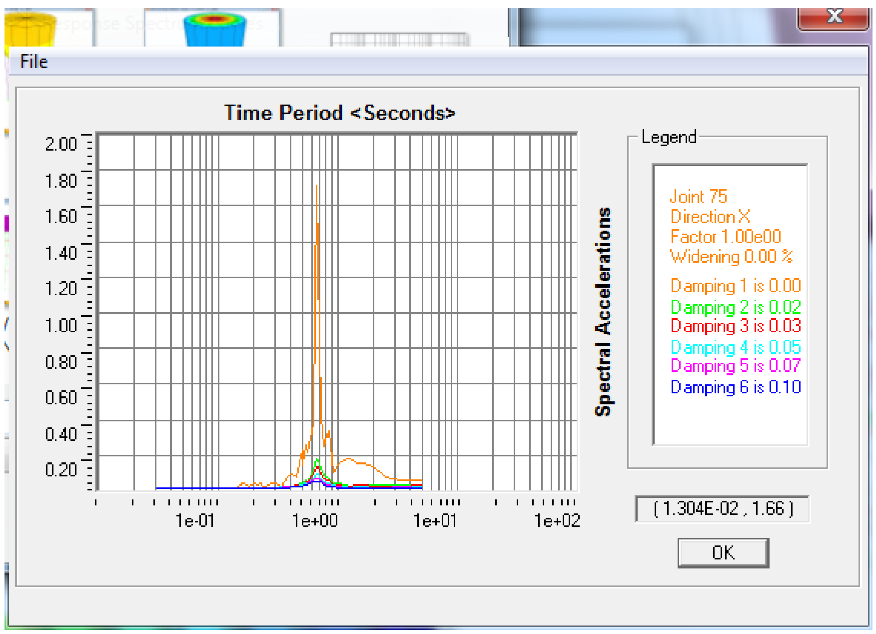

Figure 4.22: Acceleration response spectrum

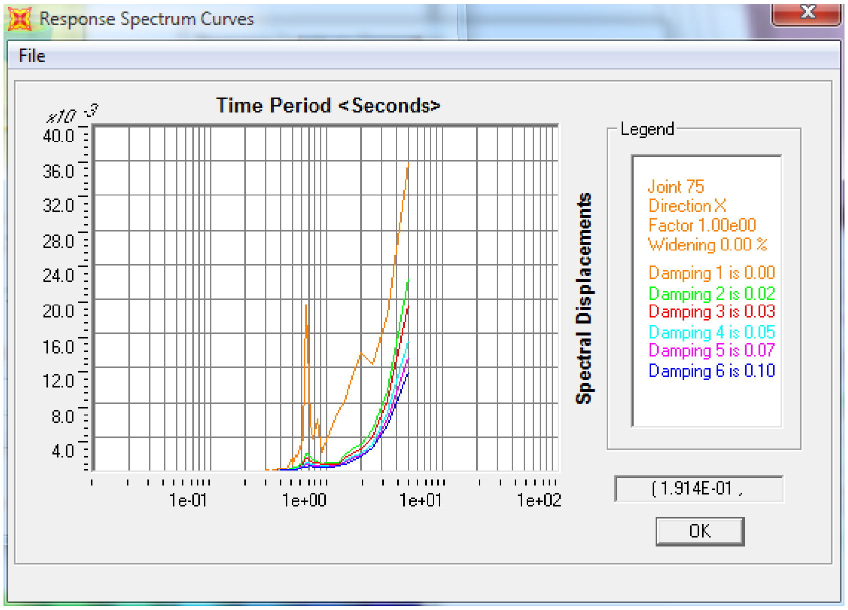

Figure 4.23: Displacement response spectrum

4.3: SUMMARY ANALYSIS

4.3.1 Modal Analysis

Based on the analysis and result, the best three mode shape of the structure is the first three which are mode shape 1, 2 and 3. The Table 4.2 as follow shows the type of mode shape with their natural frequency and period.

Table 4.2: Type of mode shape, natural frequency and period.

Mode Shape	Period, T (s)	Frequency, f (Hz)
1	0.67189	1.48834
2	0.67189	1.48834
3	0.53477	1.86997

4.3.2 Characteristic of elevated water tank during earthquake

When the earthquake occurred on the ground, the structure will vibrate horizontally. They must have effect the displacement and the acceleration of the building. Acheh earthquake data was attached on the elevated water tank and after the simulation of the structure in the computer software finished, the result as follow:

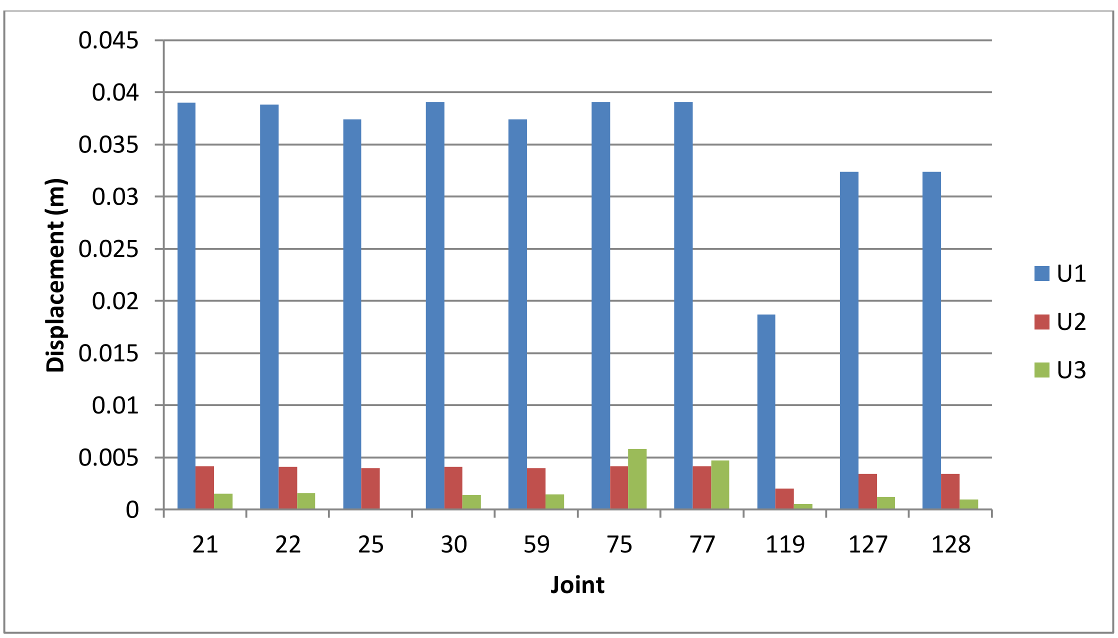

Figure 4.24: The bar graph show the data of joint versus the displacement on x, y and z axis.

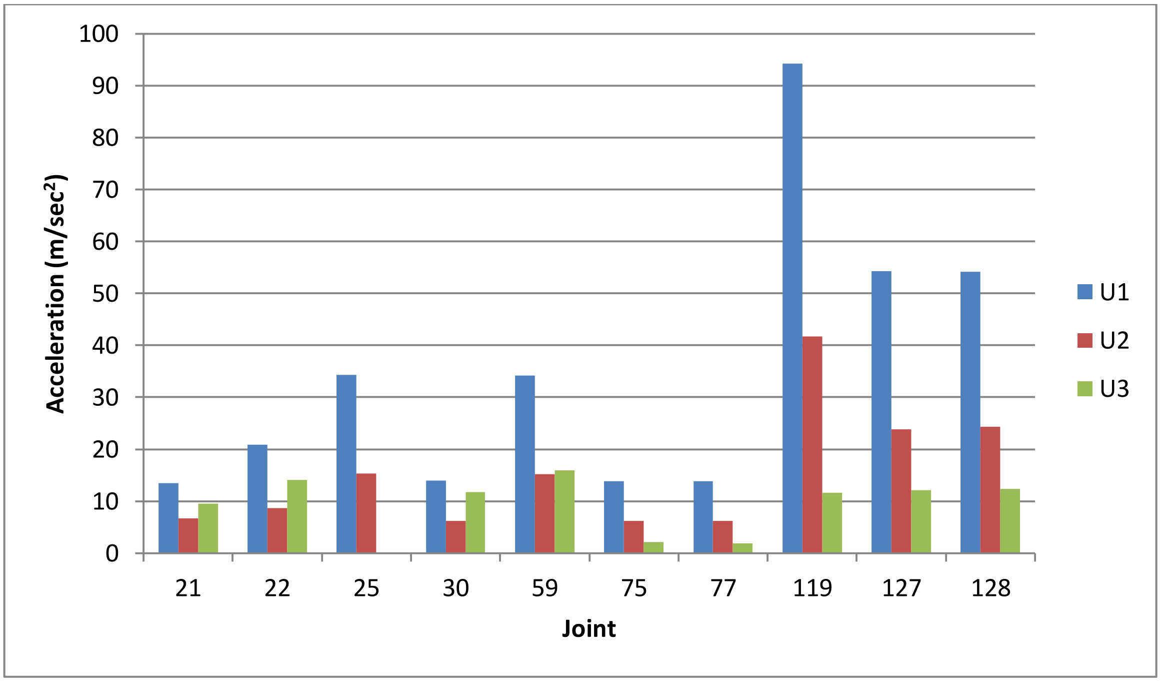

Figure 4.25: The bar graph show the data of joint versus the acceleration on x, y and z axis.

In seismic design, structural engineer always consider the displacement on the structure when the earthquake happened. To obtain the critical joint of the structure, average values of displacement are calculated. Based on the calculation, joint 75 is the most critical joint with the average of 0.016319 m. Table 4.3 below shows the response spectrum data of joint 75.

Table 4.3: Table of data response spectrum joint 75

Joint	Damping	Spectral Acceleration, g	Spectral Displacement, g
75	0.05	0.12	16.0

Figure 4.26 below show the location of joint 75 on the structure of elevated water tank.

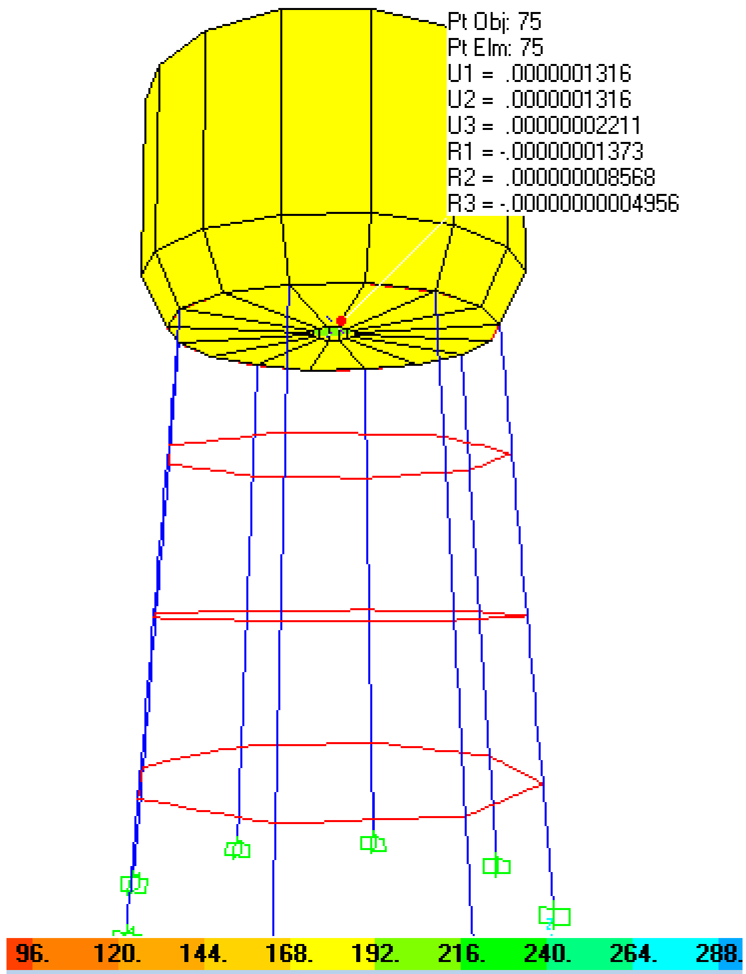

Figure 4.26: Screen capped of a selected joint on elevated water tank

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 0.61789.

iii. SAP2000 software can consider the earthquake load.

iv. The mode shape of the elevated water tank is different when the earthquake occurred as the structure move based upon the ground motion.

v. The value of spectral displacement and spectral acceleration can be determined when the earthquake occurred.

vi. Based on the analysis, the critical joint is at joint 75 where it have the highest average of displacement value 0.016319 m.

vii. The critical joint can be considered at the bottom center of the tank as the joint 75 is located at the bottom of the tank.

viii. The building structure in Malaysia shall be design with considering the earthquake loading.

5.2 RECOMMENDATION

Further studies need to be done on this research as it only covered the behavior and dynamic characteristics of the elevated water tank under earthquake loading. The future study can be done by analyse the different types of the elevated water tank used in Malaysia region. Furthermore, the researcher also can consider the volume in the water tank either it is fully or half fill. To increase the accuracy on the seismic study, always update the data used in the analysis. In addition, the researcher can also analyse the behavior of the material of the structure used when the earthquake approach the structure. By doing the analysis, the structural engineer can design the structure with the recommendation material strength based on the result and analysis that have achieved in the research.

The recent earthquake event occurred in Ranau, Sabah has open many eyes on the structure affected by the earthquake. The earthquake or time history in Ranau, Sabah can be used to analyse the structure in Malaysia. Even though it is an average magnitude value, it can be the reference in the future to enhance the safeguard of the population.

Presently, Malaysia did not apply any earthquake regulations in designing structure of building. The design of building structure in Malaysia should consider the seismic or earthquake loading regulations. The seismic regulations must adaptable with the specific condition of the country, the land management, disaster prevention and environment protection.

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