SEISMIC PERFORMANCE OF TRUSSES UNDER EARTHQUAKE LOADINGS

NOR ARES BIN YAHYA

B.ENG (HONS.) OF CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : NOR ARES BIN YAHYA

Date of Birth : 11/09/1996

Title : SEISMIC PERFORMANCE OF TRUSSES UNDER EARTHQUAKE LOADINGS

Academic Session : SEMESTER II 2018/2019

I declare that this thesis is classified as:

☐	CONFIDENTIAL	(Contains confidential information under the Official Secret Act 1997)*
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done)*
☑	OPEN ACCESS	I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

_____	_____
(Student's Signature)	(Supervisor's Signature)
960911-03-5609	IR. SAFFUAN BIN WAN AHMAD
Date:	Date:

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

SUPERVISOR's DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor (Hons.) of Civil Engineering.

_____

(Supervisor's Signature)

Full Name : IR SAFFUAN BIN WAN AHMAD

Position : LECTURER

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

(Student's Signature)

Full Name : NOR ARES BIN YAHYA

ID Number : AA 15163

Date : 01 JUNE 2019

SEISMIC PERFORMANCE OF TRUSSES UNDER EARTHQUAKE LOADINGS

NOR ARES BIN YAHYA

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

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

MAY 2019

ACKNOWLEDGEMENTS

Alhamdulillah, praise be to Allah, the most Gracious and most Merciful. With His guidance and strength, this research study has reached its end. With great pleasure, I would like to extend my sincere appreciation and thanks to my supervisor, Ir Saffuan bin Wan Ahmad for her never ending assistance and support throughout completing my research project. His comments and suggestions are very valuable for my research and without her meaningful advises it would be difficult path for me to complete this study.

I also want to express my gratitude to thank all my friends under same supervision of Ir Saffuan that gives a helpful assistance since the first day I start my research works. Their help is highly appreciated in the completion of this research.

A special thanks to my family, Yahya bin Mat Nasir and Jamilah binti Abd Hamid and my sibling who supported me in writing and motivated me to achieve my goal. Your prayers for me are greatly appreciated and encouraged me this far.

Last but not least, I would like to thank to Muhammad Aimran Amzar bin Kamaruddin, my co-supervisor for being so supportive along the way of doing my thesis. Not to forget to all who were involved directly and indirectly in helping me either through ideas, time and energy consuming, it was a great experience to work with all of you.

ABSTRACT

The study was conducted because there might be a tremors in Malaysia because we are at active tectonic plate and also there will be seismic wave generated from the earthquake that occurred in neighbouring countries. Therefore, engineers are concerned about the seismic vulnerability of trusses structures due to lack of earthquake consideration in Malaysia's building design procedure. Trusses structure is the critical structure that will damage cause by the seismic effect and also important component in building system. With this, trusses is modelled and analysed using Finite Element Modelling (FEM) by SAP2000 software under various type of analysis that cover Free Vibration Analysis (FVA), Time History Analysis (THA) and Respond Spectrum Analysis (RSA) under the different earthquake loading. The earthquake loading data is taking from Acheh and El-Centro earthquake that had been record by Malaysia Meteorological Department. Implementation between two types of different earthquake loading will represent the contrasting of dynamic characteristic of trusses structure. Furthermore, the overall seismic performance of trusses significantly enhanced in longitudinal and transverse directions. It can summarize that the design of the trusses is stable and ability to withstand under major and minor earthquake and also can yield adequate resistance against different earthquake loading.

ABSTRAK

Tujuan kajian ini dijalankan adalah Malaysia berkemungkinan besar menerima gegaran gempa bumi kerana negara kita ini berada di plat tektonik yang aktif dan juga akan menerima gelombang seismik yang dihasilkan dari gempa bumi yang berlaku di negara-negara jiran. Oleh itu, para jurutera perlu prihatin tentang kerentanan seismik bagi kekuda atap sesebuah struktur kerana kurangnya pertimbangan tentang gempa dalam prosedur reka bentuk bagi bangunan di Malaysia. Struktur kekuda atap adalah struktur kritikal yang boleh rosak sepenuhnya disebabkan beban seismik dan ianya juga komponen penting dalam system reka bentuk bangunan. Dengan ini, kekuda atap boleh dimodelkan dan dianalisis dengan menggunakan perisian SAP2000 Pemodelan Elemen Finite (FEM) dalam pelbagai jenis analisis yang merangkumi Analisis Getaran Percuma (FVA), Analisis Sejarah Masa (THA) dan Analisis Spektrum Responden (RSA) di bawah beban gempa yang berlainan. Data beban gempa yang diambil adalah dari gempa Acheh dan El-Centro yang telah diperoleh dari Jabatan Meteorologi Malaysia. Dengan mengambil kira dua jenis beban gempa yang berbeza akan menghasilkan ciri-ciri susunan dinamik yang berlainan. Tambahan pula, prestasi seismik bagi keseluruhan kekuda atap meningkat dengan ketara dalam dua arah membujur dan melintang. Ia boleh diringkaskan bahawa reka bentuk kekuda atap ini adalah stabil dan keupayaannya untuk bertahan daripada bebanan gempa yang besar mahupun kecil juga tinggi. Kekuda atap ini juga boleh menghasilkan daya tahan yang mencukupi terhadap bebanan gempa yang berbeza.

TABLE OF CONTENT

DECLARATION

TITLE PAGE

ACKNOWLEDGEMENTS **ii**

ABSTRACT **iii**

ABSTRAK **iv**

TABLE OF CONTENT **v**

LIST OF TABLES **viii**

LIST OF FIGURES **ix**

LIST OF SYMBOLS **xii**

LIST OF ABBREVIATIONS **xiii**

CHAPTER 1 INTRODUCTION **14**

1.1 Background of Study 14

1.2 Problem Statement 16

1.3 Research Objective 18

1.4 Scope of Study 18

1.5 Research Significance 18

CHAPTER 2 LITERATURE REVIEW **19**

2.1 Earthquake 19

2.2 Seismic Waves 20

2.3 Measuring Earthquake 22

2.3.1 Locating Earthquakes 22

2.4 Magnitudes 23

2.5 Intensity 25

2.6 Types of Trusses 27

2.6.1 2D Trusses 27

2.6.2 3D Trusses 28

2.6.3 Steel Trusses 30

2.7 Type of Roof Trusses 31

2.7.1 King Post Truss 31

2.7.2 Queen Post Truss 32

2.7.3 Pratt Truss 33

2.7.4 Howe Truss 33

2.7.5 Fan Truss 34

2.7.6 North Light Roof Truss 35

2.7.7 Quadrangular Roof Truss 36

2.7.8 Parallel Chord Roof Truss 37

2.7.9 Scissor Roof Truss 38

2.7.10 Raised Heel Roof Truss 39

2.8 Introduction to SAP 2000 40

2.9 Summary 41

CHAPTER 3 METHODOLOGY 42

3.3 Introduction 42

3.2 Literature Review 44

3.3 Information and Data Collection 44

3.4 Step Analysis in SAP 2000 45

CHAPTER 4 RESULTS AND DISCUSSION **57**

4.1 Introduction 57

4.2 Analysis of Truss Structure 57

4.3 Modal Analysis (Free Vibration Analysis) 57

4.4 Time History Earthquake Analysis 64

4.4.1 Dead Load and Live Load 65

4.4.2 Dead Load (DL) + Live Load (LL) + Earthquake Load 65

4.5 RESPONSE SPECTRUM 73

4.6 Shear Force 78

4.6.1 Tension member (Tie) 78

4.6.2 Compression member (Strut) 79

4.6.3 Bottom Chord 79

4.6.4 Top Chord 80

4.7 Bending Moment 80

4.7.1 Tension Member (Tie) 80

4.7.2 Compression member (Strut) 81

4.7.3 Bottom Chord 81

4.7.4 Top Chord 82

4.8 Summary of Results 82

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS **85**

5.1 Conclusions 85

5.2 Recommendations 86

REFERENCES **87**

LIST OF TABLES

Table 4.1	Spectral displacement vs time period graph for both earthquake loadings	74
Table 4.2	Spectral acceleration vs time period graph for both earthquake loadings.	76
Table 4.3	Shear force diagram on tension member	78
Table 4.4	Shear force diagram on compression member	79
Table 4.5	Shear force diagram on bottom chord member.	79
Table 4.6	Shear force diagram on top chord member.	80
Table 4.7	Bending moment diagram on tension member.	80
Table 4.8	Bending moment diagram on compression member.	81
Table 4.9	Bending moment diagram on bottom chord member.	81
Table 4.10	Bending moment diagram on top chord member.	82
Table 4.11	Summarize result on displacement for El- Centro earthquake.	83
Table 4.12	Summarize result on displacement for Acheh earthquake.	83
Table 4.13	Summarize result on acceleration for El-Centro earthquake.	83
Table 4.14	Summarize result on acceleration for Acheh earthquake.	84

LIST OF FIGURES

Figure 1.1	Dip-slip fault and strike-slip fault.	14
Figure 1.2	Steel structures	16
Figure 1.3	Maps of Malaysia that surrounded by active tectonic plate.	17
Figure 2.1	View of epicentre and focus of earthquake.	19
Figure 2.2	Shallow and deep earthquake.	20
Figure 2.3	Different types of seismic waves	21
Figure 2.4	Epicentre from 3 different shock waves.	22
Figure 2.5	How is the Richter Scale calculated.	24
Figure 2.6	The severity of an earthquake	26
Figure 2.7	The types of 2D trusses.	27
Figure 2.8	The 2D trusses analysis	28
Figure 2.9	Method of joint	29
Figure 2.10	Method of section.	30
Figure 2.11	King post truss.	31
Figure 2.12	Queen post truss.	32
Figure 2.13	Pratt truss.	33
Figure 2.14	Howe truss.	34
Figure 2.15	Fan truss.	34
Figure 2.16	North light roof truss	35
Figure 2.17	North light roof trusses in 2D view.	36
Figure 2.18	Quadragular roof truss.	37
Figure 2.19	Quadragular roof truss double structure.	37
Figure 2.20	Parallel chord roof truss.	38
Figure 2.21	Scissor roof truss.	38
Figure 2.22	Raised heel roof truss.	40
Figure 2.23	SAP 2000 version 2014.	41
Figure 3.1	Flowchart.	43
Figure 3.2	Selection of Grid Only template.	45
Figure 3.3	Define grid system data.	45
Figure 3.4	Choose section label at frame properties.	46
Figure 3.5	Import double angle as property type.	46
Figure 3.6	Change section name and choose section.	47
Figure 3.7	Replicate tool for draw the component.	48

Figure 3.8	Assign frame releases for diagonal member.	48
Figure 3.9	Defines area section for the base.	49
Figure 3.10	Define the section and the thickness.	49
Figure 3.11	The 3D view of the drawn trusses.	50
Figure 3.12	The preferred choice of joint restraint.	50
Figure 3.13	The 3D view of the drawn trusses with restraint joint.	51
Figure 3.14	Define load or added new load pattern.	51
Figure 3.15	Assign the uniform load area.	52
Figure 3.16	Stiffness modification for analysis.	52
Figure 3.17	The display options for active window in 3D view.	53
Figure 3.18	Added function type for the time history.	53
Figure 3.19	Added function type for the time history.	54
Figure 3.20	Part to change the load cases that need to be run.	55
Figure 3.21	The 3D view after the analysis	55
Figure 3.22	The result of analysis.	56
Figure 4.1	Mode shape 1 with value of natural period,T and frequency,f.	58
Figure 4.2	Mode shape 2 with value of natural period,T and frequency,f.	59
Figure 4.3	Mode shape 3 with value of natural period,T and frequency,f..	59
Figure 4.4	Mode shape 4 with value of natural period,T and frequency,f.	59
Figure 4.5	Mode shape 5 with value of natural period,T and frequency,f.	60
Figure 4.6	Mode shape 6 with value of natural period,T and frequency,f.	60
Figure 4.7	Mode shape 7 with value of natural period,T and frequency,f.	60
Figure 4.8	Mode shape 8 with value of natural period,T and frequency,f.	61
Figure 4.9	Mode shape 9 with value of natural period,T and frequency,f.	61
Figure 4.10	Mode shape 10 with value of natural period,T and frequency,f.	61
Figure 4.11	Mode shape 11 with value of natural period,T and frequency,f.	62
Figure 4.12	Mode shape 12 with value of natural period,T and frequency,f.	62
Figure 4.13	The modal case analysis data after the analysis on the structure is run.	63
Figure 4.14	The graph of time data versus acceleration from Acheh earthquake.	64
Figure 4.15	The graph of time data versus acceleration from El-Centro earthquake.	64
Figure 4.16	Deformed shape on structure for combination of live and dead load.	65
Figure 4.17	Graph joint vs displacement, U1 using El- Centro earthquake data.	66
Figure 4.18	Graph joint vs displacement, U1 using Acheh earthquake data.	67

Figure 4.19	Graph joint vs displacement, U2 using El- Centro earthquake data.	67
Figure 4.20	Graph joint vs displacement, U2 using Acheh earthquake data.	68
Figure 4.21	Graph joint vs displacement, U3 using El- Centro earthquake data.	68
Figure 4.21	Graph joint vs displacement, U3 using Acheh earthquake data.	69
Figure 4.23	Graph joint vs acceleration, U1 using El- Centro earthquake data.	70
Figure 4.24	Graph joint vs acceleration, U1 using Acheh earthquake data.	70
Figure 4.25	Graph joint vs acceleration, U2 using El- Centro earthquake data.	71
Figure 4.26	Graph joint vs acceleration, U2 using Acheh earthquake data.	71
Figure 4.27	Graph joint vs acceleration, U3 using El- Centro earthquake data.	72
Figure 4.28	Graph joint vs acceleration, U3 using Acheh earthquake data.	72

LIST OF SYMBOLS

km	Kilometre
M_L	Local magnitude scale
Mb	Body wave magnitude
Ms	Surface wave magnitude
kgf	Kilogramforce

LIST OF ABBREVIATIONS

SAP 2000	Structural Analysis Program 2000
3D	3 Dimension
2D	2 Dimension
A.E.H.L	Augustus Edward Hough Love
OSB	Oriented Strand Board
MMD	Malaysia Meteorology Department
FVA	Free Vibration Analysis
LL	Live Load
DL	Dead Load

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Earthquakes is a ground shaking caused by sudden release of energy in the earth's crust (Earthquake, 2012). An earthquake happens when two blocks of the earth suddenly slip from each other and the surface where it slip named the fault. There are two types of fault which are dip-slip fault and strike slip fault. In dip-slip fault, the blocks move from each other vertically and under this fault there being separated into two normal fault and reverse fault. Normal fault being figured as the footwall moves away from hanging wall that caused by tension and it is different with reverse fault that happen by compression that makes the footwall moves toward the hanging wall. Other than that, the strike-slip fault happens when the adjacent block moves horizontally past one another. Figure 1.1 show both types of faults.

Figure 1.1 Dip-slip fault and strike-slip fault.

Sources: ("Keywords SEO Tool and Images Suggestion | SEO News | SEO Blog," n.d.)

Earthquake recently happen by smaller earthquakes first then larger earthquake follows. Earthquake being detected as foreshock until the larger earthquake happens. When the larger earthquake occurs, it being called as the mainshock and it is always have aftershocks that follow. Then the aftershock being categorized as smaller earthquakes that occur afterwards in the same place as the mainshock. Aftershocks can continue for weeks, months, and even years after the mainshock and it is depend with the size of mainshock. The most important facts is earthquakes strike entirely without warning not like hurricanes, tornados, monsoons and blizzards where can be tracked in advanced (Al-Taie & Albusoda, 2019).

All around the world, steel has become very important construction material by the end of the 19^{th}. There are many buildings used steel as truss structure and even historic monuments used iron and steel as trusses (Luong, Zabel, Lorenz, & Rohrmann, 2017). It is not just the structure was a steel but the connection between structures also used steel like pins, rivets, bolts, and welds. Structural steel very low self-weight that can give minimum load to the beam and column if the steel being use for trusses construction steel structure also high in quality and dimension precision, it is because the structure being made at factory that can protected the steel from the weather before haul to the site also the section was precise because being made using machine in the factory. Moreover, it is the most economical construction material and easy to handle and alter.

However, steel was susceptible to buckling if there any high load being applied because steel was a thin element that will lead to failure. Other than that, fire resistance are very important in steel structure it is because the strength will decreased according to heat that being applied. It also susceptible to corrosion if exposed to water and air and also can reduced the strength. In addition, fatigue also can happen especially at welded connection due to the high tensile residual stress. Figure 1.2 give a clear vision about steel trusses.

Figure 1.2 Steel structures

Sources: (“SteelConstruction.info,” n.d.)

1.2 Problem Statement

As everyone know, earthquake rarely happen in Malaysia. Even when it happened in Malaysia, it just hit in Sabah and Sarawak areas where there is many earthquake centre that have focus under it. However, it doesn’t means that peninsular Malaysia areas can’t have the earthquake. Actually the areas in Peninsular Malaysia also have the centre of earthquake but hasn’t considered as seismically active country (Shuib et al., 2017). As example of place that have the fault zone and might be reactivate fault line in peninsular Malaysia are Bukit Tinggi, Kuala Lumpur, Seremban and others.

At the same time, Malaysia is surrounded by so many active tectonic plate boundaries and also the Sunda Shelf make the country like Malaysia is being compressed. Sundaland is another name for Peninsular Malaysia because of our country are at the centre of the Sunda Shelf and our country absorbing all the stress from Sunda Shelf. There is also others country that being marked as Sundaland, as example Sumatra, Madura, Bali, Borneo, Java and smaller islands around them. So, as there is too many stress that need to be release from earth the old fault line systems might be activate as the medium to release energy from earth. Active tectonic plate around Malaysia can be seen in Figure 1.3.

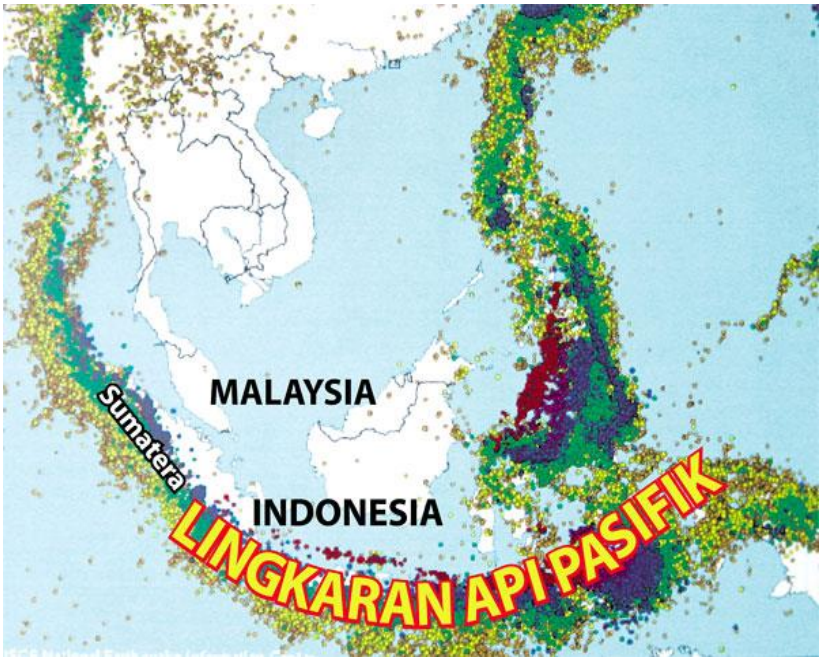


Figure 1.3 Maps of Malaysia that surrounded by active tectonic plate. Sources: (“Quantum Na,” n.d.)

The quakes were not strong in Peninsular Malaysia but in future it might be increasing in magnitude. The strongest one that have being detected so far is a magnitude 3.5 in Bukit Tinggi. So, when we have epicentres like Ranau in Sabah which was recently hit by a magnitude 6.0 there is high possibility of earthquakes hitting the fault line zone in Peninsular Malaysia that already had some tremors from places like Philippines and Sumatera. Now, there was evidence of seismic activity in fault lines detected in the Peninsular itself.

Therefore, seismic effect need to be considered since the minor disaster had shown up. Furthermore, most of the buildings in Malaysia are designed for wind effect only rather than seismic effect. All building will have trusses that also cannot avoid from the effect of earthquake. The building itself will need a proper designed of trusses as the trusses are the upper member of the building that transfer load through the other members under it. So, most of the building in Malaysia needs optimization of truss structure which is subjected to seismic load.

1.3 Research Objective

The main objective of this research are:

I. To study the resistances of existing 3D trusses using vulnerability assessment.
II. To compare the capability and resistance of the 3D trusses under Acheh EL-Centro at citation.
III. To study dynamic characteristic of 3D trusses under different type of loading.

1.4 Scope of Study

In this research, the earthquake behaviour and performance of steel trusses will be investigated. The scopes of study for this research are:

I. Type of trusses will be used is steel structure.
II. The case of study are related to Acheh earthquake that affected the 3D trusses in Malaysia region.
III. Test the 3D trusses by using analysis factors like free vibration analysis, response spectrum earthquake analysis and time history earthquake analysis.
IV. The software that will be used for this research analysis is SAP2000

1.5 Research Significance

Throughout this research, the vulnerability of existing 3D trusses structure in Malaysia region could be determined. Due to earthquake in Acheh, Indonesia the capability of the structure can be studied. In addition, the characteristics of the structure also could be known when earthquake occurred. In designing the 3D trusses structures it is better to consider the seismic effect on structures in Malaysia. Seismic effect is amplification of seismic waves. By explored the seismic effect, any damaged when earthquake happened can prevented besides it can save many live.

CHAPTER 2

LITERATURE REVIEW

2.1 Earthquake

Earthquake is not a disaster that can be taken as minor environmental problems. It is related to the earth plate move with respect to one another. Then, the elastic strain energy build up due to the friction happen between rocks when the plate move and it being stored in the rocks (Murty, 2008). Next, the stress being released in form of seismic wave which induce ground shaking. There are many terms regarding to the earthquake that we need to know. One of it is focus which is point under the earth surface where rupture is said to have originated. In addition, there also term that being called as epicentre where the projection of the focus on the ground surface happen here. Epicenter and focus layer likely same as figure 2.1.

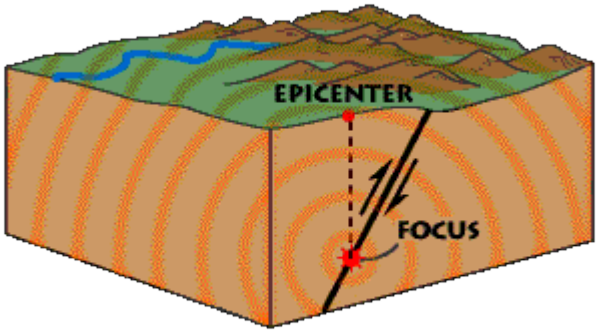


Figure 2.1 View of epicentre and focus of earthquake.
Sources: (“USGS.gov | Science for a changing world,” n.d.)

Furthermore, there are three different earthquake that can happen. First, shallow earthquake that being classified as originate within 60 km from Earth's outer surface. Next, intermediate earthquake that occurred in a range of 60 km to 300 km of focal depth. Moreover, deep earthquake also can happen as the focal depth increase up to 700 km has been studied. Figure 2.2 show how the layer of epicenter in different depth of focus.

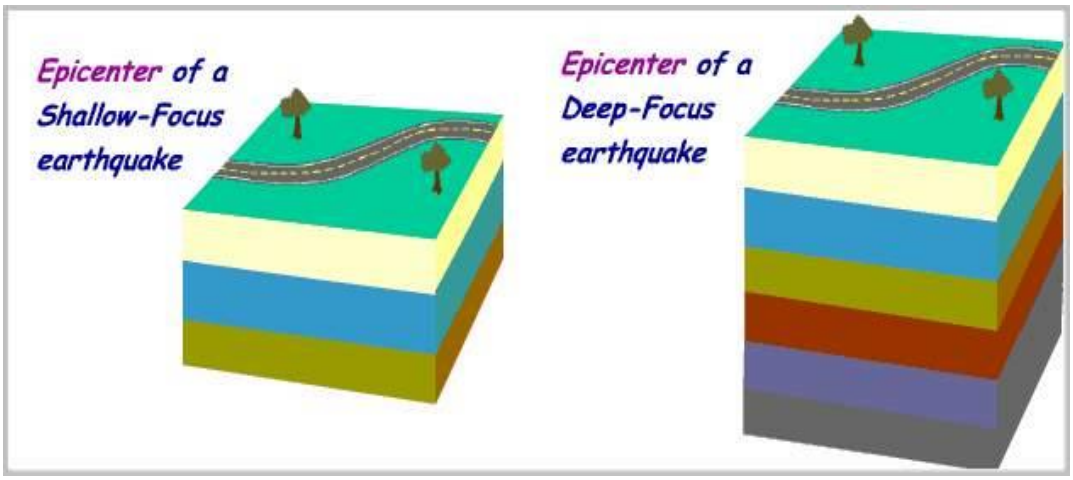


Figure 2.2 Shallow and deep earthquake.

Sources: ("Difference between Shallow Focus and Deep Focus Earthquakes | Actforlibraries.org," n.d.)

2.2 Seismic Waves

Seismic waves have 2 types which are body waves and surface waves. Body waves travel through the interior ground layer and surface waves travel through ground surface. First, body waves separated into two which are P waves and S waves. Next, surface waves that can being categories into love waves and rayleigh waves.

P waves was primary waves that being classified as compression waves, it also known as push-pull waves. P waves was individual waves that push against one another that causing a constant parallel and straight motion. Then, S waves was secondary waves or transverse waves and it vibrate up and down that perpendicular to the motion of the wave as they travel (AKIMA, 2017). S waves also can be can be identify by it characteristic which is the wave moves forward and particles travel up and down exactly like sine wave.

Rayleigh Wave is named after Lord Rayleigh who found this kind of wave in 1885. If we see a wave rolls across an ocean or a lake it is the same like Rayleigh wave rolls along the ground. The ground moving up and down and side to side in the same direction that the wave is moving it is because of rolling movement (UpSeis, 2007). Love Wave are named after A.E.H L, a person who come out with the mathematical model for this kind of wave in 1911 it is the fastest surface wave that moves the ground from side to side.

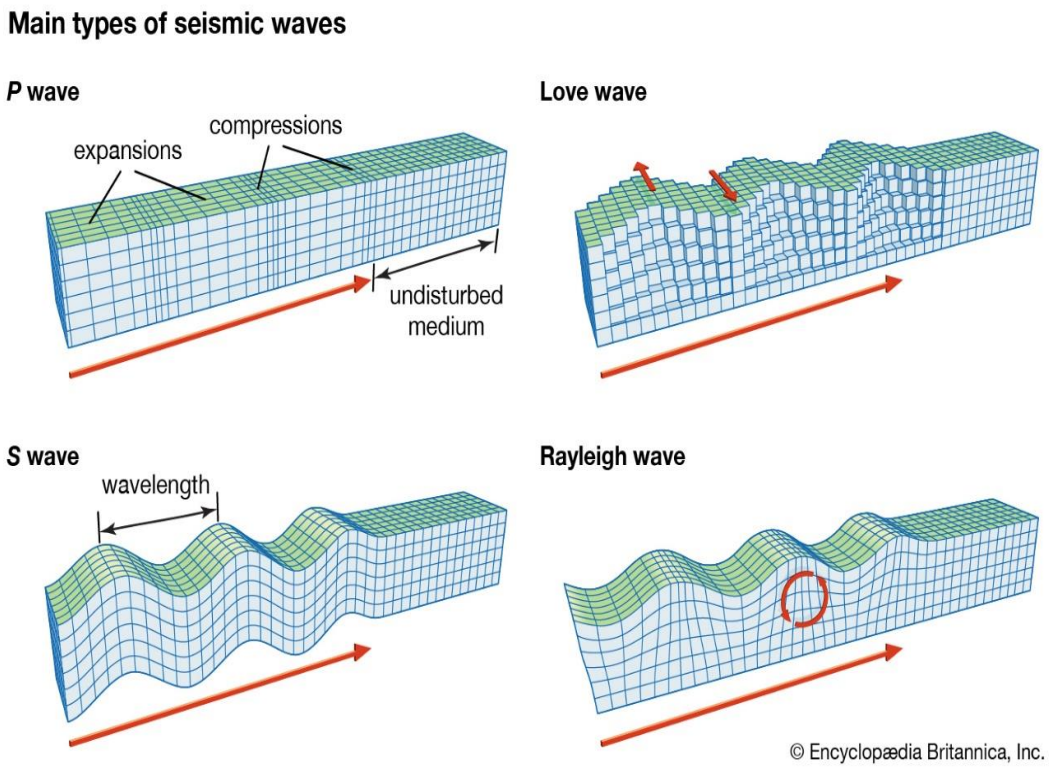


Figure 2.3 Different types of seismic waves

Sources: ("Difference between Shallow Focus and Deep Focus Earthquakes | Actforlibraries.org," n.d.)

2.3 Measuring Earthquake

2.3.1 Locating Earthquakes

It is simple geometry to locate the precise centre of the earthquake by finding the distance to an earthquake. The distance can be calculated from the arrival times of different shock waves that happens. It just need information of three different locations. The centre of earthquake are named as epicentre. Focus may be determined once an earthquake's distance from several stations is known as example the stations are located in d1, d2 and d3. The epicenter is found within the area where the circles overlap (Havskov, 2011). Thus, from that we can know type of focus and their characteristics like deep focus can give small amplitude and etc. Figure 2.4 show the determination of focus from different stations.

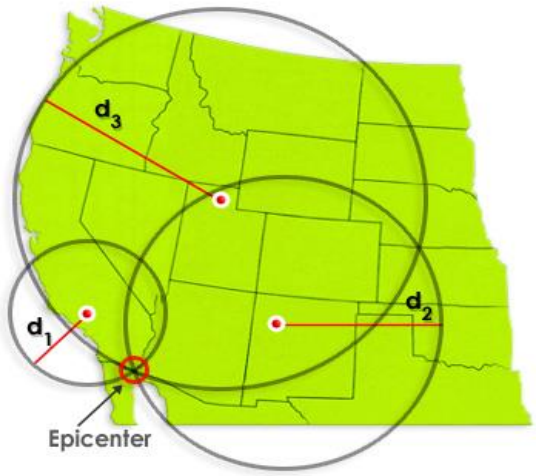


Figure 2.4 Epicentre from 3 different shock waves.
Sources: (Havskov, 2011)

2.4 Magnitudes

Earthquake size is a quantitative measure about the size of the earthquake. It cannot be measured by watching the damage after it happen. It can measures the amount of seismic energy released by an earthquake through force and duration (Concept, 2010). The richter magnitude scale is a medium to calculate it and act as the first method used that also known as local magnitude scale, M_L. When an earthquake occurs, a single numerical value on the Richter Magnitude Scale will be the magnitude of that particular earthquake.

Charles F. Richter, an American seismologist originally definition about the earthquake magnitude just held for California earthquakes occurring within 600 km with a particular type of seismograph. Presently, Richter's magnitude scale was then extended to observations of earthquakes of focal depths ranging between 0 and 700 km at any distance. There also body wave and surface wave magnitudes Mb and Ms that important in many applications. Richter scale classification can be conclude in Figure 2.5.

Understanding the Richter Scale:

Richter Magnitude	Feels like KG of TNT	Extra Information
0-1	0.6-20 kilograms of dynamite	We can not feel these
2	600 kilograms of dynamite	Smallest Quake people can normally feel
3	20,000 kilograms of dynamite	People near the epicenter feel this quake
4	60,000 kilograms of dynamite	This will cause damage around the epicenter. It is the same as a small fission bomb
5	20,000,000 kilograms of dynamite	Damage done to weak buildings in the area of the epicenter
6	60,000,000 kilograms of dynamite	Can cause great damage around the epicenter
7	20 bilion kilograms of dynamite	Creates enough energy to heat New York city for one year. Can be detected all over the world. Causes serious damage
8	20 bilion kilograms of dynamite	Causes death and major destruction. Destroyed San Francisco in 1906
9	20 trillion kilograms of dynamite	Rare, but would causes unbelievable damage!

Figure 2.5 How is the Richter Scale calculated.

Sources: (“Richter Scale & Magnitude,” n.d.)

2.5 Intensity

The seriousness of earthquake shaking is assessed by using a descriptive scale called the Modified Mercalli Intensity Scale where it is the most used versions (Musson, 2012). Generally, intensity is qualitative measure of the actual shaking at a location during an earthquake and is assigned as Roman capital Numerals. The intensity is variable over the area affected by the earthquake, high intensities will be near the epicentre and lower values of intensities further away from epicenter. According to the Modified Mercalli Intensity Scale, these are allocated a value depends on the effects of the shaking. Intensity value being assigned by zip code and the data for zip code come through information gathered from people near the earthquake combined with damage reports. Figure 2.6 give a classification about intensity of earthquake.

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Abridged from *The Severity of an Earthquake*, a U. S. Geological Survey General Interest Publication. U.S. GOVERNMENT PRINTING OFFICE: 1989-288-913

Figure 2.6 The severity of an earthquake

Sources: ("Innovatieblog: Alles kan anders...en beter: Wat de schaal van Mercalli me leert over innovatie...," n.d.)

2.6 Types of Trusses

2.6.1 2D Trusses

Steel buildings and bridges are commonly using trusses for it structures (*Chapter 6 : Analysis of Structures*, 2009). The clear vision of trusses are railway bridges and transmission towers. A truss is a type of structure that consists of straight members that being connected together with pin joints and it is connected only at the ends of the members. Then, all external forces included loads and reactions must be applied only at the joints. External forces being defined as loads acting on structures and it includes also reactions from supports. Other than that, internal forces being developed inside the structures in order to hold different components together. There are some types of 2D trusses in Figure 2.7 and Figure 2.8 is about software use for 2D analysis.

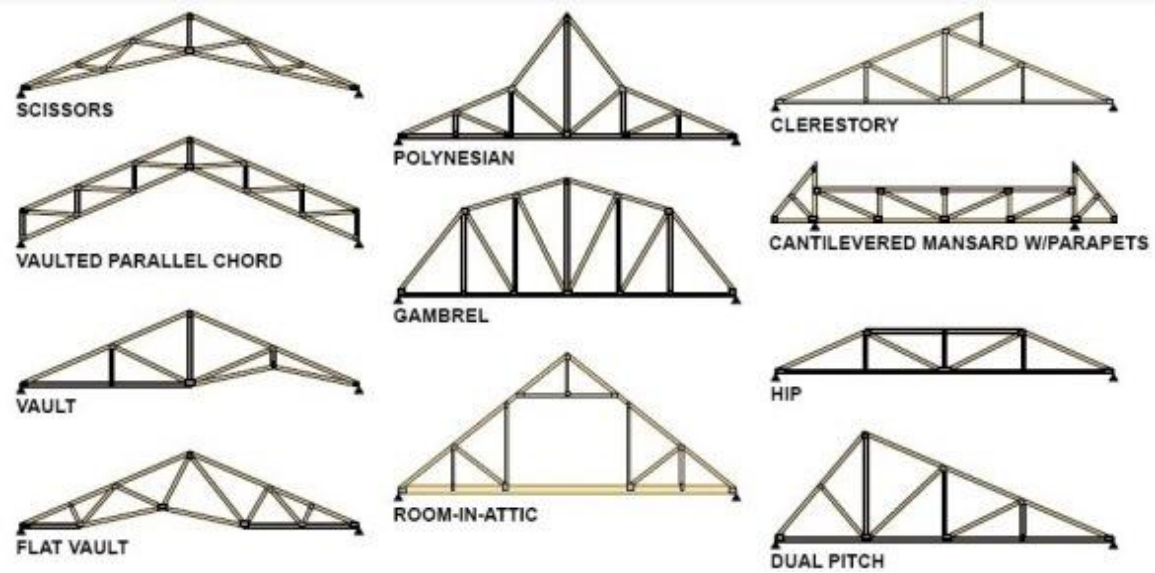


Figure 2.7 The types of 2D trusses.
Sources: ("Mohammad Rasoul Abazari | Developing of a program to analyze the general 2D trusses," n.d.)

There are many powerful application that can be used to design the 2D trusses. The best application was 2D Truss Analysis that uses optimized finite elements in order to perform static analysis of trusses. It is versatile interface as well as its easy customization make it a leader-product in truss analysis. The creation of the model very easy and quick as the user can use all tools in the application that really need basic knowledge.

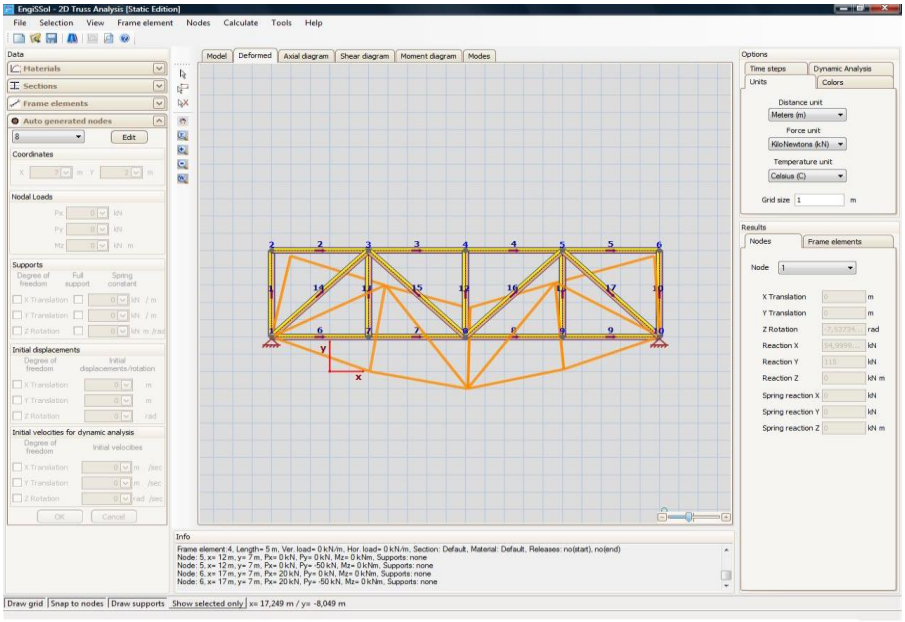


Figure 2.8 The 2D trusses analysis

Sources: (“2D Frame Analysis software | Engissol Ltd.- Structural Engineering Software,” n.d.)

2.6.2 3D Trusses

3D trusses also known as space trusses that require all members to have a pin joint at each end. It also have all loads that act at the joints just like 2D trusses. This two conditions insure that forces of the member act in their exact direction of the members. The direction of the load is needed, if not truss problems could not be solved just by using static equilibrium equations (Felipe, Leonel, Haach, & Beck, 2019).

3D truss problems can be solved by using method of joint like in Figure 2.9. Method of joint started by choosing a joint with one or more known load forces and only three unknown member forces. The forces at the joint will be sum up in all three directions x, y, and z that can produce three equations with three unknowns.

$$\Sigma Fx = 0 \quad \Sigma Fy = 0 \quad \Sigma Fz = 0 \qquad 2.1$$

The moment equilibrium equations are difficult to apply in 3D so that we can conclude that the method of joint is the easiest one. The complexity of 3D geometry make the vector notation should be used for 3D problems.

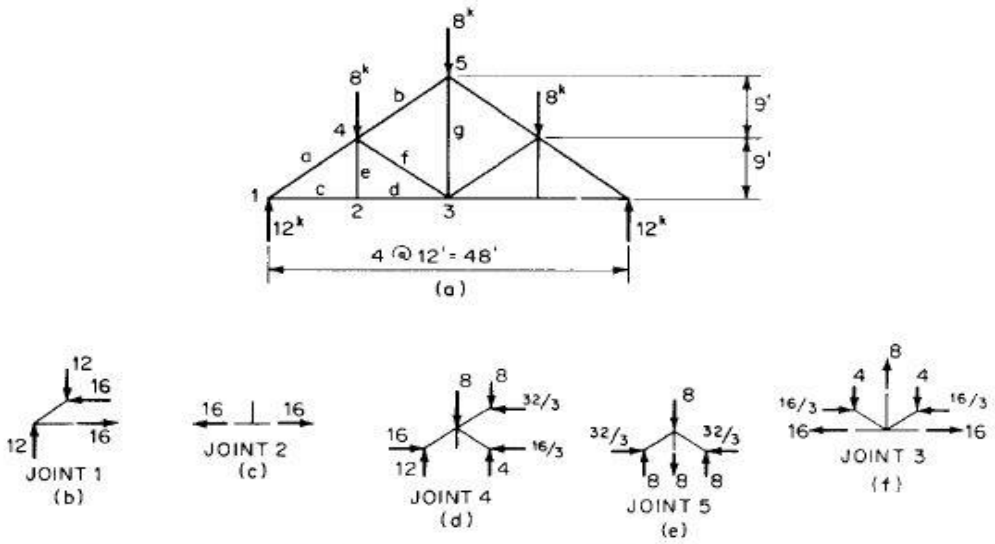


FIGURE 3.68 Calculation of truss stresses by method of joints.

Figure 2.9 Method of joint

Sources: (“Method of Joints of construction | Civil Engineering,” n.d.)

Furthermore, 3D trusses also can be solved by using method of section like in Figure 2.10 where If there only a single-member load that need to be calculate, then the method of sections is the best way to do it just like 2D planar trusses. However, in 3D trusses, the section that being cut will have three force equation like method of joint but have additional equation which are three moment equations in order to find the unknowns.

$$\Sigma Fx = 0 \quad \Sigma Fy = 0 \quad \Sigma Fz = 0 \qquad 2.2$$

$$\Sigma Mx = 0 \quad \Sigma My = 0 \quad \Sigma Mz = 0 \qquad 2.3$$

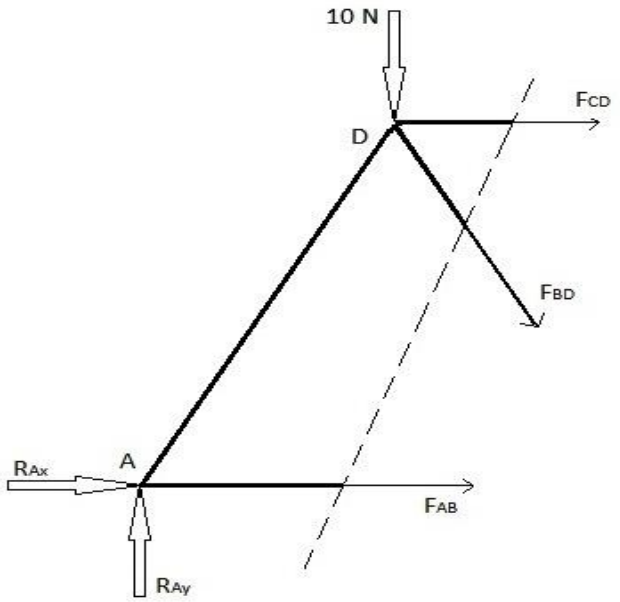


Figure 2.10 Method of section.

Sources: ("Method of Joints of construction | Civil Engineering," n.d.)

2.6.3 Steel Trusses

Trusses are used in a broad range of buildings. More specific it being used where there is requirement for long spans. Equally important, trusses used to be transfer structures and carry heavy loads. Steel roof trusses are usually more expensive than wooden trusses, but the main reason for using steel is simplicity and strength. Steel also good in term of durability, usability, low cost, flexibility, aesthetics, low weight and performance characteristics (Aksel & Eren, 2015). Steel also last a lot longer than timber and require very little maintenance in other word is simple.

Steel trusses give many benefits to construction projects as example they do not need chemical treatments to maintain the frame. It also lightweight, allowing easy and quick installation on site. Steel frames can also be recycled easily, making this option an ideal one for the environmentally conscious home or business owner. Although steel frame roof trusses require more skill to install, an experienced team should be able to fit them quickly and efficiently.

In Eurocode EN 1994-2: 6.6.2.3, actually there is no exact recommendation in design of composite truss, except there is formulas for the distribution of the longitudinal shear force into the local shear force in between steel section and concrete slab. There also formulas for the local on concentrated longitudinal force. In fact, the longitudinal forces are effected into the concrete slab only where at the points of increase in axial force at the chord and the web members are connected to the compressed chord where the panel points located. The most important fact for a standard truss was any construction that does not permit the roof or ceiling insulation in order to achieve the required R-value over the exterior walls (No, 2016).

2.7 Type of Roof Trusses

2.7.1 King Post Truss

A king post truss is a central vertical post used in bridge designs or even in architectural designs where it taking tension to support a beam below from a truss apex above exactly like in Figure 2.11. It is usually being used for wooden truss but it can also being built as combination of wood and steel. In addition, it can be used for roof spans up to 8 metre and limited to 3 m centre to centre.

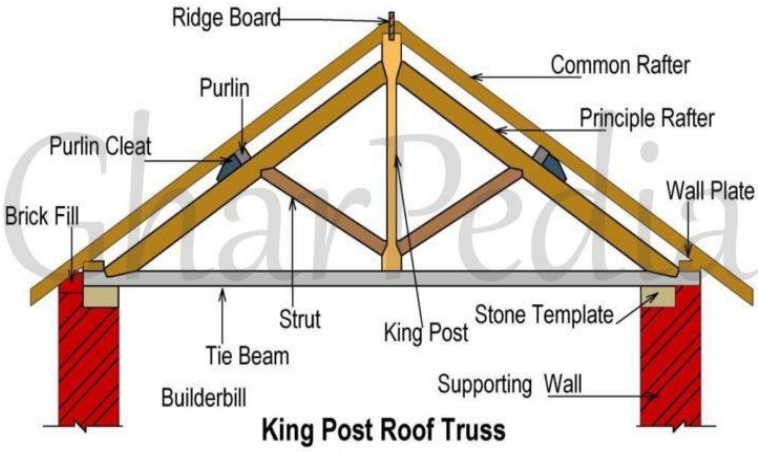


Figure 2.11 King post truss.

Sources: ("King Post Truss: All You Need to Know," n.d.)

In king Post truss, in order to prevent wall from spreading out due to thrust the tie beam receives the ends of the principal rafters. The king post at the middle is used to prevent the sagging of tie beam at the centre of a span. The struts connected into tie beams and principal rafters in inclined direction. Ridge beam is provided at the top of the roof in order to provide end support for the common rafters.

2.7.2 Queen Post Truss

Queen Post Truss is defined as a pitched roof. It being support by using two vertical tie posts that connected between the tie beam and the rafters that can be referred in Figure 2.12 . It also more to wooden trusses but can be used for up to 10 metre spans.

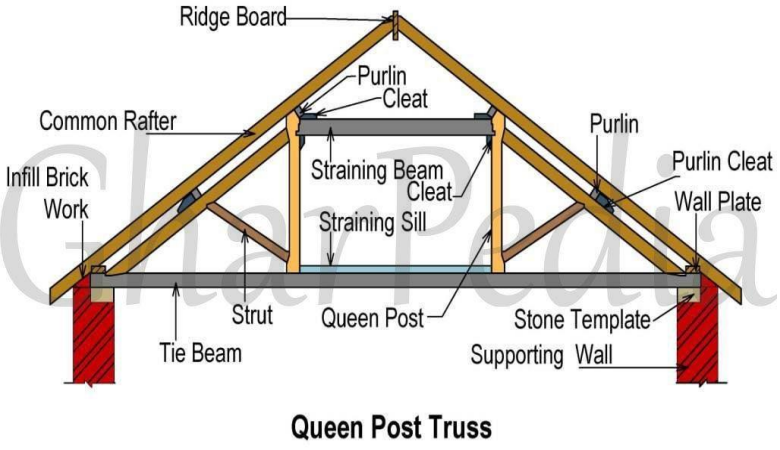


Figure 2.12 Queen post truss.

Sources: ("Queen Post Truss: All You Need to Know," n.d.)

A straining sill is fixed on the tie beam. It also fixed in between at the lower part of queen post. This straining sill can reduce the thrusts from struts and the queen posts and tie beam are in tension members. Other than that, are in compression members like the principal rafters, straining beams, struts and straining sill. The queen post truss is lighter and simpler. It is different like king post truss because it does not put weight on the centre of the main tie beam.

2.7.3 Pratt Truss

Pratt truss is made of steel and most common type of truss. There are two members for this trusses the vertical members are in tension and diagonal members are in compression. This type of truss have being classified as very economical form of roof trusses. Furthermore, pratt truss can be used for spans from 6 to 10 metre. Figure 2.13 show the structure of pratt truss.

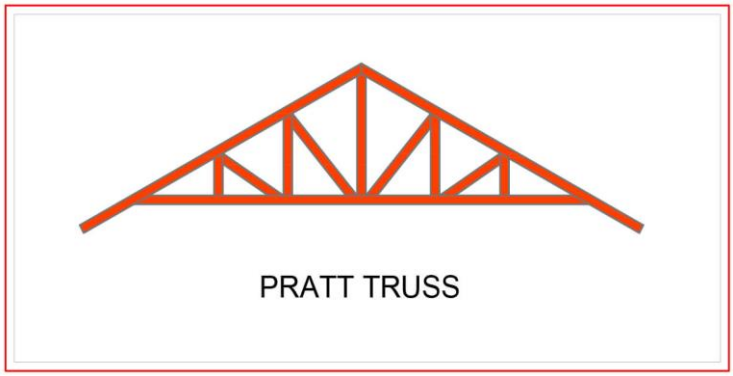


Figure 2.13 Pratt truss.
Sources: (“Weblet Importer,” n.d.)

2.7.4 Howe Truss

The name of Howe Truss was from it finder William Howe and originally designed to combine between vertical iron rod tension members and diagonal timber compression members as example the Comstock Bridge (Brown, 2016). After a few years, the Howe Truss was later used in steel bridges. It is impressive strength over long spans that is related to the railroad bridge not building trusses such as Figure 2.14.

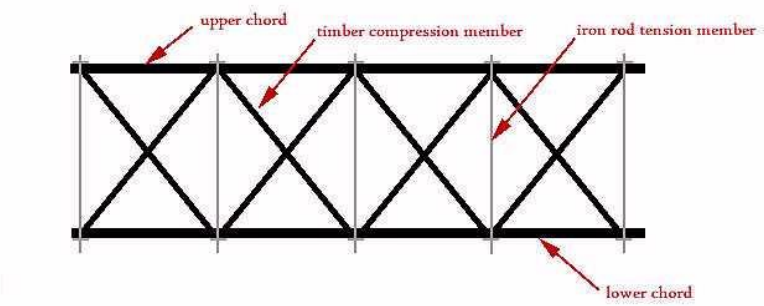


Figure 2.14 Howe truss.

Sources: (“Howe Truss,” n.d.)

Howe truss is made of combination of wood and steel. It being separated in their materials for different members where vertical members or tension members are made of steel and others in compression are using wood. The range of spans in between 6 up to 30 metre.

2.7.5 Fan Truss

Fan trusses is made of steel where it can be used for truss that have spans 10 to 15 metre. In fan trusses it need more support for purlins so it have top chords that being divided into small lengths exactly same in Figure 2.15.

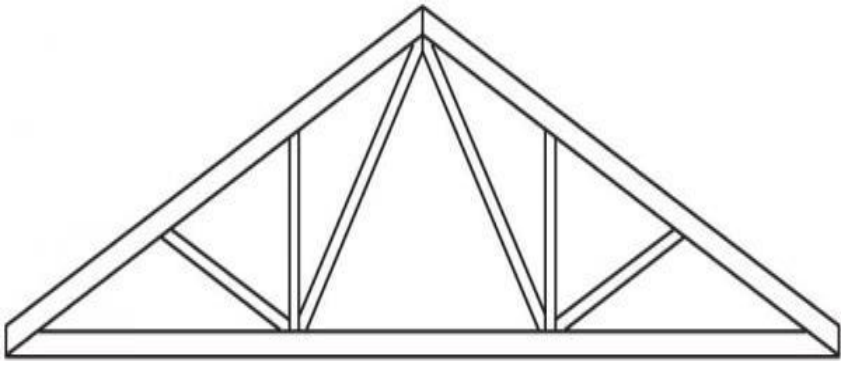


Figure 2.15 Fan truss.

Sources: (“Utah Building Lumber | Sunroc Building Materials,” n.d.)

2.7.6 North Light Roof Truss

North light roof trusses usually used for short span of roof. It is commonly used in industrial workshop - type buildings as example in Figure 2.16 and for 2D view exactly like figure 2.17. It is being called north light because it allow the building to get maximum benefit from natural lighting by using glazing on the steeper pitch that generally faces north or north-east in order to reduce solar gain. It also known as one of the oldest and economical methods of covering large areas (Adriaenssens, Liu, Wahed, & Zhao, 2013).

Figure 2.16 North light roof truss

Sources: ("R021b North Light Engine Shed - Scalescenes," n.d.)

Moreover, one employing wide span that can support trusses at right angle being used for floor span that exceeds 15 metre because it more economical than simple truss arrangement. In addition, side lighting provision must also be made for ventilation purposes for the roof. This roof consists of series of trusses that being fixed to girders. The short vertical side of the truss is glazed, it being used so that when the roof is used in Northen Hemisphere, the glazed part will faced north that give the best light.

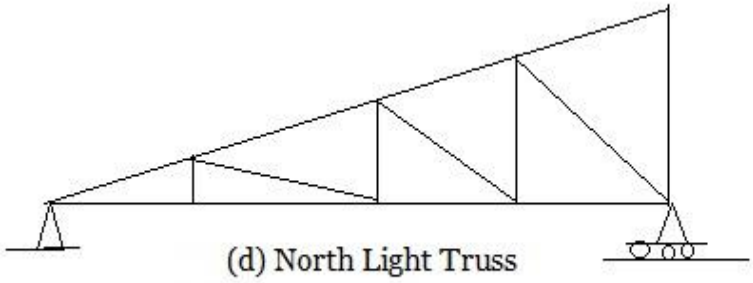


Figure 2.17 North light roof trusses in 2D view.
Sources: (“Structural analysis - Wikipedia,” n.d.)

2.7.7 Quadrangular Roof Truss

Quadrangular roof trusses more likely for long span trusses such as railway sheds and auditoriums. This truss may be considered as two trussed rafters that held in place by the tie T at the centre as shown in Figure 2.18 and 2.19. The portions of the truss which are in compression are indicated by double lines while the single lines represent the tension members. The dotted lines represent counter-braces or ties, which might be brought into action in case of a heavy snow load on one side only or during a severe gale.

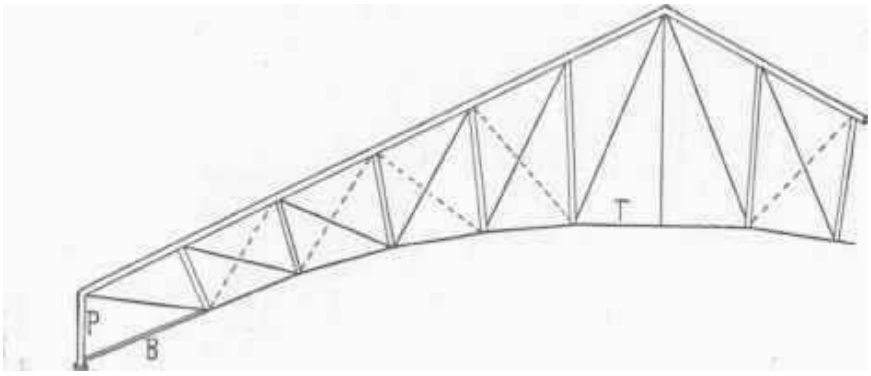


Figure 2.18 Quadragular roof truss.

Sources: (“36. The Quadrangular Truss,” n.d.)

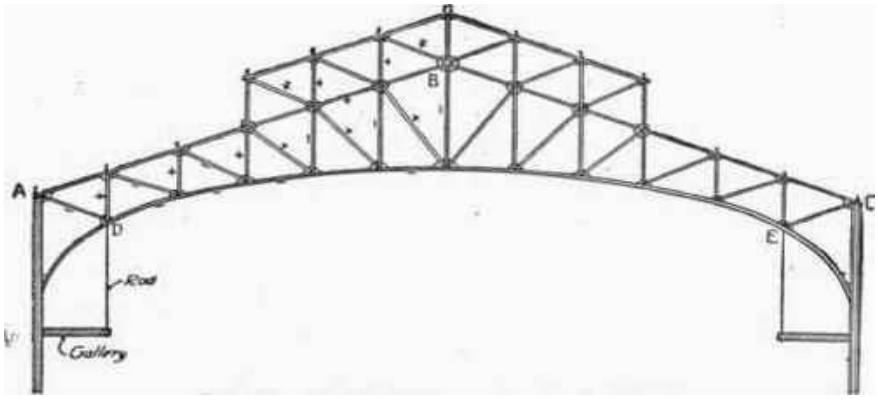


Figure 2.19 Quadragular roof truss double structure.

Sources: (“36. The Quadrangular Truss,” n.d.)

2.7.8 Parallel Chord Roof Truss

Parallel chord roof trusses have two chord that parallel which are top and bottom. It is being used as a rafter of trusses. This type of trusses are very light and economical for a larger spans of trusses because of the space provided like Figure 2.20. Other than that, this trusses give an easy access for services or maintenance. Although, it have many advantages if it being used, it also have drawback that can be seen on site where this type of trusses cannot be site modified.

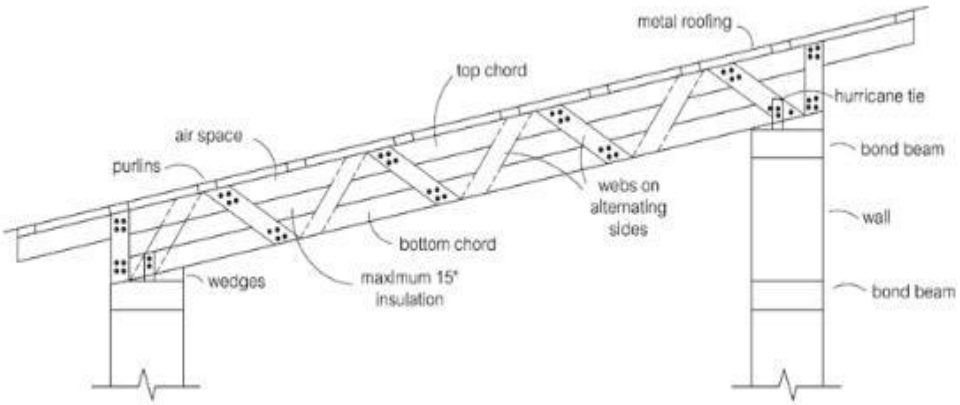


Figure 2.20 Parallel chord roof truss.

Sources: ("Parallel Chord Pallet Trusses," n.d.)

2.7.9 Scissor Roof Truss

Figure 2.21 show a scissor truss is a truss that has sloped bottom chords that create a sloping inverted-V shape inside the room under the truss. Actually, scissor units build from two bars connected by a revolute joint (Mele, Temmerman, Laet, & Mollaert, 2010). A scissors truss is a really good roof framing option to most of the house. When the scissor roof being used the speed of framing with common trusses can be obtain but also the added benefits of an interior sloped ceiling. Scissors trusses attach to two wall sections and the builder usually spaced trusses 24 inches on centre.

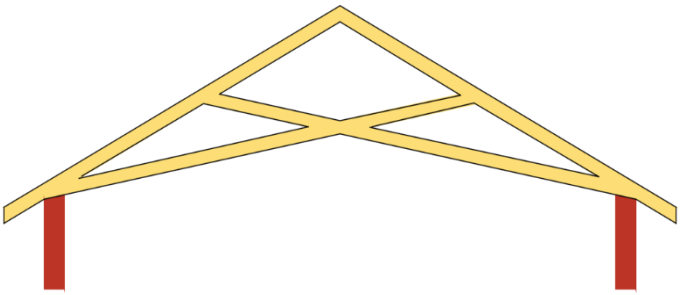


Figure 2.21 Scissor roof truss.

Sources: (Harris, 2006)

2.7.10 Raised Heel Roof Truss

Raised-heel trusses are engineered wood trusses that fitted with a heel where the bottom chord intersects with the perimeter wall plate which raises the top chord. This additional space allows you to increase the amount of insulation you can use without compressing it. As with all modern trusses, raised heel trusses are engineered utilizing advanced manufacturing, quality materials and advanced design techniques. Other than that, these type of trusses exceed building code requirements, also ensure uniformity and accuracy in roof framing.

The raised-heel provides additional space for cheaper attic insulation and for the full depth of insulation to be extended right to the outside of the top plate. The R-value can be reduced, when insulation is compressed. With a raised heel truss, you have enough space to utilize cheaper insulation methods such as fiberglass batts or blown cellulose. When a raised-heel truss roof is combined with an efficient building envelope and a well-ventilated attic, it reduces the pressure and temperature differences between the home and the attic space.

Raised-heel trusses being installed exactly like conventional trusses, so no different tools or technique is needed to build them so it is easy to build. Another, Raised-heel trusses using continuous plywood or OSB sheathing that can saving time and expense that can be referred to the requirements in section R602.10.8.2 of the 2015 International Residential Code. Next, by using raised-heel trusses, it compress the attic insulation over the top plate that compromises the insulation value exactly like Figure 2.22.

The high of raised-heel trusses enough to leave the insulation value intact and the energy code. So, it allows the use of less insulation for the ceiling system when this type of trusses being used. The wall to truss connection in raised-heel trusses is like a toenailing. This results will improved resistance to lateral forces like winds or seismic activity in walls. The raised-heel trusses also can improved ceiling insulation where it can eliminates cold spots at the top of exterior walls that can give more stable temperature in the house.

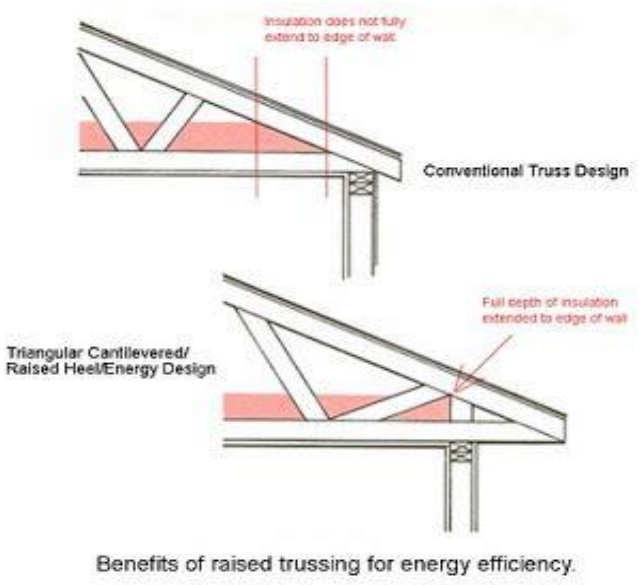


Figure 2.22 Raised heel roof truss.

Sources: ("RAISED-HEEL TRUSS : Also called an energy truss, is a roof truss that is designed to reduce energy losses. A vertical extension at th… | ARE : SS terms in 2019…," n.d.)

2.8 Introduction to SAP 2000

SAP2000 software is a Structural Analysis Program is stand-alone finite-element-based structural program that used to analyze and design any civil structural system (Binder, Binder, & Kwong, 2016). The software provided 2D to 3D model of structure and the version 14 can be seen in Figure 2.23. 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.

Figure 2.23 SAP 2000 version 2014.

Sources: ("SAP2000 v14 Structural Analysis Software | KulasCivilWorks," n.d.)

2.9 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

METHODOLOGY

3.3 Introduction

In this chapter, detail of process of collecting information and data being explain in order to making decision. The planning of study already done in the first month of semester. In the planning process, the important thing was the title so that scope of the study and problem statement can be decided. The title chosen was about performance of 3D trusses under earthquake loading that being modelling and analyses by using software called SAP 2000.

Actually, the earthquake loading data come from time history earthquake data that have been obtained from Malaysian Meteorology Department (MMD) right after the proposed title being approved. Then, the earthquake data being used along the study to analyze the 3D trusses structure model. So, to make sure the project can be finish on time the planning and schedule are as follow in Figure 3.1:

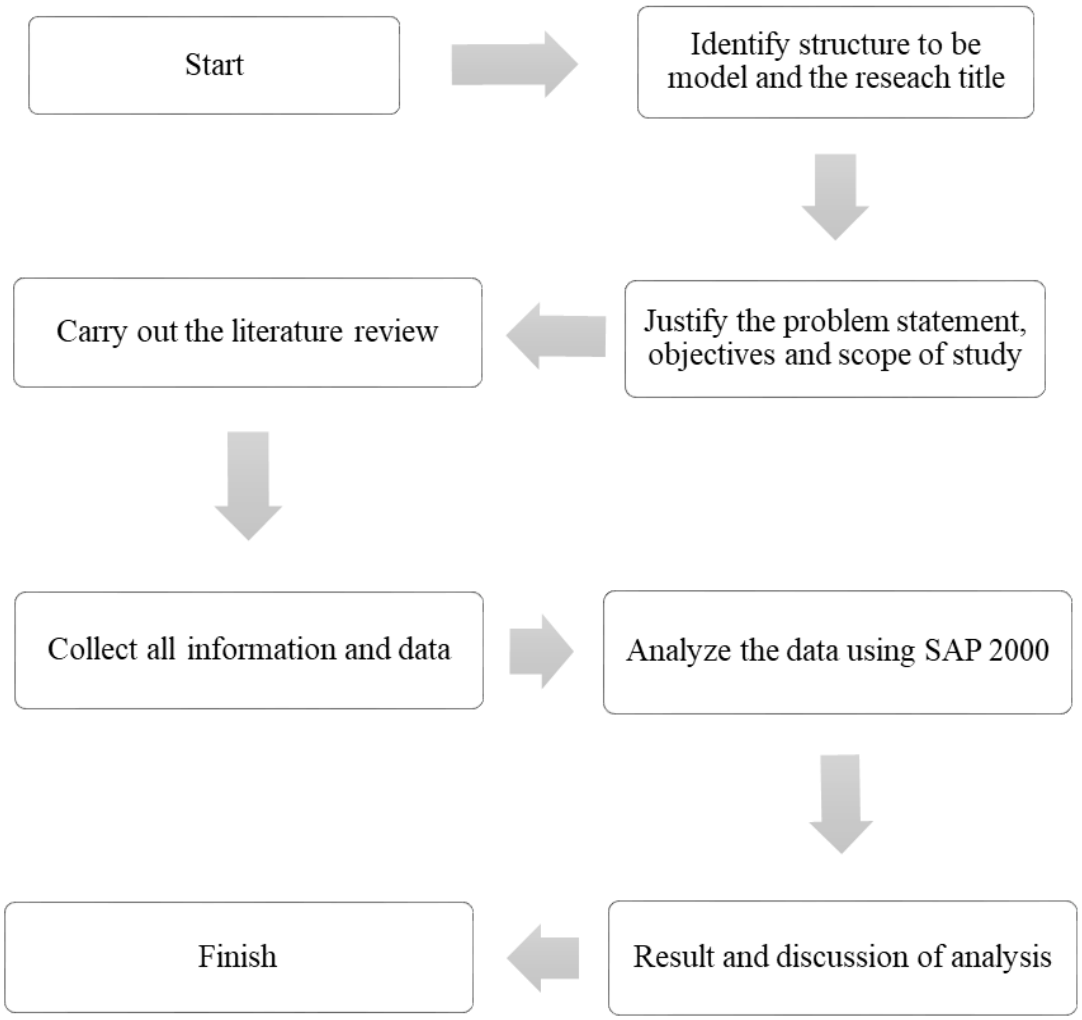


Figure 3.1 Flowchart for this thesis.

3.2 Literature Review

Literature review is very important chapter where it provided the understanding about this research. The sources of obtaining the literature review is info from article, journal, education book, magazines and a research paper or thesis. All the sources acted as evidence to the statement in the research.

Data collections should be conducted during this literature review chapter. The type of data that collected are about earthquake, causes of earthquake, seismic wave, measurement of earthquake, 3D trusses and SAP 2000 software program. The main source for this research literature review is from a journal; Earthquake Tips: Learning Earthquake Design and Construction by C.V.R Murty and time history of earthquake data from Malaysian Meteorology Department (MMD).

3.3 Information and Data Collection

During this process, all the important information and data for the structure need to be obtained so that the modelling and analysis can be done at the end of this research. The information and data needed are as follow:

I. Earthquake data from Malaysia Meteorology Department (MMD)
II. Location of the research study for the 3D trusses structure
III. Drawing of 3D trusses
IV. Types of 3D trusses use around the world
V. Material used for the 3D trusses structure

3.4 Step Analysis in SAP 2000

Step 1: Define the coordinate of grid line

First of all, grid line need to be created by choosing “grid only” template. In making all process become easier, the unit need to be changed to “KN, m, C”. Then, edit the coordinate and grid at “Define Grid System Data”.

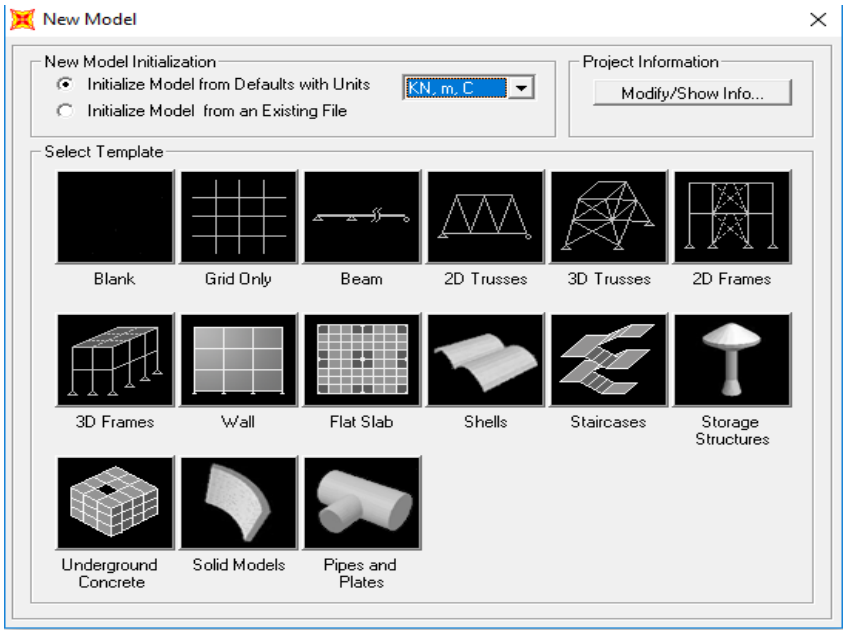


Figure 3.2 Selection of Grid Only template.

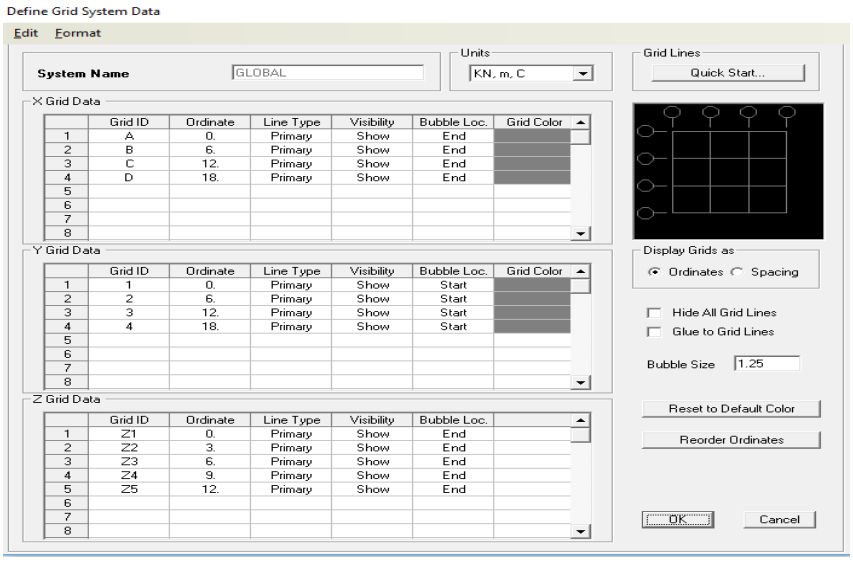


Figure 3.3 Define grid system data.

Step 2: Section name

Select button section properties >frame section>import double angle>add new property>choose section label>add auto select>change section name to truss>choose section.

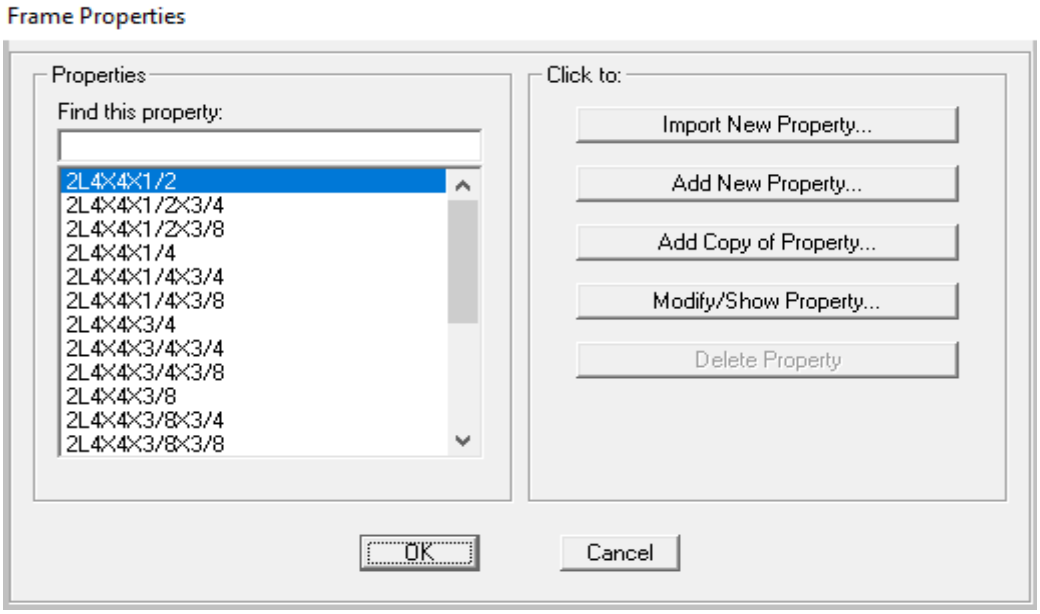


Figure 3.4 Choose section label at frame properties.

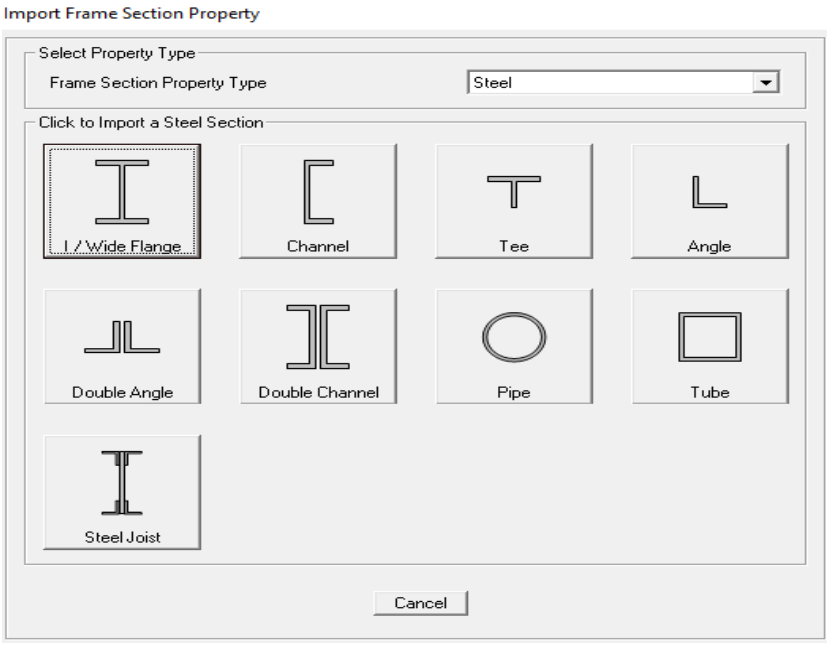


Figure 3.5 Import double angle as property type.

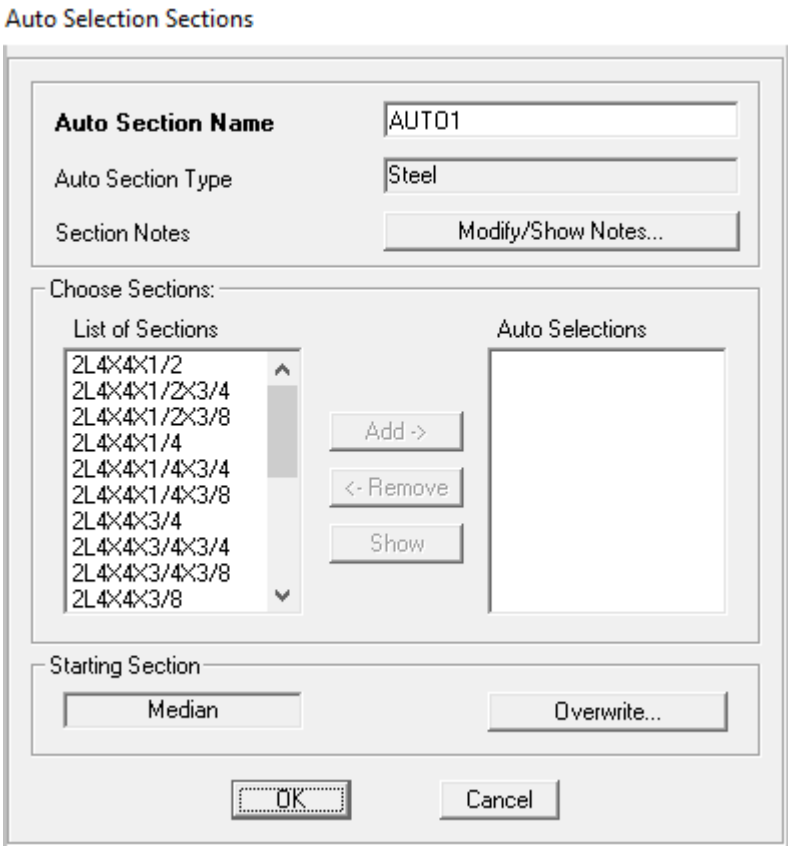


Figure 3.6 Change section name and choose section.

Step 3: Draw the trusses

Use the draw frame to draw the trusses. Draw the bottom part first, then it can be replicate to other parts. The values at replicate can be change for different plate that being drawn. The diagonal member need to be assigned with moment so it can be done by clicking assign> release/partial fixity. Next, the area of trusses can be build by area of section. Then draw the area by using draw rectangular area tool.

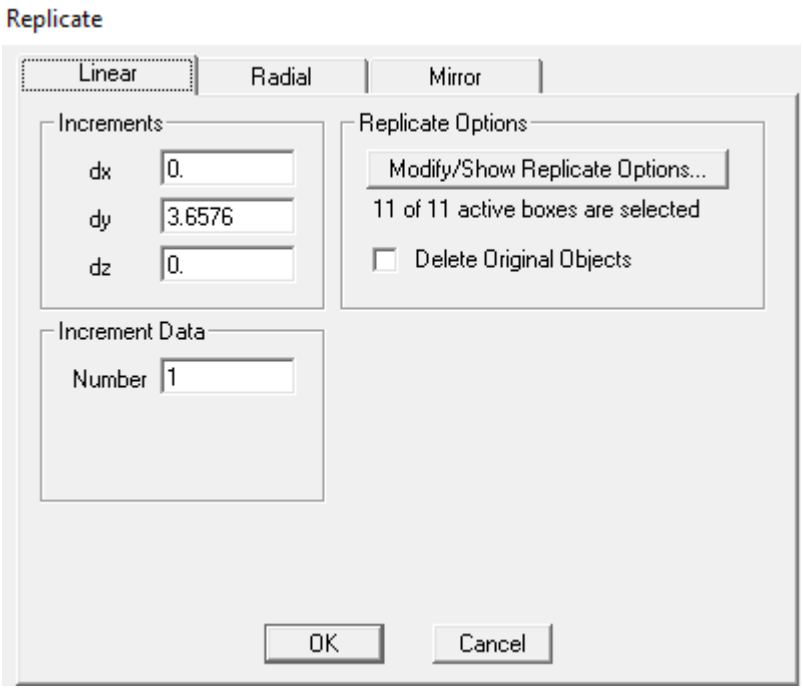


Figure 3.7 Replicate tool for draw the component.

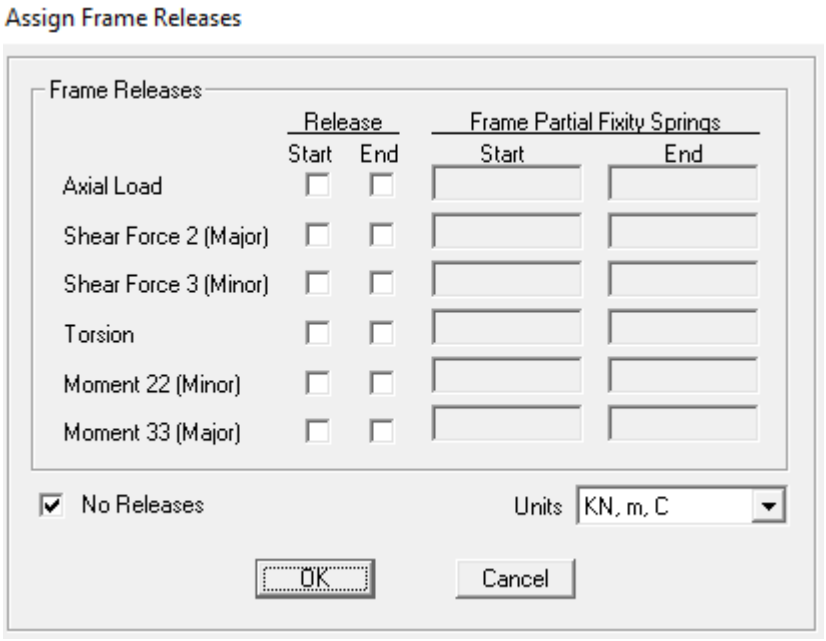


Figure 3.8 Assign frame releases for diagonal member.

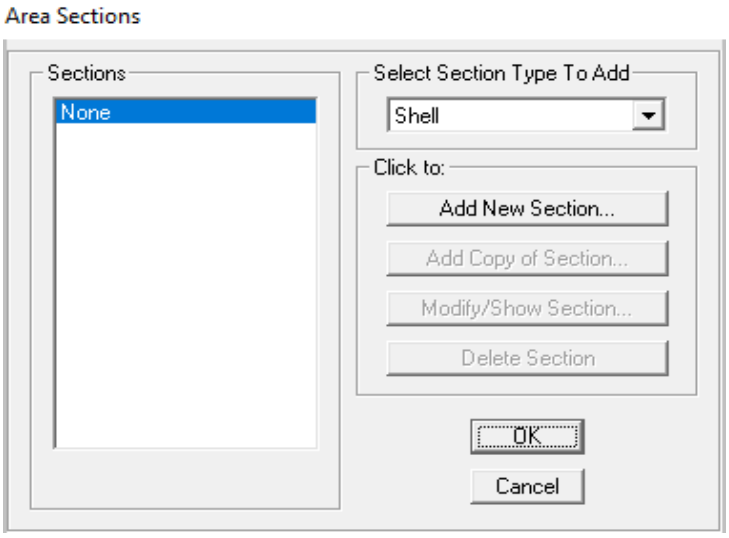


Figure 3.9 Defines area section for the base.

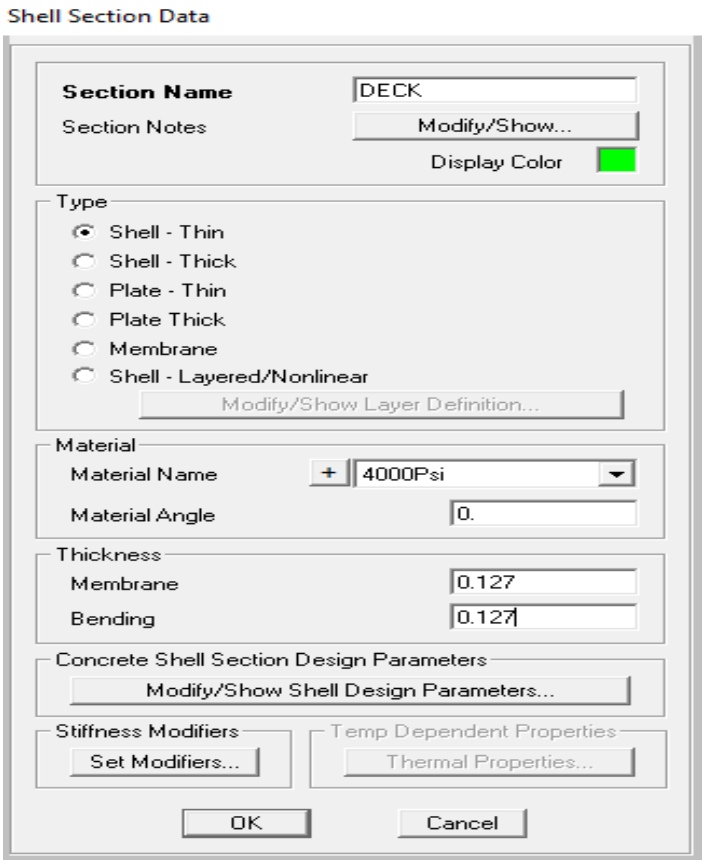


Figure 3.10 Define the section and the thickness.

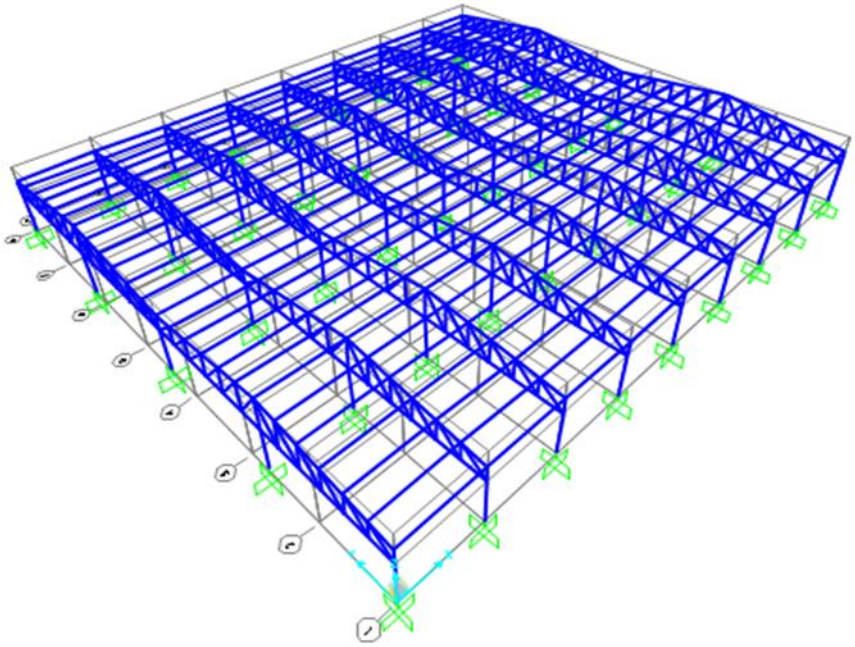


Figure 3.11 The 3D view of the drawn trusses.

Step 4: Add restraint

Choose selected joint and add the restraint on that chosen joint.

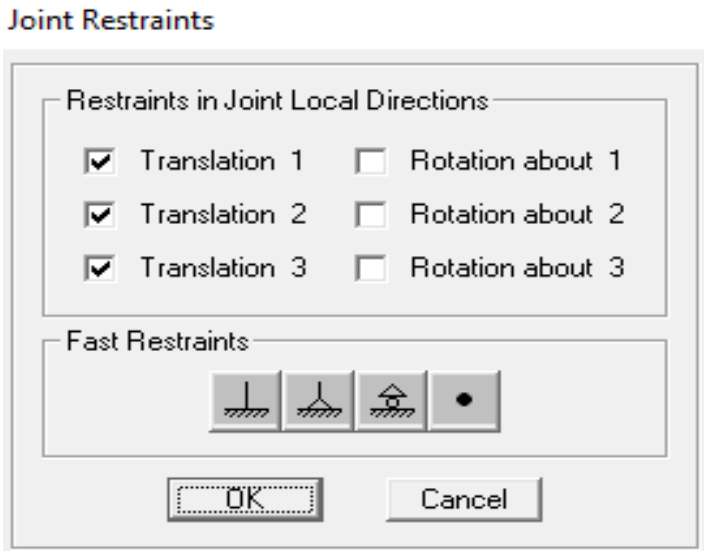


Figure 3.12 The preferred choice of joint restraint.

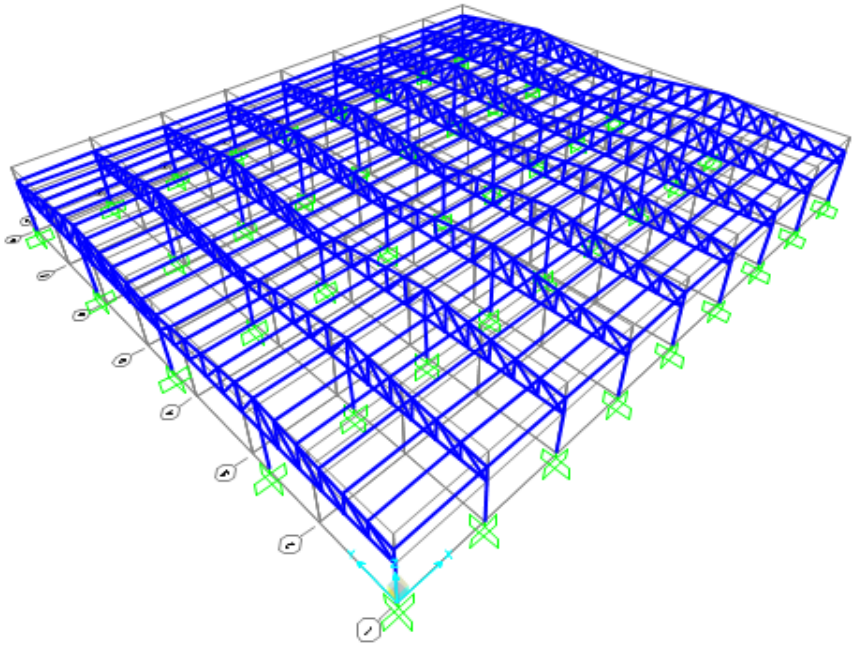


Figure 3.13 The 3D view of the drawn trusses with restraint joint.

Step 5: Defines the Load

Before run the analysis, the load need to be assign. The dead load already there but need to be added the live load. Other than that, the stiffness modification also need to be filled up. So, to make the 3D view more clear click the “display options for active window”.

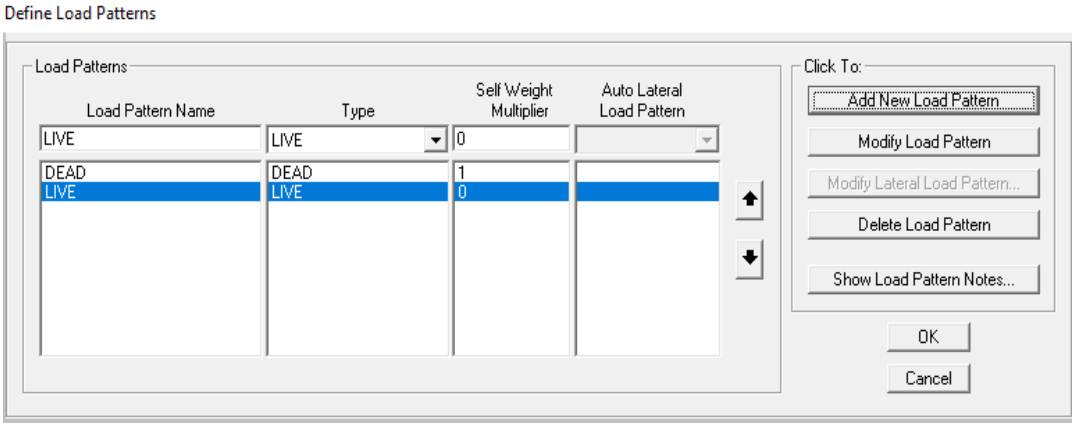


Figure 3.14 Define load or added new load pattern.

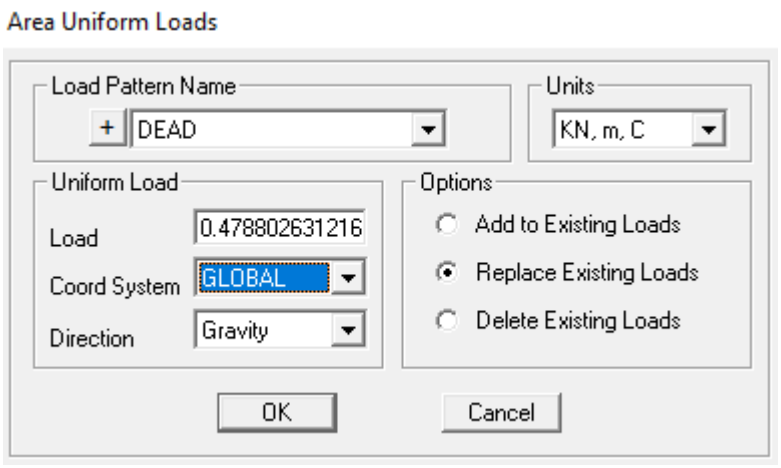


Figure 3.15 Assign the uniform load area.

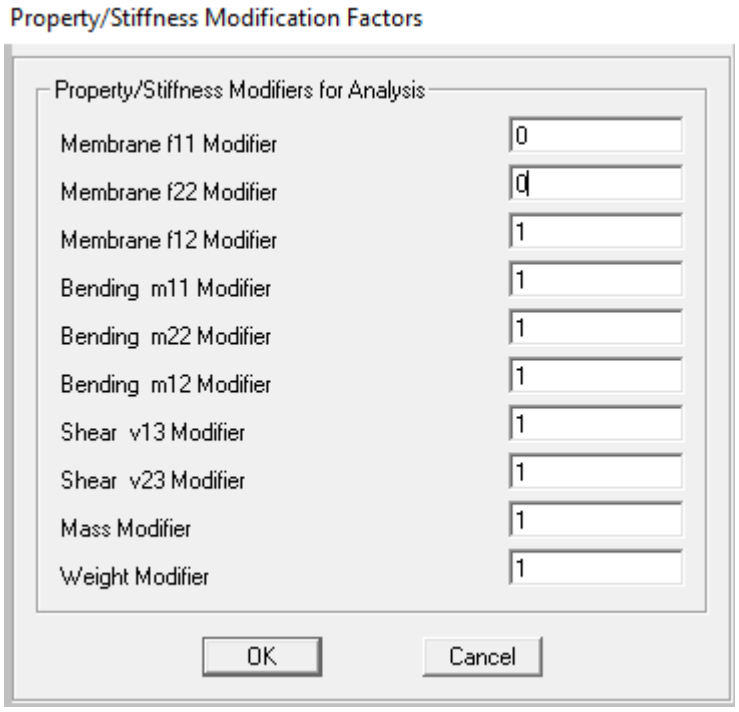


Figure 3.16 Stiffness modification for analysis.

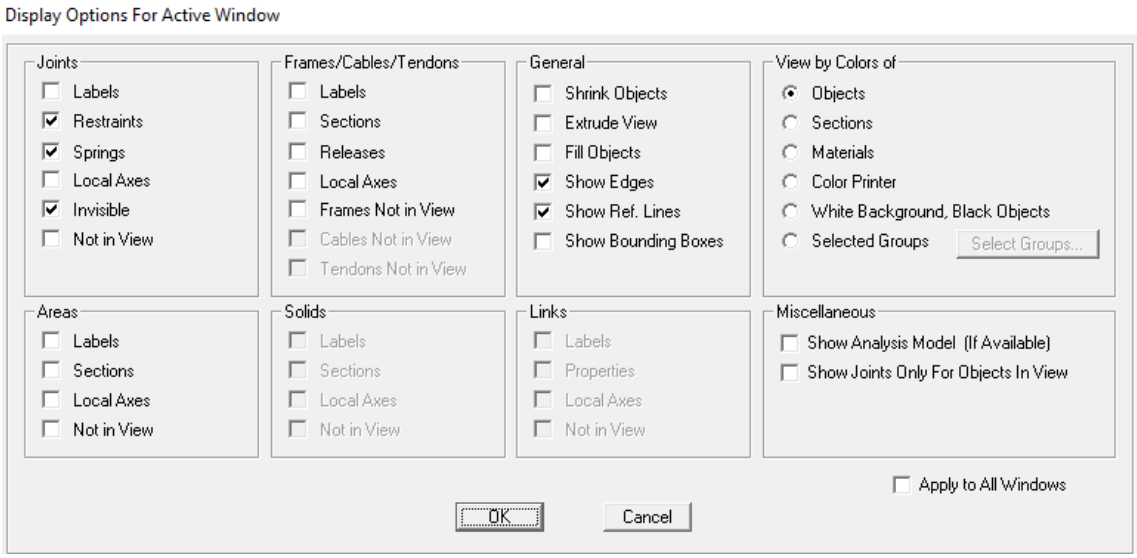


Figure 3.17 The display options for active window in 3D view.

Step 6: Defines 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. The time history need to be added function type.

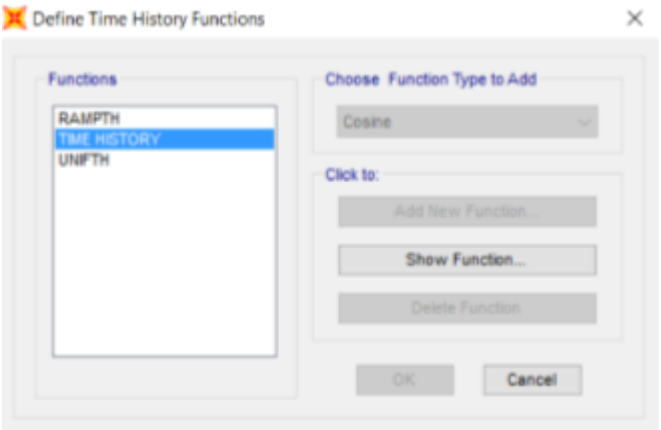


Figure 3.18 Added function type for the time history.

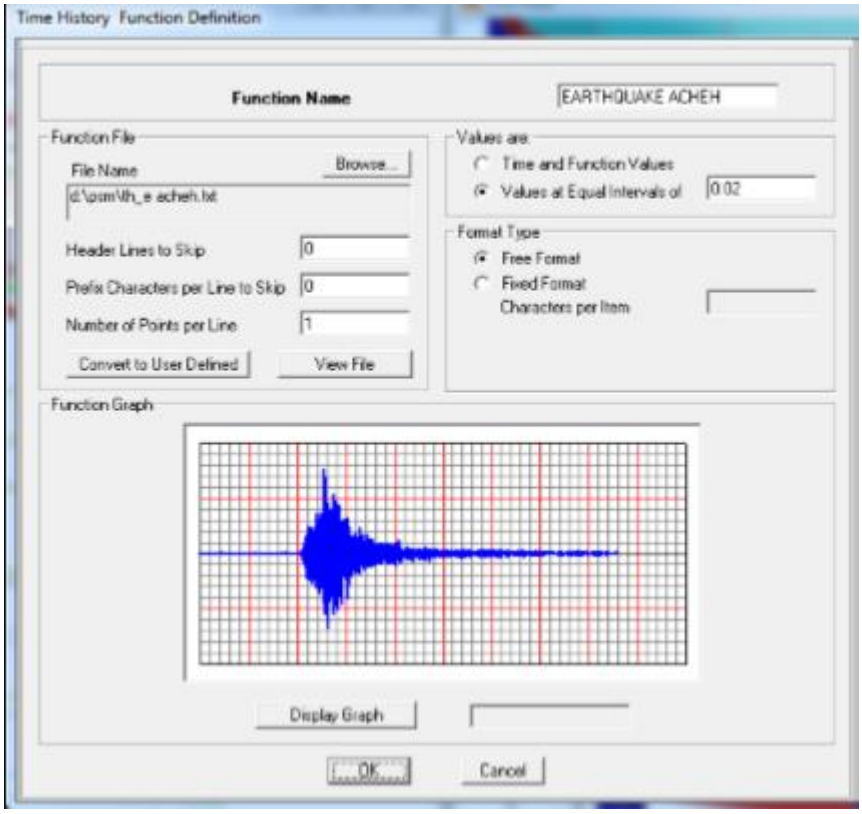


Figure 3.19 Added function type for the time history.

Step 7: Run Analysis

To start analysis the project, load case should be define. To load cases click "Analyze", and choose set load cases to run. The load cases choose are free vibration analysis (FVA), dead load (DL) + live load (LL), and free vibration analysis (FVA) + dead load (DL) + live load (LL). After clicking "run now "we can see the different shape of structure.

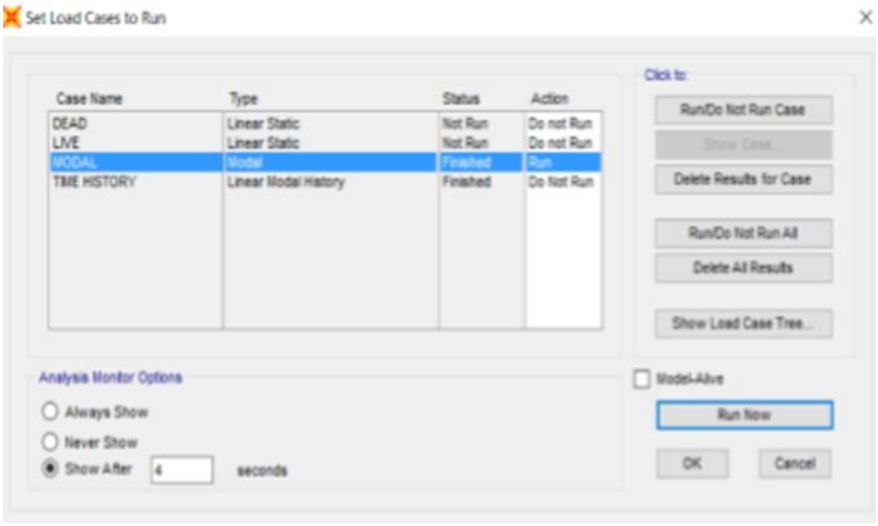


Figure 3.20 Part to change the load cases that need to be run.

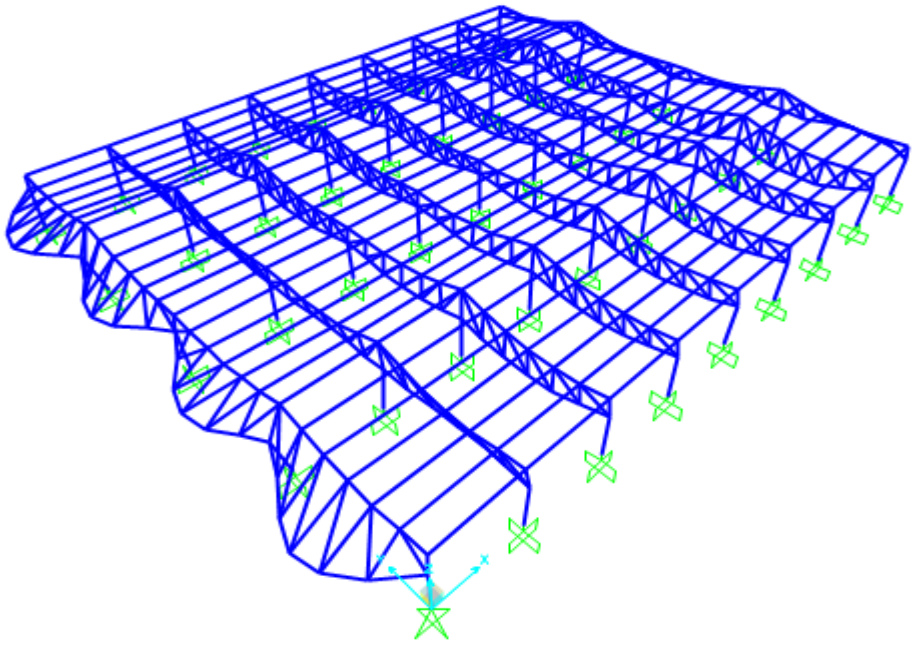
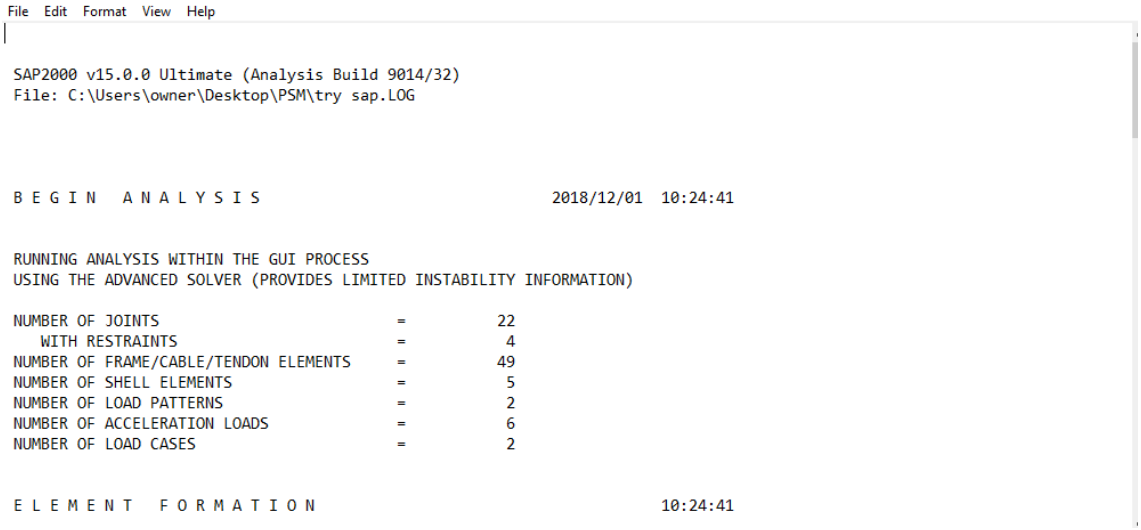


Figure 3.21 The 3D view after the analysis



File Edit Format View Help

SAP2000 v15.0.0 Ultimate (Analysis Build 9014/32)
File: C:\Users\owner\Desktop\PSM\try sap.LOG

B E G I N A N A L Y S I S 2018/12/01 10:24:41

RUNNING ANALYSIS WITHIN THE GUI PROCESS
USING THE ADVANCED SOLVER (PROVIDES LIMITED INSTABILITY INFORMATION)

NUMBER OF JOINTS	=	22
WITH RESTRAINTS	=	4
NUMBER OF FRAME/CABLE/TENDON ELEMENTS	=	49
NUMBER OF SHELL ELEMENTS	=	5
NUMBER OF LOAD PATTERNS	=	2
NUMBER OF ACCELERATION LOADS	=	6
NUMBER OF LOAD CASES	=	2

E L E M E N T F O R M A T I O N 10:24:41

Figure 3.22 The result of analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter represent the analysis of truss structure under earthquake loading. Earthquake loading that imposed to the structure are time history from Acheh and El–Centro earthquake but receiver in Malaysia. Euro Code or seismic code check are neglectable in this analysis.

4.2 Analysis of Truss Structure

There are 3 type of loads are imposed to spherical dome structure which are dead load, live load and earthquake load. Software used are SAP2000 to analysis the behaviour of truss structure under earthquake loading. By using SAP2000 there are 3 combination load cases that will be carry out in this analysis, which are:

i) Modal analysis (Free vibration analysis)
ii) Dead Load + Live Load
iii) Dead Load + Live Load + Acheh's Earthquake Loading
iv) Dead Load + Live Load + El-Centro's Earthquake Loading

4.3 Modal Analysis (Free Vibration Analysis)

Modal analysis also known as free vibration analysis is the analysis of the structure in motion movement and without any support motion or external forces. It can helps you understand how a structure vibrates in term of frequency, damping and mode shapes (Yashavantha Kumar & Sathish Kumar, 2017). It can be carried out by using SAP 2000 software. Structure which is trusses will be moved away from the equilibrium position due to the modal analysis.

From the free vibration analysis, there are 12 mode-shape of the truss structure can be obtained. Frequency and period of each mode shape are recorded, where the vibration of the structure occurs when the existing of frequency from the ground that being transfer to the structure the natural period which include the natural frequency, displacement and joint. Each of the mode shape of truss structure produce different natural period, natural frequency, circle frequency and lastly is eigenvalue.

By mastering the modes of vibration, it will help to easier and better design structure to withstand when earthquake happened. The figure below shown the 12 mode shape of the truss structure:

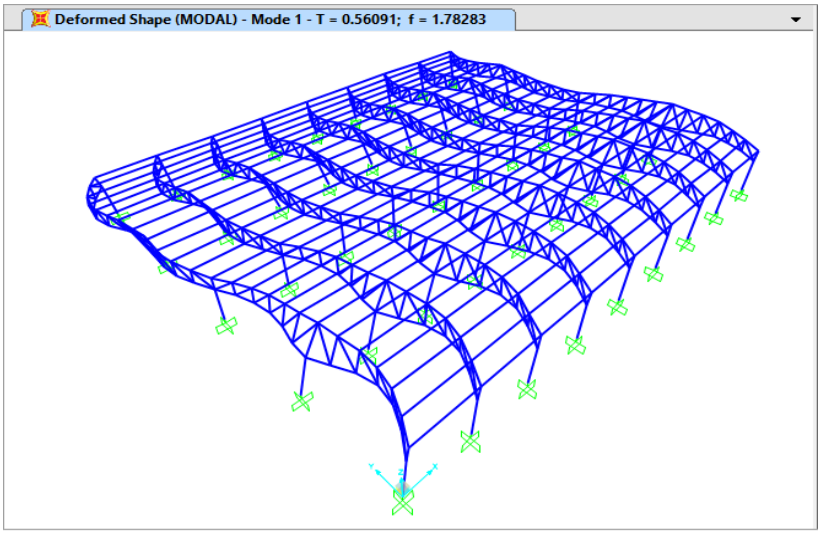


Figure 4.1 Mode shape 1 with value of natural period,T and frequency,f.

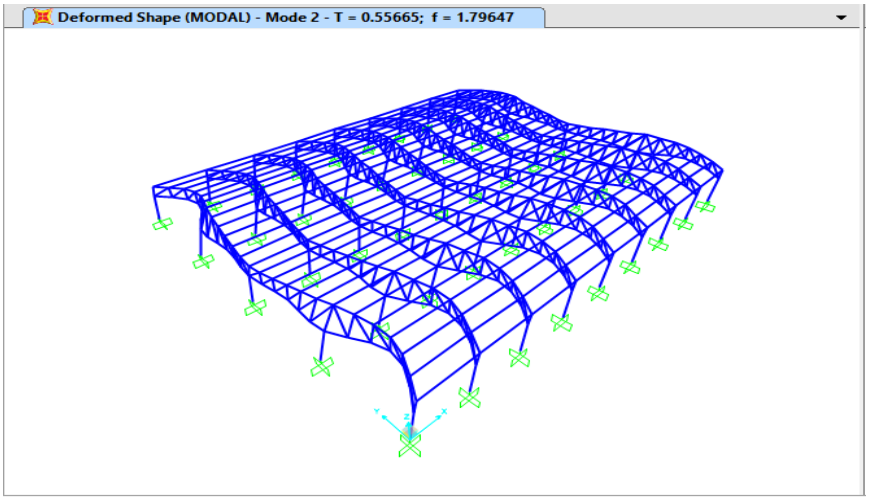


Figure 4.2 Mode shape 2 with value of natural period,T and frequency,f.

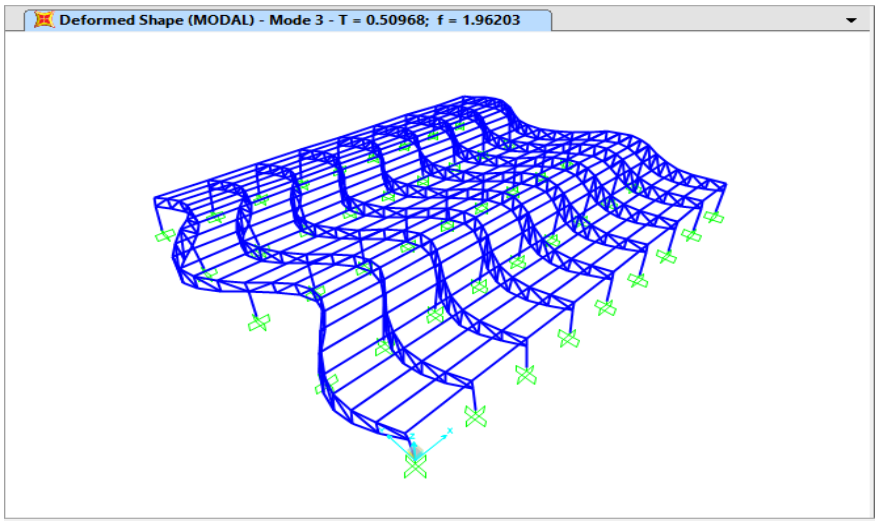


Figure 4.3 Mode shape 3 with value of natural period,T and frequency,f..

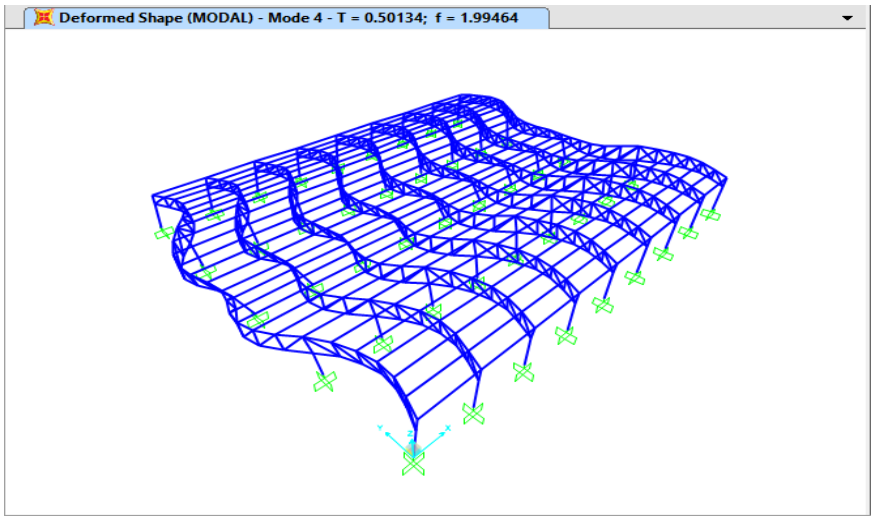


Figure 4.4 Mode shape 4 with value of natural period,T and frequency,f.

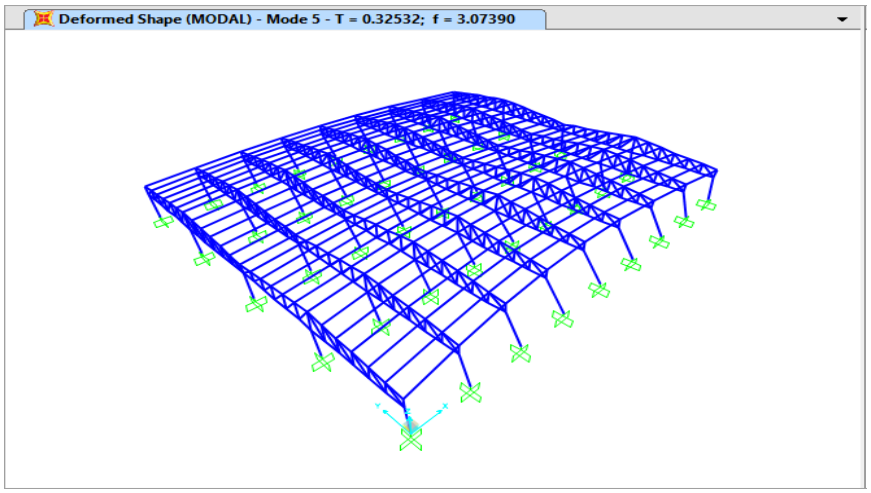


Figure 4.5 Mode shape 5 with value of natural period,T and frequency,f.

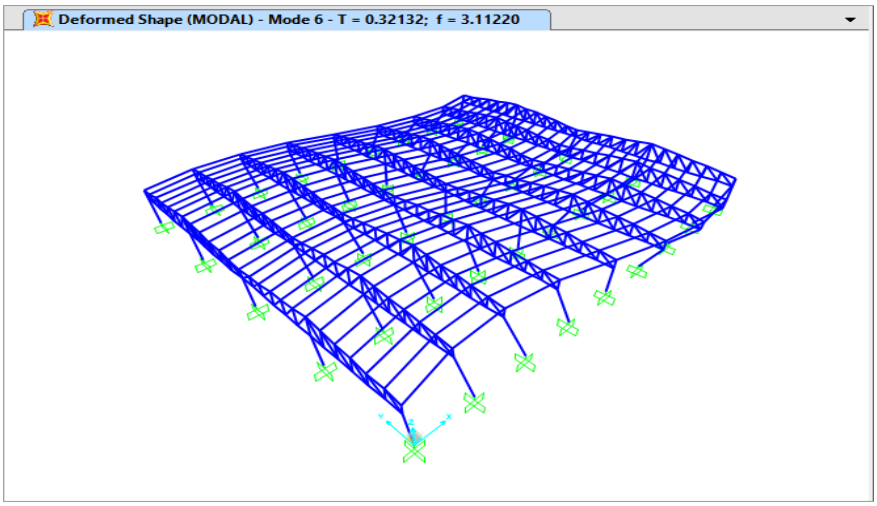


Figure 4.6 Mode shape 6 with value of natural period,T and frequency,f.

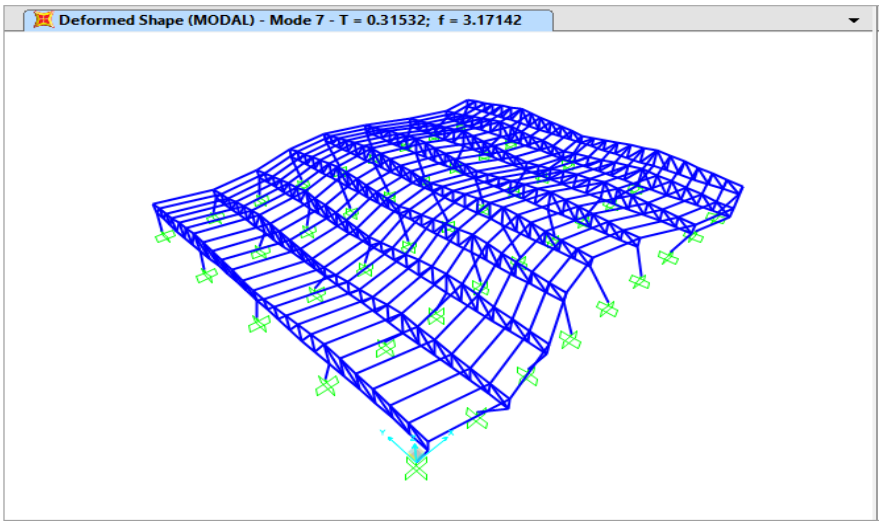


Figure 4.7 Mode shape 7 with value of natural period,T and frequency,f.

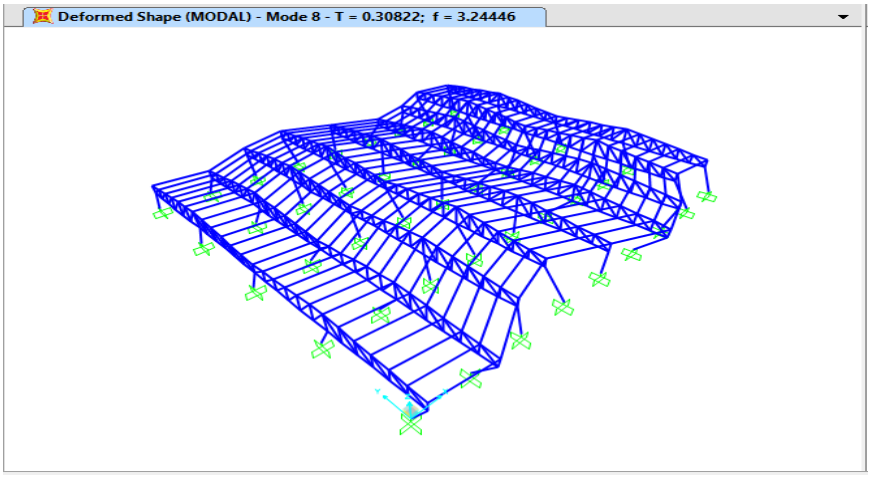


Figure 4.8 Mode shape 8 with value of natural period,T and frequency,f.

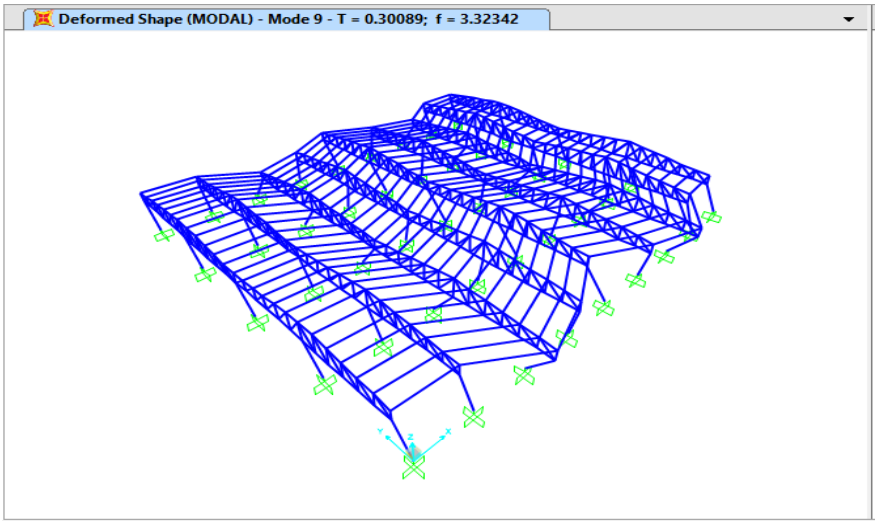


Figure 4.9 Mode shape 9 with value of natural period,T and frequency,f.

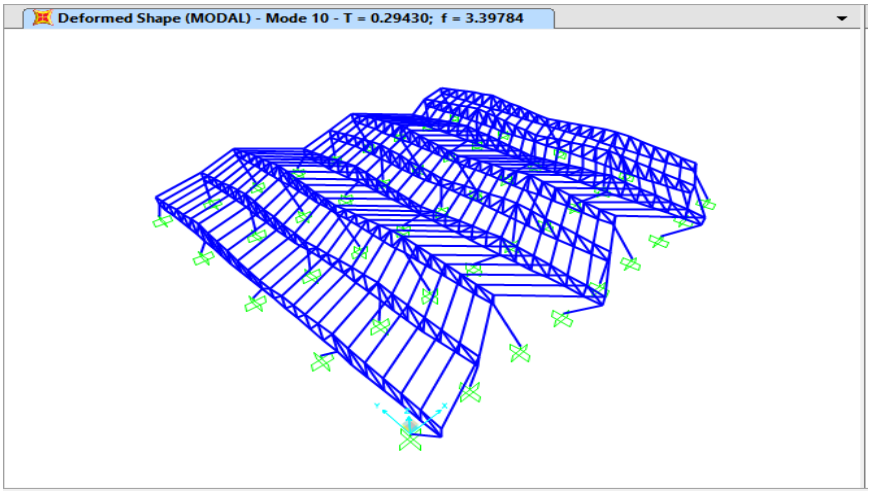


Figure 4.10 Mode shape 10 with value of natural period,T and frequency,f.

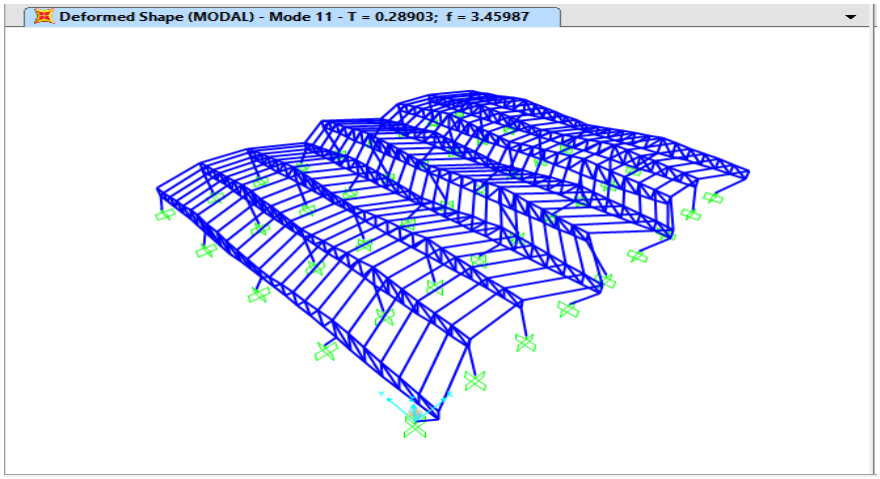


Figure 4.11 Mode shape 11 with value of natural period,T and frequency,f.

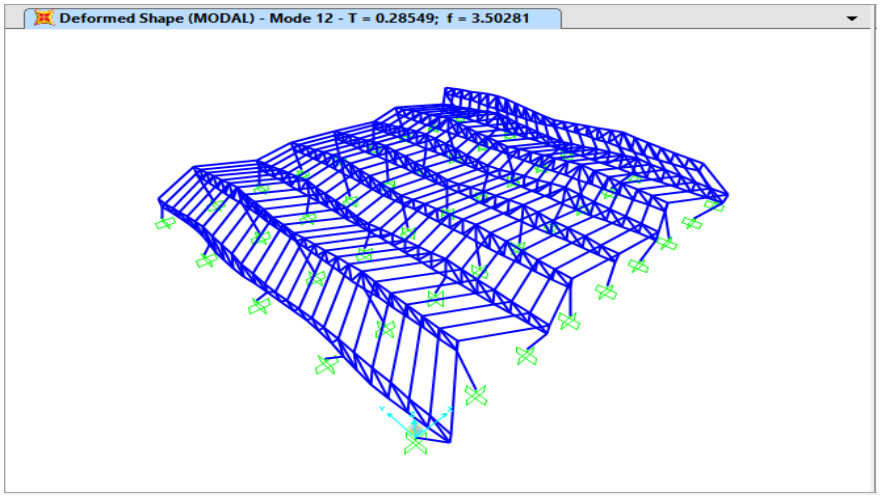
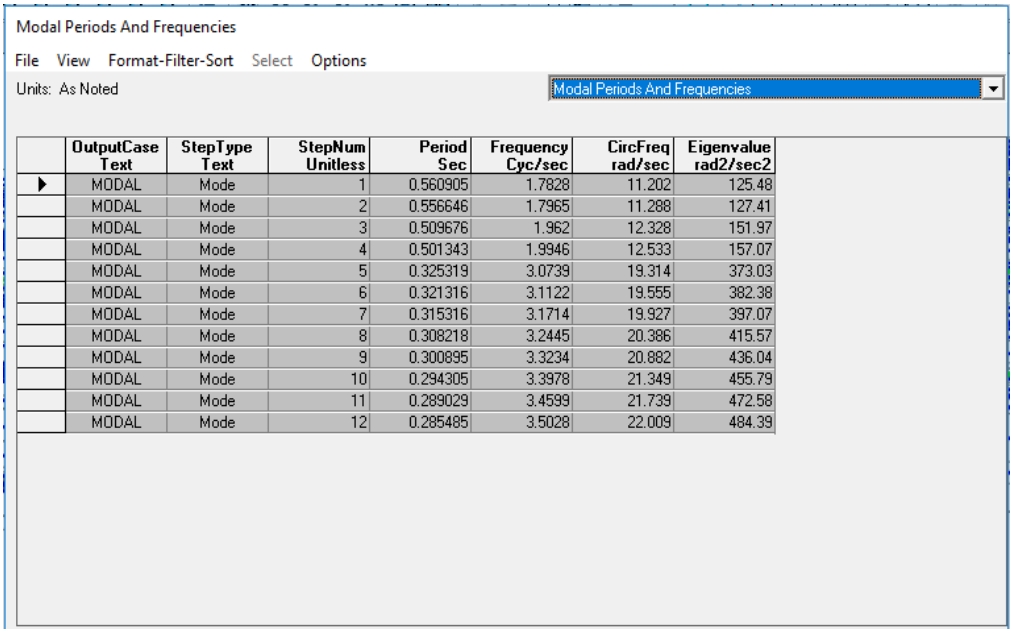


Figure 4.12 Mode shape 12 with value of natural period,T and frequency,f.



	OutputCase Text	StepType Text	StepNum Unitless	Period Sec	Frequency Cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
▶	MODAL	Mode	1	0.560905	1.7828	11.202	125.48
	MODAL	Mode	2	0.556646	1.7965	11.288	127.41
	MODAL	Mode	3	0.509676	1.962	12.328	151.97
	MODAL	Mode	4	0.501343	1.9946	12.533	157.07
	MODAL	Mode	5	0.325319	3.0739	19.314	373.03
	MODAL	Mode	6	0.321316	3.1122	19.555	382.38
	MODAL	Mode	7	0.315316	3.1714	19.927	397.07
	MODAL	Mode	8	0.308218	3.2445	20.386	415.57
	MODAL	Mode	9	0.300895	3.3234	20.882	436.04
	MODAL	Mode	10	0.294305	3.3978	21.349	455.79
	MODAL	Mode	11	0.289029	3.4599	21.739	472.58
	MODAL	Mode	12	0.285485	3.5028	22.009	484.39

Figure 4.13 The modal case analysis data after the analysis on the structure is run.

From the result of modal analysis, the modal shape 1 have the lowest frequency and higher natural period which are 1.7828 and 0.560905. Apparently, the modal shape 1 also have the lowest circle frequency and eigenvalue with 11.202 and 125.48 respectively. The modal shape 12 have the highest frequency and time period which are 3.5028 and 0.285485. This is showing that the first modal shape is the best modal shape among of twelve modal shape because it has the highest natural period and the lowest frequency.

Frequency also can be calculated by using formula of:

$$\text{Frequency} = 1 / \text{period} \qquad 4.1$$

Mode shape 1 produced period of 0.560905 sec. Frequency can be calculated by:

$$\text{Frequency} = 1 / 0.560905 = 1.7828/\text{sec}$$

4.4 Time History Earthquake Analysis

Time history analysis have been performed on the truss structure by referring to the earthquake data obtained from Malaysian Meteorological Department. Figure below show the graph of time data versus acceleration data from Acheh and El-Centro earthquakes. The result obtain from this analysis is time history responses at all joints of the truss structure. Time history analysis is used to determine the dynamic response of a structure under the action of any general time-dependent loads. This analysis can provides the best check to the safety of structure under earthquake loadings (Patil & Kumbhar, 2013).

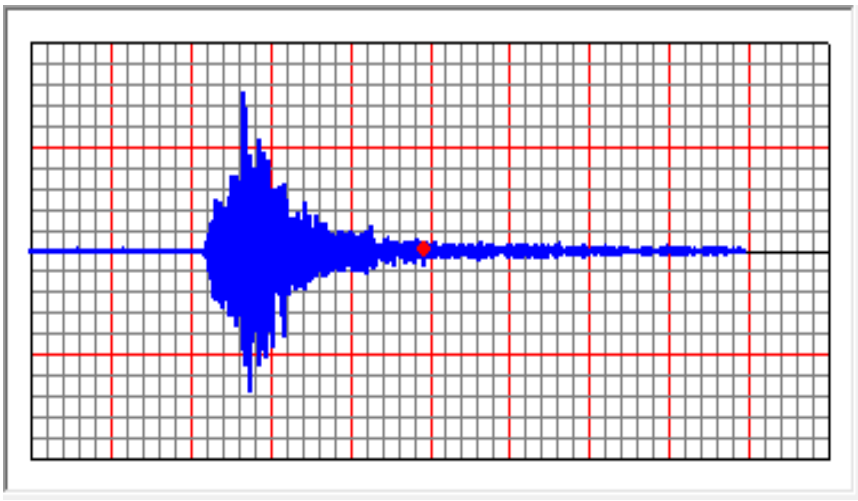


Figure 4.14 The graph of time data versus acceleration from Acheh earthquake.

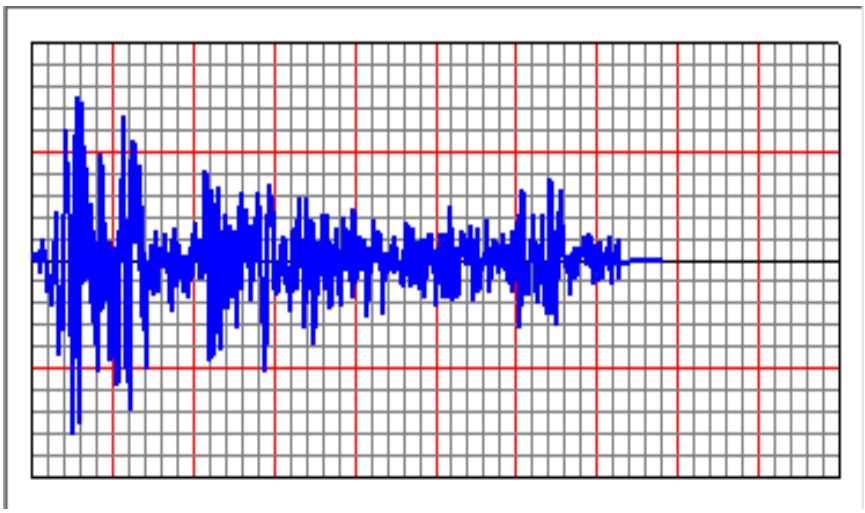


Figure 4.15 The graph of time data versus acceleration from El-Centro earthquake.

4.4.1 Dead Load and Live Load

The first load combination are between dead load and live load where the analysis used to obtain the maximum strength and loading situation without considering earthquake load. The dead load represent the permanent load on the structure while live load is the moving or imposed load of the structure. Both of the load used value of 1 as their scale factor.

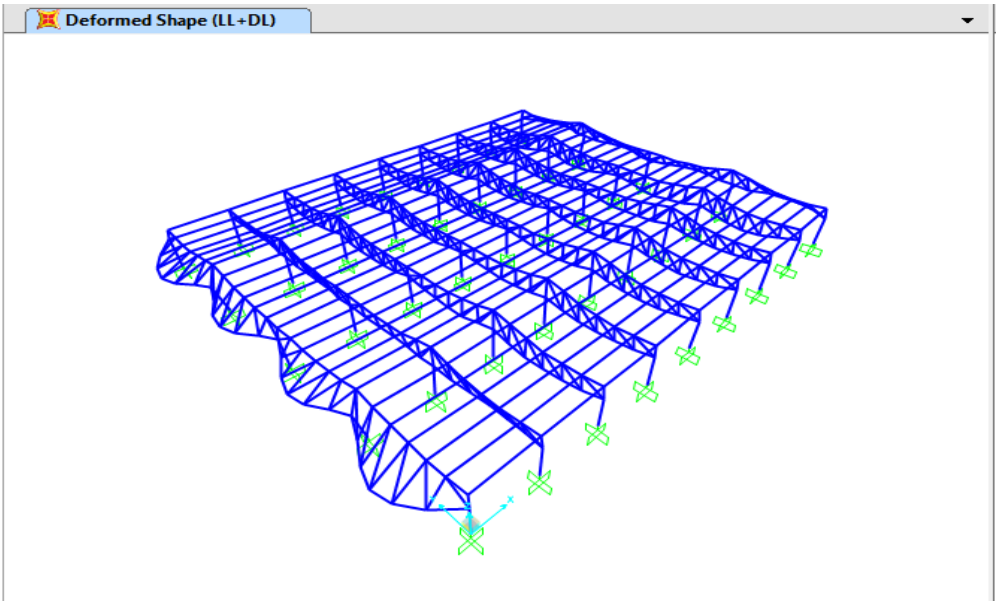


Figure 4.16 Deformed shape on structure for combination of live and dead load.

4.4.2 Dead Load (DL) + Live Load (LL) + Earthquake Load

The load combination are between dead load, live load and earthquake loading where the analysis used to obtain the maximum strength and loading situation by considering earthquake load. The load combination analysis showed the behavior of the truss structure when the earthquake loading being applied.

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 in order to show the result of the spectral displacement and acceleration of the selected joint.

4.4.2.1 Displacement

When earthquake occur, the structure will undergoes an inertia where the base of the building suddenly moves to the right but the building will move to the left that is relative to the base. These process are complex since the ground moves simultaneously in three mutually perpendicular direction during earthquake occur and it is simply occur displacement.

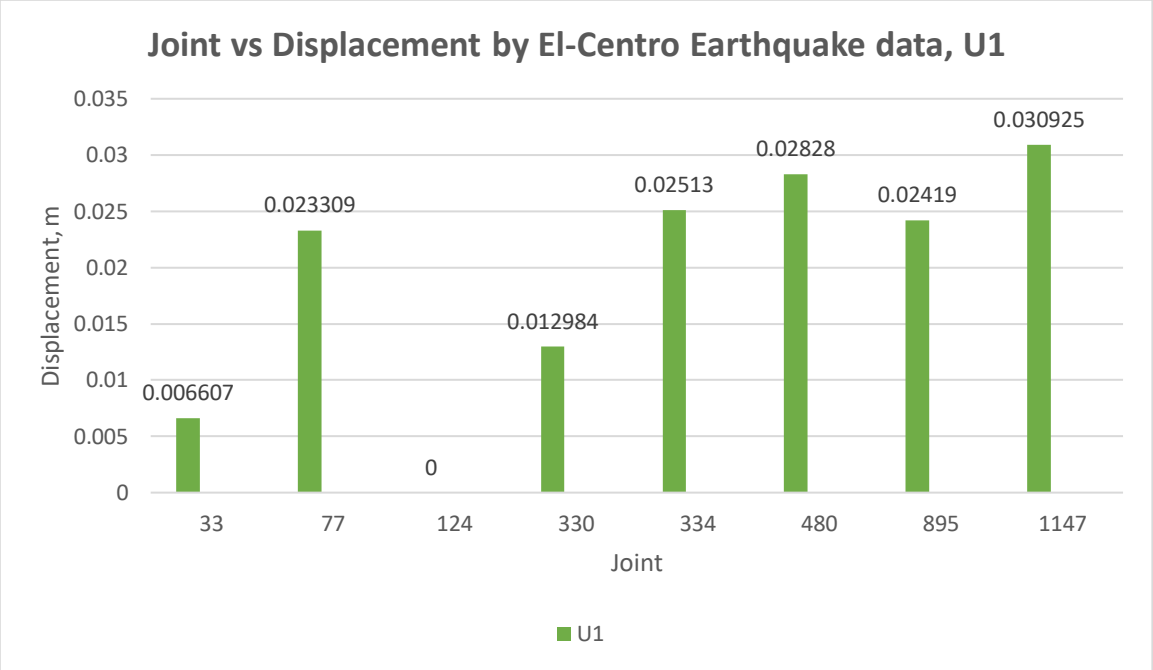


Figure 4.17 Graph joint vs displacement, U1 using El- Centro earthquake data.

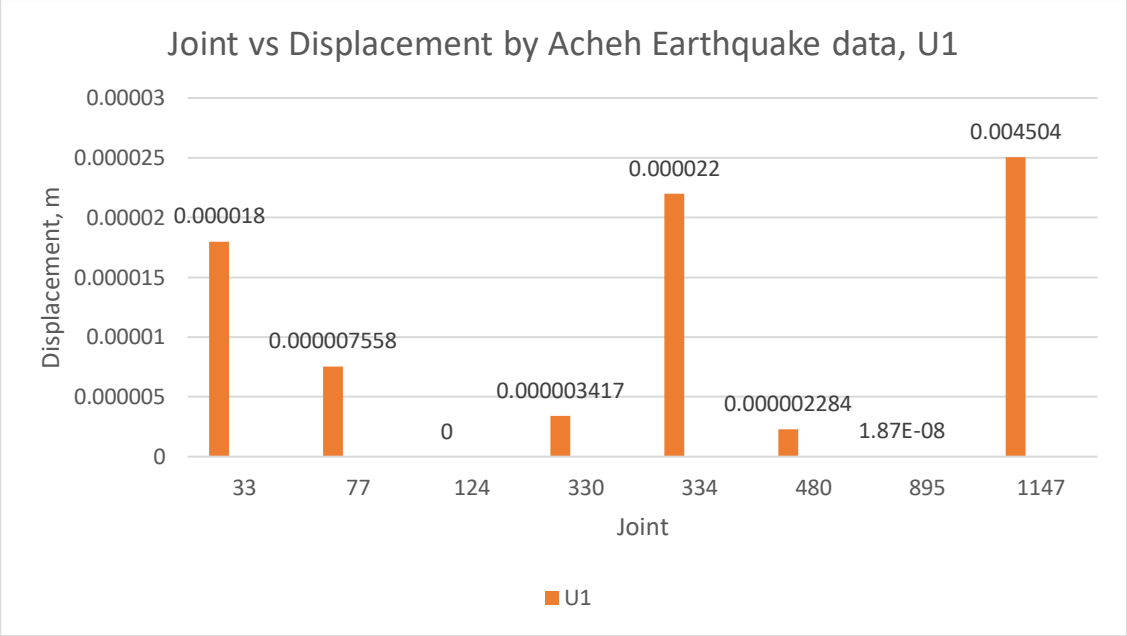


Figure 4.18 Graph joint vs displacement, U1 using Acheh earthquake data.

From both figure above, can be conclude that the displacement at X-axis occur for Acheh earthquake are less than the displacement occur for El- Centro earthquake. As stated that the maximum displacement for El –Centro earthquake that is higher than maximum displacement for Acheh earthquake which are 0.030925 and 0.004504 respectively. The maximum displacement are at joint 1147 for both earthquake.

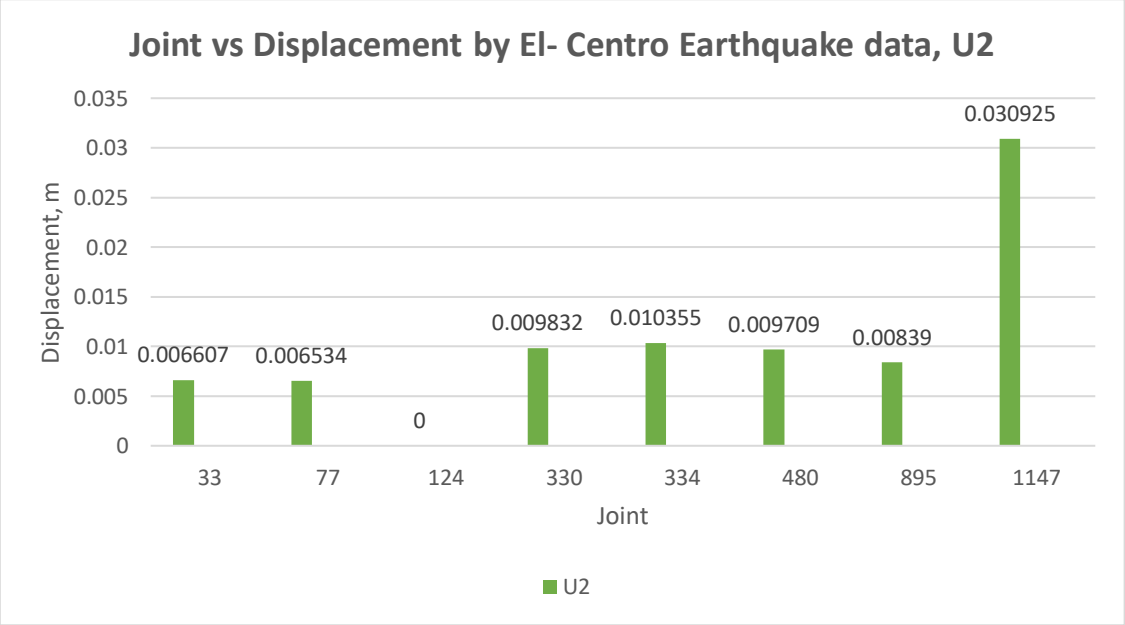


Figure 4.19 Graph joint vs displacement, U2 using El- Centro earthquake data.

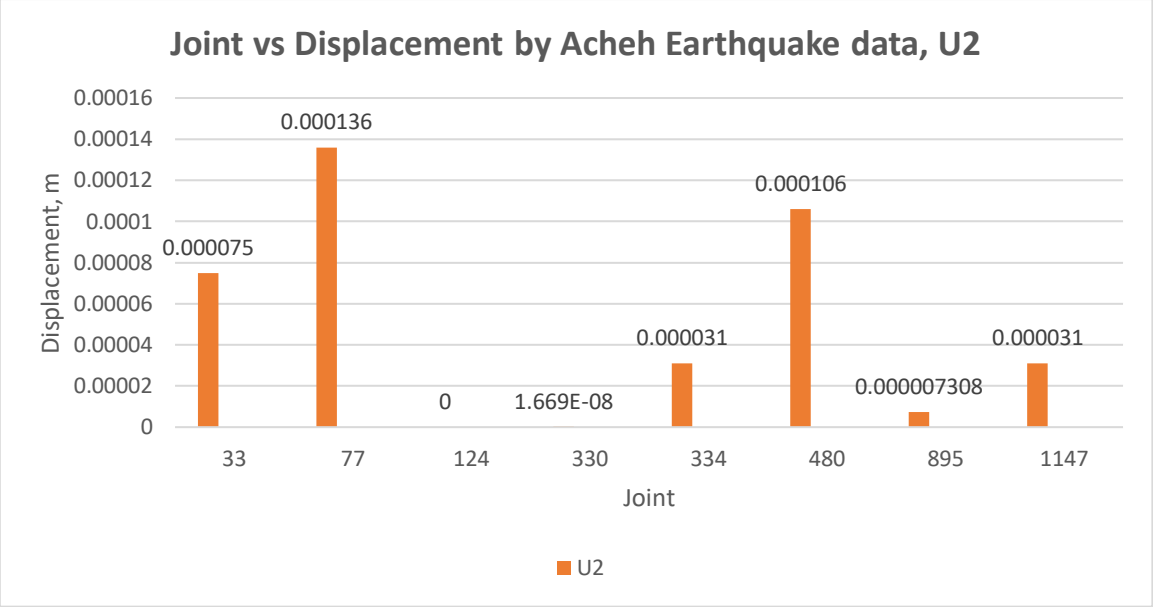


Figure 4.20 Graph joint vs displacement, U2 using Acheh earthquake data.

From both figure above, it is the same conclusion like at X-axis where the displacement occur for Acheh earthquake is less than displacement happen for El-Centro earthquake. The highest displacement for Acheh earthquake is 0.000136 differ with El-Centro earthquake which is 0.030925. The highest displacement also at different joint which are for Acheh earthquake at joint 33 but for El- Centro at joint 1147.

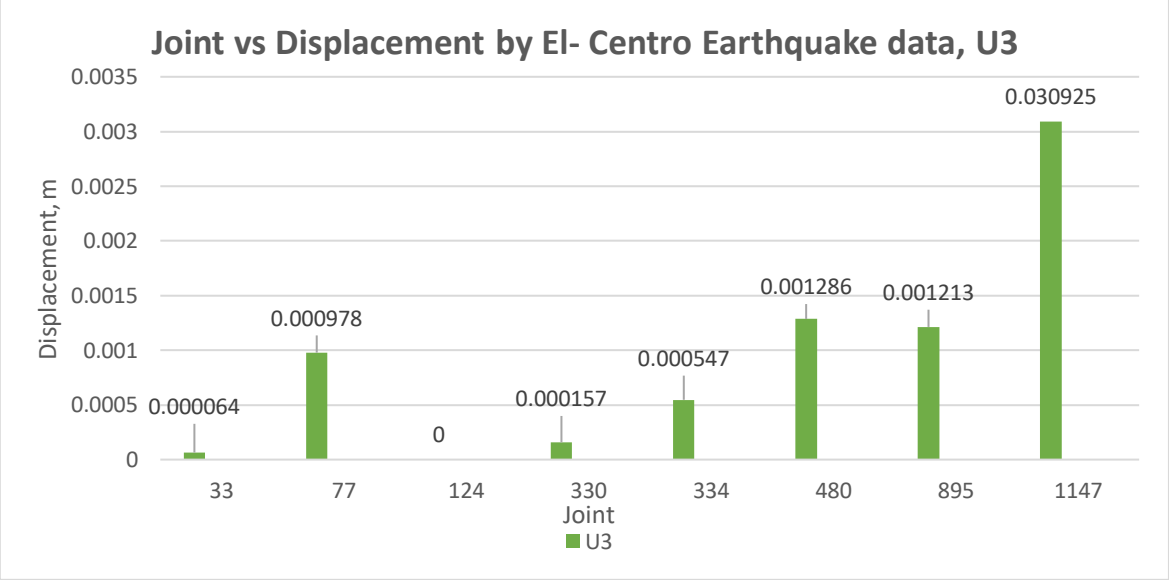


Figure 4.21 Graph joint vs displacement, U3 using El- Centro earthquake data.

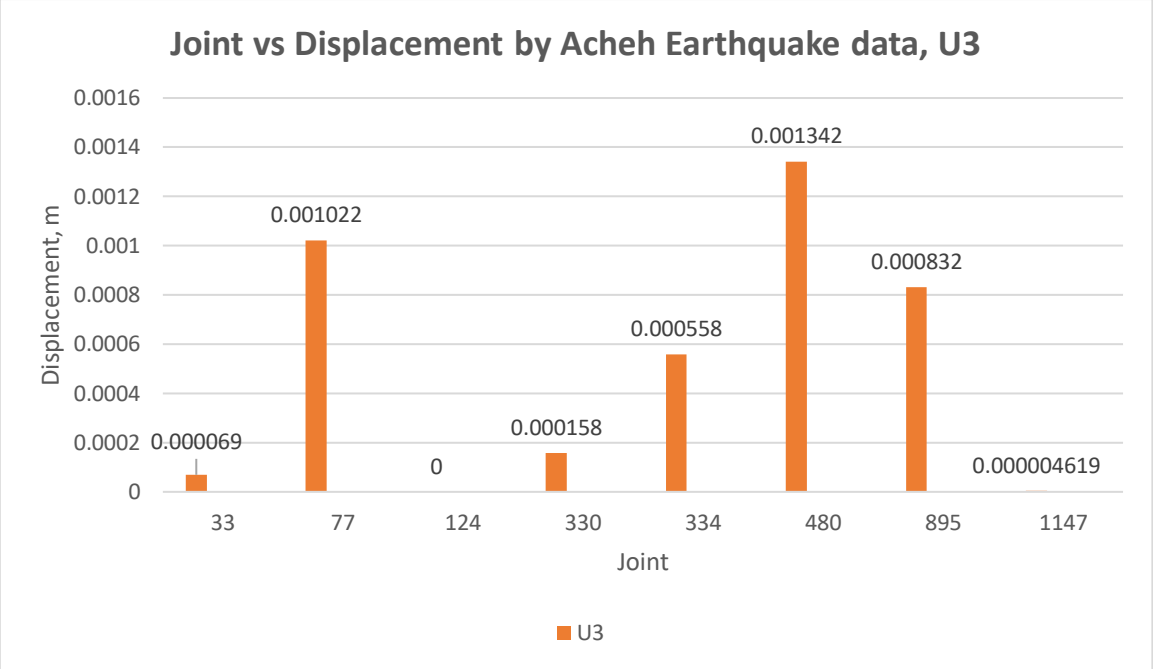


Figure 4.22 Graph joint vs displacement, U3 using Acheh earthquake data.

From both figure above, the value of displacement on Z-axis mostly in negative value which means the displacement occured in another direction. The maximum displacement for El-Centro earthquake is 0.030925 at joint 1147 but it is different for Acheh earthquake the maximum displacement happen at joint 480 with the value 0.001342. So, the displacement for Acheh is lesser than El-Centro.

4.4.2.2 Acceleration

During an earthquake there will be ground shaking that can produce acceleration to the structure. The largest velocity recorded we called it peak acceleration. Technically, acceleration is rate of velocity changes in a unit time. There are three acceleration which are acceleration on x-axis, acceleration y-axis and acceleration on z-axis.

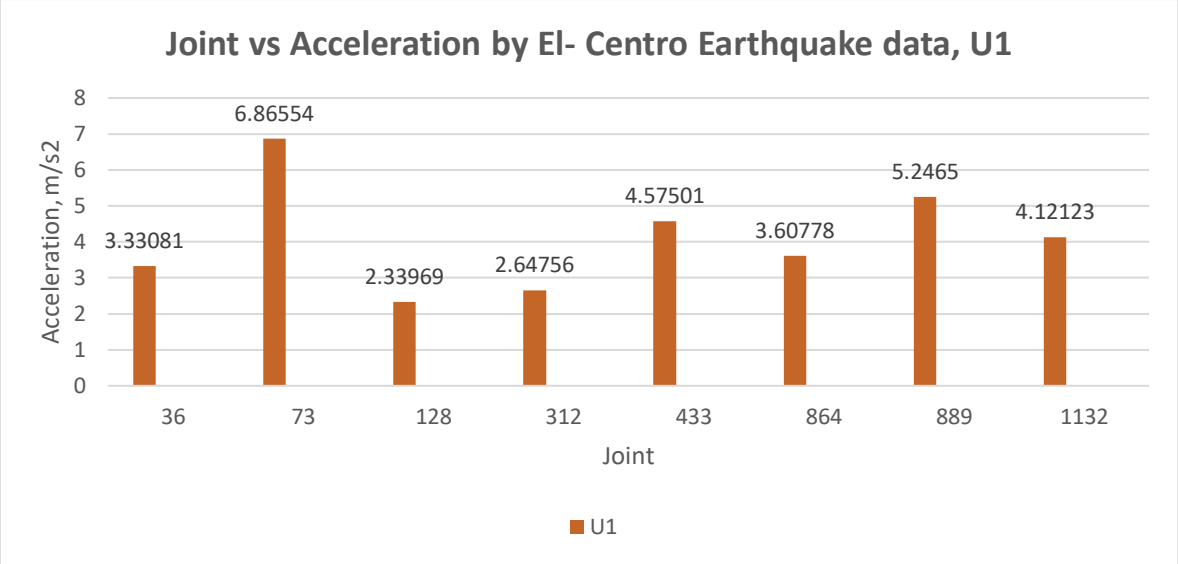


Figure 4.23 Graph joint vs acceleration, U1 using El- Centro earthquake data.

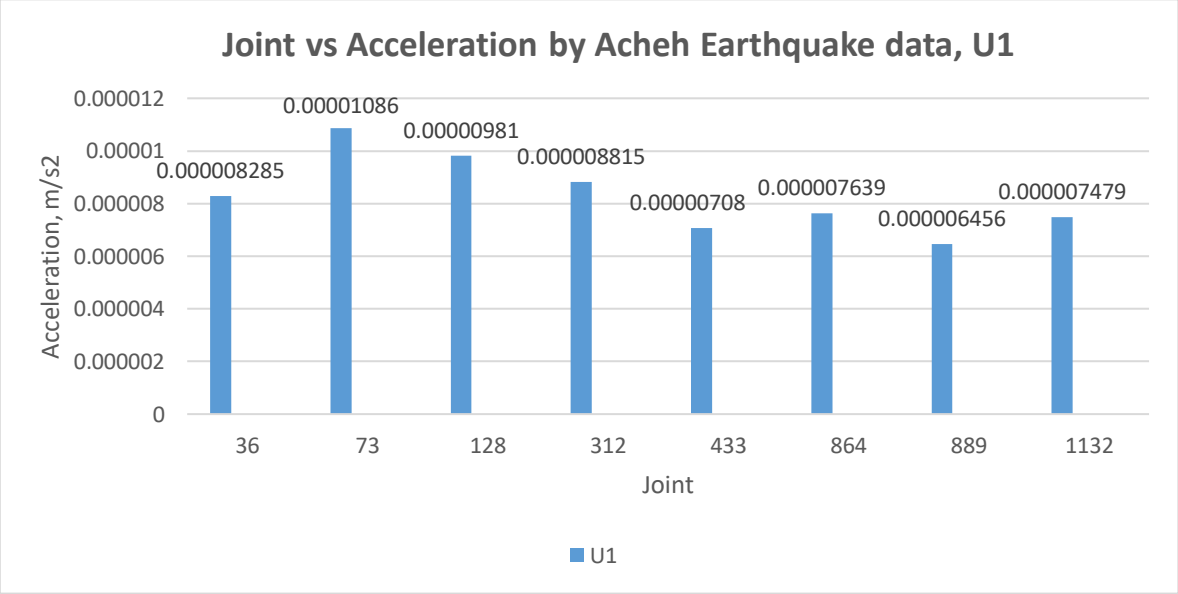


Figure 4.24 Graph joint vs acceleration, U1 using Acheh earthquake data.

Both data above are acceleration at X-axis, show that the joint number 73 give the highest value of acceleration at with the highest value come from El-Centro earthquake, 6.86554. The Acheh earthquake give very low reading of acceleration with the lowest reading was 0.00006456. All the reading from Acheh earthquake not even exceeding 0.0001 but El- Centro earthquake have lowest reading 0.00.

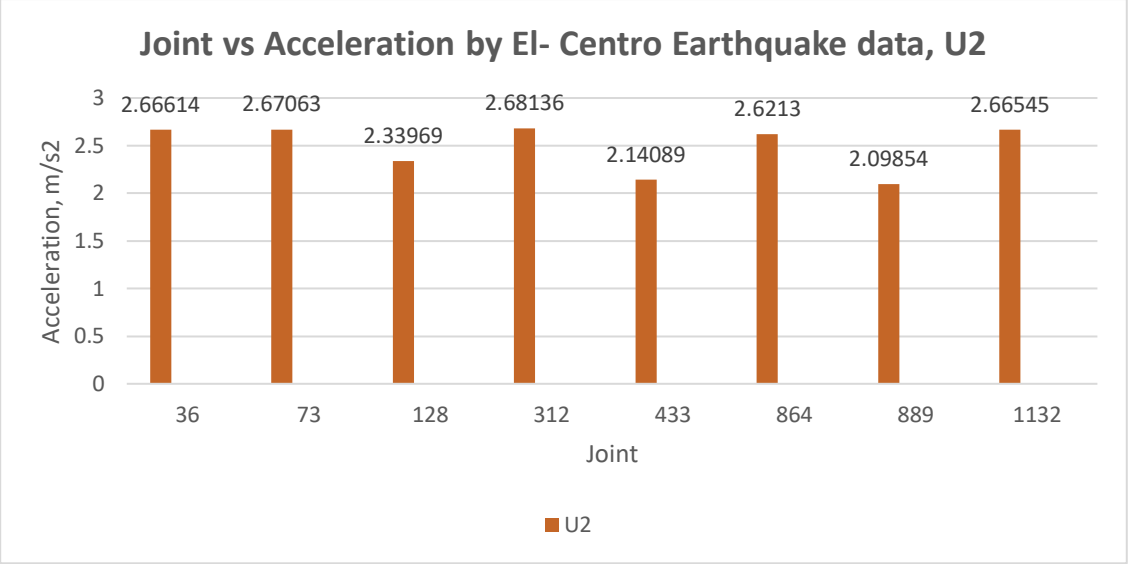


Figure 4.25 Graph joint vs acceleration, U2 using El- Centro earthquake data.

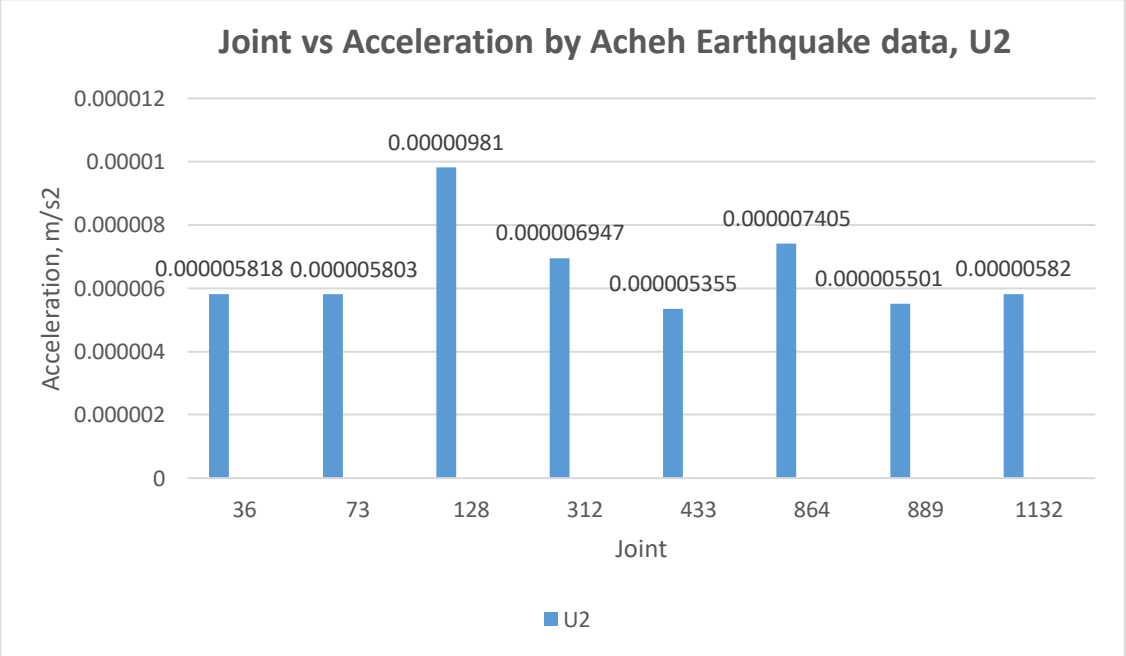


Figure 4.26 Graph joint vs acceleration, U2 using Acheh earthquake data.

Figures above show reading of acceleration on Y-axis that still have the same result which are the El-Centro earthquake give higher value than Acheh earthquake. It is different for the joint that have highest acceleration value where El- Centro at joint number 312 but the value is slightly different to another values. Acheh earthquake has the highest value at joint 128 with value 0.00000981.

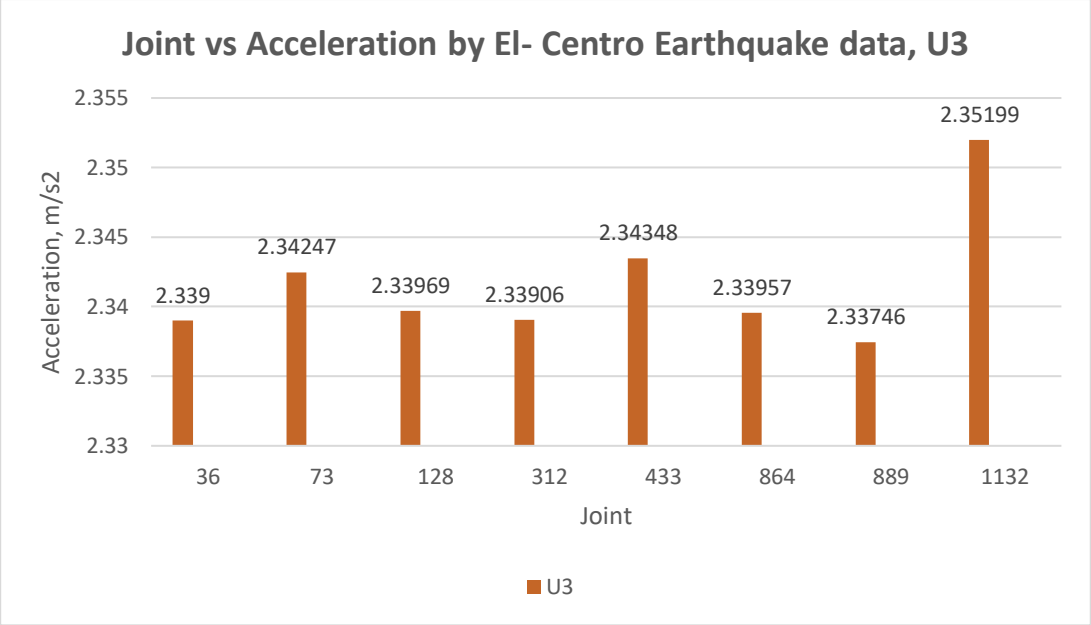


Figure 4.27 Graph joint vs acceleration, U3 using El- Centro earthquake data.

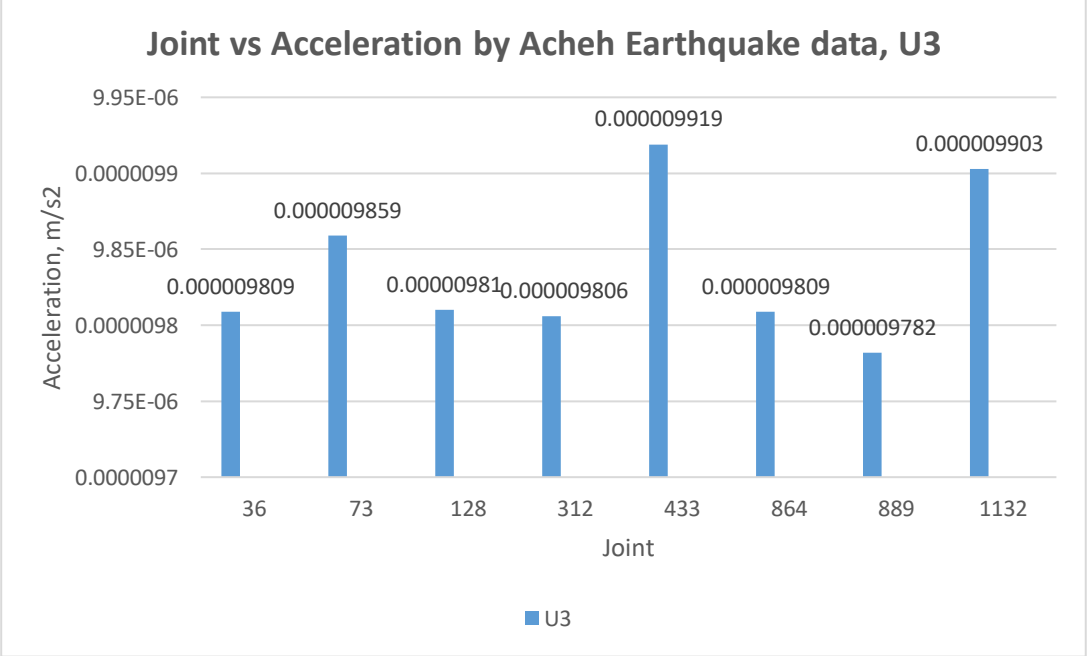


Figure 4.28 Graph joint vs acceleration, U3 using Acheh earthquake data.

Both figure above, give another result of acceleration on Z- axis due to Acheh and El- Centro earthquake. The different values between these two earthquakes are still bigger. The joint that have highest values of acceleration also different. Acheh earthquake have the highest value of 0.000009919 at joint 433 and for El- Centro have the highest value of 2.35199 at joint 1132.

4.5 RESPONSE SPECTRUM

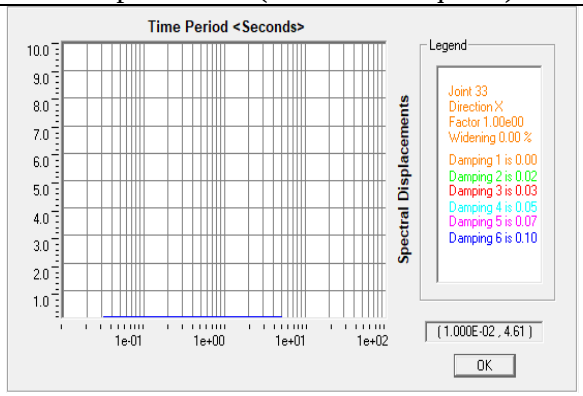
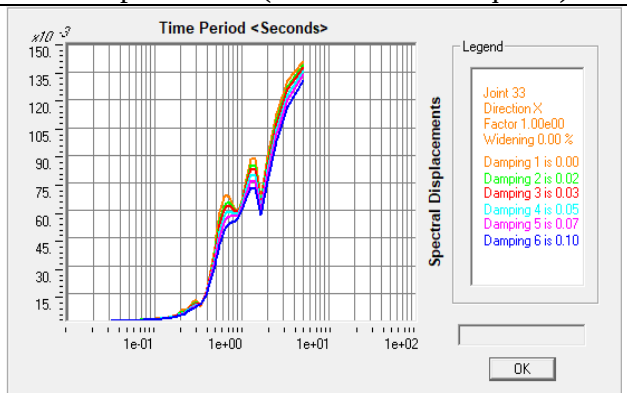
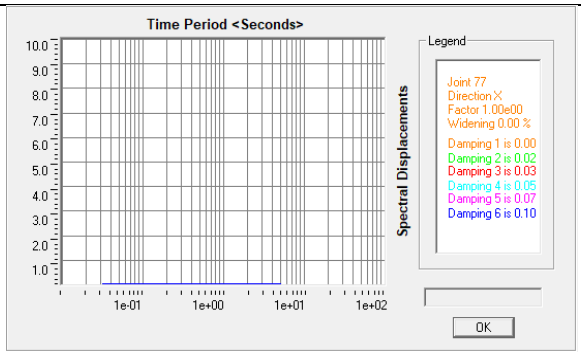
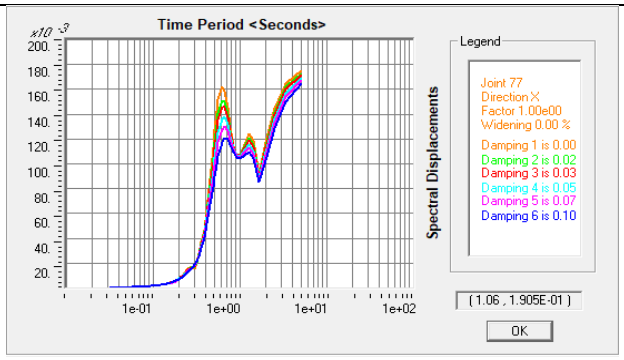
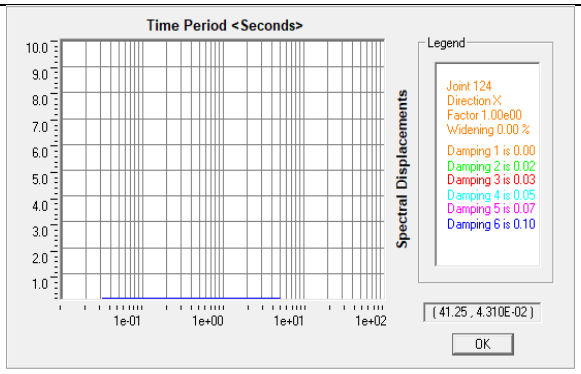
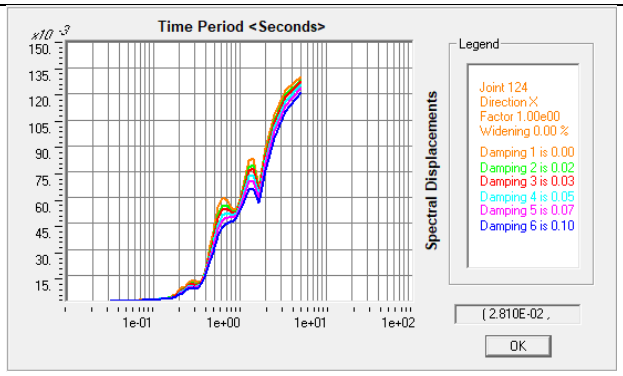
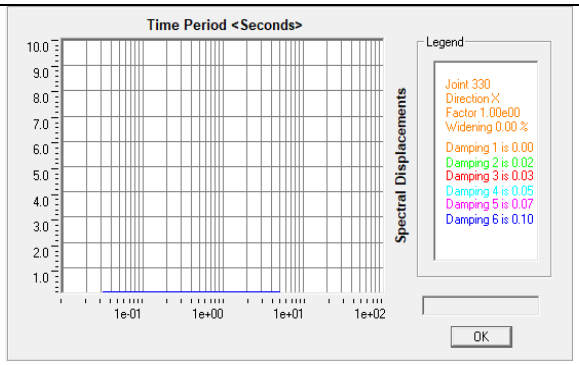
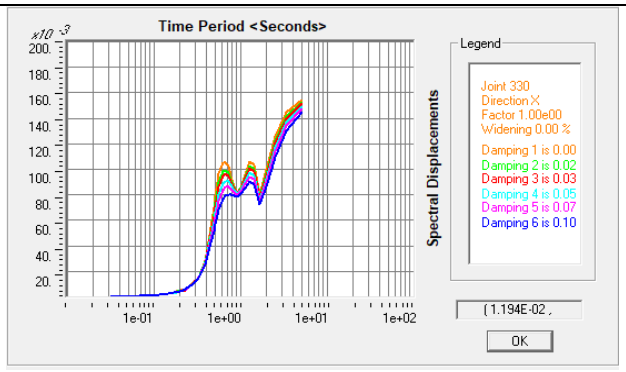
Response Spectrum Analysis is a linear-dynamic statistical analysis method. It can measures the contribution from each natural mode of vibration simply can plot of the peak or steady state response such as displacement , velocity and acceleration with series of oscillators that varying natural frequency. Furthermore, it can indicate the likely maximum seismic response of an essentially elastic structure.

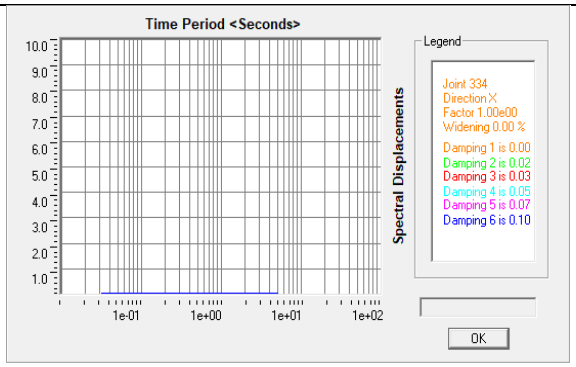
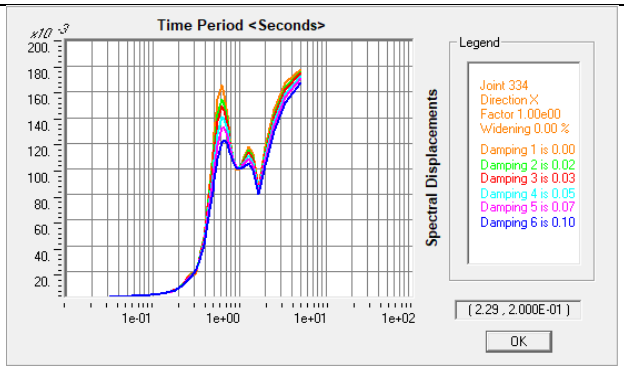
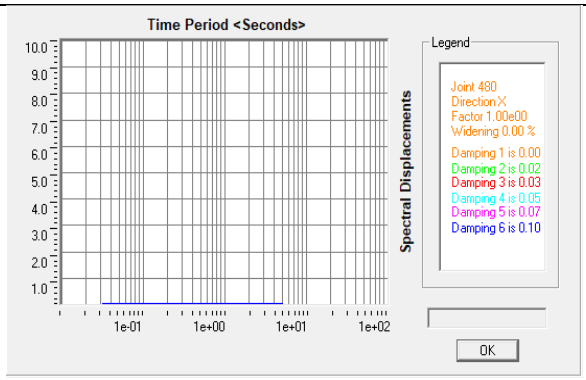
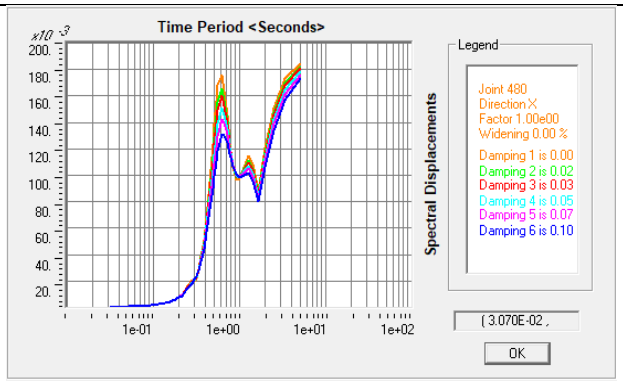
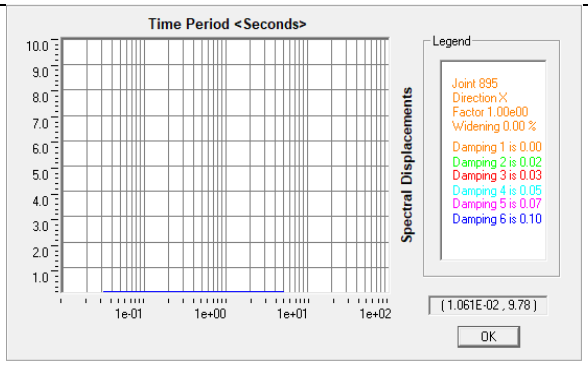
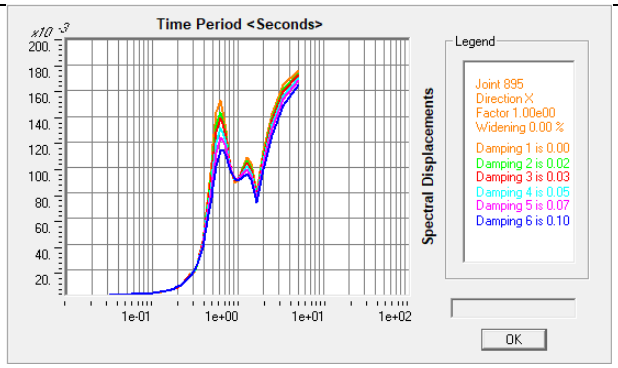
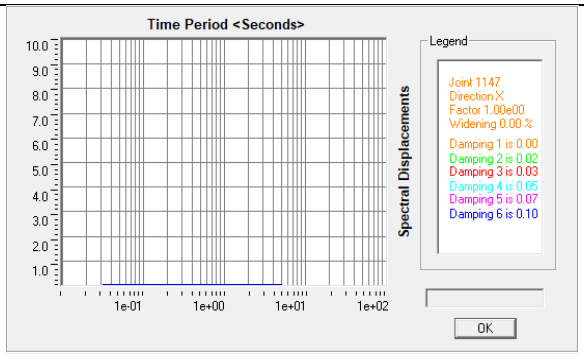
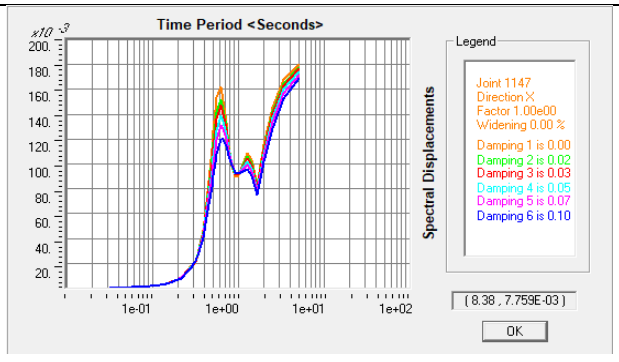
Response spectra can also be used in assessing the response of linear systems with multiple modes of oscillation which means multi-degree of freedom systems, although they are only accurate for low levels of damping. Earthquake response spectrum is the most popular tool in the seismic analysis of structure, it is because by using the response spectrum method of seismic analysis to have prediction about the displacements and member force for the structural system.

Damping curve show in the response spectrum depends on the materials used for the structures. Damping occurred when there is motion in the internal friction within the structures. 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). Below is the response spectrum analysis for x and y direction in term of time period. The staircase RSA shown in 5 specs which are:

- **Spectral Displacements**
- **Spectral Accelerations**
- Spectral Velocities
- Pseudo Spectral Velocities
- Pseudo Spectral Acceleration

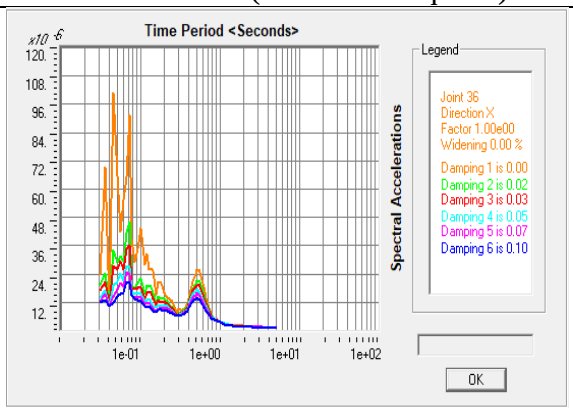
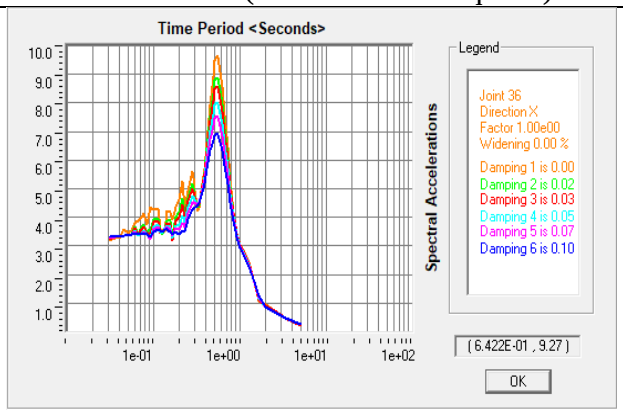
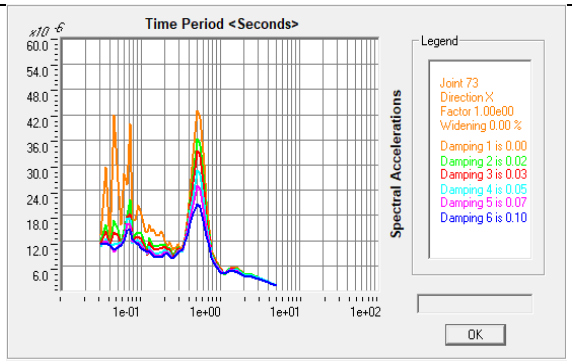
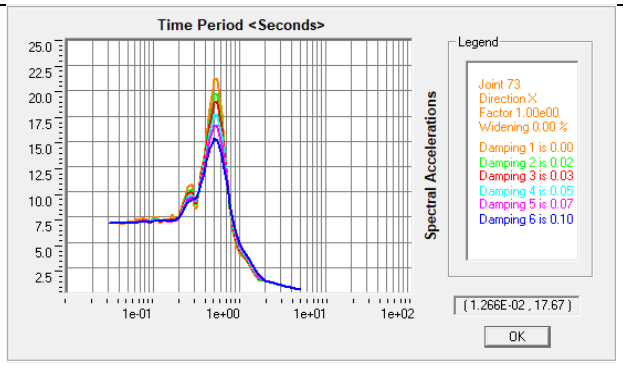
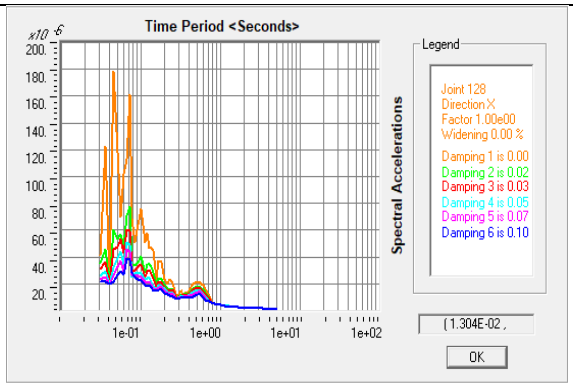
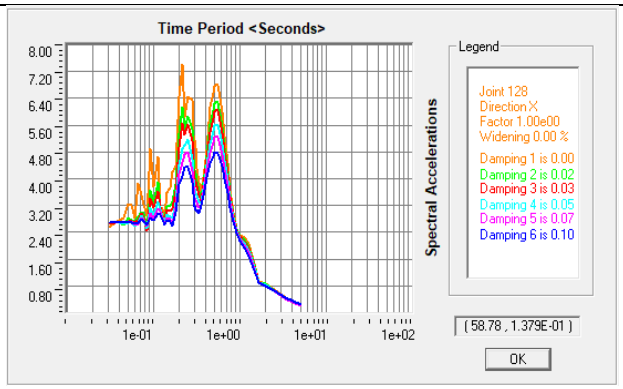
Table 4.1 Spectral displacement vs time period graph for both earthquake loadings.

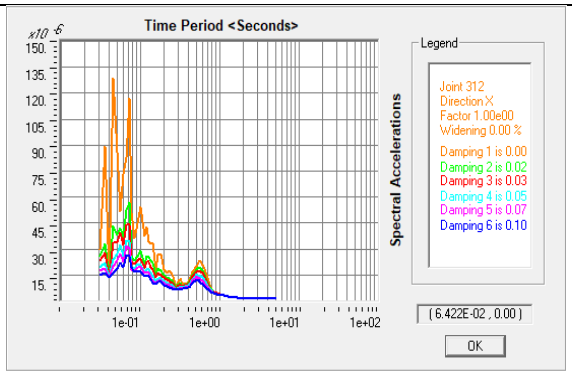
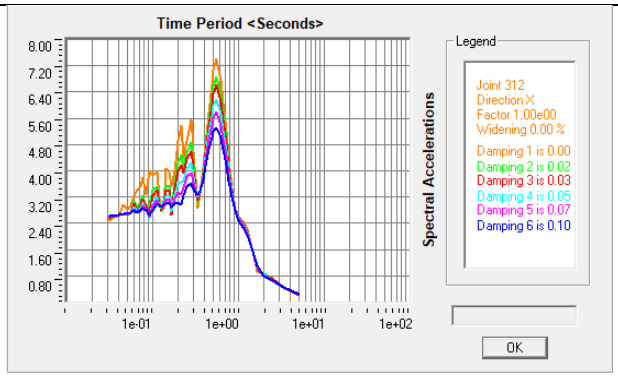
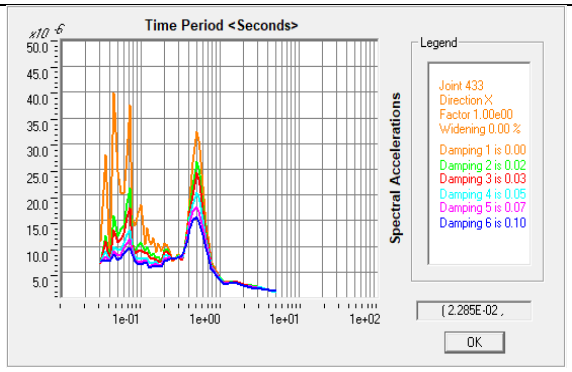
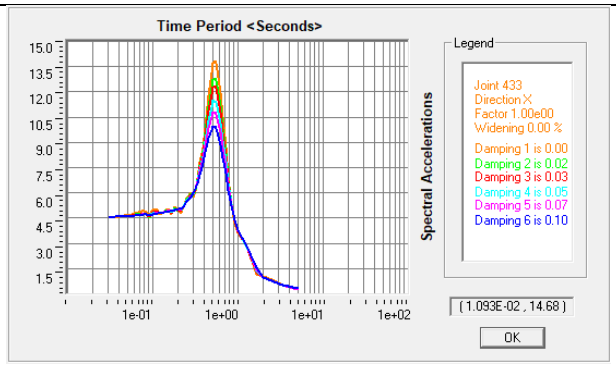
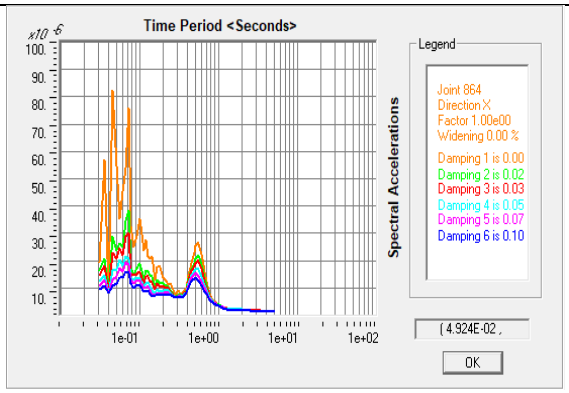
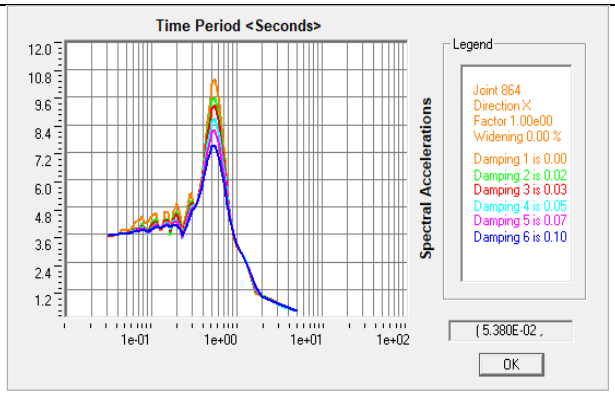
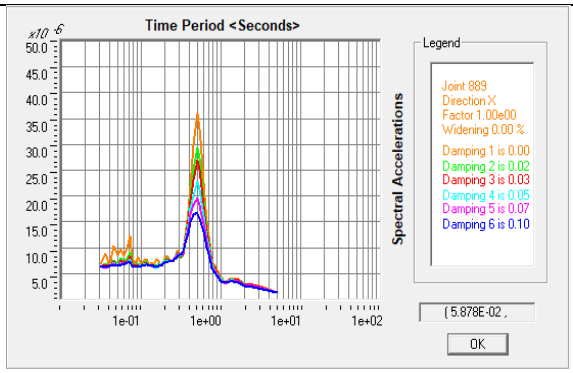
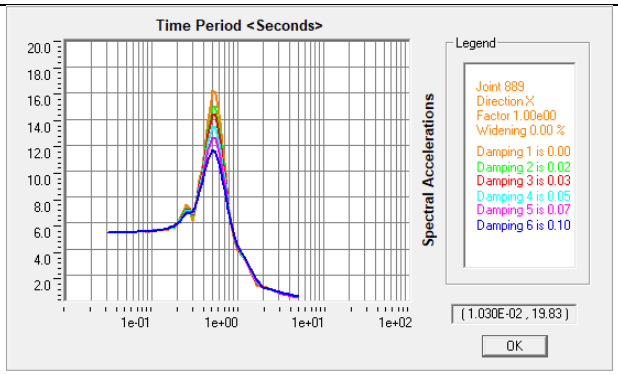
Type	Displacement (Acheh Earthquake)	Displacement (El- Centro Earthquake)
Joint 33		
Joint 77		
Joint 124		
Joint 330		

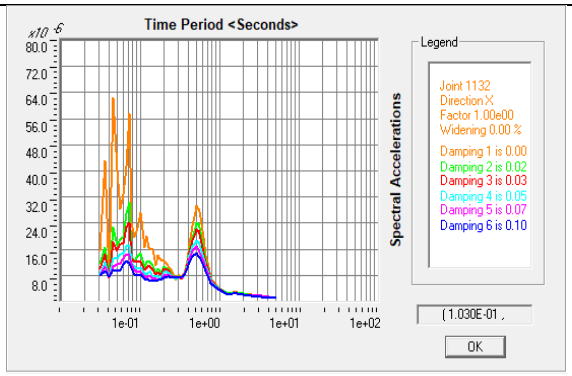
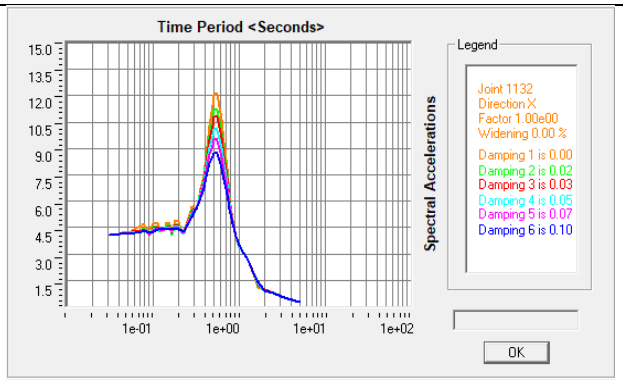
Joint 334		
Joint 480		
Joint 895		
Joint 1147		

The conclusion for the spectral displacement above, there is no graph for the all joint under Acheh earthquake. It is because the values of displacement for these earthquake are very small and also there is some of the values are negative. Otherwise, El- Centro earthquake give a very clear graph of respond spectrum where the spectral displacement for these earthquake give some values.

Table 4.2 Spectral acceleration vs time period graph for both earthquake loadings.

Type	Acceleration (Acheh Earthquake)	Acceleration (El- Centro Earthquake)
Joint 36		
Joint 73		
Joint 128		

Joint 312		
Joint 433		
Joint 864		
Joint 889		

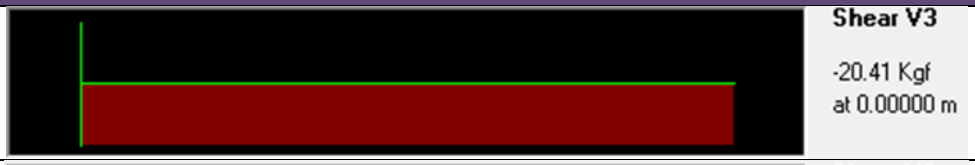
Joint 1132		

In spectral acceleration graph, both of the earthquake have values so both have their own graph. The spectral acceleration for El- Centro earthquake is bigger than Acheh earthquake, it can be seen through the graph that being presented. Most of the spectral acceleration for Acheh earthquake are in same range then get slightly high at certain point but for the El- Centro it started with a low acceleration then increases rapidly until certain point.

4.6 Shear Force

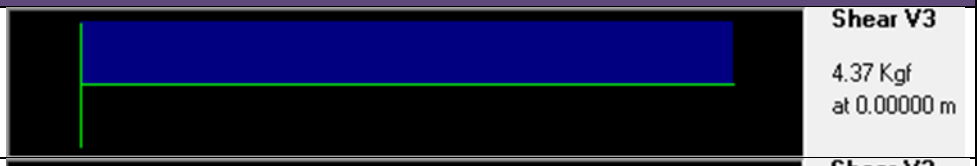
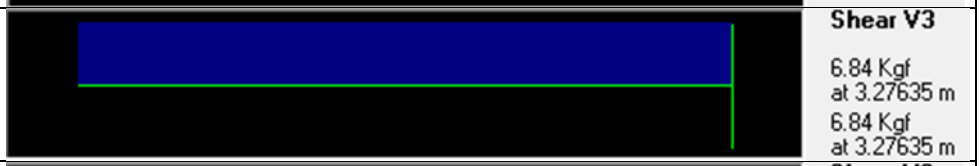
4.6.1 Tension member (Tie)

Table 4.3 Shear force diagram on tension member.

Load Combination	Shear Force Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

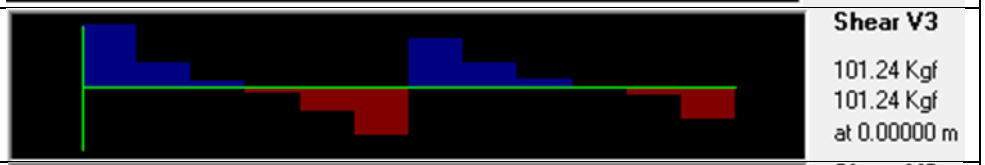
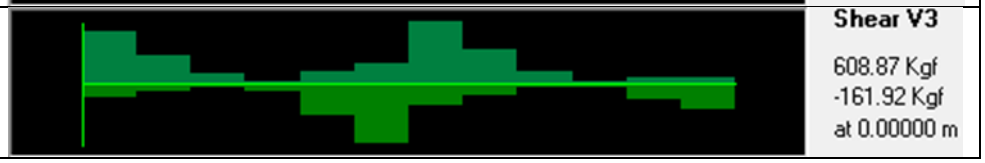
4.6.2 Compression member (Strut)

Table 4.4 Shear force diagram on compression member.

Load Combination	Shear Force Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

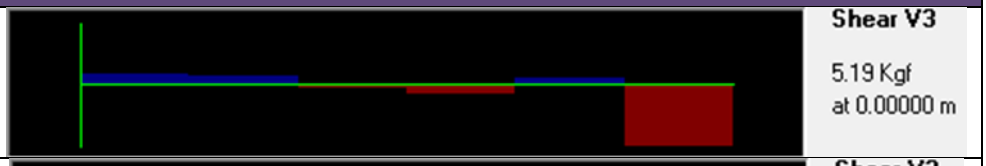
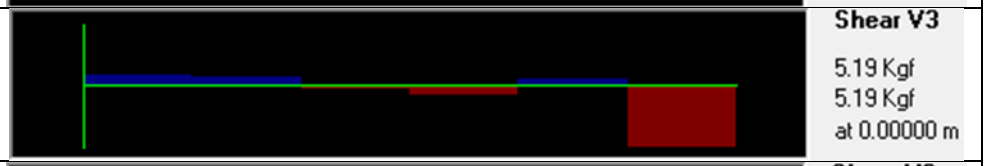
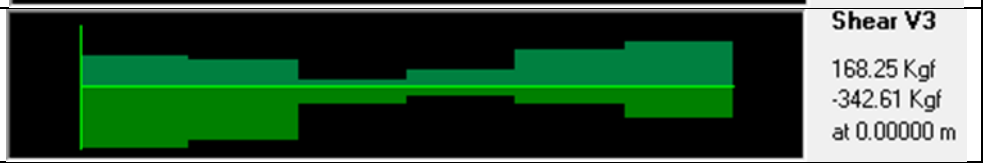
4.6.3 Bottom Chord

Table 4.5 Shear force diagram on bottom chord member.

Load Combination	Shear Force Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

4.6.4 Top Chord

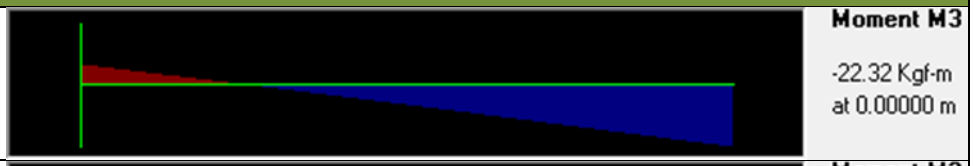
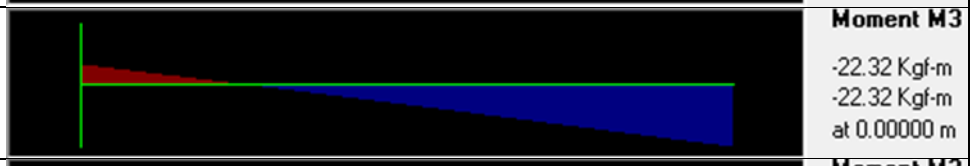
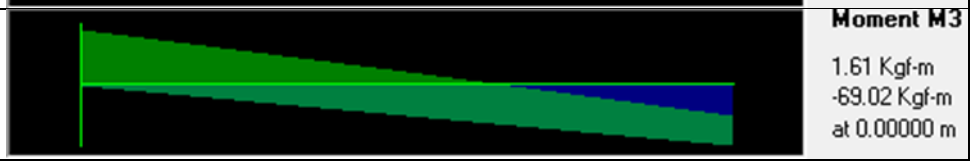
Table 4.6 Shear force diagram on top chord member.

Load Combination	Shear Force Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

4.7 Bending Moment

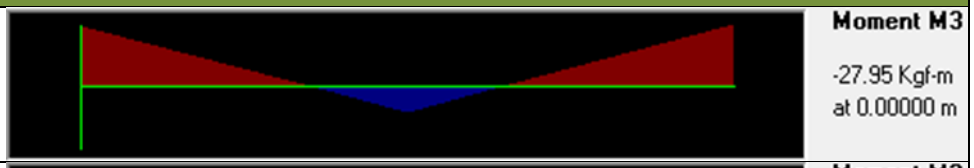
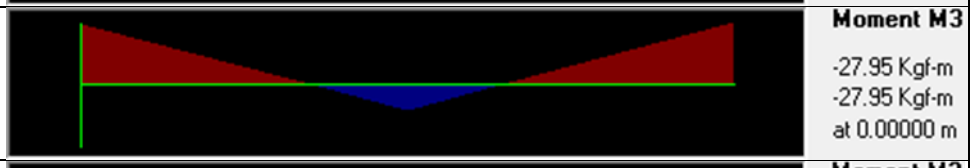
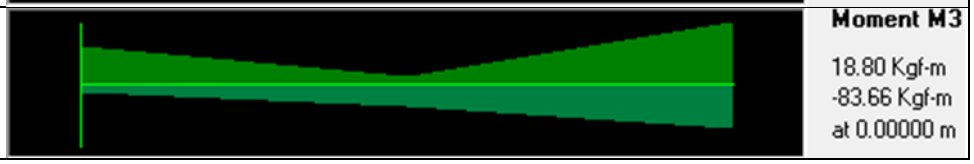
4.7.1 Tension Member (Tie)

Table 4.7 Bending moment diagram on tension member.

Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

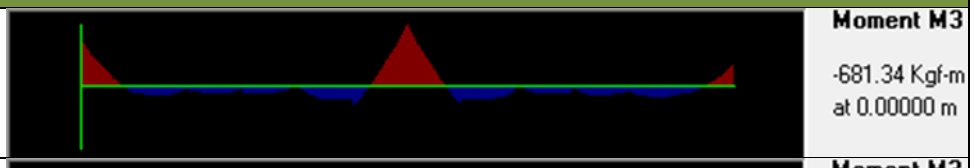
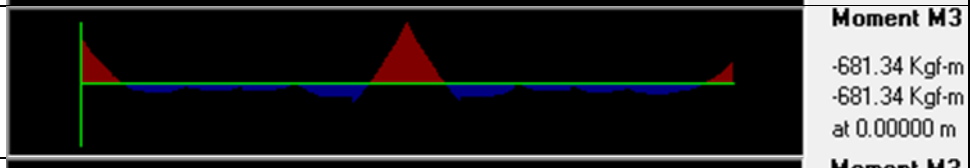
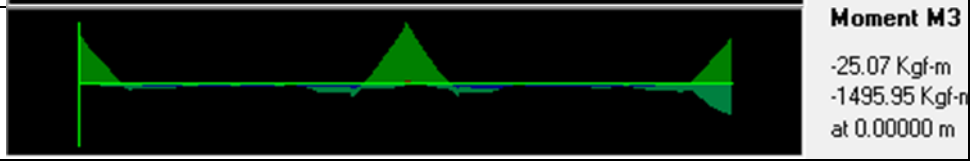
4.7.2 Compression member (Strut)

Table 4.8 Bending moment diagram on compression member.

Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

4.7.3 Bottom Chord

Table 4.9 Bending moment diagram on bottom chord member.

Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

4.7.4 Top Chord

Table 4.10 Bending moment diagram on top chord member.

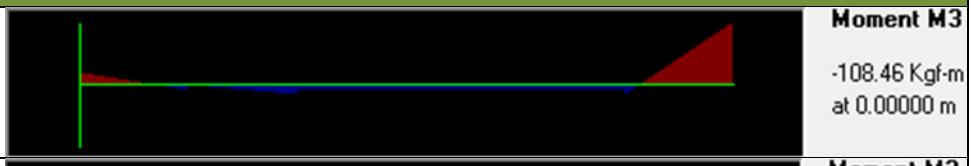
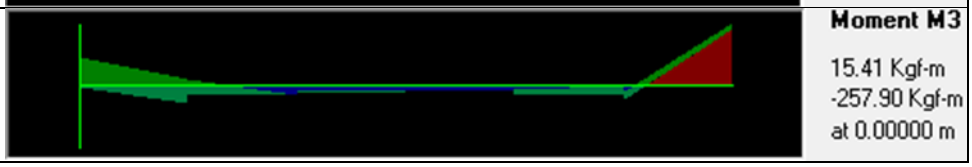
Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + TH (ACHEH)	
DL + LL + TH (El-CENTRO)	

Table 4.3 until Table 4.10 showed the shear force and bending moment diagram of three different combination of load cases that being applied for the analysis for each component of trusses. From the shear force diagram, the maximum shear force happen at bottom chord member under El-Centro earthquake loading with the value 608.87 kgf while for the Acheh earthquake loading the maximum shear force happen at the same member with the value 102.24 kgf. In addition, the maximum bending moment happen at bottom chord for both earthquake loadings (El –centro and acheh) with values -1495.95 kgf and -681.34kgf respectively. So, load combination including El- Centro loading produce the highest shear force and bending moment compare to load combination including Acheh loading.

4.8 Summary of Results

In the end of this study, the mode shape, displacement and acceleration of the trusses structure have been determined for both type of earthquake (Acheh and El-Centro). The mode shape result has been obtained from the free vibration analysis while displacement and acceleration of the trusses structure have been obtain from time history analysis. Then, the spectral displacement and spectral acceleration can be determined through response spectrum analysis. All sections and joints passed the stress capacity and moment check since the shape of the structure is rigid.

Table 4.11 Summarize result on displacement for El- Centro earthquake.

Joint	U1	U2	U3	Average
33	0.006607	0.006607	0.000064	0.00443
77	0.023309	0.006534	0.000978	0.01027
124	0	0	0	0
330	0.012984	0.009832	0.000157	0.00766
334	0.02513	0.010355	0.000547	0.01201
480	0.02828	0.009709	0.001286	0.01309
895	0.02419	0.00839	0.001213	0.01126
1147	0.030925	0.030925	0.030925	0.030925

.

Table 4.12 Summarize result on displacement for Acheh earthquake.

Joint	U1	U2	U3	Average
33	0.000018	0.000075	0.000069	0.000054
77	0.000007558	0.000136	0.001022	0.000389
124	0	0	0	0
330	0.000003417	0.0000000166	0.000158	0.000054
334	0.000022	0.000031	0.000558	0.000204
480	0.000002284	0.000106	0.001342	0.000483
895	0.0000000187	0.000007308	0.000832	0.000280
1147	0.004504	0.000031	0.000004619	0.00151

Table 4.13 Summarize result on acceleration for El-Centro earthquake.

Joint	U1	U2	U3	Average
36	3.33081	2.66614	2.339	2.77865
73	6.86554	2.67063	2.34247	3.95955
128	2.33969	2.33969	2.33969	2.33969
312	2.64756	2.68136	2.33906	2.5560
433	4.57501	2.14089	2.34348	3.01979
864	3.60778	2.6213	2.33957	2.8562
889	5.2465	2.09854	2.33746	3.2275
1132	4.12123	2.66545	2.35199	3.04622

Table 4.14 Summarize result on acceleration for Acheh earthquake.

Joint	U1	U2	U3	Average
36	0.000008285	0.000005818	0.000009809	0.000007971
73	0.00001086	0.000005803	0.000009859	0.000008841
128	0.00000981	0.00000981	0.00000981	0.00000981
312	0.000008815	0.000006947	0.000009806	0.00000852
433	0.00000708	0.000005355	0.000009919	0.00000745
864	0.000007639	0.000007405	0.000009809	0.00000828
889	0.000006456	0.000005501	0.000009782	0.00000725
1132	0.000007479	0.00000582	0.000009903	0.00000773

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

At last, the analysis indicates the responsibility for us to act in order to control the damage that may cause by an earthquake. The most important things is the design of structure need to consider seismic loads that can avoid the structure from exposed to collapse. For a trusses to remain safe during earthquake shaking, columns that receive forces from trusses should be stronger than trusses which means the column need to be strong enough to cater the earthquake loads.

From the result and discussion of the analysis, the time history analysis consume shows the huge difference when the seismic load is applied because it can be compared in two characteristics which are displacement and acceleration. The result also be more cleared because it is comparison between the small magnitude of earthquake and high magnitude of earthquake which are Acheh earthquake and El-Centro earthquake respectively. So, based on the research, the conclusion that can be made are:

- SAP2000 software can consider the earthquake load.
- Modal analysis from SAP2000 can produced 12 mode shape with their natural period and frequency.
- From modal analysis, the highest natural period is mode shape 1 which is 0.56091 and the frequency is 1.78283.
- The time history analysis can give every joint the values of displacement and acceleration

- The value of spectral displacement and spectral acceleration can be determined through response spectrum analysis.
- Based on the time history analysis, the critical joint is at joint 1147 where it have the highest average of displacement values for both Acheh and El-Centro earthquake which are 0.030925 and 0.00151 respectively.
- Based on the time history analysis, the critical joint is at joint 73 where it have the highest average of acceleration values for El-Centro earthquake 3.95955.
- Based on the time history analysis, the critical joint is at joint 128 where it have the highest average of acceleration values for Acheh earthquake 0.00000981.
- The building structure in Malaysia shall be design with considering the earthquake loading.

5.2 Recommendations

It is already clear that nowadays there are some earthquake happen especially in Malaysia. Further studies need to be done about trusses structure under earthquake loading. The further study can be done by using earthquake loading from Malaysia earthquake itself. It is because the study will come out with result that suitable for design in Malaysia in order to follow Malaysia standard design structure. The latest one was in Ranau, Sabah. 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 of an earthquake, it can be the best reference for the future use to enhance the safeguard of the population. By doing the further study, the structural engineer can design the structure with the recommendation material strength based on the result and analysis that have achieved from the study. So, the best thing to do for the future is all engineers need to consider earthquake loading as one of the important part in designing a structures.

REFERENCES

2D Frame Analysis software | Engissol Ltd.- Structural Engineering Software. (n.d.). Retrieved May 23, 2019, from https://www.engissol.com/2d-frame-analysis-software.html

36. The Quadrangular Truss. (n.d.). Retrieved May 24, 2019, from https://chestofbooks.com/architecture/Construction-Superintendence/36-The-Quadrangular-Truss.html

Adriaenssens, S., Liu, H., Wahed, M., & Zhao, Q. (2013). Evaluation and optimization of a traditional north-light roof on industrial plant energy consumption. *Energies*, *6*(4), 1944–1960. https://doi.org/10.3390/en6041944

AKIMA, T. (2017). Seismic Surface Waves. *Zisin (Journal of the Seismological Society of Japan. 2nd Ser.)*, *6*(1), 36–60. https://doi.org/10.4294/zisin1948.6.1_36

Aksel, H., & Eren, Ö. (2015). *A Discussion on the Advantages of Steel Structures in the Context of Sustainable Construction*. *2*(3), 46–53. https://doi.org/10.14621/tna.20150405

Al-Taie, A. J., & Albusoda, B. S. (2019). Earthquake hazard on Iraqi soil: Halabjah earthquake as a case study. *Geodesy and Geodynamics*, (April), 1–9. https://doi.org/10.1016/j.geog.2019.03.004

Binder, R., Binder, R., & Kwong, N.-H. (2016). Introductory Tutorial. *Optical Properties of Graphene*, 3–40. https://doi.org/10.1142/9789813148758_0001

Brown, J. L. (2016). The Howe Truss: From Timber to Iron. *Civil Engineering Magazine Archive*, *82*(6), 40–43. https://doi.org/10.1061/ciegag.0000563

Chapter 6 : Analysis of Structures. (2009). 1–16.

Concept, L. (2010). Richter scale. *Glossary*, 1–8. Retrieved from http://earthquake.usgs.gov/hazards/qfaults/glossary.php

Difference between Shallow Focus and Deep Focus Earthquakes | Actforlibraries.org. (n.d.). Retrieved May 23, 2019, from http://www.actforlibraries.org/difference-between-shallow-focus-and-deep-focus-earthquakes/

Earthquake, D. A. N. (2012). *Defining an earthquake*. (August).

Felipe, T. R. C., Leonel, E. D., Haach, V. G., & Beck, A. T. (2019). A comprehensive ductile damage model for 3D truss structures. *International Journal of Non-Linear Mechanics*, *112*(March), 13–24. https://doi.org/10.1016/j.ijnonlinmec.2019.02.010

Harris, C. M. (2006). *Dictionary of architecture & construction* (4th ed.). Retrieved from https://en.wikipedia.org/wiki/Scissors_truss

Havskov, J. (2011). *Earthquake location*. 1–36. https://doi.org/10.2312/GFZ.

Howe Truss. (n.d.). Retrieved May 24, 2019, from http://www.past-inc.org/historic-bridges/image-howetruss.html

Innovatieblog: Alles kan anders...en beter: Wat de schaal van Mercalli me leert over innovatie... (n.d.). Retrieved May 23, 2019, from http://kurtpeys.blogspot.com/2015/02/wat-de-schaal-van-mercalli-me-leert.html

Keywords SEO Tool and Images Suggestion | SEO News | SEO Blog. (n.d.). Retrieved May 25, 2019, from http://keywordsuggest.org/gallery/266887.htm

King Post Truss: All You Need to Know. (n.d.). Retrieved May 23, 2019, from https://gharpedia.com/king-post-truss/

Luong, H. T. M., Zabel, V., Lorenz, W., & Rohrmann, R. G. (2017). Non-destructive Assessment of the Axial Stress State in Iron and Steel Truss Structures by Dynamic Measurements. *Procedia Engineering*, *199*, 3380–3385. https://doi.org/10.1016/j.proeng.2017.09.447

Mele, T. Van, Temmerman, N. De, Laet, L. De, & Mollaert, M. (2010). Scissor-hinged retractable membrane structures. *International Journal of Structural Engineering*, *1*(3/4), 374. https://doi.org/10.1504/ijstructe.2010.033489

Method of Joints of construction | Civil Engineering. (n.d.). Retrieved May 23, 2019, from http://www.civilengineeringx.com/construction/method-of-joints/

Mohammad Rasoul Abazari | Developing of a program to analyze the general 2D trusses. (n.d.). Retrieved May 23, 2019, from https://mrabazari.mech.iut.ac.ir/content/developing-program-analyze-general-2d-trusses

Murty, C. V. R. (2008). Learning earthquake design and construction. *Resonance*, *10*(3), 88–91. https://doi.org/10.1007/bf02835843

Musson, R. (2012). Intensity and Intensity Scales. *New Manual of Seismological Observatory Practice 2*, 1–41. https://doi.org/10.2312/GFZ.NMSOP-2

No, S. R. R. (2016). *Truss Heel Heights and the Energy Requirements Structural Building Components Association (SBCA)*. (1605).

Parallel Chord Pallet Trusses. (n.d.). Retrieved May 24, 2019, from https://www.motherearthnews.com/green-homes/parallel-chord-pallet-trusses

Patil, A. S., & Kumbhar, P. D. (2013). Time History Analysis of Multistoried Rcc Buildings for Different Seismic Intensities. *International Journal of Structural and Civil Engineering Research*, *2*(3), 195–201.

Quantum Na. (n.d.). Retrieved May 25, 2019, from http://quantumna.blogspot.com/

Queen Post Truss: All You Need to Know. (n.d.). Retrieved May 23, 2019, from https://gharpedia.com/queen-post-truss/

R021b North Light Engine Shed - Scalescenes. (n.d.). Retrieved May 24, 2019, from https://scalescenes.com/product/r021b-north-light-engine-shed/

RAISED-HEEL TRUSS : Also called an energy truss, is a roof truss that is designed to reduce energy losses. A vertical extension at th… | ARE : SS terms in 2019…. (n.d.). Retrieved May 24, 2019, from https://www.pinterest.com/pin/524247212846529172/

Richter Scale & Magnitude. (n.d.). Retrieved May 23, 2019, from https://www.sms-tsunami-warning.com/pages/richter-scale#.XOa8Q4gzbIV

SAP2000 v14 Structural Analysis Software | KulasCivilWorks. (n.d.). Retrieved May 24, 2019, from https://kulascivilworks.wordpress.com/2010/07/13/sap2000-v14-structural-analysis-software/

Shuib, M. K., Manap, M. A., Tongkul, F., Bin, I., Rahim, A., Jamaludin, T. A., … Ahmad, Z. (2017). *Active Faults In Peninsular Malaysia With Emphasis On Active Geomorphic Features Of Bukit Tinggi Region*. *1*(1), 13–26.

SteelConstruction.info. (n.d.). Retrieved May 23, 2019, from https://www.steelconstruction.info/The_Steel_Construction_Information_System

Structural analysis - Wikipedia. (n.d.). Retrieved May 23, 2019, from https://en.wikipedia.org/wiki/Structural_analysis

UpSeis. (2007). What are seismic waves? *2007*. Retrieved from http://www.geo.mtu.edu/UPSeis/waves.html

USGS.gov | Science for a changing world. (n.d.). Retrieved May 25, 2019, from https://www.usgs.gov/

Utah Building Lumber | Sunroc Building Materials. (n.d.). Retrieved May 24, 2019, from https://sunrocbuildingmaterials.com/products/lumber/

Weblet Importer. (n.d.). Retrieved May 23, 2019, from https://www.cs.princeton.edu/courses/archive/fall09/cos323/assign/truss/truss

Yashavantha Kumar, G. A., & Sathish Kumar, K. M. (2017). Free vibration analysis of smart composite beam. *Materials Today: Proceedings*, *4*(2), 2487–2491. https://doi.org/10.1016/j.matpr.2017.02.101