SEISMIC PERFORMANCE FOR CABLE STAYED BRIDGE UNDER DIFFERENT EARTHQUAKE LOADINGS

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ABSTRAK

Penyelidikan ini adalah berkaitan dengan analisis seismik struktur jambatan kabel yang berada di Malaysia dengan tujuan untuk mengira maklum balas dan menilai kapasiti rintangan struktur yang dipengaruhi oleh kekuatan gempa yang berbeza. Walau bagaimanapun, keadaan sempadan struktur jambatan dianggap sebaga tetap dan factor berkaitan tanah tidak timasukkan. Kajian ini dijalankan kerana gegaran di Malaysia adalah disebabkan oleh gelombang seismik yang dijana daripada gempa bumi yang berlaku di negara-negara jiran. Oleh itu, jurutera-jurutera bimbang tentang kelemahan seismik struktur jambatan kerana kekurangan pertimbangan gempa dalam prosedur reka bentuk bangunan Malaysia. Struktur jembatan adalah struktur kritis yang akan musnah d akibat gelombang seismik dan juga komponen penting dalam sistem pengangkutan. Dengan ini, jambatan kabel kekal dimodelkan dan dianalisis dengan menggunakan perisian *Finite Element Modeling* (FEM) oleh perisian SAP2000 di bawah pelbagai jenis analisis yang meliputi Analisis Getaran Bebas (FVA) dan Analisis Sejarah Masa (THA) di bawah pemuatan gempa yang berbeza. Beban angin auto dalam SAP2000 telah digunakan dalam kedua-dua analisis. Data kekuatan gempa diambil daripada gempa Acheh dan El-Centro yang telah direkodkan oleh Jabatan Meteorologi Malaysia. Kegunaan dua jenis kekuatan gempa yang berbeza akan menghasilkan nilai ciri-ciri pergerakkan struktur jambatan yang berbeza. Selain itu, prestasi seismik keseluruhan jambatan kabel kekal ketara dipertingkatkan dalam arah membujur dan melintang. Ia boleh meringkaskan bahawa reka bentuk jambatan kabel dan keupayaan untuk bertahan gelombang seismik besar dan kecil serta juga boleh menghasilkan daya tahan yang mencukupi terhadap pemuatan gempa yang berbeza.

ABSTRACT

The paper deals with the seismic analysis of a stayed cable bridge structure in Malaysia with the aim to compute the response and assess the resistance capacity of the structure under different earthquake loading. Nevertheless, the border state of the stayed cable is assumed as fixed to the ground and type of soil has been neglected. The study was conducted because the tremors in Malaysia were due to the seismic wave generated from the earthquake that occurred in neighbouring countries. Therefore, engineers are concerned about the seismic vulnerability of bridge structures due to lack of earthquake consideration in Malaysia's building design procedure. Bridge structure is the critical structure that will damage cause by the seismic effect and also important component in transportation system. With this, stayed cable bridge is modelled and analysed using Finite Element Modelling(FEM) by SAP2000 software under various type of analysis that cover Free Vibration Analysis (FVA) and Time History Analysis (THA) under the different earthquake loading. Auto wind load in SAP2000 has been used in both analyses. The earthquake loading data is taking from Acheh and El-Centro earthquake that had been record by Malaysia Meteorological Department. Implementation between two type of different earthquake loading will represent the contrasting of dynamic characteristic of bridge structure. Furthermore, the overall seismic performance of stayed cable bridge significantly enhanced in longitudinal and transverse directions. It can summarize that the design of the stayed cable bridge is stable and ability to withstand under major and minor earthquake and also can yield adequate resistance against different earthquake loading.

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LIST OF SYMBOLS

km	kilometer
cm/yr	centimetre per year
m/s^2	metre per square second
Hz	Hertz
M	Meter
Nm	Newton meter
Mm	Milimetre
N	Newton
m/s	Meter per second
m^2	Meter square
g	Gal
s	second

LIST OF ABBREVIATIONS

3D	Three dimensional
DL	Dead load
LD	Live load
RSA	Response Spectrum Analysis
SAP	Structural Analysis & Design Program
WL	Wind load
EC	Euro code
P	Primary
S	Secondary
L	Love
R	Rayleigh

CHAPTER 1

INTRODUCTION

1.1 Background of study

Earthquake is natural disaster that happens in an instant without any early signs. It usually occurs when rock underground suddenly breaks along a fault. This sudden produce of energy and causes the seismic wave that make the ground shaking. Seismic waves are created from the energy released from the earthquake. Structure buildings may be affected and suffered great damage due to the seismic waves. The structures building may defect in term of deflection and cracking that may reduce the aesthetic value of the building. For example, an earthquake with a magnitude of 9.3 occurred on December 26th, 2004, outside the beach of the Indonesian island of Sumatra, at 7.59 a.m. local time. Wide seismic breakdown to engineering infrastructure and construction development happened in northern and north-western Sumatra. A destroyer tsunami was produced with height of power wave exceeding 20 m, involve extensive ruination in Malaysia, Indonesia, Thailand, Burma , Sri Lanka , and other countries around the Indian Ocean.

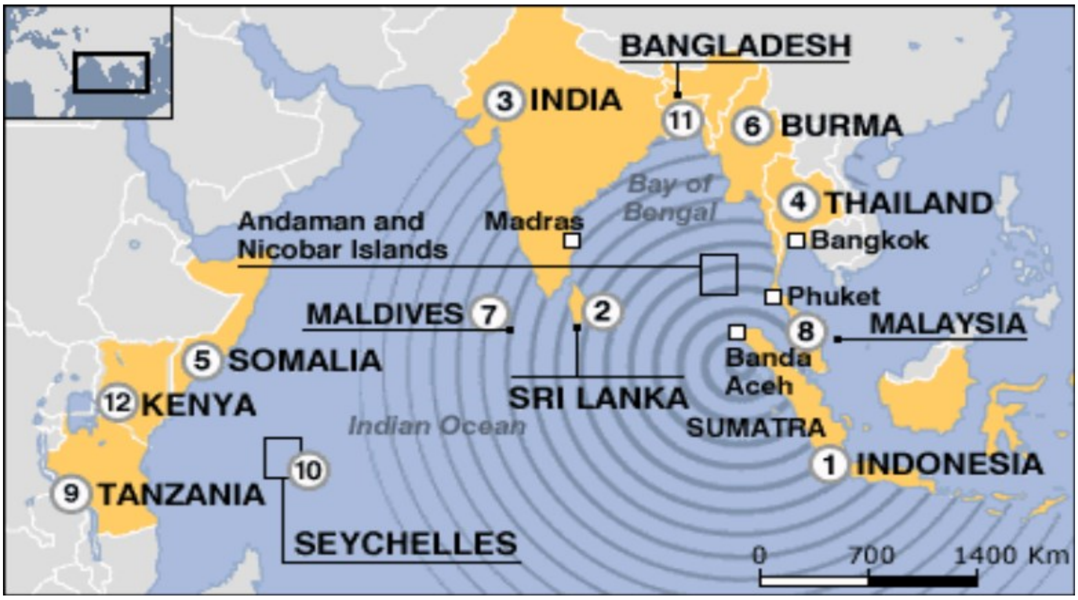


Figure 1.1 Countries in the Indian Ocean affected by the 26 December 2004 tsunami (source: BBC)

The occurred of tsunami were sensed as far away along the east coast of Africa. The total fatalities more than 300,000. Many of people were impressed, many people missing their house, property and suffering very sad.

Cable-stayed bridges have emerged as the dominant structural system for long span bridge crossings during the past thirty years. That success is due to a combination of technical advancements and pleasing aesthetics attributes. Cable-stayed bridges can be categorizing as a justifiable solution for connecting wide-span crossings. There are more than 600 cable stayed bridge were constructed until now. Usually, the span of cable bridges is between 100m to 500m wide while the length of widest cable bridges has increased up to 1000m during this decade. Cable-stayed bridges are studied from many aspects such as number of spans, number of towers, number of cables and girder types. This type of bridges must take into all aspects design including the earthquakes loading because earthquakes occur without any initial warning. Bridge failure during strong earthquakes poses not only a threat of fatalities but causes a substantial interruption of emergency efforts. The bridge failure is actually influence by combination of poor design and inclement weather condition. Although wind induced vibrations have historically been the primary concern in the design of cable-stayed bridges, earthquake effects have also gained importance in recent decades.

1.2 Problem statement

The tectonic framework for the whole of Malaysia covers between longitudes 90 E to 140 E and latitudes of 12 S to 20 N (MMD and ASM, 2009). Malaysia is viewed to have lower active seismic fault zone and it is detected on the Eurasian plate, and closer to the two interpolate border which are the Philippines Plate in the east and Australian Plates in the west. Nowadays, there are many evidences obviously proving that initial presumption Malaysia are save from earthquake is misleading to Malaysian people. It is importance value to state that one of the phenomena from regional earthquake that bring bad high impacts Malaysian is the Indian Ocean earthquake on 2004 with the magnitude of 9.1. The strong earthquake that provide occur tsunami contingencies, terrible and frighten has killed nearly 68 lives in Malaysia and thousands of other lives in Indonesia, Sri Lanka and Thailand.

Most building structures in Malaysia are not included the earthquake load. This is because some people in Malaysia believe that the country is free from the threat of active seismic zone. But if seen through the history that has taken place, Malaysia has ever been affected by the long-term impact of the earthquake that took place in the Indian Ocean (Eurasian plate). Hence, all building structures in Malaysia need to be designed with earthquake loads to increase the safety factor of a building. The cable-stayed bridge structure in Malaysia is tabled and selected to be investigated whether the construction involves an earthquake load or not. Therefore, this research study will demonstrate the responsible earthquake to cable-stayed bridge in Malaysia region. SAP2000 was used to analyse and modelling the structure of cable-stayed bridge.

1.3 Research objective

The main objectives for this research are:

i. To study behavior of stayed cable bridge under major and minor earthquake.
ii. To study the resistance of the existing bridge structure using the vulnerability assessment.
iii. To study dynamic characteristic of stayed cable bridge under different types of loading.

1.4 Scope of study

This study focuses on the impact of the earthquake on the structure of the cable-stayed bridge. SAP2000 is software used to analyze and model the cable-stayed bridge structure. The cable-stayed bridge structure in Malaysia was chosen as a study site. The structure design of bridge is based on drawing that we had design follow the criteria bridge design. We referred the cable-stayed bridges around Malaysia and worlds such as Penang Bridge, Muar Second Bridge and other bridge around worlds. Among this process, there are many cable stayed bridges gathered around the world and has assessed them based on different parameters and has categorized these bridges in 3 categories of harp, fan and radial. Meteorological records such as magnitude earthquake data are obtained from the Malaysian Meteorological Department (MMD). Seismic data taken from the earthquake that had occur in Aceh, Indonesia during 2004.

1.5 Significant of study

The importance of study this research is to show that the earthquake is responsible for the construction of buildings in Malaysia for the future especially for bridge structure such as cable-stayed bridge. It because bridges represent critical nodes of major transportation systems. Next, we are able to know the behavior of cable-stayed bridge under far field earthquake and local earthquake. In addition, we can generate the characteristics of critical structures when earthquake occur based on recent earthquake.

Besides, by perform this research, we capable to study dynamic characteristic of existing critical structures. Deeper research about responsible earthquake to cable-stayed bridge can give understanding about the structure building in Malaysia need to include the earthquake loading for future building safety. The implementation of seismic design can lessen the bridge or building especially collapse, fatalities and loss of property when earthquake occur.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss about the causes of earthquakes for a good understanding of the overall geophysical process of the earthquake. The information regarding the propagation and measurement of seismic waves through earth will discuss in detail. The next followed section will cover about details of cable-stayed bridge to give a good understanding of the background. Consideration about design criteria of cable stayed including the method of seismic analysis will briefly explain.

2.2 Earthquake

Earthquakes are natural phenomena that occur frequently. The main process occurs caused by movement inside the earth. It occurs when two block of the earth without notice suddenly slide to each other. Fault plane or fault is representing the surface of the block slide. Hypocenter is the location where the earthquake starts and it location on the surface of the earth is called the epicenter.

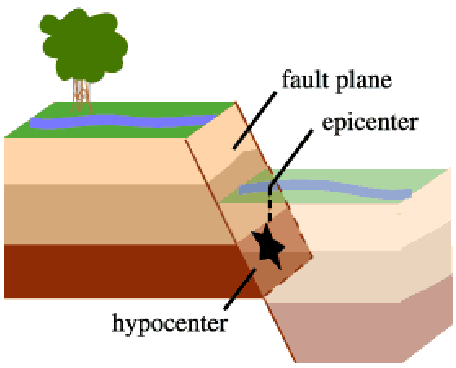


Figure 2.1 Mechanism of earthquake (USGS 2016b)

Surfaces of Earth or ‘crust’ is like a jigsaw puzzle which is not in a piece of land. The Earth is covered with 20 pieces of puzzle that are constantly moving in a slow motion (National Geographic Kids, 2016). The earth is circular but unevenly that formed with an about range 6450 km radius and it is composed of 4 major regions which is crust, a mantle, outer core and an inner core. Compared to the 6450 km radius of the earth, the thickness of the earth’s crust perilously thin.

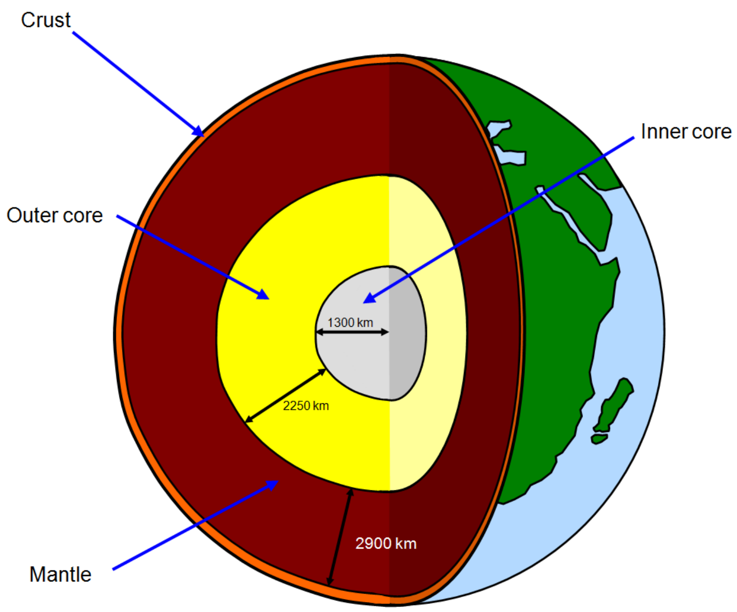


Figure 2.2 The internal structure of earth

Source : http://www.schoolphysics.co.uk/age14-16/General/text/Earth's_internal_structure/index.html

The crust region is range around one percent from volume of earth and crust is the least dense layer. The average density of crust is about 2800 kg/m³. Crust is coolest layer in temperature. Most type of crust continental rocks found is type metamorphic, igneous and sedimentary. Mantle is thicker layer that located under the crust and middle of the earth. Almost 84 % from earth is mantle. Crust and mantle is separated by a distinct layer called the Moho. Rocks from upper mantle have density about 3300 kg/m3 and it is denser compare to crust. The last internal structure of earth is core. There are two part of core which is outer core and inner core. Core has 15 % volume from earth. Overall of core density is about 13500 km/m3 and it is denser compare to mantle. Core is also responsible as magnetic field.

The world's largest earthquake with an instrumentally documented magnitude occurred on May 22, 1960 near Valdivia, in southern Chile. It was assigned a magnitude of 9.5 by the United States Geological Survey. It is referred to as the "Great Chilean Earthquake" and the "1960 Valdivia Earthquake" (USGS 2016a). As seen from earlier, it was once a major earthquake recorded in history, however, the events in Southern Chile were the largest earthquakes that have occurred since accurate range of magnitude became possible in the early 1900s. The United States Geological Survey reports this event as the "largest earthquake of the 20th Century " (USGS 2016a). Figure 2.1.3 shows the magnitude earthquake readings recorded from the beginning of 1990 to 2005. In this record, the highest magnitude reading was in the 1960s that was a Chilean earthquake.

World's Twelve Largest Earthquakes
Includes all measured earthquakes since 1900

Magnitude	Location	Date
9.5	Chile	05/22/1960
9.2	Alaska	03/28/1964
9.1	Off the coast of Northern Sumatra	12/26/2004
9.1	Honshu, Japan	03/11/2011
9.0	Kamchatka	11/04/1952
8.8	Off the coast of Chile	02/27/2010
8.8	Off the coast of Ecuador	01/31/1906
8.7	Rat Islands, Alaska	02/04/1965
8.6	Tibet	08/15/1950
8.6	Off the coast of Northern Sumatra	04/11/2012
8.6	Northern Sumatra	03/28/2005
8.6	Andreanof Islands, Alaska	03/09/1957

Data from the United States Geological Survey.

Figure 2.3 World’s Twelve Largest Earthquakes

Source: https://geology.com/records/largest-earthquake/

The situation in Malaysia shown that in the beginning Malaysia survived the earthquake as Malaysia's position was far away with active seismic plates. However, the fact that Malaysia close to a country with an active seismic plate causes Malaysia to be affected by long-distance earthquake. The long-range earthquake that give a severe impact on Malaysia was an earthquake that took place in Acheh in 2004. The quake occurred in Peninsular Malaysia where the earthquake point or also known as the epicenter was already in existence, for example from 2007 to 2009, the epicenter occurred in Bukit Tinggi (Pahang), Manjung (Perak) on 29 April 2009 and Jerantut (Pahang) in March 2009 followed by a series of earthquake recorded in Kuala Pilah, Negeri Sembilan near Ulu Bendol on November 30, 2009. According to Associate Professor Geosynthesis Associate Professor Mustaffa Kamal Shuib, the earthquake spots have begun in 2007, after the massive earthquake and tsunami in Acheh in 2004. During the earth's crust movement during the earthquake, Peninsular Malaysia experienced strong pressure and the energy was to be released. He also said that the energy release was rapid and any weak areas, especially the old faults, were reactivated and resulted in minor shocks (minor), measuring 3.6 under. Nowadays, every building in Malaysia need to include the earthquake loading to make the building more safety and can hold out during earthquake.

The scientific study of earthquakes is comparatively new. Until the 18th century, few factual descriptions of earthquakes were recorded, and the natural cause of earthquakes was little understood. Those who did look for natural causes often reached conclusions that seem fanciful today; one popular theory was that earthquakes were caused by air rushing out of caverns deep in the Earth's interior (USGS 2016b). Earthquake occur without any prediction that able to know when it happens. Many Scientist had tried numerous variant ways of forecast earthquakes, but not successful. In other way from certain fault, scientists know there will earthquake happen in the future but they cannot tell us the time and date accurately when the earthquake happen.

2.2.1 Type of earthquake

There are many type of earthquake that have occurred in world, among of that are tectonic, explosion and volcanic. The type of earthquake occur is influence by the area where it happens and the geological made up the area. Common earthquake that always happen are tectonic earthquake. Tectonic Earthquake occur when earth crust that covered by many rocks break by geological force that formed by movement tectonic plates. Beside, volcanic earthquake occurs due to phenomena volcano activity. For the explosion earthquake, it occurs when explosion of nuclear and chemical device.

2.2.2 Causes of earthquake

The earth formed with four major layer: crust with radius 1250km, mantle with radius 2900km, outer core with radius 2200km and inner core with radius 100km. The arrangement shown that the earth crust is located close to earth surface and followed by mantle with separated by distinct layer called Moho. Inner core and Outer core is located deepest inside earth. Crust and mantle make up of many pieces like puzzles that covering surface of the earth. This pieces of puzzle are called tectonic plate and the end part of the plate is called boundaries plate. Earthquake occur when the tectonic plate is moving. Even though the plate tectonic moving in slow motion, each plate will slide and keep bumping to each other. Plate boundaries is make up of many fault. Often, most of the earthquake happen in the boundaries plate when edges unstick on one of the faults and the plates are moving far from the fault.

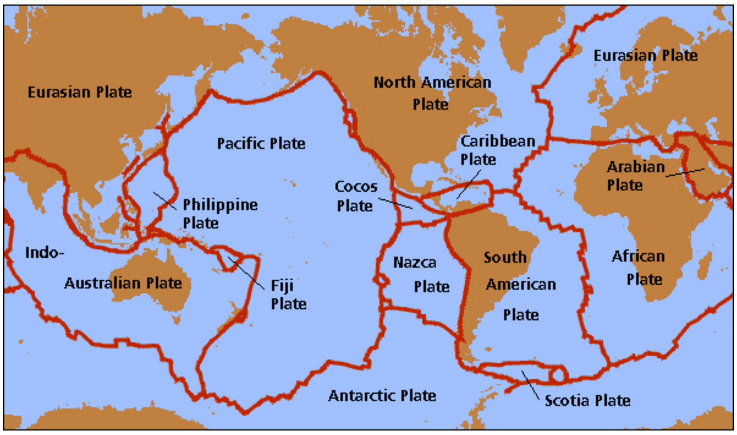


Figure 2.4 Tectonic Plate (Betters 2016)

2.2.3 Earthquake plate tectonic

The Earth is covered by thin thickness of crust and upper mantle that called the lithosphere. Theory of plate tectonic present that how lithosphere of the Earth is split into various plates and interaction each other with their boundaries. There are two types of lithosphere which is oceanic and continental. There is plate may have partial of continental and partial of oceanic lithosphere. Oceanic lithosphere is made from heavyweight minerals compare to continental lithosphere that just made from lightweight minerals. Continental lithosphere has a low density compared oceanic lithosphere due to type of mineral that inside the lithosphere. Generally, there are three types of plate boundaries which is, convergent plate boundaries, divergent plate boundaries and transform plate boundaries.

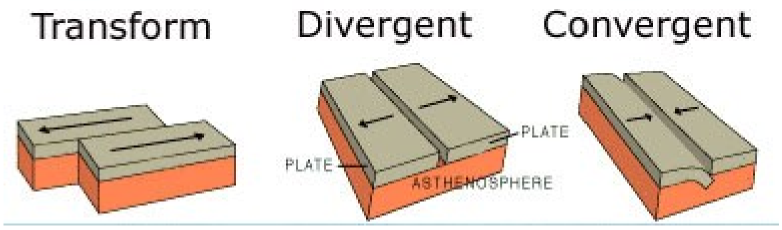


Figure 2.5 Type of Plate Boundaries

Source : https://kidsgeo.com/geology-for-kids/plate-boundaries/

2.2.4 Faults

A fault can be describing as any break in the earth's lithosphere along which movement has occurred. Most damaging earthquake created on faults and occurred at 5 miles or more depth in the Earth's crust. Actually, most of the faults are also reveal at the surface where it can be studied by geologists. Some of the faults are vertical, so that earthquake occurred at ten miles' depth is directly underneath the fault at the surface. Other faults dip at inclination or low angle, so it makes the fault at the point surface may have be various miles away from the epicenter.

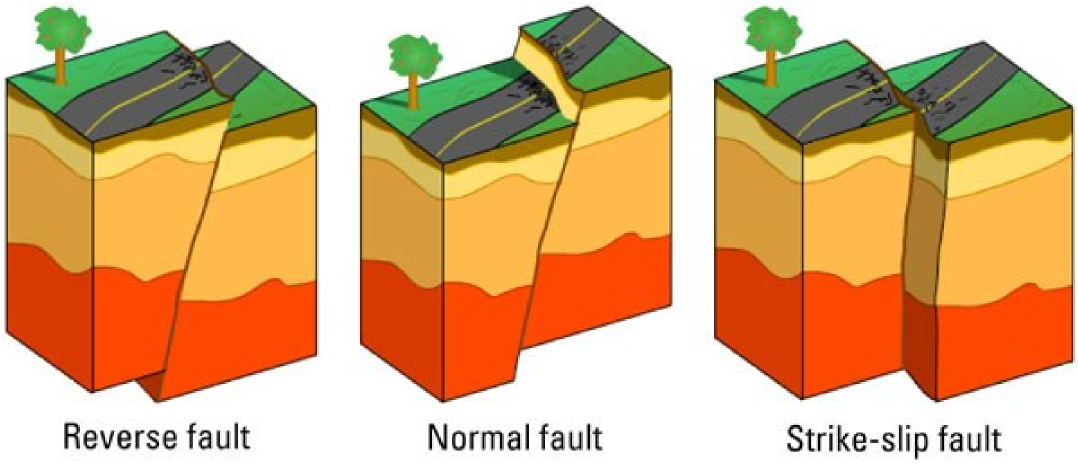


Figure 2.6 Type of Fault

Source : http://data.allenai.org/tqa/stress_in_earths_crust_L_0079/

Figure shown there is different type of geological fault occur. Reverse fault define as when hanging wall move downward relative to the footwall. It occurs when two side block of rock are jammed together by compression. A very largescale of reverse fault is at the Cascadia Subduction Zone, where the Gorda Oceanic Plate is driving beneath northern California. For normal fault, it can be describing by the hanging wall move downward relative to the footwall. Normal faults occur when crust being pulled together by tension as in the case of northeastern California, western Nevada, or at seafloor spreading centers (divergent boundaries). If the block of rock in two side of fault are slide horizontally in opposite direction right and left along the line of fault plane is called strike-slip fault.

2.3 Seismic wave

Phenomena earthquake produce a sequence of waves that pierce earth and, hinge on magnitude. It also can be traced by sensitive tools thousands of miles from epicenter. When rock fragment dramatically occurs at the inside earth or explosion, it can generate waves of energy that called as seismic wave. That energy is move via earth and indicated on seismographs. Seismic wave moves by inner part of earth or surface of earth with an element of speed and style of motion. Type of seismic wave detected through the motion of the ground. Although, we turn on personal wave paths but we need to know it like sound wave, that seismic wave moves to all direction from source. There are various types of seismic wave, and that seismic waves moving in different such ways. The two primary type of waves are surface waves and body waves. Surface waves can move toward surface of the planet only but for body waves can move to deeper inner layer of earth. The speed of wave relies on the elastic properties and density of the material that wave pass through. The waves are strengthened when it reaches the surface. At the far distance, the motion of waves is detected through sensitive seismograph stations.

2.3.1 Body wave

Body Wave have to travel through the interior of the earth rather than surface of earth. Besides, body wave arrive before the surface waves release by earthquake. Mostly, body waves have smaller amplitudes and shorter wavelengths than surface waves and body waves have higher frequency compared to surface waves. There are two different kinds of body waves which is primary waves and secondary wave.

2.3.2 Primary wave

The primary wave or P wave is the faster type of seismic wave compared to other three kind of waves. Therefore, this waves can be arriving first at seismic station and also became the first detected by seismographs. Besides, P wave can move through both solid rock and fluid such as water on the surface of earth. This wave easy to describe because it same movement like sound wave when sound wave push and pull the air. For P wave, it pushes and pulls the rock it moves same like sound wave. Due to pulling and pushing action of P wave, it also known as Compression wave. Subjected to P wave, the particle of wave moving in same direction where the energy travelling in. Occasionally it also called as a direction of wave propagation.

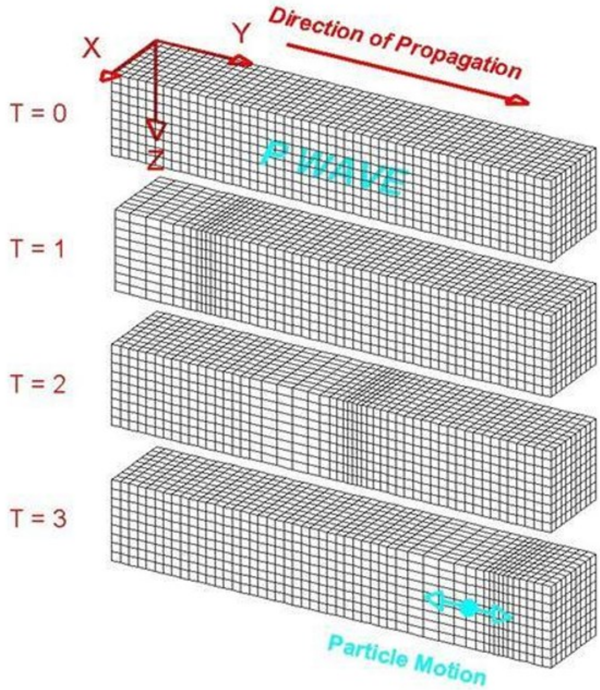


Figure 2.7 A P Wave Travels Through a Medium by Means of Compression and Dilation. (Waves and Waves 2015)

2.3.3 Secondary wave

S wave or secondary wave is the second wave that we can feel in earthquake and this wave directly follow the p wave. S wave is slower compared to P wave and S wave also only can move through the solid rock not for any fluid medium due to fluid cannot sustain shear stress. These are shear wave or transverse waves that move the particle of rock up and down through the movement of wave. S wave is hazardous compare to P wave because it has higher amplitude and create horizontal and vertical motion of the ground surface.

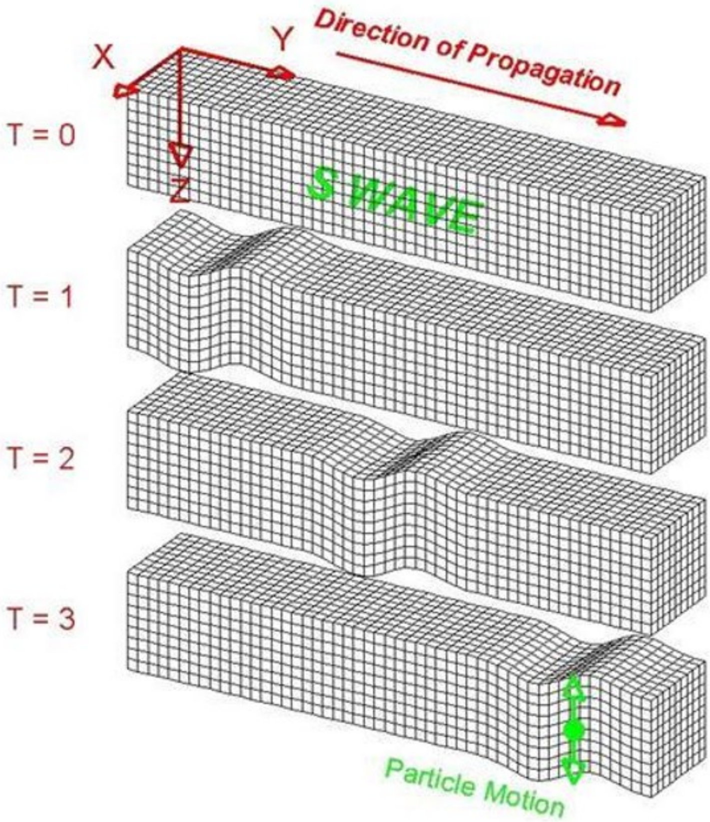


Figure 2.8 A S Wave Travels Through a Medium.

2.3.4 Surface wave

Surface wave only have to travel through the crust earth and it have lower frequency compared to body wave. Although, surface wave arrives after body wave, these wave fully responsible for the destruction and damaging that linked with earthquake. Surface wave can be divide into two kinds of waves which are Love Wave and Rayleigh Wave.

2.3.5 Love wave

Love wave named because of after A.E.K love, British mathematician who worked out mathematical model for this type of wave during 1911. These wave is the fastest wave in surface wave and also moves the ground from right to left. Love waves move same like

S wave due to both have a shearing motion in the direction of travel, but the movement of love wave is back and forth horizontally.

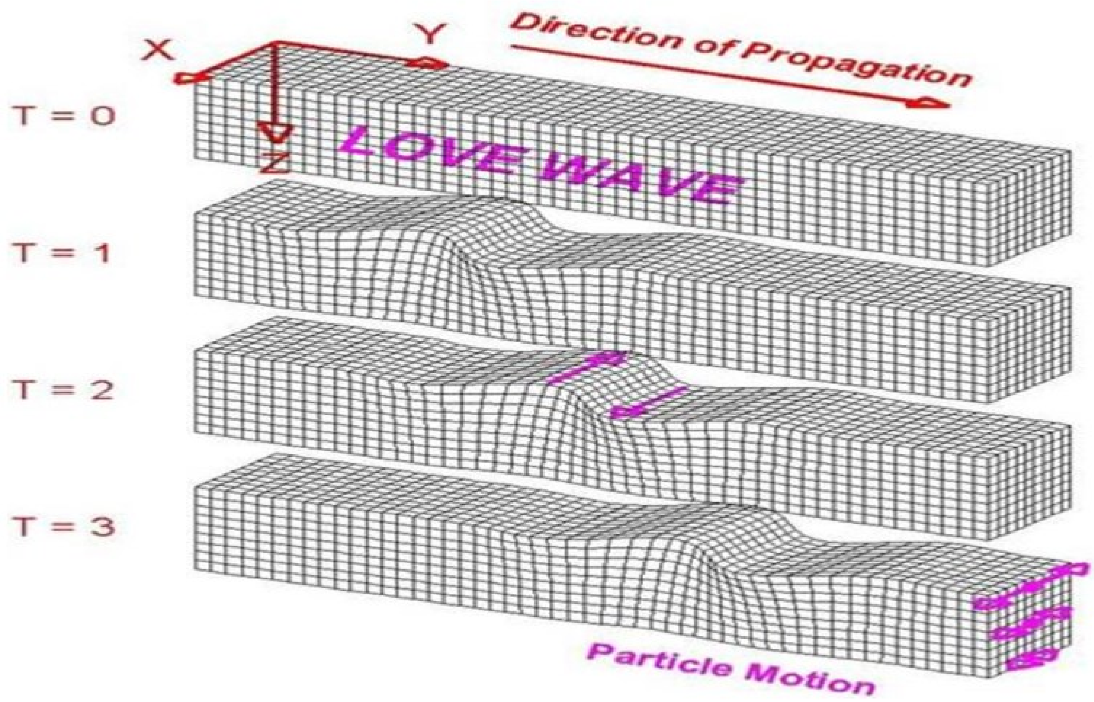


Figure 2.9 Direction of Propagation for Love Waves

2.3.6 Rayleigh wave

Another kind of wave under the surface wave is Rayleigh wave. This wave named for John William Sturtt, Lord Wayleigh, that predict using mathematically about existence of this type of wave during 1885. Rayleigh wave move vertically and horizontally in a vertical plane in the same direction that the wave is moving. Majority of the shaking felt from phenomena earthquake is because of from Rayleigh wave.

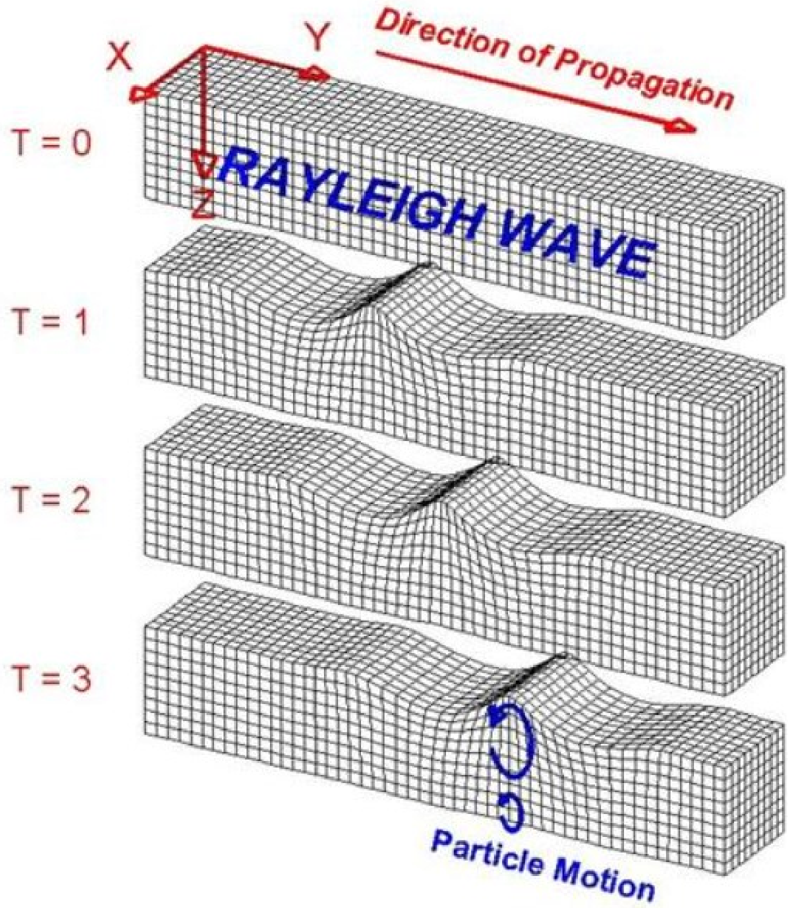


Figure 2.10 A Rayleigh Wave Travels Through a Medium.

2.4 Measurement Instrument

The earthquakes can be detected from various source in the world by using the seismographs. A seismograph is a device that function to measure the movement of the earth, and consist of a ground motion detection sensor. The use of words seismograph is always used synonymously with seismometer, but there is a difference because seismograph coupled with a recording system. A seismograph can amplify, records, detects earthquake and also the other ground motion. We can determine time, magnitude and the location of the earthquake by using seismograph. There are three components in seismograph which is the sensor, the recorder and the timer.

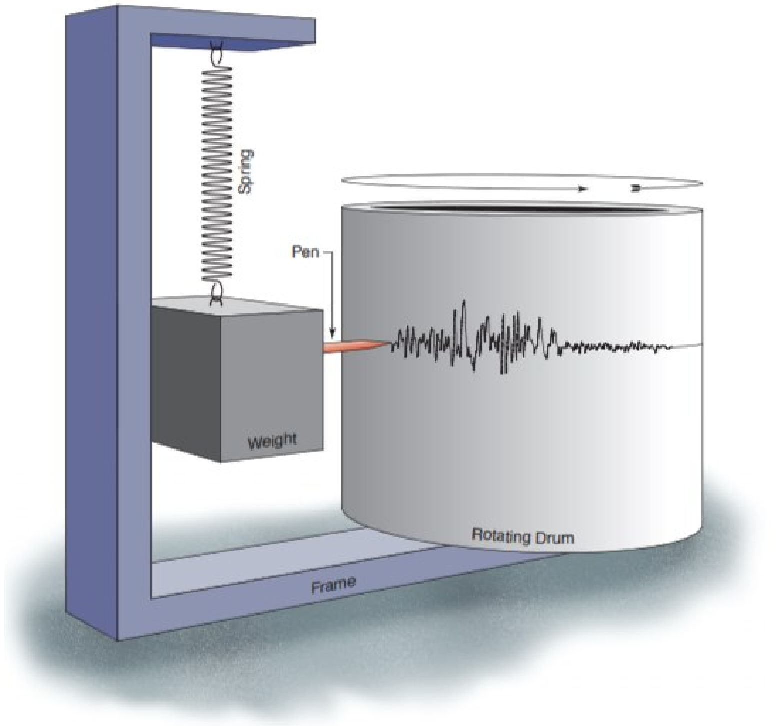


Figure 2.11 A simple seismometer by visualizing a weight hanging on a spring (IRIS 2004)

Source:
https://www.iris.edu/hq/files/publications/brochures_onepagers/doc/OnePager7.pdf

From the figure, it shown that the spring and weight are suspended from a frame that moving together with surface of earth. When earth moving, the relative motion between the earth and weight produce a dimension of the vertical ground motion. The installation of recording system such as a pen attached to the weight and rotating drum attached to the frame, this relative motion between earth and weight can be recorded to provide the history of ground motion that called seismogram.

difference in motion.

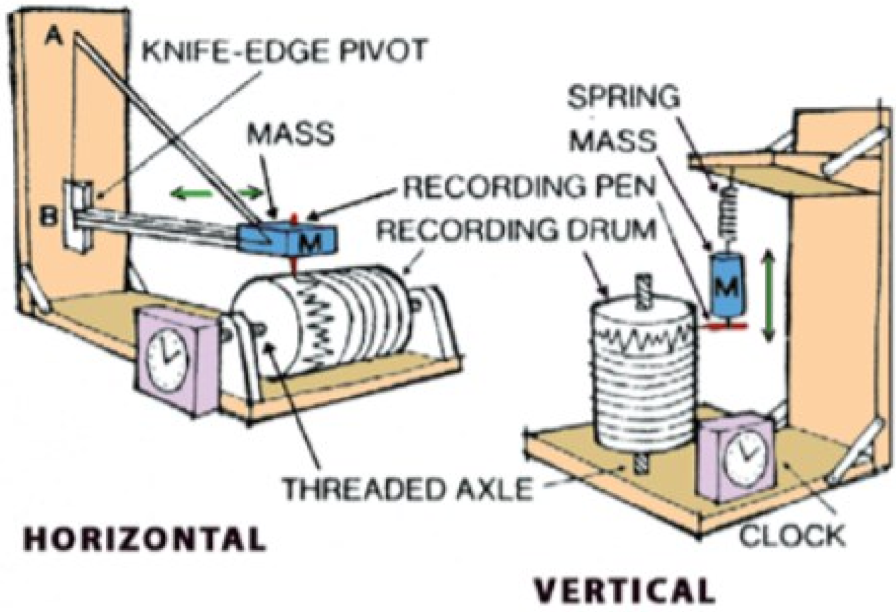


Figure 2.12 Horizontal Seismograph and Vertical Seismograph

Source: https://www.iris.edu/hq/files/programs/education_and_outreach/aotm/8/Seismograph_Background.pdf

Seismographs functioned using principle of inertia of motionless objects, such as inertial mass and in the animation where shown in figure. For inertial mass will remain move less until other force is applied to it. The weight in this way has a tendency to stay stationary following sudden movement, while the frame and drum move with the ground. Seismometers utilized as a part of earthquake studies are designed to be exceedingly sensitive to ground motion, with the motion as little as 1/10,000,000 centimetres (distances almost as small as atomic spacing) can be detected at calm locales. The biggest seismic tremors, (for example, the greatness 9.1 Sumatra-Andaman Islands quake in 2004) make ground movements over the whole earth that can be a few centimetres high a large number of miles away from the epicentre.

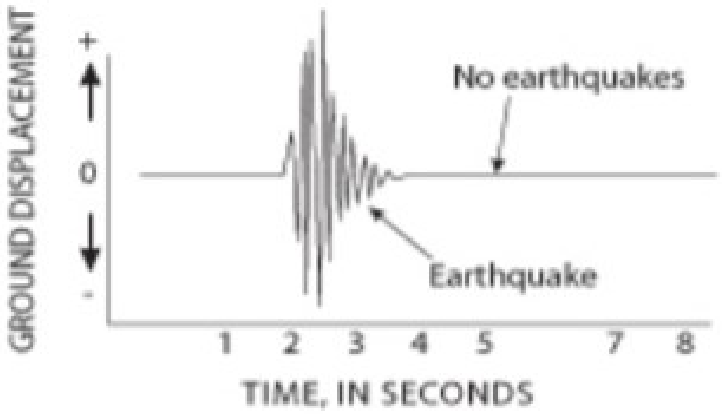


Figure 2.13: Graph of movement of the ground versus time

Source:
https://www.iris.edu/hq/files/programs/education_and_outreach/aotm/8/Seismograph_Background.pdf

In figure there is the graph of the movement of the ground versus time. They are the squiggles left by the pen or created by advanced PC records. Seismograms are utilized to figure the place and magnitude of an earthquake.

2.5 Magnitude of earthquake

The magnitude is the number that describe the relative size of an earthquake. The value of magnitude is depending on the maximum movement recorded by a seismograph. There are several scales that have been establish, yet the most normally utilized are local magnitude (ML) normally to as " Richter size ", body wave magnitude(Mb), surface wave magnitude(Ms), and moment magnitude(Mw). For local magnitude(ML), body wave magnitude(Mb), and surface wave magnitude(Ms) are have limited range and applicability and also satisfactorily measure the size of the biggest seismic tremors. In the light of the idea of seismic moment, the moment magnitude scale is consistently applicable to all size of earthquake however is more hard to process than the other types.

2.5.1 Local magnitude scale

The Richter magnitude scale was produced in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical gadget to differentiate the size of seismic tremors. The magnitude of earthquake is resolved from the logarithm of the amplitude of waves recorded by using seismographs. Modification are incorporated into the magnitude formula to offset for the variation out there between the different seismograph and the epicenter of the earthquake. The value of magnitude in Richter Scale is expressed in decimal fraction and whole number. For instance, a magnitude of 5.3 may be computed as a moderate kind of earthquake but for strong earthquake the value might be rate as magnitude 6.3. Based on the logarithmic basis of the scale, every whole number increment in magnitude represents a tenfold increment in measured amplitude. As an estimate of energy, every whole number rate in the magnitude scale equivalent to the liberation of about 31 times more energy than the sum linked with the previous whole number value.

Richter Magnitudes	Description	Earthquake Effects	Frequency of Occurrence
< 2.0	Micro	Microearthquakes, not felt.	About 8,000 per day
2.0-2.9	Minor	Generally not felt, but recorded.	About 1,000 per day
3.0-3.9	Minor	Often felt, but rarely causes damage.	49,000 per year (est.)
4.0-4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.	6,200 per year (est.)
5.0-5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.	800 per year
6.0-6.9	Strong	Can be destructive in areas up to about 160 kilometres (100 mi) across in populated areas.	120 per year
7.0-7.9	Major	Can cause serious damage over larger areas.	18 per year
8.0-8.9	Great	Can cause serious damage in areas several hundred miles across.	1 per year
9.0-9.9	Great	Devastating in areas several thousand miles across.	1 per 20 years
10.0+	Epic	Never recorded	Extremely rare

Figure 2.14 : Richter Magnitudes and Earthquake Effects (Earthquake, Size, and The 1929)

2.5.2 Body wave magnitude scale

Body wave magnitude scale is to measure the amplitude of the P-wave that not disturbed by the focal depth, and also with that we can determine body wave magnitude(Mb). The largest amplitude should be taken within the first few cycles no need to consider the whole P-wave train. (Willmore, 1979). Body wave magnitude (Mb) is usually measured out to a distance of 100◦, beyond which core diffraction has a complicated effect on the amplitude

2.5.3 Surface wave magnitude scale

The surface wave magnitude uses the largest amplitude of arriving surface waves for measuring. Richter and Gutenberg are the first creator a scale for surface waves magnitude in 1936 but during Gutenberg was develop the formula more extensively.

2.5.4 Moment magnitude scale

Most of the magnitude scale do not provide accurate estimation for the largest size of magnitude earthquake. The moment magnitude scale is preferred to use because this device work over a wider range of earthquake size and can be use throughout the global. The moment magnitude scale (Mw) is depend on the sum of moment release of the earthquake. The value of moment produced from the product of the force required to move and the distance a fault moved. It is gotten from modelling recordings of the earthquake at different stations. It is gotten from modelling recordings of the earthquake at different stations. Moment magnitude estimates are the same as Richter sizes for small to large earthquakes. The largest recorded earthquake, the 1960 Chile event, had Mw = 9.5. Moment magnitude has become the common measure of the magnitude of large earthquakes

2.6 Intensity of ground motion

Intensity can be described as a categories of the strength of shaking at any place during earthquake. Generally, Roman numerals have been utilized to represent intensity values to emphasize this point (it is difficult to state "VII"). Nowadays the utilization of Roman numerals is to a great extent a matter of taste, and most seismologists find Arabic numerals easier to process by computer. The utilization of force scales is historically important due to no instrumentation is needed, and l measurements of an earthquake can be made by an unequipped observer. There are many kind of intensity scales. Mostly the common scale that always used are the Modified Mercalli Intensity Scale a d The MSK Scale. Both these scale are quite similar and range from I to XII. The intensity scale depends on three highlights of shaking, which is perception by people and animal's execution of structures, and changes to normal environment.

2.7 Stayed-cable bridge structure

Bridges are civil works for which is required their structural integrity and accessibility after the occurrence of an earthquake. Bridges have been used since ancient history though the technique of binding log has been replaced by modern materials shaped into well-designed structures to resist applied loads. Different types of bridge have been constructed since ancient times. Tensile and compressive forces are present in all types of bridges. An efficient bridge design ensures that these forces are resisted without buckling, by either transfer of these forces to the areas of greater strength or dissipation of the forces over a larger area. The weight of the bridge is concentrated on the supports at the middle and the ends by the use or cables, girders, and arches. The supports rest on firm rocks, or reinforced boxes that are filled with concrete and sunk into the ground. The bridges are normally made from steel beams and steel since these materials possess the capability to resist the compressive and the tensile forces.

Bridges are very vulnerable structures in that way, and essential for transportation systems, consequently the understanding of their seismic behaviour is fundamental. Cable-stayed bridges, due to their large dimensions and flexibility, usually experience very long fundamental periods, which is an aspect that differentiates them from other structures, and of course, that affects their dynamic behaviour. Cable stayed bridges date back many centuries, the system was used by Egyptians for their sailing ships. Early Chinese people used the stayed-cable system to construct suspension bridges out of hemp rope and iron chains. There are many examples of ancient cable-stayed bridge systems found around the worlds. The first modern bridge structure was a combination of a stayed and suspension system. They were constructed at the end of the eighteen-century in the United States and in England

F. Dischinger identified the need to increase the stress in the cables so as to reduce the sag effect in the stiffness. This advancement gave the impulse to modern cable based structures. In 1955 he built the Stromsund bridge, located in Sweden, which is considered the first modern cable stayed bridge. Another important factor in the evolution of cable-stayed bridges was the employment of superstructure sections that act as a continuous girder along the longitudinal axis. With these improvements, modern cable-stayed bridges became very popular in the last thirty years. Significant illustrated milestones are The odor Heuss bridge in 1958, the Schiller-Steg footbridge which was constructed in Germany in 1961, the Maracabio Bridge constructed in Venezuelain 1962.

The reason of famous of contemporary cable-stayed bridges among all type of bridge around worlds can be related to the appealing aesthetics bridges, the full and efficient utilization of structural materials, the increased stiffness comparing with suspension bridges. Besides, cable-stayed bridge are the efficient and fast mode of construction and also the relatively small size of the bridges elements. The main component of stayed cable bridges is composed of cables, main girders and towers. A bridges carries vertical loads mainly by the girder. The staying cables provide intermediate supports for the girder so that it can cover a long distance. The basic structural form of a cable-stayed bridge includes a series of overlapping triangles comprising the pylon (or the tower), the cables, and the girder. All these members are under predominantly axial forces, with the cables under tension and both the pylon and the girder under compression. Axially loaded members are generally more efficient than flexural members.

As the most recent researches show, there are more than 1000 cable-stayed bridges in the world and this number is increasing rapidly. The span length has also increased significantly. Cable-stayed bridges are generally considered advantageous for spans between about 100m to 500m; however, larger spans over 1000m wide are not uncommon too

The cable-stayed bridges can be categorized by number of towers, girder type, number of cables, number of spans and other. When view based on structural systems, it usually can be distinguished to five groups which is a cable-stayed bridges with curved decks, cable-stayed bridges without back-stays, extra dosed bridges, Giscard bridges and multiple-span cable-stayed bridges. From the cable-stayed around the world's that has gathered, there are different parameters and has categorized these bridges in 3 categories of harp, fan and radial.

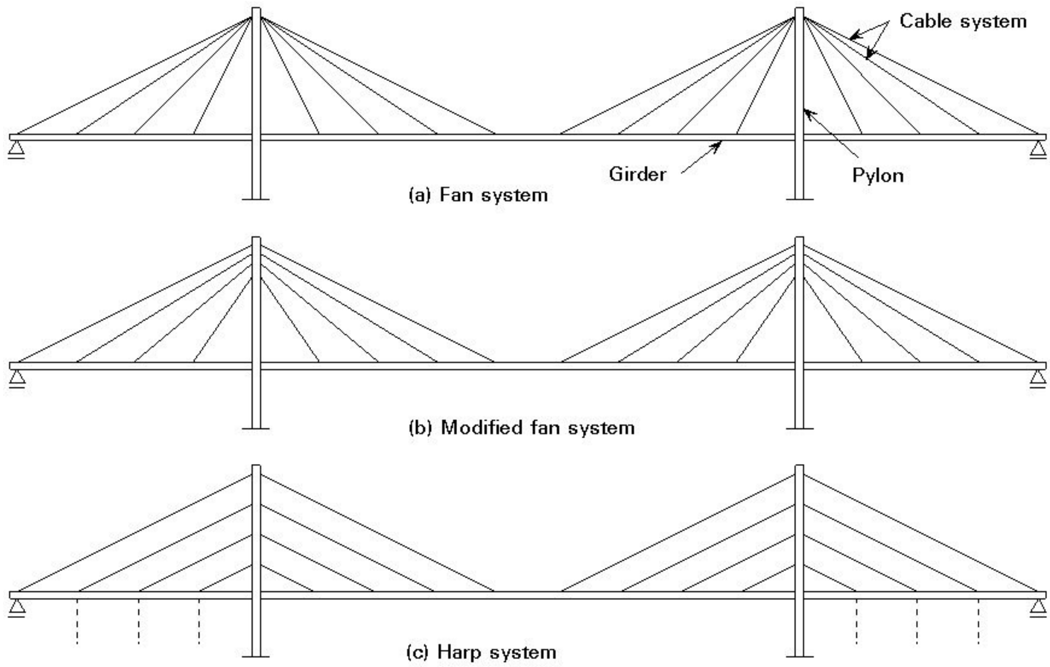


Figure 2.15 Types of Cable-stayed Bridges

2.7.1 Stayed-cable bridge in Malaysia

There are 8 stayed cable bridge that had been construct in Malaysia. Among it are:

Figure 2.16 The Langkawi Sky Bridge , Kedah

Source: https://en.wikipedia.org/wiki/Langkawi_Sky_Bridge

Figure 2.17 Muar Second Bridge, Johor

Source: https://en.wikipedia.org/wiki/Muar_Second_Bridge

Figure 2.18 Penang Bridge

Source: https://en.wikipedia.org/wiki/Penang_Bridge

Figure 2.19 Prai River Bridge, Penang

Source: http://butterworthguide.com.my/index.php/prai-discover-secrets-of-a-town-s-forgotten-heyday/46-prai-river-bridge

Figure 2.20 Seri Saujana Bridge, Putrajaya

Source: https://en.wikipedia.org/wiki/Seri_Saujana_Bridge

Figure 2.21 Seri Wawasan Bridge, Putrjaya

Source: https://en.wikipedia.org/wiki/Seri_Wawasan_Bridge

Figure 2.22 Sultan Abdul Halim Bridge, Penang

Source: https://en.wikipedia.org/wiki/Sultan_Abdul_Halim_Muadzam_Shah_Bridge

Figure 2.23 Johor river Bridge , Johor

Source: https://en.wikipedia.org/wiki/Sungai_Johor_Bridge

CHAPTER 3

METHODOLOGY

3.1 Introduction

For the planning of the study, this chapter will explain more detail about the procedure that need to carry out. Methodology is very important when doing research because it is the process of collecting information and data for purpose of making the decisions. SAP 2000 was used to create modelling and analyses the structure which is a stayed cable bridge. The data of earthquake have been obtained from Malaysian Meteorology Department (MMD). Data that have been obtain are used to analyses with consider of earthquake loading to the stayed cable bridge. In addition, the characteristics and dynamic characteristics of the structures can be known when subjected under different earthquake loadings. Planning was arranged as follow to ensure the project running successful.

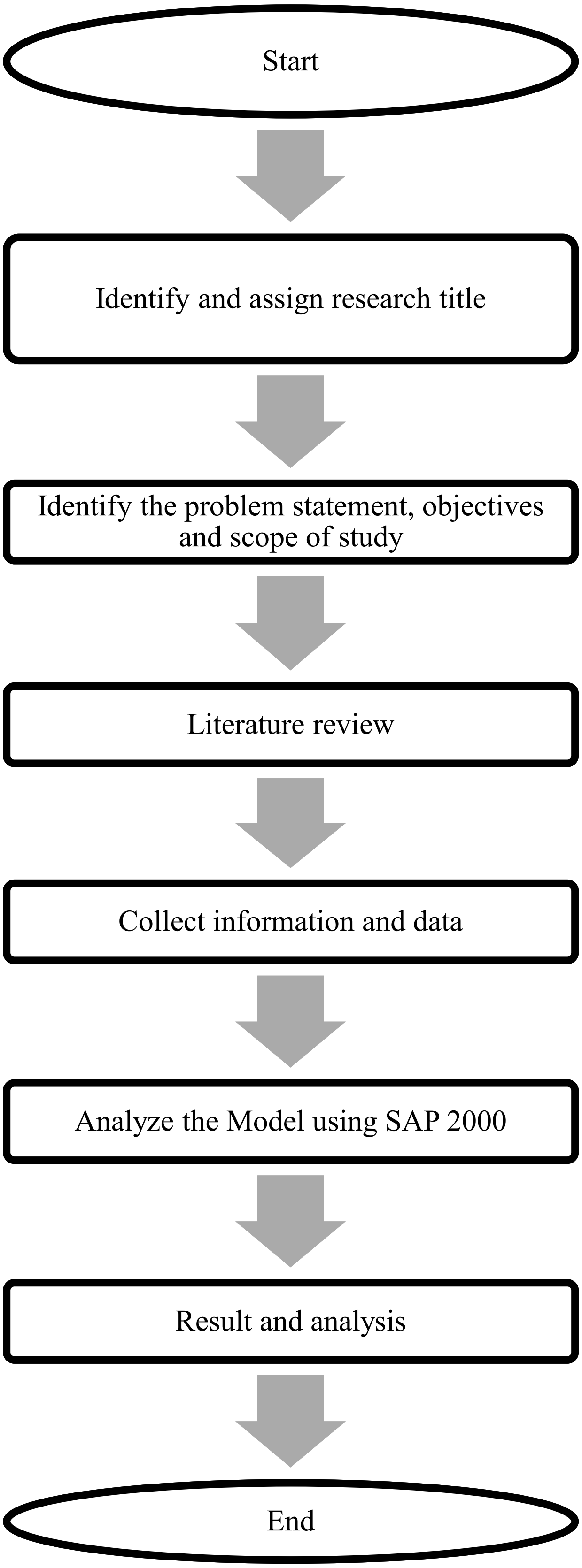


Figure 3.1 Flow chart to carry out the project

3.2 Literature review

A literature review is a search and evaluation of the available literature relate to the topics that we focus to study. The important of the literature review is to ensure that we know that we are the right path. In literature review, we need to gather all information in news, journal, conference paper, article or other source that related to the topic. Mostly, for this research the main source that we use to gather the data and information about the topic are from internet, journal, article and some reference book. One of the example journal that referred is journal written by C.V.R Murty entitle Earthquake Tips.

3.3 Material properties

During this phase, for carry out and run the analysis successfully, all the related information and data must be collected. It is because to use for modelling and analysis the structure using software SAP 2000. There are some information and data required for model and analysis. Among that are:

1. Drawing of the stayed cable bridge structure

2. Material of the structure

3. Type of loading will structure carry

4. Data of the earthquake from Malaysia Meteorological Department

3.4 SAP2000 Software

Figure 3.2 SAP2000 version20

The SAP name has been synonymous with state-of-the-art analytical methods since its introduction over 30 years ago. SAP2000 follows in the same tradition featuring a very sophisticated, intuitive and versatile user interface powered by an unmatched analysis engine and design tools for engineers working on transportation, industrial, public works, sports, and other facilities.

From its 3D object based graphical modelling environment to the wide variety of analysis and design options completely integrated across one powerful user interface, SAP2000 has proven to be the most integrated, productive and practical general purpose structural program on the market today. This intuitive interface allows you to create structural models rapidly and intuitively without long learning curve delays. Now you can harness the power of SAP2000 for all of your analysis and design tasks, including small day-to-day problems.

Complex Models can be generated and meshed with powerful built in templates. Integrated design code features can automatically generate wind, wave, bridge, and seismic loads with comprehensive automatic steel and concrete design code checks per US, Canadian and international design standards.

Advanced analytical techniques allow for step-by-step large deformation analysis, Eigen and Ritz analyses based on stiffness of nonlinear cases, catenary cable analysis, material nonlinear analysis with fiber hinges, multi-layered nonlinear shell element, buckling analysis, progressive collapse analysis, energy methods for drift control, velocity-dependent dampers, base isolators, support plasticity and nonlinear segmental construction analysis. Nonlinear analyses can be static and/or time history, with options for FNA nonlinear time history dynamic analysis and direct integration.

From a simple small 2D static frame analysis to a large complex 3D nonlinear dynamic analysis, SAP2000 is the easiest, most productive solution for your structural analysis and design needs

3.4.1 SAP2000 Software flowchart

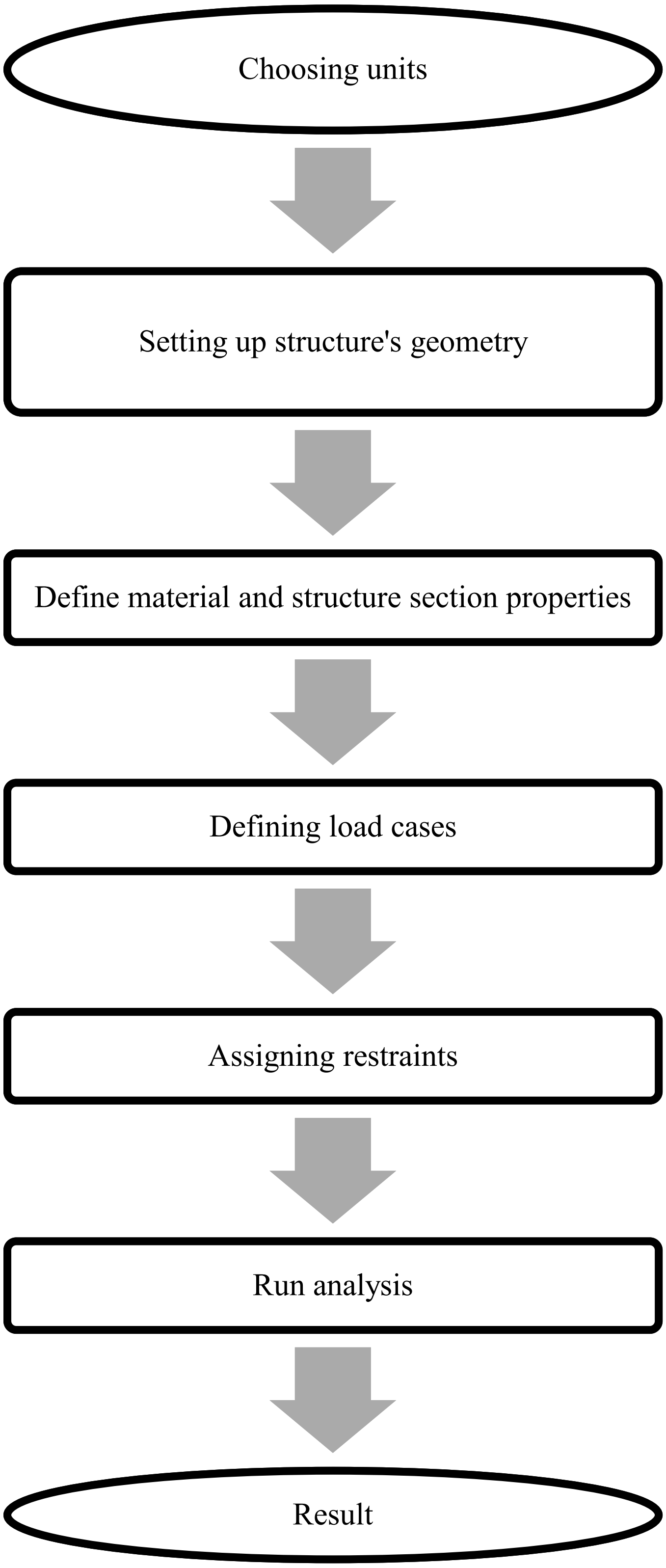


Figure 3.3 Flow chart of using SAP2000 software

3.4.2 Step in SAP2000 software

Step 1: Choosing units

The unit will be chosen base on the unit that use to design the structure. In this project the unit used was kN, m, C

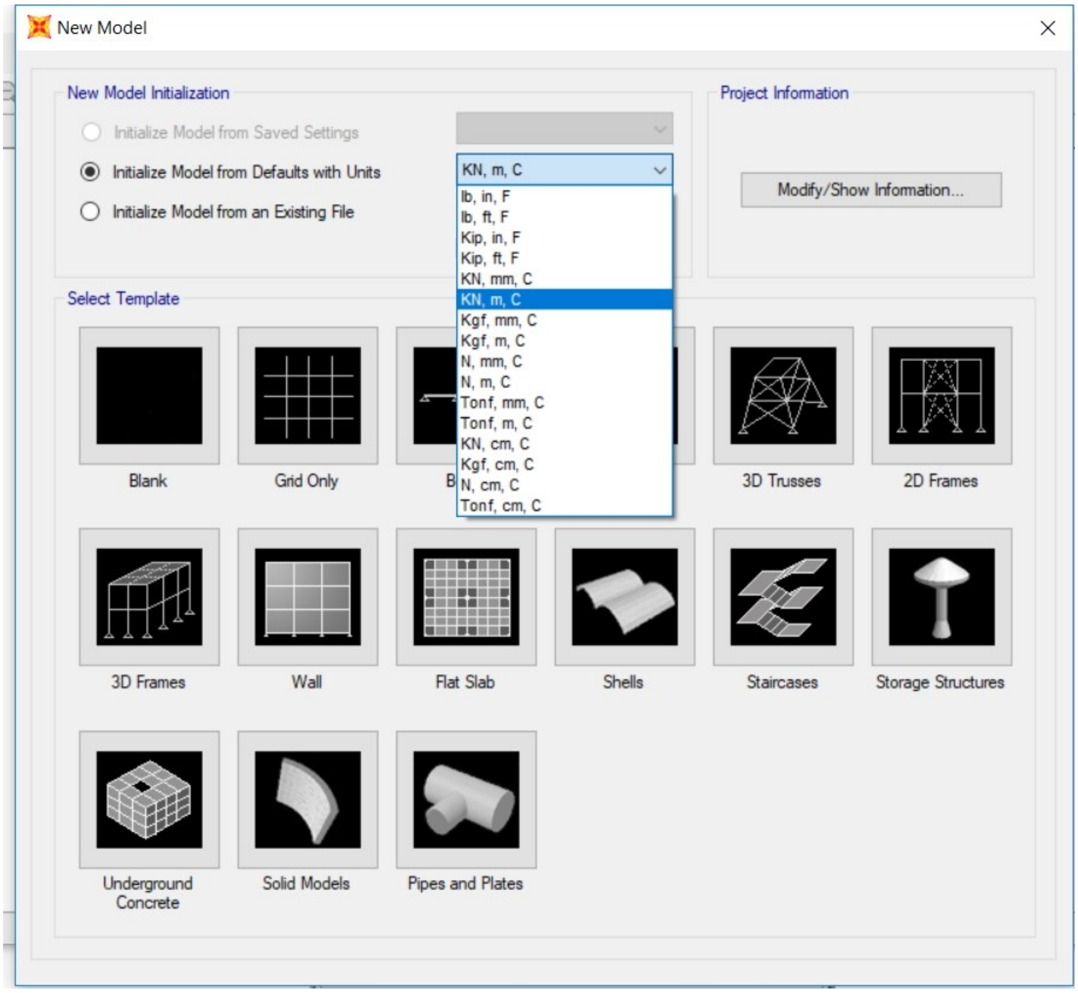


Figure 3.4 Choose the unit for the object

Step 2: Setting up structure geometry

In step 2 there are two ways to setting up the structure geometry. The first way is just using the template that provided in SAP2000 and the second way is by creating using grid line only. For this structure modal, just only used grid line to create the cable stayed structure modelling.

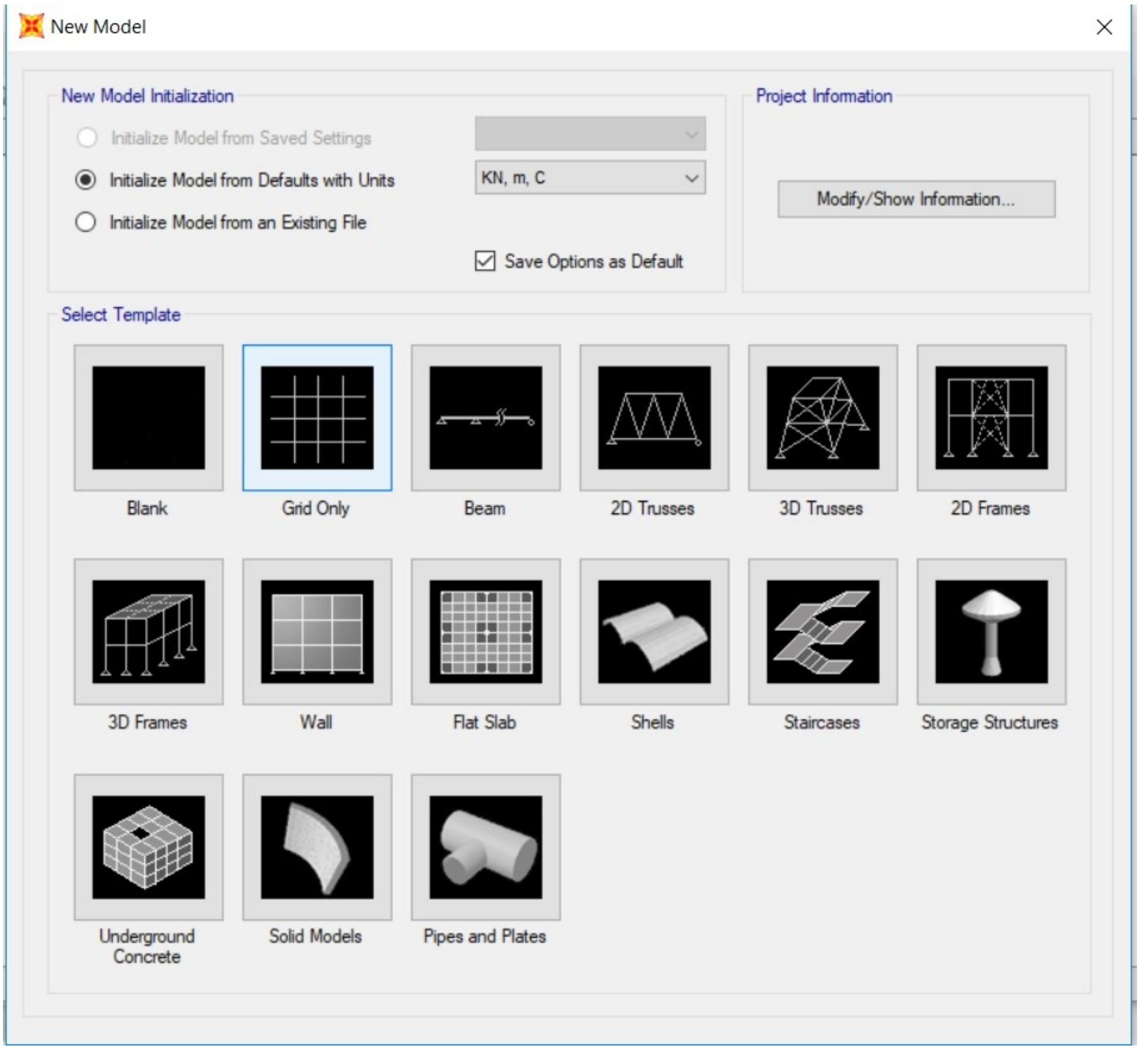


Figure 3.5 Choose template for Grid

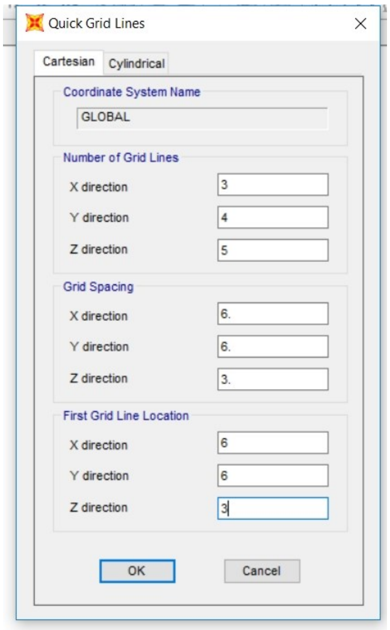
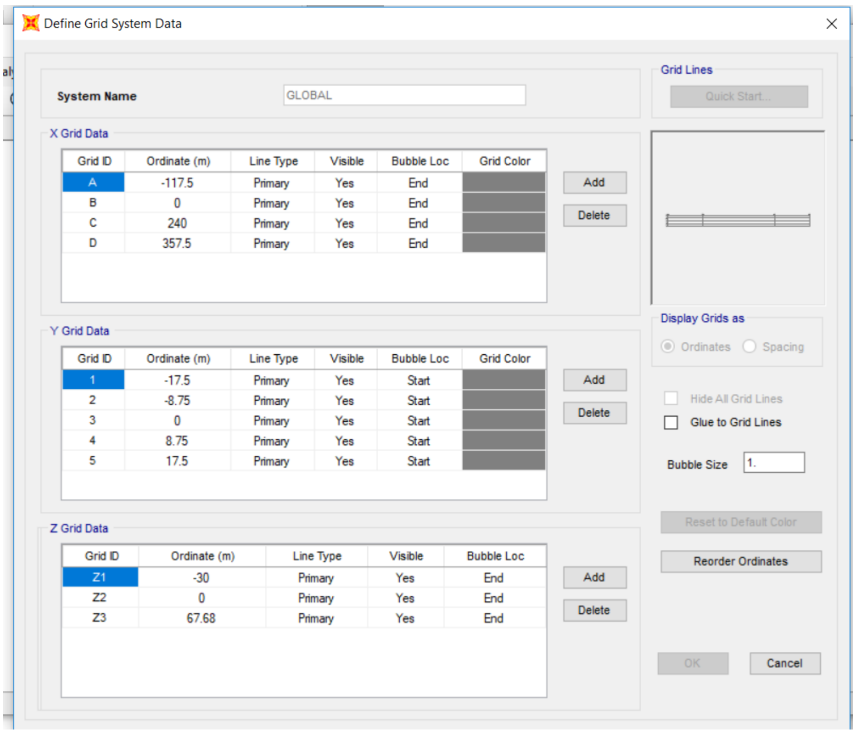


Figure 3.6 Grid lines option

Insert all the grids to allocate the frame element accordingly to the drawing. The design of the cable-stayed bridge is from Penang Bridge.



Step 3.7 Define grid system data

Step 3: Define material and structure section properties

In this step, define all material type and all the section properties used for the structure such as concrete and steel. Insert the structure component properties that have in cable stayed bridge such as cable, deck, pylon and link.

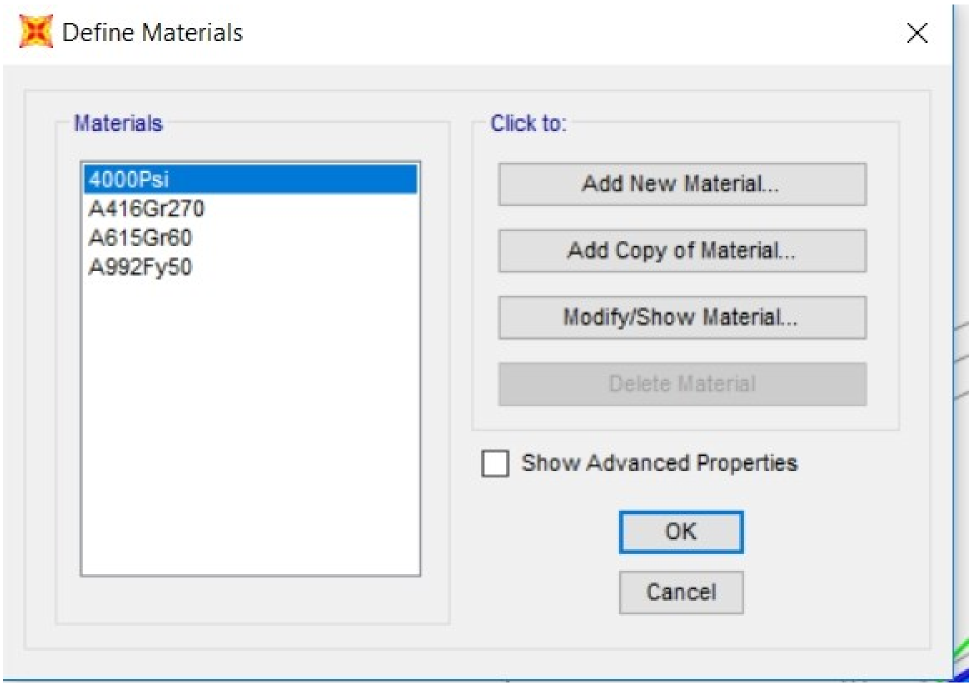
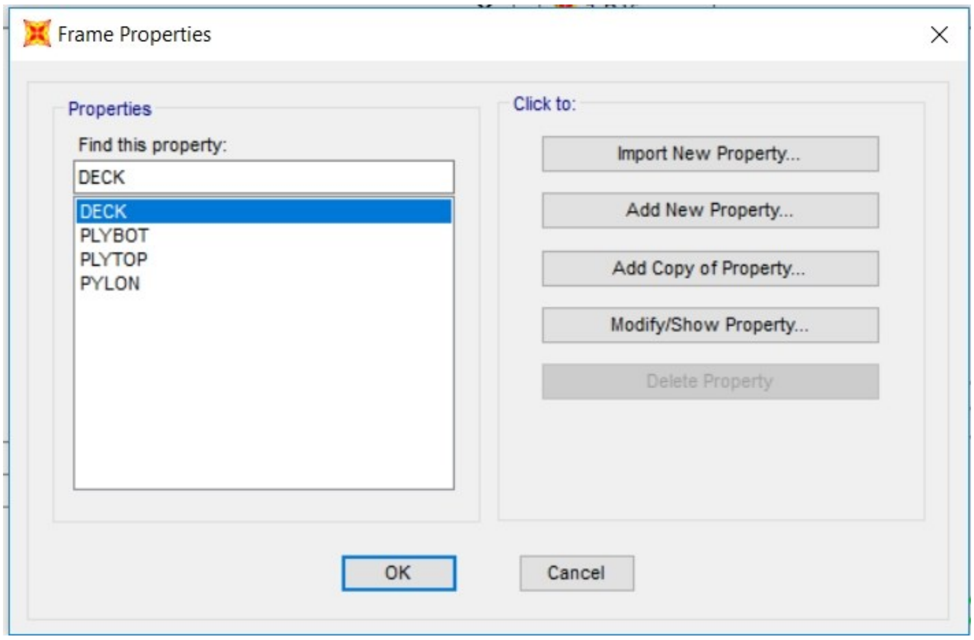
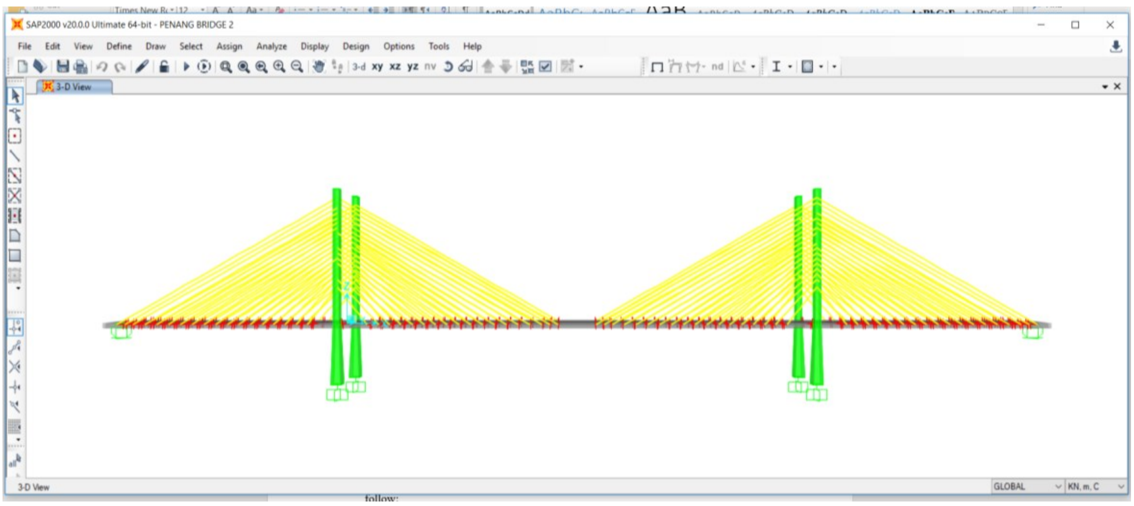


Figure 3.8 Define material



Step 3.9 Define the structure properties

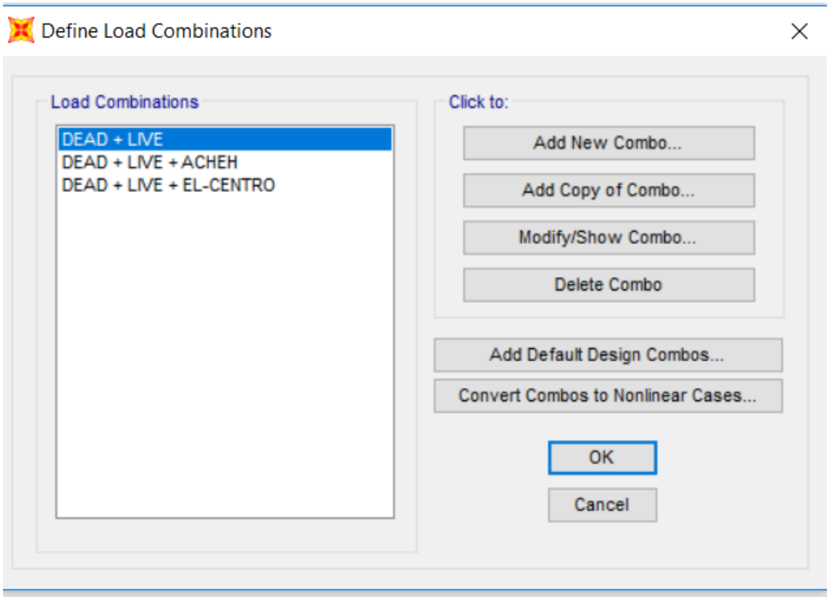


Step 3.10 Model structure of cable stayed bridge in SAP 2000

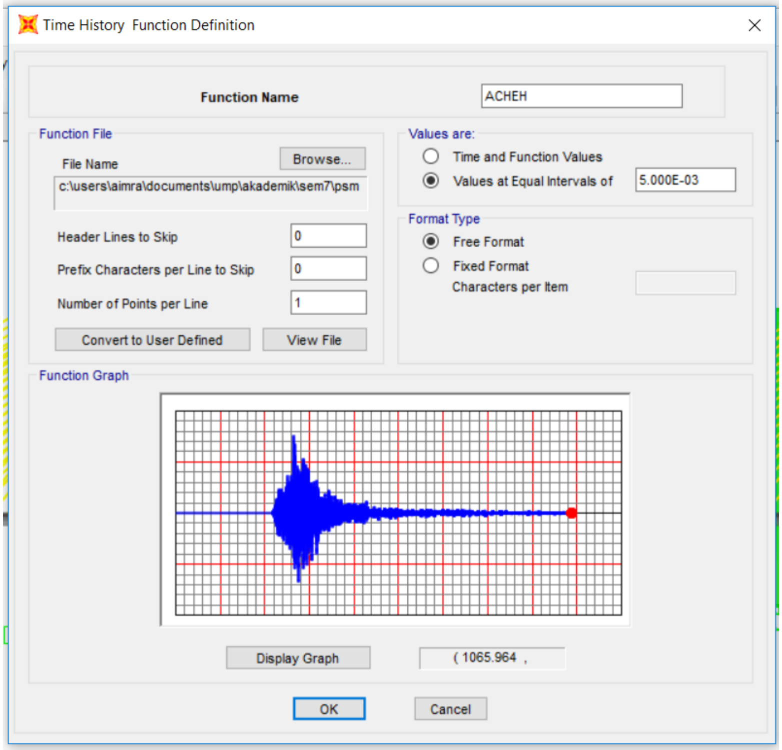
Step 4: Defining load combination

Two types of load cases being consider in analysing the structure. The load cases are as follow:

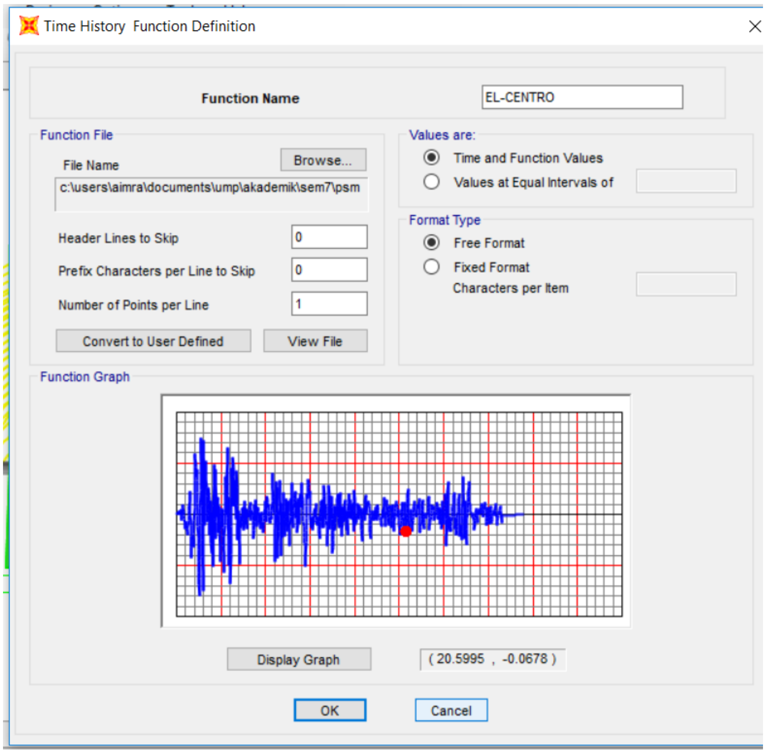
1) Dead and live load
2) Dead and live and earthquake load



Step 3.11 Define the load combination



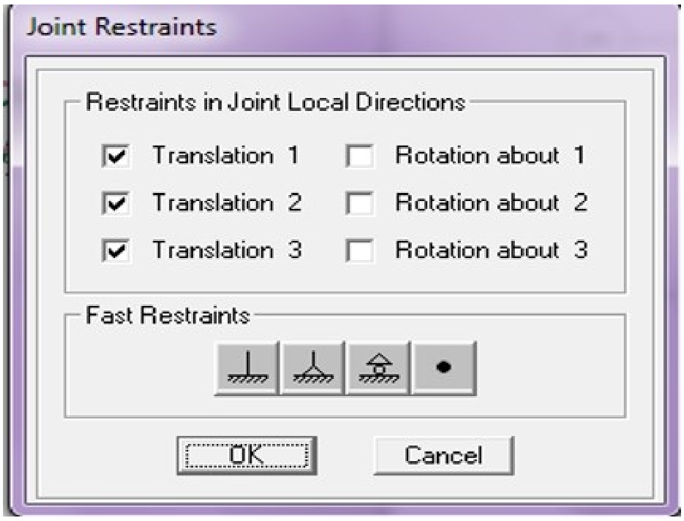
Step 3.12 Time history function (Acheh earthquake)



Step 3.13 Time history function (El-Centro Earthquake)

Step 5: Assigning restraint

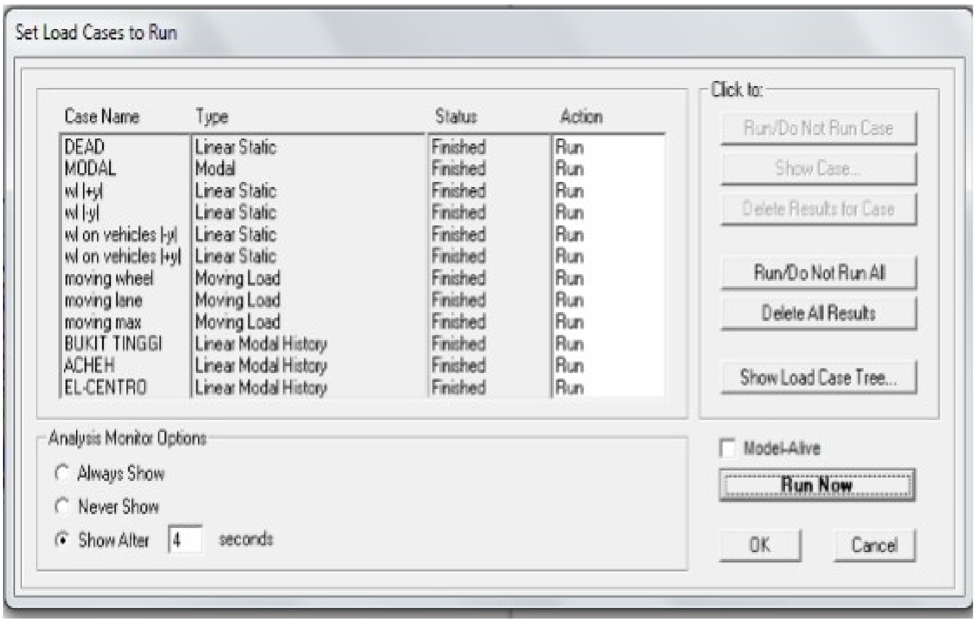
Assigning restraint to the structure is the importance step in SAP2000. This is because if the structure has not assign a restraint the structure will become unstable or a free body. As a result, SAP2000 cannot solve the analysis.



Step 3.14 Add restraint at the base condition

Step 6: Run analysis

The analysis was run for free vibration analysis. The modal load cases were selected and run the analysis to the structure. The final result after run the analysis will be discussing more in Chapter 4.



Step 3.15 Run analysis

3.5 Summary

In a nutshell, this chapter explained the step used in this research which using the computer software, SAP2000. Before analysis is conducted, the model of the structure of the cable stayed bridge is constructed. Later, the earthquake data that used to analyse the structure is applied on the structure. After the analysis is run, all the objectives of the research can be determined.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter represent the seismic performance of stayed cable bridge due to surrounding earthquake in Malaysia. Stayed cable bridge has been modelled by SAP2000 version 20. There are some assumptions, and linear characteristic have been made and used to model the structure:

I. The dimension and the details of the structure are according to actual structural drawing of stayed cable bridge.
II. Material, size, joint and section of the bridge used represent similar to the actual design.
III. Earthquake load of Al-Centro and Acheh Earthquake getting from Malaysian Meteorological Department.
IV. The support of the stayed cable bridge is assumed to be fixed on the ground instead of piled.

4.2 Bridge specification

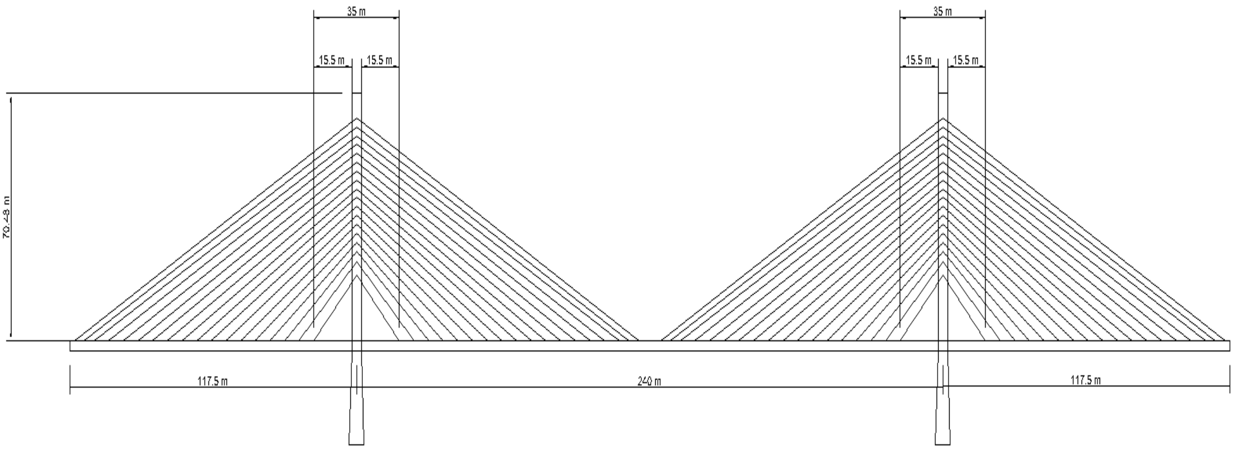


Figure 4.1 Main navigation span (Front Elevation)

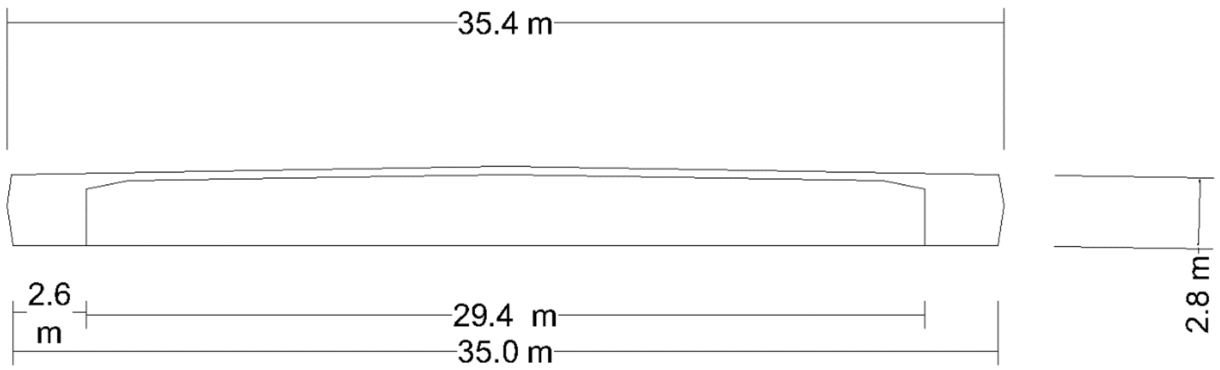


Figure 4.2 Deck cross section

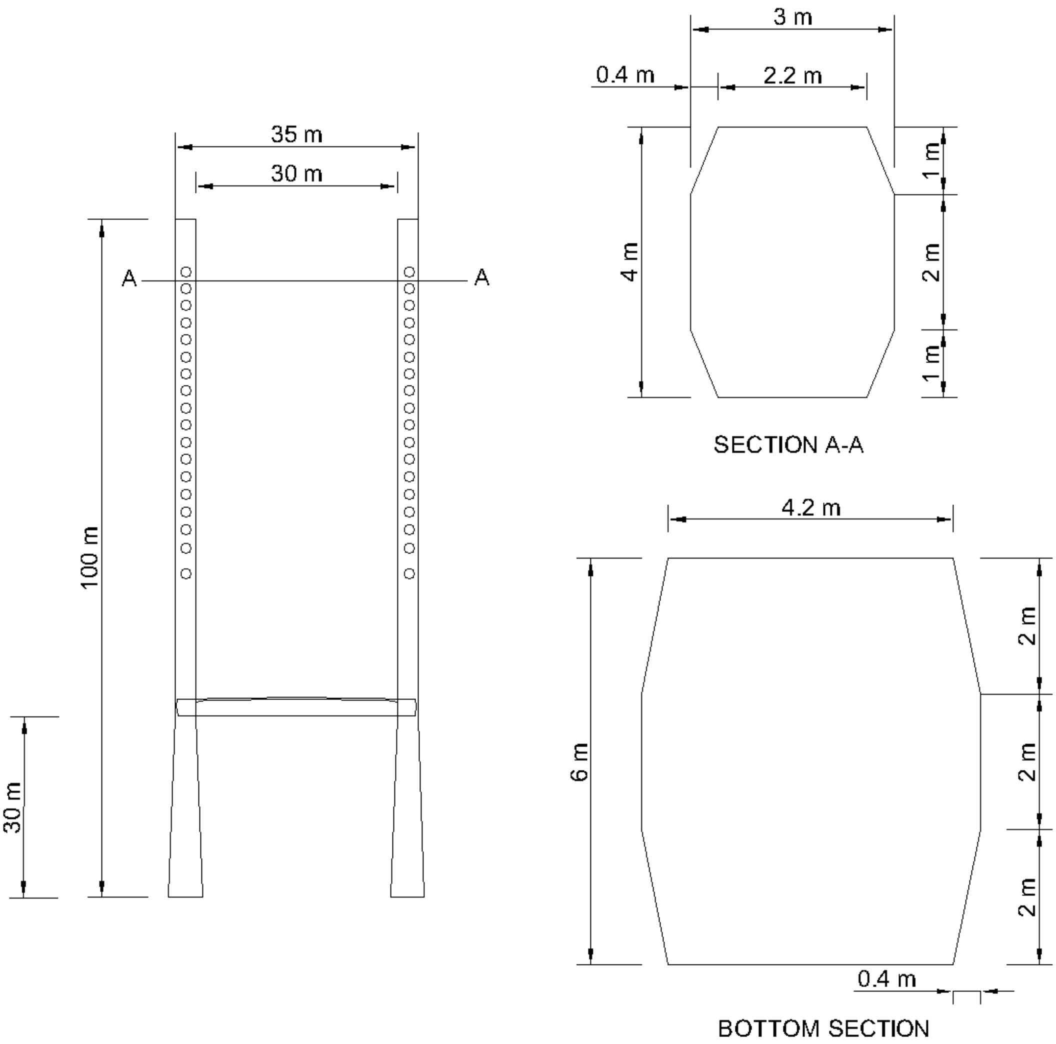


Figure 4.3 Pylon cross section at top and bottom

4.3 Design concept

Type of structure: prestressed concrete beam and slab deck

Spans arrangement: 117.5m + 240m + 117.5m

Pylon type: H shape concrete tower

Pylon size: Upper – 3.0m x 4.0m

Lower – Gradually increase from top to bottom (5.0m x 6.0m)

The pylon concrete grade: 50 N/mm

Typical beam height: 2.8m

Deck slab thickness: 28cm

The main beam concrete grade: 55N/mm

4.4 Analysis of stayed cable bridge

The stayed cable bridge was modelled and analysed using SAP 2000 version 20 software. Free vibration analysis is performed at the early stage since it does not include any loads on the structure. There are three type of load that be considered in this analysis. The loading are dead load, live load, and earthquake load with different magnitude. In addition, by using this software all loading consider can be combine through load case combination. Several combination of load cases are implementing to the analysis as below:

i. Free vibration analysis (FBA)
ii. Dead load (DL) + Live load (LL)

iii. Dead load (DL) + Live load (LL) + Wind Load (WL) + Time history load (TH)

Besides, the results that are expected to obtain from SAP 2000 are as:

i. Modal shape of stayed cable bridge
ii. Natural period and frequency of structure
iii. Maximum shear and bending moment in the member
iv. Joint displacement and acceleration under different types

4.5 Free vibration analysis

Modal analysis or known as free vibration analysis is the structure with the motion without any external forces or support motion. The structure will move away from equilibrium phase due to free vibration analysis. This mode concept is only taken as a general characteristic of specific states of oscillation as there is no real system that can perfectly fit under the standing wave framework. The vibrations occur because of the frequency. This prove that, the frequency is produce from earthquake and cause the ground motion. The modal shapes which will be vibrating which have been assumed are properties of the system and this decisive empirically by using Modal Analysis. In the analysis, the mode number applied to the structure is up to twelve (12) types of mode shape. From the modal analysis, the result will show the natural period, mode shape of modal, natural frequency, joint and displacement. Each mode shape of stayed cable bridge produced different value of natural period and natural frequency. The summary of the analysis result has been tabulated in Table 4.1.

Mode	**Natural Period, T (sec)**	**Natural Frequency, F(Hz)**
1	2.4064	0.4156
2	2.3442	0.4266
3	2.3358	0.4282
4	2.3142	0.4321
5	2.3134	0.4323
6	2.3123	0.4325
7	1.2788	0.7820
8	0.9901	1.0100
9	0.9345	1.0701
10	0.9026	1.1076
11	0.7375	1.3559
12	0.7187	1.3914

Table 4.1 Summary result of free vibration analysis

Generally, the mode shape represents the shape that the structure will vibrate in free motion and the same shape tends to dominate the motion of the structure during an earthquake. The first three mode shape of vibration is the most attention cause the first three shape produce the largest contribution to the structure's motion. There are 12 mode of shape of stayed cable bridge:

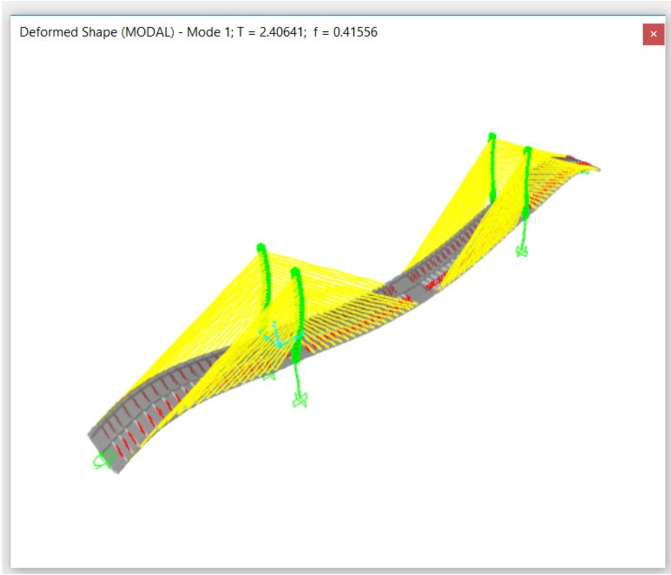


Figure 4.4 Mode shape 1 with period of 2.4064

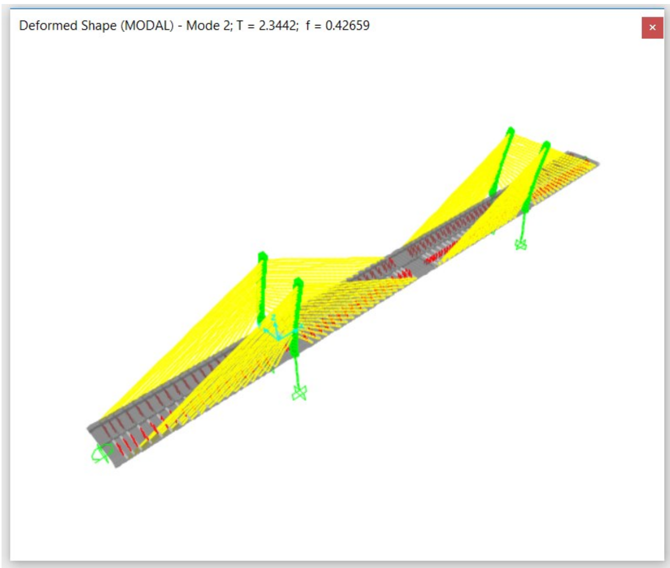


Figure 4.5 Mode shape 2 with period of 2.3442

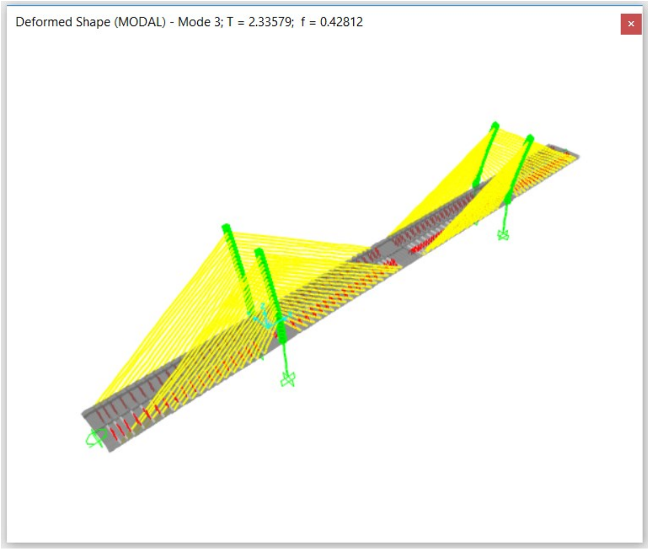


Figure 4.6 Mode shape 3 with period of 2.33579

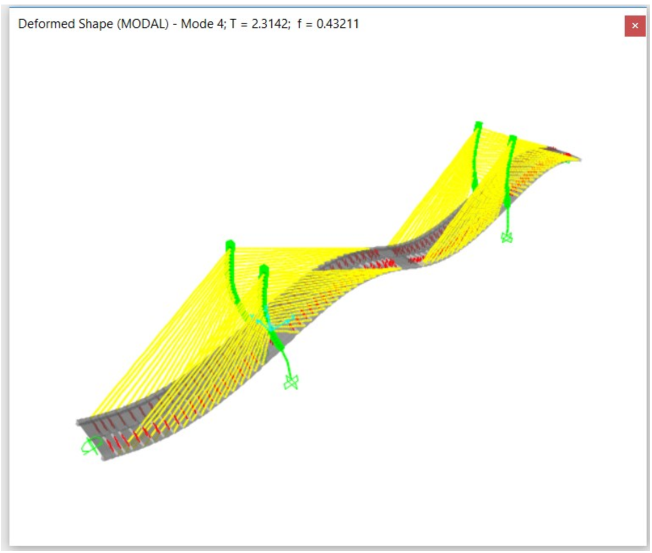


Figure 4.7 Mode shape 4 with period 2.3142

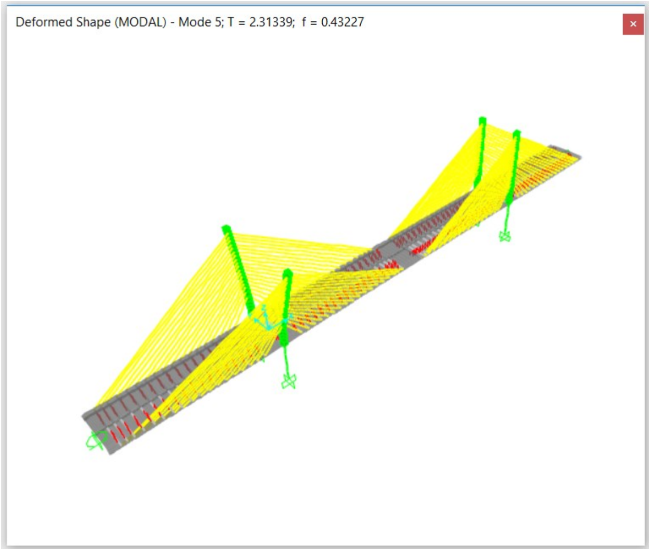


Figure 4.8 Mode shape 5 with period 2.31339

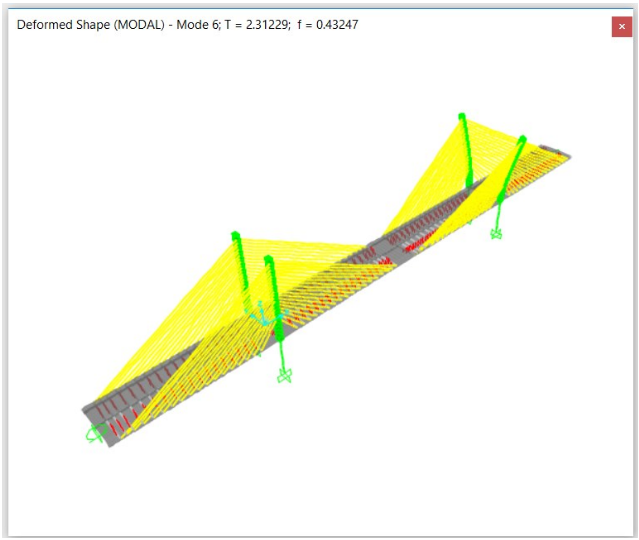


Figure 4.9 Mode shape 6 with period 2.31229

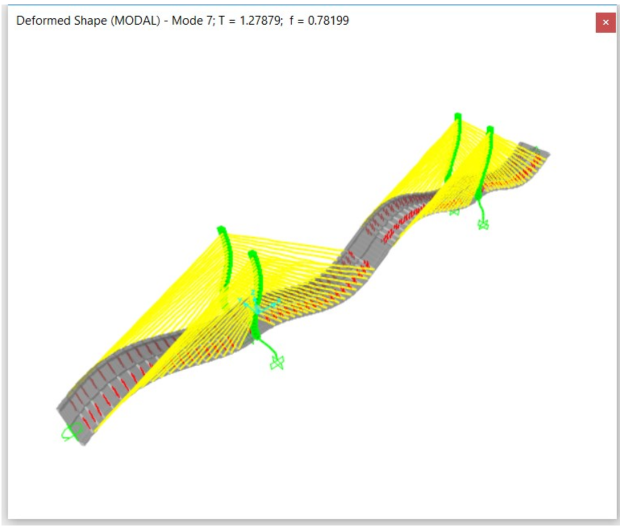


Figure 4.10 Mode shape 7 with period 1.27879

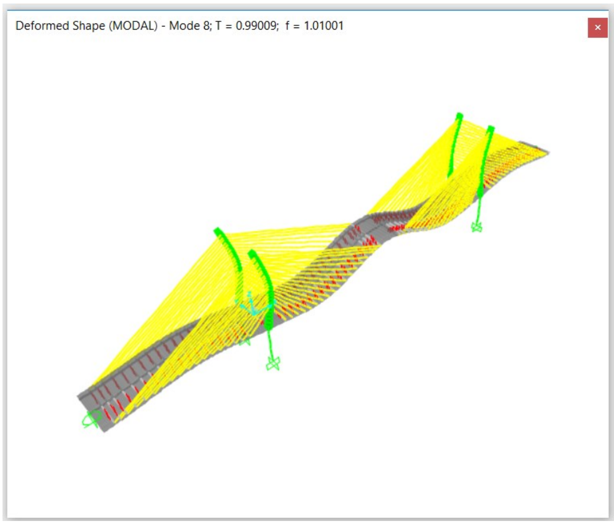


Figure 4.11 Mode shape 8 with period 0.99009

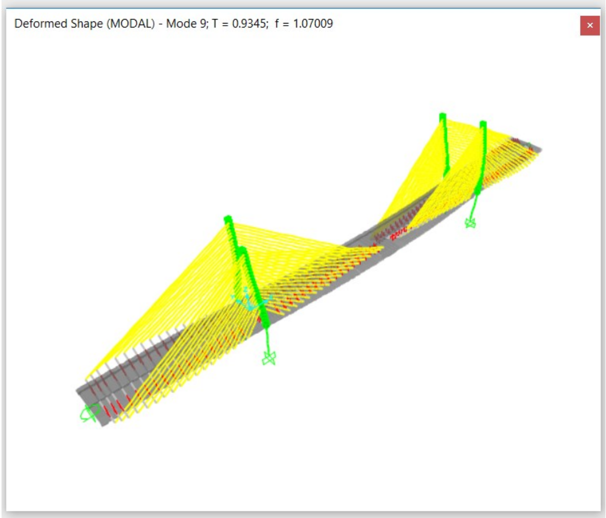


Figure 4.12 Mode shape 9 with period 0.9345

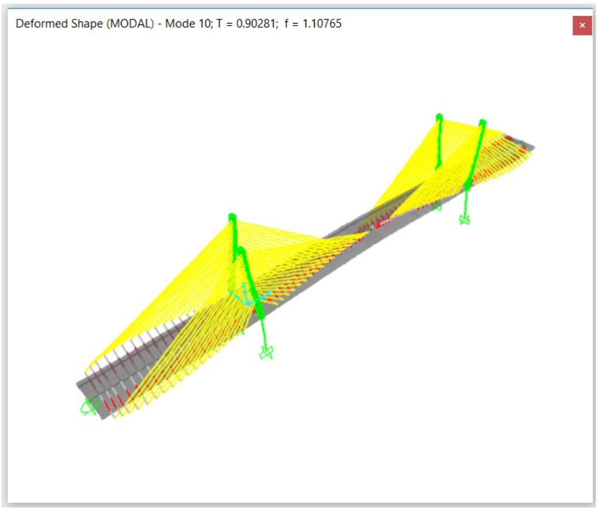


Figure 4.13 Mode shape 10 with period 0.90281

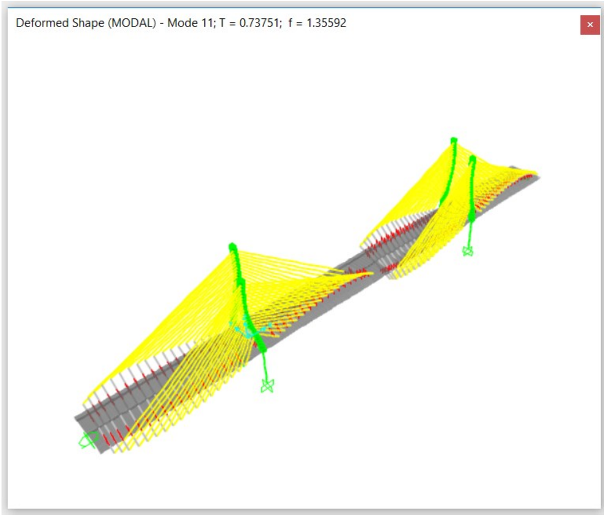


Figure 4.14 Mode shape 11 with period 0.73751

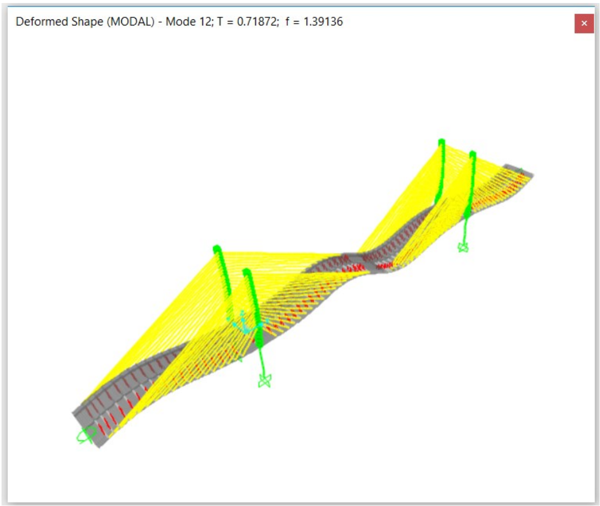


Figure 4.15 Mode shape 12 with period 0.71872

From the result of model analysis, it shows that the first model is highest value of period which is 2.4064 sec and the frequency is 0.4156 / sec. The value period of each model decreasing from model shape 1 to model shape 12. This prove that the first three mode shape of stayed cable bridge are the best mode shape compare others. This is because of the natural period of the first mode is the longest and follow by the second and third mode. The value of frequency of each model can be calculated using this formula:

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

Example:

Mode shape 1

Period (sec) = 2.406414 sec

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

$$= \frac{1}{2.406414}$$

= 0.4155561 / sec

4.6 Virtual work diagram

Virtual work is used to determine which element should be stiffened to achieve the most efficient control over the lateral displacements of a structure based on its virtual colour.

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

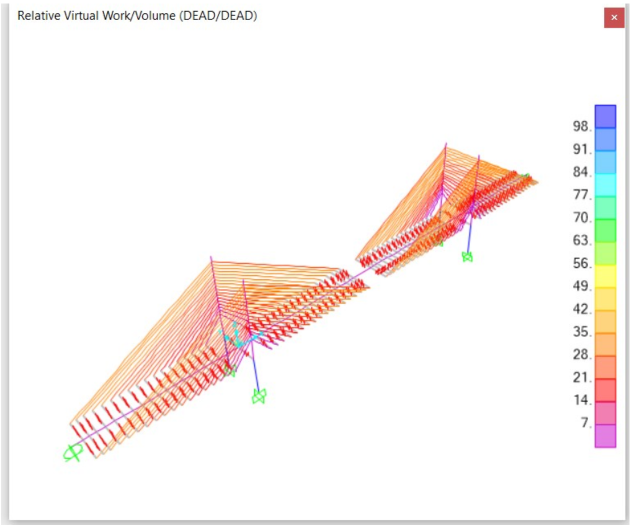


Figure 4.16: Forces – Dead and Displacement – Dead

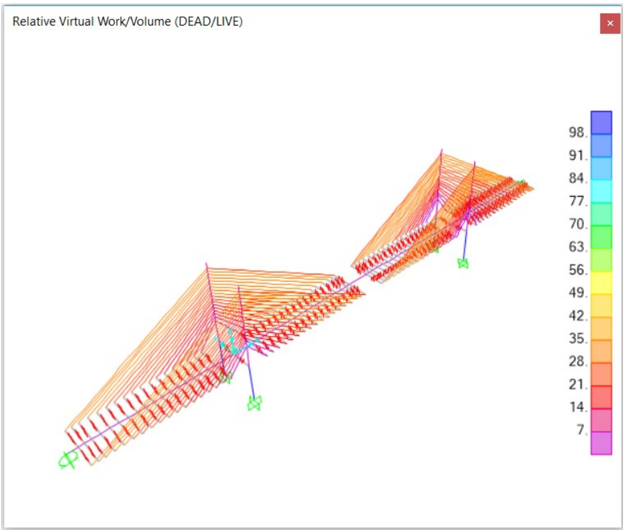


Figure 4.17: Forces – Dead and Displacement – Live

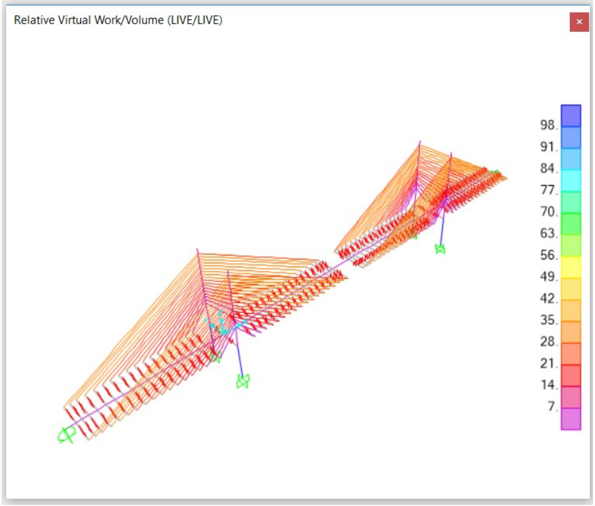


Figure 4.18: Forces – Live and Displacement – Live

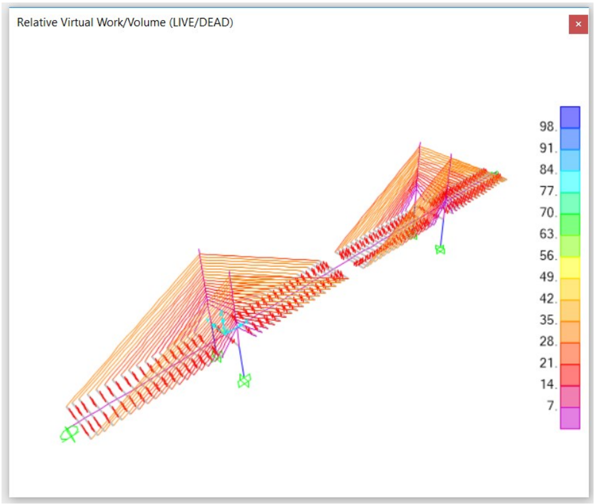


Figure 4.19: Forces – Live and Displacement – Dead

For the scale colour, blue colour represent the critical value of displacement of stayed cable bridge while the purple colour represent the least value of movement from the actual position.

4.7 Time history analysis

Time-history analysis captures the step-by-step response of structures to seismic ground motion and other types of loading such as blast, machinery, wind, waves, etc. But for this research, it focuses on earthquake loading in 2 different magnitudes scale. The earthquake loading is choosing from Acheh and El-Centro earthquake loading. Time history analysis is used to determine the dynamic response of a structure under the action of any general time-dependent loads. From the analysis results we can interprate the relationship between joint of displacement and acceleration of stayed cable bridge for U1 (x-axis) and U2 (y-axis) with two different type of earthquake loading. We compare the highest displacement and acceleration of joint based on different earthquake loading.

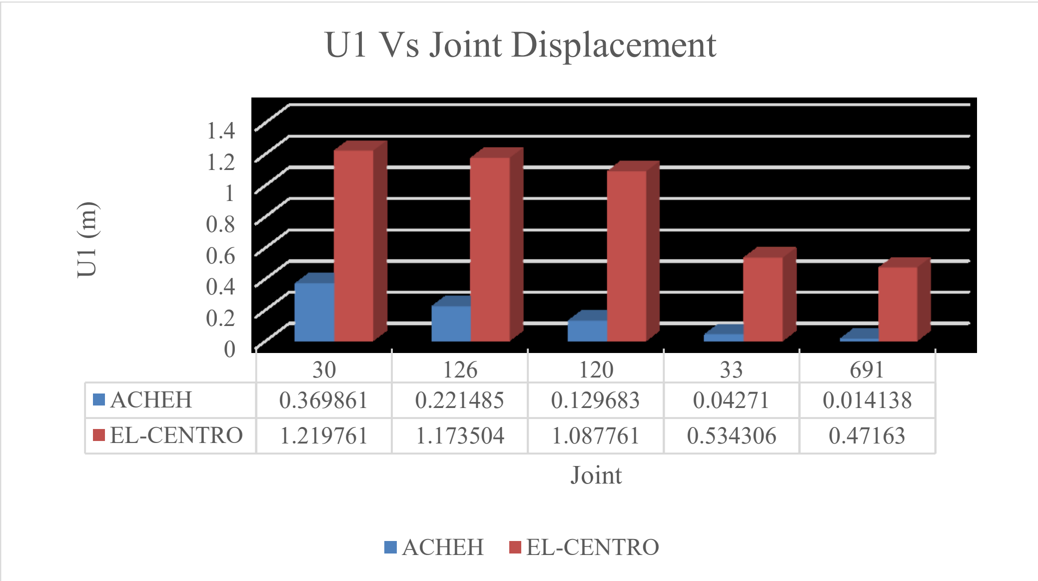


Figure 4.20 Joint Displacement vs U1 for Acheh and El-Centro seismic loading

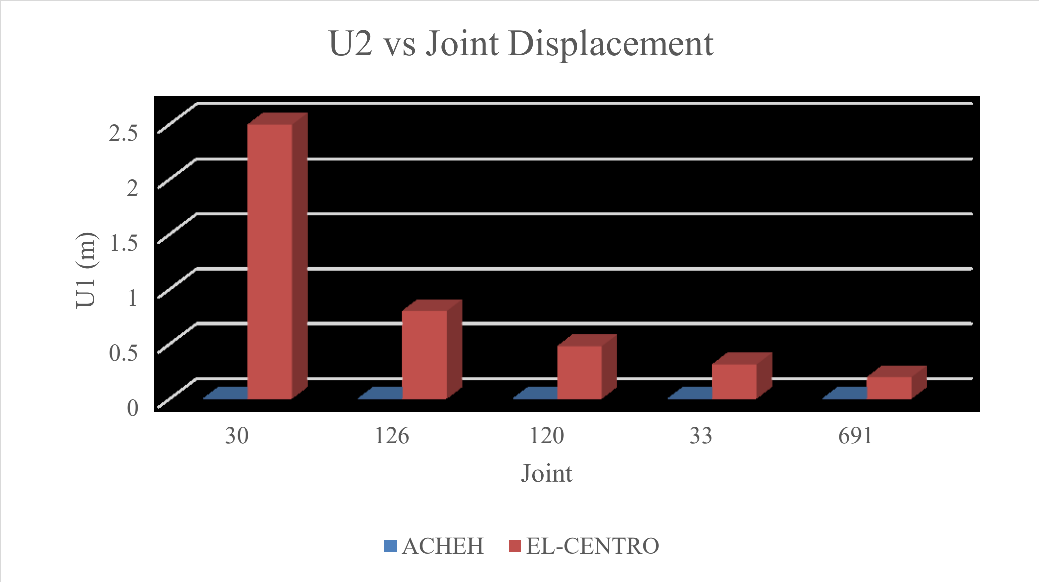


Figure 4.21 Joint Displacement vs U2 for Acheh and El-Centro seismic loading

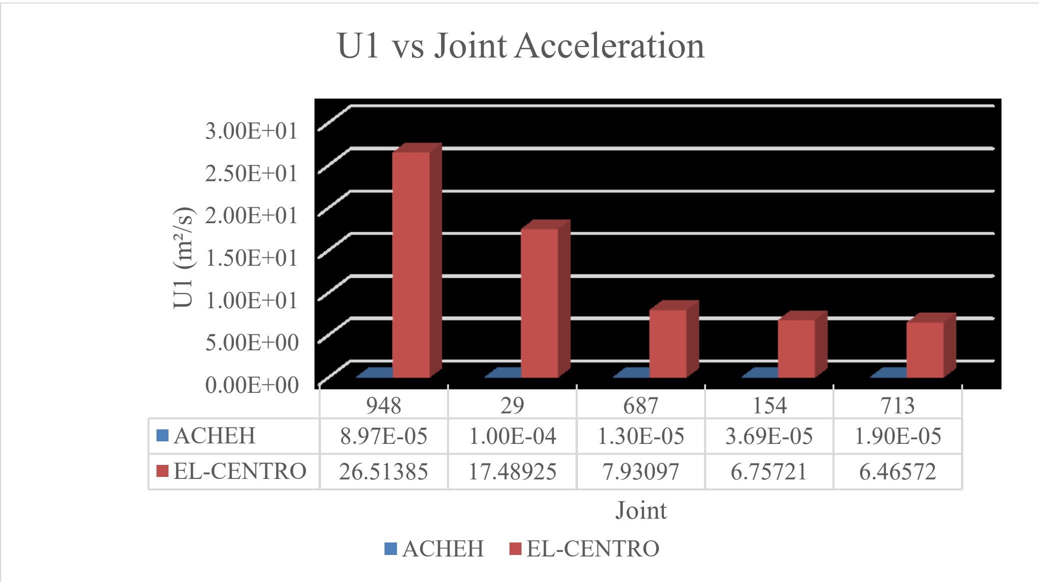


Figure 4.22: Joint Acceleration vs U1 for Acheh and El-Centro seismic loading

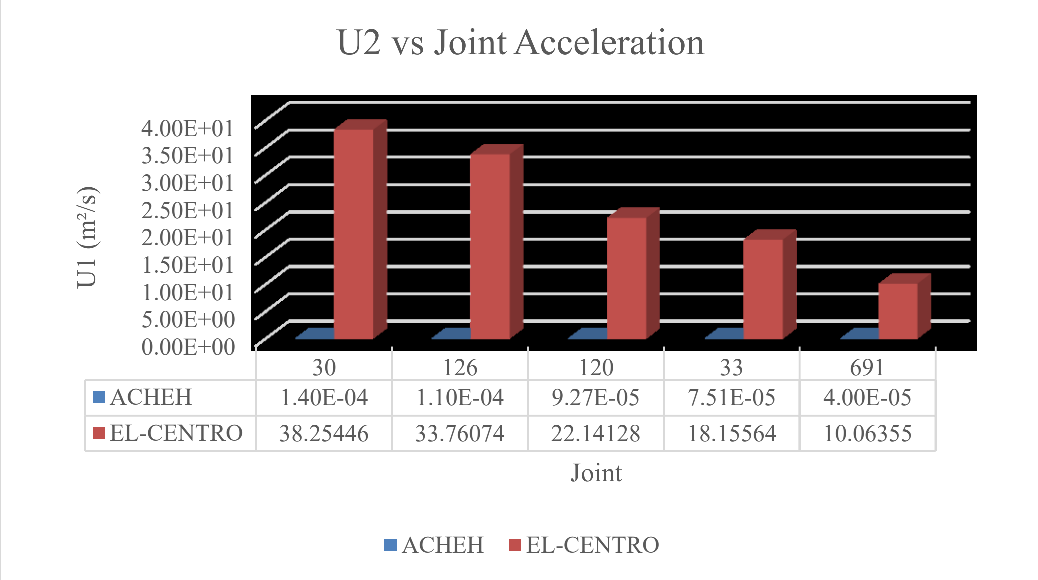


Figure 4.23: Joint Acceleration vs U2 for Acheh and El-Centro seismic loading

From the bar chart, we can declare that the both joint displacement and joint acceleration are the highest for El-Centro earthquake loading. The highest value of joint displacement in x direction for El-Centro is occurred at joint 30 which is 1.219761 m while for the Acheh earthquake loading, the highest value of joint displacement is 0.369861 m that occurred at the same joint and direction. For y direction, the highest value of displacement for El-Centro is 2.491939 m that occurred at joint 8 and for Acheh is 0.000055 m. Meanwhile, for the acceleration of joint bridge structure it shows that for the El-Centro, the highest acceleration for x direction perform at joint 948 which is 26.51385 m/s² while for Acheh earthquake the maximum value of acceleration is 1.00E-04 that occurred at joint 29. The summary table for the highest value of joint displacement and acceleration for two different earthquake data arranged as below:

Acheh		**El-Centro**	
Joint	Displacement (m)	Joint	Displacement (m)
30	0.369861	30	1.21976

Table 4.2 Maximum Joint Displacement vs U1 (x-direction)

Acheh		El-Centro	
Joint	Displacement (m)	Joint	Displacement (m)
171	0.000055	8	2.49194

Table 4.3 Maximum Joint Displacement vs U2 (y-direction)

Acheh		El-Centro	
Joint	Acceleration (m²/s)	Joint	Acceleration (m²/s)
29	1.00E-04	948	26.5139

Table 4.4 Maximum Joint Acceleration vs U1 (x-direction)

El-Centro		Acheh	
Joint	Acceleration (m²/s)	Joint	Acceleration (m²/s)
171	1.4E-04	171	38.2545

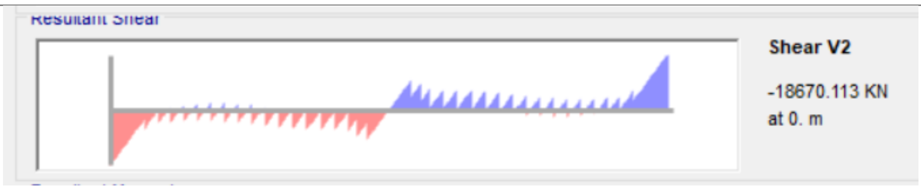
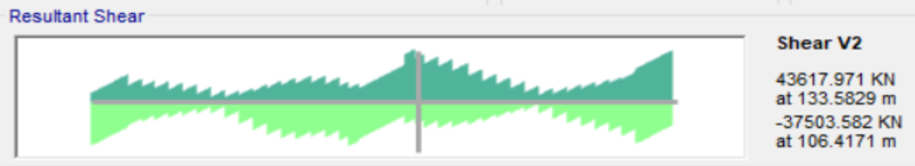
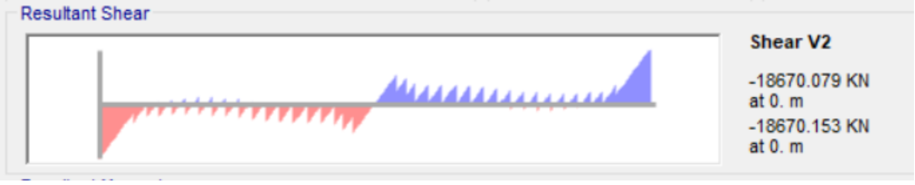
Table 4.5 Maximum Joint Acceleration vs U2 (y-direction)

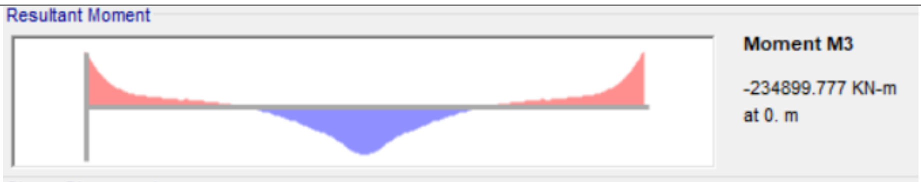
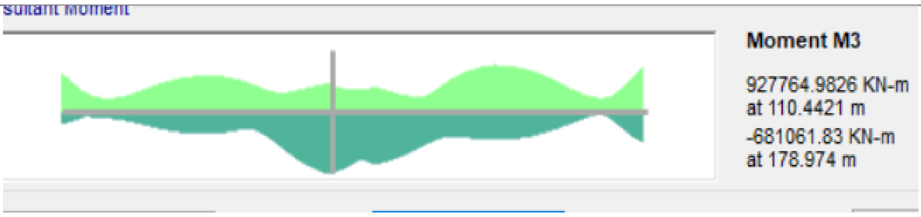
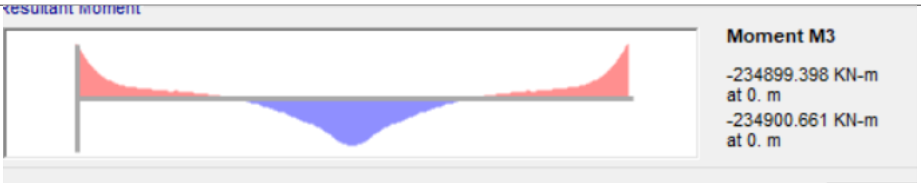
4.8 Linear analysis

This analysis applied the several combination of load cases which are dead load (DL) + live load (LL) + wind load (WL) + time history load (TH). In this analysis, different time history will be used (Acheh and El-Centro) for comparison of maximum shear and maximum moment. The maximum shear and bending moment of two main part in the bridge structure which is span and pylon has been determined based on different earthquake data. The result of the various combination of load case for pylon and span element have been determined and presented in the table and diagram form. The result and output obtained include of shear force diagram and bending moment diagram.

4.8.1 Middle span

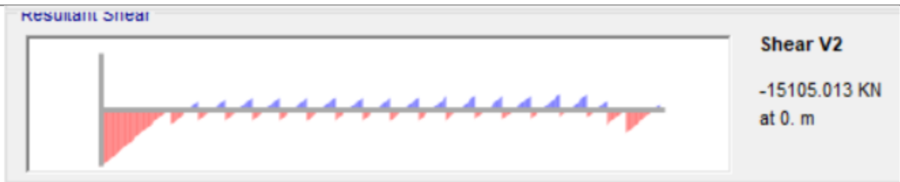
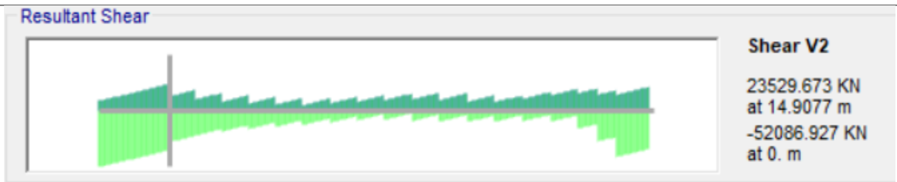
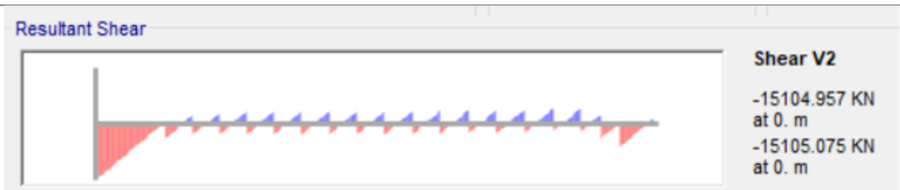
Table 4.6 Shear force diagram and bending moment diagram for several load combinations at middle span

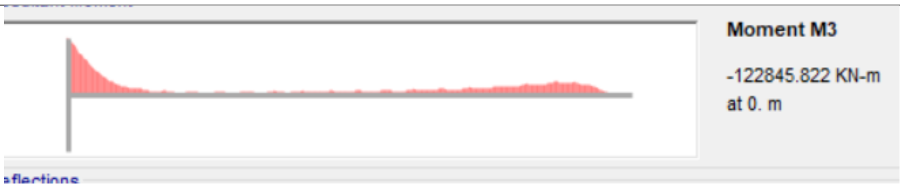
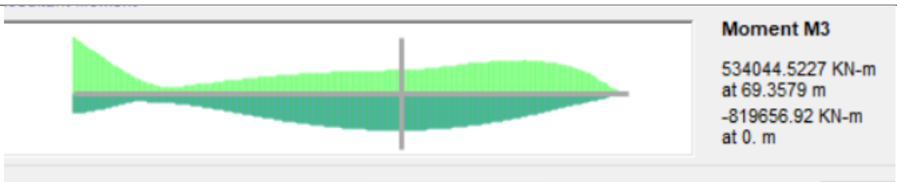
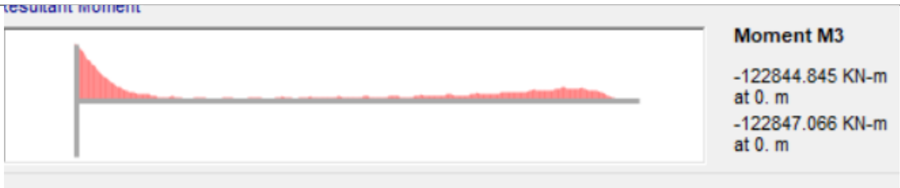
Load Combination	Shear Force Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

4.8.2 Side span (left and right)

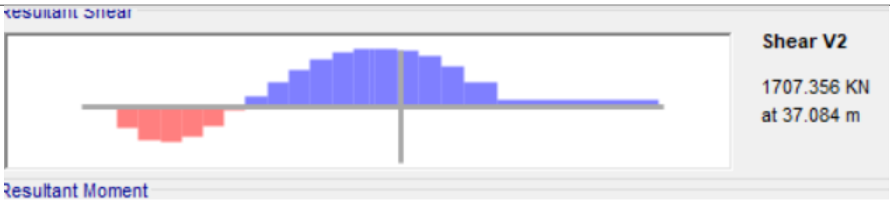
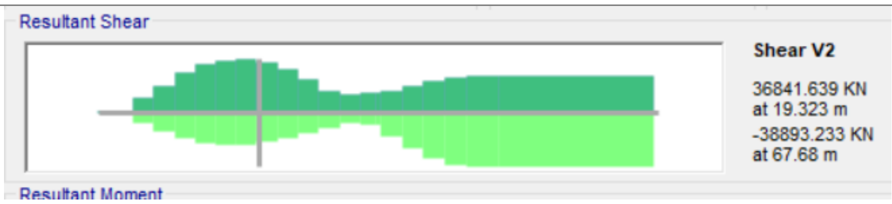
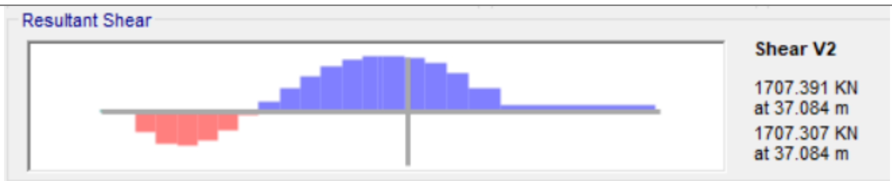
Table 4.7 Shear force diagram and bending moment diagram for several load combinations at side span

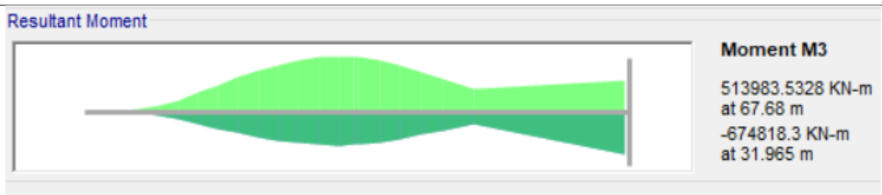
Load Combination	Shear Force Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

4.8.3 Pylon (top)

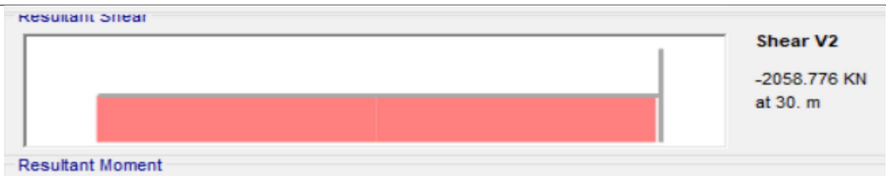
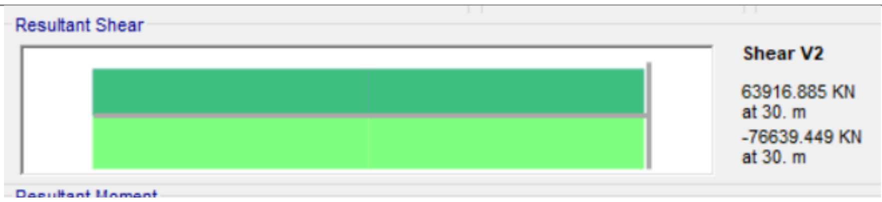
Table 4.8 Shear force diagram and bending moment diagram for several load combinations at pylon (top)

Load Combination	Shear Force Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

4.8.4 Pylon (bottom)

Table 4.9 Shear force diagram and bending moment diagram for several load combinations at pylon (bottom)

Load Combination	Shear Force Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

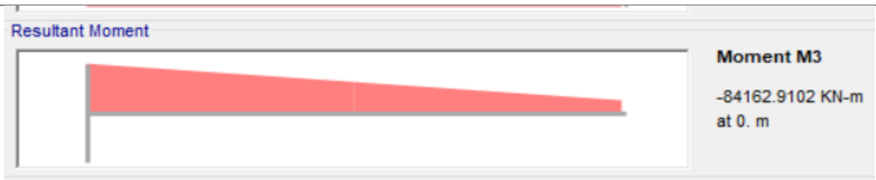
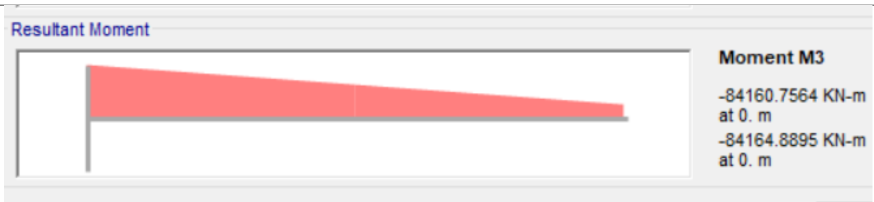
Load Combination	Bending Moment Diagram
DL + LL	
DL + LL + WL + TH (El-Centro)	
DL + LL + WL + TH (Acheh)	

Table 4.6 until Table 4.9 showed the shear force diagram and bending moment diagram of three different combination of load cases that was applied in this analysis for each component part. From the shear force diagram, the maximum shear force for Acheh earthquake loading is -15105.025 kN which happen at the side span while the maximum shear force for El-Centro earthquake loading is -57086.927 kN. Next, the maximum moment design is 927764.9826 kNm that happen at middle span for El-Centro earthquake loading while for Acheh earthquake loading the maximum bending moment design is -234900.661 kNm. For the pylon part, the maximum shear force is -76639.449 kN and -2058.859 kN for El-Centro and Acheh earthquake loading while for the maximum bending moment is 2022051.562 kNm and -84164.8895 kNm for El-Centro and Acheh earthquake loading.

Load combination including El-Centro loading produce the highest shear force and bending moment compare to load combination that include Acheh loading. Below shows the overall value of bending moment and shear force for every part of bridge structure for three different load combination.

Table 4.13 Shear force and bending moment load combination for all component part in different load combination

Structure Component	Load Combination	Design shear force, VED (kN)
Middle Span	DL + LL	-18670.113
	DL + LL + WL + TH (El-Centro)	43617.971
	DL + LL + WL +TH-Acheh	-18670.153
Side Span	DL + LL	-15105.013
	DL + LL + WL + TH (El-Centro)	-57086.927
	DL + LL + WL +TH-Acheh	-15105.075
Pylon (Top)	DL + LL	1707.356
	DL + LL + WL + TH (El-Centro)	-38893.233
	DL + LL + WL +TH-Acheh	1707.391
Pylon (Bottom)	DL + LL	-2058.776
	DL + LL + WL + TH (El-Centro)	-76639.449
	DL + LL + WL +TH-Acheh	-2058.859

Structure Component	Load Combination	Design moment , MED (kNm)
Middle Span	DL + LL	-234899.777
	DL + LL + WL + TH (El-Centro)	927764.9826
	DL + LL + WL +TH-Acheh	-234900.661
Right Span	DL + LL	-122845.822
	DL + LL + WL + TH (El-Centro)	-819656.92
	DL + LL + WL +TH-Acheh	-122847.06
Pylon (Top)	DL + LL	28381.4212
	DL + LL + WL + TH (El-Centro)	509013.7295
	DL + LL + WL +TH-Acheh	28381.9929
Pylon (Bottom)	DL + LL	-84162.9102
	DL + LL + WL + TH (El-Centro)	2022051.562
	DL + LL + WL +TH-Acheh	-84164.8895

4.9 Summary of analysis

At the end of this study, the natural frequency and natural period, dynamic characteristic (displacement and acceleration) of the stayed cable bridge structure have been determined. The mode shape result has been obtained from each analysis. All sections and joints passes the stress capacity check since the shape of the structure is rigid.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Although Malaysia is only imposed with the small earthquake, it is not likely to remain forever, this study is conducted based on a real life project of stayed cable bridge in Penang region that to check the sustainability of stayed cable structure due to minor and major earthquake resistance. The structure was modelled and analysed by using SAP2000 software. Two different earthquake data was used which is Acheh earthquake data and El-Centro earthquake data as a minor and major earthquake resistance. The objective of the study has been achieved whereby the seismic performance of stayed cable bridge in Malaysia has been computed and produce relevant result for performance evaluation parameters in the bridge structures.

In addition, to determine the seismic response of the bridge structure, seismic analysis including free vibration analysis and time history analysis by utilizing the available historical seismic data from Acheh and El-Centro earthquake. The result obtained were the mode shape, natural period, natural frequency of stayed cable bridge and also maximum value of displacement, acceleration, shear force and bending moment for each joint and member in structure under different load combination.

Based on the finding of the research, the conclusion that can be made in the following:

i. The modelled of the bridge structure is not fulfil represent the actual structured. This is because to the earlier assumptions made on restrains at the base condition and the joint connection of the bridge structure. Moreover, the detail about the cable section just considered follow standard size of cable section. The connection of the bridge structure was not designed according to Euro Code 3 design specifications.

ii. From the free vibration analysis, it produced 12 mode shape with natural period and frequency.

iii. From modal analysis, the highest natural period is mode shape 1 which is 2.4064 sec.

iv. The maximum shear force that happens at most critical span is -57086.927 kN which is at side span while for pylon part the maximum shear force is -76639.449 kN when loading combination with El-Centro earthquake loading applied.

v. The maximum bending moment that occurred at the most critical span is 927764.9826 kNm (middle span) while for the pylon part the maximum bending moment is 2022051.562 kNm when loading combination with El-Centro earthquake loading applied.

vi. For dynamic characteristic, comparison between El-Centro earthquake and Acheh earthquake shown that displacement and acceleration for El-Centro earthquake loading produce highest value for both displacement and acceleration compare to Acheh earthquake loading.

5.2 Recommendation

For the future study, the consideration of the soil interaction and joint connection of the stayed cable bridge structure should both be included in the analysis. This is due to earthquake loads are involved ground motion. In addition, for increasing the accuracy on the seismic response study, the earthquake data should be always update, so that the higher intensity of the earthquake would be considered for the design analysis of structure to prevent failure. For improving the accuracy on the seismic response study, the researcher can also analyze the behavior of material of the structure used when the earthquake approaches the structure. To provide a desirable result for seismic performance evaluation parameters, the analysis of stayed cable bridge structure considered from different locations in Malaysia.

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