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SEISMIC RESPONSE OF A TYPICAL 3-LEGGED JACKET OF FIXED OFFSHORE PLATFORM IN MALAYSIA DUE TO ACEH EARTHQUAKE

NURUL NABILA BT FAZILAN

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

Faculty of civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2015

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 of Civil Engineering (Hons.).

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Dedicated to my parents,

for their love and encouragement

to me

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ABSTRACT

A level of concern among engineers in Malaysia about the crucial aspect to consider the seismic response due to earthquake in structure design still low. Majority of buildings in Malaysia is been designing based on BS8110 .However, these standards do not have any requirements on seismic loads. Actually , Malaysia have experienced the earthquake tremors due to the neighboring countries , such as Indonesia which have experienced of seismological activities in the past few year. Thus, chance of Malaysia being jolted by at least one moderate earthquake cannot be ruled out. The purposes of this study is to estimate the earthquake ground motion due to earthquake in Aceh Indonesia for assessment of offshore platform in Malaysia. Besides , by doing this study ,we could determine the vulnerability of existing offshore platform in Malaysia when subjected to loading from earthquake. The response of the fixed steel jacket offshore platform under earthquake loading (shear , displacement and bending moment) can be also determined. The region for interested offshore platform site is in Terengganu. All the environmental loads in Terengganu is given such as wave height, current velocity and wind speed are given. The ground motion acceleration from Aceh earthquake also be given. There are three type of seismic response analysis in this study which are free vibration analysis , time history analysis and response spectrum analysis. In free vibration analysis, 12 mode shape is analyses. For the response spectrum analysis ,the analysis is based on response spectra of EuroCode 8.While for the time history analysis ,is referring to the time history of Aceh’s earthquake in 2004. SAP2000 computer software is chosen to analyses the earthquake response to the steel jacket offshore platform. The steel structure is design according to EuroCode 3 standards.

ABSTRAK

Tahap keprihatinan dalam kalangan jurutera di Malaysia mengenai kepentingan mempertimbangkan respons seismik oleh gempa bumi dalam struktur reka bentuk adalah masih rendah. Majoriti bangunan di Malaysia direka bentuk berdasarkan standard BS8110 .Walaubagaimanapun , standard ini tiada keperluan dimana tiada beban seimik. Sebenarnya , Malaysia pernah merasai gegaran gempa bumi disebabkan negara jiran seperti Indonesia yang mengalami aktiviti seismik sejak beberapa tahun ini. Oleh itu , keberangkalian Malaysia untuk mengalami sekurang-kurangya gempa bumi sederhana tidak boleh diremehkan.Tujuan kajian ini adalah untuk menganggarkan gerakan gempa bumi berpunca dari gempa bumi Aceh ,Indonesia untuk penilaian platfom luar pesisir di Malaysia.Selain itu, dengan menjalankan kajian ini , dapat menentukan kelemahan platform luar pesisir yang sedia ada di Malaysia apabila dikenakan beban gempa bumi.Respons platfom luar pesisir jaket keluli tetap oleh beban gempa bumi seperti ricih, anjakan dan momen lentur dapat ditentukan.Kawasan kajian untuk platfom di luar perisir pantai adalah di Terengganu. Semua beban persekitaran di Terengganu seperti ketinggian ombak , halaju arus dan kelajuan angin adalah diberikan. Pecutan pergerakan bumi dari Aceh ,Indonesia juga diberikan. Tiga jenis analisis dijalankan dalam kajian ini iaitu analisis getaran bebas, analisis sejarah masa dan tindak balas analisis spektrum. Dalam analisis getaran bebas , 12 bentuk mod dianalisis.Bagi tindak balas analisis spektrum, analisis berdasarkan dari respons spektra oleh Kod Euro 8.Manakala, analisis sejarah masa berdasarkan dari sejarah masa gempa bumi di Aceh pada tahun 2004. Perisian komputer SAP2000 dipilih untuk menganalisis tindak balas gempa bumi kepada platfom luar pesisir jaket keluli. Struktur keluli adalah direka bentuk mengikut piawaian Kod Euro 3.

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LIST OF SYMBOLS

$M\Delta$	Magnitude at a distance of Δ calculated from basic Richter formula
F	Wind force [N]
ρ	Mass density of air [1.2kg/m^3]
u	Wind speed [m/s]
Cs	Shape coefficient
A	Area of object [m^2]
F_D	Drag force per unit length of the member [N/m],
F_I	Inertial force per unit length [N/m],
C_D	Drag coefficient
w	Density of water [N/m^3]
V	Displaced volume of the cylinder per unit length (=$\pi D^2/4$) [m^3]
g	Gravitational acceleration [m/s^2]
U	Component of velocity vector due to wave [m/s],
|U|	Absolute value of U [m/sec],
C_m	Inertia coefficient
$\frac{\delta U}{\delta t}$	Component of local acceleration vector of the water
E	Young Modulus
G	Shear modulus
A_v	Shear area ,mm^2
f_y	Yield strength , N/mm2
γ_{M0}	Partial factor
$\sigma_{all,s}$	Allowable Shear Stress
$V_{c,Rd}$	Design Shear resistance
A_c	Area mm^2
$M_{c,Rd}$	Moment resistance for cross section
W_{pl}	Plastic Modulus ,mm^3

f_y	Yield strength , N/mm2
$\sigma_{all,b}$	Allowable bending stress
S_x	Section Modulus ,mm^3
Ved	Maximum design shear force
σ_s	Shear Stress
Med	Maximum design bending moment
σ_b	Bending stress

LIST OF ABBREVIATIONS

MMD	Malaysia Meteorology Department
P	Primary wave
S	Secondary wave
CBF	Concentric braced frames
EBF	Eccentric braced frame
AASHTO	American Association of State and Highway Transportation Officials
IEM	Institute of Engineers Malaysia
API	American Petroleum Institute
EL	Environmental load
RS	Response spectrum
D	Dead load
L	Live load
TH	Time history

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

An earthquake is the consequence of a unexpected release of energy in the Earth's crust . This sudden energy release causes the seismic waves that make the ground shake that could creates seismic waves. Due to the consequence rock breaking , have result in energy waved which is seismic wave. It kind of energy that travels all the way through the earth. Seismic waves pass through either the length of the earth's surface or through the earth's interior .

Earthquakes are usually triggered when rock underground suddenly breaks along a fault. Fault plane is the underground surface along which the rock moves and breaks. By using seismograph it will determine the magnitude or size by measuring the amplitude of the seismic wave that occur and the distance of seismograph from the earthquake. The seismograph are consists of a seismometer (the detector) and a recording device that located at every station of possibility of an earthquake occur . The seismometer device will electronically amplifies the wave motion in earth.

Earthquakes caused too many damaging effects to the surrounding they act upon. This includes damage to man-made buildings structure and in worst cases the human death. The destruction of structures such as bridges ,dams and buildings are caused by the rumbling impacts which originated from the earthquake. Besides , earthquake can also trigger landslides that have bad effect on human life and animal life.

Earthquakes usually cause dramatic changes, including ground movements, dropping, dropping, and tilting of the surface cause different in the groundwater flow. Other than producing floods and damaging the buildings, earthquakes that occur under ocean can sometimes cause tsunamis or known as tidal waves. The tsunamis' conditions are high water which travel at a short period of time. They are surely destroying area in coastlines which effect entire populations and cities.

1.2 PROBLEM STATEMENT

On 26 December 2004 ,the coastal area off northern Sumatra , Indonesia had been struck by huge and massive earthquake which then triggered tsunamis around the neighboring countries such as India , Maldives ,Malaysia ,Thailand and Sri Lanka. Due to the massive earthquake that occur in Northern Sumatra, Indonesia magnitude 9.0 in Ritcher scale ,Malaysia was affected critically by this natural disaster. The earthquake in Indonesia had triggered tsunamis in coastal area Malaysia that caused to serious injuries , loss of human life, damage to man-made structure and etc.

Although Malaysia is near to the epicenter of the earthquake, Malaysia escaped from the kind of damage that struck another countries nearby the Sumatra. Since the western coast Sumatra is the epicenter of earthquake, Malaysia is largely protected by that island from the worst case of tsunami. Even though Malaysia is safely protected but still there are some part in Malaysia that been affected such as Penang and Langkawi. It reported that number the number of life loss are 68 where in Penang (52) , Kedah (12), Perak (3) and Selangor (1) .Malaysia which located at the peripheral of the fire ring and near to Indonesia and Philippines that known had always occurs seismological activities in the past few years , shows that Malaysia could have a chance of being struck by at least one moderate earthquake.

In year 2012, Malaysian Meteorological Department had detected eight earthquakes in the eastern part Malaysia, Sabah and Sarawak which have magnitude between 2 and 4.5 scale Ritcher (Bernama, 2013).This shows that Malaysia cannot ignored the threat of an earthquake since there was record for existing earthquake even in small magnitude.Besides, in 1976 , the strongest earthquake ,magnitude 5.8 had been recorded in Lahad Datu, Sabah. "Malaysia is close to areas that have experienced strong earthquakes, including Sumatra and the Andaman Sea, while Sabah and Sarawak are located close to the earthquake zone of South Philippines and North Sulawesi. Therefore, the odds of an earthquake striking Peninsula Malaysia cannot be ruled out," (Dr.Mohd Rosaidi Che Abas).

In record , there are about less than 10% man made structure in Malaysia that consider earthquake in the design. Although tendency Malaysia to be struck by massive earthquake is quite slim, but supposed the design cannot ignored the threat for moderate earthquake. Since the damage by the moderate earthquake could defect the existing structure by presence of crack. Lately, Prime Minister 5th Abdullah Ahmad Badawi had highlighted about the importance of consider impact of earthquake in Eurocode standard toward design structure in Malaysia. Thus , it really important to take account the earthquake impact in structure especially in design of offshore platform.

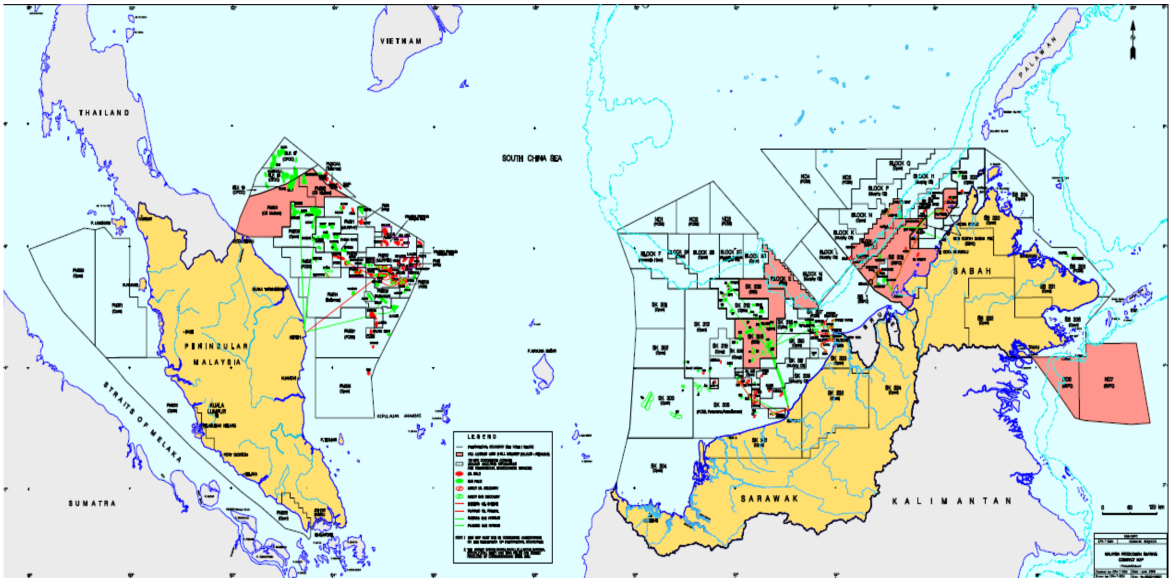


Figure 1.1 : Location of the offshore platform around Malaysia

Source:Minyakdangasmalaysia.blogspot (Online image).(2010) .Retrieved October 2, 2015 from http://minyakdangasmalaysia.blogspot.com/2010/10/malaysias-oil-gas-maps.html

1.3 RESEARCH OBJECTIVE

The main objective of this research are :

i. To estimate the earthquake ground motion due to earthquake in Aceh Indonesia for assessment of offshore platform in Malaysia.
ii. To determine the vulnerability of existing offshore platform in Malaysia when subjected to loading from earthquake.
iii. To determine the response of the fixed steel jacket offshore platform under earthquake loading (shear, displacement ,and bending moment)

1.4 SCOPE OF STUDY

The scope of study are :

i. The effect of earthquake to steel structure for jacket offshore platform.
ii. The type of offshore platform used will be 3-legged fixed offshore platform.
iii. The case study will be conducted at the Aceh earthquake region that affected the offshore platform in Malaysia.
iv. The jacket offshore structure modeling and analysis software used is SAP 2000.
v. The data analyzed for earthquake in Aceh is obtained from the Malaysia Meteorology Department (MMD).

1.5 RESEARCH SIGNIFICANCE

Throughout this research ,we could determine the behavior of the offshore structure under earthquake loading from Aceh earthquake. Thus , could identify the adequacy of existing offshore platform structure in Malaysia. By considering this earthquake resistance in our design structure, we could save more life, and prevented the worst damage in our steel structure at offshore platform

CHAPTER 2

LITERATURE REVIEW

2.1 EARTHQUAKE

2.1.1 Concept, Terminology and Source of Earthquake

The probability for a massive earthquake to struck comes in the first instance from the violent shaking of ground surface. This violent shaking could affect an area many hundreds of kilometers in radius. This is the primary damage which an earthquake engineer have to deal with. The seismic shaking causes direct effects on structures, due to the inertia forces set up by the ground accelerations, but important secondary sources of damage may also be arise (Booth & Key, 2008) .Usually large soil movement may happen due to liquefaction (the shear strength temporary loss in loose, sandy and saturated soils), consolidation, landslides or avalanches. Offshore earthquake also could triggered tsunamis (commonly referred as tidal wave) in coastal area.

Earthquake arise due to forces within the earth's crust tending to displace one mass of rock relative to another (Booth & Key, 2008). Failure in the rocks will occur when the forces occurs at point of weakness called fault plane. Besides, sudden movement which occur then will give rise to violent motions at earth's surface. The failure will starts from a point on fault plane which called the focus , and then propagates outwards until the forces are dissipated to level below the rock's failure strength. The fault plane may be in hundreds of kilometers long for large earthquake, and tens of kilometers deep. In large earthquake, usually fault plane will break up the surface, while for smaller earthquake, it will remains completely buried.

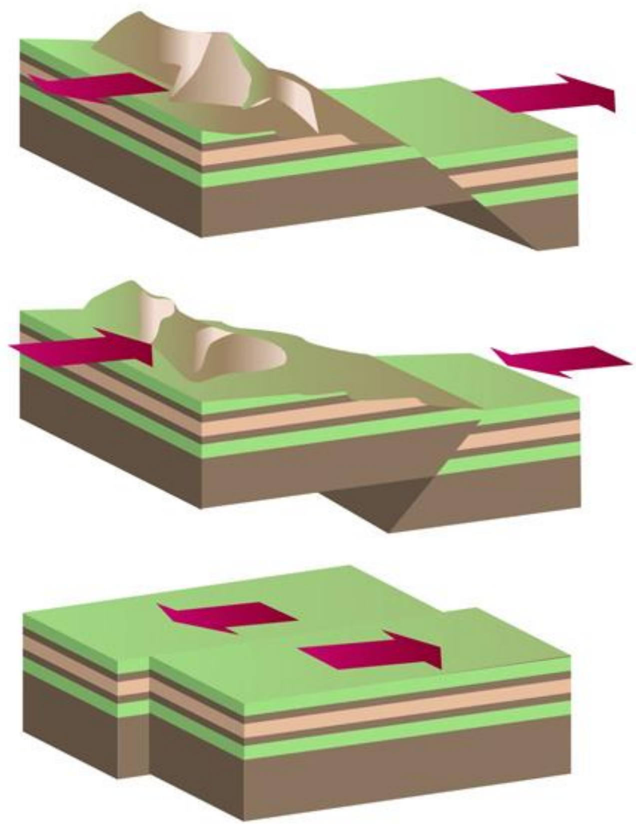


Figure 2.1 : Fault plane when earthquake occur

Source : sparkcharts.sparknotes [Online Image].(2011) .Retrieved September 23, 2014 from http://sparkcharts.sparknotes.com/gensci/geology_earthsci/section5.php

Earthquake do not usually occur as a single event as mostly assumed in seismic design, but as a series of shocks (A.Faisal, T.Majid, & G.hatzigeorgiou, 2013) .Massive earthquake have more and larger aftershocks ,foreshocks and the sequences could last for years and even longer. Earthquake aftershocks usually unpredictable and be higher magnitude which could possibly collapse building that damaged by main shock.

2.1.2 Magnitude and Intensity of Earthquake

For design in engineering, it is really critical to define the size of an earthquake .There are two measures of size of an earthquake which are in terms of magnitude and intensity .Earthquake magnitude is a fundamental property of the earthquake, related to its energy release on a logarithmic scale (Booth & Key, 2008).The energy released is from the source or focus of the earthquake. While, earthquake intensity describe the impact of the earthquake on the Earth’s surface, by observing its effect on human kind and building structures.

The impact such as ground shaking on population, structures and the natural landscape, this impact will be greater if near to the focus earthquake. Unlike magnitude, intensity given earthquake rely on the location where it is measured. In general the larger the epicentral distance, the intensity will be lower. Hence a given magnitude of earthquake will give rise to more different intensities in the affected region.

The magnitude of an earthquake is related to energy amount of energy released by the geological rupture causing it and is therefore a measure of the absolute size of the earthquake without reference to the distance from the epicenter (K.Sen, 2009). The best known measure of earthquake magnitude was introduced by Charles Richter and known as Richter Scale which now referred as local magnitude (M_L)

To compare the magnitude of earthquake, use yardstick or scale created by C.F Richter. By using a formula of standard horizontal Wood-Anderson seismograph, the magnitude

$$M = \log_{10} A \qquad (2.1)$$

Where A refer to the trace amplitude in micrometer for an epicentral distance of 100km.While for the distance from epicenter is other than 100km,

$$M = M\Delta - \frac{1.73\ \log_{10} 100}{\Delta} \qquad (2.2)$$

Where MΔ denoted magnitude at a distance of Δ calculated from basic Richter formula (Erdey, 2007).

2.2 SEISMIC WAVE

Earthquake will generate or trigger elastic wave when a block of material slides against another, hence the break between the two block is called ‘fault’. Explosions that occur will generate elastic wave by an impulsive change of volume. If the equilibrium of a solid body like the earth is disturbed due to the fault motion resulting from an earthquake or explosion seismic (elastic) wave are transmitted through the body in all directions from the focus (K.Sen, 2009) . The waves that radiated by an earthquake will lasts about tenths of seconds to several minutes. Rocks at this moment will behave like elastic solids at these frequencies. Due to the behavior of the elastic solids, it will allow the different types of wave to occur. Thus this will make ground motions quite complex to occur after an earthquake or explosion.

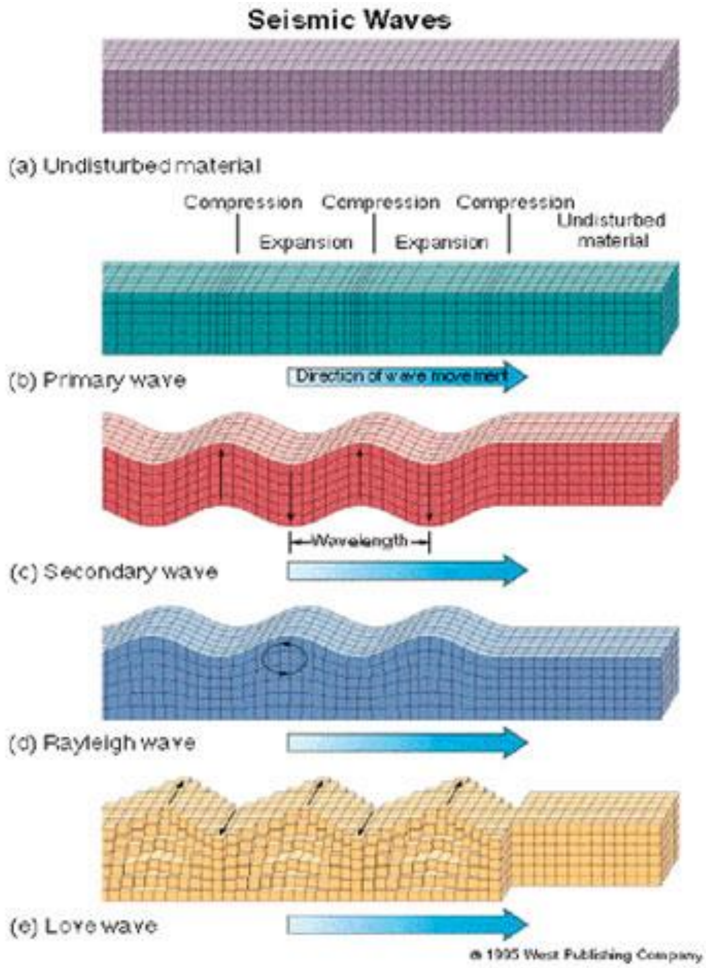


Figure 2.2 : Types of waves , P wave, S wave and Surface wave

Source : Electronic Field Trip [Online Image].Retrieved on October 10 , 2014 from http://electronicfieldtrip.org/volcanoes/teachers/classroom_causes.html

2.2.1 Body Wave

There are two categories of seismic wave that produced during an earthquake which are primary wave (P) and secondary wave (S). P and S waves travel from the focus to the surface through the interior of the earth which refer as body wave. The velocities encountered depend on the upon the elastic constant and densities of the materials and other properties of the surrounding medium (K.Sen, 2009) .

Primary wave (P) are the first wave to arrive which having the highest velocities. The second wave to arrive are the S (secundus) which have a tranverse,shear vibration in plane that perpendicular to the direction of propagation .The presence of two types of wave arise from the fact that there are two fundamental ways one can strain a solid body. Firstly by changing the volume without change the of shape. Secondly the change of shape without the change of volume.

The P or compression waves transmit the pressure changes through the Earth in a series of alternating compression and rarefactions. While for the S waves can only travel through solid ,therefore cannot travel through outer core of Earth's liquid. P wave can travel through the core,an Sv wave is one in which the ground motion (vibration) is vertical and an Sh wave refers to one where the ground motion is horizontal (K.Sen, 2009)

The reflections of waves back into the valleys and the conversion of body waves into surface waves at the boundaries of sedimentary basins, suggests that the parameters describing some horizontal dimensions of sedimentary basins should play a role in the description of the duration of strong earthquake ground motion (M.Trifunac & M.Todorovska, 2012)

2.2.2 Surface Wave

When the two types of body wave reach the surface of the Earth ,an interesting change occurs in the behavior of the waves. The combination of this two types of body wave in the presence of the surface leads to the other types of waves, which are the Rayleigh waves and Love waves.

There are surface waves as distinct from the body wave and produce large amplitude motions in the ground surface (K.Sen, 2009). They decay at a much slower than the body waves and hence result in maximum damage. Thus surface wave are more destructive than the body wave because of their low frequencies , long durations and large amplitude.

2.3 LESSON FROM EARTHQUAKE DAMAGE

2.3.1 Damage Studies

The earthquake is among the most dreaded and dangerous of all natural disaster, exacting a devastating toll on human life. In the last 100 years there have been many major earthquake, including San Francisco (1906) , Tokyo (1923), Alaska (1964) ,Iran (1968) ,Mexico (1985), Kobe (1995) and Turkey (1998) and etc. The devastating tsunami of 26 December 2004 , that struck the coastlines of the Indian Ocean , was caused by an underwater earthquake (K.Sen, 2009)

Engineers are usually accustomed to static loads. One of the most important lessons learned from damage surveys is the difference in failure patterns between static loads applied in a single direction and those due to cyclic loading (Booth & Key, 2008). There are crucial differences in the way that modes of failures may develop between the two.

An crucial aspect of post- earthquake study is realization of the important role for construction play in determine the quality for the structure. Earthquake are really not the respecter of theories , calculations, or any divisions of responsibility. Many instance of construction’s poor-quality are invariably exposed in damage buildings. Badly placed reinforcement , poorly compacted and incomplete grouting of masonry are some of the commonest examples (Booth & Key, 2008).

Since seismologists cannot directly predict when the next earthquake will happen , they rely on numerical experiments to analyses seismic wave and to accurately assess the magnitude and intensity of earthquake (K.Sen, 2009). Such analyses by the seismologist will allow scientist to estimate locations and likelihoods of future earthquake , thus helping to identify the areas of greatest risk and to ensure the safety of people and buildings that located in such hazardous areas.

2.3.2 Type of Failure

During occurrence of earthquake , hundreds of thousands of lives were lost and there is estimation about billions of dollars of damage sustained to property , and the physical suffering and mental anguish of survivor's earthquake are beyond completion.Normally infrastructure damage during earthquake is a result of structural inadequacy (Northridge,1994) , foundation failure (Mexico , 1985:Kobe , 1995) or a combination of both (K.Sen, 2009).

2.3.3 Structural failure : Overall failure

Structural failures may be categorized as overall failure and component failure. The overall failure involve collapse or overturning of whole building. The choices of the type of structure is instrumental and often a predetermining factor for failure.When an earthquake hits, the structure undergoes lateral oscillations that amplify in the longitudinal direction (Erdey, 2007). The springlike responds for the moment frame and the large floor mass have contribute to the excitation.

2.3.4 Component/Joint Failure

Component failure refers to the failure of one or more structural elements , mostly joints , due to the type of damage that makes the structural component or joint unstable (Erdey, 2007) .This failure have to be repair or replacement. This is because the failure mechanism vary according to the choice of material and structure’s type , hence it seems best to categorize the structure by the construction material used , especially for the concrete and steel and then create subcategories.

2.4 SEISMIC DESIGN

2.4.1 Building Behavior

The main objective of performance –based seismic design is to control damage to a structure subjected to an earthquake. (A.Habibi, 2012). In active seismic zones near the Pacific Rim, however seismic induced ground motions is one the most critical excitation loads to carefully evaluate when ensuring that platforms retain proper seismic resistance (M.Park, W.Koo, & K. Kawano, 2011) .The behavior of building during earthquake occur is a vibration problem. The seismic motions of the ground do not damage a building by the impact, or by externally applied pressure such as wind, but by internally generated inertial forces caused by the vibration of the building mass (S.Taranath, 2005).

An increase in mass will have two undesirable effects on the earthquake design. Firstly, it result in increasing of force. Secondly the increase in mass will caused buckling or crushing of columns and walls when the mass pushes down on member bent or plumb is moved out by lateral forces. This effect is usually known as the pΔ effect where the greater the vertical forces , greater the movement due to pΔ. It is always the vertical loads that usually make the structure collapse when earthquake occur, and the building very rarely fall over, but it will fall down.

The main concern in seismic design are the distribution of dynamics deformations caused by the ground motion and duration of motion.In general , tall buildings will respond to seismic motion differently with low rise building. The magnitude of inertia forces induced in an earthquake depends on the building mass , ground acceleration, the nature of the foundation and the dynamics characteristic of the structure (S.Taranath, 2005). Tall buildings are invariably more flexible compared to the low rise building.

In general , tall buildings experience much lower acceleration than low rise buildings. However , a flexible building that subjected to ground motion for a prolonged period may experience much higher forces if its natural period is quite near to ground wave. Hence , magnitude of lateral forces is not a function of the ground acceleration alone but influenced by type response of structure itself and also the foundation as well.

The intensity of ground motions reduces with the distance from the epicenter of the earthquake (S.Taranath, 2005) . The reduction refer as attenuation occurs at faster rate for higher frequency (short period) compared to the lower frequency (long period) . The cause of attenuation change rate is unknown but its existence is certain. Thus this is a significant factor for design in tall buildings although situated farther from the causative fault than low rise building , may experience greater seismic loads. Its happen because long period component are not attenuated as fast as the low rise building.

2.4.2 Demands of Earthquake Motions

Seismic loads result directly from the distortion induced in the structure by the motion of the ground on which it rests (S.Taranath, 2005). The base motion of structure is characterized by the displacements, velocities and accelerations that are erratic in magnitude, direction , duration, and sequence. An earthquake loads are the type of inertia forces that related to the mass , stiffness and energy- absorbing(damping and ductility) of the structure.

During its life, a building that located in a seismically active zone is generally expected to experience small, some moderate, and possibly one severe earthquake. Hence in general , it is uneconomical and impractical to design building to resist the building forces resulting from large or severe earthquake within the elastic range of stress. In severe earthquake , most buildings have been designed to experience yielding in at least one of its member. The energy-absorption capacity of yielding will minimize the damage to properly designed and detailed buildings. These kinds of yielding could survive earthquake forces better than design forces associated with an allowable stress in elastic range.

2.4.3 Role of Seismic Code in Design

In most actively seismic area , building construction is subject to a legally enforceable code which establish minimum requirements. Even when this is not so, common practice or contractual requirements will require compliance with a code: for example , US seismic code have very often been used in seismic area outside USA in past, and the same is likely to the of Eurocode 8 in the future (Booth & Key, 2008).In consequence, the part of the normal design process will be ensure meet the set of minimum code-based acceptance criteria. Code describe the minimum rules for standard conditions and cannot cover eventually.

2.5 FRAME

When the moment frame undergoes the lateral sway in the longitudinal direction , it causes serious out-of –plane flexural deformation to the shear wall (Erdey, 2007)

2.5.1 Rigid Frame (Moment frame)

A frame is considered rigid when its beam-to-column connections have sufficient rigidity to hold virtually unchanged the original angles between members (S.Taranath, 2005) . The lateral loads are resisted primarily by action of the rigid frame. This is by the development of shear forces and bending moments in the frame and joints.

Moment frame have benefit in building applications due to their flexibility in architectural planning. The moment frame may be placed at exterior of building without undergo restrictions on their depths. Besides, it also may be located throughout building interior with certain limitations on beam depths to allow for passage of mechanical and air conditioning ducts.

The strength and ductility of the connections between beams and columns are also important considerations, particularly for frames designed to resist seismic loads (S.Taranath, 2005) The Northridge , have scale Richter magnitude 6.7 earthquake of 1994 in California which have damage to over 200 steel moment-resisting frame buildings , and in the 1995, Kobe, Japan have 6.8 magnitude Richter have shaken engineers in the use of the moment frame for seismic design .In both of these earthquake , steel moment frame did not perform as well as expected.

2.5.2 Braced Frame

Concentric braced frame that proved their value in situations involving static loads have a rather poor performance in an earthquake (Erdey, 2007) Being a rather rigid structure , its shock absorption for the dynamic impact is almost negligible.

Braced frame is grouped into two categories , as either concentric braced frames (CBF) or the eccentric braced frame (EBF) , depend on their geometric characteristics . In CBF , the axes of all members, such as columns, beams and braces which intersect at a common point such that the member forces are axial. EBF utilize axis to deliberately introduce flexure and shear into framing beams. The braces can joined together to form a closed or partially closed three-dimensional cell for effectively resisting torsional loads (S.Taranath, 2005). The most efficient (but also the most destructive) bracing type are those that form in triangular vertical truss.

2.6 EARTHQUAKE IN ACEH

2.6.1 Effect Earthquake Aceh towards Malaysia

The devastating tsunami of 26 December 2004 , that struck the coastlines of the Indian Ocean , was caused by an underwater earthquake (K.Sen, 2009) .Earthquake activity is not uniformly spread across the Earth : in fact , 90% of energy release from earthquake occurs on the 'ring of fire' around the edge of the Pacific ocean, with another active belt stretching across the southern edge of Europe to the Himalayas and into Eastern China (Booth & Key, 2008)

The occurring of earthquake are mainly concentrated at the plate boundaries , but there are also area that have distributed seismic activity is remote from the plate boundaries. A normal well-constructed building , designed for the moderate wind forces , should be able to resist the minor ground shaking reasonably well (Booth & Key, 2008).

However , the structure that are unusually flexible or exceptionally brittle could be very sensitive to any small nearby earthquake or more distant larger earthquakes. The earthquake's design for a sensitive structure in area of low seismicity is usually to be a comparatively small-magnitude event which occurring close to the area. The ground motion that result from the small magnitude-event have a characteristic has a high peak acceleration but the duration is short only.

Malaysia that located at the peripheral of the ring of fire and beside two neighbors , Indonesia and Philippines, which have seen violent episode of seismological activities in the past few years , chance of being jolted by at least one moderate earthquake cannot be ruled out (Bernama)

2.7 CURRENT MALAYSIA PRACTICE OF SEISMIC DESIGN

Majority of buildings in Malaysia is been designing based on BS8110 where there are not specify the provision of seismic design, since Malaysia is not located in active seismic fault zone (Adiyanto & A.Majid, 2014).However, these standards do not have any requirements on seismic loads. Due to this deficiency, engineers normally refer to AASHTO Specifications ,Uniform Building Code or Eurocode for design guidance (Koong & Won, 2004).It had been reported that most the buildings were in good condition in Peninsular Malaysia and estimated about at least 50% of selected buildings were found to experience concrete deterioration problems due to vibration during earthquake (Adiyanto & A.Majid, 2014). The occurrence of several tremors in neighbouring countries has necessitated a relook at the seismic reliability of the existing structures. Major cities like Kuala Lumpur, Penang and Johor may have structures with significant seismic risk.

Prior to 26 December 2004 earthquake, IEM in a position document approved by IEM council had several short and long term recommendations on issues regarding earthquake (The Institution of Engineers, 2005).Hence, the issue of ground and slope stability may also be of some concern in the face of earthquake tremors. IEM is recommending the initiatives of undertake seismic vulnerability studies of existing important buildings or structures, particularly in high risk areas. Besides ,stressed the need to review of current Engineering Design & Construction Standards and Practices (The Institution of Engineers, 2005).

In Malaysia, when an engineer designs a structure, the easiest way for computing seismic load is to multiply the total weight the appropriate of structure by acceleration coefficient without applying any ductility factor (Koong & Won, 2004).The important concept is that the movement of the structure is very much different than that of the ground and the acceleration experienced by the structure varies with height (Koong & Won, 2004)The ground acceleration adopted varies from 0.03g up to 0.2g depending on the importance of the structure or the severity of outcome the structure failure can cause. The design of Penang Bridge used higher value of ground acceleration compared to design of Bakun Hydroelectric Plant (N.Potty, M.Redzuan, & A.Hamid, 2013)

2.8 OFFSHORE PLATFORM

Offshore platform are mainly used for gas and oil extraction, drilling , storage and transportation. The most typical type of fixed offshore platform is the steel jacket platform , which generally evolves into flexible superstructure. This structure are among the most important structure in the explorations and production of oil and natural gas.

Since these platforms play an important role in the production line of gas and oil , any damage that they may sustain during earthquake , could result in the devastating physical damages as well as business interruption losses (A.Ajamy, M.R.Zolfaghari, B.Asgarian, & C.E.Ventura, 2014)

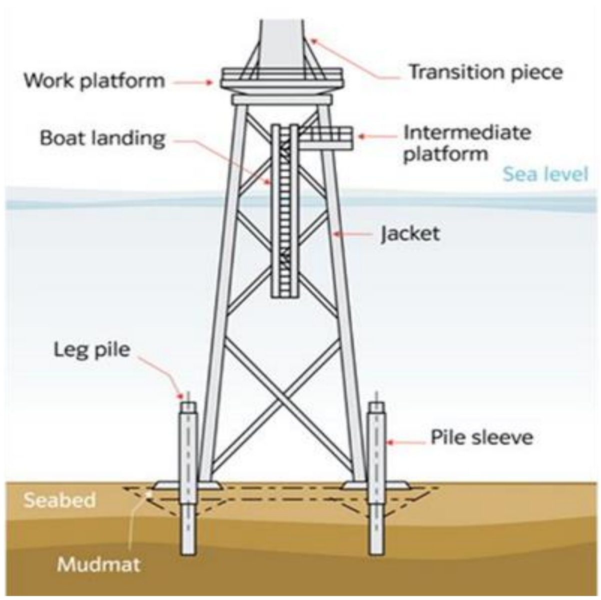


Figure 2.3 : Structure of Offshore Platform

Source : 4C Offshore [Online Image] .(2013) .Retrieved October 14 , 2014 from http://www.4coffshore.com/windfarms/jacket-or-lattice-structures-aid271.html

In the offshore industry there are two possible materials for the construction of the hull of any structure : steel and concrete. (Fernandez & M. Lamas Pardo, 2013) Steel is being widely in shipbuilding industry for build merchant ships, warships etc.The structural properties are liable to induce self-excited nonlinear hydrodynamic force which in turn make the structure large deformations and fatigue damage (Zhang, Han, Zhang, & Yu, 2012).

As offshore platform structure require more critical and complex designs, the need for accurate approaches to evaluate the uncertainty and variability in computer models, loads , geometry and material properties has increased significantly (Hezarjarbi, M.R.Bahaari, Bagheri, & Ebrahimian, 2013). Performance-based earthquake engineering (PBEE) require estimation that really accurate for the structural seismic demands. One of the factors that decrease this accuracy is the uncertainties in seismic response caused by this accuracy associated with the input parameters (El-Din & J.Kim, 2014)

Notice that offshore platform involve some uncertainties such as unknown system parameter and structure flexibility .Most importantly , they are usually subject to various nonlinear disturbance such as wave, wind, current and earthquake. Incident wave is a primary concern for the safety of structure and an array of cylinders as a common shape of offshore platform is used to predict the wave excitation forces (M.Park, W.Koo, & K. Kawano, 2011) .

Mostly anywhere in the world is thought to be susceptible to suffering an earthquake of magnitude 6 , which can give rise to very severe motions at its epicenter. At any rate in areas of low seismicity , something less than the ‘maximum credible event ‘ must be found for design , because the magnitude 6 event at a given site is very likely to be credible , although it may be extremely rare (Booth & Key, 2008). However , there is now a general consensus that a probabilistic approach to defining earthquake hazard gives the most appropriate results for engineering design (Booth & Key, 2008)

Nowadays, one third of the existing offshore platform require life extension and life extension process require structural rehabilitation (Jafarabad, Kashani, Parvar, & Golafshani,

2014) On the other hand, offshore platform are of the economic life line of oil-rich countries, so it is a serious problem on how to guarantee their immediate occupancy after earthquakes (Jafarabad, Kashani, Parvar, & Golafshani, 2014).

2.8.1 Jacket Fixed Offshore Platform

Offshore jacket platform , located at severe environmental condition , are generally subjected to two main categories of environmental loading, i.e normal –condition loads such as wave – induced hydrodynamic force and extreme – condition loads like seismic excitation (Jafarabad, Kashani, Parvar, & Golafshani, 2014).

The jacket , the piles and the deck are the main structural components for the offshore jacket platform . For installation of topside , all deck facilities are fabricated into modules and will be transported by barge and set on top of platform by a derrick . Float – over deck are a development that enables the prefabrication of the complete topside , so that it may be transported by barge and set as a complete unit on the preinstalled jacket (Jafarabad, Kashani, Parvar, & Golafshani, 2014) .

For using the float-over deck , some limitations are imposed on the platform characteristic . Float-over deck requires omission of bracings in one direction at level of water surface .This needed to allow the barge to move between jacket legs and install the deck, so the stiffness at this level is very low compared to other levels.

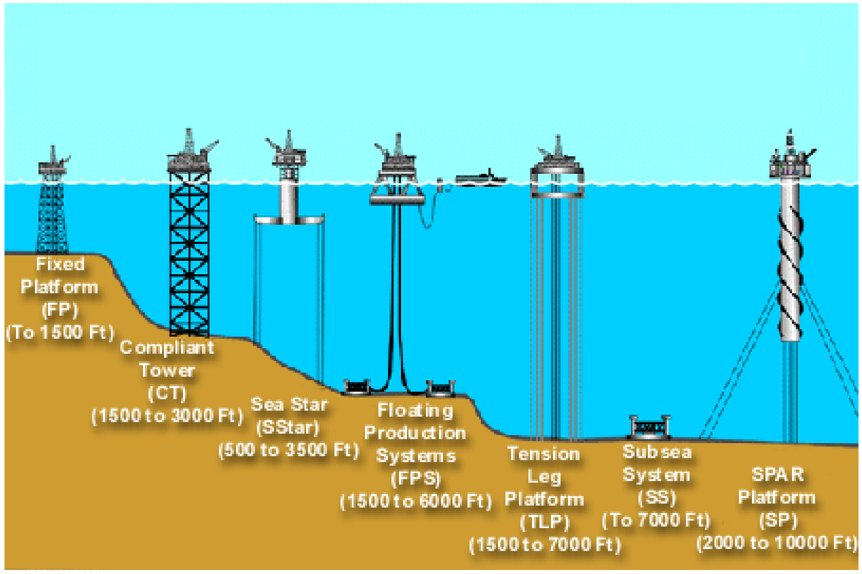


Figure 2.4 : Typical offshore drilling platform

Source : Indelac Controls [Online Image] . (2014) . Retrieved October 14 , 2014 from http://blog.indelac.com/introduction-to-oil-gas-offshore-drilling

2.9 ENVIRONMENTAL LOADS CONSIDERED FOR OFFSHORE PLATFORM

In designing the offshore platform, the designer have to consider environmental conditions that expected to occur from different direction . The environmental loads that need to be considered are combination of wind loads, wave loads, and current loads.

2.9.1 Wind Loads

Winds loads are dynamic in nature , but some structure will respond to them in a nearly static fashion (Institute, 2000). Wind speed and direction are varying according to time and space.

$$F = \left(\frac{\rho}{2}\right) u^2 C_s A \qquad (2.1)$$

2.9.2 Wave loads

Wave loads that exerted on offshore platform are dynamic in nature. For most design water depths presently encountered , these loads may be adequately represented by their static equivalents (Institute, 2000).

$$F = F_D + F_I = C_D \frac{w}{2g} AU|U| + C_m \frac{w}{g} V \frac{\delta U}{\delta t} \quad (2.2)$$

2.9.3 Current Loads

Current loads are the total vector sum of the tidal , circulational, and storm-generated currents (Institute, 2000) . The magnitude of these three components are importance in computing the loads and varies with offshore location.

$$F = F_D + F_I = C_D \frac{w}{2g} AU|U| + C_m \frac{w}{g} V \frac{\delta U}{\delta t} \quad (2.3)$$

$$F_c = F_D = C_D \frac{W}{2g} AU|U| \quad (2.4)$$

2.10 SEISMIC RESPONSE ANALYSIS

2.10.1 Free Vibration

A structure is said to be undergoing free vibration when it is disturbed from its static equilibrium position and then allowed to vibrate without any external dynamic excitation (K.Chopra, 2012).To simplify it, free vibration is a condition where there are no external forces on the system. The analysis of free vibration will produce result of natural frequency , natural period , and mode shape of structure. Mode shape is the shape that structure will vibrate during free motion , and when earthquake is occur , the same shape will dominate the shape the structure during that time.For single degree freedom (SDF) system , free vibration is leading to the natural vibration frequency and damping ratio. Damping ratio will controlled the rate of motion decay in free vibration.

2.10.2 Time History

Time history is a common way to describe the ground motion occurred during earthquake. The parameters for the time history is displacement ,velocity or acceleration or all three parameter is combined together. Time histories of ground motions are used directly for the time domain analysis of structures subjected to deterministic seismic inputs (Datta, 2010) .

Ground motions data is categorized into three orthogonal directions, where two of them are in horizontal direction and third is in vertical direction. For structural analysis, these three components will be transformed into corresponding principal directions. In El Centro earthquake, the three components of ground motions is shown in figure below.

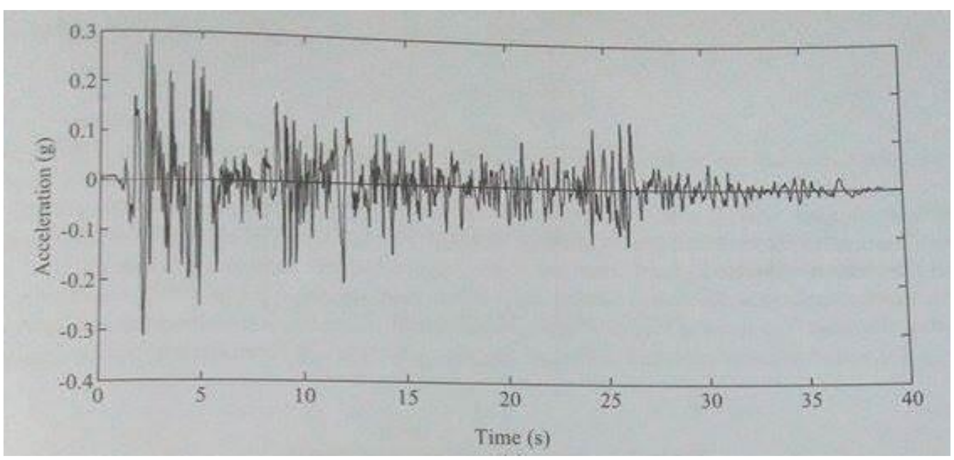


Figure 2.5 : a) Major motion (horizontal) (Datta, 2010)

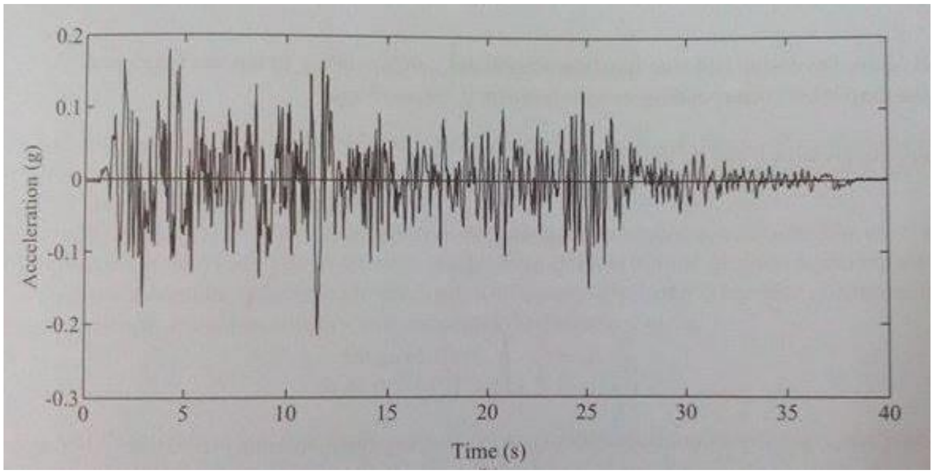


Figure 2.6 : b) Minor motions (horizontal) (Datta, 2010)

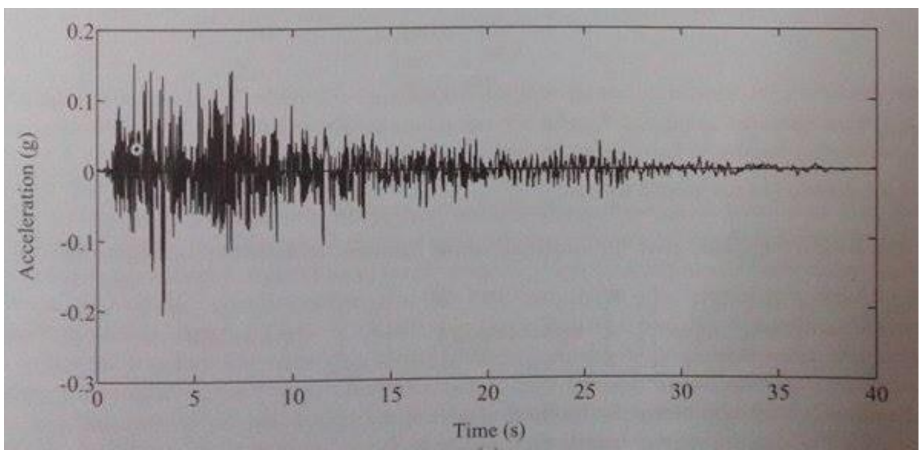


Figure 2.7 : c) Minor motions (vertical) (Datta, 2010)

2.10.3 Response Spectrum

Response spectrum provides a convenient means to summarize the peak response of all possible linear SDF system to particular components of grounds motion (K.Chopra, 2012).Analysis of response spectrum is a practical way to characterizing ground motions and their impacts towards structure. The derivation from the displacement response spectrum form basic for deriving other spectra . A displacement response spectrum is maximum displacement of SDF of certain ground motion as function of natural frequency and damping ratio (Datta, 2010).

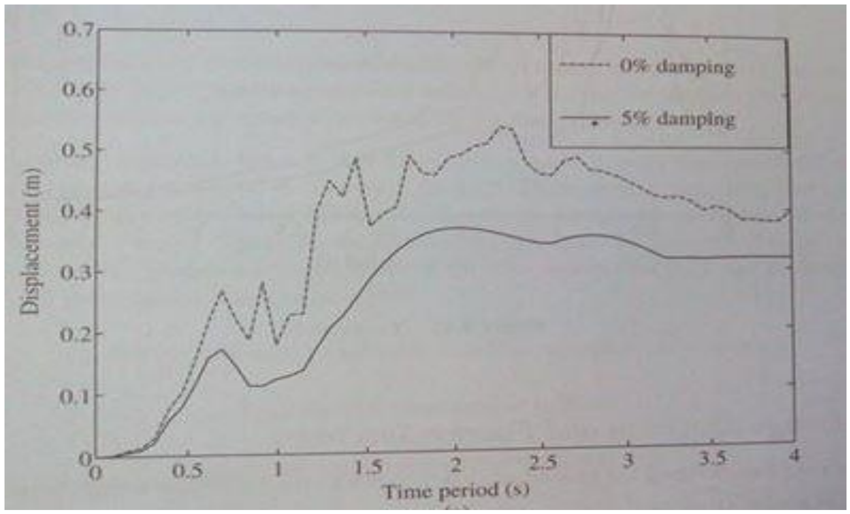


Figure 2.8 : Response spectrum of an earthquake for displacement spectrum (Datta, 2010)

2.11 SAP 2000 BUILDING ANALYSIS PROGRAM

2.11.1 Seismic Evaluation of Structure using SAP2000

Steel member sizes can be optimized based on strength per design code with user defined unto select lists of sections. Compare SAP2000 optimization to manual trial and error, analyzing section per member at a time.SAP2000 constraint options provide unique capabilities to rigidly 'link' joints which are offset from one another. In addition to rigid diaphragms, SAP2000 also provides additional constraint types which rigidly transfer forces and moments from one joint to another in all degrees of freedom, or in selected degrees of freedom, while accounting for secondary moments that occur due to the distance between the joint locations (lever arm effect).

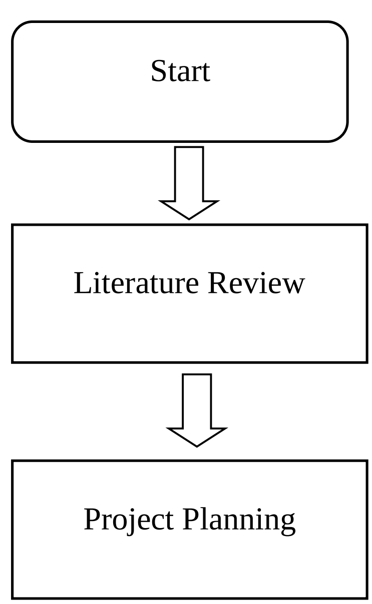
This ability to transfer secondary moments differentiates these constraints from traditional master-slave/rigid diaphragm type of constraints. This is particularly important when connecting beams with shell elements, modeling composite behavior, or joint connections offset from an element centerline which can cause secondary moments. SAP2000 constraint options become especially critical for accurate reactions in a dynamic analysis.SAP2000 enables users to review analysis results graphically by clicking on individual members or joints, or generate output reports. Output reports can be limited by graphically selected areas, or by pre-defined groups, by load case/combination.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

For the research methodology stage , all data , information and facts regarding this offshore platform are collected. The process off data collecting is focusing on earthquake , offshore structure , manual calculation using Eurocode & API standards and SAP2000 computer software. Planning have been carried out to ensure the successful of this project. The overall flow chart of this project is as follows :



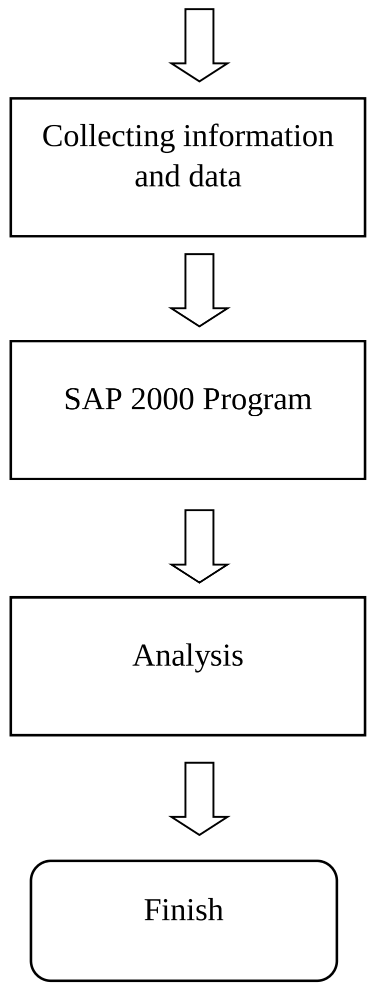


Figure 3.1 : Flowchart of study

3.2 LITERATURE REVIEW

All the relevant data, information , studies and facts regarding to this project are collected during these stage. The data collection for this project focusing on several topics which are :

i. Earthquake
ii. Offshore platform
iii. Design consideration of offshore platform
iv. SAP 2000 building analysis program

3.3 SAP 2000 PROGRAM

The analysis software used is SAP2000 which an integrated software for structural analysis and design .Generally, SAP2000 is a stand-alone finite-element-based structural program for the analysis and design of civil structures. It offers an intuitive, yet powerful user interface with many tools to aid in the quick and accurate construction of models , along with the sophisticated analytical techniques needed to do the most complex projects.

In the analysis for the offshore platform , the case study will be conducted at the Aceh earthquake region that affected the offshore platform in Malaysia .The earthquake data for Aceh, Indonesia is obtain from the Malaysian Metrological Department (MMS) which can be find in MMS website.

3.4 STEP ANALYSIS IN SAP2000 PROGRAM

3.4. 1 Collecting Information Data

To obtain the important information and data for the modeling and analyzing the model, further data collection works have been performed during these stage. The information and data needed are as below:

i. Drawing of the jacket offshore platform
ii. Location of the offshore platform
iii. Background of the offshore platform
iv. Configuration of jacket offshore platform
v. Material used for the jacket offshore
vi. Limitation of the offshore structure

3.4.2 Modelling

Modeling of the 4-legged jacket offshore platform is carried out by using SAP2000 software. Steps in the modeling of the jacket offshore platform is as below:

i. Determine the type of the model
ii. Create, define and coordinate the grid system for the model
iii. Define the type used for the structure
iv. Determine the element and area section of offshore structure
v. Determine coordinate system through actual dimension in 2D frame
vi. Draw 2D frame element to create 3D frame
vii. Replicate the 2D frame element to create 3D frame
viii. Determine the restrains at base condition

3.5 OFFSHORE PLATFORM DETAILING

3.5.1 Offshore Platform Layout

The drawing below shows the typical offshore platform in Malaysia. This is a drawing that will be used for offshore jacket analysis. The height for this jacket offshore platform is 54848 mm , Above the sea level, the height is 4448mm.while below the sea level, the height is 50400 mm. This structure have 7 level and it is 3-legged fixed offshore platform.

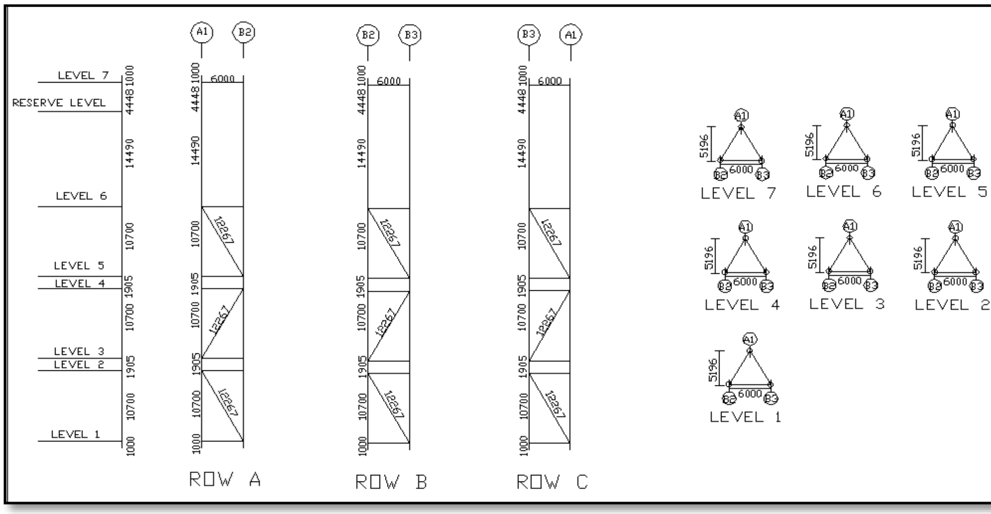


Figure 3.2 : Drawing for offshore platform from front and plan view

3.5.2 SAP2000 Model View

Below are drawing that have been draw by SAP2000 software.

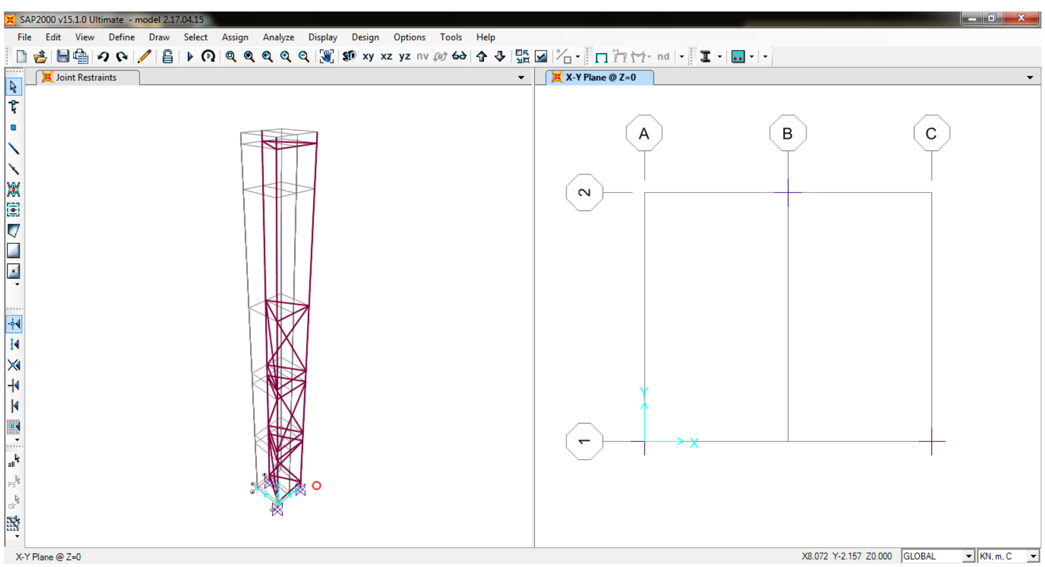


Figure 3.3 : View model from 3D view and X-Y view

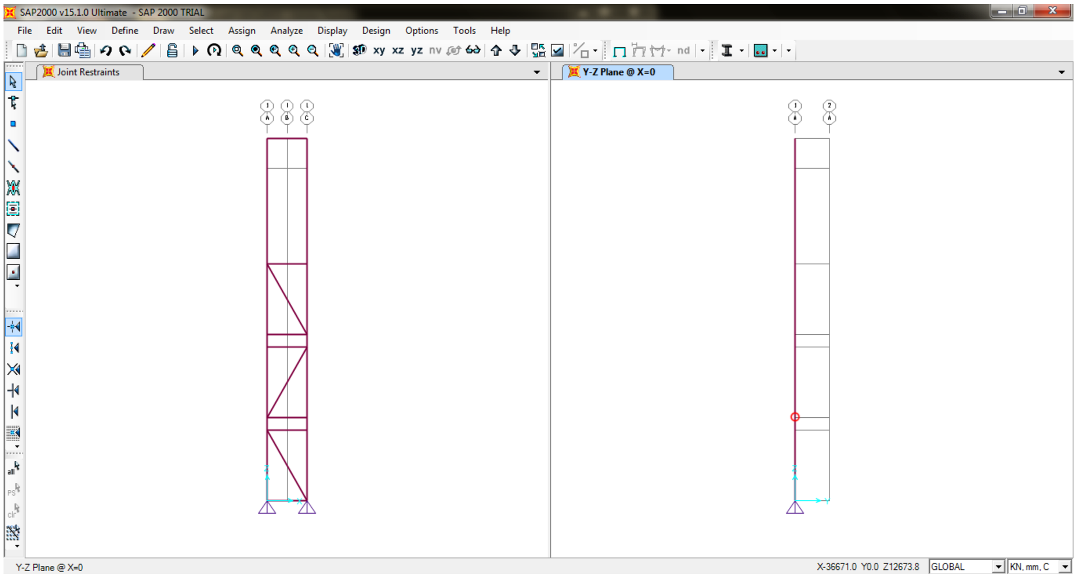


Figure 3.4 : View model from Y-Z view and X-Z view.

3.5.3 Offshore Platform Coordinate

To draw this offshore jacket in SAP200, firstly need to specify the coordinate for this structure in X,Y and Z direction. Below are the table for X,Y and Z grid data that used.

Table 3.1: Grid coordinate created for each level

LEVEL	POINT	X COORDINATE	Y COORDINATE	Z COORDINATE
1	B2	0	0	0
	A1	3	5.196	0
	B3	6	0	0
2	B2	0	0	1

	A1	3	5.196	1
	B3	6	0	1
3	B2	0	0	11.7
	A1	3	5.196	11.7
	B3	6	0	11.7
4	B2	0	0	13.605
	A1	3	5.196	13.605
	B3	6	0	13.605
5	B2	0	0	24.305
	A1	3	5.196	24.305
	B3	6	0	24.305
6	B2	0	0	26.21
	A1	3	5.196	26.21
	B3	6	0	26.21
7	B2	0	0	36.91
	A1	3	5.196	36.91
	B3	6	0	36.91
8	B2	0	0	51.4
	A1	3	5.196	51.4
	B3	6	0	51.4
9	B2	0	0	55.848
	A1	3	5.196	55.848
	B3	6	0	55.848

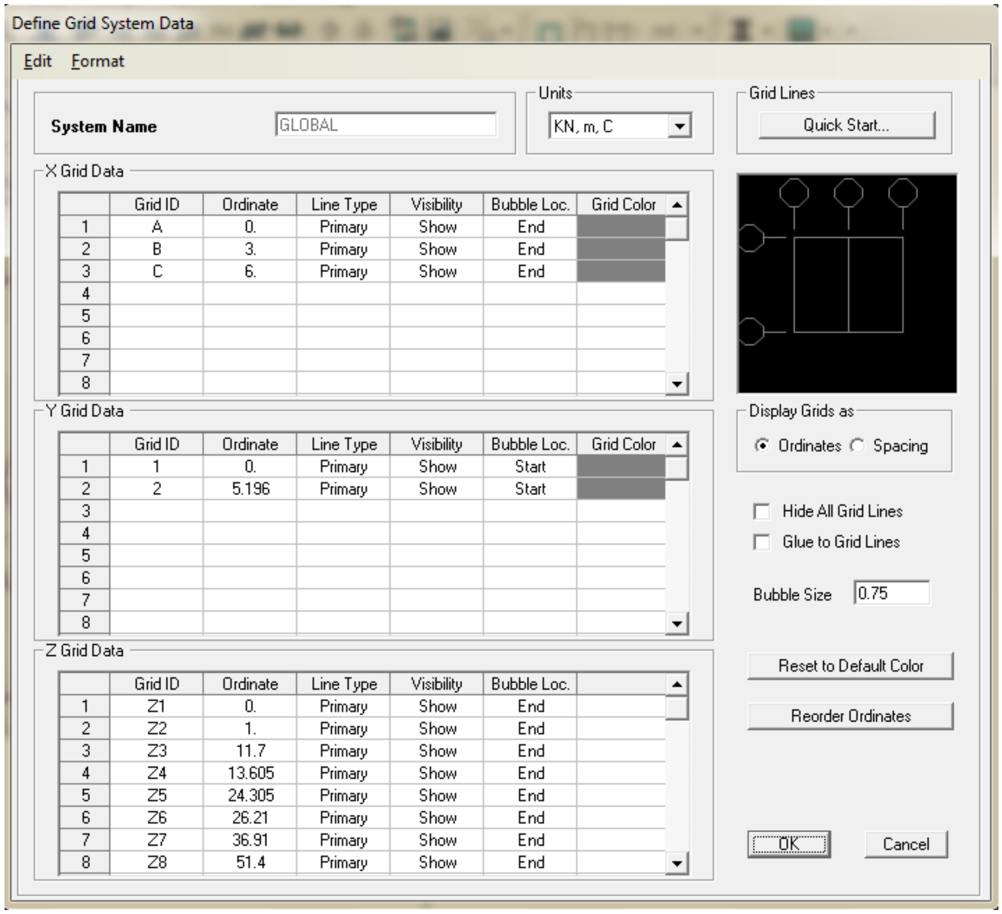


Figure 3.5: Grid system data created in SAP2000

3.6 LOADING APPLIED

The consideration of environmental loads consists earthquake load, wind load , wave load and current loads . Define all the load cases and assign load on the frame in SAP2000 software. There are various types of loading to which offshore installations are normally designed to withstand in addition to seismic loading. These are incident on the installation generally as a combination of the different loads that are of greater magnitude and complexity than onshore structures. The combination load that been defined is dead load, deck loads, wave, current, wind and earthquake loading.

3.6.1 Selfweight and Functional Loads

Table 3.2: Self weight and live loads for offshore platform

No	Load description	[MN]
1	Jacket appurtenances weight	-0.0339
2	Topside dead loads	-0.0393
3	Piping & equipment weights	-0.0400
	Total	-0.1132
4	Topside live loads	-0.1150

3.6.2 Environmental Loads

The environmental loads are based on the metocean data. Table below show the environmental criteria.

Table 3.3: Environmental loads located in Angsi Field , Terengganu

MSL		Design condition
69.20m	Wave height (m)	10.79
	Wave period (s)	10.9
	Current velocity (m/s)	0.750
	Wind speed (m/s)	21.8
	Max.tide (m)	2.0
	Storm surge (m)	0.4

1. Wind loads

Wind loading is impacted upon the various components of the platform that would include the members, the equipment, the facilities etc. These winds include steady forces and gust forces that are to be rationally applied to the structure such as being made to act at a specific height and at a specific duration such as one hour [API-RP2A].The wind force as determined by API-RP2A is calculated by the following relationship .All calculation can refer to Appendix G.

$$F = \left(\frac{\rho}{2}\right) u^2 C_s A \quad (3.1)$$

Where ,

F = wind force [N]

ρ = mass density of air [1.2kg/m^3]

u = wind speed [m/s] = 21.8 m/s

Cs = Shape coefficient = 1.0

A = area of object [m^2] = $\pi \frac{D^2}{4}$

2. Wave Action

Wave loading plays a large role in the design of platforms and is normally, in non-seismic zones, the critical design load. It is known that waves can be incident on a platform from all directions especially during design storms. The waves impose a cyclic and buoyant force on the platforms and these are to be resisted by the foundation piles. The effect of these waves on the platform is determined by the use of the Morrison's equation. All calculation can refer to Appendix G.

$$F = F_D + F_I = C_D \frac{w}{2g} AU|U| + C_m \frac{w}{g} V \frac{\delta U}{\delta t} \tag{3.2}$$

Where ,

F = hydrodynamic force vector per unit length acting normal to the axis of the member [N/m],

F_D = drag force per unit length of the member [N/m],

F_I = inertial force per unit length [N/m],

C_D = drag coefficient

w = density of water [N/m^3]

A = projected area normal to the cylinder axis per unit length (= D for circular cylinder) [m^2]

V = displaced volume of the cylinder per unit length (=$\pi D^2/4$) [m^3]

g = gravitational acceleration [m/s^2]

U = component of velocity vector due to wave [m/s],

|U| = absolute value of U [m/sec],

Cm = inertia coefficient, smooth = 1.6

$\frac{\delta U}{\delta t}$ = component of local acceleration vector of the water.

3. Current loading

Current loading is the vector sum of tidal currents, the circulatory currents and the storm generated current. In platform design , the strength and direction and profile of the current is important also for the consideration of deposits of inland and oceanic material , and for the placement of berthing and docking equipment for boats. All calculation can refer to Appendix G.

$$F = F_D + F_I = C_D \frac{w}{2g} AU|U| + C_m \frac{w}{g} V \frac{\delta U}{\delta t} \tag{3.3}$$

$$F_c = F_D = C_D \frac{W}{2g} AU|U| \tag{3.4}$$

Where

F = wind force

C_D = drag coefficient, rough = 1.05

A = area of object = m^2

w = density of water [N/m^3]

g = gravitational acceleration [m/s^2]

U = component of velocity vector due to wave [m/s],

|U| = absolute value of U [m/sec],

3.7 MATERIAL PROPERTIES

The following material properties are used for modelling and analysis of offshore structures.

Table 3.4: Material properties for modelling and analysis

No	Material Property	Value
1	Young Modulus (E)	210000 N/mm^2
2	Shear modulus (G)	81000 N/mm^2
3	Yield strength	552 MPa
4	Steel Density	8050 kg/m^3

3.8 STEP IN MICROSOFT EXCEL

3.8.1 Earthquake Data from MMS Website

The data that obtained from MMS website is in form combination of time (sec), displacement (in) , velocity (in/sec) and acceleration (g).

```
Station ID: IPM  Channel 1: HGZ  12/26/2004 0:44:11 (GMT)
Time (sec) vs. A (g), V (in/sec), D (in)
0.010 0.000001 -0.000008 0.000003
0.020 -0.000000 -0.000007 0.000003
0.030 -0.000000 -0.000008 0.000003
0.040 0.000000 -0.000008 0.000003
0.050 0.000000 -0.000006 0.000003
0.060 0.000000 -0.000006 0.000003
0.070 0.000000 -0.000005 0.000003
0.080 0.000000 -0.000004 0.000003
0.090 -0.000000 -0.000004 0.000003
0.100 -0.000000 -0.000005 0.000003
0.110 0.000000 -0.000005 0.000003
0.120 0.000000 -0.000004 0.000003
0.130 -0.000000 -0.000004 0.000003
0.140 0.000000 -0.000004 0.000002
0.150 0.000000 -0.000003 0.000002
0.160 -0.000000 -0.000003 0.000002
0.170 0.000000 -0.000003 0.000002
0.180 -0.000000 -0.000003 0.000002
0.190 -0.000001 -0.000005 0.000002
0.200 0.000001 -0.000005 0.000002
0.210 0.000000 -0.000003 0.000002
0.220 0.000000 -0.000002 0.000002
0.230 0.000001 -0.000000 0.000002
0.240 -0.000001 -0.000000 0.000002
0.250 -0.000000 -0.000002 0.000002
0.260 0.000001 -0.000000 0.000002
0.270 -0.000000 0.000001 0.000002
0.280 -0.000001 -0.000002 0.000002
0.290 0.000001 -0.000001 0.000002
0.300 0.000001 0.000002 0.000002
0.310 0.000000 0.000004 0.000002
0.320 0.000000 0.000006 0.000002
```

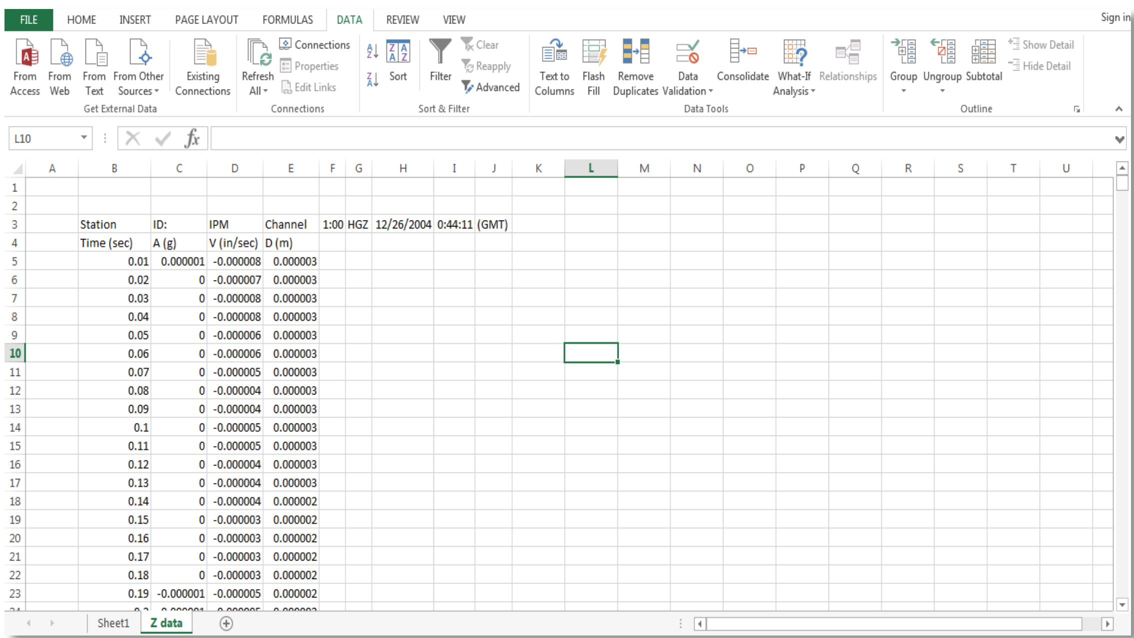
Figure 3.6: Raw data in notepad for earthquake analysis

3.8.2 Steps to Obtain Absolute Maximum and Minimum Data

The data that obtained from the MMS website then have to be analysis in Microsoft Excel. The data obtained have 3 direction which is in Z ,N and E direction that refer to earthquake direction when it strikes.

Steps 1: Convert data from notepad into Microsoft Excel

For each direction of earthquake data , the raw data will be organized according to time (t) , acceleration (g), velocity (in/sec) and displacement (in) table by using Microsoft Excel.



Station	ID:	IPM	Channel	1:00 HGZ 12/26/2004 0:44:11 (GMT)
Time (sec)	A (g)	V (in/sec)	D (m)	
0.01	0.000001	-0.000008	0.000003	
0.02	0	-0.000007	0.000003	
0.03	0	-0.000008	0.000003	
0.04	0	-0.000008	0.000003	
0.05	0	-0.000006	0.000003	
0.06	0	-0.000006	0.000003	
0.07	0	-0.000005	0.000003	
0.08	0	-0.000004	0.000003	
0.09	0	-0.000004	0.000003	
0.1	0	-0.000005	0.000003	
0.11	0	-0.000005	0.000003	
0.12	0	-0.000004	0.000003	
0.13	0	-0.000004	0.000003	
0.14	0	-0.000004	0.000002	
0.15	0	-0.000003	0.000002	
0.16	0	-0.000003	0.000002	
0.17	0	-0.000003	0.000002	
0.18	0	-0.000003	0.000002	
0.19	-0.000001	-0.000005	0.000002	

Figure 3.7 : Raw data in Microsoft Excel

Steps 2: Highlight the time(s) and acceleration (g) column by pressing ctrl+shift+down

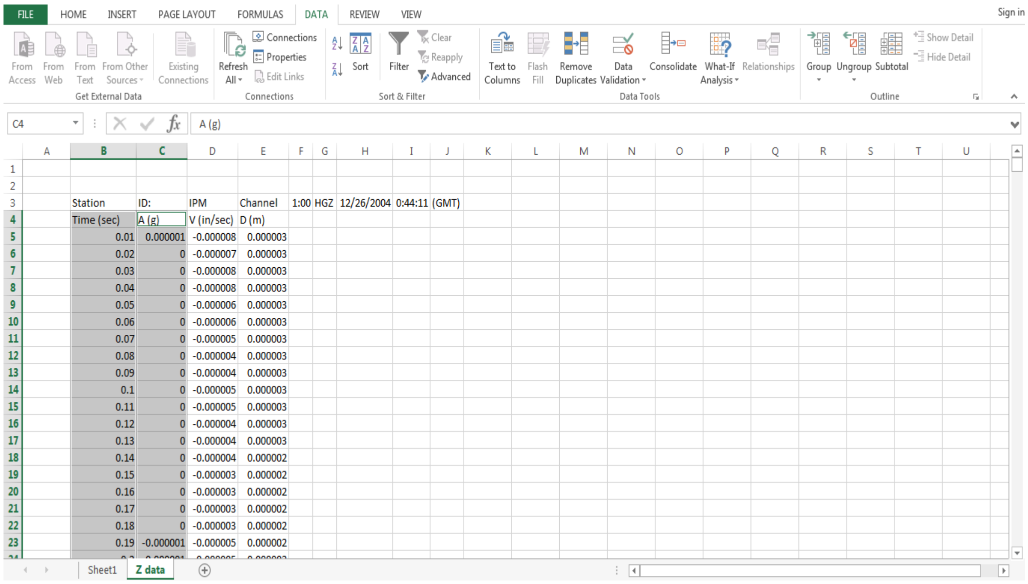


Figure 3.8 : Highlight the selected column

Steps 3 : Choose graph type of scatter with straight line.

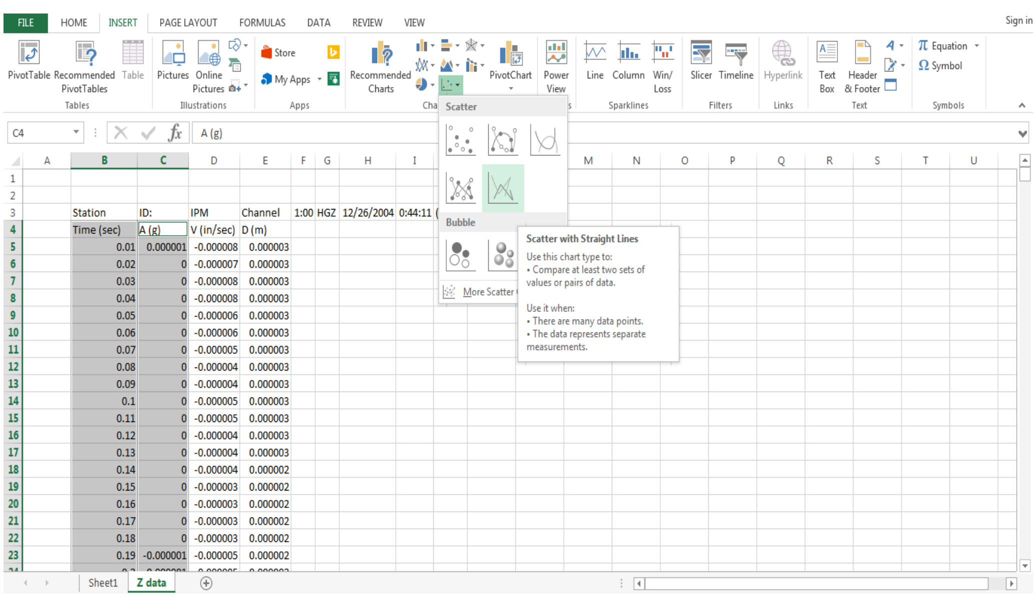


Figure 3.9 : Graph scatter is chosen

Steps 4 : Then , from the table find the maximum and minimum absolute data . To obtain the absolute maximum value need to write the formula first. Write formula =max(abs(c5:c377423))) then press ctrl+shift+enter

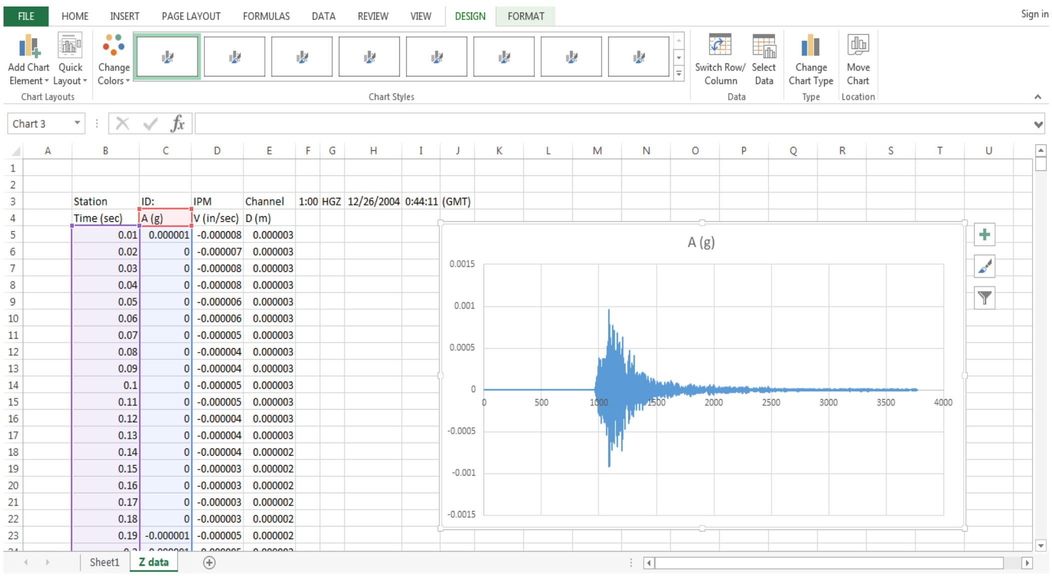


Figure 3.10 : Maximum and minimum absolute data

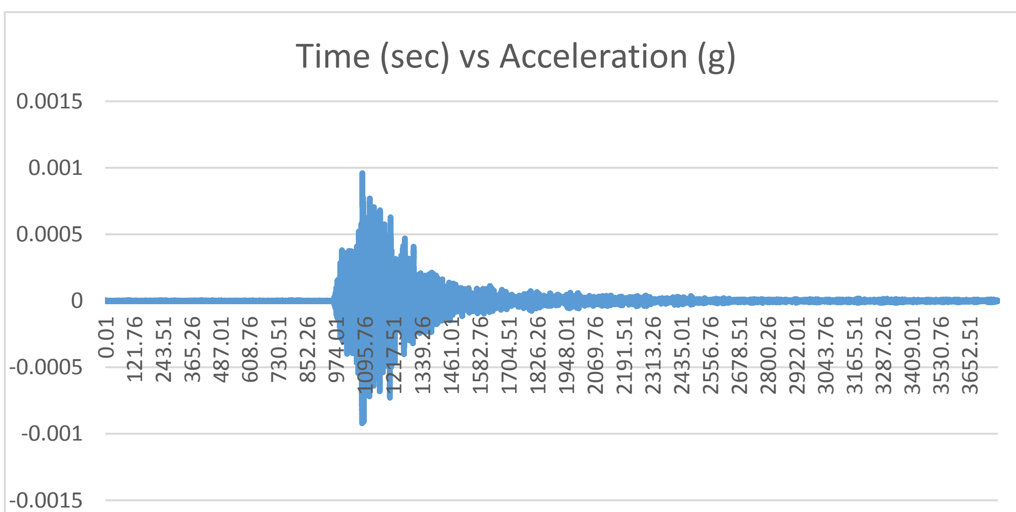


Figure 3.11 : Scatter graph

3.9 STEP IN SAP2000 COMPUTER SOFTWARE

Step 1: Begin new model

Select template : Model that need to create must define type of template first . In this design we use template grid.

i. Menu : File – New model - Grid
ii. Select :File → New model
iii. Click grid

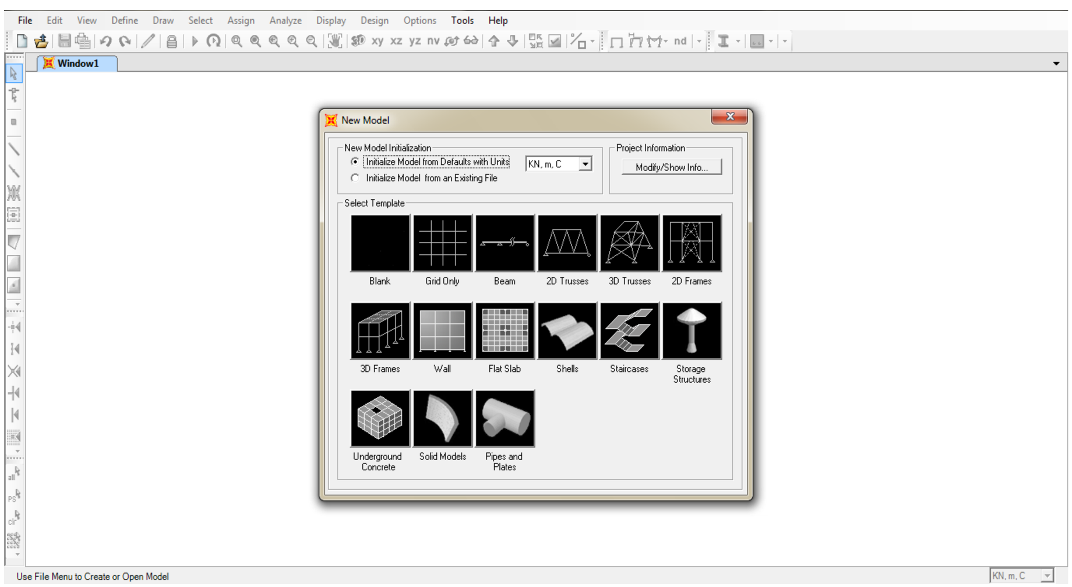


Figure 3.12 : Template grid

Step 2 : Draw model

After complete specify the coordinate for all direction , then need to draw the member at the grid line that have been created. Complete drawing of design of model in figure below.

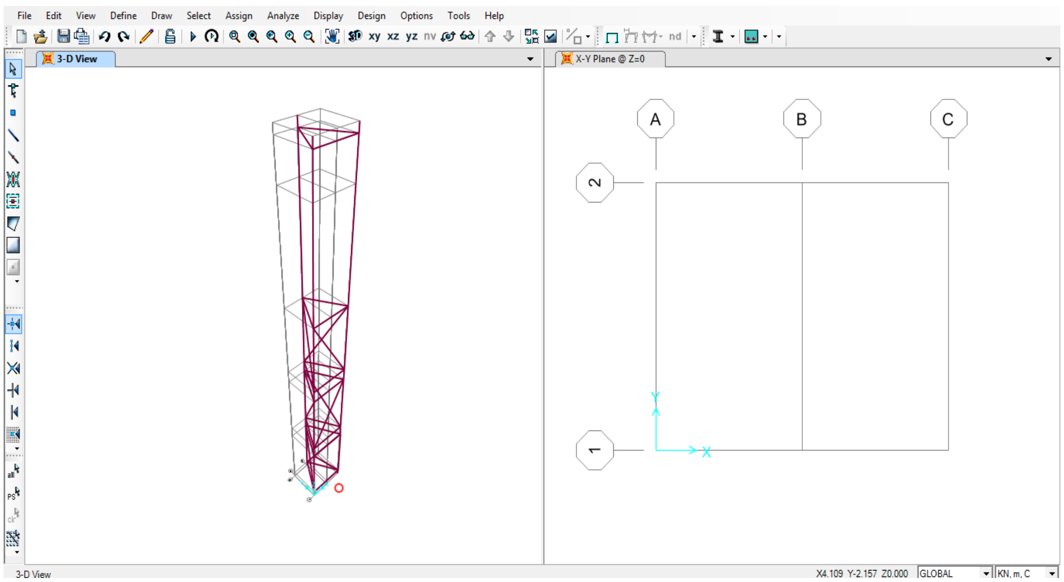


Figure 3.13 : Model drawn

Step 3 : Add restraints

For all structure, need to specify the joint restraints (support) for the stability of the structure. In this design , we choose the fixed support.

i. Select : Assign → Joint → Restraints
ii. Select fixed restraints
iii. Select Ok

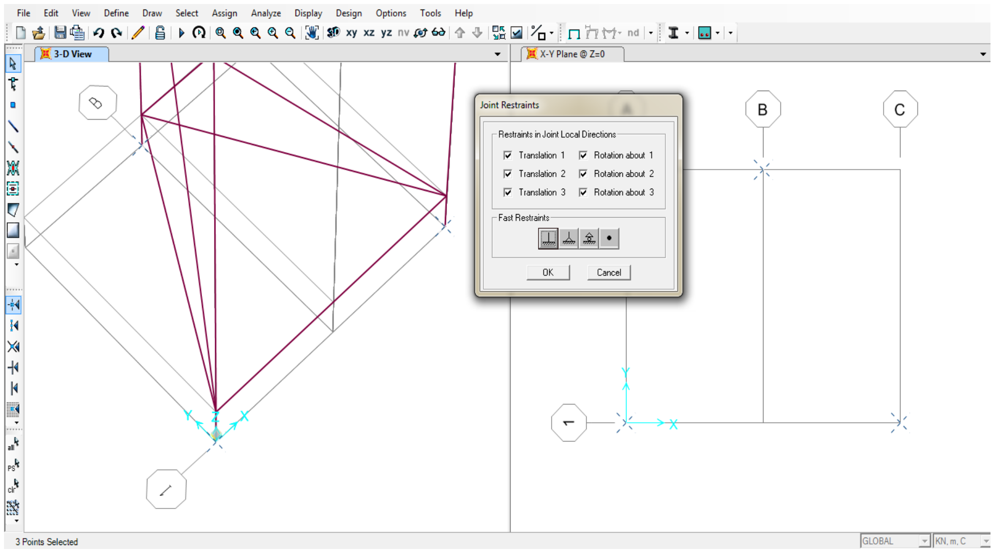


Figure 3.14 : Fixed joint restrain

Step 4 : Define load cases

The load cases for model analysis is inserted which are dead ,live, wave , wind , modal , response spectrum and time history.The analysis is based on Eurocode 8.

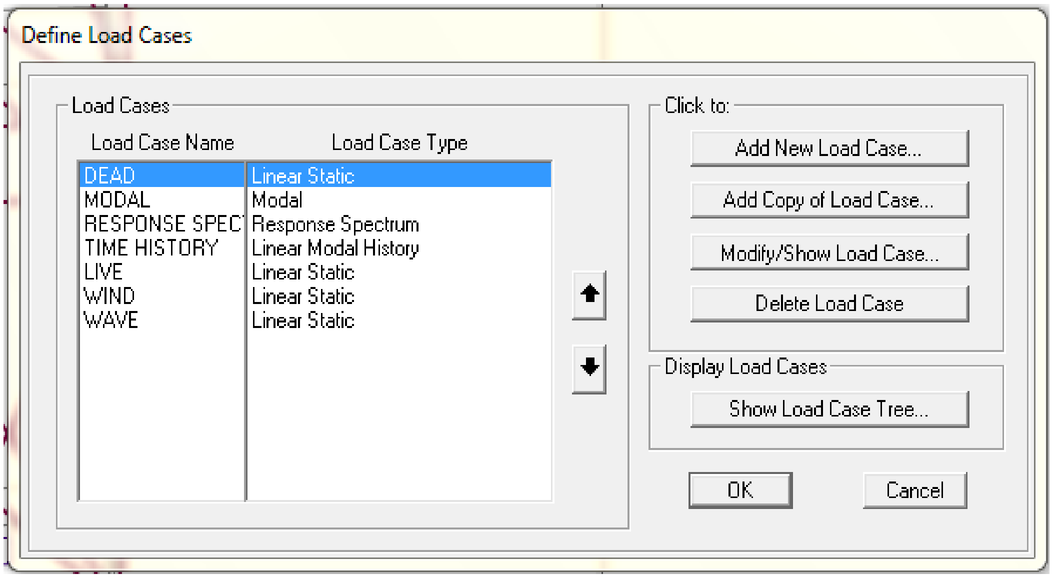


Figure 3.15 : Load cases type

Step 5 : Run analysis

The analysis is run to get the result analysis. The load combination that needed to analyzed is :

a) Response spectrum

b) Modal (Free vibration)

c) Dead + Live load

d) Environmental load

e) Dead + Live + Environmental load + Time History

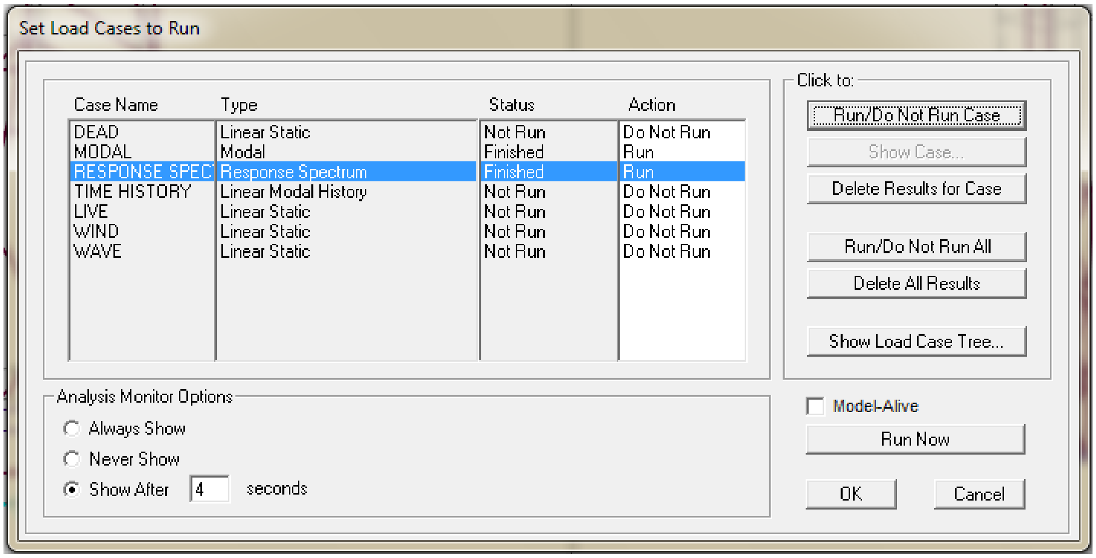


Figure 3.16 : Load cases for analysis

Step 6 : Display result & analysis

The result will display. The difference color shows the level of safe in the steel check of structure. The color is depending on the ratio of steel strength.

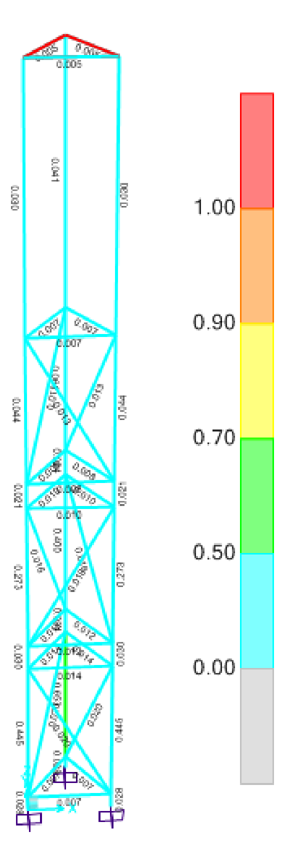
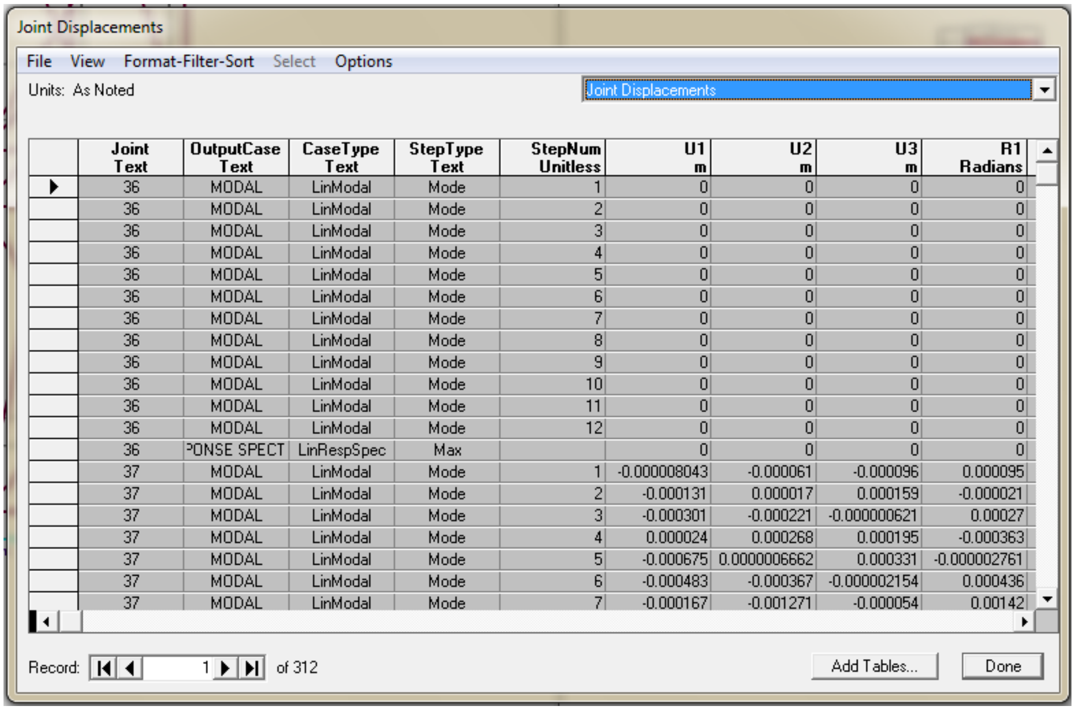


Figure 3.17 : Steel structure check

Step 7 : Analysis result table

The result table will show the analysis regarding various type of checking interested.



Joint Displacements

File View Format-Filter-Sort Select Options

Units: As Noted — Joint Displacements

Joint Text	OutputCase Text	CaseType Text	StepType Text	StepNum Unitless	U1 m	U2 m	U3 m	R1 Radians
36	MODAL	LinModal	Mode	1	0	0	0	0
36	MODAL	LinModal	Mode	2	0	0	0	0
36	MODAL	LinModal	Mode	3	0	0	0	0
36	MODAL	LinModal	Mode	4	0	0	0	0
36	MODAL	LinModal	Mode	5	0	0	0	0
36	MODAL	LinModal	Mode	6	0	0	0	0
36	MODAL	LinModal	Mode	7	0	0	0	0
36	MODAL	LinModal	Mode	8	0	0	0	0
36	MODAL	LinModal	Mode	9	0	0	0	0
36	MODAL	LinModal	Mode	10	0	0	0	0
36	MODAL	LinModal	Mode	11	0	0	0	0
36	MODAL	LinModal	Mode	12	0	0	0	0
36	PONSE SPECT	LinRespSpec	Max		0	0	0	0
37	MODAL	LinModal	Mode	1	-0.000008043	-0.000061	-0.000096	0.000095
37	MODAL	LinModal	Mode	2	-0.000131	0.000017	0.000159	-0.000021
37	MODAL	LinModal	Mode	3	-0.000301	-0.000221	-0.000000621	0.00027
37	MODAL	LinModal	Mode	4	0.000024	0.000268	0.000195	-0.000363
37	MODAL	LinModal	Mode	5	-0.000675	0.0000006662	0.000331	-0.000002761
37	MODAL	LinModal	Mode	6	-0.000483	-0.000367	-0.000002154	0.000436
37	MODAL	LinModal	Mode	7	-0.000167	-0.001271	-0.000054	0.00142

Record: 1 of 312 — Add Tables... — Done

Figure 3.18 : Table result

3.10 MANUAL CALCULATION FOR CRITICAL MEMBERS

3.10.1 Shear Resistance

All calculation can be refer to Appendices B.

i. Design Shear resistance $V_{c,Rd} = V_{pl.Rd}$

$$V_{pl.Rd} = \frac{A_v\left(f_y/\sqrt{3}\right)}{\gamma_{M0}}$$

Where

A_v = Shear area ,mm^2

f_y = yield strength , N/mm2

γ_{M0} = partial factor

ii. Allowable Shear Stress,$\sigma_{all,s}$ = $\frac{V_{c,Rd}}{A_c}$

Where

$V_{c,Rd}$ = Design shear resistance kN

A_c = Area mm^2

3.10.2 Bending Moment

All calculation can be refer to Appendices B

i. Moment resistance for cross section, $M_{c,Rd} = M_{pl.Rd}$

$$M_{c,Rd} = \frac{W_{pl}(f_y)}{\gamma_{m0}}$$

Where

W_{pl} = Plastic Modulus ,mm^3

f_y = yield strength , N/mm2

γ_{M0} = partial factor

ii. Allowable bending stress, $\sigma_{all,b} = \frac{M_{c,Rd}}{S_x}$

Where

S_x = Section Modulus ,mm^3

$M_{c,Rd}$ = Moment resistance

CHAPTER 4

RESULT & DISCUSSION

4.1 GENERAL

This chapter present the assessment of the seismic analysis of typical offshore platforms in Malaysia. This platform is fixed type offshore platform with 3-legged pile installed in 51.4 m water depth and 5.448 m above water level. For main pile ,it have outside diameter of 914 mm and wall thickness of 25 mm .There is riser and boat landing in this platform. This platform is designed without seismic code checking.

4.1.1 Design Basis

For this static and earthquake analysis, the design code referring to Eurocode 8 which cover the assessment of earthquake loading of structure. Computer software , SAP2000 is using to analysis the offshore platform model based on code design in Eurocode 8.

4.1.2 Code of Practice

Structural steel work is designed and fabricated according to Eurocode 8. In Eurocode 8 , Part 1:General Rules , Seismic Actions and Rules for Buildings ,EN1998-1:2004 is using for structural steel code check and the analysis have been performed in accordance with this specification.

4.1.3 Computer Modelling

Modelling of the model structure is using software SAP200 to analysis the static and earthquake loading. The structural steel member of this structure is modeled by using frame elements.

4.1.4 Weight

Total weight of this offshore platform structure is accordance to the drawing layout. The weight for this structure is 7.26 kN/m^2 that will be analyzed.

4.1.5 Earthquake Loading

Earthquake loading is consisted of two type seismic input ;

i. Time history
ii. Response spectrum

Time history is a common way to describe the ground motions. The motion parameters may be acceleration, velocity or displacement or all the three combined together (Datta, 2010). Usually acceleration is directly measured quantity while the other parameters are derived quantities. Response spectrum provides a convenient means to summarize the peak response of all possible linear SDF system to a particular component of ground motion (K.Chopra, 2012). There are a number of response spectra that are defined for representing the ground motion such as displacement response spectrum , absolute acceleration response spectrum and energy spectrum (Datta, 2010) .

4.2 ANALYSIS OF FIXED STEEL JACKET

For analysis, the fixed steel jacket offshore platform in 3D view is analyzed for free vibration analysis, time history and response spectrum. The analysis that involved will be consider for dead load, live load, wind load ,wave load and earthquake load.

There been a load cases that analyzed in single case to study the effect towards the structure .Among single load cases are :

i. Free vibration analysis
ii. Environmental load
iii. Response spectrum

Apart from that, load combination from load cases also been carried out. Among the load cases that been applied in this analysis are:

i. Dead load + Live load
ii. Dead load + Live load + Environmental load + Time history

The result obtained from above analysis :

i. The mode shape of the structure
ii. The natural period of the structure
iii. The shear force , bending moment , axial force and displacement under various load combination

4.3 FREE VIBRATION ANALYSIS

Free vibration is the motion of the structure without any dynamic excitation, external forces or support motion (K.Chopra, 2012) .The structure will be disturbed by some initial displacement and/or initial velocities from its equilibrium position of the structure. By carried out the free vibration analysis , natural frequency , natural period and mode shape of the structure could be obtained.

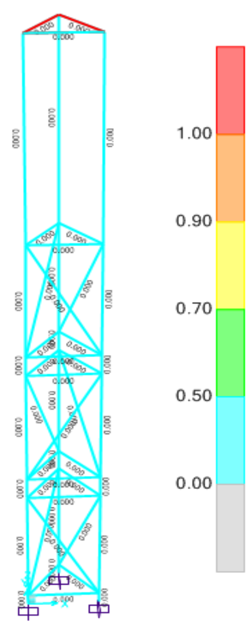


Figure 4.1 : Result free vibration analysis

Mode shape is the shape that structure that will vibrate during free motion and this same shape also happen when earthquake strike. This mode shape are orthogonal with stiffness matrix. The geometry of this structure is verify by the natural period and mode shape structure. For this analysis , the mode shape is set to have 12 modes shape. Usually, only the first few mode is giving the accurate mode shape. The result obtained shown that each structure not deflected at the same direction.

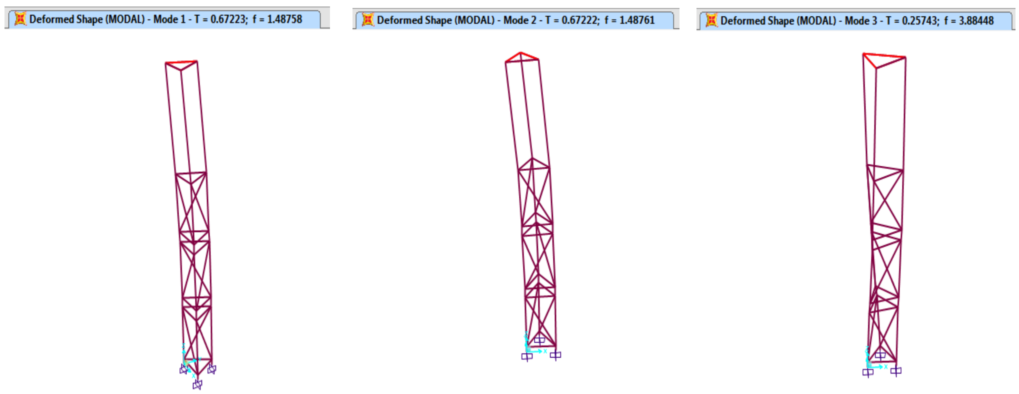


Figure 4.2 : Mode shape 1-3

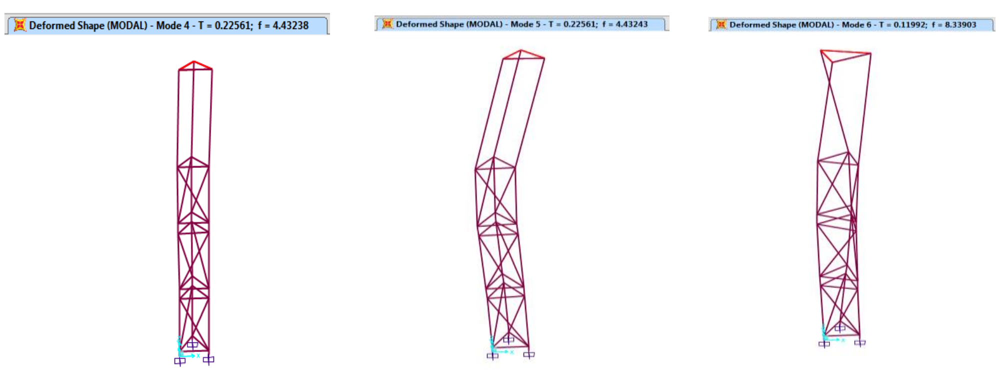


Figure 4.3 : Mode shape 4-6

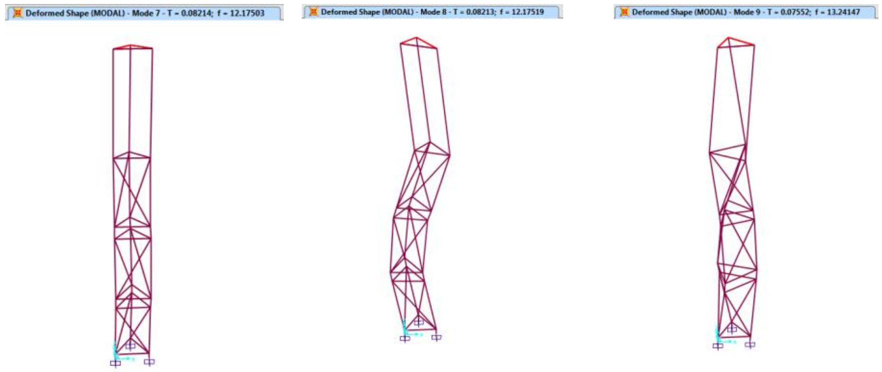


Figure 4.4 : Mode shape 7-9

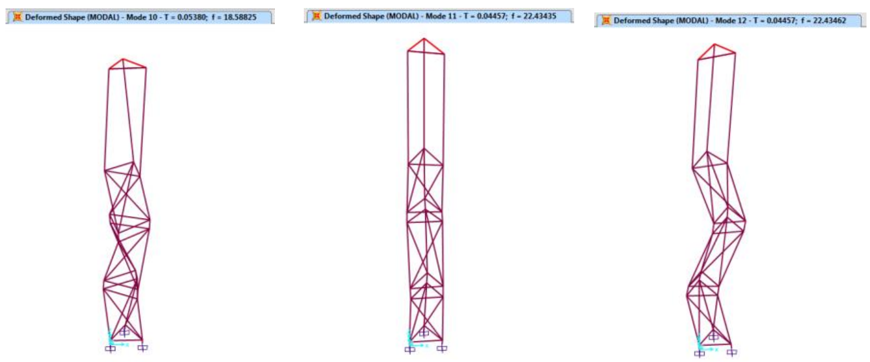


Figure 4.5 : Mode shape 9-12

Table 4.1 is the summary of the result from the analysis of free vibration analysis. The summary table provided result of period (sec) ,frequency (cyc/sec) ,circular frequency (rad/sec) and eigenvalue (rad^2/sec^2)

Table 4.1 : Result from the free vibration analysis

Output Case Text	Step Type Text	Step Num Unitless	Period Sec	Frequency Cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
MODAL	Mode	1	0.672234	1.4876	9.3467	87.361
MODAL	Mode	2	0.67222	1.4876	9.3469	87.365
MODAL	Mode	3	0.257435	3.8845	24.407	595.7
MODAL	Mode	4	0.225612	4.4324	27.849	775.59
MODAL	Mode	5	0.22561	4.4324	27.85	775.61
MODAL	Mode	6	0.119918	8.339	52.396	2745.3
MODAL	Mode	7	0.082135	12.175	76.498	5851.9
MODAL	Mode	8	0.082134	12.175	76.499	5852.1
MODAL	Mode	9	0.07552	13.241	83.199	6922
MODAL	Mode	10	0.053797	18.588	116.79	13641
MODAL	Mode	11	0.044575	22.434	140.96	19869
MODAL	Mode	12	0.044574	22.435	140.96	19870

From the free vibration analysis , the highest time period is 0.672234 second from mode shape 1.

4.4 WIND + WAVE + CURRENT (ENVIRONMENTAL LOAD)

Below shows the result of the linear analysis of the environmental load, wind + wave + current . The result is divided into several colors which depending on the ratio steel strength obtained to determine the level of strength steel structure. The higher the ratio of steel strength obtained , the less safe the steel structure will be .For my analysis of environmental load , the colors shown is green which determine the structure is safe with the highest ratio steel of 0.66.

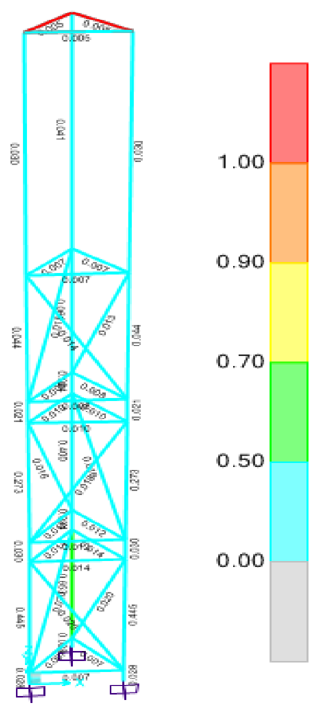


Figure 4.6: Design output for environmental load

From the critical member ,frame id 86 (1828x50) which ratio 0.653 , we found out the maximum shear and moment. The maximum shear obtain is 4.209E-03kN ,maximum moment is 0.1177 kN.m. The deflection for critical member is 5.872E-08m

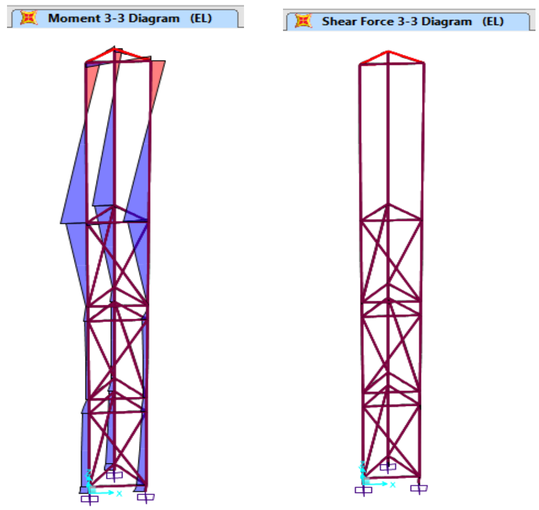


Figure 4.7 : The member moment and shear diagram

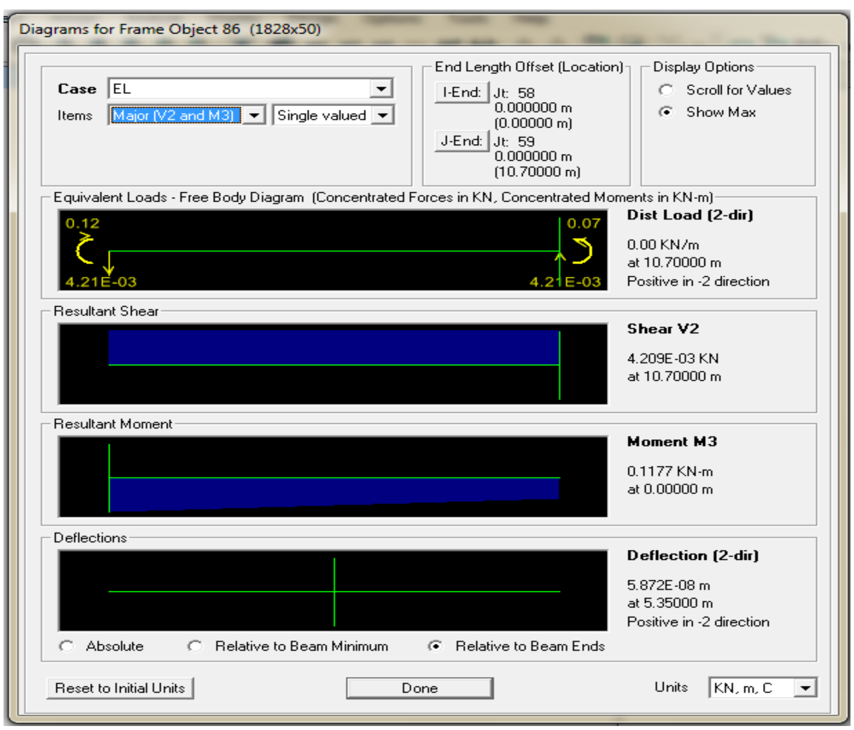


Figure 4.8 : The display result of critical member for environmental load

Based on figure 4.17 , the shear stress and allowable stress for frame 86 can be calculated. All calculation can be refer in the Appendix C.

Shear resistance of frame 86 :

i. Maximum design shear force ,Ved = 4.209x 10^{-3} kN
ii. Shear resistance of frame 86 Vcrd = 36442 kN
iii. Shear Stress, σ_s = 0.015 kN/m^2
iv. Allowable Shear Stress,$\sigma_{all,s}$ = 130616 kN/m^2

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

Bending Resistance of frame 86 :

i. Maximum design bending moment ,Med = 0.1177 kN.m
ii. Moment resistance of frame 86 Mcrd = 56090 kN.m
iii. Bending stress, σ_b= 0.745 kNm^2
iv. Allowable bending stress, $\sigma_{all,b}$= 355000kNm^2

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

Table 4.2 : The maximum shear force and shear stress for environmental load

Frame name	**Design shear force , V_{Ed} (kN)**	**Shear Resistance $V_{c,Rd}$ (kN)**	**Shear stress , σ_s(kN/m^2)**	**Allowable shear stress, $\sigma_{all,s}$(kN/m^2)**
86	0.004209	36442	0.015	130616

Table 4.3 : The maximum bending moment and bending stress for environmental load

Frame name	**Design Moment M_{Ed} (kNm)**	**Moment Resistance $M_{c,Rd}$ (kN)**	**Bending stress , σ_b(kN/m^2)**	**Allowable bending stress, $\sigma_{all,b}$(kN/m^2)**
86	0.1177	56090	0.745	355000

4.5 RESPONSE SPECTRUM ANALYSIS

Below shows the result of the response spectrum analysis. The result is divided into several colors which depending on the ratio steel strength obtained to determine the level of strength steel structure.For my analysis of response spectrum , the colors shown is green which determine the structure is safe with the highest ratio steel of 0.66.

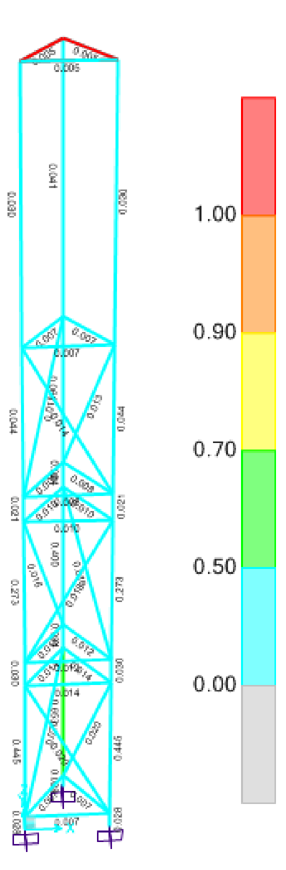


Figure 4.9 : Design output for response spectrum

From the critical member ,frame id 86 (1828x50) which ratio 0.66 , we found out the maximum shear and moment. The maximum shear obtain is 0.144kN ,maximum moment is 2.5977 kN.m.

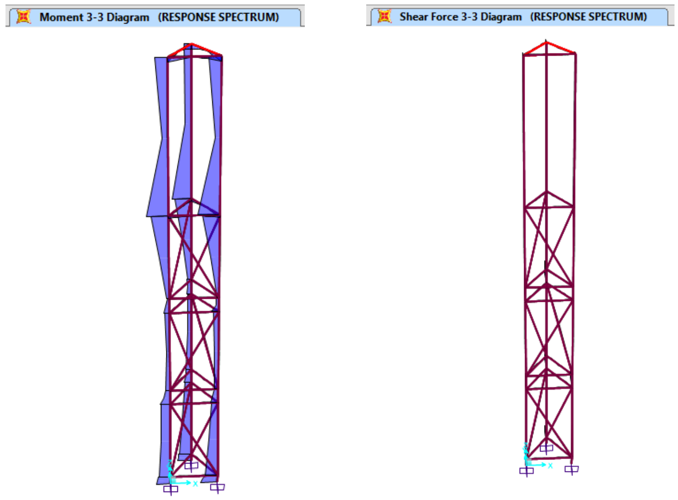


Figure 4.10: The member moment and shear diagram

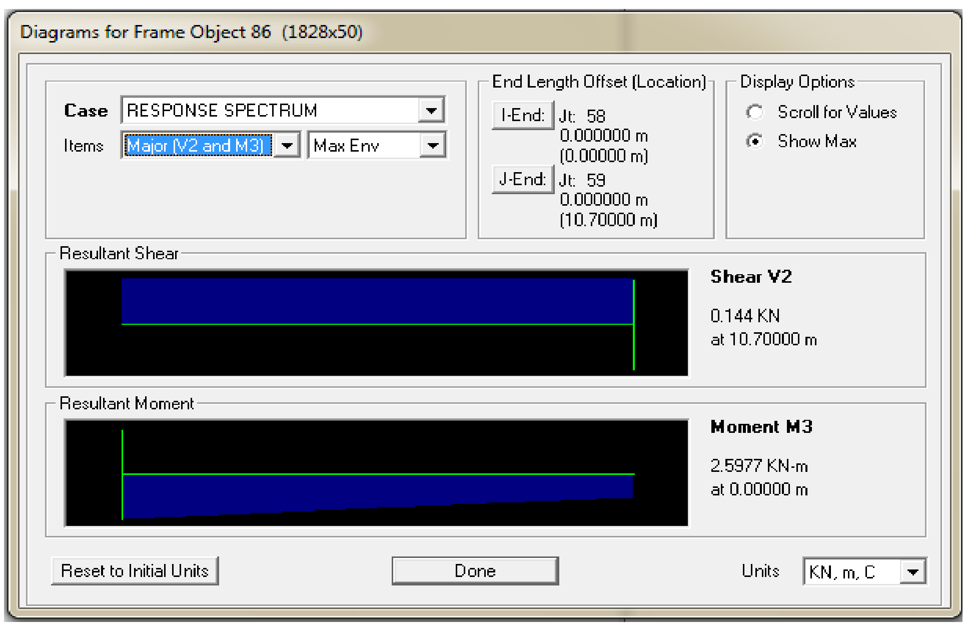


Figure 4.11 : The display result of critical member for response spectrum

Based on figure 4.17 , the shear stress and allowable stress for frame 86 can be calculated. All calculation can be refer in the Appendix D.

Shear resistance of frame 86 :

i. Maximum design shear force ,Ved = 0.144 kN
ii. Shear resistance of frame 86 Vcrd = 36442 kN
iii. Shear Stress, σ_s = 0.52 kN/m^2
iv. Allowable Shear Stress,$\sigma_{all,s}$ = 130616 kN/m^2

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

Bending Resistance of frame 86 :

i. Maximum design bending moment ,Med = 2.5977 kN.m.
ii. Moment resistance of frame 86 Mcrd = 56090 kN.
iii. Bending stress, σ_b= 16.44 kNm^2
iv. Allowable bending stress, $\sigma_{all,b}$= 355000 kNm^2

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

Table 4.4 : The maximum shear force and shear stress for response spectrum

Frame name	**Design shear force , V_{Ed} (kN)**	**Shear Resistance $V_{c,Rd}$ (kN)**	**Shear stress , σ_s(kN/m^2)**	**Allowable shear stress, $\sigma_{all,s}$(kN/m^2)**
86	0.144	36442	0.52	130616

Table 4.5 : The maximum bending moment and bending stress for response spectrum

Frame name	**Design Moment M_{Ed} (kNm)**	**Moment Resistance $M_{c,Rd}$ (kN)**	**Bending stress , σ_b(kN/m^2)**	**Allowable bending stress, $\sigma_{all,b}$(kN/m^2)**
86	2.5977	56090	16.44	355000

4.6 DEAD LOAD + LIVE LOAD

Below shows the result of the combination dead and live load analysis. The result is divided into several colors which depending on the ratio steel strength obtained to determine the level of strength steel structure. For my analysis of combination dead and live load, the colors shown is green which determine the structure is safe with the highest ratio steel of 0.66.

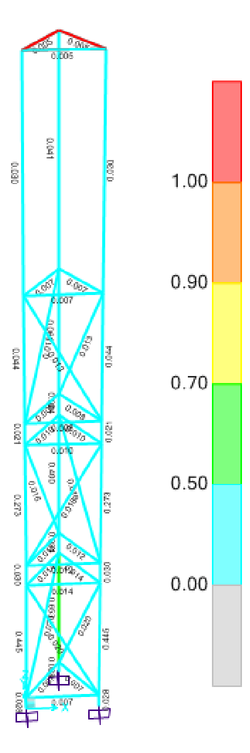


Figure 4.12 : Design output for dead load + live load

From the critical member ,frame id 86 (1828x50) which ratio 0.66 , we found out the maximum shear and moment. The maximum shear obtain is 6.980kN ,maximum moment is 45.4920 kN.m. The deflection obtained at critical member is 5.028E-06m

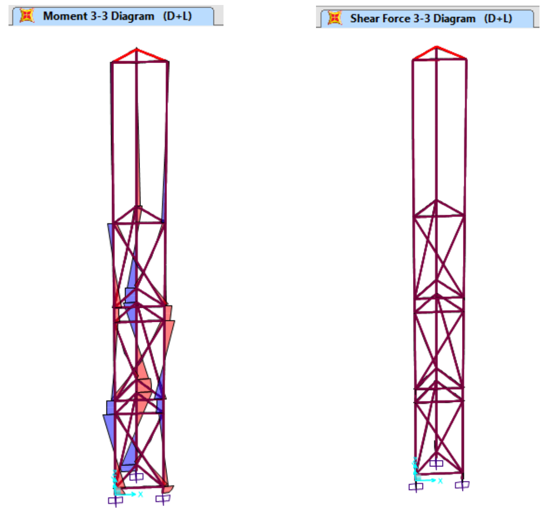


Figure 4.13 : The member moment and shear diagram

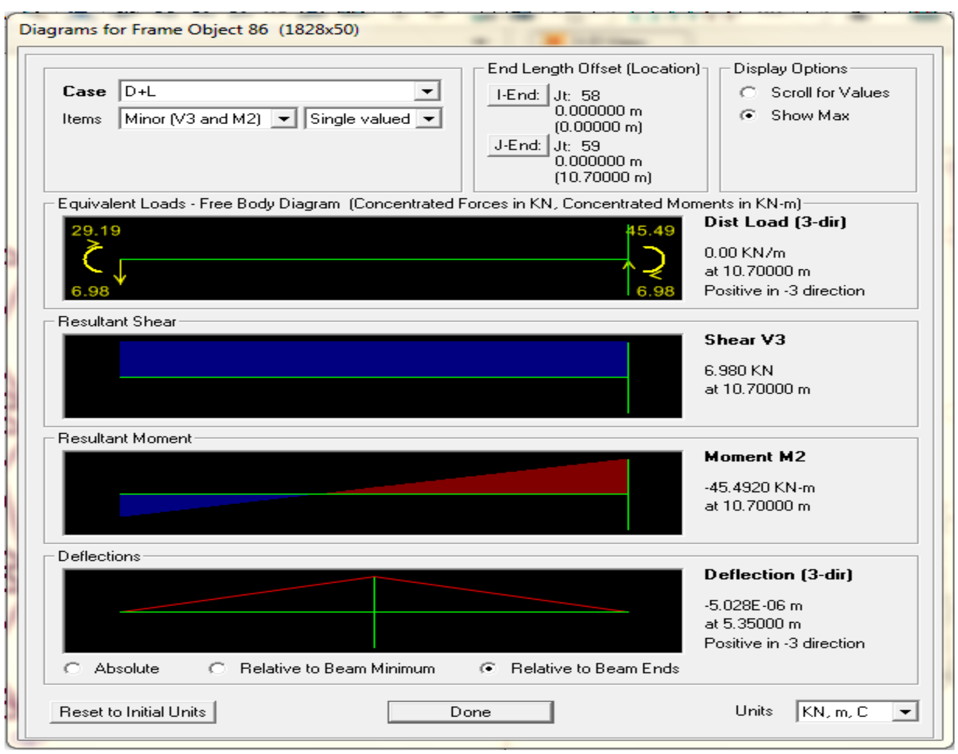


Figure 4.14 The display result of critical member for dead + live load

Based on figure 4.17 , the shear stress and allowable stress for frame 86 can be calculated. All calculation can be refer in the Appendix E.

Shear resistance of frame 86 :

i. Maximum design shear force ,Ved = 6.98 kN
ii. Shear resistance of frame 86 Vcrd = 36442 kN
iii. Shear Stress, σ_s = 25.02 kN/m^2
iv. Allowable Shear Stress,$\sigma_{all,s}$ = 130616 kN/m^2

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

Bending Resistance of frame 86 :

i. Maximum design bending moment ,Med = 45.492 kN.m
ii. Moment resistance of frame 86 Mcrd = 56090 kN.m.
iii. Bending stress, σ_b= 287.924 kN/m^2.
iv. Allowable bending stress, $\sigma_{all,b}$= 355000 kN/m^2.

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

Table 4.6 : The maximum shear force and shear stress for dead + live load

Frame name	**Design shear force , V_{Ed} (kN)**	**Shear Resistance $V_{c,Rd}$ (kN)**	**Shear stress , σ_s(kN/m^2)**	**Allowable shear stress, $\sigma_{all,s}$(kN/m^2)**
86	6.98	36442	25.02	130616

Table 4.7 : The maximum bending moment and bending stress for dead + live load

Frame name	**Design Moment M_{Ed} (kNm)**	**Moment Resistance $M_{c,Rd}$ (kN)**	**Bending stress , σ_b(kN/m^2)**	**Allowable bending stress, $\sigma_{all,b}$(kN/m^2)**
86	45.492	56090	287.924	355000

4.7 DEAD LOAD + LIVE LOAD + ENVIRONMENTAL LOAD + TIME HISTORY

Below shows the result of the combination of dead ,live ,environmental load and time history analysis. The result is divided into several colors which depending on the ratio steel strength obtained to determine the level of strength steel structure .For my analysis of combination dead ,live, environmental load and time history, the colors shown is green which determine the structure is safe with the highest ratio steel of 0.66.

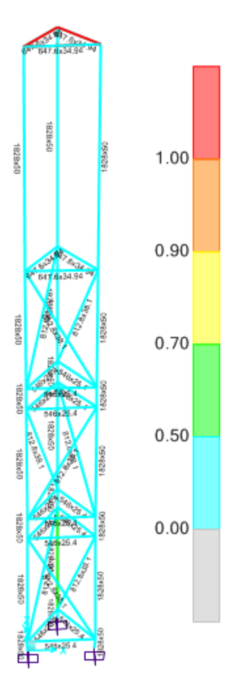


Figure 4.15: Design output for dead + live + environmental load + time history

From the critical member ,frame id 86 (1828x50) which ratio 0.66 , we found out the maximum shear and moment. The maximum shear obtain is 36.926kN ,maximum moment is 204.2667 kN.m.

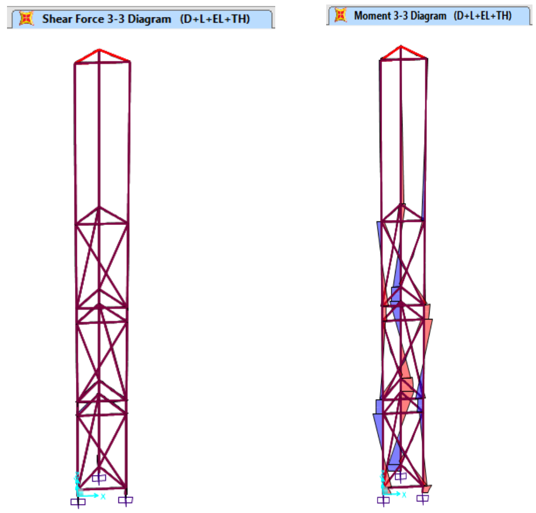


Figure 4.16 : The member moment and shear diagram

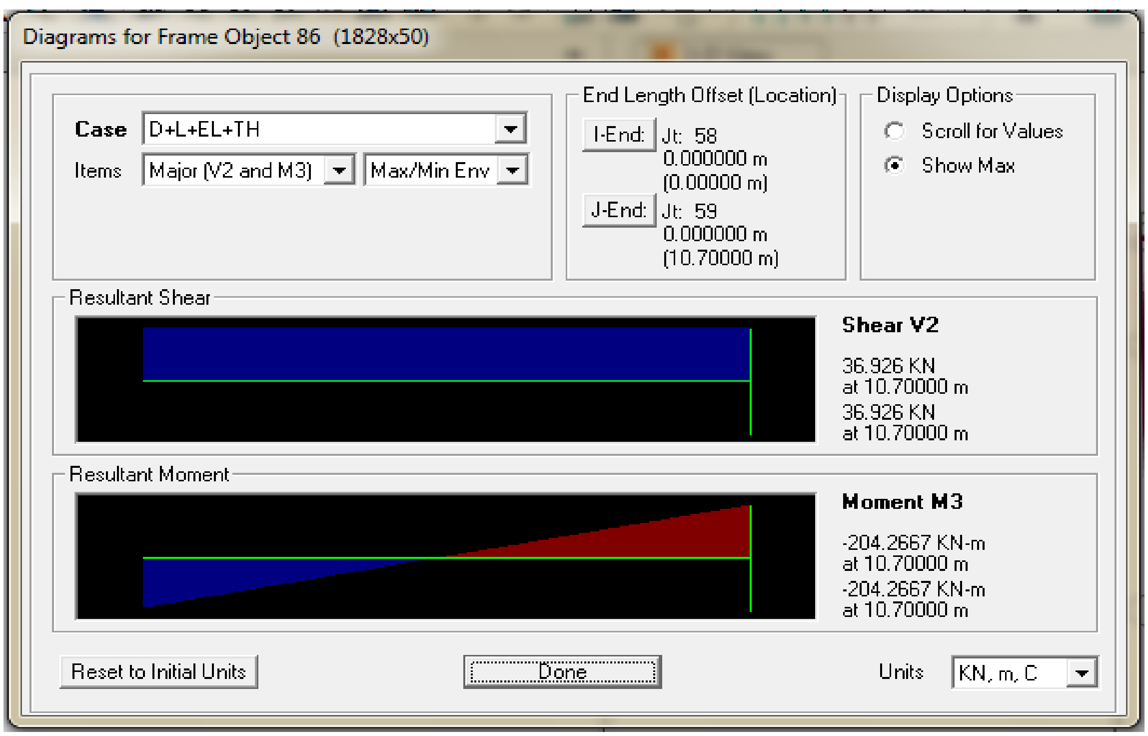


Figure 4.17 : The display result of critical member for combination dead ,live, environmental load and time history

Based on figure 4.17 , the shear stress and allowable stress for frame 86 can be calculated. All calculation can be refer in the Appendix F.

Shear resistance of frame 86 :

i. Maximum design shear force ,Ved = 36.926kN
ii. Shear resistance of frame 86 Vcrd = 36442 kN
iii. Shear Stress, σ_s = 132.35 kN/m^2
iv. Allowable Shear Stress,$\sigma_{all,s}$ = 130616 kN/m^2

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

Bending Resistance of frame 86 :

i. Maximum design bending moment ,Med = 204.267 kN.m
ii. Moment resistance of frame 86 Mcrd = 56090 kN.
iii. Bending stress, σ_b= 1293 kN/m^2.
iv. Allowable bending stress, $\sigma_{all,b}$= 355000 kN/m^2.

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

Table 4.8: The maximum shear force and shear stress for combination dead ,live, environmental load and time history

Frame name	**Design shear force , V_{Ed} (kN)**	**Shear Resistance $V_{c,Rd}$ (kN)**	**Shear stress , σ_s(kN/m^2)**	**Allowable shear stress, $\sigma_{all,s}$(kN/m^2)**
86	36.926	36442	132.35	130616

Table 4.9: The maximum bending moment and bending stress for combination dead ,live, environmental load and time history

Frame name	**Design Moment M_{Ed} (kNm)**	**Moment Resistance $M_{c,Rd}$ (kN)**	**Bending stress , σ_b(kN/m^2)**	**Allowable bending stress, $\sigma_{all,b}$(kN/m^2)**
86	204.267	56090	1293	355000

4.8 SHEAR FORCE AND SHEAR STRESS

Table 4.10 : The shear force and shear stress for each load combination cases

Case	Design shear force ,Ved (kN)	Shear resistance ,Vcrd (kN)	Shear stress , σ_s(kN/m^2)	Allowable shear stress, $\sigma_{all,s}$(kN/m^2)
EL	4.209×10^{-3}	36442	0.015	130616
RS	0.144	36442	0.52	130616
D+L	6.98	36442	25.02	130616
D+L+EL+TH	36.926	36442	132.35	130616

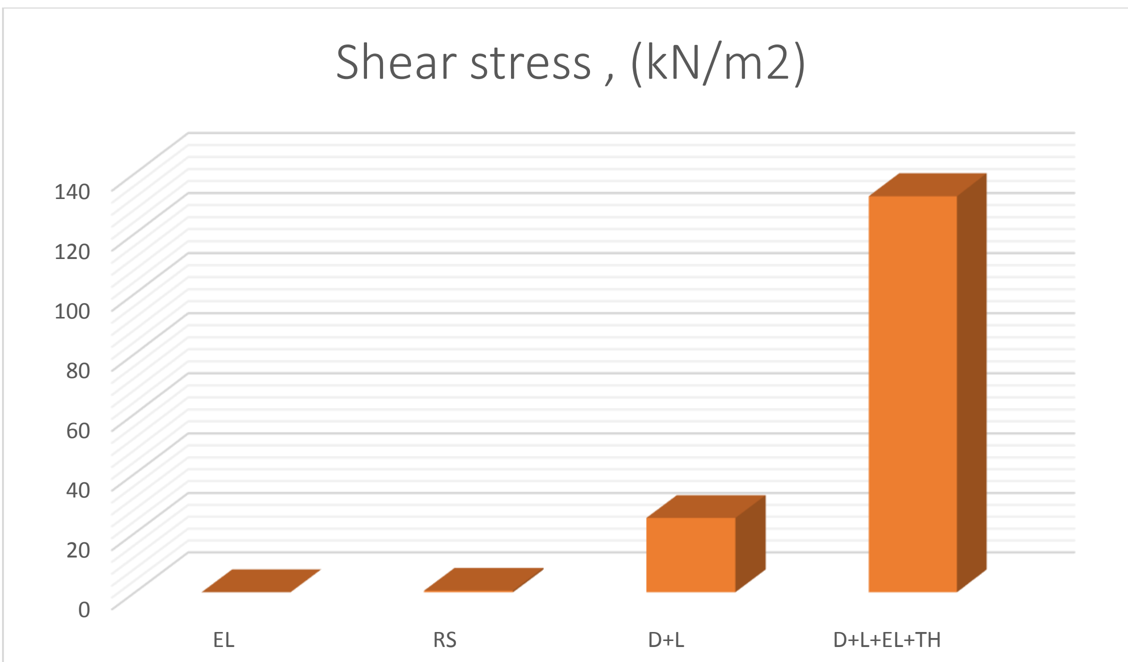


Figure 4.18 : Graph of shear stress versus load combination cases

From the figure , it shown that the highest shear stress is from the combination of dead ,live, environmental load and time history which is 132.35(kN/m^2). Following by the combination dead and live load, 25.02(kN/m^2) ,response spectrum 0.144(kN/m^2) and environmental load 4.209 X 10^{-3}(kN/m^2). The allowable shear stress which is 130616(kN/m^2) which is much higher than shear stress value thus make the offshore jacket platform is safe .

4.9 BENDING MOMENT AND BENDING STRESS

Table 4.11 : The bending moment and bending stress for each load combination cases

Case	**Design moment, M_{ed} (kNm)**	**Moment resistance, M_{rd} (kNm)**	**Bending stress, σ_b (kN/m^2)**	**Allowable bending stress, $\sigma_{all,b}$ (kN/m^2)**
EL	0.1177	56090	0.745	355000
RS	2.5977	56090	16.44	355000
D+L	45.492	56090	287.924	355000
D+L+EL+TH	204.267	56090	1293	355000

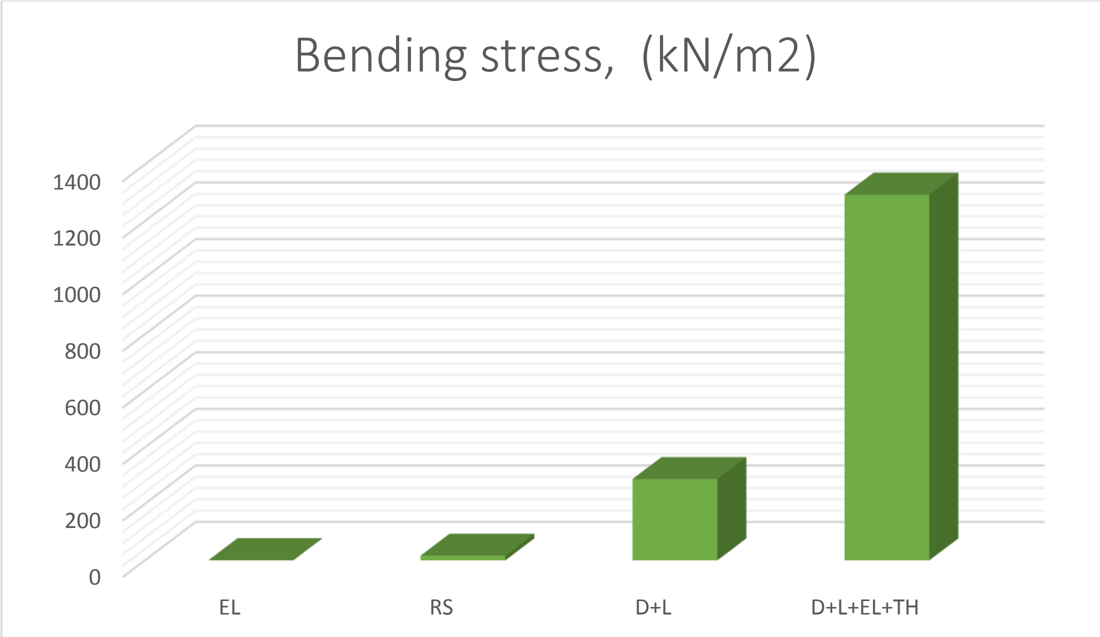


Figure 4.19 : Graph of bending stress versus load combination cases

From the figure , it shown that the highest bending stress is from the combination of dead ,live, environmental load and time history which is 1293 (kN/m^2). Following by the combination dead and live load, 287.924 (kN/m^2) ,response spectrum 16.44 (kN/m^2) and environmental load 0.745 (kN/m^2). The allowable bending stress , 355000 (kN/m^2) which is much higher than shear stress value thus make the offshore jacket platform is safe .

4.10 JOINT DISPLACEMENT

Table 4.12 : The joint displacement for each load combination cases

Cases	EL	RS	D+L	D+L+EL+TH
Maximum Value (m)	2.723E-07	0.000005113	0.000755	0.000756

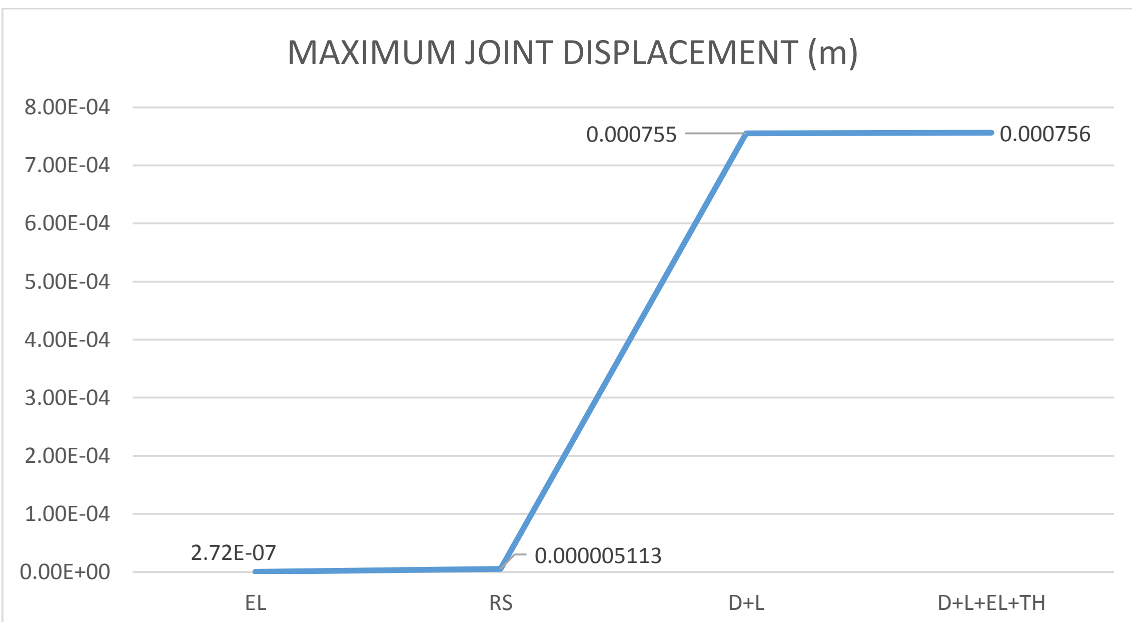


Figure 4.20 : Joint displacement versus each combination load cases

From the figure, it shown that the larger joint displacement occur when combination of dead , live , environmental load and time history cases which is 0.756 mm. While for the smallest joint displacement is 2.72×10^{-7}mm for the cases of environmental load .

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Based on this research , several conclusions can be made which are :

1. The analysis made is not accurately similar with actual fixed offshore platform. This is due to the several assumptions that have been made which are :
    i. The soil interaction is neglected for this model analysis. Suppose the support of structure is piled with soil interaction, thus make soil interaction also important to considered in design
    ii. The model is not designed with joint connection (welded connection) based on EuroCode 3.The joint connection is important part in steel structure.

2. The highest time period of free vibration analysis is 0.672234 second from mode shape 1.

3. The maximum shear stress is 132.35 kN/m^2 from the load combination of dead , live, environmental load and time history. The structure is safe due to the larger allowable shear stress which is 130616 kN/m^2.

4. The maximum bending stress is 1293 kN/m^2 from the load combination of dead , live, environmental load and time history. The structure is safe due to the larger allowable bending stress which is 355000 kN/m^2.

5. The maximum displacement is 0.756 mm when the load combination of dead , live, environmental load and time history.

5.2 RECOMMENDATIONS

For the future study , this model should be designed accurately with the actual jacket offshore platform structure . The model have to considered the soil interaction with support structure. Thus this will result in more accurate analysis between the model and structure in actual soil.

In addition , other recommendation is joint connection should be considered in the model analysis. The joint connection of welded connection which based on EuroCode 3 is important in designing the steel structure. The joint connection is play an important role also in ensuring the safeness of steel structure.

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APPENDICES A

Table of stiffness of horizontal member

Level	Modulus of Elasticity ,E	Vertical Member (mm)	Size CHS	Outer Diameter ,d0	Inner Diamter ,di	Inertia ,I	Stiffnes ,K
1	210,000	1000	914x 25	914	889	3597550419	7.55486E +11
2	210,000	10700	914x 25	914	889	3597550419	70606129 726
3	210,000	1905	914x 25	914	889	3597550419	3.9658E+ 11
4	210,000	10700	914x 25	914	889	3597550419	70606129 726
5	210,000	1905	914x 25	914	889	3597550419	3.9658E+ 11
6	210,000	10700	914x 25	914	889	3597550419	70606129 726
7	210,000	18938	914x 25	914	889	3597550419	39892575 144
						TOTAL	1.80036E +12

Table of stiffness of vertical member

Level	Modulus of Elasticity ,E	Vertical Member (mm)	Size CHS	Outer Diameter ,d0	Inner Diamter ,di	Inertia ,I	Stiffnes ,K
1	210,000	1000	914x25	914	889	3597550419	7.55486E+11
2	210,000	10700	914x25	914	889	3597550419	70606129726
3	210,000	1905	914x25	914	889	3597550419	3.9658E+11
4	210,000	10700	914x25	914	889	3597550419	70606129726
5	210,000	1905	914x25	914	889	3597550419	3.9658E+11
6	210,000	10700	914x25	914	889	3597550419	70606129726
7	210,000	18938	914x25	914	889	3597550419	39892575144
						TOTAL	1.80036E+12

APPENDICES B

MANUAL CALCULATION FOR CRITICAL MEMBERS

Shear Resistance

i) Design Shear resistance $V_{c,Rd} = V_{pl.Rd}$

$$V_{pl.Rd} = \frac{A_v({f_y}/{\sqrt{3}})}{\gamma_{M0}}$$

Where

A_v = Shear area ,mm^2

f_y = yield strength , N/mm2

γ_{M0} = partial factor

$$V_{pl.Rd} = \frac{177800\ ({355}/{\sqrt{3}})}{1.0} = 36442 \text{ kN}$$

ii) Allowable Shear Stress,$\sigma_{all,s} = \frac{V_{c,Rd}}{A_c}$

Where

$V_{c,Rd}$ = Design shear resistance kN

A_c = Area mm^2

$$\sigma_{all,s} = \frac{3.648 \times 10^3}{279287.584} = 130.75 \text{ kN/mm}^2$$

Bending Moment

i) Moment resistance for cross section, $M_{c,Rd} = M_{pl.Rd}$

$M_{c,Rd} = \frac{W_{pl}(f_y)}{\gamma_{m0}}$

Where

W_{pl} = Plastic Modulus ,mm^3

f_y = yield strength , N/mm2

γ_{M0} = partial factor

$M_{c,Rd} = \frac{W_{pl}(f_y)}{\gamma_{m0}} \frac{158 \times 10^6 (355)}{1.0} = 56090\ kNm$

ii) Allowable bending stress, $\sigma_{all,b} = \frac{M_{c,Rd}}{S_x}$

Where

S_x = Section Modulus ,mm^3

$M_{c,Rd}$ = Moment resistance

$\sigma_{all,b} = \frac{56090 kNm}{0.158 m^3}$ =355000kN/m^2.

APPENDICES C

WIND + WAVE + CURRENT (ENVIRONMENTAL LOAD)

Shear resistance of frame 86 :

i. Maximum design shear force ,Ved = 4.209x 10^{-3} kN
ii. Shear resistance of frame 86 Vcrd = 36442 kN

Design check:

$\frac{V_{Ed}}{V_{c,Rd}} = \frac{0.004209\ kN}{36442kN}$ = 1.15 x $10^{-7} \leq$ 1.0, the section is satisfactory.

i) Shear Stress, $\sigma_s = \frac{V_{ED}}{A_c} = \frac{0.004209}{0.279}$ = 0.015 kN/m^2

ii) Allowable Shear Stress,$\sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{36442}{0.279}$ = 130616 kN/m ^{2}

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

The shear stress is 0.015 kN/m^2 and the allowable shear stress is 130.62 kN/m ^{2}

Bending Resistance of frame 86 :

i) Maximum design bending moment ,Med = 0.1177 kN.m

ii) Moment resistance of frame 86 Mcrd = 56090 kN.m

Design check:

$\frac{\text{Med}}{M_{c,Rd}} = \frac{0.1177\ kNm}{56090\ \text{kN.m}}$ = 2.1 x $10^{-6} \leq$ 1.0, the section is satisfactory.

Bending stress, $\sigma_b = \frac{M_{Ed}}{S_x} = \frac{0.1177\ kNm}{0.158\ m^3} = 0.745\ kNm^2$

Allowable bending stress, $\sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{56090\ \text{kNm}}{0.158\ m^3} = 355000 kNm^2$

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

The bending stress is 0.745 kN/m^2 and allowable bending stress is 355000kN/m^2.

APPENDICES D

RESPONSE SPECTRUM ANALYSIS

Shear resistance of frame 86 :

i) Maximum design shear force ,Ved = 0.144 kN

ii) Shear resistance of frame 86 Vcrd = 36442 kN

Design check:

$\frac{V_{Ed}}{V_{c,Rd}} = \frac{0.144\ kN}{36442kN}$ = 3.95 x $10^{-6} \leq$ 1.0, the section is satisfactory.

i) Shear Stress, $\sigma_s = \frac{V_{ED}}{A_c} = \frac{0.144}{0.279}$ = 0.52 kN/m^2

ii) Allowable Shear Stress,$\sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{36442}{0.279}$ = 130616 kN/m^2

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

The shear stress is 0.52 kN/m^2 and the allowable shear stress is 130616 kN/m^2

Bending Resistance of frame 86 :

i) Maximum design bending moment ,Med = 2.5977 kN.m.

ii) Moment resistance of frame 86 Mcrd = 56090 kN.m

Design check:

$\frac{\text{Med}}{M_{c,Rd}} = \frac{2.5977\ kNm}{56090kNm}$ = 4.63 x $10^{-5} \leq 1.0$, the section is satisfactory.

Bending stress, $\sigma_b = \frac{M_{Ed}}{S_x} = \frac{2.5977\ kNm}{0.158m^3}$ = 16.44 kNm^2

Allowable bending stress, $\sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{56090kNm}{0.158m^3}$ = 355000 kNm^2

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

The bending stress is 16.44 kN/m^2 and allowable bending stress is 355000kN/m^2.

APPENDICES E

DEAD LOAD + LIVE LOAD ANALYSIS

Shear resistance of frame 86 :

i) Maximum design shear force ,Ved = 6.98 kN
ii) Shear resistance of frame 86 Vcrd = 36442 kN

Design check:

$\frac{V_{Ed}}{V_{c,Rd}} = \frac{6.98\ kN}{36442kN}$ = 1.92 x $10^{-4} \leq 1.0$, the section is satisfactory.

i) Shear Stress, $\sigma_s = \frac{V_{ED}}{A_c} = \frac{6.98}{0.279}$ = 25.02 kN/m^2

ii) Allowable Shear Stress,$\sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{36442}{0.279}$ = 130616 kN/m^2

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

The shear stress is 25.02 kN/m^2 and the allowable shear stress is 130616 kN/m^2

Bending Resistance of frame 86 :

i) Maximum design bending moment ,Med = 45.492 kN.m.
ii) Moment resistance of frame 86 Mcrd = 56090 kN.m

Design check:

$\frac{\text{Med}}{M_{c,Rd}} = \frac{45.492\ kNm}{56090kNm}$ = 8.11 x $10^{-4} \leq 1.0$, the section is satisfactory.

Bending stress, $\sigma_b = \frac{M_{Ed}}{S_x} = \frac{45.492\ kNm}{0.158m^3}$ = 287.924 kN/m^2.

Allowable bending stress, $\sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{56090kNm}{0.158m^3}$ = 355000 kN/m^2.

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

The bending stress is 287.924 kN/m^2 and allowable bending stress is 355000 kN/m^2.

APPENDIX F

DEAD LOAD + LIVE LOAD + ENVIRONMENTAL LOAD + TIME HISTORY

Shear resistance of frame 86 :

i) Maximum design shear force ,Ved = 36.926kN
ii) Shear resistance of frame 86 Vcrd = 36442 kN

Design check:

$\frac{V_{Ed}}{V_{c,Rd}} = \frac{36.926\ kN}{36442kN}$ = 1.01 x $10^{-3} \leq$ 1.0, the section is satisfactory.

i) Shear Stress, $\sigma_s = \frac{V_{ED}}{A_c} = \frac{36.926}{0.279}$ = 132.35 kN/m^2
ii) Allowable Shear Stress,$\sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{36442}{0.279}$ = 130616 kN/m ^{2}

Therefore, $\sigma_s \leq \sigma_{all,s}$, the section is satisfactory.

The shear stress is 25.02 kN/m^2 and the allowable shear stress is 130616 kN/m ^{2}

Bending Resistance of frame 86 :

i) Maximum design bending moment ,Med = 204.267 kN.m
ii) Moment resistance of frame 86 Mcrd = 56090 kN.m

Design check:

$\frac{\text{Med}}{M_{c,Rd}} = \frac{204.267\ kNm}{56090kNm}$ = 3.64 x $10^{-3} \leq$ 1.0, the section is satisfactory.

Bending stress, $\sigma_b = \frac{M_{Ed}}{S_x} = \frac{204.267\ kNm}{0.158m^3}$ =1293 kN/m^2.

Allowable bending stress, $\sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{56.09kNm}{0.158m^3}$ = 355000 kN/m^2.

Therefore, $\sigma_b \leq \sigma_{all,b}$, the section is satisfactory.

The bending stress is kN/m^2 and allowable bending stress is 355000kN/m^2.

APPENDICES G

ENVIRONMENTAL LOADS

1. Wind loads

$$F = \left(\frac{\rho}{2}\right) u^2 C_s A$$

$$F = \left(\frac{1.2\ kg/m^3}{2}\right)\left(21.8\,\frac{m}{s}\right)^2 (1.0)(\pi\,\frac{0.3238^2}{4})$$

$$F = 23.4805\ N$$

2. Wave Action

Rough condition , *Cd* = 1.05, *Cm* = 1.2 :

$$F = 1.05\,\frac{\frac{9810\ N}{m^3}}{2\left(\frac{9.81m}{s^2}\right)}(0.3238m^2)\left(\frac{0.75\text{m}}{\text{s}}\right)|0.75| + 1.2\,\frac{\frac{9810\ N}{m^3}}{\left(\frac{9.81m}{s^2}\right)}0.0823m^2(5.01 \times \frac{10^{-9}m}{s^2})$$

$$F = 95.622 + 4.948 \times 10^{-7}$$

$$F = 95.622\text{N/m}$$

Smooth Condition , *Cd* = 0.65, *Cm* = 1.6:

$$F = 0.65 \frac{\frac{9810\ N}{m^3}}{2\left(\frac{9.81m}{s^2}\right)}(0.3238m^2)\left(\frac{0.75\text{m}}{\text{s}}\right)|0.75| + 1.6\frac{\frac{9810\ N}{m^3}}{\left(\frac{9.81m}{s^2}\right)}0.0823m^2(5.01 \times \frac{10^{-9}m}{s^2})$$

$$F = 59.1947 + 6.5972e^{-7}$$

$$F = 59.1947\ \text{N/m}$$

3. Current loading

$$F = 1.05 \frac{\frac{9810\ N}{m^3}}{2\left(\frac{9.81m}{s^2}\right)}(0.0823m^2)\left(\frac{0.75\text{m}}{\text{s}}\right)|0.75|$$

$$F = 24.3042\ N/m$$