

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

SOLIHAN BINTI A. AZIZ

B.ENG (HONS.) CIVIL ENGINEERING  
UNIVERSITI MALAYSIA PAHANG

## UNIVERSITI MALAYSIA PAHANG

### DECLARATION OF THESIS AND COPYRIGHT

Author's full name : SOLIAH BINTI A. AZIZ  
Date of birth : 14 JULY 1992  
Title : SEISMIC RESPONSE OF A TYPICAL 3-LEGGED JACKET  
OF FIXED OFFSHORE PLATFORM IN MALAYSIA DUE  
TO PHILIPPINES EARTHQUAKE  
Academic Session : 2014/2015

I declare that this thesis is classified as :

- ☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)\*
- ☐ **RESTRICTED** (Contains restricted information as specified by the organization where research was done)\*
- ☒ **OPEN ACCESS** I agree that my thesis to be published as online open access (Full text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

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

Certified By:

\_\_\_\_\_  
(Student's Signature)

920714-11-5304

New IC / Passport Number

Date : 30 JUNE 2015

\_\_\_\_\_  
(Signature of Supervisor)

IR. SAFFUAN BIN WAN AHMAD

Name of Supervisor

Date : 30 JUNE 2015

### NOTES :

\*If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

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

SOLIHAN BINTI A. AZIZ

Thesis submitted in fulfilment of the requirements  
for the award of the degree of  
B.Eng (Hons.) 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.).

Signature :  
Name of Supervisor : IR. SAFFUAN BIN WAN AHMAD  
Position : LECTURER  
Date : 30 JUNE 2015

### **STUDENT'S DECLARATION**

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :  
Name : SOLIHAN BINTI A. AZIZ  
ID Number : AA11024  
DATE : 30 JUNE 2015

**Dedicated to my parents  
for their love and supports**

## ACKNOWLEDGEMENTS

First and foremost, I would like to express the gratitude to Allah S.W.T for giving an opportunity to complete this thesis. I would like to thanks my supervisor, Ir Saffuan bin Wan Ahmad for his great ideas, invaluable guiding, encouragement and constant supports besides always be patient with me all the time in making this research possible. I am really appreciates for his entire kindness and helping while complete this thesis. The knowledge and experience that I gain from you are very valuable. Without their guidance and help, I may not be able to complete this project.

My sincere thanks go to all my lecturers during my degree studies as the knowledge covers the theoretical and practical in civil engineering fields. Thank you to all because always allowing me to questions them and they are always giving prompt replies.

Many special thanks to all my friends, Lim Jia Jun, Nurul Nabila bt Fazilan, Low Yee Hwa and Hong Jia Hi who helped me in many ways and sharing the knowledge together.

Last but not least, I would like to give special thanks to my family members especially my mother, Puan Khatijah bt Abd. Rahman and my father, En A. Aziz bin Embong for their support in completing this thesis. Thank you again to all of them.

## ABSTRACT

The offshore structural design practice in Malaysia only focus more on wind and wave effects analysis rather than seismic effect. At the east of Malaysia, the Philippine plate moves westward with an estimate velocity of 80mm/year and cause micro faults in Sabah. Thus, this thesis develops the earthquake ground motion due to Philippine earthquake for assessment of offshore platform in Malaysia. Besides, the adequacy of existing design of offshore platform in Malaysia is determined when subjected to earthquake loading. The analysis of behavior of the offshore platform structures of 3-legged fixed offshore structures under the earthquake effect is obtained to develop the earthquake design criteria for the offshore structures that are located in Malaysia region. The assessment of fixed offshore structure also covers the static and dynamic for the earthquake analysis by using the code of practice of "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms (API RP-2A, 2000). As for designing the offshore platform, this analysis is considering the dead load, live load, environmental loads (wind, wave and current load) and earthquake load such that free vibration, time history and response spectrum. The SAP 2000 computer program has been used to check the steel structure based on Eurocode 3, 2005. The most critical member of jacket offshore platform for the analysis of the various load also determined by compared the element capacity with manual calculation. However, there are assumption has been made such that the structure is fixed to the ground and the geometry, material properties and section properties of the structure are represent almost the same from the actual structure.



## ABSTRAK

Amalan reka bentuk struktur luar pesisir di Malaysia hanya memberi tumpuan lebih kepada analisis angin dan gelombang berbanding daripada kesan seismik. Di timur Malaysia, plat Filipina bergerak ke arah barat dengan anggaran halaju 80mm/tahun dan menyebabkan kerosakan mikro di Sabah. Oleh itu, tesis ini membentangkan penyelidikan gerakan gempa bumi akibat gempa bumi di Filipina untuk penilaian platform luar pesisir di Malaysia. Selain itu, kecukupan reka bentuk sedia ada platform luar pesisir di Malaysia ditentukan apabila dikenakan beban gempa bumi. Analisis kelakuan struktur platform luar pesisir berkaki 3 tetap di bawah kesan gempa bumi bagi membangunkan kriteria reka bentuk gempa bumi untuk struktur luar pesisir yang terletak di rantau Malaysia. Penilaian struktur luar pesisir tetap juga meliputi statik dan dinamik untuk analisis gempa bumi dengan menggunakan kod amalan "Cadangan Amalan Perancangan, Merekabentuk dan Membina Platform Luar Pesisir Tetap (API RP-2A, 2000). Bagi mereka bentuk platform luar pesisir, analisis ini menitikberatkan beban mati, beban hidup, beban alam sekitar (angin, ombak dan beban arus) dan beban gempa bumi seperti getaran bebas, sejarah masa dan analisis tindak balas spektrum. SAP 2000 merupakan program komputer yang telah digunakan untuk memeriksa struktur besi keluli berdasarkan Eurocode 3, 2005. Elemen platform luar pesisir jaket yang paling kritikal dianalisis dengan pelbagai beban yang ditentukan oleh kapasiti elemen yang dibenarkan dengan pengiraan manual. Walau bagaimanapun, terdapat beberapa andaian telah dibuat seperti struktur adalah tetap pada tanah dan geometri, sifat bahan dan sifat-sifat struktur yang memberi gambaran hampir sama dengan struktur sebenar.

## TABLE OF CONTENTS

	<b>Page</b>
<b>SUPERVISOR’S DECLARATION</b>	ii
<b>STUDENT’S DECLARATION</b>	iii
<b>ACKNOWLEDGEMENTS</b>	v
<b>ABSTRACT</b>	vi
<b>ABSTRAK</b>	vii
<b>TABLE OF CONTENTS</b>	viii
<b>LIST OF TABLES</b>	xi
<b>LIST OF FIGURES</b>	xii
<b>LIST OF SYMBOLS</b>	xvi
<b>LIST OF ABBREVIATIONS</b>	xvii
<b>CHAPTER 1 INTRODUCTION</b>	
1.1 Background of Study	1
1.2 Problem Statement	4
1.3 Research Objectives	5
1.4 Scope of Study	6
1.5 Research Significance	6
<b>CHAPTER 2 LITERATURE REVIEW</b>	
2.1 Earthquake	7
2.2 Seismic Wave	9
2.2.1 Body Waves	12
2.2.2 Surface Waves	13
2.2.2 Rayleigh Waves	13
2.3 Measuring Earthquake	14
2.4 Earthquake Magnitude	17
2.5 Offshore Structure	18

2.5.1	Introduction	18
2.5.2	Type of Offshore Structures	20
2.5.3	Design Consideration of Offshore Platform	21
2.5.4	Current Malaysia Practice Of Seismic Design	22
2.5.5	Analysis of Offshore Platform	22
2.6	Sap 2000 Program	23

## **CHAPTER 3 RESEARCH METHODOLOGY**

3.1	Introduction	25
3.2	Literature Review	26
3.3	Gather The Information And Data	26
3.4	Steps In Microsoft Excel	28
3.5	Modelling By Autocad	33
3.6	Modelling By Sap 2000	34
	3.6.1 Coordinate System in SAP 2000 Model	35
3.7	Steps In Sap 2000	36
3.8	Offshore Design Criteria And Properties	55
3.9	Offshore Design Structure	57
	3.9.1 Wind Load	57
	3.9.2 Wave Load	58
	3.9.3 Current	59
3.10	Offshore Design Structure For Critical Member	59
	3.10.1 Shear Resistance, $V_{c,Rd}$	60
	3.10.2 Shear Stress, $\sigma_s$	60
	3.10.3 Allowable Shear Stress, $\sigma_{all,s}$	61
	3.10.4 Bending Moment Resistance, $M_{c,Rd}$	61
	3.10.5 Bending Stress, $\sigma_b$	62
	3.10.6 Allowable Bending Stress, $\sigma_{all,b}$	62

## **CHAPTER 4 RESULTS AND DISCUSSIONS**

4.1	Introduction	63
	4.1.1 Analysis of fixed steel jacket	63
4.2	Analysis Design Check	65
	4.2.1 Free vibration analysis	65
	4.2.2 Response Spectrum Analysis	67

	4.2.3 Time History Analysis (TH Analysis)	69
	4.2.4 Dead Load	71
	4.2.5 Live Load	72
	4.2.6 Wave Load	72
	4.2.7 Wind Load	73
4.3	Analysis Of Shear, Moment And Axial Force For Critical Member Of Various Loads	74
	4.3.1 Dead Load, DL	74
	4.3.2 Environmental load, EL (Wind+Wave+Current)	76
	4.3.3 Response Spectrum, RS	77
	4.3.4 Combination load (Dead Load + Time History + Wind + Wave), DL+TH+WI+WA	78
4.4	Summary of Analysis	79
	4.4.1 Shear Force and Shear Stress	79
	4.4.2 Bending Moment and Bending Stress	80
	4.4.3 Displacement	82
	4.4.4 Force	83
	4.4.5 Moment	84

## **CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS**

5.1	Introduction	85
5.2	Conclusions	87
5.2	Recommendations	88

<b>REFERENCES</b>	90
-------------------	----

<b>APPENDICES</b>	93
-------------------	----

A	Offshore Design Structure	93
B	Calculation For Critical Member	94
C	Table Of Stiffness And Mass	102
D	Free Vibration Analysis (List Of Mode Shape)	106

## LIST OF TABLES

<b>Table No.</b>	<b>Title</b>	<b>Page</b>
2.1	Modified mercalli intensity scale compared to richter magnitude	18
3.1	The result of the maximum value are obtained	30
3.2	Set of coordinates (a) X grid (b) Y grid (c) Z grid	35
3.3	Material property data based on Europe EN 1993-1-1 per EN 10025-2	56
3.4	Self-weight and functional load	56
3.5	Environmental load	56
3.6	Coefficient for wave load	59
3.7	Stiffness and mass for horizontal member	102
3.8	Stiffness and mass for vertical member	104
3.9	Summary of total stiffness and mass	105
4.1	Modal Periods And Frequencies	66
4.2	Response Spectrum Modal Information	68
4.3	Shear force and shear stress for each combination load case	79
4.4	Bending moment and bending stress for each combination load case	80
4.5	Displacement result for various load analysis	82
4.6	Force result for various load analysis	83
4.7	Moment result for various load analysis	84

## LIST OF FIGURES

<b>Figure No.</b>	<b>Title</b>	<b>Page</b>
1.1	Types of plate's movement	2
1.2	The movement of Philippine plate moves westward	3
1.3	Major tectonic plates around Malaysia	4
2.1	Earth map that showing the major divergent, convergent and transform plate boundaries and outlines of the continents	8
2.2	Mechanism of Earthquake	9
2.3	Analogy to seismic waves using slinky waves and ropes	11
2.4	Particle motions of body and surface wave propagation	14
2.5	Seismograph to measure the ground motion due to earthquake	15
2.6	Seismographs results the seismogram	16
2.7	Offshore Model	19
2.8	Types of offshore platform	20
2.9	SAP 2000 Program (Version 15)	24
3.1	Flow chart of planning and scheduling	25
3.2	A Typical 3-legged Jacket of Fixed Offshore Platform	27
3.3	Import the data to excel	28
3.4	Tick space for Delimeters and click finish	29
3.5	Locate the data into Microsoft excel	29
3.6	Use command max and abs	30
3.7	The maximum value is obtained	31
3.8	Time History graph that obtained from Microsoft excel (a) HGE direction (b) HGN direction (c) HGZ direction.	32
3.9	View A, View B and View C of offshore platform.	33

3.10	Level 1 and Level 2 of offshore platform.	33
3.11	Level 3 and Level 4 of offshore platform.	34
3.12	3D view of offshore platform	34
3.13	New model form	36
3.14	Coordinates Systems/Grids	37
3.15	Define Materials form	37
3.16	Define Frame Sections form	38
3.17	Section Property form	38
3.18	Pipe Section form	39
3.19	X-Y Plane @ Z=0	40
3.20	Draw Frame Model	40
3.21	Joint Restraints form	41
3.22	Assign Frame Releases form	42
3.23	(a) Response spectrum settings (b) Time History settings	43
3.24	Load settings (a) Response spectrum (b) Time History (c) Dead Load (d) Modal Load (e) Live Load (f) Wind Load (g) Wave Load.	45
3.25	Define Load Patterns Form	45
3.26	Wave Load Patterns Settings	46
3.27	Current Profile Data Settings	46
3.28	Contours with Horizontal Wave Velocity	47
3.29	Arrows with Resultant Velocity w/o Current	47
3.30	Vertical Cut with Horizontal Wave Velocity	48
3.31	Horizontal Cut with Horizontal Wave Velocity	48
3.32	Click on three points at Top Slab	49
3.33	Joint Forces on slab for various load (a) Dead (b) Live (c) Wind	50

3.34	Click points below mean sea level	50
3.35	Joint Forces for Wave load below mean sea level	51
3.36	Click points above mean sea level	51
3.37	Joint Forces for Wave load above mean sea level	52
3.38	Load Combination Data Forms	52
3.39	Set Load Cases to Run Forms	53
3.40	Choose Tables for Display form	54
3.41	Deformed Shape form	54
3.42	Member Force Diagram for Frames form	55
4.1	Free vibration analysis in P-M interaction ratios	65
4.2	Deformed shape for (a) mode 1 (b) mode 2 (c) mode 3 (d) mode 4	66
4.3	Response spectrum analysis in P-M interaction ratios	67
4.4	Response spectrum graph	68
4.5	Time history analysis in P-M interaction ratios	69
4.6	Time History graph that obtained from SAP 2000 (a) HGE direction (b) HGN direction (c) HGZ direction.	70
4.7	Dead load analysis (a) Critical member in P-M interaction ratios (b) Deformed shape	71
4.8	Live load analysis in P-M interaction ratios	72
4.9	Wave load analysis (a) Critical member in P-M interaction ratios (b) Deformed shape	72
4.10	Wind load analysis (a) Critical member in P-M interaction ratios (b) Deformed shape	73
4.11	Shear force graph for member 33	74
4.12	Bending moment graph for member 33	74
4.13	Bending moment diagram of offshore platform	75
4.14	Axial force graph for member 33	75



4.15	Axial force diagram of offshore platform	75
4.16	Shear force graph for frame 5	76
4.17	Bending moment graph for frame 5	76
4.18	Axial force graph for frame 5	76
4.19	Shear force graph for frame 21	77
4.20	Bending moment graph for frame 21	77
4.21	Axial force graph for frame 21	77
4.22	Shear force graph for frame 10	78
4.23	Bending moment graph for frame 10	78
4.24	Axial force graph for frame 10	78
4.25	Shear stress versus various cases	79
4.26	Bending stress versus various cases	81
4.27	Displacement graph for various load analysis	82
4.28	Force graph for various load analysis	83
4.29	Moment graph for various load analysis	84
5.1	The glass at bank in Ranau Sabah broken due to Ranau earthquake	86
5.2	The structural column fracture and collapsed due to Ranau earthquake.	87

**LIST OF SYMBOLS**

mm	Millimeter
N/mm <sup>2</sup>	Newton per millimeter square
kg	Kilogram
N	Newton
kN	Kilo newton
kNm	Kilo newton meter
kN/m <sup>2</sup>	Kilo newton per meter square
s	second
V <sub>Ed</sub>	Maximum design shear force
V <sub>c,Rd</sub>	Shear resistance
$\sigma_s$	Shear stress
$\sigma_{all,s}$	Allowable shear stress
M <sub>Ed</sub>	Maximum external design moment
M <sub>c,Rd</sub>	Moment resistance
$\sigma_b$	Bending stress
$\sigma_{all,b}$	Allowable bending stress

**LIST OF ABBREVIATIONS**

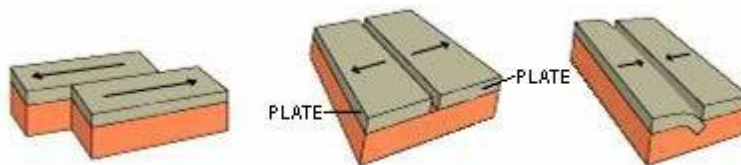
BS	British Standard
EN	European Standards
MS	Malaysia Standard
API	American Petroleum Institute
MMD	Meteorological Malaysia Department
E	Young Modulus
G	Shear Modulus
DL	Dead Load
LL	Live Load
EL	Environmental Load
TH	Time History
RS	Response Spectrum
WI	Wind Load
WA	Wave Load

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 BACKGROUND**

Most of the structural building in Malaysia is designed without considering of the earthquake effects such as Petronas Twin Tower (KLCC), KOMTAR Tower, Berjaya Times Square Tower and also offshore structure. There are no regulations requiring the tall building to be designed for earthquake in Malaysia as Malaysia does not lie in any presently demarcated seismic zone. However, Malaysia is located close to two most seismically active plate boundaries which are inter-plate boundary between Indo-Australian Plates and Eurasian Plates on the west and also the inter-plate boundary between Eurasian and Philippine Plates on the east (Husen, et al., 2013). These plates undergo many small movements against each other by time to time. The plates can slide horizontally against each other or pull away from each other or can be it coming towards each other causing one plate to dive beneath the other as in Figure 1.



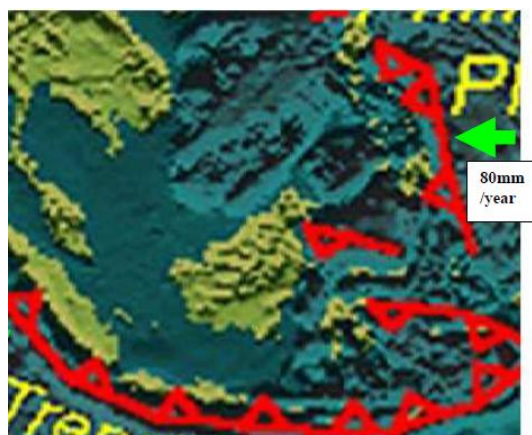
**Figure 1.1:** Types of plate's movement

Source: Ir Ng Pek Har, Hadi Golabi (2005)

The movements of involving large plates can cause the sudden movement that will results the huge energy to be released in the form of waves. These waves will travel inside the earth and along the ground which are felt by us as shakes and tremors. This is called an earthquake. The intersecting edges of the plates are called faults. Therefore, an earthquake is happen once there are both abrupt slide on a fault, causing earth trembling and emitted seismic vitality affected by the slide or through volcanic or magmatic movement or further unexpected pressure adjustments in the ground.

The tremor affects endangers such as ground shaking, liquefaction, surface faults, landslide, tsunami and also tectonic deformations. These all types of hazards depend on the geographical location, ground conditions and amount of tectonic activity along the faults. Geotechnical factors often exert a main influence on destruction patterns and loss of life in earthquake events (Aminaton Marto, et al., 2011). Along the transmission during seismic waves, the resonance effect would cause amplification behavior during upward propagation. The amplified waves make possible the soil liquefaction to be happens within the region (Marto, n.d., 2014). The impact and damage due to tsunami depends on some factors such as wave speed and height which are their coastal topography areas and also debris that carried by water (Ghobarah, et al., 2006).

Microzonation is the Mapping of seismic hazard at local scales to incorporate the effects of local geotechnical factors (Aminaton Marto, et al., 2011). At the east of Malaysia, the Philippine plate moves westward with an estimate velocity of 80mm/year and cause micro faults in Sabah (Mohd Rosaidi bin Che Abas, 2001). Sabah is the only state in Malaysia that exposed to earthquake activities if compared to other parts of Malaysia.



**Figure 1.2:** The movement of Philippine plate moves westward

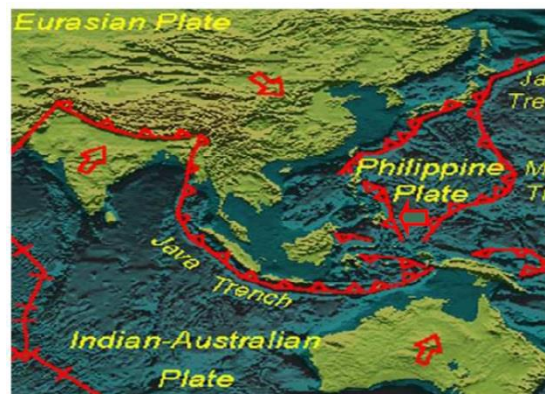
Source: Mohd Rosaidi bin Che Abas (2001)

The Peninsular Malaysia, Sabah and Sarawak located just behind the active seismic area. Therefore, there is an effort to investigate the behavior of offshore structure to sustain earthquake effect. The study is also covering the 3 legs of offshore platform and by using the software of SAP 2000 to make a model for offshore structure.

## 1.2 PROBLEM STATEMENT

Nowadays, the offshore structural design practice in Malaysia only focus more on wind and wave effects analysis rather than seismic effect. We cannot guarantee others that our offshore platform is safe for earthquake effects. This is because the wind loads damage the structure by externally applied pressures, while earthquake damage is caused by internally generated inertial forces induced by vibration of the structure's mass.

Our country, Malaysia has to worry about the earthquake effects. Year by year, our neighboring tectonic plates which are Indian plate, the Australian plate, the Eurasian plate and the Philippine plates are moving and pushing our country. Eastern Sabah is prone to trembles affected by tremors in the Southern Philippines. In 1976, one of the worst earthquakes that happened when a reading of Richter scale is 5.8 of their magnitude temblor Lahad Datu, Sabah. The highest observed intensity in Lahad Datu and Kunak was assessed of about VII on MM scale.



**Figure 1.3:** Major tectonic plates around Malaysia

Source: Mohd Rosaidi bin Che Abas (2001)

Furthermore, Sarawak also impaired by prolonged distance of tremor that started from the Straits of Macassar, Celebes Sea and Sulu Sea of the West of Philippine. The highest perceived Mercalli Intensity at Sarawak was estimated of about V on MM scale which produced by this distant earthquake. We are lucky that the earthquake effect does not cause much impact to our country. However, we must always be in precaution mode and get well prepared for the possibility of adversity earthquake occur and also damage of our structures. Thus, this research study will demonstrate the behavior of our offshore structures for 3 legs under earthquake effect. The offshore structure modelling analysis was using the computer software of SAP 2000.

### **1.3 RESEARCH OBJECTIVES**

The main objective of this research is to estimate the earthquake ground motion due to Philippine earthquake for assessment of offshore platform in Malaysia, while the sub objectives of this research are:-

1. To determine the adequacy of existing design of offshore platform in Malaysia when subjected to earthquake loading.
2. To determine the earthquake design criteria for offshore platform located in Malaysia



#### **1.4 SCOPE OF STUDY**

1. The case study of the earthquake is around the area of Philippine and their effect to Malaysia.
2. The type of offshore used will be 3-legged fixed offshore platform.
3. Study the architectural drawing of a typical 3-legged jacket of fixed offshore platform
4. Analyze the data that provided from Malaysia Meteorology Department (MMD).
5. The computer software for offshore structure modelling analysis is SAP 2000.

#### **1.5 RESEARCH SIGNIFICANCE**

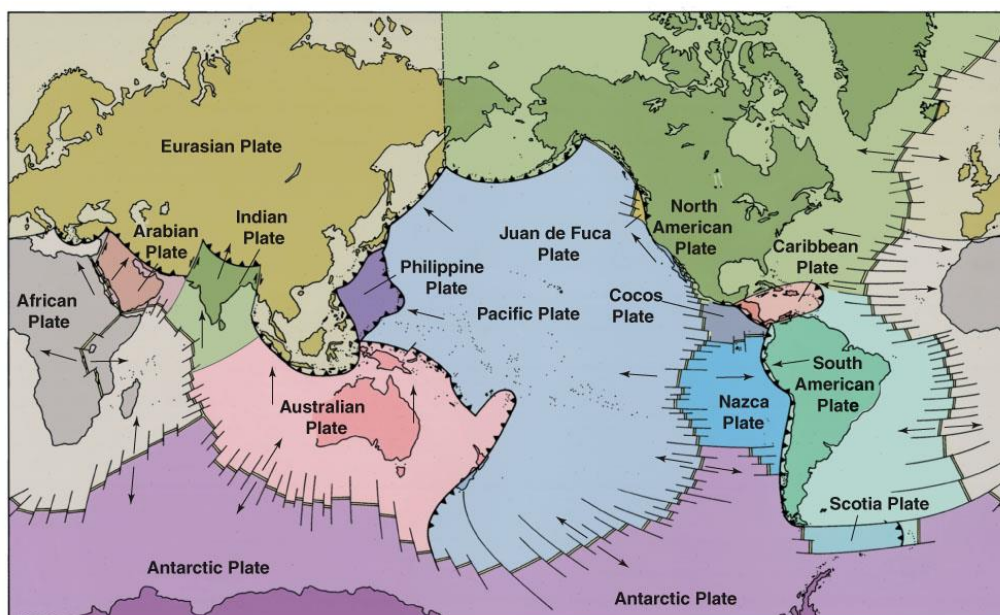
The significance of the research study is to identify the earthquake ground motion due to Philippine earthquake for assessment of offshore platform in Malaysia. Another purpose of this research study are to determine the adequacy of existing design of offshore platform in Malaysia when subjected to earthquake loading and also determine the earthquake design criteria for offshore platform located in Malaysia. The analysis of behavior of the offshore platform structures of 3-legged fixed offshore structures under the earthquake effect is obtained to develop the earthquake design criteria for the offshore structures that are located in Malaysia region. A hundreds of thousands of people could be saved if the structures are considering the earthquake effect by built it to withstand the shaking from the passage of seismic waves.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 EARTHQUAKE**

Earthquake is one of the most destructive natural hazards that can cause many deaths. An earthquake happens when there is a sudden release of energy causes the ground to shake and vibrate, associated with passage of waves of energy that been released at its sources. Earthquakes sometimes can kill till hundreds of thousands of people and leveling entire town or cities just in a few minutes or seconds. The earthquake causes the secondary hazards such as shaking, landslides, tsunamis and liquefaction. Our earth is divided into about twelve large tectonic plates and there are moving relative to other. There are also many other smaller plates. Commonly, the earthquakes in the world occurs when two of these plates meet and then moving past each other.



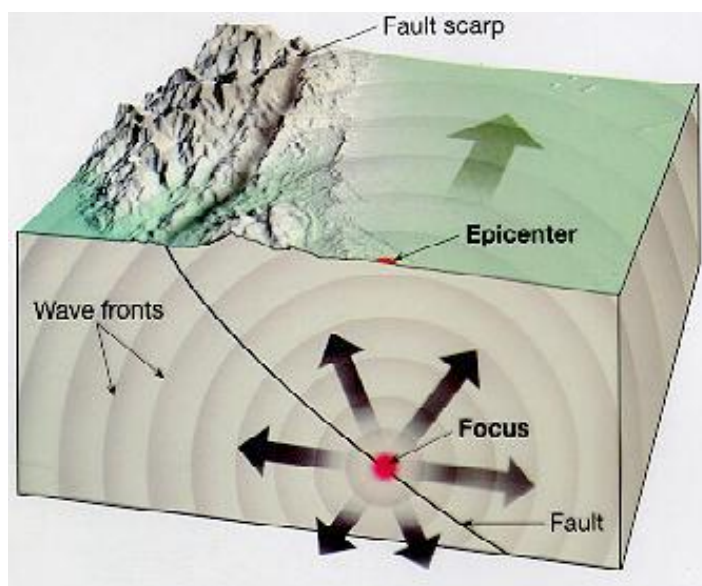
**Figure 2.1:** Earth map that showing the major divergent, convergent and transform plate boundaries and outlines of the continents

Source: Timothy Kusky (2008).

An earthquake originates from one place and later spreads out in all directions throughout the fault plane. The point in the Earth is called *focus* where the earthquake energy is released first and that will represents the area on one side of a fault that in fact moves relatively to the rocks on the other side of fault plane. While, the Earth's surface that lies through vertically above the focus is called *epicenter*. An earthquake can causes the significant defects and damages within 100-200km radius from the epicenter.

Even though Peninsular Malaysia is located in the stable Sunda Shelf and with low to medium seismic activity level, sometimes tremors can be felt from the large earthquakes that originated from the intersection areas of Eurasian plate and Indo-Australian plate near

Sumatra (Azlan Adnan, et al., 2005). The tremors that have been occurred can cause panic to the public people of several cities in Peninsular Malaysia which are Kuala Lumpur and Penang as for example, cases that have been reported on 2<sup>nd</sup> November 2002 which is the cracks on buildings in Penang due to earthquake. (Azlan Adnan, et al., 2005). While recently, in Kota Kinabalu, a mild earthquake, with a magnitude of 4.4 on the Richter scale, was recorded in Pulau Banggi, Kudat on October 24, 2014 (The Star Online, 2014)



**Figure 2.2:** Mechanism of Earthquake

Source: Ir Ng Pek Har, Hadi Golabi (2005)

## 2.2 SEISMIC WAVE

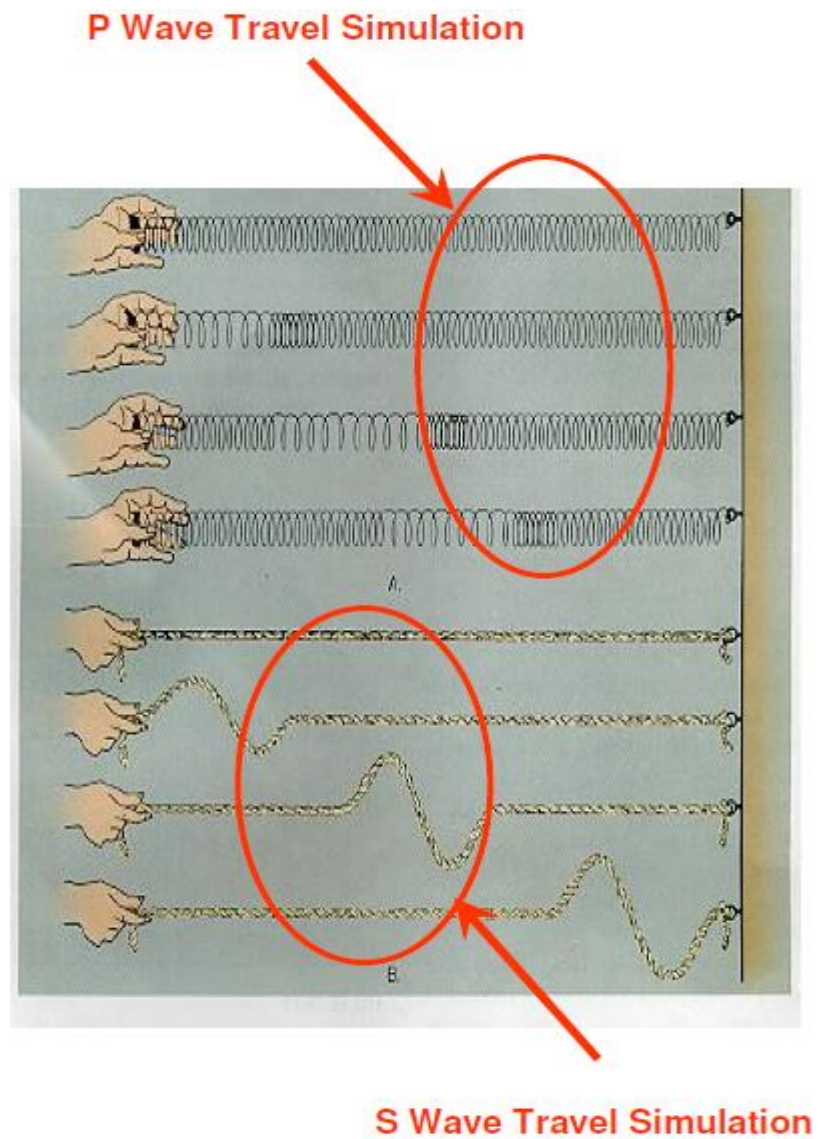
As the big earthquake occurs, the surface of the Earth then eventually forms into waves that move throughout the surface, just as in the ocean. These waves can cause

extremely destructive or also can be pretty spectacular. These seismic waves' moves of all directions just like ripples or sound waves that been formed or moved across the water as a stone is thrown in a still pond. The ground will returns to its original shape just after the seismic waves have passed through the ground, meanwhile the structures of building or others things being destroyed. The people who have experienced the large earthquakes happens eventually seen waves of rock with several feet high that being moving toward them at very high speeds.

There are three types of seismic waves which are:-

1.     Body waves
2.     Surface waves
3.     Rayleigh waves

The body waves are the seismic waves that can either radiate underground from the focus. While the surface waves are the seismic waves that can either radiate aboveground from the epicenter. In addition, the body waves travel throughout the whole body of the Earth and also move faster than surface waves. Surface waves will cause most of the destructive due to earthquakes as compared to body waves because as they pass, they actually change the shape of the surface of the Earth.



**Figure 2.3:** Analogy to seismic waves using slinky waves and ropes

Source: Ir Ng Pek Har, Hadi Golabi (2005)

### 2.2.1 Body Waves

Body waves are consists of two types which are:-

1. P waves (Primary or compressional waves)
2. S waves (Secondary or shear waves)

P waves will deform material through a change in density and volume and also can pass through three states which are solids, liquids and gases. P waves is moves with high velocity that is about 3.5-4 miles per second (6km/sec) and this type of waves is the first to be recorded by seismographs. Therefore, they are called primary waves or P waves. P waves gives the effects to a lot damage as they temporarily change the volume and area of ground that humans have built things and that requires the ground to keep its original shape, volume and their area. As the ground suddenly changes its volume by contracting or expanding, will cause the construction breaks.

S waves are the second kind of body waves which are known as shear waves or secondary waves because they only change the shape of material but not of its volume. Shear waves only can be transmitted throughout the solids, whereas liquids cannot do so. S waves can move material at right angles to the direction of wave travel; hence they have an alternating series of sideways motion. S waves moves with the velocity of two miles per second (3.5km/sec). S waves only may be able to knock the buildings off foundation when they pass.

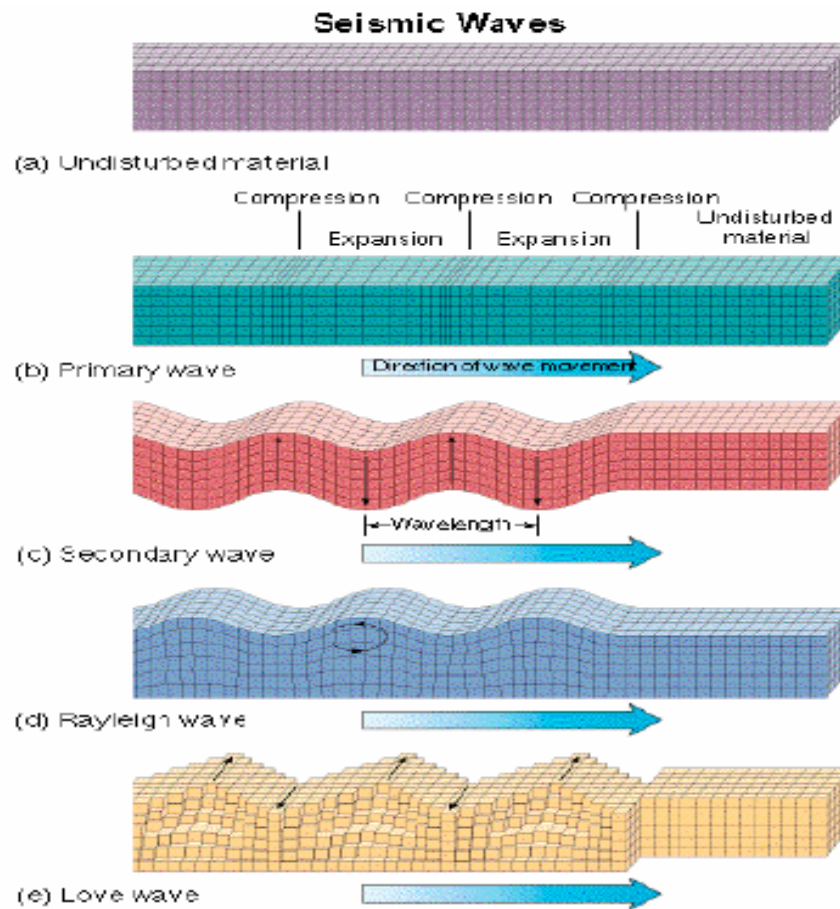
### **2.2.2 Surface Waves**

Surface waves can cause the extremely destructive due to earthquake. This is because of their complicated types of twisting and also circular motions as for example the circular motions waves out past the surf zone of the beach. Surface waves are travel much slower than body waves. However, it causes the most damages due to its types of complicated types of motion.

### **2.2.3 Rayleigh waves**

Others third type of wave is called Rayleigh which been introduced by Lord Rayleigh (1855). It is generated by the interaction of P and S waves; however have the different characteristics from P and S waves. Their particle motion at the surface is a retrograde ellipse that includes both horizontal and vertical. Rayleigh waves are the frequency-dependent penetration of the particle motions as it happens within a depth of about one wavelength. Thus, the changes in frequency or wavelength will affect the penetration depth of surface wave motions below of the ground surface.





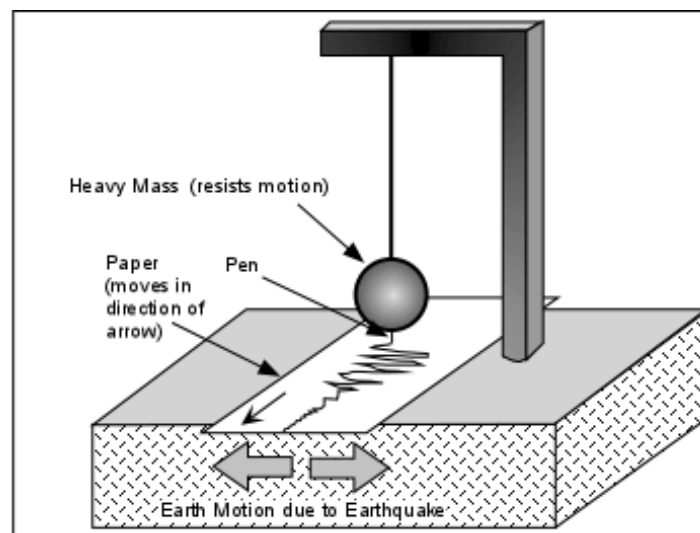
**Figure 2.4:** Particle motions of body and surface wave propagation

Source: Ir Ng Pek Har, Hadi Golabi (2005)

## 2.3 MEASURING EARTHQUAKE

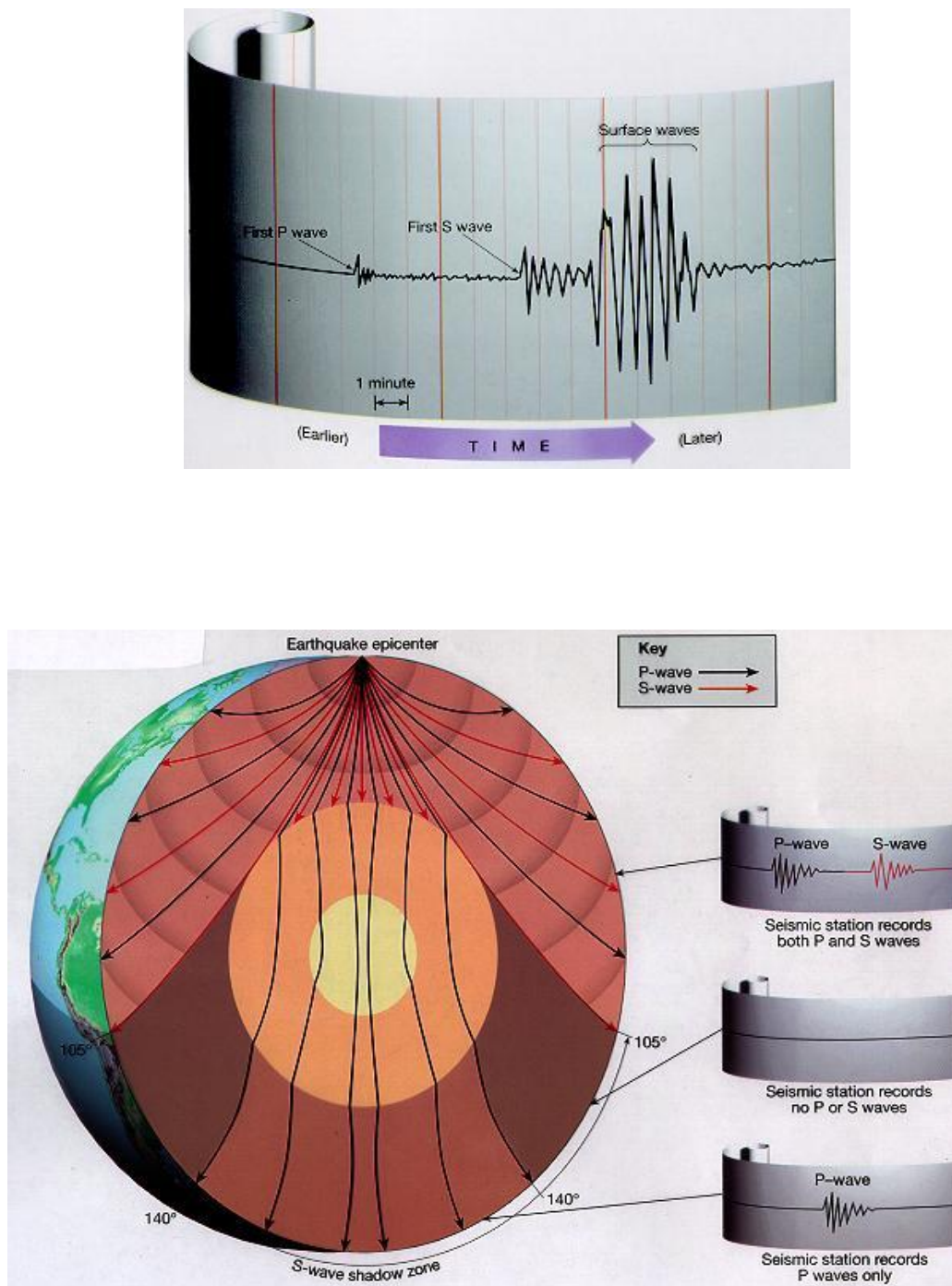
Seismographs are devices which are built to measure the amount and direction of shaking due to earthquakes. The method to measure the shaking of the Earth is by the point of reference must be free from shaking and ideally on a hovering platform. Since the

hovering platform is impractical, therefore the instrument of inertial seismograph is designed. The inertial seismograph is been used by the ink-filled stylus is attached to the heavy weight then remain constant during an earthquake. Then, the continuously turning graph paper been attached to the ground, moves back and forth during the quake, will be results the zigzag trace of the record of the earthquake motion on the graph paper. Some of the seismographs are set up as pendulums and also some others as springs to get the measurement of the ground motion in many directions.



**Figure 2.5:** Seismograph to measure the ground motion due to earthquake

Source: Professor Stephen A. Nelson (2005)



**Figure 2.6:** Seismographs results the seismogram

Source: Ir Ng Pek Har, Hadi Golabi (2005)

## 2.4 EARTHQUAKE MAGNITUDE

Ritcher Scale is used to measure earthquake magnitude based on how high the amplitude of seismic waves which in range of 100km (62miles) from the epicenter. As seismograph produce a zigzag trace for richter scale magnitude. While in the microzonation seismic mapping, use ‘gals’ that represents to the acceleration faced in a ground motion because of the seismic effect from a certain distance away from the epicenter which is  $1000\text{gals} = 1\text{g} = 9.81 \text{ m/s}^2$  (Engr. Dr. Jeffrey Chiang, Engr. M. C. Hee, 2008). Earthquake magnitude can be defined as follows:-

$$M = \log \frac{A}{A_0} \quad (2.1)$$

Where,

$A$  = Peak amplitude in seismogram which in distance of 100km from epicenter ( $\mu\text{m}$ )

$A_0$  = Zero-magnitude earthquake of a peak amplitude which is  $1\mu\text{m}$  for 100km

Before the development of using seismograph, it is measured by use modified Mercalli intensity scale. It is measured by referring the way of the people reacts with earthquake and their assessment of the damage or destructiveness of the building due to earthquake (Roberto Villaverde, 2009). This Mercalli intensity is not really accurate as compared to Ritcher Scale because it is not corrected for the distance from epicenter. The comparison of Mercalli intensity with the Richter magnitude as shown in table 2.0.

**Table 2.1:** Modified mercalli intensity scale compared to richter magnitude

<b>MERCALLI INTENSITY</b>	<b>RICHTER MAGNITUDE</b>	<b>DESCRIPTION</b>
<b>I-II</b>	<2	Not sensed by most people
<b>III</b>	3	Sense by some people indoors, especially on high floors.
<b>IV-V</b>	4	Perceived by some people. Dangling objects swing, dishes rattle.
<b>VI-VII</b>	5	All people feel. Some building destruction (esp. to masonry), waves on fishponds.
<b>VII-VIII</b>	6	Difficult to stand, people scared or panicked. Difficult to steers cars. Moderate damage to buildings.
<b>IX-X</b>	7	Major damage, general panic of community. Most masonry and frame structures ruined. Underground pipes fractured. Large landslides.
<b>XI-XII</b>	8 and higher	Near total damaged.

Source: Timothy Kusky (2008)

## 2.5 OFFSHORE STRUCTURE

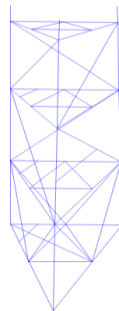
### 2.5.1 Introduction

Nowadays, offshore structures are widely used all around the world especially for oil and gas industry which includes oil exploration and production. The exploration and extraction is the oils which are lying very deep to the bottom of sea, from earth's crust. The structure of offshore structures can be steel structure and also concrete structure. The steel

used are from various grades such as from mild to high strength steel. As for selection for type of steel platform, it depends on the water depth and also their purpose.

The offshore structures are very important and really useful in the continuing for the production of oils. The offshore structures have their big roles in make sure our life to be ease as assuring the oil to be supplied. Therefore, the design criteria for the offshore structure must be concerned as to be function safely for a long times and due to the challenges of marine environment. The design must be considering of the waves, wind, strong current due to loads and last but not least the earthquake loading. The most important is when the safety design of a bottom-mounted offshore platform located in a seismic zone, the effect of earthquakes on structural response must be carefully examined so that the facilities can retain appropriate seismic resistance (Park, Koo, & Kawano, 2011).

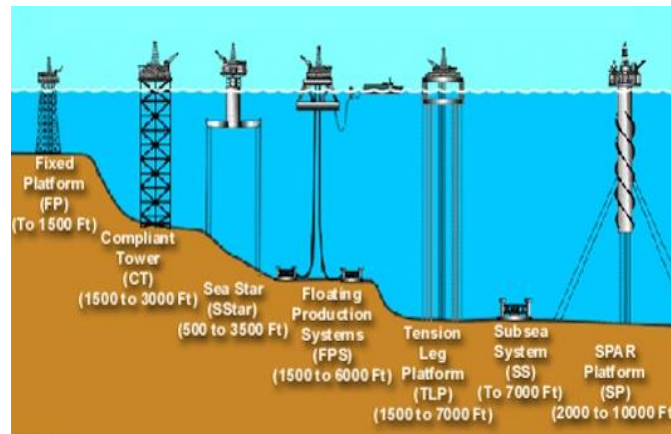
Seismic consideration covers the inspection of the subsurface soils at the platform site for instability because of liquefaction, submarine slides caused by earthquake activity, proximity of the site to faults, the features of the ground motion expected throughout the life of the platform, and the acceptable seismic risk for the type of operation intended. (Edition, 2007)



**Figure 2.7:** Offshore Model

### 2.5.2 Type of Offshore Structures

1. Fixed Platform
2. Concrete Gravity Structure
3. Compliant Towers
4. Tension Leg Platform
5. Floating Production Systems
6. Subsea systems
7. SPAR Platforms



**Figure 2.8:** Types of offshore platform

Source: Kabir Sadeghi (2007)

The selection of offshore platforms is depending on depth of water and their application. Nowadays, jacket fixed platform is been used 95% of the offshore platform, around the world. It is suitable in the shallow water and are the most stable structures because their “leg” or steel is constructed extending directly down to the sea floor. Therefore, their benefits such there is a constraint in exposure to the water and wind forces. Steel tubular structure or jacket having its feet on the sea floor supports the deck and their platform is fixed.

### **2.5.3 Design Consideration of Offshore Platform**

Offshore platform normally used the type of platform which made of steel at Gulf of Mexico in the exploration and production of oil (Sadeghi, 2001). The design and analysis of offshore platform must be concerned of many factors such as follows:-

1. Soil characteristics.
2. Environmental issues that include tides, ice, winds, currents, shallow gases, marine growth and earthquakes (Sadeghi, 2001).
3. Code necessities of the American Institute of Steel Construction “AISC” codes
4. Follows the practice of “Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms (API RP-2A, 2000).

API practices require the assessment of seismic activities and for area in low seismic action to design offshore platform. It also states such that the lowest deck should preserve at least 1.5m air gap linking the base of the deck beams and the wave peak throughout the



highest estimated level of water considering for the merges of wave peak and tides. Their minimum design principles are for 100 year design of storm.

As for designing the offshore platform, it needs to consider the dead load, live load and environmental loads. The dead loads are the permanent equipment or the structures that do not alter the form of operation and the weights of their platform structure itself. Whereas for the live loads are the loads that been forced on the platform while a mode of operation or else from one mode of operation to one another. The environmental loads are the loads which been forced on the platform by the natural phenomena such as wind, waves, current, earthquake and etc. The platform must withstand all the loads that are generated to make sure their structures to be safe.

#### **2.5.4 Current Malaysia Practice of Seismic Design**

Nowadays, structural design in Malaysia has still not considering earthquake and hurricane loading (Potty, Redzuan, & Hamid, 2013). It is an intention to implement the Eurocode 8 on seismic design as this standard code are based on the two international design codes for seismic actions that were cited as references which are Eurocode 8 and the American-based IBC 2000 (Engr. Dr. Jeffrey Chiang, Engr. M. C. Hee, 2008).

#### **2.5.5 Analysis of Offshore Platform**

Based on American Petroleum Institute's proposed the practice that states under seismic loading might be use computing structural response of response spectrum or time history analysis for planning, designing and constructing of offshore platforms. The structures may undergo vibrations by earth waves of short wavelength from nearby source

earthquakes or through vibrations stimulated from near strong vibration sources (Mohamed I.S.Elmasry, 2012). Therefore, the offshore structure used the dynamic response analysis which is the combination between live load and dead load together. In structural reliability analyses, the earthquake loads commonly been modeled as random processes or time histories (Moustafa & Mahadevan, 2011).

There are three methods need to be used in the analysis of the offshore platform such as follows:-

1. Free Vibration Analysis
2. Response Spectrum
3. Time history Analysis

As for design response spectrum, the structures are applicable for time history analysis and the ground acceleration data should be scale by the factor of G factor. The consideration of geometrical nonlinearity through base mat uplift is the method of time history nonlinear earthquake response analysis method that was proposed by Tanaka et al. (1995) and Momma et al. (1995) which are the interaction between horizontal and vertical motion to be considered (Kobayashi, et al. , 2002).

## **2.6 SAP 2000 PROGRAM**

SAP name can be testified is the art of analytical and structural program for the design and analysis of civil structures. Their featuring are very advanced, sophisticated,

versatile consumer with interface operated by design tools that really fast and perfect construction models for engineer to finish up the most complex projects.

SAP is the object based which gives the significance of the models is formed using members that characterize the physical reality. Then, the complex models can be produced and suited with powerful that formed in templates. Their integrated code characters would automatically produces wave, wind, seismic loads with inclusive automatic steel and also international design standards. It also allows analytical techniques with step by step with nonlinear analyses which would be static or nonlinear of time history dynamic analysis.

From an unsophisticated small 2D static frame analysis transforms to a great complex 3D nonlinear dynamic analysis. The software of SAP 2000 is the simplest, most helpful, practical solution for the design and structural analysis.



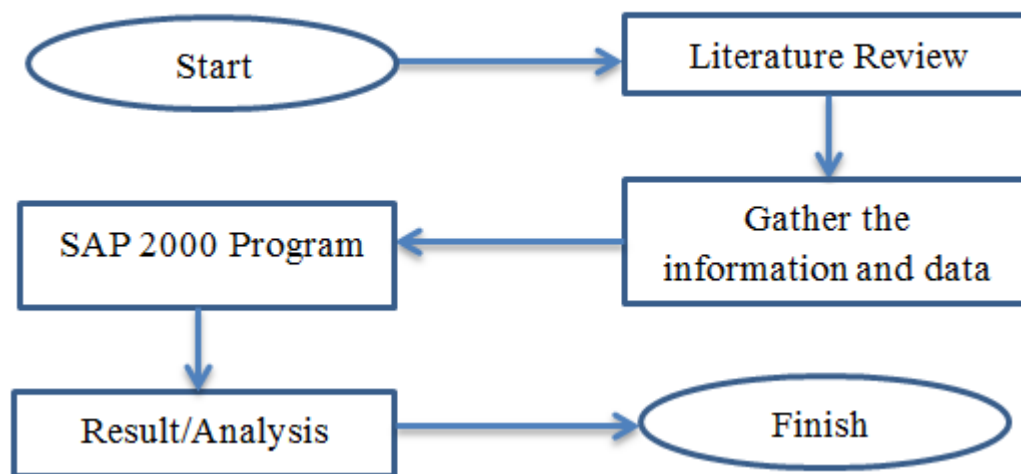
**Figure 2.9:** SAP 2000 Program (Version 15)

## CHAPTER 3

### METHODOLOGY

#### 3.1 INTRODUCTION

In order to make sure the project successful, the planning and scheduling are arranged as follows:-



**Figure 3.1:** Flow chart of planning and scheduling

### **3.2 LITERATURE REVIEW**

During this phase, all the information, data, studies and facts that related to the project are been collected. The data collecting process is focused on the major topics of this project such as follows:-

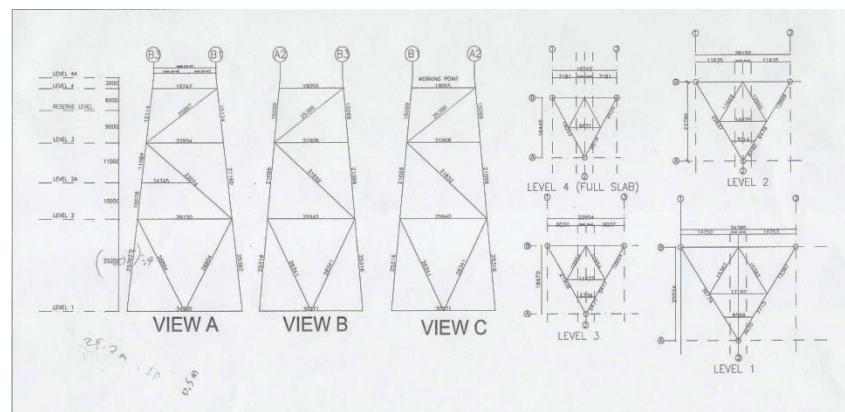
1. Earthquake
2. Seismic Wave
3. Measuring Earthquake
4. Earthquake Magnitude
5. Offshore Platform
6. SAP 2000 Program

### **3.3 GATHER THE INFORMATION AND DATA**

During this stage, as to make sure the projects is going smoothly, the further information and data for the modelling and analysis work need to be carried out. The information and data that required are as follows:-

1. Location of the case study of the offshore platform.

2. Drawing of the offshore platform.
3. Background of the offshore platform.
4. Type of the offshore platform and their legs.
5. Material used for the structure of the offshore platform.
6. Limitation of the offshore platform.



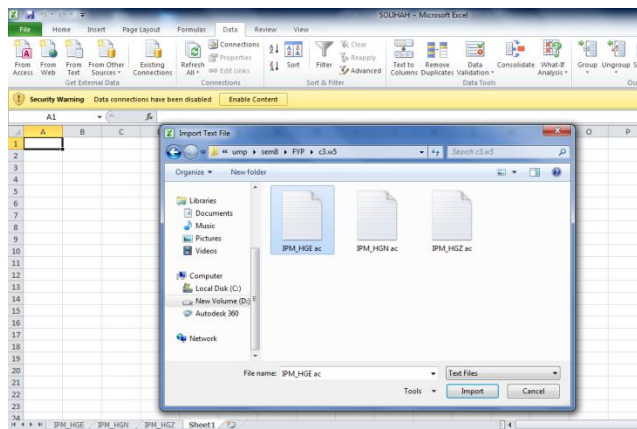
**Figure 3.2:** A Typical 3-legged Jacket of Fixed Offshore Platform

### 3.4 STEPS IN MICROSOFT EXCEL

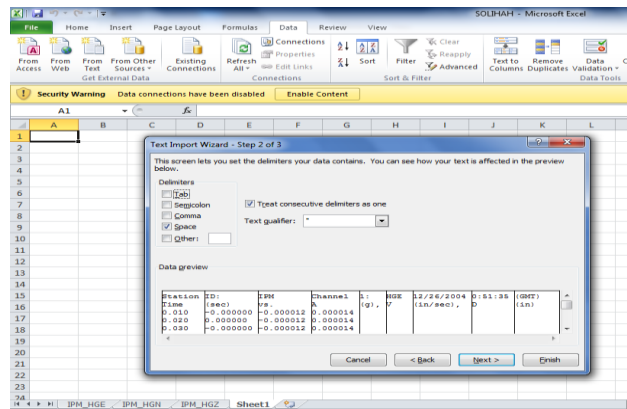
The raw data from notepad is inserted to the Microsoft excel to find the maximum value for acceleration, velocity and displacement. Besides, from Microsoft excel the graph for HGE, HGN and HGZ direction can be obtained.

#### Step 1: Insert the data to Microsoft excel

- i) Insert the raw data from 3 directions of E, N, Z from notepad into Microsoft excel. Go to Data > From Text > Browse the location of notepad file > Import the file chosen > Click next > Tick space for Delimiters > Next > Click Finish

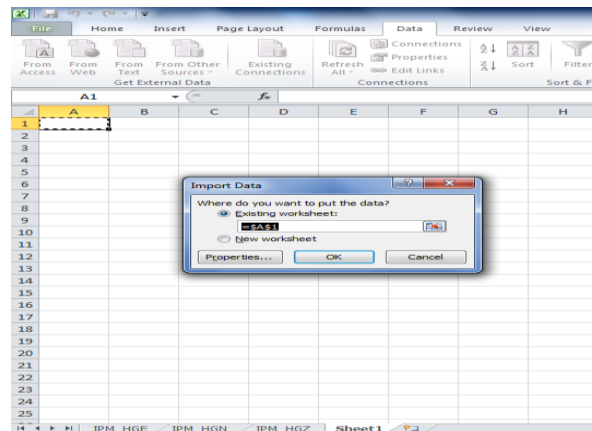


**Figure 3.3:** Import the data to excel



**Figure 3.4:** Tick space for Delimiters and click finish

- ii) Choose to locate the data in which row and column > Click Ok. > Arrange the title to be in the right column.



**Figure 3.5:** Locate the data into Microsoft excel



**Step 2:** Find the maximum value for A (g), V (in/sec), D (in)

- i)  $=\text{MAX}((\text{ABS}(\text{C3:C214531})))$ . Use command max and abs. Click the first row and do colon (:), click the last row to select the all the data in that column. Press ctrl + shift + enter to do { }, to get the maximum value.

Station ID	Time (sec)	A (g)	V (in/sec)	D (in)
1	0.01	0	-0.000012	0.000014
2	0.02	0	-0.000012	0.000014
3	0.03	0	-0.000012	0.000014
4	0.04	0	-0.000012	0.000014
5	0.05	0.000001	-0.000011	0.000014
6	0.06	0	-0.000009	0.000014
7	0.07	0	-0.000009	0.000014
8	0.08	-0.000001	-0.00001	0.000014
9	0.09	0	-0.00001	0.000014
10	0.1	0	-0.00001	0.000014
11	0.11	-0.000001	-0.000013	0.000013
12	0.12	0.000001	-0.000014	0.000013
13	0.13	-0.000001	-0.000014	0.000013
14	0.14	0	-0.000016	0.000013
15	0.15	0	-0.000017	0.000013
16	0.16	0	-0.000017	0.000013
17	0.17	0.000001	-0.000016	0.000013
18	0.18	0	-0.000015	0.000012
19	0.19	0	-0.000014	0.000012
20	0.2	0	-0.000013	0.000012
21	0.21	0	-0.000013	0.000012
22	0.22	0	-0.000014	0.000012
23	0.23	0.000001	-0.000013	0.000012

**Figure 3.6:** Use command max and abs

**Table 3.1:** The result of the maximum value are obtained

Maximum	HGE	HGN	HGZ
A (g)	0.001222	-0.00108	0.00096
V (in/sec)	0.198298	-0.21319	-0.218931
D (in)	-0.140921	0.17486	-0.168419

### Step 3: Time History graph

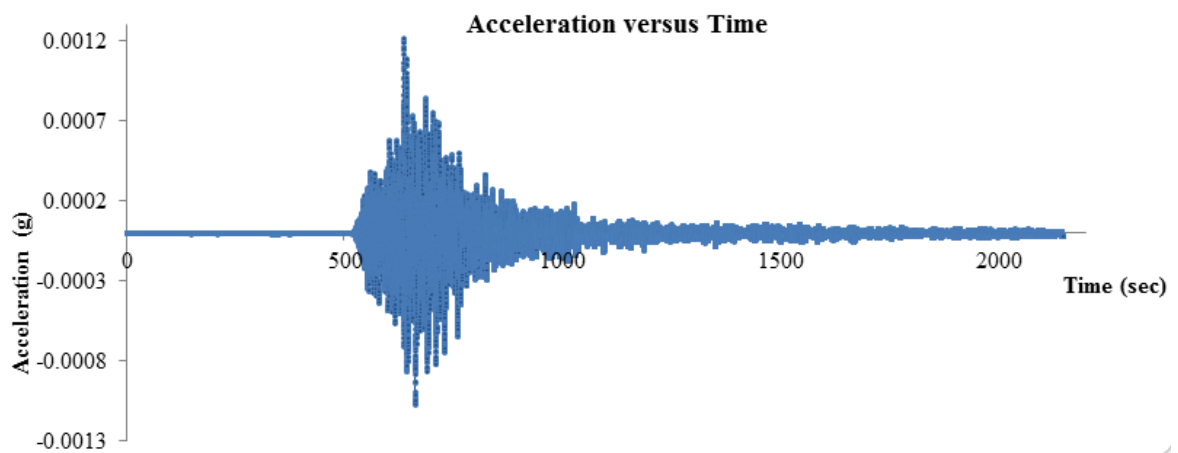
- i) Click the first row, press ctrl + shift + ↓ to select data for the axis.
- ii) Go to insert, scatter and choose the graph.

Station	ID	IPM	Channel	Time (sec)	A (g)	V (in/sec)	D (in)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

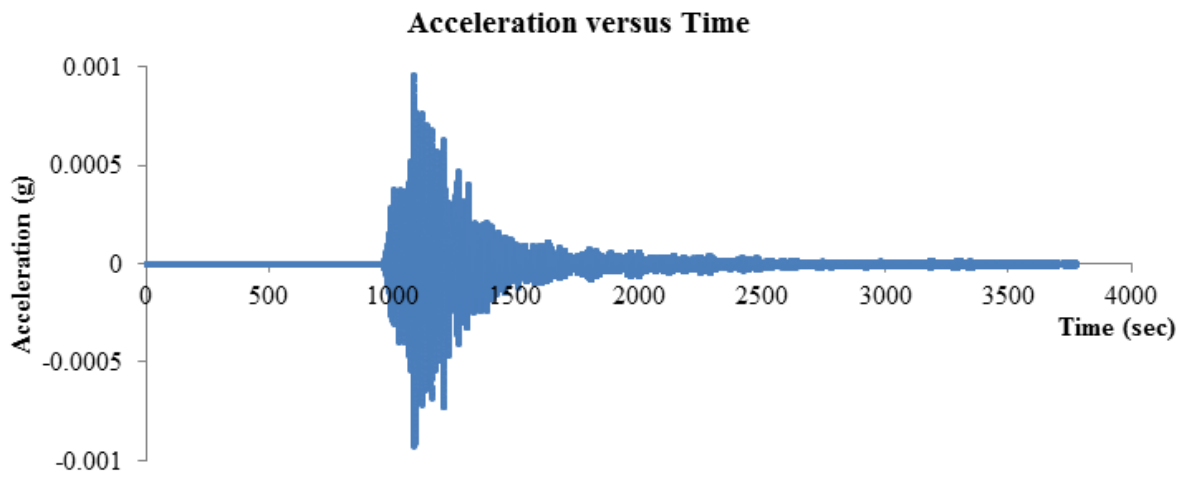
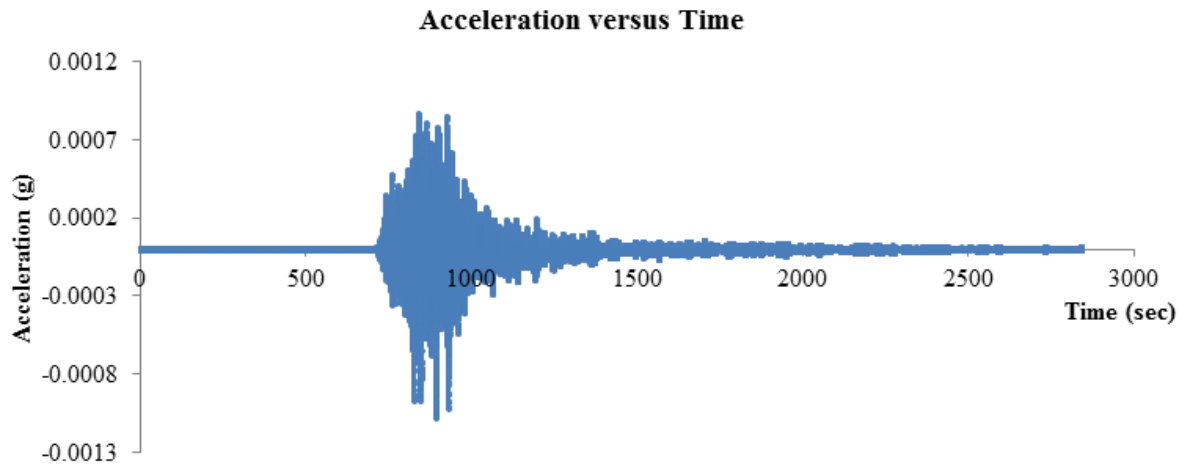
  

Maximum	HGE	HGN	HGZ
A (g)	0.001222	-0.00108	0.00096
V (in/sec)	0.198298	-0.21319	-0.218931
D (in)	-0.140921	0.17486	-0.168419

Figure 3.7: The maximum value is obtained

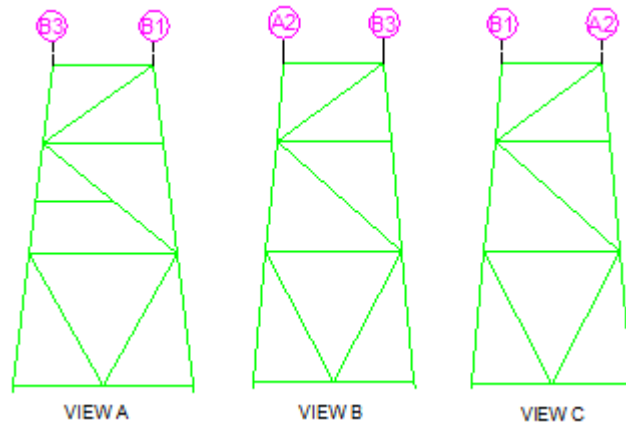


(a)

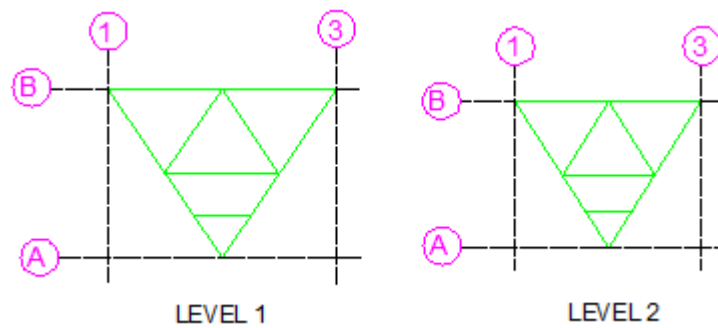


**Figure 3.8:** Time History graph that obtained from Microsoft excel.  
 (a) HGE direction (b) HGN direction (c) HGZ direction.

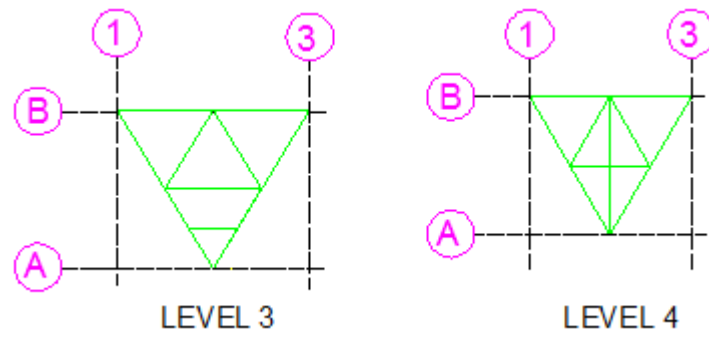
### 3.5 MODELLING BY AUTOCAD



**Figure 3.9:** View A, View B and View C of offshore platform.

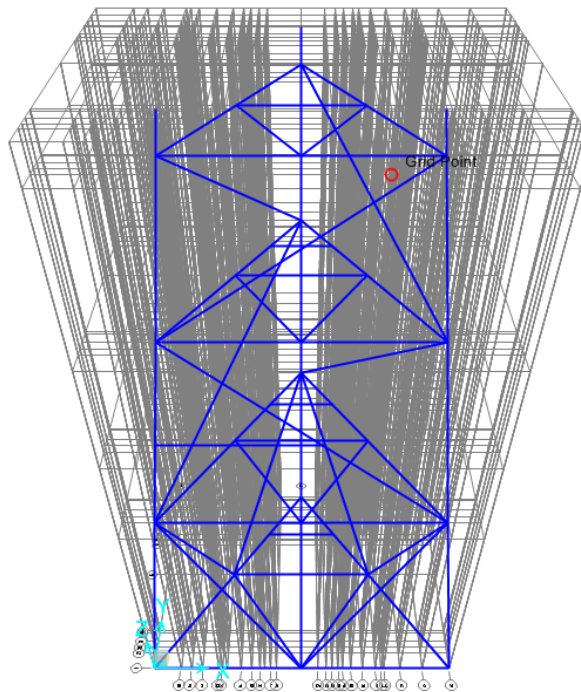


**Figure 3.10:** Level 1 and Level 2 of offshore platform.



**Figure 3.11:** Level 3 and Level 4 of offshore platform.

### 3.6 MODELLING BY SAP 2000



**Figure 3.12:** 3D view of offshore platform

### 3.6.1 Coordinate System in SAP 2000 Model

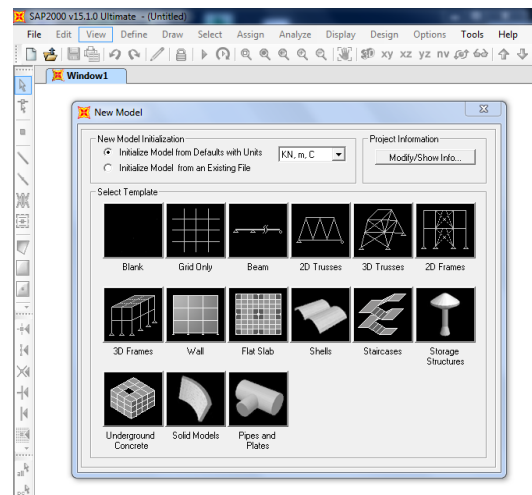
**Table 3.2:** Set of coordinates (a) X grid (b) Y grid (c) Z grid

	(a)	(b)	(c)
A	-122.8	1	0
B	0	2	1869
C	3118	3	2615
D	4355	4	3432
E	5716	5	4539.5
F	7572	6	12762
G	7943	7	17427
H	8596.5	8	18194
I	10155.5	9	19162
J	11455	10	20742
K	12382.5	11	20984.5
L	12907.5	12	22092
M	13665	13	23655
N	14324	14	25524
O	17193	15	25619.5
P	19100		
Q	20062		
R	20721		
S	21478		
T	22003.5		
U	22931		
V	24230.5		
W	25789		
X	26443		
Y	26814		
Z	28670		
A1	31268		
B1	34385		

### 3.7 STEPS IN SAP 2000

#### Step 1: Begin a new model

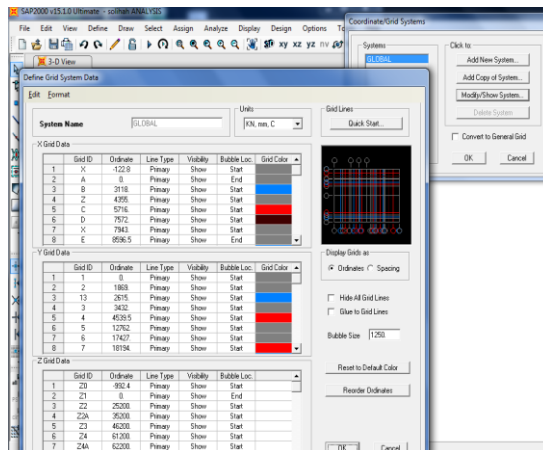
Click File menu > New Model. Choose unit set to kN, m, C. Select template for blank.



**Figure 3.13:** New model form

#### Step 2: Insert coordinates value.

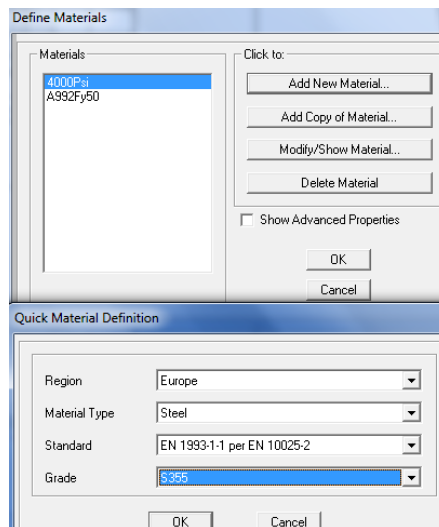
Click the Define menu > Coordinate Systems/Grids. In the system area, highlight GLOBAL and click Modify/Show System. Insert the coordinates and click OK.



**Figure 3.14:** Coordinates Systems/Grids

**Step 3:** Define material properties.

Click the Define menu > Materials. Click the Add New Material to display window as shown in Figure 3.15. Click OK to close both windows.

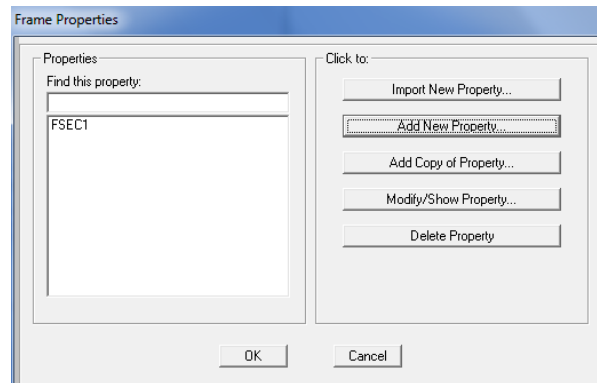


**Figure 3.15:** Define Materials form



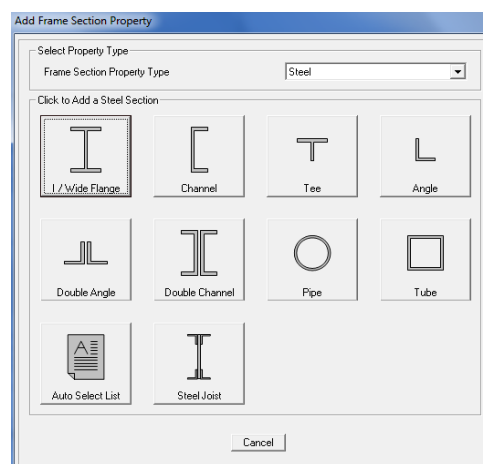
#### Step 4: Define Frame Sections

- i) Click the Define menu > Section properties > Frame Sections > Add New Property



**Figure 3.16:** Define Frame Sections form

- ii) Choose Frame Property Type > Steel. Click Steel Section > Pipe



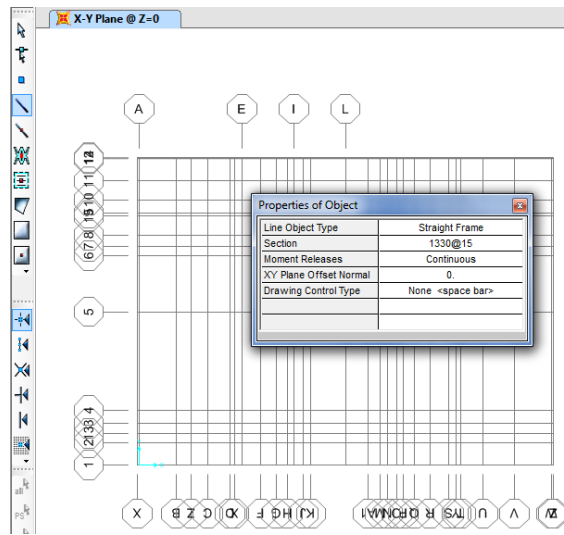
**Figure 3.17:** Section Property form

- iii) Insert the data of the section.

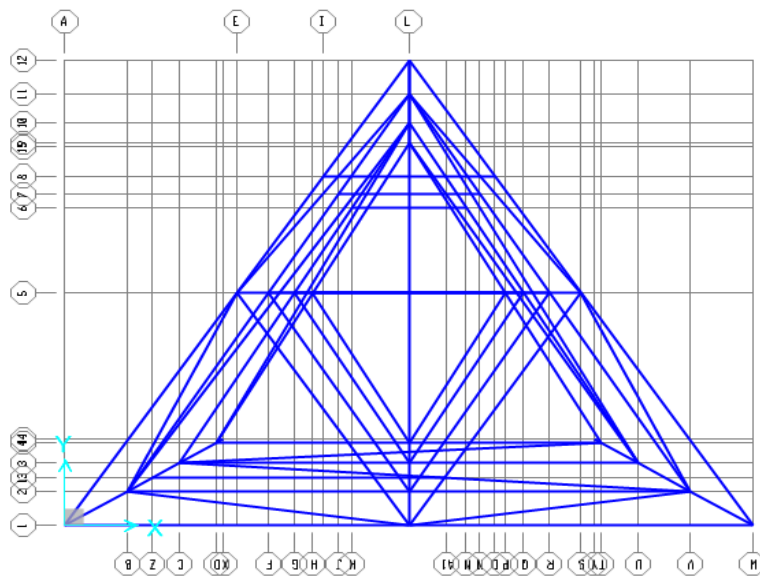
**Figure 3.18:** Pipe Section form

#### **Step 5:** Draw frame Objects

- i) Click the View menu > Set 2D view > Click on the X-Y Plane.
- ii) Click the Draw Frame button at the left side. The Properties of Object pop-up form will appear as shown in Figure 3.19.
- iii) Click in the Section drop-down list on the Properties of Object and choose the section of the members.



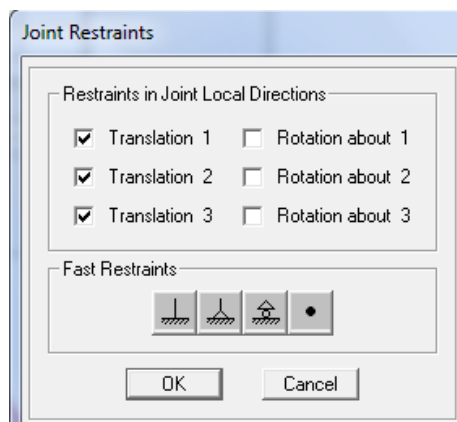
**Figure 3.19:** X-Y Plane @ Z=0



**Figure 3.20:** Draw Frame Model

**Step 6: Add Restraints**

- i) Select three joint at the end of offshore platform. Click on the Assign menu > Joints > Restraints
- ii) Click on the pinned button. Click OK.



**Figure 3.21:** Joint Restraints form

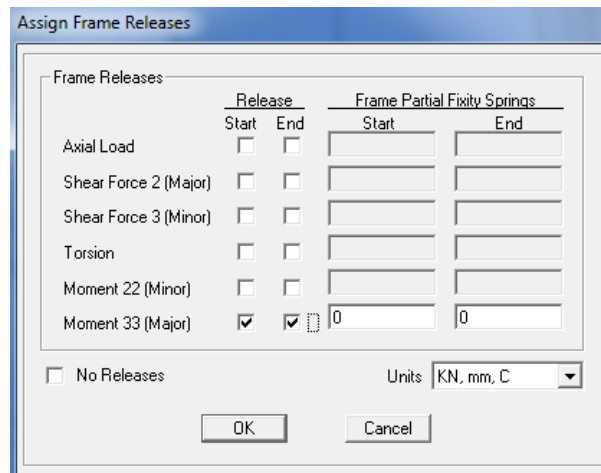
**Step 7: Save the Model**

- i) Click the File menu > Save or Save button to save model.

**Step 8: Assign Member End Releases**

- i) Select the whole of offshore platform in 3D view. Click Assign menu > Frame > Releases/partial Fixity.
- ii) Tick the Moment 33 (Major) boxes for both Start and End Release.

- iii) Click OK.



The 'Assign Frame Releases' dialog box is shown. It contains a table for defining releases and partial fixity springs. The 'Release' section has columns for 'Start' and 'End' with checkboxes. The 'Frame Partial Fixity Springs' section has columns for 'Start' and 'End' with input fields. The 'Moment 33 (Major)' row is selected with checkboxes in the 'Release' section and '0' in the 'Frame Partial Fixity Springs' section. A 'No Releases' checkbox is at the bottom left, and a 'Units' dropdown is at the bottom right. 'OK' and 'Cancel' buttons are at the bottom.

	Release		Frame Partial Fixity Springs	
	Start	End	Start	End
Axial Load	<input type="checkbox"/>	<input type="checkbox"/>		
Shear Force 2 (Major)	<input type="checkbox"/>	<input type="checkbox"/>		
Shear Force 3 (Minor)	<input type="checkbox"/>	<input type="checkbox"/>		
Torsion	<input type="checkbox"/>	<input type="checkbox"/>		
Moment 22 (Minor)	<input type="checkbox"/>	<input type="checkbox"/>		
Moment 33 (Major)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	0	0

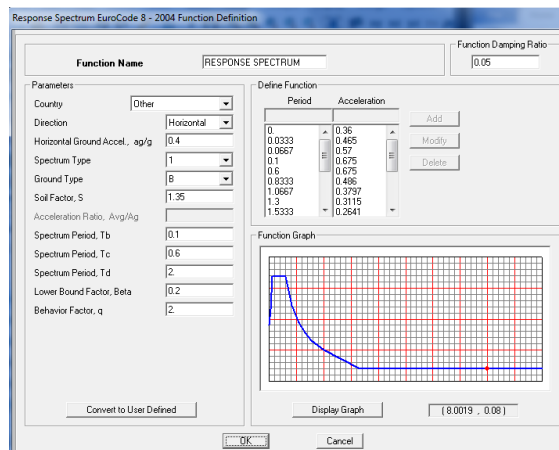
☐ No Releases      Units: KN, mm, C

OK      Cancel

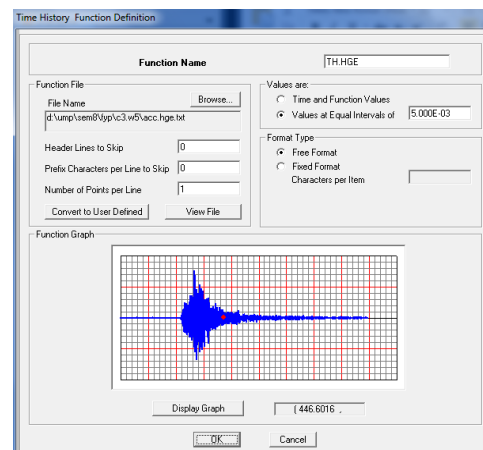
**Figure 3.22:** Assign Frame Releases form

### Step 9: Define Earthquake Analysis

- i) Click Define menu > Function > Response Spectrum > Choose Function Type to Add : Eurocode8 1994 > Add New Function
- ii) Rename the Function Name : RESPONSE SPECTRUM
- iii) Click OK. Refer to Figure 3.23 (a).
- iv) Click Define menu > Function > Time History > Add New Function
- v) Rename the Function Name
- vi) Browse the file location of the data acceleration for each direction.
- vii) Click OK. Refer to Figure 3.23 (b).



(a)

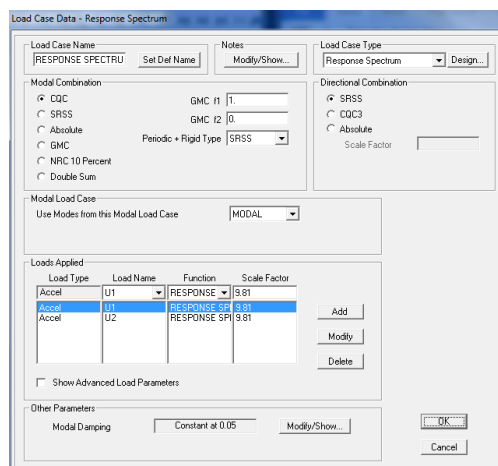


(b)

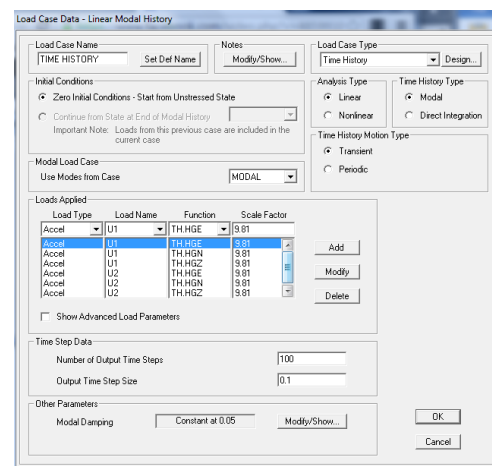
**Figure 3.23:** (a) Response spectrum settings (b) Time History settings

### Step 9: Define Load Cases

- i) Click the Define Menu > Load Cases > Add New Load Case > Rename Load Case > Choose Load Case Type > Change Setting for Loads Applied > Click OK



(a)



(b)

Load Case Data - Linear Static

Load Case Name: DEAD Set Def Name Modify/Show...

Load Case Type: Static Design...

Stiffness to Use: ☒ Zero Initial Conditions - Unstressed State ☐ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Analysis Type: ☒ Linear ☐ Nonlinear ☐ Nonlinear Staged Construction

Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	DEAD	1
Load Pattern	DEAD	1

Add Modify Delete

OK Cancel

(c)

Load Case Data - Modal

Load Case Name: MODAL Set Def Name Modify/Show...

Load Case Type: Modal Design...

Stiffness to Use: ☒ Zero Initial Conditions - Unstressed State ☐ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Type of Modes: ☒ Eigen Vectors ☐ Ritz Vectors

Number of Modes: Maximum Number of Modes: 12 Minimum Number of Modes: 1

Loads Applied: ☐ Show Advanced Load Parameters

Other Parameters: Frequency Shift (Center): 0 Cutoff Frequency (Radius): 0 Convergence Tolerance: 1.000E-09

☒ Allow Automatic Frequency Shifting

OK Cancel

(d)

Load Case Data - Linear Static

Load Case Name: LIVE Set Def Name Modify/Show...

Load Case Type: Static Design...

Stiffness to Use: ☒ Zero Initial Conditions - Unstressed State ☐ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Analysis Type: ☒ Linear ☐ Nonlinear ☐ Nonlinear Staged Construction

Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	LIVE	1
Load Pattern	LIVE	1

Add Modify Delete

OK Cancel

(e)

Load Case Data - Linear Static

Load Case Name: WIND Set Def Name Modify/Show...

Load Case Type: Static Design...

Stiffness to Use: ☒ Zero Initial Conditions - Unstressed State ☐ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Analysis Type: ☒ Linear ☐ Nonlinear ☐ Nonlinear Staged Construction

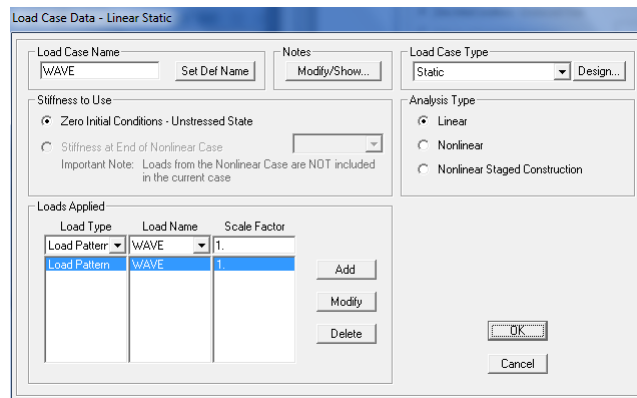
Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	WIND	1
Load Pattern	WIND	1

Add Modify Delete

OK Cancel

(f)



**Load Case Data - Linear Static**

Load Case Name: WAVE [Set Def Name] Notes: [Modify/Show...]

Load Case Type: Static [Design...]

Stiffness to Use:
 

- ☒ Zero Initial Conditions - Unstressed State
- ☐ Stiffness at End of Nonlinear Case

 Important Note: Loads from the Nonlinear Case are NOT included in the current case

Analysis Type:
 

- ☒ Linear
- ☐ Nonlinear
- ☐ Nonlinear Staged Construction

Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	WAVE	1
Load Pattern	WAVE	1

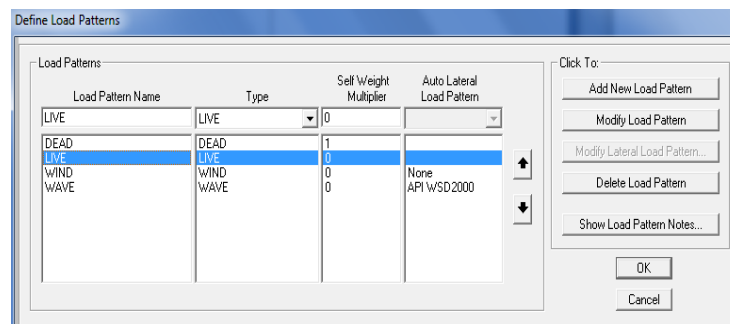
[Add] [Modify] [Delete] [OK] [Cancel]

(g)

**Figure 3.24:** Load settings (a) Response spectrum (b) Time History (c) Dead Load (d) Modal Load (e) Live Load (f) Wind Load (g) Wave Load.

### Step 10: Define Load Patterns

- i) Click the Define Menu > Load Patterns > Add New Load Pattern > Rename Load Pattern Name > Change Type > Auto Lateral Load Pattern



**Define Load Patterns**

Load Pattern Name	Type	Self Weight Multiplier	Auto Lateral Load Pattern
LIVE	LIVE	0	
DEAD	DEAD	1	
LIVE	LIVE	0	
WIND	WIND	0	None
WAVE	WAVE	0	API WSD 2000

Click To:
 

- Add New Load Pattern
- Modify Load Pattern
- Modify Lateral Load Pattern...
- Delete Load Pattern
- Show Load Pattern Notes...

 [OK] [Cancel]

**Figure 3.25:** Define Load Patterns Form



- ii) Click Load Pattern Name (WAVE) > Modify Lateral Load Pattern > Change Settings > Vertical Reference Elevation for Wave > Global Z Coordinate of Vertical Datum (Offshore Platform Depth)

The 'Wave Load Pattern' dialog box contains the following sections and fields:

- Wave Load Pattern Parameters:**
  - Wave Characteristics: Default (Add, Modify/Show, Delete)
  - Current Profile: CURRENT (Add, Modify/Show, Delete)
  - Marine Growth: None (Add, Modify/Show, Delete)
  - Drag and Inertia Coefficients: API Default (Add, Modify/Show, Delete)
  - Wind Load: WIND1 (Add, Modify/Show, Delete)
  - ☒ Include Buoyant Loads
- Wave Load Pattern Discretization:**
  - Maximum Discretization Segment Size: 1524
- Wave Crest Position:**
  - Global X Coord of Pt on Initial Crest Position: 0
  - Global Y Coord of Pt on Initial Crest Position: 0
  - Number of Wave Crest Positions Considered: 1
- Wave Direction:**
  - Wave Approach Angle in Degrees: 0
- Vertical Reference Elevation for Wave:**
  - Global Z Coordinate of Vertical Datum: 62200
- Other Vertical Elevations Relative To Datum:**
  - Mudline from Datum: -62200
  - High Tide from Datum: -1000
- Sea Water Properties:**
  - Water Weight Density: 1.005E 08
- Buttons:** Show Wave Table, Show Wave Plot, OK, Cancel

**Figure 3.26: Wave Load Patterns Settings**

- iii) Click Current Profile > Add CURRENT > Modify/Show > Change Settings > Click OK

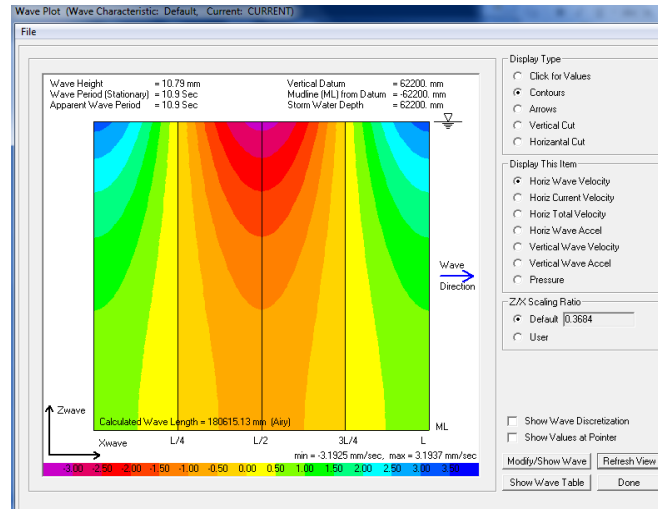
The 'Current Profile Data' dialog box contains the following sections and fields:

- Edit:**
  - Current Profile Name: CURRENT
- Current Profile Factors:**
  - Current Blockage Factor: 0.9
  - Current Profile Stretching Option: Linear
- Data Is Specified at This Number of Elevations:**
  - Number of Elevations: 1
- Current Profile Data:**

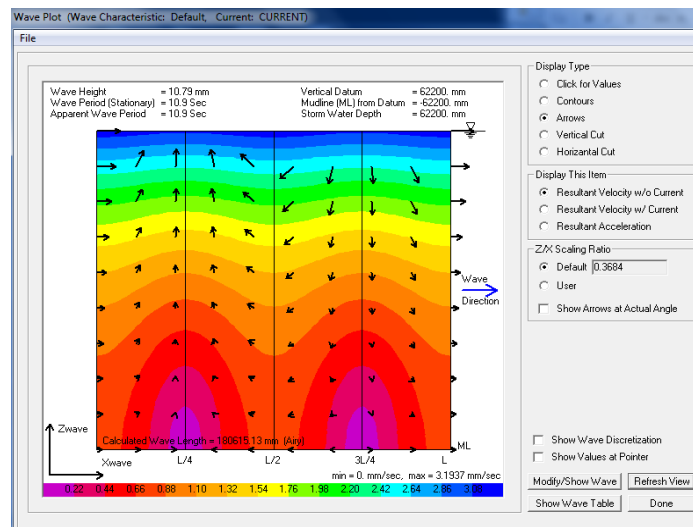
	Vent from Datum	Current Velocity	Current Direction
1	62200	750	90
- Buttons:** Order Rows, OK, Cancel

**Figure 3.27: Current Profile Data Settings**

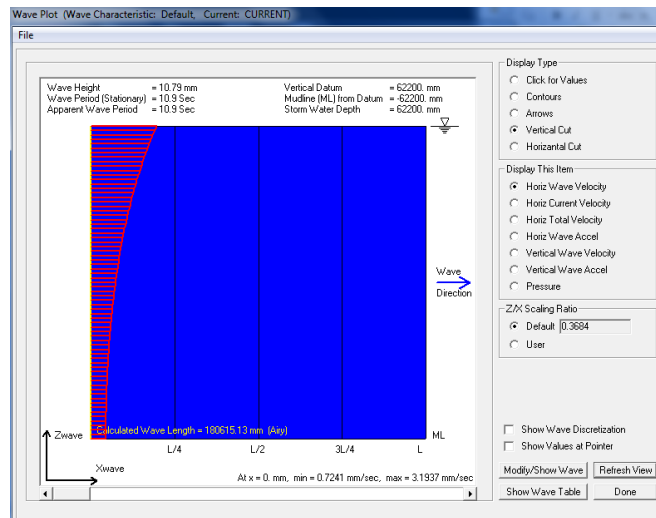
- iv) Click Show Wave Plot > Choose Display Type > Choose Display This item



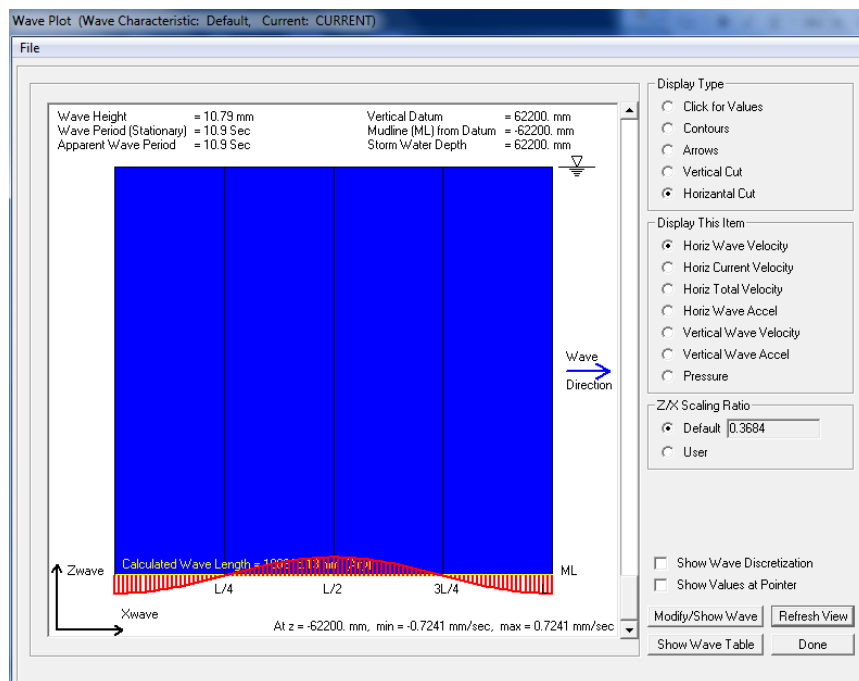
**Figure 3.28:** Contours with Horizontal Wave Velocity



**Figure 3.29:** Arrows with Resultant Velocity w/o Current



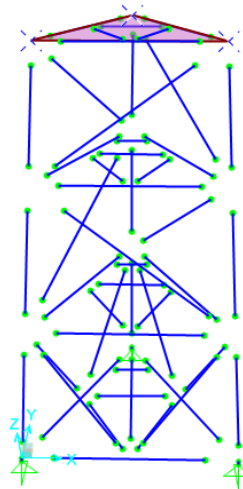
**Figure 3.30: Vertical Cut with Horizontal Wave Velocity**



**Figure 3.31: Horizontal Cut with Horizontal Wave Velocity**

### Step 11: Assign Loads

- i) Click three points at Top Slab as in figure 3.32 > Assign menu > Joint Loads > Forces > Choose Load pattern Name > Type value in the Force Global X and Y with minus sign which indicates direction of the load downward > Click OK



**Figure 3.32:** Click on three points at Top Slab

**Joint Forces**

Load Pattern Name: + DEAD

Units: KN, mm, C

Coordinate System: GLOBAL

Options: ☐ Add to Existing Loads, ☒ Replace Existing Loads, ☐ Delete Existing Loads

OK Cancel

Loads:

Force Global X	0.
Force Global Y	-1.21
Force Global Z	0.
Moment about Global X	0.
Moment about Global Y	0.
Moment about Global Z	0.

(a)

**Joint Forces**

Load Pattern Name: + LIVE

Units: KN, mm, C

Coordinate System: GLOBAL

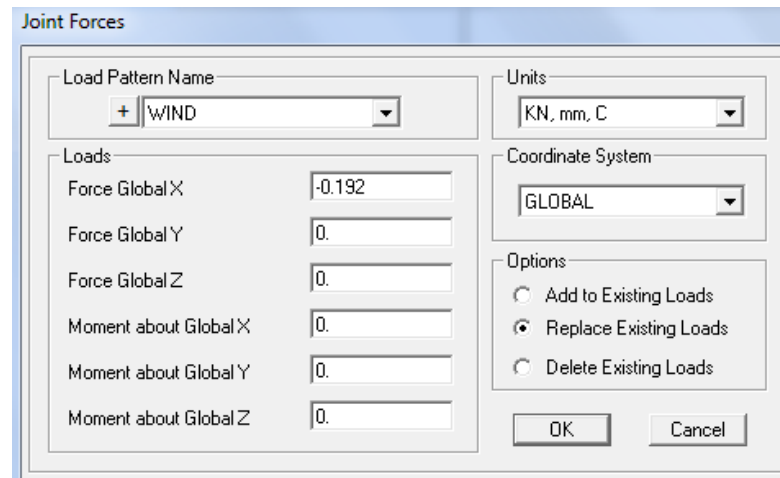
Options: ☐ Add to Existing Loads, ☒ Replace Existing Loads, ☐ Delete Existing Loads

OK Cancel

Loads:

Force Global X	0.
Force Global Y	-1.68
Force Global Z	0.
Moment about Global X	0.
Moment about Global Y	0.
Moment about Global Z	0.

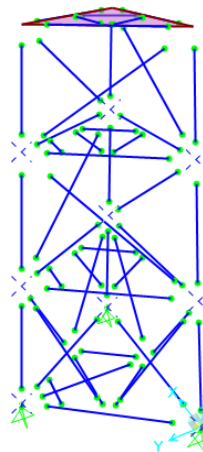
(b)



(c)

**Figure 3.33:** Joint Forces on slab for various load (a) Dead (b) Live (c) Wind

- ii) Click points below mean sea level > Assign menu > Joint Loads > Forces > Choose Load pattern Name (WAVE) > Choose Direction to test (Type 0.413 in the Force Global X) > Click OK



**Figure 3.34:** Click points below mean sea level

**Joint Forces**

Load Pattern Name: + WAVE

Units: KN, mm, C

Coordinate System: GLOBAL

Options:

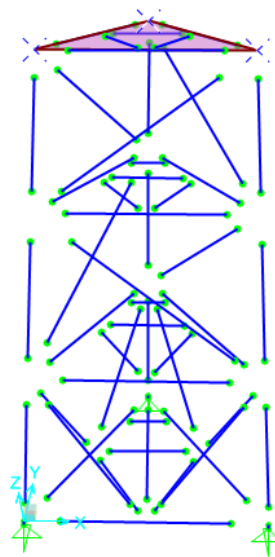
- ☐ Add to Existing Loads
- ☒ Replace Existing Loads
- ☐ Delete Existing Loads

OK Cancel

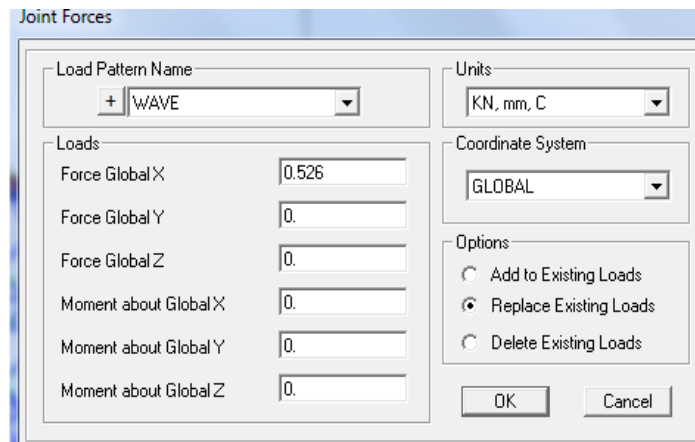
Loads:

Force Global X	0.413
Force Global Y	0.
Force Global Z	0.
Moment about Global X	0.
Moment about Global Y	0.
Moment about Global Z	0.

**Figure 3.35:** Joint Forces for Wave load below mean sea level



**Figure 3.36:** Click points above mean sea level

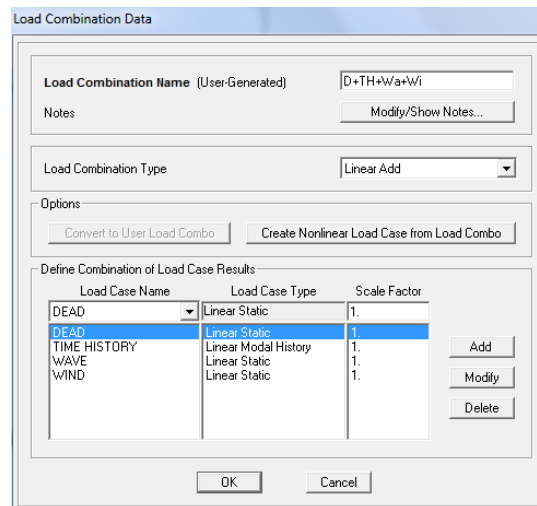


The Joint Forces dialog box is used to define load patterns. It includes a Load Pattern Name dropdown set to 'WAVE', Units set to 'KN, mm, C', and a Coordinate System set to 'GLOBAL'. The Loads section contains input fields for Force Global X (0.526), Force Global Y (0), Force Global Z (0), Moment about Global X (0), Moment about Global Y (0), and Moment about Global Z (0). The Options section has three radio buttons: 'Add to Existing Loads', 'Replace Existing Loads' (which is selected), and 'Delete Existing Loads'. OK and Cancel buttons are at the bottom right.

**Figure 3.37:** Joint Forces for Wave load above mean sea level

## Step 12: Define Load Combinations

- i) Click the Define Menu > Load Combinations > Add New Combo > Rename Load Combination Name > Change the settings > Click OK




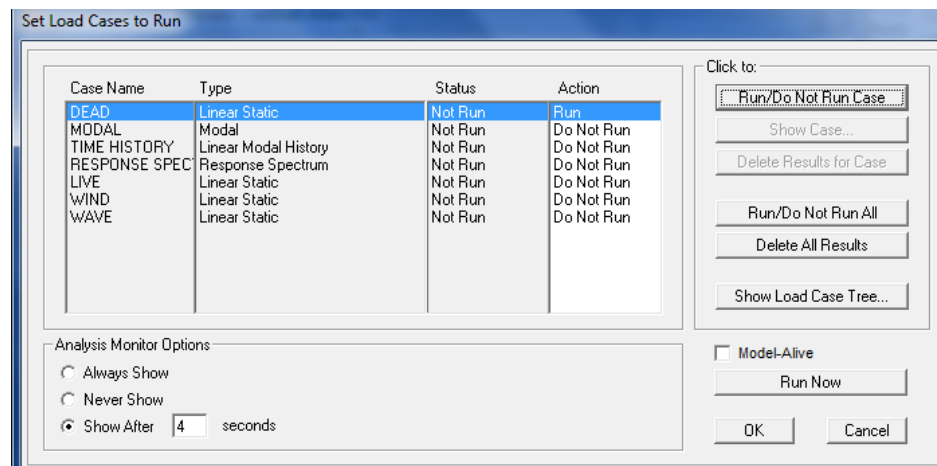
The Load Combination Data dialog box is used to define load combinations. It includes a Load Combination Name (User-Generated) field set to 'D+TH+Wa+Wi', a Notes field with a 'Modify/Show Notes...' button, and a Load Combination Type dropdown set to 'Linear Add'. The Options section has two buttons: 'Convert to User Load Combo' and 'Create Nonlinear Load Case from Load Combo'. The Define Combination of Load Case Results section contains a table with columns for Load Case Name, Load Case Type, and Scale Factor. The table lists four load cases: DEAD (Linear Static, Scale Factor 1), DEAD (Linear Static, Scale Factor 1), TIME HISTORY (Linear Modal History, Scale Factor 1), and WAVE (Linear Static, Scale Factor 1). There are Add, Modify, and Delete buttons to the right of the table. OK and Cancel buttons are at the bottom.

Load Case Name	Load Case Type	Scale Factor
DEAD	Linear Static	1.
DEAD	Linear Static	1.
TIME HISTORY	Linear Modal History	1.
WAVE	Linear Static	1.


**Figure 3.38:** Load Combination Data Forms

### Step 13: Run analysis

- i) Click the Analyze menu > Run Analysis or click the Run Analysis button  > Choose the cases that need to be tested > Click to Run/Do Not Run Case > Run Now > Click OK



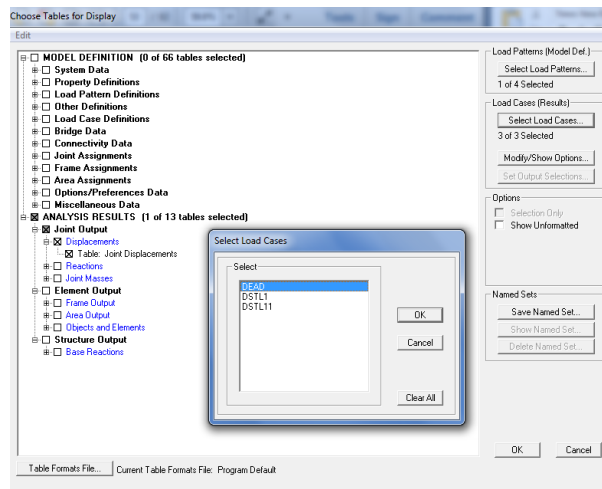
**Figure 3.39: Set Load Cases to Run Forms**

- ii) When the analysis is finished, the model is locked.  Lock/Unlocked button appears depressed. Locked the model is to prevents any changes to the model. When others cases need to be run, unlocked the model first.

### Step 14: Review the analysis result

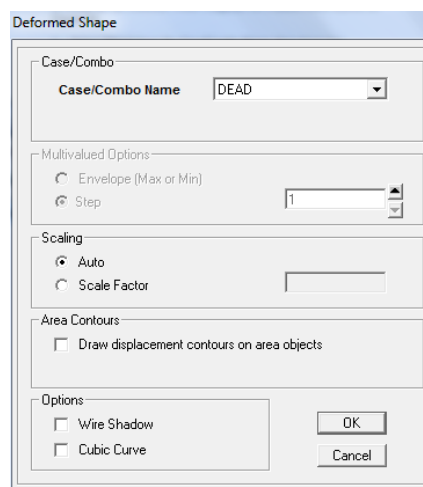
- i) Firstly, run the analysis > Display menu > Show Tables > Choose Analysis Result that need > Click Joint Output > Displacements > Select Load Cases > Click OK





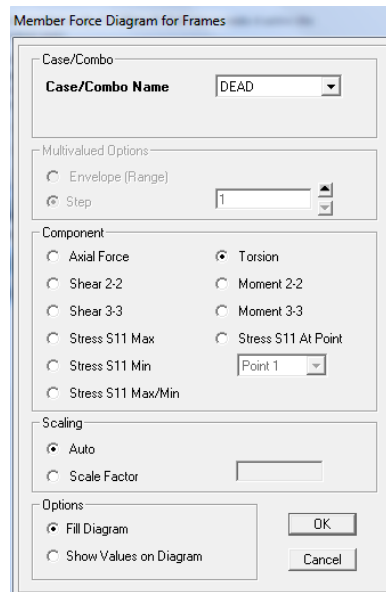
**Figure 3.40:** Choose Tables for Display form

- ii) Joint Displacements table appears > Click File > Export Current Table > To Excel > Click Done to close the tables.
- iii) Run the analysis > Display menu > Show Deformed Shape > Select the Case > Click OK



**Figure 3.41:** Deformed Shape form

- iv) Run the analysis > Display menu > Show Forces/Stresses > Frames/Cables/Tendons > Select the Case > Select the Component > Click OK



**Figure 3.42:** Member Force Diagram for Frames form

- v) Right click on the critical members to check for the graph analysis.

### 3.8 OFFSHORE DESIGN CRITERIA AND PROPERTIES

As for the total stiffness and the total mass of the 3-legged fixed offshore platforms structures can be referred to the Appendix C. The total stiffness,  $k$  of this model is  $10.5789 \times 10^{12}$  and its mass is 5125737.7 kg.

**Table 3.3:** Material property data based on Europe EN 1993-1-1 per EN 10025-2

Material type	S355	Minimum Yield Stress, $F_y$	0.355
Material type	Steel	Minimum Tensile Stress, $F_u$	0.51
Modulus of Elasticity, $E$	210	Effective Yiled Stress, $F_{ye}$	0.3905
Poisson's Ratio, $U$	0.3	Effective Tensile Stress, $F_{ue}$	0.561
Coefficient of Thermal Expansion, $A$	1.17E-05	Units	Kn,mm,C
Shear Modulus, $G$	80.7692		

**Table 3.4:** Self-weight and functional load

No.	Load descriptions	[MN]
1	Self-weight	-13.306
2	Jacket appurtenances weight	-0.553
3	Topside dead loads	-1.908
4	Topside live loads	-2.655
5	Piping and equipment weights	-29.537
<b>Total</b>		<b>-47.959</b>

**Table 3.5:** Environmental load

MSL	Design Condition
62.20m Wave height	10.79
Wave period	10.9
Current velocity	0.75
Wind speed	21.8
Max. tide	2
Storm surge	0.4

### 3.9 OFFSHORE DESIGN STRUCTURE

All the equations are based on the code of practice of “Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms (API RP-2A, 2000). All the calculations can be referred to Appendix A.

#### 3.9.1 Wind Load

Wind forces are exerted to the portion of the offshore structure platform which is above the water such as equipment, deck houses and derricks that are located on the platform (API RP-2A, 2000).

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

Where,

$F$  = wind force (N)

$\rho$  = mass density of air (1.2 kg/m<sup>3</sup>)

$u$  = wind speed (m/s)

$C_s$  = shape Coefficient

$A$  = area (m<sup>2</sup>)

### 3.9.2 Wave Load

Waves are irregular in shape, vary in length and height which can approach a platform from one or more directions simultaneously. Therefore, it is difficult to determine the intensity and distribution of the forces applied by waves. However, the complex nature of the technical factors must be considered in developing wave-dependent criteria for the design offshore platform structure. The effects of this force exerted by waves can be computed by the Morison equation:

$$F = F_D + F_I = C_D \frac{w}{2g} A U |U| + C_m \frac{w}{g} V \frac{\delta U}{\delta t} \quad (3.2)$$

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)

$F_I$  = Inertia force per unit length of the member (N/m)

$C_D$  = drag coefficient

$C_m$  = inertia coefficient

$w$  = density of water (N/m<sup>3</sup>)

$g$  = gravitational acceleration (m/s<sup>2</sup>)

$A$  = projected area (=D for circular cylinders) (m)

$V$  = displaced volume ( $=\frac{\pi D^2}{4}$  for circular cylinders) (m<sup>2</sup>)

$U$  = component of velocity vector due to wave (m/s)

$|U|$  = absolute value of  $U$  (m/s)

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

**Table 3.6:** Coefficient for wave load

	$C_d$	$C_m$
<b>Smooth</b>	0.65	1.6
<b>Rough</b>	1.05	1.2

### 3.9.3 Current

Currents are important in the design of the fixed offshore platforms as the forces on the platform and it can affect the location and orientation of boat landings and barge bumpers. The total current profile should be specified for platform design with associated the sea-state that produce extreme waves. The current force of the member for no wave conditions can be calculated using the equation 3.2 with  $\frac{\delta U}{\delta t} = 0$ .

## 3.10 OFFSHORE DESIGN STRUCTURE FOR CRITICAL MEMBER

All the equations are based on the code of practice of Eurocode 3. All the calculations can be referred to Appendix B.

### 3.10.1 Shear Resistance $V_{c,Rd}$

Shear resistance,  $V_{c,Rd} = V_{pl,Rd}$

$$V_{pl,Rd} = \frac{A_v \left( \frac{f_y}{\sqrt{3}} \right)}{\gamma_{m0}} \quad (3.3)$$

Where,

$A_v$  = shear area

$f_y$  = yield strength

$\gamma_{m0}$  = partial factor for resistance of cross-sections whatever the class is (=1)

### 3.10.2 Shear Stress, $\sigma_s$

$$\sigma_s = \frac{V_{Ed}}{A_c} \quad (3.4)$$

Where,

$V_{Ed}$  = design shear stress

$A_c$  = area of section

### 3.10.3 Allowable Shear Stress, $\sigma_{all,s}$

$$\sigma_{all,s} = \frac{V_{c,Rd}}{A_c} \quad (3.5)$$

Where,

$V_{c,Rd}$  = shear resistance

$A_c$  = area of section

### 3.10.4 Bending Moment Resistance, $M_{c,Rd}$

Moment resistance,  $M_{c,Rd} = M_{pl,Rd}$

$$M_{pl,Rd} = \frac{W_{pl}(f_y)}{\gamma_{m0}} \quad (3.6)$$

Where,

$W_{pl}$  = plastic section modulus

$\gamma_{m0}$  = partial factor for resistance of cross-sections whatever the class is (=1)



### 3.10.5 Bending Stress, $\sigma_b$

$$\sigma_b = \frac{M_{Ed}}{S_x} \quad (3.7)$$

Where,

$M_{Ed}$  = design bending moment

$S_x$  = Section modulus

### 3.10.6 Allowable Bending Stress, $\sigma_{all,b}$

$$\sigma_{all,b} = \frac{M_{c,Rd}}{S_x} \quad (3.8)$$

Where,

$M_{c,Rd}$  = Moment resistance

$S_x$  = Section modulus

## **CHAPTER 4**

### **RESULTS AND DISCUSSIONS**

#### **4.1 INTRODUCTION**

The 3-legged of fixed offshore structure has been analysed and being assess for the seismic analysis. The assessment also covers the static and dynamic for the earthquake analysis by using the code of practice of “Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms (API RP-2A, 2000). The SAP 2000 computer program has been used to check the steel structure based on Eurocode 3, 2005. However, there are assumption has been made such that the structure is fixed to the ground and the geometry, material properties and section properties of the structure are represent almost the same from the actual structure.

##### **4.1.1 Analysis of fixed steel jacket**

As for designing the offshore platform, it needs to consider the dead load, live load, environmental loads (wind, wave and current load) and earthquake load such that free

vibration, time history and response spectrum. The results that obtained from the various loads such as follows:

- i. Dead load
- ii. Live load
- iii. Free Vibration
- iv. Response Spectrum
- v. Environmental load (wind + wave + current load)
- vi. Dead load + Environmental load + Time history

The results that obtained from the analysis as follows:

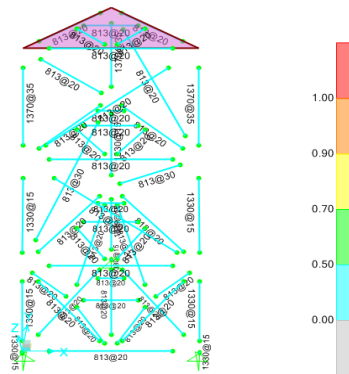
- i. The mode shape of the fixed offshore structure.
- ii. The natural period of fixed offshore structure.
- iii. The shear force, bending moment, axial force and displacement under various loads.
- iv. The maximum shear stress, bending stress and allowable capacity check of the members.

## 4.2 ANALYSIS DESIGN CHECK

### 4.2.1 Free Vibration Analysis

The period of vibration is a basic parameter in the force-based design of structures and this parameter describes the spectral acceleration and then the base shear force to which the building should be designed. This analysis takes a critical look at the way in which seismic design codes around the world have accepted the designer to assume the period of vibration to be used in both linear static and dynamic analyses. Then, for the most building design projects, empirical building period formulas are needed to be used to initiate the design process (Kwon O, 2010). The basic period of vibration,  $T$  is a function of the stiffness of the building mass and the lateral load resisting system.

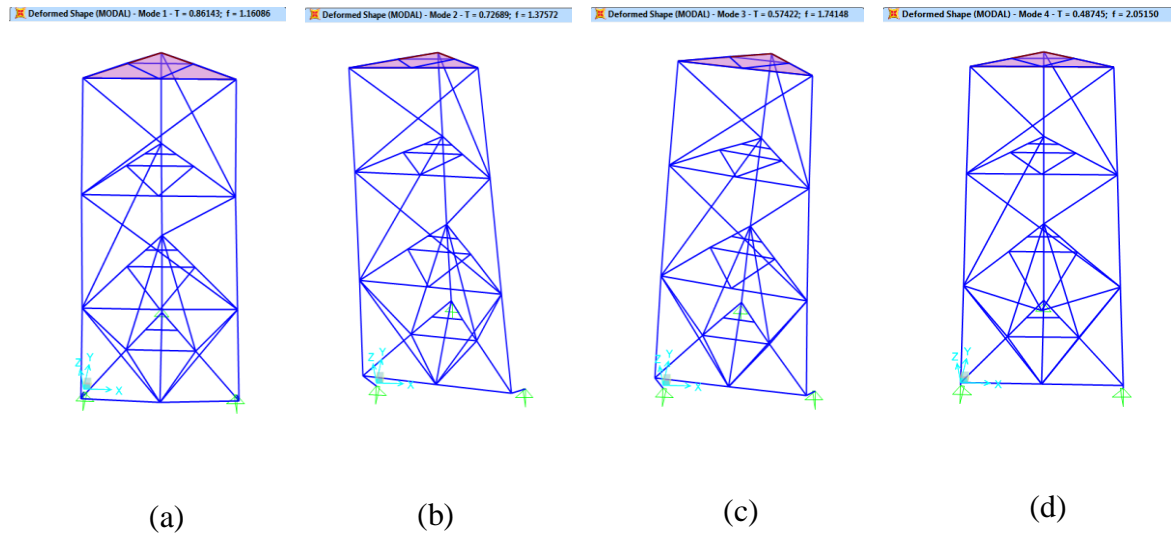
Many codes identify that the period of vibration from the simplified period–height equation is more practical, having been directly gained from the calculated periods of vibration of buildings subject to earthquake ground motions, however when higher modes are significant (in tall and/or irregular structures) the modal response spectrum method gives a more practical profile of the lateral forces (Abdel Raheem SE, 2013)



**Figure 4.1:** Free vibration analysis in P-M interaction ratios

**Table 4.1:** Modal Periods And Frequencies

Modal Periods And Frequencies							
File View Format-Filter-Sort Select Options							
Units: As Noted							
Modal Periods And Frequencies							
	OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
	Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
►	MODAL	Mode	1	0.861433	1.1609	7.2539	53.201
	MODAL	Mode	2	0.726891	1.3757	8.6439	74.717
	MODAL	Mode	3	0.574224	1.7415	10.942	119.73
	MODAL	Mode	4	0.487449	2.0515	12.89	166.15
	MODAL	Mode	5	0.440718	2.269	14.257	203.25
	MODAL	Mode	6	0.392081	2.5505	16.025	256.81
	MODAL	Mode	7	0.328374	3.0453	19.134	366.12
	MODAL	Mode	8	0.315944	3.1651	19.887	395.49
	MODAL	Mode	9	0.293286	3.4096	21.423	458.96
	MODAL	Mode	10	0.277656	3.6016	22.629	512.09
	MODAL	Mode	11	0.275475	3.6301	22.809	520.23
	MODAL	Mode	12	0.235405	4.248	26.691	712.41

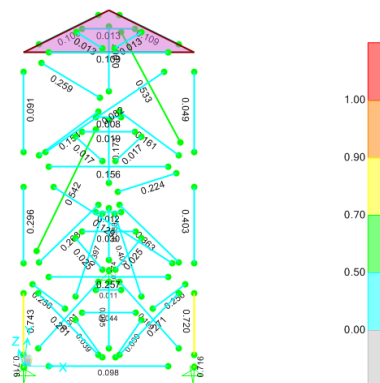
**Figure 4.2:** Deformed shape for (a) mode 1 (b) mode 2 (c) mode 3 (d) mode 4

From the analysis of free vibration cases, the results are obtained for deformed shapes that are contains of 12 mode shape with their time period. The most accurate mode shape is from mode shape 1, as shown in Figure 4.2 (a), the highest time period is 0.86143 sec with their frequency of 1.16086 cyc/sec. Figure 4.2 (b) shows for mode 2 which their

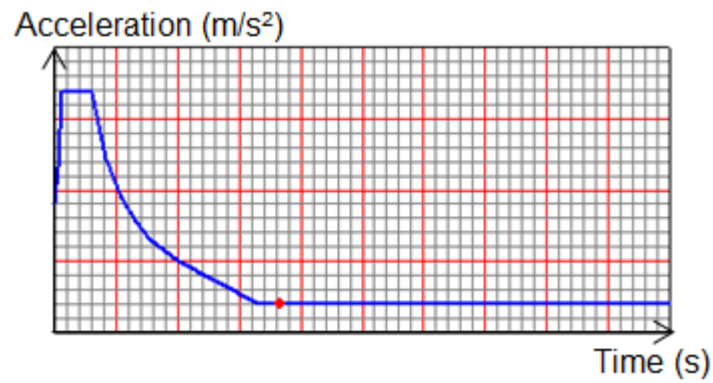
time is 0.72689 sec with frequency of 1.37572 cyc/sec. While, Figure 4.2 (c) shows for mode 3 which their time is 0.57422 sec with frequency of 1.74148 cyc/sec. Next, Figure 4.2 (d) shows for mode 4 which their time is 0.48745 sec with frequency of 2.05150 cyc/sec. The others 8 mode shapes are shown in the Appendix D.

#### 4.2.2 Response Spectrum Analysis

Response spectrum analysis were obtained by the shape of the target elastic acceleration spectrum which are then characterized by the seismic intensity that are expressed in terms of the expected design peak ground acceleration (PGA) and also their effect of soil ground types (Shehata E. Abdel Raheem, et al., 2014) Many codes recognize that a modal response spectrum method gives a more realistic profile of the lateral forces as the period-height equation is more realistic.(Crowley H, Pinho R, 2010) There are computational advantages by using this method of seismic analysis for prediction of displacements and member forces in structural systems. It involves the calculation of only the maximum values for the member forces and displacements in each mode using smooth design spectra that are the average of several earthquake motions.



**Figure 4.3:** Response spectrum analysis in P-M interaction ratios



**Figure 4.4:** Response spectrum graph

From the Figure 4.4, it shows the response spectrum graph. The maximum acceleration is  $0.675 \text{ m/s}^2$  and about 0.1022 s to 0.5905 s.

**Table 4.2:** Response Spectrum Modal Information

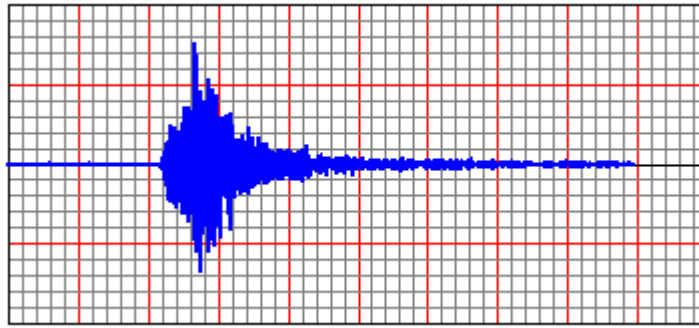
Response Spectrum Modal Information												
File View Format-Filter-Sort Select Options												
Units: As Noted												
	OutputCase Text	ModalCase Text	StepType Text	StepNum Unitless	Period Sec	DampRatio Unitless	U1Acc mm/sec2	U2Acc mm/sec2	U3Acc mm/sec2	U1Amp mm	U2Amp mm	U3Amp mm
►	RESPONSE SPECTRUM	MODAL	Mode	1	0.861433	0.05	4.64	0	0	-0.000004492	0	0
	RESPONSE SPECTRUM	MODAL	Mode	2	0.726891	0.05	5.61	0	0	0.059126	0	0
	RESPONSE SPECTRUM	MODAL	Mode	3	0.574224	0.05	6.62	0	0	-0.01462	0	0
	RESPONSE SPECTRUM	MODAL	Mode	4	0.487448	0.05	6.62	0	0	0.00000251	0	0
	RESPONSE SPECTRUM	MODAL	Mode	5	0.440718	0.05	6.62	0	0	0.00000207	0	0
	RESPONSE SPECTRUM	MODAL	Mode	6	0.392081	0.05	6.62	0	0	0.00048	0	0
	RESPONSE SPECTRUM	MODAL	Mode	7	0.328374	0.05	6.62	0	0	-0.000213	0	0
	RESPONSE SPECTRUM	MODAL	Mode	8	0.315944	0.05	6.62	0	0	0.000327	0	0
	RESPONSE SPECTRUM	MODAL	Mode	9	0.293286	0.05	6.62	0	0	-0.000161	0	0
	RESPONSE SPECTRUM	MODAL	Mode	10	0.277856	0.05	6.62	0	0	0.000188	0	0
	RESPONSE SPECTRUM	MODAL	Mode	11	0.275475	0.05	6.62	0	0	-0.000475	0	0
	RESPONSE SPECTRUM	MODAL	Mode	12	0.235405	0.05	6.62	0	0	0.00013	0	0

Record: 1 of 12

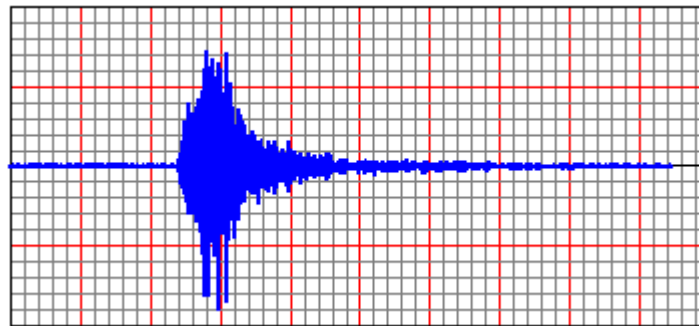
Add Tables... Done



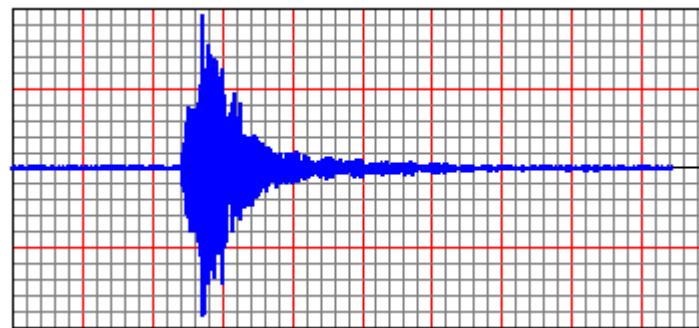




(a)



(b)

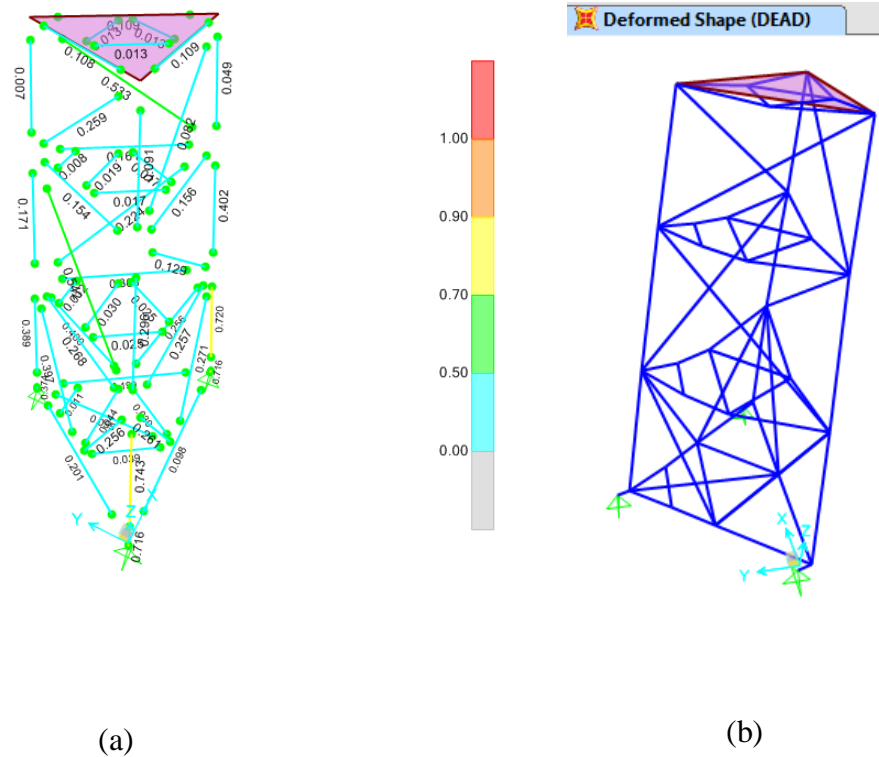


(c)

**Figure 4.6:** Time History graph that obtained from SAP 2000 (a) HGE direction  
(b) HGN direction (c) HGZ direction.

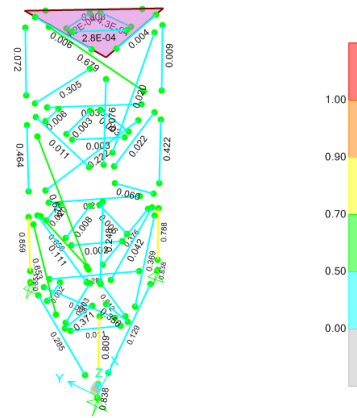
Figure 4.6 (a) shows the time history graph for HGE direction. The maximum acceleration is about 1.222 gals and at the time 636.33 sec. While, for the Figure 4.6 (b) shows the time history graph for HGN direction. The maximum acceleration is about 1.08 gals and at the time 893.65 sec. Next, Figure 4.6 (c) shows the time history graph for HGZ direction. The maximum acceleration is about 0.96 gals and at the time 1087.63 sec.

#### 4.2.4 Dead Load



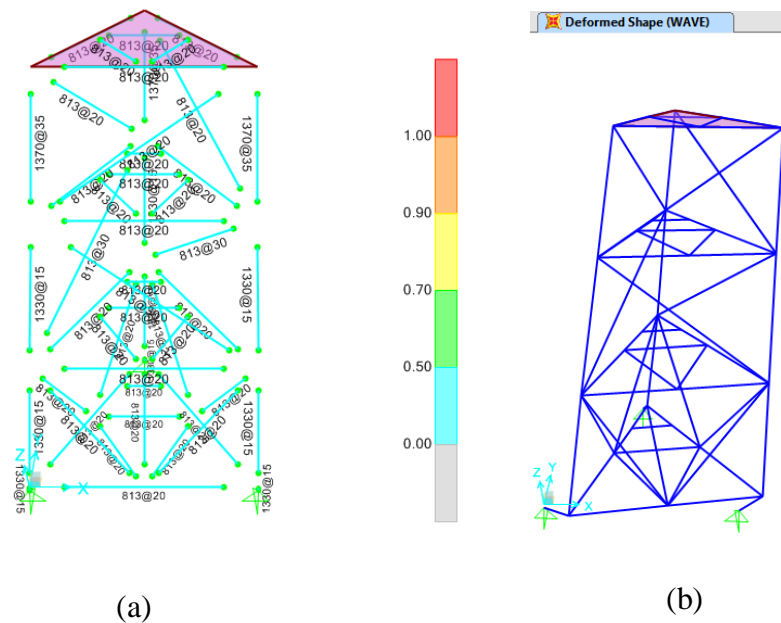
**Figure 4.7:** Dead load analysis (a) Critical member in P-M interaction ratios  
(b) Deformed shape

### 4.2.5 Live Load



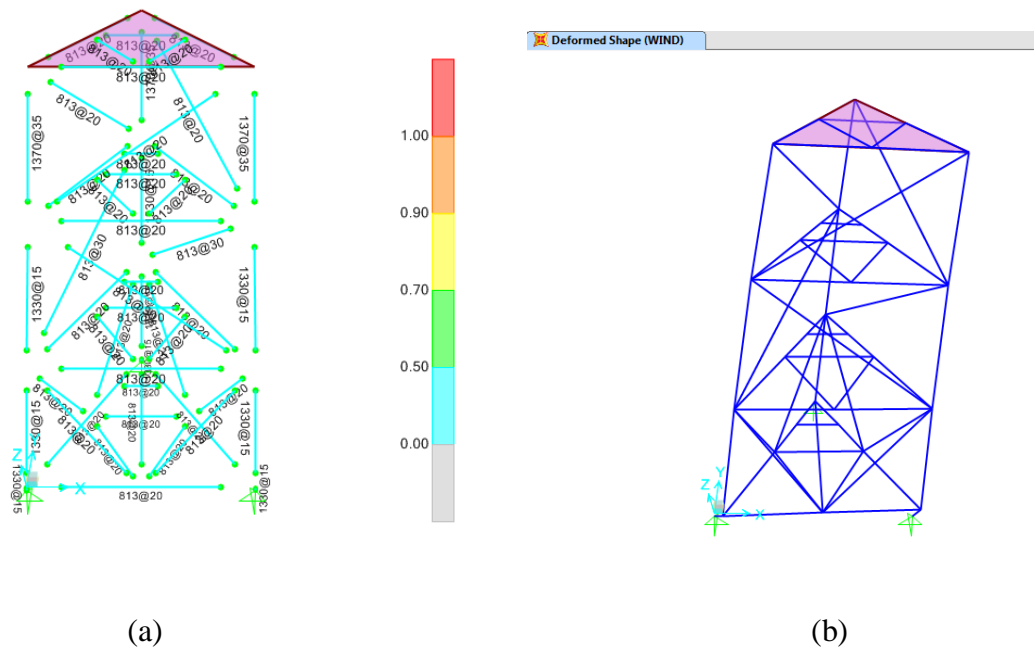
**Figure 4.8:** Live load analysis in P-M interaction ratios

### 4.2.6 Wave Load



**Figure 4.9:** Wave load analysis (a) Critical member in P-M interaction ratios  
(b) Deformed shape

### 4.2.7 Wind Load



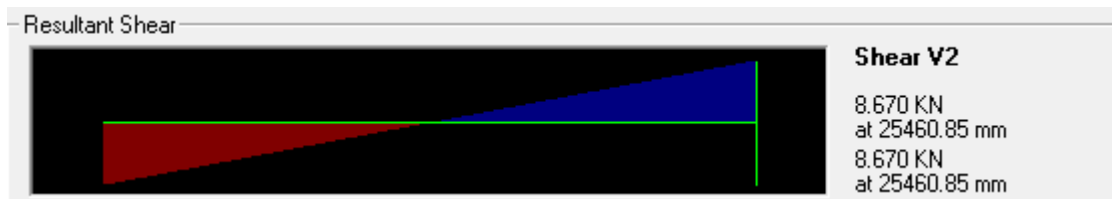
**Figure 4.10:** Wind load analysis (a) Critical member in P-M interaction ratios

(b) Deformed shape

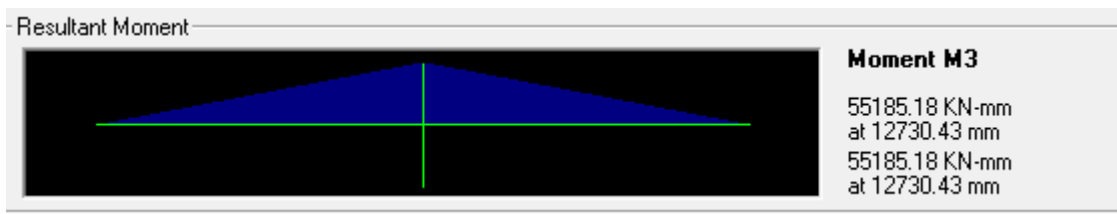
### 4.3 ANALYSIS OF SHEAR, MOMENT AND AXIAL FORCE FOR CRITICAL MEMBER OF VARIOUS LOADS

#### 4.3.1 Dead Load, DL

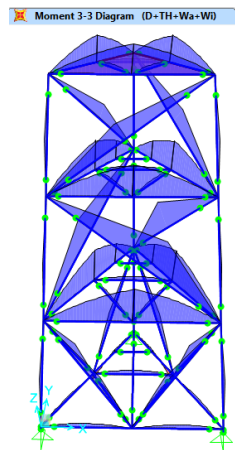
The analysis that obtained from SAP 2000 also defines the most critical part for the analysis of dead load that is frame 33 of the jacket offshore platform. Figure 4.11 shows the shear force is 8.67 kN and the bending moment is 55185.18 kN.mm as shown in Figure 4.12. While, from the Figure 4.14, the axial force is 6850.43 kN.



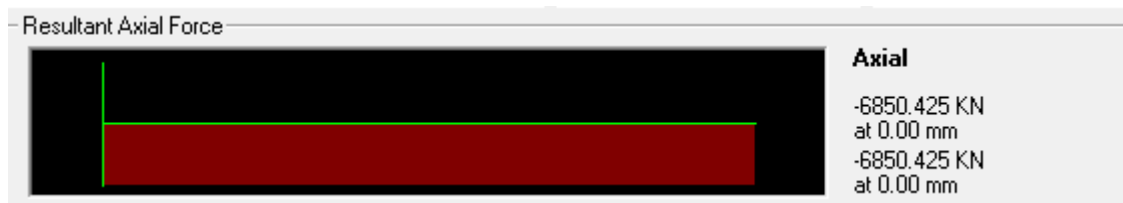
**Figure 4.11:** Shear force graph for member 33



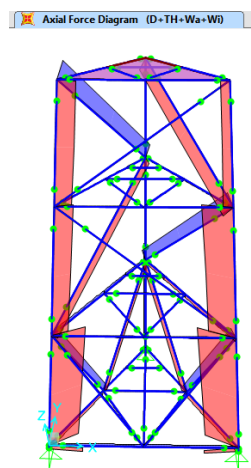
**Figure 4.12:** Bending moment graph for member 33



**Figure 4.13:** Bending moment diagram of offshore platform



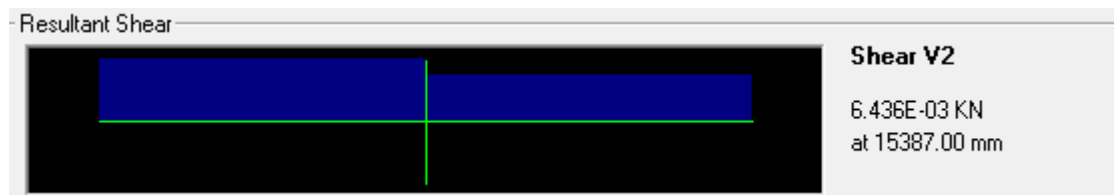
**Figure 4.14:** Axial force graph for member 33



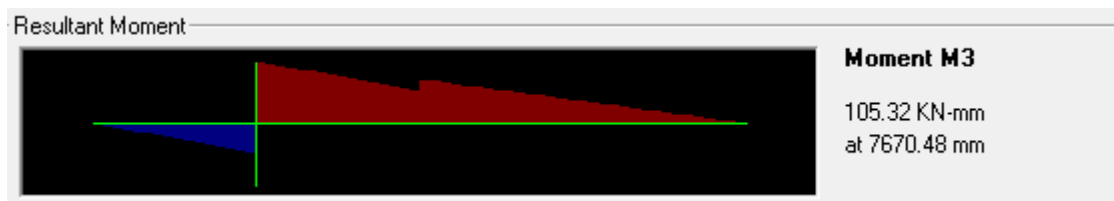
**Figure 4.15:** Axial force diagram of offshore platform

### 4.3.2 Environmental load, EL (Wind+Wave+Current)

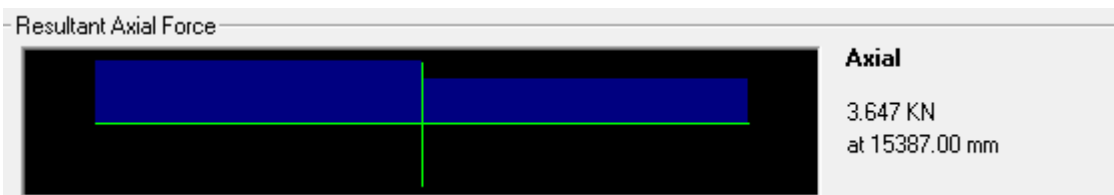
The analysis that obtained from SAP 2000 also defines the most critical part for the analysis of environmental load which are wind, wave and current that is frame 5 of the jacket offshore platform. Figure 4.16 shows the shear force is  $6.436 \times 10^{-3}$  kN and the bending moment is 105.32 kN.mm as shown in Figure 4.17. While, from the Figure 4.18, the axial force is 3.467 kN.



**Figure 4.16:** Shear force graph for frame 5



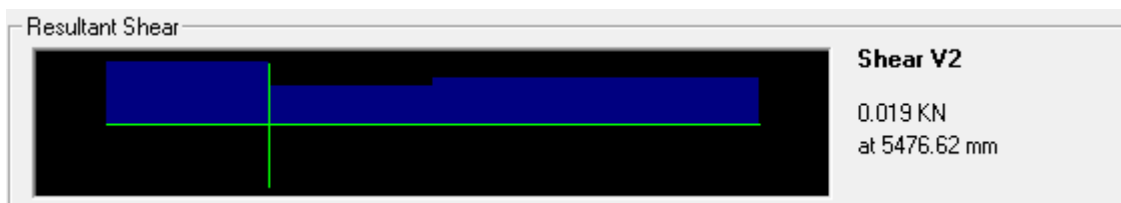
**Figure 4.17:** Bending moment graph for frame 5



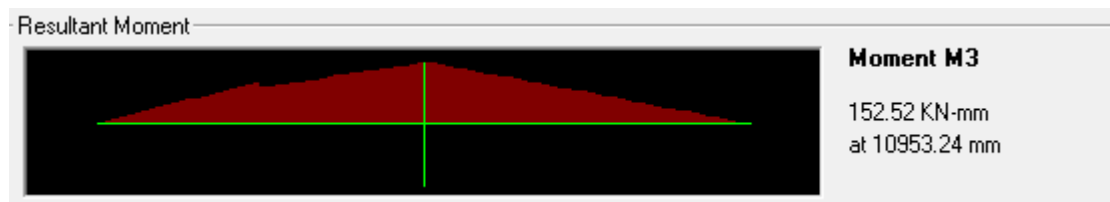
**Figure 4.18:** Axial force graph for frame 5

### 4.3.3 Response Spectrum, RS

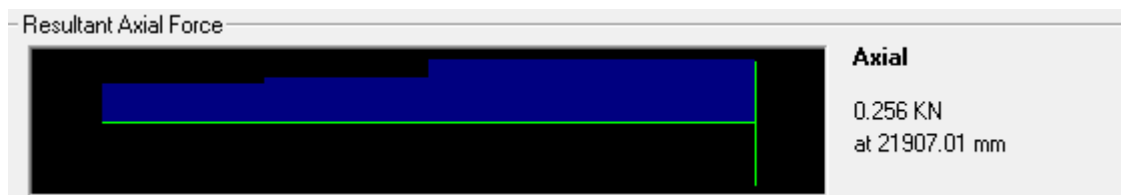
The analysis that obtained from SAP 2000 also defines the most critical part for the analysis of response spectrum that is frame 21 of the jacket offshore platform. Figure 4.19 shows the shear force is 0.019 kN and the bending moment is 152.52 kN.mm as shown in Figure 4.20. While, from the Figure 4.21, the axial force is 0.256 kN.



**Figure 4.19:** Shear force graph for frame 21



**Figure 4.20:** Bending moment graph for frame 21

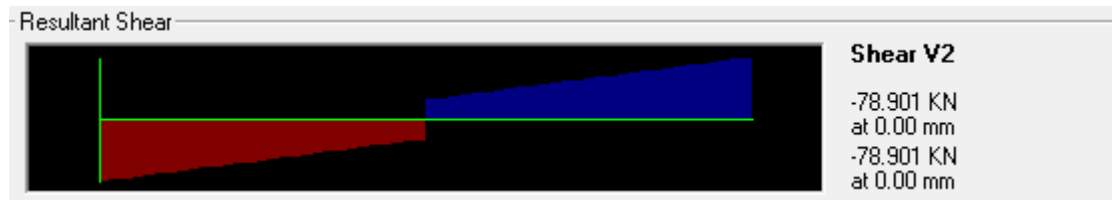


**Figure 4.21:** Axial force graph for frame 21

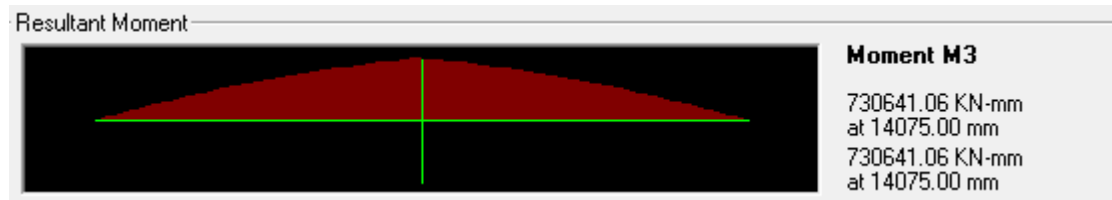


#### 4.3.4 Combination load (Dead Load + Time History + Wind + Wave), DL+TH+WI+WA

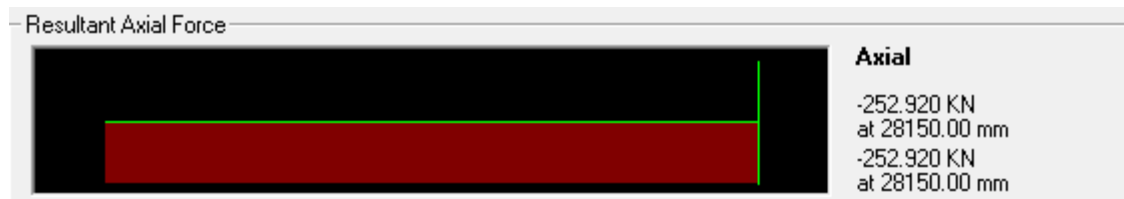
The analysis that obtained from SAP 2000 also defines the most critical part for the analysis of combination of load which are dead load, time history and environmental load that is frame 10 of the jacket offshore platform. Figure 4.22 shows the shear force is 78.901 kN and the bending moment is 730641.06 kN.mm as shown in Figure 4.23. While, from the Figure 4.24, the axial force is 252.92 kN.



**Figure 4.22:** Shear force graph for frame 10



**Figure 4.23:** Bending moment graph for frame 10



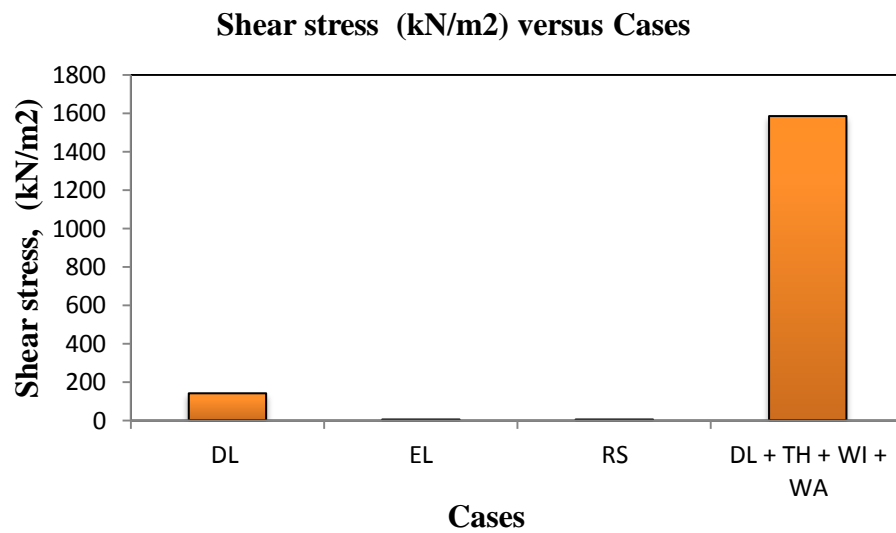
**Figure 4.24:** Axial force graph for frame 10

## 4.4 SUMMARY OF ANALYSIS

### 4.4.1 Shear Force and Shear Stress

**Table 4.3:** Shear force and shear stress for each combination load case

Case	Frame name	Design shear force, $V_{Ed}$ (kN)	Shear resistance, $V_{c,Rd}$ (kN)	Shear stress, $\sigma_s$ (kN/m <sup>2</sup> )	Allowable shear stress, $\sigma_{all,s}$ (kN/m <sup>2</sup> )
DL	33	8.67	8085.65	139.84	130413.71
EL	5	$6.436 \times 10^{-3}$	6501.31	0.129	130548.39
RS	21	0.019	6501.31	0.382	130548.39
DL + TH + WI + WA	10	78.901	6501.31	1584.36	130548.39



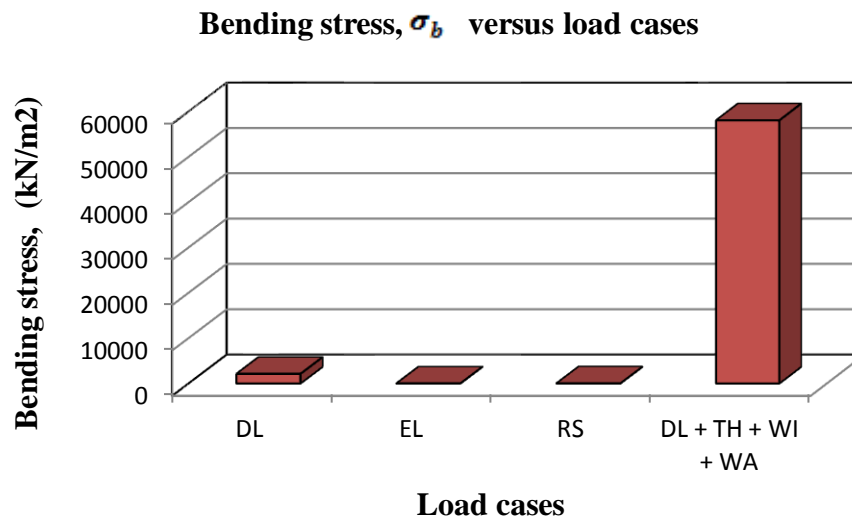
**Figure 4.25:** Shear stress versus various cases

The table 4.3 and figure 4.25 shows the shear stress at most critical member of jacket offshore platform for the analysis of the various load. All the calculation of the shear stress can be obtained in the Appendix B .It shows that the highest value for shear stress is  $1584.36 \text{ kN/m}^2$  which are the combination of dead load, time history, wind and wave load that occurs in frame 10. However, the shear stress is lower than the allowable stress which is  $130548.39 \text{ kN/m}^2$ . Therefore, the offshore platform can withstand the loading and safe.

#### 4.4.2 Bending Moment and Bending Stress

**Table 4.4:** Bending moment and bending stress for each combination load case

Case	Frame name	Max external design moment, $M_{ed} \text{ (kN.mm)}$	Moment resistance, $M_{rd} \text{ (kN.mm)}$	Bending stress, $\sigma_b \text{ (kN/m}^2\text{)}$	Allowable bending stress, $\sigma_{all,b} \text{ (kN/m}^2\text{)}$
DL	33	55185.18	9208522.5	2127	355000
EL	5	105.32	4465774.57	8.372	355000
RS	21	152.52	4465774.57	12.12	355000
DL + TH + WI + WA	10	730641.06	4465774.57	58081.21	355000



**Figure 4.26:** Bending stress versus various cases

The table 4.4 and figure 4.26 shows the bending stress at most critical member of jacket offshore platform for the analysis of the various load. All the calculation of the bending stress can be obtained in the Appendix B .It shows that the highest value for bending stress is 58081.21 kN/m<sup>2</sup> which are the combination of dead load, time history, wind and wave load that occurs in frame 10. However, the bending stress is lower than the allowable bending stress which is 355000 kN/m<sup>2</sup>. Therefore, the offshore platform can withstand the loading and safe.

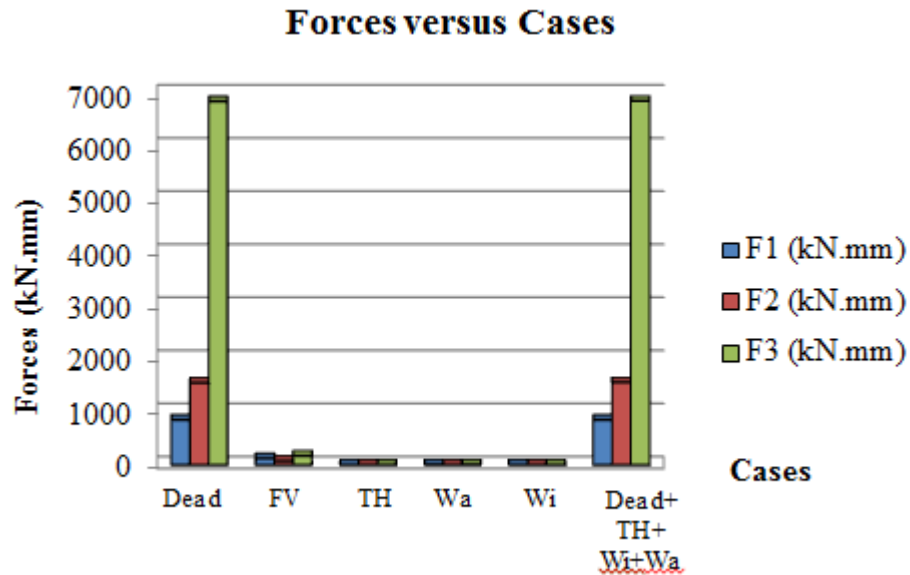


From the result as shown in table 4.5 and figure 4.27, it shows the maximum displacement is 182.38 mm for U2 direction when live load is applied.

#### 4.4.4 Force

**Table 4.6:** Force result for various load analysis

Cases	F1 (kN.mm)	F2 (kN.mm)	F3 (kN.mm)
<b>Dead</b>	847.38	1550.52	6850.42
<b>Free Vibration (FV)</b>	121.00	76.95	171.06
<b>Time History (TH)</b>	0.0000065	0.0000048	0.000018
<b>Wave (Wa)</b>	3.995	1.49	5.69
<b>Wind (Wi)</b>	0.32	0.07	1.03
<b>Dead+TH+Wind+Wave</b>	848.15	1552.08	6856.67



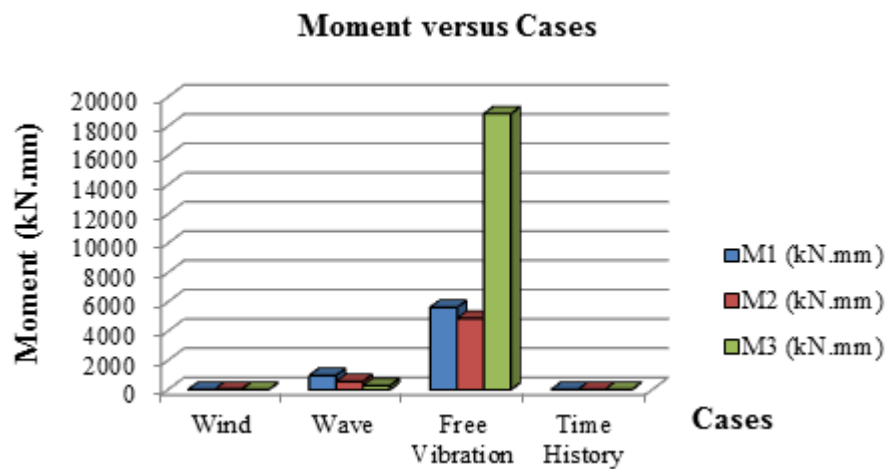
**Figure 4.28:** Force graph for various load analysis

From the result for the force that obtained as shown in table 4.6 and figure 4.28, the maximum force is 6856.67 kN.mm for F3 direction when the combination of dead load, time history, wind and wave load is applied.

#### 4.4.5 Moment

**Table 4.7:** Moment result for various load analysis

Cases	M1 (kN.mm)	M2 (kN.mm)	M3 (kN.mm)
Wind	0.52	25.54	2.98
Wave	959.37	558.67	272.68
Free Vibration	5615.01	4866.04	18850.56
Time History	0.006478	0.006478	0.000649



**Figure 4.29:** Moment graph for various load analysis

From the result of bending moment as shown in table 4.7, it gives the maximum value is 18850.56 kN.mm when earthquake loading which is free vibration is being applied.

## **CHAPTER 5**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **5.1 INTRODUCTION**

Most of the offshore platform in Malaysia is designed without considering of the earthquake effects because there are no regulations requiring the structure to be designed for earthquake as Malaysia does not lie in any presently demarcated seismic zone. However, Malaysia is located close to seismically active plate boundaries which are the inter-plate boundary between Eurasian and Philippine Plates on the east. Sabah is the only state in Malaysia that exposed to earthquake activities if compared to other parts of Malaysia. Recently, an earthquake struck the Ranau, sabah and surrounding areas such as Tambunan, Tuaran, Kota Kinabalu and Kota Belud on 5<sup>th</sup> June 2015, Friday measuring 5.9 on the Richter scale which claiming 18 lives (The Star Online,2015).

Therefore, the significance of the research study is to identify the earthquake ground motion due to Philippine earthquake for assessment of offshore platform in Malaysia. The analysis of behavior of the offshore platform structures of 3-legged fixed offshore structures under the earthquake effect is obtained to develop the earthquake design criteria



for the offshore structures that are located in Malaysia region. The related code (API) and the computer software of SAP 2000 is used for analysis are very helpful for designing offshore structure.



**Figure 5.1:** The glass at bank in Ranau Sabah broken due to Ranau earthquake

Source: <http://www.astroawani.com/foto-malaysia/gempa-bumi-melanda-ranau-sabah-2480/bank-di-ranau-27294>



**Figure 5.2:** The structural column fracture and collapsed due to Ranau earthquake.

Source: <http://www.astroawani.com/foto-malaysia/gempa-bumi-melanda-ranau-sabah-2480/tiang-rumah-yang-hampir-musnah-27305>

## 5.2 CONCLUSIONS

Based on the finding research, it can be concluded that:

- i. This fixed offshore platform is not representing 100% of the actual structure because the assumption have been made such that the structure is fixed to the ground and the connection which is welded joint is not considered to be designed in this research.

- ii. The structure can withstand the dead load, live load, environmental load and seismic load since the result shows that the maximum shear stress and bending stress are lower than allowable capacity check.
- iii. The maximum shear stress is 1584.36 kN/m<sup>2</sup> which are the combination of dead load, time history, wind and wave load that occurs in frame 10.
- iv. The highest value for bending stress is 58081.21 kN/m<sup>2</sup> which are the combination of dead load, time history, wind and wave load that occurs in frame 10.
- v. From the result of bending moment, it gives the maximum value is 18850.56 kN.mm when earthquake loading which is free vibration is being applied
- vi. The maximum displacement is 182.38 mm when live load is applied.
- vii. From the free vibration analysis, the highest value of natural period is 0.86143s that is from mode shape 1.
- viii. The analysis of behavior of the offshore platform structures of 3-legged fixed offshore structures under the earthquake effect is obtained.

### **5.3 RECOMMENDATIONS**

There are several recommendations that can be made for the further research regarding to this topic:

- i. More analysis to study the column behaviour and soil interaction method should be considered.
- ii. Improvement to the offshore structure model structure can still be done so that actual behaviour of jacket member can be obtained such as the joint connection should be model according the designed specification.
- iii. The research for this offshore structure can be made for other offshore structure, not limited to only for fixed offshore structure.

## REFERENCES

- Marto, A. (n.d.) (2014). Liquefaction Potential of Nusajaya City, 17231–17239.
- Shehata E. Abdel Raheem • Mohamed M. Ahmed • Tarek M. A. Alazrak(2014) Evaluation of soil–foundation–structure interaction effects on seismic response demands of multi-story MRF buildings on raft foundations
- Potty, N. S., Redzuan, M., & Hamid, A. (2013). Seismic Evaluation of High Rise Structures in Malaysia, 8(12), 1459–1477.
- Husen, H., Majid, T. A., Nazri, F. M., Arshad, M. R., & Faisal, A. (2013). Development of Design Response Spectra Based on Various Attenuation Relationships at Specific Location, 7(12), 1501–1506.
- Abdel Raheem SE (2013) Evaluation of Egyptian code provisions for seismic design of moment resisting frames multi-story buildings. *Int J Adv Struct Eng* 5(20):1–18
- Kharade AS, Kapadiya SV, Belgaonkar SL (2013) Earthquake analysis of tall sky-pod structures by considering the soil structure interaction effect. *Int J Emerg Technol Adv Eng* 3(1):447–454
- Elmasry, M. I. S. (2012). Response spectra for differential motion of structures supports during earthquakes in Egypt. *HBRC Journal*, 8(3), 217–227.  
doi:10.1016/j.hbrcj.2012.12.005
- Moustafa, A., & Mahadevan, S. (2011). Reliability analysis of uncertain structures using earthquake response spectra. *Earthquakes and Structures*, 2(3), 279–295.  
doi:10.12989/eas.2011.2.3.279
- Park, M., Koo, W., & Kawano, K. (2011). Dynamic response analysis of an offshore platform due to seismic motions. *Engineering Structures*, 33(5), 1607–1616.  
doi:10.1016/j.engstruct.2011.01.030
- Static, N. (2011). for SAP2000 Linear and Nonlinear Static and Dynamic Analysis and Design of Three-Dimensional, (February).
- Fulfillment, I. P., Li, B. C., & Supervisor, T. (2011). Influence of Site Conditions on Near-field Effects in Multi-channel Surface Wave Measurements of the Requirements for the Degree Master of Science, (July).

- Aminaton Marto, Azlan Adnan, Hendriyawan, & Masyhur Irsyam .  
(2011), MICROZONATION MAPS FOR KUALA LUMPUR AND PUTRAJAYA.  
23(1), 63–85.
- Kwon O (2010) Kim ES: Evaluation of building period formulas for seismic design. *Earthq Eng Struct Dynam* 39:1569–1583
- Crowley H, Pinho R (2010) Revisiting Eurocode 8 formulae for periods of vibration and their employment in linear seismic analysis. *Earthquake Eng Struct Dynam* 39:223–235
- Roberto Villaverde. (2009). *Fundamental Concepts of Earthquake Engineering*. Infobase Publishing.
- Timothy Kusky. (2008). *Earthquakes Plate Tectonics and Earthquake Hazards*. CRC Press.
- Engr. Dr. Jeffrey Chiang, Engr. M. C. Hee. (2008). Technical Review of JKR ' s “ Handbook on Seismic Design Guidelines for Concrete Buildings in Malaysia ”  
INTRODUCTION OF THE DESIGN H A N D B O O K :, (March), 26–28.
- Adnan, A., Marto, A., & Irsyam, M. (2007). SEISMIC HAZARD ASSESSMENT FOR PENINSULAR, 42, 57–73.
- Communication, S., Muiyiwa, O. A., & Sadeghi, K. (2007). Construction Planning of an Offshore Petroleum, 82–85.
- Edition, T. (2007). Recommended Practice for Planning , Designing and Constructing Fixed Offshore Platforms — Working Stress Design, (October).
- Sadeghi, K., & Sadeghi, K. (2007). An Overview of Design , Analysis , Construction and Installation of Offshore Petroleum Platforms Suitable for Cyprus Oil / Gas Fields, 2(4), 1–16.
- Ghobarah, A., Saatcioglu, M., & Nistor, I. (2006). The impact of the 26 December 2004 earthquake and tsunami on structures and infrastructure. *Engineering Structures*, 28(2), 312–326. doi:10.1016/j.engstruct.2005.09.028
- Ir Ng Pek Har, Hadi Golabi (May 2005). The Effect of Earthquake Related Tremors on Buildings in Malaysia.
- Kobayashi, T., Yoshikawa, K., Takaoka, E., Nakazawa, M., & Shikama, Y. (2002). Time history nonlinear earthquake response analysis considering materials and geometrical nonlinearity. *Nuclear Engineering and Design*, 212(1-3), 145–154.  
doi:10.1016/S0029-5493(01)00470-8

Division, S., Service, M. M., & Sultan, J. (2001). By Malaysian Meteorological Service.

American Petroleum Institute (API). (December 2000). Recommended Practice for Planning, Designing & Constructing Fixed Offshore Platforms, API-RP.2A-WSD, 21st edition.

## APPENDIX A

### OFFSHORE DESIGN STRUCTURE

#### Wind load

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

$$F = \frac{1.2}{2} \times 21.8^2 \times 1.0 \times 1.47$$

$$F = 19.23 \text{ N}$$

#### Wave load

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

#### Smooth

$$F = 0.65 \times \frac{9810}{2 \times 9.81} \times 1.37 \times 0.75 \times |0.75| + 1.6 \times \frac{9810}{9.81} \times \frac{\pi \times 1.37^2}{4} \times \frac{0.75}{10.9}$$

$$F = 250.45 + 162.29$$

$$F = 412.74 \frac{N}{m} = 0.413 \frac{kN}{m}$$

#### Rough

$$F = 1.05 \times \frac{9810}{2 \times 9.81} \times 1.37 \times 0.75 \times |0.75| + 1.2 \times \frac{9810}{9.81} \times \frac{\pi \times 1.37^2}{4} \times \frac{0.75}{10.9}$$

$$F = 404.58 + 121.72$$

$$F = 526.3 \frac{N}{m} = 0.526 \frac{kN}{m}$$

#### Current

$$F_c = F_D = C_D \frac{w}{2g} A U |U|$$

$$F_c = 250.45 \frac{N}{m} = 0.25 \frac{kN}{m}$$



## APPENDIX B

### CALCULATION FOR CRITICAL MEMBER

#### DEAD LOAD: FRAME 33

##### Shear Resistance, $V_{c,Rd}$

- i) Maximum external design shear force,  $V_{Ed} = 8.670$  kN
- ii) Shear resistance,  $V_{c,Rd} = V_{pl,Rd}$

$$\text{Where, } V_{pl,Rd} = \frac{A_v \left( \frac{f_y}{\sqrt{3}} \right)}{\gamma_{m0}}$$

From SAP 2000 computer software,

Shear Area,  $A_v = 39450 \text{ mm}^2$ ,  $f_y = 355 \text{ N/mm}^2$ ,  $\gamma_{m0} = 1$

$$V_{pl,Rd} = \frac{39450 \left( \frac{355}{\sqrt{3}} \right)}{1}$$

$$V_{pl,Rd} = 8085.65 \text{ kN}$$

- iii) Design Check,

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{8.670}{8085.65} = 0.0011 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

Area,  $A_c = 61967.915 \text{ mm}^2$

$$\text{Shear Stress, } \sigma_s = \frac{V_{Ed}}{A_c} = \frac{8.670}{0.062} = 139.84 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Shear Stress, } \sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{8085.65}{0.062} = 130413.71 \frac{\text{kN}}{\text{m}^2}$$

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

The shear stress is  $139.84 \text{ kN/m}^2$ , while the allowable shear stress is  $130413.71 \text{ kN/m}^2$ .

### **Bending Moment Resistance, $M_{c,Rd}$**

i) Maximum external design shear force,  $M_{Ed} = 55185.18 \text{ kN.mm}$

ii) Moment resistance,  $M_{c,Rd} = M_{pl,Rd}$

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

From SAP 2000 computer software,

$$W_{pl} = 25939500.00 \text{ mm}^3, f_y = 355 \text{ N/mm}^2, \gamma_{m0} = 1$$

$$M_{pl,Rd} = \frac{25939500.00(355)}{1}$$

$$M_{pl,Rd} = 9208522.5 \text{ kN.mm}$$

iii) Design Check,

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{55185.18}{9208522.5} = 0.006 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

$$\text{Section modulus, } S_x = 25939500.00 \text{ mm}^3$$

$$\text{Bending Stress, } \sigma_b = \frac{M_{Ed}}{S_x} = \frac{55185.18}{25939500.00} = 2.127 \times 10^{-3} \frac{\text{kN}}{\text{mm}^2} = 2127 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Bending Stress, } \sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{9208522.5}{25939500.00} = 0.355 \frac{\text{kN}}{\text{mm}^2} = 355000 \frac{\text{kN}}{\text{m}^2}$$

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

The bending stress is  $2127 \text{ kN/m}^2$ , while the allowable bending stress is  $355000 \text{ kN/m}^2$ .

## ENVIRONMENTAL LOAD (WIND + WAVE): FRAME 5

### Shear Resistance, $V_{c,Rd}$

- i) Maximum external design shear force,  $V_{Ed} = 6.436 \times 10^{-3}$  kN
- ii) Shear resistance,  $V_{c,Rd} = V_{pl,Rd}$

$$\text{Where, } V_{pl,Rd} = \frac{A_v \left( \frac{f_y}{\sqrt{3}} \right)}{\gamma_{m0}}$$

From SAP 2000 computer software,

Shear Area,  $A_v = 31720 \text{ mm}^2$ ,  $f_y = 355 \text{ N/mm}^2$ ,  $\gamma_{m0} = 1$

$$V_{pl,Rd} = \frac{31720 \left( \frac{355}{\sqrt{3}} \right)}{1}$$

$$V_{pl,Rd} = 6501.31 \text{ kN}$$

- iii) Design Check,

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{6.436 \times 10^{-3}}{6501.31} = 0.000001 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

Area,  $A_c = 49825.66 \text{ mm}^2$

$$\text{Shear Stress, } \sigma_s = \frac{V_{Ed}}{A_c} = \frac{6.436 \times 10^{-3}}{0.0498} = 0.129 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Shear Stress, } \sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{6501.31}{0.0498} = 130548.39 \frac{\text{kN}}{\text{m}^2}$$

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

The shear stress is  $0.129 \text{ kN/m}^2$ , while the allowable shear stress is  $130548.39 \text{ kN/m}^2$ .

**Bending Moment Resistance,  $M_{c,Rd}$** 

- i) Maximum external design shear force,  $M_{Ed} = 105.32 \text{ kN.m}$
- ii) Moment resistance,  $M_{c,Rd} = M_{pl,Rd}$

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

From SAP 2000 computer software,

$$W_{pl} = 12579646.67 \text{ mm}^3, f_y = 355 \text{ N/mm}^2, \gamma_{m0} = 1$$

$$M_{pl,Rd} = \frac{12579646.67(355)}{1}$$

$$M_{pl,Rd} = 4465774.57 \text{ kN.mm}$$

- iii) Design Check,

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{105.32}{4465774.57} = 0.000024 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

$$\text{Section modulus, } S_x = 12579646.67 \text{ mm}^3$$

$$\text{Bending Stress, } \sigma_b = \frac{M_{Ed}}{S_x} = \frac{105.32}{12579646.67} = 8.372 \times 10^{-6} \frac{\text{kN}}{\text{mm}^2} = 8.372 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Bending Stress, } \sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{4465774.57}{12579646.67} = 0.355 \frac{\text{kN}}{\text{mm}^2} = 355000 \frac{\text{kN}}{\text{m}^2}$$

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

The bending stress is  $8.372 \text{ kN/m}^2$ , while the allowable bending stress is  $355000 \text{ kN/m}^2$

.

## RESPONSE SPECTRUM: FRAME 21

### Shear Resistance, $V_{c,Rd}$

- i) Maximum external design shear force,  $V_{Ed} = 0.019 \text{ kN}$
- ii) Shear resistance,  $V_{c,Rd} = V_{pl,Rd}$

$$\text{Where, } V_{pl,Rd} = \frac{A_v \left( \frac{f_y}{\sqrt{3}} \right)}{\gamma_{m0}}$$

From SAP 2000 computer software,

Shear Area,  $A_v = 31720 \text{ mm}^2$ ,  $f_y = 355 \text{ N/mm}^2$ ,  $\gamma_{m0} = 1$

$$V_{pl,Rd} = \frac{31720 \left( \frac{355}{\sqrt{3}} \right)}{1}$$

$$V_{pl,Rd} = 6501.31 \text{ kN}$$

- iii) Design Check,

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{0.019}{6501.31} = 0.0000029 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

Area,  $A_c = 49825.66 \text{ mm}^2$

$$\text{Shear Stress, } \sigma_s = \frac{V_{Ed}}{A_c} = \frac{0.019}{0.0498} = 0.382 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Shear Stress, } \sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{6501.31}{0.0498} = 130548.39 \frac{\text{kN}}{\text{m}^2}$$

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

The shear stress is  $0.382 \text{ kN/m}^2$ , while the allowable shear stress is  $130548.39 \text{ kN/m}^2$ .

### Bending Moment Resistance, $M_{c,Rd}$

- i) Maximum external design shear force,  $M_{Ed} = 152.52 \text{ kN.m}$
- ii) Moment resistance,  $M_{c,Rd} = M_{pl,Rd}$

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

From SAP 2000 computer software,

$$W_{pl} = 12579646.67 \text{ mm}^3, f_y = 355 \text{ N/mm}^2, \gamma_{m0} = 1$$

$$M_{pl,Rd} = \frac{12579646.67(355)}{1}$$

$$M_{pl,Rd} = 4465774.57 \text{ kN.mm}$$

- iii) Design Check,

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{152.52}{4465774.57} = 0.000034 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

$$\text{Section modulus, } S_x = 12579646.67 \text{ mm}^3$$

$$\text{Bending Stress, } \sigma_b = \frac{M_{Ed}}{S_x} = \frac{152.52}{12579646.67} = 12.12 \times 10^{-6} \frac{\text{kN}}{\text{mm}^2} = 12.12 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Bending Stress, } \sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{4465774.57}{12579646.67} = 0.355 \frac{\text{kN}}{\text{mm}^2} = 355000 \frac{\text{kN}}{\text{m}^2}$$

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

The bending stress is  $12.12 \text{ kN/m}^2$ , while the allowable bending stress is  $355000 \text{ kN/m}^2$ .

**COMBINATION OF (DEAD LOAD + TIME HISTORY + WIND + WAVE):  
FRAME 10**

**Shear Resistance,  $V_{c,Rd}$**

- i) Maximum external design shear force,  $V_{Ed} = 78.901 \text{ kN}$
- ii) Shear resistance,  $V_{c,Rd} = V_{pl,Rd}$

$$\text{Where, } V_{pl,Rd} = \frac{A_v \left( \frac{f_y}{\sqrt{3}} \right)}{\gamma_{m0}}$$

From SAP 2000 computer software,

Shear Area,  $A_v = 31720 \text{ mm}^2$ ,  $f_y = 355 \text{ N/mm}^2$ ,  $\gamma_{m0} = 1$

$$V_{pl,Rd} = \frac{31720 \left( \frac{355}{\sqrt{3}} \right)}{1}$$

$$V_{pl,Rd} = 6501.31 \text{ kN}$$

- iii) Design Check,

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{78.901}{6501.31} = 0.0121 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

Area,  $A_c = 49825.66 \text{ mm}^2$

$$\text{Shear Stress, } \sigma_s = \frac{V_{Ed}}{A_c} = \frac{78.901}{0.0498} = 1584.36 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Shear Stress, } \sigma_{all,s} = \frac{V_{c,Rd}}{A_c} = \frac{6501.31}{0.0498} = 130548.39 \frac{\text{kN}}{\text{m}^2}$$

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

The shear stress is  $1584.36 \text{ kN/m}^2$ , while the allowable shear stress is  $130548.39 \text{ kN/m}^2$ .

**Bending Moment Resistance,  $M_{c,Rd}$** 

- i) Maximum external design shear force,  $M_{Ed} = 730641.06 \text{ kN.mm}$
- ii) Moment resistance,  $M_{c,Rd} = M_{pl,Rd}$

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

From SAP 2000 computer software,

$$W_{pl} = 12579646.67 \text{ mm}^3, f_y = 355 \text{ N/mm}^2, \gamma_{m0} = 1$$

$$M_{pl,Rd} = \frac{12579646.67(355)}{1}$$

$$M_{pl,Rd} = 4465774.57 \text{ kN.mm}$$

- iii) Design Check,

$$\frac{M_{Ed}}{M_{c,Rd}} = \frac{730641.06}{4465774.57} = 0.164 \leq 1.0, \text{ the section is satisfactory.}$$

From SAP 2000 computer software,

$$\text{Section modulus, } S_x = 12579646.67 \text{ mm}^3$$

$$\text{Bending Stress, } \sigma_b = \frac{M_{Ed}}{S_x} = \frac{730641.06}{12579646.67} = 58081.21 \times 10^{-6} \frac{\text{kN}}{\text{mm}^2} = 58081.21 \frac{\text{kN}}{\text{m}^2}$$

$$\text{Allowable Bending Stress, } \sigma_{all,b} = \frac{M_{c,Rd}}{S_x} = \frac{4465774.57}{12579646.67} = 0.355 \frac{\text{kN}}{\text{mm}^2} = 355000 \frac{\text{kN}}{\text{m}^2}$$

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

The bending stress is  $58081.21 \text{ kN/m}^2$ , while the allowable bending stress is  $355000 \text{ kN/m}^2$



## APPENDIX C

### TABLE OF STIFFNESS AND MASS

**Table 3.7:** Stiffness and mass for horizontal member

No.	Level	Length (mm)	Modulus of Elasticity, E (N/mm <sup>2</sup> )	Outside diameter, d <sub>o</sub> (mm)	Inside diameter, d <sub>i</sub> (mm)	Moment of Inertia, I (mm <sup>4</sup> )	Stiffness, k	Density, (kg/m <sup>3</sup> )	Volume, (m <sup>3</sup> )	Mass, (kg)
1	1	34385	210000	813	20	21448070576	1.3099E+11	7489	17.8416	133615.6
2	1	30775	210000	813	20	21448070576	1.46356E+11	7489	15.9684	119587.6
3	1	30774	210000	813	20	21448070576	1.4636E+11	7489	15.9679	119583.7
4	1	15387	210000	813	20	21448070576	2.92721E+11	7489	7.98396	59791.87
5	1	15387	210000	813	20	21448070576	2.92721E+11	7489	7.98396	59791.87
6	1	17192	210000	813	20	21448070576	2.61988E+11	7489	8.92053	66805.87
7	1	8570	210000	813	20	21448070576	5.25565E+11	7489	4.44678	33301.9
8	2	28150	210000	813	20	21448070576	1.60003E+11	7489	14.6064	109387.2
9	2	25937	210000	813	20	21448070576	1.73655E+11	7489	13.4581	100787.8
10	2	25937	210000	813	20	21448070576	1.73655E+11	7489	13.4581	100787.8
11	2	12969	210000	813	20	21448070576	3.47297E+11	7489	6.72932	50395.84
12	2	12969	210000	813	20	21448070576	3.47297E+11	7489	6.72932	50395.84
13	2	14075	210000	813	20	21448070576	3.20007E+11	7489	7.30319	54693.61
14	2	7056	210000	813	20	21448070576	6.38335E+11	7489	3.6612	27418.7

**Table 3.7:** Continued

No.	Level	Length (mm)	Modulus of Elasticity, E (N/mm <sup>2</sup> )	Outside diameter, d <sub>o</sub> (mm)	Inside diameter, d <sub>i</sub> (mm)	Moment of Inertia, I (mm <sup>4</sup> )	Stiffness, k	Density, (kg/m <sup>3</sup> )	Volume, (m <sup>3</sup> )	Mass, (kg)
15	3	22954	210000	813	20	21448070576	1.96223E+11	7489	11.9103	89196.25
16	3	21907	210000	813	20	21448070576	2.05601E+11	7489	11.367	85127.74
17	3	21907	210000	813	20	21448070576	2.05601E+11	7489	11.367	85127.74
18	3	10953	210000	813	20	21448070576	4.1122E+11	7489	5.68326	42561.93
19	3	10953	210000	813	20	21448070576	4.1122E+11	7489	5.68326	42561.93
20	3	11476	210000	813	20	21448070576	3.9248E+11	7489	5.95463	44594.24
21	3	5738	210000	813	20	21448070576	7.84959E+11	7489	2.97732	22297.12
22	4	19242	210000	813	20	21448070576	2.34076E+11	7489	9.98423	74771.9
23	4	19053	210000	813	20	21448070576	2.36398E+11	7489	9.88616	74037.47
24	4	19053	210000	813	20	21448070576	2.36398E+11	7489	9.88616	74037.47
25	4	9526	210000	813	20	21448070576	4.72821E+11	7489	4.94282	37016.79
26	4	9526	210000	813	20	21448070576	4.72821E+11	7489	4.94282	37016.79
27	4	9621	210000	813	20	21448070576	4.68152E+11	7489	4.99212	37385.95
TOTAL							8.68492E+12			1832079

**Table 3.8:** Stiffness and mass for vertical member

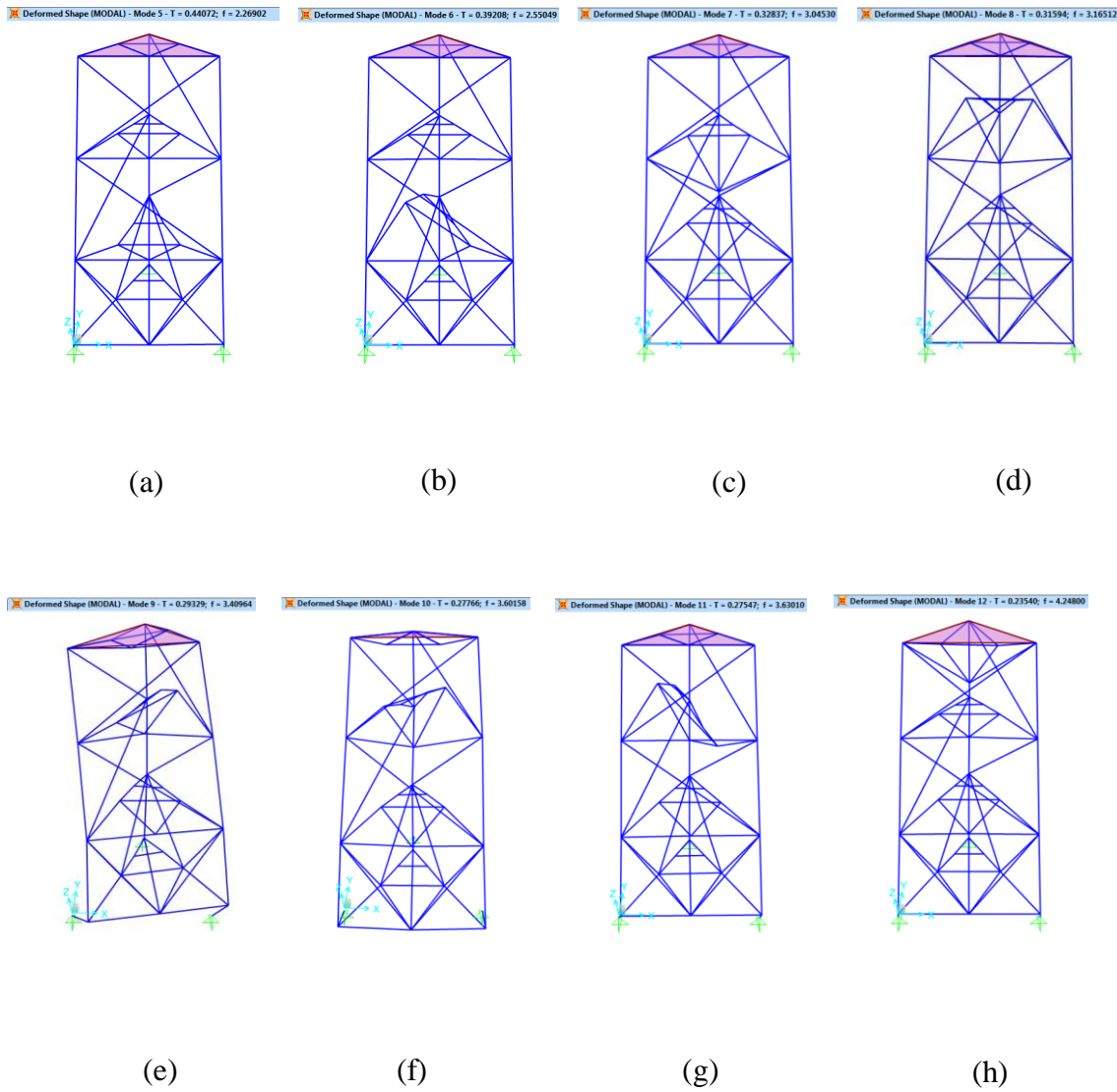
No.	Level	Length (mm)	Modulus of Elasticity, E (N/mm <sup>2</sup> )	Outside diameter, d <sub>o</sub> (mm)	Inside diameter, d <sub>i</sub> (mm)	Moment of Inertia, I (mm <sup>4</sup> )	Stiffness, k	Density, (kg/m <sup>3</sup> )	Volume, (m <sup>3</sup> )	Mass, (kg)
1	1	25460	210000	1330	15	1.53615E+11	2.4286332	7489	35.3714	264897
2	1	25460	210000	1330	15	1.53615E+11	2.4286332	7489	35.3714	264897
3	1	25269	210000	1330	15	1.53615E+11	2.4285488	7489	35.1061	262909
4	1	28925	210000	813	20	21448070576	1.557E+11	7489	15.0085	112399
5	1	28925	210000	813	20	21448070576	1.557E+11	7489	15.0085	112399
6	1	27995	210000	813	20	21448070576	1.609E+11	7489	14.526	108785
7	1	28768	210000	813	20	21448070576	1.566E+11	7489	14.9271	111789
8	1	27995	210000	813	20	21448070576	1.609E+11	7489	14.526	108785
9	1	28768	210000	813	20	21448070576	1.566E+11	7489	14.9271	111789
10	2	21218	210000	1330	15	1.53615E+11	2.9141766	7489	29.478	220761
11	2	21218	210000	1330	15	1.53615E+11	2.9141766	7489	29.478	220761
12	2	21058	210000	1330	15	1.53615E+11	2.9141894	7489	29.2558	219096
13	2	33111	210000	813	30	21448038665	1.36E+11	7489	17.1675	128568
14	2	32374	210000	813	30	21448038665	1.391E+11	7489	16.7854	125706
15	2	31332	210000	813	30	21448038665	1.438E+11	7489	16.2451	121660
16	3	15155	210000	1370	35	1.72945E+11	4.0800396	7489	22.3285	167218
17	3	15155	210000	1370	35	1.72945E+11	4.0800396	7489	22.3285	167218
18	3	15040	210000	1370	35	1.72945E+11	4.0802527	7489	22.1591	165949
19	3	25910	210000	813	20	21448070576	1.738E+11	7489	13.4441	100683
20	3	25784	210000	813	20	21448070576	1.747E+11	7489	13.3787	100193
21	3	25013	210000	813	20	21448070576	1.801E+11	7489	12.9787	97197.3
TOTAL							1.894E+12			3293659

**Table 3.9:** Summary of total stiffness and mass

MEMBER	Stiffness, k	Mass (kg)
HORIZONTAL	$8.6849 \times 10^{12}$	1832078.7
VERTICAL	$1.894 \times 10^{12}$	3293659
TOTAL	$10.5789 \times 10^{12}$	5125737.7

## APPENDIX D

### FREE VIBRATION ANALYSIS (LIST OF MODE SHAPE)



**Figure 4.29:** Deformed shape for (a) mode 5 (b) mode 6 (c) mode 7 (d) mode 8  
(e) mode 9 (f) mode 10 (g) mode 11 (h) mode 12