UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's full name : LOW YEE HWA

Date of birth : 27 JANUARY 1991

Title : ANALYSIS OF A 4-LEGGED FIXED OFFSHORE STRUCTURE IN MALAYSIA UNDER SEISMIC LOADING

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)	(Signature of Supervisor)
910127-14-5614	IR. SAFFUAN BIN WAN AHMAD
New IC / Passport Number	Name of Supervisor
Date : 30 JUNE 2015	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.

ANALYSIS OF A 4-LEGGED FIXED OFFSHORE STRUCTURE IN MALAYSIA UNDER SEISMIC LOADING

LOW YEE HWA

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 B.Eng (Hons.) Civil Engineering.

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	:	LOW YEE HWA
ID Number	:	AE11041
DATE	:	30 JUNE 2015

Dedicated to my parents,

for their love and devotion

making me be who I am today

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my university, University Malaysia Pahang and all the lectures that had taught me for equipping me with knowledge and skills and providing platform for me to successfully completed this study.

I would also like to express my greatest appreciation and gratitude to my supervisor, Ir. Saffuan bin Wan Ahmad, who has been very supportive in guiding me and providing useful information and recommendations throughout this study. His consistent encouragement and motivation hence allowed me to perform and unleash my capabilities in this research field.

In addition, I would like to express my gratitude to my panel, Dr. Norhaiza binti Nordin and Mdm. Shariza binti Mat Aris for their valuable suggestions and comments on my study to allow me to improve my research and meet the objectives of this study.

Apart from that, I would like to thank the subject coordinator of BAA 3922 (Research Methodology and Pre Project), Dr. Andri Kusbiantoro and BAA 4914 (Final Year Project), Dr. Nurul Nadrah Aqilah binti Tukimat for their hard work in preparing relevant modules and outlines for the programme, thus I am able to come out with satisfactory research.

A special thanks to my friend, Hong Jia Hi, Lim Jia Jun, Solihah binti A. Aziz and Nurul Nabila binti Fazilan and many other for their sharing of precious knowledge and information related to my study and motivated me to complete this research.

Finally, I am also grateful to my family for their love and encouragement all the way to the completion of my task in this study.

ABSTRACT

Most structures in Malaysia do not consider for seismic design during its service lifetime. However, structures in Malaysia might be affected by the tremors of earthquake from neighbouring countries such as Philippines, Indonesia etc. The aim of this study is to identify the necessity of implementation of seismic design in offshore structures due to earthquake loading. Thus, this research presents a finite element simulation of a 4-legged offshore structure using SAP2000. The structure is in three-dimensional form and it is tested with dead load, live load and environmental load such as wind, wave and current load with addition of earthquake ground accelerations from Aceh earthquake. The response of the structure due to the above loadings are illustrated and discussed. Results such as the natural frequencies, vibration modes of the structure, displacement, bending moment and shear stress, interaction ratio of members etc. are collected and analyzed. Generally, the offshore structure with consideration of seismic ground motion is still within members capacity desirable range. In summary, the four-legged fixed offshore structure is yet consider safe and does not require seismic design for this moment of time.

ABSTRAK

Kebanyakan struktur di Malaysia tidak mempertimbangkan untuk rekaan perancangan seismik semasa hayat perkhidmatannya. Walau bagaimanapun, struktur di Malaysia mungkin terjejas oleh gegaran gempa bumi dari negara-negara jiran seperti Filipina, Indonesia dan lain-lain. Tujuan kajian ini adalah untuk mengenal pasti keperluan pelaksanaan rekaan perancangan seismik dalam struktur luar pesisir akibat beban gempa bumi. Oleh itu, penyelidikan ini membentangkan "Finite Element Method" simulasi untuk sesebuah struktur luar pesisir berkaki empat menggunakan perisian struktur analisis, SAP2000. Struktur ini adalah dalam bentuk tiga dimensi dan ia diuji dengan beban mati, beban hidup dan beban alam sekitar seperti angin, ombak dan arus dengan penambahan beban seismik akibat gegaran gempa bumi di negara Aceh. Tindak balas struktur disebabkan oleh beban di atas adalah diilustrasi dan dibincangkan. Hasil seperti frekuensi asli, mod getaran struktur, sesaran, momen lentur dan tegasan ricih, nisbah interaksi ahli dan lain-lain telah dikumpul dan dianalisis. Secara umumnya, struktur luar pesisir dengan pertimbangan beban seismik masih dalam kapasiti ahli. Secara ringkasnya, struktur luar pesisir berkaki empat tersebut adalah selamat dan tidak memerlukan rekaan perancangan seismik pada masa ini.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
ft/s	Feet per second
ft	Feet
N	Newton
kg/m^3	Kilogram per cubic meter
m/s	Meter per second
m^2	Square meter
N/m	Newton per meter
N/m^3	Newton per cubic meter
m/s^2	Meter per second square
m	Meter
m/s	Meter per second
N.mm	Newton millimeter
kg	Kilogram
MN	Mega Newton

LIST OF ABBREVIATIONS

API	American Petroleum Institute
WSD	Working Stress Design
BS	British Standard
EN	European Standards
MMD	Malaysia Meteorological Department
DL	Dead Load
LL	Live Load
EL	Environmental Load (Excluding Earthquake Load)
TH	Time History
RS	Response Spectrum

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

According to Offshore Book-An introduction to the offshore industry (2010), millions of years ago when living organisms died and settled to the bottom of rivers, seas, lakes etc., it forms a layer of organic materials. Due to geological shift and subsequent deposition of organic materials, these organics materials were exposed to increasing pressure and temperature as it went deeper below the earth's crust; thus converting them into hydrocarbons. The transportation fuels (petrol, diesel, etc.), heating oil and natural gas that we used presently are actually hydrocarbons trapped in subsurface rocks of oil and gas reserves.

There are two types of exploration of oil and gas from the reserves, which are onshore exploration and offshore exploration. Although onshore exploration is more economical as compared to offshore exploration; however, in Malaysia, most of the reserves are found beneath the sea bed, thus offshore exploration is adopted (Malaysia: Country Analysis Brief Overview, 2014).

For offshore exploration and production of oil and gas, the operations are to be conducted from either fixed (stationary), semi-submersibles or floating structures which required to support the necessary facilities and equipment (IPF School, 2007). In addition, Lai (2007) mention that they are about 250 fixed offshore structures in Malaysian water. Since fixed offshore structures account for quite a large portion of offshore structure in Malaysia, those fixed offshore structures' performance believe to affect greatly to Malaysia, thus, in this reseach, only fixed offshore structures are being studied.

1.2 PROBLEM STATEMENT

Oil & Gas Industry is an important sector in Malaysia. According to Economic Transformation Programme Annual Report 2013 (2014), Oil, Gas and Energy Sector contributes to about 20% of the Malaysian economy. In addition, its importance also shown in their ability to become Malaysian's 1st choice of primary energy as stated by U.S. Energy Information Administration (2014), natural gas, petroleum and other liquids accounts for more than 75% of the Malaysia Primary Energy Consumption 2012.

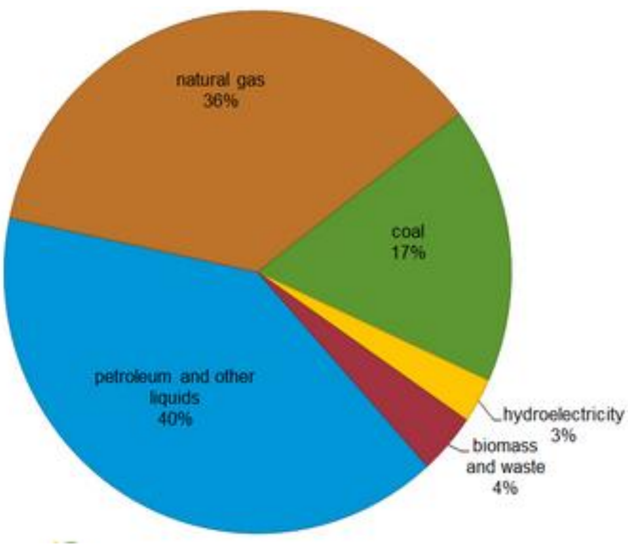


Figure 1.1: Malaysia primary energy consumption 2012

Source: U.S. Energy Information Administration, 2014

Earthquake is a natural event that its occurrence is unpredictable and causes lost of human life and resources due to damages to structures (Lai, 2007) arising economical, social and environmental problems. Offshore structures in Malaysian water are normally not design for seismic loads as Malaysian waters were categorized in no seismic zone in the ISO seismic microzonation (Mukherjee et. al., 2014). However, the authors suggest to have extensive review of the seismic effects on offshore structures in Malaysia due to the recent seismic activities and Tsunami in year 2004.

Oil & Gas industry indeed is an important sector in Malaysia and anything that happens to the Oil & Gas industry will greatly impact Malaysian in many ways and people surely would not hope that any accidents to occur to the Oil & Gas industry. Thus, it is necessary to study the seismic response of built offshore structures to check whether they are able to withstand earthquake excitation safely.

1.3 RESEARCH OBJECTIVES

1) To study the ground motion data provided by Malaysian Meteorological Department and perform computational seismic analysis of jacket due to Aceh earthquake using SAP2000.
2) To determine and study the seismic response of jacket due to Aceh earthquake.
3) To identify the necessity of implementation of seismic design or earthquake-resistant design in offshore structures.
4) To propose a suitable design criteria consideration for future offshore structures design in Malaysia.

1.4 SCOPE OF STUDY

This research is about the behaviour or response of typical 4-legged fixed offshore structure under earthquake ground motion due to Aceh earthquake. In order to achieve the objectives, research scopes are to be followed, revised and up-to-date. The following shows the research scopes:-

1) The offshore structure is located at Malaysian water Terengganu region.
2) The environmental lateral and vertical forces imposed on the 4-legged jacket of fixed offshore structure will only considered for wind, wave, current and earthquake ground motion.
3) SAP2000 version 15 will be used for the computational analysis of the jacket response.

4) The computational seismic analysis of the jacket will be conducted using linear dynamic analysis of free vibration, time history and response spectrum analysis.
5) The structure support is fixed to the ground instead of pilled and without considering for soil-pile interaction.
6) The stress that applied to the connection is assume to be within the connection capacity thus connection of the members are not defined in SAP2000.
7) The structure assume to behave linearly where deformations is directly proportional to the forces applied.

1.5 SIGNIFICANCE OF STUDY

Generally, Malaysia is a country that is not subjected to earthquake disaster. Most of the structures in Malaysia are not design for earthquake resistant because there are no any special requirements or rules about that. However, Mukherjee et. al. (2014) suggest to review seismic effects on offshore structures in Malaysia due to the recent seismic activities and Tsunami in year 2004.

In addition, Malaysia is close to the two most seismically active plate boundaries which are the boundary between Indo-Australian and Eurasian plate and boundary between Eurasian and Philippines Sea Plates (Seismicity in Malaysia and around the Region, 2013). According to Lai (2007), Malaysia experienced tremors of earthquake from neighbouring countries such as Philippines, Indonesia etc. and especially places near to the seismically active zone such as parts of the coastal water of Sabah and Sarawak.

By conducting this research, the ground motion data due to Aceh earthquake are input to the SAP2000 and seismic response of a typical 4-legged jacket of fixed offshore structure will be observed. From that, the necessity of implementation of seismic design in the 4-legged jacket design of offshore platform in Malaysia due to Aceh earthquake will be concluded.

Due to the fact that higher consideration of factor of safety in design of structures accompanied by higher cost of construction and time, an optimal design of jacket of fixed offshore structure is therefore necessary to save the cost and time but in the same time considering the safety of the structures. Thus, identifying the necessity of implementation of seismic design is crucial for an optimal design of fixed offshore structure.

Besides, a safe design of fixed offshore structure reduces the probability of structure failure which might lead to the lost of human life and resources and in addition, creates economical, social and environmental problems.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO EARTHQUAKE

2.1.1 General Introduction

There are many theories about the earthquake generation and the most famous is the elastic rebound theory. According to Datta (2010), our Earth consist of constantly slowly moving tectonic plates which are relative to each other. These movement of plates causes stress and strain leads to accumulation of elastic energy in the rocks of the plates. When the strain energy exceeding the limiting value of the rocks, which is at a weak region, the rocks crushed and tremendous movement or slip occurred. This causes the release of the accumulated elastic energy in the rocks and then the plates will back to its normal resting stage. The cycle then repeat.

The elastic energy generates elastic waves within the rocks and the wave propagate radically in all directions, transmitting the energy through different layers of the soils and finally reaches the Earth surface. The wave will causes displacement, velocity and acceleration of the soil or rocks in the ground and this is what we known as earthquake, the movement of the ground.

2.1.2 Effects of Earthquake from Neighboring Country

Focus or hypocenter is the point below the Earth surface where the strain energy exceeding the limiting value of the rocks and where the slip starts. Epicenter is the point exactly at the surface of the Earth above the hypocenter. According to Adnan, Marto & Hendriyawan (2004), the nearer the site to the epicenter, the greater the seismic effects to the site. However, significant damages might occur at longer distance when we consider the "Bowl of Jelly" phenomenon. Thus, it would be important to study the seismic effects from neighboring countries to Malaysia.

2.2 FORCES ACTING ON FIXED OFFSHORE STRUCTURE IN MALAYSIA

According to API Recommended Practice 2A-WSD (2007), an offshore structure must be designed to cater dead loads, live loads, environmental loads etc. However, in this subchapter, only environmental forces acting on the structure will be concentrated on and will be further discussed below.

Bargi et. al. (2011) mentioned that the environmental loads acted on the structures varied through the structure's life time. After filtering the environmental forces as mentioned by Bargi et. al. (2011) and API Recommended Practice 2A-WSD (2007) where it is applicable for this research, those environmental loads included wind, current, wave and earthquake loading.

According to API-RP2A 1997 as cited in Bargi et. al. (2011), apart from earthquake loading, other environmental loads should be combined and acted on the structure according to their chances of simultaneous occurrence. While for earthquake loading, it should acted separately as a different environmental loading condition.

For earthquake loading, the data of ground motion can be obtained by Malaysian Meteorological Department which gives the recorded displacement, velocity and acceleration of the ground due to the earthquake. The data obtained is directly applicable for time history analysis.

In addition, API Recommended Practice 2A-WSD (2007) further explained that the environmental forces can be acted on any directions unless there are reasonable knowledge to specify the exact direction that would causes the highest response of structure. Equations below show the formula to generate the environmental forces acted on the offshore structure.

2.2.1 Wind Load

The equations involved in determining the wind load are expressed below.

$$u(z,t) = U(z) \times [(1 - 0.41) \times I_u(z) \times \ln\left(\frac{t}{t_o}\right)] \tag{2.1}$$

where U(z, t) = 1 hour mean wind speed (ft/s) at level z (ft) above mean sea level

$I_u(z)$ = turbulence intensity at level z

$= 0.06 \times [1 + 0.0131\text{x } U_O] \times \left(\frac{z}{32.8}\right)^{-0.22}$

t = averaging time period where $t \le t_0$

t_0 = 3600s

$$U(z) = U_o \text{ x } [1 + C \times \ln\left(\frac{z}{32.8}\right)] \tag{2.2}$$

where U_0 = 1 hour mean speed (ft/s) at 32.8 ft

C $= 5.73 \times 10^{-2} \times (1 + 0.0457 \times U_0)^{\frac{1}{2}}$

z = height above mean sea level (ft)

$$F = \left(\frac{\rho}{2}\right) \mu^2 C_S A \tag{2.3}$$

where F = wind force (N)

ρ = mass density of air (kg/m^3, 1.225 kg/m^3 for standard temperature and pressure)

μ = wind speed (m/s)

C_s = shape coefficient

A = area of object (m^2)

2.2.2 Current Load

The equations involved in determining the current load is expressed as in Eq. (2.4).

$$F_c = C_d \frac{w}{2g} AU|U| \tag{2.4}$$

where F_c = current force (N/m)

C_d = drag coefficient

w = weight density of water (N/m^3)

g = gravitational acceleration (m/s^2)

A = projected area normal to the cylinder axis per unit length (=D for circular cylinders) (m)

U = component of velocity vector due to current of the water normal to the axis of the member (m/s)

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

2.2.3 Wave Load

Based on Rozaina (2006), the drag coefficient, C_D and inertia coefficient, C_m are according to the following:

Table 2.1: Drag coefficient and inertia coefficient

Coefficients	Drag coefficient, C_D	Inertia coefficient, C_m
Smooth	0.65	1.6
Rough	1.05	1.2

Source: Rozaina (2006)

The equations involved in determining the wave load are expressed as in Eq. (2.5).

$$F_w = F_D + F_I = C_d \frac{w}{2g} AU|U| + C_m \frac{w}{g} V \frac{\delta U}{\delta t} \tag{2.5}$$

where F_w = hydrodynamic force vector per unit length acting normal to the axis of the member (N/m)

F_D = drag force vector per unit length acting to the axis of the member in the plane of the member axis and U (N/m)

F_I = inertial force vector per unit length acting normal to the axis of the member in the plane of the member axis and αU/ αt (N/m)

C_d = drag coefficient

w = weight density of water (N/m^3)

g = gravitational acceleration (m/s^2)

A = projected area normal to the cylinder axis per unit length (=D for circular cylinders) (m)

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

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

C_m = inertia coefficient

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

2.3 METHOD OF SEISMIC ANALYSIS

There are three fundamental analysis to obtain the response of structure under earthquake loadings which are free vibration, time history and response spectrum analysis.

2.3.1 Free Vibration Analysis

Free vibration analysis is used to obtain the natural frequencies, natural periods with corresponding vibration modes of the structure (Lai, 2007). These are some important parameters to be used for the response spectrum analysis.

2.3.2 Time History Analysis

Time history analysis is performed to obtain the actual response of structures for a specified time history of excitation (Datta, 2010). It is based on the time history data of the ground motion such as displacement, velocity and acceleration.

2.3.3 Response Spectrum Analysis

As mention by Datta (2010), response spectrum analysis is to find the appropriate maximum displacement or stresses induced in the structure due to the earthquake excitation. It is important as for seismic resistant design of structures, these maximum stresses are of interest only, not the time history of stresses.

As to explain further, platform motion is directly related to the dominant seismic frequency and the structure's natural frequency. Severe response of structure when the seismic frequency is closer to the structure's natural frequency (Park et. al., 2011). For response spectrum analysis, the response of structure obtained is included the consideration of the frequency of the earthquake and structure.

2.4 SEISMIC RESPONSE OF STRUCTURE

After performing seismic analysis, several results related to the response of structure could be obtained. In Bargi et. al. (2011), only results of displacement at nodal point are collected for seismic response of structure. While for Huang & Syu (2014), apart from results of displacement at nodal point, the authors also collected the results of velocity response and acceleration response at nodal point of the structure. In addition, for Park, et. al. (2011), the authors recorded the maximum bending stress at nodal point apart from the displacement, velocity and acceleration response at nodal point.

Besides recording the seismic response of structure, the position of the maximum or most significant response of the structure should be identified. Huang & Syu (2014) defined that the maximum response of the structure is obtained at nodal point located at the highest or furthest position of the structure above the ground. Although not mention directly by Bargi et. al. (2011) and Park et. al. (2011), the authors also collected the response data at the highest position of the structure.

2.5 RESISTANCE CAPACITY FOR CYLINDRICAL MEMBERS

Various design codes are available for designing a structurally safe and sound buildings or civil engineering works. However, different countries have their own favorable design codes and thus follow or implement different design codes. Even though current design code for Malaysia is mainly focuses on British Standard, according to Tu (2011), Malaysia are moving towards implementation of Eurocode. Thus, this research will also be implementing Eurocode to identify the resistance of members and to determine the necessity of implementation of seismic design in offshore structure.

The following subchapter shows the governing member's resistance formulation based on Eurocode BS EN 1993-1-1:2005.

2.5.1 Resistance of Cross Sections

Resistance of cross section is the maximum design value that can be supported by the member.

2.5.1.1 Tension

If member's cross section is with holes (such as bolted), $N_{t, Rd}$ is taken as the smallest between the $N_{pl, Rd}$ or $N_{u, Rd}$. Else, $N_{t, Rd}$ is taken as $N_{pl, Rd}$.

$$N_{pl,Rd} = \frac{A \times f_y}{\gamma_{M0}} \tag{2.6}$$

where A = Area of Cross Section

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

$$N_{u,Rd} = \frac{0.9 \times A_{net} \times f_u}{\gamma_{M2}} \tag{2.7}$$

where A_{net} = Net Area of a Cross Section

f_u = Ultimate Strength

γ_{M2} = Partial Factor for Resistance of Cross Sections in Tension to Fracture

2.5.1.2 Compression

Sections with different classes use different formula to determine the design resistance for compression.

For Class 1, 2 or 3 Cross Sections,

$$N_{c,Rd} = \frac{A \times f_y}{\gamma_{M0}} \tag{2.8}$$

where A = Area of Cross Section

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

For Class 4 Cross Sections,

$$N_{c,Rd} = \frac{A_{eff} \times f_y}{\gamma_{M0}} \tag{2.9}$$

where, A_{eff} = Effective Area of Cross Section

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

2.5.1.3 Bending Moment

The design resistance for bending considering different classification of section about one principal axis of a cross section is calculated as below:

For Class 1 or 2 Cross Sections,

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} \times f_y}{\gamma_{M0}} \tag{2.10}$$

where W_{pl} = Plastic Section Modulus

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

For Class 3 Cross Sections,

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el,min} \times f_y}{\gamma_{M0}} \tag{2.11}$$

where $W_{el,min}$ = Minimum Elastic Section Modulus

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

For Class 4 Cross Sections,

$$M_{c,Rd} = \frac{W_{eff,min} \times f_y}{\gamma_{M0}} \tag{2.12}$$

where $W_{eff,min}$ = Minimum Effective Section Modulus

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

2.5.1.4 Shear

If member is subjected to shear without torsion, then the design shear resistance, $V_{c,Rd}$ is taken as $V_{pl,Rd}$.

$$V_{pl,Rd} = \frac{A_v \times (f_y/\sqrt{3})}{\gamma_{M0}} \tag{2.13}$$

where A_v = Shear Area

f_y = Yield Strength

γ_{M0} = Partial Factor for Resistance of Cross Sections Whatever the Class Is

2.5.2 Buckling Resistance of Members

A slender members when subjected to compression might fail before reaching its maximum design value due to buckling of members. Thus, it is important to check the buckling resistance of members.

2.5.2.1 Uniform Members in Compression

Design buckling resistance of the compression member is given as:

For Class 1, 2 or 3 Cross Sections,

$$N_{b,Rd} = \frac{\chi \times A \times f_y}{\gamma_{M1}} \tag{2.14}$$

where χ = Reduction Factor for the Relevant Buckling Curve

A = Area of Cross Section

f_y = Yield Strength

γ_{M1} = Partial Factor for Resistance of Members to Instability Assessed by Member Checks

For Class 4 Cross Sections,

$$N_{b,Rd} = \frac{\chi \times A_{eff} \times f_y}{\gamma_{M1}} \tag{2.15}$$

where χ = Reduction Factor for the Relevant Buckling Curve
A_{eff} = Effective Area of Cross Section
f_y = Yield Strength
γ_{M1} = Partial Factor for Resistance of Members to Instability Assessed by Member Checks

2.5.2.2 Uniform Members in Bending

Design buckling resistance moment of member where W_y is replace with suitable value of section modulus is shown below:

$$M_{b,Rd} = \chi_{LT} \times W_y \times \frac{f_y}{\gamma_{M1}} \tag{2.16}$$

where χ_{LT} = Reduction Factor for Lateral-Torsional Buckling
W_y = Effective Area of Cross Section
f_y = Yield Strength
γ_{M1} = Partial Factor for Resistance of Members to Instability Assessed by Member Checks

CHAPTER 3

METHODOLOGY

3.1 PLANNING OF THE STUDY

A duration of two semesters (approximately 9 months) is given to carry out this research. Thus, proper planning and scheduling is at most important to make this research a success.

It is important to identify what should be done and how it should be done at proposed period of research in order to achieve the objective of the research which tends to solve or alleviate the problems in the real world. Below shows the works that should be done with their respective time frame. In addition, following subchapters will explain in details of the works to be done and how it can be done.

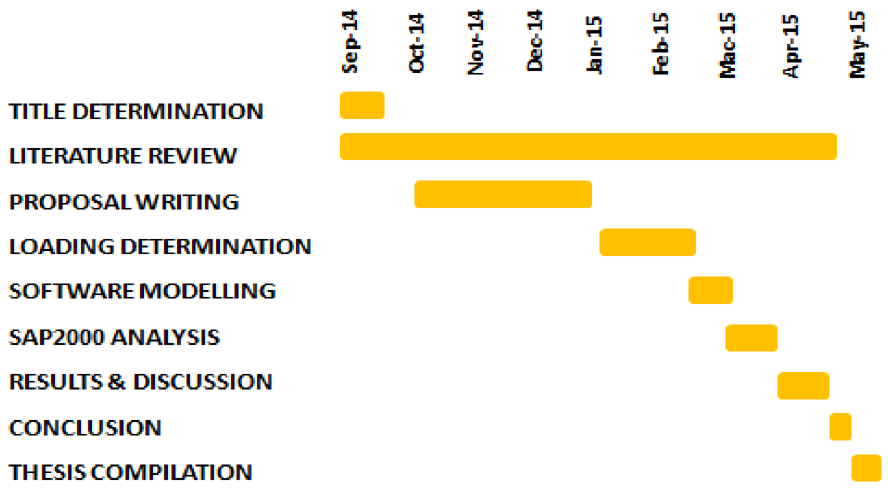


Figure 3.1: Gantt chart for proposed work

3.2 INPUT DATA COLLECTION

Research cannot be done discretely without the collection of proper and related information. The information to be collected are useful to model and analyse our structure and they are categorised in three major categories as shown in subchapters below.

3.2.1 Earthquake Data

Environmental load such as earthquake load is depends on the earthquake-induced ground motion felt by the structure such as displacement, velocity and acceleration at the structure's location. This data can be obtained from the Malaysia Meteorological Department (MMD). In addition, for response spectrum analysis, response spectra curves are needed and it can be obtained from the American Petroleum Institute (API) or the preloaded curves in the SAP2000.

Raw data of earthquake originated from Aceh which recorded in Malaysia seismic stations will be collected from Malaysian Meteorological Department (MMD). The raw data then need to be extracted to Microsoft Excel to aid in finding maximum acceleration. The maximum acceleration of each N, E and Z direction with its corresponding time will be recorded. Besides that, graphs of time (sec) vs. acceleration (g) for each direction are to be plotted. The data then will be added to the SAP2000 for analysis.

3.2.2 Information of Jacket

A correct representation of the actual structure in SAP2000 enable true results to be shown. Useful information which needed to model the structure in SAP2000 can be collected from the manufacturer of structure. The information related to the structure modelling are geometry of structure (coordinates of the nodes), configuration of structure (arrangement of members), members cross section properties (cross section shape, size, strength, etc.), stiffness and mass of structure and environment criteria of structure.

3.2.3 Loadings

Various types of loading are subjected and considered to ensure the structure's safety and stability in the ocean. Loadings such as dead load, live load and environmental load (Eg: wave, wind, earthquake load etc.) acting on the structure are some important parameter to be keyed in to SAP2000 to obtain the response of the structure.

For the dead load and live load, it depends on the type of structure, facilities and infrastructure supported by the structure. Their design value can be obtained from the manufacturer or the design company of the structure.

While for the environmental loading acting on structure such as wind, wave etc, it relies on the location of structure, environmental criteria for the structure etc. These environmental loading can be calculated by using equations provided by American Petroleum Institute Recommended Practice 2A-WSD.

3.3 MODELLING &ANALYSIS USING SAP2000

After obtaining the information needed for this research, the structure can then be modelled in SAP2000. Before start modelling, the origin of the structure's coordinate are defined first. The global x-axis and y- axis are set as zero at the centroid of the structure and pointing right and front respectively while global z-axis are set as zero at the mean sea level and pointing upward.

After modelling the structure, all the relevant geometry, member types and sizes, properties etc. are checked to ensure that they are define correctly and accurately in the SAP2000 model to ensure true representation of structure in modelling and to avoid any discrepancy that will affect the response of the structure.

There are three fundamental analysis of structure which are the free vibration, time history and response spectrum analysis. The appropriate and corresponding loading that obtained earlier will be inserted to the model according to the types of structure analysis. The basic load combinations of dead load, live load and environmental load are defined. Finally, SAP2000 analysis is carried out. Figure 3.3 to Figure 3.8 shows the detailed steps involved in SAP2000 modelling and analysis.

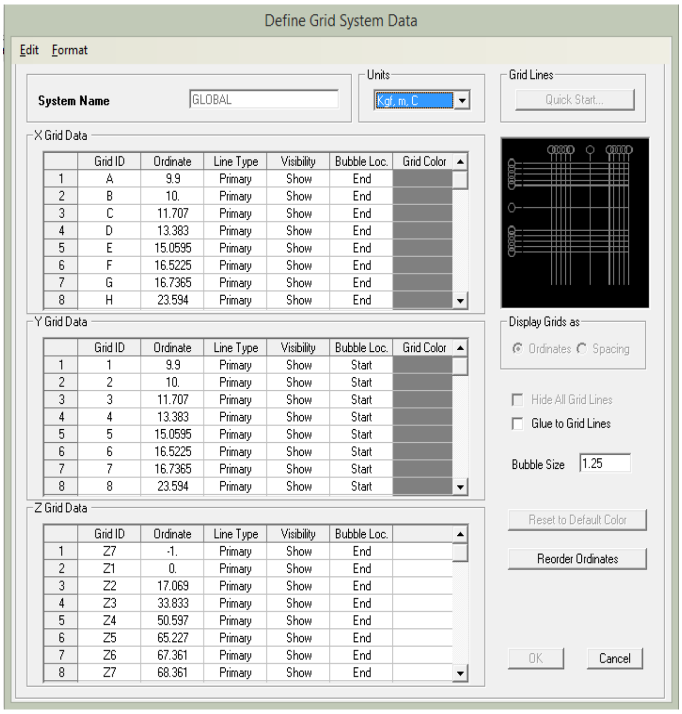


Figure 3.3: Determine nodes coordinates of structure and define grid line

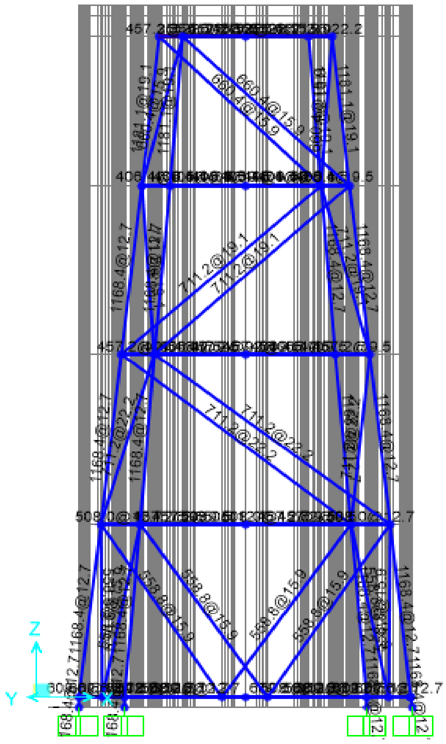


Figure 3.4: Assign members and supports to the structure

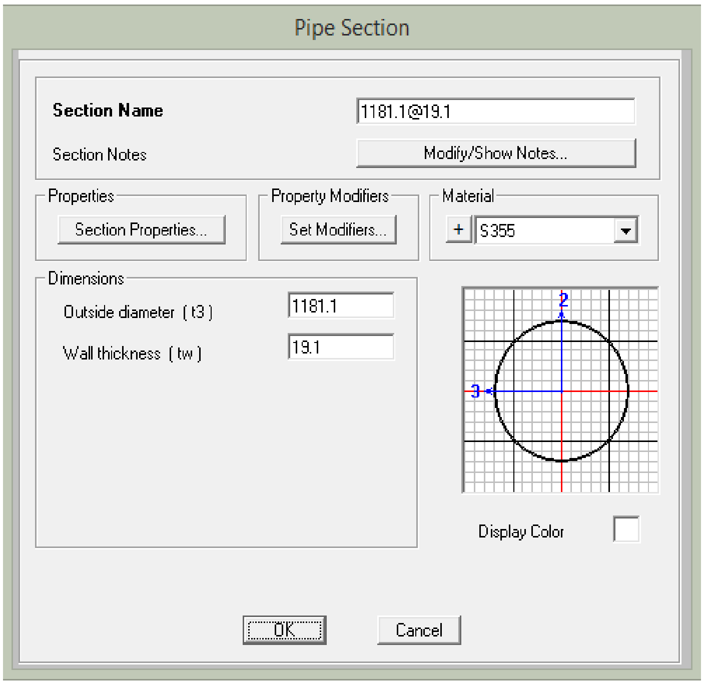


Figure 3.5: Define section properties

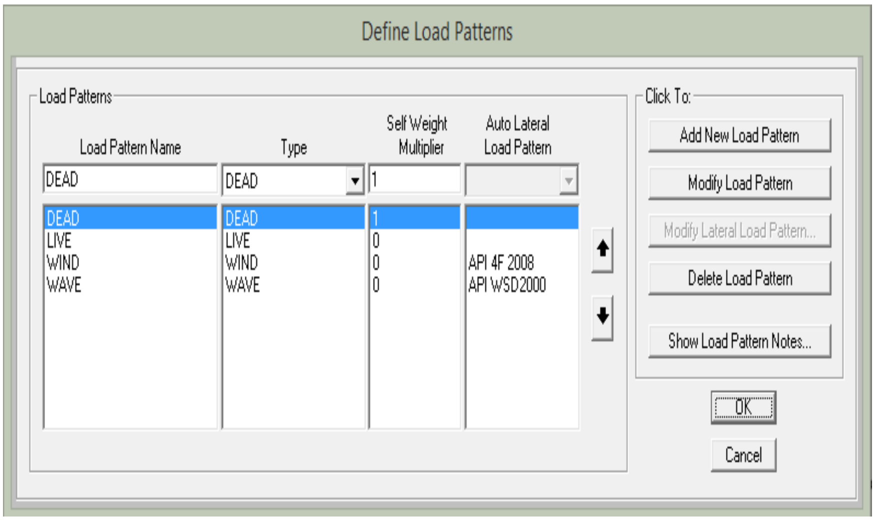


Figure 3.6: Add load cases

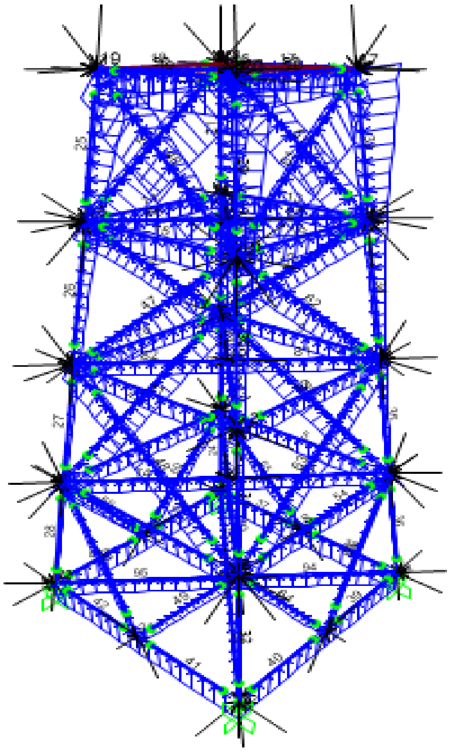


Figure 3.7: Assign corresponding loading values

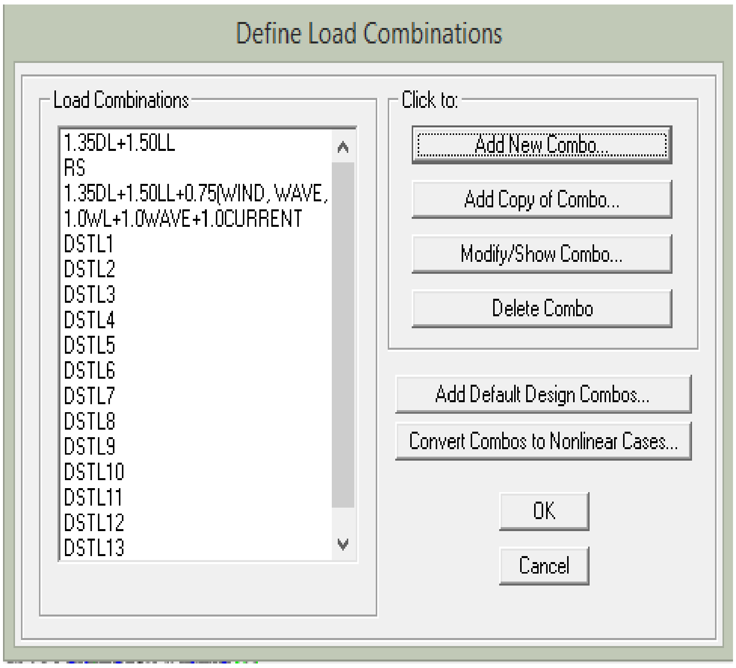


Figure 3.8: Define load combinations for the load cases

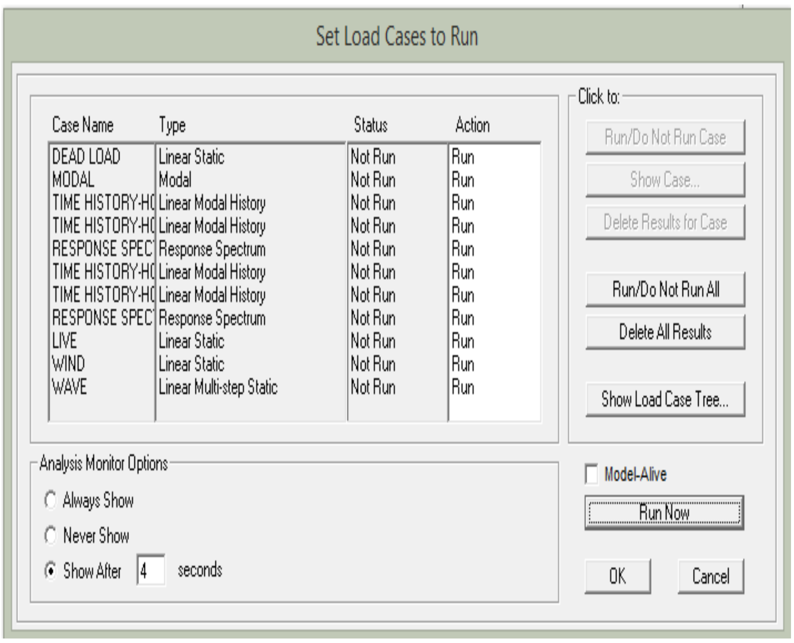


Figure 3.9: Run SAP2000 analysis

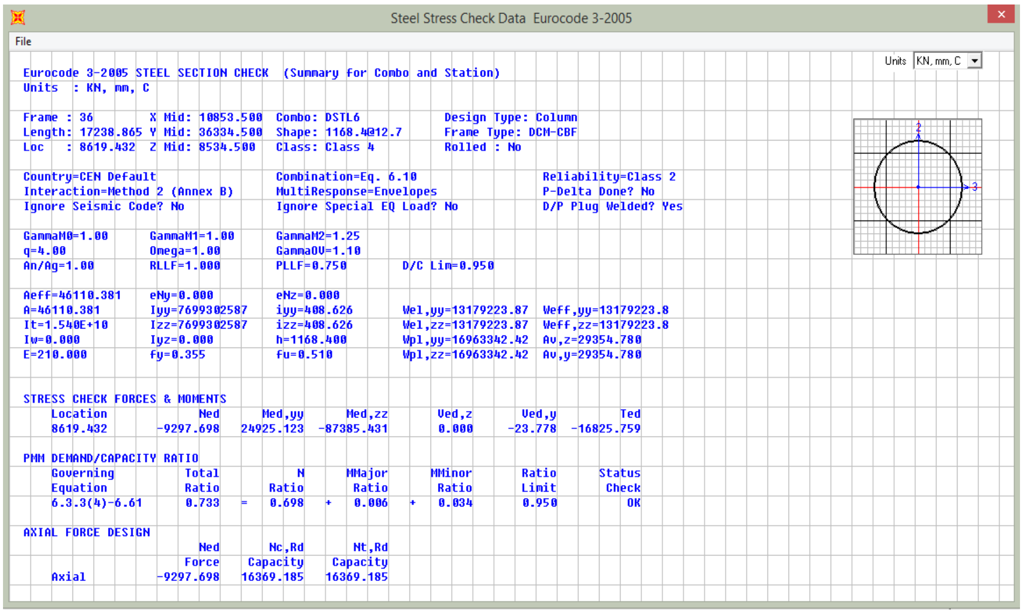


Figure 3.10: A portion of results analysed

3.4 DISCUSSION & CONCLUSION

A true representation of structures produced reliable results. Therefore, reliability of the results obtained from SAP2000 will be checked. First, the total nodes of the structure were recorded and compared with the limitation of nodes that SAP2000 Basic version can processed to ensure reliability of structural analysis. In addition, manual calculation of the critical members will be calculated and compared with SAP2000 results to ensure the reliability of the results modelled using SAP2000.

For the discussion part, first, it will start with free vibration analysis. From the free vibration analysis, natural period and the mode shape of structure can been obtained. Then, these information will be used for the response spectrum analysis to obtain the response of the structure such as displacement, velocity and acceleration of the structure subjected to earthquake loading. The response of structure obtained for the time history analysis is also collected and recorded.

To check the suitability of the members of the structure, two methods have been adopted. First method is checking the results of unity ratio of the structure produced by the SAP2000. The members shape and size are acceptable when the value of unity ratio less than one (indicating the members design is pass). Second method is calculate the resistance capacity of the members (Eg: design resistance axial load, design resistance moment, etc.) and compare them with the maximum loading response (Eg: maximum axial load, maximum moment, etc.) obtained from SAP2000. The members are acceptable when the value of maximum loading response is less than the value of members resistance capacity.

Finally, conclusion are drawn whether the structure will fail or not when subjected to earthquake loading. A conclusion of necessity of implementation of seismic design and suitable design criteria consideration can be make.

As a conclusion, Figure 3.11 shows the summary of steps involve to conduct this research.

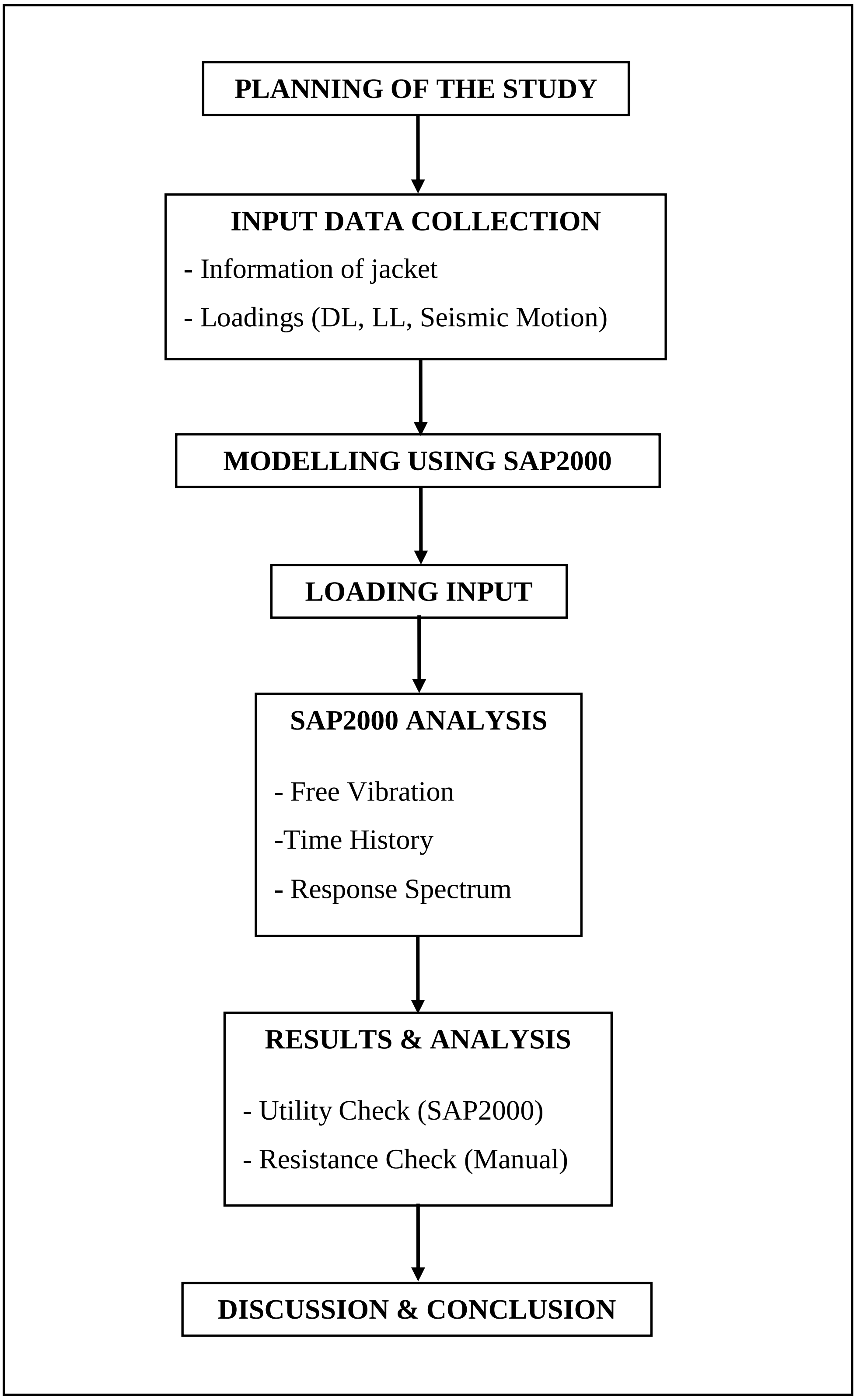


Figure 3.11: Summary of the research methodology

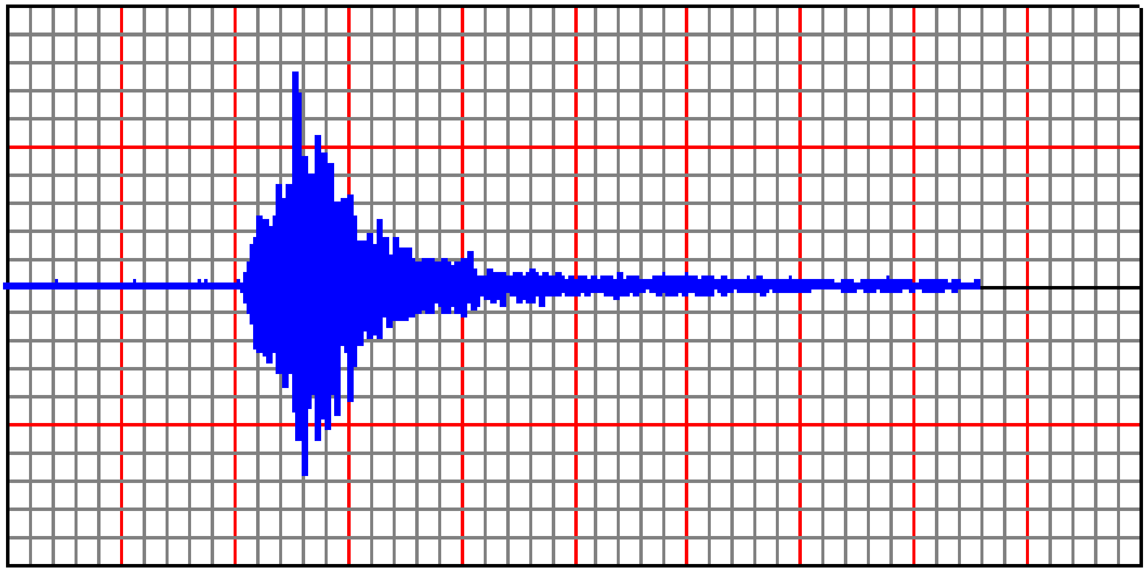
3.5 INPUT DATA COLLECTED

3.5.1 Earthquake Data

A part of the raw earthquake data extraction in notepad form is shown in Figure 3.12. Graphs of time vs. acceleration for each N, E and Z direction with its maximum acceleration and corresponding time are presented in Figure 3.12 to Figure 3.15.

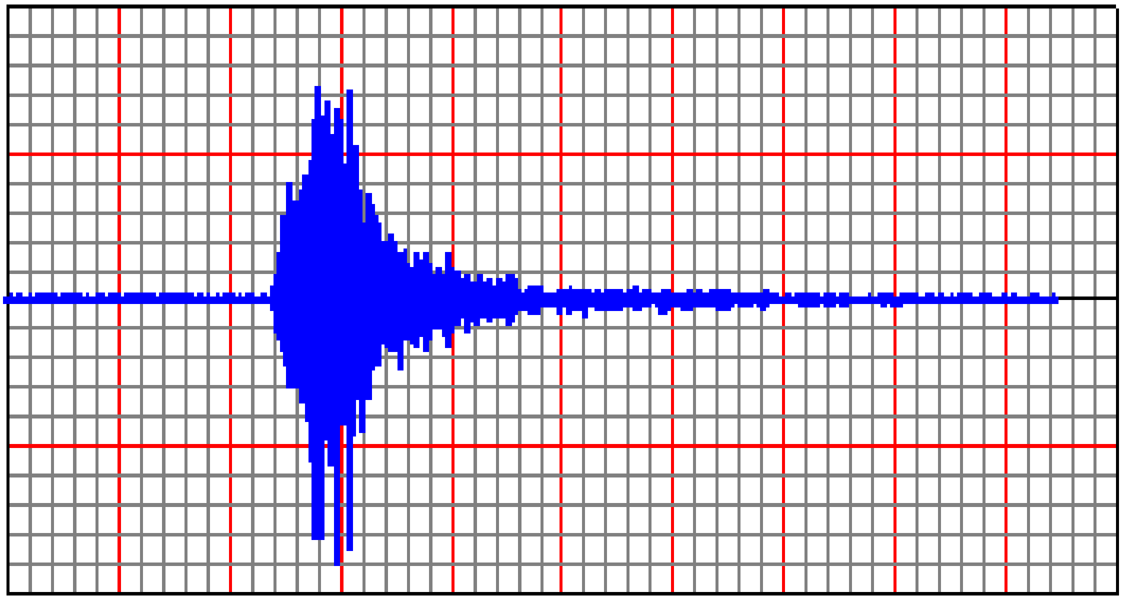
```
Station ID: IPM  Channel 1: HGZ  12/26/2004 0:44:11 (GMT)
Time (sec) vs. A (g), V (in/sec), D (in)
0.010 0.000001 -0.000008 0.000003
0.020 -0.000000 -0.000007 0.000003
0.030 -0.000000 -0.000008 0.000003
0.040 0.000000 -0.000008 0.000003
0.050 0.000000 -0.000006 0.000003
0.060 0.000000 -0.000006 0.000003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

Figure 3.12: Extraction of raw earthquake data in Z direction



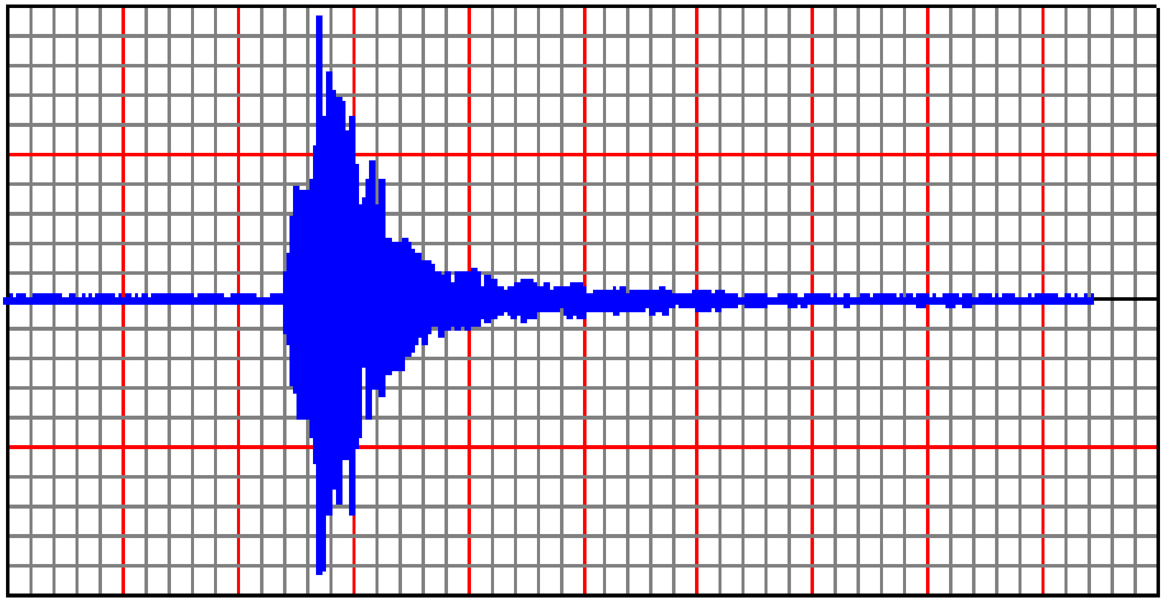
Maximum Acceleration = 0.001222g at 636.33 sec

Figure 3.13: Graph of E direction acceleration (g) vs. time (s)



Maximum Acceleration = -0.00108g at 893.65 sec

Figure 3.14: Graph of N direction acceleration (g) vs. time (s)



Maximum Acceleration = 0.00096g at 1087.63 sec

Figure 3.15: Graph of Z direction acceleration (g) vs. time (s)

3.5.2 Information of Jacket

The information of jacket to be used to model the structure in SAP2000 are as shown below.

1) Geometry of Structure (Eg: Coordinates of the nodes in SAP2000)

The coordinates of each of the nodes is shown in Appendix A.

2) Configuration of Structure (Eg: Arrangement of members of the structure)

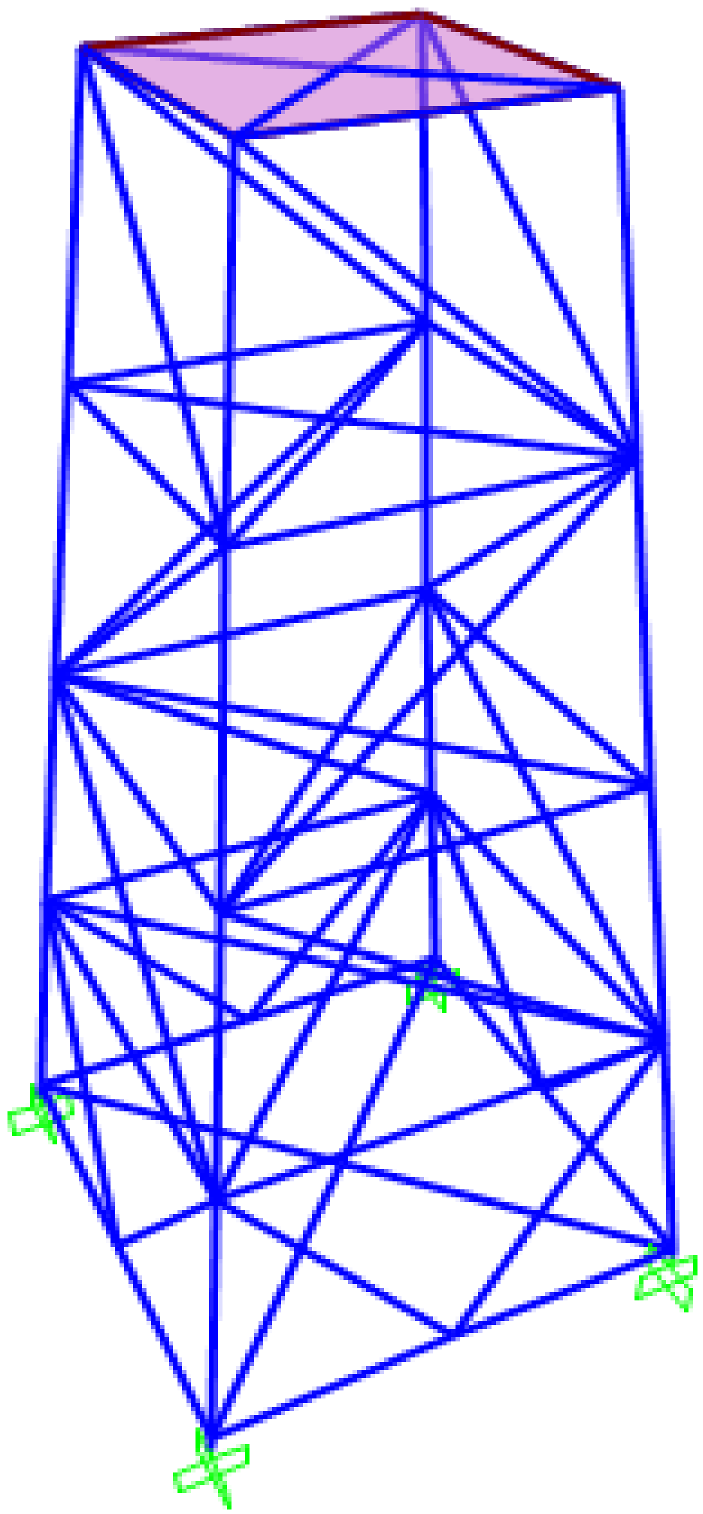


Figure 3.16: 3-dimensional view of offshore structure

3) Members Cross Section Properties (Eg: Cross section shape, size, strength, Modulus of Elasticity)

The information regarding the material properties for steel section is obtained based on BS EN 1993-1-1: 2005.

Cross Section Shape = Circular Hollow Section (Size of members are shown in Figure 3.17 to Figure 3.21)
Minimum Yield Stress, f_y = 355 N/mm^2
Ultimate Stress, f_u = 510 N/mm^2
Poisson's Ratio, U = 0.3
Modulus of Elasticity, E = 210000 N/mm^2
Shear Modulus, G = 80769.2 N/mm^2
Steel Density = 7849 kg/m^3

4) Stiffness and Mass of Structure

The total stiffness and mass of structure is the summation of stiffness and mass of each members. The total stiffness and mass of structure are 8, 326, 814, 914 N.mm and 337, 368 kg respectively. The detail summary of the total stiffness and mass of each members are shown in the Appendix B.

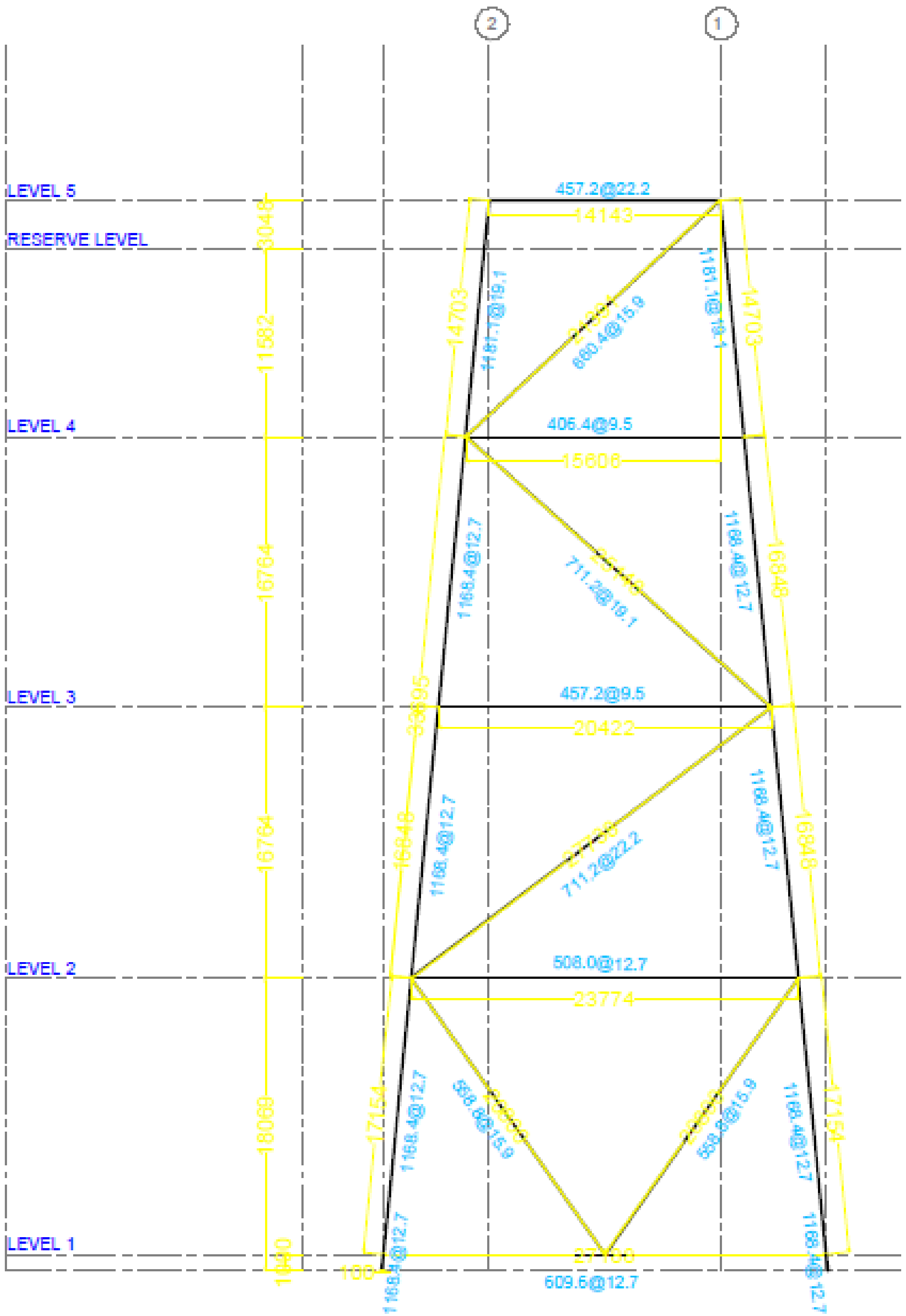


Figure 3.17: Front and back elevation of offshore structure with members sizes

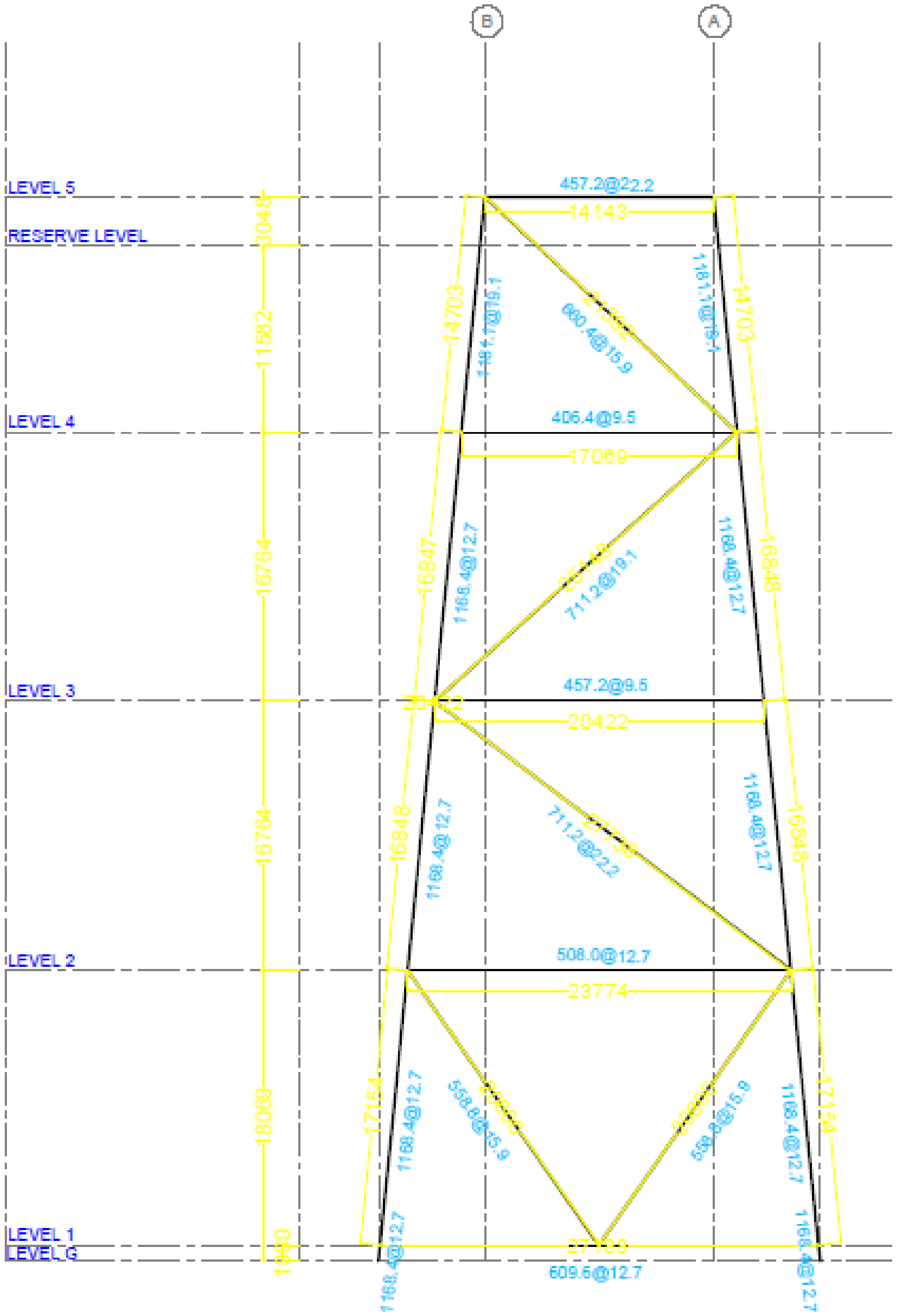


Figure 3.18: Left and right elevation of offshore structure with members sizes

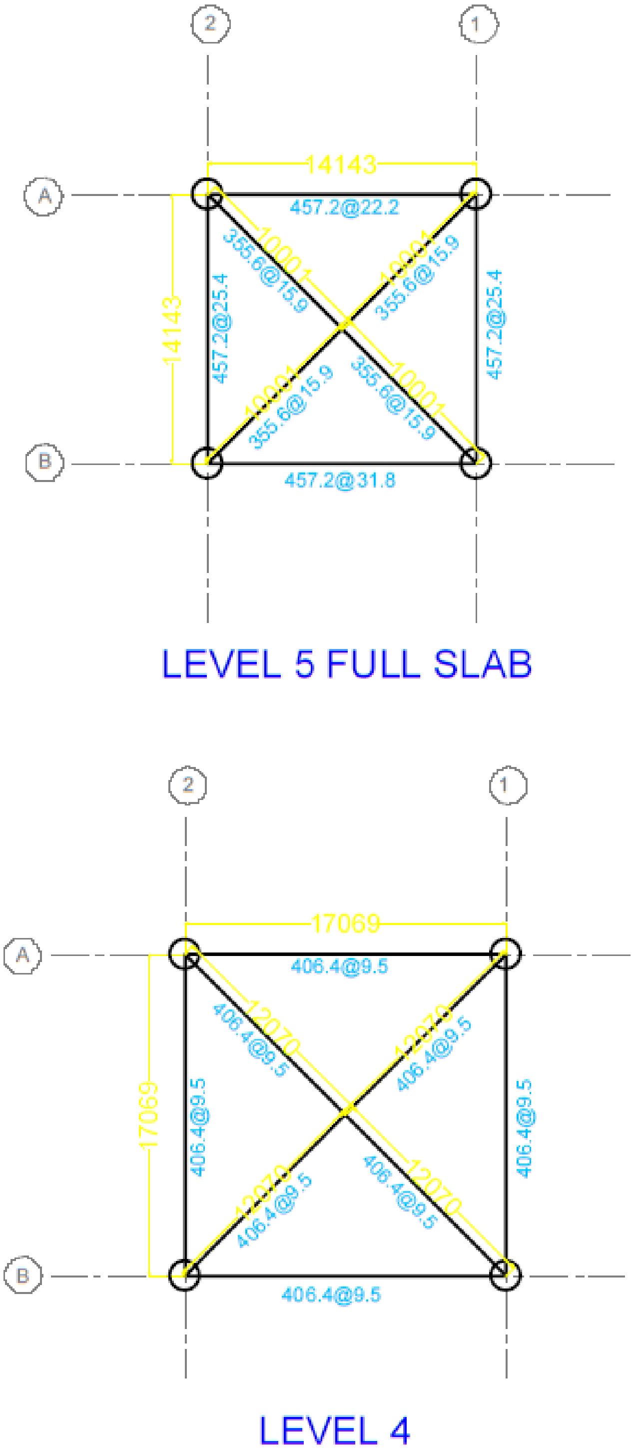


Figure 3.19: Top elevation of offshore structure-level 4 & 5 with members sizes

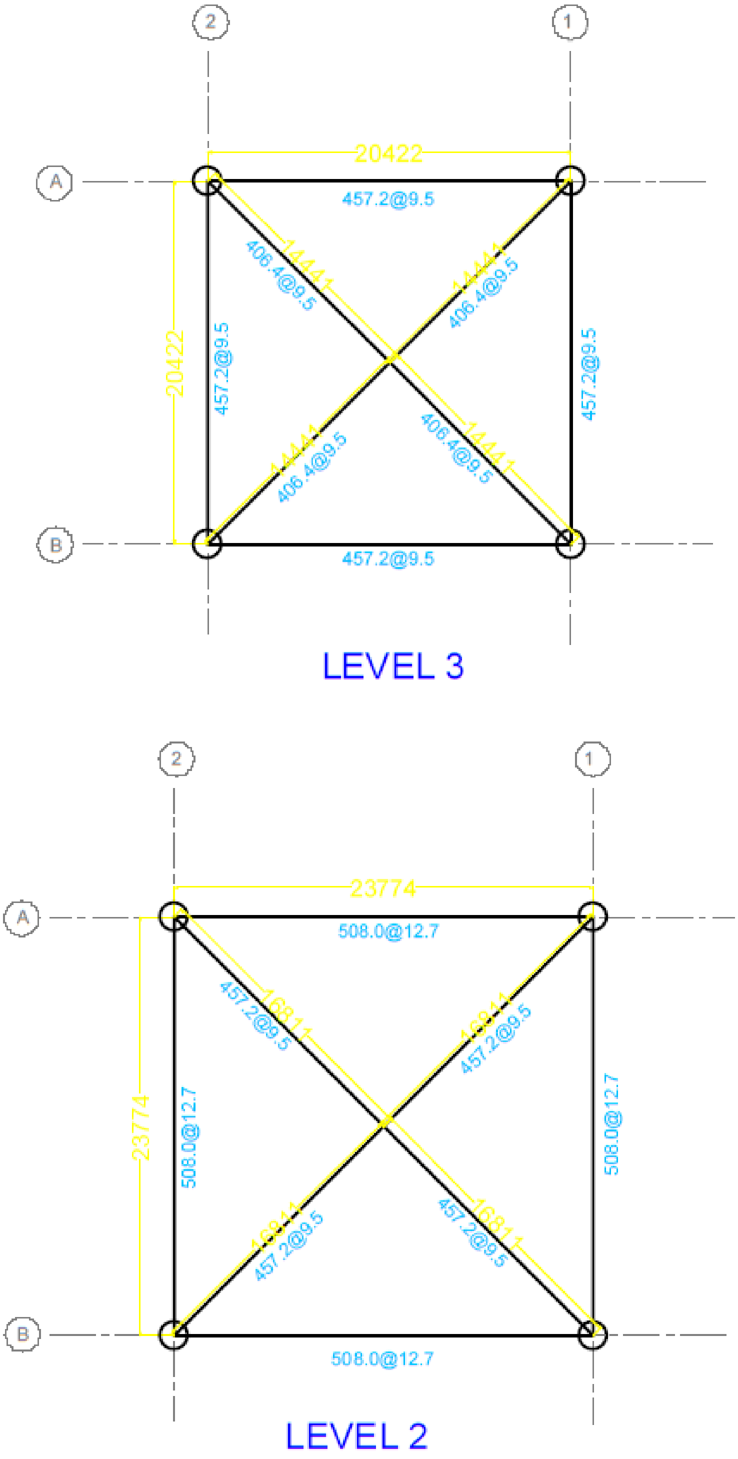


Figure 3.20: Top elevation of offshore structure-level 2 & 3 with members sizes

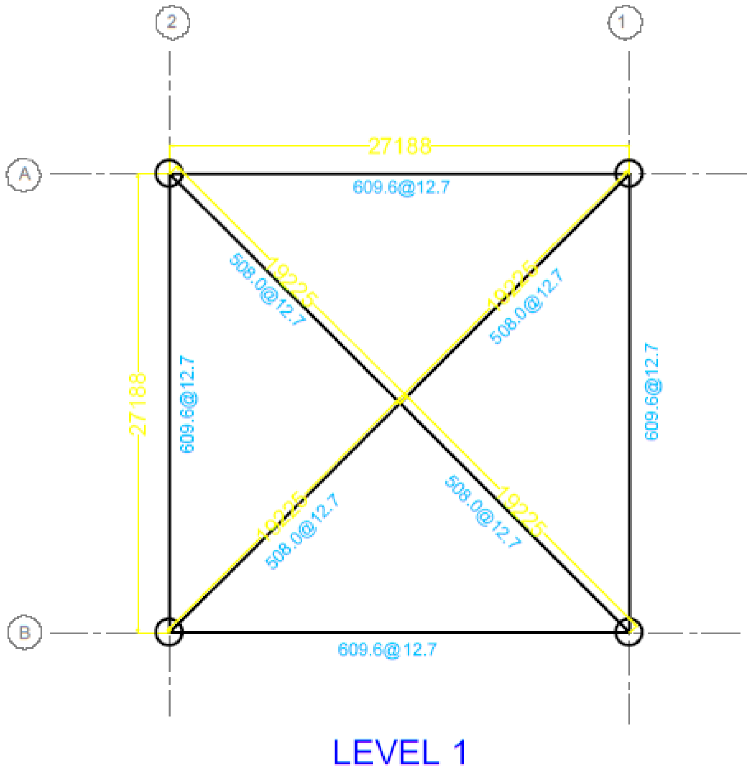


Figure 3.21: Top elevation of offshore structure-level 1with members sizes

5) Environmental Criteria for Structure

Table 3.1: Environmental criteria for offshore structure in Terengganu

MSL	Environment Criteria		Value
62.179	Wave Height	m	10.79
	Wave Period	s	10.9
	Current Velocity	m/s	0.750
	Wind Speed	m/s	21.8
	Maximum Tide	m	2.0
	Storm Surge	m	0.4

Source: Lai (2007)

3.5.3 Loadings

Loadings acted on the structure such as dead load, live load and environmental load are collected from the manufacturer of structure or calculated based on American Petroleum Institute Recommended Practice 2A-WSD. Their design values are shown below.

1) Dead Load and Live Load

Table 3.2: Dead and live loads for structure

No.	Load Descriptions	Weight (MN)
1.	Jacket Appurtenances Weight	-0.553
2.	Topside Dead Loads	-1.908
3.	Topside Live Loads	-2.655
4.	Piping & Equipment Weights	-19.537
5.	Self-Weight	[computer generate]

- **Dead Load**

$Dead\ load = 0.553\ + 1.908\ + 19.537\ = 21.998\ MN$

$$Uniform\ dead\ load\ = (21.998 \times 1000)kN\ \div (14.143\ \times 14.143)m^2$$
$$= 109.977kN\ /m^2$$

- **Live Load**

$Live\ load = 2.655\ MN$

$$Uniform\ live\ load\ = (2.655 \times 1000)kN\ \div (14.143\ \times 14.143)m^2$$
$$= 13.273\ kN\ /m^2$$

2) Environmental Load

- **Wind Load**

$$u(z,t) = U(z) \times [(1 - 0.41) \times I_u(z) \times \ln\left(\frac{t}{t_o}\right)]$$

$$= 65.976 \times [1 - 0.41 \times 0.134 \times \ln\left(\frac{120}{3600}\right)]$$

= 78.304 ft/s = 23.867 m/s

$$U(z) = U_o \, x \, [1 + C \times \ln\left(\frac{z}{32.8}\right)]$$

$$= 71.522x \, [1 + 0.118 \times \ln\left(\frac{17.001}{32.8}\right)]$$

= 65.976 ft/s

$$C = 5.73 \times 10^{-2} \times (1 + 0.0457 \times U_0)^{\frac{1}{2}}$$

$$= 5.73 \times 10^{-2} \times (1 + 0.0457 \times 71.522)^{\frac{1}{2}}$$

= 0.118

$$I_u\,(z) = 0.06 \times [1 + 0.0131x\, U_O] \times \left(\frac{z}{32.8}\right)^{-0.22}$$

$$= 0.06 \times [1 + 0.0131x\, 71.522] \times \left(\frac{17.001}{32.8}\right)^{-0.22}$$

= 0.134 ft/s

A = 2πrh

$$= 2(\pi)\left(\frac{1.1811}{2}\right)(3.048)$$

= 11.31 m^2

$$F = \left(\frac{\rho}{2}\right) \mu^2 C_S A$$

$$= \left(\frac{1.225}{2}\right)(23.867)^2(1.0)(11.31)$$

= 3.95 kN

- **Current Load**

$$F_c = C_d \frac{w}{2g} AU|U|$$

$$= 0.65 \left(\frac{10055.25}{2 \times 9.81}\right)(1.1811)(0.750)|0.75|$$

$$= \mathbf{221.32\ N/m}$$

- **Wave Load**

The wave load **above** sea water level was considered as rough:

$$F_w = C_d \frac{W}{2g} AU|U| + C_m \frac{W}{g} V \frac{dU}{dt}$$

$$= 1.05 \left(\frac{10055.25}{2 \times 9.81}\right)(1.1811)(0.75)|0.75| +$$

$$1.2 \left(\frac{10055.25}{9.81}\right)\left(\frac{\pi\ (1.1811)^2}{4}\right)\left(\frac{0.75}{100 \times 365 \times 24 \times 60 \times 60}\right)$$

$$= \mathbf{357.51\ N/m}$$

While the wave load **below** sea water level was considered as smooth:

$$F_w = C_d \frac{W}{2g} AU|U| + C_m \frac{W}{g} V \frac{dU}{dt}$$

$$= 0.65 \left(\frac{10055.25}{2 \times 9.81}\right)(1.1811)(0.75)|0.75| +$$

$$1.6 \left(\frac{10055.25}{9.81}\right)\left(\frac{\pi\ (1.1811)^2}{4}\right)\left(\frac{0.75}{100 \times 365 \times 24 \times 60 \times 60}\right)$$

$$= \mathbf{221.32\ N/m}$$

CHAPTER 4

RESULTS & DISCUSSION

4.1 RESULTS RELIABILITY

It is important to ensure the results of structural analysis is reliable so that the results shown are representing the true and correct representation of structure response subjected to different types of loading.

The reliability of the structure analysis were checked with the limitation of nodes able to be processed by SAP2000. The total number of nodes for this structure is 35 nodes. For SAP2000 Basic version, the limitation of nodes that are able to be processed by SAP2000 are 1500 nodes. The number of nodes of structure is less than the limitation of nodes able to be processed by SAP2000. Therefore, the SAP2000 software able to support and perform analysis of the offshore platform. Thus, analysis results obtained are reliable and can be trusted.

In addition, manual calculation of the critical members will be calculated and compared with SAP2000 results to ensure the reliability of the results modelled using SAP2000. The results of manual calculation are as attached in Appendix D.

4.2 RESULTS & DISCUSSION

Finite element structural analysis had been performed to the offshore structure using SAP2000. The analysis includes the consideration of dead load, live load, wind load, current load, wave load and seismic excitation on the structure. Several load combination had been considered for this structure and are as stated below:-

i) Modal Analysis
ii) Dead Load + Live Load
iii) Environmental Load (current, wind and wave load)
iv) Dead Load + Live Load + Environmental Load + Time History
v) Response Spectrum

4.2.1 Natural Frequencies, Periods and Mode Shape

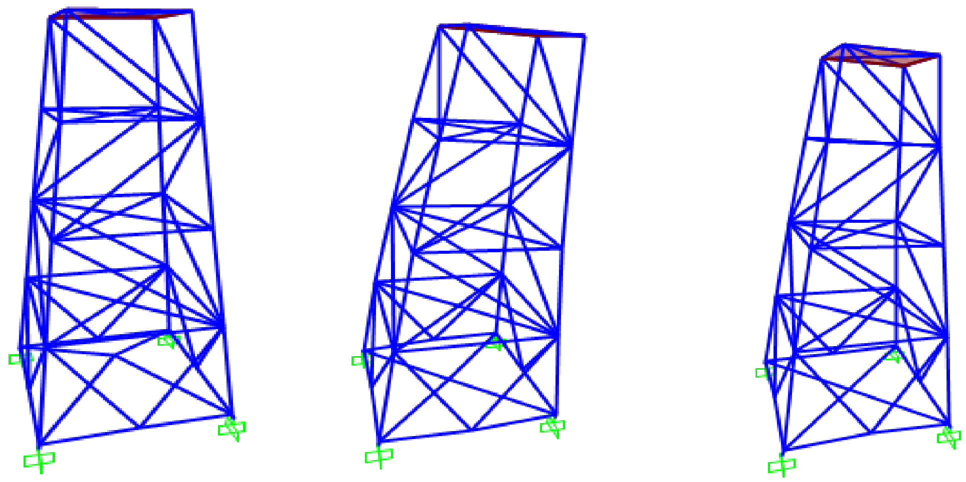
Free vibration analysis is to obtain the natural frequencies and natural periods with corresponding vibration modes of the structure where the structure is allowed to vibrate freely without the excitation of any external loading. It is an important part as earthquake causes a structure to vibrate. Engineers need to study the vibration frequency (number of oscillation per second) of earthquake as uncontrolled vibration of structure occurred when the earthquake reaches the natural frequency of the structure.

For this structure, mode shapes of the structure are observed and recorded. The first leading 12 natural frequencies and natural periods of the structure are summarized in Table 4.1 while their respective mode shapes are shown in Figure 4.1.

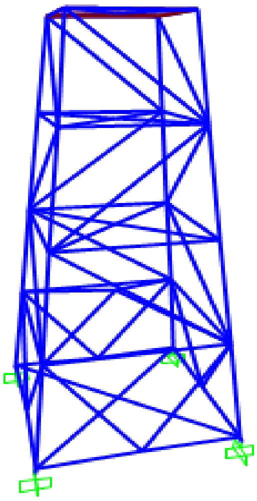
Based on Table 4.1, the natural frequencies of the structure increases with the increase of mode number while natural periods decreases with the increase of mode number. It indicate that as mode number increases, the earthquake frequency had to be increased (which means that the earthquake has to vibrate faster) to reach the natural frequency of the structure to cause uncontrolled vibration. As stated by Catherine (2011), the trend of the free vibration analysis is exactly the same thus indicating the results produced are reliable.

Table 4.1. Natural frequencies and periods of the offshore structure

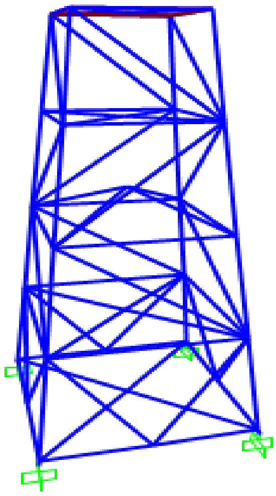
Mode No.	Natural Frequencies, *f* (Hz)	Natural Periods, *T* (s)
1	1.2466	0.802184
2	1.6885	0.592225
3	1.7113	0.584345
4	1.9971	0.500717
5	2.2566	0.443151
6	2.8096	0.355928
7	2.8153	0.355196
8	2.8177	0.354904
9	2.8576	0.349948
10	3.1657	0.315889
11	3.3223	0.301001
12	4.5043	0.22201



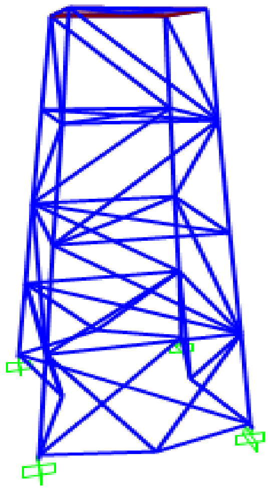
a) First Mode b) Second Mode c) Third Mode



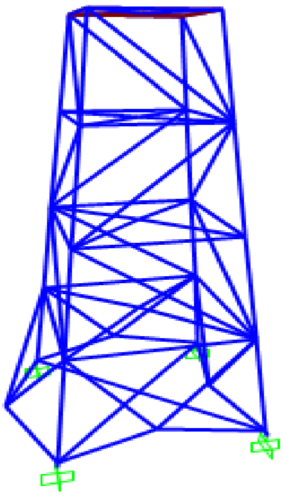
d) Fourth Mode



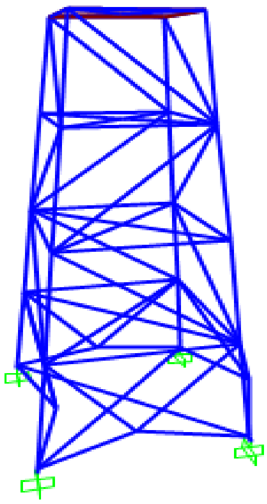
e) Fifth Mode



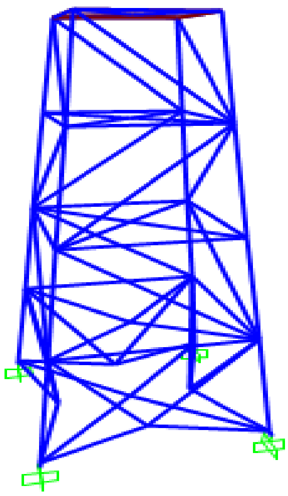
f) Sixth Mode



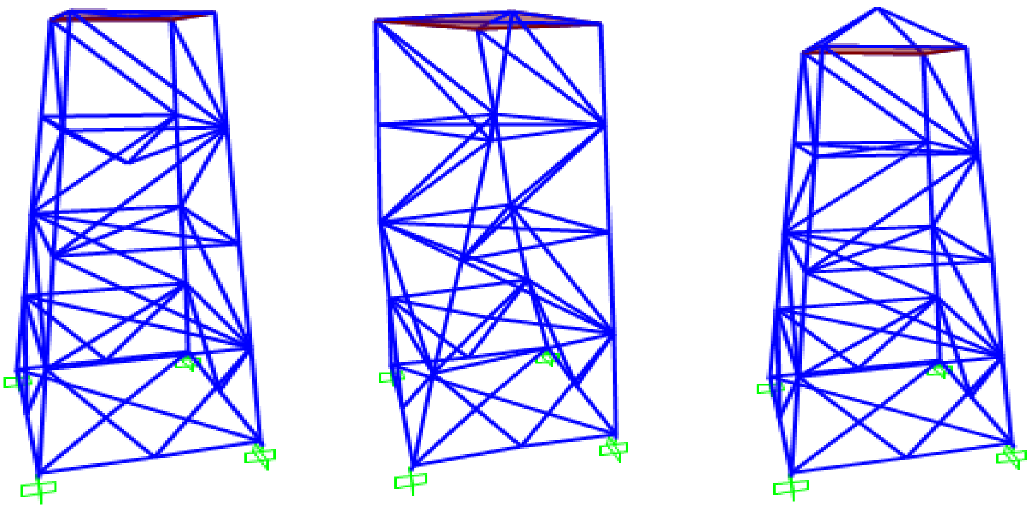
g) Seventh Mode



h) Eighth Mode



i) Ninth Mode



j) Tenth Mode   k) Eleventh Mode   l) Twelfth Mode

Figure 4.1(a-l). Vibration mode of the offshore structure with their respective mode number

4.2.2 Displacement

Displacements are significant information for considering the structural stability. Among horizontal and vertical displacement, horizontal displacement accounts for greater responsibility for structural stability than similar vertical displacement unless specially designed for it. The maximum displacement occurred at the highest nodal point (nodal no. 19) for all load combinations stated above and are summarized in Table 4.2 while graphical representation for maximum displacement is shown in Figure 4.2.

Table 4.2. Maximum displacement at nodal no. 19 for different load combinations

Load Combination	Disp. x (mm)	Disp. y (mm)	Disp. z (mm)
DL + LL	-5.3886	-5.3490	-63.6750
Wind + Wave + Current Load	15.0189	4.1884	2.0591
DL + LL + Wind + Wave + Current + Earthquake Load	5.9096	-2.0818	-59.5173
Response Spectrum Analysis	0.0557	0.0557	0.0099

As shown in Table 4.2, Load Combination Wind + Wave + Current Load exhibit greatest displacement compared to Load Combination DL + LL + Wind + Wave + Current + Earthquake because counteract of the forces acting in opposite direction of the structure had reduced the forces' effect.

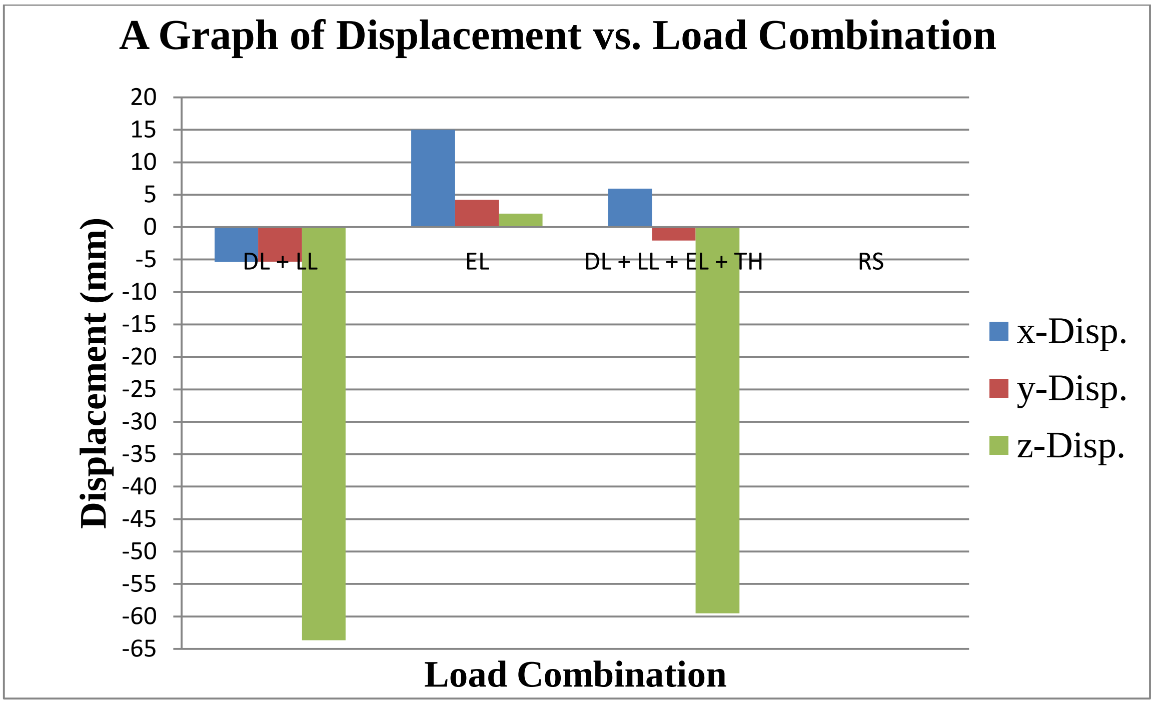


Figure 4.2. Graphical representation of maximum displacement at nodal no. 19 for different load combinations

4.2.3 Members' Resistance Capacity

4.2.3.1 Interaction Ratio

The load combination that apply the maximum loading to the offshore structure is Load Combination DL + LL + Wind + Wave + Current + Earthquake Load. The interaction ratio of maximum loading response to the resistance capacity of the structure's member elements is shown in Figure 4.3.

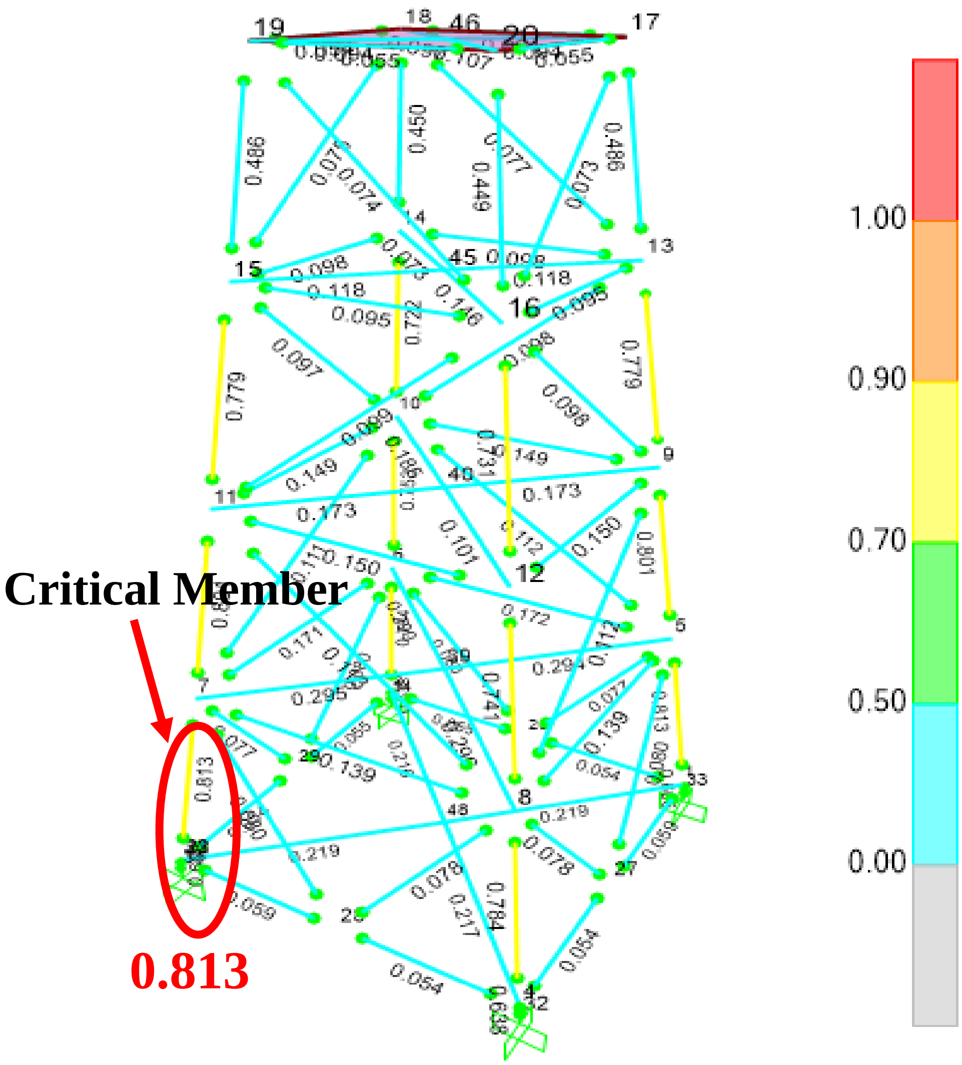


Figure 4.3. Interaction ratio for load combination DL + LL + wind + wave + current + earthquake load

Among all the members, the interaction ratio of the most critical member (member no. 36) is 0.813. All member elements of the structure is considered pass and within the range as the interaction ratio is less than 1. It shown that even under the earthquake excitation, the offshore structure still able to sustain all the loads, indicating the structure do not necessary to have seismic design since the effects of earthquake excitation on the structure is negligible.

4.2.3.2 Bending and Shear Stress of Critical Member

From the SAP2000 structural analysis, maximum bending and shear stress of the critical member are obtained. Figure 4.4 and 4.5 shows the bending and shear stresses of the critical member (member no. 36) subjected to different load combination respectively.

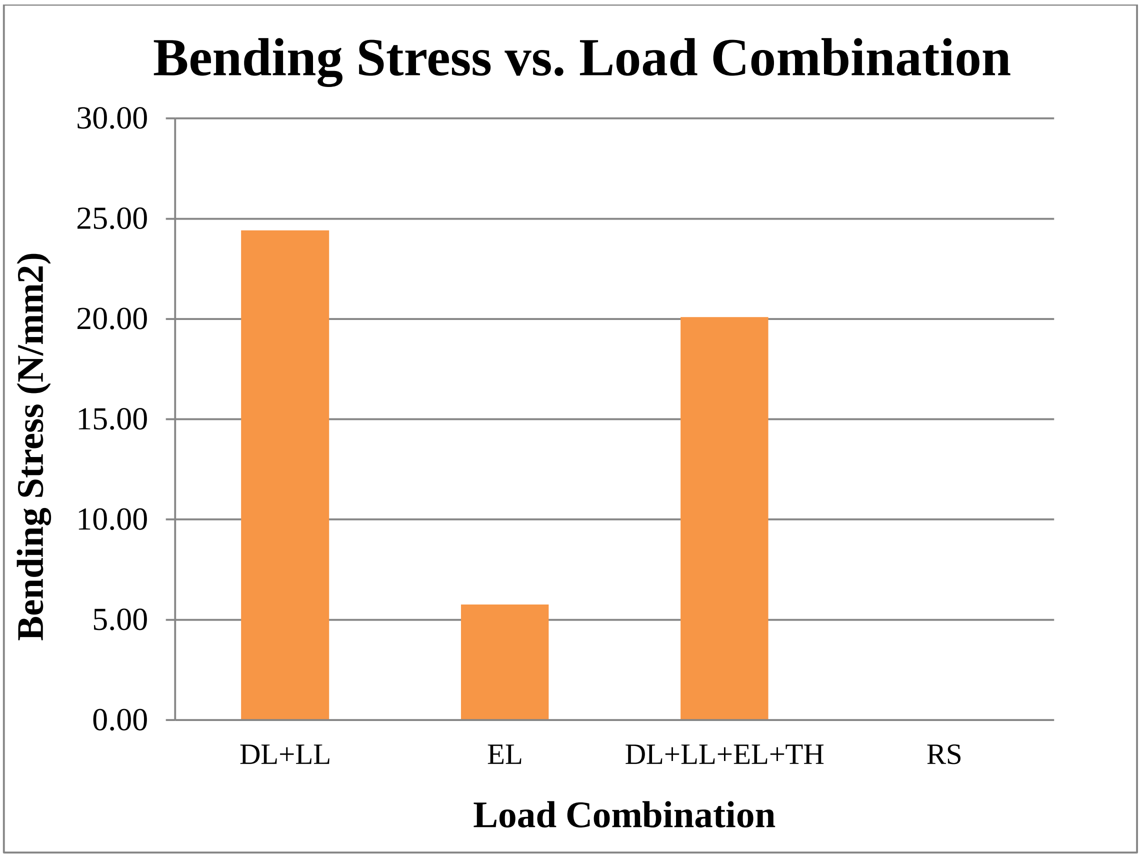


Figure 4.4. Bending stress vs. load combination for member no. 36

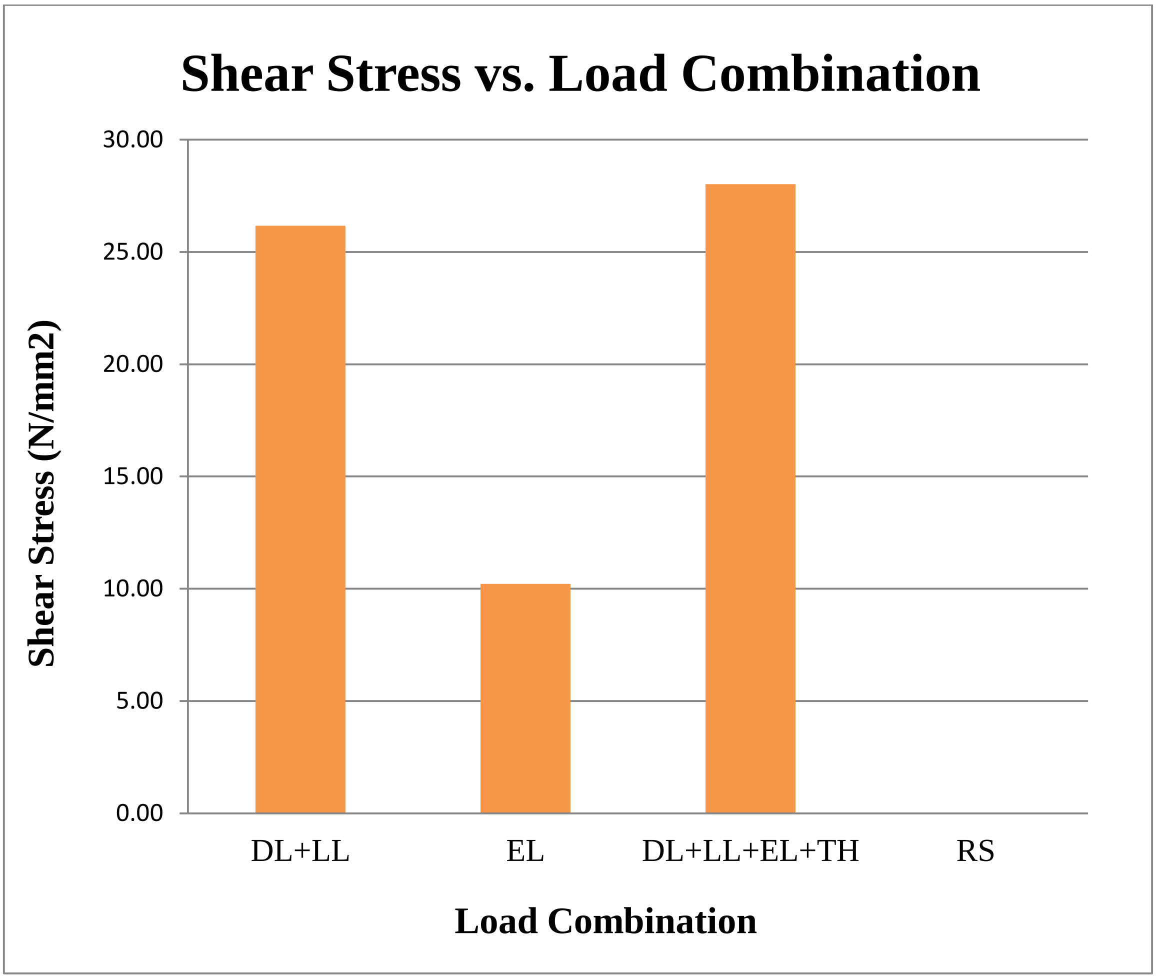


Figure 4.5. Shear stress vs. load combination for member no. 36

The maximum bending stress and shear stress subjected to the critical member is Load Combination DL + LL which are 24.4171 N/mm^2 and 0.5676 N/mm^2 respectively. While the bending and shear stress resistance capacity of member no. 36 are 456.9303 N/mm^2 and 130.4812 N/mm^2 respectively. Since maximum bending and shear stress induced by the external loading is less than the bending and shear stress resistance capacity of the member, thus, the member able to sustain the applied loading.

Although Load Combination DL + LL + Wind + Wave + Current + Earthquake Load exerted greatest loading to the structure, however, due to counteract of the forces and stresses, Load Combination DL + LL + Wind + Wave + Current + Earthquake Load exhibit lesser bending and shear stress than the Load Combination DL + LL. Besides that, a very small bending and shear stress of Load Combination Response Spectrum indicate that earthquake effects on the structure is negligible.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

In general, the objectives of this research are successfully achieved. Based on the finding of the research, the conclusions are made as below:-

i. Structural analysis of a 4-legged fixed offshore structure using SAP2000 including structure modelling, assigning load and SAP2000 computational analysis is successfully conducted.

ii. The responses of the jacket such as mode shape, bending stress, shear stress, displacement etc. subjected to different types of loadings such as dead, live, wind, wave, current load and earthquake excitation with different load combinations are determined.

iii. Based on the finding, there is not necessary to implement seismic design in jacket in Malaysia due to negligible effect of earthquake excitation on structure as the earthquake only induced little bending and shear stress towards the offshore structure and the interaction ratio check of the structure is less than 1.0.

iv. It is not necessary to include seismic excitation forces to design offshore structures in Malaysia.

5.2 RECOMMENDATIONS

Generally, there are some improvements that can be done about this research. Some recommendations are proposed as below for the future study of research of the same kind:-

i. The structure should be periodically check for seismic response by using the latest earthquake ground motion data. According to Datta, 2010, continental drift of the plate tectonics with different directions and speeds causes the generation of tectonic earthquake. As mention by Syahrul Izwan, 2008, Malaysia is moving closer to the tectonic boundary or earthquake fault. Thus, the effects of earthquake on Malaysia will be greater in the future. Therefore, it is necessary to check the seismic responses of structures using latest earthquake ground motion data.

ii. Soil pile interaction should be considered. Structure stability is not solely depend on the members' resistant capacity but also the foundation or ground that support the structure. Therefore, soil pile interaction should be considered in the analysis to represent the actual condition of the structure when subjected to the earthquake excitation.

iii. Joint connection should also be modelled in the software instead of assuming the connection able to support all the loading acted on it. Joint connection failure is usually the main reason of structure failure (Syahrul Izwan, 2008). Therefore, connection of the structure should be modelled to show the true representation of structural response towards the loading subjected to it.

REFERENCES

This research is prepared based on the following references:-

Offshore Book: An introduction to the offshore industry. 2010. Danmark: Offshore Center Danmark.

Lai, T.K. 2007. *Determination of earthquake design criteria for fixed offshore structures located in Malaysia region*. MS.c. Thesis. Universiti Teknologi Malaysia, Malaysia.

Datta, T.K. 2010. *Seismic analysis of structures.* Singapore: John Wiley & Sons (Asia) Pte Ltd.

Bargi, K., Hosseini, S.R. and Sharifian, H. 2011. Seismic response of a typical fixed jacket-type offshore platform (SPD1) under sea waves. *Open Journal of Marine Science.* (pp. 36-42).

Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings. 2005. Brussels: European Committee for Standardization.

Huang, L.J. and Syu, H.J. 2014. Seismic response analysis of tower crane using SAP2000. *37th National Conference on Theoretical and Applied Mechanics*, pp. 513-522.

Murkherjee, K., Ayob, M.S., Lai, T.K. and Nichols, N.W. 2014. New guideline for seismic assessment of fixed facilities in Malaysian water. *Offshore Technology Conference Asia.*

Park, M.S., Koo, W. and Kawano, K. 2011. Dynamic response analysis of an offshore platform due to seismic motions. *Engineering Structures*, pp. 1607-1616.

Recommended Practice for Planning, Designing and Construction Fixed Offshore Platforms- Working Stress Design. 2000. American Petroleum Institute.

Malaysia Overview. 2014. U.S. Energy Information Administration.

SAP2000 Integrated Finite Elements Analysis and Design of Structures Tutorial Manual. 1997. California: Computers and Structures Inc.

Rozaina, I. 2006. *Earthquake Design for Fixed Offshore Platform by using Visual Basic 6.0.* BS. c. Thesis. Skudai: Universiti Teknologi Malaysia.

Tu. Y.E. 2011. *Implementation of Eurocodes in Malaysia- a view point from consulting engineer.* Slide. Kuala Lumpur: MOH Engineering Conference 2011.

Seismicity in Malaysia and around the region. 2013. (online). http://www.met.gov.my/index.php?option=com_content&task=view&id=82&Itemid=1095 (15 March 2015).

Catherine, E.F. 2011. Understanding natural frequency: masses on rods. (online). https://nees.org/resources/3609 (16 may 2015).

APPENDIX A

COORDINATES OF THE NODES IN SAP2000

LEVEL	GRID	X COORDINATE	Y COORDINATE	Z COORDINATE
G	3-A	37288	37288	-1000
	1-A	9900	37288	-1000
	3-C	37288	9900	-1000
	1-C	9900	9900	-1000
1	3-A	37188	37188	0
	1-A	10000	37188	0
	3-C	37188	10000	0
	1-C	10000	10000	0
	3-B	37188	23594	0
	2-B	23594	23594	0
	1-B	10000	23594	0
	2-A	23594	37188	0
	2-C	23594	10000	0
2	3-A	35481	35481	17069
	1-A	11707	35481	17069
	3-C	35481	11707	17069
	1-C	11707	11707	17069
	2-B	23594	23594	17069
3	3-A	33805	33805	33833
	1-A	13383	33805	33833
	3-C	33805	13383	33833
	1-C	13383	13383	33833
	2-B	23594	23594	33833
4	3-A	32128.5	32128.5	50597
	1-A	15059.5	32128.5	50597
	3-C	32128.5	15059.5	50597
	1-C	15059.5	15059.5	50597
	2-B	23594	23594	50597

5	3-A	30665.5	30665.5	65227
	1-A	16522.5	30665.5	65227
	3-C	30665.5	16522.5	65227
	1-C	16522.5	16522.5	65227
	2-B	23594	23594	65227

APPENDIX B

STIFFNESS AND MASS OF STRUCTURE

LEVEL		MEMBER GRID NO.		MEMBER COORDINATES						OUTER DIA., D1 (mm)	THICKNESS, T (mm)	INNER DIA., D2 (mm)	E (N/mm2)	MOMENT OF INERTIA, I (mm4)	LENGTH (mm)	STIFFNESS, k (N.mm)	VOL. OF CROSS SEC. (m^3)	MASS, M (kg)
FROM	TO	FROM	TO	FROM			TO											
				x	y	z	x	y	z									
G	1	3-A		37288	37288	-1000	37188	37188	0	1168.4	12.7	1143	200	7699302587	1009.95	1.5E+09	0.04657	365.4751
G	1	1-A		9900	37288	-1000	10000	37188	0	1168.4	12.7	1143	200	7699302587	1009.95	1.5E+09	0.04657	365.4751
G	1	3-C		37288	9900	-1000	37188	10000	0	1168.4	12.7	1143	200	7699302587	1009.95	1.5E+09	0.04657	365.4751
G	1	1-C		9900	9900	-1000	10000	10000	0	1168.4	12.7	1143	200	7699302587	1009.95	1.5E+09	0.04657	365.4751
1		3-A	1-A	37188	37188	0	10000	37188	0	609.6	12.7	584.2	200	1061120980	27188	7805804	0.64749	5081.494
1		1-A	1-C	10000	37188	0	10000	10000	0	609.6	12.7	584.2	200	1061120980	27188	7805804	0.64749	5081.494
1		1-C	3-C	10000	10000	0	37188	10000	0	609.6	12.7	584.2	200	1061120980	27188	7805804	0.64749	5081.494
1		3-C	3-A	37188	10000	0	37188	37188	0	609.6	12.7	584.2	200	1061120980	27188	7805804	0.64749	5081.494
1		3-A	2-B	37188	37188	0	23594	23594	0	508	12.7	482.6	200	606392790	19224.8	6308437	0.37991	2981.557
1		2-B	1-C	23594	23594	0	10000	10000	0	508	12.7	482.6	200	606392790	19224.8	6308437	0.37991	2981.557
1		1-A	2-B	10000	37188	0	23594	23594	0	508	12.7	482.6	200	606392790	19224.8	6308437	0.37991	2981.557

1		2-B	3-C	23594	23594	0	37188	10000	0	508	12.7	482.6	200	606392790	19224.8	6308437	0.37991	2981.557
1	2	3-A		37188	37188	0	35481	35481	17069	1168.4	12.7	1143	200	7699302587	17238.9	8.9E+07	0.79489	6238.302
1	2	1-A		10000	37188	0	11707	35481	17069	1168.4	12.7	1143	200	7699302587	17238.9	8.9E+07	0.79489	6238.302
1	2	3-C		37188	10000	0	35481	11707	17069	1168.4	12.7	1143	200	7699302587	17238.9	8.9E+07	0.79489	6238.302
1	2	1-C		10000	10000	0	11707	11707	17069	1168.4	12.7	1143	200	7699302587	17238.9	8.9E+07	0.79489	6238.302
1	2	2-A	3-A	23594	37188	0	35481	35481	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	2-A	1-A	23594	37188	0	11707	35481	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	3-B	3-A	37188	23594	0	35481	35481	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	3-B	3-C	37188	23594	0	35481	11707	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	1-B	1-A	10000	23594	0	11707	35481	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	1-B	1-C	10000	23594	0	11707	11707	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	2-C	3-C	23594	10000	0	35481	11707	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
1	2	2-C	1-C	23594	10000	0	11707	11707	17069	558.8	15.9	527	200	999974410	20870.2	9582795	0.56597	4441.734
2		3-A	1-A	35481	35481	17069	11707	35481	17069	508	12.7	482.6	200	606392790	23774	5101311	0.46981	3687.085
2		1-A	1-C	11707	35481	17069	11707	11707	17069	508	12.7	482.6	200	606392790	23774	5101311	0.46981	3687.085
2		1-C	3-C	11707	11707	17069	35481	11707	17069	508	12.7	482.6	200	606392790	23774	5101311	0.46981	3687.085
2		3-C	3-A	35481	11707	17069	35481	35481	17069	508	12.7	482.6	200	606392790	23774	5101311	0.46981	3687.085
2		3-A	2-B	35481	35481	17069	23594	23594	17069	457.2	9.5	438.2	200	334919381	16810.8	3984584	0.22462	1762.815
2		2-B	1-C	23594	23594	17069	11707	11707	17069	457.2	9.5	438.2	200	334919381	16810.8	3984584	0.22462	1762.815
2		1-A	2-B	11707	35481	17069	23594	23594	17069	457.2	9.5	438.2	200	334919381	16810.8	3984584	0.22462	1762.815
2		2-B	3-C	23594	23594	17069	35481	11707	17069	457.2	9.5	438.2	200	334919381	16810.8	3984584	0.22462	1762.815
2	3	3-A		35481	35481	17069	33805	33805	33833	1168.4	12.7	1143	200	7699302587	16930.7	9.1E+07	0.78068	6126.796
2	3	1-A		11707	35481	17069	13383	33805	33833	1168.4	12.7	1143	200	7699302587	16930.7	9.1E+07	0.78068	6126.796
2	3	3-C		35481	11707	17069	33805	13383	33833	1168.4	12.7	1143	200	7699302587	16930.7	9.1E+07	0.78068	6126.796
2	3	1-C		11707	11707	17069	13383	13383	33833	1168.4	12.7	1143	200	7699302587	16930.7	9.1E+07	0.78068	6126.796
2	3	3-C	1-C	35481	11707	17069	13383	13383	33833	711.2	22.2	666.8	200	2854441603	27787.8	2.1E+07	1.33529	10479.37

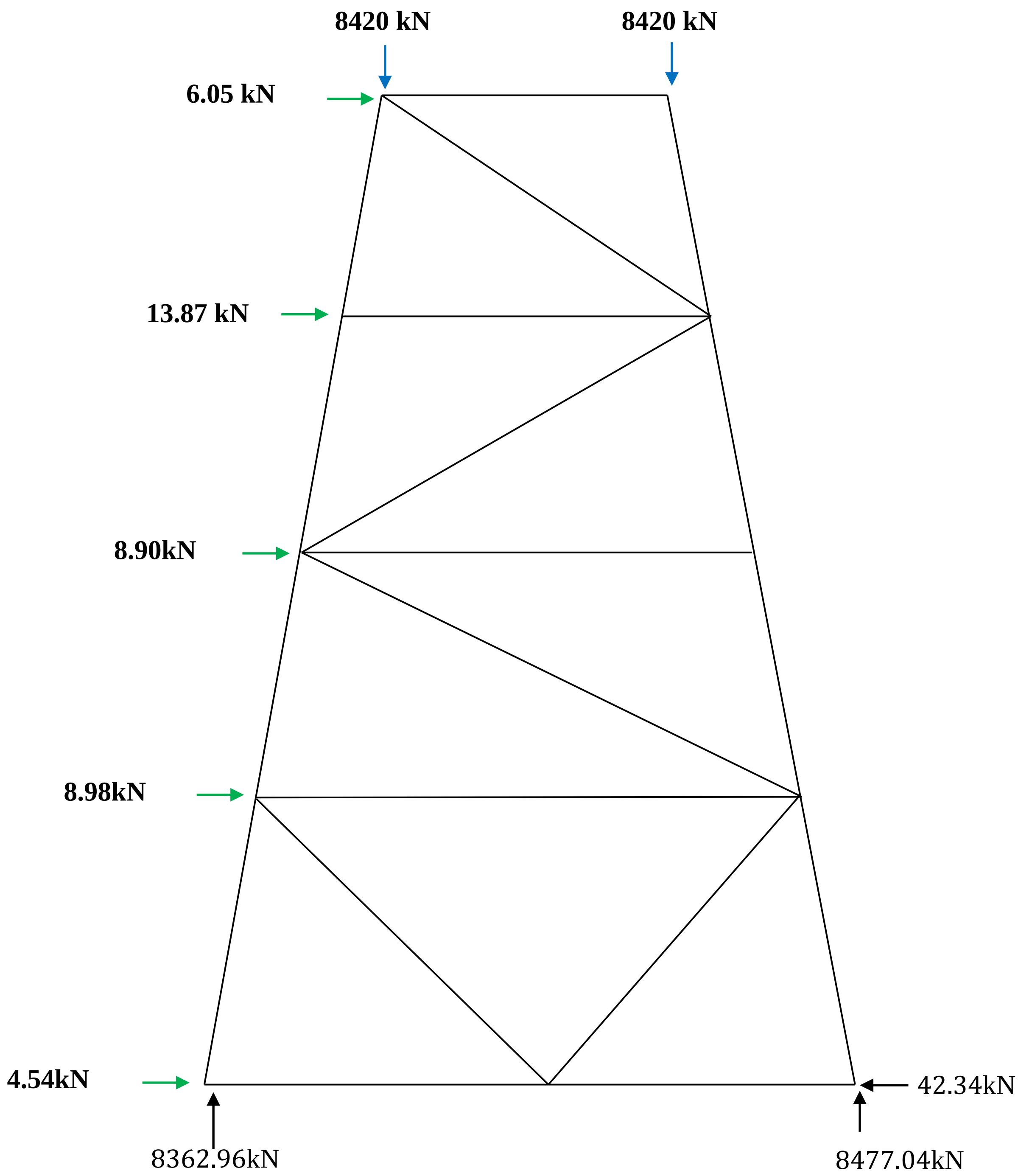
2	3	3-A	3-C	35481	35481	17069	33805	13383	33833	711.2	22.2	666.8	200	2854441603	27787.8	2.1E+07	1.33529	10479.37
2	3	3-A	1-A	35481	35481	17069	13383	33805	33833	711.2	22.2	666.8	200	2854441603	27787.8	2.1E+07	1.33529	10479.37
2	3	1-A	1-C	11707	35481	17069	13383	13383	33833	711.2	22.2	666.8	200	2854441603	27787.8	2.1E+07	1.33529	10479.37
3		3-A	1-A	33805	33805	33833	13383	33805	33833	457.2	9.5	438.2	200	334919381	20422	3279986	0.27287	2141.499
3		1-A	1-C	13383	33805	33833	13383	13383	33833	457.2	9.5	438.2	200	334919381	20422	3279986	0.27287	2141.499
3		1-C	3-C	13383	13383	33833	33805	13383	33833	457.2	9.5	438.2	200	334919381	20422	3279986	0.27287	2141.499
3		3-C	3-A	33805	13383	33833	33805	33805	33833	457.2	9.5	438.2	200	334919381	20422	3279986	0.27287	2141.499
3		3-A	2-B	33805	33805	33833	23594	23594	33833	406.4	9.5	387.4	200	233386390	14440.5	3232379	0.17106	1342.446
3		2-B	1-C	23594	23594	33833	13383	13383	33833	406.4	9.5	387.4	200	233386390	14440.5	3232379	0.17106	1342.446
3		1-A	2-B	13383	33805	33833	23594	23594	33833	406.4	9.5	387.4	200	233386390	14440.5	3232379	0.17106	1342.446
3		2-B	3-C	23594	23594	33833	33805	13383	33833	406.4	9.5	387.4	200	233386390	14440.5	3232379	0.17106	1342.446
3	4	3-A		33805	33805	33833	32129	32129	50597	1168.4	12.7	1143	200	7699302587	16930.8	9.1E+07	0.78069	6126.832
3	4	1-A		13383	33805	33833	15060	32129	50597	1168.4	12.7	1143	200	7699302587	16930.8	9.1E+07	0.78069	6126.832
3	4	3-C		33805	13383	33833	32129	15060	50597	1168.4	12.7	1143	200	7699302587	16930.8	9.1E+07	0.78069	6126.832
3	4	1-C		13383	13383	33833	15060	15060	50597	1168.4	12.7	1143	200	7699302587	16930.8	9.1E+07	0.78069	6126.832
3	4	1-C	3-C	13383	13383	33833	32129	15060	50597	711.2	19.1	673	200	2488458687	25203.9	2E+07	1.04669	8214.453
3	4	3-C	3-A	33805	13383	33833	32129	32129	50597	711.2	19.1	673	200	2488458687	25203.9	2E+07	1.04669	8214.453
3	4	1-A	3-A	13383	33805	33833	32129	32129	50597	711.2	19.1	673	200	2488458687	25203.9	2E+07	1.04669	8214.453
3	4	1-C	1-A	13383	13383	33833	15060	32129	50597	711.2	19.1	673	200	2488458687	25203.9	2E+07	1.04669	8214.453
4		3-A	1-A	32129	32129	50597	15060	32129	50597	406.4	9.5	387.4	200	233386390	17069	2734623	0.20219	1586.798
4		1-A	1-C	15060	32129	50597	15060	15060	50597	406.4	9.5	387.4	200	233386390	17069	2734623	0.20219	1586.798
4		1-C	3-C	15060	15060	50597	32129	15060	50597	406.4	9.5	387.4	200	233386390	17069	2734623	0.20219	1586.798
4		3-C	3-A	32129	15060	50597	32129	32129	50597	406.4	9.5	387.4	200	233386390	17069	2734623	0.20219	1586.798
4		3-A	2-B	32129	32129	50597	23594	23594	50597	406.4	9.5	387.4	200	233386390	12069.6	3867341	0.14297	1122.036
4		2-B	1-C	23594	23594	50597	15060	15060	50597	406.4	9.5	387.4	200	233386390	12069.6	3867341	0.14297	1122.036
4		1-A	2-B	15060	32129	50597	23594	23594	50597	406.4	9.5	387.4	200	233386390	12069.6	3867341	0.14297	1122.036

4		2-B	3-C	23594	23594	50597	32129	15060	50597	406.4	9.5	387.4	200	233386390	12069.6	3867341	0.14297	1122.036
4	5	3-A		32129	32129	50597	30666	30666	65227	1181.1	19.1	1143	200	1.1771E+10	14775.6	1.6E+08	1.03023	8085.237
4	5	1-A		15060	32129	50597	16523	30666	65227	1181.1	19.1	1143	200	1.1771E+10	14775.6	1.6E+08	1.03023	8085.237
4	5	3-C		32129	15060	50597	30666	16523	65227	1181.1	19.1	1143	200	1.1771E+10	14775.6	1.6E+08	1.03023	8085.237
4	5	1-C		15060	15060	50597	16523	16523	65227	1181.1	19.1	1143	200	1.1771E+10	14775.6	1.6E+08	1.03023	8085.237
4	5	3-C	1-C	32129	15060	50597	16523	16523	65227	660.4	15.9	628.6	200	1672592004	21441.2	1.6E+07	0.69027	5417.236
4	5	3-A	3-C	32129	32129	50597	30666	16523	65227	660.4	15.9	628.6	200	1672592004	21441.2	1.6E+07	0.69027	5417.236
4	5	3-A	1-A	32129	32129	50597	16523	30666	65227	660.4	15.9	628.6	200	1672592004	21441.2	1.6E+07	0.69027	5417.236
4	5	1-A	1-C	15060	32129	50597	16523	16523	65227	660.4	15.9	628.6	200	1672592004	21441.2	1.6E+07	0.69027	5417.236
5		3-A	1-A	30666	30666	65227	16523	30666	65227	457.2	22.2	412.8	200	719466022	14143	1E+07	0.42908	3367.384
5		1-A	1-C	16523	30666	65227	16523	16523	65227	457.2	22.2	412.8	200	719466022	14143	1E+07	0.42908	3367.384
5		1-C	3-C	16523	16523	65227	30666	16523	65227	457.2	22.2	412.8	200	719466022	14143	1E+07	0.42908	3367.384
5		3-C	3-A	30666	16523	65227	30666	30666	65227	457.2	22.2	412.8	200	719466022	14143	1E+07	0.42908	3367.384
5		3-A	2-B	30666	30666	65227	23594	23594	65227	355.6	15.9	323.8	200	245298032	10000.6	4905661	0.1697	1331.766
5		2-B	1-C	23594	23594	65227	16523	16523	65227	355.6	15.9	323.8	200	245298032	10000.6	4905661	0.1697	1331.766
5		1-A	2-B	16523	30666	65227	23594	23594	65227	355.6	15.9	323.8	200	245298032	10000.6	4905661	0.1697	1331.766
5		2-B	3-C	23594	23594	65227	30666	16523	65227	355.6	15.9	323.8	200	245298032	10000.6	4905661	0.1697	1331.766
															SUM:	8.3E+09		337368.2

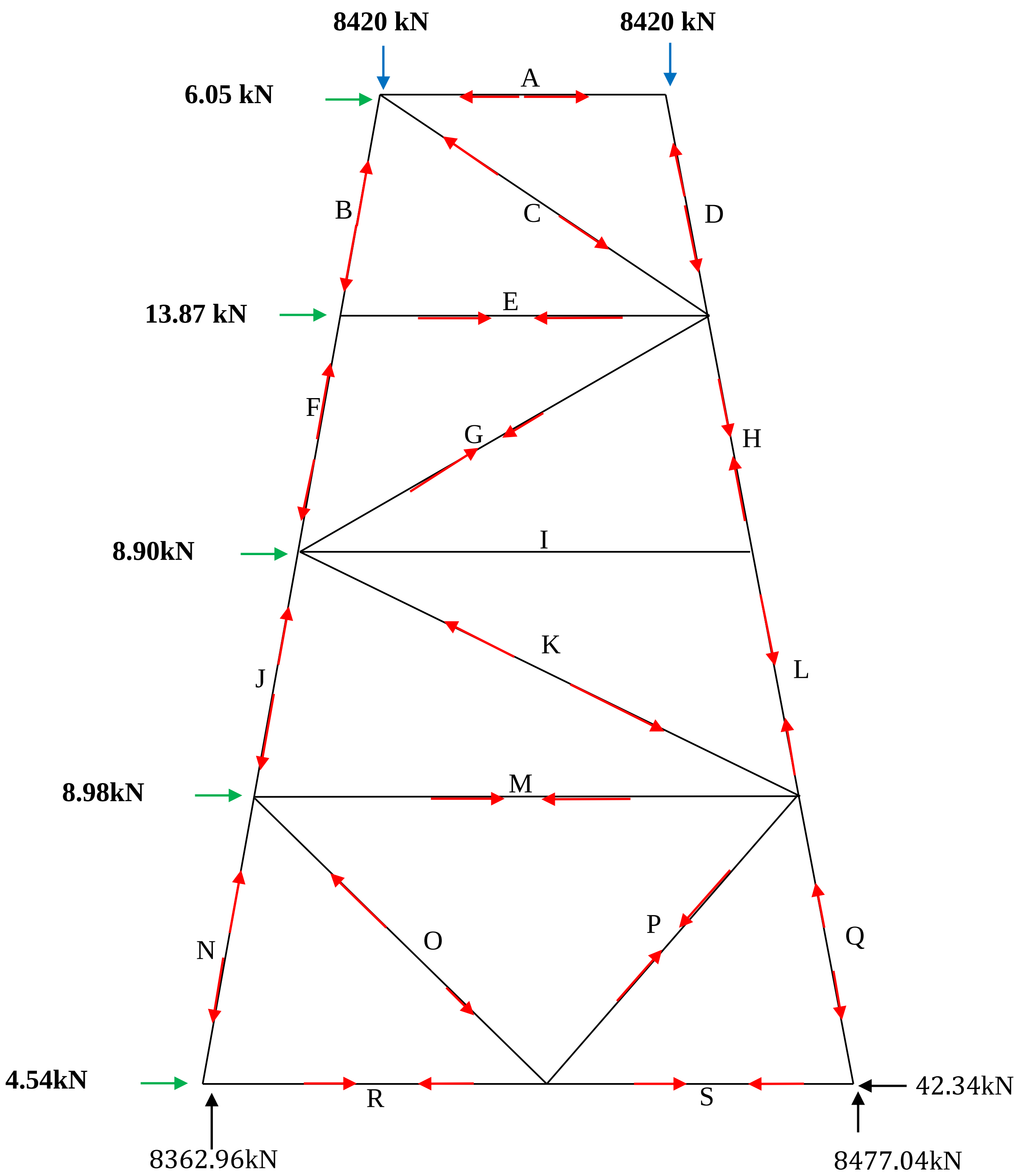
APPENDIX C

MANUAL CALCULATIONS OF CRITICAL MEMBERS

External Forces Acting on Structure



Internal Members Forces in Truss



∴ Green colour arrow indicated the environmental load (wind loads, wave load and Current)

Black colour arrow indicated the reaction forces

Blue colour arrow indicated the platform loads

Truss Member	Internal Force (kN)	Type of Force
A	1063.59	Compression
B	11866.83	Compression
C	254.24	Compression
D	8486.91	Compression
E	8522.41	Tension
F	8243.40	Compression
G	4422.14	Tension
H	7857.05	Tension
I	0	-
J	8423.59	Compression
K	5146.78	Compression
L	7857.05	Tension
M	829.00	Tension
N	8404.68	Compression
O	23.01	Compression
P	23.01	Tension
Q	8519.32	Compression
R	831.80	Tension
S	805.41	Tension

*Blue rows indicated the critical column members
*Green rows indicated the critical beam members
*Yellow rows indicated the critical tension truss members

DESIGN OF TENSION MEMBERS

- **Tension Force**

The maximum design tension force among the truss members is truss member G, $N_{ed(G)} = 4422.14\text{kN}$

Thus, Tension force, $\mathbf{N_{ed} = 4422.14\ kN}$

- **Tension Capacity**

CHS d=711.2 mm, t= 19.1 mm of steel grade S275,

A= 41529.059 mm^2, i= 244.787 mm

Design strength, f_y (Table 3.1):

t= 19.1 mm < 40 mm, steel grade S275, f_y = 275 N/mm^2, f_u = 430 N/mm^2

In this case, there is no hole for the bolts, hence no reduction in the cross sectional of the angle section.

The design tension resistance $N_{t,Rd}$ should be taken as smaller of:

i. **The design plastic resistance of the gross cross-section**

$$N_{pl,Rd} = \frac{Af_y}{\gamma_{M0}} = \frac{(41529.059\ mm^2)\left(275\frac{N}{mm^2}\right) x\ 10^{-3}}{1.0} = 11420.49\ \text{kN}$$

ii. **The design ultimate resistance of the net cross-section**

Since there was reduction in the cross section of angle, then

$A_{net} = A = 41529.059\ mm^2$

$$N_{u,Rd} = \frac{0.9A_{net}f_u}{\gamma_{M2}} = \frac{0.9(41529.059\ mm^2)\left(430\ \frac{N}{mm^2}\right) x\ 10^{-3}}{1.25} = 12857.40\ kN$$

Therefore, $\mathbf{N_{t,Rd} = 11420.49\ kN}$

- **Check for equilibrium**

$$\frac{\mathbf{N_{ed}}}{\mathbf{N_{t,Rd}}} = \frac{4422.14\ \ kN}{12857.40\ \ kN} = \mathbf{0.34} < 1.0$$

The section is **suitable** to carry the force.

DESIGN OF BEAM MEMBERS

- **Maximum Forces of Beam**

Design load, q = 8522.41 kN

Shear force, V_{Ed} $= \frac{q}{2}$

$= \frac{8522.41}{2}$

$= 4261.21\ \mathrm{kN}$

Bending Moment, M_{Ed} $= \frac{qL}{4}$

$= \frac{8522.41\ (17.069)}{4}$

$= 36367.25\ \mathrm{kN.m}$

- **Member Resistance Capacity**

Section: 406.4mm @ 9.5mm

d = 406.4 mm

t = 9.5 mm

A = 118.46 cm^2

I = 23338.64 cm^4

i = 14.04 cm

W_{el} = 1148.56 cm^3

W_{pl}= 1496.82 cm^3

I_t = 46677.28 cm^4

E = 210000 $\mathrm{N/mm}^2$

G = 81000 $\mathrm{N/mm}^2$

Design Strength:

By referring to Table 3.1, Eurocode 3 (Part 1-1)

For steel grade S275,

t = 9.5 mm<40 mm

f_y = 275 N/mm^2

f_u = 430 N/mm^2

Section Classification:

By referring to Table 5.2, Eurocode 3 (Part 1-1)

$\varepsilon = \sqrt{^{235}/_{f_y}}$ = 0.92

$\varepsilon^2 = (0.92)^2 = 0.85$

$\frac{d}{t} = \frac{406.4}{9.5} = 42.78 < 50\varepsilon^2 = 50(0.85) = 42.5$ $\frac{d}{t} > 50\varepsilon^2$ Not class 1!

$\frac{d}{t} = \frac{406.4}{9.5} = 42.78 < 70\varepsilon^2 = 70(0.85) = 59.5$ $\frac{d}{t} < 70\varepsilon^2$ Class 2

The section was classified as Class 2 as $^d/_t$ meets the Class 2 standard.

Shear Resistance of Section:

i. Maximum external design shear force, V_{Ed} = 4261.21 kN
ii. Shear resistance of the section, $V_{C,Rd}$

$V_{C,Rd} = V_{Pl,Rd}$

$V_{Pl,Rd} = \frac{A_v\left(^{f_y}/_{\sqrt{3}}\right)}{\gamma M_0} = \frac{7541.40\left(^{275}/_{\sqrt{3}}\right)}{1.00}$

= 5197.36 kN

- $A_v = \frac{2A}{\pi} = \frac{2(11846)}{\pi}$ = 7541.40 mm^2

iii. Design Check

$$\frac{V_{Ed}}{V_{C,Rd}} = \frac{4261.21}{5197.36}$$

$= 0.82 \leq 1.0$

The section is satisfactory.

- **Bending Moment Resistance**

i. Maximum external design moment, M_{Ed} = 36367.25 kNm

ii. Moment resistance for Class 2 cross section, $M_{C,Rd}$

$M_{C,Rd} = M_{Pl,Rd}$

$M_{Pl,Rd} \quad = \frac{W_{Pl}(f_y)}{\gamma M_0} = \frac{1496820\ (275)}{1.00}$

$M_{Pl,Rd} \quad$ = 411625500 Nmm

= 41162.55 kNm

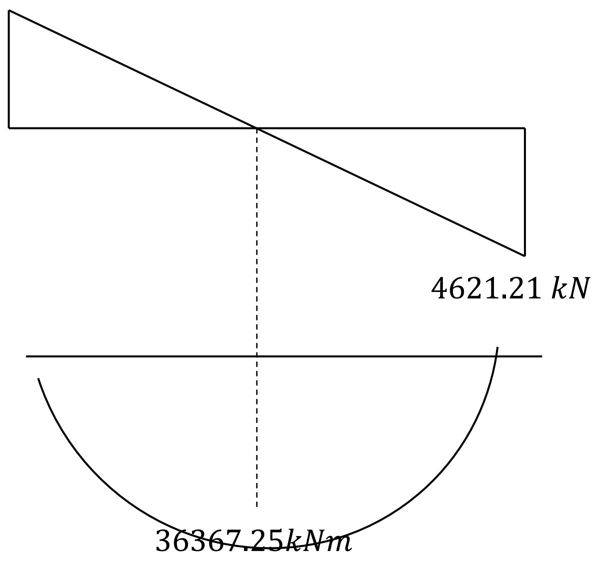
iii. Design Check

$$\frac{M_{Ed}}{M_{C,Rd}} = \frac{36367.25}{41162.55}$$

$= 0.88 \leq 1.0$

The section is satisfactory.

- **Combined Bending and Shear Resistance**



Consider a section where moment is maximum, referring to Shear Force and Moment diagrams, the mid-span section where M_{Ed} = 36367.25kNm and V_{Ed} = 0 kN is considered.

a) Shear force at maximum moment, V_{Ed} = 0 kN

b) 0.5 $V_{C,Rd}$
= 0.5 (5197.36)
= 2598.68 kN

c) Since V_{Ed}<0.5 $V_{C,Rd}$

The shear, V_{Ed} is small and it does not affect the moment resistance, $M_{C,Rd}$.

The beam section was able to carry the most critical combination of bending and shear. No reduction in the design strength of the steel, f_y and the design moment resistance remains, $M_{C,Rd}$= 41162.55 kNm .