SENSITIVITY ANALYSIS OF WAVE HEIGHTS OF TSUNAMI

FROM MANILA TRENCH,

ON OFFSHORE PLATFORMS IN SABAH.

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

JONATHAN WONG SIONG KAI

CERTIFICATION OF APPROVAL

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Jonathan Wong Siong Kai

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ABSTRACT

In this paper, the effect of tsunami waves coming from Manila Trench on offshore platforms in Malaysian waters will be studied. Malaysia has always been perceived to be a country safe from the hazards of earthquakes and tsunami as Malaysia is not located within the Pacific Ring of Fire. Therefore, the usual practice in designing offshore structures is to assume the forces induced on the structures due to these tsunami waves are minimal. Local designing standards and codes does not include any suggestions on including tsunami wave impacts in the design. Furthermore, in the year 2004, a 9.3 Mw earthquake occurred outside the Northwest Coast of Aceh, causing tsunamis which caused destruction amounting to US$ 25 million and 68 deaths, in Malaysia, has left questions on the reliability of these offshore platforms. Since then, efforts have been done to study and predict tsunami's propagation, which includes the developing a local tsunami numerical analysis model TUNA; where previous simulations have shown very satisfactory performance when compared against Cornell Multi-grid Coupled Tsunami Model (COMCOT) and on-site survey results. TUNA-M2, the software used to simulate the tsunami waves, will allow wave heights to be obtained, when it reaches the point of observation. This will be done by incrementally changing the magnitude of the earthquake, thus giving the wave height and the time it reaches the platforms from the time of occurrence. With this wave heights, the tsunami is simulated in SACS a structural analysis software, where the results, in Unity Check (UC), will define the integrity of the offshore platform.

ACKNOWLEDGEMENT

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1.0 INTRODUCTION

1.1 Background studies

Figure 1: 26th December Aceh Tsunami Waves Propagation

A 9.3 Mw earthquake at North West coast of Aceh, Indonesia, on the 26^{th} December 2004, was one of the darkest days in South East Asia. This earthquake then led to tsunami events which killed up to thousands of lives in 12 countries, in South East Asia. Since then, extensive researches was done regarding the propagation of tsunami and its effects to neighboring countries, with the hopes of educating and preparing coastal communities against tsunami attacks. This simulation will not only be beneficial to coastal communities but to those in operations at offshore platforms, who might be prone to tsunami impacts too.

Malaysia is located in an area affected by tsunamis, caused especially by earthquakes in seismically-active Philippines. In Philippines, there are a few trenches which are actively in subduction zone, namely, Manila Trench, Negros Trench, Sulu Trench, Cotabato Trench, and the Philippine Trench. The Manila Trench, is where the Sunda Plate is subducting under the Philippines Mobile Belt, at 70 millimeters per year, and is categorized by United States Geological Survey's Tsunami Sources Workshop in 2006, as one of the most risky trench, for an earthquake to happen. The simulation of the tsunami will be done using TUNA-M2, and the results will be obtained in terms of wave heights and time of arrival.

A toppled over offshore platform will not only be catastrophic national news but also a cause for concern to review and check other platforms, which are designed similarly. Hence, to check for a structure's integrity, essentially the factor controlling the design has to be decided. From the wave heights obtained from the tsunamis, caused by different magnitude earthquakes, a structural analysis can be performed on the offshore platform using SACS software.

For offshore platforms in Malaysian waters, one of the most important standards defining the designs for the regions, is the PETRONAS Technical Standard (PTS), prepared and revised regularly by PETRONAS Carigali. Checks into the PTS have shown that tsunami loadings was not included in the design loads.

1.2 Problem Statement

Many researches has rationalize that the next earthquake coming from the Manila Trench, will cause a powerful tsunami. With the occurrence of this tsunami, many have simulated the tsunamis' wave heights on nearby countries, like Taiwan, Thailand and even in the Philippines. Not many or none have actually simulated the effects of Manila Trench on Malaysia's coast, let alone in Sabah state. On the other hand, our main concern is how the offshore platform in Sabah, will stand before the integrity of the platform is affected.

As studies have not been extensive on the effects of tsunami on offshore platforms, it cannot be said with accuracy, that the assumption that tsunami loadings on the offshore platform is minimal or if the tsunami will actually cause harm to the offshore platform.

1.3 Objectives and Scope of Study

Objective One

Obtain and analyze the wave height using TUNA-M2 tsunami simulation software.

First, the parameters of the earthquake will have to be obtained, and studied. Then, the simulation of the tsunami will be done for magnitudes of earthquake for range 7.0 Mw to 9.0 Mw, to obtain wave heights. These wave heights will then be analyzed against SACS analysis results of the selected platforms' threshold reserved strength, to check for reliability.

Objective Two

Analyze offshore platform's integrity subjected to tsunami loadings, under normal operating condition.

To check for the possibility of the tsunami loadings to cause failures or even a collapse of offshore platform in Sabah, in the event of a tsunami due to an earthquake in Manila Trench.

Scope of study

Point of observations (Platforms)

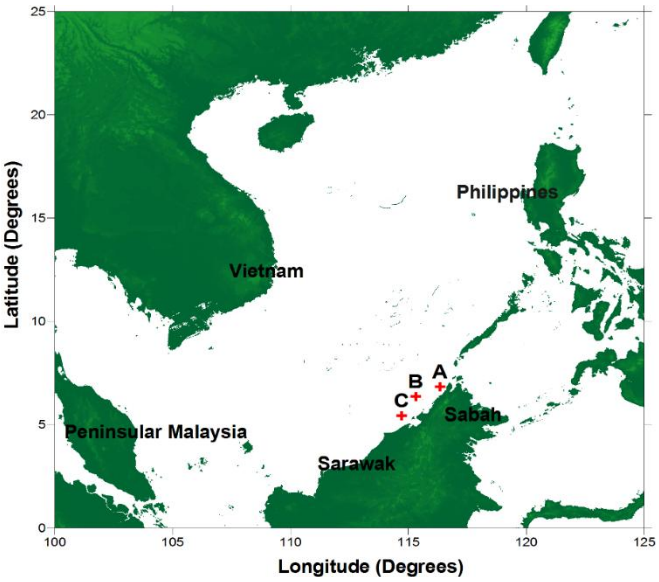


Figure 2: The map showing the position of the observation points in Sabah

The diagram above shows three point of observations that were among the three offshore platforms in Sabah. Platform A, is the Barton Vent-A, or the BTV-A platform, while platform B is the Erb West, EWQ-A platform. Lastly, platform C, is the Kinabalu Drilling Platform A, or the KNDP-A platform In Sabah water, the offshore platforms seems to be clustered near each other, but for our case of study, platform B, the Erb West, EWQ-A, is chosen to simulate the effect of tsunami waves on offshore platforms.

a. Source of Tsunami (Earthquake)

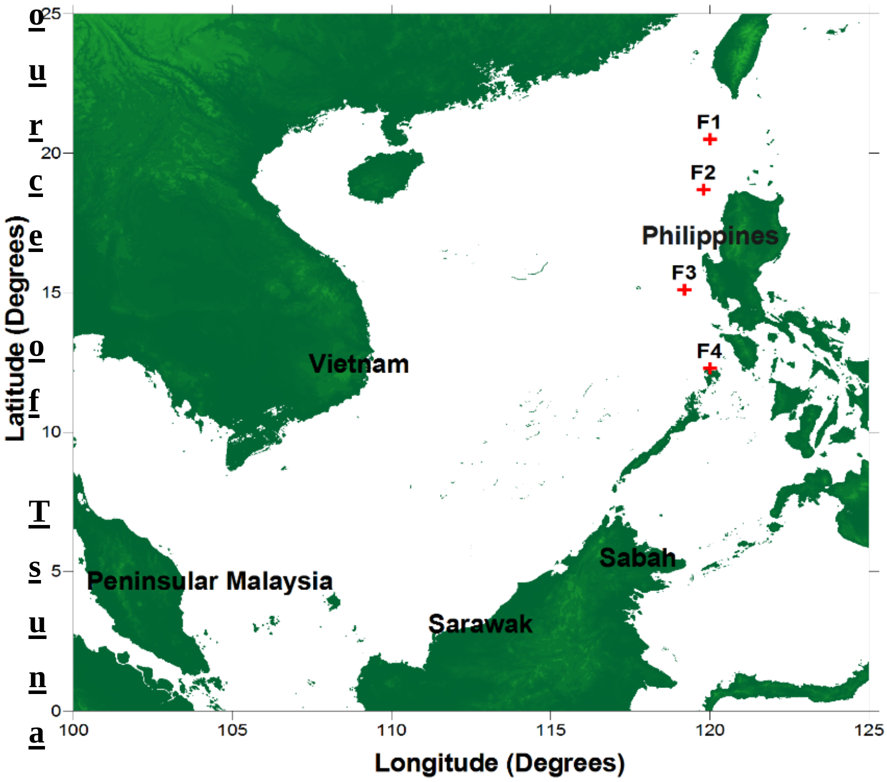


Figure 3: Map showing the epicenters of the assumed earthquake faults at Manila Trench

For this study, the scope has been narrowed down to tsunami which happens due to earthquake in the Manila Trench. The reason for this was shown by (Megawati et. al, 2008) who pointed out that the Manila Trench has been quiet for almost 440 years and this means that the strain has been in accumulation since the last earthquake. (Tsu and Hui, 2008) also added a point that the United States Geological Survey (USGS) in the Tsunami Sources Workshop 2006, has analyzed and predicted that the Manila Trench to a risky zone as a tsunami source. They further quoted (Kirby et al., 2006) saying that there are up to six possible fault planes based on the azimuth of the Manila Trench.

2.0 LITERATURE REVIEW

2.1 Earthquake and its parameters

Since the 1950s, many researches have been done to study on the global relations between earthquake fault parameters and the moment magnitude of earthquakes. Papazachos et al., (2004) mentioned that this relation between fault parameters like (fault length, fault area, fault slip) and the magnitude for the corresponding earthquake, are important for:

1. Estimation of the magnitude of an earthquake when such parameters are obtained.
2. Checking of the validity of models of the mechanics of seismic rupture.

With this estimation of the magnitude of an earthquake, a tsunami simulation will then be easily performed. Hence, it is important for the parameters of the earthquake to first, be of a reasonable and an accurate one.

For our study, the simulation will be based on Tso (2012) earthquake parameters. In his paper, he did studies on many historical tsunamis, which includes, 18-trench typed tsunami sources and 4 fault-typed tsunami sources. For all of these tsunami sources, he studied thoroughly on the construction of an earthquake, including the subsurface rupture length, and width, the scale of seismic moment, slip and the dip angle. From his study, the earthquake parameters of Manila Trench is extracted, and adjusted accordingly, for the purpose of the study.

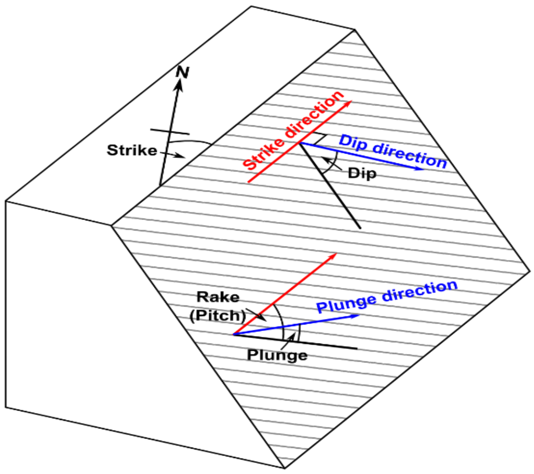


Figure 4 : Diagram showing the strike angle, rake angle, dip angle, and plunge angle.

These earthquake source parameters, includes dip angles, rake angles, strike angles, and focal depth. The dip angle is a permanent characteristic of a fault, which is the angle between the fault and a horizontal plane. The rake angle refers to the direction of a hanging wall block moves during rupture, as measured on the plane of the fault. Strike angles, refers to the direction of a line, created by the intersection of a fault plane and a horizontal surface, which is relative to North.

2.2 Simulation using TUNA-M2

Simulation of the tsunami waves will be done using the TUNA-M2 software, which is an in-house software designed after the 26th December 2004 tsunami, by Koh H. L. and Teh S.Y. from Universiti Sains Malaysia. The TUNA-M2 software is one of three parts of the TUNA software and is responsible for the propagation of the tsunami waves. According to (Koh et al., 2008) the propagation of tsunamis using TUNA is simulated by the depth-averaged 2D shallow water equations (SWE) as shown:

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{\frac{7}{3}}} M\sqrt{M^2 + N^2} = 0$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{\frac{7}{3}}} N\sqrt{M^2 + N^2} = 0$$

In the above equations (M, N) in x- and y- directions are in relation to velocities u and v by the expressions $M = u\,(h + \eta) = \mathrm{uD}$,$N = v\,(h + \eta) = \mathrm{vD}$ where h is the sea depth and η is the water elevation above mean sea level (Koh et al., 2008).

It is also in the paper that, (Koh et al., 2008) did a simulation of the Andaman 2004 tsunami to study the impact on Malaysian waters. From this paper comparison was done between TUNA and a more established tsunami simulation software COMCOT (Cornell Multi-grid Coupled Tsunami Model) simulation software developed by Professor P. L. –F Liu at Cornell University, USA. For comparison, TUNA-M2 and COMCOT, was shown to have no difference in terms of wave height time series as well as wave height color contours. In (Koh et al., 2008) which includes studies on impact on Penang, and Langkawi and (Koh et al., 2009) which did a study on Andaman tsunami’s impact on Straits of Malacca, the TUNA has proven its capability to perform to a level of accuracy and consistency with models functions like the COMCOT.

2.3 Simulation of Tsunami from Manila Trench

For this study, the scope has been narrowed down to tsunami which happens due to earthquake from the Manila Trench. The reason for this was shown by (Megawati et. al, 2008) who pointed out that the Manila Trench has been quiet for almost 440 years and this means that the strain has been in accumulation since the last earthquake. (Tsu and Hui, 2008) also added a point that the United States Geological Survey (USGS) in the Tsunami Sources Workshop 2006, has analyzed and predicted that the Manila Trench to a risky zone as a tsunami source.

Anat and Nopporn (2009) who in their studies collected data of earthquakes are from Advanced National Seismic System (ANSS) from 1963 to 2006. In their studies, fault parameters used are also based on Papazachos et al., (2004) and they considered on one fault for 9.0 M_w, two faults for 8.5 M_w and lastly 8.0 M_w with three fault cases. Using TUNAMI simulation model, they also did simulations of the 26th December 2004 tsunami, to act as validation to the model used in the simulation of tsunami coming from the Manila Trench. The results obtained show that in Thailand, if a tsunami were to happen in Manila Trench, the minimum time for tsunami to reach Thailand, was about 13.5 hours. The maximum wave height obtained in Thailand, due to tsunami in Manila Trench was at 0.42 meters.

Tso and Hui, (2009) also did simulation of tsunami due to earthquake in Manila Trench, but with point of observation being in Taiwan. For their studies, the fault planes along the Manila Trench was based on three largest tsunami earthquakes. These earthquakes are the 9.5 M_w Chile earthquake happened back in the year 1960, 9.2 M_w earthquake in Alaska in 1964 and the 2004 Sumatra tsunami. These earthquakes are analysed and found to be having similar length varying from 740 kilometers to 1300 kilometers, similar rupture width, varying from 200 to 300 kilometers. Together with Global Centroid Moment Tensor seismic database, fault parameters issued by USGS and lastly the three large earthquakes in history, the Manila Trench earthquake parameters were obtained. From this study, the first wave to hit

Taiwan takes only 20 minutes, and the first wave peak at 23 minute, has a 5 meters wave height. However, the maximum wave height happened at 40th minute, with 11 meters wave height.

Liu et al., (2008) performed studies also on the hazards of tsunami in South China Sea, but in this study, the scope of magnitude of the earthquake is fixed to only 8.0. The source parameters used in this paper incorporates fault parameters suggested by Kirby et al., (2006) together with the rupture width estimated by using the Wells and Coppersmith's relationship (1994). Results showed that the tsunami will reach southern Taiwan within 20 minutes, Vietnam in 2 hours and striking Malaysian waters in around 3 hours.

With all these papers, it can be concluded that indeed the tsunami from Manila Trench will severely affecting all the countries surrounding Philippines, and therefore it is important to study this tsunami even thoroughly.

2.4 EWQ-A Platform

The *Figure 5: Erb West Living Quarters A (EWQ-A) Platform*

EWQ-A platform located in the Erb West field, Sabah. EWQ-A deck comprises of two plan levels, a cellar deck and a main deck. The main deck includes a bridge support on the south west corner and support a main accommodation module and a helideck structure stacked one on top of the other.

The EWQ-A platform used for the point of observation for this study, is a typical 4-legged platform constructed in the year 1984. The platform is located in Erb West Field, about 60 kilometers offshore Kota Kinabalu at water depth of 63.1 meters.

2.5 Structural Analysis using SACS

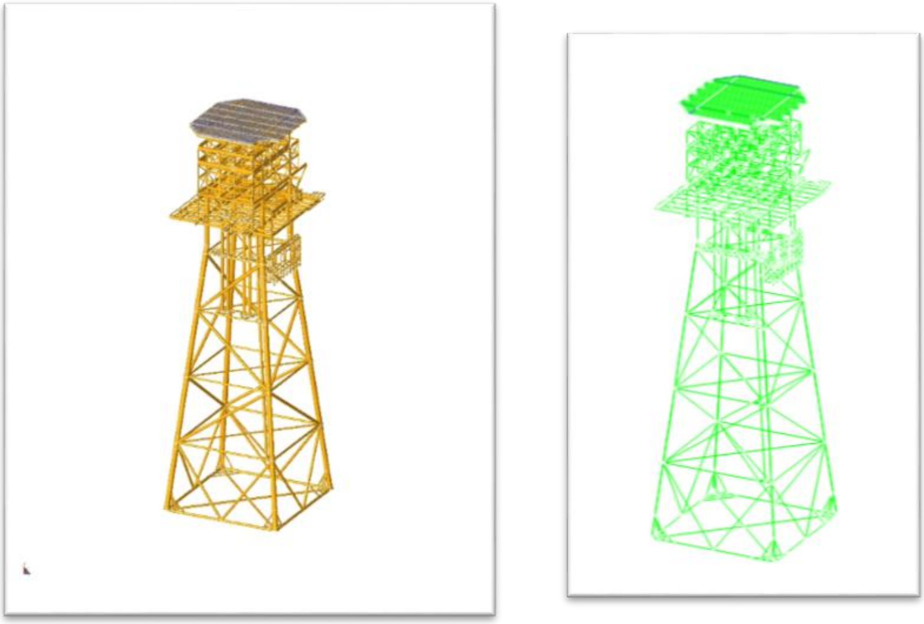


Figure 6: Model of the EWQ-A Platform in SACS

All structural analysis of the offshore platform, is to be done using the BENTLEY SACS 5.3 software. SACS, is a software which is a combination of functionality which includes modeling, analyzing, designing, fabrication and installation of offshore structures. Offshore structures in this case, include topsides, wind farm platforms and oil and gas platforms. This software has the ability to execute complex analysis while complying with international offshore design codes and checks.

SACS 5.3, provides many static analyses that can be used to simulate loadings on offshore structures. In our case, the *Static Analysis* was chose, as this static analysis, considers the linear elastic behavior of both structural material and geometry and may include, the environmental load generation by SEASTATE, and also the tubular connection check.

2.6 Return Period of an Earthquake

Return period, is an estimate of the probability of an event to happen, in our case, the return period of the earthquake. Return period of an earthquake, can be measure statistically, by collecting a series of historical data of previous earthquakes, and calculating the average recurrence of an earthquake over a span of time.

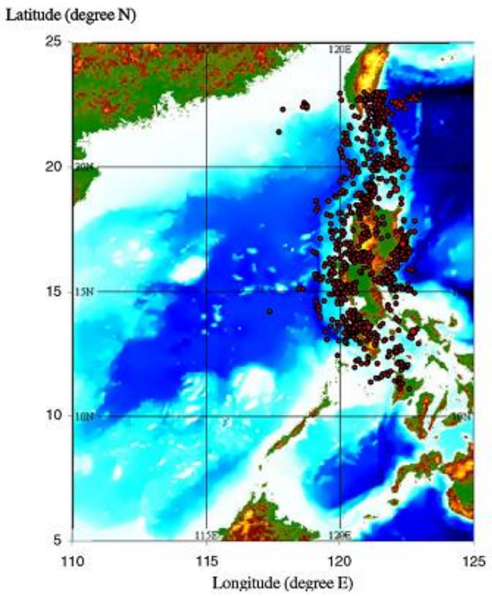


Figure 7: Seismicity map in the Philippines from ANSS database

According to Anat and Nopporn (2009), studying data of previous earthquakes which happened around the Manila Trench, and the Philippines, obtained from Advanced National Seismic System (ANSS) from 1963 to 2006. The annual rate of exceedance and magnitude relation were analysed based on Gutenberg-Richter recurrence law. With these data, the return period was summarized as shown below in Table 4.

Magnitude (Mw)	Return Period (Years)
7	6
7.5	19
8	63
8.5	205
9	667
9.5	2185

Table 1: Return Period (Anat & Nopporn, 2009)

3.0 METHODOLOGY

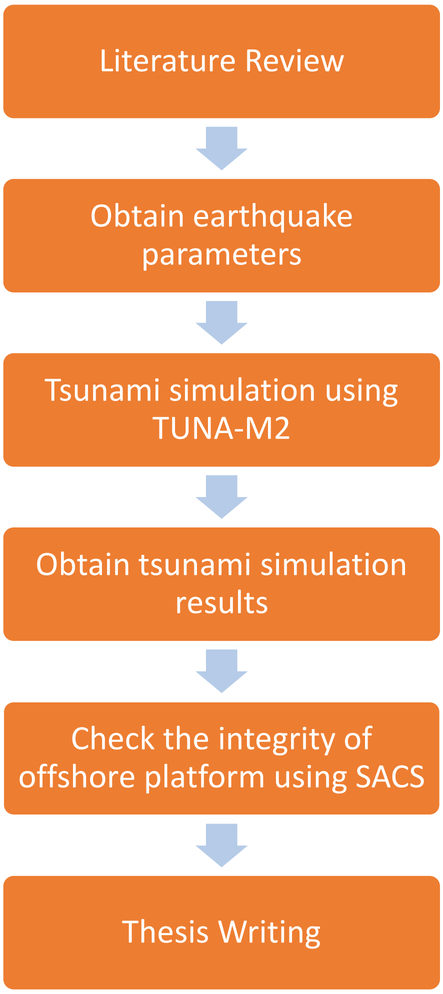


Figure 8: Summary of the milestones for Final Year Project

Methodology for this Final Year Project, is as shown in the diagram above. The literature review was continued from last semester, which was to obtain earthquake parameters. The earthquake parameters are obtained from countless researches which are obtained from deriving empirical formulas, which relates to fault length, the fault area, and fault width, from globally available relative data. The parameters for this earthquake is to be obtained will include longitude, latitude, and length, dip, rake, and strike angle.

3.1 Earthquake Parameters Input

Rupture length, and width, dip angle and rake angle, are obtained through past studies of Tso (2012). These values are further summarized in the Table 1 and Table 2. Given length, L and width, W of the subsurface rupture length and width respectively, with the values of μ, is the rigidity of the earth's mantle, given as 3×10^{11} dyn/cm^2, the M_o can be calculated. With the M_w, the M_o can be calculated using the following formula,

$$M_w = \frac{2}{3}\, log_{10} M_o - 10.7$$

The M_o formula is given as,

$$M_o = \mu DLW$$

Where the value of D, which is the slip amount, can be calculated.

Earthquake Parameters	Explanations
Rupture length, L	Value of L is assumed based on vast studies on the topography and geological conditions of the trench.
Rupture width, W	Value of W is obtained by referring to past large-scale earthquakes and their widths.
Slip of the fault, D	Value of D is calculated by converting the M_w into seismic moment, M_o and using the seismic scaling law, $M_o = \mu DLW$
Dip angle	Value of the dip angle is applied at 20˚ to study for the worst-case scenarios.
Rake angle	Value for large-scaled trench-type earthquakes and the worst-case scenarios are studied, hence rake angle is set as 90˚

Table 2: Summary of the earthquake parameters adapted from Tso (2012)

Table 2 above, shows the tabulation of earthquake parameters assimilated from Tso (2012) with the description on why those parameters were assumed in that particular sense. In Table 3 show below, shows the four (4) faults that were used in the tsunami simulation shown with the exact values of fault length, fault width, longitude and latitude of the epicenter of the faults, the dip angle, rake angle, and strike angle and lastly the focal depth of the fault.

Fault	Length (km)	Width (km)	Longitude (°)	Latitude (°)	Dip (°)	Rake (°)	Strike (°)	Focal Depth (km)
1	169.96	50	120.0	20.5	20	90	335	15
2	236.53	50	119.8	18.7	20	90	22	15
3	478.16	50	119.2	15.1	20	90	357	15
4	127.08	50	120.0	12.3	20	90	315	15

Table 3: Summary of the values adapted from Tso (2012)

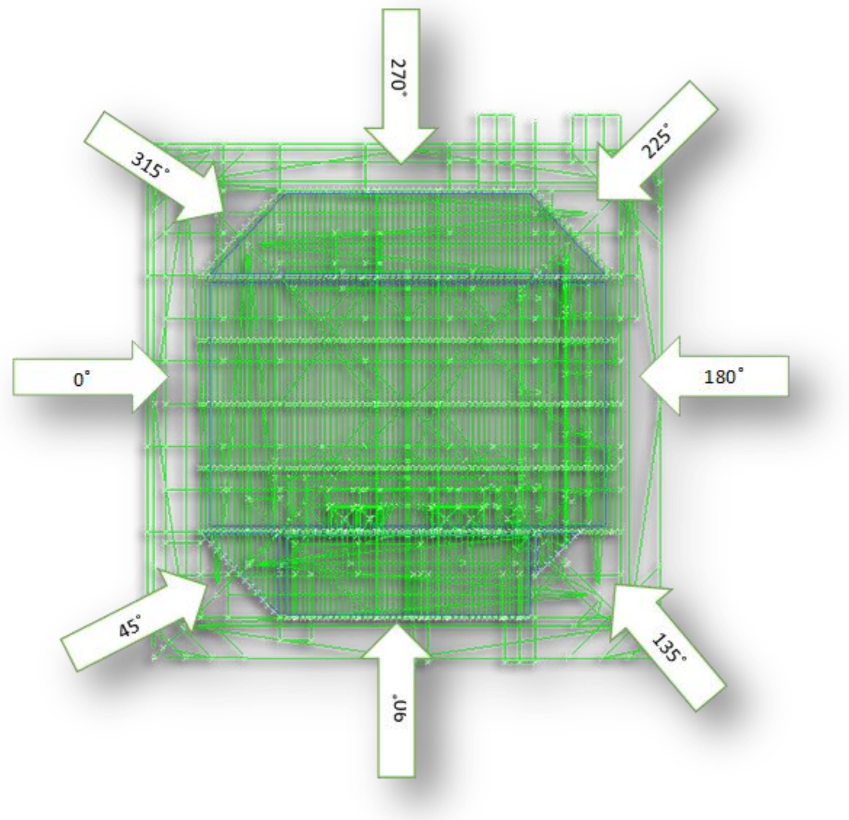
3.2 Tsunami Simulation

With these earthquake parameters, the tsunami simulation will be performed using TUNA-M2. This simulation on the TUNA-M2 will only be used to simulate the propagation of the tsunami and the wave's time of arrival. With, the point of observation being at EWQ-A, the time of arrival and the wave height at that instant, and the period after the first wave, can be studied. Lastly, with the simulation done, the tsunami simulation results can be obtained.

3.3 Structural analysis

The offshore platform's integrity will be studied, by assimilating the tsunami simulation results, the wave height into the operating condition of the offshore platform. The operating condition for the offshore platform, were first obtained from the consultant's SACS input files. For the study of tsunami waves, it is assumed that these waves will hit the offshore platform during normal operating condition, thus, it is required to edit the consultant's SACS input. The integrity of the EWQ-A platform is determined, through the runs of different wave directions, where the results will then be shown through the unity check as well as the *Collvue* function of the SACS software.

The two main analysis done on the structures, are static analysis and also the collapse analysis.



3.3.1 Static Analysis

Figure 9: Wave loading directions (Plan View)

The analysis will be performed using the inputs as mention in *section 3.1*, and the software applies loads in eight load combinations from eight directions, which is at every 45˚ as shown in the figure shown. From the "Postvue Database Directory", an interactive graphical post-processor, allows, all the respective displacements and forces to be retrieved. With this output, the maximum joint displacement, maximum lateral forces and maximum unity check of the whole structure is determined.

3.3.2 Collapse Analysis

In SACS 5.3, the non-linear analysis in statics analysis, also include collapse analysis. Collapse analysis will be done in this software by specifying the total amount of iterations of a specified loading onto the structure, before a failure of a member occur. Collapse analysis in SACS 5.3, includes large deflection, plasticity, and joint failure, and takes into consideration the non-linear material and geometric behavior in which ultimate limit conditions of the structure, are investigated. Other than shear deformation, plasticity associated to axial and bending stress, are also considered.

4.0 RESULTS AND DISCUSSION

4.1 Results

Results for this studies will be further divided into two, and be further discussed in this section:

1. Simulation of Tsunamis
2. Structural Analysis of EWQ-A Platform

4.1.1 Simulation of Tsunamis

For the simulation of tsunami, basically the simulations that were obtained will be studied and analyzed on the TUNA-M2 software. The results obtained are in wave heights, velocity of the waves and also the time of arrival of the first tsunami wave that reaches the platform. These results are simulated based on different moment magnitudes of an earthquake, ranging from 7.0 M_w to 9.5$M_{w.}$

The values obtained of (a), (b), and (c) can be clearly seen, when plotted in graphs as seen below,

a. The tsunami wave heights,
b. Time of arrival of the first wave to EWQ-A Platform
c. The velocity of the waves, given different range of moment magnitudes.

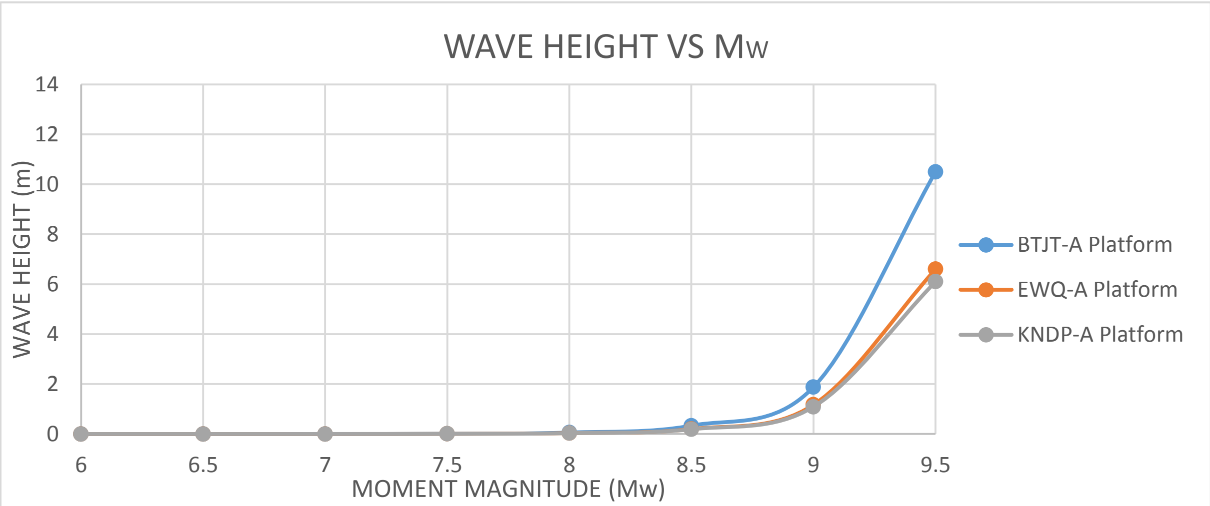


Figure 10 : Graph of wave height vs moment magnitude, Mw

	Mw =	6	6.5	7	7.5	8	8.5	9	9.5
WAVE HEIGHT	BTJT-A Platform	0	0.00001	0.001	0.011	0.06	0.335	1.88	10.5
WAVE HEIGHT	EWQ-A Platform	0	0.00001	0.001	0.007	0.037	0.2	1.17	6.6
WAVE HEIGHT	KNDP-A Platform	0	0.00001	0.001	0.006	0.0335	0.19	1.09	6.1

Table 4 : Tabulation of the first wave height vs moment magnitude, Mw

Figure 9 shows a semi log graph of the first wave height to hit the offshore platform versus the moment magnitude of the earthquake. From the graph shown above, it can be seen that the relationship clearly shows that as the moment magnitude increase from 7.5 Mw to 9.5 Mw, the tsunami heights simulated at the offshore platform, increases almost perpendicularly. At earthquake of magnitude of 6.0 Mw, 6.5 Mw, and 7.0 Mw, the wave heights can be considered insignificant as the wave heights are too low. From Table 4, it can be seen at earthquake magnitude of 9.5 Mw, at BTJT-A platform which is the first platform in Sabah to be hit by the tsunami waves, will experience a wave height of up to 10.5 meters while EWQ-A will experience wave heights of 6.6 meters and KNDP-A, will experience wave heights of up to 6.1 meters.

Points of observation	Mw =	6	6.5	7	7.5	8	8.5	9	9.5
BTJT-A Platform	TIME OF ARRIVAL (hours)	0	0	2.16	2.265	2.265	2.265	2.265	2.26
EWQ-A Platform	TIME OF ARRIVAL (hours)	0	0	1.975	1.982	1.983	1.985	1.98	1.98
KNDP-A Platform	TIME OF ARRIVAL (hours)	0	0	2.523	2.525	2.48	2.515	2.51	2.51

Table 5: Tabulation of the time of arrival (hours) first wave vs moment magnitude, Mw

Table 5 shows the tabulation of the time of arrival (in hours) of the first tsunami waves on the offshore platforms, versus the moment magnitude. It can be confirmed that as the moment of magnitude of the earthquake increases, the time of the first tsunami wave to hit the platform will be very similar. This only applies to moment magnitude of 7.0 Mw to 9.5 Mw, because tsunamis due to earthquake of magnitudes of 6.0Mw and 6.5 Mw, the wave heights of the tsunamis are almost insignificant.

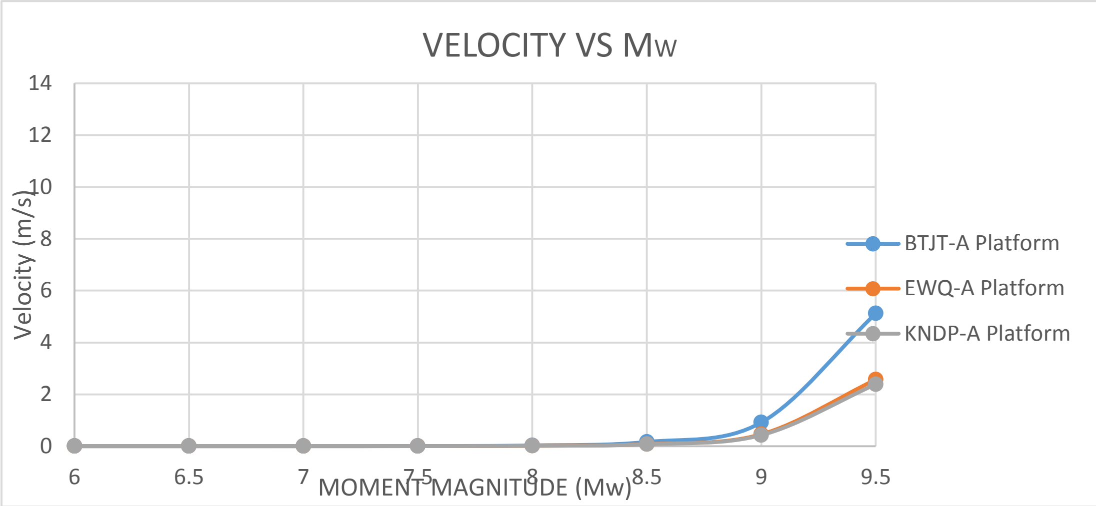


Figure 11: Graph of velocity of waves vs moment magnitude, Mw

The figure above shows a semi log graph of the velocity of the first tsunami wave to affect the offshore platforms versus the moment magnitude of the earthquake. The graph shows that the velocity of the tsunami wave heights that first affects the offshore platform will increase almost perpendicularly with the moment magnitude of the earthquake. The graph shows that at 9.5 Mw, BTJT-A platform will be affected by the first wave at 5.12 m/s, while EWQ-A platform and KNDP-A platform, will be affected by the first wave which moves at 2.57 m/s and 2.36 m/s respectively.

4.1.2 Structural Analysis of EWQ-A platform

4.1.2.1 Joint Displacements

The joint displacements are analyzed for the whole structure. This is done with the SACS software's tool, to find the maximum displacements in all three dimensions, X-dimension, Y-dimension, and Z-dimension, as well as the total maximum displacement. This tool allows, the author to include all eight load combinations, into the results, which can be seen in the table below:

LOAD CONDITION	Direction	MAXIMUM JOINT DISPLACEMENTS							
		DEFL(X)		DEFL(Y)		DEFL(Z)		DEFL(TOTAL)	
		JOINT	(CM)	JOINT	(CM)	JOINT	(CM)	JOINT	(CM)
OP01	0˚	7037	11.338	143	0.961	1103	-6.162	7037	11.443
OP02	45˚	7037	7.811	9206	7.875	1103	-6.248	9317	11.598
OP03	90˚	137	1.091	9206	10.458	1103	-6.277	1122	11.759
OP04	135˚	7037	-8.254	9207	7.846	1103	-6.24	9318	11.936
OP05	180˚	7037	-11.623	9207	1.386	1103	-6.154	7037	11.755
OP06	225˚	9093	-8.122	1300	-7.224	1103	-6.068	1182	11.155
OP07	270˚	134	-0.968	1300	-9.728	1103	-6.038	1103	10.828
OP08	315˚	7037	7.969	571	-6.865	1103	-6.076	1103	11.398

Table 6: Summary of the maximum joint displacement for the structure

From the table above, the same fourteen joints were having maximum joint displacements repeatedly. The locations of these joints are shown in the figure below, and it is seen that most of the highly displaced joints are located at the topside of the offshore platform except, a few joints having minor displacements, which occurs at the jacket of the offshore platform.

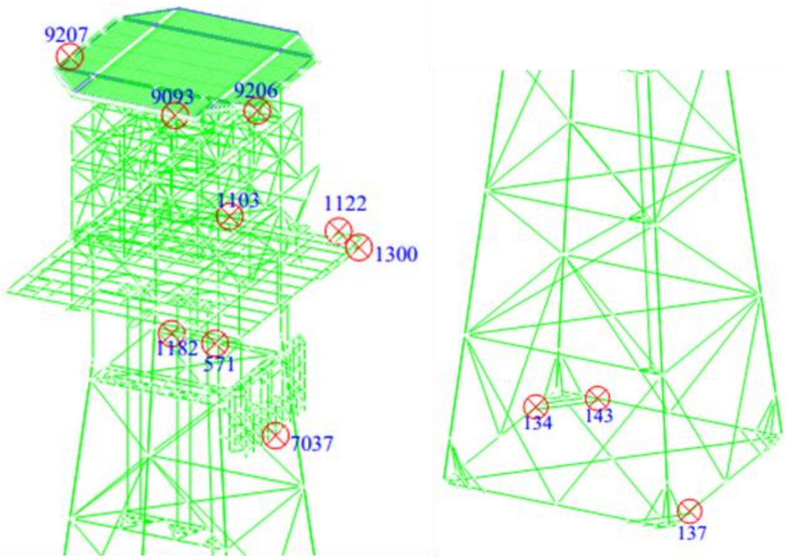


Figure 12: Location of Maximum Joint Displacements; Topside(R) & Jacket(L)

4.1.2.2 Maximum Lateral Forces due to Operating Wave Forces

From the results generated by SACS, after including the tsunami wave heights in the operating condition, the outputs are checked, in the 'Postvue Database Directory', whereby different reports, including the maximum lateral forces on the structure as a whole can be determined.

The results obtained are tabulated and can be seen clearly in the Table 6 shown below. The lateral forces acting on the whole structure increase simultaneously with the increase of the moment magnitude of the earthquake, which leads to the increase in the tsunami wave height, acting on the structure.

Load Condition	Direction	Moment magnitude (Mw)					
		9.5	9	8.5	8	7.5	7
OP01	0˚	5585.0 kN	938.0 kN	494.0 kN	438.0 kN	428.0 kN	425.0 kN
OP02	45˚	5592.0 kN	983.6 kN	531.8 kN	474.5 kN	464.6 kN	461.8 kN
OP03	90˚	5460.0 kN	922.0 kN	484.0 kN	429.0 kN	419.0 kN	416.0 kN
OP04	135˚	5571.5 kN	981.5 kN	531.0 kN	474.5 kN	464.6 kN	461.3 kN
OP05	180˚	5584.0 kN	938.0 kN	494.0 kN	438.0 kN	428.0 kN	424.7 kN
OP06	225˚	5592.7 kN	983.2 kN	533.2 kN	475.2 kN	464.6 kN	461.8 kN
OP07	270˚	5462.0 kN	922.0 kN	5461.4 kN	429.0 kN	419.0 kN	416.0 kN
OP08	315˚	5573.6 kN	981.5 kN	532.5 kN	474.5 kN	464.6 kN	461.8 kN

Table 7: Summary of the Total Lateral Forces, due to different magnitude of tsunami.

4.1.2.3 Maximum Unity Check of EWQ-A platform

Unity check is the ratio of actual load to the ratio of allowable strength of a member. This would mean that the maximum unity check (UC) is 1.0, however, due to the offshore structure being very sensitive to other loadings, the maximum UC for the tsunami wave loadings are limited to 0.8. The UC for the whole structure for each of the magnitude of earthquake is compiled and it can be seen that most of the members that failed or are close to failing are repetitive even for different moment magnitudes of an earthquake.

Moment Magnitude											
9.5MW		9.0MW		8.5MW		8.0 MW		7.5 MW		7.0 MW	
Member	UC	Member	UC	Member	UC	Member	UC	Member	UC	Member	UC
1105-1126	1.587	1105-1126	1.585	1105-1126	1.585	1105-1126	1.585	1105-1126	1.585	1105-1126	1.585
1071-1160	1.202	1071-1160	1.179	1071-1160	1.202	1071-1160	1.175	1071-1160	1.175	1071-1160	1.175
1107-1105	1.093	1107-1105	1.091	1107-1105	1.093	1107-1105	1.09	1107-1105	1.09	1107-1105	1.09
1102-1103	1.028	1102-1103	1.026	1102-1103	1.028	1102-1103	1.026	1102-1103	1.026	1102-1103	1.026
1103-1104	0.926	1103-1104	0.924	1103-1104	0.926	1103-1104	0.923	1103-1104	0.923	1103-1104	0.923
1094-1095	0.917	1094-1095	0.916	1094-1095	0.917	1094-1095	0.915	1094-1095	0.915	1094-1095	0.915
1095-1096	0.875	1095-1096	0.874	1095-1096	0.875	1095-1096	0.874	1095-1096	0.874	1095-1096	0.874
9316-9317	0.84	9316-9317	0.84	9316-9317	0.84	9316-9317	0.84	9316-9317	0.84	9316-9317	0.84
9317-9318	0.839	9317-9318	0.839	9317-9318	0.839	9317-9318	0.839	9317-9318	0.839	9317-9318	0.839
1143-1094	0.834	1143-1094	0.827	1143-1094	0.827	1143-1094	0.826	1143-1094	0.826	1143-1094	0.826

Table 8: Summary of Unity Check (Topside) of different magnitude of a tsunami

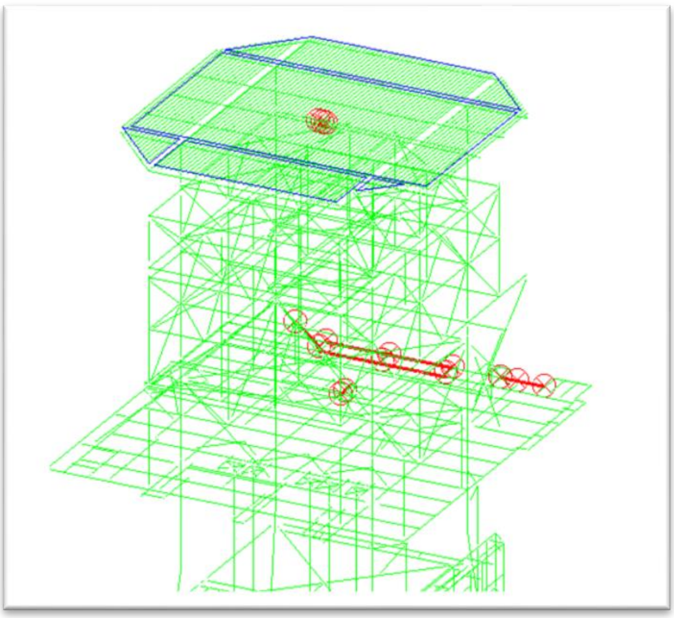


Figure 13: Location of the failed members on the topside of the platform

These members are all members of the topside of the jacket, which are considered assumed to have little influence on the structural stability. A failure of these members will not lead to a collapse of the structure. The ten (10) members are depicted on the Figure 11, to show the location of these members in relation to the whole structure. In addition to the topside, a few members have also failed in the jacket of the structure, particularly along the legs of the jacket. These members have failed only, in the tsunami waves of 9.5 Mw earthquake, which is when the tsunami waves reaches 6.6 meters.

9.5MW	
Member	UC
142- 242	0.811
	0.9
132- 232	0.832
	0.928
321- 421	0.358
	0.822
	0.317
122- 222	0.782
	0.868
112- 212	0.803
	0.896

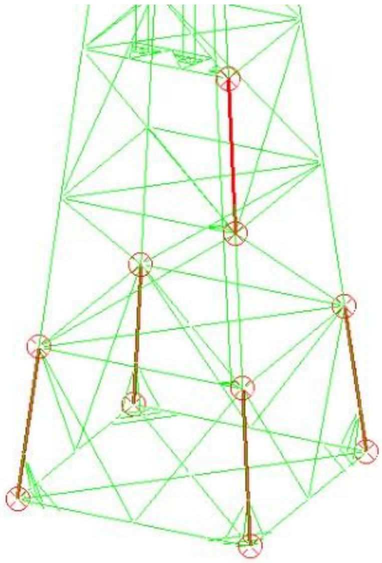


Table 9: Summary of the maximum unity check for the jacket; and location of the members on the jacket.

4.1.2.4 Collapse Analysis

The collapse analysis for the structure is to be done for all the tsunami wave heights of moment magnitudes of the earthquake from 7.0 to 9.5 Mw. With maximum of wave heights at moment magnitude of 9.5 Mw, it was found that the structure has withstand the tsunami loadings with no collapse. Further studies were done, whereby the EWQ-A platform were "pushed" until collapse, and the wave height was recorded. The figure below shows a comparison of the the buckling of the structure under, 6.6 meters wave height or 9.5 M_w and the 13 meters wave height, which is the first wave height whereby the structure collapses.

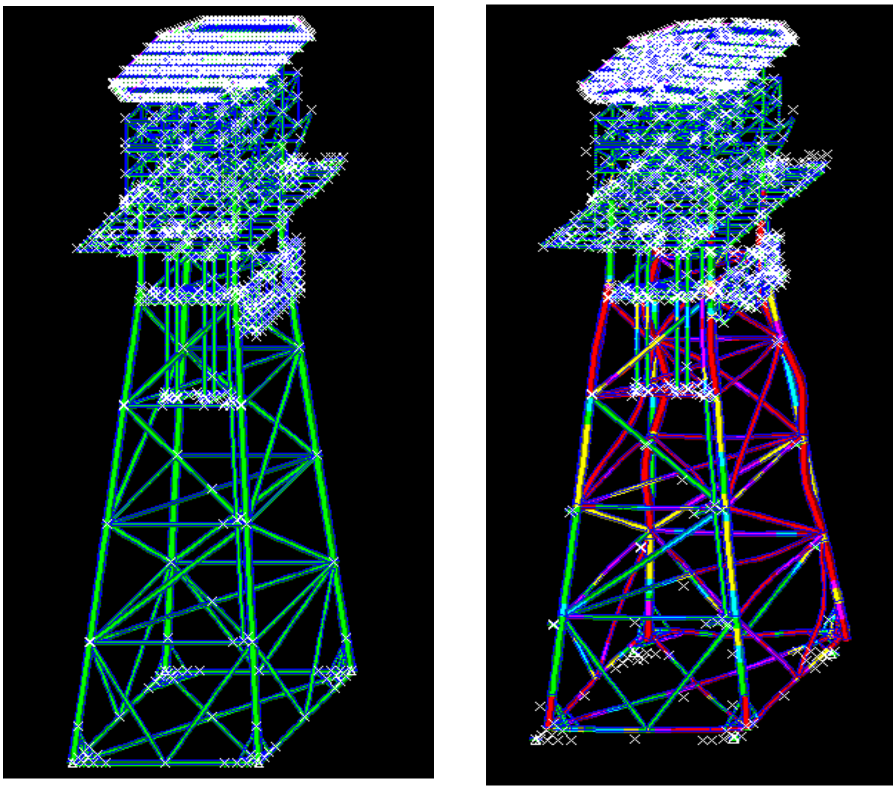


Figure 14: EWQ-A Platform at 6.6 meters wave height (left) & at 13 meters wave height (Right)

4.1.2.5 Return Period

Based on ISO 19902:2007, for an Extreme Earthquake Event (ELE), the check for the Ultimate Limit State (ULS) the return period to be taken into consideration is 100 years return period. Based on this consideration, it can be seen that based on the values in Table 4, moment magnitudes of 7.0 Mw, 7.5 Mw, and 8.0 Mw falls within this recommended 100 years return period.

Judging on ISO 19901-2, the maximum return period of an Extreme Level Earthquake (ELE), is of 200 years. Other than that, the target annual probability of failure, $P_{f,}$ defines that, the highest risk of failure due to seismic, is at 1/2450. Therefore, with these values, earthquake of magnitude of 8.5, 9.0 and 9.5 Mw, with return periods equivalent to 205 years, 667 years, and 9.5 Mw, was included in our studies to get a range of earthquake magnitudes, which could possibly affect the EWQ-A platform.

4.2 Discussion of Results

Comparing the results of maximum joint displacements, and the maximum lateral forces, the maximum joint displacement showed that the load combination of OP04 has the highest displacement, while the max lateral forces, in contrary has OP06 with the maximum lateral forces. These two results are contradicting on which load combination affects the offshore platform.

However, the lateral forces would not be representative because of a few reasons, where one, because the values are obtained through forces distributed throughout the whole structure, while the joint displacements are obtained from the member's internal stresses and forces. Next, the maximum lateral forces, are forces of Fx, and Fy, which are averaged and might not be an actual representation of the exact lateral forces exerted on the structure.

From the internal forces known, the maximum unity check can be studied also, thus showing how much capacity of the member strength is left. The collapse analysis, for the 6.6 meter wave height for 9.5 Mw tsunami, was done but with little or no failure among the jacket members. The collapse analysis, was conducted further to determine at which wave height, the structure will collapse and at 13 meters, the structure will collapse due to failure in most of the members of the jacket.

Reviewing the Unity Check of all the moment magnitudes, shows that the structure is very sensitive. Although the wave heights are very minimal, but due to the structure being check against solitary wave theory, four members have already exceed the maximum unity check of 1. However, moving on to the collapse analysis, show though although there were damages, the damages were factored in for the reserve strength. In collapse analysis, it was confirmed that the reserve strength in the platform prevents a total collapse, even at 9.5 Mw, therefore it is safe to assume that the structure is safe.

From *Section 4.1.2.5*, the results showed that the platform can withstand the ultimate limit state check of an Extreme Level Earthquake (ELE) as per the ISO standards. The displacements and the forces of operating wave condition showed that the structure can withstand the loading without collapsing.

5.0 CONCLUSION & RECOMMENDATIONS

5.1 Summary of Contents

This report, was prepared within the scope of Final Year Project, and has dealt with topic of the sensitivity analysis of tsunami waves on fixed offshore platforms. In depth, the studies were performed by combining tsunami waves into the operational condition of the design of the jacket type offshore platform located in South China Sea, located 60 kilometers off the shores of Kota Kinabalu, Sabah. The research proves, that the tsunami wave forces from the Manila Trench, can have an impact on the offshore platforms, whereby members of topside and jacket have failed or already near failure in terms of Unity Check (UC).

Before further research were done, literature reviews were prepared which addresses related topics, for example Earthquake and its Parameters, Tsunami Simulation using TUNA-M2, Structural Analysis using SACS, EWQ-A platform, and also the Return Period of Earthquakes. In addition to that, the methodology and the software used, were also summarized. In the following, results from the various researches done, were presented and discussed.

5.2 Conclusion

As a conclusion, Malaysia's offshore regions are generally described as seismically stable, though the earthquake originating from seismically active zones like Manila Trench, do have an impact on offshore structures in Malaysian waters. This can be further confirmed through many journals who have shown and predicted that Manila Trench has been quiet for a long time and this would only mean that there is a need for the simulation of the tsunami due to the possibility of a strong earthquake from Manila Trench.

Therefore, studies were done on choosing an appropriate earthquake parameters which comprises of different values due to different predictions. With this earthquake parameters, the simulation of the tsunami can be performed and lastly, the height of waves can be used to compare against the EWQ-A platform in Sabah. From the tsunami simulation also, the time of arrival of the first tsunami wave to hit the offshore platform can also be determined together, with the velocity of the waves.

The EWQ-A platform, a fixed jacket type platform, which has been modelled in SACS by the consultants of the offshore platforms, will be used as it is, but by incorporating the tsunami wave heights into the operating wave conditions of the structure. Then, the integrity of the EWQ-A platform can been checked through the different analysis of the SACS 5.3 finite element offshore structure analysis software. These analysis, includes, the static analysis which considers the linear elastic behavior of both structural material and geometry and also collapse analysis, which considers non-linear material and geometric behavior in which ultimate limit conditions of the structure are investigated. Results in terms of joint displacements, and unity check showed that the tsunami waves, indeed will cause failure in members, especially in the topside of the offshore platform. However, further analysis using the collapse analysis, shows that the structure's reserve strength is still enough to withstand the Ultimate Limit State of the tsunami wave effects.

Considering all the results, the EWQ-A platform can be assumed as safe for the tsunami wave mentioned. The 9.5 Mw though causing failures in topside and jacket, will not be experienced in a very long period of time, and is considered in the ISO as an extreme level earthquake event. Furthermore, the collapse analysis, which is done by iteration of the loadings, proved that the structure can still withstand the damages for the time being and a collapse of the structure can be prevented.

5.3 Recommendations

This Final Year Project in this research has proven that the EWQ-A platform used for our studies in Erb West field is safe, for the specified earthquake parameters. This however, cannot be said for other earthquake parameters, and definitely cannot be generalized for all offshore platforms in Malaysian waters. The reason for this, is because the parameters assumed in this studies, as well as the characteristics of the structures in other states in Malaysia, are always different.

Although Malaysian offshore jacket type platform often are overdesigned, and will not suffer extreme damages due to tsunamis, more detailed researches will have to be done based on real life case studies. The recommended future work that can be continued from this project is whereby a similar workflow is performed for offshore structures in Sabah, but using different earthquake parameters to simulate the tsunami. The author would predict that the differences may be quite significant, and that a preliminary trend can be found. With this preliminary trend, hopefully the definition of tsunami criteria can be done, and thus included in the design of offshore structures in Malaysia.

Also, as engineering studies and practices in Malaysia, especially in offshore engineering, is slowly progressing towards including seismicity in the designs, therefore, future researches could also include, seismic studies on the platform. Other than that, another concern is offshore platforms nearer to the shore, was said to have higher wave height due to the run up of the waves. This will be another interesting study, which would be very significant in predicting the tsunami wave’s impact on offshore platforms in Malaysia.

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7.0 APPENDIX

7.1 Basic Load Case Descriptions

Basic Load Case Description	
1	Computer Generated Self Weight
2	Jacket Misc. Loads
21	Topside Misc. Loads
22	Equipment Operating Loads
23	Potable Water Tank Operating Load
24	Piping Weight
25A	Jacket Walkway Live Load
25C	Accommodation Module Lower Level Live Load
25D	Accommodation Module Upper Level Live Load
25E	Top Accommodation Module Live Load
25F	Helideck Live Load
25G	Helicopter At Rest
110	Operating Current/ Wave Load in 0 Degree Direction
111	Operating Current/ Wave Load in 45 Degree Direction
112	Operating Current/ Wave Load in 90 Degree Direction
113	Operating Current/ Wave Load in 135 Degree Direction
114	Operating Current/ Wave Load in 180 Degree Direction
115	Operating Current/ Wave Load in 225 Degree Direction
116	Operating Current/ Wave Load in 270 Degree Direction
117	Operating Current/ Wave Load in 315 Degree Direction

7.2 Load Combination Specified for Operating Condition

LCOMB NAME	LOAD CASE	LOAD CASE DESCRIPTION
OPER	1	Computer Generated Self Weight
	2	Jacket Misc. Loads
	21	Topside Misc. Loads
	22	Equipment Operating Loads
	23	Potable Water Tank Operating Load
	24	Piping Weight
	25A	Jacket Walkway Live Load
	25C	Accommodation Module Lower Level Live Load
	25D	Accommodation Module Upper Level Live Load
	25E	Top Accommodation Module Live Load

LCOMB NAME	LOAD CASE	LOAD CASE DESCRIPTION
OP01	OPER + 110	Operating Condition + Operating Current / Wave Load in 0 degree direction
OP02	OPER + 111	Operating Condition + Operating Current / Wave Load in 45 degree direction
OP03	OPER + 112	Operating Condition + Operating Current / Wave Load in 90 degree direction
OP04	OPER + 113	Operating Condition + Operating Current / Wave Load in 135degree direction
OP05	OPER + 114	Operating Condition + Operating Current / Wave Load in 180 degree direction
OP06	OPER + 115	Operating Condition + Operating Current / Wave Load in 225 degree direction
OP07	OPER + 116	Operating Condition + Operating Current / Wave Load in 270 degree direction
OP08	OPER + 118	Operating Condition + Operating Current / Wave Load in 315 degree direction