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SEISMIC DESIGN RESPONSE SPECTRUM AND SOIL LIQUEFACTION ASSESSMENT FOR TANJUNG KIDURONG POWER PLANT, BINTULU, SARAWAK

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Bachelor of Engineering with Honours
(Civil Engineering)
2019

UNIVERSITI MALAYSIA SARAWAK

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SEISMIC DESIGN RESPONSE SPECTRUM AND SOIL LIQUEFACTION ASSESSMENT FOR TANJUNG KIDURONG POWER PLANT, BINTULU, SARAWAK

NAYLI BATRISYIA BINTI NORDIN

A dissertation submitted in partial fulfillment of the requirement for the degree of Bachelor of Engineering with Honours (Civil Engineering)

Faculty of Engineering

Universiti Malaysia Sarawak

2019

ACKNOWLEDGEMENT

First and foremost, I would like to express my highest gratitude to God for giving me strength and faith to carry out this study. I would also like to give my deepest appreciation to my parents who had been giving me moral support throughout this point of the research. A special gratitude I give to my research supervisor, Dr. Raudhah Ahmadi who has been giving me clear guidelines, valuable knowledge and continuous support in finishing this thesis where this research would not have been possible without her. I am forever indebted for her continuous moral support, encouragement and inspiration which pushes me to provide my very best in completing this study. A token of appreciation I would like to give to the Faculty of Engineering and University of Sarawak, Malaysia (UNIMAS) for the assistance and resources in making this study a reality. Besides that, a warm thank you to everyone who had helped me directly or indirectly throughout the period of making this paper.

ABSTRACT

Seismic conditions have been taken into account by engineers in designing structures due to a few evidences of Malaysia being vulnerable to seismic activities. The design has become a necessity in designing a building approaching the end of 2017 as the Malaysia National Annex to Eurocode 8 (MS EN 1998-1:2015) has been established. In ensuring the constant operability of power plants during earthquakes, it is recommended to improve the current design of power station in Malaysia as seismic design consideration for power station is vital. The aim of the study is for computing the seismic design response spectrum and soil liquefaction assessment while the key objective is to investigate the settlements due to liquefaction. The present study describes the seismic ground response analysis and assessment to soil liquefaction. The procedures in carrying out the ground response analysis includes: (1) obtaining ground motion data; (2) analysing soil dynamic properties; (3) carrying out analysis in one dimensional shear wave propagation; and (4) computing the site-specific design response spectra. In the other hand, analysis for the soil liquefaction involves : (1) retrieve soil data; (2) assess soil liquefaction potential; and (3) calculate soil settlements. It is found that the site-specific response spectrum have a maximum spectral acceleration of a higher value for Far-Field Earthquakes than for near-field earthquakes which shows that the longer distance of a rupture surface to the site and the type of underlying soil plays a great role in amplifying the ground motion. The maximum seismic soil amplification ratio for Tanjung Kidurong Power Plant, Bintulu Sarawak are between 2.21 and 3.7. The soil factors for type C are different from Sarawak National Annex (MS EN 1998-1:2015) which could be due to the limitation of National Annex taking the average of some soil investigation data. Based on this research, all the boreholes are at risk for liquefaction to occur. The highest settlement occurs at the borehole which contains more silt and clay than the other boreholes.

ABSTRAK

Pertimbangan seismik sudah mula diambil kira oleh jurutera di dalam mereka bentuk bangunan kerana telah terdapat beberapa bukti bahawa Malaysia kini terdedah dengan aktiviti seismik. Reka bentuk seismik sudah menjadi satu keperluan di dalam mereka bentuk bangunan menjelang akhir tahun 2017 di atas penerbitan Malaysia National Annex to Eurocode 8 (MS EN 1998-1:2015). Bagi memastikan stesen janakuasa terus beroperasi jika berlakunya gempa bumi, adalah disarankan untuk menaiktaraf dan memperbaiki reka bentuk stesen janakuasa yang sedia ada di dalam Malaysia kerana ia adalah sangat penting untuk meningkatkan keselamatan reka bentuk stesen janakuasa di dalam Malaysia apabila berlakunya gempa bumi. Matlamat penyelidikan ini adalah untuk menghasilkan spektrum tindak balas reka bentuk seismik dan untuk penilaian pencairan tanah di Stesen Janakuasa Tanjung Kidurong, Bintulu Sarawak. Di samping itu, objektif utama kajian ini adalah untuk memperoleh mendapan tanah akibat pencairan tanah. Kajian ini menghuraikan analisis tindak balas tanah terhadap aktiviti seismik dan penilaian pencairan tanah. Analisis tindak balas tanah boleh didapatkan melalui prosedur berikut: (1) memperolehi data gerakan tanah; (2) menganalisis sifat dinamik tanah; (3) mengendalikan analisis di dalam penyebaran gelombang ricih satu dimensi; dan (4) menghasilkan spektrum tindak balas reka bentuk khusus tapak. Selain daripada itu, analisis untuk pencairan tanah termasuk : (1) memperoleh data tanah; (2) menaksir potensi pencairan tanah; dan (3) mengira mendapan tanah. Didapati bahawa spektrum tindak balas khusus tapak mempunyai maksimum pecutan spektral lebih tinggi untuk gempa bumi jarak jauh berbanding gampa bumi jarak dekat yang menunjukkan jarak tapak yang lebih jauh ke permukaan pecah dan jenis tanah di bawah tapak memainkan peranan besar dalam menguatkan gerakan tanah. Maksimum nisbah penguatan tanah seismik yang didapati adalah di antara 2.21 dan 3.7. faktor tanah untuk jenis C adalah berlainan dari Sarawak National Annex (MS EN 1998-1:2015) yang mungkin diakibatkan oleh had dokumen tersebut di dalam mengambil purata data siasatan tanah. Mengikut kajian ini, semua lubang bor yang dikaji adalah berisiko untuk berlakunya pencairan tanah. Mendapan tanah paling tinggi dicatat dalam penyelidikan ini adalah 213.8 mm yang berlaku di lubang bor yang mengandungi lebih banyak lumpur dan tanah liat berbanding lubang bor lain.

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

A disastrous impact to the power supply network could be produced from failures of energy-generating plant due to earthquakes. The state and national economy could suffer a significant negative impact if the power plant cease to operate. Hospitals, hotels, airports, schools and factories could suffer power outages which influences the social and economic values to the industrial and domestic consumers. Economic losses and fatalities are the major effect of this phenomena. The areas with high risk of earthquake occurring are the areas with high density of population and structures. Besides that, disruption of the power supply network could occur because of the repair period and the complication of power restoration. Therefore, it is very important towards the state's economy for the power plant to continue functioning in ideal condition even after natural hazards like earthquake occurs.

The site is located between the Petronas MLNG and Murphy Oil. The Tanjung Kidurong Power Plant is situated in northeast of Bintulu Town, approximately 9km in straight line. The power station occupies an area of 36 hectares and the new power plant will utilize approximately 1.5 hectares within the present power station boundary. The new power plant holds a capacity of 842MW making the total capacity of the power plant to be 1340 MW after the completion of the project.

Malaysia is enclosed with the tectonic characteristics of the Sumatera area which is composed of two inter-plate boundaries which are seismically active known as Philippines Plate on the east and Indo-Australian Plate and the Eurasian Plate on the west. Therefore, Malaysia encounters tremors coming from neighbouring countries like Banda Acheh, Padang, Nias Island and other parts of Sumatera Indonesia. Tremors coming from large earthquakes in the Sumatran plate margin occasionally impacted

West Malaysia with the highest intensity recorded of VI on the Modified Mercalli (MM) scale.

In the contrary, East Malaysia is categorized as moderately active in seismicity. Earthquakes of local origin has been encountered in East Malaysia where some cases had resulted to damage of properties and also human injuries. The area has undergo seismic tremors originated locally with magnitudes of not more than 5.8 on the Richter Scale. Other than local earthquakes, East Malaysia also encounters tremors coming from large earthquakes situated in the straits of Sulu Sea, Macassar, Celebes Sea and over the Southern Philippines with the highest intensity observed was VII on MM scale.

The destruction sourcing from earthquake is not only caused by its intensity but also the vulnerability of the structures. Therefore, it is vital to perform seismic analysis in order to assess the susceptibility under predicted intensity of seismic motions. The response spectrum analysis could be utilized in dealing with probable earthquake where the particular nature is not determined in order to evaluate the safety of buildings under a ground motion. This will help in giving a clearer picture of the important design elements that must be included into the structures.

Earthquakes need not be of high magnitude to create critical damage because the level of severity for damage relies on not only the physical size of the earthquakes but also consists of other components like when and where the earthquake happens, population density in the region and also soil conditions. Engineering works for seismic must be designed, well planned and built due to the probability of being exposed to seismic hazard during its lifetime.

1.2 Problem Statement

Malaysia is formerly known as a very low seismic region leaving Malaysia with no earthquake design requirement in regulation for all the building structures. Therefore, the engineering practice in Malaysia's industry adopts Eurocode (EC) and British Standard (BS) in structural design. Nevertheless, in 2017, the Malaysia National Annex to Eurocode 8 for design of Structures for Earthquake Resistance has been established to be used by local engineering practitioners.

The Code design parameters are very general and conservative in the design provisions and is not intended to use at a specific site especially for a lifeline facilities like dams and power plants. Since a particular region has its own characteristics, it is not necessary for the region to be subjected to seismic hazard assessment. A number of studies had executed fragility curves for existing structures in Malaysia. However, most of these studies are only focusing on public buildings. This study will be showing more emphasis on power plants since it is a critical facility which provides electricity for the Bintulu town.

Soil liquefaction due to seismic motions can be extremely hazardous to the built environment. Soil liquefaction is susceptible to happen in areas with low density and saturated granular sediments. A field investigation done by Sassa and Takagawa (2018) shows extensive liquefaction happening at coastal areas. A tsunami can be generated from the gravity flow of liquefied soil mass resulted from coastal liquefaction. The collapse of coastal land due to liquefaction had lead to liquefied sediment flows which generates tsunami. This had happened on the Palu Coast of Central Sulawesi in 2018 with at least nine places suffering complete collapses and coastal land flows caused by liquefaction. The incident resulted to multiple tsunamis which according to Sassa and Takagawa (2018) was mainly generated by the submarine and coastal landslides as described by gravity flows of liquefaction. Less than 20% tsunami height was connected to the tectonic processes which was analysed from the tidal data. Figure 1 shows the Palu coast before and after the Sulawesi earthquakes. A white dotted line of the land-sea interface has been created on the image for clarification purposes.

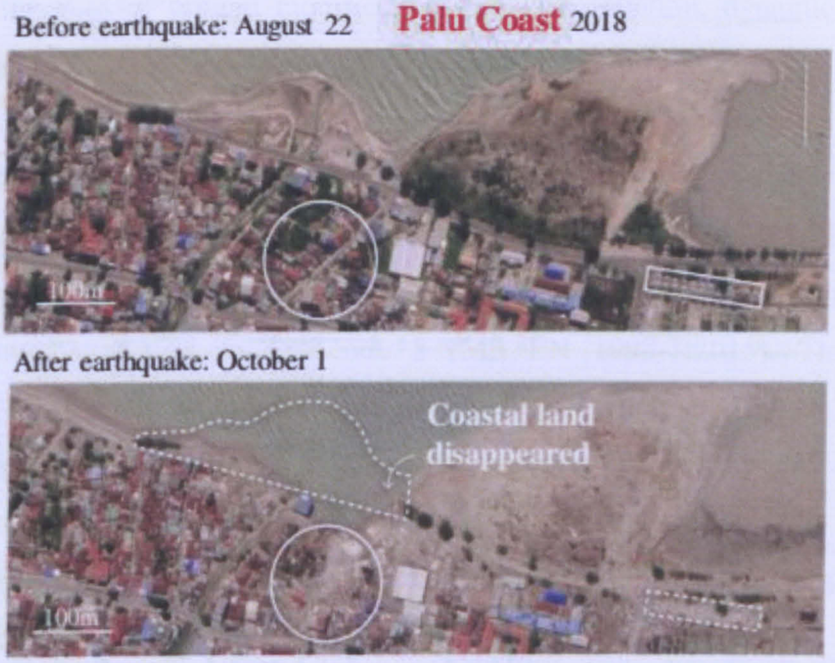

Figure 1 Palu Coast before and after the Sulawesi earthquake
(Reuters Graphics, 2018)

This shows that the evaluation for liquefaction potential is very important in this study since the Tanjung Kidurong Power Plant is located at the coastline which bears high risk of liquefaction happening due to seismic loads. The safety of superstructures and earth based structures are solely governed by the response of sub-soil strata under seismic motions at any specific sites. Excess pore water pressure increases rapidly for a region of sandy soil which has shallow water table if subjected to repetitive cyclic loading such as earthquake. In return, this will decrease the effective strength of soil which will then elevate the chances of liquefaction to occur.

Buildings or structures underlain directly on liquefied soil will encounter rapid support loss which causes irregular and drastic settlement of the structure leading to structural damage like the cracking of foundations and columns. The structure may even be unserviceable afterwards. Underground utility services might also be disrupted and break due to the irregular settlement of the ground. Pile foundations of large structures could also lose support from adjacent soil which will then buckle. Tanks and manholes buried underground could also float due to buoyancy. Liquefaction hazards can be reduced by avoiding soils prone to liquefaction and construct liquefaction restraint structures. It can also be reduced by improving soils susceptible to liquefaction by applying techniques of ground modification like vibroflotation, dynamic compaction and grouting.

1.3 Aim and Objectives of the Research

This study is to develop seismic design response spectra and assess soil liquefaction potential for Tanjung Kidurong Power Plant, Bintulu, Sarawak in comparison to Malaysia National Annex to Eurocode 8 (MS EN 1998-1:2015). The following objectives are pursued in this study:

i. To perform site specific ground response analysis considering one dimensional shearwave propagation method for the local soil investigation.
ii. To develop horizontal elastic design response spectrum and its comparison with Sarawak design response spectrum in EC8 Malaysia National Annex.
iii. To compute soil liquefaction potential and settlement by considering local soil data and seismic local effect.

1.4 Scope of Research

This research marks a significant subject that influences the seismic capacity of power plant structures. The range of this research includes:

i. Collecting soil data from Tanjung Kidurong Power Plant, Bintulu Sarawak's project (Analysis of 10 boreholes at onshore location)
ii. Analysis of the local site effect taking one dimensional shearwave propagation method into consideration
iii. Extracting ground motions at bedrock from PEER website. The magnitude of earthquake data applied for this research are ranging from 5.5Mw to 7Mw.
iv. Computing soil liquefaction potential and settlement due to the highest ground acceleration peak at the site location

1.5 Significant of the Research

This study is conducted from the identification of the fact that a few parts of East Malaysia are vulnerable to seismic activity, which creates consequential danger to the lifeline facilities, the existing facilities and any proposed critical structures to be specific. This study develop design response spectrum by producing alternative method based on a particular project soil data to compute the mean seismic parameters for which the structure has to be designed on.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The following chapter presents the seismic settings in Malaysia and the areas that are prone to earthquake. It also discusses on the fundamental aspects needed in executing the seismic response analysis. Such analysis requires to consider the seismicity settings of the area, local site effect, soil category and the liquefaction potential. This chapter contains discussions on each of the mentioned aspects on what condition does each aspects amplify or deamplify seismic waves. Major impacts of earthquake on the environment are also analysed.

2.1 Seismicity in Malaysia

According to Anbazhagan (2011) a seismic zone is an area where the amount of seismic activity is constant with some referring to a region with increased risk of seismic activity while some referring to a region with frequent seismic activity. Malaysia is a country that is located in the Southeast (SE) Asia Region which is categorized as one of the active seismic belts globally and is put through immense tectonic movements all round its geologic history (Khalil, 2017). Malaysia's tectonic framework comprises between longitudes 90 E to 140 E and latitudes of 12 S to 20 N (MMD and ASM, 2009). The country is very near to the ring of fire region where nearly all earthquake energy is released there on an international scale. However, Malaysia is a low seismic region which is surrounded by active ones. It is situated on the Eurasian plate and nearer to the Philippines plate in the East and the Australian plate in the west.

Up to present, the idea of having Malaysia free from earthquake is deceptive. In 2004, Indian-Ocean earthquake Mw 9.1 magnitude had caused tsunami with casualties from Malaysia, Sri Lanka, Indonesia and Thailand (Komoo and Mazlan, 2005).

Resulting from the event, the core of the sunda-land was deformed and the surrounding plate was disturbed causing the entire Peninsular displaced towards west southwest. The whole Southeast Asia experienced both co-seismic and post-seismic deformations. According to Balendra and Li (2008), various seismic tremors had shook tall structures in Malaysia to a detectable level and the quantity of felt occasions starts to grow currently due to fast developments of skyscrapers. In spite of the fact that tremors have never caused any damages to buildings in Kuala Lumpur, the outcomes of even a moderate level of ground movement might be tremendous as a result of the elevated concentration of inhabitants and commercial activities occurring in buildings and structures that does not cater for seismic burdens. According to Omar, Johnny and Mohamed (2010), Peninsular Malaysia encounters the worst deformation than the others. Series of mega-earthquakes at west coast of Sumatra in 2004, 2005 and 2007 had caused the peninsular Malaysia rotated anti-clockwise which resulted to a gap of displacement between the southern and the northern part of the peninsular.

The earthquakes are interpreted to be because of the reactivation of the NW-SE Bukit Tinggi, the N-S faults, the Kuala Lumpur fault zones and the NE-SW faults. Stress accumulation due to the existing tectonics in SE Asia (Sundaland) is convinced to be the major cause of the fault reactivations, especially the oblique, NE-oriented subduction of the Indo–Australian plate under the Sundaland (Shuib, 2009). The figure below shows a less complicated tectono-geographical map of SE Asia showing various fault zones and tectonic blocks.

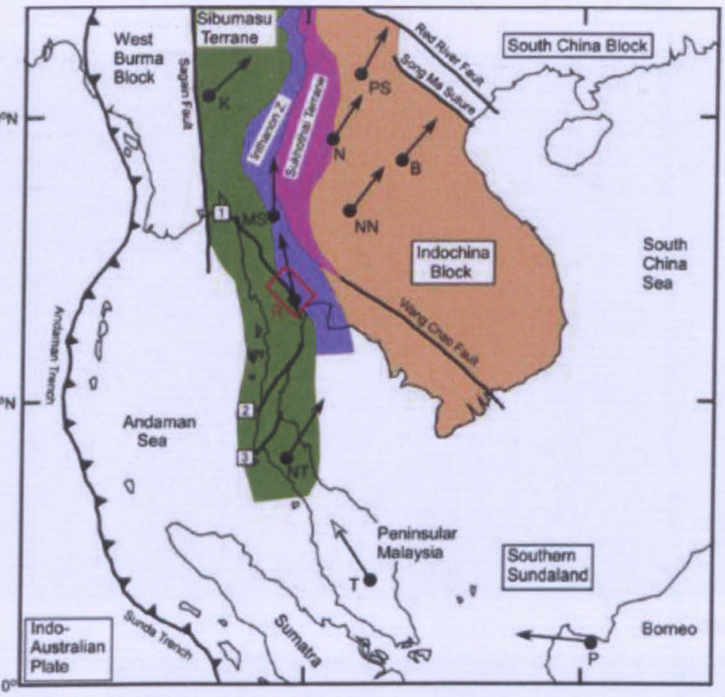

Figure 2.1 Map of SE Asia showing different fault zones and tectonic blocks (Fujiwara et al., 2014)

Recorded by the Malaysia Seismological Network of Malaysia Meteorological Department (MMD) from 2007 to 2009, 30 local earthquakes within Peninsular Malaysia has happened (Sze Wah, 2011). Consisting of magnitude of less than 4.3 Mb, these earthquakes were developed from several fault lines which lies within Bukit Tinggi (Pahang), Jerantut (Pahang), Kuala Pilah (Negeri Sembilan) and Manjung (Perak).

Situated in a tectonically dynamic margin of Borneo, Sabah is on the Sunda Plate where it is enclosed by active plates of the Indo-Australian, Philippines Sea and Sunda plates. Figure 2.2 is the seismological data obtained from Incorporated Research Institutions for Seismology (IRIS) which shows a highly clustered distribution of earthquakes around the area but within North West Borneo, the earthquake distribution is little. Nonetheless, this interpretation is questionable since several earthquakes ranging from small to medium magnitude have took place in this region.

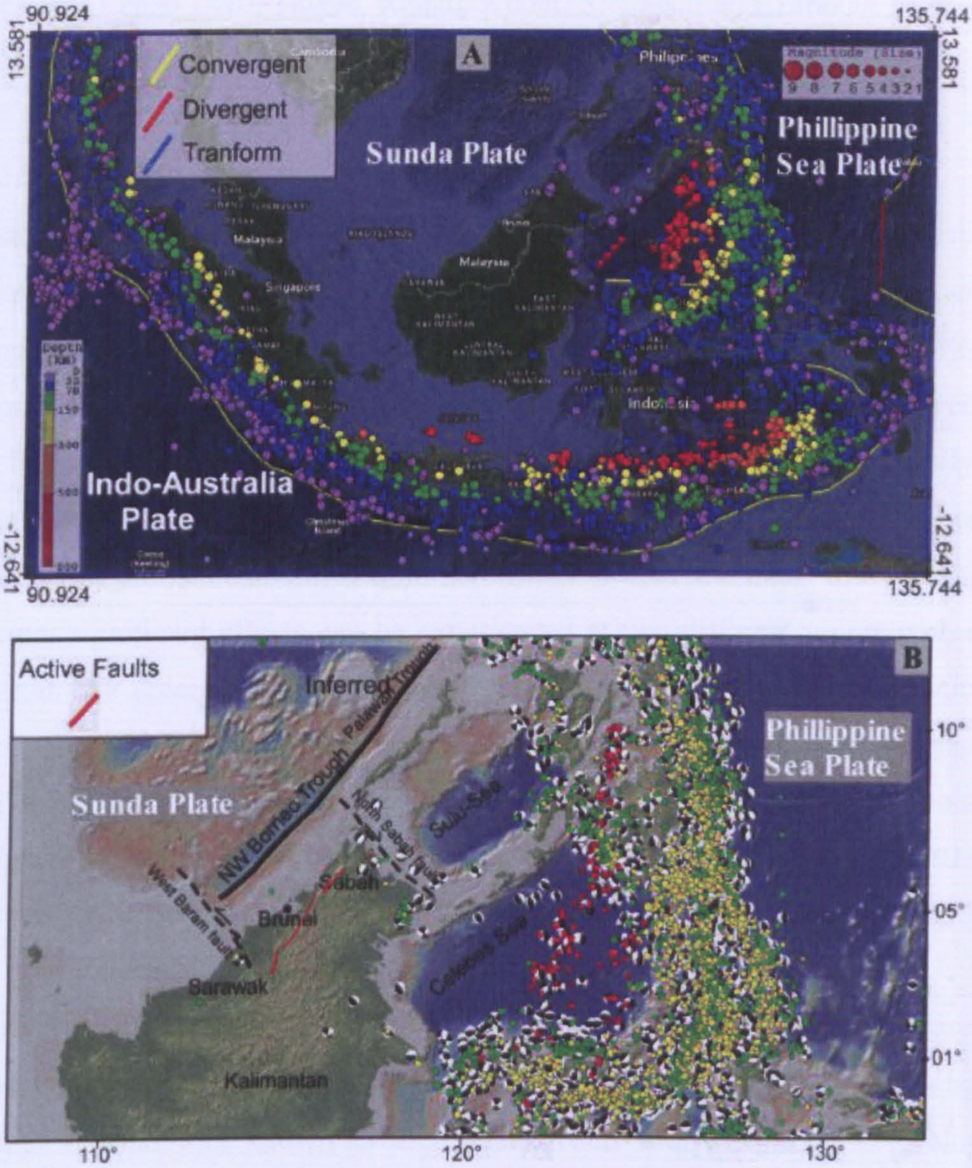

Figure 2.2 Regional tectonic setting of North West Borneo (Shah, 2016)

According to Shah (2016), the mapping of active and inactive geological structures shown in Figure 2 is needed to have a wider conception of tectonic-complexity scale in the region. On 5th June 2015, one of the strongest earthquake recorded in Malaysia (Earthquake Track, 2015), the Moment Magnitude-6 earthquake took place 19 km north of Ranau which lasted 30 seconds that lead to 18 fatalities and property damage. A study using the Grey System Theory done by Kuei-hsiang Cheng (2016) had shown that a critical point of mass seismic energy have been attained by Semporna, Sandakan and Celebes Sea. There is a high chance for any earthquakes ranging from moderate to heavy magnitudes to occur if any trigger factor happens. Over and above that, it is anticipated that Lahad Datu, Tawau, Ranau, Kudat, Sitangkai and Tarakan have a high possibility of earthquakes happening within the year 2015 to 2022.

2.2 Local Site Effect

As stated by Pitilakis and Anastasiadis (2007), site effect is the characteristics of the incoming wavefield which is modified by soil formations and topography developing the amplification and deamplification of ground motion. Nowadays, the impacts of surface geology on seismic activities has been widely acknowledged and accepted by the engineering practitioners as the effects can be large. Generally, the earthquake damage is less over firm rock outcrops than on soft sediments. The Earth is covered with soil profiles that varies from hard rocks to mud and many more and this is why different significant effects can be experienced at two different points with equal distance from the epicentre of an earthquake (Nolan, 2018). The ground motion of earthquake shows a high degree of variability because of the site resonances, constructive and destructive interference, basin-edge induced surface waves, directivity and non-linear sediment amplification (Field, 2013). Therefore, the local site effect is important to study due to many present-day urban and industrial settlements have happened by the side of river valleys which consists of soft surface deposits.

Published in 2000, the Southern California Earthquake Centre (SCEC) "Phase III" Report had talked about the shaking experienced in an earthquake contributed by the local geological conditions known as site effects. There are two important geological factors at a site distinguished in the study which are the softness of the soil or rock close to the surface and the thickness of sediments over hard bedrock. In the study conducted by the SCEC, it is identified that in softer rocks and thicker sediments, the shaking is amplified. The fullness of soft deposits and the succeeding motion amplification or the bedrock surface under soft deposits can cause the site effects to alter the seismic activity into certain frequency domain (Lacave, Koller, Lestuzzi and Salameh, 2013).

According to Adnan, Marto and Hendriyawan (2004), the local site effects can also manipulate the characteristics of ground surface motions such as the shape of response spectra and the peak acceleration amplitudes. Obvious trends in amplification behaviour was shown through the contrast of peak acceleration attenuation relationships for sites with various kinds of underlying soil profiles.

As stated by Idris (1990), the surface of soil deposits shows a moderately higher peak accelerations than that on rock. The non-linearity and the low stiffness of soft soils usually avoid them from amplifying peak ground accelerations as high as those observed in rocks. The frequency content of surface motions are also affected by the local site conditions hence the response spectra they developed. The usual response spectra shows that the spectral amplification is much greater at sites with soil than in rock sites at extended periods. The effect is very notable especially with long period structures like tall buildings and bridges are established on such deposits. As stated by Afak (2001), the event, familiarly known as site amplification where the seismic waves' amplitudes grows especially as they progress through layers of soft soils close to the surface of the Earth is the utmost factor manipulating the size of destruction on structures. Therefore, when there is a design for structures on soft soils, it is very crucial to include the site amplification.

The sites' sediment non-linear amplification shows to be more pervasive than what seismologists had thought and a number of studies on the strong and weak motion had proposed that it is very common (Aki, 1993). In the occasion of weak motion, higher amplification factor is usually seen at younger sediments for all frequencies not more than 12 Hz. However, in the case of strong motion, the relation is backwards for frequencies above 5 Hz. The strong motion at sediment sites is overestimated by the implementation of the amplification factor that is found out from weak motion as observed during Loma Prita earthquake of about 50 km within the epicentral distance. The higher earthquake value correlates with the variation of peak ground accelerations around the mean curve as it declines.

As reported by Fatahi, Far and Samali (2014), analytical models and field tests can be done to estimate the features of site amplification at a particular site. The geometry of each layers of soil from surface to bedrock, their dynamic features such as wave velocity, density and damping, and the bedrock motions are required as inputs when doing analytical models. As for the field tests, the recordings and analysis of the dynamic reaction of sites to ambient forces, artificial excitations and real earthquakes are needed. However, the analysis of indicated motions of the site during high magnitude earthquakes are the most reliable estimates of site amplification.

2.2.1 Site Characterization

One or more pattern of soil profiles must be chosen for the site of interest depending on the results of the laboratory testing as well as geotechnical and the geophysical investigations. In that regard, complete dynamic site characterization incorporates the following:

i. Shear wave velocity profile with depth which is through geophysical testing procedure such as the Spectral Analysis of Surface Wave (SASW) method.
ii. Variation of damping with strain or modulus reduction curve
iii. Variation of shear modulus with strain or modulus reduction curve

In such case, this study will be carried out by obtaining the difference of shear modulus and damping with strain.

2.2.2 Local Surface Fault Rupture

Surface rupture, which is the first main earthquake hazard happens when either side of a ruptured fault experiences horizontal or vertical displacement, which can have an impact on enormous areas of land (tectonic movement). A fault rupture can get through to the Earth's surface which deforms the ground. This in return, produces steep banks, deep ruts, and lateral displacements which causes critical damage to structures, railways, roads and buried infrastructures like pipelines.

Surface fault rupture is well known to swerve around more sturdy structures because of the soil's localised compression and strength of the foundation. Nonetheless, this is not generally the situation during or after a surface rupture. Lightweight structure quite often experience severe damage which usually tears small buildings apart.

2.2.3 One-dimensional Nonlinear Site Response Analysis

One dimensional shear wave propagation theory is used in carrying out the site response analyses in this study. The parameter estimates of ground motion such as the peak surface acceleration (PSA) and surface spectral acceleration can be determine by using this theory. The analyses is executed using Deepsoil software. According to Day (1979), the nonlinear wave propagation method make use of limited element schemes. In some models, a great amount of effort has been done in order to foresee irreversible distortion while others contained dissipation and increase in pore pressure. Strain reliance of material properties from research facility information is generally observed.