SUBDUCTION EARTHQUAKE EFFECT ON LATERAL GROUND MOVEMENT FOR OFFSHORE STRUCTURE IN MALAYSIA WATER

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I dedicate with love and gratitude

to my beloved wife Aida Hayati bt Wan Ahmad and my children Nur Sharina, Muhammad Syafiq, Ahmad Zharfan, Aishah Zahirah and Aqilah Qaisara

for being with me till the very end of my thesis completion.

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ABSTRACT

Peninsular Malaysia is located in a low seismic region. Although Malaysia is not located in an active fault seismic area, it is in the vicinity of the Sumatran and Philippines active seismic zones. Tall buildings frequently felt the tremor generated from Sumatran subduction and fault zones especially in states that are near the coastal area of Peninsular Malaysia such as Johor, Penang and Terengganu. In general, offshore engineering is known to be one of the most high-risk and ultimately extreme engineering field where extra attention and precaution are needed when analyzing, designing, monitoring or maintaining a structure in order to ensure the integrity of the many structures and components that are involved in this field. Fixed offshore structures in Malaysian waters are not designed to resist earthquake ground motion. However, Malaysia actually experienced the tremors due to the earthquakes which happened in neighboring countries. Furthermore, any offshore structure design should consider several factors such as wind, wave and seismic loads which affect the stability and the integrity of the offshore structure. This research was carried out to achieve the main objective which is to develop new attenuation equation. The development of new attenuation equation is to determine the ground motion parameter which is Peak Ground Acceleration (PGA). The new attenuation equation is In $Y = 3.25 - 2.27M + 2.28M^{1.13} - 2.22\ln(R + 360.46 \exp(0.05M)) - 0.005H$. An earthquake source parameter such as magnitude of earthquake, source to site distance and focal depth of site characteristics function must be considered to determine the value of PGA by using the new attenuation equation. The range of the PGA values for this study is from 0.00006g to 0.0003g. The value of PGA can be used to analyse all the types of structure in mainland and offshore. Non-Linear Earthquake Response Analysis (NERA) program was used to determine the time history on the specific location of the offshore structure and Finite Element Method (FEM) analysis was used to determine deflection of piles effected by the ground movement. The findings in this research suggest that seismic loading effects should be considered in the design of offshore structure due to displacement of pile arising from ground movement.

ABSTRAK

Semenanjung Malaysia terletak di rantau seismik yang rendah. Walaupun Malaysia tidak terletak di kawasan seismik aktif, ia terletak di persekitaran Sumatera dan Filipina iaitu zon seismik aktif. Bangunan tinggi sering merasakan gegaran yang terhasil daripada Sumatera dan zon sesar terutama negeri yang berdekatan dengan kawasan persisiran pantai Semenanjung Malaysia seperti Johor Bahru, Pulau Pinang dan Terengganu. Secara umumnya, kejuruteraan luar pesisir dikenali sebagai salah satu bidang kejuruteraan yang paling berisiko tinggi di mana perhatian tambahan dan langkah berjaga-jaga diperlukan apabila menganalisis, merekabentuk, memantau atau mengekalkan struktur untuk memastikan integriti daripada banyak struktur dan komponen yang terlibat dalam bidang ini. Struktur tetap di luar pesisir di perairan Malaysia tidak direka untuk menahan gerakan tanah apabila berlaku gempa bumi. Walau bagaimanapun, Malaysia sebenarnya mengalami gegaran akibat gempa bumi yang berlaku di negara-negara jiran. Tambahan pula, struktur luar pesisir yang direka perlu mengambil kira beberapa faktor seperti angin, ombak dan beban seismik yang memberi kesan kepada kestabilan dan integriti struktur. Kajian ini telah dijalankan untuk mencapai objektif utama iaitu mewujudkan persamaan atenuasi baru. Persamaan atenuasi baru diwujudkan untuk menentukan parameter pergerakan tanah iaitu *Peak Ground Acceleration* (PGA). Persamaan atenuasi baru adalah In Y = 3.25 – 2.27M + 2.28M$^{1.13}$– 2.22ln(R + 360.46 exp (0.05M)) – 0.005H. Parameter gempa bumi seperti magnitud, jarak antara sumber dengan lokasi dan kedalaman fokus mengikut ciri-ciri lokasi perlu diambil kira untuk menentukan nilai PGA dengan menggunakan persamaan atenuasi baru ini. Nilai julat untuk kajian ini adalah di antara 0.00006g hingga 0.0003g. Nilai PGA boleh digunakan untuk menganalisis semua jenis struktur di kawasan daratan dan luar pesisir. Program *Nonlinear Earthquake Response Analysis* (NERA) digunakan untuk menentukan *time history* di lokasi platform luar pesisir dan Kaedah Unsur Terhingga (Finite Element Method) digunakan untuk menentukan pesongan cerucuk kesan dari pergerakan tanah. Penemuan dalam kajian ini menunjukkan bahawa kesan beban seismik perlu dipertimbangkan dalam reka bentuk struktur luar pesisir berdasarkan anjakan cerucuk yang terhasil daripada pergerakan tanah.

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LIST OF ABBREVIATIONS

BNWF	-	Beam on Non Linear Winkler Foundation
FEM	-	Finite Element Method
LVDT	-	Linear Variable Differential Transducers
MMD	-	Malaysian Meteorology Department
NERA	-	Non Linear Response Analysis
PGA	-	Peak Ground Analysis
RSA	-	Response Spectrum Analysis
SA	-	Spectrum Acceleration
SSI	-	Soil-Structure-Interaction

LIST OF SYMBOLS

A	-	0.9 for cyclic loading
A_p	-	Gross end area of pile
A_s	-	Side surface area of pile
d	-	Diameter of pile
D	-	Material damping constant of the soil layer
d_{cone}	-	Diameter of the CPT cone
d_{eq}	-	The diameter of solid pile of equivalent steel area
DR	-	Displacement ratio of the pile
f	-	Unit skin friction
f_a	-	Absolute value of acting axial stress
F_b	-	Allowable bending stress
f_{bx}	-	Bending tensile stress, x-direction
f_{by}	-	Bending tensile stress, y-direction
F_{xc}	-	Critical buckling stress
g	-	Unit for Peak Ground Acceleration (PGA)
gal	-	Unit for Peak Ground Acceleration (PGA) (cm/s^2)
H	-	Focal depth of earthquake
i	-	An imaginary unit
k	-	Depth gradient of the initial subgrade reaction modulus
M	-	Magnitude
Mw	-	Moment magnitude
$\bar{N}_s$	-	Average SPT Value

p	-	Actual lateral resistance (kPa)
p_a	-	Atmospheric pressure
P_r	-	The reference soil resistance
Q_f	-	Skin friction resistance
Q_p	-	Total end Bearing
q	-	End unit bearing capacity
q_{bu}	-	Limited bearing pressure
q_c	-	Cone penetration value
R	-	Distance from the source (hypocentral distance)
R	-	Yield stress ratio/apparent over-consolidation ratio
r_0	-	Pile radius
r_1	-	Outer radius of the inner zone
S_t	-	The sensitivity
s_u	-	Cohesion (kPa)
V_s	-	Shear wave velocity
$\bar{V}_s$	-	Average shear wave velocity
y	-	Actual lateral deflection (mm)
Y	-	Ground motion parameters
ε	-	Strain
ρ	-	Area ratio
δ	-	Interface friction angle
υ	-	Poisson’s ratio of the soil stratum
ω	-	Frequency of loading
σ'_{vo}	-	Effective overburden stress (Kpa)
σ'_m	-	The initial men effective stress

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

According to Balendra et al. (1990), the earthquake in Sumatera caused the far field effect to occur to buildings situated on soft soil elsewhere. Peninsula Malaysia is located on the stable part of the Eurasian plate. However, neighboring countries with an unstable plate can also feel the tremors due to the far field effect from the earthquake. Tall buildings in Singapore and peninsula Malaysia can feel these tremors from the Sumatera Earthquake. The mechanism for such tremors for far field effect of earthquakes is illustrated in Figure 1.1 (Balendra and Li, 1993).

The Sumatera Earthquake produces the seismic wave which travels for a long distance before reaching the Singapore bedrock. This is called wave propagation. In the wave propagation, the high magnitude of earthquake will dampen out rapidly while the low magnitude of waves are more vigorous to energy dissipation. Since the wave travels for a long distance. Thus, the seismic waves reach the bedrock of Singapore or Peninsula Malaysia in long period waves and the seismic waves also significantly amplify due to resonance when they propagate upward through the local soft soil sites. The period of propagation is close to the main period of the seismic waves. Residents in the building can feel shaking from the amplified waves because of the resulting motion. Many researchers have conducted studies to find out whether the motions from earthquake can cause damage to the buildings. This includes researchers such as Balendra et al. (2002), Megawati and Pan (2002), Megawati et al. (2003) and Megawati et al. (2005).

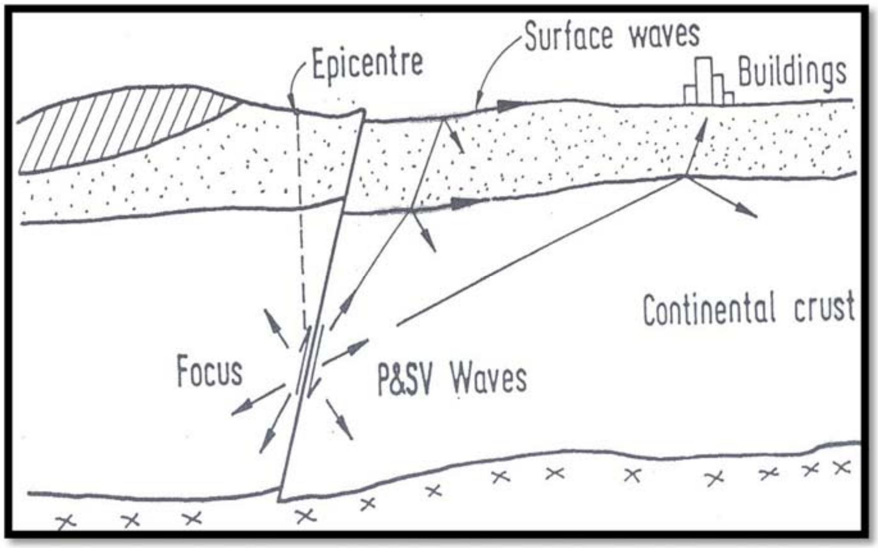

Figure 1.1 : Schematic diagram for far-field effects of earthquakes (Balendra and Li, 2008)

According to Vigny et al. (2005), three general seismic patterns occur in Peninsular Malaysia which are inter-seismic or pre-seismic, co-seismic and post-seismic. These three patterns occur in the subduction zone. The Subduction zone are the zones where the widespread recycling of hydrated material such as sediment, upper mantle and hydrated oceanic crust occurs at great depth, followed by the metamorphic process that will transform it into a series of high pressure mineral (Lallemand and Funiciello, 2009).

The pre-seismic is a seismic pattern which occurs before an earthquake and the accumulation of elastic deformation of the upper plate. The pre-seismic pattern takes decades or even a century to deform. When the energy is released to the crustal, the co-seismic pattern is produced. It is also known as an earthquake occurrence. Co-seismic pattern occurs in short period of times which is a couple of seconds or minutes. The last pattern is the post-seismic pattern. It occurs after the co-seismic pattern and is also referred to as the stage of equilibrium. After this stage, the seismic pattern returns to a steady condition. However, it will take a couple of months, years or decades to go back to that state. Peninsula Malaysia is also involved in these three stages of seismic patterns due to the immense earthquake that happened in the west coast of Sumatera in 2004, 2005 and 2007. Peninsular Malaysia can be assumed to be included in seismic changes because it is located about 350 km away from circumstances by tectonically stable crust, Indosina-Sundaland and surrounded by active seismically zone (Marto et al., 2013). The distance of subduction zone is quite near to Malaysia.

According to Abu et al. (2006), the first earthquake in the East-West component had a displacement with a magnitude of 18cm. The geodetic technique was used by modeling the back to back earthquake of the Sumatera waters to determine the displacement magnitude. GPS data was used to analyze the effect on the Malaysia Active GPS System (MASS) and the Real-Time Kinematic Net (RTK Net) station. The data were recorded from 19 December 2004 to 6 January 2005 and from 20 Mac 2005 to 2 April 2005 in Langkawi Island, Penang Island and Arau, Perlis. Figure 1.2 and Figure 1.3 show the displacement vector in the station nearer to the epicenter for the first earthquake and second earthquake respectively.

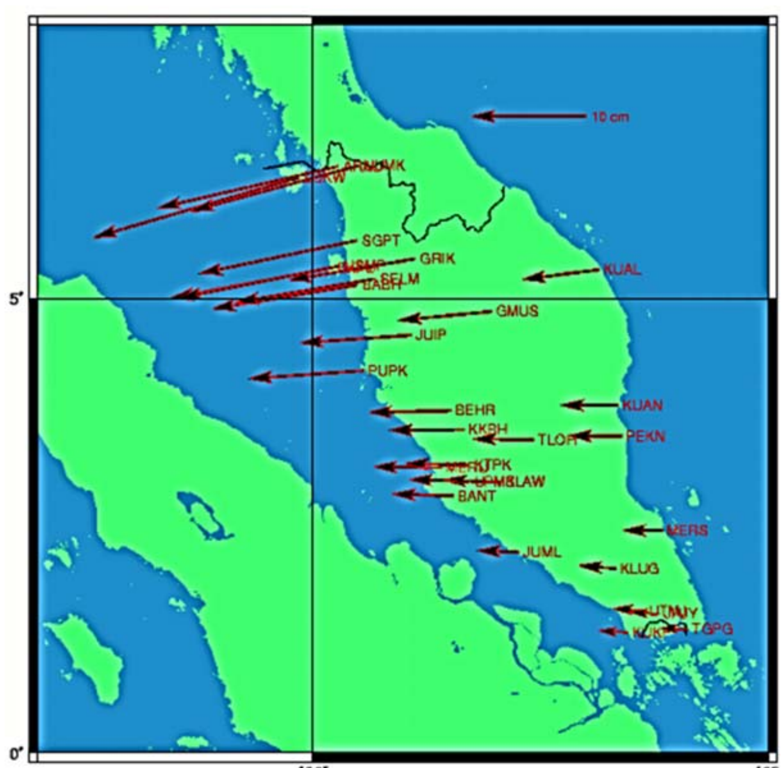

Figure 1.2 : Displacement vector from 26th December 2004 earthquake (Abu et al. 2006)

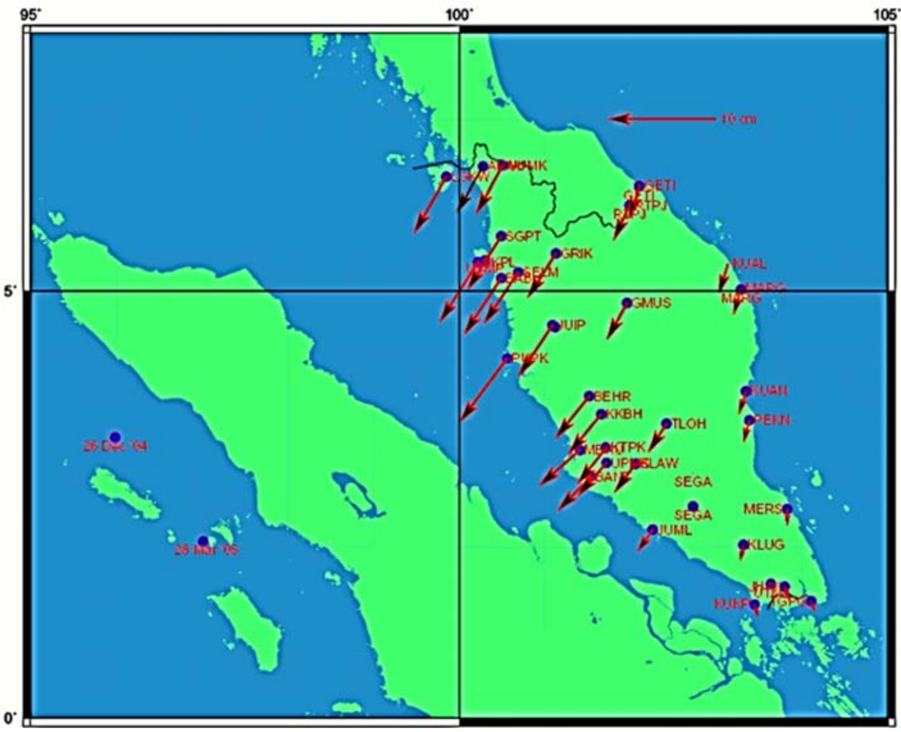

Figure 1.3 : Displacement vector from 28th March 2005 earthquake (Abu et al. 2006)

1.2 Research Background

The Peninsular Malaysia is located in a low-seismic region where the closest seismic zones are located approximately 350 km away from the Sumatran seismic zones namely Sumatran subduction and fault zones. Although Peninsular Malaysia lies on a seismically stable region but structures in this region frequently felt the earthquake generated from the Sumatran seismic zones with magnitudes as low as 5.0.

During an earthquake, fixed offshore structures have a risk of facing strong ground motion. The strong motion can cause the deformation of the structure with the inelastic range. Earthquake excitation needs to be considered in the design of the offshore structure in seismic area. It is to ensure no global structural failure occurs. In seismic design, an earthquake is considered by conducting dynamic analysis that accounts for non-linear pile soil structure interaction effects.

The offshore structures vary depending on purpose and location. The types of offshore structure range from fixed platforms, floating, production and operating vessels. With a focus on offshore piles; these vary in strength, configuration and lengths. They vary in type but are basically designed to be either compression piles or tension piles. In the jacket type platform, in its simplest configuration, a pile is hammered through each of its four legs. For larger platforms, additional “skirt” piles may be used around each of the leg through sleeves that are attached to the legs. Grouting is used for the space between the piles and steel sleeves of the jacket. Figure 1.4 shows the schematic of typical Gulf of Mexico offshore oil or gas platform.

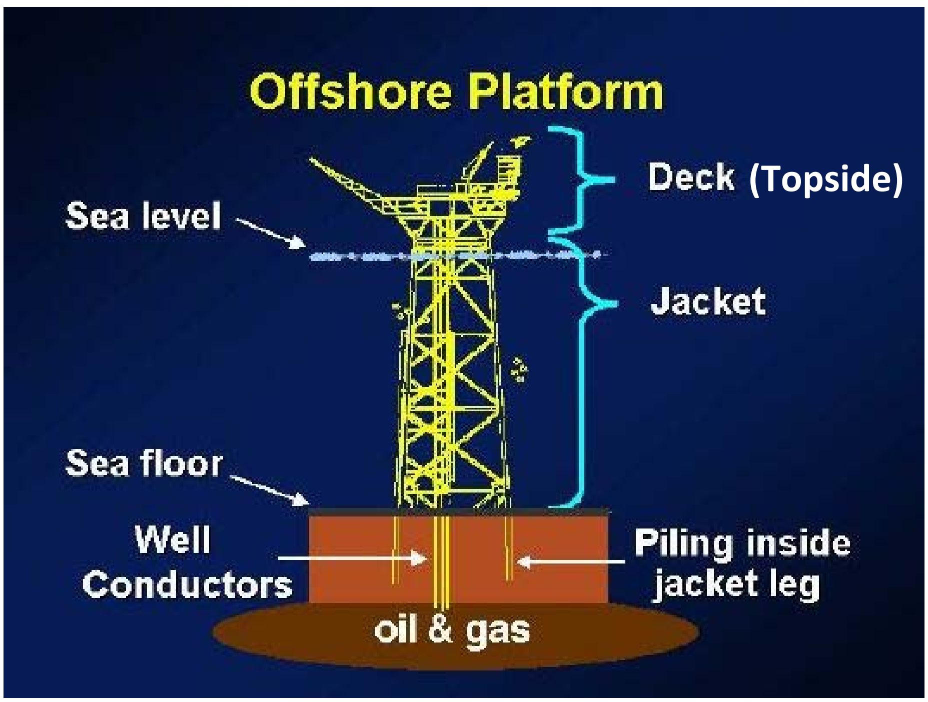

Figure 1.4 : Schematic of typical Gulf of Mexico offshore oil and gas platform (National Oceanic and Atmospheric Administration, n.d.)

1.3 Problem Statement

Malaysia is not considered a seismically active zone. However, lately the issue of earthquakes within the region is quite alarming. With respect to this issue, a comprehensive work is inevitable to source out factors which affect the ground movement in offshore structures. Deficiency in analysis on ground movement due to earthquake responses is rather a new issue in oil rig designs in Malaysia. Most of the design assumed that the dynamic loading is mainly due to the wavy impact of the surrounding area without any contribution from the seismic effect.

According to Salem and Haggag (1998), earthquake is one of the contributing factors affecting the piles stability. The study showed that the piles experienced complete failure when the magnitude of earthquake is 8.0 while some loss of pile capacity for the magnitude of 7.5 and below. Therefore, the wave from the epicenter is reduced by distance and time. For far field earthquake, the new attenuation equation can be established and the effect of shear wave velocity can be investigated by considering soil profile using new attenuation equation.

The attenuation relations for earthquake was analyzed on the bedrock. The vibration from the earthquake can also be felt for the structure on the ground. It is because one of the soil behavior is that it can absorb the vibration with its types and properties. The soil profile and depth of each layer of soil is not the same for every place. Therefore, the consideration for soil profile and the depth for each layer is important in the structural design especially for offshore structures. The Non Linear Earthquake Site Response (NERA) was used to investigate the effect of shear wave velocity which considers soil profile.

1.4 Objectives

The objectives of this research study are as follows:

i. To establish new attenuation equation of subduction zone fault for far field earthquakes.

ii. To investigate the effect of shear wave velocity considering soil profile.

iii. To analyse the effect of seismic patterns to the p-y curves of the pile.

iv. To investigate the travelling distance of wave with respect to soil stratification.

1.5 Scope of Study

The scopes of this research study are to:

i. identify the soil profile variability.

ii. produce new attenuation relationship for subduction zone for offshore structures.

iii. employ software such as Nonlinear Earthquake Site Response Analysis (NERA). NERA software was used to analyze the collected data, based on some input parameters such as the Peak Ground Acceleration (PGA), the strong motion data and soil data of each of borehole.

iv. employ software ANSYS to perform finite element study for evaluation of pile deflection.

1.6 Significant of Study

The stability of pile in the offshore structures depends on several factors which include earthquake, lateral pressure, vertical loading, etc. Malaysia is a region considered free from earthquake. However, the effect of earthquake cannot be neglected in offshore structure design because energy from the earthquake can be felt for a few miles from the epicenter. Therefore, the attenuation relationship was derived to calculate the magnitude that can be felt by the structure in Malaysia. The attenuation in the signal of ground motion intensity plays an important role in the assessment of possible strong ground shaking.

After deriving the attenuation relationship, the Nonlinear Earthquake Site Response Analysis (NERA) program was used to get the information on the output of each event of earthquake. The exact magnitude of earthquake, acceleration, amplification and frequency are the important output produced by NERA. The experimental work was modelled to produce the same situation by resulting the relationship between soil force reaction, p, and the pile deflection, y, which produced the p-y curve graph. The last topic for this study is the Finite Element Program (ANSYS) to analyze the Pile-Soil Interaction which is important for earthquake design of offshore structures in seismic active areas.

1.7 Thesis Organization

This thesis is consist of eight chapters. The body of this thesis begins with Chapter one; Introduction. Following this introduction chapter is chapter two which represents a Literature Review for the past and present body of knowledge pertaining to attenuation effects on ground movement, subduction zone and attenuation relationship. Chapter three presents the methodology for the research. The development of new attenuation equation for subduction mechanisms is presented in chapter four, followed by chapter five which presents the analysis and discussion of the results from the Non Linear Response Analysis (NERA) program. Chapter six

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