SEISMIC PERFORMANCE OF FIXED OFFSHORE STRUCTURES UNDER FAR FIELD EARTHQUAKE

SAFFUAN BIN WAN AHMAD

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JULY 2016

To My Beloved Father and Mother:

Haji Wan Ahmad bin Wan Su

Hajjah Zabariah binti Yahya

To My Beloved Wife:

Syahirul Akmal binti Ani@Mahbar

To My Beloved Sons:

Adam Hassan bin Saffuan

Amjad Hussaini bin Saffuan

ACKNOWLEDGEMENT

Bismillahirrahmanirrahim…
Alhamdulillah ***YA ALLAH***

The greatness of gratitude to The Almighty Allah for blessing, protecting and guiding me throughout this period until I successfully accomplished this study.

First and foremost, I would like to express my warmest appreciation to my supervisor, Professor Dr. Azlan Adnan for his guidance, encouragement, motivation and valuable advice. Appreciations are also goes to Professor Ir. Dr. Ramli Nazir and Professor Ir. Dr. Shahir Liew because of strong support since day one of my study. Without their support and guidance, this thesis would not have been the same as presented here.

Special thanks go to the members of Engineering Seismology and Earthquake Engineering Research, (e-SEER UTM) for the noble guidance and valuable advice throughout the period of study. Unfortunately, it is impossible to list all of e-SEER UTM members and my friends who have supported my PhD in this limited space. Their patience, time, and understanding are very highly appreciated.

My special sincere appreciation also extends to my supportive and lovely wife Syahirul Akmal binti Ani@Mahbar, my lovely sons Adam Hassan bin Saffuan and Amjad Hussaini bin Saffuan, my lovely parents Haji Wan Ahmad bin Wan Su and Hajjah Zabariah binti Yahya and family members who have been supportive at all times. Finally, I would like to thank all my dearest friends who were involved directly and indirectly in completing this thesis.

ABSTRACT

Malaysia is located at a very low seismic activity area but the active earthquake fault line is through the centre of Sumatran, Indonesia which lies just approximately 350km from Peninsular Malaysia. The earthquake that occurs in Indonesia was due to the strike-slip fault that has affected the building structure in Malaysia. It happens because of the amplification process generated from the source of the event. The aim of this study was to evaluate performance and vulnerability of offshore structures using real peak ground acceleration. Between 2004 and 2012, a few interpolate earthquake events with magnitudes of Mw $\geq$ 3.5 were recorded. These data were provided by Malaysia Meteorological Department Malaysia (MMD) and 10 of the events were shallow strike-slip events. The earthquake Off West Coast of Sumatra that happened on 26th December 2004 has been selected as the biggest earthquake event in the Malaysia region during that time. By using regression analysis, attenuation function that has been developed and the value of maximum ground acceleration that hit offshore platform was identified. Using the real peak ground acceleration, vulnerability and performance of 5 models of typical offshore platforms were evaluated. The typical fixed offshore platform was analysed by using SAP 2000 finite element software. Time history analysis and pushover analysis were done on the models in which the results were compared to the resistance value itself and the performance indicator produced by FEMA-365. The offshore structure was analysed by several steps in pushover in terms of x-direction and y-direction and some parts of the structure were classified as Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) level of performance. Moreover, the results retrieved from the real scale analysis were compared to the experimental work that employed the harmonic shaking table machine. In conclusion, the findings contribute to the seismic performance of offshore platforms in Malaysia. It proves that the offshore platforms in the country is very well sustained with a high-end performance.

ABSTRAK

Malaysia adalah sebuah negara yang terletak dalam kawasan aktiviti gempa yang sangat rendah, tetapi jarak garis sesar yang melalui Sumatera adalah di dalam lingkungan 350km dari Semenanjung Malaysia sahaja. Gempa bumi yang berlaku di Indonesia disebabkan strike slip fault memberikan kesan terhadap struktur bangunan di Malaysia. Perkara ini berlaku kerana proses peralihan tenaga yang tercetus dari pusat punca gempa. Matlamat kajian ini adalah untuk menilai prestasi dan tahap kelemahan pelantar minyak menggunakan nilai sebenar ground acceleration. Antara tahun 2004 dan 2012, beberapa kejadian gempa bumi telah direkodkan berlaku dengan magnitude $Mw \geq 3.5$. Kesemua data gempa tersebut telah disediakan oleh Malaysia Meteorological Department (MMD) dan 10 daripadanya adalah dari aktiviti strike slip. Gempa Off West Coast of Sumatra yang telah berlaku pada 26th December 2004 telah dipilih sebagai gempa terbesar yang berlaku dalam tempoh tersebut. Dengan menggunakan analisis regression, fungsi attenuasi dibina dan nilai tertinggi ground acceleration yang menghentam pelantar minyak telah dikenalpasti. Dengan menggunakan nilai sebenar ground acceleration, kelemahan dan prestasi 5 pelantar minyak telah dilakukan. Pelantar minyak tersebut telah dianalisis menggunakan perisian kaedah unsur tidak terhingga iaitu SAP2000. Analisis time history dan pushover telah dibuat untuk kesemua model di mana hasilnya telah dibandingkan dengan nilai keupayaan struktur itu sendiri dan petunjuk prestasi yang dihasilkan oleh FEMA-365. Pelantar minyak tersebut dianalisis dengan beberapa langkah dalam pushover pada arah-x dan arah-y dan sebahagian dari struktur telah diklasifikasikan kepada peringkat prestasi Immediate Occupancy (IO), Life Safety (LS), dan Collapse Prevention (CP). Selain itu, keputusan yang didapati dari analisis skala sebenar telah dibandingkan dengan kerja-kerja eksperimen yang dibuat menggunakan mesin harmonic shaking table. Kesimpulannya, hasil dari kajian ini telah menyumbang kepada prestasi pelantar minyak di Malaysia terhadap gempa bumi. Ini telah membuktikan bahawa pelantar minyak di negara ini adalah sangat kukuh dengan prestasi yang amat mengagumkan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Δ	-	From the seismograph to the epicenter distance, it measured in degree
A	-	Maximum trace amplitude (mm)
A'	-	Maximum ground displacement (mm)
M_L	-	Richter magnitude scale/local magnitude
Ms	-	Surface wave magnitude scale
M_w	-	Seismic moment (Nm)
μ	-	Shear modulus of material along fault plane (N/m^2)
A_f	-	Area of fault plane undergoing slip (m^2)
D	-	displacement of ruptured segment of fault (m)
M_V	-	Any associated moment with eccentric loading of the platform
V	-	The self-weight of the topside and structure
L_W	-	Cyclic loading due to waves
M_W	-	Cyclic moment due to waves
E	-	Seismic loads
G_k	-	Permanent load
Q_k	-	Variable load
W_k	-	Environmental load
V_{Ed}	-	Shear force
M_{Ed}	-	Bending moment
E	-	Modulus of elasticity
G	-	Modulus of rigidity
D	-	Depth

T	-	Thickness
$V_{C,Rd}$	-	Design shear resistance
A_v	-	Shear area
f_y	-	Yield strength
$M_{C,Rd}$	-	Design bending moment
W_{Pl}	-	Plastic modulus
γ_{Mo}	-	Partial factor for resistance of cross sections
U(z,t)	-	1 hour mean wind speed (ft/s) at level z (ft) above mean sea level
$I_u(z)$	-	Turbulence intensity at level z
T	-	Averaging time period
U_0	-	1 hour mean speed (ft/s) at 32.8 ft
Z	-	Height above mean sea level (ft)
F	-	Force (N)
P	-	Mass density of air (kg/m^3, 1.225 kg/m^3 for standard temperature and pressure
M	-	Wind speed (m/s)
C_s	-	Shape coefficient
A	-	Area of object (m^2)
F_c	-	Current force (N/m)
C_d	-	Drag coefficient
W	-	Weight density of water (N/m^3)
g	-	Gravitational acceleration (m/s^2)
A	-	Projected area normal to the cyclinder axis per unit length
U	-	Component of velocity vector due to current of the water
$\lvert U \rvert$	-	Absolute value of U (m/s)
C_m	-	Inertia coefficient
F_w	-	Hydrodynamic force vector per unit length acting normal to the axis of the member (N/m)
F_D	-	Drag force vector per unit length acting to

		the axis of the member in the plane of the member axis and U (N/m)
F_I	-	Inertial force vector per unit length acting normal to the axis
W	-	Weight of water (N/m^3)
G	-	Gravitational acceleration (m/s^2)
γ_{M2}	-	Partial factor for resistance of cross sections in tension to fracture
f_u	-	Ultimate strength
A_{net}	-	Net area of cross section
A_{eff}	-	Effective area of cross section
$W_{el,min}$	-	Minimum elastic section modulus
$W_{eff,min}$	-	Minimum effective section modulus
χ	-	Reduction factor for relevant buckling curve
γ_{M1}	-	Partial factor for resistance of members to instability assessed by member checks
χ_{LT}	-	Reduction factor for lateral-torsional buckling
Y	-	Mean of ground motion (PGA) in gal
M	-	Magnitude of the earthquake (moment magnitude)
R	-	Distance from the source to the site being considered
H	-	Focal depth of site characteristics function in km
NH	-	Geometry
NM	-	Mass
NT	-	Time
NF	-	Force
NE	-	Material property

LIST OF ABBREVATIONS

KLCC	-	Petronas Twin Tower
US	-	United State
USGS	-	United States Geological Survey
ESEER	-	Engineering Seismology and Earthquake Engineering
RC	-	Reinforced Concrete
MMD	-	Malaysia Meteorological Department
ASTM	-	American Society and Testing Materials
GR	-	Grade
CHS	-	Circular hollow sections
EN	-	Eurocode
PGA	-	Peak ground acceleration
M	-	Magnitude
GMPE	-	Ground-motion prediction equation
CMT	-	Harvard centroid moment tensor
NEIC	-	National Earthquake Information Center
KUM	-	Kulim
IPM	-	Ipoh
FRM	-	Frim Kepong
KTM	-	Kuala Terengganu
KGM	-	Kluang
KDM	-	Kota Tinggi
JRM	-	Jerantut
BNM	-	Bakun
SPM	-	Sapulut
KSM	-	Kuching
SBM	-	Sibu

BTM	-	Bintulu
KKM	-	Kota Kinabalu
KDM	-	Kudat
SDM	-	Sandakan
TSM	-	Tawau
LDM	-	Lahad Datu
PYSM_B0	-	Putrajaya Basement
PYSM_B9	-	Putrajaya Level 9
BKSM	-	Bukit Kiara
SASM	-	Shah Alam
GTSM	-	Goh Tong Jaya
JBSM	-	Janda Baik
KNSM	-	Kundang
SRSM	-	Serendah
BRSM	-	Beranang
DTSM	-	Dusun Tua
PJSM	-	Wetland
UYSM	-	Ulu Yam
BTSM	-	Bukit Tinggi
PLATFORM	-	Terengganu
DBEGM	-	Design basis earthquake ground motion
UD	-	User-defined
FEMA	-	Federal Emergency Management Agency
IO	-	Immediate Occupancy
LS	-	Life safety
CP	-	Collapse Prevention
UTM	-	Universiti Teknologi Malaysia
LVDT	-	Linear variable differential transformer

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 Introduction

Earthquakes are one of the world's most devastating and frightening natural disasters. Undoubtedly, we are aware of the hazards, effects and damages caused by this unpredicted natural disaster. Basically, earthquakes do not kill people, but they collapse buildings and their contents down. The greatest hazard in an earthquake is the collapse or fall of man-made and natural structures that causes extensive losses of life and property.

As a result, the seismic effects should not only be considered in the countries that have a high risk of a strong earthquakes, but also for countries that are subject to low-to-moderate earthquakes for instance Malaysia since the power of an earthquake has proven to be unpredictable.

Most Malaysians may feel that the country is generally free from any major active seismic activities as a consequence of its strategic location. In fact, positioned at the periphery of the ring of fire and beside the Philippines and Indonesia, two neighbouring countries which have seen violent occurrences of seismological activities, the possibility of being jolted by moderate earthquakes cannot be excluded.

Moreover, the Malaysian Meteorological Department detected the occurrence of eight earthquakes in East Malaysia in the magnitude range of 2 to 4.5 Richter scale in the year 2012. The exploration and production activities in oil and gas industry remain vital for economy in Malaysia, where fixed offshore platforms are involved in most operations.

Fixed offshore platforms will be good choice because of large number of those exploration and production platforms in Malaysia. They might be very vulnerable to the earthquake but have to prove with some research data and support using real fixed offshore platforms.

1.2 Earthquakes in Malaysia

Most of the structural buildings in Malaysia are designed without considering the earthquake. It had been reported that most buildings were in good condition in Peninsular Malaysia and at least 50% of selected buildings were found to experience concrete deterioration problems due to vibration during earthquake (MOSTI, 2009).

However, Malaysia is located close to two most seismically active plate boundaries which are inter-plate boundary between Indo-Australian Plate and Eurasian Plate on the west and also the inter-plate boundary between Eurasian and Philippine Plates on the east (Husen *et al.*, 2013). These plates undergo many small movements against each other from time to time. The plates can slide horizontally against each other or pull away from each other or can be coming towards each other causing one plate to dive beneath the other as shown in Figure 1.0.

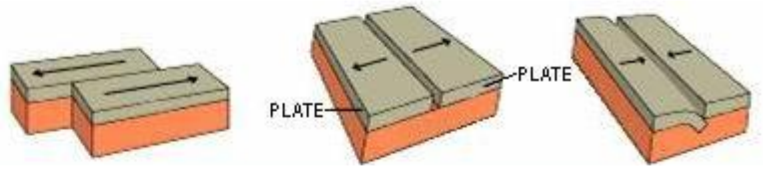

Figure 1.0: Types of Plate Movements (Ng Pek Har & Hadi Golabi, 2005)

The movements of involving large plates can cause a sudden movement that will result in huge energy to be released in the form of waves. These waves will travel inside the earth and along the ground which are felt by us as shakes and tremors.

The intersecting edges of the plates are called faults. Therefore, an earthquake happens once there are both abruptslide on a fault, causing earth to tremble and emit seismic vitality affected by the slide or through volcanic or magmatic movement or further unexpected pressure adjustments in the ground. The tremor effects are dangerous such as ground shaking, liquefaction, surface fault, landslide, tsunami and also tectonic deformation.

The types of hazards depend on the geographical location, ground conditions and amount of tectonic activities along the faults. Geotechnical factors often exert a main influence on destruction patterns and loss of life in earthquake events (Aminaton Marto *et al.,* 2011). Along the transmission during seismic waves, the resonance effect would cause amplification behavior during upward propagation. The amplified waves make the soil liquefaction possible to happen within the region (Aminaton Marto *et al.,* 2014). The impact and damage due to tsunami depends on some factors such as wave speed and height of their coastal topography areas and also debris that are carried by water (Ghobara *et al.,* 2001).

Microzonation is the mapping of seismic hazards at local scales to incorporate the effects of local geotechnical factors (Aminaton Marto *et al.*, 2011). Figure 1.1 shows in the east of Malaysia, the Philippine Plate moves westward with an estimate velocity of 80mm/year and causes micro faults in Sabah (Rosaidi, 2001). Sabah is the only state in Malaysia that is exposed to earthquake activities compared to other parts of Malaysia.

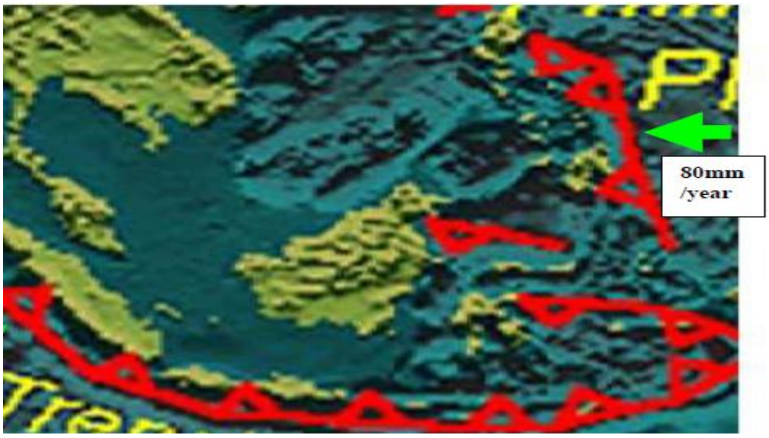

Figure 1.1 : Philippine Plate Moves Westward (Rosaidi, 2001)

The Peninsular Malaysia, Sabah and Sarawak are located just behind the active seismic area. Therefore, there is an effort to investigate the behavior of offshore structures to sustain earthquake effects. The study covers the three legs and four legs of offshore platforms by using the software of SAP 2000 to make a model for the offshore structure.

1.3 Problem Statement

For along time, we have known that Malaysia are safe from earthquake disasters since Malaysia is in the earthquake-free zone. Even though Malaysia is regarded as stable, but it still faces slow magnitude earthquakes in Bukit Tinggi, Pahang and it has revealed that Malaysia is not free from seismic activities.

Furthermore, if an earthquake occurs in the nearby countries such as Indonesia, Malaysia will also get the impact. Adnan *et al*., (2007) stated that Peninsular Malaysia does lie strictly on faults but they have been known to be strictly non-active faults. Malaysia is located in a very low seismic activity area but the active earthquake fault line is through the centre of Sumatera which lies just around 350 km from Peninsular Malaysia.

Therefore when an earthquake occurs, buildings or any structures face some unpredicted risks from earthquake hazards. Since most of the structures in Malaysia do not include earthquake factors in their design consideration, this study is important to increase the awareness of earthquake design consideration.

On 26 December 2004, the coastal area off northern Sumatra, Indonesia had been strucked by a massive earthquake which then triggered tsunamis around the neighboring countries such as India, Maldives, Malaysia, Thailand and Sri Lanka. Due to the massive earthquake that occured in Northern Sumatra, Indonesia with the magnitude of 9.0 in Ritcher scale, Malaysia was affected critically by this natural disaster.

The earthquake in Indonesia triggered tsunamis in the coastal areas of Malaysia that caused serious injuries, loss of human lives, damage to man-made structures and etc. Although Malaysia is near to the epicenter of the earthquake, Malaysia escaped from the kind of damages that struck other countries near Sumatra. Since the western coast of Sumatra is the epicenter of earthquake, Malaysia is largely protected by that island from the worst case of tsunami.

Even though Malaysia is safely protected but still there are some parts in Malaysia that have been affected such as Penang and Langkawi. It was reported that the number of lives lost was 68 in Penang (52), Kedah (12), Perak (3) and Selangor (1). Malaysia which is located at the peripheral of the fire ring and near to Indonesia and Philippines that are known for seismological activities in the past few years, shows that Malaysia could have a chance of being strucked by at least one moderate earthquake.

In year 2012, Malaysian Meteorological Department detected eight earthquakes in the eastern part of Malaysia, Sabah and Sarawak with the magnitude between 2 and 4.5 Scale Ritcher (Bernama, 2013). This shows that Malaysia cannot ignore the threat of earthquakes since there was a record for earthquake occurrences even in small magnitudes.

Besides, in 1976, the strongest earthquake with a magnitude of 5.8 has been recorded in Lahad Datu, Sabah. “Malaysia is close to areas that have experienced strong earthquakes, including Sumatra and the Andaman Sea, while Sabah and Sarawak are located close to the earthquake zones of South Philippines and North Sulawesi. Therefore, the odds of an earthquake striking Peninsular Malaysia cannot be ruled out,” (Rosaidi, 2001).

Although the tendency for Malaysia to be struck by massive earthquakes is quite slim, but the designs cannot ignore the threats for moderate earthquakes. The damage by moderate earthquakes could defect the existing structures by the presence of cracks. Thus, it is really important to take into accounts earthquake impacts in structures especially in designing offshore platforms.

1.4 Objectives

There are many matters that require analyses in this research, but the main objectives of this research are:

1) To develop the attenuation relationship for strike slip fault (data collection and statistical analysis)
2) To determine the vulnerability and performance of existing fixed offshore structures in Malaysia under earthquake loads
3) To study the dynamic characteristics and behaviors of offshore platforms

1.5 Scope of Study

This research is about the behaviour or response of fixed offshore structures under real earthquake ground motions. In order to achieve the objectives, the research scopes below are to be carried out:

1) Study architecture, structural and detailed drawings of offshore platforms.
2) Analyze the data that given by Malaysian Meteorological Department (MMD) with the record starting from year 2004 to 2012
3) Produce the attenuation relationship to the platform based on dataset provided by MMD.
4) Model offshore platforms using computer *SAP 2000 Analysis Software.*
5) Perform dynamic loads from real ground motions that were analysed.
6) Perform time history analysis by using time history with the intensity of earthquake ground motions based on real data that are from the attenuation function.
7) Perform software analysis to get the performance and vulnerability of an offshore platform under earthquake loads.
8) Build a scale-down model to do a real data comparison with the *SAP 2000 Analysis Software* analysis.

1.6 Significance of Study

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

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

By conducting this research, the ground motion earthquake data are input to the SAP2000 and seismic responses of fixed offshore structures will be observed. From that, the necessity of the implementation of seismic designs in the jacket design of offshore platforms in Malaysia due to critical earthquakes will be concluded.

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

REFERENCES

Adnan, A., Marto, A., & Irsyam, M. (2007). Seismic Hazard Assessment for Penisular Malaysia Using Gumbel Distribution Method. *Jurnal Teknologi*. 42(B): 57-73.

Ahmed Yakut, Guney, O. & Yucemen, M.S. (2006). Seismic Vulnerability Assessment using Regional Emprical Data. *Earthquake Engineering and Structural Dynamics*. 35: 1187-1202.

Aminaton Marto, Azlan Adnan, Hendriyawan, & Masyhur Irsyam (2011). Microzonation Maps for Kuala Lumpur And Putrajaya. *Malaysian Journal of Civil Engineering*.23(1), 63–85.

Aminaton Marto, Tan, C.S., Esa, N.N., Pakir, F. and Jusoh, S.N. (2014). Liquefaction Potential of Nusajaya City, *EJGE*. 19: 17231–17239.

Anson, M., Ko, J. M., Lu, H. S., Wen, Z. P., Chau, K. T., Hu, Y. X., Kong, H. (2002). A GIS System Integrated with Vulnerabilityfor Seismic Damage and Loss Estimation of Hong Kong . *Advance in Building Technology*, 1, 303–310.

Applied Technology Council, ATC-40 (1996). Seismic Evaluation and Retrofit of Concrete Buildings. Redwood City, CA: Seismic Safety Commission, ATC, Report SSC 96-01, Volume 1.

Arya, A.S. (2011). *Rapid Structural and Non-Structural Assessment of School and Hospital Buildings in SAARC Countries, SAARC Disaster Management Centre, New Delhi*.

Ashraf Habibullah, S.E., & Stephen Pyle, S. (1998). Practical Three Dimensional Nonlinear Static Pushover Analysis. *Structure Magazine, Winter*. 2.

Atkinson, G.M. 2015. Ground-motion prediction equation for small-to-moderate events at short hypo central distance, with application to induced-seismicity hazards. *Bulletin of the Seismological Society of America*. 105(2A):981-992.

Aulov, A., & Liew, M. S. (2013). Seismic Hazard Analysis (SHA) Considerations for South China Sea Territories of Malaysia, *Recent Advances in Energy and Environmental Management.* 173–178.

Azdarpour. A, R. Junin, M. Asadullah, H. Hamidi, M. Manan & A. R. Mohamad Daud. (2014). Calcium Carbonate Production through Direct Mineral Carbon Dioxide Sequestration.. *Applied Mechanics and Materials*, Vol. 699, pp. 1020-1025.

Barbat, A. H., Carreño, M. L., Pujades, L. G., Lantada, N., Cardona, O. D., & Marulanda, M. C. (2010). Seismic Vulnerability and Risk Evaluation Methods for Urban Areas. A Review With Application to A Pilot Area. *Structure and Infrastructure Engineering*, *6*(1-2), 17–38.

Barbieri, G., Biolzi, L., Bocciarelli, M., Fregonese, L., & Frigeri, A. (2013). Assessing the Seismic Vulnerability of A Historical Building. *Engineering Structures*, *57*, 523–535.

Bargi, K., Hosseini, S.R. and Sharifian, H. (2011). Seismic Response of A Typical Fixed Jacket-Type Offshore Platform (SPD1) Under Sea Waves. *Open Journal of Marine Science.* (pp. 36-42).

Baxter, P., Asce, M., Miller, T. H., & Gupta, R. (2007). Seismic Screening, Evaluation, Rehabilitation , and Design Provisions for Wood-Framed Structures. *American Society of Civil Engineers*, (November), 200–209.

Beben, D. (2013). Dynamic Amplification Factors of Corrugated Steel Plate Culverts. *Engineering Structures.* 46:193-204.

Bernhard Maidl, Leonhard Schmid, Willy Ritz, Martin Herrenkrecht (2008). *Hardrock Tunnel Boring Machine*. Erast and Sohn A Wiley Company.

Brian, G.H. 2010. Extending the life of an ageing offshore facility. *Society of Petroleum Engineer*. 1-11.

Calvi, G. M., Pinho, R., Magenes, G., Bommer, J. J., & Crowley, H. (2006). Development of Seismic Vulnerability Assessment Methodologies Over 30 Years, *ISET Journal of Eathquake Technology*. *43*(472), 75–104.

Catherine, E.F. 2011. Understanding Natural Frequency: Masses on Rods. (online). https://nees.org/resources/3609 (16 May 2015)

Chakrabakti, S K., (2005*). Handbook of Offshore Engineering*, Elsevier, Oxford, UK.

Chen, W., & Scawthorn, C.(2003). *Earthquake engineering handbook*. Boca Raton, FL: CRC Press.

Choi, S.J., Lee, K.H. and Gudmestad, O.T. (2015). The Effect of Dynamic Amplification Due to A Structure's Vibration on Breaking Wave Impact. *Ocean Engineering.* 96:8-20.

Chopra, A. K. (2001). *Dynamics of structures: Theory and Application to Earthquake Engineering*. New Jerse: Prentice-Hall

Chopra, A. K., & Goel, R. K. (2002). A Modal Pushover Analysis Procedure for Estimating Seismic Demands for Buildings. *Earthquake Engineering & Structural Dynamics*, *31*(3), 561–582.

Crowley H, Pinho R (2010). Revisiting Eurocode 8 Formulae for Periods of Vibration and Their Employment In Linear Seismic Analysis. Earthquake EngStructDynam 39:223–235

D'Ayala, D., & Ansal, a. (2011). Non Linear Push Over Assessment of Heritage Buildings in Istanbul to Define Seismic Risk. *Bulletin of Earthquake Engineering*, 10(1), 285–306.

Datta, T.K. (2010). *Seismic Analysis of Structures.* Singapore: John Wiley & Sons

Day, R. W. (2002). *Geotechnical Earthquake Engineering Handbook.* New York: McGraw-Hill.

Dean, R. (2005/6) *CVNG 3006 Environmental Geotechnics, Module 1: Offshore Foundation Engineering.*Lecture Notes: University of the West Indies, Trinidad

Dinh, T. & Inchinose, T. (2005). Probabilistic Estimation of Seismic Story Drifts in Reinforced Concrete Buildings. *Journal of Structural Engineering,* 131(3), 416-427.

Dolce, M., Kappos, A., Masi, A., Penelis, G., & Vona, M. (2006). Vulnerability Assessment and Earthquake Damage Scenarios of The Building Stock of Potenza (Southern Italy) Using Italian And Greek Methodologies. *Engineering Structures*, 28(3), 357–371.

Dowrick, D. (2003). *Earthquake Risk Reduction*. Hoboken, NJ: John Wiley

Elmasry, M. I. S. (2012). Response Spectra for Differential Motion of Structures Supports During Earthquakes in Egypt. *HBRC Journal*, *8*(3), 217–227. doi:10.1016/j.hbrcj.2012.12.005

Elsayed, T, El-Shaib, M and Tore Holmas. 2014. Earthquake Vulnerability Assessment of a Mobile Jackup Platform in the Gulf of Suez. *Ships and Offshore Structures.* **10**(6):609-620.

Eurocode 3, Design of Steel Structures, Part 1: General Rules, and General Rules for Buildings.

Eurocode.8, Design of Structure for Earthquake Resistance, Part 1: General Rules, Seismic Actions and Rulesfor Buildings.

Federal Emergency Management Agency, FEMA-154. (2002). Rapid Visual Screening of Buildings for Potential Seismic Hazards.

Federal Emergency Management Agency, FEMA-356 (2000). Prestandard and commenttary for seismic rehabilitation of buildings. Washington (DC).

Ghobarah, A. (2001). Performance-Based Design in Earthquake Engineering: State of Development, *Engineering Structures*. 23(10): 878-884.

Gryphon Scientific, LLC. Supplemental Information-Calculating Earthquake Risk.

Haldar, P., & Singh, Y. (2009). Seismic Performance and Vulnerability of Indian Code Designed RC Frame Buildings. *Journal of Earthquake Technology,* 46(502), 29-45.

Hendriayawan (2007). *Seismic Microzonation of Malaysia and Microzonation of Kuala Lumpur City Center and Putrajaya*. Universiti Teknologi Malaysia: Ph.D. Thesis.

Hesam, S., Khosro, B., and Mohamad, Z. 2015. Ultimate strength of fixed offshore platforms subjected to near-fault earthquake ground vibration. *Shock and Vibration.* **2015:**19 pages.

Huang, L.J. and Syu, H.J. (2014).Free Vibration and Seismic Responses of Power Transmission Tower Using ANSYS and SAP2000 *International Journal of Emerging Technology and Advanced Engineering.*. 4(8):15-24.

Huang, L.J. and Syu, H.J. (2014). Passive Vibration Control Synthesis of Power Transmission Tower Using ANSYS:Part II - Control of Seismic Response.*International Journal of Emerging Technology and Advanced Engineering.* 4(9):42-46.

Huang, L.J. and Syu, H.J. (2014). Seismic Response Analysis of Tower Crane Using SAP2000. *37th National Conference on Theoretical and Applied Mechanics*,pp. 513-522.

Husen, H., Majid, T. A., Nazri, F. M., Arshad, M. R., & Faisal, A. (2013). Development of Design Response Spectra Based on Various Attenuation Relationships at Specific Location, *Journal of Civil Engineering and Architeture.* 7(12), 1501–1506.

Joshi, G. C., & Kumar, R. (2010). Preliminary Seismic Vulnerability Assessment of Mussoorie Town, Uttarakhand (India). *Journal of Building Appraisal*, *5*(4), 357–368.

Kadid, A.& Boumrkik, A. (2008). Pushover Analysis of Reinforced Concrete Frame Structures. *Asian Journal of Civil Engineering*, 9, 75-83.

Kamatchi, P. (2011). Methodologies for Vulnerability Assessment of Built-Environment Subjected to Earthquakes. *International Journal of Earth Science and Engineering,* 04(06), 183–188.

Kharade AS, Kapadiya SV, Belgaonkar SL (2013). Earthquake analysis of tall sky-pod structures by considering the soil structure interaction effect. *Int J Emerg Technol Adv Eng* 3(1):447–454

Khosro. B, S. R. Hosseini, Mohammad H. T& H.Sharifian (2011). Seismic Response of a Typical Fixed Jacket-Type OffshorePlatform (SPD1) under Sea Waves.*Open Journal of Marine Science*, 2011, 1, 36-42

Kobayashi, T., Yoshikawa, K., Takaoka, E., Nakazawa, M., & Shikama, Y. (2002). Time History Nonlinear Earthquake Response Analysis Considering Materials and Geometrical Nonlinearity. *Nuclear Engineering and Design*, *212*(1-3), 145–154. doi:10.1016/S0029-5493(01)00470-8

Kumawo K. (2010). Nonlinear Dynamic Response of a Large Structures. *American Journal of Applied Sciences* 5(11): 1448-1460

Kwon O (2010) Kim ES: Evaluation of Building Period Formulas for Seismic Design. EarthqEngStructDynam 39:1569–1583

Lai, Tze Khai. (2007). *Determination of earthquake design criteria for fixed offshore structures located in Malaysia region.*Master. Thesis. University Technology Malaysia, Malaysia.

Lee, W. H. K., Kanamori, H., Jennings, P. C. and Kisslinger, C. (Eds.) (2002). *International Handbook of Earthquale& Engineering Seismology*. London: Academic Press.

Leedy, P.D. and Ormrod, J,E. 2010. Practical Research: Planning and Design, Ninth Edition. NYC: Mercil.

Lin, P.S. and Lee, C.T. 2008. Ground-motion attenuation relationships for subduction-zone earthquake in northeastern Taiwan. *Bulletin of the Seismological of America.* **98**(1):220-240.

Lior, I., Ziv, A. and Madariaga, R. 2016. P-eave attenuation with implications for earthquake early warning. *Bulletin of the Seismological of America.* **106**(1):1-10

Martins, V. N., e Silva, D. S., & Cabral, P. (2012). Social Vulnerability Assessment to Seismic Risk Using Multicriteria Analysis: The Case Study of Vila Franca Do Campo (São Miguel Island, Azores, Portugal). *Natural Hazards*, *62*(2), 385–404.

Moustafa, A., & Mahadevan, S. (2011). Reliability Analysis of Uncertain Structures Using Earthquake Response Spectra. *Earthquakes and Structures*, *2*(3), 279–295. doi:10.12989/eas.2011.2.3.279

Mozos, C.M. and Apricio, A.C. (2009). Static Strain Energy And Dynamic Amplification Foactor on Multiple Degree of Freedom Systems. *Engineering Structires.* 31:2756-2765.

Murkherjee, K., Ayob, M.S., Lai, T.K. and Nichols, N.W. (2014). New Guideline for Seismic Assessment of Fixed Facilities in Malaysian Water. *Offshore Technology Conference Asia.*

Murty, C. V. R. (2005). Earthquake Tips Learning Earthquake Design and Construction..IITK-BMPTC, *Building Material and Technology Promotion Council, Ministry of Urban Development and Poverty Alleviation*, Government of India, New Delhi.

Muthukkumaran, K. and Arun, K.S. 2015. Erratum to: Effect of Seabed Slope on the Pile Behavior of a Fixed Offshore Platform Under Lateral Forces. *Journal of Ocean Engineering Marine Energy.* **1**:223-236.

Muyiwa, O. A., & Sadeghi, K. (2007). Construction Planning of an Offshore Petroleum, *Short Communnication.* 82–85.

Nanda, R. P., & Majhi, D. R. (2014). Rapid Seismic Vulnerability Assessment of Building Stocks for Developing Countries. *KSCE Journal of Civil Engineering*, *18*(7), 2218–2226.

Ng PekHar & HadiGolabi (May 2005). The Effect of Earthquake Related Tremors on Buildings in Malaysia.

Norhamizah, N. (2011). *Analysis of Fixed Steel Jacket under Seismic Load.* Degree. Final Year Project. University Technology Malaysia, Malaysia

Papanikolauo, V.K & Elnashai, A.S. (2005). Evaluation of Conventional and Adaptive Pushover Analysis I: Methodology. *Journal of Earthquake Engineering*, *9*(6), 923-941.

Park, M., Koo, W., & Kawano, K. (2011). Dynamic Response Analysis of An Offshore Platform Due to Seismic Motions. *Engineering Structures*, *33*(5), 1607–1616.

Pasticier, L., Amadio, C., & Fragiacomo, M. (2008). Non-Linear Seismic Analysis and Vulnerability Evaluation of A Masonry Building By Means of the SAP2000 V . 10 code. *Earthquake Engineering and Structure Dynamic,*(November 2007), 467–485.

Paul, J. 2006. Structural Analysis of North Adriatic Fixed Offshore Platform. *SORTA.* 1-12

Phillips, E.D. and Chadwick, M. (2002). Three-Dimensional Attenuation Model of Shallow Hikurangi Subduction Zone in the Raukumara Peninsula, New Zealand. *Jouranal of Geophysical Reesearch Atmospheres.* 107(B2):1-8.

Polat, G. and Erol, K. 2002. Attenuation modeling of recent earthquakes in Turkey. *Journal of Seismology.* **6:** 397-409.

Potty, N. S., Redzuan, M., & Hamid, A. (2013). Seismic Evaluation of High Rise Structures in Malaysia, *8*(12), 1459–1477.

Raheem., S.E.A., Ahmed, M.M. and Alazrak, T.M.A.. (2014). Evaluation of Soil–Foundation–Structure Interaction Effects On Seismic Response Demands Of Multi-Story MRF Buildings on Raft Foundations.*International Journal of Advance Structural Engineering.* &:11-30.

Raju, K. R., Cinitha, A., & Iyer, N. R. (2012). Seismic Performance Evaluation of Existing RC Buildings Designed as Per Past Codes Of Practice, 37(April), 281–297.

Ramli, M. Z., & Adnan, A. (2004). Earthquake Engineering Education Plan For Low Intensity Earthquake Region, 1–5.

Rashed, T., & Weeks, J. (2003). Assessing Vulnerability to Earthquake Hazards Through Spatial Multicriteria Analysis of Urban Areas. *International Journal of Geographical Information Science*,17, 547-576.

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

Rezaiguia, A., Ouelaa, N., Laefer, D.F. and Guenfound, S. (2015). Dynamic Amplification of a Multi-Span, Continous Orthotropic Bridge Deck Under Vehicular Movment. *Engineering Structures.* 100:718-730.

Roberto Villaverde. (2009). *Fundamental Concepts of Earthquake Engineering.* Infobase Publishing

Roca, a., Goula, X., Susagna, T., Chávez, J., González, M., & Reinoso, E. (2006). A Simplified Method for Vulnerability Assessment of Dwelling Buildings and Estimation of Damage Scenarios in Catalonia, Spain. *Bulletin of Earthquake Engineering*, *4*(2), 141–158.

Rofooei, F. R., Kaveh, A., & Farahani, F. M. (2011). Estimating the Vulnerability of the Concrete Moment Resisting,*International Journal of Optimization in Civil Engineering*, 3, 433–448.

Rozaina. I. (2006). *Earthquake Design for Fixed Offshore Platform by using Visual Basic 6.0.*Degree. Final Year Project. University Technology Malaysia, Malaysia

Sadat, M. R., Huq, M. S., & Ansary, M. A. (2010). Seismic Vulnerability Assessment of Buildings of Dhaka City. *Journal ofCivil Engineering (IEB)*,*38*(2), 159–172.

Sadeghi, K., & Sadeghi, K. (2007). An Overview of Design , Analysis , Construction and Installation of Offshore Petroleum Platforms Suitable for Cyprus Oil / Gas Fields, 2(4), 1–16.

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

Schmedes, J. and Archuleta, R.J. (2008). Near-Source Gound Motion Along Strike-Slip Faults: Insights Into Magnitude Saturatin of PGV and PGA. *Bulletin of the Seismological Society of America.* 98(5):2278-2290.

Shehata, E.A.R. 2014. Nonlinear behavior of steel fixed offshore platform under environmental loads. *Ships and Offshore Structures.* **11**(1):1-15.

Si, H. and Midoriakwa, S. (2000). Attenuation Relationships of Peak Ground Acceleration and Velocity Considering Effects of Fault Type and Site Condition. *Proceedings of the 12th World Conference on Earthquake Engineering.* Paper No 532.

Singh, Y., Lang, D. H., Prasad, J., & Deoliya, R. (2013). An Analytical Study on the Seismic Vulnerability of Masonry Buildings in India. *Journal of Earthquake Engineering*, *17*(3), 399–422.

Sinha, R. & Goyal, A. (2004). *A National Policy for Seismic Vulnerability Assessment of Buildings and Procedure for Rapid Visual Screening of Buildings for Potential Seismic Vulnerability*, http:www.civil.iitb.ac.in.

Static, N. (2011). for SAP2000 Linear and Nonlinear Static and Dynamic Analysis and Design of Three-Dimensional, (February).

Swapna. C, H.R. Prabhakara. (2014). Seismic Response of Transmission Tower Using SAP2000. *International Journal of Advanced Research.* 2(6), 574-585

Syahrul. I. A. (2008). *Seismic Structural Vulnerability of Offshore Structure in Malaysia.* Degree. Final Year Project. University Technology Malaysia, Malaysia

Timothy Kusky. (2008). *Earthquakes Plate Tectonics and Earthquake Hazards.*CRC Press.

Trevon. J (2009). *Assessment of Kinematic Effects on Offshore Piled Foundations.* Master. Dissertation.Universitario di StudiSuperiori (IUSS) di Pavia, Italy.

Tsai, M.H. and You, Z.K. (2012). Experimental Evaluation of Ineslastic Dynamic Amplification Factors for Progressive Collapse Analysis Under Sudden Support Loss. *Mechanics Research Communications.* 40:56-62.

Vicente, R., Parodi, S., Lagomarsino, S., Varum, H., & Silva, J. a. R. M. (2010). Seismic Vulnerability and Risk Assessment: Case Study of the Historic City Centre of Coimbra, Portugal. *Bulletin of Earthquake Engineering*, *9*(4), 1067–1096.

Wieland, M., Pittore, M., Parolai, S., Zschau, J., Moldobekov, B., & Begaliev, U. (2012). Estimating Building Inventory for Rapid Seismic Vulnerability Assessment: Towards An Integrated Approach Based on Multi-Source Imaging. *Soil Dynamics and Earthquake Engineering*, *36*, 70–83.

Wong, K. K. F. (2011). Seismic Applications of Nonlinear Response Spectra Based on the Theory of Modal Analysis. *Procedia Engineering*, *14*(2011), 1645–1652.

Yakut, A. (2004). Preliminary Seismic Performance Assessment Procedure for Existing RC Buildings. *Engineering Structures*, *26*(10), 1447–1461.