

SEISMIC PERFORMANCE OF FIXED OFFSHORE STRUCTURES  
UNDER FAR FIELD EARTHQUAKE

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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  $M_w \geq 3.5$  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 26<sup>th</sup> 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 magnitudo  $M_w \geq 3.5$ . 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 26<sup>th</sup> 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

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	ii
	<b>DEDICATION</b>	iii
	<b>ACKNOWLEDGEMENT</b>	iv
	<b>ABSTRACT</b>	v
	<b>ABSTRAK</b>	vi
	<b>TABLE OF CONTENTS</b>	vii
	<b>LIST OF TABLES</b>	xiii
	<b>LIST OF FIGURES</b>	xv
	<b>LIST OF SYMBOLS</b>	xx
	<b>LIST OF ABBREVIATIONS</b>	xxiii
	<b>LIST OF APPENDICES</b>	xxv
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Introduction	1
	1.2 Earthquake in Malaysia	2
	1.3 Problem Statement	4
	1.4 Objectives	6
	1.5 Scope Of Study	6
	1.6 Significance of Study	7

<b>2</b>	<b>LITERATURE REVIEW</b>	<b>9</b>
2.1	Introduction	10
2.1.1	Body Waves	10
2.1.2	P-Waves	10
2.1.3	S-Waves	10
2.1.4	Surface Wave	10
2.1.5	Love-Waves	11
2.1.6	Rayleigh Waves	11
2.2	Offshore Exploration	12
2.3	The Idea of An Earthquake	13
2.4	Offshore Platforms in Malaysia	15
2.5	Response Models for Platforms	16
2.6	Offshore Platform Overview	19
2.6.1	Fixed Offshore Platform	20
2.7	Earthquake Magnitude And Frequency	23
2.7.1	What Causes Earthquakes	24
2.7.2	Plate Tectonics	25
2.7.3	Fault	26
2.8	Earthquake In Aceh, Indonesia	27
2.9	Measurement Of Earthquake	30
2.9.1	Magnitude of an Earthquake	30
2.9.1.1	Local Magnitude Scale, $M_L$	30
2.9.1.2	Surface Wave Magnitude Scale, $M_s$	31
2.9.1.3	Moment Magnitude Scale, $M_w$	31
2.9.2	Intensity of Ground Motion	32
2.10	Seismic Design Code (EuroCode 8)	33
2.11	Definition of Attenuation Function	34
2.12	Attenuation Function Development	36
2.12.1	Fault Mechanism by the Earthquake	36
2.12.2	Attenuation Relationships for Shallow Crustal Mechanism	37

2.13	The Location of Malaysia as A Specific Region	40
2.13.1	Sumatran Subduction and Strike Slip Zone	40
2.13.2	Movement of Plate and Type of Fault	43
2.14	Variation of Attenuation Function	44
2.14.1	Seismic Hazard Analysis	45
2.15	Federal Emergency Management Agency (FEMA-356)	46
2.16	Gap Analysis	48
2.17	Concluding Remarks	50
<b>3</b>	<b>RESEARCH METHODOLOGY</b>	<b>52</b>
3.1	Introduction	52
3.2	Current Design Code Used	53
3.2.1	Eurocode 3 Part 1-1: General Rules and Rules for Buildings	53
3.2.2	Eurocode 3 Part 1-1: Design of Joints	53
3.2.3	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms- Working Stress Design by American Petroleum Institute RP 2A-WSD (2000)	53
3.3	Offshore Design Criteria	54
3.4	Theories of Earthquake Generation	56
3.5	Method of Seismic Analysis	57
3.5.1	Free Vibration Analysis	58
3.5.2	Time History Analysis	58
3.5.3	Response Spectrum Analysis	59
3.6	Seismic Responses of Structures	59
3.7	Planning of the Study	60
3.8	Information and Data Collection	61
3.8.1	Offshore Structure Description	61
3.8.2	Modelling Using AutoCAD	62



	3.8.3	Material Properties	65
	3.8.4	Dead and Live Loads	66
	3.9	Steps in Excel Software	67
	3.9.1	Inserting Data to Microsoft Excel	67
	3.10	SAP2000 Computational Program	70
	3.10.1	Defining the Type of Model	71
	3.10.2	Setting up the Coordinates of Grid Lines	71
	3.10.3	Define Material and Structural Section Properties	72
	3.10.4	Draw the Frame Geometry and Assigning Member Section Properties	74
	3.11	Concluding Remarks	75
<b>4</b>		<b>ATTENUATION RELATIONSHIP DEVELOPMENT FOR STRIKE SLIP EARTHQUAKE</b>	<b>76</b>
	4.1	Introduction	76
	4.2	The Development of Attenuation Relationship	76
	4.3	New Attenuation Equation	78
	4.4	Peak Ground Acceleration (PGA)	88
	4.5	Comparison Between PGA Attenuation and MMD Data	93
	4.6	Concluding Remarks	96
<b>5</b>		<b>ANALYSIS OF OFFSHORE STRUCTURE USING FINITE ELEMENT MODELLING</b>	<b>97</b>
	5.1	Introduction	97
	5.2	SAP2000 Software Analysis	98
	5.2.1	Design Basis	98
	5.2.2	Code of Practice	98
	5.2.3	Analysis of Fixed Offshore Platform	98
	5.3	Offshore Structure Modelling	99
	5.4	Free Vibration Analysis For Model A To E	102
	5.5	Critical Component on Offshore Structure	108

5.5.1	Time History Analysis for 4-Legged Offshore Platform (Model A)	109
5.5.2	Time History Analysis for 3-Legged Offshore Platform (Model D)	111
5.6	Performance of Offshore Structure	113
5.6.1	Description of Pushover Analysis	113
5.6.2	Background of Pushover Analysis	114
5.6.3	Acceptance Criteria	115
5.6.4	Building Performance Level Verification	118
5.6.5	Structural Load Case	118
5.6.6	Performance for 4-Legged Offshore Platform (Model A)	119
5.6.7	Performance for 3-Legged Offshore Platform (Model D)	123
5.7	Concluding Remark	127
<b>6</b>	<b>DYNAMIC CHARACTERISTIC OF OFFSHORE PLATFORM AND EXPERIMENTAL TEST</b>	<b>129</b>
6.1	Introduction	129
6.2	Similitude Law	132
6.3	Experimental Validation	134
6.4	Procedure of Experimental Work	136
6.5	Dynamic Characteristic Analysis	138
6.5.1	Acceleration	139
6.5.2	Displacement	139
6.5.3	Acceleration and Displacement of Experimental Work	139
6.5.4	Characteristic of 4 Legged Offshore Platform (Model A)	142
6.5.5	Characteristic Summary for All Offshore Platform Model	143
6.5.6	Verification for Offshore Models	145
6.6	Concluding Remark	146

<b>7</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>147</b>
	7.1 Conclusions	147
	7.1.1 Attenuation Function Relationship	148
	7.1.2 Vulnerability and Performance of Fixed Offshore Platform	148
	7.1.3 Dynamic Characteristic of Fixed Offshore Platform	149
	7.2 Recommendation	149
	<b>REFERENCES</b>	<b>151</b>
	Appendices A - H	160 - 295

## LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	Earthquake Magnitude And Frequency	24
2.2	Modified Mercalli Intensity Scale	33
2.3	Summary of Attenuation Functions	38
2.4	Literature Study on Performance Level Building	48
2.5	Literature Study on Attenuation Function	49
2.6	Literature Study on Offshore and Experimental Work	50
3.1	Information of Offshore Platforms	62
3.2	Dead Load and Live Load Description	66
3.3	The Result of the Maximum Value	68
4.1	Summary of Attenuation Coefficient	79
4.2	Historical Data Using Solver Analysis	80
4.3	Summary of Strike Slip Selected Earthquakes	83
4.4	Ground Motion Recorded Stations	85
4.5	Summary of Peak Ground Acceleration (PGA)	89
4.6	Comparison of Peak Ground Acceleration (PGA)-N Direction	91
4.7	Comparison of Peak Ground Acceleration (PGA)-E Direction	91
4.8	Comparison of Peak Ground Acceleration (PGA) – N Direction	94
4.9	Comparison of Peak Ground Acceleration (PGA) – E Direction	94
5.1	Resistance Check with Stress on Structure Model A	111

5.2	Resistance Check with Stress on the Structure	112
5.3	Load Cases Applied in SAP2000 Software	119
5.4	Resistance Value for All Platform Models	127
6.1	Scaled Test Specimens	132
6.2	Verification Study on Laboratory Work on Displacement	145
6.3	Verification Study on Laboratory Work on Displacement	146

## LIST OF FIGURES

<b>FIGURES</b>	<b>TITLE</b>	<b>PAGE</b>
1.0	Types of Plate's Movement	2
1.1	Philippine Plate Moves Westward	4
2.1	Motion of Body and Surface Waves	11
2.2	Some Locations of Offshore Platforms in Malaysia	15
2.3	Beam-Column of Offshore Platform	17
2.4	Typical Connection of Offshore Platform	17
2.5	Types of Offshore Drilling Platforms	18
2.6	A Typical Offshore Oil and Gas Platform	18
2.7	A Typical Offshore Oil and Gas Platform	19
2.8	Fixed Offshore Platform	21
2.9	Fixed Offshore Platform	21
2.10	Schematic Figure of a Jacket-Type Platform with Skirt Pile Being Hammered into Place	22
2.11	Topside Module being Placed on Installed Jacket	23
2.12	Earth Portions	24
2.13	Normal Fault	26
2.14	Strike-Slip Fault	26
2.15	Magnitude of Aceh Earthquake	27
2.16	2012 Aceh Earthquake Details	28
2.17	9.1 magnitude of Aceh Earthquake, 2004	29
2.18	Cities in Malaysia Affected by Aceh 2004 Earthquake	29
2.19	Source to Site Distance Measurements for Attenuation Models	35

2.20	Active Tectonics and Seismologic Summary of the Sumatra Plate Boundary	41
2.21	Visual of Dip Slip Faults and Strike Slip Faults	42
2.22	Major Tectonic Plates on the Earth's Surface	42
2.23	Movements of Plate under the Earth's Surface	43
2.24	Probabilistic Seismic Hazard Assessment (PHSA) Model for California	46
3.1	Combination of Different Loads	55
3.2	Environmental Loads	55
3.3	Structure of Design Concept for Earthquakes	58
3.4	Flow Chart of Methodology	60
3.5	Side Views of Offshore Structure in Grid System	62
3.6	View A and Elevation Row 1 of Offshore Platform (Model A)	63
3.7	View A and Elevation Row 1 of Offshore Platform (Model B)	63
3.8	Elevation Row of Offshore Platform (Model C)	64
3.9	View A and View B of Offshore Platform (Model D)	64
3.10	View A and Elevation Row B of Offshore Platform (Model E)	65
3.11	Material Properties for Structural Steel	66
3.12	The Result of Maximum Value	68
3.13	Time History Graph Obtained from Microsoft Excel (E-Direction)	69
3.14	Time History Graph Obtained from Microsoft Excel (N-Direction)	69
3.15	Time History Graph Obtained from Microsoft Excel (Z-Direction)	69
3.16	Select the Structure Model Type	71
3.17	Define Grid System Data	72
3.18	Define Material Type	73
3.19	Material Property Data	73
3.20	Structure Layout in SAP2000(3D)	74

4.1	Distance of Offshore Platform from Kerteh	83
4.2	Location of Offshore Platform	84
4.3	Strike Slip Earthquake Location on Maps	86
4.4	Recorded Earthquake Station in Malaysia on Maps	87
4.5	Summary of PGA at Offshore Platform Using Attenuation Function	90
4.6	Comparison of Peak Ground Acceleration (PGA) - N Direction	92
4.7	Comparison of Peak Ground Acceleration (PGA) - E Direction	92
4.8	Ratio versus Sources of Earthquake- N Direction	95
4.9	Ratio versus Sources of Earthquake-E Direction	95
5.1	Time History Graph of Off West Cost Northern Sumatera	98
5.2	3D Model A of the Fixed Offshore Structure-4 Legged	99
5.3	3D Model B of the Fixed Offshore Structure-4 Legged	100
5.4	3D Model C of the Fixed Offshore Structure-4 Legged	100
5.5	3D Model D of the Fixed Offshore Structure-3 Legged	101
5.6	3D Model e of the Fixed Offshore Structure-3 Legged	101
5.7	Mode Shape 1 to 4 for Model A	104
5.8	Mode Shape 5 to 8 for Model A	105
5.9	Mode Shape 9 to 12 for Mode A	106
5.10	Natural Period versus Mode with Different Models	107
5.11	Natural Frequency versus Mode with Different Models	107
5.12	Critical Components in a Jacket-Type Platform	108
5.13	Shear and Moment Data for Frame 27	110
5.14	Shear and Moment on Structure Model A	110
5.15	Shear and Moment on Structure Model D	112
5.16	Typical Load-Deformation Relation and Target Performance	115
5.17	Description of Acceptance Criteria	117
5.18	Modal Mass Participation Ratio	118
5.19	Model A Performance Level (Pushover X)	120



5.20	Total Number vs Performance Level Model A (Pushover X)	120
5.21	Performance Level Model A by Percentage (Pushover X)	121
5.22	Model A Performance Level (Pushover Y)	121
5.23	Total Number vs Performance Level Model A (Pushover Y)	122
5.24	Performance Level Model A by Percentage (Pushover Y)	123
5.25	Model D Performance Level (Pushover X)	124
5.26	Total Number vs Performance Level Model D (Pushover X)	124
5.27	Performance Level Model D by Percentage (Pushover X)	125
5.28	Model D Performance Level (Pushover Y)	125
5.29	Total Number vs Performance Level Model D (Pushover Y)	126
5.30	Performance Level Model D by Percentage (Pushover Y)	126
6.1	Model A Plan View For EL +3-48 and EL -11382	130
6.2	Model A Plan View For EL -28346 and EL -43110	130
6.3	Model A Plan View For EL -62199	131
6.4	Model A to E in UTM Structural and Material Lab	131
6.5	Accelerometer Validation Process Setup	134
6.6	Accelerometer Set in the Laboratory	135
6.7	LVDT Set in the Laboratory	135
6.8	Transferring the Model to the Structural and Material Lab, UTM	136
6.9	Weighing Process of Specimen	137
6.10	Welding of Foundation	137
6.11	Sample Arrangement for Model A	138
6.12	Displacement vs Frequency and Acceleration vs Frequency (Model A)	140

6.13	Displacement vs Frequency and Acceleration vs Frequency (Model B)	140
6.14	Displacement vs Frequency and Acceleration vs Frequency (Model C)	140
6.15	Displacement vs Frequency and Acceleration vs Frequency (Model D)	141
6.16	Displacement vs Frequency and Acceleration vs Frequency (Model E)	141
6.17	Total Displacement vs Frequency	142
6.18	Total Acceleration vs Frequency	143

## LIST OF SYMBOLS

$\Delta$	-	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
$M_s$	-	Surface wave magnitude scale
$M_w$	-	Seismic moment (Nm)
$\mu$	-	Shear modulus of material along fault plane (N/m <sup>2</sup> )
$A_f$	-	Area of fault plane undergoing slip (m <sup>2</sup> )
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
$\gamma_{Mo}$	-	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 ( $\text{kg/m}^3$ , $1.225 \text{ kg/m}^3$ for standard temperature and pressure)
$M$	-	Wind speed (m/s)
$C_s$	-	Shape coefficient
$A$	-	Area of object ( $\text{m}^2$ )
$F_c$	-	Current force (N/m)
$C_d$	-	Drag coefficient
$W$	-	Weight density of water ( $\text{N/m}^3$ )
$g$	-	Gravitational acceleration ( $\text{m/s}^2$ )
$A$	-	Projected area normal to the cylinder axis per unit length
$U$	-	Component of velocity vector due to current of the water
$ U $	-	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 <sup>3</sup> )
$G$	-	Gravitational acceleration (m/s <sup>2</sup> )
$\gamma_{M2}$	-	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
$\chi$	-	Reduction factor for relevant buckling curve
$\gamma_{M1}$	-	Partial factor for resistance of members to instability assessed by member checks
$\chi_{LT}$	-	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 ABBREVIATIONS

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**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Earthquake Event Details	160
B	Peak Ground Acceleration on Platform Site	173
C	Resistance Calculation for Offshore Platform	178
D	Experimental Work Detail Result	199
E	Picture of Lab Models	224
F	Drawings & Malaysian Meteorological Earthquake Data	229
G	FEM Result and Lab Graph	270
H	List of Publications	295



## **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.

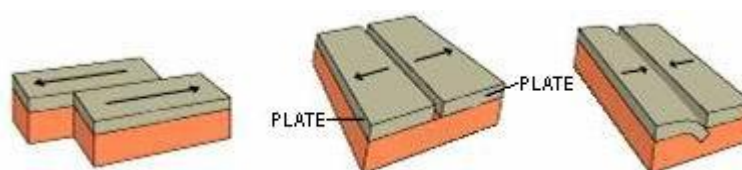
Moreover, the Malaysian Meteorological Department detected the occurrence of eight earthquakes in East Malaysia in the magnitude range of 2 to 4.5 Richter scale in the year 2012. The exploration and production activities in oil and gas industry remain vital for economy in Malaysia, where fixed offshore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



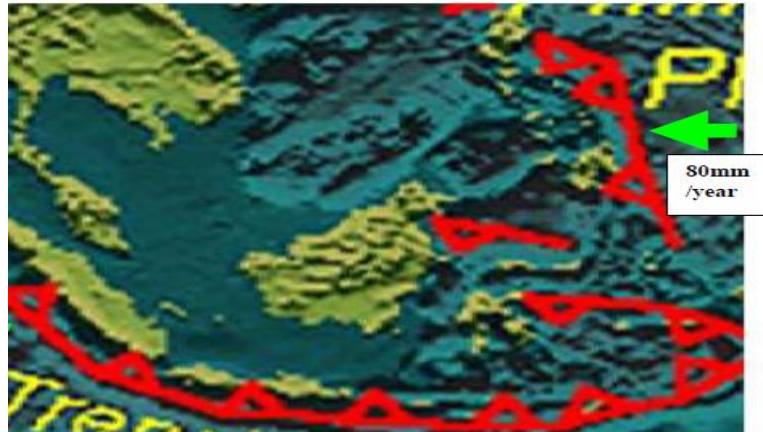
**Figure 1.0:** Types of Plate Movements (Ng Pek Har & Hadi Golabi, 2005)

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 occurred in Northern Sumatra, Indonesia with the magnitude of 9.0 in Richter 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 Richter (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.



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