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DETERMINATION OF EARTHQUAKE DESIGN CRITERIA FOR FIXED OFFSHORE STRUCTURES LOCATED IN MALAYSIA REGION

LAI TZE KHAI

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil – Structure)

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ABSTRACT

Fixed offshore structures in Malaysia region are not designed to resist earthquake ground motion. However, Malaysia actually experienced the tremors due to the earthquakes happened in the neighbouring countries. The purpose of this study is to investigate the vulnerability of existing fixed offshore structures in Malaysia region under earthquake ground motion and propose adequate earthquake design criteria for new fixed offshore structures in Malaysia region. Three (3) sites in Malaysia region are considered: Sabah, Sarawak and Terengganu. Ranges of wave height and ground motion acceleration are given. Response spectrum earthquake analysis has been performed using response spectra curves of API (*American Petroleum Institute*) with the intensity of earthquake ground motion 0.02g, 0.05g, 0.075g, 0.10g, 0.15g, 0.20g, 0.25g and 0.35g. Time history earthquake analysis has been performed by referring to time history earthquake El Centro, 1940. The results of response spectrum and time history analysis have been compared. Generally, fixed offshore structures in Malaysia region are able to resist low seismic activity up to 0.15g. This is because the design of fixed offshore structures for environmental loading, which is slightly different from onshore structures, can provide sufficient resistance against potential low seismic effects. Some members' failure may be expected but the overall system remains stable in the event of rare and intense earthquake at site. Earthquake design for fixed offshore structures is a challenging process because many uncertainties and issues still exist in the development of seismic design parameters. For further study, more numbers of fixed offshore structures from various locations in Malaysia region shall be considered and analysed. Besides that, the inelastic stage response of the fixed offshore structures shall also be considered.

ABSTRAK

Struktur luar pantai di sekitar Malaysia adalah direkabentuk tanpa mengambilkira beban gempa bumi. Namun demikian, Malaysia sebenarnya mengalami gegaran akibat daripada gempa bumi yang terjadi di negara-negara jiran. Tujuan kajian ini adalah untuk menyiasat ketahanlasakan struktur luar pantai di sekitar Malaysia di bawah beban gempa bumi dan seterusnya mencadangkan suatu panduan gempa bumi yang memuaskan untuk rekabentuk struktur luar pantai yang baru di sekitar Malaysia. Dalam kajian ini, tiga (3) lokasi telah diambilkira: Sabah, Sarawak dan Terengganu. Ketinggian ombak dan pecutan gempa bumi telah dinyatakan. Analisis tindakbalas spekrum telah dijalankan dengan keamatan pecutan gempa bumi 0.02g, 0.05g, 0.075g, 0.10g, 0.15g, 0.20g, 0.25g dan 0.35g. Analisis sejarah masa pula dijalankan dengan merujuk kepada gempa bumi El Centro, 1940. Keputusan kedua-dua analisis ini telah dibandingkan. Secara umum, struktur luar pantai di sekitar Malaysia mampu menanggung beban gempa bumi yang rendah sehingga 0.15g. Ini kerana rekabentuk struktur luar pantai ini mengambilkira beban alam sekitar yang agak berbeza daripada struktur biasa dan ini memberikan keupayaan lebih kepada struktur luar pantai ini untuk menanggung beban gempa bumi yang rendah. Kegagalan sesuatu elemen mungkin berlaku tetapi sistem keseluruhan struktur masih stabil apabila berlaku gempa bumi. Rekabentuk struktur untuk beban gempa bumi adalah suatu tugas yang mencabar kerana banyak ketidakpastian akan timbul dalam proses menghasilkan parameter rekabentuk struktur untuk beban gempa bumi. Untuk analisis lanjutan, lebih banyak struktur luar pantai dari pelbagai lokasi di sekitar Malaysia harus diambilkira dan dianalisis. Tindakbalas plastik struktur luar pantai kepada gempa bumi harus diambilkira.

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LIST OF SYMBOLS

A	-	Maximum trace amplitude, mm
A'	-	Maximum ground displacement, µm
A_f	-	Area of fault plane undergoing slip, m^2
A	-	Cross sectional area, m^2
C	-	Critical elastic buckling coefficient
D	-	Average displacement of ruptured segment of fault, m
D	-	Outside diameter, m
E	-	Young's modulus of elasticity, MPa
F_a	-	Allowable axial compressive stress
F_b	-	Allowable bending stress
F_t	-	Allowable tensile stress
F_v	-	Allowable beam shear stress
F_{vt}	-	Allowable torsional shear stress
F_{xc}	-	Inelastic local buckling stress
F_{xe}	-	Elastic local buckling stress
F_y	-	Yield strength, MPa
f_v	-	Maximum shear stress, MPa
f_{vt}	-	Maximum torsional shear stress, MPa
g	-	Gravity = 9.81 m/s^2
I_p	-	Polar moment of inertia, m^4
K	-	Effective length factor
L	-	Unbraced length, m
M_L	-	Local magnitude (also often referred to as Richter magnitude scale)
M_0	-	Seismic moment, N.m
Ms	-	Surface wave magnitude scale

M_t	-	Torsional moment, MN-m
r	-	Radius of gyration, m
t	-	Wall thickness, m
V	-	Transverse shear force, MN
Δ	-	Epicenter distance to seismograph measured in degrees
μ	-	Shear modulus of material along fault plane, N/m^2

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CHAPTER 1

INTRODUCTION

1.1 Background of Project

Among the natural phenomena that have worried human kind, earthquakes are without doubt the most distressing one. The occurrence of earthquakes has been unpredictable and this makes them especially feared by the common citizens because they feel there is no way to assure an effective preparedness.

The most feared effects of earthquakes are collapse of constructions because they not only usually imply human casualties but represent huge losses for individuals as well as for the community. It is the aim in this project to study earthquake ground motion from the point of view of the natural hazard it poses to construction, and particularly to fixed offshore structures.

The fundamental goals of any structural design are safety, serviceability and economy. Achieving these goals for design in seismic region is especially important and difficult. Uncertainty and unpredictability of when, where and how an earthquake event will strike a community increases the overall difficulty. In addition, lack of understanding and ability to estimate the performance of constructed facilities makes it difficult to achieve the above mentioned goals.

Malaysia is generally located out of the seismically active areas and it is still questionable whether the fixed offshore structures in Malaysia region shall be designed to resist earthquake ground motion. In fact, portions of the coastal water of the state of Sarawak and Sabah are very near to the seismically active zone and we actually experienced the tremors due to the earthquakes happened in our neighbouring countries.

There are about 250 fixed offshore structures in Malaysia region. However, none of them are designed to resist earthquake ground motion due to the ignorance of earthquake load in PETRONAS Technical Standards PTS 20.073, Technical Specification for Design of Fixed Offshore Structures (1983).

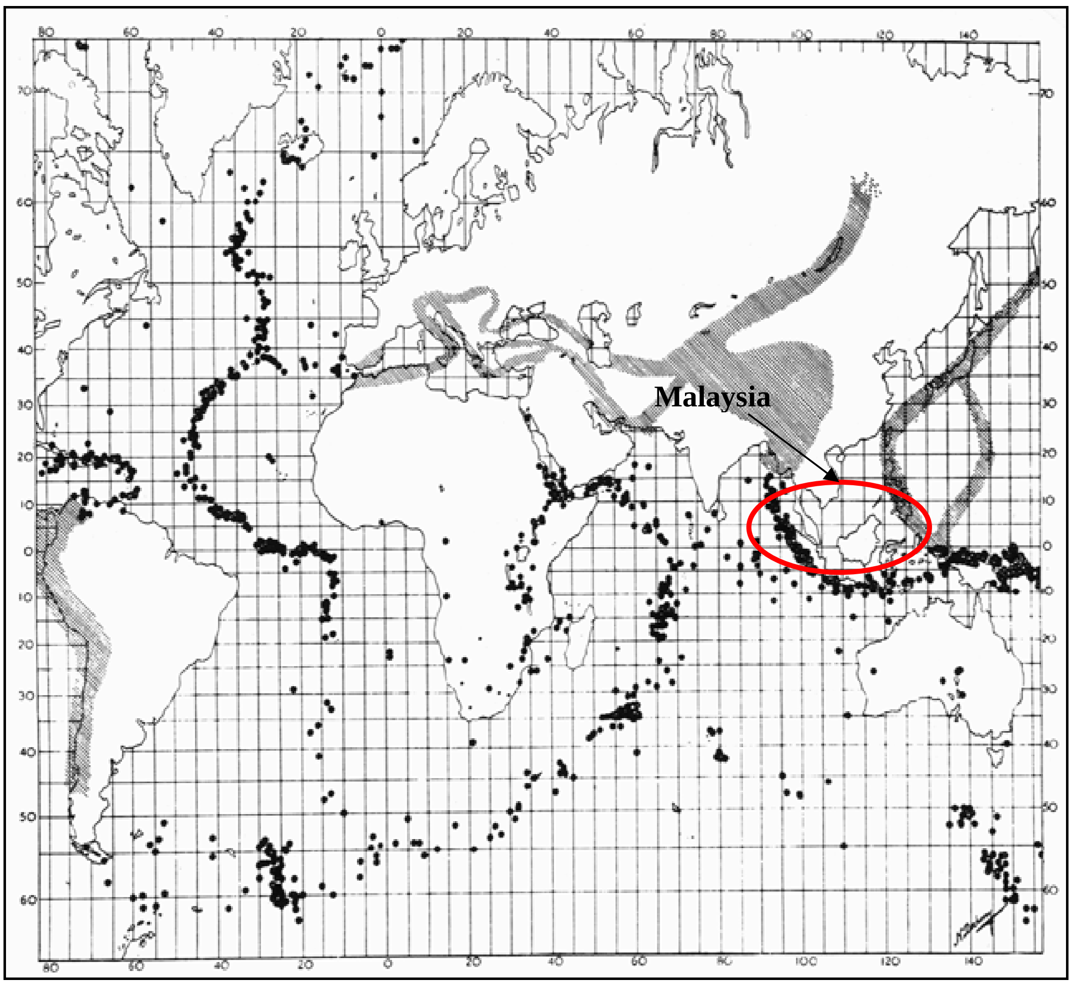

Figure 1.1 Earthquake activity map for Asia region

1.2 Objectives

The objectives of this project are:

- To estimate the seismic ground motion due to actual earthquakes around Malaysia region for the assessment of fixed offshore structures located in Malaysia
- To determine the vulnerability of existing fixed offshore structures in Malaysia under earthquake load
- To determine the earthquake design criteria for new fixed offshore structures located in Malaysia region

1.3 Scope of Study

The scopes of this study:

i) Three (3) PETRONAS fixed offshore structures from different locations have been identified for the analyses. The fixed offshore structures are as follows:

- Sarawak Baram Cluster-Drilling Platform (BAJT-D)
- Sabah Erb-West Drilling Platform (EWDP-B)
- Terengganu Angsi-A Production and Gas Compression Platform (ANPG-A)

ii) Linear earthquake analyses have been performed on the identified fixed offshore structures

- Response spectrum analysis has been performed by using response spectra curves of API with the intensity of earthquake ground motion 0.02g, 0.05g, 0.075g, 0.10g, 0.15g, 0.20g, 0.25g and 0.35g
- Time history earthquake analysis has been performed with reference to time history earthquake El Centro, 1940
- The analysis software used is *Structural Analysis Computer System (SACS*)

1.4 Importance of the Study

This study gives us some general ideas about earthquake ground motion in Malaysia and the effects it possess to the fixed offshore structures located in Malaysia region. The vulnerability of the fixed offshore structures in Malaysia region under earthquake load has been determined from the study. Besides that, the behaviours and stability of fixed offshore structures in Malaysia region obtained from the earthquake analyses may be used to develop some earthquake design criteria for new fixed offshore structures located in Malaysia region.

CHAPTER 2

LITERATURE REVIEW

2.1 Earthquake

Earthquakes are naturally occurring broad-banded vibratory ground motions, caused by a number of phenomena including tectonic ground motions, volcanism, landslides, rock bursts, and human-made explosions. Of these various causes, tectonic-related earthquakes are the largest and most important.

The most feared effects of earthquakes are collapses of constructions. Most earthquake related deaths result from the collapse of building; this is because people standing in an open field during a large earthquake would just be knocked down. Thus, it is often stated that in general “earthquakes do not kill people, buildings kill people”. As a result, proper design and construction is the primary method to reduce earthquake risks.

Structural design of buildings for seismic loading is primarily concerned with structural safety during major earthquakes, but serviceability and the potential for economic loss are also of concern. Seismic loading requires an understanding of the structural behaviour under large inelastic and cyclic deformations. Behaviour under this loading is fundamentally different from gravity loading, requiring much more detailed analysis and application of a number of stringent detailing requirements to assure acceptable seismic performance beyond the elastic range. Some structural damage can be expected when the building experiences design ground motions because almost all building codes allow inelastic energy dissipation in structural systems.

2.2 Causes of Earthquakes and Faulting

2.2.1 Plat Tectonics

Earthquakes occur from the deformation of outer, brittle portions of tectonic plates, the earth's outer most layers of crust and upper mantle. Due to the heating and cooling of the rock below these plates, the resulting convection causes the adjacently overlying plates to move, and under great stresses, they deform. Relative plate motion at the fault interface is constrained by friction and asperities which are the areas of interlocking due to protrusions in the fault surfaces. However, strain energy accumulates in the plates, eventually overcomes any resistance, and causes slip between the two sides of the fault. This sudden slip, termed elastic rebound releases large amounts of energy, which constitutes or is the earthquake.

2.2.2 Fault

A fault is defined as a fracture or a zone of fractures in rock along which displacement has occurred. The fault length can be defined as the total length of the fault or fault zone. Faults are typically classified according to their sense of motion. Typical terms used to describe different types of faults are as follows:

- Strike-slip fault: A fault which the movement is parallel to the strike of the fault
- Normal fault: A fault where two sides in tension move away from each other

- Reverse fault: A fault where two sides in compression move towards each other (Scawthorn, 1999)

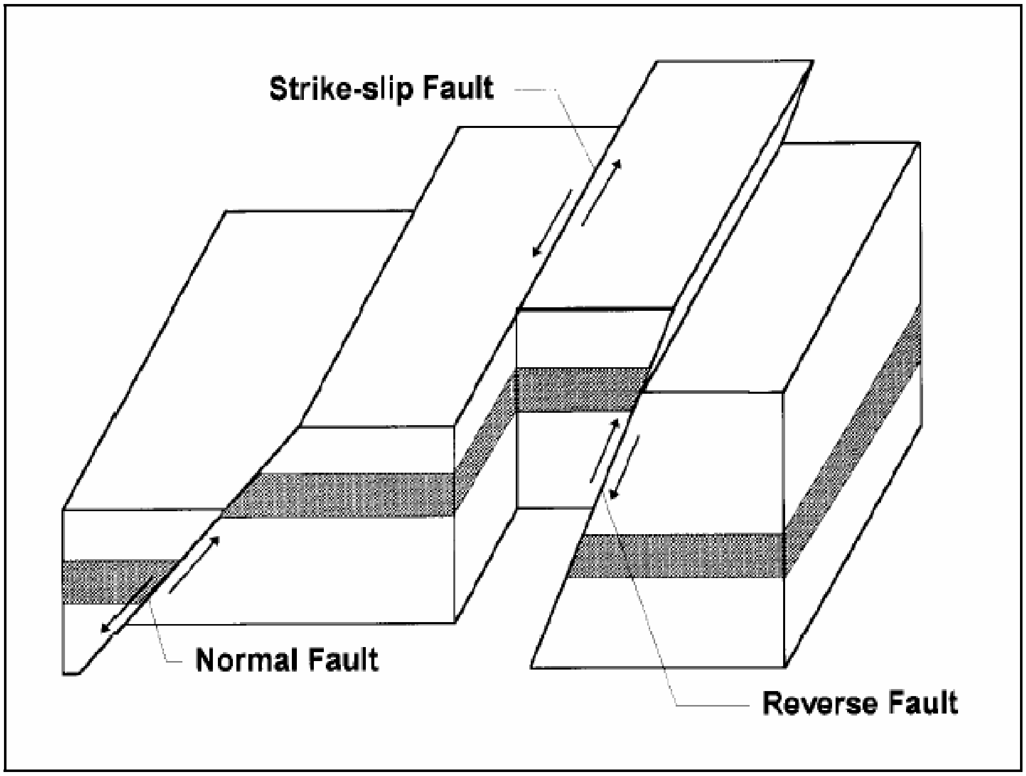

Figure 2.1 Types of faulting

2.3 Seismic Wave

The acceleration of the ground surface is due to various seismic waves generated by the faults rupture. There are two basic types of seismic waves: body waves and surface waves. P and S waves are both called body waves because they can pass through the interior of the earth. Surface waves are only observed close to the surface of the earth, and they are sub-divided into Love waves and Rayleigh waves. Surface waves result from the interaction between body waves and the earth surface materials. The four types of seismic waves are as follows:

- P wave (Body wave): The P wave is also known as the primary wave, compression wave or longitudinal wave. It is a seismic wave that causes a series of compressions and dilations of the materials through which it travels. The P wave is the fastest wave and is the first to arrive at a site. Being a compression-dilation type of wave, P waves can travel through both solids and liquids. Soil and rock are relatively resistant to compression-dilation effects, so the P wave usually has the least impact on ground surface movements

- S wave (Body wave): The S wave is also known as the secondary wave, shear wave or transverse wave. The S wave causes shearing deformations of materials through which it travels. S waves can only travel through solids because liquids have no shear resistance. The shear resistance of soil and rock is usually less than the compression-dilation resistance, and thus an S wave travels more slowly through the ground than a P wave. Soil is weak in terms of its shear resistance and S waves typically have the greatest impact on ground surface movements

- Love wave (Surface wave): Love waves are analogous to S waves and in that they are transverse shear waves that travel close to the ground surface

- Rayleigh wave (Surface wave): Rayleigh waves have been described as being similar to the surface ripples produced by a rock thrown into a pond. These seismic waves produce both vertical and horizontal displacement of the ground as the surface waves propagate outward.

2.4 Measurement of Earthquakes

Earthquakes are complex multi-dimensional phenomena and the scientific analysis of earthquakes requires measurement. Prior to the invention of modern scientific instruments, earthquakes were qualitatively measured by their effect or intensity. Intensity is based on the damage to buildings and reactions of people, which differed from point to point. With the deployment of seismometers, an instrumental quantification of the entire earthquake event or the unique magnitude of the event became possible. Magnitude measures the amount of energy released from earthquake event. These are still the two most widely used measures of an earthquake and a number of different scales for each have been developed, which are sometimes confused. Engineering design, however, requires measurement of earthquake phenomena in units such as force or displacement.

2.4.1 Magnitude of an Earthquake

An individual earthquake is a unique release of strain energy and the quantification of this energy has formed the basis for measuring the earthquake event. There are many different earthquake magnitude scales used by seismologists.

2.4.1.1 Local Magnitude Scale, M_L

In 1935, Professor Charles Richter, from the California Institute of Technology, developed an earthquake magnitude scale for shallow and local earthquakes in southern California. This magnitude scale has often been referred to as the Richter magnitude scale. This magnitude scale was developed for shallow and local earthquakes, so it is also known as the local magnitude scale M_L. This magnitude scale is the best known and most commonly used magnitude scale. The magnitude is calculated as follows:

$$M_L = \log A - \log A_0 = \log A/A_0$$

Where,

M_L = local magnitude (also often referred to as Richter magnitude scale)

A = maximum trace amplitude, mm, as recorded by a standard Wood-Anderson seismograph that has a natural period of 0.8s, a damping factor of 80 %, and a static magnification of 2800. The maximum trace amplitude must be the amplitude that would be recorded if a Wood-Anderson seismograph were located on firm ground at a distance of exactly 100 km from the epicenter of the earthquake. Charts and tables are available to adjust the maximum trace amplitude for the usual case where the seismograph is not located exactly 100 km from the epicenter.

A_0 = 0.001 mm. The zero of the local magnitude scale was arbitrarily fixed as amplitude of 0.001 mm, which corresponded to the smallest earthquakes then being recorded.

2.4.1.2 Surface Wave Magnitude Scale, M_s

The surface wave magnitude scale is based on the amplitude of surface waves having a period of about 20s. The surface wave magnitude scale, M_s is defined as follows:

$$M_s = \log A' + 1.66 \log \Delta + 2.0$$

Where,

M_s = surface wave magnitude scale

A' = maximum ground displacement, μm

Δ = epicenter distance to seismograph measured in degrees (360° correspond to circumference of earth)

The surface wave magnitude scale has an advantage over the local magnitude scale in because it uses the maximum ground displacement, rather than the maximum trace amplitude from a standard Wood-Anderson seismograph. Thus, any type of seismograph can be used to obtain the surface wave magnitude. This magnitude scale is typically used for moderate to large earthquakes, having a shallow focal depth and the seismograph should be at least 1000 km from the epicenter.