

DEVELOPMENT OF DESIGN RESPONSE SPECTRA FOR IPOH

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DEVELOPMENT OF DESIGN RESPONSE SPECTRA FOR IPOH

by

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LIST OF SYMBOLS

1 gal	1cm/s^2
a, b	Gutenberg-Richter zone dependent constant
a_g	design ground acceleration
BH	borehole
C_v, C_a	design response spectra
D	crustal depth
$E(n_1), E(n_2)$	approximated exponential integral function in Kijko-Sellevoll estimator
F_a, F_v	site coefficient
G	shear modulus of the soil
$G(R,D)$	Geometrical attenuation factor with $R > 2.5D$
g	gravity (9.81 m/s^2)
M	Gutenberg-Richter considered magnitude
m_b	body wave magnitude
M_L	richter local magnitude
m_{max}	maximum earthquake magnitude
M_{max}	possible maximum earthquake magnitude in a given region
M_{min}	possible minimum earthquake magnitude in a given region
M_S	surface wave magnitude
M_w	moment magnitude
\overline{M}	mean value of earthquake magnitudes
$N(m)$	number of earthquakes with a magnitude equal to or greater than a magnitude of m

$N(M_{\min})$	number of earthquakes with magnitude equal to or greater than magnitude minimum considered
n_1, n_2	parameter of exponential integral function in Kijko-Sellevol estimator
$^{\circ}\text{E}$	East
$^{\circ}\text{N}$	North
$^{\circ}\text{S}$	South
$^{\circ}\text{W}$	West
PS_A	pseudo-spectrum response acceleration
$\text{PS}_{A1.0\text{sec}}$	spectrum response acceleration of pSA at 1.0 second period
$\text{PS}_{A\text{max}}$	peak value or maximum pseudo-spectrum response acceleration
PS_V	Pseudo-response
$\text{PS}_{v\text{max}}$	peak value or maximum pseudo-spectrum response of velocity
Q	quality factor
R	source to site distance
r_{epi}	epicentral distance
r_{hypo}	hypocentral distance
R_o	earthquake probability occurrence
S	soil factor
S_1	mapped spectral acceleration for a 1 second period
S_a	design spectrum response acceleration
S_{DI}	design spectrum acceleration at 1 second period
S_{DS}	design spectral response acceleration at short period
$S_e(T)$	elastic response spectrum
S_{MI}	the maximum considered earthquake spectrum response acceleration for 1 second period

S_{MS}	the maximum considered earthquake spectrum response acceleration for short period
S_S	mapped spectral acceleration
T	fundamental period (in seconds) of the structure
T_B, T_C	limits of the constant spectral acceleration branch
T_D	value defining the beginning of the constant displacement response range of the spectrum
T_1	first corner period
T_2	second corner period
T_o	first corner period in design spectrum acceleration
T_r	time span considered in probability of occurrence equation
T_s	second corner period of design spectrum acceleration
V_s	shear wave velocity
$\alpha(M)$	source factors
β	parameter of Kijko-Sellevol estimator
$\beta(R,Q)$	anelastic attenuation factor
γ_s	unit weight of soil
ρ	bedrock density
σ	standard deviation
$^\circ$	degree
η	viscosity of the soil
η_c	exponent in anelastic attenuation factor
λ	Lagrangian multipliers parameter in Dong <i>et al.</i> relationship
ξ	damping factor of the soil

LIST OF ABBREVIATION

CAM	Component Attenuation Model
CENA	Central and Eastern North America
COSMOS	Consortium of Organizations for Strong Motion Organization
DSHA	Deterministic Seismic Hazard Analysis
IRIS	Incorporated Research Institution for Seismology
ISC	International Seismological Centre
MMI	Modified Mercalli Intensity Scale
MMS	Malaysia Meteorological Service (Jabatan Meteorologi Malaysia)
NEHRP	National Earthquake Hazard Reduction Program (United States)
NEIC - USGS	National Earthquake Information Centre – United States Geological Surveys
NERA	Nonlinear Earthquake site Response Analysis
PEER	Pacific Earthquake Engineering Research Center
PGA	Peak Ground Acceleration
PSHA	Probabilistic Seismic Hazard Analysis
RSA	Response Spectrum Acceleration
SFZ	Sumatran Great Fault Zone
SPT	Standard Penetration Test
SSZ	Sumatran Subduction Zone
UBC	Uniform Building Code
WNA	Western North America

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PEMBANGUNAN SPEKTRA SAMBUTAN REKABENTUK UNTUK IPOH

ABSTRAK

Kesedaran mengenai bahaya risiko seismik semakin meningkat di Malaysia selepas mengalami beberapa siri gegaran akibat gempa di Sumatra. Walaupun terletak di para sunda yang stabil, beberapa buah negeri di pantai barat Semenanjung Malaysia turut merasai gegaran pada jarak yang jauh berpunca daripada gempa bumi di Aceh dan Nias. Objektif kajian ini ialah untuk membangunkan spektra sambutan rekabentuk di satu kawasan yang spesifik. Bandar Ipoh dijadikan kawasan kajian kes dimana pelbagai jenis kelas tanah disimulasikan untuk menganggar daya dan kesan akibat daripada gempa bumi. Jangkaan magnitud maksimum, m_{max} ditentukan melalui formula Kijko-Sellevol. Daripada kajian yang dijalankan, dianggarkan bahawa magnitud maksimum bagi zon gelinciran (SFZ) dan zon subduction di Sumatra (SSZ) adalah 7.8 dan 9.24. Selain itu, jangkaan pemecutan bumi puncak (PGA) di dasar batuan untuk kawasan Ipoh adalah 0.0257 g bagi SFZ dan 0.0174 g untuk SSZ. Analisis dinamik yang dijalankan menunjukkan bahawa tanah di Ipoh boleh dibahagikan kepada tiga jenis kelas iaitu, S_C (tanah tumpat), S_D (tanah kukuh) dan S_E (tanah lembut). Nilai maksimum spektra sambutan (RSA) menunjukkan nilai 0.25 g, 0.28 g dan 0.31 g untuk tanah jenis S_C , S_D dan S_E . Spektra sambutan rekabentuk telah dibangunkan berdasarkan tiga jenis kod iaitu UBC 1997, NEHRP 2000 dan Eurocode 8.

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ABSTRACT

Seismic awareness becomes a critical issue in Malaysia after experienced a series of tremors originated from Sumatra. Although situated in stable shelf, several places in west coast Peninsular Malaysia have experienced ground shaking effect due to long distance earthquake which occurred in Aceh and Nias. The main objective of this study is to develop design response spectra on the site-specific. The city of Ipoh was selected as case study areas to evaluate the soil effects that involve the site response characteristics of various soil types. Prediction of the maximum magnitude for the future earthquake was determining using Kijko-Selleval estimator. The maximum magnitude m_{max} for Sumatran fault zone (SFZ) and Sumatran subduction zone (SSZ) are found to be 7.8 and 9.24 respectively. Besides that, prediction of ground motion is the critical step to perform seismic hazard analysis. Results show that the peak ground acceleration (PGA) on the bedrock at Ipoh was 0.0257g for (SFZ) and 0.0174 g for (SSZ). The analysis of dynamic response performed shows that generally Ipoh consists of three types of soil conditions; S_C (very dense soil and soft rock), S_D (stiff soil) and S_E (soft soil). The peak response spectra acceleration (RSA) value for these soil types is 0.25g, 0.28g and 0.31g for site class S_C , S_D and S_E , respectively. The smoothed response spectrum or design response spectra of seismic force was established according to Uniform Building Code (UBC 1997), National Earthquake Hazards Reduction Program (NEHRP 2000) and Eurocode 8 (EN 1998 – 1). Results show that there is no significant different in term of peak design response spectra except for the period of design response spectra..

CHAPTER 1 INTRODUCTION

1.0 General

An earthquake is a phenomenon that caused by sudden movements in the earth's crust that caused a rupture or slip at the intersection of two tectonic plates. The energy arises mainly from stresses built up during tectonic processes, which consists interaction between the crust and the interior of the earth. When the shear stress increases on the fault plane, the rock material begins to fail and released the stored energy. The underground location where the rock first broke apart or shifted are called the focus of an earthquake. At some locations, earthquake also can be associated with the volcanic activity.

Currently, there are seven major plate tectonics namely; Pacific, Eurasian, North American, South America, Australian, Africa, and Antarctic. The earthquake that occurs at boundaries of those plates termed as tectonic earthquake. Classification of the earthquakes can be made according to the depth of the focus whether it was shallow, intermediate or deep earthquake. The earthquakes with closer focus to the ground surface will give the heavier impact to the affected site. Significant hazards may occur due to earthquake, such as fault movements, tsunami, flood, ground shaking, liquefaction and landslide.

Peninsular Malaysia is located within the stable Sunda tectonic plate with low to moderate seismic activity level and affected seismically by far field earthquake events. The closest active seismic zones are located more than 300 km away, generated from the Sumatran seismic zones namely Sumatran subduction zone (SSZ) and Sumatran

great fault zone (SFZ). The historical records from Sumatran fault shows that the great earthquake has occurred up to moment magnitude (M_w) of 7.8 and subduction zone has a capability to generate very large earthquake until M_w 9.0.

Since Malaysia is classified in low to moderate seismicity area, it is assumed that the historical earthquake never caused real problems. However, the other region shows that distant earthquakes from several hundred kilometers away, can possibly cause considerable damage. The Michoacán earthquake of 1985 is one of the examples. On 19 September, 1985, Mexico City was shaken by earthquake with a surface wave magnitude (M_s) of 8.1. Although the focus of the earthquake was about 400 km away, severe damage occurred in Mexico City.

The facts are more reliable when the recent earthquake in Sumatra on the 26th December 2004 recorded a magnitude of 9.3, on March 2005 registered a magnitude 8.6 and recently February 2008 with magnitude 7.2 on Richter scale also felt in some parts of Peninsular Malaysia. There have been reports from urban residents in Kuala Lumpur Melaka and Penang that the quakes has caused some panic and cracks on their building, especially whom were living in multi storey buildings.

In addition, Malaysian Meteorological Services has reported that from the year 1909 to September 2007, Malaysia has felt 46 earthquakes in Kuala Lumpur and Selangor, 36 earthquakes in Penang, 27 earthquakes in Johor and 22 earthquakes in Perak with intensity III to VII in Modified Mercalli Scale. Due to the significant hazard that could occur by distant earthquakes, it is compulsory to have awareness to the hazard and perform with seismic hazard analysis that can contribute further

understanding towards the distant earthquake hazard in Peninsular Malaysia. The Potential hazards and effects on the distant areas in Peninsular Malaysia should be investigated for further research.

1.1 Problem Statement

Ipoh city is situated in west coast of Peninsular Malaysia which is bounded on the north and south by the line of latitude $4^{\circ} 45'$ N and $4^{\circ} 15'$ N respectively, on the east by line of longitude $101^{\circ} 15'$ E and on the west by $101^{\circ} 00'$ E. The city was densely populated and growth with lots of commercial and economic activities. However, the existing buildings and structures in Ipoh are not constructed to withstand earthquake force.

Malaysia is in the process of establishing guide lines for building to withstand the earthquake force. For a few past years the earthquake resistant building construction is not always the first consideration. Although, no significant damage was reported but the fact that Ipoh is situated close earthquake source with more than 350 km away from Sumatran fault zone may demand a review on the existing guide line for designing structures.

Ipoh faces a large and growing risk from danger of seismic hazards. It needs to begin the process of managing the disaster risk to ensure the survival and protect the residents. The obtained data and information from this study is very useful to be applied in design for the buildings and structures especially at the affected or predicted area. As the result of this study, the development design response spectra could be made as a guideline to the agency, organizations and resident of the area.

1.2 Objectives

This study is based on the distant earthquake from Sumatra. The evaluations of soil effects involve the site response characteristics of various soil types in Ipoh. The main objectives of this study are as follows:

- i. To predict the maximum earthquake magnitude (m_{max}) due to distant earthquake from Sumatran subduction zone (SSZ) and Sumatran fault zone (SFZ).
- ii. To predict peak ground acceleration (PGA) using existing attenuation model.
- iii. To develop response spectra acceleration (RSA) and design response spectra for Ipoh according to Uniform Building Code (UBC 1997), National Earthquake Hazards Reduction Program (NEHRP 1997) and Eurocode 8 (EN 1998 – 1).

1.3 Scope of Works

In order to obtain the seismic hazard assessment, the following works are to be carried out:

- i. Developing earthquake catalogue for the study area of 90°E to 110°E longitude and 10°S to 10°N latitude from the years 1900 to 2005.
- ii. Performing seismic hazard assessment in order to determine maximum earthquake magnitude (m_{max}) that probably could occur in the future.
- iii. Determining peak ground acceleration (PGA) for Sumatra subduction zone and Sumatra fault zone by adopted the attenuation relationship from Lam *et al.* (2000c).
- iv. Developing response spectrum accelerations (RSA) based on local soil site condition by using Non-linear Earthquake site Response Analysis (NERA) program.

- v. Using real strong motion records as alternative approach to represent the mechanism of Sumatran transform zone.
- vi. Defining design response spectra from smoothed response spectrum obtained based on peak response spectra and period according to UBC 1997, NEHRP 2000 and EN 1998-1. These three standards are commonly adopted in a country with no design provision for earthquake.

1.4 Research Methodology

This study has been carried out in five phases and elaborated as follows:

a) Phase 1: Data collection

The seismic hazard methods are very dependent to data of seismicity and geology of earthquake sources. In this study, data related to selected site in Ipoh are collected. Data collection consists of two parts, which are Sumatran Hazard data and the geological and geotechnical data from site investigation report (S.I report). Earthquake events data from 1900 to 2005 were collected from various existing catalogue such as International Seismological Centre (ISC), United States Geological Surveys – National Earthquake Information Centre (NEIC-USGS) and Incorporated Research Institutions for Seismic (IRIS). The geological and geotechnical data from soil investigation report were collected from Malaysia Public Work Department and private sectors.

b) Phase 2: Prediction of Maximum Earthquake Magnitude (m_{max})

The Maximum Earthquake Magnitude (m_{max}) has been predicted by using Kijko–Sellevoll estimator. This particular estimator has proposed from deductive-historic approach.

c) Phase 3: Prediction of Peak Ground Acceleration (PGA)

The determination of peak ground acceleration (PGA) on the bedrock is based on Component Attenuation Model (CAM) method adopted from Lam *et al.* (2000c) by using geological conditions in Peninsular Malaysia. This particular attenuation function is reliable in handling long-distance attenuation and suitable for the regions in a low to moderate level of seismicity. The value of PGA will be used to perform response spectra acceleration.

d) Phase 4: Development of Response Spectra Acceleration (RSA)

Response spectra acceleration on the soil surface can be obtained by using Non-linear Earthquake site Response Analysis (NERA) program. The input parameters for this software were peak ground acceleration (PGA), dynamic soil properties, soil profile data and input motion. The ground motion time history of Mexico earthquake was adopted from Consortium of organizations for Strong – Motion Observation Systems (COSMOS) to represent the mechanism of Sumatra transform zone. This earthquake was selected based on the close value of PGA 0.0257 as derived in 4.3.3. The evaluations of site response characteristics will produce difference sets of response spectrum according to soil site condition.

e) Phase 5: Development of Design Response Spectra

The average of all response acceleration is calculated by employing mean plus one standard deviation in order to define the appropriate seismic force for each soil site condition. The smoothed response spectra acceleration or design response spectra were obtained according to three selected codes, namely

Uniform Building Code (UBC 1997), National Earthquake Hazards Reduction Program (NEHRP 2000) and Eurocode 8 (EN 1998 – 1).

1.5 Organization of Thesis

This thesis is presented in five chapters. Chapter 1 introduces the general background, the objectives and summary of the methodology of this study.

The recent studies from previous researchers which are related to the topic are described in Chapter 2. These include the basic principles of earthquake, geological condition and seismic hazard analysis in Malaysia. The Methodology that covers the theoretical background and also seismic hazard analysis procedure include the deterministic and probabilistic, CAM method for peak ground acceleration and wave propagation on the soil are all in Chapter 3. All the parameters and equations also presented in this chapter.

The results and discussions are presented in Chapter 4, while Chapter 5 highlighted the important findings and concluding remarks, followed by some recommendations for future study.

CHAPTER 2 LITERATURE REVIEW

2.0 Introduction

This chapter is divided into five main topics that are relevant to this research. Figure 2.1 shows the flow of literature review. The first topic provides a discussion on general basic earthquake principles including of tectonic plates, earthquake faulting, seismic waves and earthquake scales.

The second topic discusses the seismic sources that affect Peninsular Malaysia. It can be divided into two different classifications: Sumatran subduction zone (SSZ) and Sumatran fault zone (SFZ). The study on seismic hazard analysis in Malaysia is provided in the third topic. The findings from several researchers are reviewed in this section. Tectonic setting, earthquake felt and geological condition of Ipoh are also briefly discussed.

The fourth topic explains the methods to carry out seismic hazard analysis. It covers both; deterministic and probabilistic methods seismic hazard analysis. The final topic discusses the ground motion attenuation, which consists of peak ground acceleration, response spectra acceleration and design response spectra. This is a very important part of this study.

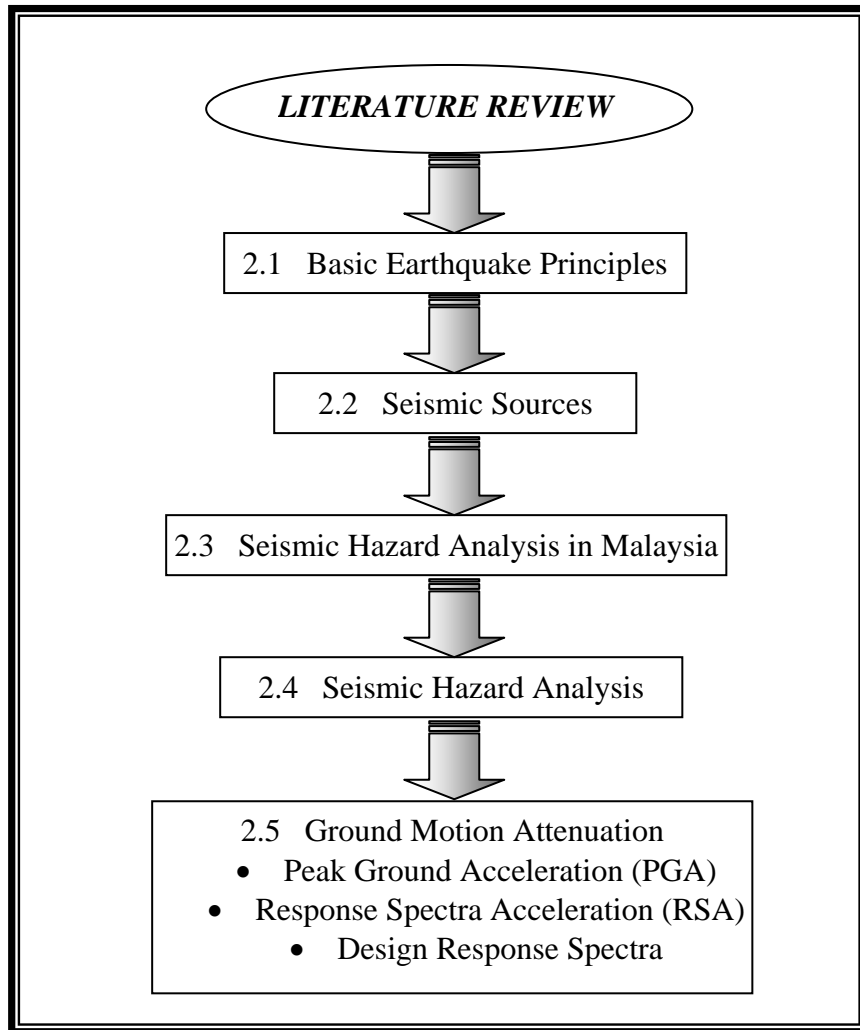


Figure 2.1: Flow of literature review

2.1 Basic Earthquake Principles

Most of earthquakes are produced by sudden movements in the earth's crust that caused a rupture or slip at the intersection of two tectonic plates (Kramer, 1996). The sudden release of energy at the focus or hypocenter of the earthquake causes seismic waves. Then, the seismic waves that formed into different types propagate through the earth's crust and produces vibrations on the earth's surface (Williams, 2003).

The earthquakes epicenter is classified according to the depth of the focus. The closer a site to the source of the earthquake (the focus or hypocenter), the more structural damages. Earthquake generally can be classified into three types according to the depth of the focus (Table 2.1).

Table 2.1: Earthquake classified according to depth of the focus

(<http://mediatheek.thinkquest.nl/~11125/en/earthqke.htm>)

Depth	Earthquake Type
0-43 miles (0-70 km)	shallow earthquakes
43-186 miles (70-300 km)	intermediate earthquakes
deeper than 186 miles (300 km)	deep earthquakes

In general, earthquake begins with light vibrations called foreshocks. These are the initial fractures in the rocks. The one with the largest magnitude is called the main shock and there may be minor aftershocks after the main shock occurs. Earthquakes can be considered as aftershocks if it is located within a characteristic distance from the main shock. The distance is usually about one or two times the length of the fault rupture associated with the main shock (Reasenber and John, 2005). For the seismic hazard analysis only the mainshocks are considered, while foreshocks and aftershocks will be eliminated. Gardener and Knopoff (1974) and Reasenber and John (2005) have introduced methods to eliminate foreshocks and aftershocks.

2.1.1 Tectonic Plates

The earth surface consists of a number large intact block called plates which moves with respect to each other (Kramer, 1996). Some plates slide past each other and can cause a heavy pressure on the rocks, so they finally crack. According to the plate

tectonic theory, the earth can be divided into three main layers: the crust, the mantle and the core (Robert, 2002). Figure 2.2 shows the interior structure of the earth.

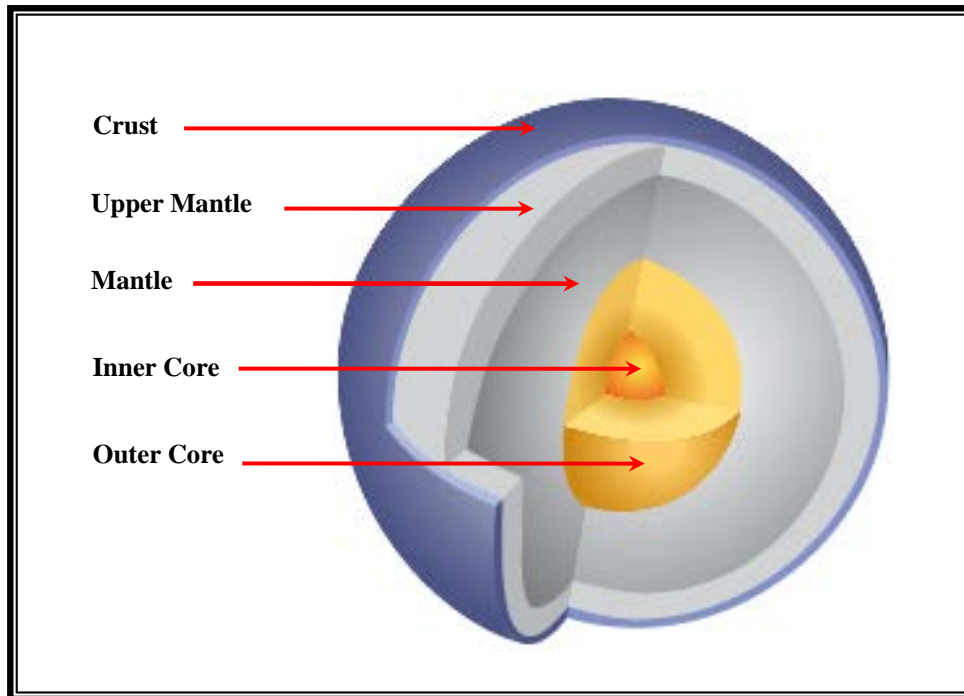


Figure 2.2: Earth's structure

The core is the inner part of the earth and can be divided into inner core and outer core. Similarly, the mantle can be divided into the upper and the lower mantle. The crust is composed of a number of plates, called continental plates, which float on the mantle and moving relatively to each other. The earth's crust is divided into seven major plate tectonics namely; Pacific, Eurasian, North American, South America, Australian, Africa, and Antarctic. Figure 2.3 shows the locations of the major tectonic plates. The study of tectonic plates will give an explanation about the continental drift, the spreading of the sea floor, volcanic eruptions and mountains formation.

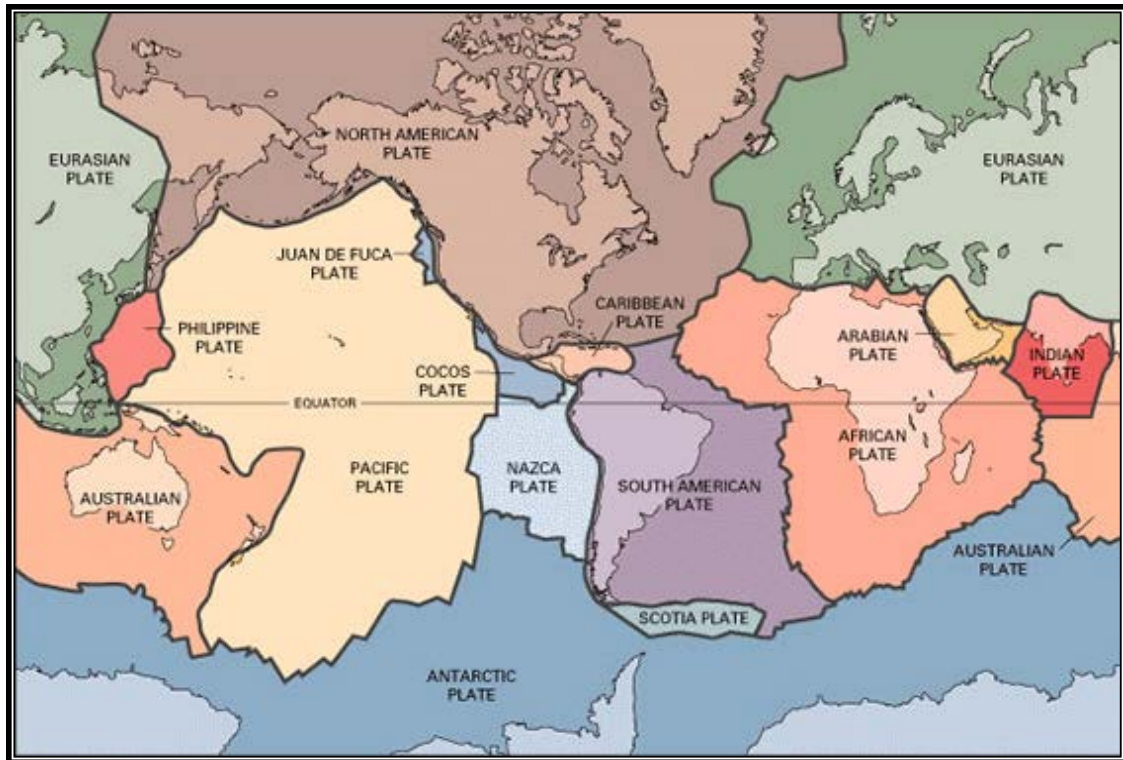


Figure 2.3: Major tectonic plates (Kious & Tilling, 2001)

Most of the earthquakes occur close to the boundaries between plates. Depending on the direction of the plate's movement, there are three types of plate boundaries, namely: divergent boundary, convergent boundary and transform boundary (Robert, 2002; Dowrick, 2003). Divergent boundary occurs when the relative movement of two plates is away from each other. This type of earthquake tends to be relatively small and occurs at shallow depth. When divergent boundary occurs in one area, a convergent boundary must occur in another area. The relative movement of the two plates toward each other will form a convergent boundary. There are three types of convergent boundaries: oceanic-continental subduction zone, oceanic-oceanic subduction zone and continent-continent collision zone (Robert, 2002). The transform boundary or transform fault involves the plate sliding past each other, without the construction or destruction of the earth's crust. When the two plates move parallel to

each other, strike slip fault zones can develop at the plate boundaries. Table 2.2 gives the summary of plate tectonic theory.

The theory of plate tectonics helps to explain the location and nature of earthquakes. Those faults that generated earthquakes in the past have the possibility to produce earthquakes in the future.

Table 2.2: Summary of plate tectonic theory (Robert, 2002)

Plate boundary type	Type of plate movement	Categories	Types of earthquakes
Divergent boundary	Relative movement of two plates is away from each other.	Seafloor spreading ridge	Earthquakes on spreading ridge are limited to the ridge crest, where new crust is being formed. Small earthquake and occur at shallow depths.
		Continental rift valley	Earthquakes generated along normal faults in the rift valley
Convergent boundary	Relative movement of the two plates is toward each other.	Oceanic-continental subduction zone	Shallow interplate thrust events caused by failure of the interface between the down-going plate and the overriding plate.
		Oceanic-oceanic subduction zone	Shallow earthquakes caused by deformation within the upper plate. Earthquake at depths from 25 to 430 mi (40 to 700 km) within the down-going plate. Earthquake that are seaward of the trench, caused mainly by the flexing of the down-going plate, but also by compression of the plate.
		Continent-continent collision zone	Earthquake generated at the collision zone, such as at reverse faults and thrust faults.

Continue

Plate boundary type	Type of plate movement	Categories	Types of earthquakes
Transform boundary	Plate slide past each other, without the construction or destruction of the earth's crust	Strike-slip fault zone	Earthquake often generated on strike-slip faults.

2.1.2 Earthquake Faulting

The earthquake faulting known as the movement which produces relative displacement of adjacent rock masses along a fracture. The characteristic of strong motions are strongly influenced by the type of faulting. There are three main types of faulting which should be considered in the study of destructive earthquakes as illustrated in the Figure 2.4 (Kramer, 1996).

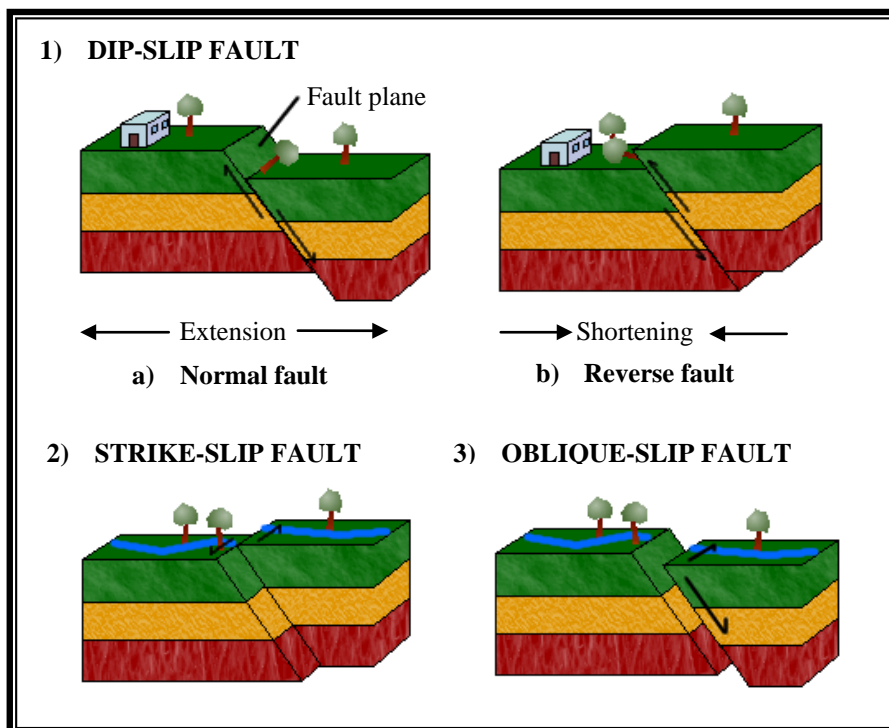


Figure 2.4: Earthquake Faulting

(<http://www.iris.edu/gifs/animations/faults.htm>, 2007)

1) Dip-Slip Fault

Dip-Slip Fault can be divided into two categories; normal fault and reverse fault. The normal fault is under tension where the overlying blocks moves down the dip or slope of the fault plane. In a normal fault, the block above the fault moves down relative to the block below the fault (Kramer, 1996). This fault motion is caused by tensional forces and results in extension.

The reverse fault is under compression where the overlying block moves up the dip or slope of the fault plane. In a reverse fault, the block above the fault moves up relative to the block below the fault. This fault motion is caused by compressional forces and results in shortening. A reverse fault is called a thrust fault if the dip of the fault plane is small.

2) Strike-Slip Fault

Strike slip faults are caused by relative horizontal displacement of the two sides of faults along vertical of the fault plane (Kramer, 1996). In a strike-slip fault, the movement of blocks along a fault is horizontal. If the block on the far side of the fault moves to the left, the fault is called left-lateral. If the block on the far side moves to the right, the fault is called right-lateral. The fault motion of a strike-slip fault is caused by shearing forces.

3) Oblique-Slip Fault

Oblique-slip faulting consists of both dip-slip faulting and strike-slip faulting (Robert, 2002). It is caused by a combination of shearing and tension of compressional forces.

2.1.3 Seismic Waves

Earthquakes are generated by mechanism of the rock's rupture. Rock is elastic and will accumulate strain. When the stress exceeds the strength of rock, the rock breaks along the fracture plane called a fault and the point in the earth where the rocks first break is called focus, also known as epicenter of the quake (Rose, 1983). The breaking of rock releases energy that travels through the earth in the form of vibrations called seismic waves. Different kind of seismic wave are produced depending on the deformation of rock materials. There are two main types of seismic wave namely body waves and surface waves (Kramer, 1996; Robert, 2002). Body waves which travel from the hypocenter directly through the earth's lithosphere and surface waves which travel from the epicenter along the surface of the earth.

Body waves consist of the primary, or P wave, which is compression wave and the secondary, or S wave, which is a transverse shear wave. Compressional waves are the fastest seismic waves. For this reason, compressional wave also called primary (P) waves. P-waves can travel through solids, liquids or gases. At a depth of less than 25km, compression waves travel at a about 6.8km per second (Rose, 1983). Shear wave that travels slower than P wave and called Secondary (S) waves and can only travel through solids. Figure 2.5 shows the different types of seismic waves.

Surface wave consist of the Love wave which produces a sideways motion and the Rayleigh wave which produces a rotary wave-like motion (Robert, 2002). Body waves have a higher frequency range and attenuate more rapidly than surface waves. Hence, structures with longer natural periods, such as high-rise buildings and bridges,

are more at risk some distance from the epicenter than low-rise buildings which have a short natural period (Williams, 2003).

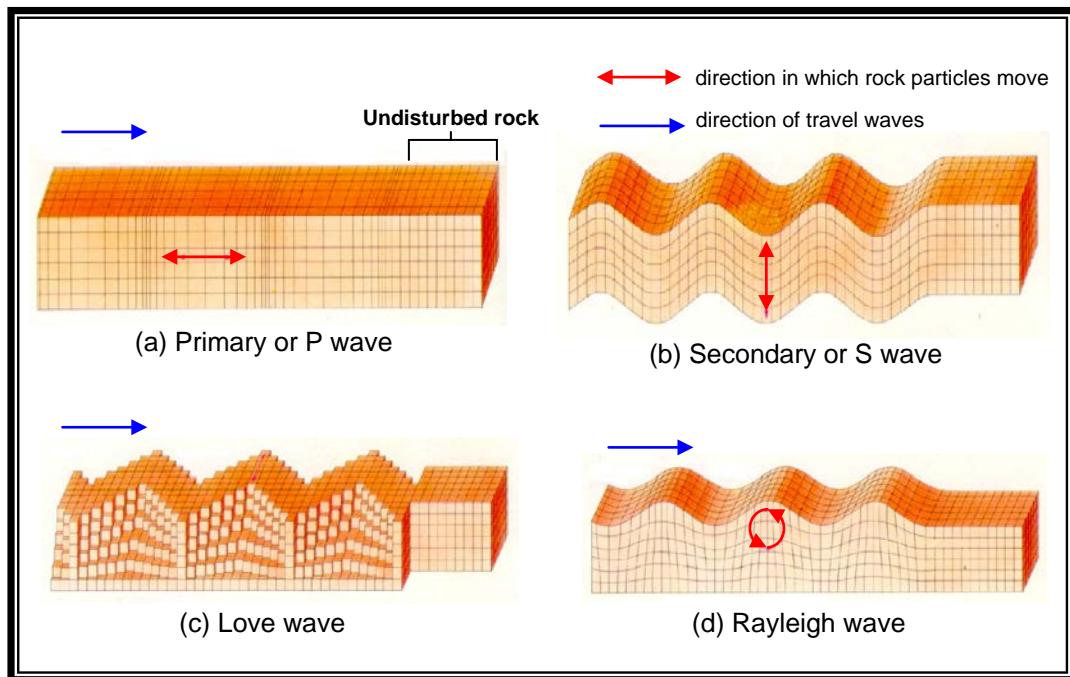


Figure 2.5: Main type of earthquake waves: (a) P-wave, (b) S-wave, (c) Love wave and (d) Rayleigh wave (Rose, 1983)

2.1.4 Earthquake Scales

A seismic scale is used to measure and compare the relative severity of an earthquake. It was difficult to find an adequate way of measuring the size of earthquakes, but two concepts commonly used are intensity and magnitude. Magnitude and intensity are both measures of an earthquake, but they describe different characteristics (Rose, 1983). The original force or energy released at the source of the earthquake is measured on a magnitude scale, while the intensity measures the strength of shaking produced by the earthquake at a certain location.

Magnitude is determined from measurements on seismographs and the intensity is determined from effects on people, human structures, and the natural environment. Theoretically, calculations of magnitude from various seismic stations should be described by only one magnitude for the same earthquake (Rose, 1983) but in much intensity since the earthquake effects are vary and depended on distance from the epicenter and local site conditions. Each measurement has its own uses and commonly used by seismologists to describe earthquakes.

2.1.4.1 Earthquake Intensity

Intensity is a measure of the effect that the vibration had on natural and human made structures. The intensity differs from the magnitude which is related to the energy released by an earthquake. It is based on qualitative measurement description of the effect of the earthquake at a particular location by an observation of damages and human reactions (Kramer, 1996). To determined intensities, information is gathered from replies to questionnaires, and report of damage. Because of the subjective nature of the Mercalli scale, different values of intensity may assigned by different observers. The most common measurement of intensity is the Mercalli scale. The Mercalli scale originated from the simple ten-degree Rossi-Forel scale, which was revised in 1880's (Kramer, 1996). The ten-degree Mercalli scale was expanded to twelve degrees and known as the Modified Mercalli Intensity (MMI). This scale has been widely used by the seismologist as well as Malaysian Meteorologist Services.

Modified Mercalli Intensity scale has twelve degrees of intensity, expressed in Roman numerals that range from I to a value of XII. Index value VII is classified as strong shaking causing damage to older masonry structures, chimneys and furniture.

Index value VIII is classified as very strong shaking causing collapse of unreinforced masonry structures, towers and monuments. The seismic damage caused at a particular site is influenced by the magnitude, duration and frequency of the ground vibration, distance from epicenter, geological conditions between the epicenter and the site, soil properties at the site, and the building type and characteristic. The commonly used Modified Mercalli Intensity Scale, number I to XII, is shown in the Table 2.3.

Table 2.3: The Modified Mercalli Intensity (FEMA, 2007)

The Modified Mercalli Intensity			
MMI Value	Severity	Full Description	Magnitude Scale
I – IV	Instrumental to Moderate	No Damage	≤ 4.3
V	Rather Strong	Damage negligible. Small, unstable objects displaced or upset; some dishes and glass are broken.	4.4 – 4.8
VI	Strong	Damage slight. Windows, dishes, glassware broken. Furniture moved or overturned. Weak plaster and masonry cracked.	4.9 – 5.4
VII	Very Strong	Damage slight to moderate in well-built structures; considerable in poorly built structures. Furniture and weak chimneys broken. Masonry damaged. Loose bricks, tiles, plaster, and stones will fall.	5.5 – 6.1
VIII	Destructive	Structural damage considerable, particularly to poorly built structures. Chimneys, monuments, towers, elevated tanks may fail. Frame houses moved. Trees damaged. Cracks in wet ground and steep slopes.	6.2 – 6.5

Continue

MMI Value	Severity	Full Description	Magnitude Scale
IX	Ruinous	Structural damage severe; some will collapse. General damaged to foundations. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.	6.6 – 6.9
X	Disastrous	Most masonry and frame structure foundations destroyed. Some Well-built wooden structures and bridges destroyed. Serous damage to dams, dikes, embankments. Sand and mud shifting on beaches and flat land.	7.0 – 7.3
XI	Very Disastrous	Few or no masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of services. Rails bent. Widespread earth slumps and landslides.	7.4 – 8.1
XII	Catastrophic	Damage nearly total. Large rock masses displaced. Lines of slight and level distorted.	> 8.1

2.1.4.2 Earthquake Magnitude

Earthquake magnitude is a measurement of an amplitude of the earthquake waves, which is related to the amount of the energy that earthquake releases. Magnitude is calculated from the size of the earthquake waves arriving at a seismic station. Magnitude is a concept initially developed by C.F. Richter for comparing sizes of Californian earthquakes (Rose, 1983). To cover the huge size range of earthquakes, the magnitude scale is logarithmic, each unit representing a ten fold increase in amplitude

of the measured waves, and nearly a 30-fold increase in energy. There are several types of magnitudes scales used, but the most commonly used are:

- **Richter Local Magnitude (M_L)**

The traditional way to measure the magnitude is by using the Richter scale. The Richter magnitude is a logarithmic measurement (one unit increase corresponds to a 10 times increase in ground motion) based on the amplitude of ground motion as it registered on seismographs, and the distance to the earthquake. Charles Richter introduced the Richter scale in California in 1935, which is based on local magnitude as the logarithm of the maximum trace amplitude recorded on a Wood-Anderson seismometer located on 100km from the epicenter of the earthquake (Kramer, 1996). Richter's local magnitude is a well known magnitude scale but not always an appropriate scale for measurement an earthquake size. Besides, it is also does not distinguish between types of waves.

- **Surface Wave Magnitude (M_S)**

The surface wave magnitude scale is based on the amplitude of Rayleigh waves with a period of about 20s (Kramer, 1996; Robert, 2002). This magnitude scale typically used to measure for moderate to large earthquake, having shallow focal depth less than 70km and further distance about 1000km from the epicenter. At deep focus earthquakes, surface waves are often too small, to permit reliable evaluation in surface wave magnitude scale (Kramer, 1996).

- **Body Wave Magnitude (m_b)**

The body wave magnitude is based on the amplitude of the first few cycles of p-waves. Commonly, m_b not strongly influenced by the focal depth (Kramer, 1996)

- **Moment Magnitude (M_w)**

The new magnitude scale called moment magnitude (M_w) has been proposed due to the limitation of other scales to specify the size of any earthquake within the whole range of sizes (Kramer, 1996). The moment magnitude scales has become the more commonly used method for determining the magnitude of large earthquake.

2.2 Seismic Sources

Earthquake sources area that affected Peninsular Malaysia can be divided into two difference classifications, Sumatran fault zone of transform zone (SFZ) and Sumatran subduction zone (SSZ) (Kramer, 1996). Figure 2.6 shows the active tectonic and seismic sources of Sumatran subduction and fault zones.

Earthquakes that occur near the convergent boundaries where an oceanic plate is being subducted under an island arc are classified into subduction zones. Those earthquakes that felt along the mountain line, call Barisan of a segment fault are classified into fault zone (Kramer, 1996; Sun and Pan, 1995).

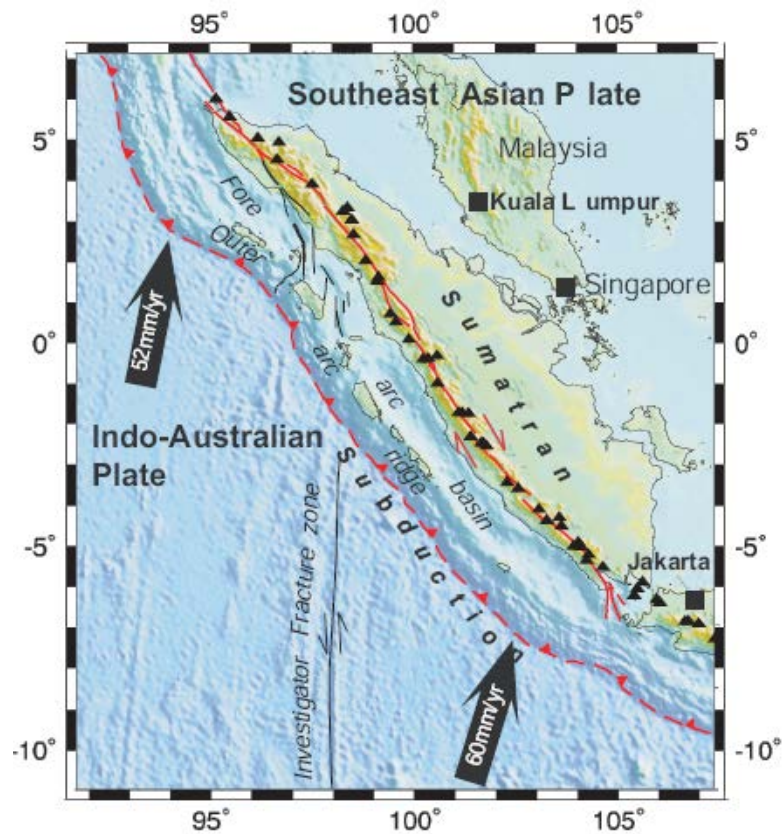


Figure 2.6: Active tectonic and seismic sources of Sumatran subduction and fault zone.

(Sieh and Natawidjaja, 2000)

2.2.1 Sumatran Subduction Zone (SSZ)

Subduction occurs when the oceanic crust is subducted beneath the continental platform of Sumatra and western Java (Newcomb and McCann, 1987). The India-Australia plate subducts below the Eurasia plate along Sunda arc at a convergent rate ranging from 52 to 60 mm/yr (Sieh and Natawidjaja, 2001). The Sunda arc, extending over 5,600 km from the Andaman islands in the northwest to the Banda arc in the east (Megawati *et al.*, 2005). The displacement between the two plates is partly accommodated by sudden movements, which caused earthquakes.

Historically, it shows that Subduction zone has a capability to generate very large earthquakes until more than $M_w = 9.0$. The largest earthquake reported occurs in 1833 with estimated moment magnitude between M_w 8.8 to M_w 9.2 (Megawati et al., 2003). In 1861, another earthquake ruptured the long arc segment between Banyak and Pini Islands with an estimated moment magnitude between 8.3 and 8.5.

The latest great earthquake tremor occurred on the 26 December 2004. The Sumatran-Andaman earthquake was the largest seismic event with moment magnitude, $M_w = 9.3$. This earthquake caused tsunami, which also hit the west coast of Kedah, Penang and North Perak. Another earthquake hits the Sumatran subduction zone was on 28 March 2005 registered a magnitude of 8.6 (USGS, 2005).

2.2.2 Sumatran Fault Zone (SFZ)

Sumatran Fault zone with the 1900 km long runs through the western side of Sumatra Island, coinciding with the Bukit Barisan mountain chain (Pan and Megawati, 2002; Sieh and Natawidjaja, 2001). Sun and Pan (2005) reported that the Sumatran fault is more than 1500 km and about 350 km away from Singapore and Kuala Lumpur.

This fault system, consisting of about 20 separate segments (Tjia, 1978). The lengths of the segments range are from 35 to 220 km (Megawati *et al.*, 2003). The Fault segments geometrically vary from west to coast and from west to east as the sediment thickness on the subducted plate decrease (Newcomb and McCann, 1987). The slip rate inferred for the Sumatran fault about 36 mm/year (Newcomb and McCann, 1987). Figure 2.7 shows the Sumatran fault system and also the Sumatran subduction zone.