SEISMIC MACROZONATION OF PENINSULAR MALAYSIA AND MICROZONATION OF KUALA LUMPUR CITY CENTER AND PUTRAJAYA

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

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MARCH 2007

"Thou seest the mountains and thinkest them firmly fixed: but they pass like the passing of the clouds: (such is) the artistry of God, who disposes of all things in perfect order: for He is well acquainted with all that ye do."
(The Noble Quran, An Naml:88)

Specially dedicated to:

To my beloved Mother, Father (alm), my Wife, Brothers, and Sister

ACKNOWLEDGEMENTS

Praise to Allah Almighty, the Most Gracious and Most Merciful, Who has created mankind with wisdom and give them knowledge. May peace and blessings to Rasulullah Muhammad Shollallahu’ Alaihi Wassalam, all the prophets, his families, his close friends and all Muslims.

Firstly, I wish to express my deep sincere appreciation to my main thesis supervisor and advisor, **Assoc. Prof. Dr. Azlan Adnan**, for his gratitude, encouragement, friendly advice, earnest guidance, and motivation. He charmed me in both his energy and the eagerness to do the best work. I am also very thankful to my co-supervisors **Assoc. Prof. Dr. Aminaton Marto** and **Assoc. Prof. Dr. Masyhur Irsyam** for their advices, concern and impetus. Without continuous support and curiosity from my main supervisor and my co-supervisor, this thesis would not have been the same as presented here.

I am also indebted to UTM and Construction Industry Development Board (CIDB) Malaysia for funding my Ph.D. study under VOT number 73303. This support is gratefully acknowledged.

Secondly, I would like to thank the Dean, Head of Department, all lecturers and staff in the Faculty of Civil Engineering UTM for their support and providing me the facilities for my research. Special gratitude is addressed to Structural Earthquake Engineering Research Center (SEER) members i.e. En. Rosaidi, Jati Sunaryati, Suriana, Suhana, Sofia, Ilhami, Meldi and Rozaina. My sincere appreciation also extends to all my colleagues and others who have provided supports at various occasions especially Mr. Anis Saggaf and Mr. Deni Suwardhi.

I also would like to express my gratitude to Mark D. Petersen, David M. Boore, and Arthur Frankel from USGS for their helpful discussion and some data, Dr. Andrej Kijko and Prof. Bardet for their valuable software and papers, Prof. Cornel, Prof. Campbell, and Robin K McGuire for their valuable papers and monograph, respectively, Randall W. Jibson and Matthew W. Jibson for the time histories data and software, IKRAM especially Dr. Ch’ng Guan Bee and Tn. Hj Rahmat for their soil data, Dr. Saim Suratman (JMG) for his helpful discussion, and Malaysian Meteorological Department (MMD) for the earthquake data.

Last but not least, I want to express grateful thanks to my family; my mother, Allah Yarham my father, my mother and father-in-law, my wife: Fitri Hayati, my brothers and sister: Reza, Ferda, Yovita, and Bobby (brother-in-law), for their unlimited espousal on my study. Without their consistent supports and encouragement, it is impossible for me to finish my work.

ABSTRACT

This thesis presents seismic hazard assessment (SHA) which covers macrozonation analysis for Peninsular Malaysia and microzonation analysis focused on Kuala Lumpur City Centre (KLCC) and Putrajaya. The SHA is needed for mitigation of the effects of large earthquakes that may occur in the future. KLCC and Putrajaya are the two major areas selected because these are the main business centres and administration centres of Malaysia, respectively; hence they have significant numbers of settlements, high rise buildings, monumental structures and other critical facilities. Therefore, the risks of these areas are relatively higher than other cities in Peninsular Malaysia. Generally, there are four steps involved in conducting the macrozonation study: (1) collecting and analyzing earthquake data; (2) developing and characterizing seismic source models; (3) developing and selecting appropriate attenuation relationships; and (4) calculating seismic hazard using total probability theory. The results from this study are macrozonation maps for Peninsular Malaysia, uniform hazard spectra at bedrock and synthetic time histories for KLCC and Putrajaya. The probabilistic seismic hazard assessment (PSHA) is performed for 10% and 2% probability of exceedance (PE) in design time period of 50 years or the corresponding to return period of approximately 500 and 2,500 years, respectively. The results show that the peak ground acceleration (PGA) across Peninsular Malaysia are in the range of 20-100 gals and 40-200 gals for 10% and 2% PE in 50-year hazard levels, respectively. The hazard levels show that the trend of contour increasing consistently from the northeast to the southwest of Peninsular Malaysia. Microzonation study is performed in order to obtain ground motion parameters such as acceleration, amplification factor and response spectra at the surface of KLCC and Putrajaya. The analyses are carried out by using nonlinear one dimensional shear wave propagation analysis approach. The results of site response analysis at several points were used to develop contour of acceleration and amplification factors at the surface of KLCC and Putrajaya for 500 and 2,500-years return periods. The results show that the accelerations at the surface of KLCC are in the range of 80-220 gals and 170-340 gals for 500 and 2,500 years return periods, respectively. The amplification factors for those two hazard levels range between 1.2 and 2.9. The accelerations at the surface of Putrajaya are in the range of 130-190 gals and 220-340 gals for 500 and 2,500 years return periods, respectively. The amplification factors for those two hazard levels range between 1.6 and 2.6. Finally, the design response spectra for structural design purposes are proposed based on this research.

ABSTRAK

Tesis ini berkenaan pengiraan risiko sismik (SHA) yang meliputi analisis *macrozonation* untuk Semenanjung Malaysia dan analisis *microzonation* yang difokuskan untuk pusat bandar Kuala Lumpur (KLCC) dan Putrajaya. SHA diperlukan untuk mengurangkan risiko gempa bumi besar yang mungkin terjadi di masa akan datang. Dua kawasan utama KLCC dan Putrajaya dipilih kerana kedua kawasan ini masing-masing merupakan pusat perniagaan dan pentadbiran di Malaysia yang memiliki kawasan perumahan, bangunan-bangunan tinggi dan kemudahan awam dengan jumlah yang besar. Oleh kerana itu risiko sismik di kedua-dua kawasan tersebut melebihi kawasan-kawasan lain di Semenanjung Malaysia. Secara umum, kajian *macrozonation* terdiri dari empat langkah: (1) pengumpulan dan analisis data gempa bumi; (2) penghasilan dan pengiraan parameter-parameter model sismik ; (3) penghasilan dan pemilihan fungsi *attenuation* yang sesuai; dan (4) Pengiraan risiko sismik dengan menggunakan teori jumlah probabiliti. Hasil dari kajian ini adalah peta *macrozonation* untuk semenanjung Malaysia, *uniform hazard spectra* pada batuan dasar dan *time histories* untuk KLCC dan Putrajaya. Analisis dengan kaedah probabilistik dilakukan untuk 10% dan 2% kebarangkalian terlampaui untuk waktu reka bentuk 50 tahun atau bersesuaian masing-masing dengan tempoh ulang 500 dan 2,500 tahun. Hasil analisis menunjukkan nilai pecutan puncak di batuan dasar untuk Semenanjung Malaysia adalah antara 20-100 gals dan 40-200 gal untuk masing-masing 10% dan 2% kebarangkalian terlampaui untuk waktu reka bentuk 50 tahun. Aras risiko menunjukkan pola kontur yang meningkat dari bahagian timur laut ke arah barat daya Semenanjung Malaysia. Kajian *microzonation* dilakukan untuk mendapatkan parameter-parameter gerakan tanah seperti pecutan, faktor penguatan dan tindak balas spektra di permukaan KLCC dan Putrajaya. Analisis dilaksanakan dengan menggunakan analisis perambatan gelombang satu dimensi dengan pendekatan tak linear. Hasil dari analisis tindak balas tanah di beberapa lokasi digunakan untuk menghasilkan kontur pecutan dan faktor penguatan di permukaan KLCC dan Putrajaya untuk tempoh ulang 500 dan 2,500 tahun. Hasil analisis menunjukkan pecutan di permukaan KLCC adalah antara 80-220 gals dan 170-340 gals untuk masing-masing tempoh ulang 500 dan 2,500 tahun. Faktor penguatan untuk aras risiko tersebut adalah antara 1.2-2.9. Pecutan di permukaan Putrajaya adalah antara 130-190 gals dan 220-340 gals untuk masing-masing tempoh ulang 500 dan 2,500 tahun. Faktor penguatan untuk aras risiko tersebut adalah antara 1.6 dan 2.6. Akhirnya, berdasarkan kajian ini, bentuk tindak balas spektra dihasilkan untuk tujuan reka bentuk struktur bangunan.

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LIST OF SYMBOLS/ABBREVIATIONS

C_a - Seismic coefficient for short period
C_v - Seismic coefficient for long period
DSHA - Deterministic Seismic Hazard Assessment
F_a - Spectral amplification factor for short period (0.2 second)
F_v - Spectral amplification factor for long period (1.0 second)
G - Shear modulus
G_{max} - Maximum shear modulus
g - Gravity = 9.81 m/s^2
gal - cm/sec^2
M_L - Richter local magnitude
M_o - Seismic moment
M_S - Surface wave magnitude
M_W - Moment magnitude
MCE - Maximum credible earthquake
m_b - Body wave magnitude
m_{max} - Minimum magnitude
m_{min} - Maximum magnitude
PE - Probability of exceedance
$\overline{N}_{ch}$ - The average standard penetration resistance for cohesionless soil layers
PGA - Peak Ground Acceleration (at Bedrock)
PSA - Peak Surface Acceleration
PSHA - Probabilistic Seismic Hazard Assessment
R_a - Mean annual total frequency of exceedance
R_n - Probability of exceedance during N year
r - Coefficient of Correlation

r^2 - Multiple coefficient of determination
r_a^2 - Adjusted multiple coefficient of determination
Sa - Spectral acceleration
Sd - Spectral displacement
SFZ - Sumatra Fault Zone
SHA - Seismic Hazard Assessment
SSZ - Sumatra Subduction Zone
s_u - Undrained shear strength
Sv - Spectral Velocity
T_n - Natural period
T_R - Return Period
V_S - Shear wave velocity
V_{S-30} - The mean shear wave velocity of the top 30 m
Z - Seismic zone factor
β_s - Damping factor
σ - Standard deviation
λ - Rate of earthquake occurrence
ρ - Mass density
ω - Angular frequency = $2\pi f$

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CHAPTER 1

INTRODUCTION

1.1 General

Earthquake is one of the most devastating natural disasters on the earth. Generally, the effects of strong earthquakes are caused by ground shaking, surface faulting, liquefaction, and less commonly, by tsunamis. Ground shaking is a term used to describe the vibration of the ground during an earthquake caused by body and surface seismic waves. Surface faulting is caused by differential movement of the two sides of a fracture at the Earth's surface. Liquefaction is a physical process that takes place during some earthquakes that may lead to ground failure. In this phenomenon, the strength of the soil decreases, often drastically, to the point where it is unable to support structures or remain stable. At this stage, the soil deposits will appear to flow as fluids. Tsunamis are water waves that are caused by sudden vertical movement of a large area of the sea floor during an undersea earthquake. As tsunamis reach shallow water around islands or on a continental shelf; the height of the waves could increase many times.

Although it is impossible to prevent earthquakes from happening, it is possible to mitigate the effects of strong earthquake shaking and to reduce loss of life, injuries and damages. The most effective way to reduce disasters caused by earthquakes is to estimate the seismic hazard and to disseminate this information for used in improved building design and construction so that the structures posses adequate earthquake resistant capacity (Hu, 1996).

Earthquake engineering can be defined as the branch of engineering devoted to mitigating earthquake hazards. Earthquake engineering deals with the effects of earthquakes on people and their environment and with methods of reducing those effects. In this broad sense, earthquake engineering covers the investigation and solution of the problems created by damaging earthquakes, and consequently the works involved in the practical application of these solutions, i.e. in planning, designing, constructing and managing earthquake-resistant structures and facilities.

It has become customary in earthquake engineering and related areas to distinguish between seismic hazard and seismic risk, although the semantics of both words is the same. Seismic hazard is used to describe severity of ground motion at a site regardless of the consequences, while the definition of seismic risk is based also on the consequences (Todorovska *et al.*, 1995; Gupta, 2002). High hazard does not automatically imply high risk and vice versa. The hazard may be high at a site close to an active fault, whereas the risk may not be high if there is no settlement and industrial facility. Along the same line, the seismic risk is large at the site of critical facilities, such as a dam or a nuclear power plant, even if the location is not so close to active faults and there is not much evidence of historic earthquake activities.

Both seismic hazards and seismic risks analyses are required to develop the elements that can be used to make rational decisions on seismic safety (McGuire, 2004). McGuire (2004) shows the connection between seismic hazard and seismic risk (Figure 1.1). He divided the methodology for evaluating the effects of future earthquakes (and the uncertainty about those effects) on people and structures into four steps. First is probabilistic seismic hazard analysis (PSHA), which gives a probabilistic description (a frequency of exceedance) of earthquake characteristics such as ground motion amplitudes and fault displacements. Second is the estimation of earthquake damage to the artificial and perhaps the natural structures. Third is the translation of seismic hazards into seismic risks (frequency of damage or loss). Fourth is the formal analysis or the informal analysis of earthquake mitigation decisions. The decision process should incorporate uncertainties in the earthquake process and ground motion characteristic, uncertainties in the effects of the earthquakes on people and structures, costs of seismic safety and potential losses, and aversion to risk.

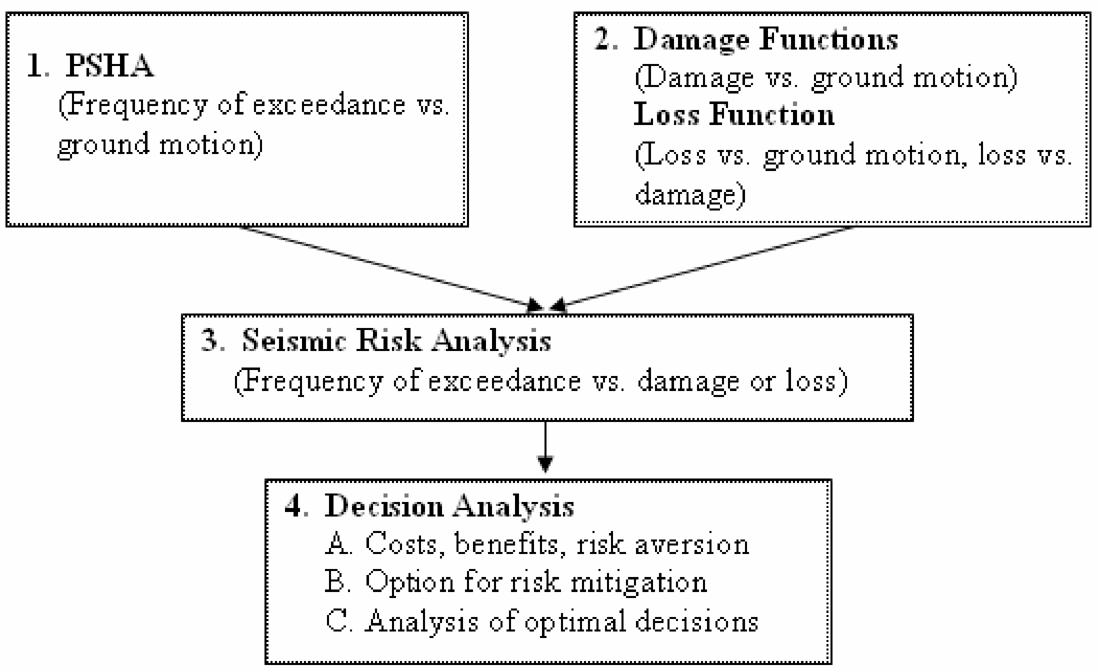

Figure 1.1: Steps in the mitigation of earthquake risk (McGuire, 2004).

According to Figure 1.1, the seismic hazard assessment using probabilistic method is the first step that should be done by engineers or researchers in the mitigation of earthquake risks. Clear and well documented assessments of seismic hazard are the first and fundamental step in the mitigation process (Abrahamson and Shedlock, 1997). This step is critical because it involves so many factors and uncertainties to be considered. It should be noted that the method of seismic hazard assessment, which was applied in a certain region, may not be necessarily employed in other regions since an individual region has its own characteristics. Therefore, it would be necessary to perform seismic hazard analysis for each region and to develop seismic design code suitable with the characteristics on that particular region rather than just adopt the existing code from other regions.

Generally, seismic code used to design dynamic load for civil structures such as buildings, retaining walls, dams, bridges and other structures are based on compilation of earthquake engineering multidisciplinary field, i.e. seismology, geology, geotechnical and structural engineering. The design parameter is typically acceleration, velocity or spectral acceleration with a specified probability of exceedance. These parameters are mapped on a national or a regional scale for a standard ground condition, usually rock or stiff soil. Mapping to such a scale is called macrozonation (Finn *et al.,* 2004).

Geotechnical factors often exert a major influence on damage patterns and loss of life in earthquake events. For example, the localized patterns of heavy damage during the 1985 Mexico City and 1989 Loma Prieta earthquakes provide illustrations of the importance of understanding the seismic response of deep clay deposits and saturated sand deposits (Bray *et al.*, 1994).

The pronounced influence of local soil condition on the characteristics of the observed earthquake ground motions also can be seen during 1957 San Francisco Earthquake (Seed *et al*., 1991). Even within an area of a city, building response and damage are varied significantly due to variation of soil profiles in that particular city (Seed *et al.*, 1991). In other countries, several attempts have been made to identify their effects on earthquake hazards related to geotechnical factors in the form of maps or inventories. Mapping of seismic hazard at local scales to incorporate the effects of local geotechnical factors is called microzonation (Finn *et al.,* 2004).

Microzonation for seismic hazard has many uses as mentioned by Finn *et al.* (2004). It can provide input for seismic design, land use management, and estimation of the potential for liquefaction and landslides. It also provides the basis for estimating and mapping the potential damage to buildings.

1.2 Background

Although Malaysia is located in the stable Sunda Shelf with low to moderate seismic activity level, it is surrounded by Indonesia and Philippine, which are close to active seismic faults. The fact that Malaysia has not experienced any major earthquake disasters should not be used as an argument to dismiss the need for taking any pro-active steps to look into the earthquake threat.

In recent years, Malaysia is more aware to the seismic effect on their buildings because the tremors were repeatedly felt over the centuries from the earthquake events around Malaysia (SEASEE, 1985). Peninsular Malaysia has felt tremors several times from some of the large earthquakes originating from the intersection areas of Eurasian plate and Indo-Australian plate near Sumatra, and some of the moderate to large earthquakes originating from the Great Sumatran fault. For instance, the earthquakes occurred on 2 November 2002 has caused cracks on some buildings in Penang, although the location of the epicentre is more than 500 km away from Penang. The moment magnitude and the depth of this earthquake are 7.4 and 33 km below the surface, respectively. Another earthquake having magnitude, M_W7.3 occurred on 25 July 2004 in South Sumatra. Although the location of the epicentre and the depth of the earthquake are more than 400 km from Johor Bahru and 576 km below surface, respectively; the earthquake has caused cracks on one apartment building in Gelang Patah, Johor Bahru. There were no casualties or major damages reported due to those earthquakes, however, the tremors have caused panic to the people around that particular area.

East Malaysia has experienced small to moderate earthquakes from local origin and tremors originating from the southern part of the intersection area of Eurasian and Philippines plates as listed by Surat (2001) and Rosaidi (2001). The 1976 earthquake of magnitude 5.8 in Lahad Datu caused some houses and buildings to develop cracks in the walls. A four storey police complex nearing completion suffered severe structural damage. Several roads in the district were reported to have cracked too, causing damage. Similarly, the 1991 Ranau earthquake of magnitude 5.2 on Richter scale caused extensive damages to a four-storey teacher’s quarters and were verified unfit for occupancy. The earthquake of magnitude 4.8 that occurred on 2 May 2004 near Miri, Sarawak likewise caused some damages to the non-reinforced concrete buildings and developed cracks on the ground (Bernama, 2004).

The frequent occurrence of tremors within the country and nearby region seems to suggest that seismic risk in Malaysia is evident. The question now is the level of risk and its regional variation and whether it is necessary to consider seismic factors in the planning and design of structures and/or infrastructures. These questions have so far remained unanswered due to a lack of understanding of seismicity and inadequate seismic data in Malaysia. Hence, the level of seismic risk in Malaysia is still barely known. It is not known if such risk should be considered in future design of structures and/or infrastructures. This is further compounded by the fact that Malaysia is rapidly developing and major installations and high-rise structures are being constructed at a rapid pace. These structures, especially those in the west coast of Peninsular Malaysia, may be susceptible to long period of ground motions originating from distant earthquakes.

Based on the above facts, the earthquake engineering research is urgently required in order to predict the possibility of earthquakes in the future that can cause damages to the buildings and structures in Malaysia and to find the solutions for mitigating the effects. The engineers have a responsibility to quantify the earthquake risks in Malaysia quantitatively and find the optimal solutions to deal with those effects.

The research works regarding earthquake engineering in Malaysia are relatively behind compared to other engineering fields. This is because the historical earthquake event in Malaysia especially in Peninsular Malaysia is not so profound. Moreover, the nearest distance of earthquake epicentre from Peninsular Malaysia is about 300-400 km. Generally, the earthquakes can cause significant damages within 100-200 km radius from the fault or epicentre. At farther distance, amplitudes of incoming seismic shear waves are generally small (Lee, 1987), however, the “Bowl of Jelly” phenomenon, as what had happened to Mexico City in 1985 should be considered more seriously. The phenomena have shown that an earthquake can have a significant effect although at longer distance due to the long period component of shear waves.

In the case of the 1985 Mexican earthquake, the greatest concentration of damages occurred in the Lake Zone of Mexico City at which the location is approximately 400 km from the epicentre. Distant fault together with soft soil amplified the vibration from the source to the ground surface at the site. This effect becomes more dangerous for high-rise building or structures, which have fundamental periods close to that of the soil. Therefore, seismic hazard assessment accommodates geotechnical considerations such as geological, seismological and local soil conditions are required in order to anticipate the catastrophic effects due to potential large earthquakes in the future.

This research is proposed to apply seismic hazard assessment for Malaysia. In light of the previous discussion, it can be concluded that geotechnical considerations play an integral role in the development of accurate safety against earthquake hazards and sound earthquake resistance designs. The considerations that shall be included in the research to obtain accurate safety against earthquake hazards are geological and seismological conditions, attenuation of earthquake wave propagation in base rock, specific acceleration time histories, and local soil conditions. Hence, in order to cover the above considerations comprehensively, this research focuses on Peninsular Malaysia for macrozonation analysis while Kuala Lumpur City Centre (KLCC) and Putrajaya are two major areas selected for microzonation analyses. These two major areas are selected because they have significant numbers of settlements, high rise buildings, monumental structures and other critical facilities. Moreover, since Kuala Lumpur and Putrajaya are the main centres for business and administration in Malaysia, respectively, therefore the seismic risks are relatively higher than other cities in Peninsular Malaysia. They have a lot of population, investments and assets that should be protected against earthquake hazard.

1.3 Problem Statement

Seismic hazard assessment for Peninsular Malaysia is needed in order to mitigate the effects of large earthquake that may happen in the future. The seismic hazard assessment should consider the seismology and geology of Peninsular Malaysia as well as the local site conditions. This is because all these conditions are related to each other so as to develop a reliable seismic code for designing dynamic loads for civil structures.

1.4 Objectives

There are three (3) primary objectives in this research. The objectives are:

1. To develop macrozonation maps as a function of return period using the probabilistic method for Peninsular Malaysia. The analysis considered the geological and seismological conditions around Peninsular Malaysia.
2. To develop microzonation maps of KLCC and Putrajaya. The microzonation maps cover iso-acceleration and iso-amplification factor contours on the surface of KLCC and Putrajaya.
3. To propose designed response spectra for structural design purposes on KLCC and Putrajaya. In this study, the procedures proposed by 1997 UBC and 1997 NEHRP (or 2000 IBC) were used as references for developing a design spectrum for a particular site category in KLCC and Putrajaya.

The research works regarding the effects of distant earthquakes are not as many as short distance (less than 200 km). This can be seen in the number of papers presented in international journals or conferences on earthquake engineering. Therefore, it is expected that the research will also contribute to the enhancement of earthquake geotechnical engineering knowledge and improvement in seismic resistance building design especially for countries that are affected by distant earthquakes such as Peninsular Malaysia.

In addition, a software for preparing seismic hazard assessment has also been developed for supporting the research. At this moment the software has the capabilities as follows: 1) to show visually the location of epicentre, 2) to make a cross section for plotting the depth of earthquake events, 3) to collect earthquake data from some region, 4) to analyze catalogue completeness, 5) to separate main shock and accessory shock events, 6) to analyze the peak ground acceleration (PGA) at a particular location deterministically, and 7) to assess seismic hazard probabilistically using extreme value method from Gumbel.

1.5 Scope and Limitations

There are many parameters that may have effects on the results of analysis; therefore the analysis is limited to the following parameters:

1. Data collection and preparation.
    a. Compiling the reliable earthquake catalogues.
    b. Obtaining homogeneous magnitude size.
    c. Separating between main shock and dependent shock earthquake events.
    d. Analyzing of earthquake catalogue completeness.
    e. Performing soil investigations including static and seismic tests on selected locations in KLCC and Putrajaya.

2. Macrozonation Study.
    a. Developing reliable seismic source models for Peninsular Malaysia.
    b. Characterizing seismic source models. The analysis is restricted only to find the a-b value, the rate and the maximum magnitude of the seismic source models.
    c. Developing and selecting appropriate attenuation functions for Peninsular Malaysia.
    d. Developing macrozonation maps of Peninsular Malaysia for 10% and 2% probability of exceedance (PE) in 50 years or correspond to 500 and 2500 year return periods of earthquake, respectively.

   e. Developing uniform hazard spectra (UHS) for KLCC and Putrajaya.
   f. Generating artificial time-histories for KLCC and Putrajaya.

3. Microzonation study.
   a. Analyzing soil dynamic properties on selected locations in KLCC and Putrajaya.
   b. Analyzing one dimensional shear wave propagation analysis on selected locations in KLCC and Putrajaya.
   c. Developing maps of iso-acceleration and iso-amplification factors on the ground surface of KLCC and Putrajaya.
   d. Proposed design response spectra of KLCC and Putrajaya for structural design purposes.

1.6 Methodology

The research design of this thesis is shown in Figures 1.2. In the figures, the symbols I, O, and P stand for input, output and process of the analysis, respectively, while the arrows show the flows of input required by the process and the output as a result of the analysis.

1.6.1 External Data

As shown in Figure 1.2, there are three external input data required in the analysis: the historical earthquake data and the seismotectonic data for macrozonation study and the soil data for microzonation study (ground response and response spectra analyses).

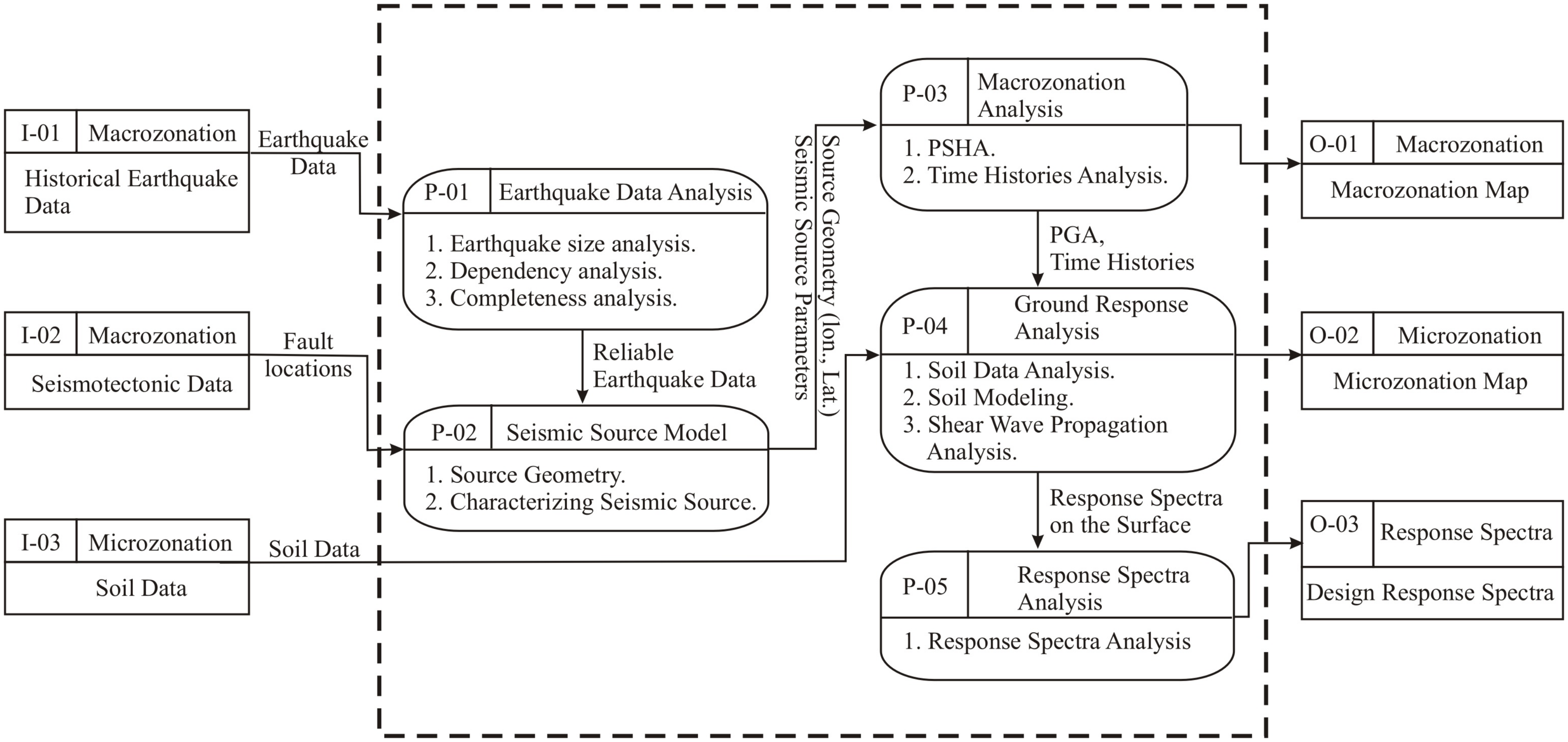

Figure 1.2: Methodology of research.

The following works were performed in order to obtain external inputs for the macrozonation study:

1. Collect historical earthquake data from national and international institutions. The earthquake data required in the analysis are the magnitude, location of epicentre (longitude and latitude), focal depth, and date of the earthquake (year, month, and day).
2. Study literature on the previous research works regarding the seismology and geology conditions in order to identify the location, the length, the rate of displacement, the direction, and the mechanism of active faults around Peninsular Malaysia.

In this thesis, the collection of earthquake data and the identification of seismology condition around Peninsular Malaysia are discussed in more detailed in **Chapter 3**.

The microzonation study requires soil data such as soil stratigraphy, ground water level and soil dynamic properties. The measurement of soil dynamic properties from field tests can be performed on the ground surface (surface tests) or by drilling boreholes or by the advancement of probe into the soil. Surface tests are often less expensive and can be performed relatively quickly. On the other hand, borehole tests have the advantage of gaining the information directly from the boring: visual and laboratory-determined soil characteristics, and water table location. Moreover, the interpretation of borehole tests is usually more direct than surface tests. Alternatively, the soil data may also be obtained from static field test to find static soil parameters such as N_{SPT} or other soil strength parameters. The static soil parameters are then converted to soil dynamic parameters using empirical correlations.

In this research, the following works were performed in order to obtain external inputs for microzonation study:

1. Conduct the standard soil investigations and seismic tests in KLCC and Putrajaya.

2. Compile the existing soil data on selected points in KLCC and Putrajaya.

In this research, the seismic down-hole tests were performed in order to measure dynamic soil properties in KLCC and Putrajaya. The procedure for seismic down-hole test is described in more detail in **Chapter 6**.

1.6.2 The Analyses

Generally, there are five main processes performed in this research as shown in Figure 1.2: earthquake data analysis, seismic source model analysis, macrozonation analysis, ground response analysis, and response spectra analysis.

1.6.2.1 Earthquake Data Analysis

In this study, the historical earthquake data were compiled from several catalogues from local and International Institutions. Typical characteristics of earthquake catalogues are as follows:

1. The magnitude scales used in the catalogues are not uniform. This is because the earthquake events were not recorded using only one type of instrument.
2. The earthquake catalogues are mixed between main shock and accessory shock events. Therefore, the data is not valid when the temporal occurrence of earthquakes is analyzed using Poisson model.
3. The small events are usually incomplete in earthquake catalogue. This is because of the limitation of the sensitivity and the coverage area of the seismographic networks.

The first problem is solved by choosing a consistent magnitude for SHA, and then the other magnitude scales are converted to this magnitude scale. In this research, a moment magnitude, M_w, is chosen as the measurement to quantify the size of earthquake. Other types of magnitude in the catalogue were then converted to M_w. Several formulas have been proposed to convert from other magnitudes to moment magnitude. In this study, the new formulas for converting M_S and m_b to M_w and M_L to m_b were developed. The statistical analyses were carried out to test the reliability of the formulas.

The second problem is solved by declustering the catalogue using time and distance windows criteria (e.g. Gardner and Knopoff, 1974; Uhrhammer, 1986). Some previous research works were analyzed and selected in this thesis in order to separate the main shock and the accessory shock events (foreshock and aftershock).

The third problem is solved by catalogue completeness analysis. In this study, historical earthquake data occurred between 1900 and 2004 were analyzed for completeness using Stepp (1973) method. The completeness analysis is applied only for main shock earthquake events.

The procedures for process earthquake data are described in more detail in **Chapter 3**. The output of this process is a reliable earthquake data.

1.6.2.2 Seismic Source Modelling

Seismic source models were developed in this study. Generally, there are four steps were performed in this study for developing the new seismic source model for Peninsular Malaysia. The four steps are as follows:

1. Locating the source.
2. Assessing the source dimensions.
3. Assessing the source orientation.
4. Representing the source.

Steps 1 to 3 were performed based on the distribution of historical earthquake data and seismotectonic setting around Peninsular Malaysia. The source orientations have considered not only the strike angles of the source but also the dip angles as well.

Step 4 was conducted by assessing and evaluating seismic hazard parameters for all source zones. The seismic hazard parameters are represented by frequency-magnitude relationship (i.e. a-b values and maximum magnitude). Several methods were considered in determining seismic hazard parameters in order to cover epistemic uncertainties. Three methods for assessing seismic hazard parameters were used in this research; i.e., Least Square (LS), Weichert (1980), and Kijko & Sellevoll (1989).

The procedure for developing seismic source model is described and discussed in more detail in **Chapter 3**. The outputs of this process are the seismic source zone models including the geometries and the seismic hazard parameters. These outputs are required for macrozonation analysis.

1.6.2.3 Macrozonation Analysis

Macrozonation analysis is performed in order to obtain characteristics of ground motion at base rock such as maximum acceleration and targeted response spectra for certain return periods of earthquake. In this study, the seismic hazard assessment (SHA) is performed using probabilistic approach for the following reasons:

1. The probabilistic seismic hazard assessment (PSHA) approach is more appropriate to be used for highly quantitative decisions such as development of seismic design code, regional mitigation plans, and insurance.
2. The probabilistic approach is convenient for comparing risks in various parts of a country and for comparing the earthquake risk with other natural and man-made hazards (e.g. floods, wind, and landslide).
3. The probabilistic approach opens the possibility for risk-benefit analyses and respective design motions (Gupta, 2002). The motivation for such a design principle is that, at the time of construction or strengthening, if it is

invested in strength beyond that required just to prevent collapse (e.g., by codes), the monetary losses during future likely earthquakes may be reduced significantly.

The analysis includes as follows:

1. Develop and select appropriate attenuation functions for Peninsular Malaysia. This analysis is described in more detail in **Chapter 4**.
2. Perform probabilistic seismic hazard analysis (PSHA), which gives a probabilistic description (a frequency of exceedance) of earthquake characteristics such as ground motion amplitudes.
3. Develop uniform hazard spectra at bedrock for KLCC and Putrajaya.
4. Perform time histories analysis to generate artificial time histories for KLCC and Putrajaya. The time histories were generated so as to match the uniform hazard spectra given in PSHA. This data is required for shear wave propagation analysis in microzonation study.

Chapter 5 are discussed more detail the procedures for PSHA and time histories analysis. The outputs of this process are macrozonation maps for Peninsular Malaysia and time histories at bedrock of KLCC and Putrajaya. These outputs are required for ground response analysis.

1.6.2.4 Ground Response Analysis

This study is performed in order to obtain ground motion parameters such as acceleration, amplification factor and response spectra at the surface. Analysis covers as follows:

1. Analysis of soil dynamic parameters on the selected points to obtain shear modulus (G), damping ratio (D), and shear wave velocity (V_S).
2. Determination of site categories for selected locations in KLCC and Putrajaya.

3. Analysis of shear wave propagation from base rock to ground surface for each selected points to obtain peak surface acceleration, amplification factor, and response spectra at the surface. In this analysis, local soil dynamic properties and several alternative input motions were considered.
4. Development of iso-acceleration and iso amplification factor contours on KLCC and Putrajaya.

The site categories proposed by the recent codes of UBC or 2000 IBC are used for classifying the selected site locations in KLCC and Putrajaya. The determination of site category is based on the average shear wave velocity, V_S to a depth of 30 m. The ground response analyses were performed using nonlinear approach. These analyses are discussed in **Chapter 6**.

1.6.2.5 Response Spectra Analysis

The response spectra analysis was performed in order to develop design response spectra for structural design purposes. In this step, the response spectra at the surface (from the ground response analysis) were analyzed and compared to the response spectra proposed by the existing codes such as 1997 UBC and 2000 IBC. The process is described in more detail in **Chapter 6**. The output of this process is a smooth or a design spectrum for a particular site category in KLCC and Putrajaya.

1.7 Organization of Thesis

The methodology of the research as discussed in the preceding section is implemented into seven chapters. The connection between the methodology and each chapter is shown in Figure 1.3. The second column in the figure shows the content for each chapter and the last column on the right side points up the output from the related chapter. The dashed lines show input-output relations among the chapters.

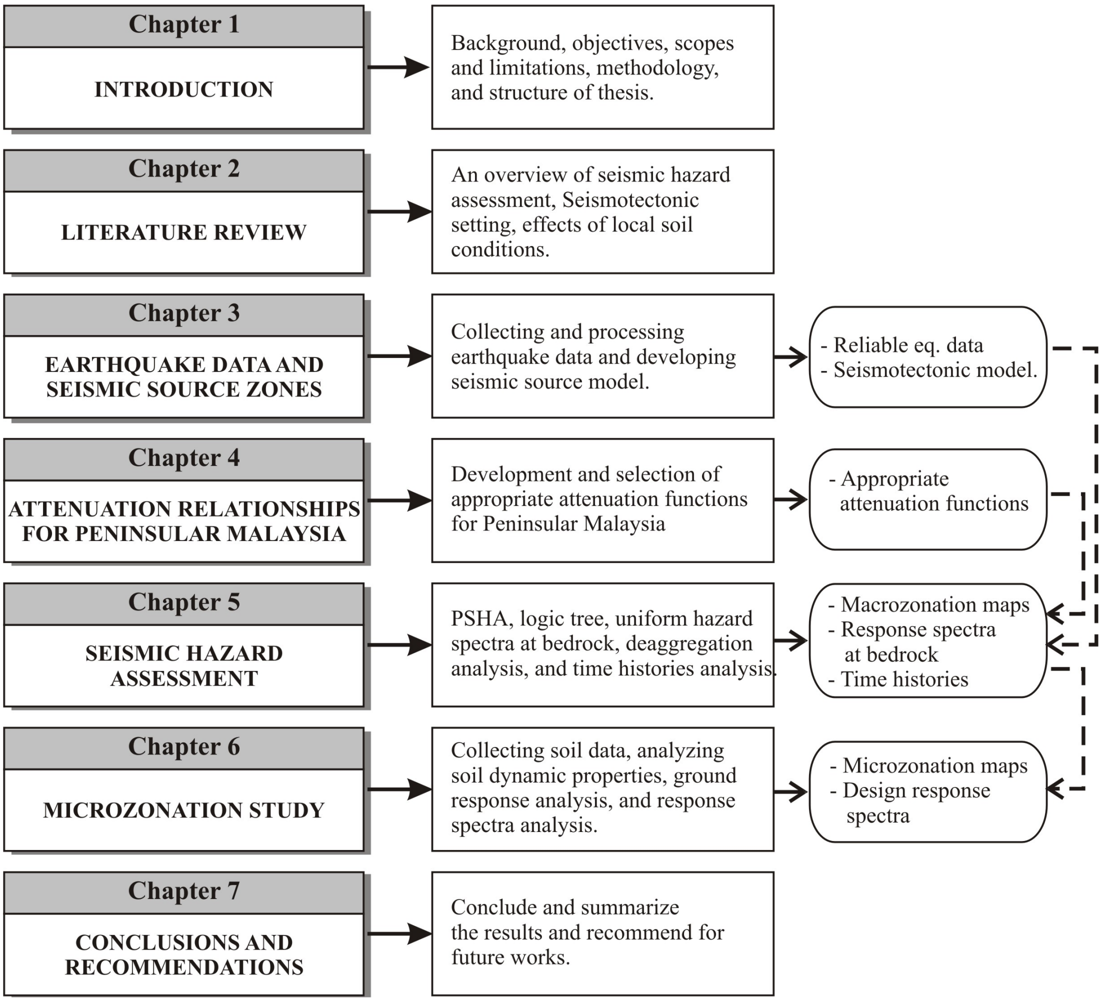

Figure 1.3: Implementation of the methodology in the organization of thesis.

The content of each chapter can be described briefly as follows:

- ***Chapter 1 Introduction.*** This chapter describes the background of the research, the objectives to be achieved, the research scopes, the methodology, and the structure of the thesis.

- ***Chapter 2 Literature Review***. This chapter reviews and evaluates the topics which are related to earthquake engineering. In this chapter, several methodologies for seismic hazard assessment including the effects of local soil conditions are discussed briefly. Literature study regarding historical earthquake and seismotectonic setting around Peninsular Malaysia are also discussed in this chapter.

- ***Chapter 3 Earthquake Data and Seismic Source Zones.*** In this chapter, earthquake data around Peninsular Malaysia are collected and processed so as to obtain reliable data for seismic hazard assessment in Chapter 5. Seismic source model and the seismic hazard parameters are also developed and analyzed in this chapter.

- ***Chapter 4 Development and Selection Attenuation Functions***. Attenuation function is one of the most critical point in seismic hazard assessment. Hence, this topic requires detailed analysis and discussion. This chapter reviews and evaluates the appropriate attenuation functions for Peninsular Malaysia. In this chapter, the proper attenuation functions are developed and selected. The result is then applied in Chapter 5.

- ***Chapter 5 Seismic Hazard Analysis***. This chapter analyzes seismic hazard for Peninsular Malaysia using total probability theory. Seismic hazard parameters and attenuation functions from Chapter 4 are applied in probability seismic hazard analysis (PSHA) to develop peak ground acceleration (PGA) map for Peninsular Malaysia. Time histories analysis is also discussed in this chapter. PGA map and time histories obtained from this chapter are then applied in Chapter 6.

- ***Chapter 6 Microzonation Study.*** This chapter describes the effects of local soil conditions in Kuala Lumpur city centre and Putrajaya. The analysis is based on soil investigation carried out in several locations around these two cities. Finally, peak surface acceleration maps and design response spectra are developed for KLCC and Putrajaya.

- ***Chapter 7 Conclusions and Recommendations***. This chapter concludes and summarizes the results on the previous chapters and also gives recommendations for further study.

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