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## **SEISMIC HAZARD ASSESSMENT OF KUALA LUMPUR USING PROBABILISTIC METHOD**

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**Abstract:** This paper presents the seismic hazard assessment which involved spectral hazard for 10 % probability of exceedance in 50 years or correspond to return period of approximately 475 years for bedrock of Kuala Lumpur city. The analysis was performed using the total probability theorem with 2D seismic source model. Time history data for this site was generated synthetically by modifying the existing time history data using spectral matching analysis. In this study, design response spectra were developed by applying the methods proposed by 1997 NEHRP. The final result are the spectral acceleration and the synthetic time histories on the bedrock, and the design response spectra on Kuala Lumpur ground surface for 475 years return periods.

**Keywords:** *Seismic hazard, Total Probability Theorem, Response spectra, Synthetic time histories*

### **1.0 Introduction**

Kuala Lumpur, the capital of Malaysia, may well represent the classic examples of area with low seismic hazard but with high consequence. The city is located on a stable part of the Eurasian plate and is in a region of low seismicity. Active seismic sources are located more than 300 km away along and of the western coast of Sumatra. Although earthquakes have never caused any structural damage in Kuala Lumpur however, buildings on soft soil are occasionally subjected to tremors generated from the long distance earthquakes in Sumatra. In the last few years, tremors were felt several times in tall buildings in Kuala Lumpur due to large earthquakes in Sumatra.

Seismic hazard analysis was conducted in order to predict peak ground acceleration (PGA) and spectral acceleration of bedrock in Kuala Lumpur. The analysis was carried out using probabilistic method and appropriate attenuation relationship. The seismic hazard for PGA was calculated with 10 % probabilities of exceedance in 50 years. As part of the effort to assess the seismic hazards of Kuala Lumpur, representative bedrock motion prediction models and design response spectra were established.

## 2.0 Tectonic Setting of Peninsular Malaysia

Malaysia is situated close to two most seismically active plate boundaries namely; the inter-plate boundary between the Eurasian Plates and Indo-Australian Plates on the west, and the inter-plate boundary between the Eurasian and Philippines Sea on the east. Generally, tectonic features that affect Peninsular Malaysia can be of two sources. The first source is subduction zone. All those earthquakes that occurred near convergent boundaries where Indo-Australian plate is being subducted under Eurasian plate are triggered in this zone. The second source is fault zone. All of those earthquakes occurred due to strike slip movement along clearly defined fault in the frontal arc area such as Sumatra Fault are classified as transform fault. The Sumatra fault is about 1900 km long structure that accommodates right lateral strike slip associated with the oblique convergence along the plate margin.

## 3.0 Source Models

### 3.1 Earthquake Catalog

Estimation of future seismicity is based on the rate of past earthquake as determined from earthquake catalogue. In this study, the catalogue were compiled by combining several sources such as Preliminary Determination of Epicenters (PDE) catalogs of U.S. Geological Survey, ISC catalogue (bulletins of the International Seismological) and Engdahl *et al.* (1998). Since the earthquake data have been reported in different magnitude and intensity scale by source catalogues, therefore all data has to be converted to moment magnitude (Hank and Kanamori, 1979). The combined catalogue covers an area from 90°E to 112°E longitude and from 8°S to 10°N latitude. The minimum moment magnitude ( $M_w$ ) is 5.0 and maximum focal depth is 200 km. The catalogue covers the range of events between 1900 and 2007. The location of earthquake epicenter during that period of observation is shown in Figure 1.

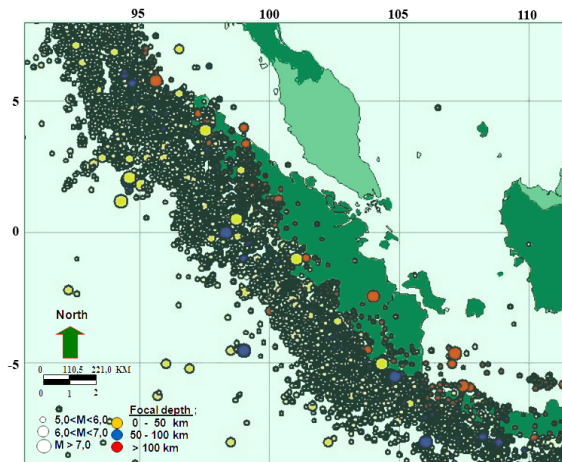


Figure 1: Epicenter distribution of earthquake events from 1900 to 2007 (PDE-USGS; ISC; Engdahl *et al.* 1998)

According to Gardner and Knopoff (1974), catalogues that are used to estimate future seismic activity must be free of dependent events such as foreshock and after shock. Gardner and Knopoff indentified duration,  $D$ , and dimension,  $S$ , of aftershock sequence as function of main shock magnitude,  $M$ , and from this conditions we can scan for events within a  $D(M)$ ,  $S(M)$  window. Figure 2 shows the epicenter distribution of main earthquake events of the combined catalogue during the period of observation.

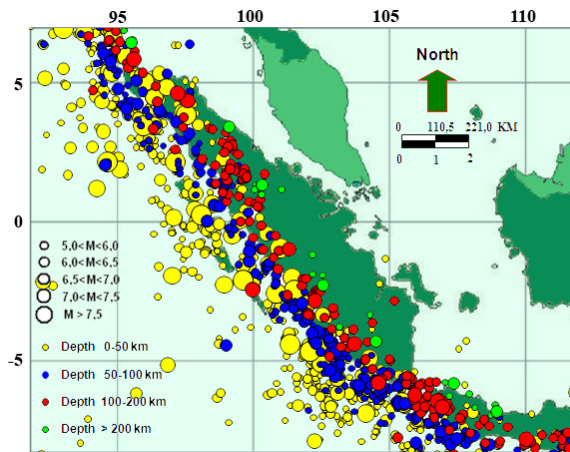


Figure 2: Epicenter distribution of main earthquake events from 1900 to 2007 (PDE-USGS; ISC; Engdahl *et al.* 1998)

Knowledge of the earthquake history and homogeneity of the earthquake catalogue are key factors in the evaluation of recurrence interval and evaluation of seismic hazard risk for a particular site. The small events are usually incomplete in earthquake catalogues. This is due to the limited sensitivity and coverage of the earth by seismographic

networks. The problem is solved by performing catalogue completeness analysis. In this study, the combined earthquake catalogue in period of observation ranging between 1900 and 2007 have been analyzed for completeness using Stepp method (1973). Based on the analysis, the earthquakes within interval  $5.0 \leq M_w < 7.0$  are completely reported only during the most recent 42-year interval and the magnitude more than 7.0 are completely reported over 107-year sample interval (Figure 3).

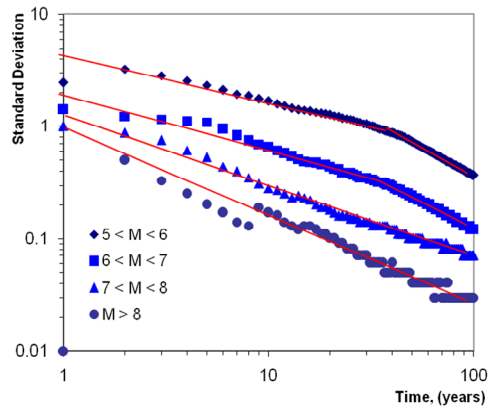


Figure 3: Completeness time of earthquake

### 3.2 Seismic Source Zones

A seismic source zone is defined as a seismically homogenous area, in which every point within the source zone is assumed to have the same probability of being the epicentre of future earthquakes. Source zones are defined on the basis of the distribution and focal mechanisms of the cataloged earthquakes, and on the locations of the earthquakes with respect to the boundaries of major tectonic plates.

The two source zones used in this study are: subduction zones and transform/shallow crustal faults zones. Based on the focal depth and dip angle, subduction zones were divided into interplate (megathrust) zones and intraplate (benioff) zones. Megathrust zone earthquake events occurred at shallow depth of less than 50 km, and depth of 50 to 200 km were considered as Benioff zone. The background earthquake was generally assumed to occur throughout the site region and is incorporated into the hazard through the use of an area source zone representing the stable interior of the Sunda plate.

There are three parameters that are most commonly considered in seismic hazard assessment, i.e. a–b parameter, recurrence rate, and maximum size of future earthquakes for each source. The simplest method to obtain a–b value is the least square (LS) method. The disadvantage of the LS method is that it cannot be used directly to calculate the mean annual rate of exceedance from combination of different completeness catalogues.

Other researchers such as Dong *et al.* (1984) has proposed alternative methods to obtain a–b values and to minimize bias. The method accounted for the relationship between earthquake data and interval time when the catalogues are homogeneous. In this study, a-b parameters are obtained using Gutenberg-Richter equation (1944) and Dong *et al.* (1984).

The Sumatra interplate subduction zone is a very active feature that has ruptured in 91 independent events with magnitude greater than or equal to  $M_w = 5$  within the past 42 years. The largest of these events was  $M_w = 8.6$ , which occurred on 9 December 2007. Using a range of magnitudes between 5 and 9, the calculated b-value is 0.64 for this distribution.

The Sumatra intraplate subduction zone is a very active feature that has ruptured in 130 independent events with magnitude greater than or equal to  $M_w = 5$  within the past 42 years. The largest of these events was  $M_w = 7.0$ , which occurred on April 1983 near Aceh. Using a range of magnitudes between 5 and 9, the calculated b-value is 1.03 for this distribution.

The transform zone encompasses the area around the Sumatran fault in the highlands and to the north of the fault. Fifty-eight events with magnitude greater than or equal to  $M_w = 5$  have occurred during the last 42 years. The largest of these events was  $M_w = 7.2$ . This zone has not been as productive as the Sumatra subduction zone. A b-value of 0.75 was calculated between  $M_w = 5$  and  $M_w = 8$  for this zone.

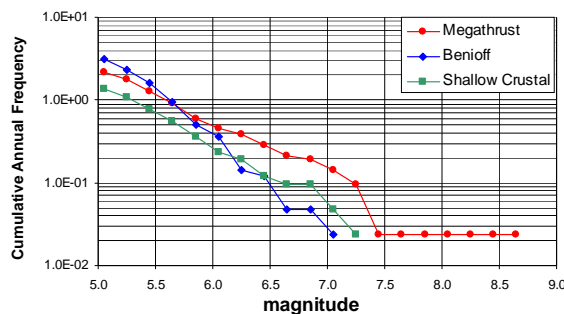


Figure 4: Frequency of earthquake event

Three different models were developed to account for seismicity on the Sumatra Subduction zone and the Sumatran fault zone (Figure 5). The first model were represented as megathrust zone that accounts for smaller earthquakes less than  $M_w = 9.0$  can occur anywhere along the interface. The average calculated a-value is 3.54. The model is based on rupture zone in west coastal Sumatera (Figure 6). The second model were represented as Benioff zone that accounts for smaller earthquakes less than  $M_w = 9.0$  can occur anywhere along the interface. The average calculated a-value is 5.72. The

third model were represented as shallow crustal faults zone that accounts for smaller earthquakes less than  $M_w = 7.9$  can occur anywhere along the interface. The average calculated a-value is 3.91. The third model is based on the segments of the Sumatran fault system (Figure 7).

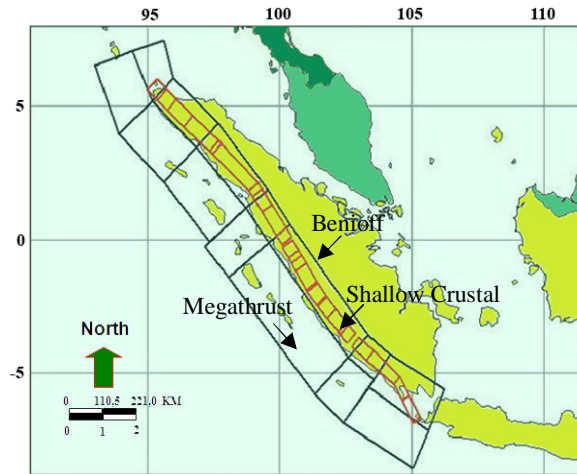


Figure 5: Seismic source zones for site location

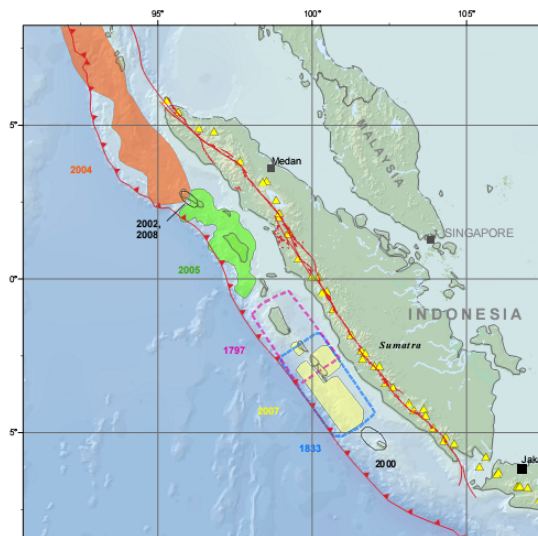


Figure 6: Rupture zone offshore west coastal Sumatra (Briggs, 2007)

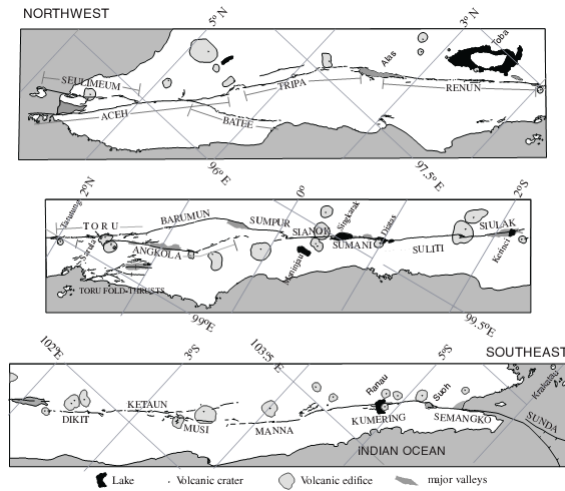


Figure 7: Segments of the Sumatran fault system (Sieh and Natawidjaja, 2000)

### 3.3 Attenuation Models

There have been a number of attenuation functions derived in the last two decades. Most of them were derived in a certain region where peak ground acceleration records had been available. We adopt attenuation function derived in other region, which is similar to Indonesian/Malaysian region tectonically and geologically. It is of importance that the selection was based on earthquake mechanism, which is generally categorized into subduction zone earthquake and shallow crustal earthquake. In this study, the attenuation relationships for subduction zone at rock sites developed by Young *et al.* (1997) and that for shallow crustal developed by Boore *et al.* (1997) are selected.

### 4.0 Seismic Hazard Analysis

The total probability theorem developed by McGuire (1976) is based on the probability concept that developed by Cornell (1968), which assumed the earthquake magnitude  $M$  and the hypocenter distance  $R$  as a continuous independent random variable.

The total probability theorem can be represented in the most basic form as follows,

$$P_{(a \geq a^*)} = \int_M \int_R P_{(a \geq a^*; m, r)} f_M(m) f_R(r) dr dm \quad \text{Eq. (1)}$$

where :

- $f_M$  = density function of magnitude
- $f_R$  = density function of hypocenter distance

$P(a \geq a^*; m, r)$  = conditional probability of (random) intensity  $a$  exceeding value  $a^*$  at the site for a given earthquake magnitude  $m$  and hypocenter distance  $r$ .

The annual total probability of earthquakes with intensity  $a$  equal or greater than  $a^*$  at a particular site is determined by totaling the probability of each source. It can be written in mathematical form as follows,

$$\lambda(a \geq a^*) = \sum_{i=1}^{N_s} v_i \cdot P(a \geq a^*) \quad \text{Eq. (2)}$$

where :

$P(a \geq a^*)$  = the risk of single event with intensity  $a$  equal or greater than intensity  $a^*$  for one seismic source

$v_i$  = the annual earthquake occurrence with magnitude  $M$  equal or greater than magnitude  $m$  for one source zone

Logic tree are used in this study in order to allow uncertainty in selection of models for recurrence model to be considered. The logic tree model is illustrated in Figure 8 and 9 for the respective zone.

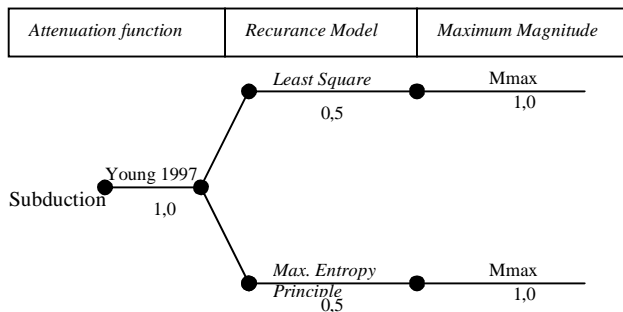


Figure 8: Logic tree used in this study for Subduction zone

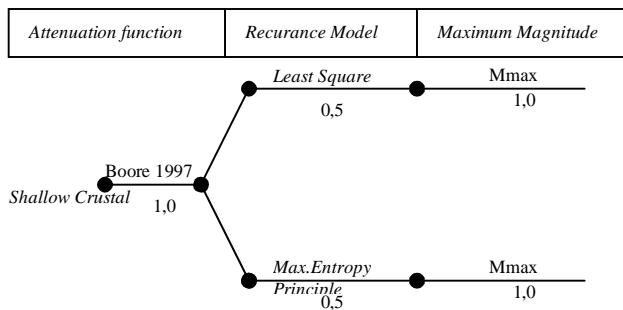


Figure 9: Logic tree used in this study for Shallow Crustal zone



Spectral acceleration of difference return period for Kuala Lumpur is shown in Figure 10. Respon spectra hazard at bedrock for PGA, T=0.2 and T=1.0 seconds is shown in Figure 11. From PGA response spectra hazard, the mean spectral acceleration is 0.08g for return period of 475 years. From T=0.2 and T=1.0 seconds response spectra hazard, the mean spectral acceleration are 0.17g and 0.06g for return period of 475 years, respectively.

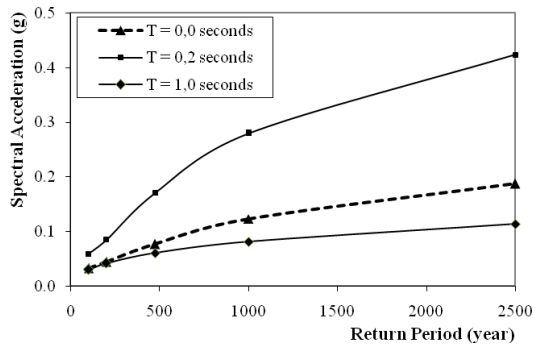


Figure 10: Seismic hazard exposure for various return period

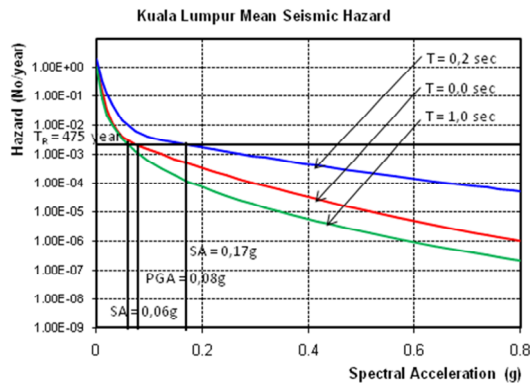


Figure 11: Probabilistic hazard for T=0.0 seconds, T=0.2 seconds and T=1.0 seconds, 5% damped response spectra

Uniform hazard spectrum is a spectrum of which each point has the same probability of being exceeded (Figure 12). Deaggregation of the tentative uniform hazard spectra resulting from a probabilistic seismic hazard assessment (PSHA) is used to determine which sources that contribute most to the hazard at site by identifying the mean magnitude and distance of earthquakes that control the ground motions at these response spectral frequencies. This information will be used to generate scaled response spectra at bedrock of Kuala Lumpur.

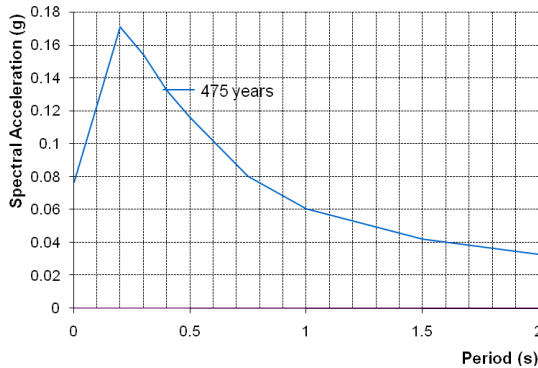


Figure 12: Uniform hazard spectra at bedrock of Kuala Lumpur

Since the hazard is computed independently for each spectral period, in general, a uniform hazard spectrum does not represent the spectrum of any single earthquake. It is common to find that the short period ( $T < 0.2$  seconds) ground motions are controlled by nearby moderate magnitude earthquakes, whereas, the long period ( $T > 1$  seconds) ground motions are controlled by distant large magnitude earthquakes. Hence, the seismic hazard curves for  $T=0.2$  and  $T=1.0$  seconds were deaggregated to determine the controlling magnitudes and distances. The deaggregation hazard for 475 years return period for  $T = 0.2$  and  $T = 1.0$  seconds are shown in Figure 13 and 14, respectively. The results of deaggregation hazard are summarized in Table 1.

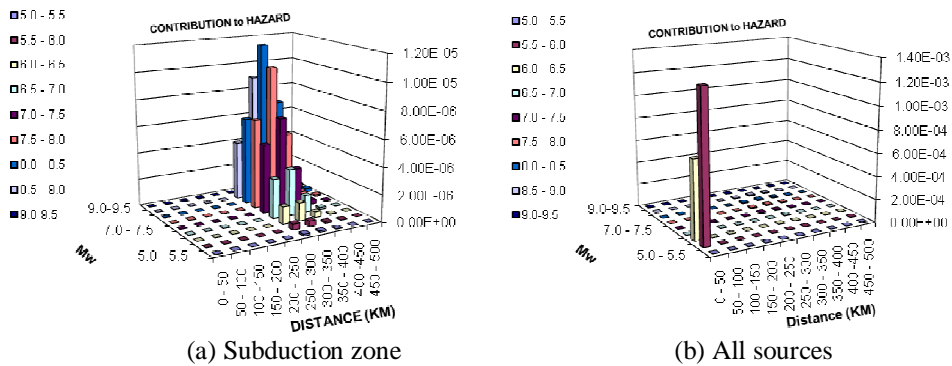


Figure 13: Deaggregation hazard for  $T=0.2$  seconds and 475 year return period

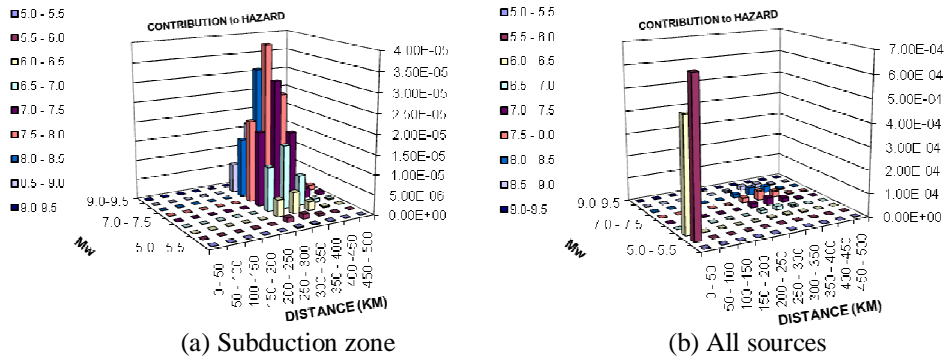


Figure 14: Deaggregation hazard for T=1.0 seconds and 475 year return period

Table 1: Summary of controlling earthquake from deaggregation result for 475 year return period

Seismic Sources	(T = 0.2 seconds)		(T = 1.0 seconds)	
	R (km)	M <sub>w</sub>	R (km)	M <sub>w</sub>
Megathrust	550	8.7	570	8.7
Benioff	438	7.9	472	7.9
Background	30	5.6	29	5.6

The information from the analysis may instead be used to assist in the development of ground motion time histories. To do this, the ground motion amplitudes (and possibly frequency content) is scaled such that the spectrum of the scaled ground motion closely matches the uniform hazard spectrum. Figure 15 shows the response spectra for these events scaled to the T=0.2 and T=1.0 seconds, respectively.

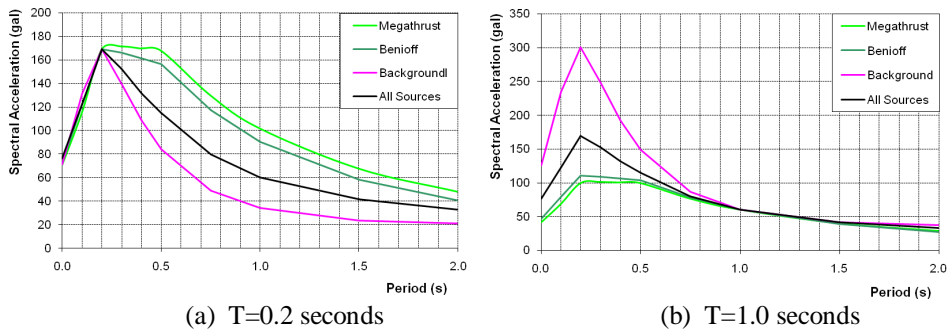


Figure 15: Spectra for dominant events for the 475 year return period of hazard

Acceleration time histories are required in the analysis of shear wave propagation in soil deposits. Selection of time histories appropriate for specific geological and seismological conditions play an important role for obtaining accurate results. In this study, the selection and generation of time histories are based on their similarity of their characteristic with the most likely and mean contribution magnitude-distance

combinations to give the seismic hazard level 475 year return periods. Three sets of time histories were recommended to simulate the rock motion at site location. The time histories data represent background event was obtained from 1980 Livermore earthquake (Figure 18(a)). This record was downloaded from Pacific Earthquake Engineering Research (PEER) Strong Motion Database Record (<http://peer.berkeley.edu/smcat/search.html>). Since there is no record available for other magnitude and distance combinations, therefore the two time histories for these two combinations were generated synthetically using Stochastic Method (Boore, 2000).

Synthetic time histories were generated based on estimated target spectrum at bedrock. The results of the synthetic time histories are shown in Figures 16(b), 17(b) and 18(b).

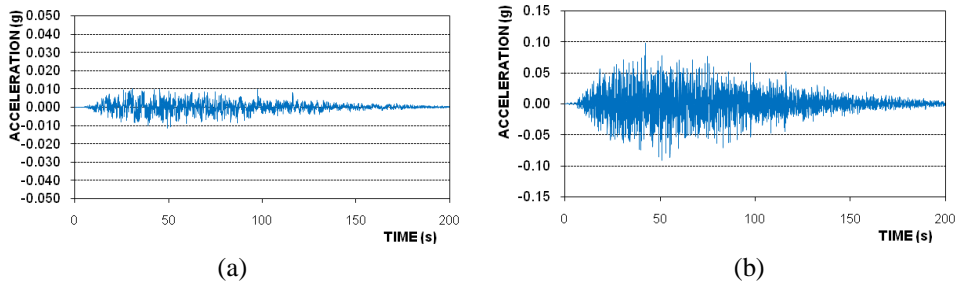


Figure 16: (a) Time histories represent megathrust event ( $M_w=8.7$  and  $R=550$  km), generated synthetically using Stochastic Method (Boore 2000). (b) Synthetic bedrock time histories represent megathrust event for 475 year return period of hazard.

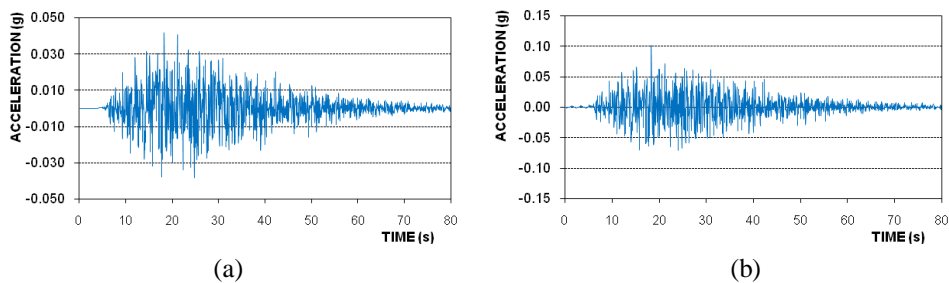


Figure 17: (a) Time histories represent benioff event ( $M_w=7.9$  and  $R=438$  km), generated synthetically using Stochastic Method (Boore 2000). (b) Synthetic bedrock time histories represent benioff event for 475 year return period of hazard.

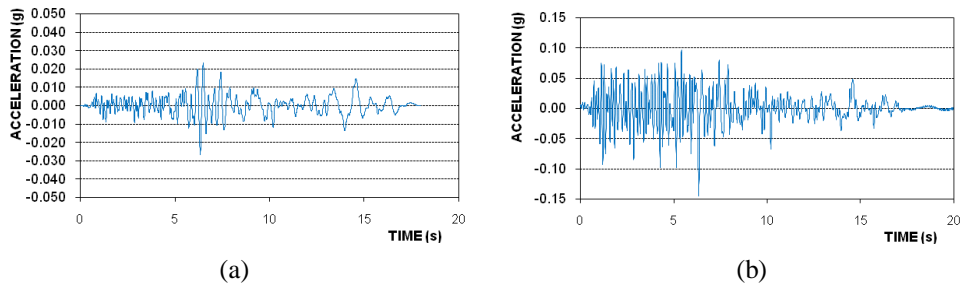


Figure 18: (a) Bedrock time histories of Livermore Earthquake 1980. (b) Synthetic bedrock time histories represent background event for 475 year return period of hazard.

## 5.0 Design Response Spectra

The influence of soil conditions on the ground motion can be translated into the modification of response spectra shapes by using spectral amplification factors. Since the amplification factors are very sensitive to the reference site conditions, the application of amplification factor must appropriately consider the site conditions corresponding to the reference motion. Therefore, in most building codes or provisions, the influence of local soil conditions is considered by using spectral amplification factors for different soil classes.

In this study, the procedures proposed by 1997 NEHRP was used as reference for developing the design response spectra of Kuala Lumpur ground surface. The NEHRP Provisions apply a series of amplification factors depending on the characteristics of the soil at the site. There are two sets of factors: one for the short period (0.2 seconds) acceleration and one for the long period acceleration. The classification of a particular site was determined by referring specifications from the code. Based on  $V_s-30$  or  $N_{SPT-30}$  or  $S_u-30$ , the site categories can be classified as site class  $S_A$  (hard rock),  $S_B$  (rock),  $S_C$  (very dense soil),  $S_D$  (stiff soil) or  $S_E$  (soft soil).  $V_s-30$  or  $N_{SPT-30}$  or  $S_u-30$  represent the average value of the parameter over the top 30 m (100 ft) of soil.

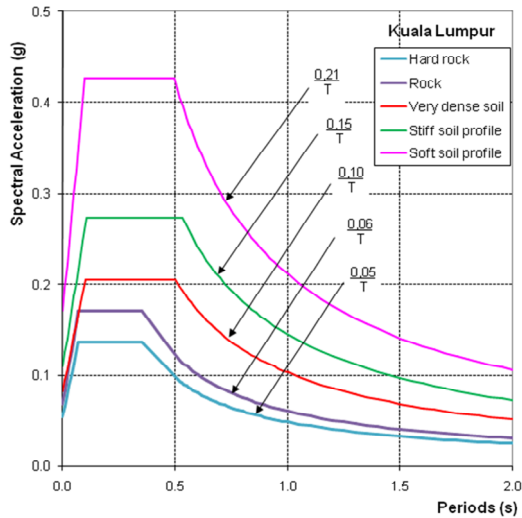


Figure 19: Surface spectral response for Kuala Lumpur, 5% damping, 475 years return period

## 6.0 Summary and Conclusion

Seismic hazard analysis was conducted in order to predict peak ground acceleration (PGA) and spectral acceleration at bedrock of Kuala Lumpur. Analysis was carried out using probabilistic method for hazard levels of 10% probability of exceedance in 50 years. Based on the analysis, the PGA is 0.08g for return period of 475 years. As part of the effort to assess the seismic hazards of Kuala Lumpur, representative bedrock motion prediction models were generated. Also, design response spectra developed based on 1997 NEHRP was established.

## References

- Boore, D.M., Joyner, W.B., Fumal, T.E. (1997). *Equations for estimating horizontal response spectra and peak acceleration from Western North American earthquakes : a summary of recent work*, Seismological Research Letters, 68: 128–153.
- Boore, D. M. (2000). SMSIM – Fortran Programs for Simulating Ground Motions from Earthquakes: Version 2.0—A Revision of OFR 96-80-A, U.S.Geological Survey Open-File Report, OF 00-509, 55 pp.
- Briggs, R. (2007) Sumatra, Indonesia, Earthquakes, EERI Newsletter, 41(10).
- Cornell, C. A. (1968). *Engineering seismic risk analysis*, Bulletin of the Seismological Society of America, 58: 1583-1606.
- Dong, W. M., Bao, A. B., Shah, H. C. (1984). *Use of Maximum Entropy Principle in Earthquake Recurrence Relationship*, Bulletin of the Seimological Society of America, 74 (2): 725-737.

- Engdahl, E. R., Van der Hilst, and Bulland, R. (1998). *Global Teleseismic Earthquake Relocation With Improved Travel Times and Procedures for Depth Determination*, Bulletin of the Seismological Society of America, 88.
- Gardner, J.K., Knopoff, L. (1974). *Is the Sequence of Earthquakes in Southern California, with After-shocks removed, Poissonian ?*, Bulletin of the Seismological Society of America, 64(5): 1363-1367.
- Gutenberg, B., Richter, C.F. (1944). *Frequency of Earthquakes in California*, Bulletin of the Seismological Society of America, 34(4): 185–188.
- Hanks, T. C., dan Kanamori, H. (1979). *A Moment Magnitude Scale*, Journal of Geophysical Research, 84: 2348-2350.
- International Seismological Centre, On-line Bulletin, <http://www.isc.ac.uk/Bull>, International Seismological Center, Thatcham, United Kingdom.
- McGuire, R. (1976). Fortran Computer Program for Seismic Risk Analysis, Open-File Report 76-67, U.S. Geological Survey.
- National Earthquake Information Center United States Geological Survey, <http://neic.usgs.gov/neis/epic/epic.html>.
- Sieh, K., Natawidjaja, D. (2000). *Neotectonics of the Sumatran fault, Indonesia*, Journal of Geophysical Research, 105: 28295–28326.
- Stepp, J.C. (1973). *Analysis of the Completeness of the Earthquake Hazard Sample in the Puget Sound Area*, NOAA Technical Report, ERL 267-ESL 30, Boulder, CO, pp. 16-28.
- The 1997 edition of NEHRP Recommended Provisions. *NEHRP Recommended Provisions (National Earthquake Hazard Reduction Program) for Seismic Regulation for New Buildings and Other Structures (FEMA 302), Part 1: Provisions*, Prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D.C.
- Youngs, R.R., Chiou, S.J., Silva, W.J., Humphrey, J.R. (1997). *Strong ground motion attenuation relationships for subduction zone earthquakes*, Seismological Research Letters, 68: 58–73.