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SEISMIC HAZARD ASSESSMENT OF PENINSULAR MALAYSIA USING PROBABILISTIC METHOD

Delfebriyadi

Department of Civil Engineering, Andalas University, Padang 25163, Indonesia

Corresponding Author: *delfebri@ft.unand.ac.id*

Abstract: This paper presents the seismic hazard assessment which involved spectral hazard for 2% and 10% probabilities of exceedence in 50 years ground motions for bedrock of Peninsular Malaysia. The analysis was performed using the total probability theorem with 2D seismic source model. The final result are the peak ground acceleration contour maps and the spectral acceleration contour maps for those two hazard levels. These spectral acceleration contour maps represent short period (0.2 sec) and long-period (1.0 sec) spectra values at the bedrock.

Keywords: *Seismic hazard, Total Probability Theorem, Spectral acceleration*

1.0 Introduction

Peninsular Malaysia may well represent the classic examples of area with low seismic hazard but with high consequence. The area 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. For instance, 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 of Peninsular Malaysia. The analyses were carried out using probabilistic method and appropriate attenuation relationship. Current earthquake design practice for conventional structures is nominally based on the use of 10% or 2% probability of exceedence in 50 years ground motions (BSSC, 1998). In order to cover those two design ground motions, the analyses were performed for 10% and 2% probabilities of exceedence in design time period of 50 years or correspond to return period of approximately 475 and 2475 years, respectively.

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 Earthquake Catalogue

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 Epicentres (PDE) catalogues 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 epicentre during that period of observation is shown in Figure 1.

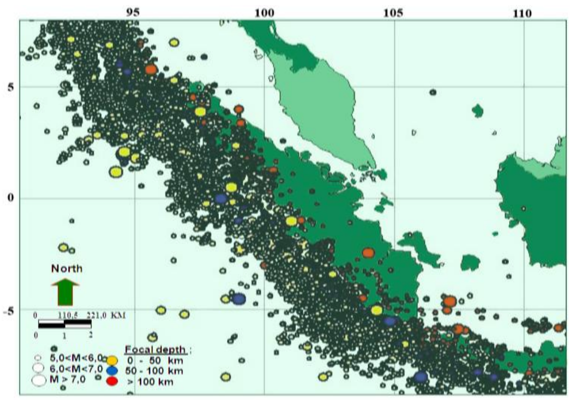


Figure 1. Epicenter distribution of earthquake events from 1900 to 2007 (PDE-USGS; ISC; Engdahl *et al.* 1998)

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 identified 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.

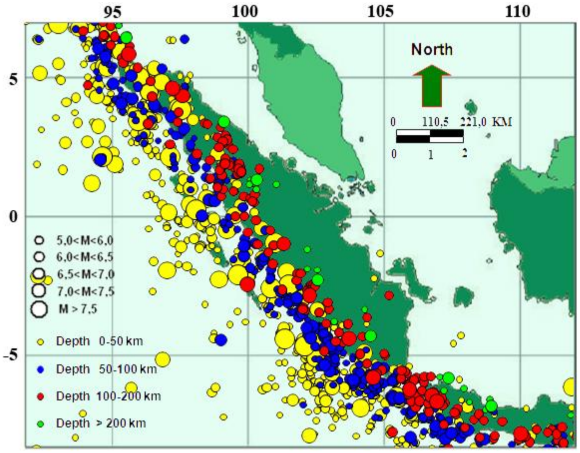


Figure 2. Epicenter distribution of main earthquake events from 1900 to 2007 (PDE-USGS; ISC; Engdahl *et al.* 1998)

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 has 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).

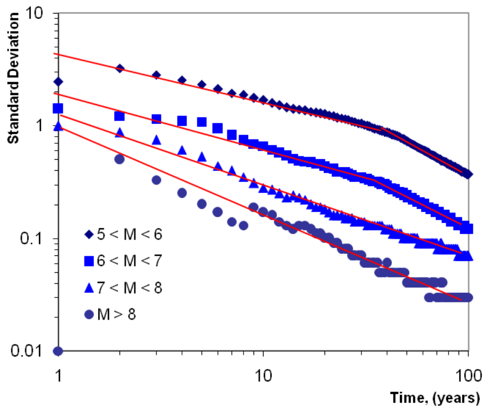


Figure 3. Completeness time of earthquake

4.0 Seismic Source Modelling

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 catalogued 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 exceedence from combination of different completeness catalogues. Other researchers such as Dong *et al.* (1984) have 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 the standard Gutenberg-Richter law (1965) 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.

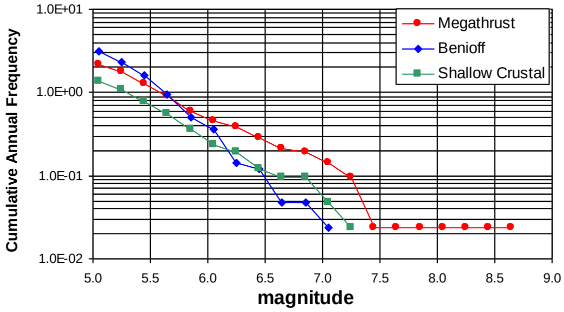


Figure 4. Frequency of earthquake event

Three different models were developed to account for seismicity on the Sumatra Subduction zone and the Sumatran fault zone (Figure 7). The first model was 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 5). The second model was 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 was 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 6).

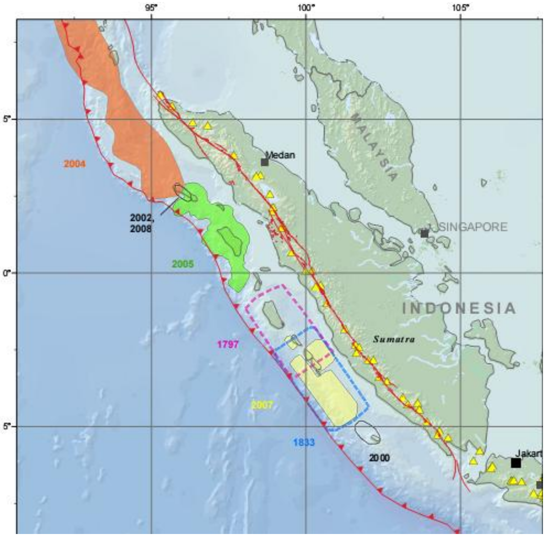


Figure 5. Rupture zone offshore west coastal Sumatera (Briggs, 2007)

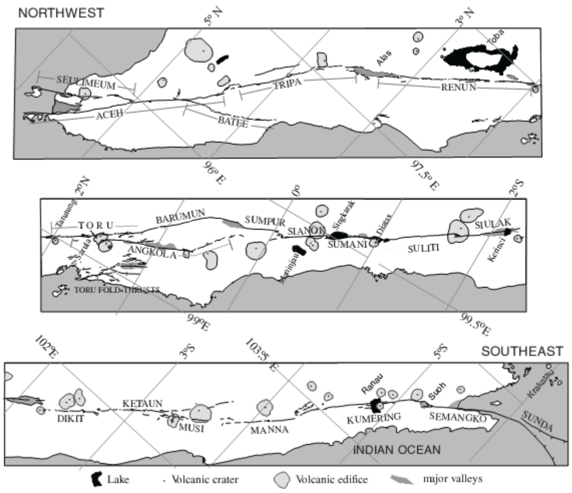


Figure 6. Segments of the Sumatran fault system (Sieh and Natawidjaja, 2000)

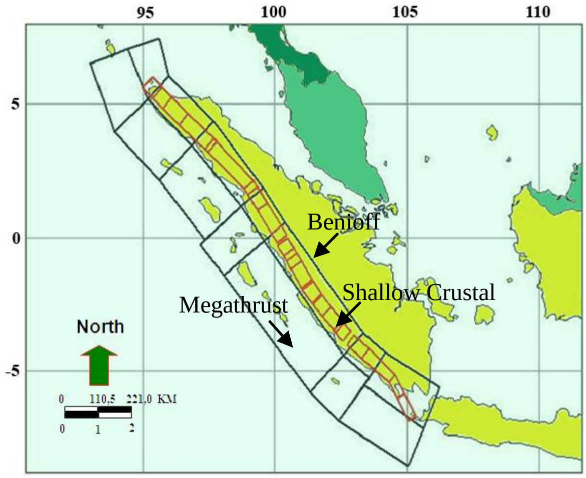


Figure 7. Seismic source zones for site location

5.0 Attenuation Models

There has 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 Youngs *et al.* (1997) and that for shallow crustal developed by Boore *et al.* (1997) are selected.

6.0 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,

$$P_{(a \geq a^*)} = \int_M \int_R P_{(a \geq a^*; m,r)} f_{M(m)} f_{R(r)} drdm \qquad (1)$$

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 totalling the probability of each source. It can be written in mathematical form as follows,

$$\lambda(a \geq a^*) = \sum_{i=1}^{Ns} \nu_i . P(a \geq a^*) \qquad (2)$$

where :

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

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

In PSHA, aleatory uncertainties, which are inherently random, are accounted for by considering earthquake events with all possible magnitudes and distances; epistemic uncertainties, which are due to the lack of knowledge, can come from the uncertainty in identifying correct models such as ground motion prediction models. Logic tree are used in this study in order to allow uncertainty in selection of models to be considered. Figure 8 depicts the uncertainties in PSHA calculation through a logic tree with various weights assigned to recurrence models and attenuation equations.

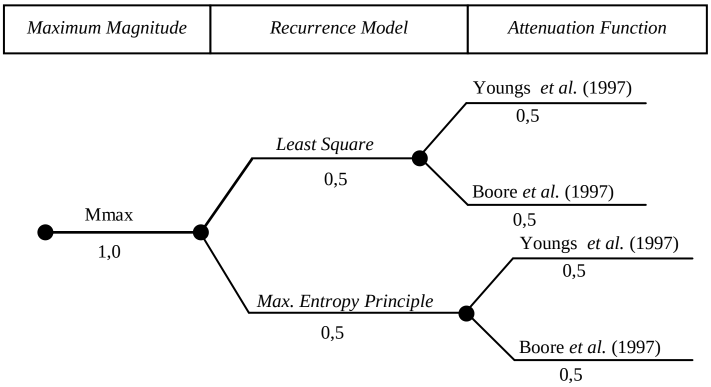


Figure 8. Logic tree used in the analysis

The spectral hazard maps of Peninsular Malaysia were developed based on total probability theorem. Maps of the peak ground accelerations expected at 2% and 10% probabilities in 50 years show acceleration of 0.18g and 0.08g for Kuala Lumpur, respectively (Figure 9 and 12). In this study, maps of the 0.2 sec and 1.0 sec spectral accelerations expected at 2% and 10% probabilities in 50 years on bedrock were also constructed (Figure 10, 11, 13 and 14). Maps of spectral acceleration at periods of 0.1 sec or greater can be more relevant to the siting of tall buildings than map of peak ground acceleration, since tall structures are generally more sensitive to these longer periods than to peak ground acceleration, however maps of PGA may be useful for the design of foundations resistant to liquefaction. From T=0.2 and T=1.0 seconds response spectra hazard (Figure 10 and 11), the mean spectral acceleration for Kuala Lumpur are 0.17g and 0.06g for return period of 475 years, respectively. From T=0.2 and T=1.0 seconds response spectra hazard (Figure 13 and 14), the mean spectral acceleration for Kuala Lumpur are 0.42g and 0.11g for return period of 2475 years, respectively. Figure 15 and 16 show the deaggregation hazard for Kuala Lumpur for 475 years return period for T=0.2 and T=1.0 seconds, respectively. The deaggregation hazard for Kuala Lumpur for 2475 years return period for T=0.2 and T=1.0 seconds are shown in Figure 17 and 18, respectively.

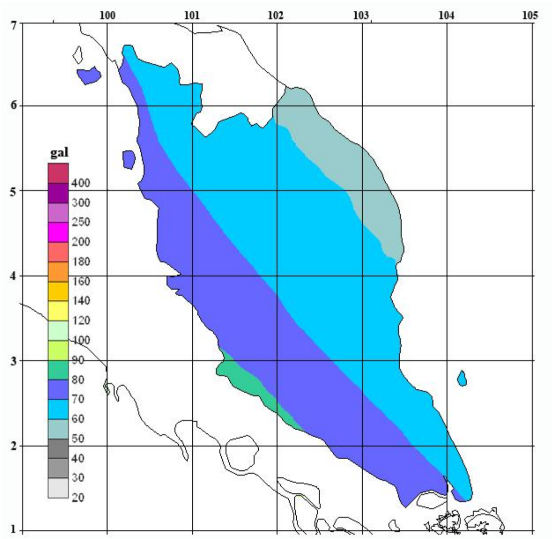


Figure 9. Probabilistic seismic hazard map of peak ground acceleration expected at 10% probability in 50 years on bedrock

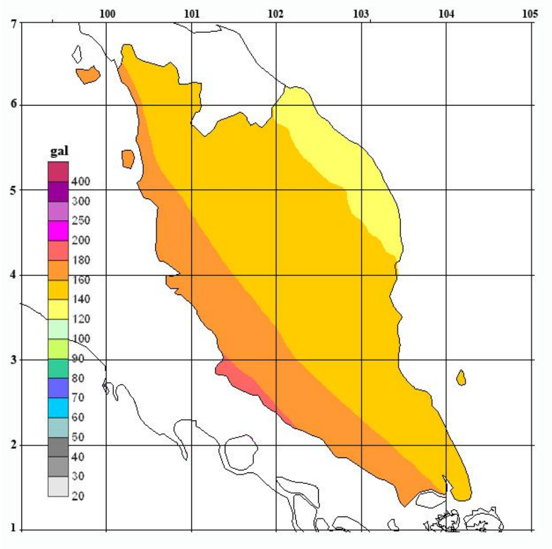


Figure 10. Probabilistic seismic hazard map of 0.2 sec spectral acceleration expected at 10% probability in 50 years on bedrock

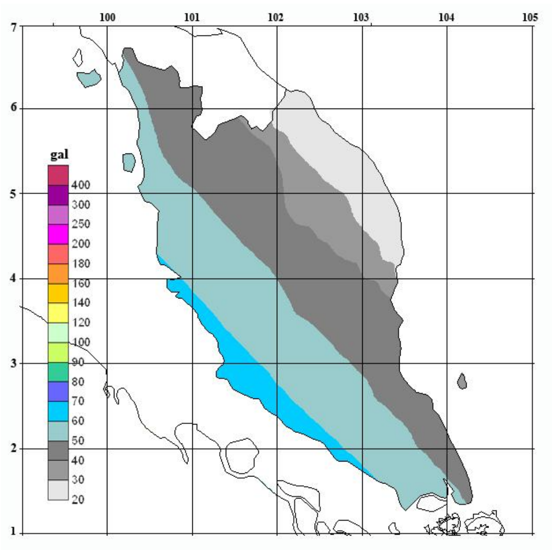


Figure 11. Probabilistic seismic hazard map of 1.0 sec spectral acceleration expected at 10% probability in 50 years on bedrock

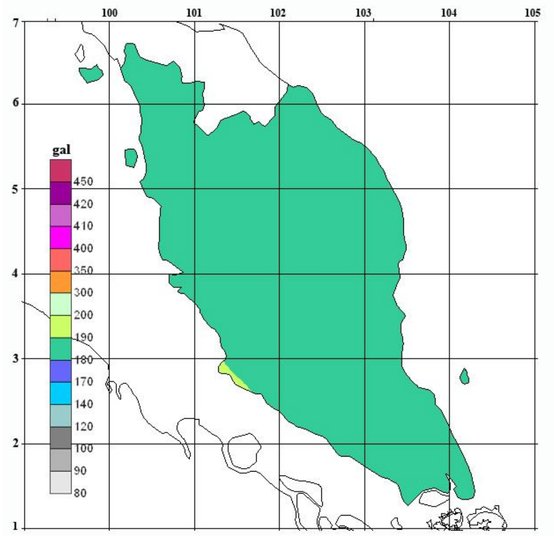


Figure 12. Probabilistic seismic hazard map of peak ground acceleration expected at 2% probability in 50 years on bedrock

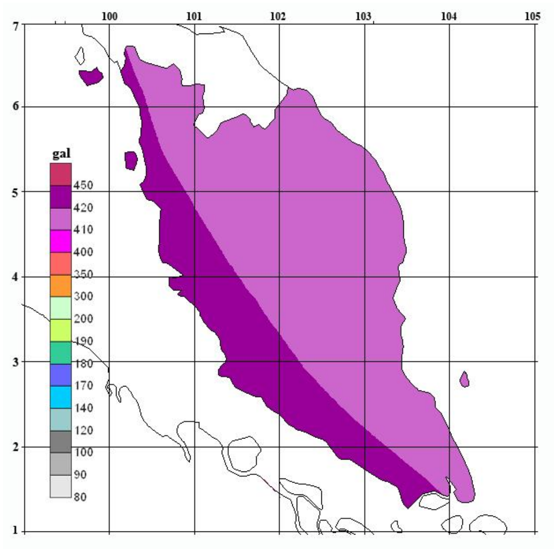


Figure 13. Probabilistic seismic hazard map of 0.2 sec spectral acceleration expected at 2% probability in 50 years on bedrock

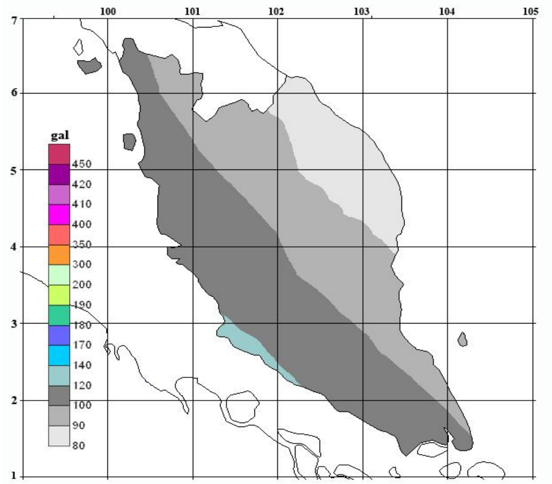
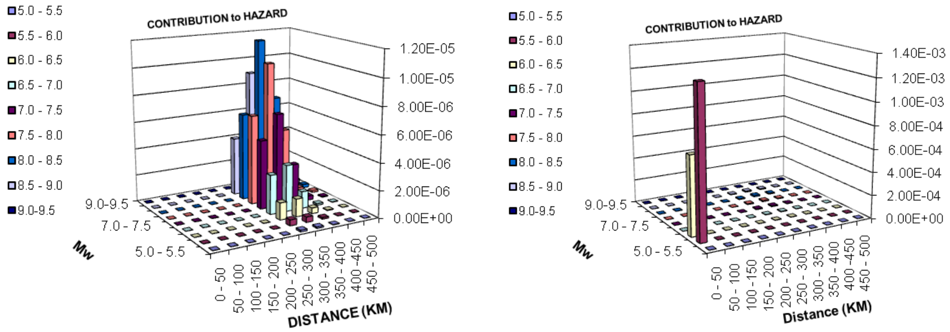
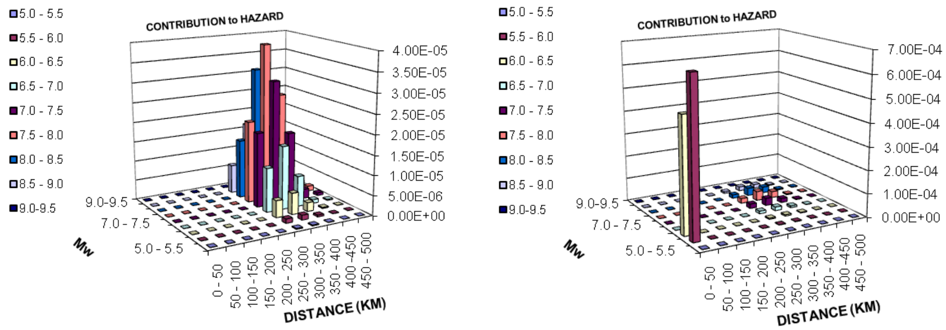


Figure 14. Probabilistic seismic hazard map of 1.0 sec spectral acceleration expected at 2% probability in 50 years on bedrock



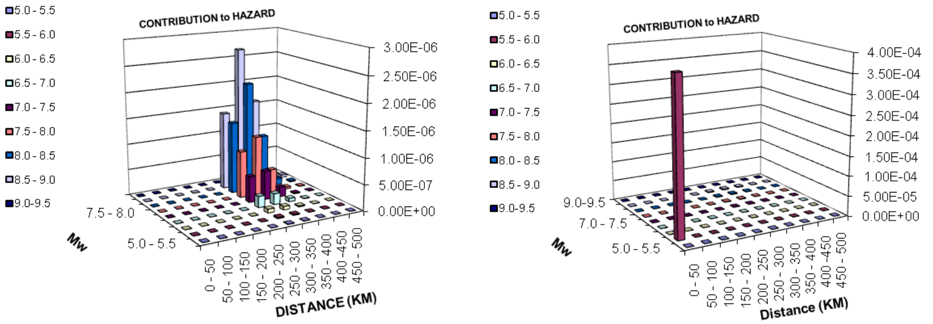
(a) Subduction zone (b) All sources

Figure 15. Deaggregation hazard for T=0.2 seconds and 475 year return period



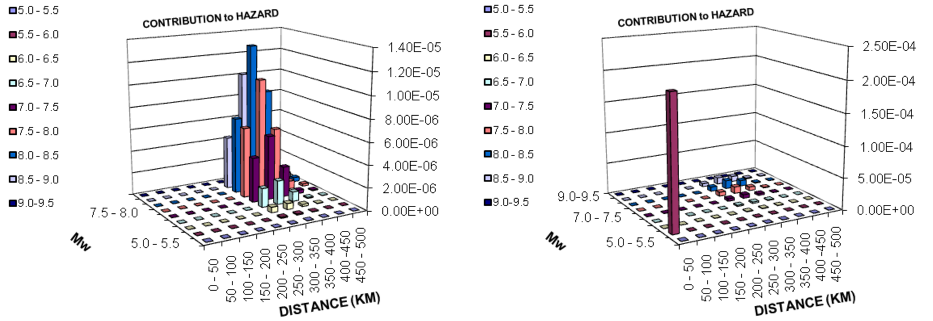
(a) Subduction zone (b) All sources

Figure 16. Deaggregation hazard for T=1.0 seconds and 475 year return period



(a) Subduction zone (b) All sources

Figure 17. Deaggregation hazard for T=0.2 seconds and 2475 year return period



(a) Subduction zone (b) All sources

Figure 18. Deaggregation hazard for T=1.0 seconds and 2475 year return period

7.0 Summary and Conclusion

This study has produced the spectral hazard maps based on probabilistic seismic hazard analysis, which gives not only peak ground acceleration but also short period (0.2 sec) and long-period (1.0 sec) spectra values at the bedrock of Peninsular Malaysia. Two hazard levels were considered in this study to represent 10% and 2% probabilities of exceedence in design time period of 50 years or the corresponding to return period of approximately 475 and 2475 years, respectively. Based on the analysis, the PGA at bedrock of Kuala Lumpur are 0.08g and 0.18g for return period of 475 years and 2475 years, respectively.

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