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LESSON LEARNED FROM THE EFFECT OF RECENT FAR FIELD SUMATRA EARTHQUAKES TO PENINSULAR MALAYSIA

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SUMMARY

This paper presents the results of seismic hazard study of two large earthquakes occurred near Sumatra at the end of 2002 (M_w =7.4) and in the early of 2003 (M_w = 5.8). The objective of this study is to evaluate the effect of those Sumatra Earthquakes to Peninsular Malaysia. This paper discusses the following items: 1) tectonic setting of Sumatra, 2) location, mechanism, and size of recent earthquake, 3) analysis of ground acceleration at bedrock for Penang and Kuala Lumpur, and 4) analysis of local site effect for Penang and Kuala Lumpur.

Seismic analysis was conducted in order to predict peak ground acceleration (PGA) and spectral acceleration at bedrock of Penang and Kuala Lumpur. Analysis was carried out using deterministic method and appropriate attenuation relationship. The selection of attenuation functions were based on the similarity of faulting mechanism between site region and that in which attenuation formulas were derived. The result showed that the PGA at bedrock for Penang and Kuala Lumpur range between 2 and 5 gals.

Local site effect had also been analyzed for Penang and Kuala Lumpur. The analysis was carried out using 1-D shear wave propagation theory by using three-acceleration time histories records (i.e. Elcentro N-S 1940, Loma Prieta, and synthetic) as input data. Synthetic acceleration time histories were generated using random vibration theorem. The results of shear wave propagation analysis showed that strong motion data influenced amplification of motion and the shape of response spectrum. According to the results, acceleration at the bedrock had been amplified about 2 to 7 times at the surface of Penang and Kuala Lumpur.

INTRODUCTION

The researches regarding earthquake engineering in Malaysia are relatively behind compared to other engineering fields. This is due to the fact that Malaysia earthquake event in history is not so profound and the nearest distance of earthquake epicenter from Malaysia is approximately 350 km. Generally; earthquake can cause significant damages within 100-200 km radius from the fault or epicenter. At farther distance

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amplitudes of incoming seismic shear waves are generally small [1], however, the "Bowl of Jelly" phenomenon as what had happened to Mexico City in 1984 should be considered more seriously. The phenomena have shown that an earthquake could have a significant effect although at longer distance due to long period component of shear waves.

Although Peninsula Malaysia is located in the stable Sunda Shelf with low to moderate seismic activity level, tremors due to Sumatra earthquake had been reported several times. For instance, there are two large earthquakes near Sumatra occurred at the end of 2002 (M_w =7.4) and in the early of 2003 (M_w = 5.8). Although no casualties or damages were reported due to those earthquakes, the tremors have been causing panic to a lot of people in several cities in Peninsula Malaysia. Cracks on a few buildings in Penang due to the earthquake on 2 November 2002 also have been reported as well.

This research is proposed to analyze the effects of those two earthquakes to Wilayah Persekutuan Kuala Lumpur and Putrajaya cities. The considerations that are included in this study are geological and seismological conditions, attenuation of earthquake wave propagation in bedrock, specific acceleration time histories, and local soil condition.

TECTONIC SETTING

Malaysia is located on the southern edge of major tectonic plate of Eurasian. This position is relatively closed to the boundary between Eurasian Plate in the northern side and Australian Plate in the southern side. Based on that location, generally tectonic features that affect Peninsular Malaysia can be divided into two classifications. The first classification is subduction zone. All of those earthquakes that occurred near convergent boundaries where Indo-Australian plate is being subducted under Eurasian plate are classified into this zone. The Indo-Australian plate is sliding approximately northward beneath Sumatra and Java, where the direction of convergence is N20oE and the overall rate convergence is 7.7-cm/year [2]. Generally, this Subduction zone can be divided into three segments, i.e. Sumatra Segment, Sunda Strait segment, and Java Segment. The Sumatra subduction zone is a very active feature. The largest thrust-fault earthquakes in the Sumatra subduction zone in the last two centuries were in the year of 1833, with the magnitude of 8.8-9.2, and that of 1861, with the magnitude of 8.3-8.5.

The second classification is transform 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. Several large earthquakes have occurred in this zone. These events were included the 1926 Padang Panjang (MS = 6.75), the 1933 Liwa (MS=7.5), the 1964 Aceh (mb = 6.7) and the 1993 Liwa (MS = 7.2) earthquakes. Tectonic setting around Peninsular Malaysia can be seen in Figure 1.

According to USGS, the earthquake on 2 November 2002 (NS2002) occurred on Sumatra subduction zone whereas the earthquake on 22 January 2003 (NS2003) occurred as a result of strike slip mechanism of Sumatra fault. In order to verify the mechanism of that earthquake, spatial distribution of earthquakes nearby NS2002 and NS2003 were constructed from earthquake data occurred from the year 1900 to 2002. The distribution of epicenters is presented in Figure 2. The hypocentral profile revealed downward dipping zone of seismicity nearby those two earthquakes are depicted in Figure 3 and 4.

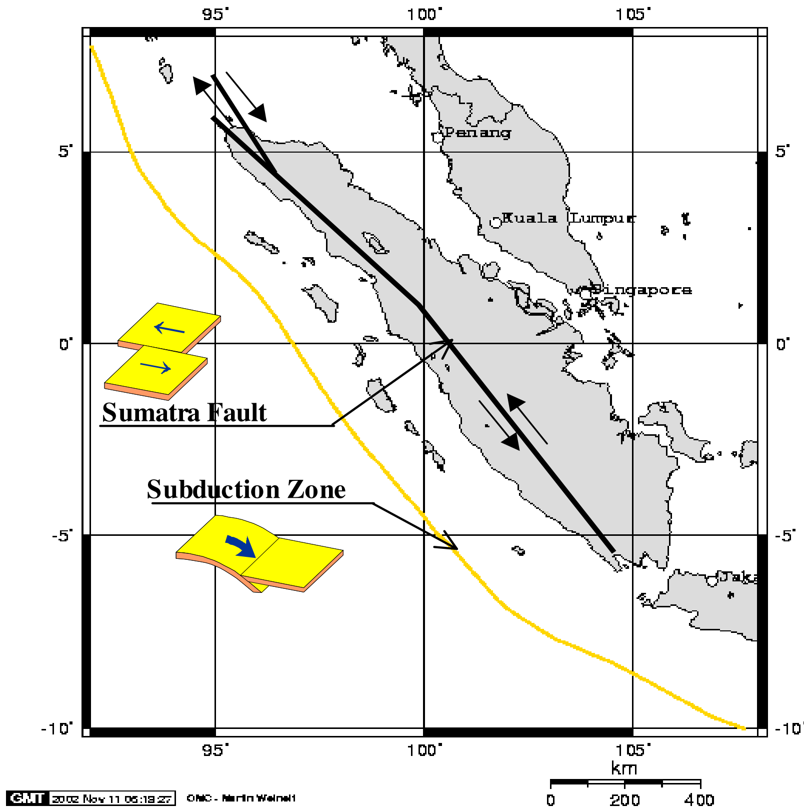


Figure 1. Tectonic setting of Sumatra

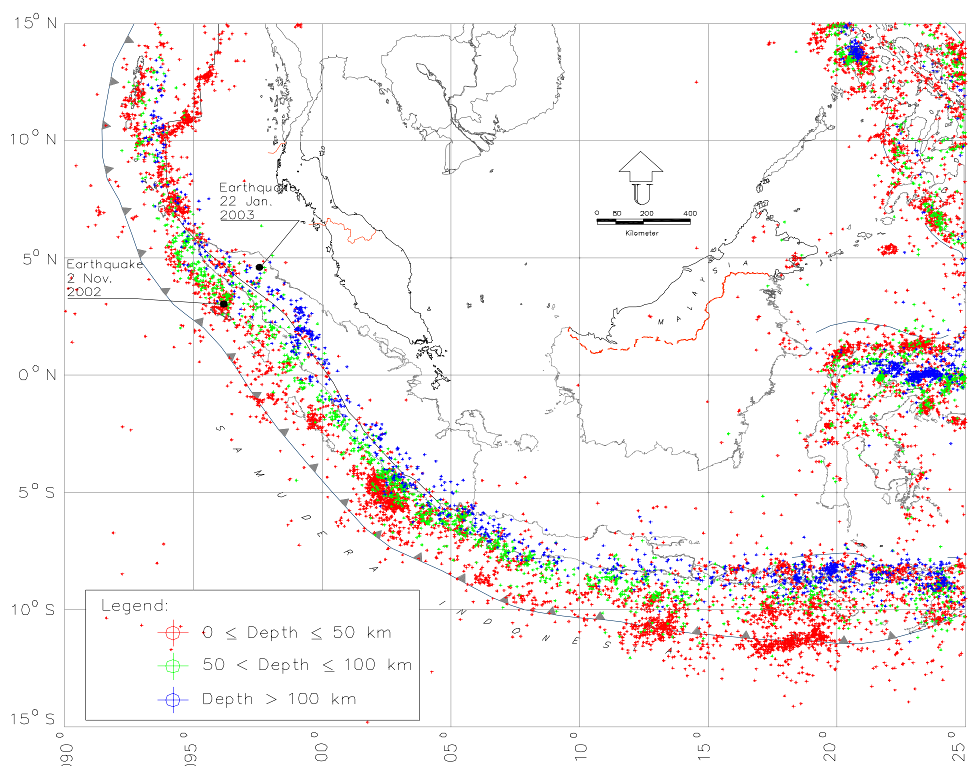


Figure 2. Location of epicenter of earthquake from 1900-2003 (USGS-NEIC)

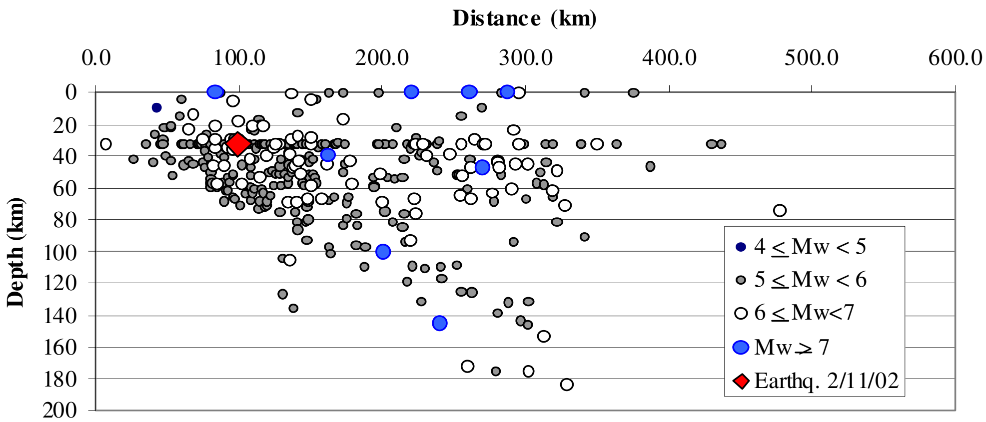


Figure 3. Hypocentral profile around NS2002

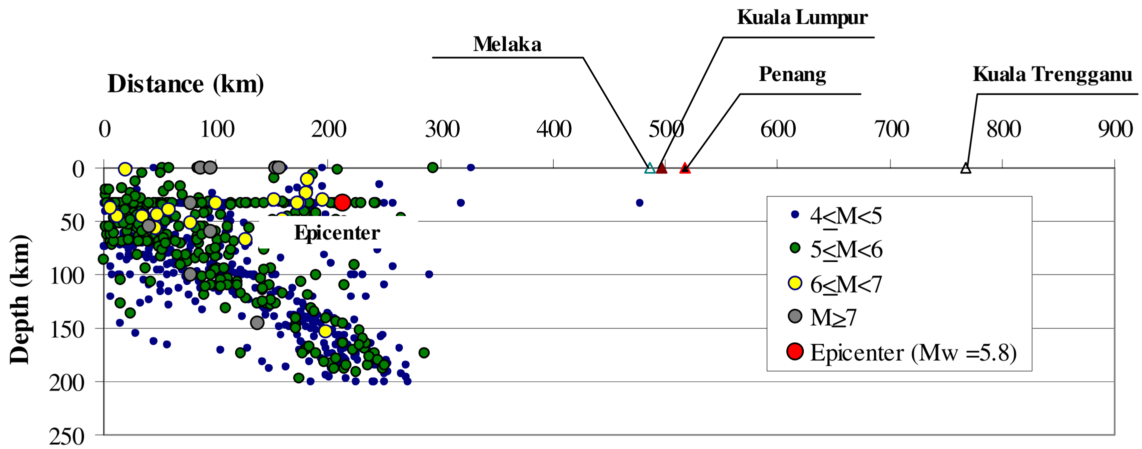


Figure 4. Hypocentral profile around NS2003

Based on Figure 3 and Figure 4, it can be seen the NS2002 was located on subduction zone and the NS2003 occurred on transform zone of Sumatra.

SEISMIC HAZARD ASSESSMENT

Seismic hazard assessment is performed in order to obtain peak ground acceleration (PGA) at bedrock for Penang and Kuala Lumpur. Analysis is carried out using deterministic method and using several appropriate attenuation relationships. In the study, the attenuation function proposed by Atkinson and Boore [3] was used to calculate PGA for subduction earthquake event whilst Campbell [4] formula was used for strike-slip earthquake event.

Based on the calculation, the PGA's at bedrock for Penang and Kuala Lumpur due to NS2002 event were 4.84 gal and 3.32 gal, respectively and the PGA's at bedrock for those two cities due to NS2003 event were 4.86 gal and 2.23 gal, respectively. The contours of iso-acceleration of those two events at bedrock of Peninsular Malaysia are presented in Figure 5 and 6.

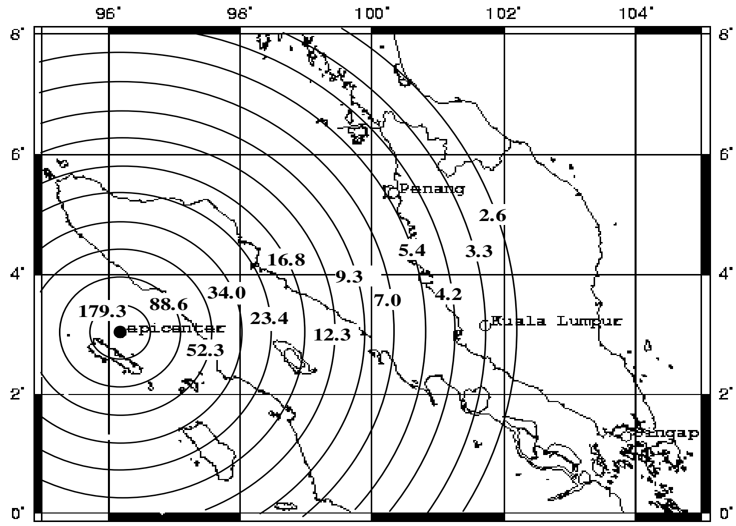


Figure 5. PGA contour at bedrock due to NS2002 event using Atkinson and Boore [3] formula

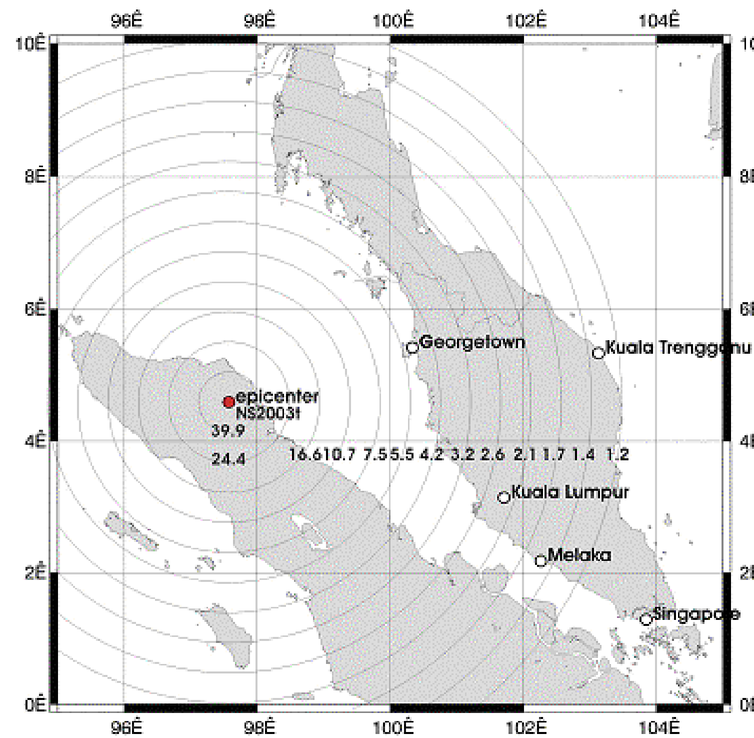


Figure 6. PGA contour at bedrock due to NS2003 event using Campbell [4] formula

GENERATION OF SYNTHETIC GROUND MOTION

Acceleration time-histories are required in the analysis of shear wave propagation in soil deposits. Selection of time-histories appropriates for specific geological and seismological conditions play an important role for obtaining accurate results because the characteristics of motion such as peak acceleration, duration and frequency content will affect the result of shear wave propagation analysis. Several procedures can be used to select earthquake acceleration time-histories at bedrock. These procedures include: (1) utilization of motions previously detected near the site; (2) utilization of motions previously recorded at other locations during similar size earthquake and at distance comparable to those under consideration; (3) estimation of a target spectrum and then generation of a synthetic time history whose spectral ordinates provide a reasonable envelope to those of the target spectrum. Procedure number (1) is rare to be conducted in Malaysia because there are no representative strong motions that can be used for analysis. Procedure number (2) is difficult to utilize at most locations because the number of recorded motions is not extensively enough to cover a sufficiently wide range of possibilities. The most commonly method to cover this shortcoming is by modifying the actual ground motion records. By using this method, acceleration time-histories can be obtained from rescaling the actual ground motions record. The disadvantage of this procedure is the seismological and geological mechanism may not appropriate with the local condition. The ground motion time histories recorded from Elecntro, Pasadena, and Mexico have been widely used in analyzing dynamic response in soil deposits and structure in region in which a lack of recording data such as Malaysia.

In this study, procedure (3) is performed to generate synthetic ground motions using random vibration theorem. Procedure for generating synthetic ground motion based on random vibration theorem has been described by Gasparini and Vanmarcke [5]. This procedure is based on the fact that any periodic function can be expanded into a series of sinusoidal waves:

$$x(t) = \sum_{i} A_i \cdot \sin(\omega_i t + \phi_i) \tag{1}$$

Where A_i is the amplitude and ϕ_i is the phase angle of the i^{th} contributing sinusoidal. The amplitude A_i are related to the (one side) spectral density function $G(\omega)$ in the following way:

$$A_i = \sqrt{2 \int_{o}^{\omega_i} G(\omega_i) \cdot d\omega} \tag{2}$$

A relationship between the response spectrum and the spectral density function of ground motion at site can be seen in the following equation.

$$G(\omega_n) = \frac{1}{\omega_n \left[\frac{\pi}{4\zeta_s} - 1 \right]} \left\{ \left(\frac{\omega_n \cdot Sv}{r_{s,p}} \right)^2 - \int_{0}^{\omega_n} G(\omega) d\omega \right\}^{1/2} \tag{3}$$

where:

$$\zeta_s = \frac{\zeta}{1 - e^{-2\zeta \cdot \omega_n \cdot t}} \tag{4a}$$

$$r_{s,p} = \left[2 \cdot \log \left\{ 2n \left[1 - \exp(-\delta_y(s) \sqrt{\pi \cdot \log 2n} \right] \right\} \right]^{1/2} \tag{4b}$$

$$\delta_y(s) = \left(\frac{4\zeta \cdot t}{\pi} \right)^{1/2} \tag{4c}$$

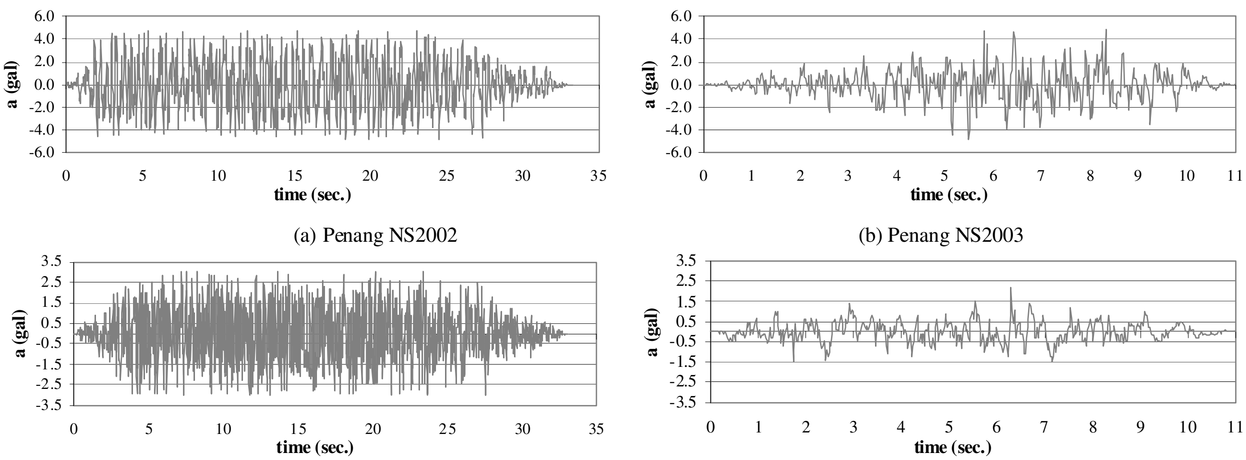
$$n = \frac{-\omega_n \cdot t}{2\pi} \cdot \frac{1}{\log \cdot 0.368} \tag{4d}$$

The response spectrum in the equation (3) is obtained from seismic hazard analysis by using attenuation relationships for response spectrum. The power of the motion produced by using equation (1) does not vary with time. To simulate the transient character of real earthquakes, the steady-state motions are multiplied by a deterministic envelope function I (t). The artificial motion X (t) becomes:

$$X(t) = a(t) = I(t)\sum_{n} A_n \cdot \sin(\omega_n t + \phi_n) \quad (5)$$

There are three different intensity envelope functions available such as trapezoidal, exponential, and compound [5]. In this study, duration and envelope intensity function were calculated based on a procedure proposed by Kuda [6].

In this study, the generation of synthetic ground motions by random vibration theorem was performed using SIMQKE [5]. The results of analysis can be seen in Figure 7.



(a) Penang NS2002

(b) Penang NS2003

(c) KL NS2002

(d) KL NS2003

Figure 7. Synthetic Accelerations at Bedrock of Penang and Kuala Lumpur

LOCAL SITE EFFECT

Local site effect strongly influences the characteristic of ground surface motions, i.e. peak acceleration amplitudes and shapes of response spectra. Comparison of peak acceleration attenuation relationships for sites underlain by different types of soil profiles shows distinct trends in amplification behavior [7]. According to Idriss [7], peak accelerations at the surface of soil deposits are slightly greater than that on rock. At higher acceleration levels, however, the low stiffness and nonlinearity of soft soils often prevent them from developing peak ground accelerations as large as those observed on rock.

Local site conditions also influence the frequency content of surface motions and hence the response spectra they produce. The average normalized response spectra from Seed et al. [8] also show that at longer periods, spectral amplification is much higher for soil sites than for rock sites. This effect can be very significant, particularly when long period structures such as bridges and tall buildings are founded on such deposits.

In this study, site response analyses is carried out using 1-D shear wave propagation theory resulting in the estimate of ground motion parameter, i.e. peak surface acceleration (PSA) and surface spectral acceleration. The analysis is performed using program NERA [9], which stands for **N**onlinear **E**arthquake **R**esponse **A**nalysis. In this program, soil model proposed by Iwan [10] and Mroz [11] were used in order to model nonlinear stress-strain curves of soil. This model used series of n-mechanical elements, having different stiffness and sliding resistance.

Dynamic Soil Properties

The dynamic soil properties that are required in a site response analysis are maximum shear modulus, G_{max} or shear wave velocity, V_s. Several researchers such as Seed [12] and Ohsaki and Iwasaki [13] have proposed correlations to convert the results from static soil test obtained from laboratory or in situ testing to obtain dynamic soil properties such as G_{max}, and V_s.

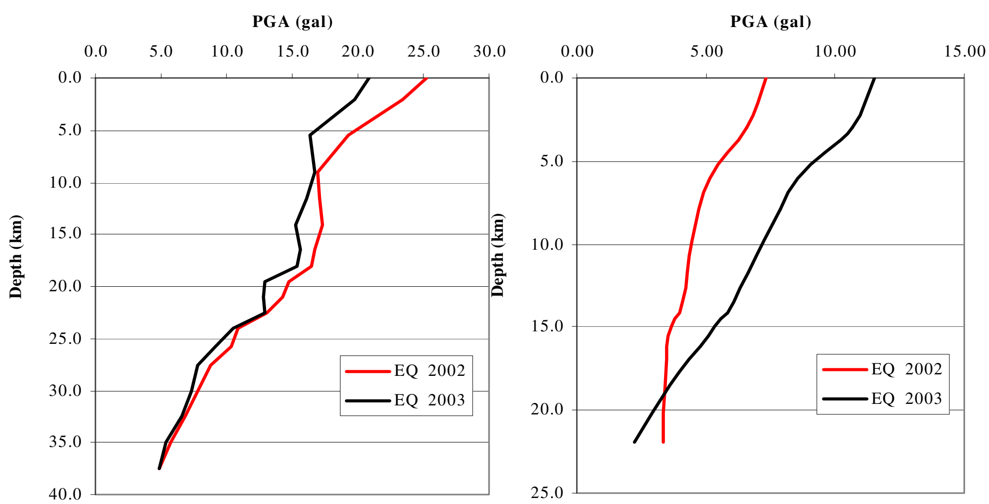
Locations of study in this analysis are Sekolah Kebangsaan Sungai Penang, Penang and Bandar Baru Sentul, Kuala Lumpur. In this study, dynamic soil properties were obtained using empirical correlations proposed by Seed et al. [12] for non-cohesive soil and Ohsaki and Iwasaki [13] for cohesive soil.

Shear Wave Propagation Analysis

In this study, shear wave propagation analysis had been analyzed using three strong motion data i.e. Elcentro N-S 1940, Loma Prieta and synthetic. The average PGA obtained from the results of shear wave propagation analysis using NERA [9] is presented in Figure 8. The results can be summarized in Table 1.

Table 1. The results of shear wave propagation analysis

No.	Event	Location	PGA (gal)	PSA (gal)	Amplification
1	2nd Nov. 2002	Penang	4.84	25.3	5.2
2		Kuala Lumpur	3.32	7.3	2.2
3	22nd Jan. 2003	Penang	4.86	20.8	4.3
4		Kuala Lumpur	2.23	11.6	5.2



(a) Penang (b) Kuala Lumpur

Figure 8. Distribution of acceleration against depth

The results of analysis show that the peak acceleration at bedrock increase about 2 to 5 times at the surface due to the effect of local soil condition and characteristic of ground motion. According to Modified Mercalli Intensity (MMI) Scale [14], generally the intensity at the surface due to those earthquakes in Penang and Kuala Lumpur approximately correlate with scale V and IV on MMI scale, respectively.

Figures 9 and 10 show the comparison of response spectrum between earthquake on 2 November 2002 and 22 January 2003. Response spectrum are obtained by averaging the results from three acceleration time histories, i.e. Elcentro N-S 1940, Loma Prieta and synthetic. These figures showed the strong motion data influence amplification of motion and the shape of response spectra. According to these figures, the locations of maximum spectral acceleration are between period of 0.1 sec and 1.0 sec. It means that practically, the maximum effect of the motion will occur on the 1 to 10- storey building in Penang and Kuala Lumpur.

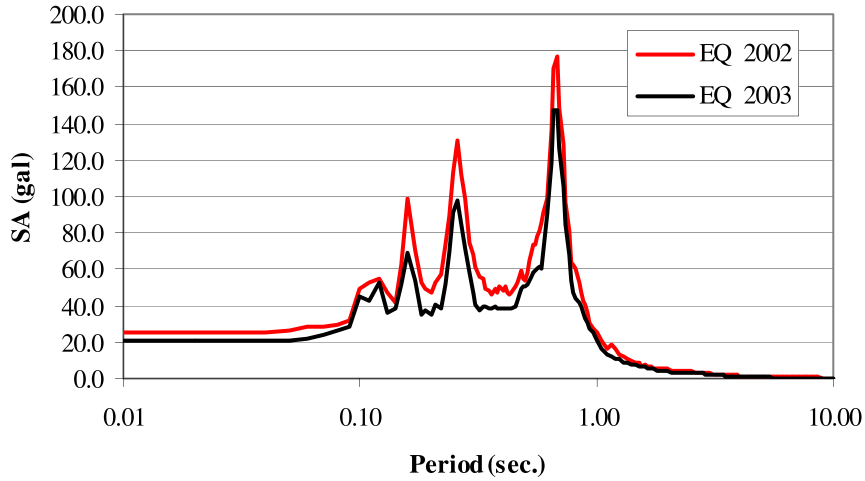


Figure 9. Response spectrum at the surface of Penang

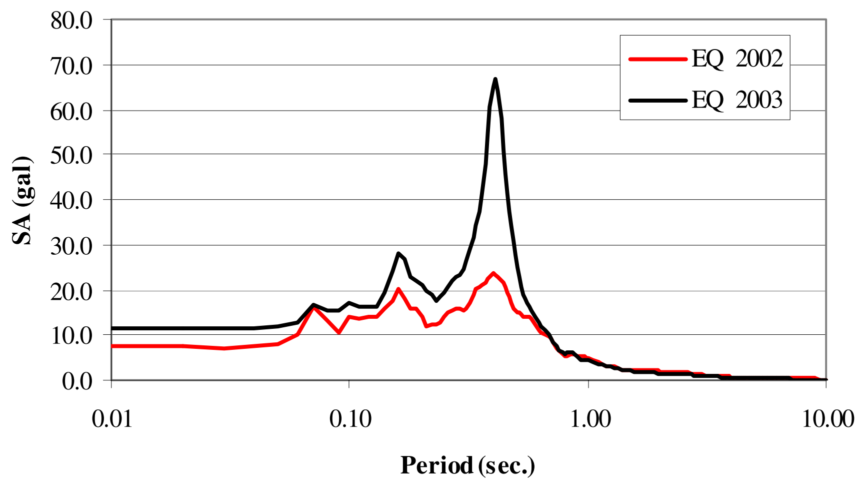


Figure 10. Response spectrum at the surface of Kuala Lumpur

CONCLUSION

Based on the results of the attenuation formula, the PGA's at bedrock for Penang and Kuala Lumpur due to earthquake on 2 November 2002 were 4.84 gal, and 3.32 gal, respectively and the PGA's at bedrock for Penang and Kuala Lumpur due to earthquake on 22 January 2003 were 4.86 gal and 2.23 gal, respectively.

Acceleration time-histories are required in the analysis of shear wave propagation in soil deposits. Selection of time-histories appropriates for specific geological and seismological conditions play an important role for obtaining accurate results because the characteristics of motion such as peak acceleration, duration and frequency content will affect the result of shear wave propagation analysis. In this study, synthetic ground motions have been generated in the frequency domain by using random vibration theorem.

Local site effect strongly influences the characteristic of ground surface motions, i.e. peak acceleration amplitudes and shapes of response spectra. Therefore, site response analysis is needed in order to predict the effect of the motion at the surface. The analysis was carried out using 1-D shear wave propagation analysis theory at Sekolah Kebangsaan Sungai Penang and Bandar Baru Sentul The results showed that the peak accelerations at bedrock increase about 2 to 5 times at the surface due to the effect of local soil condition and characteristic of ground motions. It can be concluded that intensities at the surface due to those two earthquakes in Penang and Kuala Lumpur approximately correlate with scale V and IV on Modified Mercalli Intensity (MMI) scale, respectively. The effect of the earthquake to building depends on the natural period of the building. The maximum effect of the motion will occur on the 1 to 10- storey building in Penang and Kuala Lumpur.

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