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MICROZONATION MAPS FOR KUALA LUMPUR AND PUTRAJAYA

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Abstract: Geotechnical factors often exert a major influence on damage patterns and loss of life in earthquake events. Even within an area of a city, building response and damage are varied significantly due to variation of soil profiles in that particular city. The existing codes or provisions, which were applied in a certain region, may not be necessarily employed directly in other region since 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 that is suitable with the characteristics of that particular region rather than adopting the existing code. This paper presents the results of microzonation study for Kuala Lumpur city center and Putrajaya in Peninsular Malaysia. The microzonation study consists of two stages: (1) determination of the local geological and local geotechnical site conditions; and (2) computation of the ground response through soil deposit from base rock motions. Ground response analyses were performed using one dimensional shear wave propagation method. The analyses were conducted using nonlinear approach in order to consider the actual nonlinear response of a soil deposit. The results show that the accelerations at the surface of Kuala Lumpur city center are in the range of 90 to 190 gals and 180 to 340 gals for 500 and 2,500 years return periods, respectively. The accelerations at the surface of Putrajaya are in the range of 130 to 190 gals and 220 to 340 gals for 500 and 2,500 years return periods, respectively. Generally, the amplification factors on each city for those two hazard levels, ranges between 1.2 and 2.6. As a conclusion for this study, eight microzonation maps have been produced for each city that could be used as input for seismic design, land use management, and estimation of potential liquefaction and landslides.

Keyword: *microzonation study, local site effects, ground response analysis*

1. Introduction

Earthquake is one of the most devastating natural disasters on earth. Generally, the effects of strong earthquakes are caused by ground shaking, surface faulting, liquefaction, and less commonly, by tsunamis. 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 are 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 [1].

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 [2]. The pronounced influence of local soil conditions on the characteristics of the observed earthquake ground motions also can be seen during 1957 San Francisco Earthquake [3]. Even within an area of a city, building response and damage are varied significantly due to variation of soil profiles in that particular city [3]. 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.

In recent years, Malaysia is more aware to the seismic effects on the buildings because the tremors were repeatedly felt over the centuries from the earthquake events around Malaysia. 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 in which the location of epicenter is more than 500 km from Penang has caused cracks on some buildings in Penang. Other earthquake having magnitude, Mw, 7.3 occurred on 25 July 2004 in South Sumatra caused cracks on one apartment building in Gelang Patah, Johor Bahru. There are no casualties or major damages were reported due to those earthquakes, but the tremors caused panic to a lot of people around that particular area.

Due to 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. This paper presents the results of microzonation study for developing microzonation maps for Kuala Lumpur (KL) city center and Putrajaya. Those two cities are selected because they have significant number of high rise and monumental buildings. Moreover, Kuala Lumpur and Putrajaya are the business center and administration center in Malaysia, respectively. Hence, these cities have a lot of investments and assets that should be protected against earthquake hazard. Microzonation for seismic hazard has many uses as mentioned by Finn et al. [4]. It can provide input for seismic design, land use management, and estimation of potential liquefaction and landslides. It also provides the basis for estimating and mapping the potential damage to buildings.

2. Ground Response Analysis

Ground response analyses are used to predict ground surface motions for the development of microzonation maps and design response spectra, to evaluate dynamic stresses and strains for evaluation of liquefaction hazards, and to determine the earthquake-induce forces that can lead to instability of earth and earth-retaining structures. Generally, the methods for analyzing ground response can be grouped according to the dimensionality of the model where the incoming shear waves propagate from the underlying bedrock: one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) shear wave propagation methods. Most of these methods are based on the assumption that the main responses in a soil deposit are caused by the upward propagation of horizontally polarized shear waves (SH waves) from the underlying rock formation.

1-D method is based on assumption that all boundaries are horizontal and that the response of a soil deposit is predominantly caused by shear wave propagating vertically from the underlying bedrock. Although the soil layers are sometimes inclined or bent, they are regarded as horizontal in most cases. Furthermore, the length of a layer is infinite compared with its thickness. It is thus practical to model them as 1-D horizontal layers. Analytical and numerical procedures based on this concept, incorporating linear approximation to nonlinear soil behavior, have shown reasonable agreements with field observations in a number of cases [5].

1-D method is most widely used in ground response analysis because it is more practical to be used for high quantitative analyses compared to 2-D or 3-D methods. Therefore, most of current seismic codes were developed by using this method such as UBC 1994, UBC 1997, and IBC 2000 [6, 7, 8]. The other two methods (2-D or 3-D) are usually used for analyzing special cases or for special structures (e.g. dams, high-rise buildings, and nuclear power plants). In this study, the ground response analyses were carried out using 1-D shear wave propagation theory.

2.1. Soil Modeling

The ground response analysis should consider the nonlinearity of soil behavior to provide reasonable results. There are two approaches to include the effect of nonlinearity of soil material into the analysis: equivalent linear and nonlinear approaches. In equivalent linear approach, the strain-compatible soil properties are assumed to be constant throughout the duration of the earthquake, regardless of whether the strains at a particular time are small or large. Equivalent linear models imply that the strain will always return to zero after cyclic loading, and since a linear material has no limiting strength, failure cannot occur. The nonlinear of soil behaviors are approximated by determining the values that are consistent with the level of strain induced in each layer. The equivalent linear approach to 1-D ground response analysis of layered site has been coded into a widely used computer program such as SHAKE [9], SHAKE91 [10], and EERA [11]. The equivalent linear approach is incapable of representing the changes in soil stiffness that actually occurs during the earthquake. It also means that it cannot be used directly for problems involving permanent deformation or failure. An alternative approach is to analyze the actual nonlinear response of a soil deposit using direct numerical integration in the time domain. The advantages of nonlinear method are [5]: (1) the stiffness of an actual nonlinear soil changes over the duration of large earthquake, such high amplification levels that occur in equivalent linear approach, will not develop in the field; and (2) nonlinear method can be formulated in terms of effective stresses to allow modeling of the generation, redistribution, and eventual dissipation of excess pore pressure during and after earthquake shaking.

In this study, the ground response analyses were performed using nonlinear approach. The analyses were carried out using program NERA [12], which stands for Nonlinear Earthquake Response Analysis. This program uses soil model proposed by Iwan [13] and Mroz [14] to model nonlinear stress-strain curves of soil.

2.2. Dynamic Soil Properties

Ground response analysis requires profile of dynamic soil parameters such as maximum shear modulus, G_{max} or shear wave velocity, V_S and damping, β. This parameter can be obtained from field dynamic tests or by converting from static field tests using empirical formula. Numerous researchers have investigated the relationship between maximum shear modulus or shear wave velocity and N-value of Standard Penetration Test (N_{SPT}-values). Most of the studies were performed in the 1970's in Japan. Since then, some similar studies have been reported in the United States. Some of the correlations compiled by Barros [15] are listed in Table 1. Comparisons among the correlations are presented in Figure 1. As can be seen in the figure, correlations for V_S are almost identical, while in the correlations for G_{max}, an appreciable amount of deviation is evident especially at large N_{SPT}-values. Therefore, the static parameters from standard penetration test (SPT) were converted into V_S by using the formula proposed by Ohta & Goto [16] and Imai & Tonouchi [17].

Reference	**Correlations G_{max} (kPa)**	**Correlations V_s (m/sec.)**	**Soil type**
Ohsaki & Iwasaki [18]	$G_{max}=11500\ N^{0.8}$		all (Japan)
Ohta & Goto [16]		$V_s=85.3\ N^{0.314}$	all (Japan)
Imai & Tonouchi [17]	$G_{max}=14070\ N^{0.68}$	 $V_s=96.9\ N^{0.314}$	all (Japan) all (Japan)
Seed *et al.* [19]	$G_{max}=6220\ N$		sand (USA)

Table 1. Correlations between G_{max} or V_S and N-SPT [15]

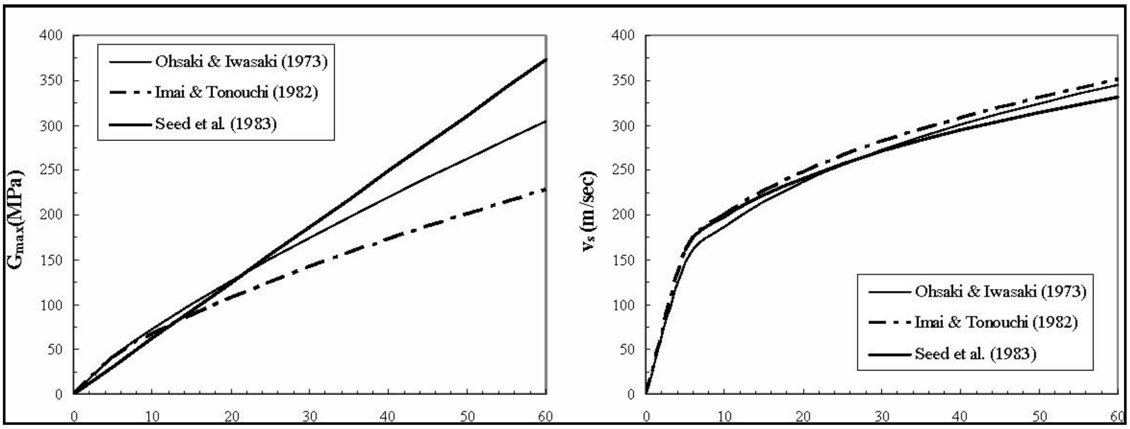


Figure 1. The relationship between shear modulus , G_{max} and shear wave velocity, V_S with N_{SPT}

3. Geologic Setting of Kuala Lumpur and Putrajaya

The general geology of the Kuala Lumpur area has been well documented by Gobbett [20] and Yin [21]. Basically, the Kuala Lumpur area consists of a flat alluvial plain bounded on the east and west by predominantly granitic ranges. The floor of the valley consists of extensive limestone bedrock which is overlain by alluvial deposits. An isolated limestone hill, namely the Batu Caves, and several other hillocks formed by the Hawthornden and Dinding schists occur in the northern areas of Kuala Lumpur. The general geology of the Kuala Lumpur area is shown in Figure 2 and the diagrammatic bedrock profiles are shown in Figure 3.

The general geology of Putrajaya is relatively similar to Kuala Lumpur. Most of the bedrock of Putrajaya is dominated by schist and phyllite, and some of quartzite. The general geology of the Putrajaya area is shown in Figure 4.

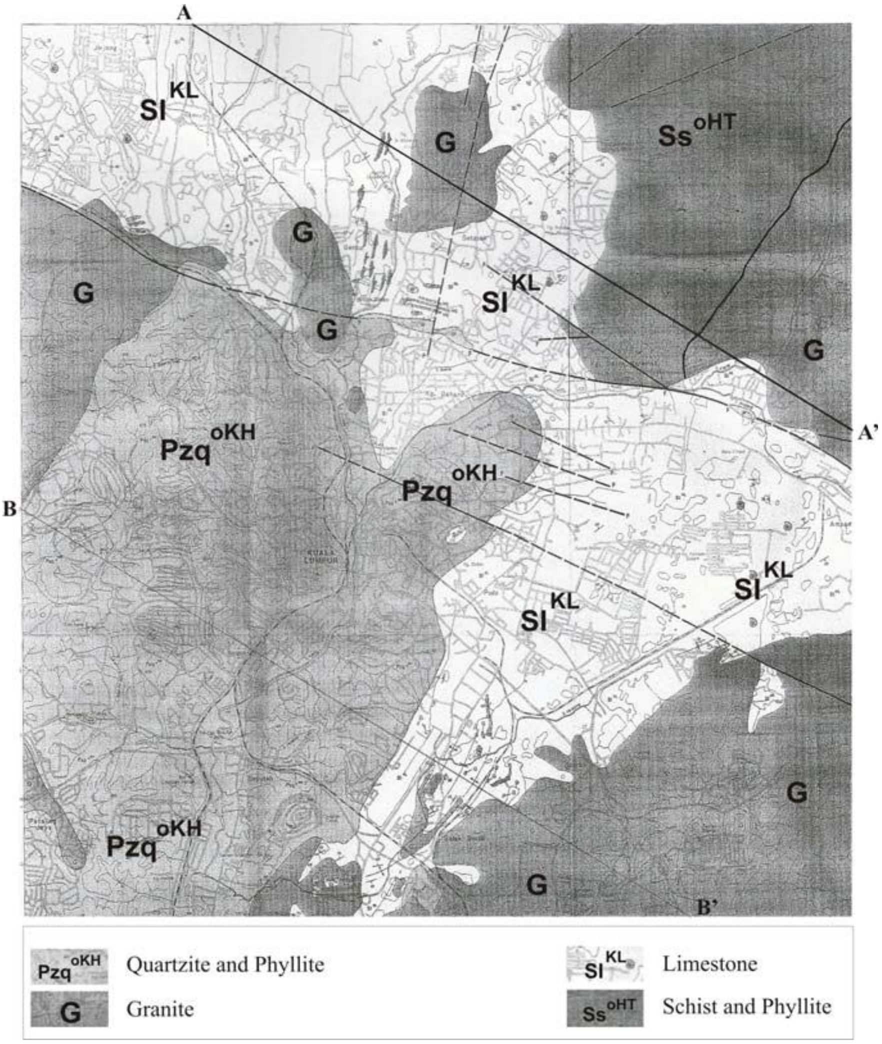


Figure 2. Bedrock geology of Kuala Lumpur [22]

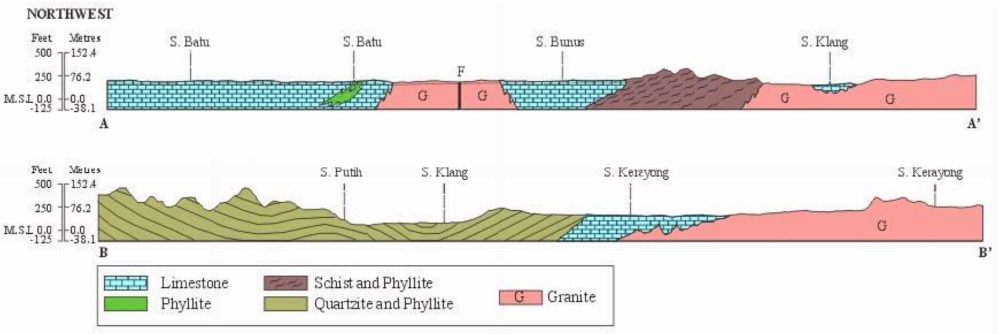


Figure 3. Diagrammatic sections along cross section AA' and BB' [22]

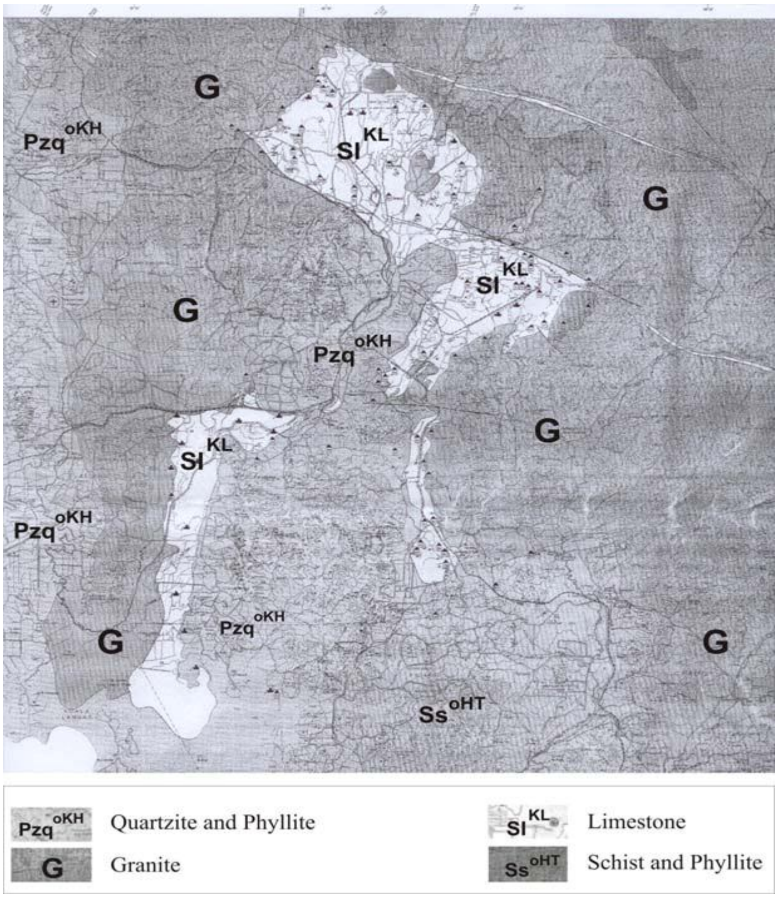
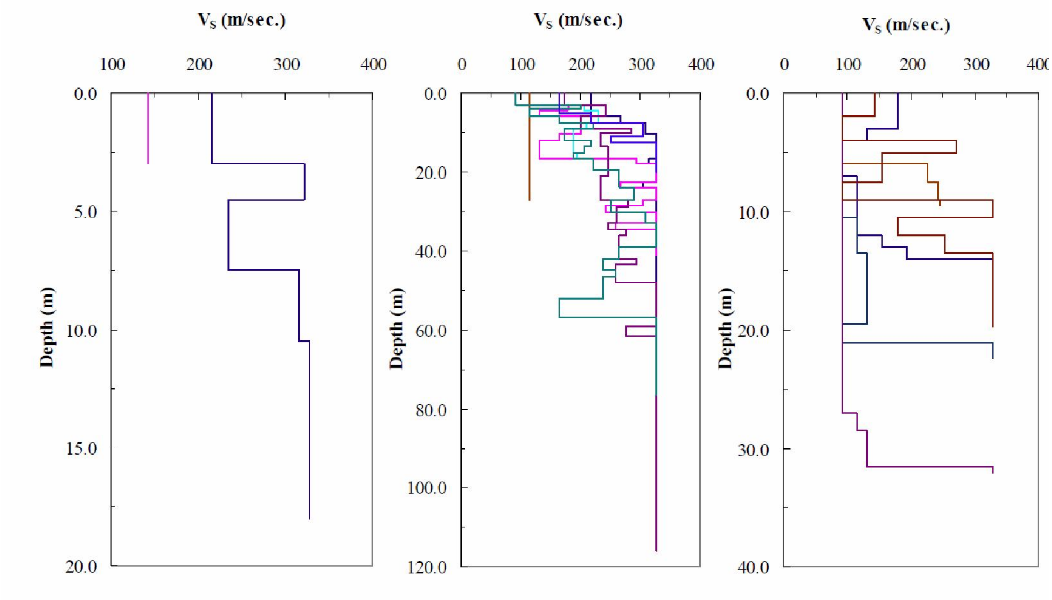


Figure 4. Bedrock geology of Putrajaya [23]

4. Site Classification

Several existing soil data in KL city center and Putrajaya had been used in this study for classifying and calculating the dynamic parameters of the soil. For each data, the soil dynamic properties were obtained by converting the static parameters from N_{SPT} values using the formulas proposed by Ohta & Goto [16] and Imai & Tonouchi [17]. Some of the results are summarized in Figure 5 and Table 2 for KL city center and Figure 6 and Table 3 for Putrajaya. The classification of a particular site was determined by referring three specifications: 1997 UBC/2000 IBC [7, 8], Eurocode 8 [24], and Bray and Rodriguez-Marek [25].

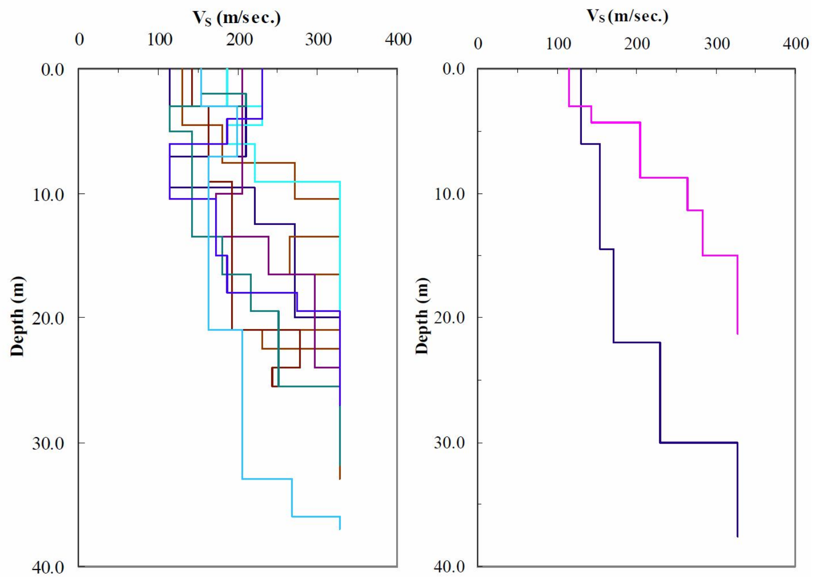


a) Site Class S_C b) Site Class S_D b) Site Class S_E

Figure 5. Soil dynamic properties for KL city center

Table 2. Soil Classification of KL city center

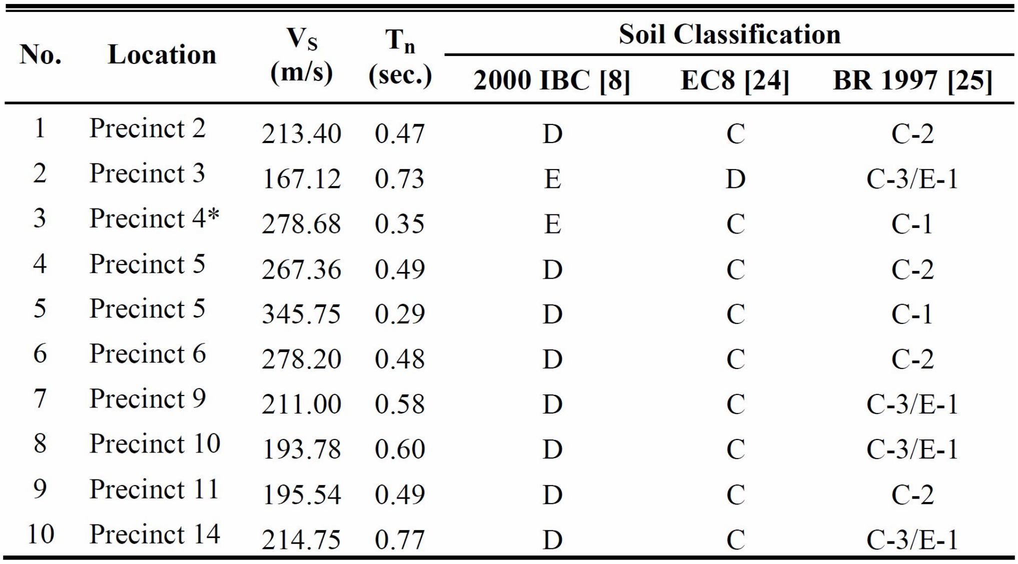
No	**Location**	**V_S (m/s)**	**T_n (sec.)**	**Soil Classification**		
				2000 IBC [8]	**EC8 [24]**	**BR 1997 [25]**
1	Location-1	319.00	0.67	D	C	C-3/E-1
2	Location-2	191.02	0.66	D	C	C-3/E-1
3	Location-3	228.13	0.45	D	C	C-2
4	Location-4	305.25	0.34	D	C	C-1
5	Location-5	217.48	1.59	D	C	D-3
6	Location-6	395.95	0.25	C	B	C-1
7	Location-7	182.78	1.20	D	C	D-1/D-2/E-2
8	Location-8	316.43	0.31	D	C	C-1
9	Location-9	150.57	0.42	E	D	C-2
10	Location-10	625.85	0.08	C	B	A
11	Location-11	107.56	0.75	E	D	C-3/E-1
12	Location-12	178.98	0.35	E	D	C-1



a) Site Class S_D b) Site Class S_E

Figure 6. Soil dynamic properties for Putrajaya

Table 3. Soil Classification of Putrajaya



No.	Location	V_S (m/s)	T_n (sec.)	Soil Classification		
				2000 IBC [8]	EC8 [24]	BR 1997 [25]
1	Precinct 2	213.40	0.47	D	C	C-2
2	Precinct 3	167.12	0.73	E	D	C-3/E-1
3	Precinct 4*	278.68	0.35	E	C	C-1
4	Precinct 5	267.36	0.49	D	C	C-2
5	Precinct 5	345.75	0.29	D	C	C-1
6	Precinct 6	278.20	0.48	D	C	C-2
7	Precinct 9	211.00	0.58	D	C	C-3/E-1
8	Precinct 10	193.78	0.60	D	C	C-3/E-1
9	Precinct 11	195.54	0.49	D	C	C-2
10	Precinct 14	214.75	0.77	D	C	C-3/E-1

5. Results of Shear Wave Propagation Analysis

Shear wave propagation analyses were performed for all existing soil data to obtain peak acceleration and amplification factor at the surface. Two hazard levels were used in the analysis to represent 10% and 2% Probability Exceedance (PE) in design time period of 50 year or correspond to return period of approximately 500 and 2,500 years, respectively. These hazard levels were calculated using total probability theorem as proposed by Cornel [26]. Based on the previous study, the peak ground accelerations for Putrajaya are 0.073g (73.4 gal) and 0.149g (149 gal) for 500 and 2,500 years return periods of ground motions, respectively [27, 28]. The seismic hazard map of Peninsular Malaysia for those two hazard levels is shown in Figure 7.

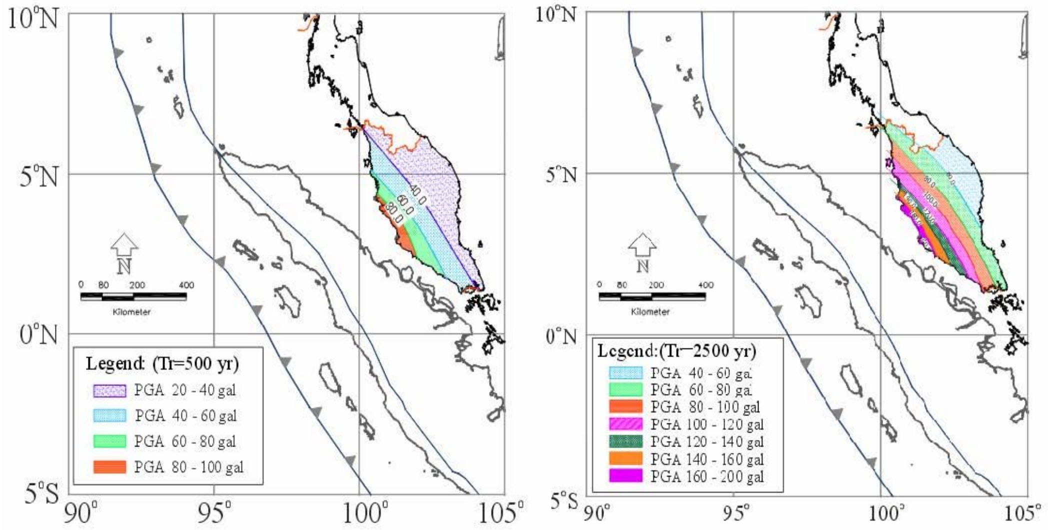


Figure 7. Seismic hazard maps of Peninsular Malaysia (site class S_B) [27]

Four time histories were used in the analysis: Synth-1, Synth-2, Synth-3, and Synth-4. Synth-1 and Synth-2 represent ground motion for 500 years return period, while Synth-3 and Synth-4 represent for 2,500 years return period [28]. The time histories used in the analysis are as shown in Figure 8.

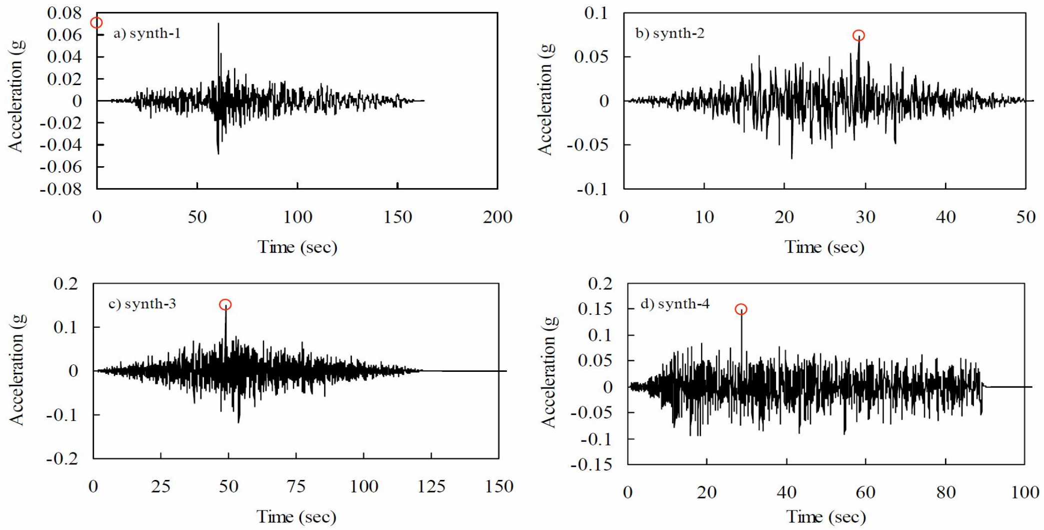


Figure 8. The time histories used in ground response analysis [28]

Some of the results of acceleration and amplification factors at the surface of KL city center and Putrajaya are summarized in Tables 4 and 5, respectively. The amplification factors show the ratio between acceleration at bedrock and at surface. Based on the results, it is found that most of the ground motions have been amplified at the surface. Generally, the amplification factors for 500 years return period are higher than 2,500 years return period.

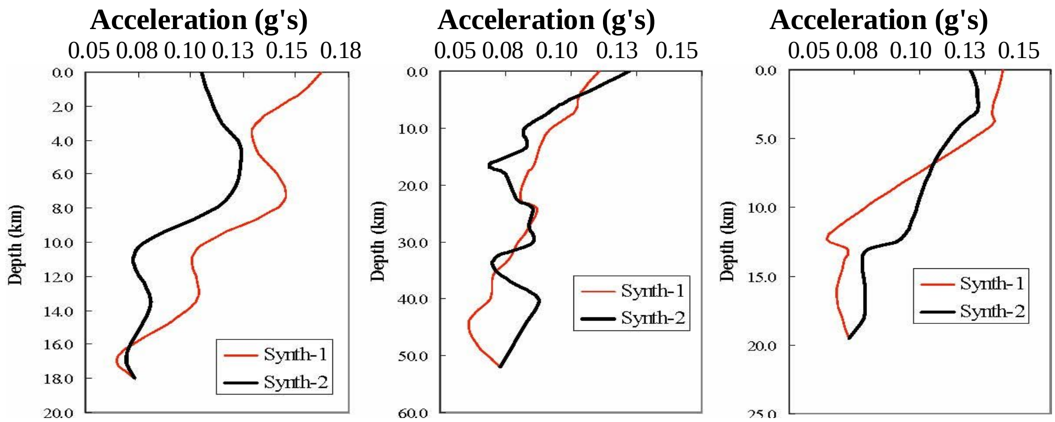
Table 4. Results of 1-D analyses for KLCC

No	**Location**	**Soil Type**	**PSA (g's)**				**Amplification Factor**			
			Synt1	**Synth2**	**Synth3**	**Synth4**	**Synth1**	**Synth2**	**Synth3**	**Synth4**
1	Location-1	SD	0.111	0.122	0.297	0.232	1.52	1.67	1.99	1.56
2	Location-2	SD	0.158	0.146	0.238	0.245	2.16	2.00	1.60	1.65
3	Location-3	SD	0.180	0.165	0.307	0.304	2.47	2.26	2.06	2.04
4	Location-4	SD	0.143	0.135	0.232	0.289	1.96	1.85	1.56	1.94
5	Location-5	SD	0.112	0.087	0.154	0.169	1.53	1.19	1.03	1.13
6	Location-6	SC	0.162	0.105	0.280	0.267	2.22	1.44	1.88	1.79
7	Location-7	SD	0.160	0.113	0.221	0.223	2.20	1.55	1.48	1.50
8	Location-8	SD	0.189	0.165	0.329	0.314	2.59	2.27	2.21	2.11
9	Location-9	SE	0.132	0.119	0.203	0.211	1.81	1.63	1.36	1.42
10	Location-10	SC	0.077	0.090	0.225	0.175	1.05	1.23	1.51	1.17
11	Location-11	SE	0.119	0.100	0.162	0.170	1.64	1.36	1.09	1.14
12	Location-12	SE	0.157	0.147	0.230	0.232	2.16	2.02	1.54	1.56

Table 5. Results of 1-D analyses for Putrajaya

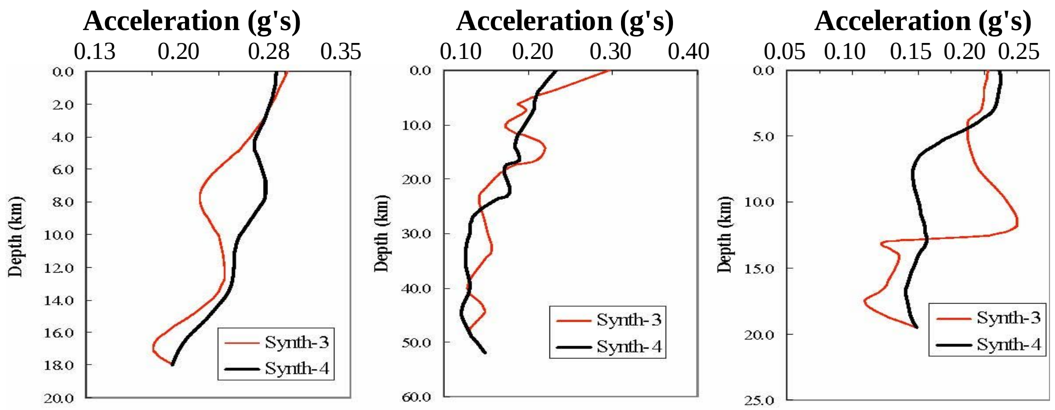
No	**Location**	**Soil Type**	**PSA (g's)**				**Amplification Factor**			
			Synt1	**Synth2**	**Synth3**	**Synth4**	**Synth1**	**Synth2**	**Synth3**	**Synth4**
1	Precinct 2	SD	0.168	0.143	0.236	0.270	2.30	1.95	1.58	1.81
2	Precinct 3	SE	0.144	0.128	0.297	0.260	1.98	1.75	1.99	1.75
3	Precinct 4	SE	0.201	0.185	0.348	0.337	2.76	2.54	2.33	2.26
4	Precinct 5	SD	0.197	0.162	0.366	0.337	2.69	2.22	2.46	2.26
5	Precinct 5	SD	0.174	0.168	0.319	0.315	2.39	2.29	2.14	2.11
6	Precinct 6	SD	0.134	0.118	0.182	0.193	1.84	1.61	1.22	1.29
7	Precinct 9	SD	0.160	0.141	0.250	0.315	2.20	1.93	1.68	2.12
8	Precinct 10	SD	0.173	0.153	0.225	0.285	2.36	2.10	1.51	1.91
9	Precinct 11	SD	0.157	0.149	0.213	0.258	2.15	2.04	1.43	1.73
10	Precinct 14	SD	0.137	0.129	0.234	0.225	1.87	1.77	1.57	1.51

The effects of using different time histories can be seen from Figures 9 to 12 for 500 and 2,500 years return periods of ground motions, respectively. The results indicate that the selection of appropriate time histories is one of the most critical factors in ground response analysis. The selection of time histories could change the results of accelerations at the surface significantly. The accelerations at the surface could be different up to about 35%.



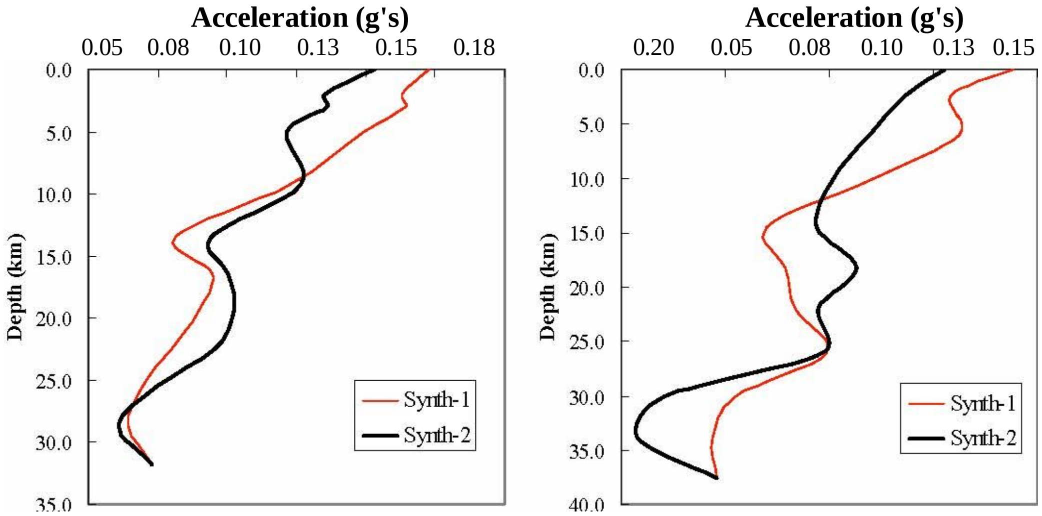
a) Site Class S_C b) Site Class S_D c) Site Class S_E

Figure 9. 1-D analysis using time histories for 500 years return period (KL city center)



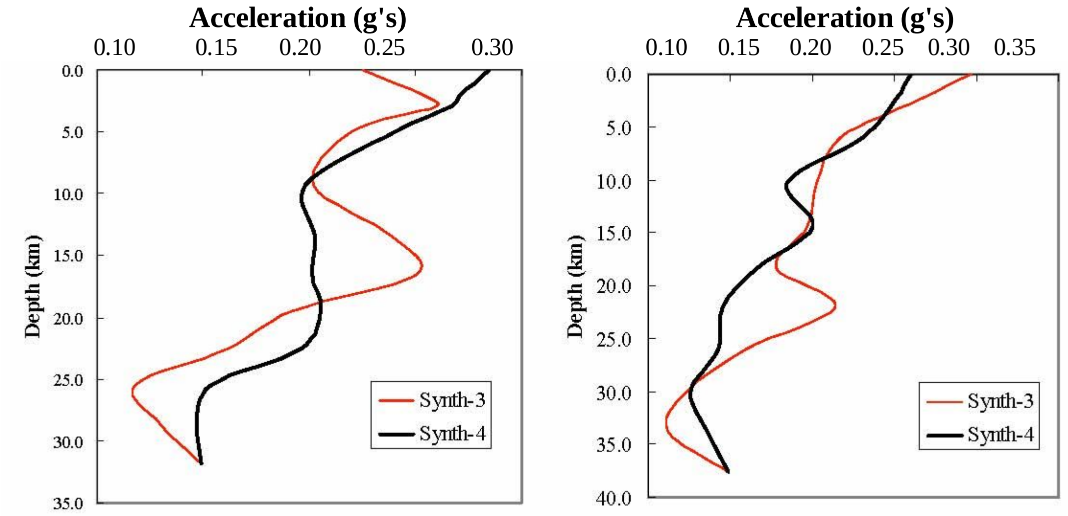
a) Site Class S_C b) Site Class S_D b) Site Class S_E

Figure 10. 1-D analysis using time histories for 2,500 years return period (KL city center)



a) Site Class S_D b) Site Class S_E

Figure 11. 1-D analysis using time histories for 500 years return period (Putrajaya)



a) Site Class S_D b) Site Class S_E

Figure 12. 1-D analysis using time histories for 2,500 years return period (Putrajaya)

Time histories also influence the amplitude of spectral acceleration at the surface produced by ground response analysis as shown in Figures 13 and 14. It can also be seen in the figures that the frequency content of the spectrum is relatively not much different. On the other hand, Figure 15 shows that the frequency content of the spectrum is more affected by the stiffness of the soil. As can be seen in the figure, soft soil deposits produce greater proportions of long period (low frequency) motions than stiff soil. The results of site response analysis at several points were used to develop contour map of surface acceleration and amplification factor for 500-years and 2,500-years return periods. The iso-acceleration contour maps for KL city center are shown in Figures 16 to 17, while the contour of amplification factors can be seen in Figures 18 to 19.

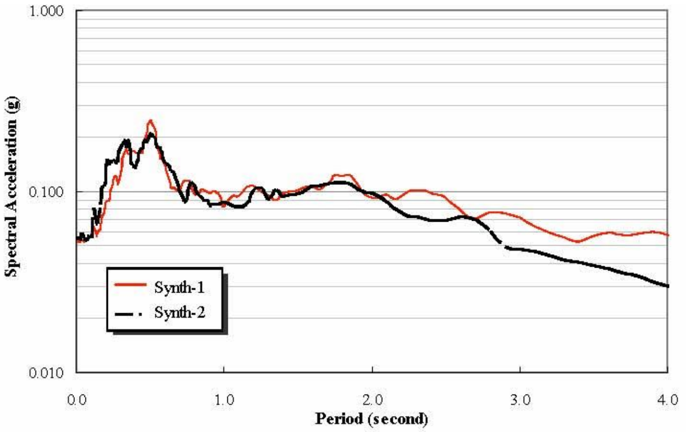


Figure 13. Spectral acceleration at surface (for 500 years return period)

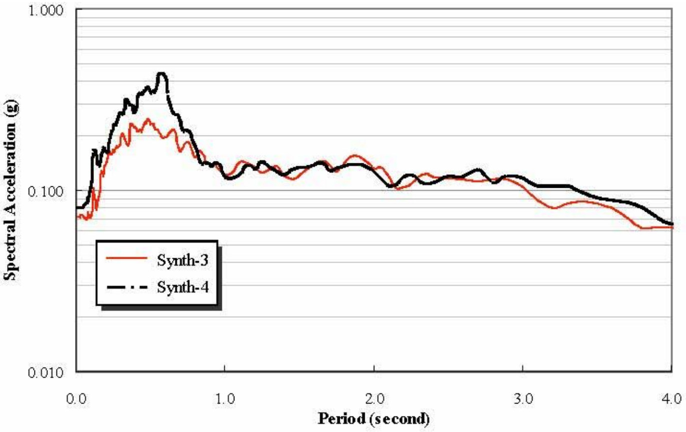


Figure 14. Spectral acceleration at surface (for 2,500 years return period)

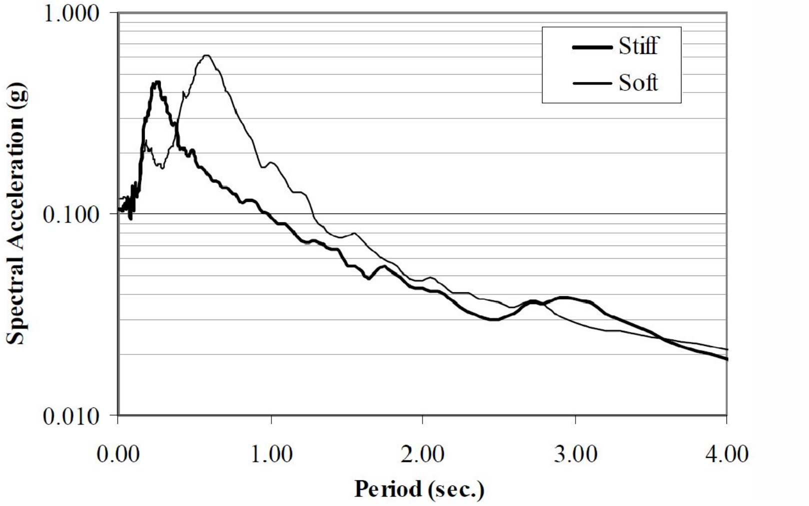
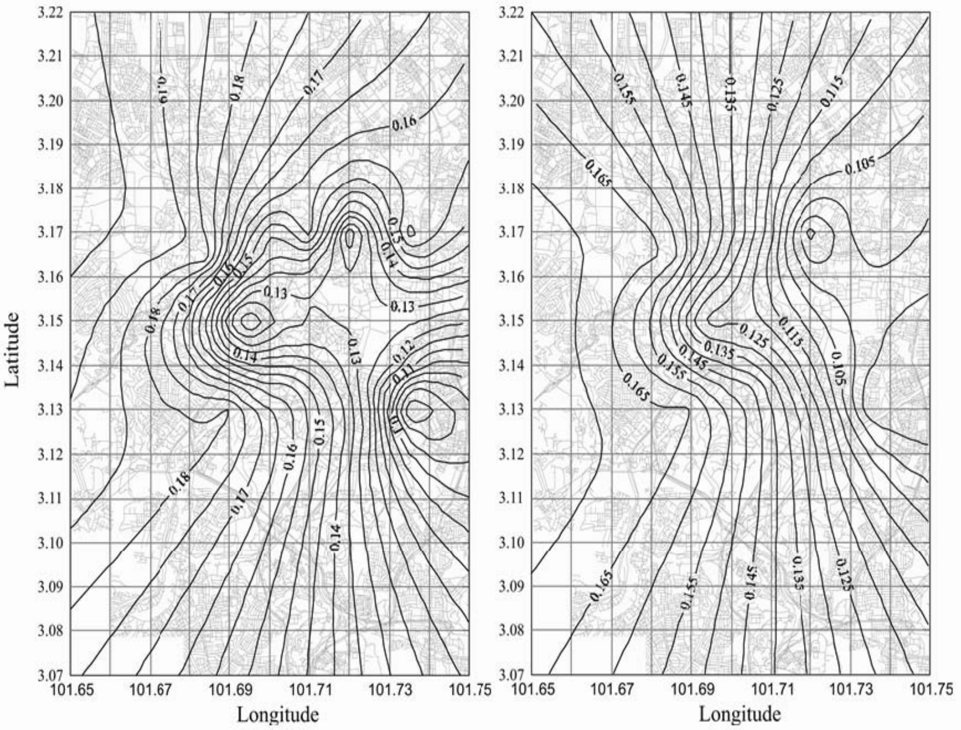
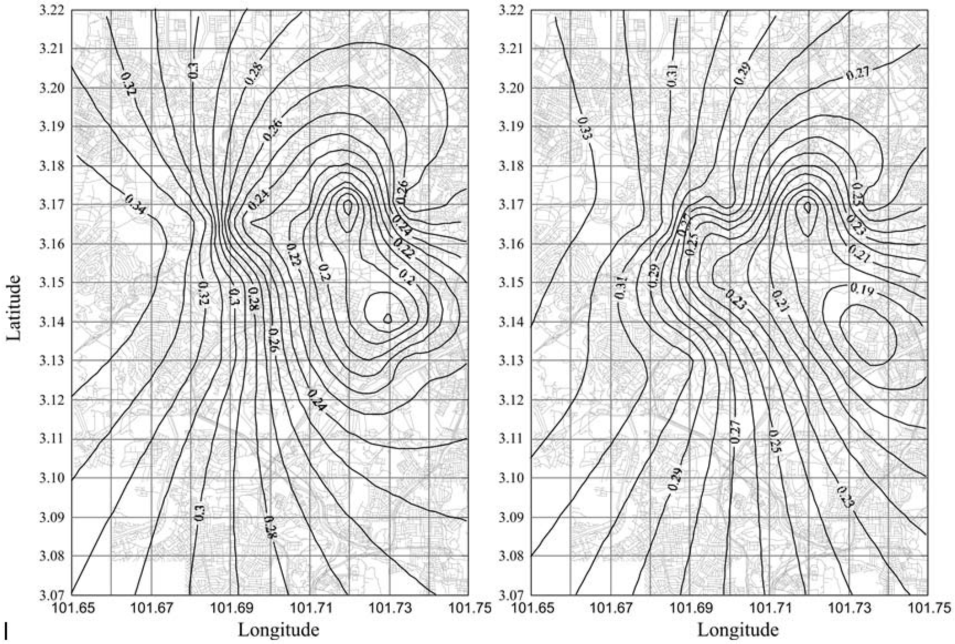


Figure 15. Effect of soil stiffness



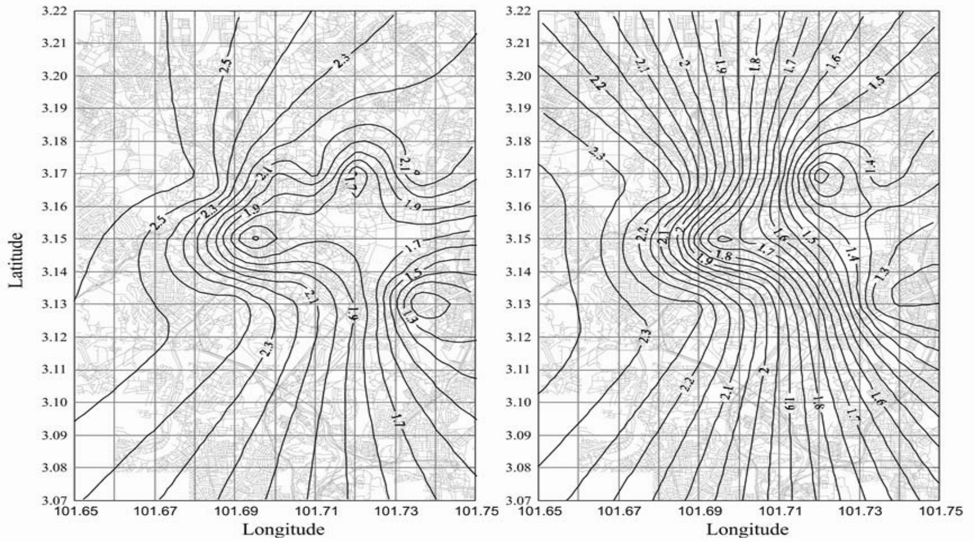
(a) Synth-1 (b) Synth-2

Figure 16. Contour of acceleration at surface of KL city center for 500 years return period (PGA=0.073 g)



(a) Synth-3 (b) Synth-4

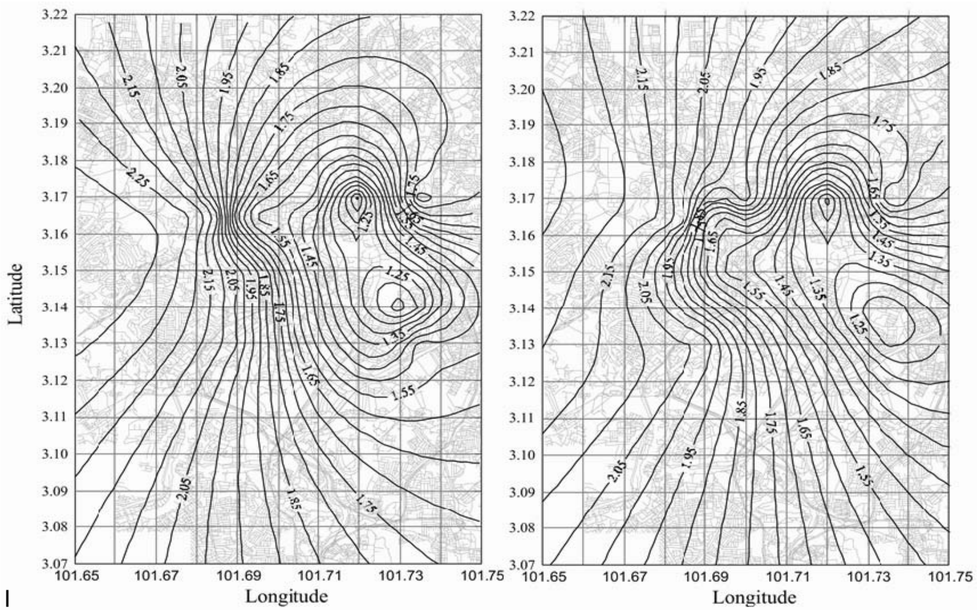
Figure 17. Contour of acceleration at surface of KL city center for 500 years return period (PGA=0.149 g)



(a)

Synth-1 (b) Synth-2

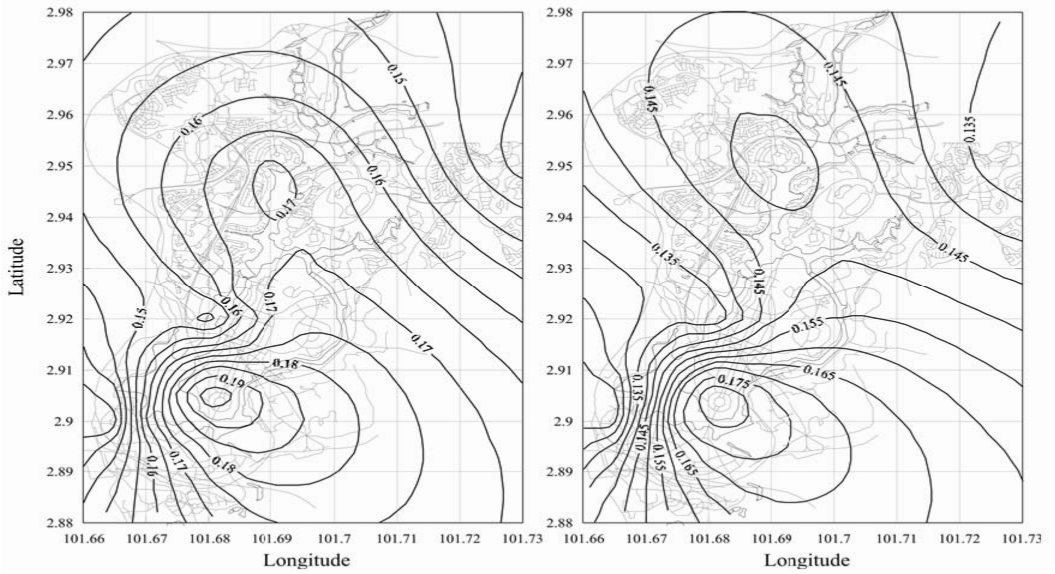
Figure 18. Contour of amplification factor of KL city center for 2,500 years return period (PGA=0.073 g)



(a) Synth-3 (b) Synth-4

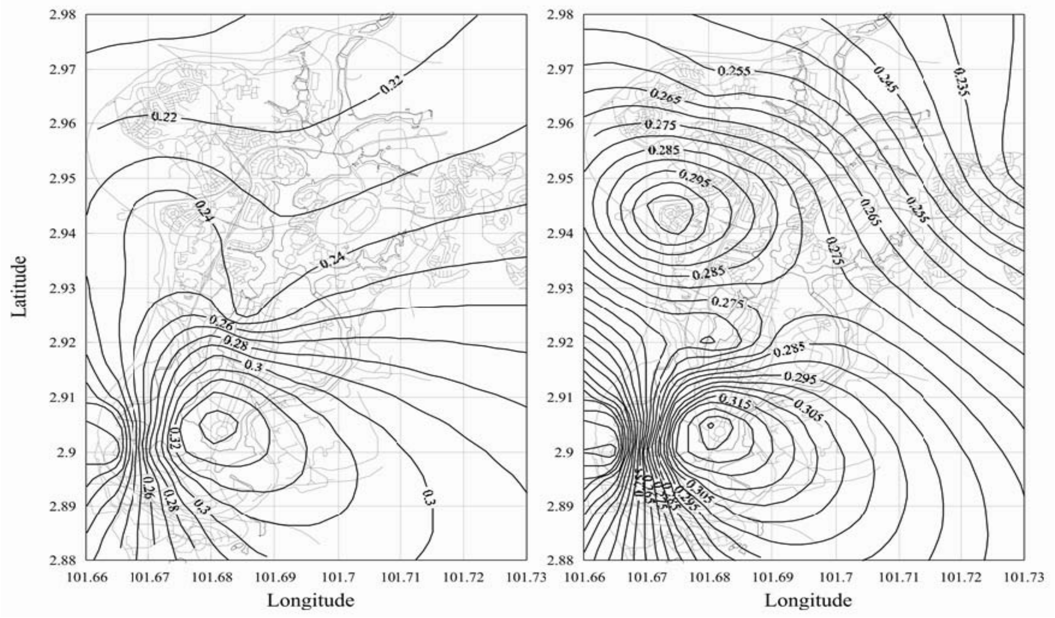
Figure 19. Contour of amplification factor of KL city center for 2,500 years return period (PGA=0.149 g)

From the figures, it can be seen that the accelerations at the surface of KL city center range between 9% g (90 gal) and 19% g (190 gal) for 10% PE in 50-year hazard levels and between 18% g (180 gal) and 34% g (340 gal) for 2% PE in 50-year hazard levels. The amplification factors for those two hazard levels (10% and 2% PE in 50 years) range between 1.2 and 2.6. Generally, the accelerations and amplifications factors decrease from the west to the east side of KL city center. The iso-acceleration contour maps for Putrajaya are shown in Figures 20 to 21, while the contours of amplification factors are shown in Figures 22 to 23. According to the figures, the accelerations at the surface of Putrajaya range between 13% g (130 gal) and 19% g (190 gal) for 10% PE in 50-year hazard levels and between 22% g (220 gal) and 34% g (340 gal) for 2% PE in 50-year hazard levels. The amplification factors for those two hazard levels range between 1.5 and 2.6.



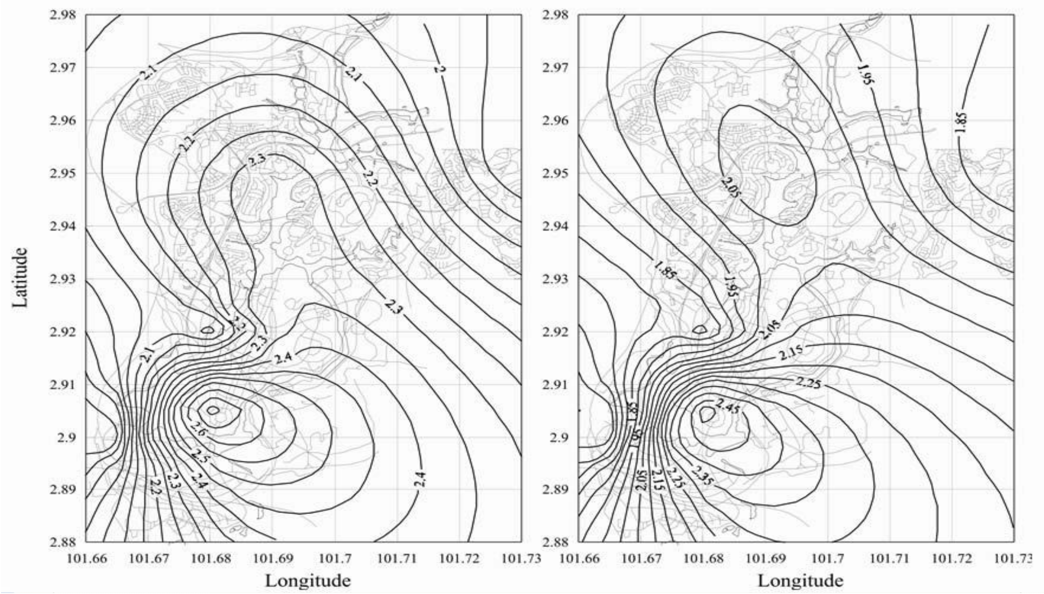
(a) Synth-1 (b) Synth-2

Figure 20. Contour of acceleration for 500 years return period (PGA=0.073 g) (Putrajaya)



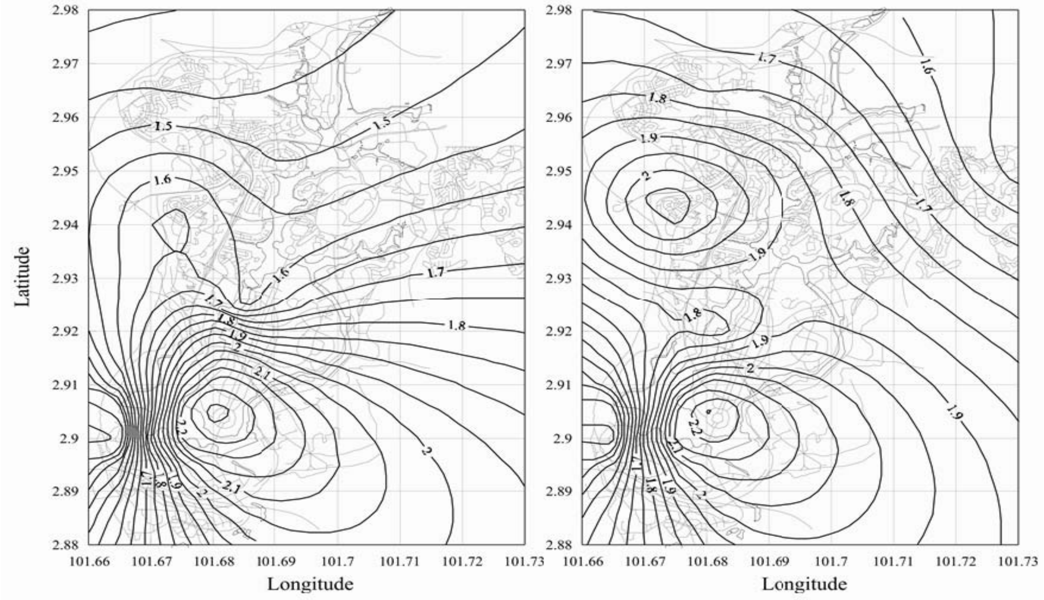
(a) Synth-3 (b) Synth-4

Figure 21. Contour of acceleration for 500 years return period (PGA=0.149 g) (Putrajaya)



(a) Synth-1 (b) Synth-2

Figure 22. Contour of amplification factor for 2,500 years return period (PGA=0.073 g) (Putrajaya)



(a) Synth-3 (b) Synth-4

Figure 23. Contour of amplification factor for 2,500 years return period (PGA=0.149 g) (Putrajaya)

6. Summary and Conclusion

This paper has described the microzonation study for KL city center and Putrajaya in Peninsular Malaysia. Ground response analyses were performed using 1-D shear wave propagation analysis. The analysis was performed for two hazard levels that represent 500 and 2,500 years return periods of earthquake. Four time histories were used in the analysis to represent ground motion for 500 years (Synth-1 and Synth-2) and 2,500 years (Synth-3 and Synth-4) return periods. In this study, the analysis was performed using nonlinear approach in order to consider the actual nonlinear response of a soil deposit. The results of site response analysis at several points were used to develop microzonation maps of KL city center and Putrajaya for 500 and 2,500-years return periods. Eight microzonation maps were produced for each city in this research that can be used as input for seismic design, land use management, and estimation of potential liquefaction and landslides.

The results of ground response analysis show that both the time histories and local soil conditions (soil stiffness, stratigraphy and ground water level) are critical to the results of ground response analysis. Generally, time histories affect the amplitude of spectral acceleration, whilst the soil conditions influence the frequency content of the spectrum. Therefore, these two subjects should be considered and determined carefully in ground response analyses.

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