CHAPTER V
SEISMIC RESPONSE ANALYSIS

This chapter provides an overview of one dimensional wave propagation analysis which is used to assess the site response characteristics of Bangkok. The computer program Shake is utilized to quantify the response of these deposits to bedrock motions as represented by the amplification factors.

5.1 Effects of Site Conditions on Earthquake Ground Motion

Local geologic and soil conditions have considerable effect on the propagating seismic waves during earthquakes. Soft soil deposits tend to intensify certain frequencies of ground motion and extend the duration of motion. This soft strata allows shear waves to propagate easily but the hard layer underneath behaves like a reflector that bounces the downward propagating waves. As a result, seismic waves are trapped in the uppermost soft layer creating a wave resonance that amplifies the ground motions significantly (Tuladhar, 2002).

Site amplification is a phenomenon that has been a source of discussion to a number of researchers. Since structures built on soft sediments are vulnerable to the effects of amplified ground motions, seismic hazard assessment is necessary so as to identify the variation of ground motion in accordance to local site conditions (Tuladhar, 2002).

Further to this, various cases of site amplification are cited. The Michoacan earthquake that occurred in September 1985 is a classic example of this scenario wherein the sharp discontinuity of shear wave velocity between the uppermost soft clay layer and the underlying layer created tremendous ground motion amplification. The October 1989 Loma Prieta earthquake has induced an analogous mechanism wherein clay deposits in San Francisco Bay area magnify the ground motion enormously leading to severe damage in parts of San Francisco and Oakland.

5.2 Geologic Setting of Bangkok

For over 200 years, Bangkok has been the capital city of the Kingdom of Thailand. As shown in Figure 5.1, the city is situated within the latitudes of 13.5°N and 15.75 °N and longitudes ranging from 99.50°E to 101.75 °E on a huge flat plain underlain by alluvial, deltaic and shallow marine sediments of the Chao Phraya basin. This area is commonly known as *lower central plain* or the greater Bangkok area which resides approximately 20 km north of the Gulf of Thailand (Santoso, 1982).

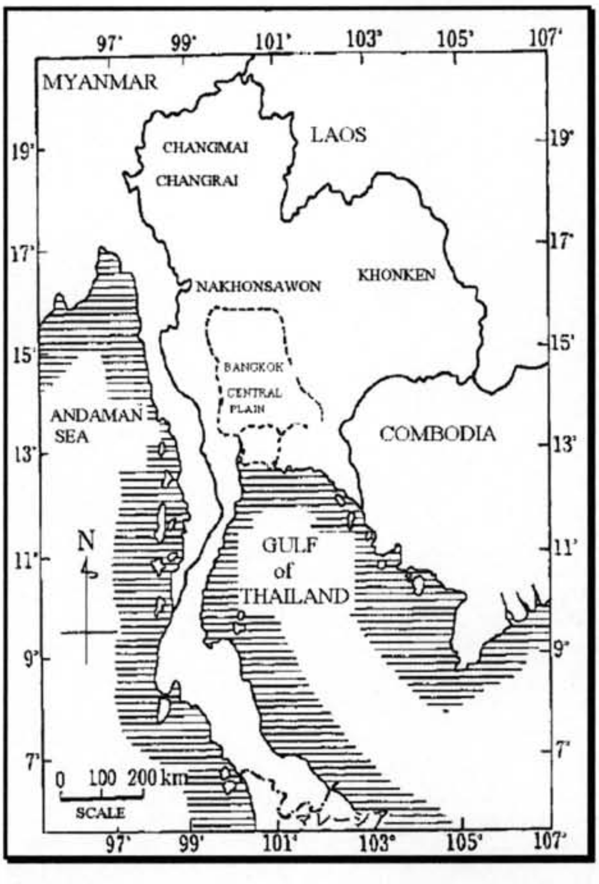

Figure 5.1 Map of Thailand showing location of Central Plain and Bangkok located at lower Central Plain (Shibuya *et al.*, 2003)

Chao Phraya plain is bounded by the Tanowsri Mountain Range in the west, Khorat Plateau in the east, Gulf of Thailand in the south and Nakhonsawon Depression in the north. Bangkok subsoil is characterized by Quaternary deposits of marine and terrestrial sediments. The terrestrial deposits start from elevation of zero to approximately 4 to 5 meters above the mean sea level while the marine sediments originated as a result of changes in sea level. Chao Phraya River and its tributaries from the neighboring highlands made up the major drainage system of the plain. Alternate layers of sand, gravel and clay made up the sedimentary soil deposits of Chao Phraya basin. Its uppermost marine clay layer, known as Bangkok clay, is about 10 to 18 km thick and is believed to be formed approximately 4,000 years ago. The depth of bedrock is about 550 to 2000 meters (Shibuya *et al.*, 2003).

The lower central plain was under a shallow sea about 3,000 years ago and at this period, Bangkok soft clay was deposited within the area. Around 2,700 years ago, such soft layer is exposed due to the regression of the sea. In time, one to two meters of the top layer was subjected to weathering. No mechanical consolidation has taken place in this stratum. As such, it is characterized as highly compressible with extremely low shear strength. The soft clay is underlain by the first stiff clay layer of higher shear strength and less compressibility. Alternate layers of sand and stiff clay deposits of relatively high strength exist at deeper strata. A geological map of Bangkok area is depicted in Figure 5.2 and a description of the typical soil profile after Sambhandharakasa and Ptupakonr (1985) and cited by Shibuya *et al.* (2003) is presented in Table 5.1 (Tuladhar, 2002).

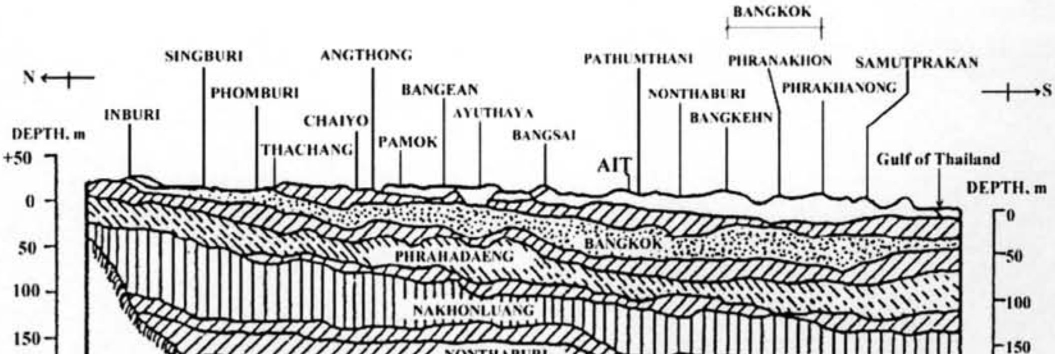

Figure 5.2 Geological map of Bangkok area (Shibuya *et al.*, 2003)

Table 5.1 Typical soil profile in Bangkok area (Shibuya *et al.*, 2003)

Depth (m)	Strata
0 to 14	Bangkok soft clay – dark grey highly compressible soft clay with 2m weathered zone forming a hard crust
14 to 25	First stiff clay – light grey and brown fissured stiff clay
25 to 40	First sand layer – dense alluvial non-uniform sand, occasionally interbedded with stiff clay; classified in parts as clayey sand
40 to 44	Second stiff clay – light grey and brown, stiff often fissured silty clay
44 to > 70	Second sand layer – clean light grey silty sand

5.3 Soil Properties

Ashford *et al.* (2000) indicated in their study that the soil profile underlying Bangkok has capability to amplify earthquake ground motions 3 to 7 times. Ground response analysis is carried out to quantify this potential amplification. A generalized soil profile is developed based on the detailed site specific data from 9 sites around the Bangkok metropolitan area which is presented in Table 5.2. Using empirical relationships proposed by Dickenson (1994), Seed and Idriss (1970) and Hardin and Drnevich (1972b), shear wave velocities of various soil layers are estimated. Correlations using SPT N-values are also used for soil layers below 25 m. Through shear wave velocity measurements by downhole method from four areas around the city namely Asian Institute of Technology, Chulalongkorn University, Lad Krabang and Nong Ngu Hao, these estimated values are checked. The estimated shear wave velocities are in excellent agreement with the measured shear wave velocities.

Table 5.2 General properties of soil layers in Bangkok (Ashford *et al.*, 2000)

Layer	Depth Interval (m)	Unit Weight (t/m^3)
Soft Bangkok Clay	0-15	1.52
First Stiff Clay	15-25	1.92
First Sand	25-50	2.08
Second Stiff Clay	50-80	2.16

Based on the experiments carried out by Ashford *et al.* (2000), soft Bangkok clay has a very low shear wave velocity approximately less than 100 m/s. V_s of underlying first stiff clay increase up to 170 to 200 m/s. The first sand layer has considerable increase in V_s too in the range of 250 m/s. Afterwhich, the consequent layers of clay and sand have relatively high V_s values up to 400 m/s.

In the process, the variation of shear modulus and damping ratio with shear strain is determined based on relationships proposed by Vucetic and Dobry (1991) for clays and by Seed *et al.* (1984) for sand without any laboratory tests. However, it was cited by Padermkul (1999) that Shibuya and Tamrakar conducted a series of in-situ and laboratory tests of Bangkok soil in 1999 which include cyclic torsional shear test (CTS) and seismic cone test (SCT). Dynamic soil properties including shear modulus and damping ratio with cyclic shear strain are obtained from CTS while for SCT, it was found out that the shear wave velocity of Bangkok's soft soil is approximately 80 m/s which is consistent with that proposed by Ashford and his co-workers. Further to this, as cited by the same author, Warnitchai and Sangarayakul re-analyzed the response of ground motion in 1998 using the soil profile developed by Ashford *et al.* and the dynamic soil properties tested by Shibuya and Tamrakar in 1999. The obtained amplification properties confirmed the results of Ashford, *et al.* (2000). The average plasticity index of soft Bangkok clay is estimated to have a value of 50 which is in excellent agreement with Vucetic and Dobry's equation for clays.

5.4 Seismic Response Analysis Using Shake

In this research, one dimensional site response analysis is performed using the computer program Shake. It is an equivalent linear approach that incorporates the non-linear behavior of soils by means of an iterative procedure to attain modulus and damping values based on an average strain level for each soil layer (Schnabel *et al.*, 1972).

The program models the soil system as homogenous, viscoelastic media of infinite horizontal extent associated to vertical propagation of shear waves. Corresponding values of shear modulus G, critical damping ratio β, mass density ρ and thickness h define each layer in the system. These soil properties are independent of frequency. The upward propagation of shear waves from the underlying rock formation causes the response in the media. Shear waves are specified in terms of acceleration values of equally spaced time intervals. The analysis entails cyclic repetition of this acceleration time history (Schnabel *et al.*, 1972).

A simplified representation of the program is shown in Figure 5.3. The responses for a design motion applied anywhere in the system can be computed. Accelerogams recorded by instruments on soil deposits can be utilized to develop new rock motions. This can then be used as design motion for other soil deposits. (Schnabel *et al.*, 1972)

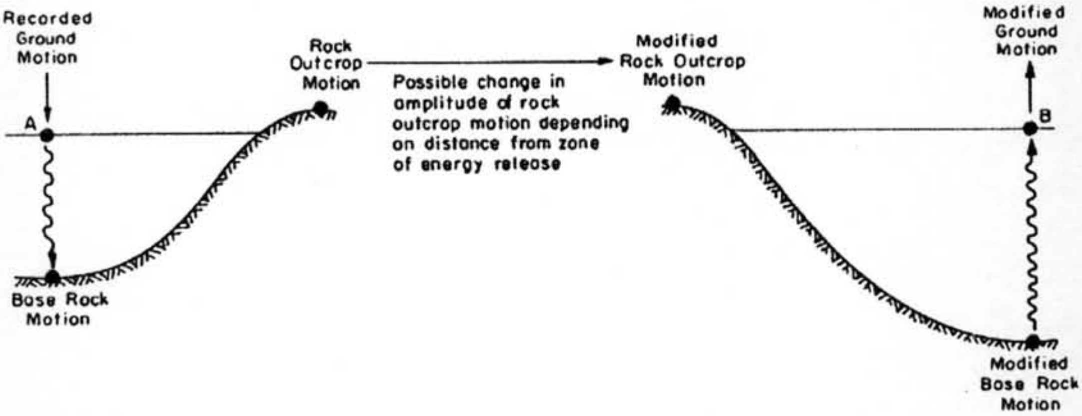

Figure 5.3 Schematic diagram to quantify local soil effects on ground motions (Schnabel *et al.*, 1972)

5.4.1 Development of Generalized Soil Profile

For this study, the best-estimate, upper-bound and lower-bound shear wave velocity profiles, developed by Ashford *et al.* (2000) for the generalized Bangkok soil, are used. These profiles are estimated up to a depth of 80 meters as shown in Figure 5.4. As discussed in the paper of Ashford *et al.*, the upper-bound profile is not actually the upper-bound shear wave velocity but rather the upper-bound V_s in soft Bangkok clay and lower-bound V_s in the underlying strata. The converse is true for the lower-bound profile. Furthermore, it was mentioned that this combination is selected in order to yield an upper-bound spectral acceleration by decreasing the contrast of the specific impedances at the soft soil-stiff soil interface.

Since no data is available to approximate V_s below 80 m, it was assumed that a rock-like material exists below this depth with V_s equals to 900 m/s. Based on a series of site response analyses conducted to support this assumption, it was found out that only minor effect on the amplified motions at the surface exists due to this assumed depth of rock-like stratum.

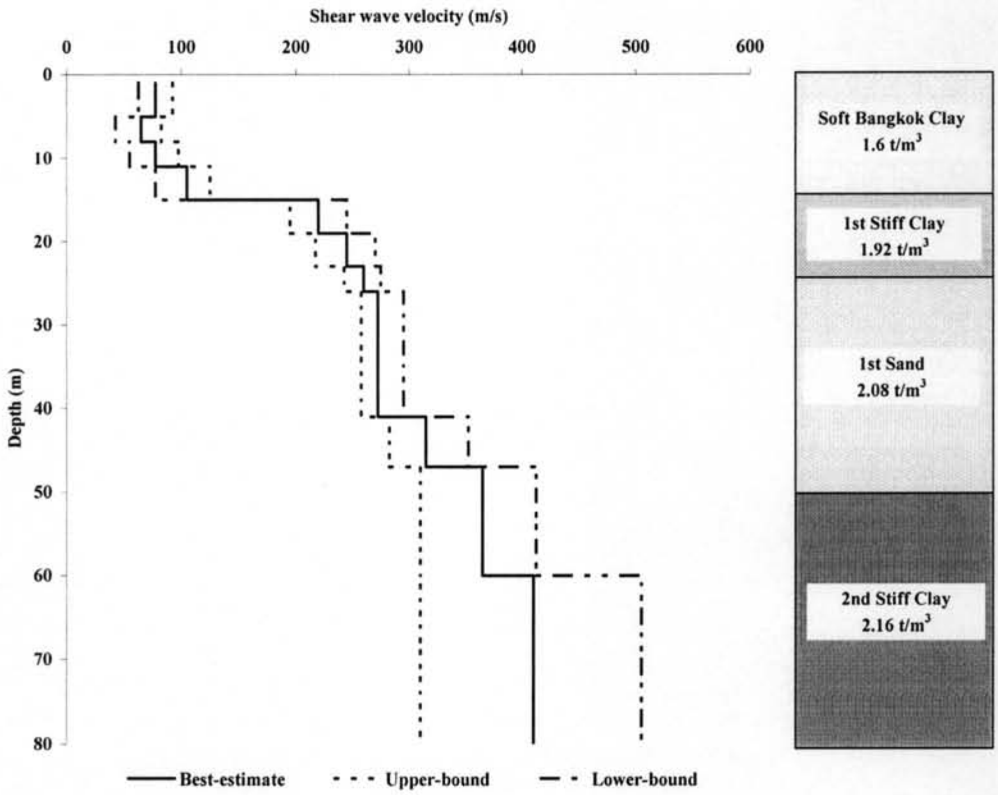

Figure 5.4 Best-estimate, upper-bound and lower-bound shear wave velocity profiles of Bangkok used in this study (Ashford *et al.*, 2000)

5.4.2 Selection of Strong Motion Records

The analysis in this study considers two sets of input rock accelerograms. In the first case, rock outcrop motions in Bangkok are represented by six accelerograms from actual acceleration records adopted from global earthquake events. The magnitudes of these earthquakes range from 6.4 to 7.6 at site-to-source distances of about 80 to 380 km. The corresponding peak acceleration values of these records are within 0.005g to 0.08g. These strong ground motion records are chosen to embody far-field earthquake events since Bangkok is at risk from distant earthquakes. On the other hand, the second part of the analysis takes into consideration five local acceleration time histories chosen from the records taken at rock sites in Thailand by

TMD. These accelerograms were generated by non-subduction zone events of magnitude ranging from 5 to 6 at distance ranging from 330 to 450 kilometers from the epicenter. The peak acceleration values of these local field records vary from 0.00002g to 0.0003g. Note that the acceleration values are significantly lower compared with the peak values from global sources.

The details of earthquakes selected for each case are summarized in Tables 5.3 and 5.4. Acceleration time histories are shown in Appendix D.

Table 5.3 Summary of strong ground motion records from global earthquakes

Earthquake	Date	Station	Local Geology	Distance (km)	Magnitude (Mw)	PGA (g)
Izmit (Turkey)	August 17, 1999	Denizli	stiff soil	330	7.6	0.08
Duzce (Turkey)	November 12, 1999	Denizli	stiff soil	372	7.2	0.04
Dinar (Turkey)	October 1, 1995	Balikesir	stiff soil	257	6.4	0.05
Loma Prieta (US)	October 18, 1989	Yerba Buena Island	rock	80	6.9	0.07
San Fernando (US)	February 9, 1971	Cholame-Shandon	stiff soil	223	6.6	0.005
Kern County (US)	July 21, 1952	Pasadena	stiff soil	127	7.4	0.05

Table 5.4 Summary of strong ground motion records from local earthquakes

Record Filename	Date	Station	Distance (km)	Magnitude (Mw)	PGA (g)	Horizontal Component
414ABE09.TA2	September 17, 2004	Tak	376	5.7	0.00002	NS
3F698DAB.TA2	September 18, 2003	Tak	414	5.5	0.00005	EW
3F69910B.CM2	September 18, 2003	Chiang Mai	332	5.5	0.00023	EW
3FA12A29.CM2	October 30, 2003	Chiang Mai	333	5.3	0.00009	EW
3FA1299E.TA2	October 30, 2003	Tak	449	5.3	0.00007	EW

These records are scaled to various peak acceleration values between 0.002g to 0.1g. These input rock outcrop motions are computed from the attenuation models proposed by Idriss (1993), Sadigh *et al.* (1997) and Campbell (1997) by considering a number of probable earthquake scenarios that could reasonably induce significant effect to Bangkok. The potential seismic sources in the region surrounding the city that may significantly contribute to its seismic hazard are presented and discussed in Chapter 4. The ranges of magnitude and distance values are approximated in accordance to the source parameters of potentially active faults in Thailand.

As stated in the assessment conducted by Ashford *et al.* (2000), active faults that may pose a potential threat to Bangkok are located some 400 kilometers away from the city which is capable of generating earthquake of magnitude 8 or more. Based on the study carried out by Warnitchai (2004), active faults that could generate a magnitude 7.5 earthquake are located 120 to 300 km away from Bangkok. Padermkul (1999), in his study about seismic damage assessment, estimates a distance of more than two hundred kilometers away from the nearest active fault in the western part of the country to Bangkok. Based on neotectonic evidences along Three Pagoda Fault Zone, which is considered to be the fault zone nearest to Bangkok, it is located 150 km northwest of the city (Won-in, 1999).

Hence, in this research, a lower bound of 150 km is considered to be the distance to Bangkok of the nearest active fault based on the estimate provided by various researchers mentioned above. Magnitude from 6.5 to 7.5 is considered as the reasonable range of earthquake size that may probably yield significant earthquake ground motions affecting the city based on the seismic source parameters of major faults in Thailand as specified in Chapter 4 (Table 4.2).

Table 5.5 lists the peak outcrop motions computed using the most appropriate median attenuation relationships for rock sites as discussed in Chapter 3. Based on the scenarios which include magnitudes 7.0 and 7.5 at epicentral distances of about 150 to 200 km, the range of the estimated PRA is from 0.7 to 3.5% g. The highest estimate of PRA (3.5% g) is from the case with magnitude equal to 7.5 and distance equal to 150 km. In the process, acceleration values greater than the predicted values of attenuation models, such as 0.05g, 0.075g and 0.1g, are incorporated in the site response analyses to identify the trend of soil amplification at higher rock outcrop acceleration inputs.

Table 5.5 Predicted peak rock outcrop accelerations (PRA) in Bangkok

Magnitude	Distance (km)	Idriss (1993)	Sadigh et al. (1997)	Campbell (1997)
		PRA (g)		
7.5	*150*	0.035	0.019	0.017
	200	0.025	0.012	0.011
	250	0.018	0.008	0.008
	300	0.015	0.005	0.006
7.0	*150*	0.021	0.012	0.011
	200	0.014	0.007	0.007
	250	0.010	0.005	0.005
	300	0.008	0.003	0.004
6.5	*150*	0.012	0.008	0.007
	200	0.007	0.004	0.004
	250	0.005	0.003	0.003
	300	0.004	0.002	0.002

5.4.3 Results of Analyses

Individual site response analyses of the generalized soil profile of Bangkok representing the best-estimate, upper-bound and lower-bound soil properties are conducted. The peak ground acceleration and amplification factors as results of this assessment are listed in Tables 5.6 to 5.11 for both sets of selected global and local rock outcrop motions. The values for the amplification factors represent the average amplification per input motion. The detailed results of these analyses are provided in Appendix E.

Amplifications of bedrock and outcrop motions are calculated. These factors are determined by computing the ratio of PGA measured at ground surface to PGA at bedrock as well as the ratio of PGA at ground surface to peak rock outcrop acceleration. As expected, the latter yield lower values compared with the former.

Based on the results of seismic response analyses, the soil profile underlying Bangkok is capable of amplifying the incoming seismic waves. In general, the soil underlying Bangkok has the potential to amplify bedrock ground motions 3.4 to 6.4 times (Table 5.9). Potential amplification of outcrop rock motions is in the order of 2.4 to 4.2 times based on the result using the best-estimate soil profile for local rock outcrop motions (Table 5.9). At an estimated PRA of 0.7% g, the corresponding average value of amplification is about 3.8 resulting to PGA on soil of about 2.66% g. For the scenario of highest PRA, which is 3.5% g (Table 5.5), the PGA on soil in Bangkok would have an average value of 11.2% g.

Table 5.6 Input acceleration values and soil amplification factors for global rock outcrop motions using best-estimate soil profile

Peak Rock Outcrop Acceleration (g)	Amplification Factors	
	Bedrock	Outcrop
0.002	6.1	3.6
0.011	4.5	3.3
0.025	4.3	3.1
0.035	4.1	3.0
0.050	4.0	2.9
0.075	4.0	2.9
0.100	3.5	2.6

Table 5.7 Input acceleration values and soil amplification factors for global rock outcrop motions using upper-bound soil profile

Peak Rock Outcrop Acceleration (g)	Amplification Factors	
	Bedrock	Outcrop
0.002	4.4	2.9
0.011	3.6	2.9
0.025	3.6	2.8
0.035	3.8	2.8
0.050	3.8	2.8
0.075	3.4	2.5
0.100	2.9	2.3

Table 5.8 Input acceleration values and soil amplification factors for global rock outcrop motions using lower-bound soil profile

Peak Rock Outcrop Acceleration (g)	Amplification Factors	
	Bedrock	Outcrop
0.002	4.6	4.0
0.011	4.5	3.7
0.025	3.8	3.0
0.035	3.5	2.8
0.050	3.1	2.5
0.075	2.5	2.0
0.100	2.3	1.8

Table 5.9 Input acceleration values and soil amplification factors for local rock outcrop motions using best-estimate soil profile

Peak Rock Outcrop Acceleration (g)	Amplification Factors	
	Bedrock	Outcrop
0.002	6.4	4.2
0.011	5.7	3.8
0.025	5.1	3.4
0.035	4.8	3.2
0.050	4.4	3.0
0.075	3.8	2.6
0.100	3.4	2.4

Table 5.10 Input acceleration values and soil amplification factors for local rock outcrop motions using upper-bound soil profile

Peak Rock Outcrop Acceleration (g)	Amplification Factors	
	Bedrock	Outcrop
0.002	5.5	3.4
0.011	4.3	3.1
0.025	4.0	2.9
0.035	3.8	2.8
0.050	3.7	2.7
0.075	3.5	2.2
0.100	3.1	2.3

Table 5.11 Input acceleration values and soil amplification factors for local rock outcrop motions using lower-bound soil profile

Peak Rock Outcrop Acceleration (g)	Amplification Factors	
	Bedrock	Outcrop
0.002	7.4	3.7
0.011	4.7	2.9
0.025	3.9	2.4
0.035	3.5	2.2
0.050	3.2	2.1
0.075	2.8	1.8
0.100	2.4	1.6

In most cases, amplification factors increase with decreasing rock outcrop motions (PRA) as depicted in Figures 5.5 to 5.8. These figures are based on the results obtained using the best-estimate shear wave velocity profile. Figures 5.9 to 5.12 show the comparison of results using upper-bound, best-estimate and lower-bound soil profiles for global and local accelerograms. Best-estimate results are not in between upper and lower bounds since the upper-bound represents the V_s in the soft Bangkok clay with the lower-bound V_s at lower soil depth while the lower-bound profile represents the converse combination as discussed in Section 5.2.1.

This site response analyses confirm the results of previous studies. In addition, these analyses manifest comparatively similar results with other studies conducted about amplification of ground motions in Bangkok such as those carried out by Ashford *et al.* (2000) which estimated amplification of bedrock ground motions of about 3 to 7 times and by Warnitchai *et al.* (2000) which approximated amplification of outcrop motions about 3 to 4 times.

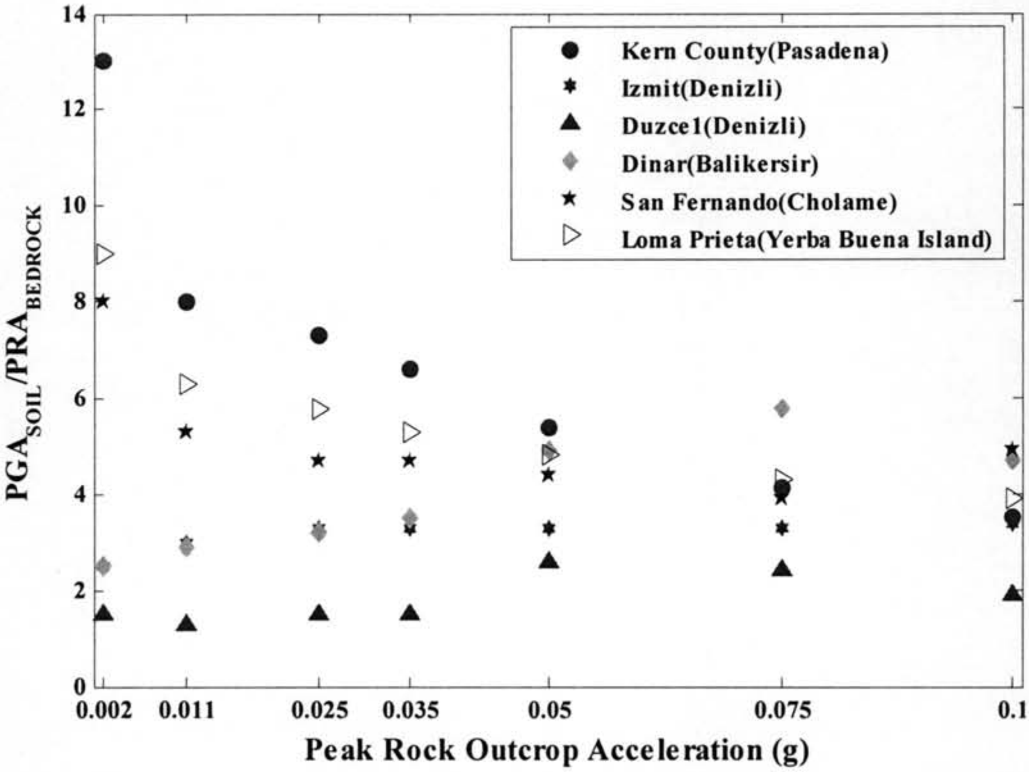

Figure 5.5 Relationship between computed amplification of bedrock motions and peak rock outcrop acceleration using global accelerograms

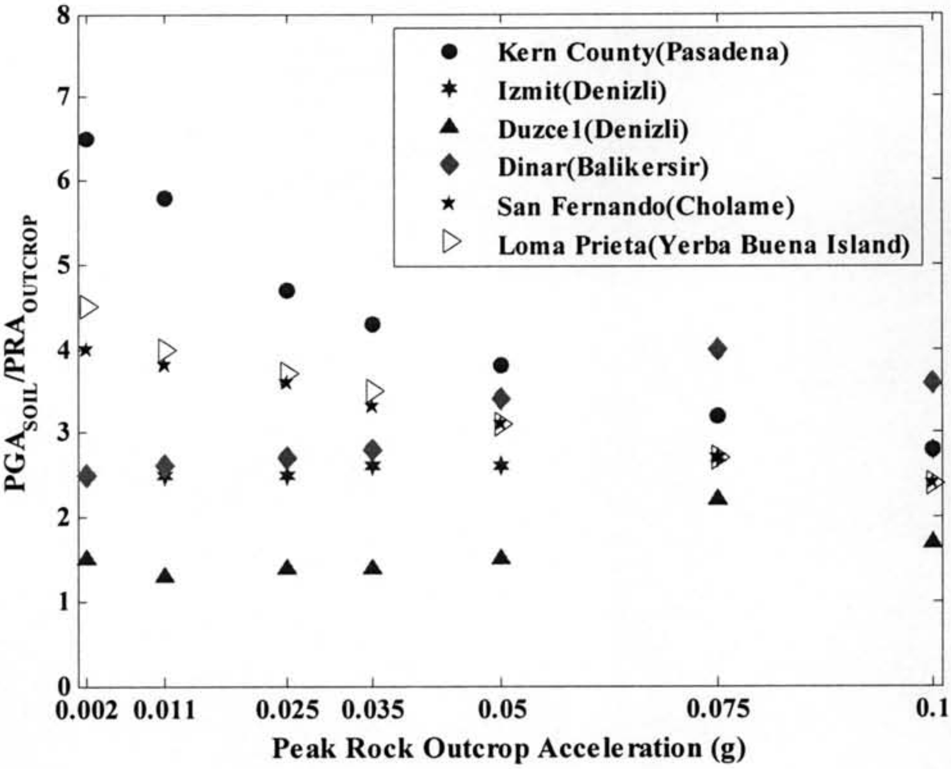

Figure 5.6 Relationship between computed amplification of outcrop motions and peak rock outcrop acceleration using global accelerograms

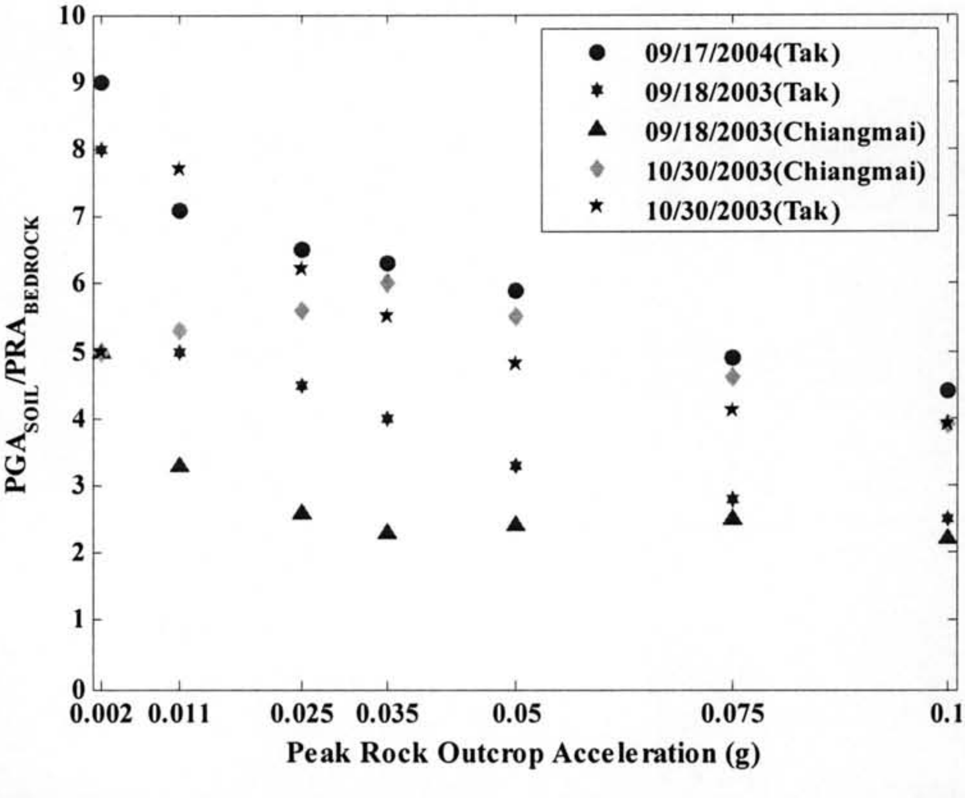

Figure 5.7 Relationship between computed amplification of bedrock motions and peak rock outcrop acceleration using local accelerograms

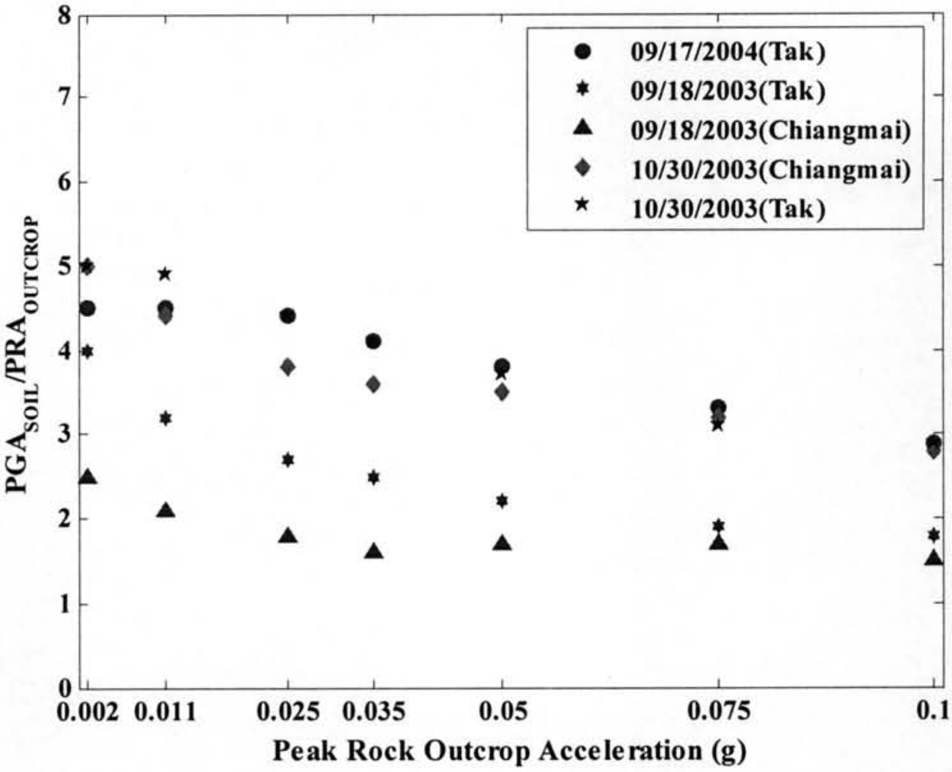

Figure 5.8 Relationship between computed amplification of outcrop motions and peak rock outcrop acceleration using local accelerograms

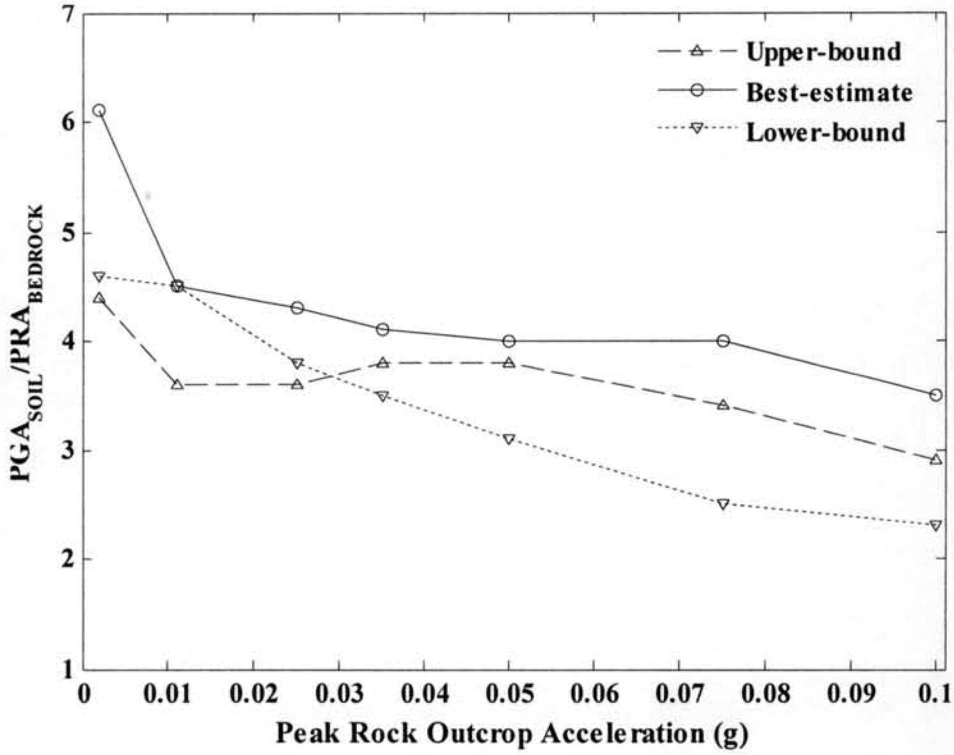

Figure 5.9 Comparison of computed amplification of bedrock motions and peak rock outcrop acceleration using global accelerograms for upper-bound, best-estimate and lower-bound soil profiles

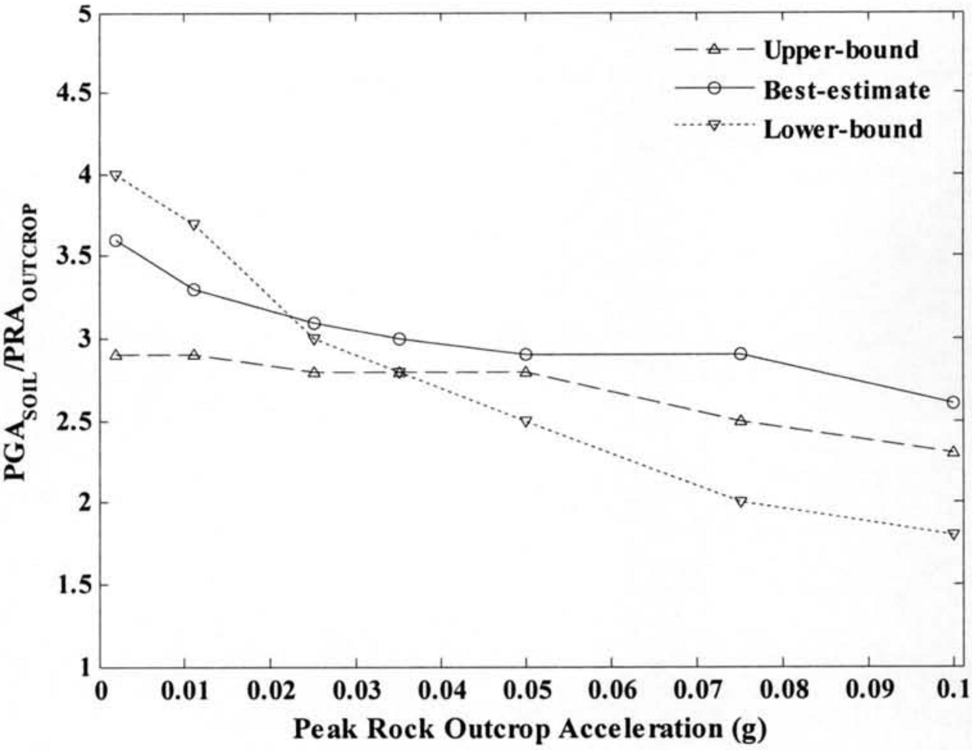

Figure 5.10 Comparison of computed amplification of outcrop motions and peak rock outcrop acceleration using global accelerograms for upper-bound, best-estimate and lower-bound soil profiles

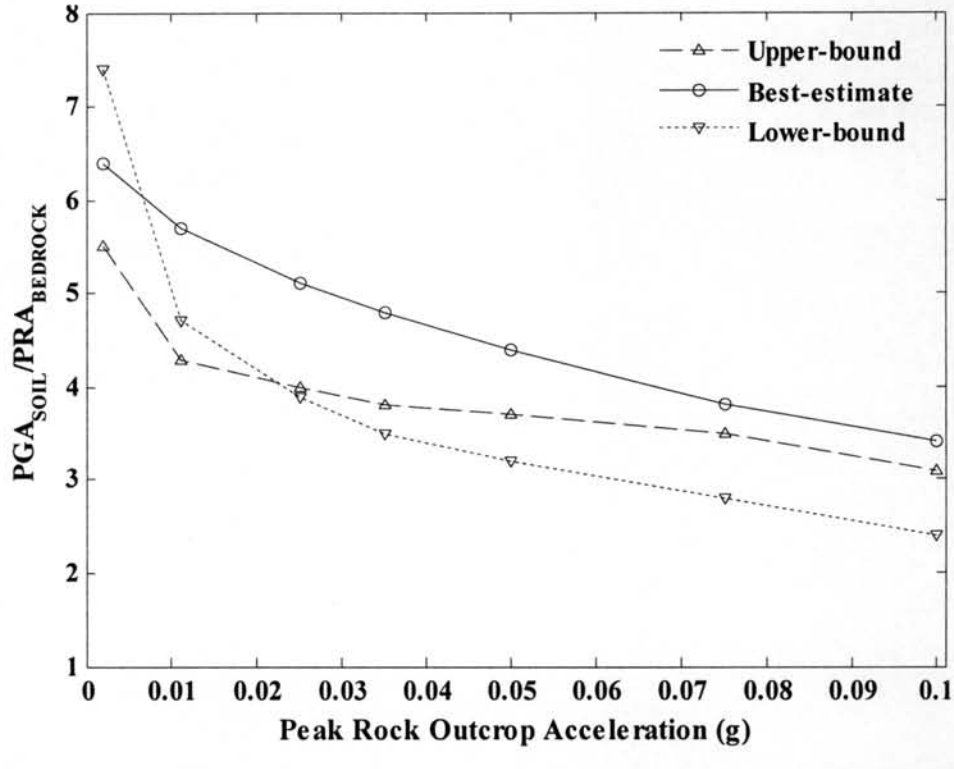

Figure 5.11 Comparison of computed amplification of bedrock motions and peak rock outcrop acceleration using local accelerograms for upper-bound, best-estimate and lower-bound soil profiles

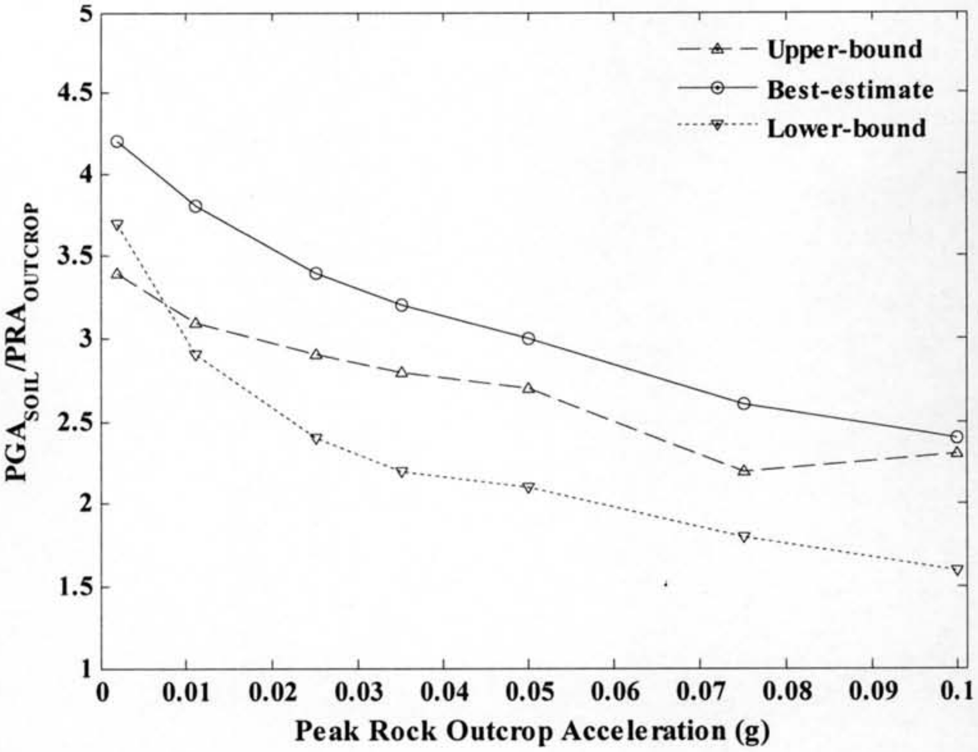

Figure 5.12 Comparison of computed amplification of outcrop motions and peak rock outcrop acceleration using local accelerograms for upper-bound, best-estimate and lower-bound soil profiles