

## AMPLIFICATION OF EARTHQUAKE GROUND MOTIONS IN BANGKOK

Scott A ASHFORD<sup>1</sup>, Warrasak JAKRAPIYANUN<sup>2</sup> And Panitan LUKKUNAPRASIT<sup>3</sup>

### SUMMARY

This paper presents the results of a study on the amplification of earthquake ground motions in Bangkok. Seismic site response analyses were conducted using the equivalent linear method. Soil properties used as input to the analysis, specifically shear wave velocity, were first estimated using existing correlations with field and laboratory data, then confirmed by a limited number of insitu tests by the downhole method. In addition, the effect of the assumed depth to rock-like material was studied. Five input strong motion records were selected from actual far-field sites, a distance of 80 to 350 km from the fault rupture. These five records were scaled to peak acceleration values of 0.02, 0.05, 0.07, and 0.10g to encompass the range of expected rock accelerations in Bangkok from previous studies. Based on the results of the study, it was concluded that the soils underlying Bangkok has the ability to considerably amplification earthquake ground motion, both in peak ground acceleration and spectral acceleration.

### INTRODUCTION

Following the 11 September 1994 Phan earthquake in northern Thailand and the 17 January 1995 Kobe earthquake, there is increased awareness of the seismic risk facing Thailand, and Bangkok in particular; the capitol city with an estimated population of nearly 8 million people. Though Bangkok lies a considerable distance from any known active fault, it is still at risk of strong ground shaking from distance earthquakes due to soils' ability to amplify certain ground motions. The city lies upon soft Bangkok clay, and the ability of soft clay to amplify earthquake ground motions has been well documented in the 1985 Michoacan earthquake and the 1989 Loma Prieta earthquake. The devastation in Mexico City was caused by the 1985 Michoacan earthquake with an epicenter over 350 kilometers away. This is approximately the same distance from Bangkok to the Andaman Sea, a potential source of large earthquakes. Since Thailand currently does not have seismic provisions in the building code, even relatively low levels of ground shaking from distance earthquakes, potentially amplified by local soil conditions, can cause considerable damage.

The objective of this study was to quantify the potential amplification of earthquake ground motions in Bangkok due to soil effects. The research first consisted of selecting a range of peak rock outcrop accelerations and appropriate acceleration time histories to be used in this study based on previous studies and the seismicity of the region. Second, a shear wave velocity profile was developed for use in the study based on available information and insitu testing. Third, one-dimensional equivalent linear seismic site response analyses were conducted for a generalized soil profile for Bangkok to quantify the potential amplification of earthquake ground motions. The scope of this study was rather limited in nature, with the objective to quantify *potential* amplification of earthquake ground motions. Many of the results of this preliminary study will also identify topics where additional work is necessary in order to better quantify the seismic response of the soil underlying Bangkok, and more importantly, the effect of that seismic response on building foundations and structures on the ground surface.

<sup>1</sup> University of California, San Diego, Dept of Structural Eng, , La Jolla, CA 92093-0085, USA. E-mail: sashford@ucsd.edu

<sup>2</sup> University of California, San Diego, Dept of Structural Eng, , La Jolla, CA 92093-0085, USA. E-mail: wjakrapi@ucsd.edu

<sup>3</sup> Chulalongkorn University, Department of Civil Engineering, Phayathai, Bangkok 10330, Thailand, E-mail: lpanitan@chula.a

## SEISMICITY OF THAILAND

The seismicity of Thailand has often been characterized as low. However, between 1994 and 1996, Thailand has been subjected to three magnitude 5+ earthquakes within the country and one magnitude 7+ earthquake in the Yunnan province of China, felt in both Chiang Mai and Chiang Rai. In fact, in the last 60 years, we have had 8 earthquakes of magnitude 5.0 or greater with epicenters in Thailand [Warnitchai and Lisantono, 1996], and eight earthquakes have been felt in Bangkok [Yensuang, 1986].

A limited number of probabilistic seismic hazard studies have been conducted, resulting in estimated peak bedrock acceleration maps for Thailand. One of the earliest studies [Natalaya and Shrestha, 1990] estimated that the peak rock acceleration in Bangkok with a 20% probability of exceedance in 90 years was approximately 0.015g. A later study [Lukkunaprasit and Kuhatanadeekul, 1993] estimated the peak rock acceleration in Bangkok as approximately 0.03g, with a 10% probability of exceedance in 50 years. The most recent study [Warnitchai and Lisantono, 1996] estimates the peak rock acceleration for Bangkok to be approximately 0.075g with a 10% probability of exceedance in 50 years.

Based on the seismicity of Thailand and earthquakes felt in the Bangkok area, it is apparent that Bangkok is at the greatest risk from strong, distant earthquakes. The frequency content of such earthquakes will be much different from closer events because of the tendency for high frequency motions to be damped out. Taking this into consideration, the acceleration time histories used in the analyses for this study are actual strong motion records recorded at rock sites in the far-field. Five such records were selected for this study.

Two of the records were recorded during the 17 October 1989 Loma Preita earthquake at rock sites in San Francisco, 80 kilometers from the fault rupture surface. These acceleration time histories were recorded at the Cliffhouse and Diamond Heights stations. Two other records were selected from earthquakes in Mexico. Since conditions in Bangkok are often compared to those in Mexico City, one of the selected motions was from the 19 September 1985 Michoacan earthquake (or simply the Mexico City earthquake). The rock outcrop motion recorded was by the National Autonomous University of Mexico (UNAM) on the hills surrounding Mexico City at a site designated CUIP. This motion was recorded about 350 km from the fault rupture. The second record from Mexico was recorded at Caig, about 160 km from the fault rupture of the 14 September 1995 Copala earthquake ( $M_w = 7.5$ ). The final record selected for analysis was the Pasadena record from the 1952 Kern County, California, earthquake ( $M_L=7.6$ ). This record was primarily selected because it has been used in earlier studies of seismic site response of Bangkok (Bergado et al., 1986). A summary of all the rock outcrop motions used in this study are presented in Table 1.

In order to encompass the estimates for peak rock acceleration in Bangkok from previous studies, these time histories were scaled to a range of values for analysis: 0.02g, 0.05g, 0.07g, and 0.10g. This does not imply that rock accelerations of 0.1g are expected for Bangkok; it is clearly well above the highest estimate. Rather, it was selected as an upper-bound for this parametric study.

**Table 1. Summary of Rock Outcrop Motions used in Analyses**

Earthquake	Date	Station	Distance (km)	$a_{max}$ (g)	$T_{eq}$ (sec)
Loma Preita	17-10-89	Cliffhouse	80	0.09	0.95
Loma Preita	17-10-89	Diamond Heights	80	0.06	0.4
Michoacan	19-9-85	CUIP	350	0.03	2
Copala	14-9-95	Caig	160	0.005	0.2-0.8
Kern County	21-7-52	Pasadena	126	0.05	0.65

## CHARACTERIZATION OF BANGKOK SOILS

The soil underlying Bangkok generally consist of alternating layers of clay and sand. The clay layers can be subdivided into three main types: soft to medium clay, stiff clay, and very stiff to hard clay. Generally, the thickness of soft to medium clay is 15 to 20 m and is commonly referred to as *soft Bangkok clay*. The soft clay is underlain by a layer of stiff clay known as the *first stiff clay*. This layer is underlain sequentially by the *first sand layer*, the *second stiff clay*, and the *second sand layer*. *Bedrock* is estimated to be at depths in excess of 500 meters, but for practical purposes, rock-like material with relative high stiffness will likely occur at a much shallower depth.

In conducting a seismic site response analysis using the equivalent linear method, one of the key input parameters is the shear modulus at low-strain ( $\gamma \approx 5 \times 10^{-4}$  %), generally represented as  $G_{\max}$ . Though  $G_{\max}$  is difficult to accurately measure in the laboratory due to the effects of sample disturbance, it can be readily determined from the insitu shear wave velocity ( $V_s$ ) and the mass density ( $\rho$ ) from the relationship  $G = V_s^2 \times \rho$ . The level of strain associated with crosshole or downhole methods of determining  $V_s$  is approximately  $5 \times 10^{-4}$  %. With the need to estimate values of  $G_{\max}$  or  $V_s$  for a generalized soil profile for Bangkok, several empirical correlations based on available field and laboratory measurements were reviewed.

Jakrapiyanun et al. [1995] compared soft Bangkok clay to San Francisco Bay Mud, and showed the two to be quite similar. Therefore, the relationship for estimating shear wave velocity by Dickenson [1994] based on San Francisco Bay Mud strength data was applied to the laboratory data from 9 sites around Bangkok to estimate shear wave velocity, as well as the relationships developed by Seed and Idriss [1970] and Hardin and Drnevich [1972]. For subsequent layers, essentially standard penetration test (SPT) N-values were the only available data below 25 m, so selected correlations based on N-value were used for other layers.

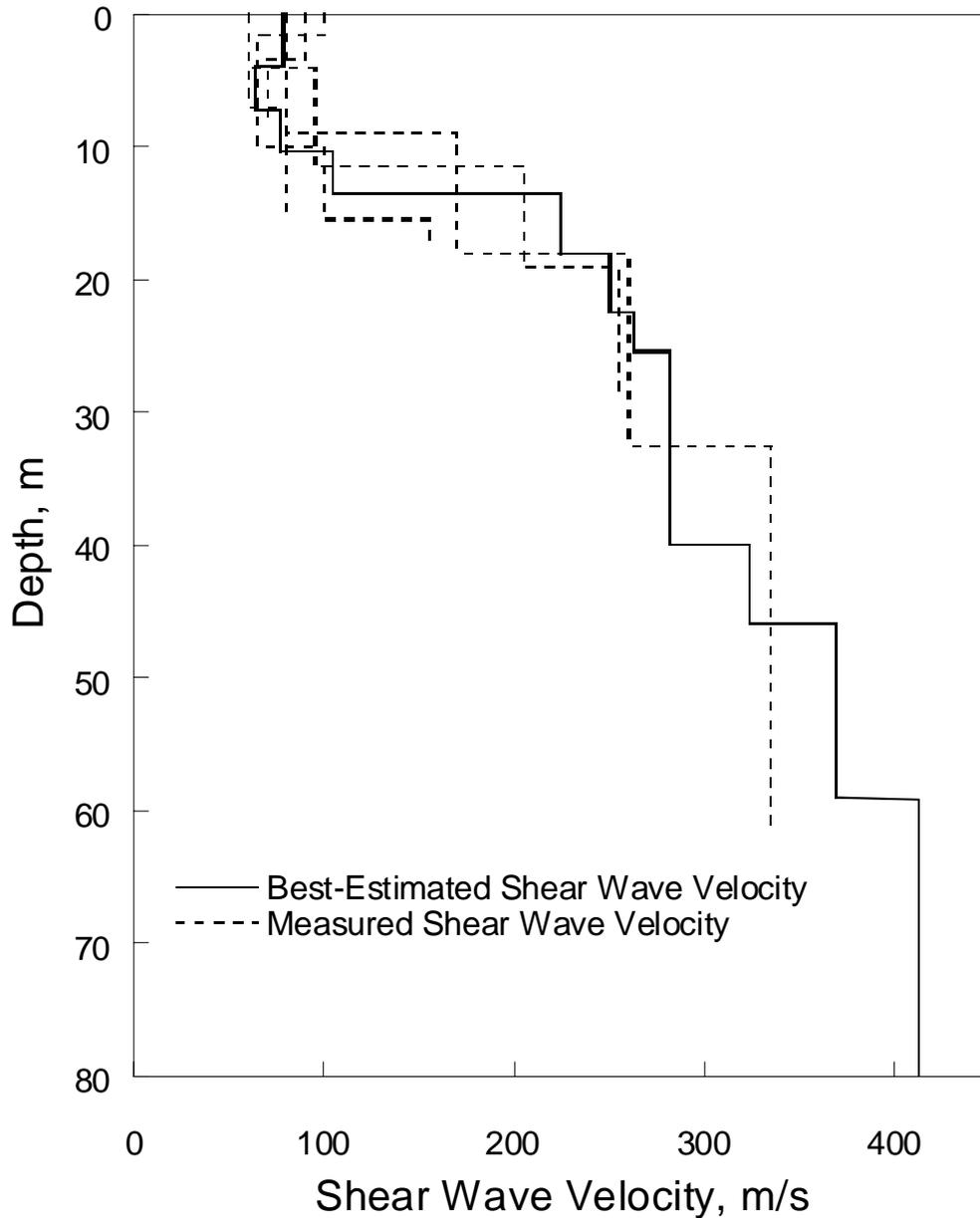
Though much effort was put forth in this research program using empirical relationships to estimate the shear wave velocity profile for Bangkok, when possible, it is desirable to confirm such estimates with actual insitu measurements. With this purpose, the insitu shear wave velocity profile was measured at 4 locations around Bangkok using the downhole. These are believed to be the first such measurements obtained for the soil underlying Bangkok, including for the soft Bangkok clay. The comparison shows excellent agreement for all layers. The best estimate shear wave velocity profile based on empirical relationships is compared to the measured data in Figure 1.

Since laboratory testing to determine the variation of  $G$  with  $\gamma$  for Bangkok soils was beyond the scope of this current study, it was decided to use the latest normalized relationships available. For clays, Vucetic and Dobry [1991] combined the results of many previous studies, including studies of Mexico City clay, to develop normalized relationships of  $G$  and  $\gamma$  as a function of plasticity index. For sand, the relationships proposed by Seed et al. [1984] were used. Both the relationships by Vucetic and Dobry [1991] and by Seed et al. [1984] are in wide use for estimating shear modulus and damping variation with shear strain of soil for purposes of site response analysis.

## SEISMIC RESPONSE ANALYSIS

The equivalent linear method of modeling non-linear soil behavior was utilized for this study, as coded in the computer program SHAKE91 [Idriss and Sun, 1992]. This computer program models the response of a system of homogeneous, viscoelastic soil layers of infinite horizontal extent subjected to vertically travelling shear waves. The program is based on the continuous solution to the wave-equation modified for use with transient motions through the Fast Fourier Transform algorithm.

The non-linear behavior of shear modulus and damping is accounted by the use of equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer. In the program, each layer is defined by shear modulus, damping ratio, mass density, and thickness. The response in the system is induced by the upward propagation of shear waves from the underlying rock formation. The shear waves are defined as acceleration values at equally spaced time intervals.



**Figure 1: Comparison of measured shear wave velocity profile to best-estimate profile for Bangkok based on empirical correlations.**

### RESULTS OF ANALYSIS

The seismic site response analyses were conducted using range of scaled peak rock accelerations (0.02 to 0.10g) for the five input motions Mexico City seismogram as discussed above. The results of the analyses are shown in Table 1. It can be seen that there is considerable amplification of the input rock motion in all cases, which ranges from approximately 2.5 to 5.5. The amplification in general decreases with increasing input acceleration. Amplification of the 0.02g input motion ranges from 2.5 to 5.5, resulting in peak accelerations at the ground surface of 0.05 to 0.11g. For higher input accelerations, for example 0.07g as suggested by Pennung and Lisantono [1], the amplification is considerably less (approximately 2.8 to 3.9), but result in ground surface accelerations exceed 0.25g.

**Table 4.1: Peak ground acceleration ( $a_{\text{soil}}$ ) and soil amplification ( $A_s$ ) for 5 rock outcrop motions scaled to peak acceleration values ( $a_{\text{rock}}$ ) of 0.02g through 0.1g using the best-estimate soil profile. All acceleration values are in g's.**

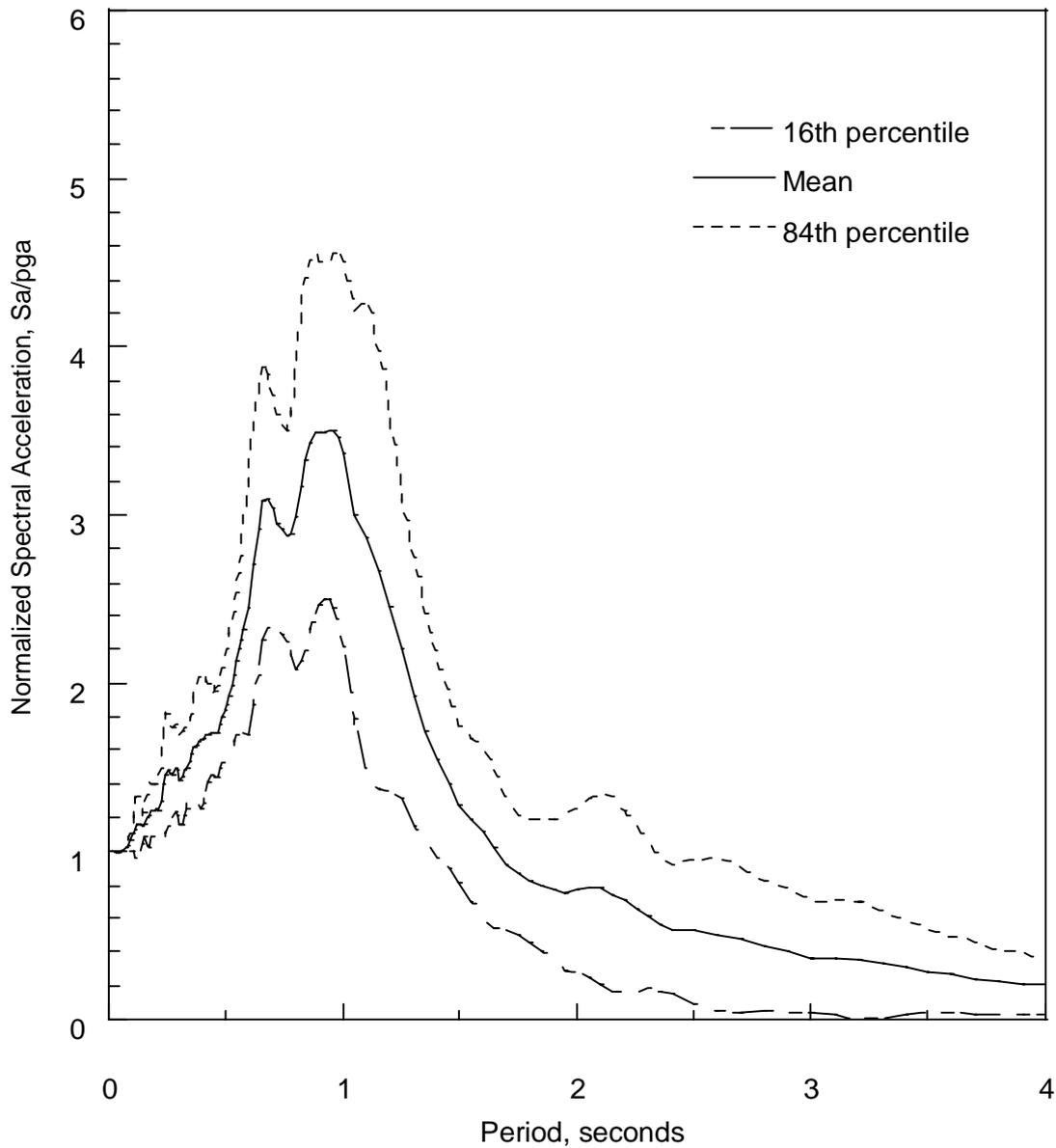
Outcrop Motion	Cliffhouse		Diamond Heights		CUIP		CAIG		Pasadena	
$a_{\text{rock}}$	$a_{\text{soil}}$	$A_s$								
0.02	0.08	3.82	0.07	3.44	0.05	2.52	0.07	3.74	0.11	5.47
0.05	0.19	3.75	0.17	3.37	0.14	2.73	0.17	3.39	0.21	4.18
0.07	0.27	3.88	0.23	3.28	0.20	2.81	0.23	3.22	0.25	3.60
0.10	0.39	3.9	0.31	3.13	0.26	2.61	0.30	3.02	0.31	3.07

The mean normalized acceleration response spectra, combining the results from all peak rock outcrop accelerations, for the best estimate soil profile are presented in Figure 2, along with the 16th- and 84th- percentile spectra. It can be seen from Figure 2 that the mean peak spectral amplification is approximately 3.5, with a relatively sharp peak occurring at 1 second period. Based on the available data, upper- and lower-bound analyses were also conducted for the stiffness contrast at the soft clay-stiff clay interface. Similar results were observed, though the response spectra were somewhat broadened. Analyses were also conducted for the site specific shear wave velocities obtained at the four locations around Bangkok. These results also agreed well with the results from the best estimate soil profile. In order to account for the variability of the soil properties around the Bangkok metropolitan area, the 84<sup>th</sup> percentile spectrum may be more appropriate for use in the Bangkok area, as recommended by Seed and Idriss (1982) for soft clay sites.

One of the unknowns in the above analyses is the depth to *rock-like* material. A limited number of borings to bedrock have been completed in the lower Central Plain. These wells encountered bedrock very deep below the ground surface, ranging from quartzite at 500 meters in Rangsit to granite at over 1800 meters in Thonburi [Bergado et al., 1986]. However, for the purposes of seismic site response analyses, the depth to *bedrock* itself is not as important as the depth to *rock-like* material that behaved essentially as bedrock [Lysmer et al., 1970], that is, material having a shear wave velocity on the order of 800 to 1200 m/s. In fact, Lysmer et al. found that the response at the ground surface was relatively independent of the shear wave velocity of the assumed rock-like material. Some effect was observed, however, on the assumed depth to rock-like material, and whether or not an intermediate rock-like layer was modeled between the bottom of the soil profile and the surface of the *bedrock*. This effect was mainly on the frequency content of the motion at the ground surface; the peak ground acceleration was relatively unaffected. Lysmer et al. concluded that effect of depth to rock-like material can have a significant effect on the computed response, especially the shape of the response spectra, and that the effect on the analyses of the assumed bedrock conditions should be considered. In the above analyses, the depth to rock-like material ( $V_s = 900$  m/s) was assumed to be 80 m, the depth of the deepest data available. As part of this study, this interface was also taken as deep as 300 m. It was found that this depth had little effect on the amount of amplification, but did result in additional peaks in the response spectra at longer periods. Clearly, more information is needed on the deeper sediments underlying Bangkok.

## CONCLUSIONS

The soil beneath Bangkok has the ability to significantly amplify earthquake ground motions, sometimes in excess of a factor of 5, with this ability decreasing with increasing input accelerations. The levels of amplification estimated for Bangkok are similar to those *recorded* at soft clay sites in downtown Mexico City and in the San Francisco Bay Area. It must be clearly stated that the amount of amplification and the shape of the response spectra will vary with the input motion used.



**Figure 2: Best-estimate normalized acceleration response spectra for Bangkok.**

Clearly, the estimate of expected peak rock acceleration, as well as the frequency content of the expected motion in Bangkok, must be refined. This should necessarily include characterization of active faults that are likely to affect the city. The soil properties used in the analyses must also be better defined. This would include additional insitu testing for shear wave velocity and sophisticated laboratory testing for determining the variation of shear modulus and damping with shear strain. Though the published relationships used in this study are often sufficient, it would seem prudent to develop relationships specifically for soil underlying Bangkok; the capitol of Thailand, center of commerce, and city of nearly 8,000,000 people.

#### ACKNOWLEDGMENTS

The support of the Royal Thai Government Public Works Department is greatly appreciated.

## REFERENCES

- Dickenson, S. E. (1994). *Dynamic Response of Soft and Deep Cohesive Soils During the Loma Prieta Earthquake of October 17, 1989*, Dissertation presented to the Regents of the University of California at Berkeley in partial fulfillment of the requirements for the degree of Ph.D. in Engineering, 331p.
- Hardin, B., and Drnevich, V. (1972). "Shear Modulus and Damping in Soils: Design Equations and Curves," *Journal of the Soil Mechanics and Foundations Division*, American Society of Civil Engineers, Volume 98, No. 7, pp. 667-691.
- Idriss, I. M., and Sun, J. I. (1992). *User's Manual for SHAKE91*, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California at Davis.
- Jakrapiyanun, W., Ashford, S. A., and Lukkunaprasit, P. (1995). "Estimation of In-situ Shear Wave Velocity of Soft Bangkok Clay," *Proceedings, 2nd National Convention on Civil Engineering*, pp. 321-326.
- Lukkunaprasit, P., and Kuhatasanadeekul, N. (1993). "Seismic Zoning and Seismic Coefficients for Thailand," *Proceedings, 1993 Annual Conference, Engineering Institute of Thailand*, pp. 268-287.
- Nutalaya, P., and Shrestha, (1990), "Earthquake Ground Motions and Seismic Risk in Thailand", *Proceedings, 1990 Annual Conference, Engineering Institute of Thailand* pp. 57-77.
- Seed, H. B., and Idriss I. M. (1970), *Soils Moduli and Damping Factors for Dynamic Response Analyses*, U.C. Berkeley, Earthquake Engineering Research Center, Report No. EERC 70-10.
- Seed, H. B., Wong, R. T., Idriss, I. M., and Tokimatsu, K. (1984), *Moduli and Damping Factors for Dynamic Analyses of Cohesionless Soils*, University of California at Berkeley, Earthquake Engineering Research Center, Report No., UCB/EERC-84/14, 37p.
- Vucetic, M. and Dobry, R. (1991), "Effect of Soil Plasticity on Cyclic Response," *Journal of Geotechnical Engineering*, ASCE, Vol 117, No. 1, pp.89-107.
- Warnitchai, P., and Lisantono, A. (1996), "Probabilistic Seismic Risk Mapping for Thailand," *Proceedings, 11th World Conference on Earthquake Engineering*, Acapulco, Mexico.
- Yensuang, S. (1986), "Instrumental Earthquake Records in Thailand," *1st Workshop on Earthquake Engineering and Hazard Mitigation*, Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE), and National Earthquake Committee of Thailand, Bangkok, pp. 105-136.