

# Seismic Site Effects of Soil Amplifications in Bangkok

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## Abstract

In this paper, seismic site effects resulting from amplification of soft soil in Bangkok are presented. Site characteristics were surveyed using the microtremor observation technique. The method of Centerless Circular Array (CCA) was employed to examine the shear wave velocity profile of subsoil from surface to bedrock level of 20 sites. The average shear wave velocity of each site is not significantly different; however, the depth of bedrock varies from 400 to 800 m. The area was subdivided into two zones according to the depth of bedrock. The results of shear wave velocity were then used to construct a model for ground response analysis for prediction of earthquake motion at the surface. The design response spectral accelerations were presented for the two zones. The results show that higher ground accelerations could occur in the area having shallow depth of bedrock, less than 700 m. The design response spectral accelerations are generally high in the periods range from 0.5 to 4 second.

**Keywords:** Site effects; shear wave velocity; microtremor; Bangkok

## 1. Introduction

Local soil conditions, especially soft soil deposits, always contribute great influence in amplification of seismic waves. To examine these effects, soil characterization and ground response analysis of the area are required. Understanding of the effects could enable engineers to establish appropriate measures for earthquake resistant design of structures.

Problems of soil amplification of earthquakes in Bangkok have been occasionally observed. The major sources of earthquakes are from active faults in the northern and western part of Thailand, and the subduction zone in the Andaman Sea. Soils beneath Bangkok are known as soft deposits but the effects of seismic amplification have not been completely investigated.

In this study, seismic site effects of soil amplifications in Bangkok were studied.

The first part of the research was an investigation of shear wave velocity (Vs) of subsoil using the microtremor observation technique. Vs profiles of 20 several hundred-meter depth sites were surveyed. Then, the Vs profiles were used to construct soil models for analysis of seismic ground response of the area. The design spectrum accelerations of Bangkok were proposed for earthquake resistant design of buildings.

The paper begins with an explanation of the study area and the microtremor technique focusing on the Centerless Circular Array method (CCA). The ground response analysis using the equivalent linear method was summarized. The results were presented as Vs profiles and depth of bedrock. Finally, the obtained ground responses were used to establish design spectral accelerations for Bangkok.

## 2. Area of Study

Bangkok is situated on the central part of a large lower plain known as the Chao Phraya basin. The plain consists of deep Quaternary deposits. Generally, subsoil is relatively uniform inside the basin. Soil underlying this area can be described as alternating layers of clay and sand. The first layer is the uppermost layer of weathered crust of one to five meters. The second layer is soft clay with very low shear strength, known as soft Bangkok clay. The thickness of this layer is about 15 to 20 meters in the central area. The soft clay is underlain by alternate layers of stiff clay and sand. The depth of bedrock is estimated to be 500 meters or deeper, but there is no sufficient data available at present. Recent research on seismic site characteristics by small array microtremor observations showed that the average shear wave velocity from the surface to a depth of 30 m ( $V_{s30}$ ) was very low over the basin [1].

The area of investigation is located within latitudes  $13^{\circ} 30' N$  to  $13^{\circ} 57' N$  and longitudes  $100^{\circ} 22' E$  to  $100^{\circ} 51' E$ . Figure 1 shows the location of the investigated area in which 20 observation sites are distributed.

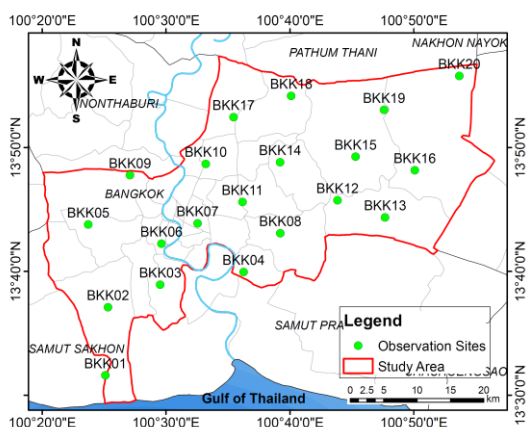


Figure 1. Map of observation stations.

## 3. Microtremor Observation Techniques

Microtremors represent constant vibration of the Earth's surface at seismic frequencies, which are present at anytime. The amplitudes are extremely small, as displacements are in the order of  $10^{-4}$  to  $10^{-2}$  mm [2]. Recently, techniques of microtremor survey have been commonly applied to extract information for seismic study. In the first part of the study, key parameters for site characterization and ground response analysis, such as shear wave velocity and depth of bedrock at a site, were determined by microtremor survey. Field measurements were conducted to provide site characteristics useful for examination of ground motion amplifications. Two techniques of determining phase velocities from microtremors, the Spatial Autocorrelation method (SPAC) and the Centerless Circular Array Method (CCA), were firstly examined for further application. The observed phase velocities were subsequently inversed to shear wave velocity profile of subsoils.

### 3.1 Spatial Autocorrelation method (SPAC)

The basis of this technique, proposed by Aki in 1957 [3], is to simultaneously record the vertical component of microtremors for several positions to measure Rayleigh wave samples propagating from different azimuthal angles. The coherency spectrum is computed for any pair of sensors in the array to evaluate the correlation between them, and to determine dispersive phase velocity characteristics. The coherencies for all measurement pairs having the same spatial distance are then azimuthally averaged to provide the spatial autocorrelation (SPAC) coefficients of interstation distance  $r, \rho(\omega, r)$ . By assuming that the wave energy propagates with only one velocity at each frequency,  $\omega$ , it can be shown that the spatial autocorrelation coefficient for a circular array is given by equation (1) [3].

$$\begin{aligned}\rho(\omega, r) &= \frac{\text{Re}[E[C_{A,B}(\omega)]]}{\sqrt{E[C_{A,A}(\omega)]E[C_{B,B}(\omega)]}} \\ &= J_0(k(\omega)r) = J_0\left(\frac{\omega r}{c(\omega)}\right)\end{aligned}\quad (1)$$

Where  $E[\ ]$  denotes an ensemble average over time,  $C_{A,B}(\omega)$  is cross spectra of vertical records at two stations, A and B,  $J_0$  is the Bessel function of the first kind with the zero-th order, and  $k(\omega)$  and  $c(\omega)$  are the wavenumber and phase velocity, respectively, for the Rayleigh waves with the fundamental mode. The phase velocity can be determined by fitting the observed SPAC coefficients at various  $r$  for each frequency with  $J_0(\omega r/c(\omega))$ .

### 3.2 Centerless Circular Array method (CCA)

This technique was proposed and developed by Cho *et. al.* [4] based on spectral ratio representations which can be considered as a general case of the SPAC method. The spectral ratio which contains information of phase velocities is an integration of all information on the field of the vertical component of microtremors. Field work requires deployment of a circular array of radius  $r$  and recording the vertical component of the microtremor  $z(t, r, \theta)$ . Define the average value  $Z_0(t, r)$  along the circumference and its weighted average  $Z_1(t, r)$  as

$$Z_0(t, r) = \int_{-\pi}^{\pi} z(t, r, \theta) d\theta \quad (2)$$

$$Z_1(t, r) = \int_{-\pi}^{\pi} z(t, r, \theta) \exp(i\theta) d\theta \quad (3)$$

Assuming that the fundamental Rayleigh wave mode dominates the vertical component of the microtremor field, the ratio of their power spectra densities,  $G_0(r, r; \omega)$  and  $G_1(r, r; \omega)$ , can be written as

$$\frac{G_0(r, r; \omega)}{G_1(r, r; \omega)} = \frac{J_0^2(rk(\omega))}{J_1^2(rk(\omega))} \quad (4)$$

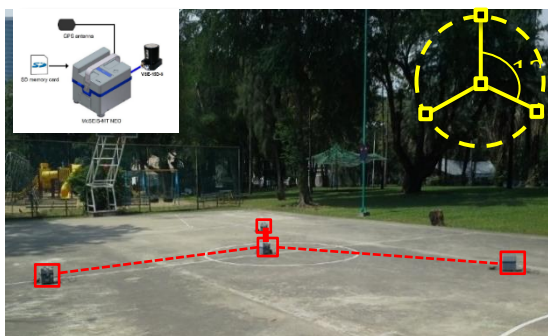
Where  $J_1$  is the Bessel function of the first kind with the first order. The wavenumber and phase velocity are then estimated by fitting the observed spectral ratio with a theoretical ratio of  $J_0^2(rk(\omega))/J_1^2(rk(\omega))$ .

### 3.3 Inversion of shear wave velocity profile

From the dispersion relation of phase velocity and frequency, the results from field observations were compared with those derived theoretically from a horizontally layered earth model by iteration procedure. The results of best-fit shear wave velocity–depth profile were determined from the inversion analysis.

### 3.4 Instrument and field observation

The instrument used for microtremor observation consists of velocity sensors having frequency range of 0.1 to 70 Hz connected to the receivers with 24 bit A/D convertors. There were 4 sets of equipment, each set measured simultaneously by time synchronization using a GPS clock with a resolution of 1/100 second. The array configuration was an equilateral triangular array network. Three sensors were placed at the corners of a triangle (or a circle), and one at the center. Figure 2 shows arrangement of sensors. The radius sizes of the arrays were 5, 30, 100 and 250 meters, respectively. The duration for collecting vibration data was about 40 minutes for each array.



**Figure 2.** Array configuration.

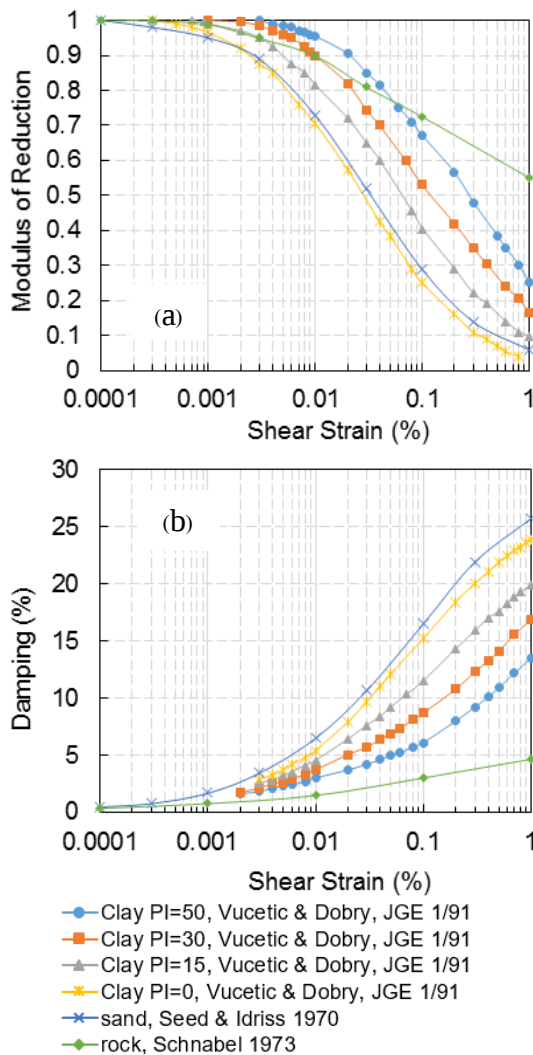
#### 4. Ground Response Analysis

In order to evaluate seismic site effects, ground responses at the site are analyzed by one-dimension analysis using the SHAKE computer program [ 5] . This technique applies an equivalent linear analysis which takes into the account the soil non-linearity by the use of strain compatible shear modulus and damping ratio in a sequence of linear analyses through an iterative process. The output of the analysis provides acceleration time-histories of ground response and response spectrum for a set of input motions.

In this study, the relationships for Bangkok clay down to 13.5 m depth were taken from Shibuya and Tamrakar [6] for the shallow layers. For deep structures, alternate layers of sand and clay having different plasticity index were modeled according to data taken from a deep boring log. The selected relationships for soil layers are presented in Table 1, and the modulus reduction and damping curves are shown in Figure 3.

**Table 1.** Dynamic soil properties for equivalent linear analysis.

| No. | Depth (m)     | Material Type | Dynamic Soil Properties |
|-----|---------------|---------------|-------------------------|
| 1   | 0 - 5.5       | Clay          | Ref. [6]                |
| 2   | 5.5 - 10.3    | Clay          | Ref. [6]                |
| 3   | 10.3 -13.5    | Clay          | Ref. [6]                |
| 4   | 13.5 - 20     | Clay          | Ref. [7]                |
| 5   | 20 - 35       | Sand          | Ref. [8]                |
| 6   | 35 - 50       | Clay          | Ref. [7]                |
| 7   | 50 - 75       | Sand          | Ref. [8]                |
| 8   | 75 - 85       | Clay          | Ref. [7]                |
| 9   | 85 - 100      | Sand          | Ref. [8]                |
| 10  | 100 - Bedrock | Sand          | Ref. [8]                |
| 11  | Rock          | Rock          | Ref. [9]                |



**Figure 3.** Dynamic properties of subsoil; (a) modulus reduction, and (b) damping.

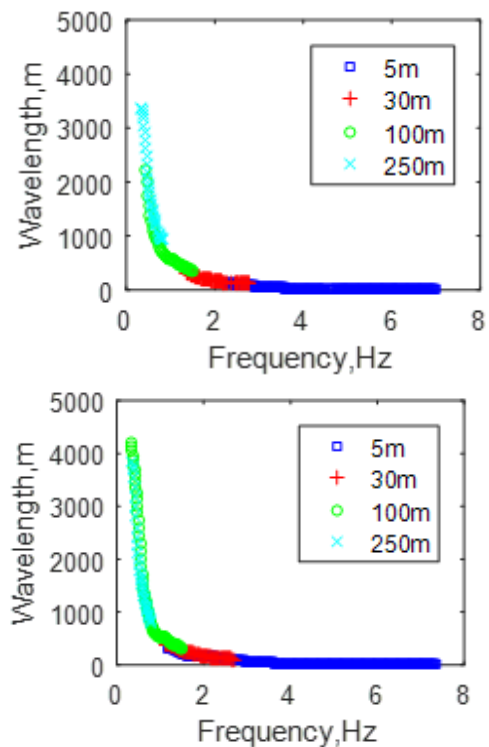
## 5. Results and Discussions

### 5.1 Comparison of SPAC and CCA results

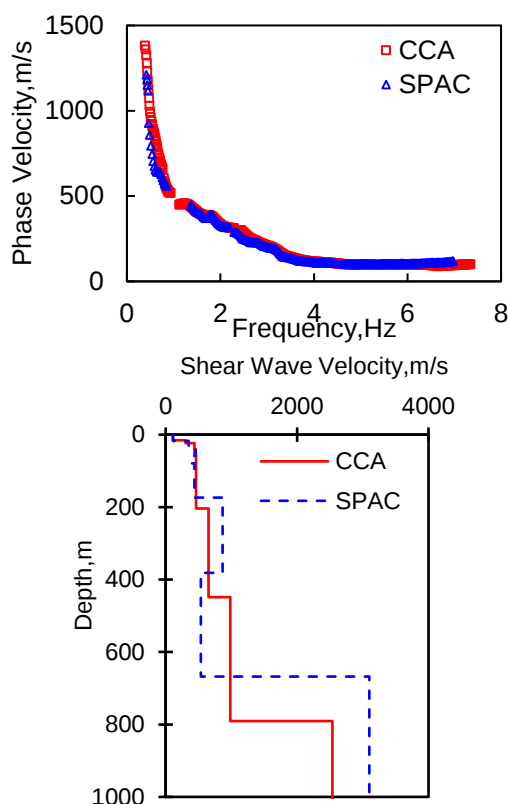
Figure 4 shows a comparison of the computed wavelength from SPAC and CCA techniques using the same data set. The CCA method provides longer detectable wavelengths and lower frequency ranges than the SPAC method does. It can be inferred that more accurate inversion analysis of the Vs profile from phase velocity dispersion can be achieved by the CCA method, especially in deeper structures. The results from other sites

exhibit similar findings so this study presents the following results as those obtained from the CCA method.

The final dispersion curves obtained by both techniques are shown in Figure 5(a). By using inversion analysis of phase velocities, shear wave velocity profiles from both methods are obtained and shown in Figure 5(b). From these results, the depth of bedrock can be estimated at the level where a shear wave abruptly increases to more than 2,000 m/s. There is very significant difference in the shear wave velocity profiles and the estimated depth of bedrock obtained from both methods.



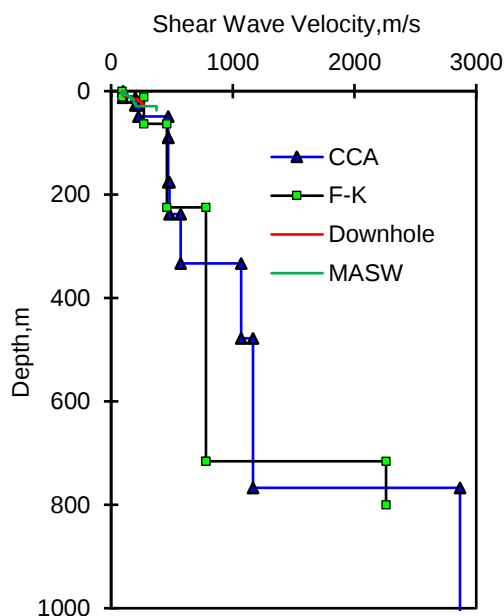
**Figure 4.** Computed wavelength (a) from the SPAC method, (b) from the CCA method.



**Figure 5.** (a) Phase velocity (b) Shear wave velocity profiles from CCA and SPAC method.

## 5.2 Comparison of Vs with different techniques

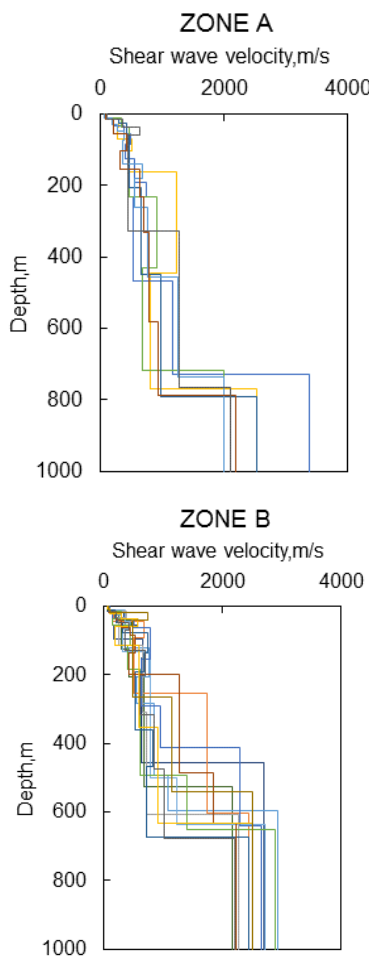
In order to validate the results, Vs profiles from inversion analysis of dispersion curves obtained by this study were compared with results from several techniques from previous researchers. These works are microtremor with frequency-wave number (F-k) spectral analyses by Arai and Yamazaki (2002) [10], seismic downhole tests by Palasri and Ruangrassamee (2009) [11], and multichannel analysis of surface waves (MASW) method by Chantamas (2007) [12]. This research conducted the measurement at approximately the same location in Chulalongkorn University. The results of shear wave velocity profile are shown in Figure 6, and they are found to be in good agreement with different techniques done in the same sites.



**Figure 6.** Comparison of Vs profiles from different observation methods.

## 5.3 Results of shear wave velocity (Vs)

An example of the Vs profile as shown in Figure 5(b) can be considered as a representative result. Generally, Vs of the first 100 m deposits are less than 500 m/s. The velocity increases gradually along depth and the underneath layers of stiffer soil exhibit moderate Vs of about 1000 m/s. There are clear contrasts of shear wave velocity in which the velocity changes sharply to be higher than 2000 m/s. The depth of such high velocity contrast in each site varies from 400 m to 800 m inferring the level of bedrock at the site. All results of Vs profiles are plotted in Figure 7 as they are subdivided into two groups: A and B. The inferred depth of bedrock ranges from 718 to 791 m for sites in group A, and from 410 to 679 m in group B.



**Figure 7.** Shear wave velocity profile for 20 observation sites; (a) Zone A, and (b) Zone B.

Table 2 summarizes the results of the average shear wave velocity from the surface to depths of 30, 100, 500 m and depth of bedrock. The average values for each zone are provided at the end of the Table. From these results,  $V_{s30}$  of all sites are less than 180 m/s indicating that soil in Bangkok can be classified as NEHRP site class E (soft soil and soft to medium clay) [13]. In the last column, the asterisk symbol denotes a site in zone A, while the remaining sites are in zone B.

The observation sites in Zone B exhibit lower average  $V_s$  from surface down to 100 m depth. Below this level, influence of  $V_s$  of the upper deposits becomes less

pronounced as the value of  $V_{s500}$  in two zones are almost the same.

**Table 2.** Result of average shear wave velocity for 20 sites.

| Site               | $V_{s30}$<br>(m/s) | $V_{s100}$<br>(m/s) | $V_{s500}$<br>(m/s) | Bedrock<br>(m) |
|--------------------|--------------------|---------------------|---------------------|----------------|
| BKK01              | 118                | 177                 | 439                 | 455            |
| BKK02              | 122                | 218                 | 428                 | 525            |
| BKK03              | 131                | 232                 | 504                 | 597            |
| BKK04              | 120                | 235                 | 579                 | 605            |
| BKK05              | 162                | 263                 | 528                 | 636            |
| BKK06              | 145                | 243                 | 596                 | 769*           |
| BKK07              | 145                | 265                 | 464                 | 727*           |
| BKK08              | 145                | 212                 | 461                 | 607            |
| BKK09              | 135                | 267                 | 513                 | 718*           |
| BKK10              | 161                | 293                 | 504                 | 791*           |
| BKK11              | 116                | 215                 | 468                 | 737*           |
| BKK12              | 120                | 258                 | 598                 | 410            |
| BKK13              | 130                | 210                 | 422                 | 650            |
| BKK14              | 132                | 223                 | 458                 | 788*           |
| BKK15              | 128                | 224                 | 468                 | 673            |
| BKK16              | 114                | 214                 | 548                 | 634            |
| BKK17              | 151                | 290                 | 503                 | 765*           |
| BKK18              | 117                | 190                 | 433                 | 633            |
| BKK19              | 124                | 218                 | 483                 | 679            |
| BKK20              | 143                | 287                 | 559                 | 542            |
| <b>Ave. Zone A</b> | 141                | 257                 | 501                 | 756            |
| <b>Ave. Zone B</b> | 129                | 226                 | 496                 | 588            |

\* denotes a site in zone A

Figures 8 and 9 present a contour map for  $V_{s30}$  and  $V_{s500}$ , respectively. There is no clear tendency of variation of the average  $V_s$  distribution in the area. On the other hand, a map of bedrock depth, as presented in Figure 10, shows two distinct zones as discussed previously.

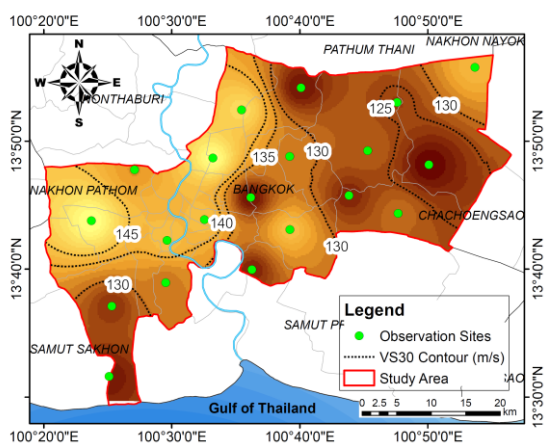


Figure 8. Vs30 map of Bangkok.

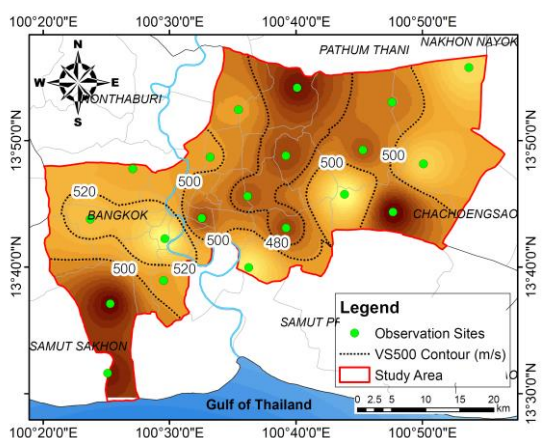


Figure 9. Vs500 map of Bangkok.

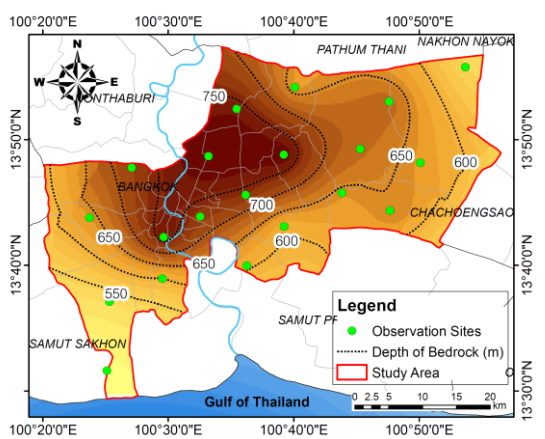


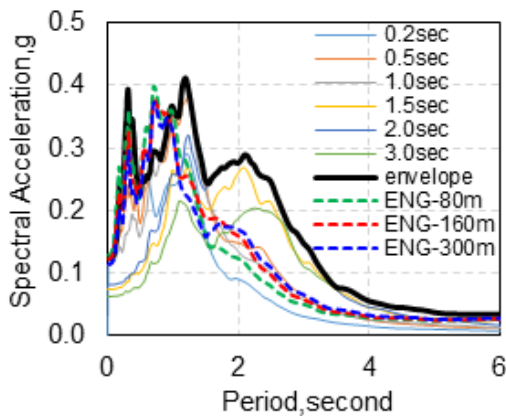
Figure 10. Bedrock map of Bangkok.

### 5.3 Results of ground response analysis

Ground motion samples taken from Probabilistic Seismic Hazard Assessment [14] were used as input rock outcrop acceleration time histories and the propagations through the model of soil profile were analyzed by the equivalent linear analysis. From 36 input motion accelerations, the spectral response accelerations ( $S_a$ ) at surface ground responses were considered for 5% structural damping. Then the average  $S_a$  were used to evaluate the Maximum Credible Earthquake (MCE) design spectrum for each site. The following example demonstrates the results for the site BKK16.

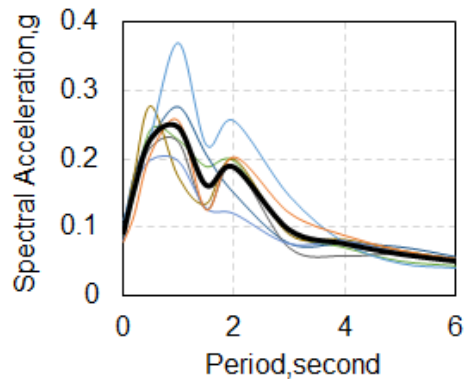
In Figure 11, thin lines are the average  $S_a$  resulting from each set of input motion, and their envelop was considered as the design spectrum, shown as a solid thick line. The design  $S_a$  exhibits high value in a wide range of periods. The long period effects, where  $S_a$  is over 0.2 g, are clearly indicated for the period up to 3 seconds.

For comparison, the models with shallower engineering bedrock are also shown in this figure.  $V_s$  of 900 m/s was assumed at three different depths, at 80 m, 160 m and 300, as denoted as ENG- 80m, ENG- 160m and ENG- 300m. In Figure 11, the results of design  $S_a$  obtained from the same analysis procedures are shown as dash lines for different engineering bedrock levels. It is clear that information of deep structures is important as  $S_a$  at long period increased significantly from the shallower engineering bedrock assumptions.

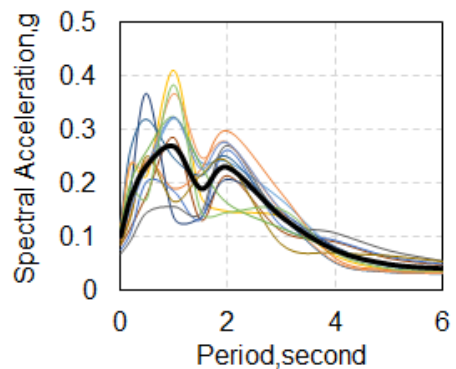


**Figure 11.** Average spectral response acceleration at surface.

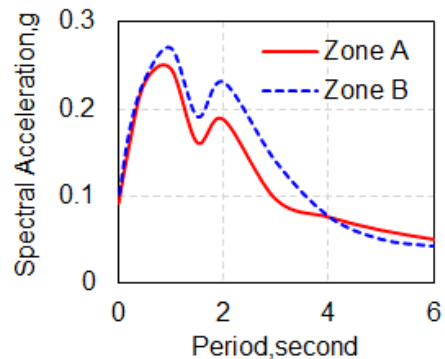
The results of  $S_a$  for all sites were considered for their similarity, and then the area is divided into two zones having the plots shown in Figure 12 and 13 for zone A and B, respectively. In these figures,  $S_a$  of each site is plotted as a thin line and the average is plotted as a thick line. Comparison of the average design spectrum of the two zones is shown in Figure 14. The  $S_a$  results of zone B are higher, especially from period about 0.5-4 second, which is the range of natural period of most buildings. This observation suggests that Vs profiles having high contrast between the bedrock and soil layers as in zone B amplify seismic waves more strongly than rather uniform and deep soil layers such as zone A. For very long periods, greater than 4 seconds, the effect of deep bedrock caused somewhat higher amplification. Finally, a seismic microzonation map based on the design  $S_a$  for Bangkok is presented in Figure 15.



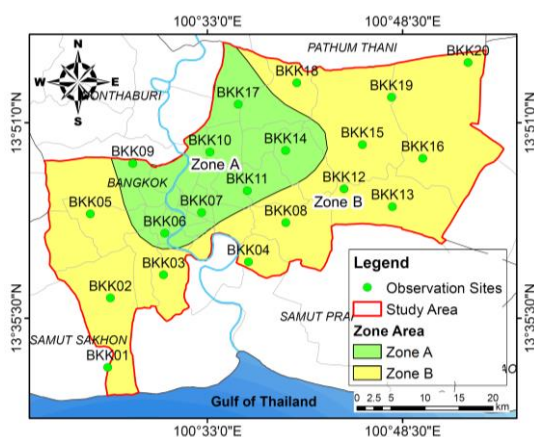
**Figure 12.**  $S_a$  of the observation sites (thin lines) and their average (thick line) in zone A.



**Figure 13.**  $S_a$  of the observation sites (thin lines) and their average (thick line) in zone B.



**Figure 14.** Comparison of the average  $S_a$  for zone A and zone B.



**Figure 15.** Seismic zonation map of Bangkok from Sa.

## 6. Concluding Remarks

This paper presents results of investigation of seismic ground motion amplified by soft soil conditions of Bangkok. The main findings can be summarized as follows;

- The microtremor technique of the Centerless Circular Array method (CCA) was successfully employed to explore Vs profiles of 20 sites.
- The average Vs from surface to 30 m, Vs30, of all sites are less than 180 m/s indicating that soil layers in Bangkok are soft soil or soft to medium clay, and classified as NEHRP site class E.
- Depth of bedrock at each site was inferred from the level at which Vs was higher than 2000 m/s. The identified depths vary from 400 to 800 m. The area was subdivided into 2 zones according to depth of bedrock.
- Vs profiles were used to model ground structure and the equivalent linear analysis was performed to estimate earthquake motions at the surface. The results were presented as the design spectral accelerations, Sa.
- Generally, Sa is amplified significantly in the period range from 0.5 to 4 seconds. It was indicated that Sa values in the area of shallower depth of bedrock were higher as a

result of high contrast between the bedrock and soil layers

## 7. Acknowledgement

This study is supported by the Thailand Research Fund, research number RDG5630018, and the scholarship for Ph.D. Student, Thammasat University. The sources of support are gratefully acknowledged.

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