New Design Spectral Acceleration of Soft and Deep Deposits in Bangkok

N. Poovarodom & A. Jirasakjamroonsri  
Department of Civil Engineering, Faculty of Engineering, Thammasat University, Thailand  
pnakhorn@engr.tu.ac.th

T. Ornthammarath  
Department of Civil Engineering, Faculty of Engineering, Mahidol University, Thailand

P. Warnitchai  
School of Engineering and Technology, Asian Institute of Technology, Thailand

ABSTRACT:

In this paper, seismic site effects considering deep deposits were investigated in order to propose new design spectral acceleration (Sa) for Bangkok. Site characteristics such as predominant periods and shear wave velocity profiles from surface to basement were surveyed using microtremor observation techniques; the H/V spectral ratio and the Centerless Circular Array method (CCA). The results of shear wave velocity were used to construct soil models for site response analysis using the input motions selected and scaled to match the uniform hazard spectra with the Conditional Mean Spectrum (CMS) concept. The results of Sa were considered for their similarity of shape and the vicinity, then the area is sub-divided into three zones. The proposed Sa curves are considerably distinct from the Sa in the present design standard which was derived based on limited information of site characteristics. The new Sa exhibit long period amplifications resulting from effects of deep deposits.

Keywords: Site effects, Soft soil amplification, Microtremor, Microzonation, Bangkok

1. INTRODUCTION

Bangkok, the capital city of Thailand, has been urbanized rapidly during the past few decades. A number of high rise buildings and infrastructure have been constructed in the metropolis with a population more than ten million. A recent survey reveals that there are more than 2 million buildings in Bangkok. Among these numbers, more than 1,000 buildings are 12 to 25-story high and more than 350 buildings are taller than 25 stories.

The city is located approximately 120 km away from low to moderate seismicity faults and 400 km from highly active Sumatra subduction zone. The area lies on a large plain underlain by thick alluvial and deltaic sediments of the Chaophraya River. The upper part of this plain is 15 to 20-thick layers of soft clay having undrained shear strength lower than 25 kPa. Alternate layers of sand and stiff clay exist at deeper strata and the basin depth is estimated to be several hundred meters. Several events of long period motion caused by distant earthquakes have been occasionally observed especially in tall buildings.

The current seismic design standard for Thailand (DPT 1302) was established after the Probabilistic Seismic Hazard Assessment (PSHA) studies by Ornthammarath et. al. (2010), and Palasri and Ruangrassamee (2010). Site characteristics of soils underneath Bangkok was limited when the standard was written so that the design spectral considering site effects was constructed based on crucial assumptions. Shear wave velocity (Vs) profiles were estimated from empirical relationships with the field standard penetration resistance of shallow boring log data and assumed basement rock level. The soil layers were modelled accordingly and the spectral acceleration at the ground surface were computed from the propagation of simulated seismic waves, selected to match the Uniform Hazard Spectral (UHS) for the entire range of periods, through these layers.

In this study, the main objective is to investigate site effects of Bangkok and proposed new spectral acceleration for the design of structures. The first part of the research is an exploration of site...
characteristics using microtremor observations for shear wave velocity profiles from surface to bedrock. The array microtremor technique, the Centerless Circular Array (CCA) method (Cho et al., 2006), was conducted at 31 sites. Then, site response analysis was performed in order to examine ground responses and to propose seismic microzonation accordingly. The input motions for the site response analysis were selected from strong motion database and scaled to match the UHS with the conditional mean spectrum (CMS) at period 0.2 to 3.0 second.

2. METHOD OF STUDY

2.1 Area of study

The area of investigation is located within latitudes 13° 30’ N to 13° 57’ N and longitudes 100° 22’ E to 100° 51’ E. Figure 1 shows the location where 31 observation sites are distributed. This area lies on a large alluvial plain where the Chaophraya River run through and empty into the Gulf of Thailand in the south which have brought down thick sediment deposit and formed alternative layers of sand, gravel and clay. The marine clay on the top layer is generally found in this deltaic area. Formation of the subsurface layer is estimated to be approximately 4000 years ago which is now the lower central plain. Soil underlying the central Bangkok can be described as alternating layers of clay and sand. The uppermost layer of weathered crust exists down to the depth of 1 to 5 meters. The second layer is soft clay with very low shear strength, and is commonly referred as soft Bangkok clay. The soft clay is underlain by the first stiff clay and subsequently underlain by layers of the first sand, the second stiff clay, and the second sand. The depth of bedrock is estimated to be several hundred meters, but there is no sufficient information (AIT, 1981).

2.2 Microtremor technique

The techniques of microtremor observations employed in this study are the Horizontal-to-Vertical spectral ratio (H/V) method to estimate the predominant period of amplification and the Centerless Circular Array (CCA) method to determine shear wave velocity profiles.

2.2.1 Horizontal to Vertical (H/V) Spectral Ratio Method

Nakamura (1989) proposed this technique to interpret records of microtremor for the dominant period of subsoil sediments and also the estimated amplification level. In this method, the ratios of horizontal to vertical Fourier Spectra of microtremor are used to eliminate the source effect. This technique requires
the horizontal and vertical component of microtremor measured at a single station only. The H/V spectrum plots are obtained by taking the ratio of the Fourier Spectra of the horizontal to the Fourier Spectra of the vertical component. It is assumed that the horizontal to vertical spectral ratio is similar to the transfer function for horizontal motion of surface layer. The ratios of horizontal to vertical Fourier Spectra of microtremor are used to eliminate the source effect. This technique requires the horizontal and vertical component of microtremor measured at a single station only. The H/V spectrum plots are obtained by taking the ratio of the Fourier Spectra of the horizontal to the Fourier Spectra of the vertical component, as shown in Eq. 1.

\[ \frac{F_{\text{NS}}}{2F_{\text{UD}}} \]

where \( F_{\text{NS}}, F_{\text{EW}} \) and \( F_{\text{UD}} \) are the Fourier amplitude spectra in the north-south, east-west and up-down directions, respectively. The period and amplitude at a peak of the H/V spectrum plot are interpreted as predominant period and amplification ratio, respectively.

2.2.2 Centerless Circular Array method (CCA)

This technique was proposed and developed by Cho et. al. (2006) based on spectral ratio representations. The spectral ratio which contains information of phase velocities is an integration of all information on the field of vertical component of microtremors. Field works require to deploy a circular array of radius \( r \) and record the vertical component of 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:

\[ Z_0(t, r) = \frac{1}{\pi} \int_{-\pi}^{\pi} z(t, r, \theta) d\theta \]

\[ Z_1(t, r) = \frac{1}{\pi} \int_{-\pi}^{\pi} z(t, r, \theta) \exp(i\theta) d\theta \]

Assume 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:

\[ \frac{G_0(r, r; \omega)}{G_1(r, r; \omega)} = \frac{J_0^2(rk(\omega))}{J_1^2(rk(\omega))} \]

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 \( J_0^2(rk(\omega))/J_1^2(rk(\omega)) \).

2.3 Inversion analysis of shear wave velocity profile

The shear wave velocity profile from surface to basement rock level can be derived by an inversion analysis. The dispersion relation of phase velocity and frequency from field observations are compared with those derived theoretically from a horizontally layered earth model by iteration procedure to provide the best-fit shear wave velocity–depth profile. However, there are always be several possible solutions from the inversion analysis indicating the problem of non-uniqueness solutions. This study carefully selects the solutions with minimum level of misfits and employs two algorithm for inversion
3. RESULTS OF SITE CHARACTERISTICS

The results from microtremor observations are presented in this section as the predominant period (Tp), the shear wave velocity profile (Vs) and the depth of basement rock. Vs profiles are represented by their average from surface to the level of 30 m (Vs30), and the deeper average of 400 m (Vs400). The depth of basement rock is considered as the level that Vs is about 2,000 m/s or higher.

The results are illustrated as maps in Figure 2 to 5 for Tp, Vs30, Vs400 and depth of basement rock, respectively. In Figure 2, the H/V results show that Tp in most area is about 0.8 -0.9 second, where the shortest Tp of 0.6 second and longest Tp of 1.1 were found near the edge of the study area. It should be noted that short period urban noises contributed largely in the microtremors so that the peak of the H/V spectrum at long period which is resulted from deep structures could not be clearly detected. Figure 3 shows the distribution of shallow site characteristics in terms of Vs30. For all sites, Vs30 are less than 180 m/s indicating that soil in Bangkok is soft soil or soft to medium clay and can be classified as NEHRP site class E (BSSC, 2001) The area located in the south-eastern part has lowest Vs30, where the north-western part of the city shows highest Vs30. This average shallow Vs is in accordance with the distribution of soft clay thickness, where the south-east part of Bangkok contains the deepest layer of soft deposits and the thickness is gradually decreased toward the north and the west. Deep information of Vs can be examined through Vs400 as plotted in Figure 4 and depth of basement rock in Figure 5. There are intrinsic discrepancies among these results. The Vs400, which is an average of the deposits excluding bedrock layer shows that the area with stiffer deep deposits is located in the north and west with certain spatial distribution characteristics. The depth of basements rock was identified in a range of 400 to 900 m. The central and western area has the deepest level while the eastern area has shallower depth of basement rock.

4. SITE RESPONSE ANALYSIS

4.1 Equivalent linear analysis

In the second part, Vs profile of each site was used to construct models of soil column as a series of homogenous, viscoelastic infinite horizontal layers. The ground responses at the site were analysed from a set of selected input motions propagating through soil models by equivalent linear analysis. The nonlinearity of the shear modulus and damping of soil were taken into account by equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer. Average relationships between the dynamic shear moduli and damping ratios of soils, as functions of shear strain and static properties, have been established for various soil types. In this study, the relationships for Bangkok clay down to 100 m depth were selected according to the plasticity index and the representative data from boring log. For deep structure, dynamic properties of sand and rock were taken from Seed and Idriss (1970) and Schnabel (1973) respectively as presented in Table 1.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth (m)</th>
<th>Material Type</th>
<th>Dynamic Soil Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-15</td>
<td>Clay with PI=50</td>
<td>Vucetic and Dobry 1991</td>
</tr>
<tr>
<td>2</td>
<td>15-30</td>
<td>Clay with PI=30</td>
<td>Vucetic and Dobry 1991</td>
</tr>
<tr>
<td>3</td>
<td>30-60</td>
<td>Clay with PI=15</td>
<td>Vucetic and Dobry 1991</td>
</tr>
<tr>
<td>4</td>
<td>60-100</td>
<td>Clay with PI=0</td>
<td>Vucetic and Dobry 1991</td>
</tr>
<tr>
<td>5</td>
<td>100-basement rock</td>
<td>Sand (average)</td>
<td>Seed and Idriss 1970</td>
</tr>
</tbody>
</table>
4.2 Selected input ground motions

The objective of ground response analysis is to establish and elastic acceleration response spectra for design of structures. It is common to begin with the derivation of Uniform Hazard Spectrum (UHS)
that is a response spectrum which have the same probability of being exceeded in a given period of time. The UHS was defined at rock outcrop level and the representative ground motions could be artificially simulated by generating ground accelerations having spectrum that match the UHS for the entire range of periods. However, this approach was considered to be conservative as it implies that large-amplitude spectral values would occur at all periods by a single ground motion. The Conditional Mean Spectrum (CMS) (Baker, 2011), was proposed as an alternative to provide the expected response spectrum, conditioned on occurrence of a target spectral acceleration value at the period of interest. In this study, ground motion parameters were obtained from Probabilistic Seismic Hazard Assessment study (Ornthammarath et.al., 2010) considering the effects of possible earthquakes of different magnitudes, occurring at different locations in different seismic sources and at different probability of occurrence. The PSHA results were considered in terms of the UHS at return period of 2475 years (Maximum Considered Earthquake). Then six sets of input motions were selected from strong motion database having similar seismic mechanisms as in Bangkok. The ground motions in each set were scaled to match the UHS with the CMS at 0.2, 0.5, 1.0, 1.5, 2.0 and 3.0 second. For each period of target spectra matched, six ground motion accelerations were considered and their average results are considered in the following discussions. Figure 6 shows the average acceleration response spectra (from six ground motions) at rock outcrop of the selected input ground motions. From these acceleration time histories, the propagations through the model of soil profile were analysed by the equivalent linear analysis.
5. RESULTS OF SITE RESPONSE ANALYSIS

From 6 input motions for each 6 CMS periods as discussed in the previous section, the accelerations response spectral (Sa) at surface of each site were computed for 5% structural damping. Then the average Sa at CMS period was considered. The envelop from all average Sa was used to represent the Maximum Credible Earthquake (MCE) design spectrum for that site. The results of MCE Sa were considered for their similarity of shape and the vicinity, then the area is sub-divided into three zones having the plots of Sa shown in Figure 7, 8 and 9 for zone A, B and C, respectively. In these figures, Sa of each site is plotted as a thin line and the average is plotted as a thick line. The Vs profiles for sites in each zone are included in these figures. Comparisons of the average Sa of the three zones are shown in Figure 10.

In zone A, Sa is narrowband around 0.8 second, which is related to the peak from UHS and general values of Tp observed by microtremor. The response gradually diminished for long period after 0.8 second. The shape of Sa becomes broader from short period to long period in zone B and C, where higher responses are observed in zone C. The long period response is clearly indicated at the period of 2 second for the sites in zone C.

Vs profiles for sites in each zone are presented in Figure 7 to 9. Generally, Vs of the first 100 m deposits is 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. The estimated depth of basement rock, inferred from the level with in which the velocity changes abruptly to be about 2000 m/s or more, varies from 400 to 900 meters.

Figure 10 shows the comparison of an average of Sa in each zone. The responses spectra at short period are similar in all zones, with the maximum of about 0.3g for period about 0.6 to 1.0 second. For period longer than 1.0 second, the values are highest in zone C with the maximum of 0.35g at 2.0 second, follow by zone B (0.25g) and A (0.2g), respectively. This suggests that site characteristics in the area govern the amplification significantly in the period from 1.0 to 3.0 second. High amplification at long period exists in zone C due to its inherent site characteristics. The design Sa in the present Thai national standard (DPT 1302), based on almost the same UHS but assumed Vs models, is also compared in Figure 10. The DPT standard gives lower design Sa than all zones for short period. The standard does not distinguish amplification characteristics for period greater than 1.0 second.

Finally, the seismic microzonation map based on the design Sa for Bangkok is presented in Figure 11. The map is more comparable to the map of average deep velocity structure, Vs400 as shown in Figure 4, than other site characteristics. Shallow site classification as Vs30 is not a good proxy for the city due to the influence of the structure of deep deposits.

From the new Sa curves, long period amplifications resulted from the effects of Bangkok deep deposits can be clearly observed. This finding indicates potential risks from distant earthquakes for tall buildings having long natural periods coincided with the amplified ground responses.
Figure 7. (a) Spectral acceleration, and (b) shear wave velocity profile of sites in Zone A.

Figure 8. (a) Spectral acceleration, and (b) shear wave velocity profile of sites in Zone B.

Figure 9. (a) Spectral acceleration, and (b) shear wave velocity profile of sites in Zone C.
Figure 10. Average spectral acceleration for Zone A, Zone B, and Zone C, and comparison with Sa from DPT 1302 standard.

Figure 11. Seismic zonation map for Bangkok based on spectral acceleration

6. CONCLUDING REMARKS

This paper presents researches to establish new design spectral acceleration for Bangkok considering soft and deep deposits. The main concluding remarks from field observations and ground response analysis can be summarized as follows;

- Site characteristics of the area were successfully investigated by microtremor techniques using the H/V spectral ratio for predominant periods (Tp) and the Centerless Circular Array method (CCA) for shear wave velocity (Vs) profiles of 31 sites.

- Tp in most area is about 0.8-0.9 second, where the shortest Tp of 0.6 second and longest Tp of 1.1 were found near the edge of the study area.

- Shallow information of Vs is presented by an average from surface to 30 m, Vs30, and deep Vs is presented by Vs400 and depth of basement rock. Vs30 of all sites is less than 180 m/s. The south-eastern part has lowest Vs30, where the north-western part of the city shows highest Vs30. Vs400 in the north and west is higher, indicating stiffer deep deposits. The depth of basements rock in the central and western area is deepest, about 900 m, while the eastern area is shallower, about 400-500 m.

- Site response analysis was performed by one dimensional equivalent linear analysis. The input ground motions were selected to match the target of the uniform hazard spectrum at 6 conditional periods. The envelop from all average Sa was used to represent the Maximum Credible Earthquake design spectrum for that site. The results of MCE Sa were considered for their similarity of shape and the vicinity, then the area is sub-divided into three zones.

- The seismic microzonation map based on the design Sa for Bangkok is presented. The map is more comparable to the map of average deep velocity structure (Vs400). The proposed Sa curves are considerably distinct from the Sa in the present design standard.

- The proposed Sa curves exhibit long period amplifications resulted from the effects of Bangkok deep deposits. This observation indicates potential risks from distant earthquakes for tall buildings having long natural periods coincided with the amplified ground responses.

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