# Evaluation of Site Effects in the Greater Bangkok by Microtremor Observations

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**SUMMARY:**
This paper presents results of microtremor observations conducted in the Greater Bangkok area where site effects have been regularly observed from distant earthquakes. The objective is to characterize subsoils for seismic hazard assessment and microzonation study. The technique of single point observation with Horizontal-to-Vertical spectral ratio (H/V) to estimate the predominant period ($T_P$) and the technique of array observation with Spatial Autocorrelation (SPAC) for exploration of shear wave velocity ($V_S$) down to about 90 m were conducted for 75 sites in approximately 125 by 180 km$^2$ area. Site classifications based on $T_P$ and the average $V_S$ are presented and discussed with the distribution of thickness of soft clay. Using a number of site characteristics investigated, relations among the average $V_S$ at different depth and $T_P$ were examined. Seismic site response analyses were conducted using equivalent linear method. The result revealed the spectral amplification ratio of about 4 to 6 found at long periods, from 0.6 to 2.5 second. This observation was justified by a record of ground motion due to the magnitude 6.9 at 780 km distant event.

*Keywords: Site effect, average shear wave velocity, predominant period, microtremor, Bangkok*

## 1. INTRODUCTION

It has been well recognized that dynamic properties of sediments such as shear wave velocity ($V_S$) and predominant period ($T_P$ or characteristic site period) are the key parameters which can substantially influence the characteristics of ground shaking at the site. As a result, the local site effects are taken into account for seismic design by classifying site into categories based upon the geotechnical properties of the site related to their dynamic properties and different levels of design ground motion are provided. The common practice focusing on the average of shear wave velocity from the surface to 30-m depth ($V_{S30}$) has been established as a tool for site classification by the National Earthquake Hazard Reduction program (NEHRP 1994). Recent studies have discussed on limitation on using $V_{S30}$ to predict site amplification and attempted to include site predominant period obtained by the Horizontal-to-Vertical spectral ratio (H/V) (Lang and Schwartz 2006, Gallipoli and Mucciarelli 2009, Di Alessandro et. al. 2012). An alternative site classification based on the site predominant period inferred from the H/V spectral ratio has been proposed in the seismic design of highway bridge in Japan (Japan Road Association, 1990).

Bangkok, the capital city of Thailand, and its vicinity area have been urbanized rapidly from the regional economic growth during the past few decades. A number of high rise buildings and infrastructures have been constructed in the metropolis with a population about ten million. The area is situated on a large plain underlain by thick alluvial and deltaic sediments, and known as the Chaophraya Basin. Thickness of about 15 to 20 m is usually found in the metropolitan area. Some recent studies (Ornthammarath et. al. 2010, Palasri and Ruangrassamee 2010) revealed moderate seismic risks from several active faults located in the northern and western parts of the country and highly active earthquake belts, in the Thailand-Burma-Indochina region and the Sumatra fault system and subduction zone. In fact, tremors have been occasionally observed especially in long period structures even though the earthquake epicentres were located several hundreds kilometres away. In the progress of understanding the seismic risks of the area, however, there is limited study on the site effects of the area. This research mainly focuses on exploration of site characteristics of subsoils by efficient and economical technique of microtremor observation. The objective is to construct the microzonation map based on the predominant period and shear wave velocity of the area. The technique of H/V spectral ratio of ambient noise and the Spatial Autocorrelation (SPAC) methods are employed. Field investigations are conducted for 75 sites in approximately 125 km (north-south) by 180 km (east-west) area. Site classifications based on the predominant period and the average shear wave velocity are presented and discussed with the distribution of thickness of soft clay. Seismic site response analyses are conducted using the one-dimension equivalent linear method and the results are compared with the record of the magnitude 6.9 at 780 km distance event.

## 2. AREA OF INVESTIGATION

The area of investigation is located within latitudes 13° 15’ N to 14° 20’ N and longitudes 99° 45’ E to 101° 15’ E, covering Bangkok and the vicinity provinces. This area lies on a large alluvial plain where there are four main rivers of the country 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 (AIT 1981) which is now the lower central plain. Soil underlying the central Bangkok can be described as alternating layers of clay and sand (Tuladhar 2003). The uppermost layer of weathered crust exists down to the depth of one to five meters. The second layer is soft clay with very low shear strength, and is commonly referred as soft Bangkok clay. Generally, the thickness of this layer is 15 to 20 meters at the central area. The soft clay is underlain by the first stiff clay. This layer is subsequently underlain by layers of the first sand, the second stiff clay, and the second sand. The plain consists of thick soft clay in which the thickness increases gradually from the north to the south, more sharply near the edge of the basin in the west and east direction as shown in Fig. 2.1 (AIT 1981). The depth of bedrock is estimated to be in excess of 500 meters, and there is no sufficient information at present.

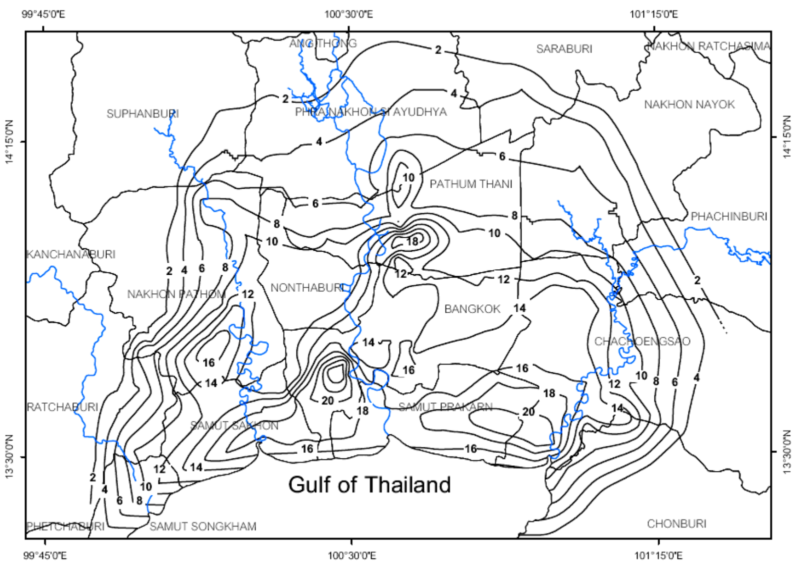


**Figure 2.1.** Isopach map of soft clay thickness in the Greater Bangkok (AIT 1981)

Probabilistic seismic hazard assessment for the Greater Bangkok area (Ornthammarath et. al. 2010) revealed that the major contributors to short- and long-period ground motion hazard in the area are from the nearby active faults (in the northern and western directions) and Sunda subduction zones (in the south-western direction), respectively. It was pointed out that the subduction zone could result in noticeable large expected ground motion at 2 second, emphasizing the important influence of long distance earthquakes.

## 3. FIELD TEST OF SITE CHARACTERISTICS BY MICROTREMOR TECHNIQUES

### 3.1 Microtremor Techniques

Site characteristics, especially the shear wave velocity, are measurable in the field by several practical means which include borehole seismic tests (down-hole, up-hole, and cross-hole test) and surface geophysics tests (reflection, refraction survey). These methods have major drawbacks as they are costly, time consuming and rather difficult to be conducted in urban areas. Recently the microtremor observation techniques have been evolved as a more practical technique for exploration of site characteristics; both shear wave velocity and predominant period of the site. These techniques have several advantages such as economical, less time and manpower required, and environment friendly for urban area. This study applies two microtremor observation techniques to explore site characteristics useful for ground motion evaluation in the Greater Bangkok. The technique of single point microtremor measurement with Horizontal-to-Vertical spectral ratio (H/V) method (Nakamura 1989) is applied to estimate the predominant period and the technique of array microtremor measurement with Spatial Autocorrelation (SPAC) technique (Aki, 1957, Okada, 2003) is applied for exploration of phase velocity characteristics and the subsequent shear wave velocity profile from inversion analysis (Yokoi 2005). Recent discussions on application of both techniques were provided by Chavez-Garcia (2009).

### 3.2 Field Observation

The measurement system consists of a portable data acquisition with 24 bit A/D converter and four units of the three components, moving coil type, velocity sensor with 2-second natural period. The sensors are connected to the data acquisition unit through cables. Before conducting measurement in each site, huddle test was performed for coherency and phase differences among the sensors. The applicable range of frequency was identified as from 0.8 to 17 Hz. At each record, data was recorded for 20 minutes with sampling frequency of 200 Hz. The data was divided into segment of 4096 data points and used for the analysis.

The arrangement of sensors for SPAC observation was selected as equilateral triangular array where one unit is placed at the center of circular and the other three are on the perimeter. Four array arrangements were set for each site, with radius ($r$) of 9, 25, 35 and 50 m. In addition, pairs of peripheral stations with inter-station distance $\left(\sqrt{3}r\right)$ of 15.9, 43.3, 60.6 and 86.6 m are also included for calculating of SPAC coefficients. The maximum depth for inversion analysis was set to 90 m. The data of single station measurement were used to determine H/V spectrum ratio.

## 4. RESULTS OF MICROTREMOR MEASURMENTS

### 4.1 Estimation of $V_{S30}$

At the beginning of discussion on the result, this study remarks on a simple way to estimate $V_{S30}$ from dispersion curve, without inversion analysis. Konno et. al. (2007) proposed that the phase velocity of Rayleigh wave with wave length of 40 m ($C_{40}$) can be used to estimate $V_{S30}$. The results from this study are presented in Fig. 4.1 in which the applicability of the approximation technique can be clearly observed in spite of some degree of under estimation existed for the data of high $V_{S30}$.

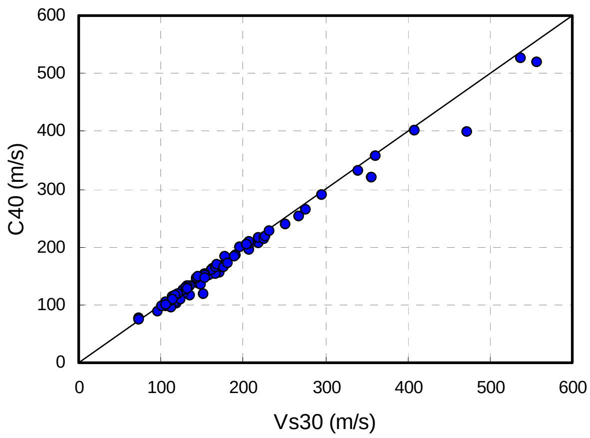


**Figure 4.1.** Comparison of $V_{S30}$ and its estimation by phase velocity with wave length of 40 m

## 4.2 Results from Microtremors and Soil Data

The shear wave velocity and predominant period obtained from microtremor of 75 sites are discussed with soil profile classification in this area. Tuladhar (2003) used the boring log data to classify soil profile into several classes, which is re-drawn in Fig. 4.2 and 4.3 for the location of area and the profile, respectively.

Soil class A (A1, A2 and A3) has larger depths of soft soil layers (16 to 20 m). For class B (B1, B2 and B3), the thickness of soft clay is about 10 to 14 m. Soft clay is followed by first stiff clay and first sand for these soil classes. In soil class C (C1 and C2), which represents area nearby the boundary of the plain, the first layer is medium stiff clay about 8 to 10 m, and follow by first stiff clay or first sand layer. Soil class D (D1 and D2) are used for the soil profile outside the boundary of the lower central plain. The top layer in this class is either stiff clay or dense sand, followed by very dense sand or very stiff clay.

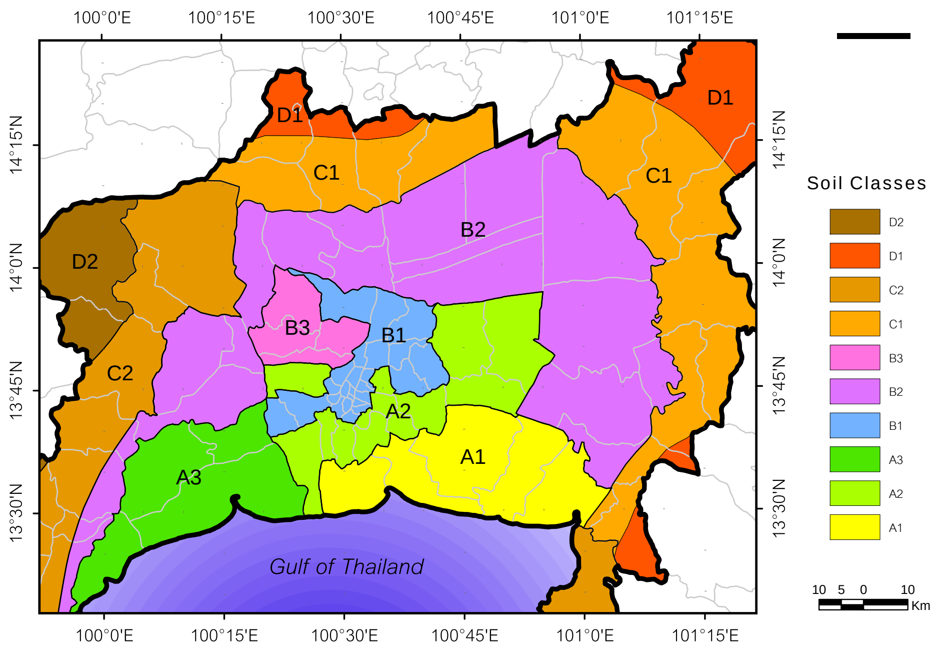


**Figure 4.2.** Location of Soil Classification Area

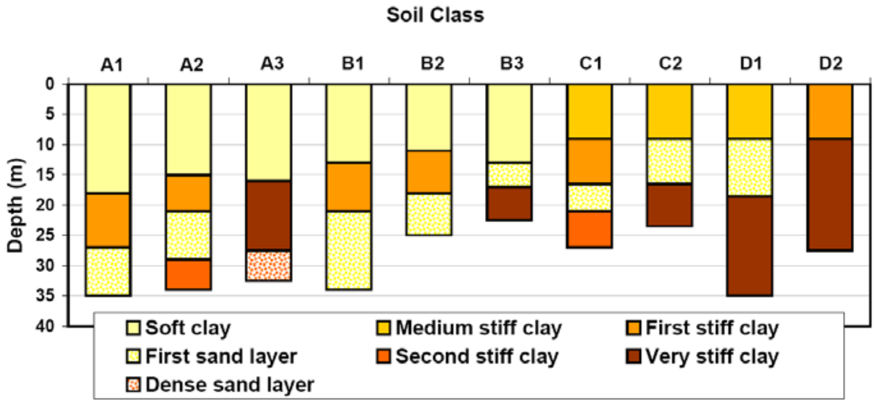


**Figure 4.3.** Generalized Soil Profiles in the Study Area

The results of average of shear wave velocity from the surface to 30-m depth ($V_{S30}$) and predominant period ($T_P$) are depicted in Fig. 4.4 and 4.5, respectively. The variation of the values can be clearly distinguished where $V_{S30}$ varies from 70 to 550 m/s and $T_P$ varies from 0.2 to 1.1 second. The area with lowest $V_{S30}$ and longest $T_P$ is located in the south-east part where soil class is A1, which contains the deepest layer of soft soil. Area along the Gulf of Thailand exhibits low $V_{S30}$ and long $T_P$, which is also consistent with properties of soil class A1, A2 and A3. For soil class B, C and D, $V_{S30}$ is increased and $T_P$ is shortened as soil becomes stiffer. The hardest soil sites in this study are located outside the boundary of the plain which yields highest $V_{S30}$ and shortest $T_P$. The variations in $V_{S30}$ and $T_P$ in Fig. 4.4 and 4.5 are similar to the distribution of soft clay thickness presented in Fig. 2.1.

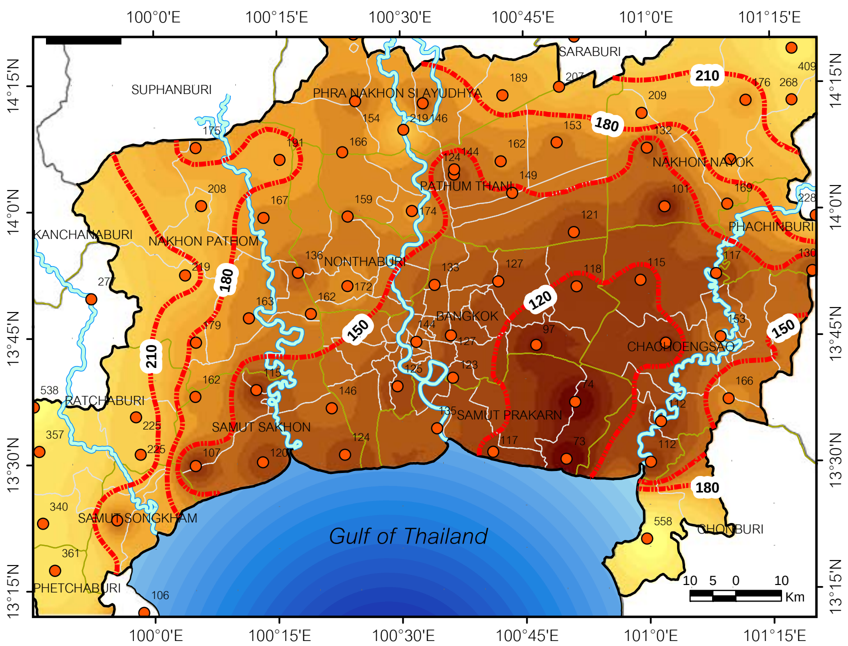


**Figure 4.4.** Map of $V_{S30}$ for the Greater Bangkok

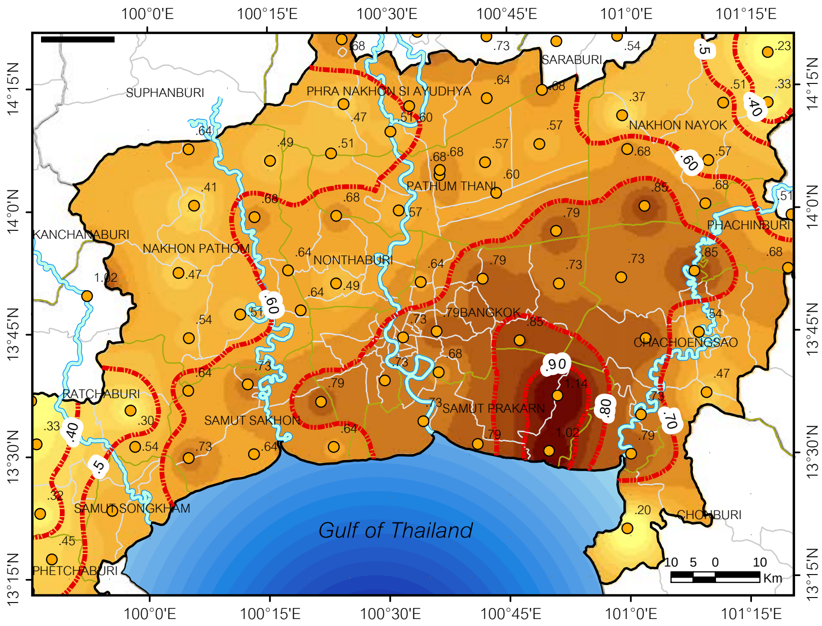


**Figure 4.5.** Map of Predominant Period for the Greater Bangkok

### 4.3 Discussion on Average Shear Wave Velocity and Predominant Period

Using a number of site characteristics from the investigations, relations among the average shear wave velocity at different depth, from 10 m to 90 m, and the predominant periods can be examined. Firstly, the investigation on relations among shear wave velocity at different depth, from 10 m to 90 m is presented. The depth of average shear wave velocity is specified at 30 m by NEHRP 1994 and has been widely accepted in many countries. On the other hand, shallow shear wave profiles, $V_{S10}$, was proposed for an economical site classification scheme (Gallipoli and Mucciarelli 2009). The average shear wave velocities at four different depth levels are calculated for 10 m ($V_{S10}$), 30 m ($V_{S30}$), 60 m ($V_{S60}$) and 90 m ($V_{S90}$).

The relations between $V_{S10}$ with $V_{S30}$ are examined to inspect if the shallow shear wave velocity profile can be used as a substitute of $V_{S30}$, and the relations between $V_{S60}$ and $V_{S90}$ with $V_{S30}$ are examined to inspect how $V_{S30}$ can represent deeper shear wave velocity profile for this area. The generalized relations among $V_{SD}$ and $V_{S30}$ can be presented as a form in Eqn. 4.1.

$$V_{SD} = \alpha_1 (V_{S30})^{\beta_1} \tag{4.1}$$

Eqn. 4.1 can be used for the regression analysis to determine the coefficient $\alpha_1$ and $\beta_1$ by re-written in a form of linear relationship as:

$$y = a + \beta x \tag{4.2}$$

In which $y = \log(V_{SD})$, $a = \log(\alpha_1)$, $x = \log(V_{S30})$ and $\beta = \beta_1$. The plots of Eqn. 4.2 can provide the interception $a$ at $x = 0$ and slope $\beta$ of the straight line by minimizing the standard error of estimate between the measured and the predicted values. Fig. 4.6 presents the plot of $x = \log(V_{S30})$ and $y = \log(V_{SD})$, and the results of regression analyses are shown for $\alpha_1$, $\beta_1$ and the coefficient of determination, $R^2$ in Table 4.1.

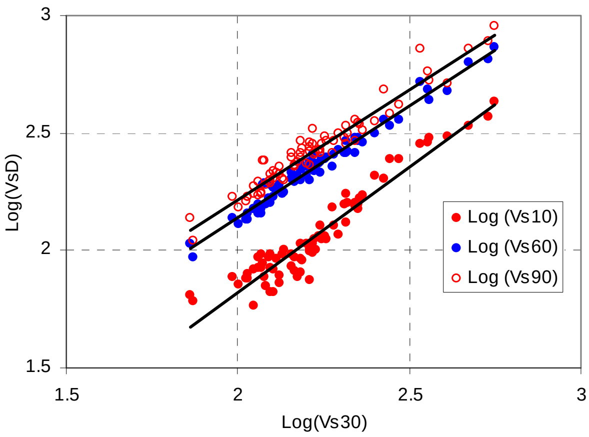


**Figure 4.6.** Relations among $V_{S30}$ and $V_{S10}$, $V_{S60}$, $V_{S90}$

**Table 4.1.** Results of Regression Analysis for $V_{S30}$ and $V_{S10}$, $V_{S60}$, $V_{S90}$

| | $\alpha_1$ | $\beta_1$ | $R^2$ |
|---|---|---|---|
| $V_{S10}$ | 0.473 | 1.072 | 0.912 |
| $V_{S60}$ | 1.715 | 0.952 | 0.971 |
| $V_{S90}$ | 2.212 | 0.936 | 0.944 |

It can be observed from the regressions that the exponent $\beta_1$ is almost unity in each pair, or the relation between $V_{SD}$ and $V_{S30}$ is almost in linear proportion. From $R^2$, highly correlated relations among the average shear wave velocity at different depth are obtained. It is noticeable that less correlation exists between $V_{S10}$ and $V_{S30}$. In addition, Fig. 4.6 shows more scatter plot of $V_{S10}$ and $V_{S30}$ especially at low value of shear wave velocity. This observation could be the result of softer soil or thicker layer of sediments at those sites which significantly influence the shallow shear wave velocity. Therefore, $V_{S10}$ may not appropriately represent deeper velocity structures in the case of thick deposits as in Bangkok area.

Similar regression analyses are conducted for determination of correlation among the average shear wave velocity at different depth and the predominant periods obtained in this study. The relations among $V_{SD}$ and the predominant frequency $(1/T_P)$ can be presented in Eqn. 4.3.

$$V_{SD} = \alpha_2 (1/T_P)^{\beta_2} \qquad (4.3)$$

**Table 4.2.** Results of Regression Analysis for Predominant Period and $V_{S10}$, $V_{S30}$, $V_{S60}$, $V_{S90}$

| | $\alpha_2$ | $\beta_2$ | $R^2$ |
|---|---|---|---|
| $V_{S10}$ | 71.2 | 0.894 | 0.537 |
| $V_{S30}$ | 104.7 | 0.883 | 0.660 |
| $V_{S60}$ | 141.4 | 0.870 | 0.686 |
| $V_{S90}$ | 167.4 | 0.875 | 0.699 |

Eqn. 4.3 is then re-written in the linear equation form of Eqn. 4.2 to determine the coefficient $\alpha_2$ and $\beta_2$ from regression analysis, in which $y = \log(V_{SD})$, $a = \log(\alpha_2)$, $x = \log(1/T_P)$ and $\beta = \beta_2$. The results of regression analyses are shown for $\alpha_2$, $\beta_2$ and the coefficient of determination, $R^2$ in Table 4.2. It can be noticed again that, the relations between $V_{SD}$ and $(1/T_P)$ are close to linear function and

$(1/T_P)$ has higher correlations with deeper shear wave velocities than $V_{S10}$. This could support the applicability of H/V spectral ratio technique that the information of deep ground structure can be achieved in the area where the uppermost layers do not absolutely dominate the results.

## 5. ONE-DIMENSION SITE RESPONSE ANALYSIS

The results of site characteristics obtained from the microtremor measurements are useful for site response analysis to determine the spatial and temporal variation of seismic motions in a soil profile from a motion specified at the site. In this section, the one-dimension site analyses are performed by the SHAKE computer program (Schnabel et.al. 1972) considering linear method to compare site transfer function with the results obtained from the microtremor measurements and equivalent linear method to evaluate the site response compared with a record observed at the site from a long distant earthquake.

### 5.1 Linear analysis of transfer function

In this analysis, the soil column is modeled as a series of horizontal layers with the observed values of shear wave velocity profile. The base layer with $V_S$ = 550 m/s is assumed at 120 m depth level for all sites. The damping of soil is assumed as 0.02. Transfer function of each site is calculated in order to determine the predominant period as well as the amplification factor. The results from this linear analysis could be compared to the results from microtremor observations which were measured under very low strain level of vibration. Fig. 5.1a shows the predominant periods obtained from the two approaches where the results are in good agreement. Fig. 5.1b shows the amplification factor where more scatter data are obtained from the two methods.

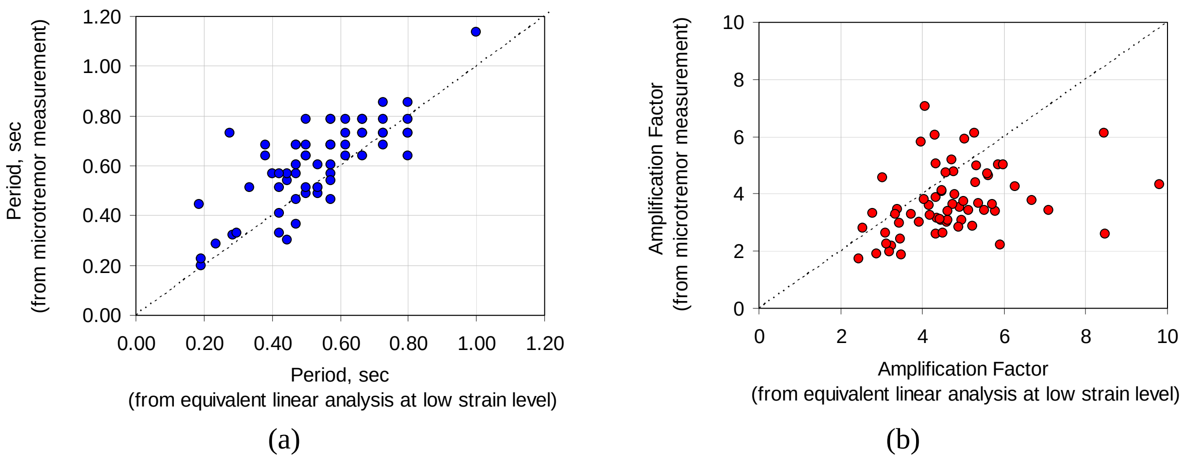


**Figure 5.1.** Comparison of results from microtremor measurements and linear analysis; (a) Predominant period and (b) Amplification factor.

### 5.2 Equivalent linear analysis of site response

To evaluate the site effects of the area, site response analysis of a specified ground motion is conducted by using ground motion record from a distant event. On March, 24 2011 13:55 UTC an earthquake of magnitude 6.9 and depth 8 km struck an area near the border of Thailand and Myanmar. Although the distance to Bangkok is approximately 780 kilometers, long period effects were strongly experienced in high-rise buildings. The equivalent linear analysis to investigate the site effects is performed and compared with the observed records. Due to the lack of the record on rock outcrop at Bangkok site, it is assumed that the record at Surin station which is on very stiff soil site and at approximately the same distance from the epicenter will be used as the input ground motion at the bedrock. The deeper velocity structures at the sites are assumed from Arai and Yamazaki (2002) in which the bed rock with $V_S$ = 2000 m/s was found at 400 m depth. Three sample sites with different

$V_{S30}$ are used to examine the site effects namely; Site A ($V_{S30}$ = 490 m/s), Site B ($V_{S30}$ = 300 m/s), and Site C ($V_{S30}$ = 120 m/s). Site C is located near the location of the seismometer station. The amplification factor which is defined as the ratio of spectral acceleration at ground surface to the spectral acceleration of the input ground motion for each site is presented along with the results from the measured record in Fig. 5.2.

The results from the observed data show that wide range of period, from 0.6 to 2.5 second has large amplification factor about four to six. From one-dimension analysis, the amplification at Site A is insignificant, with little amplification around the site period. For softer soil models in Site B, a distinct peak of amplification is observed about 0.85 second. The responses from analysis of Site C are comparable to the measured results in which the long period amplifications are justified.

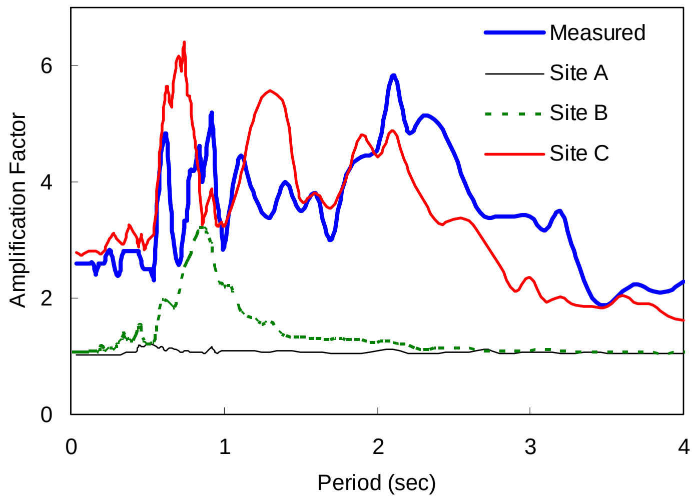


**Figure 5.2.** Amplification factor of four sample sites from the effect of an earthquake of magnitude 6.9 at 780 km distance.

## 6. CONCLUDING REMARKS

In this paper, attempts to characterize subsoils by microtremor observations and to evaluate site effects by one-dimension analysis in the Greater Bangkok, Thailand were presented. The area of microtremor investigation was approximately 125 by 180 km$^2$ area where 75 sites were tested by single point measurement (H/V spectral ratio) and array microtremor survey (SPAC). The obtained results of the predominant period ($T_p$) and the average shear wave velocity to depth $D$ ($V_{SD}$) are examined for their consistencies and discussed with the distribution of soft clay. The area along the Gulf of Thailand and the south-east part of the study area exhibit very low $V_{S30}$ of 70 m/s and long predominant period of 1.1 second while high $V_{S30}$ of 550 m/s and short predominant period of 0.2 second are found outside the basin boundary. This characterization is in accordance with generalized classification of soil types and distribution of soft clay from boring log data.

It was shown that shallow shear wave velocities to 10 m depth, influenced by thick soft clay in this study, were not reasonably correlated with deep shear wave velocities. The predominant periods were shown to be able to represent shear wave velocity profiles down to 90 m.

Site transfer functions calculated by linear one-dimension analyses were used to compare with the results obtained from microtremor. It was shown that the predominant period from the two approaches were in agreement while the amplification factors were not. Spectral amplifications from a distant earthquake were examined by using shear wave structures at sites and compared with the observed data. The long period effect, with amplification factor about four to six in the period range from 0.6 to 2.5 second, obtained from the record was reasonably justified by the results from the one-dimension analysis using the velocity structures at the site. These results are valuable for seismic hazard assessment and further microzonation study in the Greater Bangkok area.


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## REFERENCES


Aki, K. (1957). Space and Time Spectra of Stationary Stochastic Waves with Special Reference to Microtremors. Bulletin of the Earthquake Research Institute. No. 22: 415–456.

Arai, H., and Yamazaki, F. (2002). Exploration of S-Wave Velocity Structure Using Microtremor Arrays in the Greater Bangkok, Thailand. Earthquake Disaster Mitigation Research Center. EDM Technical Report No.15.

AIT (1981). Investigation of land subsidence caused by deep well pumping in the Bangkok area. Asian Institute of Technology, Thailand.

Building Seismic Safety Council, (1995). 1994 Edition NEHRP Recommended Provisions for Seismic Regulations for New Buildings, FEMA 222A/223A, Vol. 1 (Provisions) and Vol. 2 (Commentary), developed for the Federal Emergency Management Agency. Washington, D.C.

Chavez-Garcıa, F.J. (2009). Ambient Noise and Site Response: From Estimation of Site Effects to Determination of the Subsoil Structure. In M. Mucciarelli et al., (eds.). Increasing Seismic Safety by Combining Engineering 53 Technologies and Seismological Data, NATO Science for Peace and Security Series C: Environmental Security, Springer Science Business Media B.V.

Di Alessandro, C., Bonilla, L.B., Boore, D.M., Rovelli, A. and Scotti, O. (2012). Predominant Period Site Classification for Response Spectra Prediction Equations in Italy. Bulletin of the Seismological Society of America 102:2,680-695.

Gallipoli, M.R. and Mucciarelli, M. (2009). Comparison of Site Classification from VS30, VS10, and HVSR in Italy. Bulletin of the Seismological Society of America 99:1,340-351.

Japan Road Association, 1990. Specifications for Highway Bridges Part V, Seismic Design. Maruzen Co., LTD

Konno, K., Suzuki, T., Kamata, Y. and Nagao, T. (2007). Estimation of Average S-wave Velocity of Ground Using Microtremors at Strong-Motion Sites in Yokohama. Journal of Japan Society of Civil Engineering. 63: 639-654 (in Japanese with English abstract).

Lang, D.H., and Schwarz, J. (2006). Instrumental Subsoil Classification of Californian Strong Motion Sites based on Single-Station Measurements. Proc. of the 8th U.S. National Conf. of Earthquake Engineering, San Francisco. Paper No.120.

Nakamura, Y. (1989). A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface. Q. Rep. Railw. Tech. Res. Inst. 30. No.1: 25–33.

Okada, H. (2003). The Microtremor Survey Method (translated by Koya Suto), Geophysical Monograph Series, No.12, Society of Exploration Geophysicists.

Ornthammarath, T., Warnitchai, P., Worakanchana, K., Zaman, S., Sigbjörnsson, R., and Lai C.G. (2010). Probabilistic seismic hazard assessment for Thailand, Bulletin of Earthquake Engineering, 9:2, 367-394.

Palasri, C. and Ruangrassamee, A. (2010). Probabilistic seismic hazard maps of Thailand, Journal of Earthquake and Tsunami, 4:4, 369-386.

Schnabel, P.B., Lysmer, J. and Seed, H.B. (1972). SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites. Report No. UCB/EERC-72/12, Earthquale Engineering Research Center, University of California, Berkeley.

Tuladhar, R. (2003). Classification of Soil Profile and Seismic Response Analysis (Elastic) in the Greater Bangkok Area. Internal Report, Structural Engineering Field of Study, Asian Institute of Technology, Thailand.

Yokoi, T. (2005). Combination of Down Hill Simplex Algorithm with Very Fast Simulated Annealing Method-an Effective Cooling Schedule for Inversion of Surface Wave's Dispersion Curve. Proc. of the Fall Meeting of Seismological Society of Japan. B049.