Deep Shear Wave Velocity of Southern Bangkok and Vicinity

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Abstract: Bangkok is located on the soft marine clay in the Lower Chao Phraya Basin which can amplify seismic wave and can affect the shaking of buildings during an earthquake. Deep shear wave velocity of the sediment in the basin are useful for study the effect of the soft sediment on the seismic wave and can be used for earthquake engineering design and ground shaking estimation, especially for a deep basin. This study aims to measure deep shear wave velocity and create 2D shear wave velocity profile down to a bedrock in the southern Bangkok by the Microtremor measurements with 2 seismographs using Spatial Autocorrelation (2-SPAC) technique. The data was collected during a day time on linear array geometry with offsets varying between 5-2,000 m. Low frequency of natural tremor (0.2-0.6 Hz) was detected at many sites, however, very deep shear wave data at many sites are ambiguous due to man-made vibration noises in the city. The results show that shear wave velocity of the sediment in the southern Bangkok is between 100-2,000 ms⁻¹ and indicate that the bedrock depth is about 600-800 m, except at Bang Krachao where bedrock depth is unclear.

1. Introduction

Bangkok is located in the Lower Chao Phraya Basin which contains rather thick sediment which can amplify the seismic wave generated by an earthquake. Average shear wave velocity down to 30 meters (Vs30) in Bangkok have been measured in order to provide a shallow sediment property in earthquake engineering and earthquake ground motion estimation (i.e. Poovarodom, 2014). Although these studies have revealed relative low shear wave velocity on shallow layer of the entire, the shear wave velocities down to the bedrock which are important parameter to evaluate the basin effect are still absent. So far there are no direct and publically accessible evidence of the bedrock depth of Bangkok and vicinity. In addition, there are some contradiction reports about the depth to the bedrock in Bangkok area. Sinsakul (2000) proposed that the bedrock should be at depth between 500-2,000 m while Poovarodom and Jirasakjamroonsri (2014) suggested that the bedrock depths were between 400-800 m using microtermor measurement. This study aims to measure the deeper shear wave velocity in the southern Bangkok and make an attempt to identify the depth to bedrock of the study area.

SPAC (Spatial Autocorrelation) technique is considered to provide better resolution on dispersion image in the low frequency region and can generate a broader range of dispersion curve, compared to an F-K technique (Zhao and Li, 2010). In this study the two microtremor array (2-SPAC) technique was selected to measure the shear wave velocity down to 2 km at eight sites in the southern Bangkok and vicinity. The final results are displayed as shear wave velocity models.

2. Theories and techniques

Long period seismic wave from natural noise or microtremor are generated by natural phenomena such as ocean wave, atmospheric change and can be measured by microtremor observation. Spatial Autocorrelation was introduced by Aki (1957) using 4-7 sensors on triangle array
and one in its center. Assuming that microtremor propagates from all direction equally, Cho et al. (2006) and Margaryan (2009) showed that two-sensor SPAC yields almost identical phase velocities as those using 4 or 7 sensors. Hayashi and Underwood (2012) demonstrated that S-wave velocity profiles down to depth 2-3 km can be measured by using only 2 sensors. The phase velocity is calculated from the ambient noise using a formula:

$$\text{SPAC} (\Delta x, \omega) = J_0 \left( \frac{\omega}{c(\omega) \Delta x} \right)$$

whereas $x$ is a distance between receivers, $\omega$ is an angular frequency, $c(\omega)$ is a frequency-dependent phase velocity and $J_0$ is a zero order Bessel’s function.

The fundamental concept of SPAC is to record the vertical microtremor composition in several positions of the target sites to collect varied azimuthally angle propagation of Rayleigh wave identity. The data pair is calculated to compare its wave coherency spectrum. Then it conducts correlation, generates phase velocity and SPAC coefficient which fits to the formula above. The phase velocity model displays correlation of a velocity for each frequency. Then, it is converted to a 1D velocity-depth model by an inversion for the final result.

3. Data Acquisition and Processing

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** A map showing survey locations in the southern Bangkok. The cross-section of velocity profiles are shown in Figures 5 and 6.

**Figure 2.** Example of a geometry of 2-SPAC methods at Bang Namphung site.

The survey locations were designed as line points to cover the southern Bangkok and its vicinity in quiet environment and less human activity. Inter-station location distance was about 15-18 km. Most observation areas are in parks, near abandoned buildings or agricultural lands. The data acquisition was done in day times during local winter period when the microseism from the Gulf of Thailand are strongest. Two MT-Neo seismographs (Geometrics Inc.) were placed as a linear array. One seismograph was fixed and acquired the data for entire time at each survey location. The second seismograph recoded the data at separation of 5, 10, 20, 40, 80, 160, 320, 640, 1,000 and 2,000 m with a record length of between 20-90 minutes or 2 hours at noisy site. The recording time were extended when the separation of two seismographs was increased. We used 2 ms sampling interval in this survey. The obtained data was divided into many blocks with about 160 seconds long for each block. Fast Fourier Transform (FFT) was used to convert these waveforms to frequency domain for calculating coherence of each data group. Summation of average complex coherence defined SPAC coefficient. Picked values of highest coherence are used for generating a phase-velocity relationship, aka. a dispersion curve. Then the shear wave velocity-depth models were generated by an inversion of dispersion curve. Figure 3 and 4 show phase-velocity images at Samut Sakhon and Samut Prakan sites. Their biggest coherence frequencies are between 0.5 and 0.2 Hz respectively. Red dots represent maximum coherence which are manually picked for generating a shear wave velocity-depth model by an inversion.
4. Results and Discussion

The phase velocity images show good coherence at minimum frequency of 0.2 - 0.6 Hz to maximum frequency of 5 Hz. Interference of the local long wavelength reduced clarity of deeper part of phase velocity image even though the possible longest wavelength obtained through the SPAC method is 2 to 4 times of receiver separation (Koichi, 2013). Joint Inversion (Suzuki and Yamanaka, 2010) were applied to all observed-selected dispersion curves to generate final 1D velocity-depth models. For the top 50 m depth, shear wave velocities are between 80-180 ms⁻¹. At deeper part, shear wave velocities range from 200-800 ms⁻¹ which could be sand and saturated clay layer that was found at depth between 100-500 m. On line 1, we found shear wave velocities of 1,000-2,000 ms⁻¹ at depth between 600-800 m: 600 m at Krathumban and 800 m at Bang Bond, Bang Namphueng and Savannabhum.

![Phase velocity image at Samut Sakhon](Figure 3)

![Phase velocity image at Bang Namphueng](Figure 4)

On line 2, the shear wave velocities of 1,000-2,000 ms⁻¹ were found at depth of 400 m at Bang Krachao, 700 m at Samut Sakhon, 800 m at Sakha and 1,000 m at Samut Prakan. This velocity layer can be interpreted as sandstone and claystone bedrock which corresponds to Bangkok's geological structure (Sinsakul, 2000).

At the deeper level of some sites, we found the layer of shear wave velocity of 2,000-3,200 ms⁻¹ at depth of 1,500-1,900 m. It is expected to be quartzite basement layer. This shear wave velocity range was found in Krathumban at about 1,500 m depth. The same shear wave velocity range is also found at 1,700m depth in Bang Namphueng, Samut Sakhon and Sakha and 1,900 m in Samut Prakan. This information conforms to the well data (Department Mineral Fuels, 1988).

There are some survey locations that the low frequency coherences are noisy due to location limitation of seismograph installation and surrounding activities. It affects the detection ability at deeper part, especially at basement level. The unclear deep velocity profiles are at Bangbon, Savannabhum and especially at Bang Krachao. The surface condition of these sites are soft soil, salt farm and near estate developing area.

![1D velocity models of W-E transect line 1](Figure 5)

**Figure 5.** 1D velocity models of W-E transect line 1: (a) Krathumban (b) Bangbond (c) Bang Namphung and (d) Savannabhum respectively. The upper dashed line indicates the depth of the bedrock with shear wave velocity of 800-2,000 ms⁻¹ at depth of 700-800 m. The lower dashed line is a basement boundary with shear wave velocity of 2,000- 3,000 ms⁻¹ at depth of 1,500-1,700 m.
Figure 6. 1D shear wave velocity models of W-E transect line 2: (a) Bang Krachao (b) Samut Sakhon (c) Sakhla and (d) Samut Prakan respectively. The upper dashed line indicates bedrock depth level of shear wave velocity of 800-2,000 m/s at depth of 400, 700-1,000 m. The second lower dashed line showing the boundary of basement with shear velocity of 2,000-3,200 m/s at depth 1,700-1,900 m.

5. Conclusion

Shear wave velocity profiles of the Southern Bangkok can be determined by a SPAC technique using 2-measurement station array (2-SPAC). Minimum value of 0.2 Hz phase velocity frequencies were found largely in most sites. The shear wave velocities of the topmost layer (50 m) are about 80-180 m/s. The shear wave velocities of the lower layers are interpreted as saturated sand, claystone and sandstone which is considered bedrock. Its depth varies from 600-800 m in the southern Bangkok, except at Bang Krachao. Basement depth with velocities of 2,000-3,200 m/s are found between depth of 1,500 to 1,900 m which corresponds to the well data.

One of the limitations of the data acquisition is strong noise interference of long wavelength which appeared in many areas. This interference reduces accuracy of the analysis or even tampers with all bedrock depth information. In the future, the 2-SPAC survey should be conducted throughout the Greater Bangkok with appropriate sites, spacing and correlate the result with data from other geophysical methods in order to create accurate bedrock map of the entire Greater Bangkok.

Acknowledgement

We would like to thank the Faculty of Science, Kasetsart University for their financial support and Geometrics Inc. for supporting the seismographs. We also like to thank all assistance their help in collecting data.

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