DEEP SUBSURFACE STRUCTURE OF BANGKOK BASIN USING MICROTREMOR OBSERVATIONS

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Abstract

Bangkok does not have active fault zones in its near vicinity. Many distant earthquakes have been felt in high-rise buildings of Bangkok. Recorded seismic waves in the Bangkok basin show a clear peak at a frequency of 0.2 Hz. This study used the results of the microtremor survey to create a deep subsurface model of the Bangkok basin. The predominant frequency of the ground from horizontal-to-vertical spectrum ratio (HVSR) analysis on single-point microtremor records was used to find the seismic discontinuity. The higher predominant frequency was well established but the lower one was not clear; the deeper seismic discontinuity could not be established. The CCA and SPAC methods were employed to derive the Rayleigh wave phase velocity dispersion curve from the microtremor records in an array and the curves were inverted. The results of array analysis were used to make a 3-Dimensional (3D) layer structure of the Bangkok Metropolitan Region. A four-layered profile above the bedrock was taken with first, second, third and fourth layers from the top corresponding to the shear wave velocity Vs of 82–120 m/s, 330–337 m/s, 605–650 m/s, and 900 m/s, respectively. The bedrock has Vs of 2000 m/s. The generated 3D profile will be used to simulate the long period ground motions using the 3-Dimensional Finite Difference Method.

Keywords: microtremor survey; Bangkok basin; long-period ground motion; shear wave velocity profile; 3D model

1. Introduction

The Bangkok Metropolitan Region, comprising of Bangkok and five adjacent provinces has a population of more than 14 million according to the 2010 census [1]. Active faults with low seismic activities are located at around 120 to 300 km from Bangkok and those with high seismicity are located at around 400 km to 1000km [2]. The magnitude and location of historical earthquakes in and around Thailand from 1912 to 2007 can be found in Fig. 2 of Ornthammarath et al. [3]. The northern part of Thailand and the Sunda-subduction zone has high seismicity. The Bangkok Metropolitan Region has a few, moderate-sized earthquakes in its vicinity [3]. Many earthquakes with large epicentral distances have been felt in Bangkok. The Kanchanaburi earthquake (April 1983) with body-wave magnitude (mb) of 5.8 was felt strongly in Bangkok at the epicenter of ~200 km [4]. The 2011 Mw 6.8 Tarlay (Myanmar) earthquake at ~775 km and the 2014 Mw 6.1 Mae Lao (Thailand) earthquake at ~670 km from Bangkok were also felt in Bangkok [5][6]. Lukkunaprasit P. gives a list of magnitude 5 or larger earthquakes felt in Thailand from 1912 to 1992 [7] and the ones felt in Bangkok were extracted from the list (Table 1).

Table 1 Earthquakes felt in Bangkok from 1912 to 1992 (Magnitude 5 or larger) [7]

Year.Month.Day Local Time	Epicenter (Lat °N Lon °E)	Distance (Km)	Magnitude (Richter)	Remarks
1912.05.23 09:24	Burma (21.0, 97.0)	887	7.9	MM scale IV
1930.05.05 20:46	Burma (17.0, 96.5)	560	7.3	MM scale V
1930.12.04 01:52	Burma (18.2, 96.5)	653	7.3	MM scale V
1967.02.13 08:36	Andaman Sea (13.7, 96.5)	432	5.6	MM scale IV
1983.04.04 16:24	Northern Sumatra Islands (5.7, 94.7)	1098	6.6	MM scale IV
1983.04.15 16:24	Si Sawat District, Kanchanaburi (14.95, 99.14)	198	5.3	-
1983.04.22 10:22	Si Sawat District, Kanchanaburi (14.96, 99.06)	205	5.2	-
1988.04.06 07:36	Burma-India Border (25.1, 95.1)	1382	6.8 M_b 7.2 M_s	MM scale III; in high rise buildings
1988.11.06 20:03	Burma-China (22.79, 99.61)	1009	6.1 M_b 7.3 M_s	MM scale V-VI; in high-rise buildings
1990.11.15 09:34	Northern Sumatra (3.91, 97.46)	1145	6.1 M_b	In high-rise building
1991.01.05 21:57	Burma (23.61, 95.90)	1198	6.2 M_b	In high-rise Buildings
1991.04.01 10:53	Burma (15.65, 95.69)	559	6.5M_b	In high-rise buildings
1991.06.12 10.05	Andaman Sea (14.85, 96.31)	468	5.0 M_b	In some high-rise buildings
1992.06.15 09:48	Burma (23.98, 95.89)	1198	5.7 M_b	In high-rise buildings
1992.10.28 14:02	Burma (18.3, 96.8)	642	6.0 M_l	In high-rise buildings

Most of the earthquakes felt in Bangkok are from the Kanchanaburi area (distance of ~200 km), Myanmar and Thailand-Myanmar northern border (~560 km to 1400 km), and Northern Sumatra-Andaman sea (~430 km to 1150 km). They were felt in high-rise buildings despite their large epicentral distance. The horizontal-to-vertical spectrum ratio (HVSR) of earthquake waves from the 2008 Mw 7.9 Sichuan earthquake, 2011 Tarlay (Myanmar) earthquake, and the 2014 Mae Lao (Thailand) earthquake recorded at the Thai Meteorological Department (TMD) at Bangkok basin show a clear peak at 0.2 Hz (Fig. 2a, 2c, 2d; Subedi et al [8]).

Bangkok lies in the lower part of the Central Plain of Thailand, the Lower Central Plain or Chao Phraya Plain. The Lower Central Plain is a wide depositional flat plain with an irregular basement at the depth of 500-2000 m below ground surface. The basement is filled with a sequence of fluvial, alluvial, and deltaic sediments [9]. The top clay layer is soft and highly compressible [10]. When low-velocity sedimentary soil exists in a basin, there is an amplification of seismic waves in long period range. Mexico City suffered extensive damage during the 1985 Michoacan earthquake due to such amplifications although the epicenter was at a large distance of 350 km. Basin amplifications also occurred in the Taipei basin in the 1999 Chi-Chi earthquake and the Kathmandu basin during the 2015 Gorkha-Nepal earthquake, where the peak ground acceleration recorded inside the basin was amplified than at the surrounding rocky sites. Bangkok is a populous city with many high-rise buildings and long-period structures and is built on a sedimentary basin. To study the basin amplification of waves in long-period range, a 3-Dimensional (3D) shear-wave velocity model is required. Such a model can be used to simulate the ground motions using the Finite Difference Method (3D-FDM).

2. Results of microtremor survey and discussions

This study uses results of single point and array analysis of microtremor records after Subedi et al. [8] to create a deep subsurface model of the Bangkok basin. The microtremor survey was carried out at five sites of the Bangkok Metropolitan Region. Four-point array geometry, with 3 sensors along the radius and one at the center was used. In four of the sites (AIT, CU, KU, MU in Fig. 3), six array observations at different radii (ranging up to 340 m) were carried out. For the site TMD, three array radii were used. Four sets of Mini Seismometers HS-1 by OYO SI (HS-1) and one set of Data loggers HKS-9700 by Keisokugiken Corporation were used at the sampling frequency of 100 Hz for 3-, 5- and 10-m array observations. For the rest of the array observations, four sets of microtremor recorders DATAMARK JU410 by HAKUSAN Co. Ltd., (JU410) [11] at a sampling frequency of 200 Hz were used to record data along three perpendicular measurement channels.

The HVSR results from single point records by applying Eq. (1) [12] were used to find the predominant period of the ground. For a single uniform layer of soil above bedrock, the thickness of the soil deposit can be calculated using Eq. (2) [13].

$$H/V(\omega) = \frac{\sqrt{F_{NS}(\omega)^2 + F_{EW}(\omega)^2}}{F_{UD}(\omega)} \tag{1}$$

$$T = \frac{4H}{V_s} \tag{2}$$

where T: Predominant period of site, H: thickness of the soil deposit, V_S: Shear wave velocity of soil deposit

In the HVSR plots of the single point microtremor measurements (Figure 8; [8]), the higher predominant frequency is well established but the lower one is not clear. The deeper seismic discontinuity corresponding to lower predominant frequency cannot be calculated from Eq. (2). For a single layer of soil sediment with V_S as 760 m/s as in Mase et. al [14], the depth of the sediment calculated from higher predominant frequency using Eq. (2) is shown in Fig. 1. The depth of sediment at MU and TMD is larger than the other three sites due to the larger predominant period. The boundary estimated is shallow and the deeper boundary cannot be reliably estimated from the results of the accelerometer (JU410).

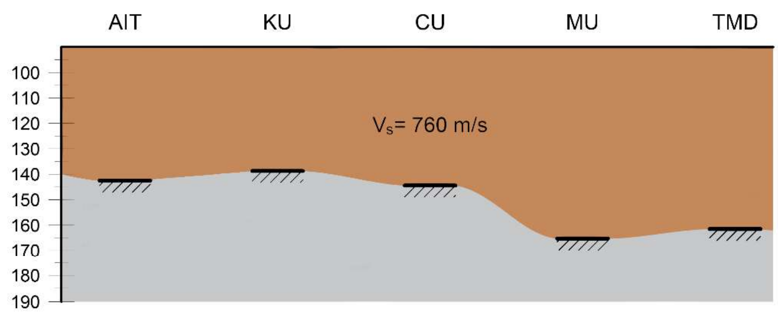

Fig. 1 – Depth of sediment calculated for a single uniform layer using results of HVSR analysis

Table 2 – Velocity profiles from the inversion of the dispersion curves shown in Fig. 2, after Subedi et al. [8]

AIT

ρ(g/cm³)	V_s(m/s)	V_p(m/s)	Thickness(m)
1.6	90	1120	11
1.7	337	1568	90
1.9	650	2025	320
2.2	1450	2960	∞

KU

ρ(g/cm³)	V_s(m/s)	V_p(m/s)	Thickness(m)
1.6	96.3	1130	12
1.7	330	1552	100
1.9	620	1984	120
1.97	760	2168	∞

CU

$\rho(g/cm^3)$	$V_s(m/s)$	$V_p(m/s)$	Thickness(m)
1.6	96.7	1130	13
1.7	330	1552	70
1.9	605	1957	268.4
2.05	900	2341	370
2.3	2000	3600	∞

MU

$\rho(g/cm^3)$	$V_s(m/s)$	$V_p(m/s)$	Thickness(m)
1.6	120	1180	14.3
1.7	330	1450	70
1.9	650	2025	200
2.05	900	2340	330
2.3	2000	3600	∞

TMD

$\rho(g/cm^3)$	$V_s(m/s)$	$V_p(m/s)$	Thickness(m)
1.6	82	1100	11.5
1.7	330	1450	70
1.9	650	2340	∞

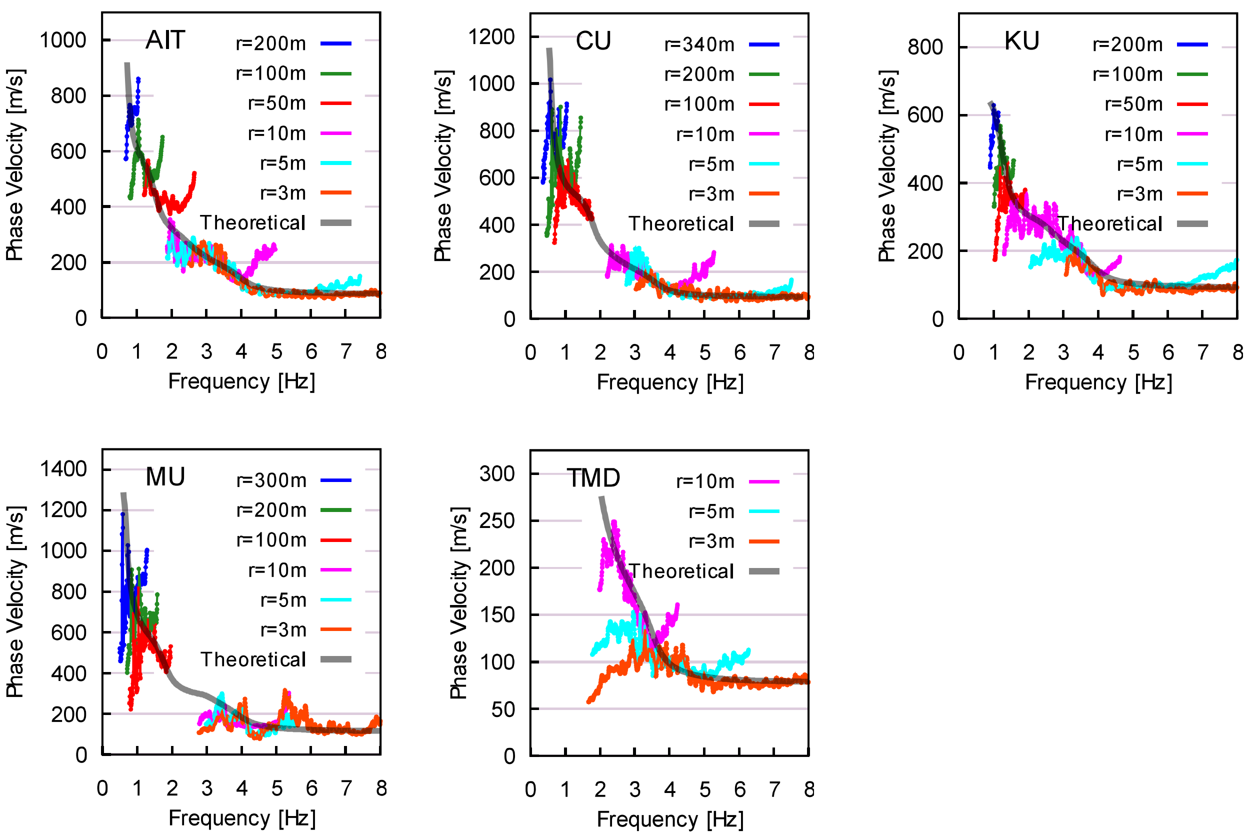

Fig. 2 – Phase velocity dispersion curves plotted with colored lines for different array sizes, after Subedi et al. [8]

The Spatial Autocorrelation (SPAC) method [15] and Centerless Circular Array (CCA) method [16] were used to calculate the Rayleigh-wave phase velocity dispersion curve from array records. The CCA method can analyze longer wavelengths than the SPAC method for small array radius [17] and was used for 3-, 5-, and 10-m arrays. For array radius larger than 10 m, the method was chosen based on the clarity of the peaks of the dispersion curve. Fig. 2 shows details of the array radius used and the corresponding dispersion

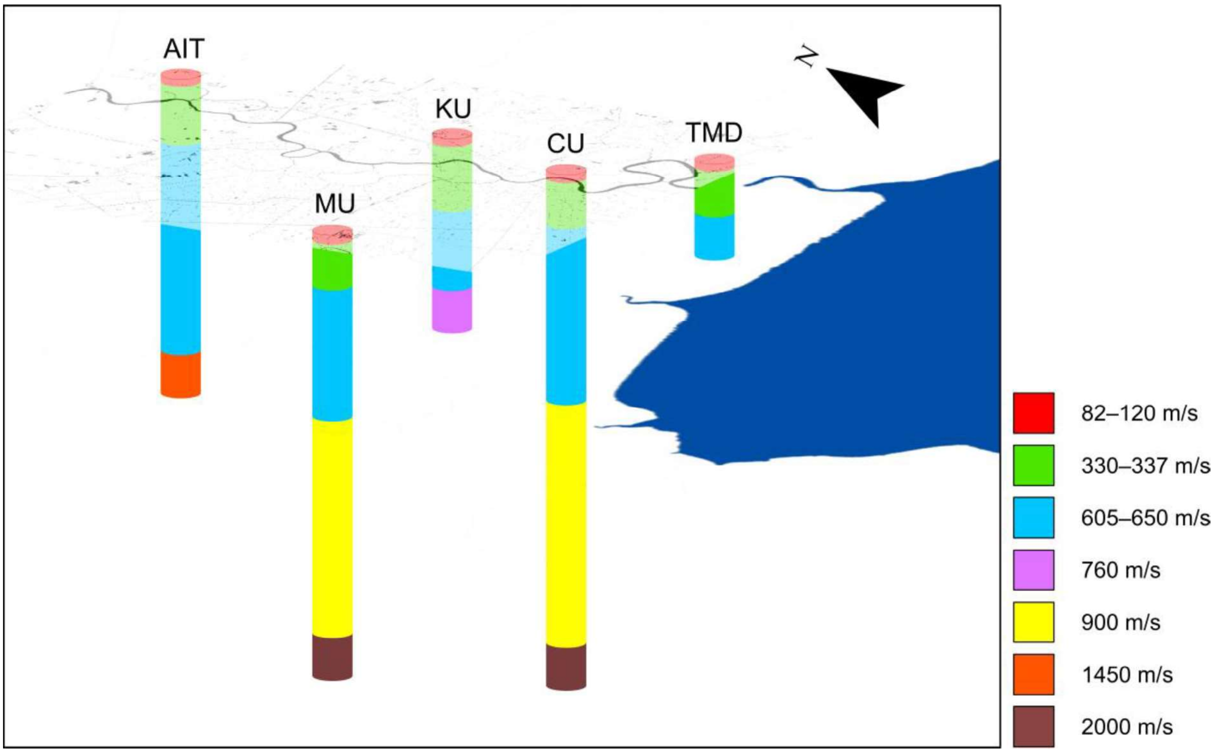

Fig. 3 – Velocity profiles in Table 2 shown in site map of the Bangkok basin

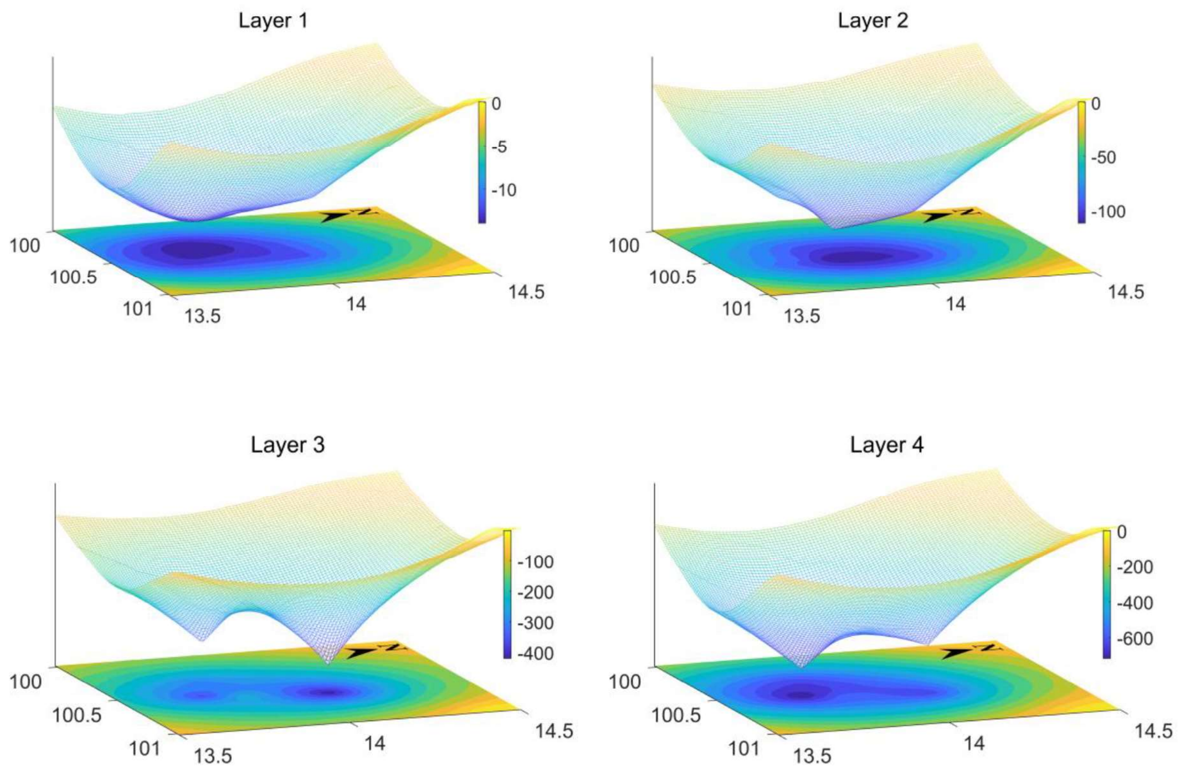

Fig. 4 – Bottom of four layers of the 3D structure. Layer 1, Layer 2, Layer 3, and Layer 4 correspond to the shear wave velocity of 82–120 m/s, 330–337 m/s, 605–650 m/s, and 900 m/s, respectively.

curve at each site [8]. The largest array radius at site CU is 340 m, MU is 300 m, and at sites AIT and KU are 200 m. The Rayleigh wave dispersion curves for CU and MU are extracted until a lower frequency than AIT and KU. Using the curves, the shear wave velocity profiles were inverted (Table 2). The results in Table 2 were used to plot S-wave velocity profiles along the two lines in Fig. 10; Subedi et al. [8]. The velocity profiles at the sites were combined with the site map of the study area (Fig. 3). The results (Table 2, Fig. 3) were then used to prepare the 3D subsurface profile of the Bangkok basin.

Four layered profile above the bedrock was prepared. The first (Layer 1), second (Layer 2) and third (Layer 3) layers from the top correspond to the shear wave velocity of 82–120 m/s, 330–337 m/s, and 605–650 m/s, respectively. As the fourth layer (Layer 4) does not have a uniform Vs as of layers 1–3 (Fig. 3), Vs of 900 m/s was assumed for the layer. A bedrock of Vs 2000 m/s was taken based on results of MU and CU. Points with zero sediment depth overlying the bedrock were added during interpolation, from Nutalaya and Rau [18]. Universal Kriging in 'gstat' package in R was used for data interpolation [19]. Fig. 4 shows the bottom geometry of four layers. The 3D velocity structure prepared will be used to simulate the long-period ground motions using the 3D-FDM.

3. Conclusions

We used the results of the microtremor survey (after Subedi et al. [8]) to make a 3D shear wave velocity model of the Bangkok basin. The higher predominant frequency of the ground from HVSR analysis on single point microtremor records was used to find the shallow seismic discontinuity. The lower predominant frequency was not clear, and the deeper seismic discontinuity could not be estimated. The inverted profiles from the analysis of array records were used to make a four-layered 3D structure of the Bangkok Metropolitan Area. The first, second, third, and fourth layers from the top correspond to the shear wave velocity Vs of 82–120 m/s, 330–337 m/s, 605–650 m/s, and 900 m/s above a bedrock with Vs of 2000 m/s. The 3D layered profile created will be used to simulate the long-period ground motions to study the basin amplification of the Bangkok basin using 3D FDM.

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