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Identification of engineering bedrock in Jakarta by using array observations of microtremors

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Abstract

The bedrock depth is one of the most important parameters in seismic hazard analysis. This parameter has not been identified well in Jakarta. This study was conducted to determine the bedrock depth in Jakarta based on S-wave velocity parameters. Microtremors array method was applied in this study to obtain 1D and 2D S-wave velocity profiles. The spatial autocorrelation (SPAC) method was used to estimate dispersion curves, while S-wave velocity structure was derived by genetic algorithm. Reffering to the geological condition in the study area, microtremors array measurements were conducted for two East-West lines in the northern and southern parts of Jakarta. The result of 2D construction of S-wave velocity structure shows stratigraphy cross sections that consists of four layers, where the bedrock depths in northern Jakarta can be depicted in the range from 519 to 662 m and in the southern part in the range from 353 m to 399 m. It has a positive correlation with the local geological condition i.e the sediment thickness increases to the north.

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1. Introduction

Due to the seismicity and geological condition, Jakarta is an earthquake prone area as shown in the Indonesian seismic hazard map [1]. The development of infrastructure and high population density in Jakarta will also lead to the high risk owing to earthquake occurrences in its surroundings. In preparation for seismic risk reduction strategies in Jakarta, microzonation studies are indispensable by considering the local geology. Information of bedrock depth in Jakarta is one of the most important factors for seismic hazard analysis, in which this parameter has not been available.

In this study, estimation of bedrock depth in Jakarta, which is in accordance with international standards, was carried out by applying the microtremors array method to determine the subsurface models based on the S-wave velocity structure. This method has been widely performed in some countries especially in Japan, because the operational fieldwork is quite simple. Moreover, this method does not require a source of vibration. Therefore, it can be conducted in densely populated areas. The data acquisition conducted during the field work used a triangular array configuration that enabled us to conduct the analysis using the SPAC method to obtain the dispersion curve [2, 3, 4], while the S-wave velocity structure can be estimated by using a genetic algorithm [5].

The objective of this study is to determine the depth of bedrock in Jakarta. Here, we show two East-West (E-W) cross sections of the S-wave velocity structure in the northern and southern parts of Jakarta. The two cross sections depict a significant difference in depth of the bedrock beneath northern and southern Jakarta.

2. Data Acquisition and Method

2.1 Data Acquisition

The survey sites were designed in accordance with the geological condition in Jakarta, in which the sediment thickness increases northward. Hence, the microtremor array observations were carried out at seven sites throughout E-W lines in the northern part and four sites in the southern part (Figure 1a). In this research, we used triangular arrays configuration with four sensors, where each sensor was placed as shown in Figure 1b. The time duration for microtremors data record was 1 - 1.5 hours for each array. Figure 1c shows an example of the array configurations for microtremors observations carried out in the PDRG site (southeast Jakarta).

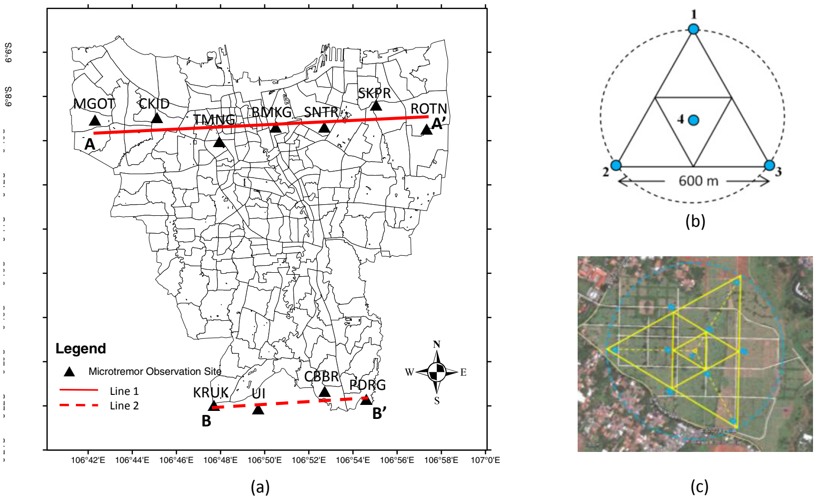

Fig. 1. a) Map of Jakarta and the location of microtremors array measurements along E-W lines in the North and South (Line 1 and Line 2, respectively); b) Configuration of the array and location of sensors; c) Example of microtremors array measurements at the PDRG site.

2.2 Method

The microtremors data records of vertical component were used in the data processing after being digitized using a sampling interval of 0.01 second and divided into several blocks that consist of 16.384 seconds in length. Estimation of phase velocity was conducted by the Spatial Autocorrelation (SPAC) method [2-4]. On the circular array with distance r between two stations, the SPAC function $\phi(\omega,r,\theta)d\theta$ can be calculated for a pair of stations. Then the SPAC coefficient $\rho\ (\omega,\ r)$ was estimated by averaging all azimuths, θ. It can be expressed by the following equation [6] :

$$\rho(\omega,r)=\frac{1}{2\pi.\phi(r=\omega,o,o)}\int_{0}^{2\pi}\phi(\omega,r,\theta)d\theta \tag{1}$$

The SPAC coefficient for circular array can also be expressed as a Bessel function as follows :

$$\rho(\omega,r)=Jo\left(\frac{\omega r}{c(\omega)}\right) \tag{2}$$

where J_o = Bessel function of the first kind zero order, $c(\omega)$ = phase velocity as a function of frequency $\boldsymbol{\omega}$, r = distance between two stations. Following Yamanaka and Ishida [5], estimation of S-wave velocity structures was conducted by using genetic algorithm to the dispersion curves for the specified initial models.

3. Results and Discussion

The analysis results of dispersion curves at each site were calculated by using equation 2 and shown in Figure 2. From the dispersion curves in Figure 2 we clearly observe a difference, in which dispersion curves are separated into two groups. The dispersion curves have a frequency range of 0.3 – 5 Hz, where the phase velocity in north Jakarta is smaller than that in the south.

The difference of dispersion curves at each observation site reflects the differences in subsurface condition. It is noted that at the surveyed sites, the difference of dispersion curves in E-W direction is not significant.

However, the northern and southern parts show a significant difference. This indicates that the thickness of the sediment layer changes significantly from the south to the north, but it is rather flat in the E-W direction.

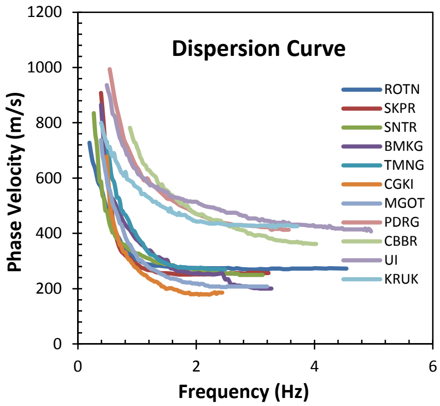

Fig. 2. Dispersion curves of microtremor for Lines 1 and 2.

The estimation of phase velocity was conducted through inversion of dispersion curves for the specified initial models. By considering the geological condition of the Jakarta area, we used five layers for the initial model. Then we conducted the inversion using genetic algorithm to generate close fits between the calculated and observed dispersion curves.

The inversion of dispersion curve resulting 1D S-wave velocity profiles at each site as shown in Figures 3 and 4 for Lines 1 and 2, respectively. For Line 1 which is located in the northern part of Jakarta, the bedrock with S-wave velocity > 750 m/s [1] is at a depth range of 581 - 657 m, while Line 2, in the south, the depth range of the bedrock is 346-388 m. This shows a very significant difference in depth between the northern and southern parts of Jakarta. This has a positive correlation with the geological condition of Jakarta in which the thick sediment is located in the northern part. Again, it is noted that the difference in the east - west direction is relatively small.

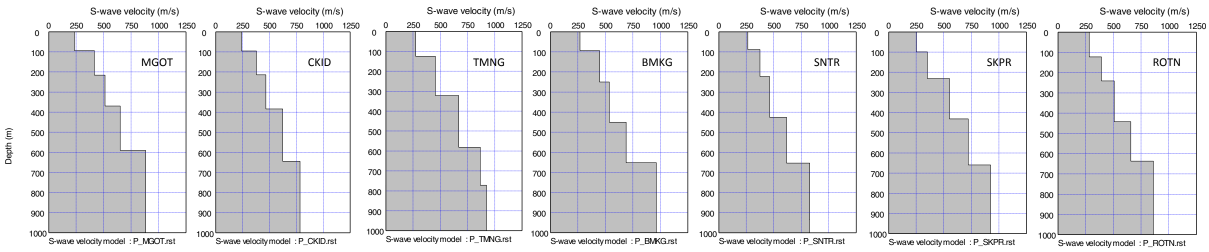

Fig. 3. 1-D S-wave velocity profiles for Line 1 at the 7 surveyed sites.

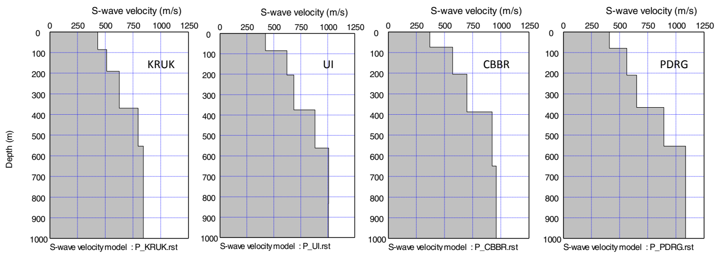

Fig. 4. Same as Figure 3, but for Line 2 at the 4 surveyed sites.

The first inversion at each site generate the differences among S-wave velocity for each layer. Therefore it is difficult to conduct S-wave velocity correlation. Here, we applied a technique proposed by Yamanaka and Yamada [7] to construct 2D cross sections. With this technique the most similar S-wave velocity of each layer were grouped, and then the average was used for the initial models. These initial models were then inverted again to obtain a depth. The results of the second inversion are described in Figures 5 and 6 for Lines 1 and 2, respectively. These results were utilized to conduct S-wave velocity correlation for 2D cross sections.

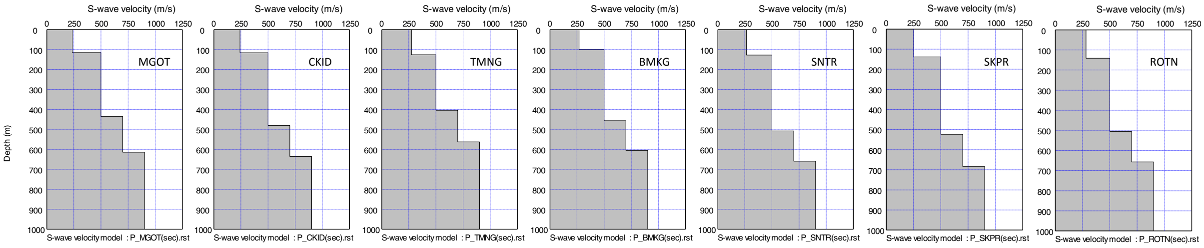

Fig. 5. 1-D S-wave velocity profiles for Line 1 at the 7 surveyed sites resulting from the second inversion.

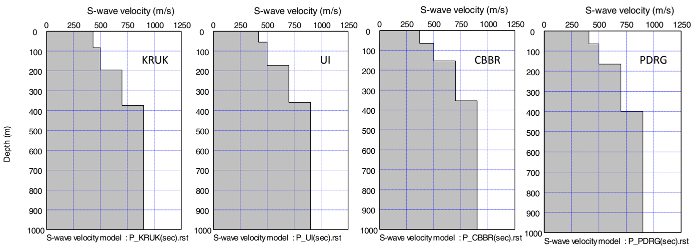

Fig. 6. Same as Figure 5, but for Line 2 at the 4 surveyed sites.

Figure 7 shows 2D cross sections in E-W direction as a result from 1D S-wave velocity correlation. They depict the subsurface model for Jakarta that consists of four layers. The uppermost layer is associated with the Quarter sediment, while the second to fourth layers are associated with the Tertiary sedimentary formation. Based on these cross sections, the engineering bedrock that has Vs > 750 m/sec [1] can be identified in the fourth layer, where Line 1 (north Jakarta) depicts bedrock depths in the range of 519 to 662 m, while Line 2, located in the south, indicates bedrock depths in the range of 353-399 m.

The differences in bedrock depths contrast vastly between north and south Jakarta. However, that is not the case for the E-W direction. It is also indicated from the dispersion curves that they are sparated into two groups. This result of microtremors analysis indicates that in general the morphology of bedrock in Jakarta is slanting toward the north, while in the east-west direction is relatively flat, except in the northern part, in which a gentle slanting toward the east is observed. This estimated morphology is related to the geological condition for Jakarta, where the Ciputat sub-basin has a very thick sediment located in the northern part [8 and 9].

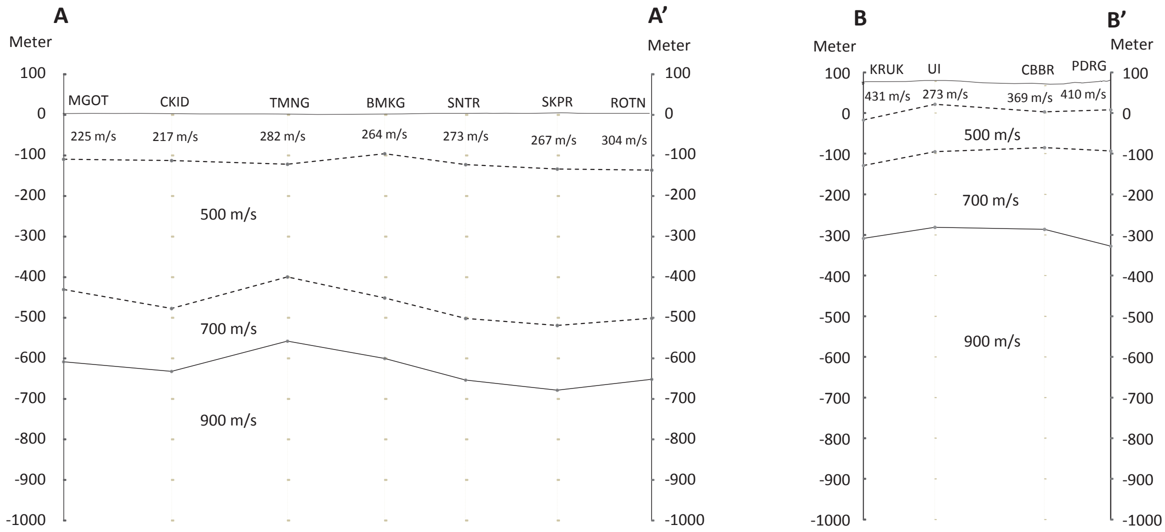

Fig. 7. E-W cross sections of S-wave velocity structure in the northern (left) and southern (right) parts of Jakarta. Solid line depicts the estimated bedrock depths.

4. Concluding Remarks

The result of microtremors array observations along Lines 1 and 2 located in the north and south of the Jakarta area depicts that Jakarta is located on a thick sediment. This result also depicts that the subsurface model for Jakarta consists of four layers with varying thickness. The thickness of layers in the E-W direction in the northern part slightly increases to the east and in the south it is relatively flat (see Figure 7). The position of bedrock in Jakarta is at the top of the fourth layer which has an S-wave velocity of 900 ms^{-1}. The depth of the bedrock in the north is much deeper than that in the south. This is in agreement with the regional geological condition in the Jakarta area, where very thick sedimentary rock is located in the northern part. This implies that the amplification factor in northern Jakarta would be higher than in the south. For future work, further microtremors measurements are needed to obtain the bedrock morphology for Jakarta in more detail.

Acknowledgements

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