

# ESTIMATION OF SHEAR WAVE VELOCITY STRUCTURE USING ARRAY OBSERVATION OF SHORT PERIOD MICROTREMOR IN KOSHIGAYA CITY, JAPAN

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## ABSTRACT

In this study, Spatial Autocorrelation Method (SPAC Method) was carried out in Koshigaya City, Saitama Prefecture, Japan. Additionally, we applied H/V spectral ratio or Nakamura method to the same area.

We obtained that in the western part of the study area the engineering bedrock ( $V_s > 400$  m/sec) is as shallow as 10-15 m, where as in the eastern part it is much deeper and reaches to 50-60m. The former is categorized in Class D or Stiff Soil of NEHRP (2001) Ground Classification, and the latter in Class E or Soft Soil. We could obtain the same soil classification by implementing the method proposed by Kon'no et al. (2007), which allow us to skip the inversion of the dispersion curve.

Finally, H/V spectral ratio could not show any correlation of its predominant period with the underground velocity structure determined by SPAC method. Furthermore, with the provided information from Nakamura method it is difficult to obtain the ground classification at a site.

**Keywords:** Microtremor, SPAC method, H/V spectral ratio, S-wave structure.

## 1 INTRODUCTION

The interaction of the Caribbean and Cocos plates in the subduction area of Nicaragua provokes a great number of earthquakes per year. Many important cities are located in this zone, where mitigation of Seismic Risk is essential. This is the case of Managua, the capital of Nicaragua that has been impacted for two destructive earthquakes in current times (1931 and 1972). This situation led to the elaboration of the seismic microzonation map, by using H/V spectral ratio (Nakamura method). This method, however, is under criticism for its validity and it is suggested that a better result can be obtained by using new techniques of microtremor observation.

Thus, the purpose of this study is to understand the effectiveness, limitations and advantages of the SPAC method using microtremor array measurement as a tool for seismic microzonation and earthquake disaster mitigation by applying them to the study area in Koshigaya City where a complicated underground structure is expected. Nakamura method is conducted additionally.

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## 2 DATA

The microtremor field measurements were performed in the urban area of Koshigaya city, approximately in the coordinates: lat. 35° 52' 12''N, lon. 139° 48' 36''E, at the southeast of Saitama Prefecture, approximately 25km from central Tokyo (Figure 1).

The measurements were conducted at 12 sites, on June 12 and 13, 2008 in day time. The arrays were deployed in the shape of the letter "L" for SPAC method, which consists of eleven geophones (Natural frequency 2Hz) and simultaneously, we used the three-component seismometer GEO-SPACE LP of Geometrics (Natural frequency 1Hz) for H/V spectral ratio at each site.

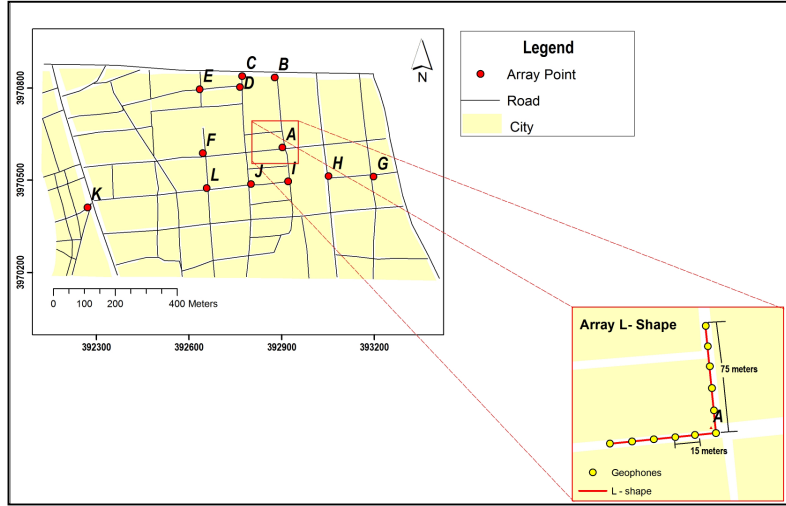


Figure 1 Map showing array configuration adopted in microtremor measurements. The test field is located in Koshigaya City, Saitama Prefecture, Japan. The box in the right-down side indicates the L-shape array with the distance among sensors.

## 3 METHOD

### 3.1 SPAC Method

The SPAC Method is based on the theory developed by Aki (1957) to comprehend the relationship between the temporal and spatial correlation of seismic waves and microtremors, which it became the key to successful extraction of dispersion characteristics of Rayleigh waves. (Okada, 2003).

The SPAC coefficients denoted by equation (1) can be directly calculated in a frequency domain using the Fourier Transform of the observed microseism, that is,

$$\rho(\omega; r) = \frac{1}{2\pi} \int_0^{2\pi} \frac{\text{real}[S_{cx}(\omega, r, \theta)]}{\sqrt{S_{cc}(\omega, 0, 0) \cdot S_{xx}(\omega, r, \theta)}} d\theta \quad (1)$$

where  $\text{real}[\cdot]$  stands for the real part of a complex value, and  $S_{cc}(\omega; 0, 0)$  and  $S_{xx}(\omega; r, \theta)$  are the power spectra of the microseism at two sites,  $C(0, 0)$  and  $X(r, \theta)$ , respectively.  $S_{cx}(\omega; r, \theta)$  is the cross spectrum between  $u(t; \omega, 0, 0)$  and  $u(t; \omega, 0, \theta)$ . The two autocorrelations in the denominator make the local amplification effect canceled out (Okada, 2003).

Then, the velocity that makes the misfit function minimum is searched for each available frequency using all considered inter-station distance. The obtained value of  $c$  is considered as the phase velocity at the corresponding frequency. After that, we obtained the optimum underground structure for the given dispersion curve of Rayleigh wave based on the Down Hill Simplex Method (DHSM) combined with the Very Fast Simulated Annealing (VFSA) approach (Yokoi, 2005).

The initial model used has five surface layers and a half space that represents the bedrock of which  $V_s$  is about 400 m/sec (Table 2). For making this initial model, the information obtained from a borehole GS-SK-1A was considered (Ishihara, 2004; Hayashi et al., 2006).

Table 2 Initial Model for all the sites

$h_{min}$ (Km)	$h_{max}$ (km)	$V_{s_{min}}$ (km/sec)	$V_{s_{max}}$ (Km/sec)
0	0.03	0.08	0.15
0.001	0.03	0.1	0.15
0.001	0.03	0.08	0.15
0.001	0.03	0.15	0.25
0.001	0.03	0.25	0.35
998	999	0.35	0.45

The  $V_p$  and the density  $\rho$  are calculated using the following empirical formulas for each step of iteration (Ludwig et al., 1970; Kitzunezaki et al., 1990, respectively).

$$V_p = 1.11 V_s + 1.29 \quad (\text{Km/sec}) \quad (2)$$

$$\rho = 1.2475 + 0.399 V_p - 0.026 V_p^2 \quad (\text{g/cm}^3) \quad (3)$$

### 3.2 Nakamura method

Nakamura (1989) proposed a method of inferring site amplification factors from incident seismic shear waves using microtremor H/V spectral ratios at a single site. This method is easily applied and directly estimates the site amplification factors without reference site, and many researchers have done to investigate the validity by observation and in theory. (e. g., Horike et al., 2001; Lermo and Chavez-Garcia, 1994).

The calculation is done by the following formula

$$H/V_{spectralratio} = \sqrt{\frac{\sum P_{NS}(\omega) + \sum P_{EW}(\omega)}{\sum P_V(\omega)}} \quad (4)$$

where  $P_{NS}(\omega)$ ,  $P_{EW}(\omega)$  and  $P_V(\omega)$  are the power spectra of NS, EW and the vertical component respectively, summation is taken over data blocks.

## 4 RESULTS AND DISCUSSION

### 4.1 SPAC method

We obtained the dispersions curves or phase velocity for each observation site. The result indicates phase velocities lower than 0.5 (Km/sec) at all the sites and suggests that the region is covered by soft sediments up to the depth that can be explored in this research (Figure 2).

Figure 2 shows the result of dispersion curve for all the sites except the site G where unusual phenomena occurred in SPAC coefficients. Namely, the usual order, in which those of longer inter station distance, has smaller value in the range from  $k_l=0$  to the first zero cross, is not observed.

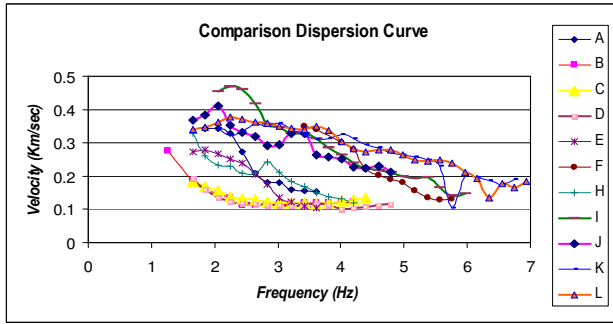


Figure 2 Dispersion curves for all sites except the site G.

This may be interpreted as the failure of the assumption: horizontal stratified layers or unrecognized human made noise. Therefore, the site G is excluded from the analysis.

The sites can be separated into four groups by the similarity of the shape and values of the dispersion curves. Namely, *Group 1* corresponds to the sites B, C and D. *Group 2* corresponds to the sites A, E and H. *Group 3* corresponds to sites F, I, and J. *Group 4* corresponds to the sites K and L.

After obtaining dispersion curve, the result was inverted to Vs structure.

Figure 3 shows Vs structure for all the sites

except the site G. It is evident that even though we conduct array measurements in a small area, a clear variation exists in Vs structures among the observation sites.

For *Group 1*, we found the engineering bedrock (Vs about 0.400 (Km/sec)) at depth of 0.055 (Km), except at the site D where it appears at about 0.040 (Km); the layer with Vs approximately 0.200 (Km/sec) appears at depth about 0.030 (Km). For *Group 2*, the depth of the engineering bedrock varies from 0.030, 0.024 and 0.053 (Km), at the site A, E, and H, respectively; the layer with Vs approximately 0.200 (Km/sec) appears at depth of about 0.15 (Km/sec), but at the site A appears at 0.022 (Km). For *Group 3*, the engineering bedrock was found at depth from 0.015 to 0.018 (Km); the layer with Vs approximately 0.200 (Km/sec) appears at depth of about 0.008 (Km). Finally *Group 4*, the engineering bedrock was found at depth from 0.010 to 0.015 (Km); the layer with Vs approximately 0.200 (Km/sec) appears at depth less than about 0.008 (Km).

We can judge clearly that *Group 1* located at north-east part of the study area corresponds to the thickest sediment, while *Group 4* located at the south-west part corresponds to the thinnest and that the thickness of the soft sediment is decreasing from north-east to south-west.

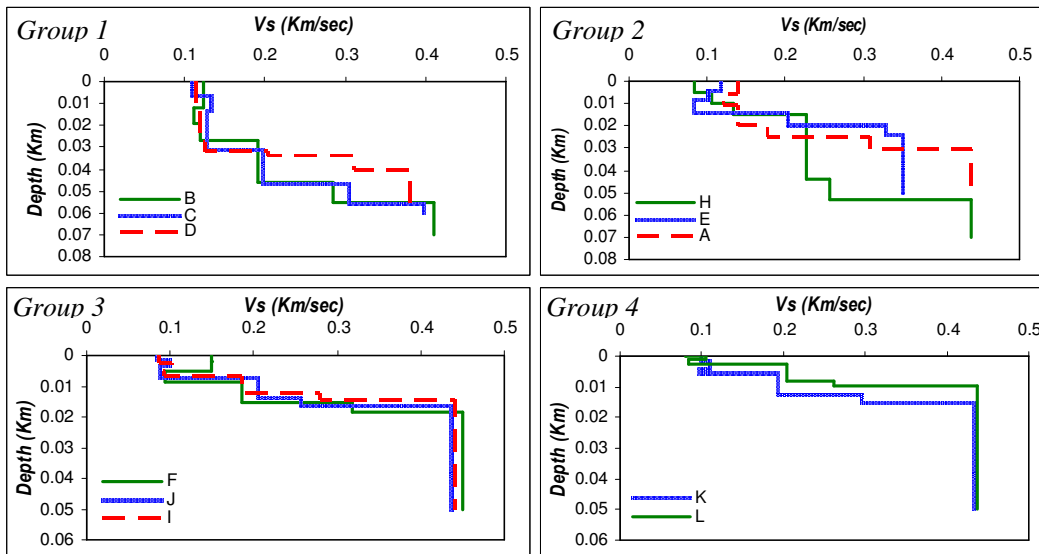


Figure 3 S-wave structures of four groups.

### 4.1.1 Soil profile

By using the result about Vs structure, we drew two soil profiles. The *profile one* connects the sites KFDB with direction south-west to north-east, and the *profile two*, connects the sites KLJIH from west to east in a straight line. (Figure 4)

The *profile one* shows that, the depth change considerably with difference around 23 m in a distance of 246 m between site F and D. After this point, the depth increases up to about 55 m at the site B. Here, the sub-area at west side of the site F including the site K may correspond to the buried terrace, while at north – east of the site F may correspond to the slope between buried terrace and the buried channel.

For the *profile two*, the depth change considerably between site I and H (136.33 m of distances between these sites) which is significant for the layers four and five. The maximum depth reached is about 53 m for layer 5.

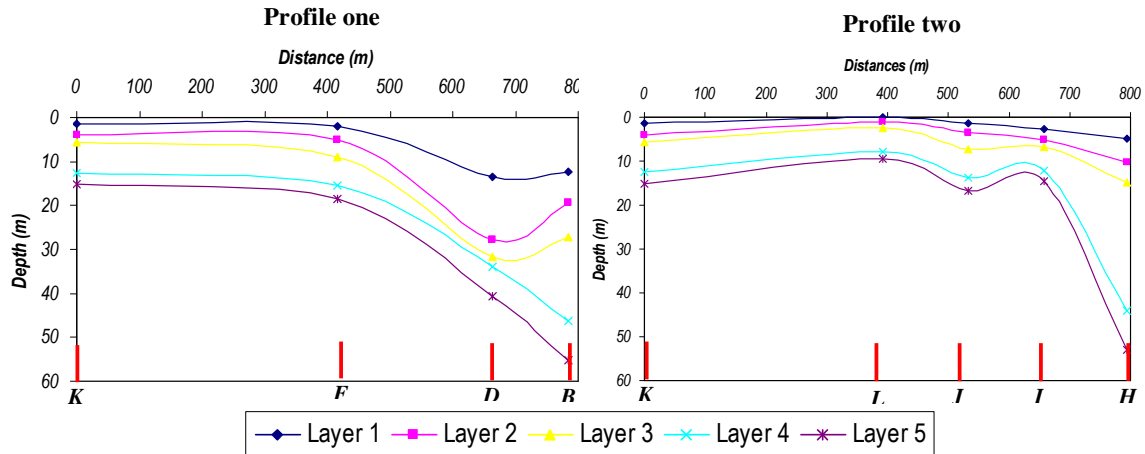


Figure 4 Soil profile along the sites K-F-D-B (left) and K-L-J-I-H (right).

### 4.1.2 Ground classification

By using the result from SPAC method, the ground classification is conducted based on AVS30, based on the following equation:

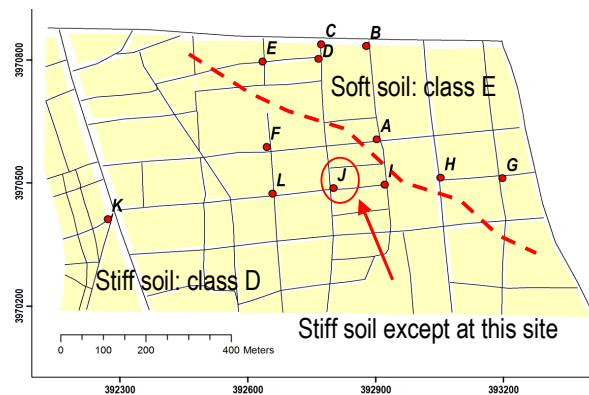


Figure 5 Map showing the site classification for observation sites, indicating soft soil at the northeast and stiff soil at the southwest of the study area (except at the site J that is soft soil).

$$AVS\ 30 = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{V_{s_i}}}, \quad (5)$$

where  $V_{s_i}$  is the shear wave velocity in m/sec,  $d_i$  the thickness of  $i$ -th layer between 0 and 30 m. (NEHRP, 2001).

The result was Soft soil (Class E:  $AVS30 < 180$  m/sec) at the north-east parts (the sites A, B, C, D, E, H, and J) and Stiff soil (Class D:  $180 \text{ m/s} \leq AVS30 \leq 360$  m/s) at the south-west (the sites F, I, K and L). Even though it is not visible on the topography, there is a lateral variation of the bedrock depth. As

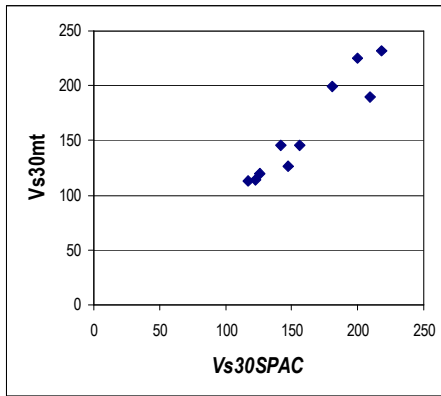


Figure 6 Comparison of Vs30mt with Vs30SPAC

the calculated values for the sites I and J are close to the threshold, it is better to consider that these two sites are in transition between Class D and Class E (Figure 5).

Also, we use the method proposed by Kon'no et al. (2007) as an approximate way to estimate AVS30 without performing the inversion of the dispersion curve. They have proposed the use of the phase velocity provide by SPAC method for the wavelength 40m as an approximation of AVS30 (Vs30mt).

The result was the same as that of the previous method. Only for the case of the site J of which value was not found due to limitation of the available frequency. However, Vs30mt can be guessed less than 213 (m/sec) for this site at least. In Figure 6 the comparison between these two methods is shown, of which deviation is acceptable.

#### 4.2 H/V spectral ratio (Nakamura Method)

The sites in *Group 1* show a clear peak of predominant period less than 1sec. For the rest of Groups, the predominant period is longer than 1 sec, except at the site A where was around 0.9 sec.

Taking into account the soil classification provide by SPAC method, we can say that the longer period corresponds to Stiff soil class, and shorter one is found at Soft soil class. This is opposite of the relation of the predominant period of amplification of up-coming S-wave. The result is an evidence of the failure of Nakamura method in the study area, which predominant period of amplification is supposed to be shorter at Stiff soil and longer at Soft soil.

### 5 CONCLUSION

SPAC method could give a quantitative estimate of shear wave velocity structure that is consistent with previous information about the depth of bedrock and geology of the area. Namely, in the western part of the study area the engineering bedrock ( $V_s > 400$  (m/sec)) is as shallow as 10-15 m, where as in the eastern part it is much deeper and reaches to 50-60 m. The former is categorized in Class D or Stiff Soil of NEHRP (2001) Ground Classification, and the latter in Class E or Soft Soil.

We could obtain the same soil classification by implementing the method proposed by Kon'no et al. (2007), which use phase velocity for the wavelength 40m as an approximation of AVS30 (Vs30mt), without performing the inversion of the dispersion curve.

### REFERENCES

- Aki, K., 1957, Bull. Earthq. Res. Inst. Univ. Tokyo, 35, 415-457.
- Hayashi, K., et al., 2006, Bull. Geol. Surv. Japan, 57, 309 – 325.
- Horike, M., B. Zhao and H. Kawase, 2001, Bull. Seism. Soc. Am., 91, 1526-1536.
- Ishihara, Y. et al., 2004, Bull. Geol. Surv. Japan, 55, 183-200.
- Kitzunezaki, C., et al., 1990, Jour. of Japan Soc. for Natural Disaster Science, 9-3, 1-17
- Kon'no, K., et al., 2007, Jour. of Japan Society of Civil Engineering, 63, 639-654.
- Lermo, J and Chavez-Garcia F. J, 1994, Bull. Seism. Soc. Am. 84, 5, 1350-1364.
- Ludwig, W. J., et al., 1970, Seismic refraction, The Sea 4-1, 53-84.
- Nakamura, Y, 1989, QR of RTRI 30, no 1, February, 25-33.
- NEHRP, 2001, Part 1. Provisions (FEMA 368), Washington DC. Building Seismic Safety Council.
- Okada, H., 2003, Geophysical Monograph Series No. 12, Society of Exploration Geophysicists, Tulsa.
- Yokoi, T., 2005, Programme and abstracts, The Seismological Society of Japan, Fall meeting.