2D MICROTREMOR ARRAY MEASUREMENTS IN TSUKUBA CITY

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Abstract

We conducted 2D microtremor array measurements to delineate a deep subsurface S-wave velocity model in Tsukuba City. The survey line length was 12 kilo-meter, and was divided to five sub-linear arrays with overlap. Forty single-component nodal seismograph (McSEIS-AT) with geophone (natural frequency is 2 Hz, SUNFULL; PS-2B) were used for the measurement of each sub-array, and the measurement time for each sub-array was 45 minutes. Total number of observation points was 200. Before the measurement, a huddle test was performed, and high coherence was observed in a frequency range of about 0.2 to 10 Hz between any pairs of the geophones. Twenty-four phase velocity dispersion curves were obtained at every 400 m by CMP-SPAC method (Hayashi et al, 2015). The frequency range of the valid dispersion curves was about 0.3 to 5 Hz. The phase velocity dispersion curves by linear array were consistent with the dispersion curve obtained by cross-shaped array conducted at several cross-sections on the survey line. In addition to the linear array measurement, we conducted single-station microtremor measurements at 20 points on the survey line using three-component nodal seismograph (McSEIS-AT3C). We observed that the peak period of H/V spectral ratio changed from about 1s to 4s. We conducted multi-station inversion using the phase velocity and the H/V spectral ratio. Genetic algorithm (Yamanaka and Ishida, 1996) was used in the inversion process. The result of the multi-station inversion showed that the upper depths of sediments and of basements (Vs3.2km/s) were more appropriate than that of individual inversion results. The depth of the top of the basement varies from about 600 m to 200 m. The results were consistent with PS logging results.

Keywords: microtremor array measurements; S-wave velocity; subsurface model; multi-station inversion

1. Introduction

Microtremor array measurements are widely used in civil engineering, construction and prevention of earthquake as a simple method to estimate S-wave velocity model. In addition to one-dimensional exploration, two and three-dimensional explorations were developed recently [1]. In this study, two-dimensional microtremor array measurements was conducted in Tsukuba City for the purpose to estimate the deep subsurface structural model.

2. Measurement and analysis methods

The survey line was 12 kilo-meter long, and was divided to five sub-linear arrays with overlap. Forty single-component nodal seismograph (McSEIS-AT) with geophone (natural frequency is 2 Hz, SUNFULL; PS-2B) were used for the measurement of each sub-array, and the measurement time for each sub-array was 45 minutes. The total number of observation points was 200. Twenty-four phase velocity dispersion curves were obtained at every 400 m by CMP-SPAC method (Hayashi et al, 2015). Figure 1 indicates locations of observation points. The observation interval was about 100 to 150m in the southern area of the survey line, about 20 to 50m in the northern area, where the basement depth was estimated to be shallow. Cross-shaped arrays were conducted in the southern, central, and northern sections of the survey line to compare with the phase velocities by the linear array. In addition to the linear array measurements, we conducted single-station microtremor measurements at 20 points on the survey line using three-component nodal seismographs (McSEIS-AT3C). Before the measurement, a huddle test was performed, and high coherence was observed in a frequency range of about 0.2 to 10 Hz between any pair of the geophones. CMP spacing was 400m and 24 phase velocities were estimated. The frequency range of the observed phase velocity was about 0.3-5 Hz. The phase velocities estimated by linear array were consistent with those estimated by cross shaped arrays (Figure 2). Figure 3 indicates observed phase velocities and H/V spectral ratios. The phase velocity tends to increase as the CMP number increases. In particular, the phase velocity sharply increases in the north from near the CMP15. As for the H/V spectral ratio, the peak frequency is higher to the north of the CMP14 point.

3. Estimation of S-wave velocity structural model by multi-station inversion

We conducted multi-station inversions using the phase velocity and the H/V spectral ratio using genetic algorithm.[3] Figure 4 indicates conceptual diagram of the multi-station inversion. At points other than the reference point, Vs was set to the same at the reference point of the last generations.

To evaluate the validity of multi-station inversion, we performed numerical experiments. Figure 5 indicates S-wave velocity structure, phase velocity and H/V spectral ratio used in numerical experiments. The synthetic data was added 10% random noise. The reference point was Model001. Figure 6 indicates inversion results at Model002. Basement depth is estimated to be about 300m shallower than that of by single-station inversion. Figure 7 indicates inversion results at all station. The upper depth of 3rd layer by multi-station inversion is closer to the target model than that of single-station inversion results.

Multi-station inversion analysis was applied to the data obtained in Tsukuba City. First, CMP12 was set as a reference point. We conducted single-station inversion using the phase velocity and the H/V spectral ratio at CMP12. Next, S-wave velocity other than the reference point was constrained to be the same as the S-wave velocity at the reference point. Figure 8 indicate inversion result. Although the residual of the result of the single-station inversion is smaller, the result of the multi-station inversion also explains the observed data well. And it is also consistent with the PS logging results. In the single-station inversion results, irregularities are seen in the upper depth of third layer and basement (Figure 9). In the multi-station inversion result, since the S wave velocity of each layer is common, the upper depth of each layer changes smoothly. It is considered that the effect of stacking was obtained by multi-station inversion and the influence of random noise in time and space was reduced.

4. Conclusions

In Tsukuba-city, two-dimensional microtremor array measurements were performed. The S-wave velocity structure was estimated using phase velocity and microtremor H/V spectral ratio. As a result of multi-station inversion, a structural model with a smooth upper depth of each layer was estimated. Results of multi-station inversion are consistent with PS logging results.

5. References

[1] Hayashi K., C. Konishi, H. Suzuki, Y. Liu, M. Tahara, K. Falkenstein, M. Craig, and L. T. Wong (2018): Development and application of 2D/3D ambient noise tomography for near-surface S-wave velocity delineation, SEG Technical Program Expanded Abstracts, https://doi.org/10.1190/segam2018-2996064.1

[2] Hayashi K., M. Craig, T. Kita, T. Inazaki (2015): CMP spatial autocorrelation analysis of multichannel passive surface-wave data, SEG Technical Program Expanded Abstracts 2015, DOI: 10.1190/segam2015-5913708.1

[3] H. YamanakaH. Ishida(1996): Application of Genetic Algorithms to an Inversion of Surface-Wave Dispersion Data, B.S.S.A, 86.

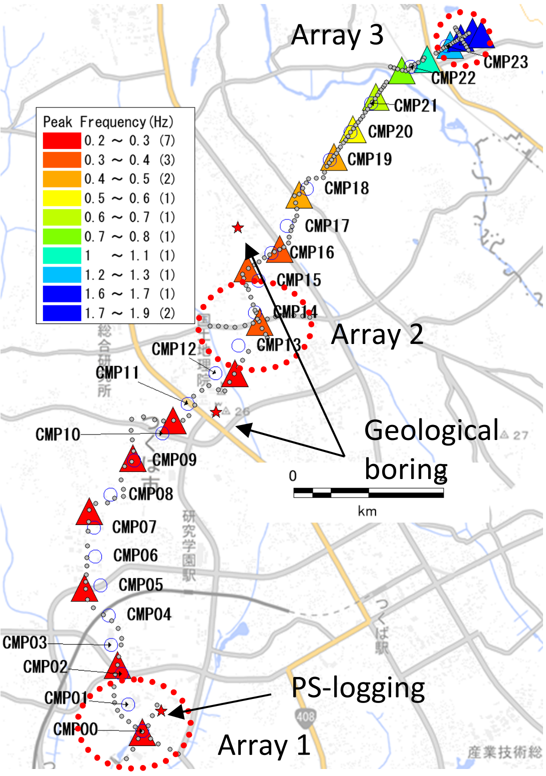

Figure 1 Observation point position (gray circle) and H / V spectrum peak frequency

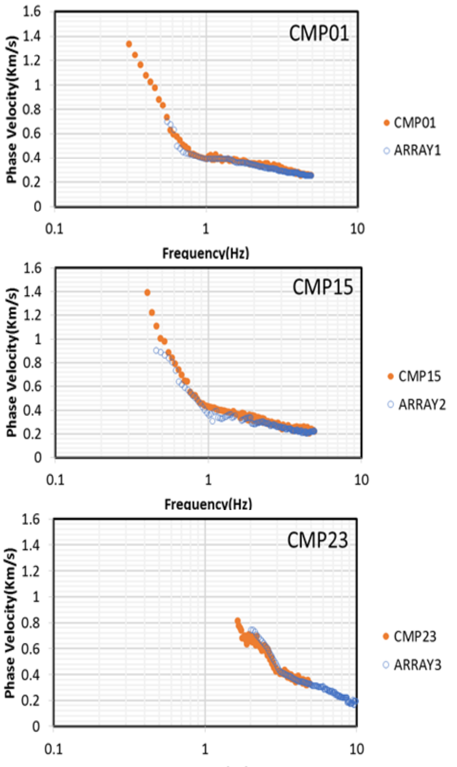

Figure 2 Comparison of phase velocity between cross sphaped array(blue) and linear array(orange)

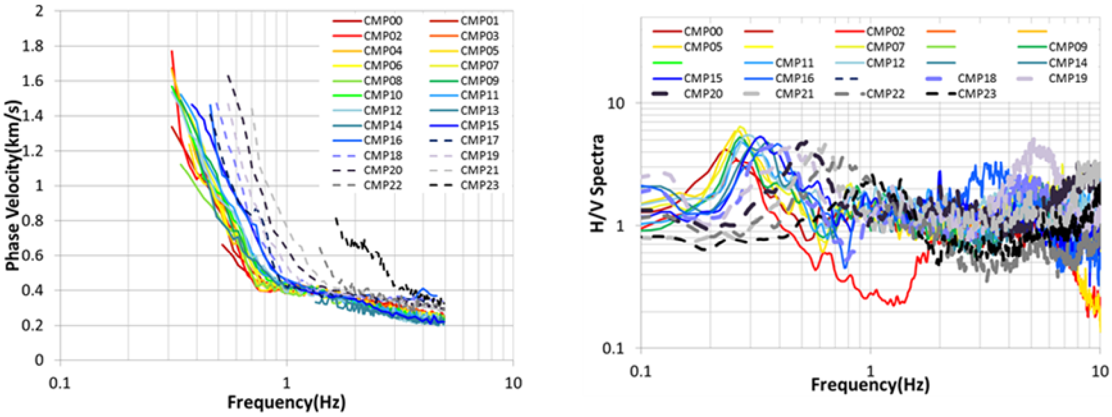

Figure 3 Observed phase velocities(left) and H/V spectral ratios(right).

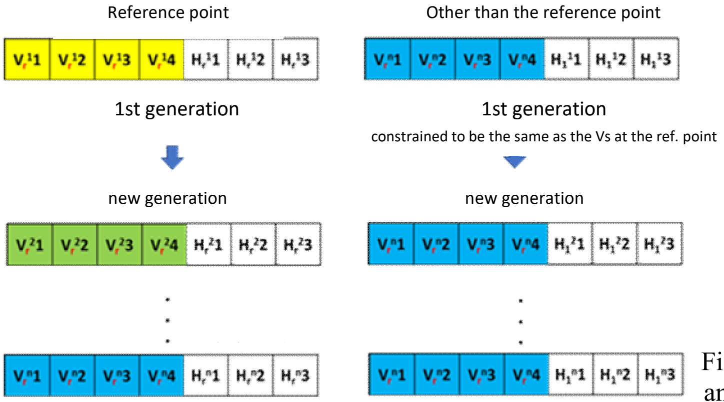

Figure 4 Conceptual diagram of muti-station inversion

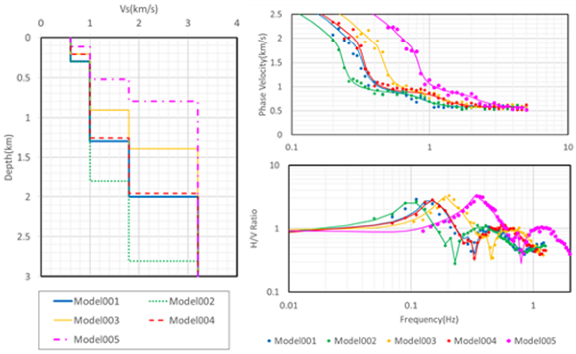

Figure 5 S-wave velocity structure and phase velocity and H/V spectral ratio used in numerical experiments

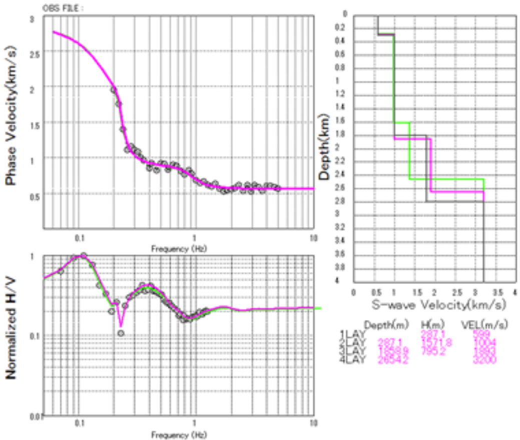

Figure 6 Invesion results of numerical test at Model002. Muti-station inversion result(red line) Single-station inversion result(green line) Target model(gray line)

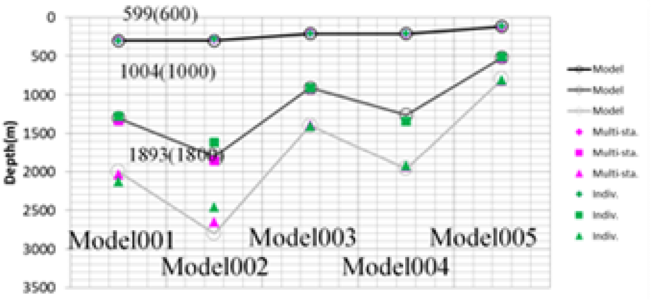

Figure 7 Invesion results of numerical test Muti-station inversion results(red triangles) Single-station inversion result(green circles) Target model(black and gray lines)

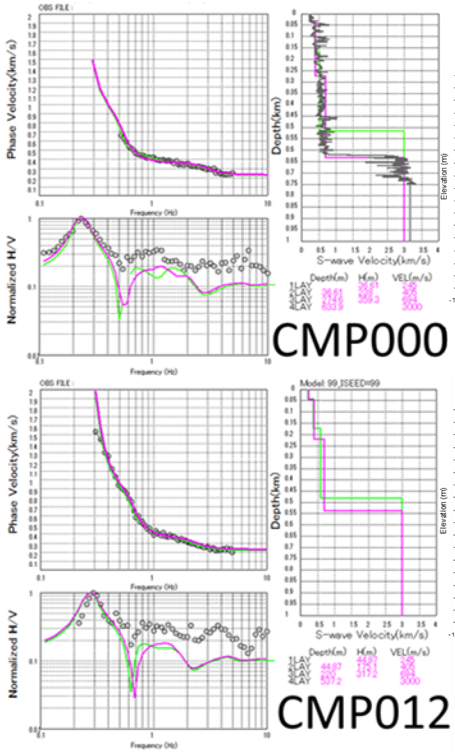

Figure 8 Invesion results Muti-station inversion results(red triangles) Single-statio inversion result(green circles) PS-logging result(gray line)

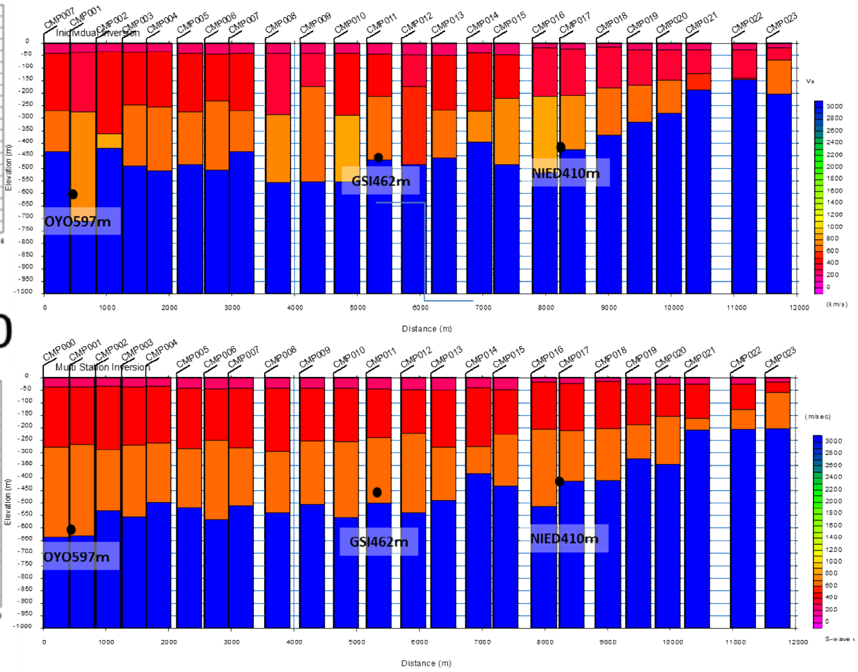

Figure 9 Invesion results Single-statio inversion result(upper row) Muti-station inversion results(lower row) Basement depth of geological boring (black circles)