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Estimation of ground structure based on shallow underground structure survey using microtremor array method

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Abstract

It is well known that seismic motions and earthquake damages varied greatly depending on the characteristic of the soil involved and the propagation characteristics of the seismic motions. Furthermore, advances in IT technologies and analysis technologies have been improving the accuracy of seismic motion estimation on a daily basis, making it ever more important to assess ground structure in greater detail to provide the basic information for estimating seismic motions. We selected some of the site as the study target and used the miniature array proposed by Cho et al. (2013) ［1］ to estimate 1D and 2D velocity profiles. We compared the result with the s-wave velocity profile obtained from boring survey and the existing single-point microtremor observation results. And also we performed the drawing of estimated 2D velocity structures at the target sites where there have specific configuration of the ground. Based on this model, we were able to confirm the distribution of the loam layer near the ground surface and also to infer the existence of several gaps in the velocity structure inside the Basin.

Keywords: microtremor array method, 2D velocity structures, shallow underground structure, Miniature array

1. Introduction

It is well known that seismic motions and earthquake damage vary greatly depending on the characteristic of the soil involved and the propagation characteristics of the seismic motions. Furthermore, advances in IT technologies and analysis technologies have been improving the accuracy of seismic motion estimation on a daily basis, making it ever more important to assess ground structure in greater detail to provide the basic information for estimating seismic motions.

Two- or three-dimensional soil structure is usually estimated by conducting a boring survey at multiple locations, as well as considering the geology, topography, sedimentary environment, etc. Such methods, however, require large investments in terms of money, time, etc. and require advanced specialized technologies related to topography, geology, etc. Meanwhile, one of the methods available for easily estimating the velocity profile of the surface layer uses microtremors. In particular, microtremor array observation, which employs multiple microtremor meters to measure microtremors, is a powerful method that can easily estimate the velocity profile of the ground.

We selected Hadano City, Kanagawa Prefecture (Hadano Basin) as the study target and used the miniature array proposed by Cho et al. (2013)［1］ and Senna et al. (2013)［2］ to estimate a 2D velocity profile. We also compared the result with the velocity profile obtained from boring histograms and the existing single-point microtremor observation results.

2. Overview of the Topography and Geology of Hadano City

Hadano City is located slightly off to the western side of the central part of Kanagawa Prefecture, spanning approximately 14 km east-west and approximately 13 km north-south. The Hadano Basin, which is the only basin within Kanagawa Prefecture, is located on the southern side of Hadano City. The Hadano Basin is located between the Tanzawa Mountains to the north and the Oiso Hill to the south, and is separated from the Oiso Hill by the Shibusawa Fault, which runs east-west. ［3］

The following three rivers are located within the Hadano Basin: the Mizunashi River originating from Mount Tōno in the central part of the Basin, the Kuzuha River originating from Sannotou Mountain on the eastern side of the Mizunashi River, and the Kaname River originating from the Yabitsu Pass area on the eastern side of a mountain mass. The interior of the Basin is an alluvial fan formed by these rivers and its depositional surface forms approximately a two-stepped hill surface. The geological strata comprising the Basin are gravel and loam layers forming an alluvial fan, with no marine stratum whatsoever. The floor of the basin, which is also the ground surface of the alluvial fan, has a low groundwater level, and therefore hardly any rice paddies are seen.

Figure 1 shows a micro topography classification diagram with a 50m mesh created by Enomoto et al. (2007)[4). The Hadano Basin is surrounded by a topographical feature formed during the Neogene period on the north side and a hilly area on the south side. The interior of the Basin is mostly an alluvial fan, and a valley plain, loam plateau, and artificially transformed land can be seen near the center of the Basin, matching the topographical overview well.

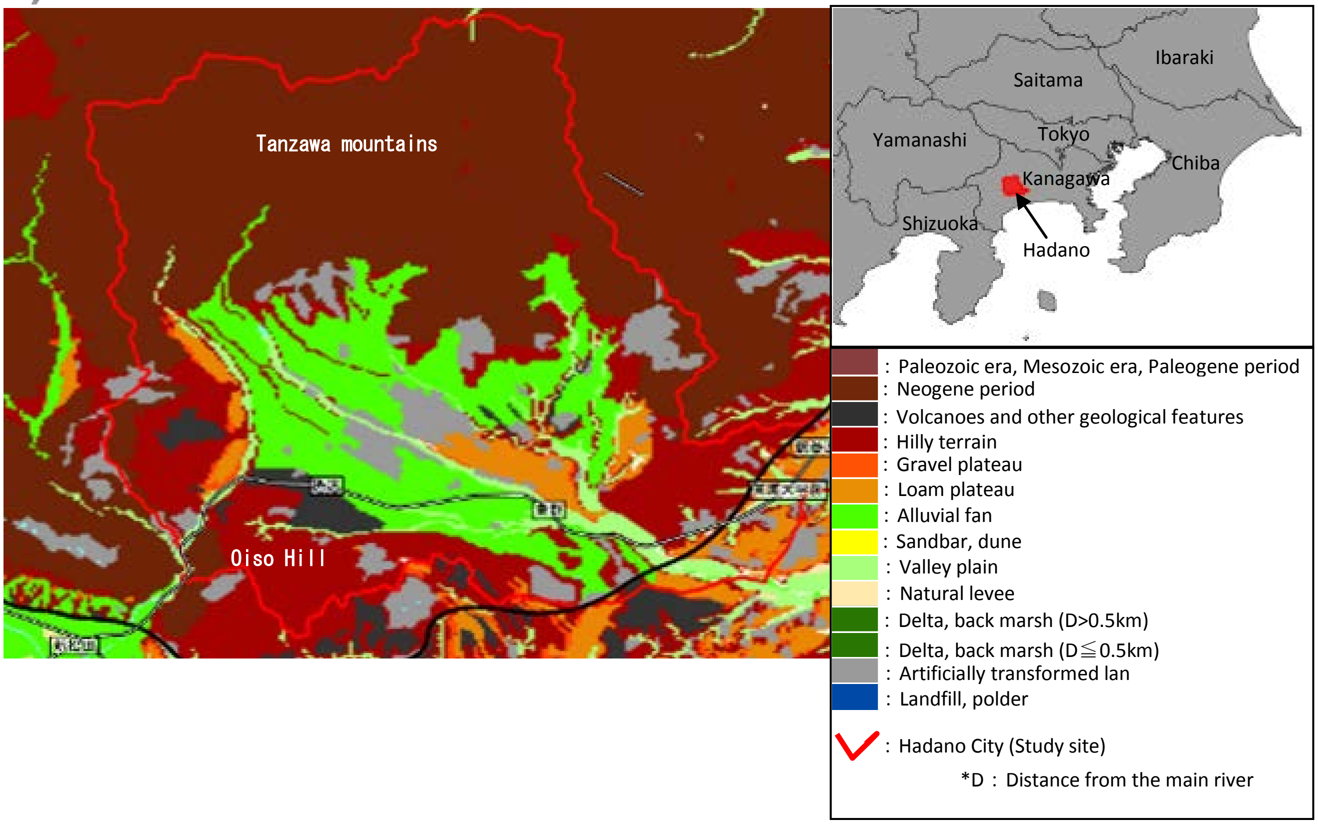


Fig. 1 Micro topography classification surrounding the Hadano Basin

3. Collected Data and Observation Results

3.1 Boring Data

The boring data in from Hadano City was collected and organized. Most of the boring data was concentrated inside the basin (in the alluvial fan, loam plateau, and valley plain) in the center of the city (Figure 2).

Figure 3 shows an example of a boring data (simplified histogram) from the center of the basin. This data also confirms that the basin consists of alternate gravel and loam layers forming an alluvial fan, which are the characteristics described under Section 2 above, implying that the area went through a complex topographical formation process that included deposition of volcanic ash and igneous rock, and inflow of sand and gravel from mountainous areas via rivers, etc.

It is presumed that most of the boring data had been obtained for the purpose of designing structures. In the Hadano Basin, the terrace deposits in shallow areas are relatively hard with SPT N values reaching 50 or more at most of the sites, and little information is available for the base under these sites.

3.2 Single-point Microtremor Observation Results

(1) Method

Single-point microtremor observations were made in a mesh layout measuring approximately 250 m by 250 m centered on the Hadano Basin. Observations were made with a sampling frequency of 100 Hz and lasted for 3 minutes at each site. Except for areas with external disturbances from factors such as traffic-caused vibration, Fourier spectra were determined and predominant periods were obtained from the H/V spectral ratio.

(2) Results

Figure 2 shows the distribution of the predominant periods obtained from single-point microtremor observations. Generally speaking, the predominant periods tended to be longer on the eastern side of the Basin, measuring between 0.6 and 0.8 seconds. Although the predominant periods varied slightly more widely inside the Basin, measuring between 0.2 and 0.5 seconds, they were in general around 0.3 seconds in the areas surrounding the Basin, with a few areas having exceptional values. Especially long predominant periods, measuring between 0.8 and 1.0 seconds, were noted in areas near the Tsurumaki-Onsen Station and Tokai University Station of the Odakyu Line located on the eastern side of the Basin.

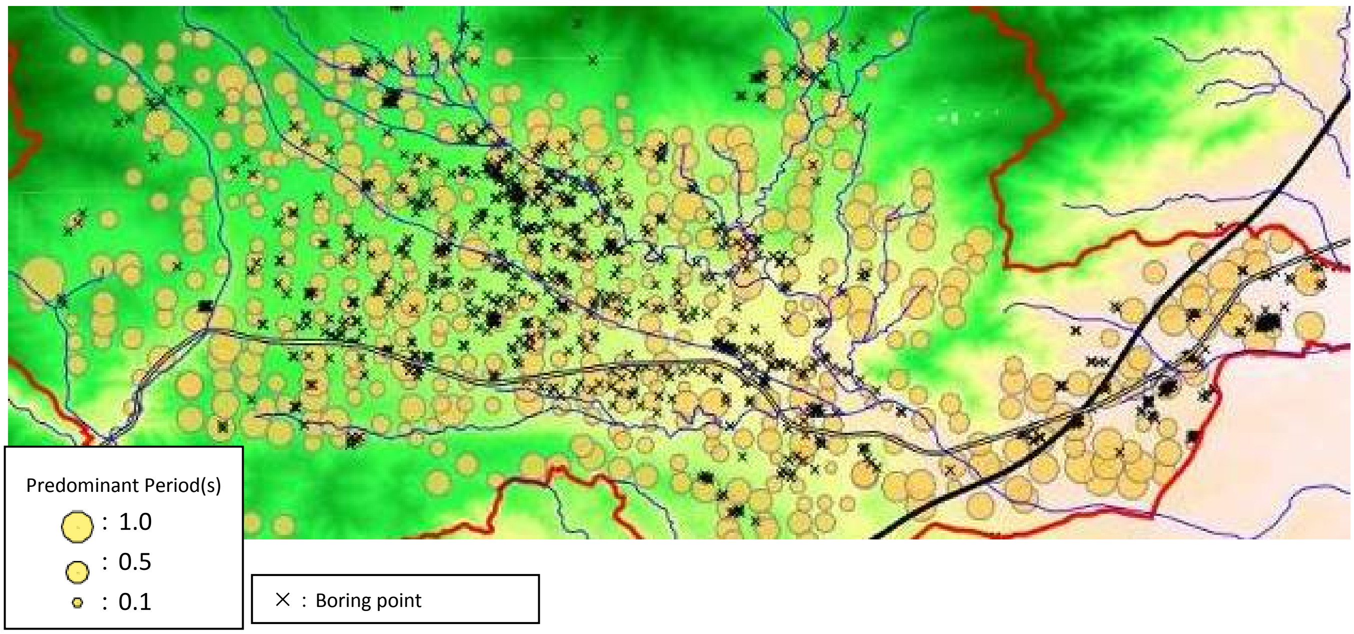


Fig. 2 Boring points and distribution of predominant periods from Single-point microtremor observations

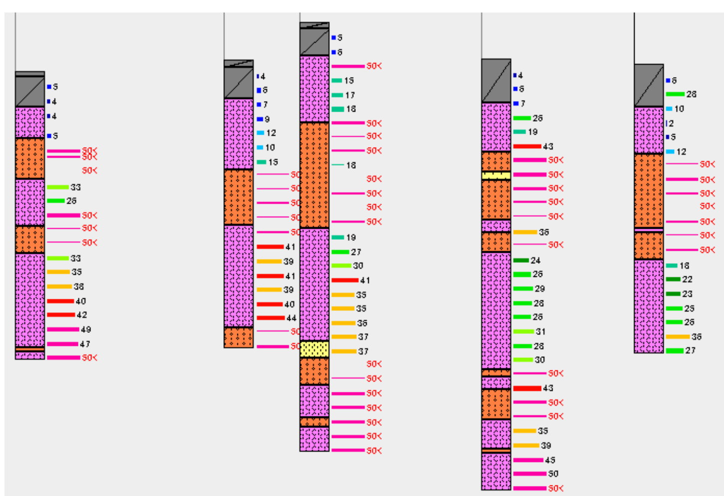


Fig. 3 Example of boring histogram (simple histogram)

3.3 Miniature Array Microtremor Observation Results

(1) Method

The method employing miniature array for microtremor observation has been examined by Cho et al. (2013) [1] . Recently, efforts have been ongoing to simplify observation and analyses and to increase the sophistication level of observation methodology (Chou et al. (2013) [5]). Because these simplifications allow the method to be easily used even by non-specialists, observations using this method are expected to be made in many areas in the future. Although details about the observation and analysis methodologies are described in References [1] and [5], an overview is provided below.

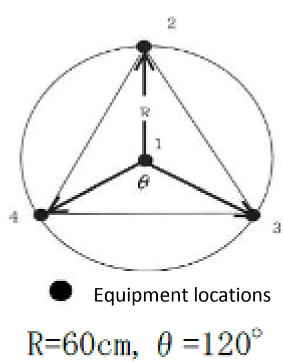
At R = 60 cm (R is Distance of observation) and θ - 120˚ (θ is angle of the center) , miniature array can be used to take measurements at a spacing roughly equaling the distance from one hand to the other of a person with outstretched arms (Figure 4). The individual microtremor meters are synchronized based on a GPS, and each site was observed for 15 minutes. During observation, the data can be monitored using a wireless LAN to check whether the observation was being made correctly.

Two kinds of empirical methods were used, i.e., the Simple Profiling Method (SPM) (e.g., Cuellar, 1994) [6] , which determines the S-wave velocity structure through direct conversion of a distribution curve, and the Simple Inversion Method (SIM) proposed by Pelekis and Athanasopoulos (2011) [7] , which determines the S-wave velocity structure of the layer structure through simple inversion analysis.

Observations were made in a grid shape inside the Hadano Basin, that is, at intervals of approximately 200 m to 300 m on six measurement lines in the north-south direction and along three measurement lines in the east-west direction. The observation sites are shown in the 2D velocity profile diagram in Figure 7. Although observations were also made near the Tsurumaki-Onsen Station and Tokai University Station of the Odakyu Line located on the eastern side of the Basin, which were confirmed to have long predominant periods through single-point microtremor observations, that data is omitted from this report due to insufficient analysis.

(2) Results

While the details of the observation results will be described in Section 4 along with a comparison with other results, Figure 4 shows an example of phase velocity. The phase velocity resulting from each frequency is automatically read from the analysis result.



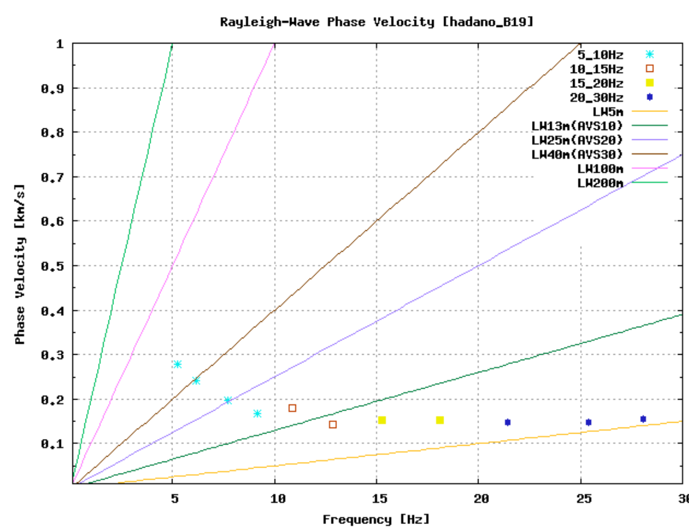


Fig. 4 Positioning of miniature array and an example of phase velocity obtained from results (site B)

4. Comparison and Sorting of Observation Results

4.1 Comparison between the boring histogram and the miniature array observation results

The S-wave velocity structure was estimated using the N value, etc. obtained from the boring histogram and the method suggested by Ohta and Goto (1978) [8] . Figure 5 shows the estimation results (Bor) at five typical sites. This figure also shows the S-wave velocity structures obtained from micro array observation results (SPM and SIM) obtained in the vicinity.

Ignoring the variability caused by non-uniformity, etc. near the surface, the S-wave structure (Bor) obtained from boring matches the SPM data obtained from micro arrays extremely well. On the other hand, SIM data obtained from micro arrays deviates very far from Bor in some deeper areas. Although we are currently investigating details of the cause, we believe that it is necessary to reevaluate the layer classification used when carrying out inverse analysis.

4.2 Comparison between the single-point microtremor observation results and the miniature array observation results

Figure 6 shows the transfer function computed from the aforementioned boring histogram (Bor_ratio), the transfer function computed from the ground structure (SIM) obtained using miniature array (array_ratio), and the H/V spectral ratio obtained from single-point microtremors in the vicinity (H/V ratio), all overlaid on top of each other. (Note that the individual observation sites are close to each other but not the same.)

Although the peaks deviate from each other in some areas, it is possible to identify the common peaks (indicated by ▼). Sites where the primary peak of single-point microtremors is not captured in other results (sites A and B) are presumed to be affected by a ground structure that is deeper than the depth modeled by boring or miniature array. Furthermore, the results from miniature arrays do not correspond very well to other results at site E. As mentioned in the previous section, it is necessary to reevaluate the layer boundaries used when carrying out analysis using SIM.

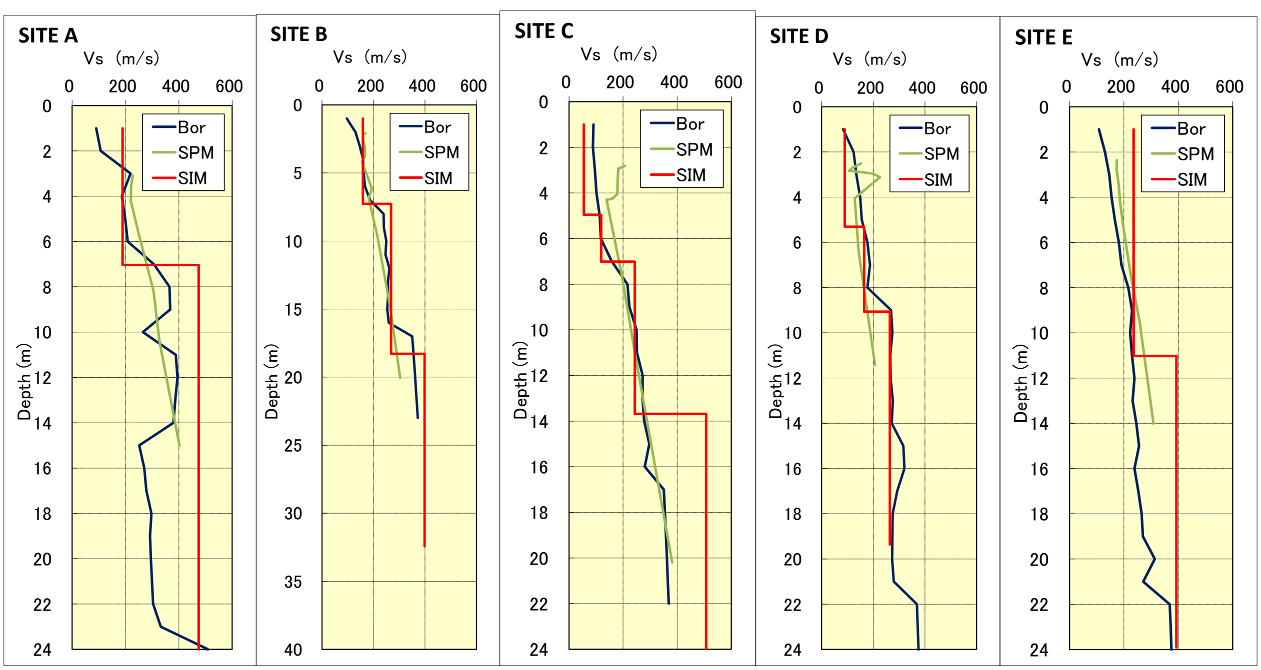


Fig. 5 S-wave velocity structure determined from boring (Bor) and miniature arrays (SPM and SIM)

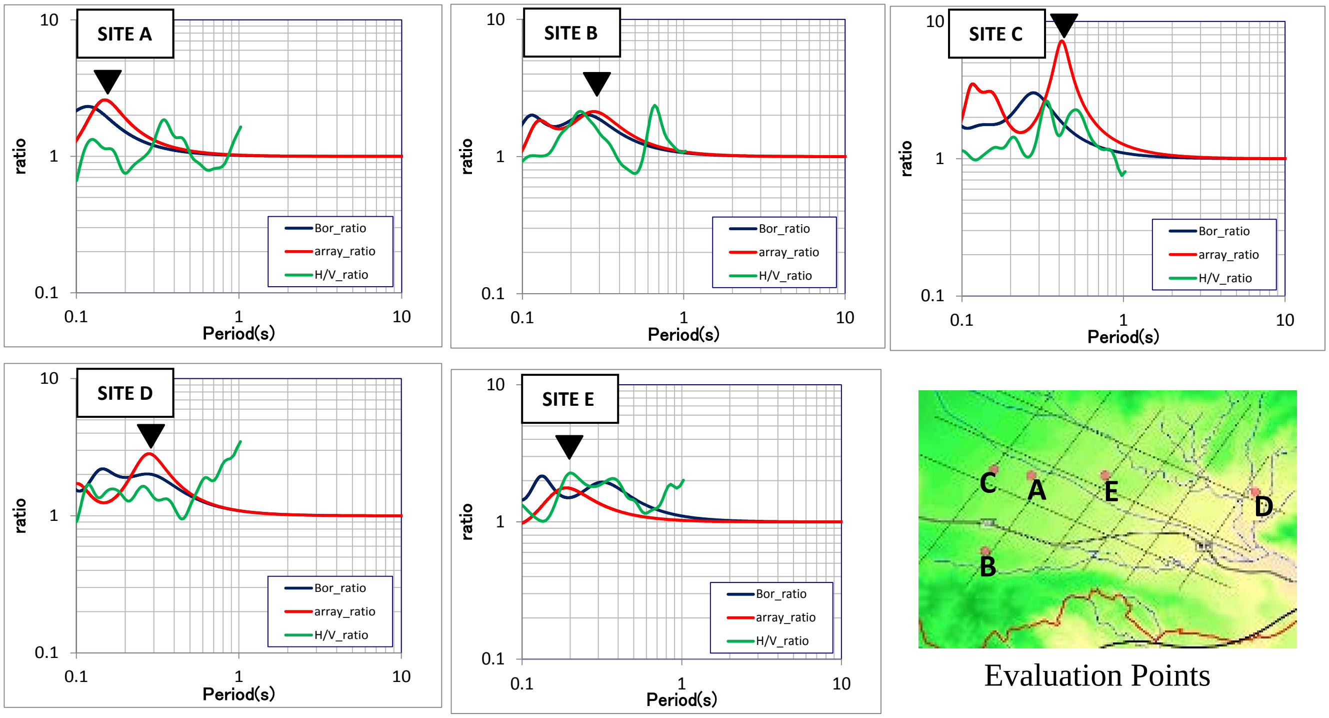


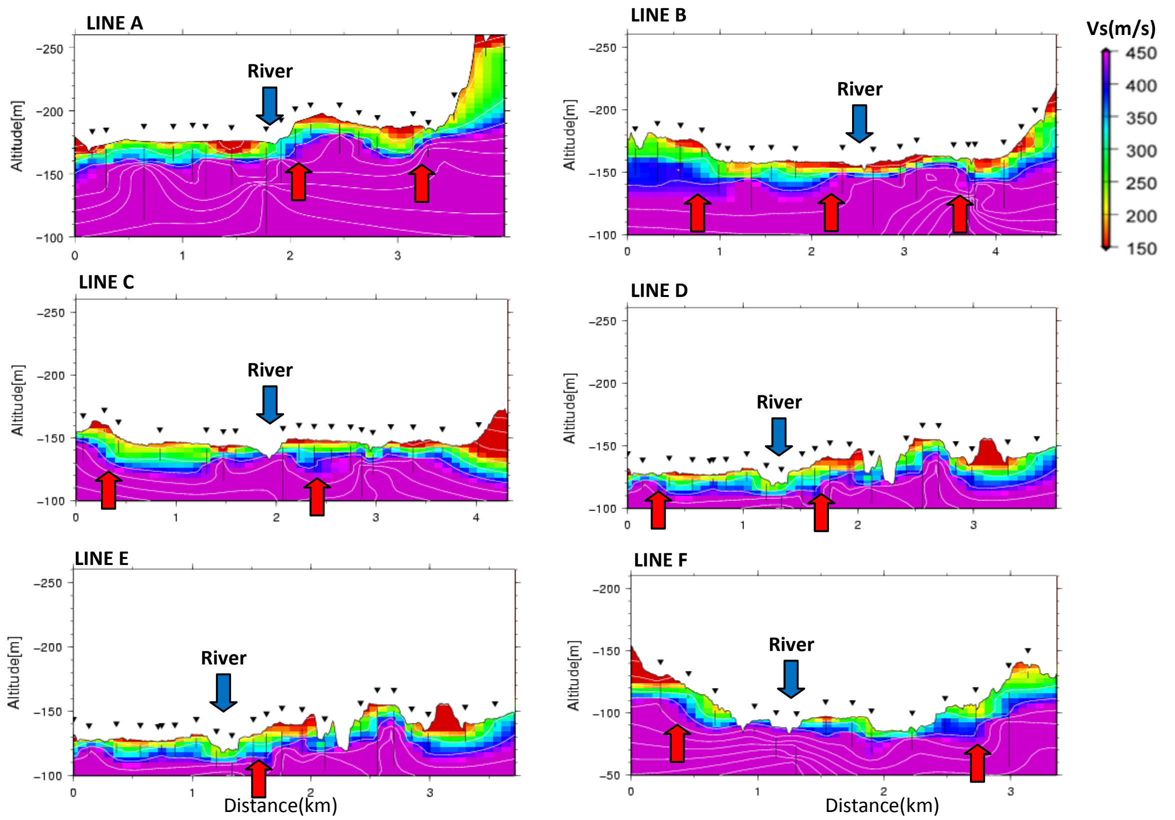
Fig. 6 Transfer functions obtained from boring and miniature arrays (SIM) and H/V spectral ratio

4.3 Creation of a 2D velocity profile model

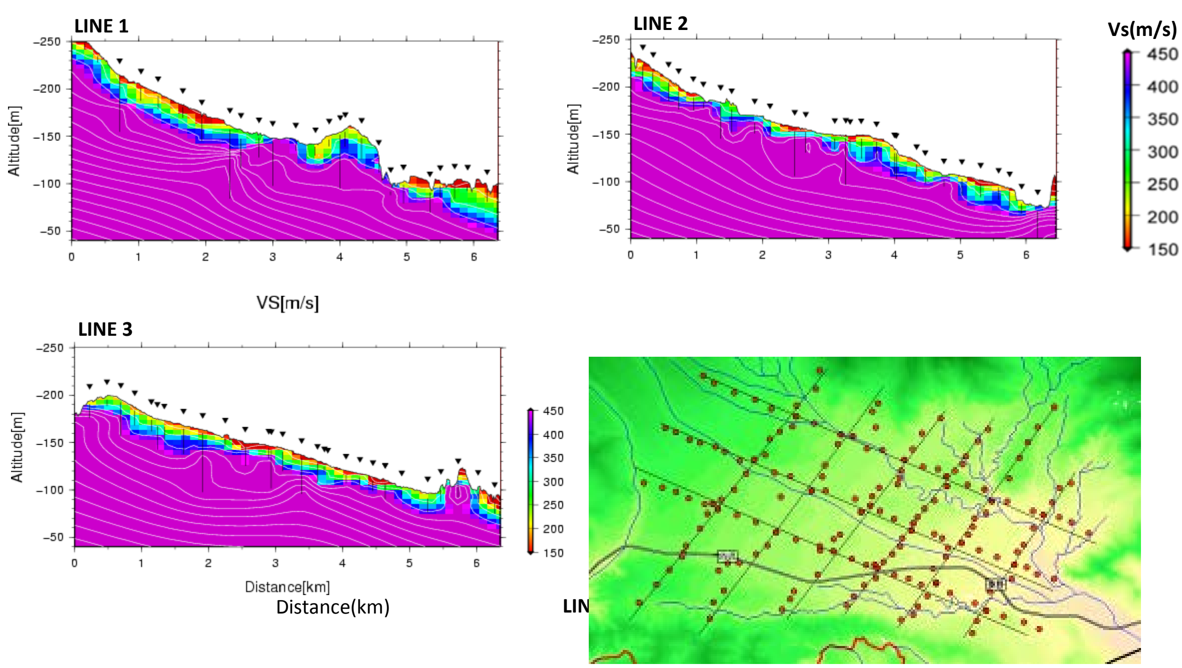
The velocity profiles obtained from the miniature arrays were arranged continuously to estimate a 2D velocity profile model. Figure 7 shows the created velocity profile model.

The figure shows that layers with an S-wave velocity of 100 to 200 m/s (mostly loam layers) are widely distributed near the ground surface in the Hadano Basin, but a lack of loam layers (erosion) can be seen along rivers. The figure also shows that the loam layers vary in thickness depending on the area, and have been thickly deposited to a depth of as much as 20 m in some locations.

The figure also shows gaps in the velocity structure estimated from analysis (red arrows). The gap locations correspond to known faults in some areas, but gaps were also found in sites not known for faults. These details will be studied further in the future.



Short Cross-section



Cross-section lines and miniature array implementation locations

Long Cross-section

： Velocity structure gap

Fig. 7 2D velocity profile along measurement lines

5. Summary

In this study, we estimated the 2D velocity profile of Hadano City, Kanagawa Prefecture (Hadano Basin) using miniature arrays to measure microtremors, and compared the results with the velocity profile obtained from boring histograms and the existing single-point microtremor observation results.

Comparison of the velocity profile obtained from miniature array observations with that obtained from boring histograms generally showed a good match, although there is some room for reevaluating the method for classifying layers, etc. The transfer function obtained from the velocity profile created from miniature array observations and the H/V spectral ratio obtained from single-point microtremor observation results also showed excellent correspondence, confirming common peaks.

A 2D velocity profile model was estimated from the velocity profile obtained from miniature array observations, which provided an overview of the ground structure of the entire Hadano Basin. Based on this model, we were able to confirm the distribution of the loam layer near the ground surface and also to infer the existence of several gaps in the velocity structure inside the Basin.

In the future, we plan to increase the observation density and try to create a 3D velocity profile model that also comprehensively takes into account other information (faults, groundwater, strong ground motion records, etc.). We hope to improve modeling accuracy so that we can develop a single underground structure model capable of assessing many events such as movements of groundwater, in order to be able to forecast seismic motions.

6. References

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