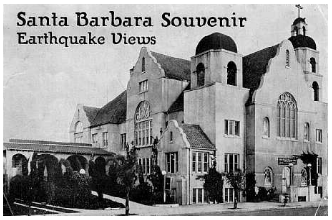

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TOMOGRAPHIC ESTIMATION OF SURFACE-WAVE GROUP VELOCITY USING SEISMIC INTERFEROMETRY IN SOUTHERN KANTO, JAPAN

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ABSTRACT

Tomographic estimation of surface-wave group velocity based on the seismic interferometric theory was conducted in the southern Kanto, Japan using observed long-term continuous microtremor data. We use cross correlations of long-term microtremor data from 16 stations in the area to extract the group velocities of surface-wave at periods of 2 – 6 seconds between two stations. These group velocities are used for tomographic analysis to understand the regional differences of surface wave group velocities in the southern Kanto. The resulting tomographic map showed good agreement qualitatively with theoretical one. However this comparison showed some differences especially in the bay area. Surface-wave group velocities obtained by tomographic analysis at the periods are used for group velocity inversion to deduce the S-wave velocity model at each cell of the tomographic map. The determined model by inversion explained the dispersion curves of group velocities better than previous one and S-wave velocity profile also clarified the difference in the bay area.

INTRODUCTION

Tokyo metropolitan area is located on the Kanto plane which is one of the large sedimentary basins in Japan. It is well known that ground motion is amplified in the basin filled with such a huge amount of sediment. Especially, long-period strong motion is observed in such a large sedimentary basin. Recent study shows that high-rise buildings and oil tanks are mainly damaged by long-period strong motion. Therefore, it is emergent problem to estimate this kind of effect in the metropolitan area which is located on a huge sedimentary basin such as Tokyo, California, Mexico city and so on. However it is so difficult to estimate the effects of long-period surface wave because we are lack of knowledge of the parameters of subsurface structure which mainly control long-period surface wave. Therefore, several methods of exploration for deep sediment layers using microtremors such as Spatial Autocorrelation (SPAC) Method or Frequency-Wavenumber (F-K) method are well used to know deep S-wave profiles because of its easy field operation and required cost. This conventional microtremor exploration is also conducted in the Kanto plane and it has been constructed some precise maps of S-wave profiles in the area (e.g. Yamanaka and Yamada 2006). Recently, a new exploration method is developed using microtremors called Seismic Interferometry. It has been already demonstrated that the cross correlation of two seismic waves leads to Green's function that would be observed at one of these receiver positions if there were an impulsive source at the other (e.g. Snieder 2004, Wapenaar and Fokkema 2006) and also applied to seismic coda waves (Campillo and Paul 2003) and microtremor data (e.g. Shapiro and Campillo 2004). The advantage of this method is the applicability for long distance station pairs and it only needs two stations at least while it needs long-term microtremor data. Therefore in order to apply this method in the southern Kanto and to validate the previous 3D S-wave velocity model, we started the long-term observation of microtremors and conducted tomographic analysis based on the seismic interferometry.

DATA PROCESSING OF CROSS CORRELATING AND ESTIMATION OF GROUP VELOCITY

Continuous microtremor observation was conducted to apply seismic interferometry method and the cross correlation analysis is

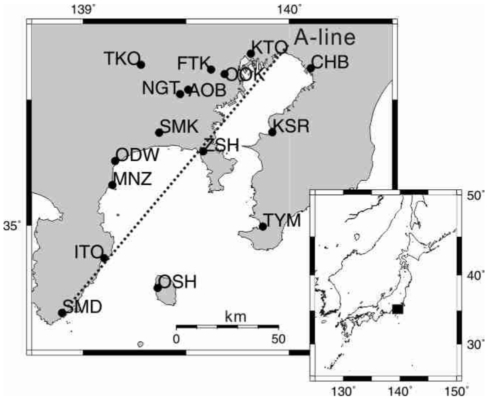

Fig.1 locations of stations

applied to more than half a year long-term microtremor data collected at the 16 stations in the southern Kanto (Fig.1) using a 100Hz sampling frequency. The cross correlation functions were computed using 24 hour data for all the station pairs separated by a 3.8-141 km distance after data resampling to 10 Hz. The final cross correlation functions at each station were averaged all the daily cross correlation functions. In order to remove the effect of noise and seismic event, we disregarded the amplitude completely by considering only one-bit signals (e.g. Shapillo and Campillo 2004). The selected period band for computing the cross correlation functions are 2.0 - 6.0 seconds. The horizontal components are then rotated to radial and transverse orientations as defined by the great circle path between the two stations. Fig. 2 shows all the cross correlation functions with vertical-vertical and transverse-transverse components. The arrival times of each cross correlations are different because of the complexity of the subsurface structure in this area.

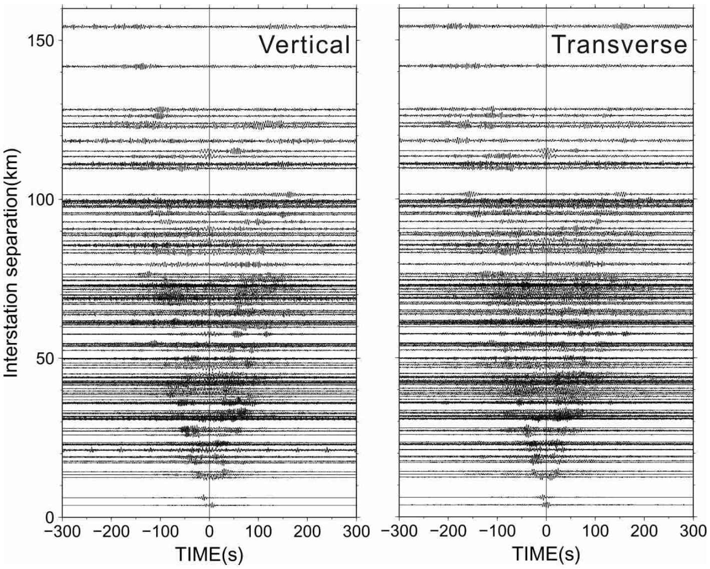

Fig.2 All cross correlations between vertical (left) and transverse (right) components.

Group velocity is estimated from the arrival time of the cross correlation using a multiple filter analysis (e.g. Dziewonski *et al.*,1969). Fig.3 shows the result of the analysis at the station pair of AOB and ZSH in Fig.1. Because the previous studies have been illustrated some precise subsurface structure maps, we computed the theoretical dispersion curves of Rayleigh wave group velocities based on one of the 3D S-wave velocity model constructed using many microtremor exploration data by Yamanaka and Yamada (2006) are also shown in the figure, which agrees well with the observed dispersion curve of Rayleigh wave group velocity of both fundamental mode and 1st higher mode. This analysis is applied to all cross correlations for estimation of all the velocities between two stations of fundamental mode of both Rayleigh and Love waves.

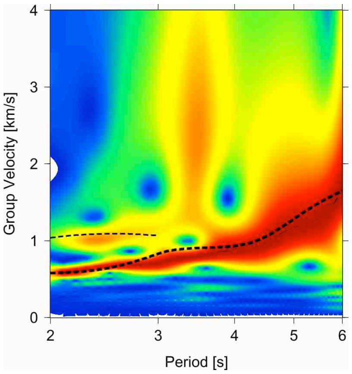

Fig.3 Rayleigh wave group velocity at the station pair of AOB and ZSH. Thick broken line shows the theoretical Rayleigh wave group velocity of fundamental mode computed by Yamanaka and Yamada (2006). Thin broken line shows the 1st higher mode.

TOMOGRPHIC ANALYSIS

A lot of recent studies show the possibility to use the travel times for a detailed surface wave tomographic analysis (e.g. Sabra et al. 2005). Therefore we applied this tomographic analysis based on the arrival time of Rayleigh and Love waves at periods of 2 to 6 seconds in order to validate the previous model. The southern Kanto area is divided into 0.125 degree cells of constant group velocity for the tomographic analysis. More than 100 ray paths are used assuming straight rays. A traditional tomographic inversion called Simultaneous Reconstruction Technique is used to construct the group velocity map (Clayton and Comer 1983). Fig.4 shows the result of tomographic analysis for the Rayleigh wave group velocity using the vertical component of the cross correlation at the period of 6 seconds. This result shows good agreement with previous knowledge of subsurface structure in this area. For example, regions of slow Rayleigh wave velocity correspond to sedimentary basins and bay area while fast group velocity region correspond to Izu peninsula (southwestern part of the figure) and western marginal part of Kanto basin (western part of the figure). Theoretical tomographic map computed from the 3D model by Yamanaka and Yamada (2006) is also shown in Fig.4. The computed map agrees qualitatively with the observed tomographic map. However, there is some quantitative difference in some of the area, such as Sagami bay (center part of the figure). Furthermore, we could obtain the group velocity at Izu peninsula where no S-wave velocity data are available in the previous model.

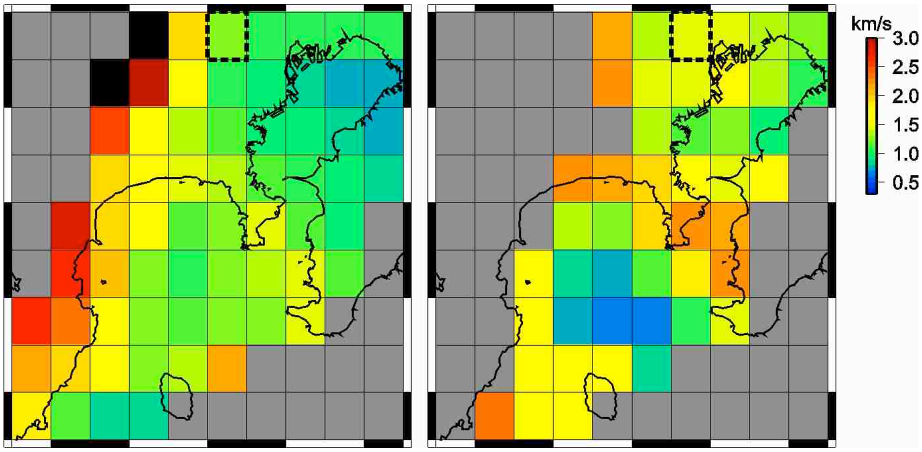

Fig.4 Tomographic map of Rayleigh wave group velocity at the period of 6.00s. Left figure show the observed tomographic map and right figure shows the theoretical one computed by Yamanaka and Yamada (2006).

Since the tomographic analysis is conducted at periods of 2 to 6 seconds of both Rayleigh and Love waves, it is possible to get the dispersion curves at each cell. Fig.5 shows an example of the observed and theoretical dispersion curves at the particular cell shown in Fig.4. The observed dispersion curves of the Rayleigh and Love waves group velocities of fundamental mode at the rectangular cell shown in Fig.4 agree well with the theoretical ones.

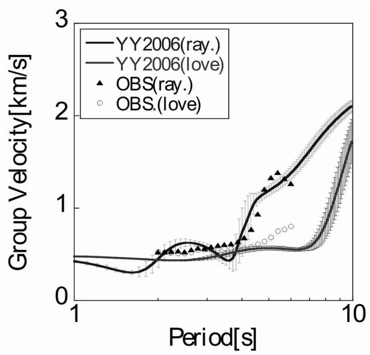

Fig.5. Observed group velocities of Rayleigh (triangle) and Love (circle) waves by tomographic analysis with theoretical Rayleigh (black line) and Love (gray line) waves by Yamanaka and Yamada (2006) at the rectangular cell shown in fig.4. Error bar shows the standard deviation of theoretical group velocity.

INVERSION OF DISPERSION CURVE

The group velocities estimated at each cell are inverted to an S-wave velocity profile by the genetic inversion using Yamanaka and Ishida (1996). In the inversion of all the group velocities, we assumed a 4 layers model having S-wave velocities of 0.5, 1.0, 1.5 and 3.0 km/s since there are three major geological units in this area; one is Quatanary layer and the other two units are of Tertinary age. Fig.6 shows the result of joint inversion of the group velocity of Rayleigh and Love waves observed at the rectangular cell shown in Fig.4. The resulting theoretical dispersion curves of the Rayleigh and Love waves in the inverted model better explain observed dispersion curves than theoretical ones computed from the previous model by Yamanaka and Yamada (2006) (Fig.5). The 3rd layer of the determined model at the cell is deeper than previous model by Yamanaka and Yamada (2006) while 2nd layer is shallower than previous model (Fig.7). The same method was applied at the cells along A-line shown in Fig.1. The previous model by Yamanaka and Yamanaka (2006) is shown in Fig.9 along the same line to Fig.8. Comparing Figs.8 and 9, the deep sedimentary areas are similar in the two results even though the absolute values for the basement depth are slightly different from each other. Because the previous model has been constructed using S-wave profiles from many micrtremor array explorations, there are less information on S-wave velocity in the bay area than in the land area. Therefore this study implies a high applicability of this exploration method, especially in the area where explorations are not easy to conduct such as bay area.

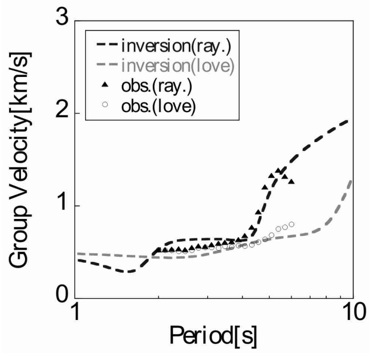

Fig.6. Group velocities by the joint inversion of Rayleigh (black broken line) and Love (gray broken line) waves with observed Rayleigh (triangle) and Love (circle) waves at the rectangular cell shown in fig.4.

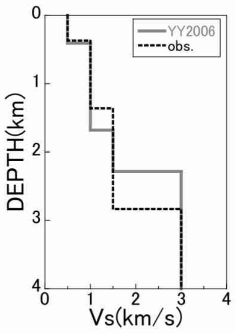

Fig.7. Profiles of S-wave velocity structure estimated by inversion (black broken line) with previous model by Yamanaka and Yamada (2006) (gray line) at the rectangular cell shown in fig.4.

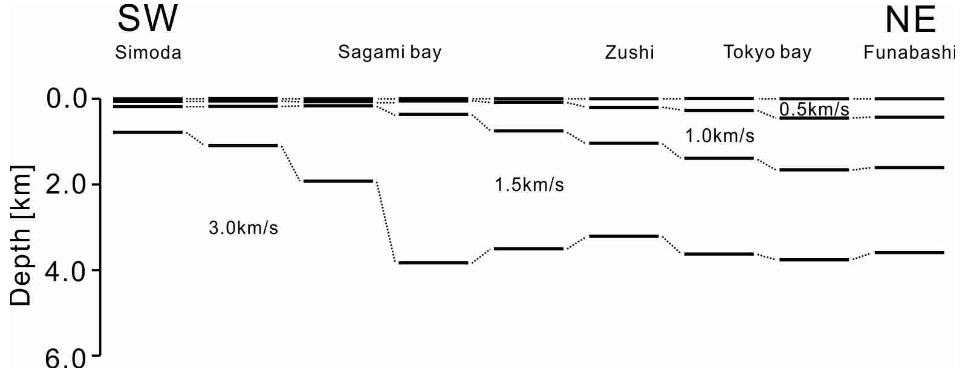

Fig.8 Profiles of S-wave velocity estimated by inversion at sites along A-line shown in Fig.1.

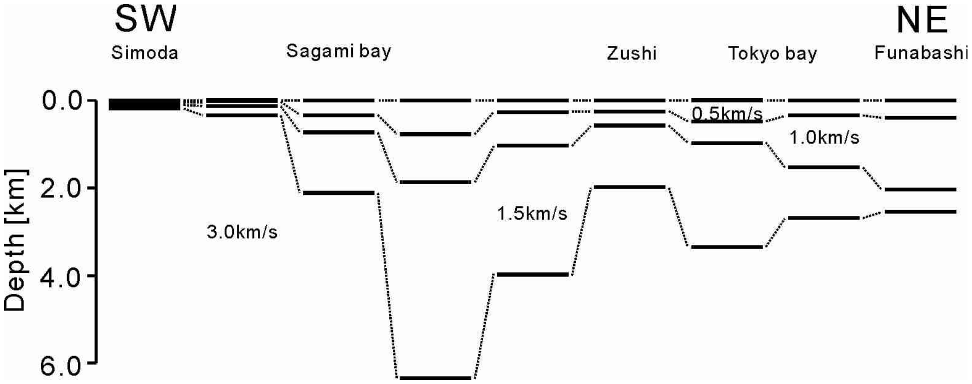

Fig.9. Profiles of S-wave velocity made by previous model by Yamanaka and Yamada (2006) at the same line to Fig.8.

CONCLUSIONS

In order to apply seismic interferometry method to long-term microtremor data, we conducted long-term continuous microtremor observation in the southern Kanto. More than half a year microtremor data was used for the cross correlation analysis at all the station pairs. Almost all the surface wave group velocities at periods of 2 to 6 seconds between the two stations were estimated from cross correlations using multiple filter analysis. The estimated group velocities were used for tomographic analysis to know the regional differences in the southern Kanto. The area was divided into 0.125 degree cells of constant velocities and more than 100 ray paths were used for the analysis. Simultaneous Iterative Reconstruction Technique was used to make tomographic map from the arrivaltime at each station pairs. The resulting map of Rayleigh wave group velocity was qualitatively similar with the theoretical tomographic map computed by previous 3D S-wave velocity model. However, the group velocity in the bay area was faster than previous model and we could obtain group velocity at the marginal part of the southern Kanto. Joint inversion of Rayleigh and Love waves group velocity was applied to deduce S-wave profiles of sedimentary layers down to a depth of the basement with an S-wave velocity of 3 km/s. The dispersion curves computed by new 1D models explained better than that of the previous model. The 2D cross section for the S-wave velocity profiles in this area clarified the difference in Sagami bay area.

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