Estimation of ground structure around damaged area by 2008 Iwate-Miyagi Nairiku earthquake

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1. Introduction

Iwate-Miyagi nairiku earthquake of M7.2 has occurred on June 14, 2008. The source region was Kurikoma area where is located about 100 km northwest of Sendai, Japan. After the earthquake, the discriminative behaviour of tombstones has been observed near the source. For example, most of tombstones in Hozo-ji temple fell down in a similar way. On the other hand, in Kongo-ji temple, where is just 5 km away from Hozo-ji temple, their behaviours were quite different from those at Hozoji-temple.

These behaviours have many possible causes: source effects, path effects, local site effects, and so on. To understand the reasons, Kobayashi *et al.*[1] have focused on site effects, especially shallow ground structure. They suggest that not shallow structure but large scale factors such as deep structure might contribute to discriminatory behaviour of tombstones. We would like to focus on deep structures to know the behaviour of tombstones in this study. For this purpose, microtremor and gravity surveys were carried out around Kurikoma area.

2. Observations and Results of Microtremor Array Survey

To determine the velocity structure of shear wave, we carried out observation of mictrotremor array at MNJ, WRN, INY and KGJ as shown in Figure 1 during September, 2009. We used moving-coil-type velocity seismometers (natural period 2 sec), and digital recorders (24 bit resolution and 800 Hz sampling rate) with GPS clock and analog-gained filter. The observed data are synchronized by the GPS clock, and recorded through low pass filter with cut off frequency of 10 Hz. Before the observation, a step response of the pendulum is recorded to perform the correction of instrumental properties during the process of analysis. The duration of observations is more than 30 min.

For analysis of microtremor, we apply the spatial autocorrelation (SPAC) Method[2], and phase velocities are estimated. Figure 2 shows the results. Moreover, we compute the spectral ratio of a horizontal component to a vertical one (H/V), which includes NS/UD and EW/UD. The peak periods of H/V can be found in the very low frequency range around 0.5 Hz. This means that these peaks reflect the very deep structure at the sites.

Figure 1: Map of the Target area

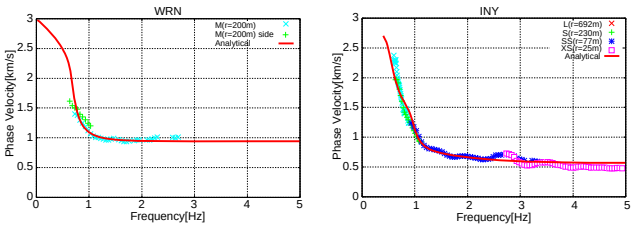

Figure 2: Estimated phase velocities at WRN and INY

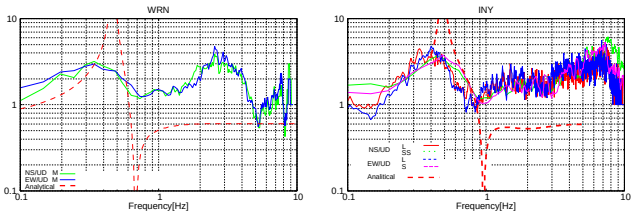

Figure 3: H/V obtained from observed data and estimated structures at WRN and INY

3. Observations and Results of Gravity Survey

To obtain the 3-dimensional ground structure accurately, we carried out the relative gravity measurement around Kurikoma area (38°47'N–38°54'N, 140°50'E–141°03'E; 15km NS×19km EW) during December 2009. For the observation, type G gravimeter by LaCoste &

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Table 1: Estimated structures of WRN and INY

WRN				
	P-wave Vel.(km/s)	S-wave Vel.(km/s)	Density (g/cm^3)	thickness(km)
1	2.400	1.000	2.000	0.500
2	4.400	1.600	2.200	0.450
3	6.800	3.200	2.400	∞
INY				
	P-wave Vel.(km/s)	S-wave Vel.(km/s)	Density (g/cm^3)	thickness(km)
1	1.500	0.600	1.800	0.002
2	2.000	0.800	2.000	0.009
3	4.400	1.800	2.300	0.070
4	6.800	3.200	2.400	∞

Romberg was used to measure the gravity values. To determine the accurate positions of the observation sites, the differential survey with the GPS was performed. Errors of positions were less than 1 m. We have obtained 146 absolute values of the gravity. We analyze gravity data. After some data corrections [3], the Bouguer anomaly can be obtained using the assumed density of 2.40 t/m^3.

4. Discussion

To estimate the velocity structure, we search up appropriate structure to satisfy the observed phase velocity and H/V using heuristic approach on forward calculations. For this calculations, we have an assumption that the microtremors propagate through the horizontally and parallel layered medium, and they consist of the fundamental mode of Rayleigh wave. As a result, the layers with some different shear wave velocities (V_s) are determined for deep structure (Figures 2 and 3). The profiles of the velocity structures are shown in Table 1.

On the basis of the Bouguer anomaly and the velocity structures obtained from microtremor survey, we estimate a 3-D shape of the bedrock surface under the assumption of 2-layered medium. The density of sediment is estimated to be 2.05 t/m^3. To obtain a realistic model of gravity basement, we consider the follows: 1) To remove the contribution for Bouguer anomaly from deeper structure such as mantle with band-pass filter; 2) To constrain the depth to the bedrock with giving control points, 2 site from microtremor array WRN, INY.

As a result, depth of gravity basement reaches to more than 1200m at the center of the area. A concave-shape structure of basement around the center of the target area is different from the rest: its strike directs from north to south and its width is about 5km in east to west. Hozo-ji temple is located on the steep slope of the bedrock. This suggests that 3-D shape of the bedrock contributes possibly to the behaviour of tombstones.

To understand the reasons the behaviour of tombstones, we apply Haskell's matrix method to compare property of site amplification with natural period of tombstone as caused by resonant mode. According to Kobayashi *et al.*[1], the own natural period of the tombstone at Hozo-ji (T_b) is 0.913 sec (=1.095 Hz). The site amplification is obtained from structure model at INY, where is located close to Hozo-ji temple. However, there

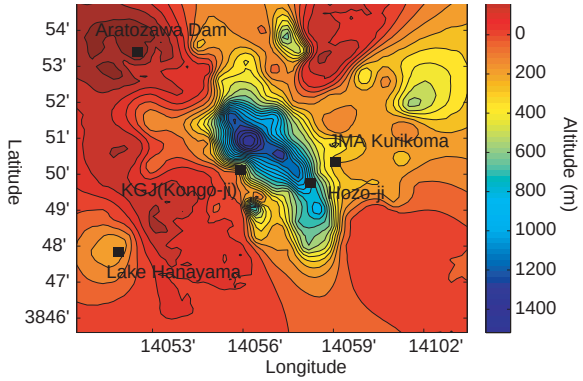

Figure 4: Altitude of gravity basement (density of sediment ρ =2.05 t/m^3)

is no site amplification around T_b. This indicates that the deep structure might not necessarily contribute to the behaviour or that the mode of tombstone's falling was not generated resonantly.

This also suggests that the other factors such as the source effect or path effect might contribute to discriminatory behaviour of tombstone. To understand this, it will be required to consider such factors and run a numerical simulation.

5. Conclusions and Future Developments

We have carried out microtremor array and gravity surveys around Kurikoma area, Japan. We estimated the phase velocities and velocity structures applying SPAC method to microtremor data. Furthermore, 3-D shape of the bedrock is obtained from Bouguer anomaly. The results from this study are listed below:

1. Depths of the bedrock are estimated as WRN = 950 m, INY = 81 m.
2. The ellipticities of Rayleigh waves obtained from the estimated velocity structure agree with the observed H/V spectra.
3. Densities of the bedrock and sediments are estimated to be 2.40 t/m^3 and 2.05 t/m^3, respectively.
4. A concave-shape structure of basement around the center of the target area is observed.

For detailed and further discussion of the earthquake ground motions, we will introduce ground motions of after shocks observed around the target area and try to perform some numerical simulations.

References:

[1] Kobayashi, T. , Goto, H. , Ichimura, T. and Morikawa, H.: Estimation of the shallow structure around Kurikoma, Miyagi, Japan, using the microtremor array survey, *Abstract Japan Geoscience Union Meeting*, 2009.

[2] Aki, K. : Space and time spectra of stationary stochastic wave, with special reference to microtremor, *Bull. Earthq. Res. Inst.,* **35**, pp.415–456, 1957.

[3] Komazawa, M. :"Gravity Survey," *Hand Book of Exploration Geophysicists,vol.4*, pp.195–225, Society of Exploration Geophysicists of Japan, 1998.