SAFETY ASSESSMENT OF UNDERGROUND TANK AGAINST LONG-PERIOD STRONG GROUND MOTION - ESTIMATION OF DEEP SUBSURFACE STRUCTURE BY OBSERVING MICROTREMOR AND STRONG-MOTION IN AKITA DISTRICT -

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ABSTRACT :

In considering the safety of oil storage, it is important to grasp the characteristics of long-period ground motion causing sloshing, and it is also useful to investigate deep subsurface structures at the site, as well as to analyze the characteristics of long-period ground motion by the observed earthquake waves.
In this study, we conducted the above investigation and analysis in Oga area where Akita National Petroleum Stockpiling Base is located and Akita City/Sanno area around Oga area. As s result, we obtained the following results: 1) In both areas, we estimated deep subsurface structures to reproduce both phase velocity and H/V ratio of microtremor observation records. 2) We confirmed that the group velocity of the strong-motion observation records approximately corresponded to the theoretical dispersion curve of the estimated deep subsurface structures in both areas. 3) According to the estimated deep subsurface structures, the depth of Vs=3km/s to be the seismic bedrock was 0.8km in the Oga area and 1.8km in the Sanno area, revealing that the structure in the Sanno area tends to amplify the long-period ground motion more than that in the Oga area.

KEYWORDS: long-period ground motion, oil storage tank, deep subsurface structure, microtremor observation, strong-motion observation

1. INTRODUCTION

In the Tokachi-Oki Earthquake of 2003, a fire accident of oil storage tank was caused by sloshing due to the vibration of long-period component amplified by a deep subsurface structure several kilometers deep in Tomakomai area (Hatayama et al, 2004). In the Nihonkai-Chubu Earthquake of 1983 as well, a fire accident due to sloshing occurred in oil storage tank in Akita City, showing that the deep subsurface structure in Akita City has such characteristics as to amplify the long-period component of earthquake motion (Yoshihara et al, 1984).
Akita National Petroleum Stockpiling Base (hereinafter called “Akita Base”) is located on the bedrock in the Oga area. Since it is also in the vicinity of Akita City, there is a possibility of sloshing of oil storage being excited when the long-period component of a large earthquake occurring at a faraway place reaches the Akita Base after passing through the Akita City. We, therefore, estimated deep subsurface structures in the Oga area and Akita City/Sanno area, and investigated the characteristics of long-period ground motions occurring in both areas.

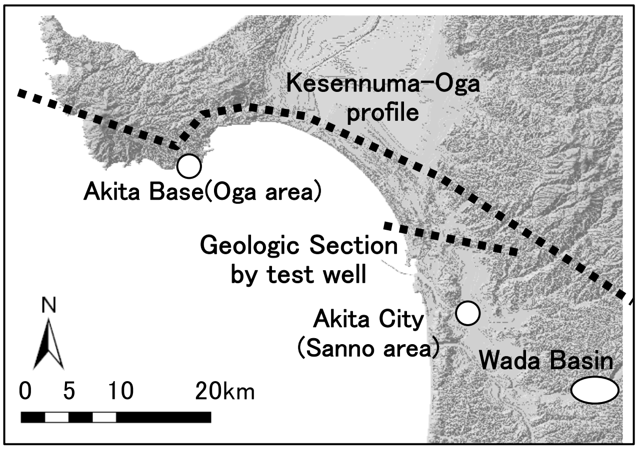


Figure 1 Investigation points of deep subsurface structure in Akita district

Figure 1 shows the investigation points of the deep subsurface structures in Akita district. The previous researches report the analysis results of explosion data observed along the Kesennuma-Oga profile (Yoshii and Asano, 1972) and elevations diagrams of bedrock surface throughout Japan (Headquarters for Earthquake Research Promotion, 2005), which were both macro information. The subsurface structures several kilometers under the surface layer that affect sloshing have not been sufficiently investigated. As to the information on the several kilometers under the surface layer, the estimation results of P- and S- wave velocity in the Wada Basin, east of Akita City (Kitsunezaki et al, 1990) and the geologic section by means of test well in the Akita Plain (Fujioka et al, 1977) have been publicly announced, and these places are a little far away from the Oga and Sanno area.

In this paper, we simultaneously conduct the observation of vertical component by means of two-dimensional array on the ground surface of long-period microtremors in the Oga and Sanno areas and 3-components observation at the array center position, so as to estimate the deep subsurface structures in both areas. As the analysis method of the observation records, we adopt the method of Ishida et al (1998) applied for estimating the deep subsurface structures, east of Kobe City, and identify the deep subsurface structures to reproduce both the phase velocity of the observation records and H/V ratio (spectral ratio of horizontal component to vertical component). This method is based on the condition that the deep subsurface structure is a horizontal stratification; however the gravity basement in the Akita district is not horizontal because it gradually becomes deeper toward the sea westward from the Sanno area and very shallow near the Oga area (Hiroshima et al, 1992). Therefore, we collect strong-motion records observed in both areas, and compare the deep subsurface structures estimated and the group velocity computed by strong-motion observation records, thereby confirming that proper deep subsurface structures can be estimated even in the Akita district where the gravity basement is not horizontal.

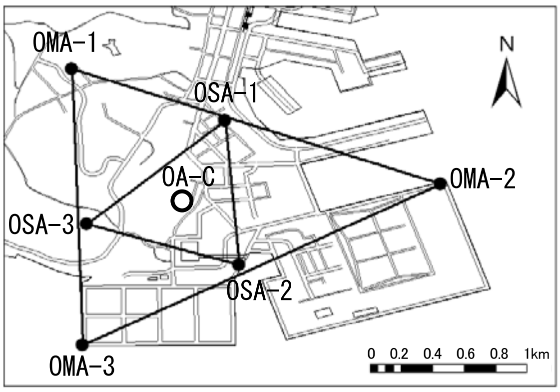
2. ESTIMATION OF DEEP SUBSURFACE STRUCTURE THROUGH MICROTREMOR OBSERVATION

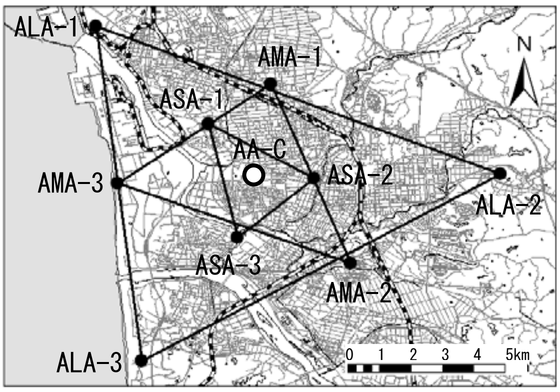
2.1. Observation outline and observation records

The microtremor observation was conducted in the Oga and Sanno areas. In consideration of the fact that the gravity basement is shallow in the Oga area and relatively deep in the Sanno area, we formed triangular arrays of maximum side length of about 1.8 km in the Oga area and maximum side length of about 11 km in the Sanno area. Figure 2 shows the arrangement of array observation points. The array arrangement was formed by combining triangles with each apex arranged with observation points. The observation points in the Oga area were composed of medium and small arrays and the observation points in the Sanno area composed of large, medium, and small arrays. The observation component of each array observation point is vertical component. The reference observation points were arranged almost at the center position of each array in both areas, to observe two horizontal components (NS, EW) and vertical component.

As the seismometer to observe microtremor, we used PELS-73H, V (manufactured by Shindo Giken). The data were recorded through 100Hz sampling after they were amplified through the high-cut filter of 1 Hz.

Figure 3 shows an example of Fourier spectrum of velocity records of vertical component observed at the reference observation point AA-C (Akita local meteorological observatory) in the Sanno area. The spectrum





Oga area Sanno area

Figure 2 Arrangement of microtremor observation points shown was obtained by dividing the observation records in 90 minutes in units of 160 seconds and then superposing them. Since the observation was conducted late at night, so that the data was stable with less variance in wave motion due to difference in observation time. The result was the same as observation records at other points.

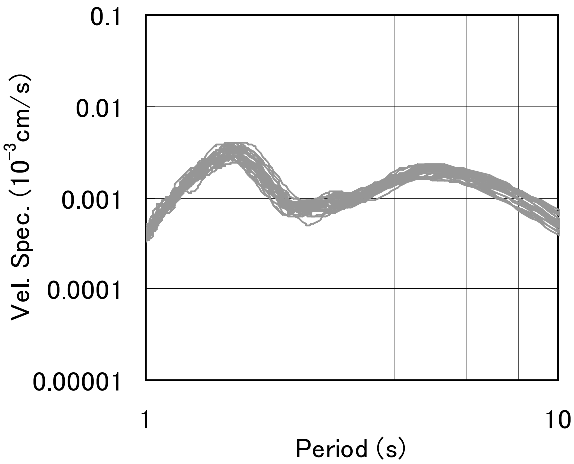


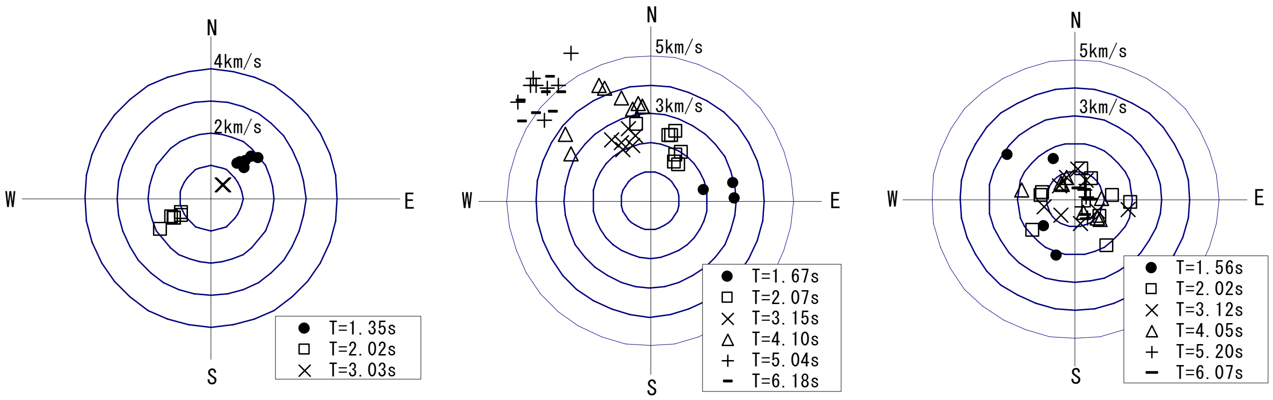
Figure 3 Velocity response spectrum observed at reference observation point AA-C in Sanno area

2.2. Phase velocity by f-k spectrum analysis

As to the records of vertical component obtained through the array observation of microtremors, we conducted frequency wavenumber spectrum analysis (f-k spectrum analysis) by the method of Capon (1969), so as to estimate the phase velocity. Records for 90 minutes were obtained at each observation point, and we selected record for about 330 seconds with less artificial noise from among all the records. We divided this record into multiple pieces of data, averaged the phase velocity calculated for each period against each data, and determined the phase velocity of all the data. For the wavelength range of Rayleigh wave that can be estimated from the array observation of microtremors, the maximum wavelength is set to about two times the maximum edge length of the triangle array and the minimum wavelength to about two times the minimum edge length thereof, respectively, referring to Matsushima and Okada (1990).

Figure 4 shows the examples of propagation direction and phase velocities obtained through the array observations in the Oga and Sanno areas. For the Sanno area, they are separately shown as the results of medium array and those of large array. The phase velocity is velocity corresponding to the peak of the f-k spectrum, and the propagation direction is the direction of the peak (direction of microtremors).

In the array observation in the Oga area, wave groups different in period arriving from northeast and southwest were observed, which seems to be related to the fact that the northeast side is land area and the southwest side is sea area. In the array observation in the Sanno area, the phase velocity tends to differ in the medium array depending on the propagation direction; however, no particular correlation was recognized between the propagation direction and phase velocity in the large array. Namely, it is considered that the shallow subsurface structure expressed by the medium array is uneven while the deep subsurface structure expressed by the large array is relatively horizontal.



Array observation in Oga area

Medium array observation in Sanno area

Large array observation in Sanno area

Figure 4 Relationship between propagation direction and phase velocities obtained for each period in array observation

Figure 5 shows the phase velocities from microtremor array measurements in the Oga and Sanno areas. The data of the Sanno area in this figure were added with the data of small-scale array obtained at the Akita local meteorological observatory by Yasuda et al (2008).
Since the array observation records used are vertical component, they are considered as Rayleigh wave, and the velocity shows dispersion in both areas. The phase velocity in the Oga area increases at around 1.6 seconds, suggesting that the bedrock is shallow. In the Sanno area, on the other hand, the phase velocity is small at 0.8 km/s in the period of 1 second or less, and it is considered that a low-velocity layer exists at the surface.

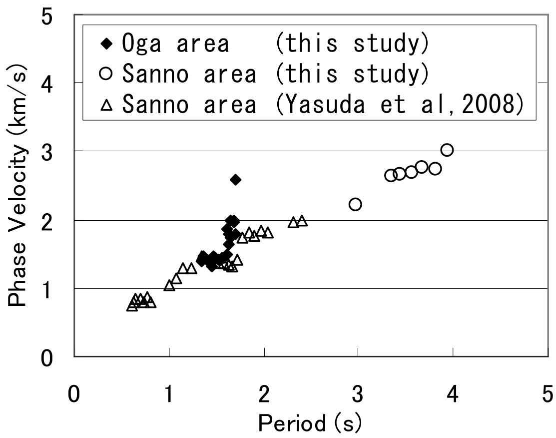


Figure 5 Phase velocities of Rayleigh wave estimated in Oga and Sanno areas

2.3. Identification of deep subsurface structure through inverse analysis of phase velocity

The phase velocity of the obtained microtremor observation records was inversely analyzed for the deep subsurface structure by using genetic algorithm (Yamanaka and Ishida, 1995). We assumed a 4-layer model consisting of one quaternary deposit and three tertiary deposits as the layered structure in the Oga area, referring to the geologic map by Fujioka et al (1973). For the Sanno area, we assumed a 6-layer model consisting of one quaternary deposit and five tertiary deposits, referring to the measurement results of P- and S-wave velocity in the Wada Basin, east of Akita City, by Kitsunezaki et al (1990), and the geologic map by Fujioka et al (1977). The P-wave velocity and the S-wave velocity were related by using the empirical formula [Vp=1.11･Vs+1.29 (km/s)] of Kitsunezaki et al (1990), and the density was made constant for all the layers. Table 1 shows the search limit in the inverse analysis by the genetic algorithm.
Figure 6 shows the S-wave velocity profile identified by the inverse analysis. Table 2 shows the estimated deep subsurface structure. In the Oga area, the depth of seismic bedrock (S-wave velocity Vs=3 km/s) is very shallow at 0.8km, and layers of Vs=0.6 - 1.1 km/s exist in the surface layer. In the Sanno area, the depth of the seismic bedrock is 1.8km, and the layers of Vs=0.7 - 2.1 km/s exist in the surface layer.
Figure 7 compares the phase velocity observed and the phase velocity of fundamental-mode Rayleigh wave for the estimated S-wave velocity profile. The phase velocities observed in both areas were well in agreement with the theoretical phase velocity against the estimated S-wave velocity profile.

Table 1 Search limits of inverse analysis by genetic algorithm

Oga area

	Layer	H(km)	Vs(km/s)	ρ(t/m³)
Quaternary deposit	1	0.02～0.05	0.5～0.7	2.2
Tertiary deposit	2	0.60～0.80	0.9～1.1	2.4
	3	0.30～0.40	3.0	2.6
	4	∞	4.1～4.3	2.8

Sanno area

	Layer	H(km)	Vs(km/s)	ρ(t/m³)
Quaternary deposit	1	0.01～0.50	0.1～1.0	1.8
Tertiary deposit	2	0.01～0.50	0.1～1.5	1.9
	3	0.01～1.00	1.2～1.7	2.2
	4	0.01～1.00	2.0～2.6	2.4
	5	0.50～1.50	3.0	2.6
	6	∞	4.0～5.0	3.0

Table 2 Estimation results of deep subsurface structure

Oga area

Layer	H(km)	Vs(km/s)	Vp(km/s)	ρ(t/m³)
1	0.03	0.60	2.00	2.2
2	0.77	1.09	2.50	2.4
3	0.36	3.00	4.60	2.6
4	∞	4.11	5.90	2.8

Sanno area

Layer	H(km)	Vs(km/s)	Vp(km/s)	ρ(t/m³)
1	0.25	0.73	2.10	1.8
2	0.17	1.10	2.50	1.9
3	0.70	1.44	2.90	2.2
4	0.68	2.09	3.60	2.4
5	1.18	3.00	4.60	2.6
6	∞	4.40	6.20	3.0

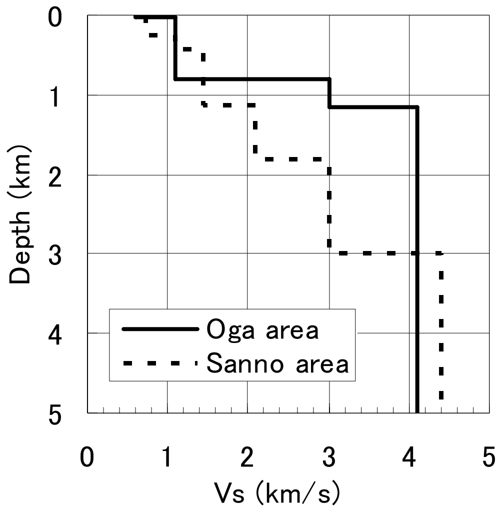
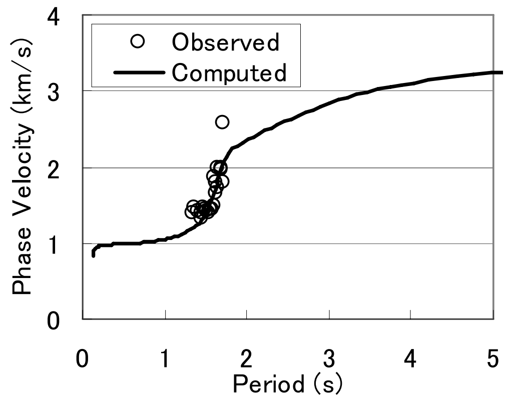
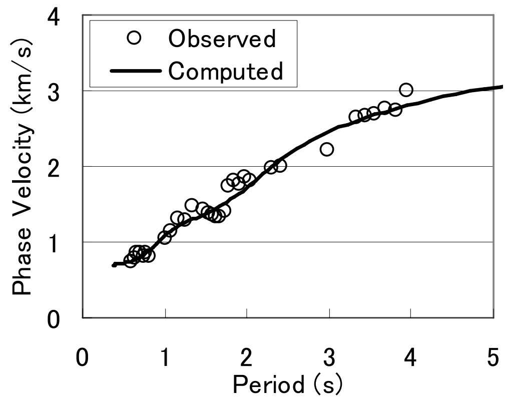


Figure 6 Estimated S-wave velocity profile



Oga area

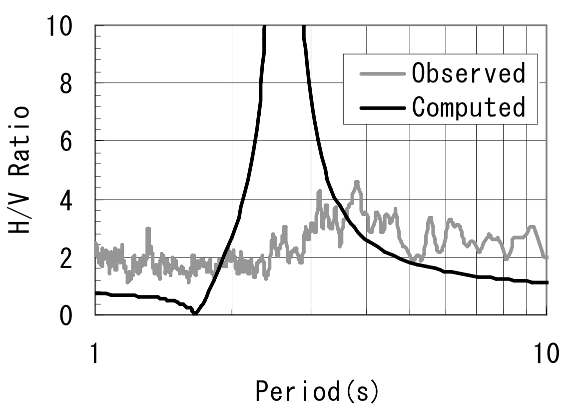


Sanno area

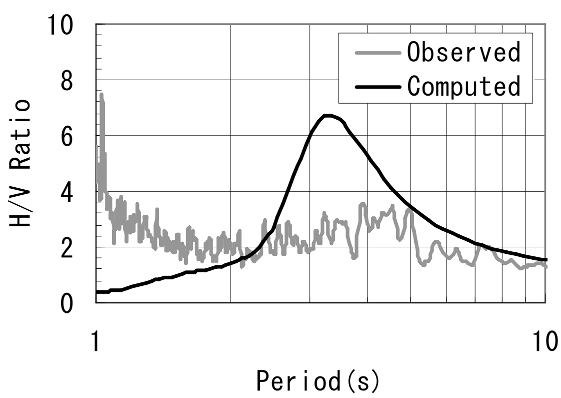
Figure 7 Comparison between observation value and theoretical value for phase velocity of Rayleigh wave

2.4. Confirmation of estimated deep subsurface structure by H/V ratio of observation records

Figure 8 shows the observation H/V ratio of the observation values recorded at the reference observation points in the Oga and Sanno areas, as well as the theoretical H/V ratio of fundamental-mode Rayleigh wave obtained from the estimated deep subsurface structure. The observation H/V ratio and theoretical H/V ratio are not in agreement in the period of 2-3 seconds or less. In the long-period component of 2-3 seconds or more, however, the general tendency was almost in agreement, though a cycle where the H/V ratio of the observation value becomes the maximum becomes smaller by around 0.5-1 second than that where the H/V ratio of the theoretical value becomes the maximum. As reasons why the observation H/V ratio and theoretical H/V ratio were not completely in agreement, the effect of other waves than the Rayleigh wave, effect of higher mode Rayleigh wave, and inadequacy of the horizontal stratification assumed in theory are listed. However, it is presently difficult to judge, and further investigation and analysis is required in the future.



Oga area



Sanno area

Figure 8 Comparison between observation H/V ratio based on microtremor observation records and theoretical H/V ratio based on estimated deep subsurface structure

3. VERIFICATION OF DEEP SUBSURFACE STRUCTURE BY STRONG-MOTION OBSERVATION RECORDS

3.1. Strong-motion observation records

The method of estimating the deep subsurface structure using the microtremor observation records is based on the assumption that the subsurface structure is a horizontal stratification; however, the gravity basements in the Oga and Sanno areas are inclined. To confirm that the adopted method can be applied in both areas, we compare the group velocity of the observed strong-motion records and the theoretical value of the deep subsurface structure.

At the Akita Base located in the Oga area, the earthquake observation with the strong-motion seismograph has been conducted since 1998. In the Sanno area, the strong-motion observation point of K-NET Akita exists in the vicinity of the Akita local meteorological observatory as the reference observation point in the microtremor observation. We, therefore, collect strong-motion observation records of Akita Base and K-NET Akita, selected records with relatively large response spectrum of period 5-10 seconds from among them, and calculated the group velocity of tremors at each place.

Table 3 shows the earthquake list of selected strong-motion observation records, and Figure 9 shows the hypocenter locations of selected earthquakes, respectively.

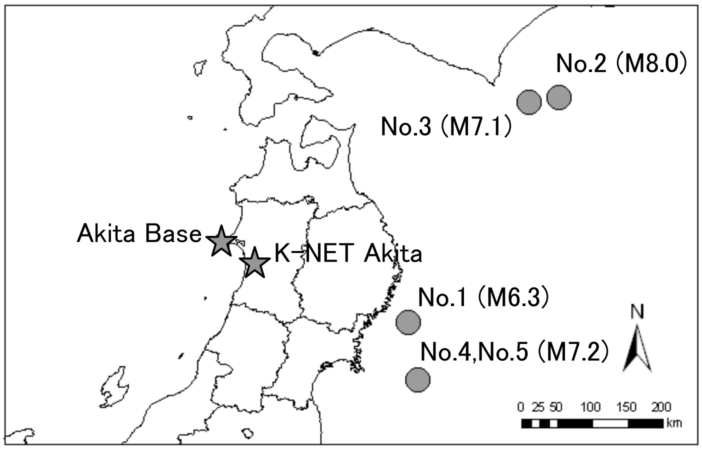


Figure 9 Hypocenter locations of selected earthquakes

Table 3 Earthquake list of strong-motion observation records

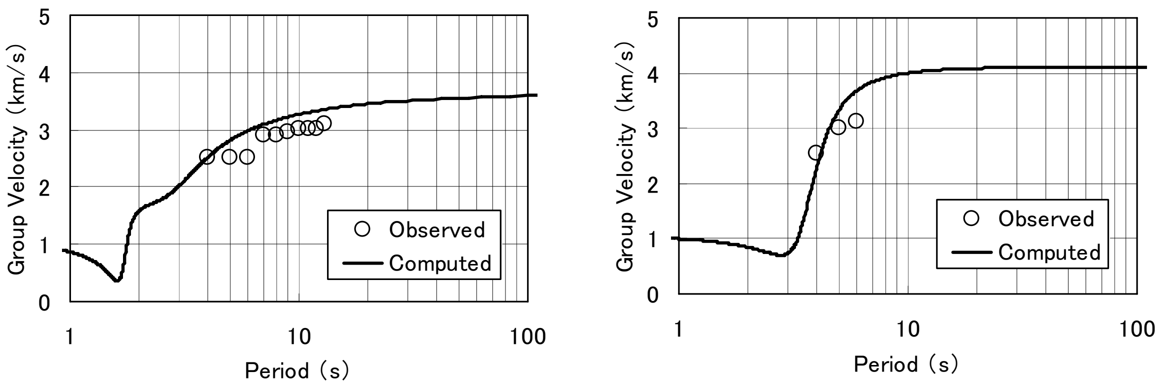
Observation point	No.	Earthquake location name	Date of occurrence	Epicenter latitude	Epicenter longitude	M	Depth of hypocenter	Epicentral distance
Akita Base	1	Near Kinkazan	2002/11/3	38°53.61'	142°08.53'	6.3	46km	225km
	2	Off Tokachi District Southeast	2003/9/26	41°46.71'	144°04.71'	8.0	45km	415km
	3	Off Erimomisaki Southeast	2003/9/26	41°42.59'	143°41.49'	7.1	21km	384km
	4	Off Miyagi Prefecture	2005/8/16	38°08.97'	142°16.67'	7.2	42km	294km
K-NET Akita	5	Off Miyagi Prefecture	2005/8/16	38°08.97'	142°16.67'	7.2	42km	257km

3.2. Comparison of group velocity through multi-filter analysis

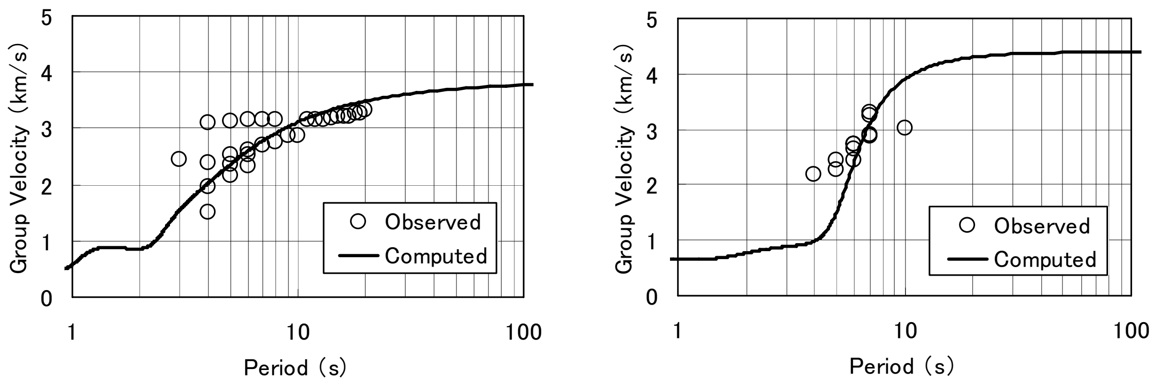
We conducted multi-filter analysis to take out earthquake waves for each frequency band by continuously applying the band-pass filter of 1 Hz to the strong-motion observation records selected. Thus, we read discrepancy in arrival time on the wave group in each period contained in the earthquake records, and calculated the group velocity in each period of the earthquake wave from the relationship between the propagation time of each wave group and the epicentral distance. We compared these results with the group velocity of the dispersion curve theoretically determined from the deep subsurface structure estimated.

Figure 10 and Figure 11 shows the comparison between the theoretical dispersion curves obtained from the deep subsurface structures in the Oga and Sanno areas and the group velocities obtained from the strong-motion observation records at the Akita Base and K-NET Akita. Among the observation records of the Akita Base, the No. 1 and No. 4 earthquakes shown in Figure 9 passed Akita City and reached the Akita Base. Therefore, we considered that the characteristics of the deep subsurface structure of the Sanno area were reflected on the observation records, and we made the group velocity correspond to the deep subsurface structure of the Sanno

area. The Radial component of the observation records was made corresponding to the Rayleigh wave, and the transverse component to the Love wave.
The theoretical dispersion curve and the group velocity of the observation value show a good correspondence for both the Oga area and Sanno area. In terms of the period where the velocity of the theoretical dispersion curve increases, the Rayleigh wave is about 1.6 seconds in the Oga area and about 2 seconds in the Sanno area, and the Love wave is about 3 seconds in the Oga area and about 4 seconds in the Sanno area, revealing that the ground in the Sanno area tends to amplify the long-period ground motion more than that in the Oga area.



Group velocity of Rayleigh wave Group velocity of Love wave
Figure 10 Comparison between theoretical dispersion curve by deep subsurface structure in Oga area and group velocity of strong-motion observation records



Group velocity of Rayleigh wave Group velocity of Love wave
Figure 11 Comparison between theoretical dispersion curve by deep subsurface structure in Sanno area and group velocity of strong-motion observation records

4. CONCLUSION

To grasp the characteristics of the long-period ground motion arriving at the Akita Base, we investigated the deep subsurface structures through microtremor observation in the Oga area where the base is located and Akita City/Sanno area around it, furthermore, we analyzed the strong-motion observation records. As a result, we obtained the following results:

1. We calculated the phase velocity through f-k spectrum analysis using simultaneous array observation records of vertical component, and estimated the deep subsurface structure to reproduce the phase velocity.
2. Furthermore, we calculated the H/V ratio using 3-components observation records of the reference observation point, and confirmed that it approximately matches the theoretical value of the deep subsurface structure.

3. The inverse analysis used for estimating the deep subsurface structure is based on the assumption that the subsurface structure is a horizontal stratification. The deep subsurface structures in both areas are substantially inclined. We, therefore, calculated the group velocity from the strong-motion observation records in both areas, and confirmed that it approximately corresponds to the group velocity by the theoretical dispersion curve of the deep subsurface structure. Thus, it can be considered that the deep subsurface structure estimated is a model capable to expressing the amplification characteristics of the long-period ground motion of the actual ground.
4. The depth of the seismic bedrock (Vs=3km/s) of the deep subsurface structure estimated is 0.8km in the Oga area and 1.8km in the Sanno area, respectively, revealing that the structure in the Sanno area tends to amplify the long-period ground motion more than that in the Oga area.

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