SPATIAL DISTRIBUTION FEATURES OF VELOCITY RESPONSES OF Mw=8.0 EARTHQUAKE -CASE STUDY IN THE 2003 TOKACHI-OKI EARTHQUAKE-

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ABSTRACT :

The 2003 Tokachi-oki earthquake, a large (Mw=8.0) inter-plate earthquake, is the first earthquake with a magnitude of 8 after the nation wide high-density strong-motion network was installed. We make the spatial distribution maps and attenuation relationships for velocity responses. The spatial distribution maps show different features depending on the period. The short period (T:natural period =0.1) sec map shows strong attenuation of the response at back-arc side of the volcanic front; this can be explained by the S-wave attenuation structure beneath the northern Japan. The long-period (T~10sec) maps and relations are in part controlled by the source effect and the deep subsurface structure.

KEYWORDS: Velocity Response, Attenuation of Strong Ground Motion, Subsurface Structure, The 2003 Tokachi-oki Earthquake

1. INTRODUCTION

The 2003 Tokachi-oki earthquake, a large (Mw=8.0) interplate earthquake, occurred on 26 September, 2003 (Figure 1). This is the first earthquake with a magnitude of 8 after the nation wide high-density strong-motion network was installed. A lot of strong-motion data obtained by the network provide a good opportunity for studying spatial distribution features of strong ground motion.

The attenuation relation of earthquake strong ground motion, which is predictable in wide areas, is important in earthquake engineering. Many experimental attenuation formulas for estimation of ground motion severity have been developed by means of a regression analysis (e.g., Boore and Joyner, 1982; Atkinson and Boore, 2003). These formulas are useful to predict strong ground motion and to evaluate the newly observed data. However, these are based on the homogenous subsurface structure, hence the predicted values are distributed on a concentric circle. It is nowadays known that the heterogeneous upper mantle structure exists beneath subduction zones such as Japan. This structure causes a region of anomalous seismic intensity in the northern Japan. For this region, we have to consider effects of the heterogeneous structure on the attenuation relation.

The objective of this study is to examine the spatial distribution features of velocity response for the 2003 Tokachi-oki earthquake. We make the spatial distribution maps and attenuation relations of velocity responses for various natural periods, in order to clarify their period dependence. This study is also the base for developing the advanced attenuation formulas mentioned above.

2. DATA AND METHOD

We use two data sets. The data set 1 consists of strong motion data in the north Japan, obtained by the K-NET and KiK-net of National Research Institute for Earth Science and Disaster Prevention (NIED). This set is used to examine the spatial distribution of velocity responses in north Japan. The data set 2 consists of the data in Hokkaido obtained by the K-NET, KiK-net, JMA (Japan Meteorological Agency), WISE (Warning Information

System of Earthquake of Civil Engineering Research Institute for Cold Region) and Intensity Network of Hokkaido government. This set is used to examine the detailed spatial distribution velocity responses in Hokkaido. The total numbers of stations used are 655 and 512 for the data set 1 and 2, respectively. Figure 1 shows the station distribution and the epicenter of the 2003 Tokachi-oki earthquake.

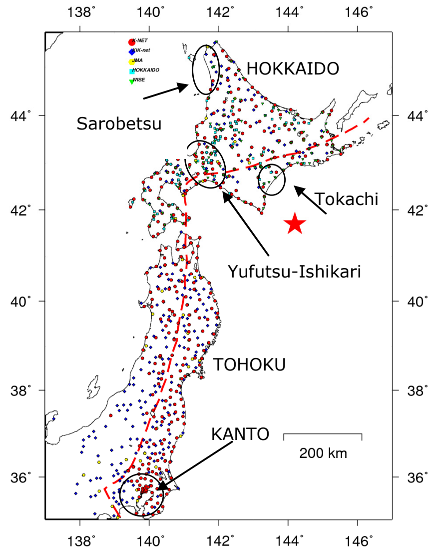


Figure 1. Distribution of stations used in this study and epicenter of the 2003 Tokachi-oki earthquake (a red star). A red broken curve shows the volcanic front (V.F.).

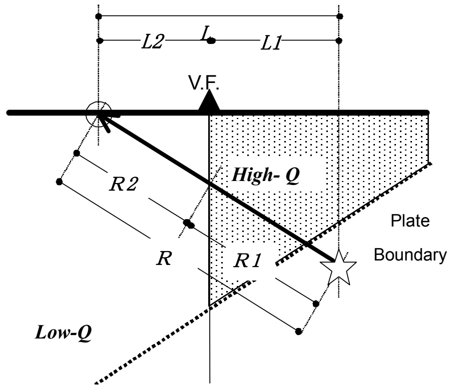


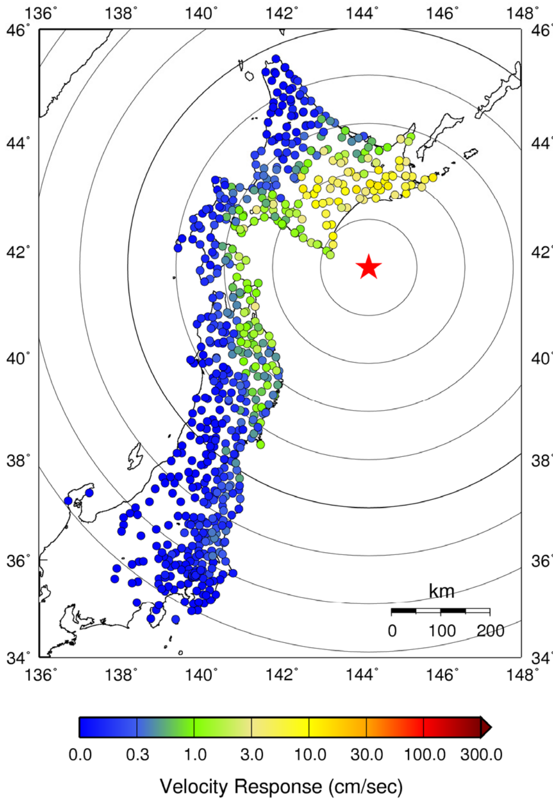
Figure 2. Schematic vertical section of the Japan subduction zone. Definition of distances of L1 and L2 is also shown. An open star: hypocenter, an open circle: observation station, and a solid triangle: volcanic front.

We calculate velocity responses (damping factor h=0.05) with natural periods of T=0.1, 0.3, 1.0, 3.0, 5.0, 10.0, 20.0 and 30.0sec for two horizontal components at a station. Then we make a vector sum for the two horizontal responses, and take the maximum value as the velocity response at the station. In the following discussion, we show only T=0.1, 1.0, 5.0 and 10sec responses for limitation of space.

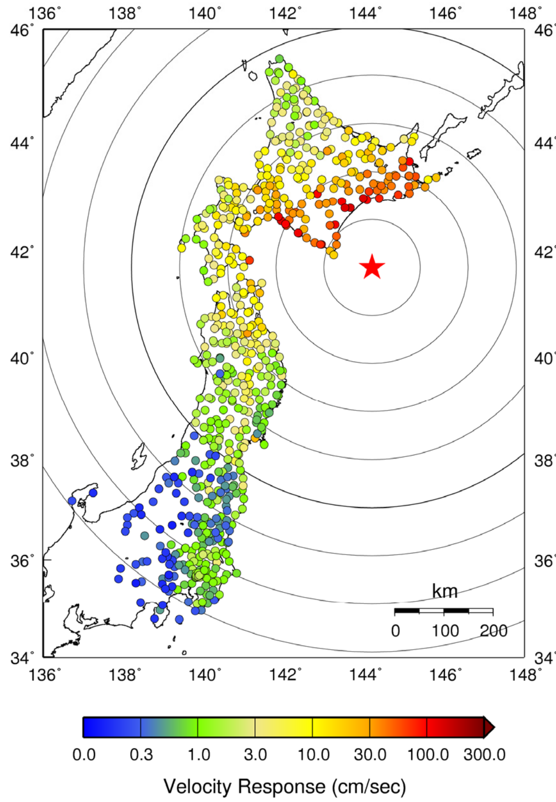
Takai et al. (2004) made the attenuation formula taking a complex Q structure beneath Japan arc into account. They divide the total epicentral distance at the volcanic front (V.F.) into the fore-arc side distance (L1) and the back-arc side distance (L2) in order to consider a heterogeneous Q structure (Figure 2); the V.F. location in northern Japan is shown in Figure 1. We use the ratio of the fore-arc side distance to the total epicentral distance, L1/(L1+L2), to grasp the effect of heterogeneous Q structure for several natural period of velocity response.

3. SPATIAL DISTRIBUTION FEATURES OF VELOCITY RESPONSES IN NORTHERN JAPAN

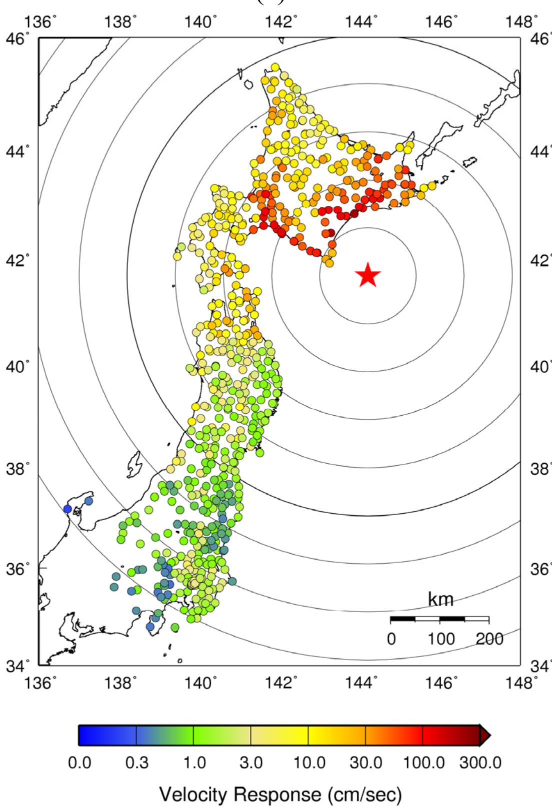
Figure 3 shows the spatial distribution maps of T=0.1, 1.0, 5.0 and 10sec velocity responses; concentric circles are epicentral distances at intervals of 100km. These maps show different features depending on the period. The response values increase with periods all over northern Japan. In the T=0.1 sec map, the high response values are located along the Pacific Ocean side, that is, along the fore-arc side of the V.F. Except for the T=0.1sec map, the V.F. has no effects on the spatial distributions for T=1.0, 5.0 and 10.0sec. This feature is more clearly seen in Figure 4. Figure 4 shows the attenuation relations of the velocity responses for T=0.1, 1.0, 5.0 and 10sec. The data points are classified by a ratio of L1/(L1+L2); the red color means the site located at the fore-arc side. A scattering of the data points decreases with the periods.



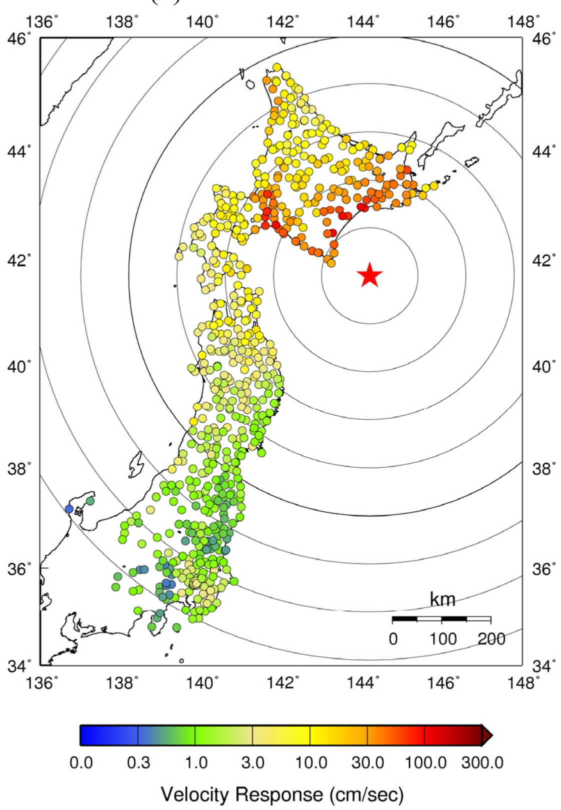
(a)T= 0.1sec



(b) T= 1.0sec

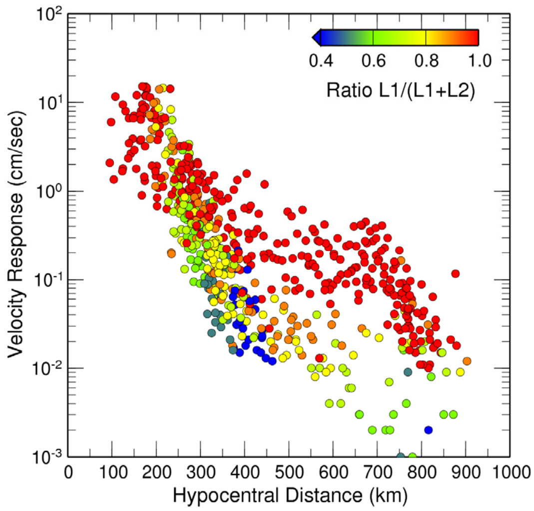


(c)T= 5.0sec

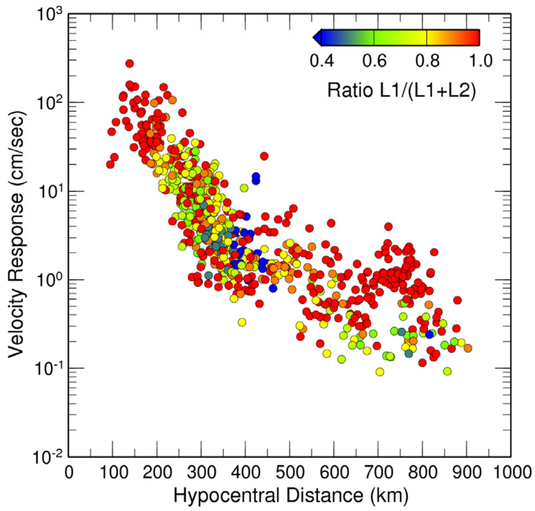


(d) T= 10sec

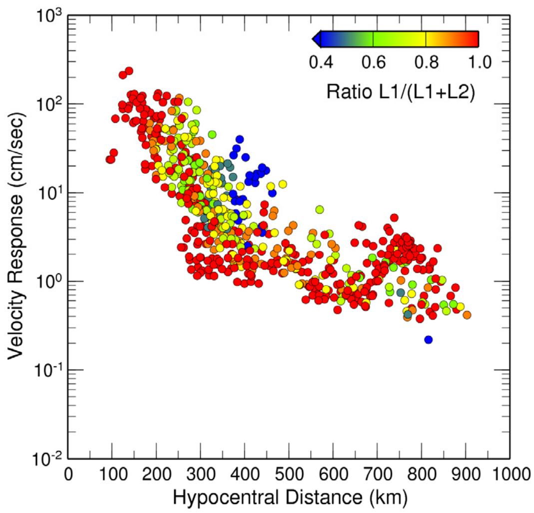
Figure 3. Spatial distribution maps of velocity responses during the 2003 Tokachi-oki earthquake for a dumping factor of 5% and natural periods of (a) 0.1 and (b) 10.



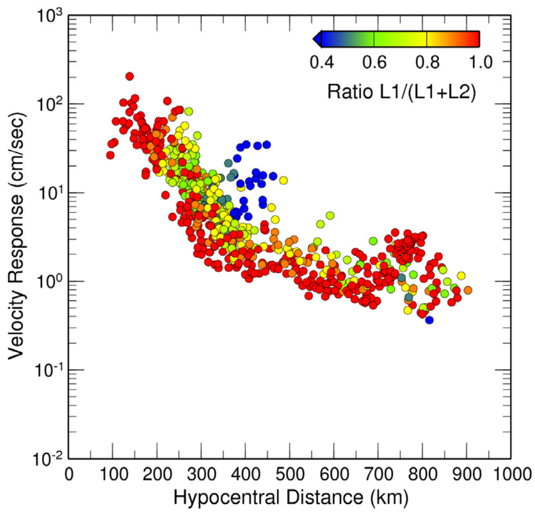
(a)T= 0.1sec



(b) T= 1.0sec



(c)T= 5.0sec



(b) T= 10sec

Figure 4. Attenuation relationships of velocity responses during the 2003 Tokachi-oki earthquake for a dumping factor of 5% and natural periods of (a) 0.1 and (b) 10.

The T=0.1sec relation shows a large scattering over two orders at distances longer than about 300km, while the T=10sec relation shows a considerably small scattering except data around 400km. The decay rates also change with the periods. We consider that these features result from the seismic source, propagation path and site effects on velocity responses.

The T=0.1sec map and attenuation relation are similar to those of Peak ground acceleration (PGA) (Maeda and Sasatani, 2006) at least for the fore-arc side data. For the fore-arc side data, the decay rate changes at about 300 km; the decay rate decreases at distances longer than about 300 km. Maeda and Sasatani (2006) explain these features of PGA by an S-wave path effect; the extremely high Qs values of the lower slab contribute the decay rate change at about 300km. On the other hand, the response values at the back-arc side strongly decrease with decreasing the ratio of L1/(L1+L2); the values decrease with increasing the back-arc side distance. This is caused by extremely Low Qs values at the back-arc side mantle wedge (Fig. 2). These complex Qs structures beneath Japan island arc consequently cause the large scattering of data points as shown Fig. 4(a).

We find a difference of the attenuation relations between the T=0.1sec and 1.0sec; in the T=1.0sec relation, the back-arc side data have a similar decay rate as the fore-arc side data. This is due to similar Qs values at about 1 sec for the fore- and back-arc side mantle wedges (Maeda, 2003).

The over T=10 sec map (Figure 3.) and the attenuation relation (Figure 4.) are comparable to those for peak ground velocity (PGV) by Maeda and Sasatani (2006). They concluded that the attenuation relation less than 300 km is due to direct S-waves, while the relation longer than 300 km is due to surface waves (Rayleigh waves). In Figure 4(d), a fairly large scattering exists at about 400km. Further the blue points with large values are sites located at north end of Hokkaido, that is, at the back-arc side of the V.F.; this is contrary to the T=0.1sec relation. Maeda and Sasatani (2006) concluded that this large scattering is a source effect, a radiation pattern of Rayleigh waves. The scattering of responses at distances over 450km becomes extremely small. This is explained by the limited data sampling area; the area is located at nearly the same direction from the epicenter (see Fig. 3). Namely, the response values of this area are affected by attenuation of Rayleigh waves; the decay rate is similar to $(1/\sqrt{R})$, where R is distance from the epicenter.

The T=5.0sec attenuation relation also shows similar nature as the T=10sec one. However, the scatterings at distances of about 400km and 750km are somewhat larger compared with the T=10sec ones. These are in part due to the site effects of a large sedimentary basin. The relatively large values at 750km are obtained at the Kanto plain and the large values at the back-arc side at 400km are obtained at the Sarobetsu plain in Hokkaido (Fig. 4(c); for locations, see Fig. 1).

4. SPATIAL DISTRIBUTION FEATURES OF LONG-PERIOD RESPONSES IN HOKKAIDO

We have examined spatial distribution features of velocity responses in northern Japan. In this section, we try to examine regional site effects in Hokkaido using data set 2. In Figure 3, wide basins, such as the Ishikari depression and the Tokachi basin as indicated in Figure 1, have the larger response values in the T=10sec map. Here we compare the response distribution with deep subsurface structure in Hokkaido to discuss the local variation of the long-period responses.

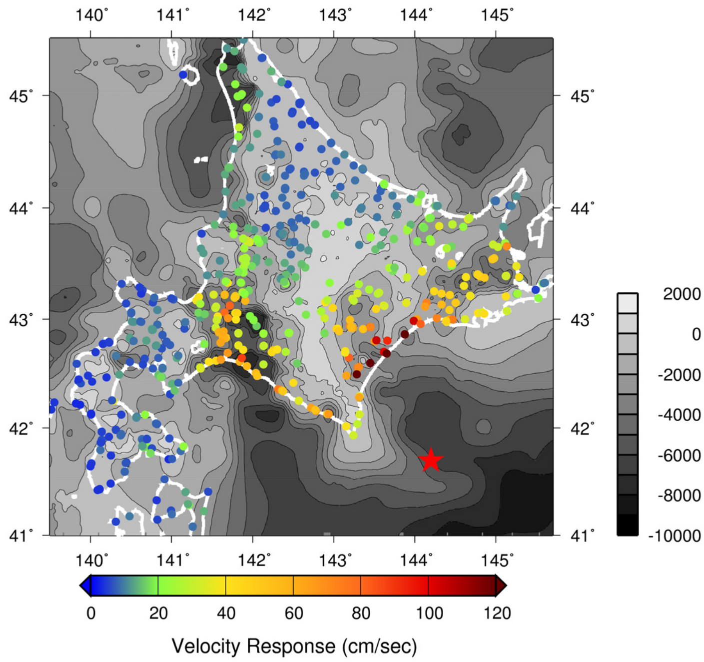


Figure 5. Spatial distribution maps of velocity responses during the 2003 Tokachi-oki earthquake for a dumping factor of 5% and a natural period of 10sec. Also shown are the depths of seismic basement (Vs=3.2km/s).

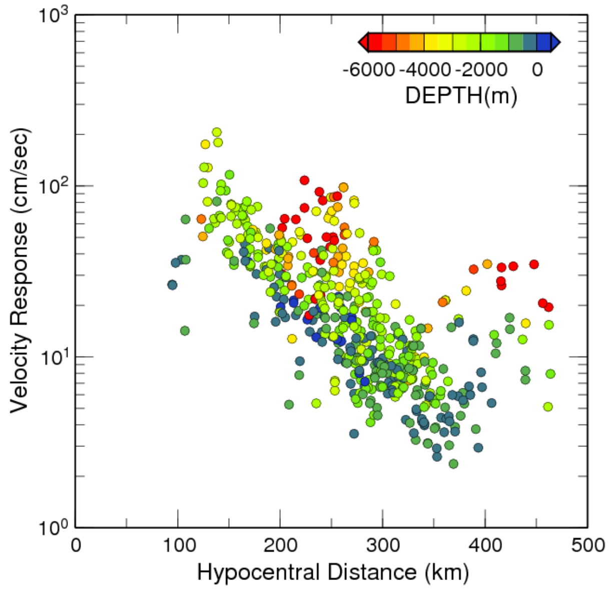


Figure 6. Attenuation relationships of velocity responses during the 2003 Tokachi-oki earthquake for a dumping factor of 5% and a natural period of 10sec. The plots are colored by the depths of upper boundary of Vs 3.2km/s layer.

Figure 5 shows depths of seismic basement (upper boundaries of Vs=3.2km/s layer; Suzuki et al., 2004) together with the T=10sec velocity responses. The Yufutsu-Ishikari and Sarobetsu plains have the extremely deep basement. The velocity responses are also large in these areas compared with other areas with a comparable distance. This relation is easily seen by making the attenuation relation with plots colored depending on the basement depth. In Figure 6, red points at a distance of about 250km correspond to stations in the Yufutsu-Ishikari plain; red points at a distance of about 450km correspond to stations in the Sarobetsu plain. Further, Figure 6 shows a relation between the response values and depths of the basement; deeper basement sites have larger response values.

Figure 7 shows a comparison of velocity response and cross section of subsurface structure in Hokkaido. As almost tendency, velocity response values in short period range decrease with the hypocentral distance. And, in long period range, values increase with the depth of basement. Especially, in Figure 7(a) this tendency is remarkable in north direction. However, in Figure 5, stations in the Yufutsu-Ishikari plain with the deep basement have various response values; some stations have the large responses, but some ones have not so large responses. In Figure 7(b) velocity response values doesn't increase with the basement (Vs=3.2km/s) depth, but change with shallow part structure. This figure shows that the basement (Vs=3.2km/s) depth is not always a factor of large long-period response.

5. CONCLUSION

We have examined velocity responses in northern Japan based on strong ground motion data from the 2003 Tokachi-oki earthquake (M8). We made spatial distribution maps and attenuation relations of velocity responses (damping factor h=0.05) for various natural periods. We found that the short-period (T~0.1sec) distribution maps and attenuation relations are mainly controlled by the path effect due to heterogeneous Qs structure beneath the northern Japan arc, and that the long-period (T~10sec) maps and relations are in part controlled by the source effect, the radiation pattern of Rayleigh waves. Finally we discussed a relationship between the deep subsurface structure and the long-period responses (T~10sec). We concluded that the source, path and site effects control the spatial distribution features of velocity responses for a large earthquake such as the Tokachi-oki earthquake. Yadab et al. (2008) developed prediction formula of pseudo-velocity response spectrum. In the study, it has been proven that to use L1, L2 distance is effective. By taking these findings into account, we try to develop a prediction method of a wide-band, high-precise response spectrum for a large earthquake.

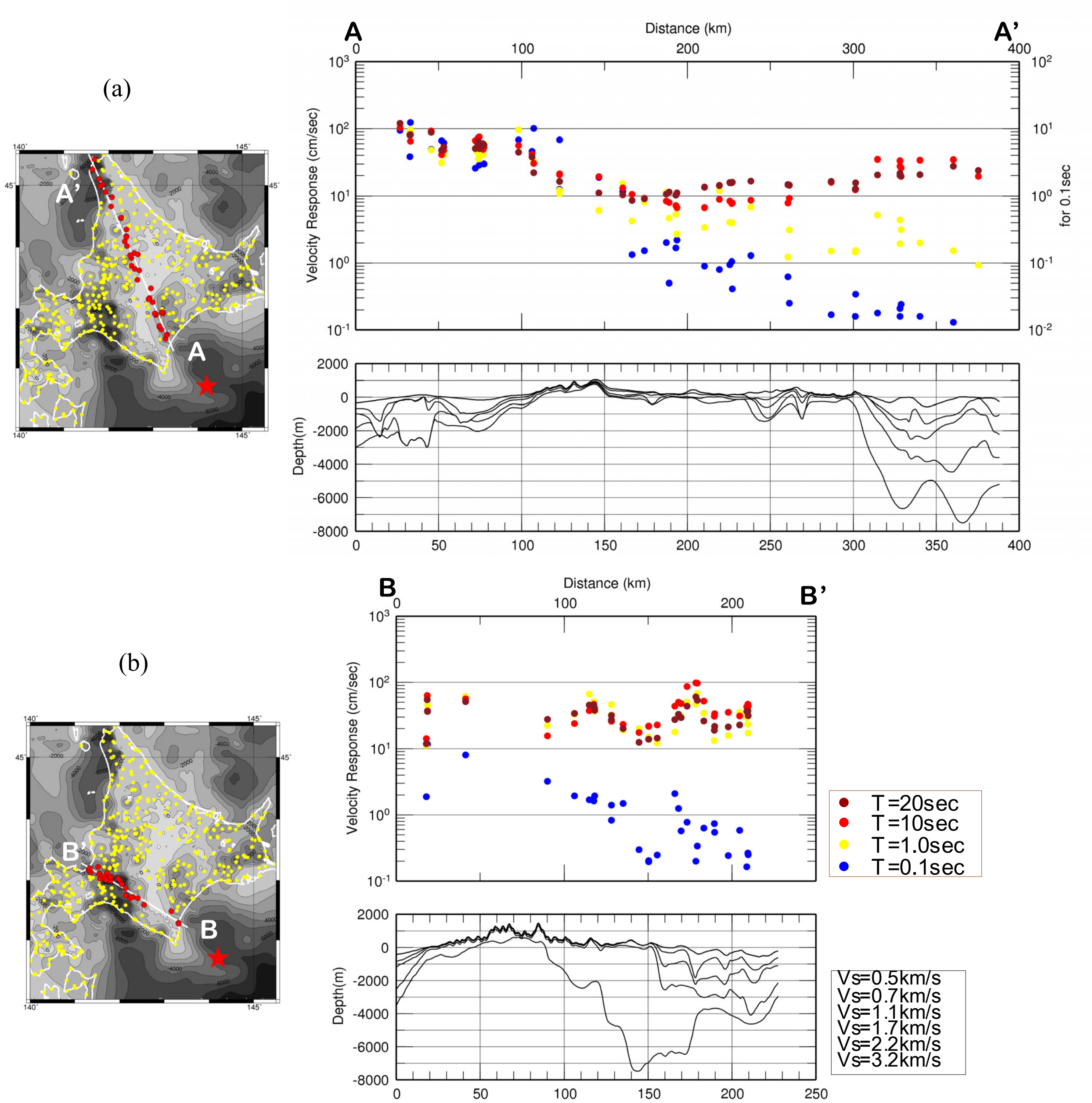


Figure 7. Cross section of underground structure and velocity responses. (a) is for Tokachi to Sarobetsu plain, and (b) is for Tokachi to Ishikari plain.

6. ACKNOWLEDGMENT

The strong ground motion records are collected by NIED (National Institute of Disaster), JMA (Japan Meteorological Agency), Hokkaido government office and CERI (Civil Engineering Research Institute for cold region). The deep underground structure data is constructed by NIED. We gratefully appreciate all organization.

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