



3-D Q STRUCTURE OF THE CRUST AND THE UPPER MANTLE BY TOMOGRAPHIC INVERSION AND PREDICTING STRONG MOTION

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SUMMARY

We usually perform the smoothing operation to Q structure obtained by block inversion to emphasize general tendency of spatial variation. We studied the effects of smoothing and grid size on strong motion prediction. First, we studied the effect of the smoothing of 3-D Q structure to seismic ground motion prediction by comparing between observed and calculated acceleration distribution of the 2001 Iwate-Ken earthquake (M6.3, H=130km). The result shows that the small and sharp variety of Q is important for ground motion prediction. Next, we estimated more detailed Q structure in Tohoku district with small block size and without smoothing. Low-Q zones coincident with the positions of Quaternary volcanoes. The result of PGA prediction is consistent with the observed acceleration distribution.

INTRODUCTION

Utsu[1] reported abnormal seismic intensity distribution caused by inhomogeneity of attenuation (Q-value) in upper mantle, and Ikami[2] reported sharp change of intensity across the volcanic front. After that, study of the 3-D attenuation structure started with development of seismic tomography techniques using spectrum of seismic records and seismic intensity data [3-6].

Nakamura and Uetake[7,8] evaluated 3-D attenuation structure for Japan Islands area in frequency domain by using a large quantity of strong motion records of K-NET and JMA87 seismometers and studied frequency dependency of Q-value. Frequency dependency may be important for predicting strong motions.

Hashida and Shimazaki[9] and Nakamura et al.[10] tried to predict seismic intensity distribution using 3-D attenuation structure. Nakamura and Uetake [11] tried to predict acceleration response spectrum in frequency range 1 to 10 Hz. They compared two records observed at same epicenter distance of 100km during the 1996 Hyuga-nada, Japan earthquake (M6.6) and showed that Q inhomogeneity strongly affected to the ground motion characteristics.

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In this report, we will introduce above prediction method briefly, and we will show the effects of smoothing operation, which frequently used in block inversion scheme, and block size of inversion on the strong motion prediction.

3-D ATTENUATION STRUCTURE

Fig.1 shows the Q structure of Nakamura and Uetake[7,8] in the depth of 30-60km. There are High-Q area along the Pacific Sea Plate and around the volcanic front is Low-Q. Here, we took the block size as 0.5 deg. * 0.5 deg. * 30km in latitude, longitude and depth respectively. Since variability of Q obtained by inversion is considered to be large, the smoothing of Q-value is commonly operated by taking moving average. Nakamura and Uetake[7,8] also took moving average of neighboring blocks with equal weights of 1/7 as shown in Fig.2. By using smoothing operation, we can see whole tendency of Q-value distribution but not see small size variety. Real attenuation structure may be more complex than that obtained by previous studies. In previous studies, size of the block is about 50km originally and about 100km after smoothing operation. The size in previous studies is too large to predict strong motion at specific site. So, we need to construct more detail Q-value structure.

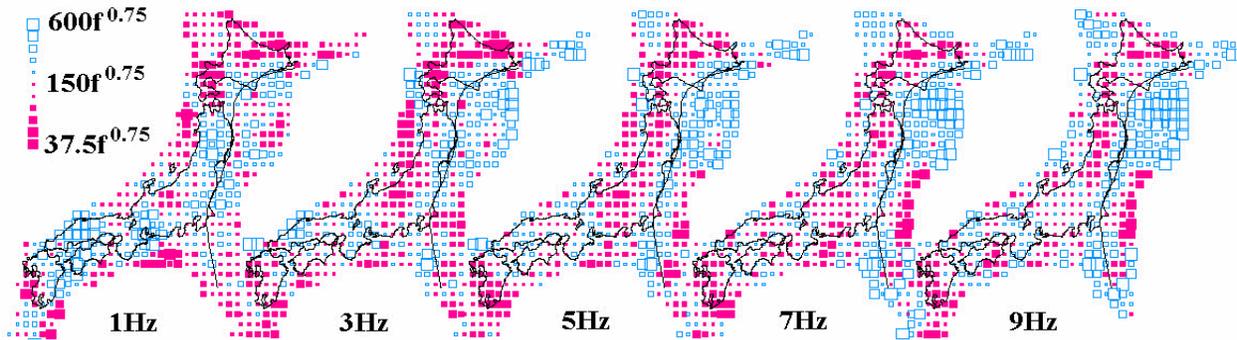


Fig.1 Example of Q structure obtained by inversion. Center value of symbol is $Q=150f^{0.75}$. (after Nakamura and Uetake [7,8])

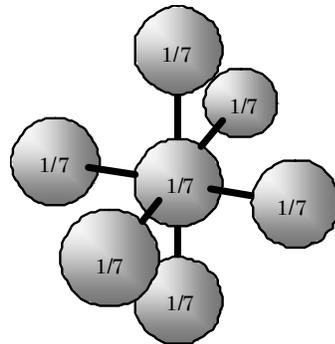


Fig.2 Weights for smoothing used after obtained Q value by inversion. Fig.1 shows the result after smoothing

To examine the smoothing effect, first, we make Q distribution map using smoothed and non-smoothed data. Second, we calculate acceleration distribution map of the 2001/12/2 earthquake of Iwate prefecture occurred at the depth of 130km.

Fig3(1) and Fig3(2) show the distribution of Q in the depth range of 0-30km and 30-60km respectively. The non-smoothing map has higher contrast and more complex rather than the smoothing map. In the depth range of 30-60km, there are High Q zone along the coast of Pacific Ocean side in both maps. Spatial variation of Q-value in smoothed map show more stable than that of the non-smoothed map. Therefore, smoothed map is suitable for studying general trend of Q structure. It was reported that melted zone under volcanoes show very Low-Q (ex. Yamanaka and Kikuchi [12]). These melted zone size are about a few km. If we smoothed Q structure strongly, we could not detect them at all.

EFFECTS OF SMOOTHING Q STRUCTURE ON GROUND MOTION PREDICTION

In the case of predicting seismic motion using 3-D Q structure. We can take two methods. One is using ray path calculation using tomographic inversion as forward calculation. The other is according to wave theory like as FDM i.e[13]. In this study, we use the ray path method. Although, the calculated value is Fourier acceleration amplitude in this method, we convert this to response spectrum for the purpose of engineering usage. We, here, reproduced PGA ground motion of the 2001 Iwate pref., Japan Earthquake (M6.3, h=130km). The 3-D Q data used here are both smoothed and non-smoothed Q.

Acceleration Fourier spectrum $a(f)$ obtained by equation as follows,

$$\alpha(f) = Sa(f) \cdot Ge \cdot g \cdot \exp\left[-\pi \cdot f \cdot \sum (T_k / Q_k)\right], \quad (1)$$

here, $Sa(f)$ is source acceleration spectrum, Ge is geometrical spreading factor, g is site amplification factor and Q_k , T_k is Q value and travel time in k-th block. Σ is sum of blocks ray path penetrated. Source spectrum are given by the method of Boore[14]. Response spectrum obtained from calculated Fourier acceleration spectrum by the method of Ohsaki[15] shown as follows,

$$\eta = \frac{1}{\sqrt{1+17(h-0.05)e^{-2.5T/Te}}}, \quad (2)$$

here, T is period of spectrum in second, Te is effective duration time which given by the equation of $Te=10^{0.31M-1.2}$. As Fourier spectrum of seismic motion is same as velocity response spectrum at damping 0%, response spectrum of any damping can be converted with equation (2). So, we can obtain response spectrum from Fourier spectrum.

We examine PGA distribution of the event occurred in Iwate prefecture, Japan at the depth of 130km in 2001. This acceleration data was not contained in the dataset of Nakamura and Uetake[7,8]. The PGA distribution of K-NET data of this earthquake is shown in Fig.4. High acceleration area expands to northward and southward along the coastal line, and PGA at Kushiro region in Hokkaido is larger than that at Urakawa region in Hokkaido while larger epicentral distance.

Fig.5 and Fig.6 show the result of ground motion prediction at 5Hz using the smoothed data and the non-smoothed data respectively. We simply assumed 100bar as stress drop of this earthquake in calculation, because we would only to know the feature of the distribution. Site amplification factors are used the value obtained by the inversion (Nakamura and Uetake[7,8]). The distribution by calculation does not

expand to N-S and southward. The result for the non-smoothed data slightly expands to N-S, and explains the phenomena of larger PGA at Kushiro region than that at Urakawa region.

MORE DETAILED Q STRUCTURE AND GROUND MOTION PREDICTION

We could understand that the prediction using the Q structure obtained on whole of Japan could interpret field PGA like as the abnormal intensity distribution, although it could not explain that in near field.

Then, we re-examined Q structure by calculation in the smaller area; Tohoku region (138-144E., 36-42N.), and add data observed by K-NET, KiK-net and JMA95 seismometers. We took smaller block size in inversion as 0.2deg.*0.2deg.*30km instead of 0.5deg.*0.5deg.*30km used in Nakamura and Uetake [7,8]. The other calculation conditions are as same as previous studies.

Fig.7 shows the result of more detailed and smaller area Q structure at 10Hz. The area of high resolution by the checkerboard test is shown here, so the area of the Pacific plate slab is not shown by the reason of low resolution because number of path penetrate in the slab might be few. Contrasts between High-Q and Low-Q are clear in higher frequency.

We could obtain clear Low-Q along the volcanic front in the depth range of 0-30km. There are Low-Q zone at Mt. Iwaki, Mt. Chokai, Mt. Kampuzan and Mt. Gassan which are Quaternary volcanoes. The Dewa mountain range is High-Q.

Next, we tried to predict PGA distribution using this detail Q structure. The predicted PGA distribution expand to northward and southward as shown in Fig.8, and this distribution feature is consistent with the observed PGA distribution shown in Fig.4.

CONCLUSION

We usually perform the smoothing operation to Q structure obtained by block inversion to emphasize general tendency of spatial variation. Although smoothing hide a small size variety of Q like a melt under the volcano. We studied the effects of smoothing and grid size on strong motion prediction.

We studied the effect of the smoothing of 3-D Q structure to ground motion prediction by comparing between observed and calculated acceleration distribution of the 2001 Iwate-Ken earthquake (M6.3, H=130km). Non-smoothed Q model represented the distribution of PGA better than smoothed model. The result shows that the small and sharp variety of Q is important for ground motion prediction.

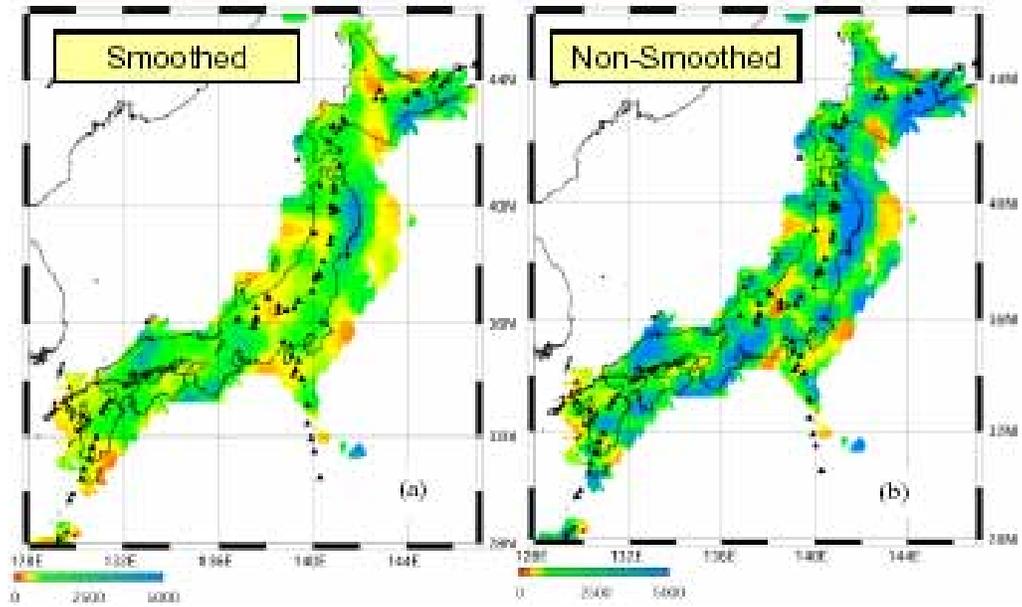
We estimated more detailed Q structure in Tohoku region with small block size without smoothing. We obtained clear Low-Q zone along the volcanic front in the depth range of 0-30km. Low-Q zones coincident with the positions of Quaternary volcanoes. We tried to predict PGA distribution using this detail Q structure and the distribution of PGA was consistent with the observed data.

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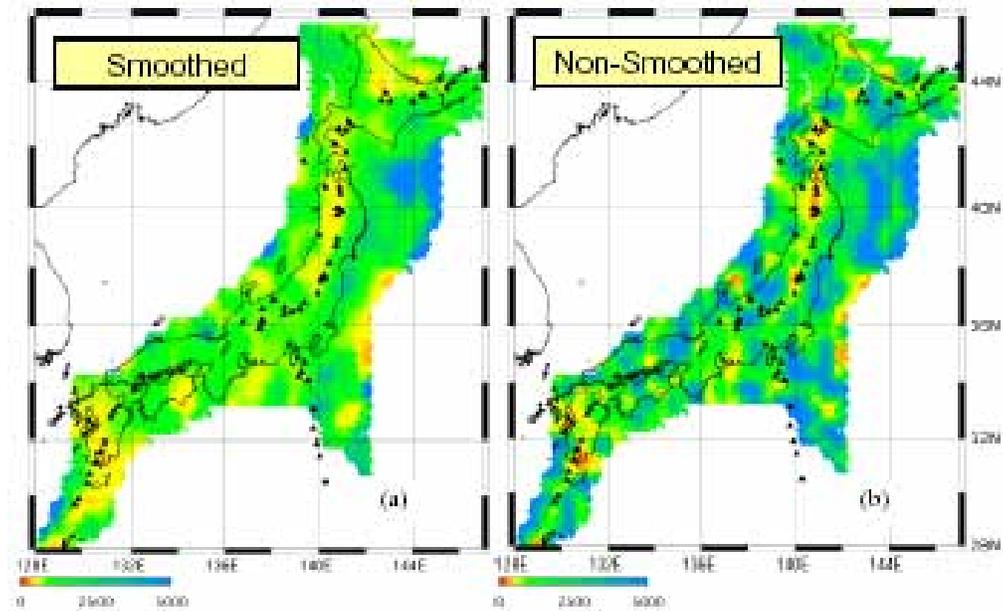
The records of K-NET, KiK-net and JMA95 seismometer used in this study. K-NET and KiK-net are strong motion observation network run by National Institute for Earth Science and Disaster Prevention, Japan. JMA95 observation network are run by Japan Meteorological Agency. We thanks to the effort of maintenance and data distribution.

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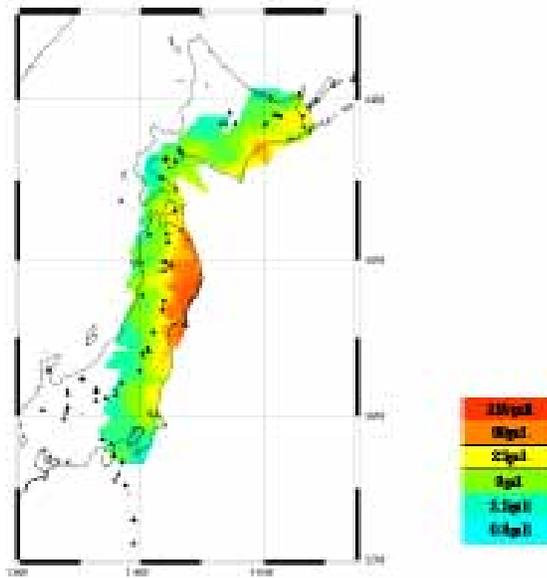
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**Fig.3(1) Qs structure in the depth range of 0-30km at 10Hz.
The block size used is 0.5deg*0.5deg*30km.
Solid triangles denote active volcanoes.**



**Fig.3(1) Qs structure in the depth range of 30-60km at 10Hz.
The block size used is 0.5deg*0.5deg*30km.**



**Fig.4 PGA distribution by K-NET observation data.
The 2001/12/2 M6.3 earthquake at Iwate prefecture in the depth of 130km**

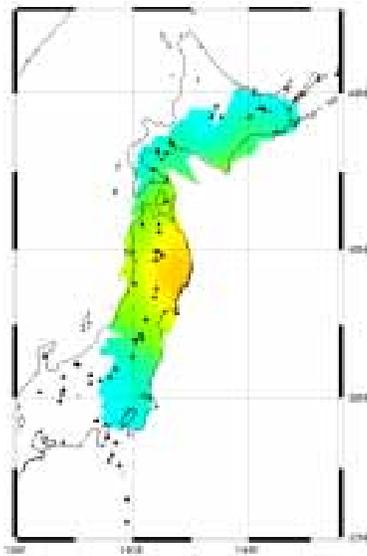


Fig.5 Predicted PGA distribution by using data of smoothed Qs(fig.3a).

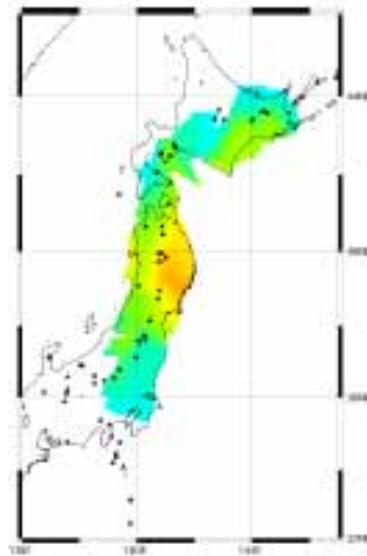


Fig.6 Predicted PGA distribution by using data of non-smoothed Q(fig.3b).

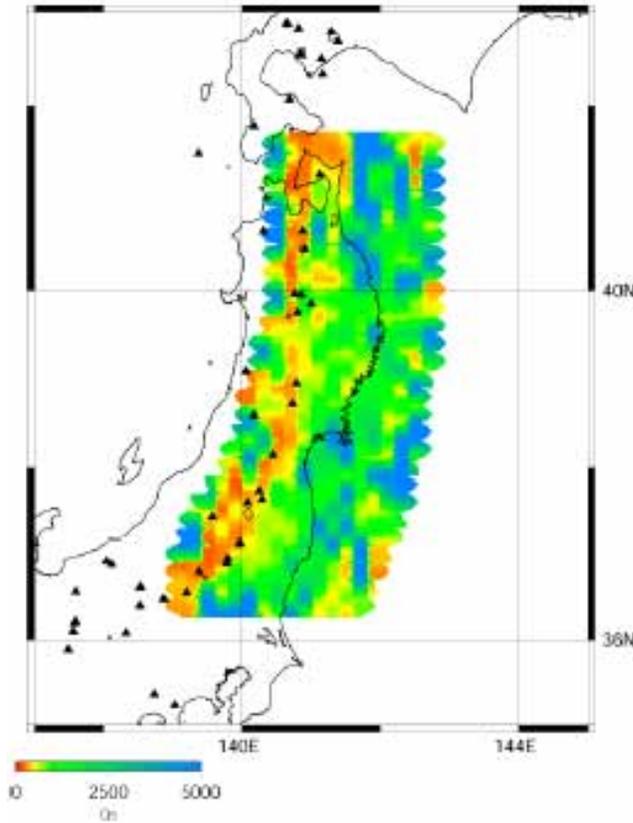


Fig.7 Result of Q structure obtained with limiting analysis area, adding data and making block size smaller. The block size used is $0.2\text{deg} \times 0.2\text{deg} \times 30\text{km}$. Solid triangles denote active volcanoes.

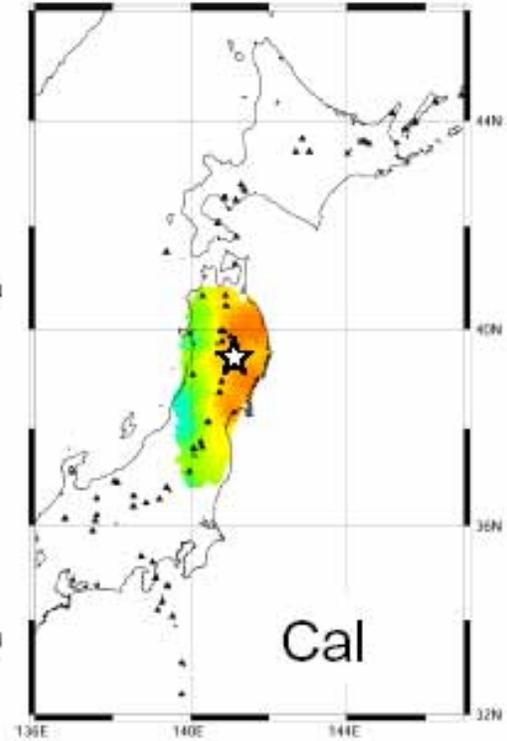


Fig.8 Predicted PGA distribution by using the Q (fig.7) obtained with limiting analysis area, adding data and making block size smaller.