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ESTIMATION OF SUBSURFACE STRUCTURE IN NIIGATA AREA, JAPAN, USING SURFACE-WAVE DISPERSION DATA FOR EVALUATION OF LONG-PERIOD GROUND MOTION

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ABSTRACT

The characteristics of long-period ground motions observed in the southern part of Niigata, Japan were studied by a band-pass filtering technique and the mean subsurface structures between the observatory and epicenters were estimated as a multi-layered model by an inversion of the group velocities using genetic algorithm. The estimated pre-Tertiary basement depths vary according to the epicentral regions. The features of models correspond to the regional variation of geological data and gravity anomaly in this area. Furthermore, long-period ground motions at the observatory were evaluated by normal mode theory using the subsurface model obtained in this study and existing fault model. The seismograms synthesized using the mean models demonstrate that the subsurface structure estimated from single station data is so useful to evaluate long-period ground motions. The method used in this study has the advantage of application to evaluate the long- period strong ground motion for given site when earthquake observation was made at the site.

KEYWORDS

Subsurface structure, Surface wave dispersion, Long-period ground motion, Genetic algorithm, Niigata area

INTRODUCTION

The information about the deep ground structure is important to evaluate long-period ground motion. There are thick sedimentary layers around Niigata, Japan. It is well known that these layers amplified long-period ground motion during the 1964 Niigata Earthquake and the 1983 Nihonkai-chubu Earthquake and caused the damage at Niigata city (Kudo and Sakaue, 1984; Kudo, 1992; Yokoyama et al., 1990). However the knowledge about subsurface structure and its effect on seismic motion in the southern part of Niigata are very limited. In this study, the ground motion data observed in the southern part of Niigata are analyzed to understand the characteristics of long-period ground motions and the deep subsurface structure is estimated from dispersion characteristics of observed surface waves. Usually deep ground structure is obtained as a local structure by seismic surveys or array observation of microtremors. Although the subsurface model in this study are obtained as mean structures between observatory and epicenters, the method used in this study has the advantage of application to single station data. Furthermore long-period ground motions at the observatory are evaluated using the estimated model and existing fault parameter to confirm application of estimated model.

DATA

The earthquake ground motion data observed at Kashiwazaki, Niigata Prefecture, Japan are used in this study. The earthquake observation at the observatory started in 1982 and many ground motion records were obtained. The observation system specifications are shown in Table 1. Although many seismometers are installed in ground (Uetake, 1992), only data near the ground surface are used in this study. The strong motion records which have sufficient amplitude over noise levels in the period range of 1-15 seconds were selected to evaluate dispersion characteristics by a band-pass filtering technique. The observation site and selected earthquake epicenters are shown in Fig.1 and the parameters of the events are shown in Table 2. The earthquakes with relatively large magnitudes and shallow hypocenters were selected. Most of the earthquakes are located in the west of observation site.

Table 1. Specifications of observation system

Sensor type	Frequency range	A/D converter	Sampling rate	Auto gain control	Sensibility
acceleration (vel. feedback type)	0.1-30Hz	12bits	100Hz	3 steps (1/1, 1/8, 1/32)	50 (400, 1600) (cm/s/s)/(full scale)

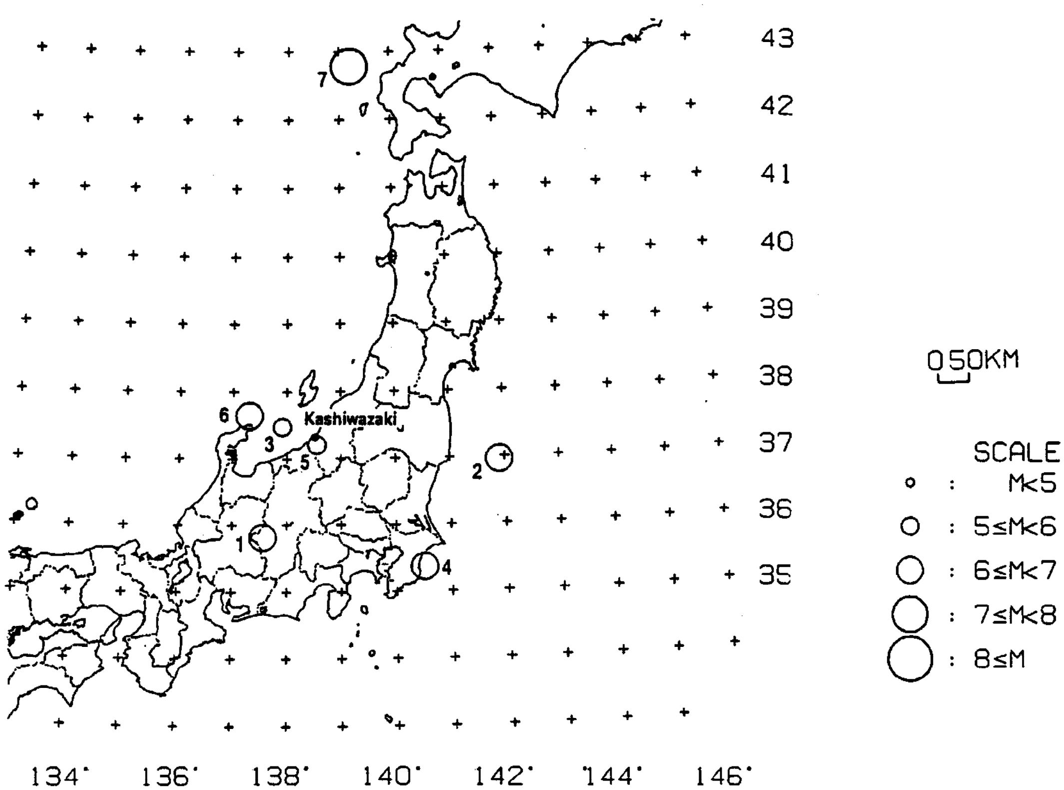

Fig.1. Locations of observatory and epicenters of selected earthquakes.

Table 2. Parameters of selected earthquakes

No.	Region or earthquake name	Date	Time	Long.	Lat.	M	Depth	Distance
1	The 1984 Naganoken-seibu eq.	1984/09/14	08:48	137.56	35.82	6.8	2km	203km
2	Fukushimaken-toho-oki	1987/02/06	22:16	141.90	36.96	6.7	35km	292km
3	Niigataken-nanbu-oki	1987/03/24	21:49	137.91	37.48	5.9	21km	67km
4	The 1987 Chibaken-toho-oki eq.	1987/12/17	11:08	140.50	35.37	6.7	58km	280km
5	Niigataken-chubu	1990/12/07	18:40	138.56	37.21	5.3	4km	29km
6	The 1993 Noto-hanto-oki eq.	1993/02/07	22:27	137.30	37.65	6.6	25km	124km
7	The 1993 Hokkaido-nansei-oki eq.	1993/07/12	22:17	139.20	42.78	7.8	34km	597km

MULTI-PASS FILTERING ANALYSIS AND GROUP VELOCITY

The data were integrated to displacement because the original data were acquired in acceleration. The integrated horizontal displacement in NS- and EW-directions were transformed to radial- and transverse-components. To reveal dispersion characteristics of the waveform data, the data were analyzed by a multi-pass filtering technique. The data were processed by a narrow-band Gaussian type filter with central periods 1 to 15 seconds, and envelopes of filtered waveforms are calculated. The band-pass filter used in this study is defined by

$$W(T0)=\exp(-\alpha((T0-Ti)/Ti)^2)$$

where, T0, Ti denote the center period of the filter and discrete frequencies gained by FFT respectively, and α is 50 in this study.

The results of the multi-pass filtering analysis for transverse component of the 1984 Naganoken-seibu earthquake are shown in Fig.2. The central periods were selected as the equal interval on logarithmic scale. The solid circles in Fig.2 denote the maximum value points of the envelopes of the waveform, which show a smoothly varying arrival time in period range of 2.5 to 15 seconds. The time of maximum value points are changing smoothly. It is realized that it corresponds to the dispersion of Love waves. Group delay time calculated as a difference of origin time and maximum value points time, and apparent group velocities of Love waves were estimated from group delay times and epicentral distance. Radial- and UD-components data were processed in the same manner. The velocities obtained from radial or UD components were assumed the group velocities of Rayleigh waves. Furthermore the data of other earthquakes are analyzed in the same manner.

The estimated Love and Rayleigh waves' velocity are shown in Fig.3. The dispersion characteristics of records in the period range of 1-15 seconds show the different characteristics according to the epicentral regions. The apparent group velocities of Love waves for the earthquakes located between the southern part of Niigata and Noto peninsula are very low in period range shorter than 5 seconds. It is interpreted that it is the effect of thick low velocity sedimentary layers around Toyama trough. The data of earthquake of Fukushimaken-oki doesn't show clear dispersion.

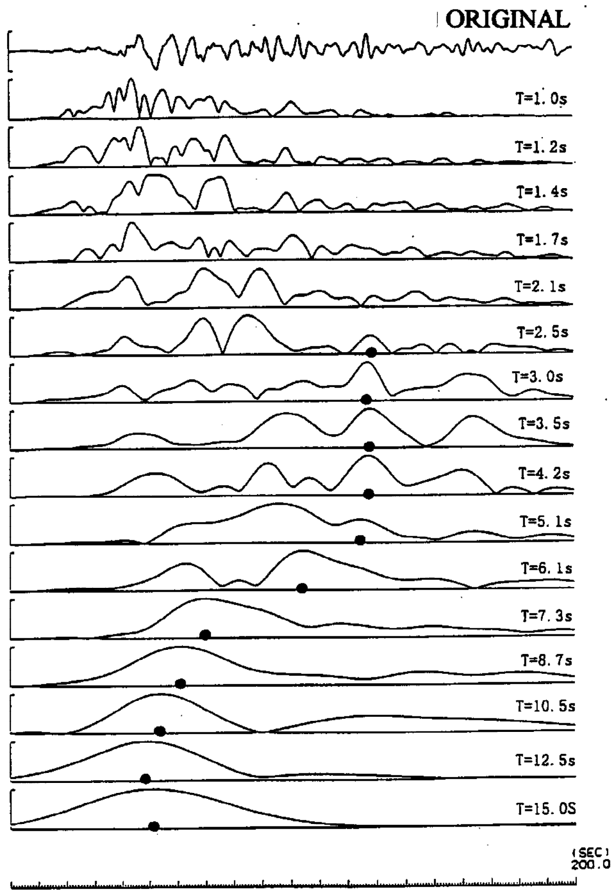

Fig.2. Results of multiple band-pass filtering analysis for transverse component of the 1984 Naganoken-seibu earthquake. The left top trace is displacement waveform and others are envelopes of filtered waveforms.

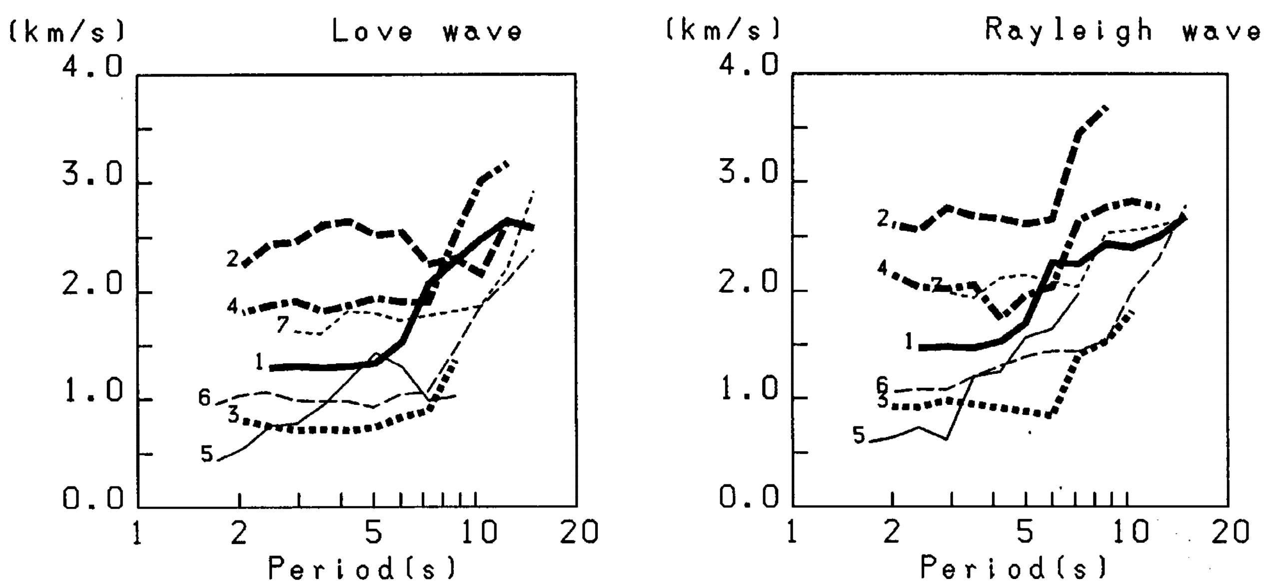

Fig.3. The estimated group velocities of Love and Rayleigh waves. The numbers in this figure denote the earthquake numbers in Table 2.

ESTIMATION OF SUBSURFACE STRUCTURES

The mean subsurface structures between the observatory and epicenters were deduced as a multi-layered model by an inversion of the group velocities using genetic algorithms (Goldberg, 1989; Yamanaka and Ishida,1995). Objective function in the optimization was defined as a misfit which is the sum of squared differences between observed and calculated group velocities of both Love and Rayleigh waves. In the calculation of the misfit, it was assumed that the theoretical velocity was fundamental mode velocity in this study. In the inversion analysis, only thickness of each layer was optimized, and P- velocity , S-velocity and density of each layer were fixed at those of Uetake(1992), who analyzed the wave propagation in Kashiwazaki site. The assumed parameter and the detection range of thickness are shown in Table 3. The forth layer corresponds to pre-Tertiary basement rock. Although Uetake(1992) used four layered model, the layer with Vs=3.8km/s was added as the deepest layer and the thickness of the layer with Vs=3.4km/s was assumed 10km in this study. The parameters used in the genetic algorithm were as follows; the number of individual models was 20, crossover probability was 0.9, mutation probability was 0.03, alternation number of generations were 100 times. The 10 inversions with different initial values of random number were calculated, and a final inverted model was obtained as the average of each result.

The several different subsurface structure models were obtained by an inversion of the group velocities for each event except for Fukushimaken-oki in which the data didn't show clear dispersion. The obtained models are shown in Fig.4. The features of the models vary according to the epicentral regions. The models in south and east sides of the site have a shallow pre-Tertiary basement and the models for north west side epicenters have relatively deep basement. Especially the model for the event located near Toyama bay have deepest basement. These features are in agreement with the regional variation of geological data and gravity anomaly of this area. The gravity anomaly of this area after Kohno and Furuse(1989) is shown in Fig.5. The low gravity anomaly zone in the sea area penetrates into Toyama bay. This zone correspond to Toyama trough where there are thick deposits. The epicenter of Niigataken-nanbu-oki earthquake located in the low gravity anomaly zone and the other two epicenters are located high gravity anomaly area. The estimated pre-Tertiary depths of the models for these three events vary according to the variation of gravity anomaly. Kamata et al.(1994) analyzed the data in this area during the 1994 Noto-hanto-oki earthquake. They analyzed dispersion characteristics of Rayleigh waves and obtained the structural models between the epicenter and observatory by assuming a three layered model. Their models vary according to the variation of gravity anomaly and model for TAKADA in Fig.5 show almost similar basement depth as the model between Kashiwazaki and epicenter of 1993 Noto-hanto-oki earthquake in this study.

Table 3. The assumed parameter and the detection ranges of subsurface structure model

Vp(km/s)	Vs(km/s)	density(g/cm^3)	thickness(km)
2.0	0.9	2.0	0.01-1.0
3.1	1.6	2.2	0.01-3.0
4.7	2.2	2.5	0.5-6.0
6.0	3.4	2.7	10.0
6.8	3.8	2.9	∞

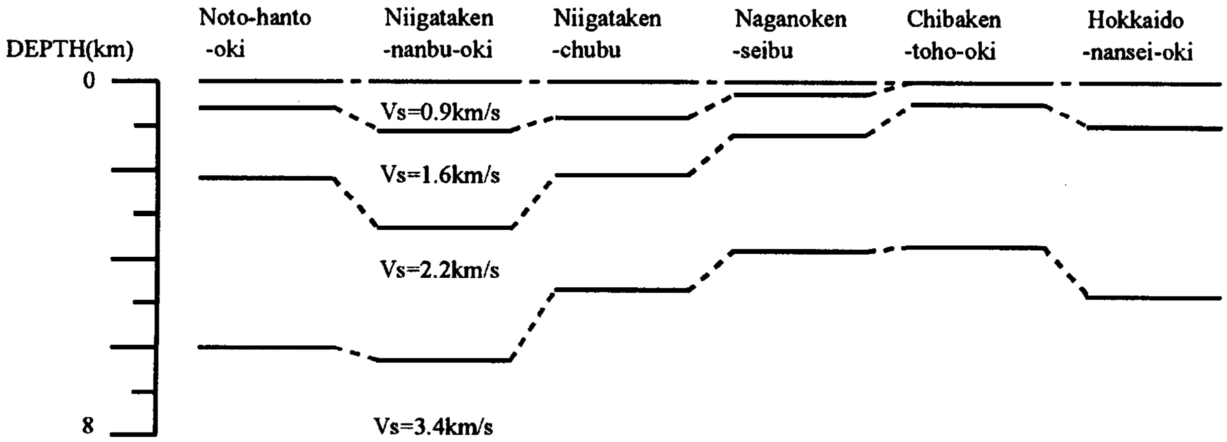

Fig.4. The subsurface structure models estimated by group velocity inversions.

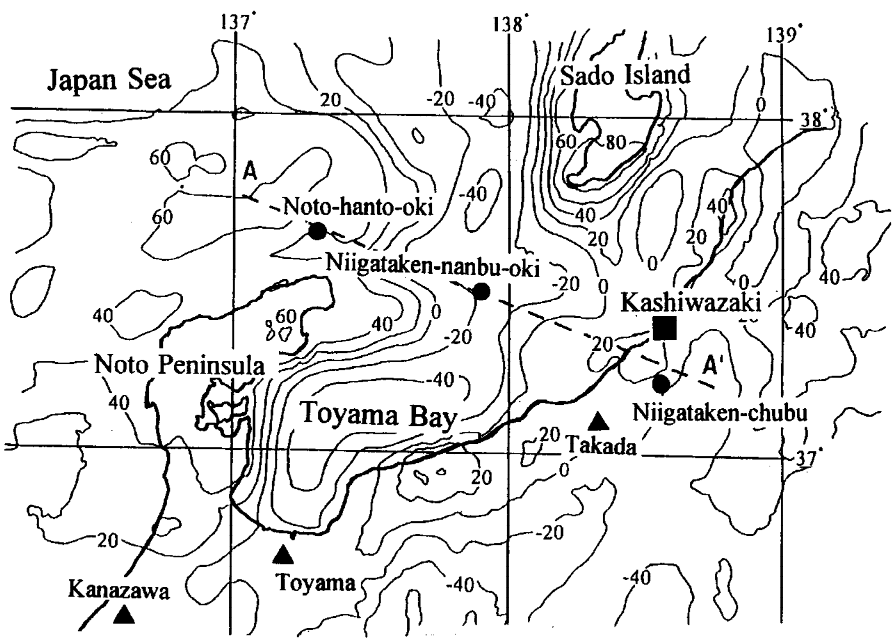

Fig.5. The gravity anomaly around Toyama bay after Kohno and Furuse(1989). The contour lines indicate gravity anomaly in mgal. The closed circles and square denote the epicenter and the observatory used in this study. The triangles denote the Japan Meteorological Agency station where the data analyzed by Kamata et al.(1992) were recorded.

SIMULATION OF OBSERVATION RECORDS

The long-period ground motions at the observatory were evaluated by normal mode theory using the estimated subsurface model and existing fault parameter models. Normal mode theory is used in many study to evaluate the long-period strong ground motion(ex. Harrmann and Nuttli,1975; Kudo, 1980).

The comparison of synthesized and observed displacements of the 1984 Naganoken-seibu earthquake is shown in Fig.6. Correspondently velocity response spectra with 5% damping are shown in Fig.7. The fault model presented by Takeo and Mikami(1987) was used for calculation. The maximum amplitude of synthesized vertical motion is bigger than that of observed waveform. Radial and transverse components are slightly smaller than those of observed ones. However the synthesized seismograms simulate the arrival time of major phases of the observed records well. For response spectra, radial component shows a good agreement, but calculated one is smaller than observed one in transverse component and the calculated one is greater than observed one in UD-component. Although the alternation of faults parameters may obtain a better agreement between observed and calculated waveform, it is advantage that the overall features of long-period ground motions can be represented to a certain degree using the mean subsurface structure estimated from single station data.

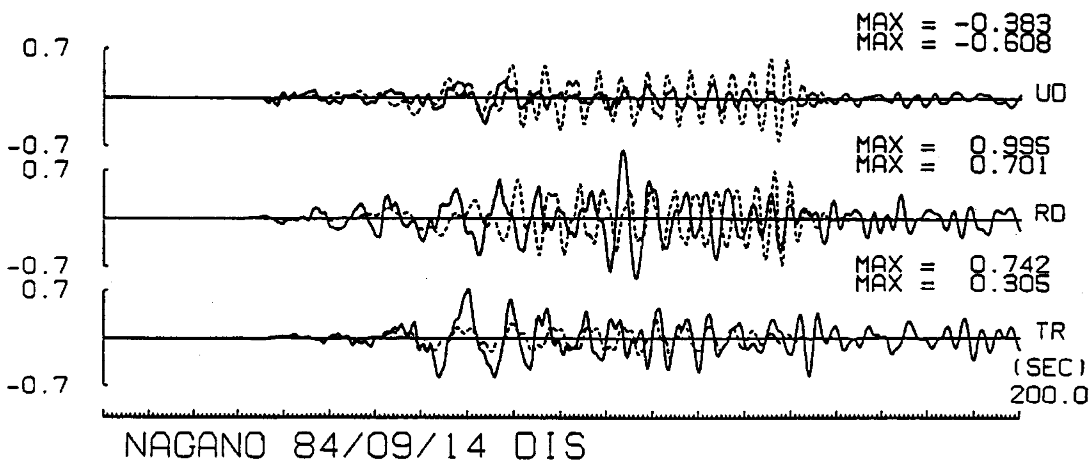

Fig.6 The comparison of observed displacement with calculated ones for the 1984 Naganoken-seibu earthquake. The solid lines denote observed waveform and break lines denote calculated ones.

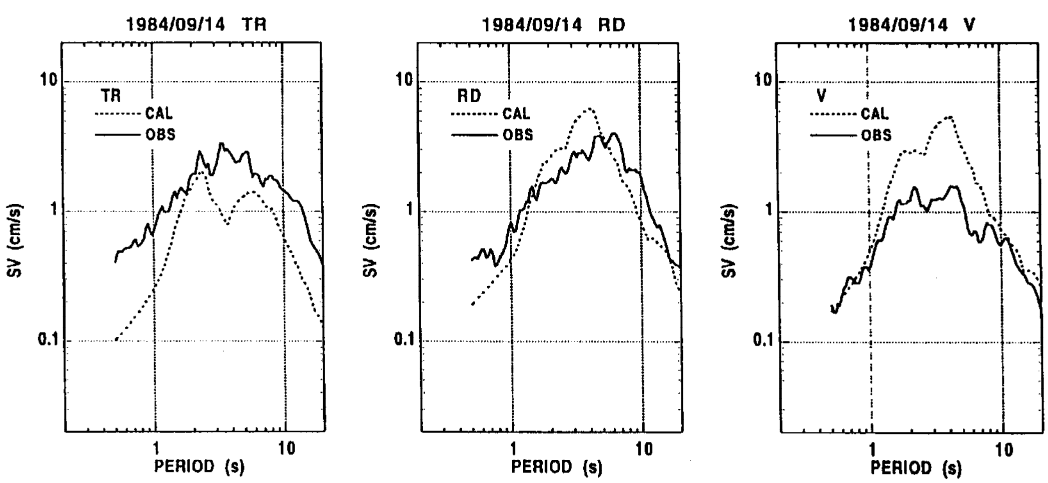

Fig.7 The comparison of velocity response spectra for the 1984 Naganoken-seibu earthquake. The solid lines denote observed waveform and break lines denote calculated ones.

CONCLUSIONS

The subsurface structure models in the southern part of Niigata were estimated by an inversion of surface wave group velocities as mean model between the observatory and the epicenters. Their pre-Tertiary basement depth vary according to the epicentral regions, especially the model for the event located near Toyama trough have the deepest pre-Tertiary basement. The features of models correspond to the regional variation of geological data and gravity anomaly in this area. It seems that these analysis help us to realize the spatial variation of subsurface structure.

The comparison between synthesized and observed seismograms demonstrated that the subsurface structure estimated from single station data is so useful to evaluate long-period ground motions. The method used in this study have the advantage of application to evaluate the long period strong ground motion for given site when earthquake observation was made at the site.

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