Estimation of Irregular Underground-Structure From Seismic Ground Motions

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Abstract

Phinney's method was extended so as to be able to extract the seismic effects of the underground structures containing irregular interfaces. The spectral ratios of the vertical component to the horizontal one of P- and S-wave motions were expressed as a function of only the propagation-media parameters. The underground structure model was iteratively determined by finding out the theoretical values consistent with the observed ones. The validity and the range of applicability of this method were examined by using the seismic data observed at two sites: one obtained with the array observation in the area across the buried fault (Obaku fault in the south-eastern side of Kyoto basin) and the other, at a single station near a seaside (Urakawa observatory at the southern coast of central Hokkaido). The spectral ratios of the seismic waves with the array observation show the spatial variation, being related to the lateral variation of the layer thickness. Further, even with a single station observation from the azimuthal variation of the spectral ratios, we can estimate the irregularities of the underground structure.

1. Introduction

The earthquake disaster at nearby sites for the same earthquakes was reported often to change site by site, indicating the strong role that the seismic effects due to local structures play in determining the characteristics of the ground motions. This problem has interested many investigators since preliminary works by Kanai and his colleagues[1]. At present we can calculate the seismic responses due to local structures not only for flat layered media, using e.g. Thomson-Haskell matrix[2], but also for irregular layered media, using e.g. discrete wavenumber method (Aki and Larner[3]), boundary integral method (e.g. Kobori and Shinozaki[4]), boundary element method (e.g. Toki and Sato[5]), and so on, as long as the underground structures are estimated by some methods. The profiles of underground structures are possible to determine by seismic prospecting, especially the reflection method. This is not applicable everywhere, because of the necessity of bulky instruments, massive data processing and high costs. For seismic microzoning in urban areas, the seismic responses have been estimated, using the readily observable data of microtremors in Japan (Kanai et al.[6]). Microtremor data were treated at an earlier time, based on a rough assumption of multiple reflections of SH-waves. Recently, array observation of microtremors becomes feasible so that high-quality information about underground structures could be extracted through the dispersive natures of the phase velocities (Horike[7]). However the validity of this method is limited to flat layer models.

This paper describes a method of estimating the structures containing irregular interfaces by means of three-component seismic data observed at the surface. The initial attempt based on this idea was made by Phinney[8]. The spectral ratios of the vertical to the radial components of P-waves are given as a function of only the elastic coefficients and the thicknesses of the layers, independent of the source parameters. Phinney determined the underground structures from the comparison of the observed spectral ratios with the calculated ones by the Thomson-Haskell matrix method[2], assuming the flat layer model. This method can be extended to apply to the multi-layer model with irregular interfaces when the scattered wave field is described as a superposition of plane waves.

We have applied this method to 2 cases in order to examine the validity and the range of applicability. One case is that of the seismic data obtained from array observation at 6 points across the buried Obaku fault where the thickness of surface layers are estimated to have a lateral variation. The spatial distribution of the spectral ratios in this area is related to the lateral variation of the layer thicknesses. The other case is that of seismic data from a single station. The earthquake ground motions from the aftershocks of the earthquake Off Urakawa of 1982 were observed at Urakawa observatory (URK, belonging to JMA) located near a seaside. The structure near this station was reported to show dipping shapes according to a gravity survey and seismic explorations. The spectral ratios at URK vary with the directions of the seismic arrivals. We can estimate the laterally varying structures from the azimuthal variations of peaks and troughs of the spectral ratios, even though the observation is made at a single station.

2. Method of Analysis

2.1 Extension of Phinney's Method

We will describe a method of separating the seismic effects of underground structures from the ground motions at the free surface. A convenient method for this problem was first proposed by Phinney[8]. He considered the seismic wave field in a semi-infinite medium made up of n-parallel, homogeneous isotropic layers. Assuming an incident compressional plane wave in the substratum, he expressed the vertical and the horizontal component spectra of the ground motions at the free surface as

$$\begin{aligned} u_0(k_0, \omega) &= A(k_0, \omega)\, U_p(\omega) \\ w_0(k_0, \omega) &= A(k_0, \omega)\, W_p(\omega) \end{aligned} \qquad (1)$$

where $A(k_0, \omega)$ is the spectrum of the incident P-wave, and U_p and W_p are the horizontal and the vertical components of the spectral transfer functions, which are calculated for the multi-layered model by the Thomson–Haskell matrix method[2].

The ratio

$$\frac{u_0}{w_0}=\frac{A\cdot U_p}{A\cdot W_p}=\frac{U_p(\omega)}{W_p(\omega)}=T_p(\omega\,;\,c) \qquad \cdots\cdots (2)$$

gave us only the information concerning n-layered media. The ratio of spectra T_p is the function of the frequency and the apparent velocity in this model. Practically, however, T_p almost does not vary with the apparent velocity, i. e. the incident angle by Kurita[9]. Phinney applied this method to teleseismic body waves in the study of crustal structures. He assumed that plane P-wave incident from the upper mantle to the crust. In practice, such a spectral ratio was used only in the frequency range lower than 0. 1 Hz, where the spectra were little influenced by complex superficial structures. Phinney's method has been used succesfully to estimate the crustal structures by many authors (e. g. Kurita[9], Takanami[10], Kubota[11], Hurukawa[12]).

In our case, we would like to use this method under the two different conditions: shallower structures (i. e. ground structures) and irreguar interfaces. The former condition needs to use the higher frequency range (higher than 0. 1 Hz). The latter needs to extend Phinney's method as follows. We consider the flat layers underlaid by an irregular basement. A practical method of calculating the seismic wave field for this problem was developed by Aki and Larner[3] based on Rayleigh's idea[13]. In their method, the scattered wave field caused by an irregular boundary is represented as a integration of plane waves with horizontal wavenumbers (including inhomogeneous waves). The details were shown by Aki and Larner[3]. Assuming an incident plane wave in the basement with an irregular boundary, we can rewrite the vertical and the horizontal component spectra at the free surface as

$$\begin{aligned} u_0(k_0,\ \omega) &= \int A(k_0,\ \omega)\, U_c'(k,\ \omega)\, dk \\ w_0(k_0,\ \omega) &= \int A(k_0,\ \omega)\, W_c'(k,\ \omega)\, dk \end{aligned} \qquad \cdots\cdots (3)$$

where $A(k_0,\ \omega)$ remains the spectrum of incident plane wave, U_c' and W_c' are the horizontal and the vertical components of the transfer functions of the flat layered media up to the irregular boundary for a certain wave number and the subscript c indicates an appropriate incident wave type, P or SV. The integral is required for the scattering effect due to the irregular boundary. Since the incident plane wave has a constant wavenumber, we can isolate $A(k_0,\ \omega)$ from the integration, and then the ratio is

$$\frac{u_0}{w_0}=\frac{\int A\cdot U_c'\, dk}{\int A\cdot W_c'\, dk}=\frac{A\int U_c'\, dk}{A\int W_c'\, dk}=T_c'(k_0,\ \omega). \qquad \cdots\cdots (4)$$

Although T_c' is more complex compared with T_p given by (2), we notice T_c' is dependent on the frequency and apparent velocity the same as T_p, and independent

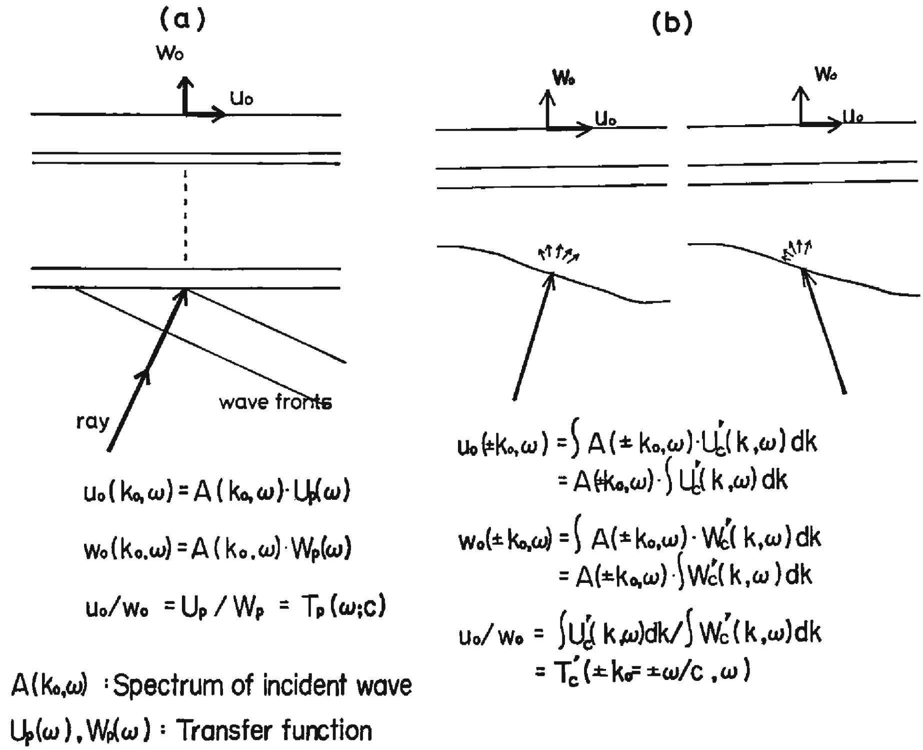


Fig. 1: Extension of Phinney's method for irreguar interfaces. (a): Phinney's method (Phinney[8]), (b): an extension of Phinney's method applied to irregular interfaces.

of the incident plane wave type. T'_c is significantly changed by the incident angle, especially, the direction of arrival of the incident wave. These schematic models are illustrated in **Fig. 1.** **Fig. 1** (a) shows the flat layer case, and (b) shows the irregular boundary case.

2.2 Seismic Responses of a Layered Medium Having an Irregular Interface Due to Incident Plane Waves

In n-parallel-layered media, to obtain the thickness or wave velocity of each layer from T_p, we may compare the observed T_p with the theoretical one derived from the famous Thomson-Haskell matrix method[2]. In fact, T_p changes with the ratio of the wave velocity to the thickness. To obtain the underground structure (i.e. each layer's thickness), we give the wave velocity of each layer from other experiments. To calculate numerically T'_c in the layered media with an irregular boundary, we use discrete wavenumber representation of elastic wave field[14]. They introduced periodicity in the irregular interface shape and described the scattered wave field to replace the integral with a superposition of homogeneous and inhomogeneous plane waves (wavenumber K_n). The validity of this calculation method was discussed by Bard and Bouchon[15] for P and SV waves. They pointed out this representation must be limited to values of K_n such that $K_n < K_N = \frac{2\pi N}{L}$ where K_N was greater than the corresponding fundamental Rayleigh wave mode wavenumber, and the truncation number N was chosen so that the amplitudes of the corresponding scattered waves inside the layer converge toward zero when K_n tends toward K_N. We choose values of K_n satisfying the above criteria. We also use the complex frequency for smoothing spectra. The ratio of the imaginary part of a frequency to the real part (ε) is chosen to be 0.05 in all our calculations. The demerit of this method is an increase in the intrinsic calculation error as the lateral variation of the interface in the model is more steep, therefore we must use interfaces whose irregularity is not too great.

3. Data Analysis and Interpretation

3.1 Data from Array Observation across Obaku Fault

(1) Data from array observation

We observed ground motions with the array observation in the area across Obaku fault at the eastern side of the south-eastern part of Kyoto basin, presented by Kasuga and Irikura[16]. **Fig. 2** shows the topographical map in the vicinity of the

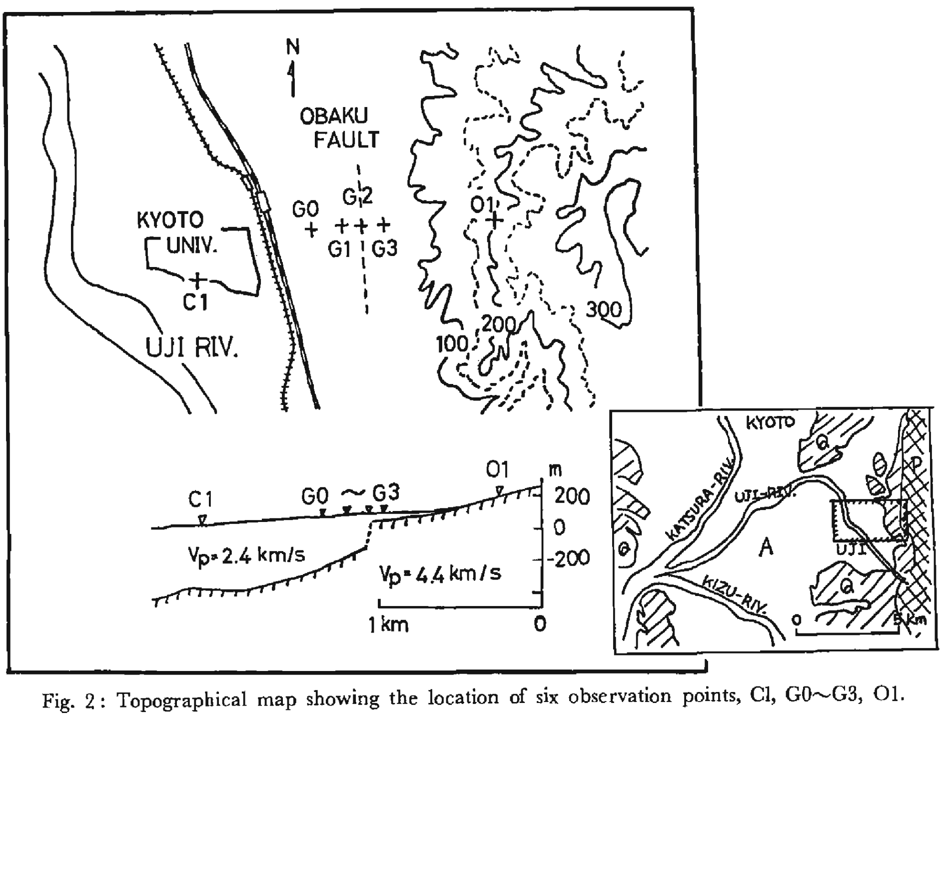


Fig. 2: Topographical map showing the location of six observation points, Cl, G0~G3, O1.

observation points and the underground structure determined by Kitsunezaki et al.[17] The symbols O1, G0～G3, and C1 are the routine observation points (marked by + on **Fig. 2**). We set up the new observation point G0 and moved the point G2 to form a line to intersect perpendicularly to the strike of the inferred Obaku fault. Therefore, our G2 is a different point from the G2 shown by Kasuga and Irikura[16]. Each interval of the observation points G0～G3 is 150～200m; Point O1 is located at about 1 km east of the inferred fault and is on the rock outcrop. Point C1 is about 1 km west of the fault on the thick soft layers. The sensing instruments are 3-component sets of velocity type seismometers with a natural period of 2. 0 sec, a sensitivity of 1. 0 volt/kine and a damping ratio of 0. 64. Those were placed at points G0～G3 and O1. Those at C1 have the constants of 3. 0 sec, 2. 0 volt/kine and 0. 64, respectively. The output signals of these seismometers were amplified 50 to 200 times through a DC type amplifier, and recorded in analog form using a magnetic tape recorder. The data on the magnetic tape are converted to the digital form at the sampling frequency 100 Hz through an A/D converter. This observation system is the same as that of Kasuga and Irikura[16].

The geological and geometrical profiles in the vicinity of this observation area have a steeply lateral variation in the E-W cross section, but little in the N-S one (Kitsunezaki et al.[17]). The fault is inferred to extend in a nearly NS direction. Regarding this observation as the two-dimensional *in*-plane problem, we choose the xz-plane as perpendicular to NS. To extract the information about the effects of the lateral variation of the ground structure on the earthquake motion, we select the observed data from each seismic wave that arrives from east or west and whose S-P time is larger than 10 sec. To attempt the analysis method mentioned in section **2. 1**, we obtain the spectrum of the surface ground motion at each observation point. We can regard UD-component as w_o, and EW-component as u_o in (3).

(2) Comparison of Synthesis with Observation

We calculate the spectra of observed earthquake motions using M. E. M. (prediction filter length of 2 sec) for data length of 10 sec from the onset of P-waves in this analysis. **Fig. 3** shows these spectral ratios obtained at each observation point G0, G1, and G3. The numbers 2, 6, 9, 10, 11 and 16 indicate earthquake numbers. These earthquakes have magnitudes of 3～4 and epicentral distance of about 100 km. No. 2, 6 and 10 are the event records from the east (i. e. thin soft layer side), and No. 9, 11 and 16, those from the west (i. e. thick soft layer side). We will compare the spectral ratios of these two groups. The spectral ratios at G1 have peaks around 5Hz and troughs around 2. 5 Hz in the case of the waves arriving from the east, but peaks around 2. 5 Hz in the case of the ones arriving from the west. That is, the spectral ratios appear to have significantly different features, dependent on the directions of the wave arrivals. On the other hand, we do not notice the significant variation of the spectral ratios at G0 and G3 being dependent on the direction of wave arrival. Although the spectral ratios at G3 have peaks around 4 Hz from the east, and 2 Hz from the west, they are less significant than that of G1. Every spectral ratio at G0 has peaks around 3 Hz. These results suggest that the spatial variations of the seismic

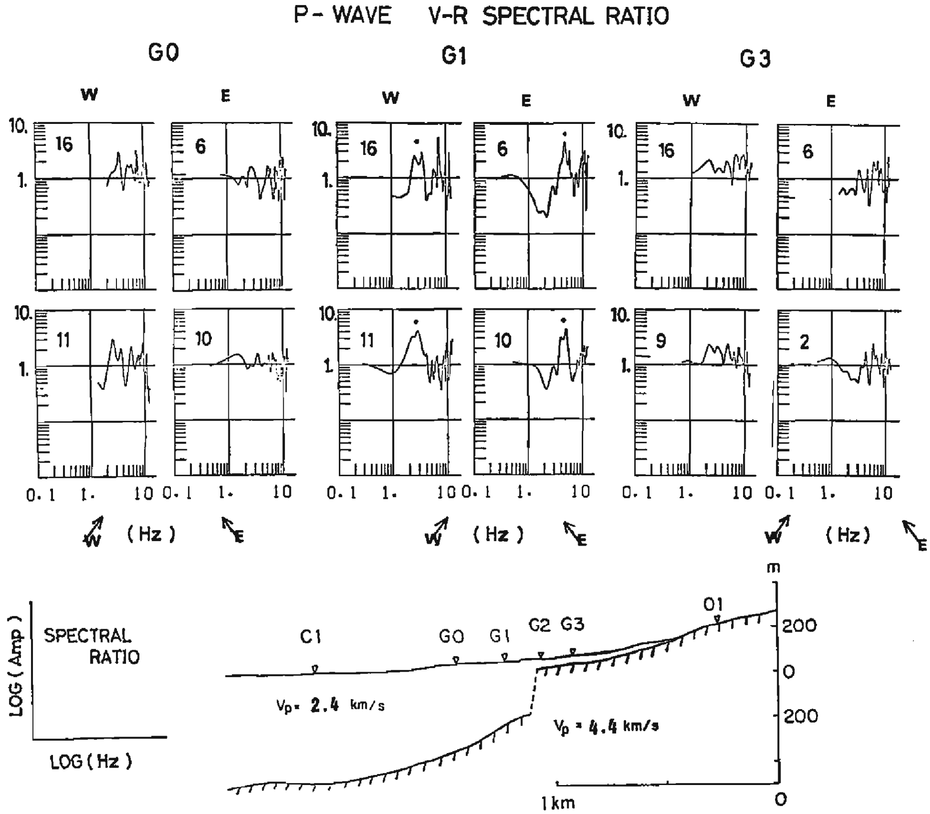


Fig. 3 : Spectral ratio of the vertical to radial component of the ground motions at each observaton point, G0, G1 and G3 with the NS cross section of the underground structure

effects are caused by the irregular boundary of the basement. This is consistent with the azimuthal variations of SH-waves amplification characteristics due to the surface layers indicated by Irikura[18] and Kasuga and Irikura[16].

Seismic responses of a layered medium having an irregular interface due to incident plane P-waves are calculated by discrete wavenumber method. The model for the calculation is adopted the underground structure determined by Kitsunezaki et al.[17] by means of the refraction method and then the steep lateral variation of the structure model is smoothed to suppress the intrinsic calculation error. **Fig. 4** shows the spatial distribution of the spectral ratios of the vertical to the radial component for the incident plane P-waves with the incident angle of 20°. The case of the wave incidence from the east, i.e. the wave arrival from the thin layer side to the thick layer side, is shown in **Fig. 4** (a) and the case from the west, i. e. the wave arrival from the thick layer side to the thin layer side in **Fig. 4** (b). We find that, at the site in the area near the laterally steep changes of the underground structure, the peak and trough frequencies of the calculated spectral ratios are significantly different with

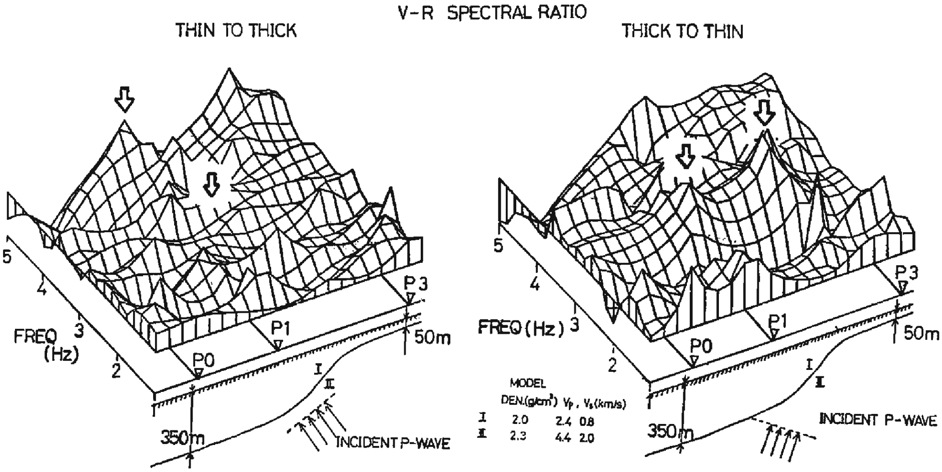
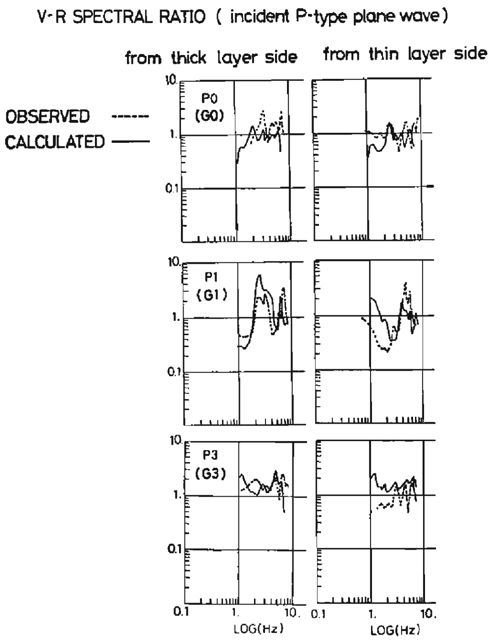


Fig. 4: Theoretical spatial distribution of the spectral ratios of the ground motions at the free surface for incident plane P waves, calculated by discrete wavenumber method. The model for the calculation is adopted the underground structure in Fig. 2 and then the steep lat^era variation of the structure model is smoothed to suppress the intrinsic calculation error.



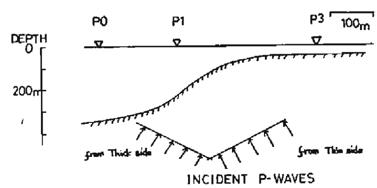


Fig. 5: Theoretical spectral ratios of the vertical to radial component at the points, P0, P1 and P3 in Fig. 4. The points, P0, P1 and P3, correspond to the observation points, G0, G1 and G3, respectively.

the direction of the wave arrival. For example, for the point correspondng to G1, the spectral ratio for the incidence from the thin layer side has a peak around 5 Hz and a trough around 2.5 Hz, while that for the incidence from the thick layer side has a peak around 2.5~3.0 Hz. Arrow marks in **Fig. 4** indicate these peaks and troughs. On the other hand, the points which are further away from the fault discontinuity have less variations of the spectral ratios with the directions of the wave arrivals. To show these results clearly, we plot the theoretical ratios on the same graphs as the observational ones in **Fig. 5.** The frequencies of peaks and troughs of the spectral ratios at the point PI, corresponding to GI, clearly change with the direction of the wave arrival. On the contrary, those of spectral ratios at the points P0 and P3, corresponding to G0 and G3, do not clearly change with the direction of the wave arrival. This result shows that the earthquake ground motions are sensitively influenced by the irregularity of the underground structure. The size of irregularity, i. e. the correlation length of the lateral variation of the structure, is comparable to the wavelength corresponding to the frequency range discussed above.

3.2 Data of Aftershocks of 1982 Off Urakawa Earthquake at URK Station

(1) Geological Feature of Observation Sites

On the 21 May 1982, the earthquake Off Urakawa in southern Hokkaido ($M_{JMA}=7.1$) occurred. The strong ground motions in the near field were recorded at URK (the JMA station at Urakawa) with type-59 seismometer and at Erimo

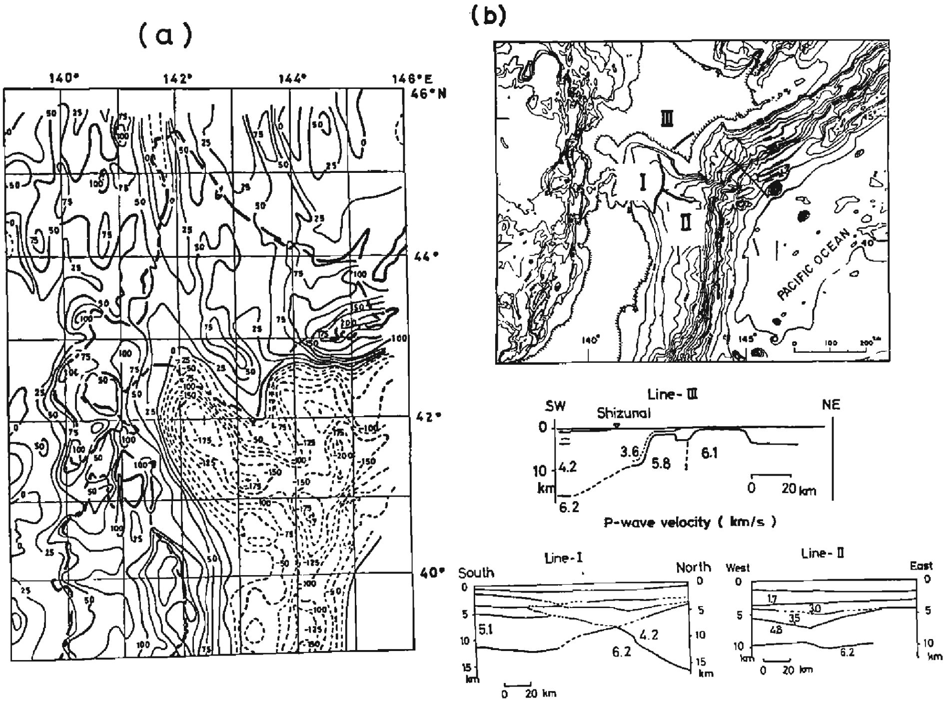


Fig. 6: Results of geological surveys. (a) shows Bouguer gravity anomaly map of the south Hokkaido region (after Tomoda et al.[19]), and (b) shows profiles of seismic exploration corresponding to the lines I, II and III in the area of south Hokkaido. (lines I and II, after Asano et al.[20] and line III, after Fujii and Moriya[21]).

geophysical observatory (Faculty of Science, Hokkaido University) with the strainmeter, although both instruments scaled out or broke down about 10 sec after the onsets. This earthquake was followed by a number of aftershocks which have been recorded with the strong velocity type seismometers set up by Muramatu at both points.

The substructure in the area near URK was reported to have a laterally irregular shape according to the gravity survey (Tomoda et al.[19]) and the seismic exploration (Asano et al.[20], Fujii and Moriya[21]). **Fig. 6**(a) shows the map of gravity anomalies and **Fig. 6** (b) shows locations of seismic refraction profiles and structure sections corresponding to each profile. The negative gravity anomaly surrounding the area off Shizunai suggests thick sedimentary layers. Profiles I and III from the seismic exploration along lines I and III in **Fig. 6**(b) show that the sedimentary layer is thick on the sea side and becomes steeply thinner toward the land side. On the other hand, profile II along line II shows that the thickness of each layer varies little. Based on these results from the above geophysical surveys, we regard the seismic wave field in the NE-SW section of the structure as a two-dimensional problem. Then, the irregular interfaces between the 6km/s-layer and the 4km/s-layer may characterize the observed ground motions at URK as will be mentioned below. Takanami[10] estimated the crustal structure models in the area near URK using Phinney's method. He showed that the structure models with thick sedimentary layer were consistent with the observed results from the teleseismic short period P-waves, when he used only the seismic waves arriving from the sea side. In this study, the seismic data observed at URK are classified into two groups, one from the land side and the other from the sea side. The differences of the spectral ratios between the two groups are discussed in relation to the lateral variation of the underground structure.

(2) Analysis of Data and Comparison of Synthesis with Observation Results

The ground motions at URK and Erimo were observed by Muramatu[22], using velocity type strong motion seismographs designed by himself. The observation system has a wide dynamic range from 100 to 0.01 kine over the period ranging from 0.05 to 50 seconds. The performance of the system was reported in detail by Muramatu[23]. Aftershocks of the earthquake Off Urakawa of 1982 were recorded on magnetic tape by means of a digital cassette recorder at the sampling frequency of 100 Hz at URK and Erimo during active aftershocks. We analyze the records at URK from seventeen aftershocks whose magnitudes ranged from 3.1 to 5.2 (M_{JMA}). **Fig. 7** and **Table 1** show the distribution of the epicenters of the analysed aftershocks. **Fig. 8** shows the earthquake ground motions of the largest aftershock recorded at URK.

The earthquake ground motions are rotated into radial and transverse components toward the epicentral direction from the observation point. The directions of the seismic arrivals are considered to be nearly consistent with the epicentral direction. The two directions, the arrival directions and the epicentral directions, are often reported to be somewhat different with each other, owing to the lateral variations of the underground structure near the observation site. We checked that the spectral ratios are not influenced by the difference of the arrival directions within 10°.

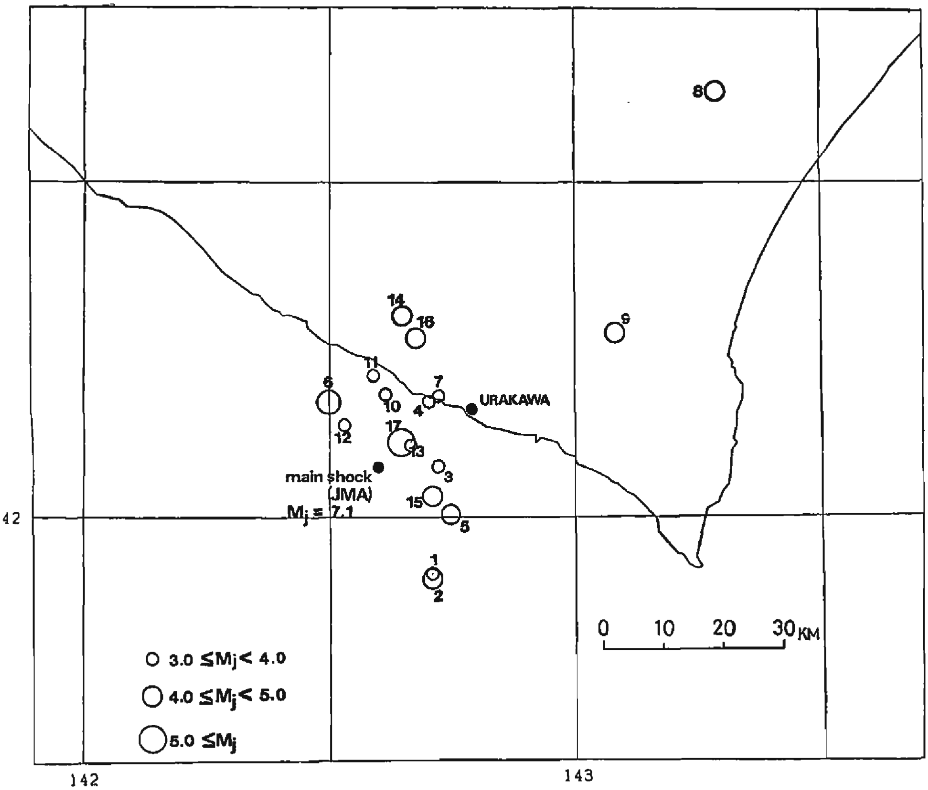


Fig. 7 : Distribution of the epicenters of the aftershocks

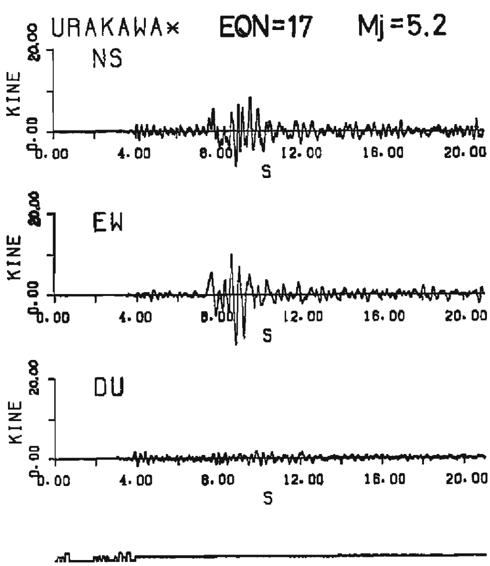


Fig. 8 : An example of ground motions observed at URK station (the largest aftershock)

Table 1 : Epicenters and magnitudes of seventeen aftershocks

EQN.	DATE	TIME	LAT. (DEG)	LONG. (DEG)	DEP. (KM)	M (JMA)
1	10 APR.	21h 58m	41° 56′	142° 40′	20	3.7
2	10 APR.	22 17	41 55	142 40	20	4.1
3	11 APR.	6 29	42 05	142 43	20	3.1
4	11 APR.	18 47	42 10	142 42	30	3.8
5	13 APR.	6 54	42 01	142 44	30	4.2
6	16 APR.	3 36	42 11	142 30	30	4.0
7	21 APR.	14 29	42 11	142 43	30	3.5
8	22 APR.	7 21	42 36	143 17	130	4.9
9	22 APR.	19 42	42 15	143 04	60	4.0
10	23 APR.	13 26	42 11	142 37	20	3.8
11	24 APR.	0 58	42 13	142 36	30	3.7
12	25 APR.	7 23	42 07	142 32	40	3.7
13	7 JUNE	2 43	42 06	142 40	40	3.8
14	24 MAY	22 11	42 16	142 38	40	4.5
15	13 APR.	6 49	42 02	142 42	30	4.8
16	11 MAY	23 26	42 14	142 38	40	4.3
17	22 MAY	10 36	42 05	142 39	30	5.2

Considering the result of geological survey, we expect the peaks and troughs of the spectral ratios to appear in the frequency range from 0.1 Hz to 0.5 Hz. To extract the information about the irregular interfaces, we need a data length of more than 20 sec concerning either the *P*-wave part or *S*-wave part. The seismic data used here have mainly *S*-*P* time of about 10 sec. Therefore we analysed only the *S*-wave part. The spectra of ground motions are calculated using M. E. M. (prediction filter length of 10 sec). Ouchi and Nagumo[24] pointed out that the spectra are valid up to the period of the same order as the filter length.

In order to find the spectral changes of the ground motions for the direction of the wave arrivals, we calculated the transverse component spectra from some events shown in **Fig. 9**. **Fig. 9**(a) shows the transverse component displacement spectra of the seismic waves arriving from the sea side and **Fig. 9**(b) shows those from the land side. No. 5, 6, 7, 9, 10, 14 and 17 correspond to the earthquake numbers in **Fig. 7** and **Table 1**. An obique line drawn in each graph together with the spectrum in **Fig. 9** represents the system noise level for the displacement spectrum (including the microtremors). We notice that the spectra of the seismic waves arriving from the sea side have a peak around 0.1~0.2 Hz in the lower frequency range, but those from the land side have a peak around 0.3~0.5 Hz. This result shows the obvious difference between two earthquake groups. The transverse component spectra contains the path effect and the source effect, and both effects can not be separated. In order to find the azimuthal variation of the seismic effects due only to the underground structure, it is necessary to take the ratio of the radial to vertical component spectra of the ground motions.

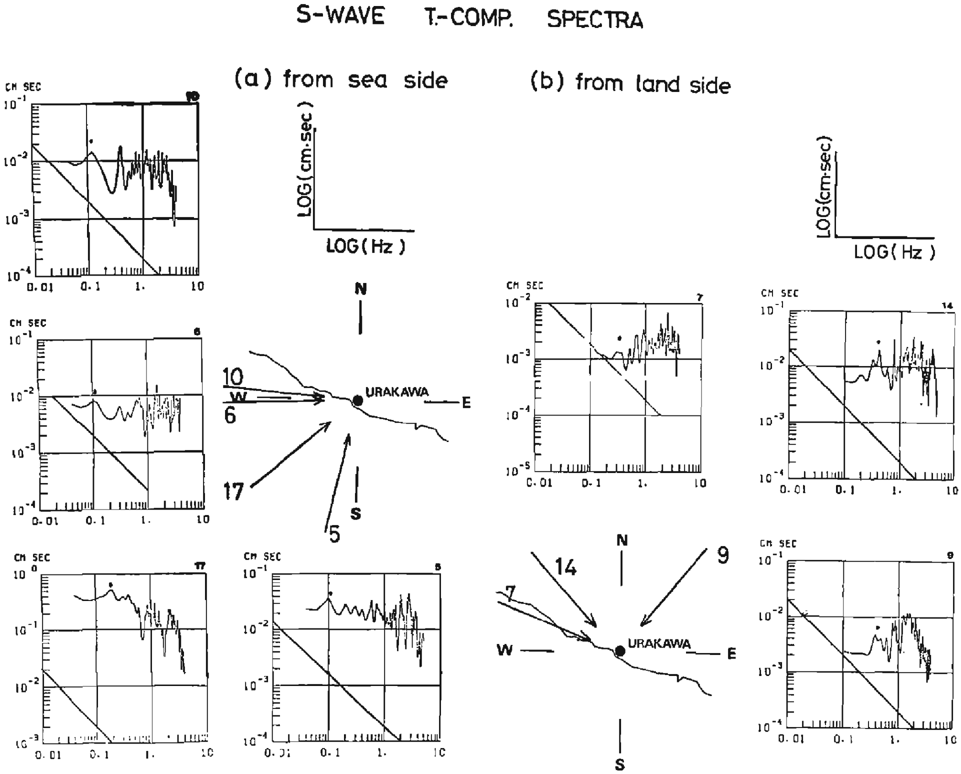


Fig. 9: Spectra of transverse component of the earthquake ground motions of S wave part observed at URK. (a): spectra of seismic waves from the sea side, (b): those from the land side.

According to Aki and Richards[25], when noise is present in the analysis data, the spectral ratio is a very dangerous quantity because of its enormous variability. Assuming that the noise is the Gaussian type, we need that the signal to noise ratio in energy spectra be greater than 19 to get the probability of 90% of the spectral ratios. **Fig. 10** shows the spectral ratios of the radial to the vertical component of the length of 20 sec after S-wave onset. We have selected five events, No. 2, 6, 9, 14 and 17, which satisfy the above criterion. The above events are classified into two groups. One is the group of the seismic waves arriving from the sea side, No. 2, 6 and 17, and the other is those arriving from the land side, No. 9 and 14. We can find the significant difference in the spectral ratios between two groups. That is, the spectral ratios of the seismic waves from the sea side have two peaks around 0.15 Hz and 0.25 Hz, and a trough around 0.2 Hz, while the one from the land side has two peaks around 0.2 Hz and 0.3 Hz, and a trough around 0.25 Hz in the notable frequency range from 0.1 Hz to 0.5 Hz. The peak and trough frequencies of the spectral ratios of the group from the land side are higher than those of the group from the sea side. These suggest that the underground structure has an irregular boundary which affects

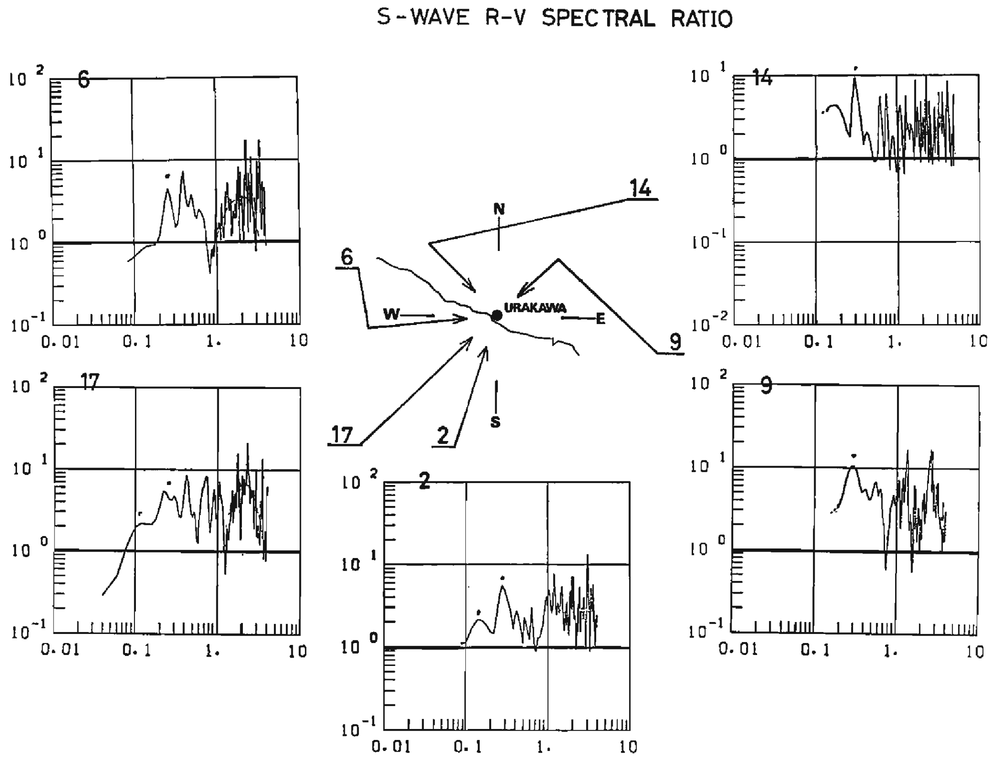


Fig. 10: Spectral ratios of the radial to vertical component of the ground motions at URK

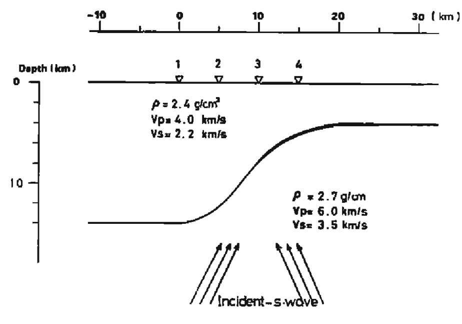


Fig. 11: Model for the calculation. V_p, V_s and the density are given by Takeo et al.[26]

these frequency ranges.

To explain these observation results, we have calculated the seismic wave field in a layered medium with an irregular boundary using discrete wavenumber method. The model for the calculation is shown in **Fig. 11.** For the sake of simplification of the calculation, we use a two layered model with the cosine type irregular boundary, based on the structures from the seismic explorations (Asano et al.[20], Fujii and

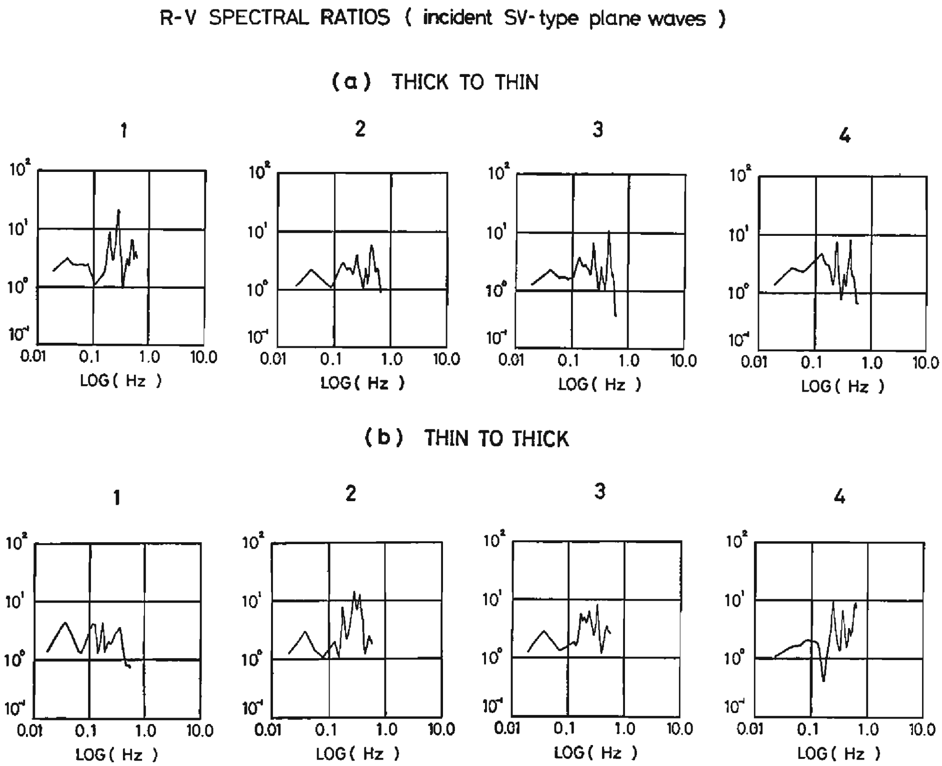


Fig. 12: Theoretical spectral ratios of the radial to vertical component of the ground motions at the free surface for the incident plane *SV*-waves. (a): the spectral ratios for the *SV*-wave from the thick layer side, (b): those from the thin layer side.

Moriya[21]). The values of P and S waves velocity and the density is given by Takeo et al.[26] The incident angle is assumed to be 25° in this calculation. The results of calculation are shown in **Fig. 12**; (a) shows the spectral ratios of the radial to vertical component of the surface motion for the incident *SV*-type plane waves from thick to thin layer (corresponding to the seismic waves arriving from the sea side) and (b) shows those from thin to thick (from the land side). The spectral ratios designated as 1∼4 in putting **Fig. 12** correspond to the points marked (▽) in **Fig. 11.** We notice that the spectral ratio for a certain incident angle varies spatially in the range from No. 1 to No. 4. Further, the spectral ratios at each point also vary with the direction of the incident waves. The peak and trough frequencies of the spectral ratios from the thin layer side are higher than those from the thick layer side. These calculated values are consistent with the features of the spectral ratios observed at URK mentioned above. From comparison of the peak and the trough frequencies of the observed spectral ratios with those of the caculated, we presume that the point URK correspond to the point No. 2 or No. 3 in this calculation model.

4. Conclusion

Based on the extended idea of Phinney's method, the spectral ratios of the vertical component to the radial one of P– and S–waves are expressed as a function of the elastic constants and the thicknesses of the layered media containing irregular interfaces. This method is applied to the two cases of the seismic data for extracting information about underground structures. One case is the seismic data obtained with the array observation in the area across the buried Obaku fault in the south-eastern side of Kyoto basin. The spectral ratios of the seismic waves in this area show spatial variation, being related to the lateral variation of the layer thickness. Further, we noticed that the spectral ratios at the sites underlaid by steep lateral variation of the layer thicknesses have different peak and trough frequencies, dependent on the directions of the seismic arrivals. The other case is the seismic data at a single station, URK (Urakawa observatory) located near a seaside. We find that the spectral ratio at URK vary with the directions of the seismic arrivals. We can estimate the laterally varying structure by fitting the azimuthal variations of the peak and trough frequencies of the spectral ratios to those calculated for the trial structure models, iteratively.

From these results, we can confirm the validity of applicability of this method for estimating the seismic effects due to the underground structures containing irregular interfaces.

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