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THE EVALUATION OF THE EFFECTS OF CURVED INTERFACES ON SEISMIC MOTIONS DUE TO THE ANALYSES OF SEISMIC ARRAY DATA AND NUMERICAL SIMULATIONS BY THE EXTENDED AKI AND LARNER METHOD

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SUMMARY

The effects of the irregularity of a shallow subsurface interface on seismic motions are investigated using array data. Comparison between low-pass-filtered seismograms at the basin sites shows the spatial waveform variation and elongation of duration of the S-wave portion. The phase and group velocities suggest that the above characteristic features are primarily caused by the excitation of surface waves at the margin of the basin. Synthetic seismograms computed by the extended AKI and LARNER method exhibit the features. However, the amplitude of the computed surface waves are smaller than the recorded amplitude.

INTRODUCTION

Estimation of the intensity and duration of seismic motions in sedimentary basins is one of the most urgent problems for earthquakehazard mitigation. In order to estimate them, we have to evaluate not only the effects of seismic source and propagation path but also those of local geological conditions. A prominent feature of subsurface structure in sedimentary basins is an irregular basin-bedrock interface with high impedance contrast. It may generate characteristic wave phenomena such as surface waves and resonance. In this recent years, many investigators have shown that the irregularity of the basin-bedrock interface strongly influences seismic motions in a sedimentary basin(for example, TORIUMI, 1980; KUDO,1980; KING and TUCKER,1984; LIU and HEATON,1984). Meanwhile, various numerical simulation methods also revealed the strong influence of the irregularity of the basin-bedrock interface on seismic motions(for example, AKI and LARNER,1970; TRIFUNAC,1971; LYSMER and DRAKE,1971; BOORE,1972; SANCHEZ-SESMA and ESQUIVEL,1978; BARD and BOUCHON,1980; DRAVINSKY, 1983).

However, these observational and numerical studies were made separately so that the effects of the irregularity of interfaces on seismic motions have not been quantitatively investigated. To make such an investigation, we first have to choose a sedimentary basin where the subsurface structure is already known. The Kyoto basin is such a basin. Thus, we investigate the effects of irregular interfaces on seismic motions here in the Kyoto basin.

OBSERVATIONS AND DATA

Observation Seismic observations have been made at three sites in the Kyoto basin as shown in Fig.1. One site(OBK) is on a rock outcrop at the eastern margin of the basin. Another site(KUC) is nearby on soft sediments. The other site(OGR) is almost at the center of the basin. At OGR, a tripartite subarray was established to distinguish wave-types. The subarray configuration is shown in Fig.2. As can be seen from Fig.1, the Kyoto basin is oriented almost north-south. Hence, its subsurface structure is assumed to be approximately two-dimensional in the EW cross section. Therefore, if an epicenter of an earthquake is located to the east or the west of the seismic observation area, then we can compute seismic responses in the context of the two-dimensional problem. The aftershock events of the 1984 western Nagano prefecture earthquake satisfied the above condition best of all the events recorded by the array. Hence we will use these aftershock events in the following analysis and simulation. In this area, various geophysical surveys have been conducted since the beginning of the 1970's. We constructed a subsurface structural model as shown in Fig. 3, referring to AKAMATSU et al.(1975), KITSUNEZAKI et al.(1970) and HORIKE(1985) with slight modifications.

Features of low-pass-filterd shear waves Fig. 4 shows low-pass filtered NS-component seismograms of the aftershock event. Comparing the traces at the three sites, we notice the following two features:

(1) In the first part of the S wave, amplitudes at site KUC are larger than at site OGR.

(2) In the later part of the S wave, the seismic waves at KUC decay in amplitude rapidly, but those at OGR remain large for a long time.

MULTIPLE-FILTER ANALYSIS OF TRIPARTITE-SUBARRAY DATA

In order to understand the cause of these features, we will examine what kinds of waves are contained in the S-wave portion. As is well known, the phase velocity of surface waves trapped within a basin is lower than the S-wave velocity of the bedrock, while the phase velocity of body waves is higher than that(EWING et al., 1957). The S-wave velocity of the bedrock below the Kyoto basin is 2.5 km/s as shown in Fig. 3. Thus, we have a criterion for discriminating between surface waves and body waves i.e., a wavelet whose phase velocity is lower than 2 km/s is assumed to be surface wave. Fig. 5 shows the results of the application of a Gaussian multiple-filter technique(DZIEWONSKI et al., 1969) to the S-wave portion shown in Fig. 4. The phase velocities and propagation directions of these wavelets were computed from the time differences of corresponding peaks and troughs, and are shown by arrows in the circle. Phase velocities higher than 3 km/s are displayed using a 3 km/s arrow because of the lack of resolving power of the tripartite array for such high phase velocities. At all frequencies, the wavelets denoted by A propagate at the phase velocity higher than 3 km/s from the approximate direction of the epicenter. Hence these wavelets are considered to be the direct S wave from the earthquake source. On the other hand, the phase velocities of the wavelets B range from 0.9 km/s to 1.9 km/s. Therefore, these wavelets are considered to be surface waves.

We will next examine where these surface waves are generated. We test the assumption that they are generated at the basin-bedrock *interface below the eastern margin of the basin when the direct S* waves are incident there. As can be seen from Fig. 1, the distance between site OGR and the eastern margin of the Kyoto basin is about 4 km, and the direct S waves are probably incident at the basin-bedrock interface at a time intermediate between the onsets of the S waves at sites OBK and KUC. We can thereby draw the group velocity axis shown below the seismograms at each frequency in Fig. 5. Using the axis, we can estimate the group velocities of prominent wavelets. As is well known, the group velocity of surface waves is less than the corresponding phase velocity(EWING et al.,1957). In Fig. 5(a), for example, at the frequency 0.62 Hz, the group velocity of the wavelet B is about 0.5 km/s. This value is obviously lower than the corresponding phase velocity (0.9km/s). At frequency 1.48 Hz. the group velocities are also lower than the corresponding phase velocities. This observation supports the assumption that the surface waves contained in the later part of the S wave are generated at the east margin of the Kyoto basin.

COMPARISON BETWEEN RECORDED AND SYNTHETIC SEISMOGRAMS

we will study whether synthetic seismogram computed by the AL method can reproduce the amplitudes and the above-mentioned features of the recorded seismograms. This will be done using comparison between recorded and simulated seismograms. The simulation of seismic waves will be made by the AKI and LARNER(1970) method. However, these authors gave the formulas only for structures with a single interface, while there are three interfaces below the Kyoto basin. Hence we extended the AL method to be applicable to structures with irregular interfaces in combination with the HASKELL method(1960) (See HORIKE,1988 in more detail).

Previously, the prediction of seismic motions has often made using the HASKELL method(1960) in which a subsurface structure is assumed to be flat layered. Therefore, it is of interest to engineering seismology to compare synthetic seismograms calculated using the HASKELL method with recorded ones. Fig. 6 show synthetic seismogram calculated using the HASKELL method corresponding to recorded seismograms shown in Fig. 4. The incident plane SH motions were estimated by the deconvolution of recorded seismogram on the rock outcrop(OBK) with computed impulse response. As can be seen from Figs. 4 and 6, synthetic seismograms by the HASKELL method are quite different from recorded seismograms. Figures 7 show synthetic seismograms calculated using the AL method. The incident plane SH motions were estimated by the same procedure as in the HASKELL method. The synthetic seismograms in the basin exhibit the spatial waveform variation and elongation of duration due to surface-wave generation. This fact means that the prediction of seismic motions in a basin-like structure requires the treatment of irregular interfaces. However, compared with the recorded seismograms, the *excitation of surface waves is not sufficient and consequently the* duration is shorter than that of the recorded seismograms. This fact probably means that we have to include the effects of three dimensional subsurface structure and non-plane wave front of incident waves.

CONCLUSION

We obtained the conclusions from the analyses of seismograms recorded by the array and the seismic wave simulations.

(1) The seismic motions observed in the Kyoto basin exhibit the feature that the S-wave portion spatially changes in waveform and elongates in duration due to surface waves which are probably excited at the eastern margin of the basin.

(2) Synthetic seismograms of the two-dimensional subsurface structure exhibit this feature, but are smaller in amplitudes compared with recorded seismograms, primarily because of less excitation of surface waves.

(3) Synthetic seismograms calculated using the HASKELL method are quite different from the recorded seismograms.

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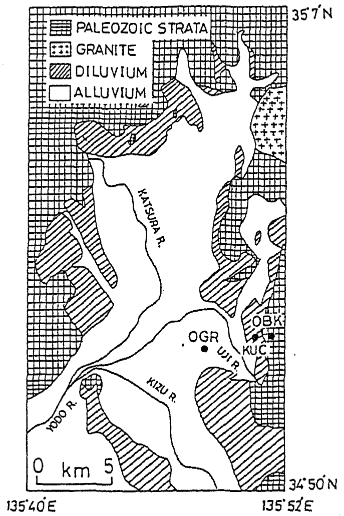

Fig. 1 Geological map of the Kyoto basin.

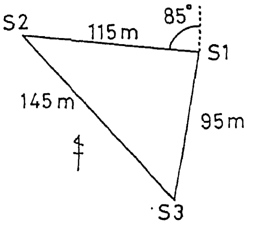

Fig. 2 Tripartite-array configuration at site OGR.

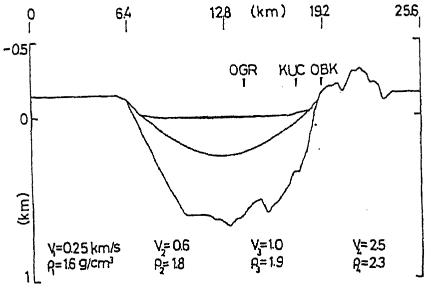

Fig. 3 E-W cross section of the subsurface structure model of the Kyoto basin.

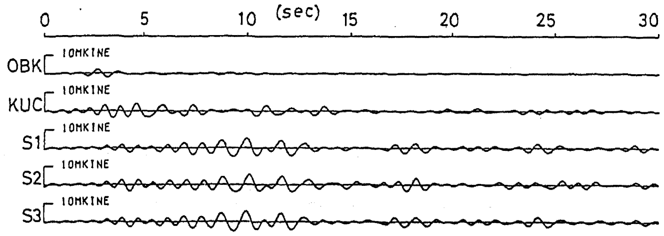

Fig. 4 Low-pass-filtered(1.4 Hz) NS-component seismograms.

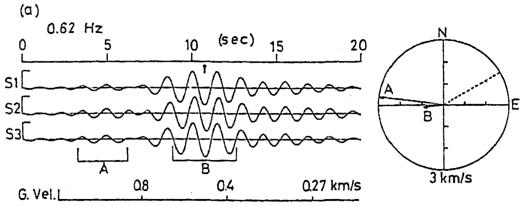

Fig. 5(a) Estimation of phase and group velocities of wavelets in the S-wave portion from the tripartite-array data by the multiple-filter technique at the center frequency 0.62 Hz. Arrows in the circle show the phase velocity and propagation direction of a prominent wavelet denoted by the capital letter. Broken line indicates the direction of the epicenter. The axis G. vel. is for the measurement of the group velocity. Solid triangle indicates the group arrival time of the wavelet.

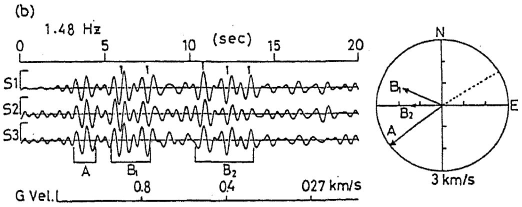

Fig. 5(b) At the center frequency 1.48 Hz.

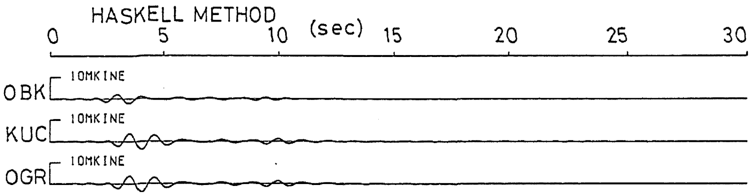

Fig. 6 Synthetic seismograms of the Kyoto basin calculated using the HASKELL method.

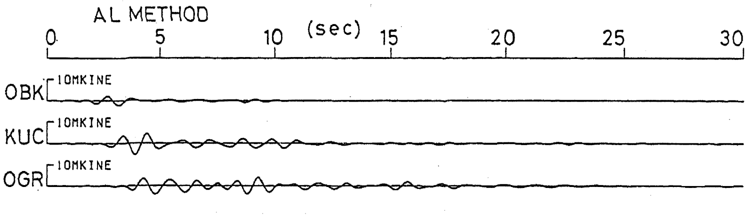

Fig. 7 Synthetic seismograms of the Kyoto basin calculated using the AL method.