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SIMPLIFIED METHOD FOR ESTIMATION OF LONG-PERIOD BASIN RESPONSE

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ABSTRACT

To estimate a time history of a long period ground motion is a crucial issue for large-scale structures in a basin. However, the calculation of basin response by a 3-D method requires a large computational effort. Here, we propose a simplified method in which direct wave and induced surface waves are independently estimated. We show the validity of the method by comparing synthetic motions with recorded ones at stations Fukushima and Amagasaki of CEORKA during the 1995 Hyogo-ken Nanbu earthquake.

Introduction

Many basins are bounded by active faults. When such a fault triggers an earthquake, not only direct body and surface waves but also basin-induced surface waves propagate in a basin. Particularly, basin-induced surface waves appear right after S-wave with significant amplitude. Thus to estimate a time history of a long-period ground motion is a crucial issue for large-scale structures in a basin. However, the calculation of basin response by 3-D simulation methods such as finite difference method and finite element method require a large computational effort (Irikura et al., 1998). We propose a simplified method for estimating the long period ground motion.

Estimation Method

Our idea is based on the assumption as illustrated in Fig.1 that the ground motion in a basin consists of direct body and surface waves from the seismic source and basin-induced surface waves. In this method, these two type waves are calculated individually. After getting time histories of individual waves, then they are summed up to get basin response at a target site.

Direct body and surface waves

We calculate direct body and surface waves by a flat layered model (Hisada, 1995). Many observational studies (such as Kinoshita et al., 1992, Hatayama et al., 1995, and Kataoka et al., 1997) pointed out that the predominant periods of ground motions in a basin can be interpreted as airy phases of surface waves using a flat layered model below each site. Thus we use a flat layered model below a target site when we calculate the ground motion by the path #1.

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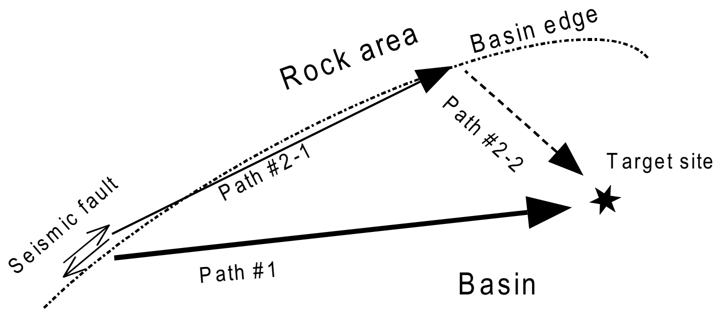

Figure 1. Paths assumed in this study. The ground motion consists of direct body and surface waves from the seismic source (Path #1) and basin-induced surface waves (Path #2-2).

Basin-induced surface waves

The location where the basin-induced surface wave is originated is determined by a ray tracing method at a frequency of an airy phase. When ray tracing is carried out, S-wave velocity of rock area is used for the path #2-1, while for the path #2-2 the phase velocity of a target surface wave is used, since we think that a surface wave induced by S-wave is most crucial.

Amplitude of a basin-induced surface wave is calculated from the energy flux of the incident ground motion at the basin edge. The energy flux of S-wave is described as eq.1.

$$V_I \;'\; \frac{1}{2}\$ D \int_0^H \sum_{i=1}^{3} (\dot{u}_i)^2 dz \tag{1}$$

where V_I is input energy flux to the basin by S-wave, $\$$ is S-wave velocity of the rock area, D is a density of rock, H is a depth of the basin, and $\dot{u}_i$ is velocity motion at the basin edge. Then we assume that the preservation of the energy flux is kept by a generated surface wave. For example, when the preservation is kept by the fundamental mode Love wave, eq.1 is described as eq.2

$$V_I \;'\; V_{Love_0} \;'\; E^2 U_0^L I_{1_0}{}^L \tag{2}$$

where, E is a coefficient to be determined later, U_0^L is group velocity of the fundamental mode Love wave and $I_{1_0}^L$ is a kinematic energy that is same notation as that in (Aki and Richard, 1980). When we accept the expression of eq.2, we can estimate the amplitude of the target surface wave as eq.3.

$$E \;'\; \sqrt{\frac{V_I}{U_0^L I_{1_0}{}^L}} \tag{3}$$

Applicability and efficiency of the proposed method were demonstrated using a 3-D simple basin model comparing with 3-D boundary element method (3D-BEM) (Kataoka and Ohmachi, 2000). The computational time of the proposed method was about 1/1000 of the 3-D BEM but both of the results were almost the same.

Application to the Osaka Basin during 1995 Hyogo-ken Nanbu Earthquake

Models

The source model estimated by (Matsushima and Kawase, 1998) is used in this study. The velocity structure of the surrounding rock area is the same as (Matsushima and Kawase, 1998). The velocity structure in the basin is constructed by combining (Matsushima and Kawase, 1998) and (Kagawa et al., 1993). An 1-D basin model used in this study is listed in the Table 1.

We focus on the fundamental mode Love wave in this study, since observational study revealed that the amplitude of Love wave is significant.

Table.1 The velocity structure for sites, Fukushima (FKS) and Amagasaki (AMG). Vp is P-wave velocity, Vs is S-wave velocity D is density, and Q is quality factor of S-wave.

Layer No.	Vp [km/s]	Vs [km/s]	D [t/m^3]	Q	Thickness [km]	
					FKS	AMG
1	1.60	0.35	1.7	20	0.23	0.20
2	1.80	0.55	1.8	30	0.31	0.42
3	2.50	1.00	2.1	50	0.65	0.77
4	5.40	3.20	2.6	400	4.45	
5	6.00	3.46	2.7	600	13.00	
6	6.70	3.87	2.8	700	16.50	
7	7.50	4.33	3.0	800	infinite	

Next, we need to determine the origin of the basin-induced Love wave. For the case of station Fukushima, the origin of basin-induced Rayleigh wave was studied by (Kataoka and Ohmachi, 1998) using propagating velocity, direction and travel time of observed ground motions. Furthermore, the propagating direction of Love wave is almost same as that of Rayleigh wave. Therefore, we used the result of previous work without applying a ray-tracing method. For the case of station Amagasaki, the propagating direction is the same as that of around Fukushima. So the origin is estimated by the same idea of Fukushima as illustrated in Fig.2.

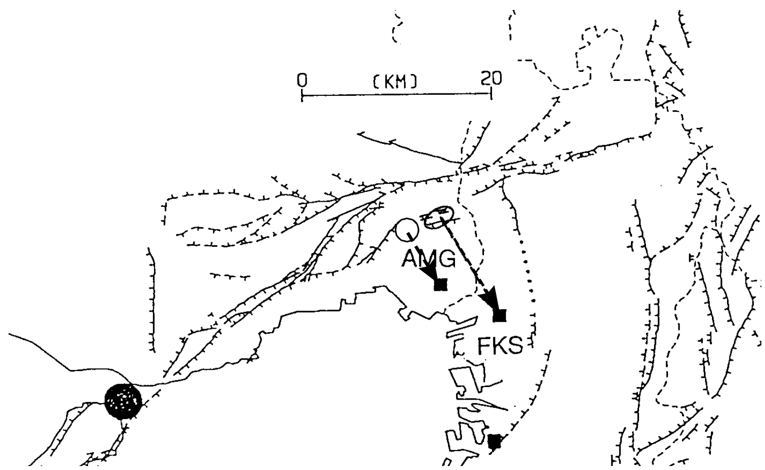

Figure 2. Schematic figure for propagation of basin-induced Love wave. The basin-induced Love waves are originated around circled areas, then propagate to the each site. Solid circle is the epicenter.

Results

Basin-induced surface waves, direct waves and estimated ground motions at Fukushima are displayed in Fig.3 with those Fourier spectra. Recorded ground motions are also shown in Fig.3.

Comparing ground motion by the 1-D model with recorded ones, the followings are pointed out.

1) Timing and pulse width of initial S-waves by the 1-D model are almost equal to recorded ones. It is indicated that the source and velocity structure models used in this study are adequate.
2) Amplitude of S-wave by the 1-D model on north-south component is very small. This phenomenon might be due to a radiation pattern. Further study for a focal mechanism is needed.
3) Later phases are not remarkable in the 1-D model, while recorded ones are significant. These facts are good evidence of 3-D effects.

Time histories of estimated ground motions are close to the recording ground motions in both amplitudes and phases. In Fourier spectra, amplitude of estimated ground motion is close to recorded one at around five second, because this period is the targeted airy phase of fundamental Love wave. However, there is a big discrepancy around one second. The reason might be the slip time functions of the fault model. This is one of the reasons that amplitude of north-south component is very small. Around two second, discrepancy is also found. We think that this period range corresponds to another mode surface wave. If we take account plural surface waves, the result will be better.

In Fig.4, results of our method and recorded ground motion at Amagasaki are shown. Features are the same as the case of Fukushima. In the time histories, the estimated and recorded ground motions are close in both amplitudes and phases. The airy phase of targeted Love wave is around six seconds. In spectra of the north-south component, the amplitude of estimated ground motion at six second is equal to the recorded one, while on the east-west component, the proposed method overestimates the amplitude.

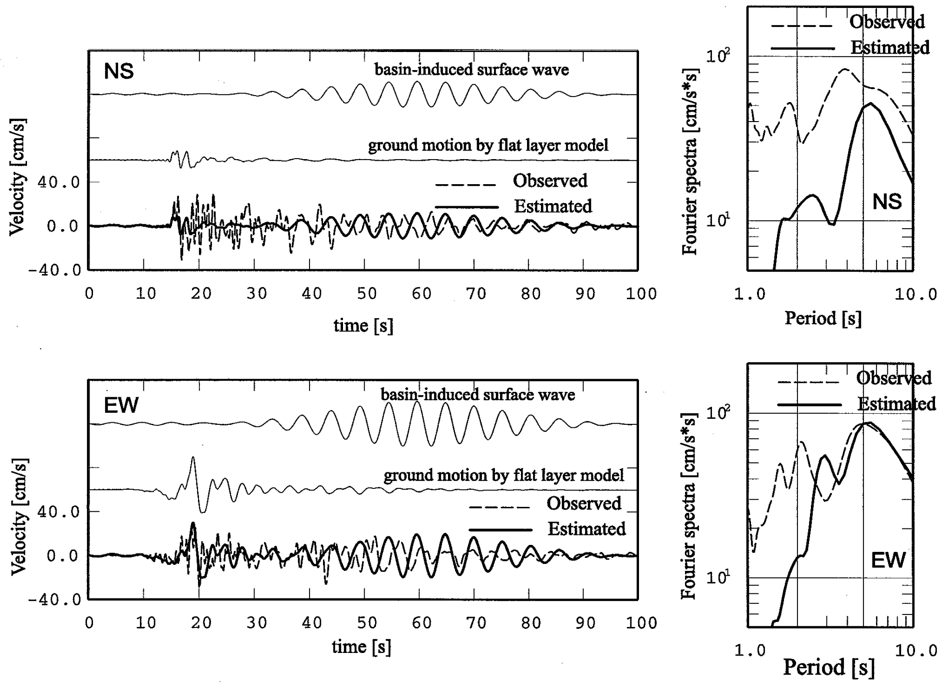

Figure 3. Estimated basin-indued Love wave, direct body and surface waves, and ground motion with oberved one at station Fukushima. Fourier spectra for estimated and recorded ground motions are shown on the right side.

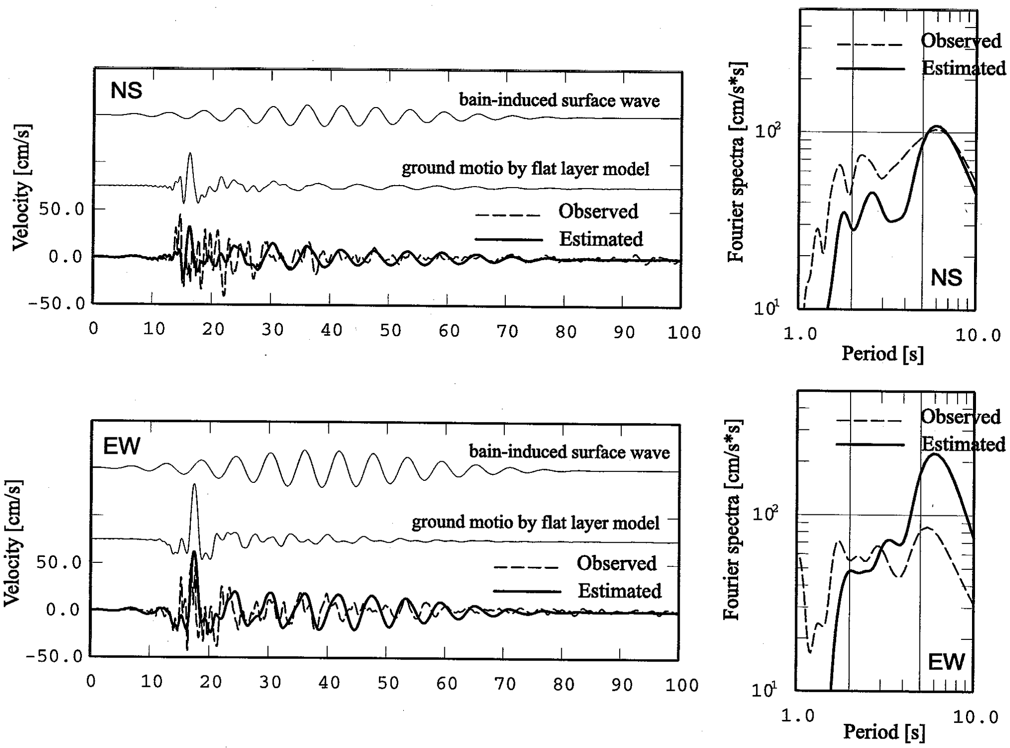

Figure 4. Same as Fig.3 but for station Amagasaki.

Conclusion

We propose a simplified method for estimation of long-period basin response and apply to the 1995 Hyogo-ken Nanbu earthquake. The estimated ground motions at stations Fukushima and Amagasaki are close to the recorded ground motions. Additionally through this study, an importance of the 3-D basin effect is pointed out. As one merit of the proposed method is less time consuming, this method works well at the stage of selecting a scenario earthquake from many earthquake models.

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