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A SEMI-EMPIRICAL METHOD TO SYNTHESIZE EARTHQUAKE GROUND MOTIONS BASED ON APPROXIMATE SOURCE SPECTRUM FOR FAR-FIELD SHEAR WAVE

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SUMMARY

A new synthesis method, to simulate ground motions during a large earthquake by utilizing records for small events as Green's functions, is proposed to apply to a period range of about 0.1 to 10 seconds. The method is based on the assumption that the source spectra of the large and the small events can be modeled by an approximate source spectrum for far-field shear wave proposed by Brune. The difference of long-period motions between the two events is taken into account by considering the seismic moment, and that of short-period motions by considering the effective stress and the fault area.

INTRODUCTION

In a semi-empirical method, it is the key to evaluate the difference of the source time functions between a small event and a large event [1]. For the synthesis of the ground displacement or velocity motions, the number of superposition of the small-event records is basically the ratio of the seismic moment between the small and the large events [2,3]. This may correspond to the fact that the seismic moment is determined from the amplitudes of the motions whose period is longer than several tens of seconds. On the other hand, for the synthesis of the acceleration motions, we must consider the efficiency of generation of short-period motions that does not directly correspond to the seismic moment. When the efficiencies per unit area of the two events are the same level, all we have to consider is the difference of the fault area of the two events [4,5].

However the mechanism of the generation of short-period motions has not been well investigated yet and it is still under research. Hence, we will adopt an approximate source spectrum for far-field shear wave proposed by Brune [6], in which the efficiency is represented as an effective stress on a rupturing fault plane. In this paper, we will show some formulas to represent the large-event motions by utilizing the small-event records based on the assumption that both of the two source spectra can be modeled by Brune's spectrum. This new method will be applied to the velocity and acceleration motions during the fore shock and the main shock of the 1980 Izu-Hanto-Toho-Oki earthquake. The predominant period of the velocity motions is about 10 seconds and that of the acceleration motions is about 0.1 to 1 seconds.

SYNTHESIS METHOD

An approximate source spectrum for the far-field shear-wave displacement proposed by Brune can be described by

$$\Omega(\omega) = F^{S}\cdot\left(\frac{\lambda}{r}\right)\cdot\left(\frac{\sigma_e}{\mu}\right)\cdot\frac{\beta}{(\omega_c + j\omega)^2}\cdot\left(1-\frac{2\pi}{Q}\right)^{\omega r/4\pi\beta} \tag{1}$$

Here F^S is the radiation pattern of the shear wave, λ the source size, r the hypocentral distance, σ_e the effective stress, μ the rigidity of the medium, β the shear wave velocity, ω_c the corner frequency, $j=\sqrt{-1}$ and Q the quality factor. According to the theoretical solution of a shear-wave displacement generated by a double-couple force, the corner frequency is given by

$$\omega_c = 2\beta\sqrt{\pi\lambda\sigma_e/M_0}, \tag{2}$$

where M_0 is the seismic moment.

Taking into account that $\lambda=\sqrt{LW/\pi}$ and $M_0=\mu LWD$, where L is the ruptured fault length, W the width and D the average dislocation and assuming that ratios of the ruptured fault length, width, average dislocation and effective stress of the large event to those of the small event are equal to a, b, c and d, the expected spectrum generated by the (p,q) element whose size is equal to that of the small event is described by

$$\Omega_{pq}(\omega) = \left(\frac{r_s}{r_{pq}}\right)\cdot d\cdot\left(\frac{\omega_{cs}+j\omega}{\omega_{cs}\sqrt{d/c}+j\omega}\right)^2\cdot\left(1-\frac{2\pi}{Q}\right)^{\omega(r_{pq}-r_s)/4\pi\beta}\cdot\Omega_s(\omega). \tag{3}$$

Here F^S, μ, β and Q for the large event are all assumed to be the same as those for the small event. The subscripts pq and s indicate values for the (p,q) element and the small event, respectively.

Consequently, the expected motion during the large earthquake is given by

$$u_l(t) = \sum_{p=1}^{a}\sum_{q=1}^{b} u_{pq}(t-t_{pq}), \tag{4}$$

where u_{pq} is the inverse Fourier transform of equation (3) and t_{pq} is the traveling time-lag for the rupture process and the wave propagation.

APPLICATION TO THE 1980 IZU-HANTO-TOHO-OKI EARTHQUAKE

Figure 1 shows the location of the fault plane for the main shock (M 6.7) projected on the surface, the epicenter of the fore shock (M 4.9) and the recording stations. The velocity motions were recorded at station Omaezaki (34.60°N, 138.21°E) and the acceleration motions at stations Takada (35.28°N,139.19°E) and Kawana (34.95°N,139.13°E). The parameters used for the simulation are summarized in Table 1. The locations are taken after Matsu'ura [7] and the ruptured fault length and the width correspond to the distribution of the swarm shown in Figure 8. Here the width is assumed to be a half of the length. The ratios a, b and c are all assumed to be equal to 6 and d equal to 1, based on the similarity relations of earthquakes proposed by Kanamori and Anderson [8]. Other parameters are obtained to fit the spectra shown in Figures 2 to 7 by the trial and error approach in reference to the results of other researchers.

Figure 2 shows the observed and modeled Fourier spectra of the velocity

Table 1. Source parameters for the synthesis of the 1980 Izu-Hanto-Toho-Oki earthquake.

			Fore shock	Main shock
Origin time			6/28, 12:05	6/29, 16:20
Latitude			34.922°N	34.892°N
Longitude			139.230°E	139.228°E
Focal depth		[km]	11.6	10.5
Magnitude	M		4.9	6.7
Fault length	L	[km]	2.7 (16/6)	16
Fault width	W	[km]	1.3 (8/6)	8
Source size	λ	[km]	1.06	6.4
Dislocation	D	[m]	0.17 (1/6)	1
Seismic moment	M_0	[dyne·cm]	2.4×10^{23}	5.1×10^{25}
Effective stress	σ_e	[bar]	30	30
Corner frequency	$\omega_c/2\pi$	[Hz]	0.79	0.13
Distance (Omaezaki)	r	[km]	100.6	99.3
Distance (Takada)	r	[km]	42.0	45.0
Distance (Kawana)	r	[km]	15.1	15.3

			Common parameters
Rigidity	μ	[dyne/cm^2]	4.0×10^{11}
Shear wave velocity	β	[km/sec]	3.8
Density	ρ	[g/cm^3]	2.8
Quality factor	Q		250

motions at station Omaezaki. Figure 3 shows the ratios of the spectra. Figures 4 to 7 show the Fourier spectra and the ratios of the acceleration motions at stations Takada and Kawana. The modeled spectra represent the observed ones pretty well and the modeled ratios, which are more important for the simulation by the semi-empirical method, agree with the observed ones in sufficient accuracy. After examining the results by changing parameters, we adopted the fault model for the synthesis shown in Figures 8 (a) and (b). The circles in Figure 8 (a) are the distribution of the swarm of the 1980 Izu-Hanto-Toho-Oki earthquake taken after Matsu'ura [7]. The square dots in Figure 8 (b) are the location of the point sources for the elements of the main shock.

Figure 9 is the result at station Omaezaki for (a) the fore-shock velocity motion (M 4.9), (b) the synthesized main-shock motion and (c) the observed main-shock motion (M 6.7). Figures 10 and 11 are the results at stations Takada and Kawana. Although the agreement of the waveforms is not so good as the result at station Omaezaki, the level and the duration time of the strong motions are considered to be simulated well. Figures 12 and 13 are the comparison of the velocity response spectra with a damping factor of 0.05 for the acceleration motions shown in Figure 10 and 11, respectively. The solid lines are for the observed motions and the dotted lines are for the synthesized motions. It is apparent that the spectral characteristics of the motions agree well in the period range of 0.02 to 5 seconds.

CONCLUDING REMARKS

The semi-empirical method proposed in this paper, based on an approximate source spectrum for far-field shear wave, simulates well the ground motions during the main shock of the 1980 Izu-Hanto-Toho-Oki earthquake. The predominant periods are in the range of about 0.1 to 10 seconds.

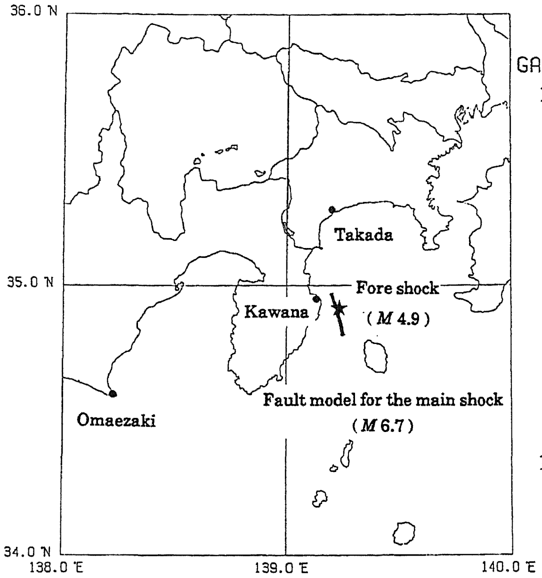


Fig. 1. Location of the 1980 Izu-Hanto-Toho-Oki earthquake. The star indicates the epicenter of the fore shock used as Green's function. Velocity motions were recorded at station Omaezaki and acceleration motions at stations Takada and Kawana.

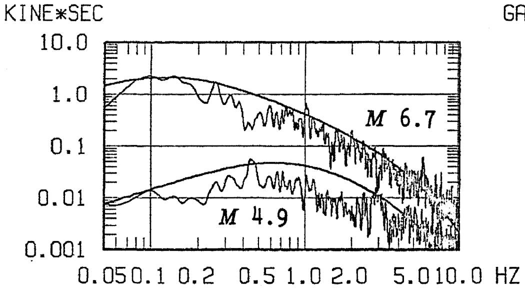


Fig. 2. Observed and modeled Fourier spectra of the velocity motions at station Omaezaki (EW component).

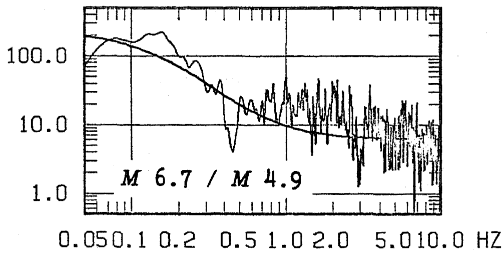


Fig. 3. Ratios of the spectra shown in Figure 2.

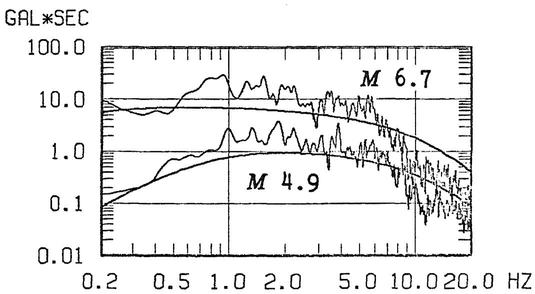


Fig. 4. Observed and modeled Fourier spectra of the acceleration motions at station Takada (EW component).

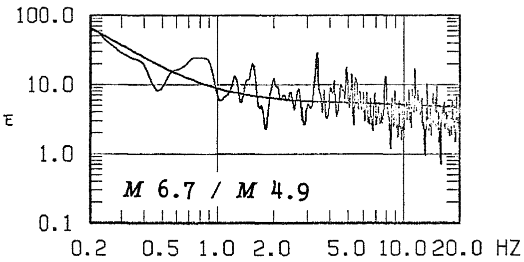


Fig. 5. Ratios of the spectra shown in Figure 4.

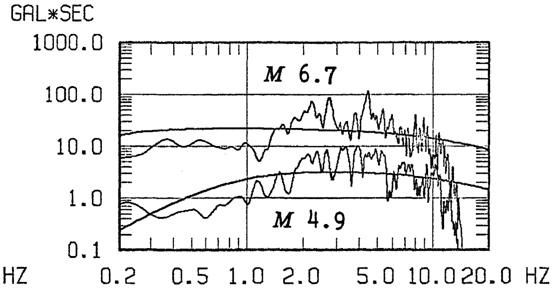


Fig. 6. Observed and modeled Fourier spectra of the acceleration motions at station Kawana (EW component).

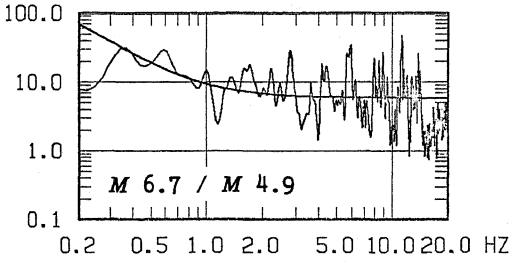
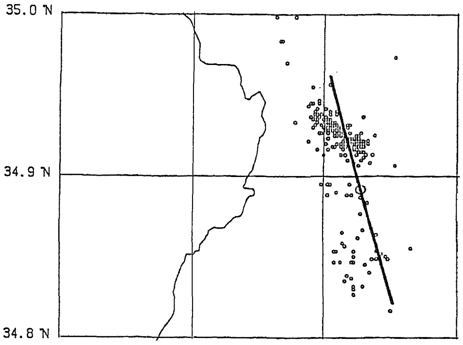
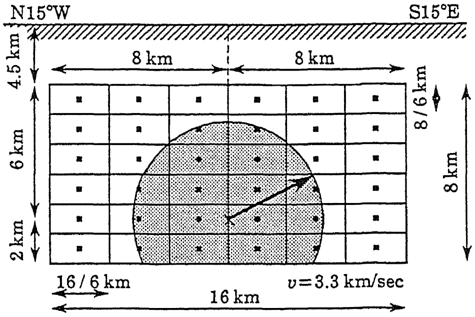


Fig. 7. Ratios of the spectra shown in Figure 6.

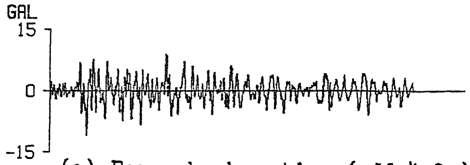


(a) Projection on the surface

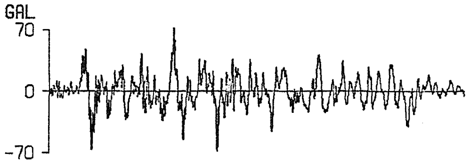


(b) Division of the fault plane

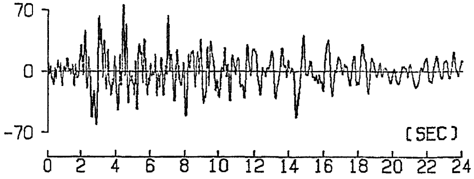
Fig. 8. Fault model for the synthesis.



(a) Fore-shock motion (*M* 4.9)

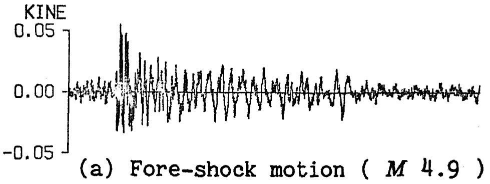


(b) Synthesized main-shock motion

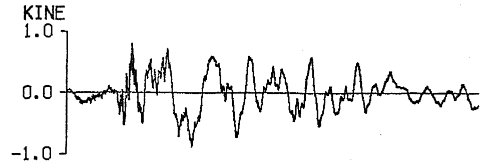


(c) Main-shock motion (*M* 6.7)

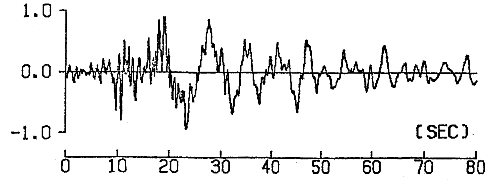
Fig. 10. Comparison of the observed and synthesized acceleration motions at station Takada (EW component).



(a) Fore-shock motion (*M* 4.9)

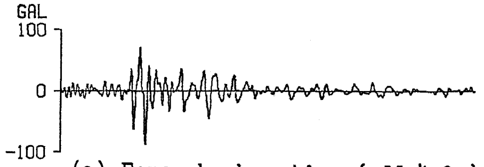


(b) Synthesized main-shock motion

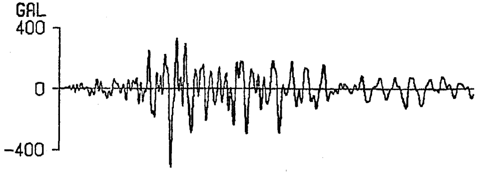


(c) Main-shock motion (*M* 6.7)

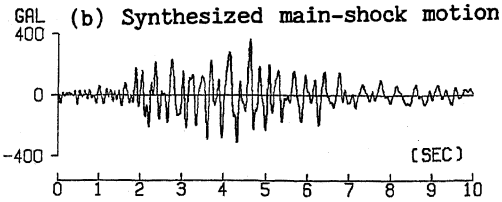
Fig. 9. Comparison of the observed and synthesized velocity motions at station Omaezaki (EW component).



(a) Fore-shock motion (*M* 4.9)



(b) Synthesized main-shock motion



(c) Main-shock motion (*M* 6.7)

Fig. 11. Comparison of the observed and synthesized acceleration motions at station Kawana (EW component).

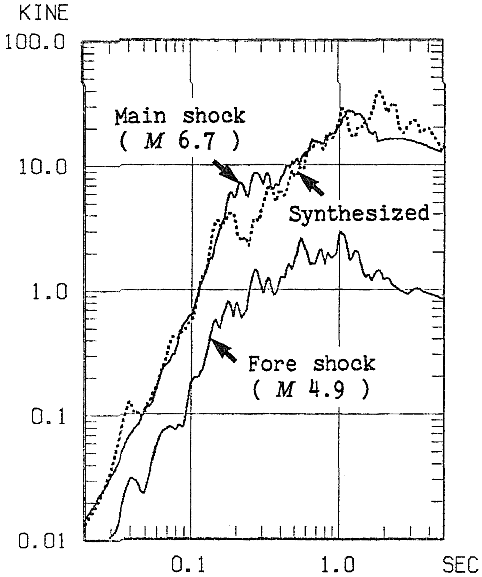


Fig. 12. Comparison of the velocity response spectra for the acceleration motions shown in Figure 10.

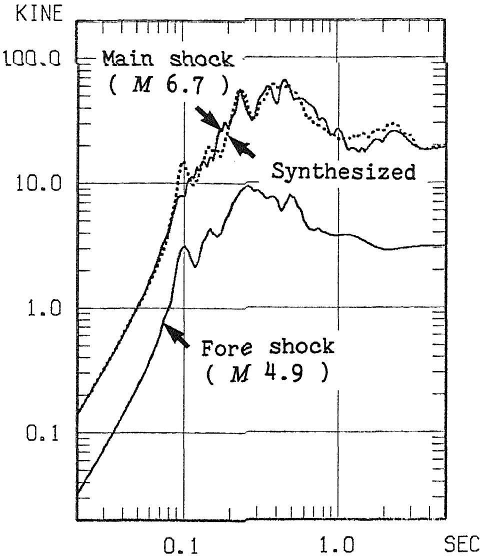


Fig. 13. Comparison of the velocity response spectra for the acceleration motions shown in Figure 11.

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