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Source model composed of asperities for the 2003 Tokachi-oki, Japan, earthquake ($M_{JMA} = 8.0$) estimated by the empirical Green's function method

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A preliminary source model composed of asperities for the 2003 Tokachi-oki, Japan, earthquake ($M_{JMA} = 8.0$) was estimated by the empirical Green's function method. The source parameters for three asperities located on the fault plane were determined from the comparisons of the synthesized broad-band ground motions with the observed ones. We found that the pulsive waveforms observed in north direction of the hypocenter were generated by the forward rupture directivity effect. Furthermore, the estimates of the stress parameter for asperities are higher than the averaged ones for past inland and subduction earthquakes.

Key words: Source model, asperity, broad-band strong ground motion, forward modeling, empirical Green's function method.

1. Introduction

The September 26, 2003 Tokachi-oki, Japan, earthquake ($M_J MA = 8.0$) occurred on the plate interface between the North American plate and the subducting Pacific plate. In this earthquake, many strong ground motions from the mainshock as well as aftershocks have been recorded by the strong motion observation networks of the K-NET, KiK-net, and so on. The understanding of the source characteristics for explaining broad-band strong ground motion recordings is very important in verification of the recipe by Irikura *et al.* (2003) for strong ground motion prediction for future subduction earthquakes. This paper provides a preliminary source model for the 2003 Tokachi-oki earthquake estimated by the empirical Green's function method (Irikura, 1986). In our simulation, we determine a source model composed of asperities which is capable of reproducing broad-band strong ground motions using a forward modeling approach. We assume that ground motions are generated from several asperities, each of which has a uniform stress drop with a finite extent on the mainshock fault plane and obeys an ω^{-2} spectral scaling. Their locations are determined based on an inverted slip model. This procedure is the same as Kamae and Irikura (1998).

2. Strong Ground Motion Data

We used borehole data at eight stations obtained by KiK-net of the National Research Institute for Earth Science and Disaster Prevention. The locations of these stations are shown in Fig. 1 together with the epicenters of the mainshock and the aftershock used here as the empirical Green's function. Table 1 shows the information of the aftershock and its source parameters estimated roughly from the borehole data of KiK-net which is not affected strongly by the reflected wave from the surface. We used the aftershock data bandpass-filtered between 0.1 and 10 Hz.

3. Source Model and Synthetics

Several inverted source models have already been estimated from teleseismic data or/and strong ground motion data. In this study, we referred to the slip model by Yamanaka and Kikuchi (2003) to determine the locations of each asperity. Figure 2 shows the slip model by Yamanaka and Kikuchi (2003). This inverted source model has three separate regions with relatively large slip, hereafter referred to as asperities. The first asperity (Asp-1) is located near the rupture nucleation point (hypocenter); the second (Asp-2) in the deeper part of north-west direction of the hypocenter; and the third (Asp-3) in the deepest part of north direction of the hypocenter. Our objective is to determine a source model capable of explaining broad-band motions containing low- and high-frequency components. To accomplish this, we assumed a simplified source model composed of asperities located on three regions shown in Fig. 2. We assumed that the ground motions should be generated only from the three subevents that correspond to Asp-1, Asp-2, and Asp-3. We adjusted the locations, sizes, and stress parameters of those three subevents to fit the simulated motions to the observed ones using a forward modeling approach. We assumed an S-wave velocity of 3.8 km/s along the wave propagation path and a rupture velocity of 2.8 km/s on the fault plane. Furthermore, we assumed that the rupture should start from the inside subevent (Asp-1) near the hypocenter and propagated radially.

After several trials, we obtained the best source model shown in Fig. 2. The source parameters for each subevent are summarized in Table 2. Here, the size and stress param-

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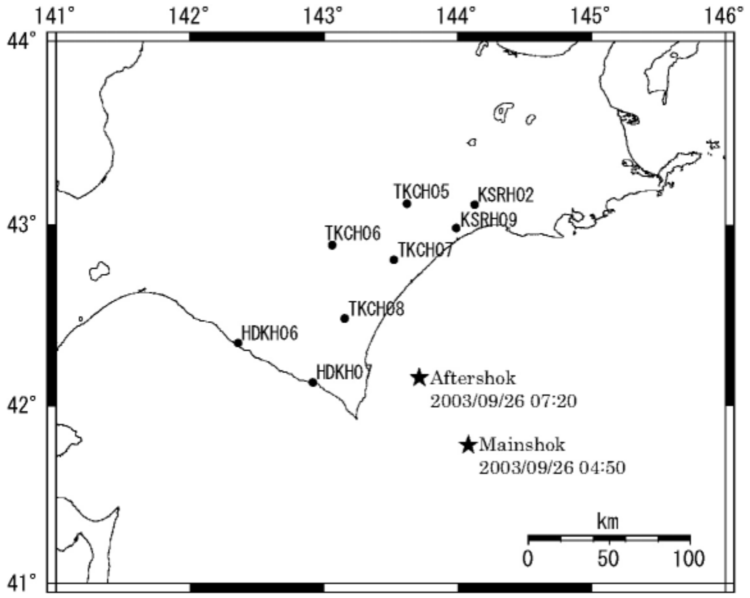

Fig. 1. Map showing the KiK-net station locations and epicenters of the mainshock and the aftershock that are used as the empirical Green's function.

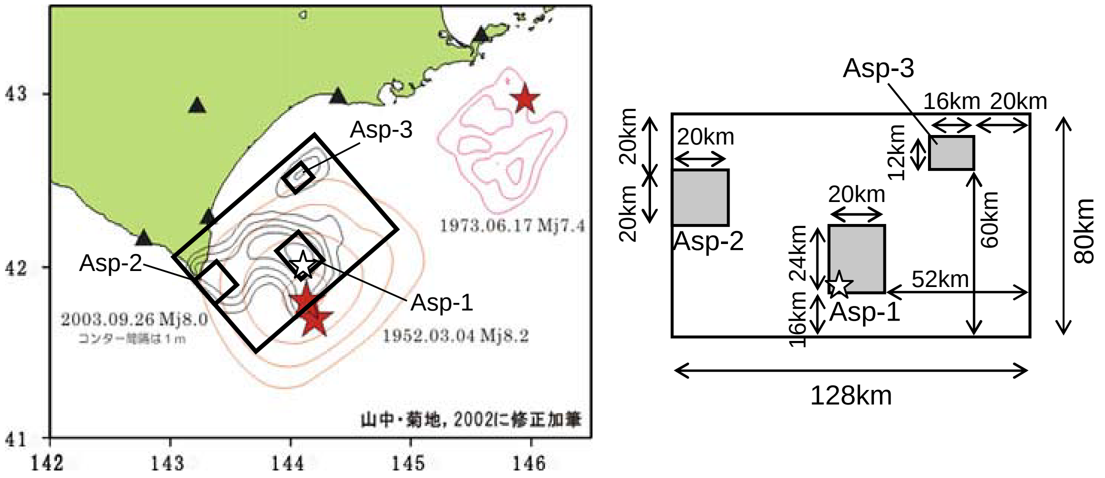

Fig. 2. Source model consisting of three asperities estimated from forward modeling using the empirical Green's function method. Our model (rectangles) is superimposed on the inverted slip model of Yamanaka and Kikuchi (2003). is the rupture starting point in our simulation.

Table 1. Aftershock and its source parameters.

Date	2003/9/26 7:20
Latitude (deg)	42.154
Longitude (deg)	143.712
Depth (km)	41.4
M_{JMA}	5.4
Strike (deg) #	43.4 / 215.8
Dip (deg) #	26.1 / 64.0
Rake (deg)#	96.8 / 86.7
Seismic moment (N*m)	1.4×10^{17}
Fault area (km^2)	16
Stress drop (MPa)	5MPa

Mechanisms by Hi-net

Table 2. Source parameters for each asperity.

	M_0 (N*m)	L(km) × W(km)	$\Delta\sigma$ (MPa)
Asp-1	2.31×10^{20}	20 × 24	50
Asp-2	8.75×10^{19}	20 × 20	25
Asp-3	2.94×10^{19}	16 × 12	25

eter for Asp-1 were determined to match the predominant period and velocity amplitude of the typical large pulse seen at TKCH07. On the other hand, the source parameters for Asp-2 and Asp-3 were roughly determined from the comparison between the synthesized waveforms (amplitude and duration) and the observed ones at the stations influenced by the contribution from each subevent. The stress parameters (stress drop) of asperities are higher than the averaged ones (about 10 MPa) for past inland and subduction earthquakes. As examples, the synthesized motions at HDKH07, KSRH02, TKCH05, TKCH06, and TKCH07 are compared with the observed ones in Fig. 3. In particular, we find

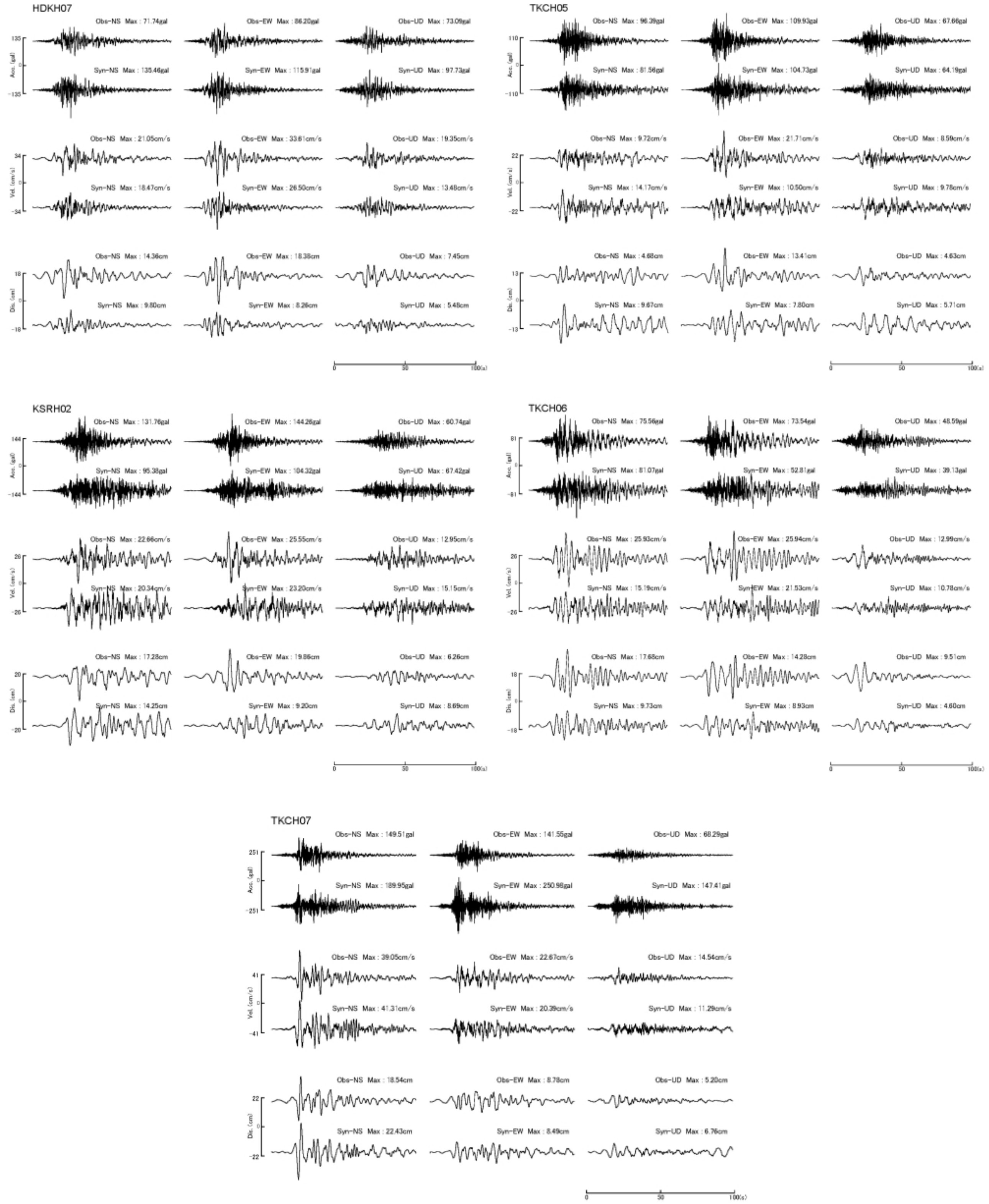

Fig. 3. Comparison between the synthesized and observed motions at HDKH07, KSRH02, TKCH05, TKCH06 and TKCH07.

that the velocity pulse from Asp-1 at TKCH07 is successfully reproduced. This pulse is generated by forward rupture directivity effect due to rupture propagation from south to north direction inside Asp-1. Figure 4 shows the comparison between the synthetic and observed pseudo-velocity response spectra (PVRS) for a damping factor of 0.05. The synthesized PVRS agree well with the observed ones over a broad period range (0.1–10.0 sec) in almost all the sites where we tried to simulate the ground motions. However, there are discrepancies of fitting in two horizontal components, especially in low frequency range. These discrepancies may be caused by the simulations without the correction of the radiation patterns, although the corresponding aftershock has slightly different focal mechanisms from

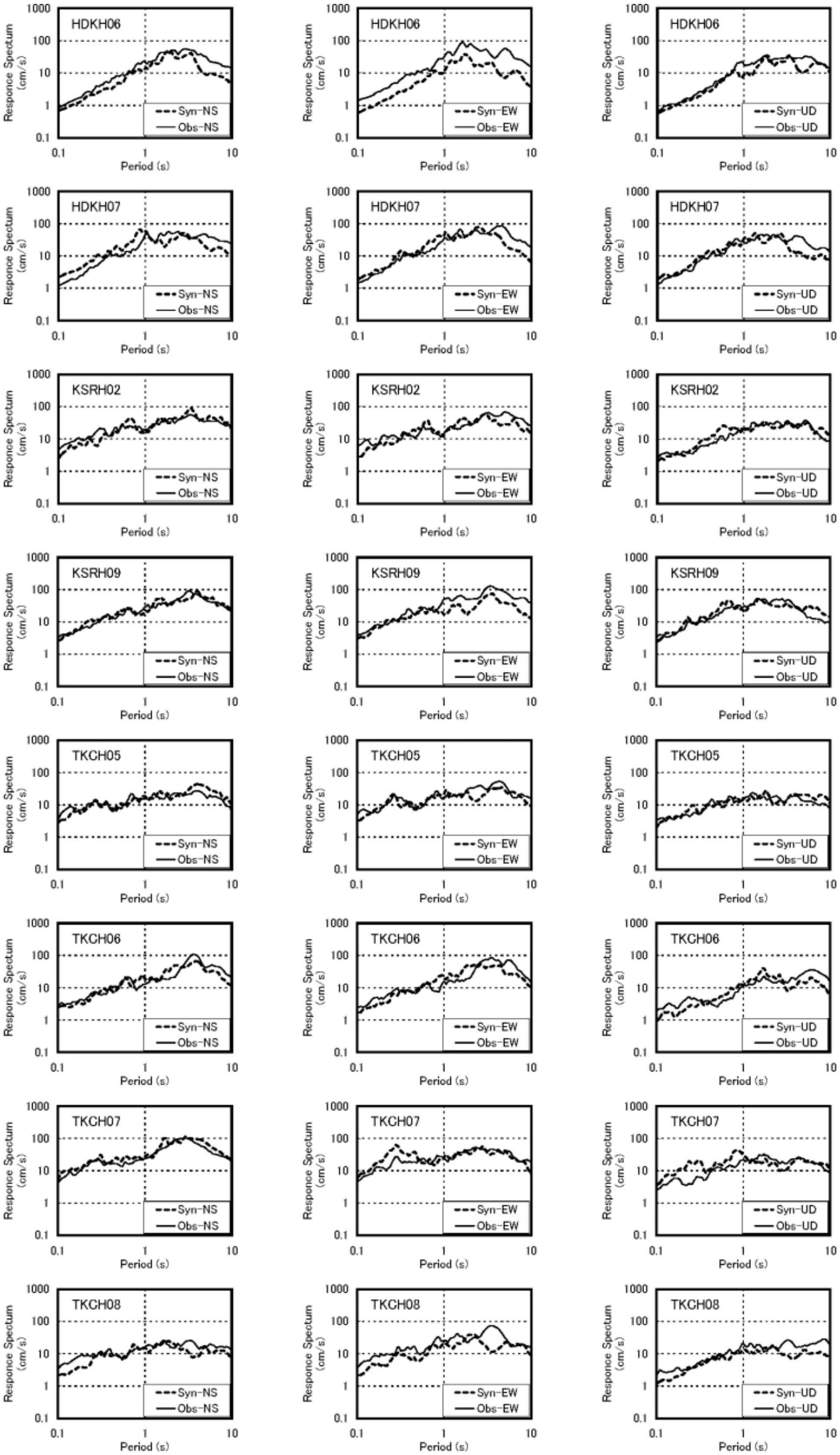

Fig. 4. Comparison of the pseudo-velocity response spectra (PVRS) with damping factor of 0.05 of the synthesized motions and those of the observed motions at eight sites. Bold dotted line shows the PVRS of the synthesized motions. Solid thin line shows the PVRS of the observed motions.

the mainshock (Strike=230°, Dip=20°, Rake=109°). To investigate this hypothesis, we calculated roughly the radiation coefficients of both horizontal components for the mainshock (only Asp-1) and the aftershock on assumption of a point source. Figure 5 shows the estimates of the radiation coefficients at eight stations. Although we cannot explain

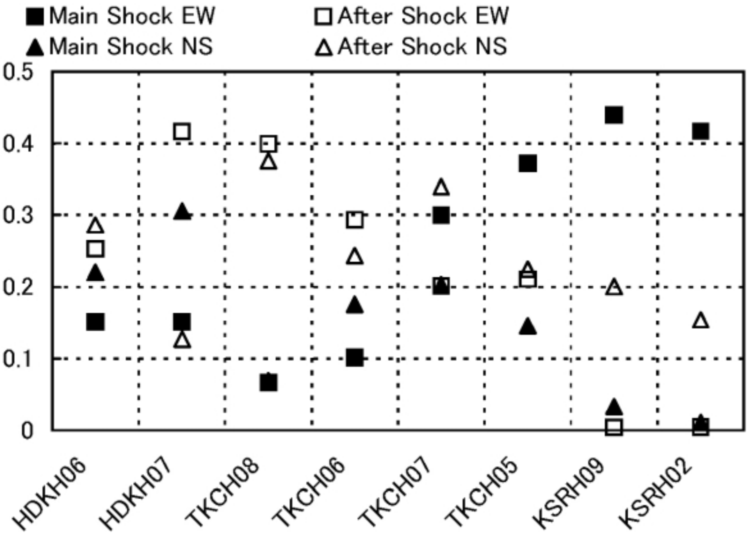

Fig. 5. Radiation coefficients for both horizontal components at eight stations calculated assuming a point source. The estimates for the mainshock are calculated for only Asp-1.

completely the discrepancies between the synthetics and the recordings by only radiation pattern, this figure shows the possibility that the conspicuous underestimation of the amplitude in EW component at KSRH02 in Fig. 3 comes from the effect of the radiation pattern. We obtained the same result at KSRH09.

4. Conclusions

We tried to estimate the source model composed of asperities by the forward modeling using the empirical Green's function method. Finally, we determined the source parameters for three asperities located on the fault plane from the comparisons between the synthesized broad-band strong ground motions and the observed ones. We need to revise the estimates of the source parameters for asperities after the more detailed analysis and investigate the validation of the framework of the strong ground motion prediction for future great subduction earthquakes based on the recipe by Irikura *et al.* (2003).

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