Source Model of the Largest Aftershock of the 2004 Mid-Niigata Prefecture Earthquake

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1. Introduction

At 17:56 (JST) on 23 October 2004, a strong earthquake of magnitude 6.8 (M_{JMA}) occurred in the Chuetsu region of Niigata prefecture, central Japan. This earthquake was followed by the number of aftershocks which has magnitude (M_{JMA}) greater than 6. The first large aftershock (M_{JMA} 6.3) occurred at 18:03 on October 23, 2004, the second (M_{JMA} 6.0) at 18:11, the third (M_{JMA} 6.5) at 18:34, and the fourth occurred on October 27 at 10:40 with a magnitude of M_{JMA} 6.1. The magnitude of these aftershocks is almost same with that of the mainshock. As an event smaller than the mainshock, usually the largest aftershock has also a magnitude smaller than the mainshock.

One of the causes occurred many large events is that the mainshock and 4 large aftershocks were generated by the different fault planes which nearly parallel or perpendicular to each other. The source faults of the mainshock and the largest aftershock were parallel[1].

Source models of the mainshock for this earthquake have already been studied from waveform inversion using strong motion data by many authors. The purpose of this study is to determine the source model of the largest aftershock in a broadband frequency range from smaller events using the EGF-method of Irikura[2] and compared with observed records. After this, we call the largest aftershock to be simulated as the mainshock. Figure 1 presents the positions of the mainshock and aftershock for this study.

2. Methodology

The idea of studying large earthquakes by means of seismograms of small earthquakes, used as Empirical Green's Function (EGF), was introduced by Hartzell in 1978. The main idea of the EGF method is that the small earthquakes carry complete information about the properties of propagation path and local site effects so that the computation of these properties is not required. The following numerical equations can be used to synthesize the simulated waveform of the large event by summing the records of small events[2].

$$U(t) = \sum_{i=1}^{N}\sum_{j=1}^{N}\frac{r}{r_{ij}}F(t) * (C \cdot u(t)) \quad (1)$$

$$F(t) = \delta(t-t_{ij}) + \frac{1}{n'}\sum_{k=1}^{(N-1)n'}\left[\delta\left\{t-t_{ij}-\frac{(k-1)T}{(N-1)n'}\right\}\right] \quad (2)$$

$$t_{ij} = \frac{r_{ij}-r_o}{v_s}+\frac{\xi_{ij}}{v_r} \quad (3)$$

where $U(t)$ is the synthesized waveform for the large event (acceleration, velocity or displacement) and $u(t)$ is the waveform of the small event.

3. Data Description

For the purpose of synthesizing the mainshock motions, we used the observed waveform data recorded at four stations (NIGH01, NIGH11, NIGH12, and FKSH21) of KiK-NET installed by National Research Institute for Earth Science and Disaster Prevention (NIED). The location of the KiK-NET stations are shown in Figure 1 together with epicenters of mainshock and aftershock.

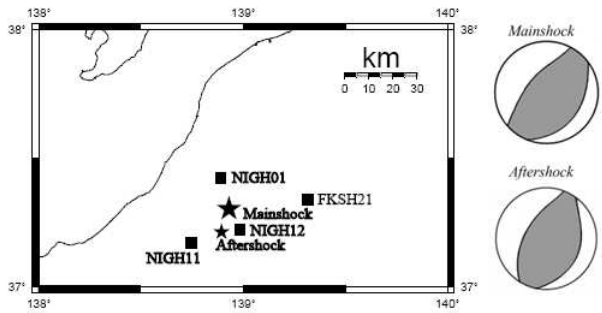

Fig. 1 Map showing the location of KiK-NET stations (square) used for analysis and epicenters of the mainshock (big star) and aftershock (small star) was made using the *Generic Mapping Tools* (GMT) software. The focal mechanisms of the mainshock and aftershock by F-NET are shown in the right.

The seismic moments and focal mechanisms of the mainshock and aftershocks were determined from the F-NET by NIED. In this work, we used two components (NS, EW) acceleration records of the M_{JMA} 4.8 aftershock at 9:28 on October 24, 2004 as the EGF. Source parameters of the mainshock and an aftershock are listed in Table 1. The range of frequency used to filter the waveforms was from 0.2 to 10 Hz.

Table 1 The information of the mainshock and an aftershock

	Mainshock	Aftershock
Latitude	37.303E	37.213E
Longitude	138.932N	138.895N
Depth (km)	14	12
Mw	6.5	4.8
Mo (N·m)	2.93×10^{18}	9.85×10^{15}
Strike, Dip, Slip	221, 59, 94	210, 53, 95

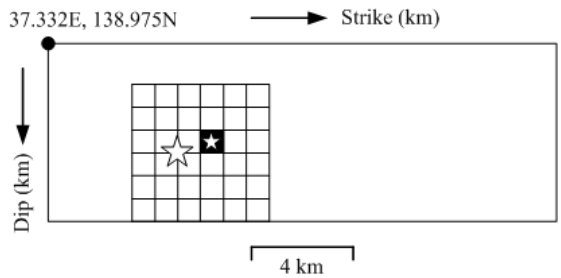

Fig. 2 Asperity model used in this study. The small star is the rupture starting point. The big one is the epicenter of the mainshock of magnitude 6.5 located at (37.317E, 138.899N).

Figure 2 shows the source model of the mainshock consisting of one asperity, which is around the epicenter of the mainshock of magnitude 6.5 (M_{JMA})[3].

4. Result and Discussion

We assumed an S-wave velocity of 3.5 km/s along the wave propagation path and a rupture velocity of 2.45 km/s on the fault plane. We obtained the best source model shown in Figure 2 after several trials. The scale parameter N was estimated to be 6. The length, width, and risetime were determined to be 5.48 km, 5.48 km, and 0.6 s, respectively. The rupture starting point was estimated (4,3) as shown in Figure 2. Seismic moment and stress drop were estimated to be 1.28×10^{18} N·m and 20 MPa, respectively. The simulated and observed seismograms of NIGH12 station for NS and EW components are shown in Figure 3. At this station simulated accelerations and velocity are close to the the actual recordings. The synthetic and observed displacement waveform is in good agreement for NS components, but for EW component the synthetic displacement records do not match appearance wise with the recorded component. A comparison of the response spectra at 5% damping presented in Figure 4 also shows that these results have no big difference between the synthetic and observed waveforms. In general, the comparisons of records at other stations (NIGH01, NIGH11, and FKSH21) were similar although the synthesized waveforms did not completely agree with the observed ones.

The difference between the synthesized and observed waveforms was caused by the source region of the earthquakes containing complex geological structures and numerous faults and cracks related to past tectonic activities[3].

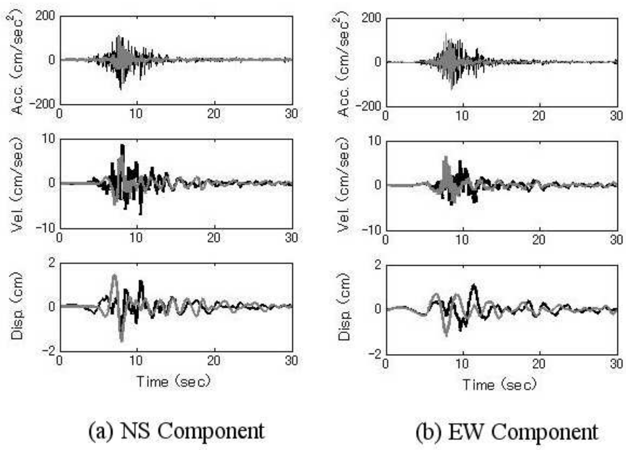

Fig. 3 Comparison of observed and synthetic waveforms at NIGH12 Station. The black and gray colors indicate the observed and synthetic waveforms, respectively.

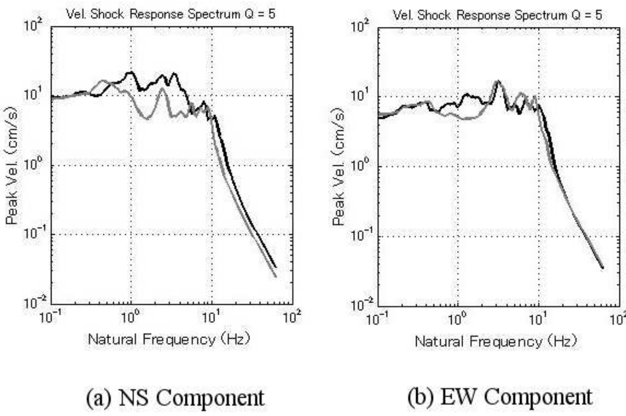

Fig. 4 Comparison of the pseudo-velocity response spectra (PVRS) of the synthesized motions (gray color) and those of the observed motions (black color) at NIGH12 station.

5. Conclusions

The EGF method formulated by Irikura was used to estimate the source model of the asperity located on the fault plane modeling of the largest aftershock. Beside geophysical and geological factors, the study of EGF method shows that the results of the simulation are dependent on the selected aftershock record and the selection of the appropriate aftershock, which can be used as EGF.

References

1) Shibutani, T. : Aftershock distribution of the 2004 Mid Niigata Prefecture Earthquake derived from a combined analysis of temporary online observations and permanents observations, *Earth Planets Space*, **57** (2005), pp. 545-549.
2) Irikura, K. : Estimation of strong ground motion in broad-frequency band based on a seismic source scaling model and an empirical Green's function technique, *Annali di Geofisica*, **37** (1994), pp. 1721-1743.
3) Hikima, K. : Rupture processes of the 2004 Chuetsu (mid-Niigata prefecture) earthquake, Japan: A series of events in a complex fault system, *Geophys. Res. Lett*, **32** (2005), pp. 1-5.