SOURCE CHARACTERIZATION OF INLAND CRUSTAL EARTHQUAKES FOR NEAR-SOURCE GROUND MOTIONS

Hiroe Miyake*, Tomotaka Iwata**, and Kojiro Irikura***

ABSTRACT

To obtain the characterized source model for prediction of strong ground motions, we estimated strong motion generation area and its rupture geometry of inland crustal earthquakes from near-source ground motion records. The source parameters related to the strong ground motion were estimated by waveform simulation using the empirical Green's function method. The synthetic waveforms from the source model with large and uniform slip velocity as strong motion generation area fit well to the observations (0.2~10Hz). We found a self-similar scaling relationship between the strong motion generation area and seismic moment, and clarified that this area was coincident with the asperity area characterized from heterogeneous spatial slip distribution estimated by waveform inversions using low frequency (<1Hz).

Introduction

A lot of waveform inversions using low frequency (<1Hz) of the strong ground motion records have been performed to examine source processes precisely. As a consequence of these analyses, it became clear that most large inland crustal earthquakes have heterogeneous spatial slip distribution. In order to catch the feature of heterogeneous source model, source characterization and scaling for heterogeneous slip distribution have been just started (e.g Somerville *et al*., 1999; Mai and Beroza, 2000). Characterized source model is expressed quantitatively including not only macroscopic fault parameters but also roughness of slip distribution such as asperity or effective source dimension. Somerville *et al*. (1999) characterized source model composed of asperities and background slip surrounding the asperities, both of which are expressed as finite extended areas with homogeneous slip distribution.

The source characterization so far done is available only for lower frequency motions less than 1Hz because of the resolution of the waveform inversion. For the purpose of the source characterization applicable to broad frequency band, we estimate source parameters related to strong ground motion using the empirical Green's function method. Then we clarify

* Graduate Student, Disaster Prevention Research Institute, Kyoto University
** Research Associate, Disaster Prevention Research Institute, Kyoto University
*** Professor, Disaster Prevention Research Institute, Kyoto University

the relationship between the strong motion generation area and heterogeneous spatial slip distribution.

Data

We examined seven inland crustal earthquakes (M_{JMA}4.9~6.5) occurring in Japan from 1996 to 1999 (Fig. 1). Strong ground motion records were provided by K-NET (Kinoshita, 1998), and nearest (within 20km) four stations surrounding the source areas were used for strong ground motion simulations. As the empirical Green's function for simulating the mainshocks, we selected the records of aftershocks whose focal mechanisms and hypocentral distance were similar to their respective mainshocks. The fault planes of the mainshocks were referred to focal mechanism solutions using moment tensor inversions (e.g. Dziewonski *et al.*, 1996, 1997; Fukuyama *et al.*, 1998) and aftershock distributions.

Procedure

Strong ground motion simulation using empirical Green's function method

Here, the strong motion generation area is defined to be a finite extended area with large and uniform slip velocity in the total rupture area. We assumed that rupture propagates radially from the hypocenter with the speed of 90% of *S*-wave velocity. In order to estimate the size and position of the strong motion generation area and the slip duration, we simulated strong ground motion using the empirical Green's function method by Irikura (1986). This method is based on the scaling laws of source parameters (Kanamori and Anderson, 1975) and source spectra, i.e. the omega-squared model (Aki, 1967). Strong ground motion simulation for the mainshocks was carried out using acceleration, velocity, and displacement records from 0.2Hz (usable lowest frequency of aftershock waveforms) to 10Hz. The parameters for the best source model were determined to minimize the summation of residuals of the displacement waveform fitting and those of the acceleration envelope fitting, by the Genetic Algorithm method or forward modeling.

We constructed source models for the earthquakes shown in Fig. 1. Most source models were expressed as a single strong motion generation area. The synthetic waveforms from the source model fit well to the observations. Fig. 2 shows comparisons of the observed waveforms with the synthetics for the source model of the Kagoshima-ken Hokuseibu earthquake of March 26, 1997 (M_{JMA}6.5, M_w6.0).

Relations for parameters of strong motion generation area

We evaluate the relation between the strong motion generation area and the seismic moment, and compare it with the scaling relationship for the characterized source model by Somerville *et al*. (1999). The seismic moment for the mainshock was determined by the moment tensor inversion using broadband seismic waveforms (e.g. Dziewonski *et al.*, 1996, 1997; Fukuyama *et al*., 1998). We determined the seismic moment for the aftershock relatively by the source spectral ratio of mainshock to aftershock in the lower frequency range.

We found a self-similar scaling relationship between the strong motion generation area and the seismic moment in this study where the range of the seismic moment was less than 1.38*10^{17}Nm (M_w6.0). For several earthquakes, we confirmed that the strong motion generation area is located at almost the same position as the asperity area characterized from heterogeneous spatial slip distribution using the waveform inversions from 0.1 to 0.5Hz (Miyakoshi *et al*., 2000) (Fig 3). They extracted asperity area based on the criterion by Somerville *et al*. (1999). Our scaling of the strong motion generation area was close to that of combined area of asperities by Somerville *et al*. (1999) (Fig. 4). This suggests that the strong motion generation area is coincident with the asperity area characterized from heterogeneous spatial slip distribution estimated by the waveform inversions using low frequency (<1Hz) motions. The effective area for generating strong ground motions in near-source area is considered to be fairly smaller than the total rupture area by the waveform inversion.

Fig. 5 shows the scaling between the slip duration and the seismic moment. The slip duration was also found to have a self-similar scaling in this study (i.e., less than 1.38*10^{17}Nm (M_w6.0) of the seismic moment), and close to the empirical relationship between slip duration and seismic moment derived by Somerville *et al.* (1999). They pointed out that slip duration was similar to the rupture duration of the largest asperity. We consider that strong ground motion generation is mainly controlled by the slip duration at lower frequencies.

Physical interpretation on strong motion generation area

Based on the characterized source model determined by Miyakoshi *et al*. (2000), we simulated ground motions from 0.2 to 10Hz for the 1997 Kagoshima-ken Hokuseibu earthquake using the empirical Green's function method. The simulated waveforms for the characterized source model was almost the same that for the strong motion generation area. The contribution of the asperity area to simulated waveforms was much larger than the background slip area in the frequency range from 0.2 to 10Hz (Fig. 6).

Das and Kostrov (1986) compared source amplitude spectra for a single asperity model and dislocation (crack) model (Fig. 7). They showed that the level of source amplitude spectra at high frequencies was almost equal for both models, although that at low frequencies was different. We consider that the main ground motions in our simulation correspond to the higher frequency motions in Das and Kostrov's asperity model. It is the reason why the ground motions only for the strong motion generation area agree well with the observations. That is, the strong motion generation area in our simulation is supposed to have correspondence to the asperity itself in Das and Kostrov (1986).

In this paper, we only discuss moderate size of inland crustal earthquake. We need to check whether the strong motion generation area corresponds to the asperity area or not for much larger earthquakes.

Conclusions

The strong motion generation area estimated in this study is coincident with the asperity area characterized from heterogeneous spatial slip distribution estimated by the waveform inversions using low frequency (<1Hz) motions. We found the strong motion generation area and the slip duration have a self-similar scaling to the seismic moment where the range of analyses was less than 1.38*10^{17}Nm (M_w6.0). Our analyses suggest that source characterization for broadband frequency ground motions needs strong motion generation area which reproduce higher frequencies as well as total rupture area which reproduce lower frequencies.

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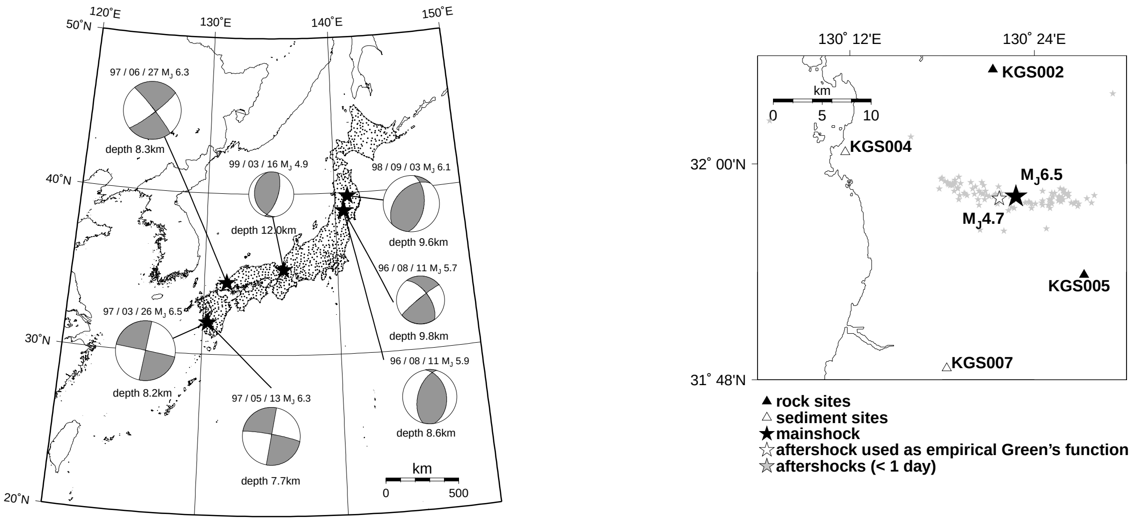

Fig. 1. Left: Epicentral locations and focal mechanisms used in this study. Black dots indicate observed stations of K-NET. Right: Map showing the dataset used for the Kagoshima-ken Hokuseibu earthquake of March 26, 1997 (M_{JMA}6.5) and aftershock distributions.

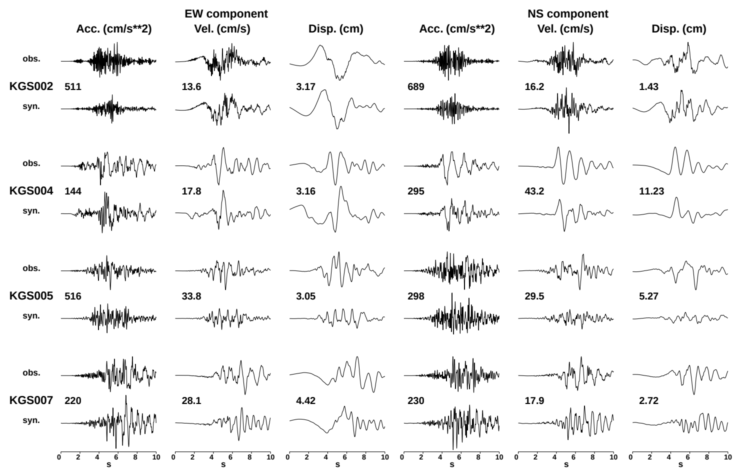

Fig. 2. Comparison of observed and synthetic waveforms (0.2~10Hz) for the source model of Kagoshima-ken Hokuseibu earthquake of March 26, 1997 (M_{JMA}6.5) at nearest four stations. Numbers between observed and synthetic waveforms indicate the maximum value of observed waveforms.

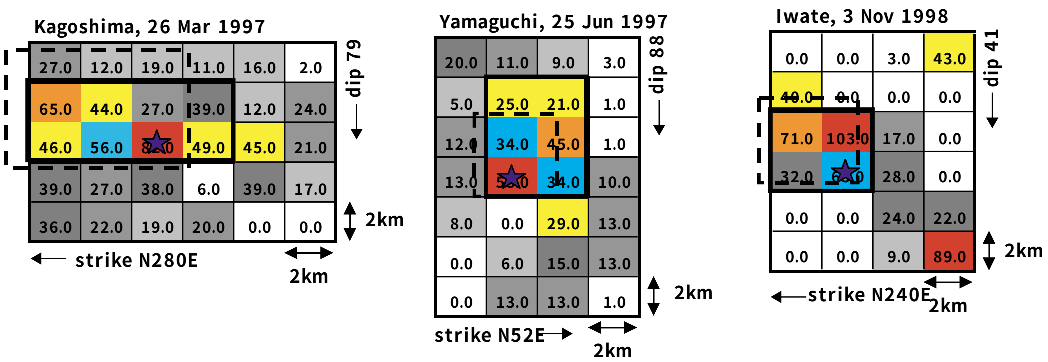

Fig. 3. Superposition of strong motion generation area on characterized source model derived from heterogeneous spatial slip distribution (Miyakoshi *et al.*, 2000). From left to right, the Kagoshima-ken Hokuseibu earthquake of March 26, 1997 (M_{JMA}6.5), the Yamaguchi-ken Hokubu earthquake of June 27, 1997 (M_{JMA}6.3) and Iwate-ken Nariku Hokubu earthquake of September 3 of 1998 (M_{JMA}6.1). Thick line on the rupture area indicates the boundary of the asperity, and dot line shows the boundary of the strong motion generation area. Number on each subfault indicates slip value estimated in the waveform inversion.

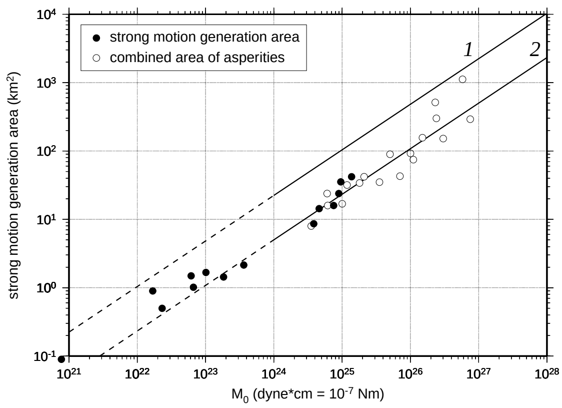

Fig. 4. Scaling between strong motion generation area and seismic moment. Closed circles show the strong motion generation area, and open circles show the combined area of aspeirties (Somerville *et al.*, 1999). The lines indicated by 1 and 2 correspond to the rupture area and the combined area of asperities, as a function of seismic moment (Somerville *et al.*, 1999), respectively.

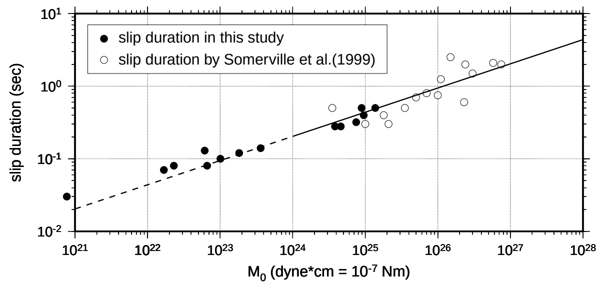

Fig. 5. Scaling between slip duration and seismic moment. Closed circles show the slip duration estimated in this study, and open circles and line correspond to the slip duration and the empirical relation as a function of seismic moment (Somerville *et al.*, 1999), respectively.

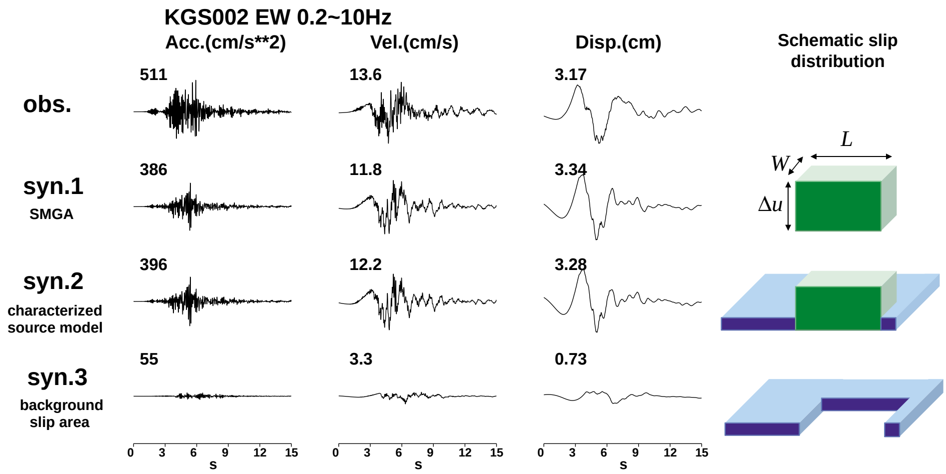

Fig. 6. Comparison of observed with synthetic waveforms (0.2~10Hz) of EW component at KGS002 for the Kagoshima-ken Hokuseibu earthquake of March 26, 1997. From top to bottom, the traces show observed waveforms, contribution of strong motion generation area, characterized source model and background slip area to synthetic waveforms, respectively.

(a) (b) (c)

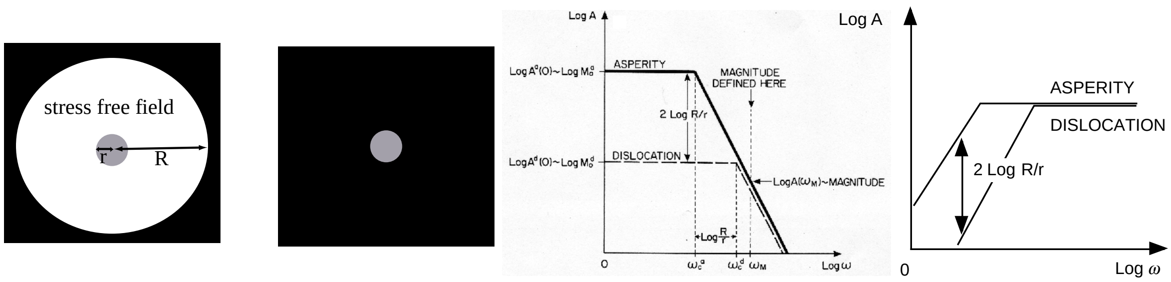

Fig. 7. (a) Geometry of the asperity model (left) and dislocation (crack) model (right) by Das and Kostrov (1986). (b) Far-field displacement spectra for asperity and dislocation (crack) models showing relation between seismic moment and corner frequency for the two models at a given magnitude. (d) Far-field acceleration spectra for asperity and dislocation (crack) models.