Variability of synthetic waveforms caused by the selection of small earthquake in stochastic Green's function method

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SUMMARY:
In the simulation method of strong ground motions based on empirical site amplification and phase characteristics [Kowada et al. 1998, Nozu et al. 2006], the Fourier phase at a target site for a small event that occurred close to the target earthquake is used. In this method, the selection of the small event does not affect the Fourier amplitude of the predicted ground motion, but the selection affects its Fourier phase and may consequently affect the response of structures. Thus, from a practical point of view, it is very important to investigate systematically how the predicted ground motion can vary due to the selection of the small event. In this paper, the variability of the predicted ground motion due to the selection of the small event is investigated.

Keywords: Fourier phase, strong motion simulation, variability

1. INTRODUCTION

In order to predict earthquake ground motions as accurately as possible, it is one of the important factors to take into consideration the effects of the sediment on earthquake ground motions. In the simulation method of strong ground motions based on empirical site amplification and phase characteristics [Kowada et al. 1998, Nozu et al. 2006], which is a variation of Stochastic Green's function method, effects of the sediment on both of Fourier amplitude and Fourier phase for a ground motion can be taken into account.

In the method, the Fourier phase at a target site for a small event that occurred close to the target earthquake is used. It has been shown that the method reproduce observed ground motions from damaging earthquakes very well, especially when a small event which is close to a main rupture area of the target large event is used [e.g., Nozu and Sugano, 2006]. Also, the selection of the small event does not affect the Fourier amplitude of the predicted ground motion, but the selection affects its Fourier phase [e.g., Wakai et al., 2012] and may consequently affect the response of structures. Thus, from a practical point of view, it is very important to investigate systematically how the predicted ground motion can vary due to the selection of the small event. In particular, it is sometimes difficult to choose a small event that is close to a target event. The performance of the method for such cases has not been investigated sufficiently.

In this paper, by using the 2003 Tokachi-oki, Japan, earthquake (M_{JMA}8.0) as an example of a large event, the variability of the predicted ground motion due to the selection of the small event is investigated.

2. ANALITICAL METHOD

In this paper, in order to evaluate the variability of the predicted ground motion, the quantitative relation between the similarity of observed and predicted ground motions and the location of epicentres of small events which happened off Tokachi Region, Hokkaido, northern Japan is investigated.

2.1. Dataset

The target sites are four permanent strong-motion stations of KiK-net [Aoi et al., 2000], that is, TKCH06 and TKCH07 around Obihiro region and TKCH02 and KSRH02 around Kushiro region. Then, records from 53 small events obtained at each permanent strong-motion station, under conditions of $4.5 \leq M_{JMA} \leq 7.0$, the depth of source ≤ 95km and the distance of epicentre ≤ 200km, are used to obtain predicted ground motions. In Fig. 2.1, four permanent stations (black triangle), the rupture starting point of the 2003 main shock by JMA (black cross), epicentres of small events (black stars), the heterogeneous source model of the 2003 main shock (contour) [Nozu and Irikura., 2008] and the characterized source model (red rectangles) [Nozu et al., 2007] are shown.

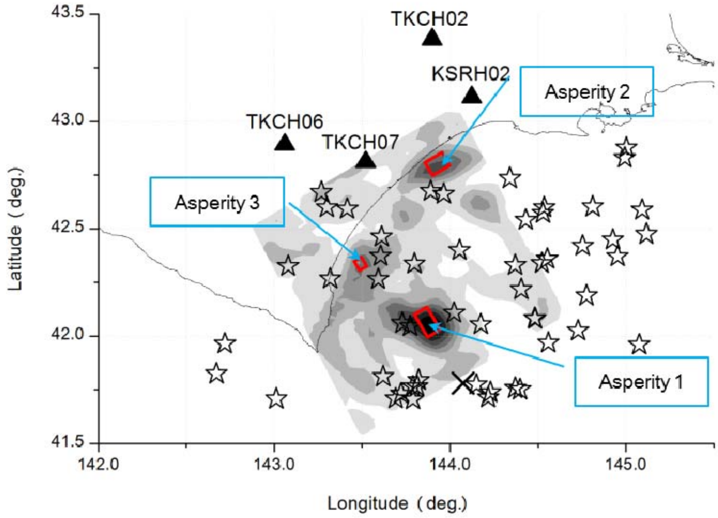

Figure 2.1. The permanent strong-motion stations (black triangle), the rupture starting point of the 2003 main shock by JMA (black cross), epicentres of small events (black stars), the heterogeneous source model of the 2003 main shock (contour) [Nozu and Irikura al., 2008] and the characterized source model (red rectangles) [Nozu et al., 2007].

2.2. Simulation method of strong motion

In this paper, as a simulation method of strong motion, the strong motion simulation based on empirical site amplification and phase characteristics is used. In this method, first, a ground motion on ground surface from a small event (Green's function) is evaluated by using the following equation,

$$A(f) = S(f) \times P(f) \times G(f) \times O(f) / \left|O(f)\right|_p \tag{2.1}$$

where A(f) is Fourier transform of a ground motion on ground surface from a small event , S(f) is source effect, P(f) is path effect, G(f) is site amplification factor, O(f) is the Fourier transform of a record at the target site from a small event and $\left|O(f)\right|_p$ is its Parzen-windowed amplitude (band width of 0.05 Hz is used).

In this method, as seen in Eqn. 2.1, the Fourier amplitude of the Green's function is evaluated as a product of the source effect, the path effect and the site amplification factor. As for Fourier phase, the Fourier phase of a record at the target site from a small event is used. The time domain Green's function can be obtained as the inverse Fourier transform of the Eqn.2.1. Finally, the time domain Green's function can be superposed in the same way as the empirical Green's function method [e.g., Miyake et al., 2003].

2.3. Characterized source model

In the conventional study about the 2003 Tokachi-oki earthquake, the characterized source model as shown in Fig. 2.1 is proposed [Nozu et al., 2007] based on the heterogeneous source model [Nozu and Irikura, 2008]. Thus, this characterized source model is utilized for the simulation here. In Table 2.1, parameters of the characterized source model are shown.

Table 2.1. Parameters of characterized source model

parameter	Asperity1	Asperity2	Asperity3
seismic moment (Nm)	4.2×10^{19}	2.1×10^{19}	2.4×10^{18}
length (km)	6.0	8.0	4.0
width (km)	12.0	6.0	4.0
rise time (s)	0.6	0.6	0.4
number of division	5×5×5	3×3×3	1×1×1

2.4. Evaluation method of variability of predicted ground motion

To evaluate the variability of predicted ground motion due to the selection of the small event, the similarity between an observed waveform and a synthetic one is systematically evaluated.

Since the arrival time of direct S-wave for the observed waveform is different from that of direct S-wave for the synthetic one, their arrival times of direct S-wave need to be fitted before the similarity is evaluated. In this paper, they are automatically fitted in the following procedure. On the first step, an envelope curve for each waveform is evaluated and the synthetic waveform is shifted on the time axis to minimize the sum of squares residual of the envelopes. On the next step, the synthetic waveform is shifted for 2 seconds at maximum to the positive and negative direction on the time axis to minimize the error defined in Eqn. 2.2.

$$ERR = \int_{t1}^{t2} (V_{syn}(t) - V_{obs}(t))^2 dt \Big/ \int_{t1}^{t2} (V_{obs}(t))^2 dt \qquad (2.2)$$

Here, $V_{obs}(t)$ is an observed velocity waveform and $V_{syn}(t)$is a synthetic one. Frequency band for velocity waveforms used in analysis is from 0.2 Hz to 1.0 Hz which is important in engineering applications.

The minimized error is shown as the similarity indexes in chapter 3 (an average value for the two horizontal components).

And then, for the purpose of visualizing the relation between the similarity index of two waveforms and location of epicenter of the small event, colored symbols according to the similarity index are put at location of epicenters on the map.

3. SIMILALITY BETWEEN OBSERVED AND SYNTHETIC WAVEFORM

In Fig. 3.1, comparison of observed waveforms during the 2003 main shock with synthetic waveforms obtained by using the method described in the former chapter is shown for each target station. These represent the case of better similarity. It is found that synthetic waveforms reproduce observed ones well on the whole. On the other hand, in Fig. 3.2, the case of worse similarity is shown. It is found that predicted ground motions vary more or less due to the selection of small event.

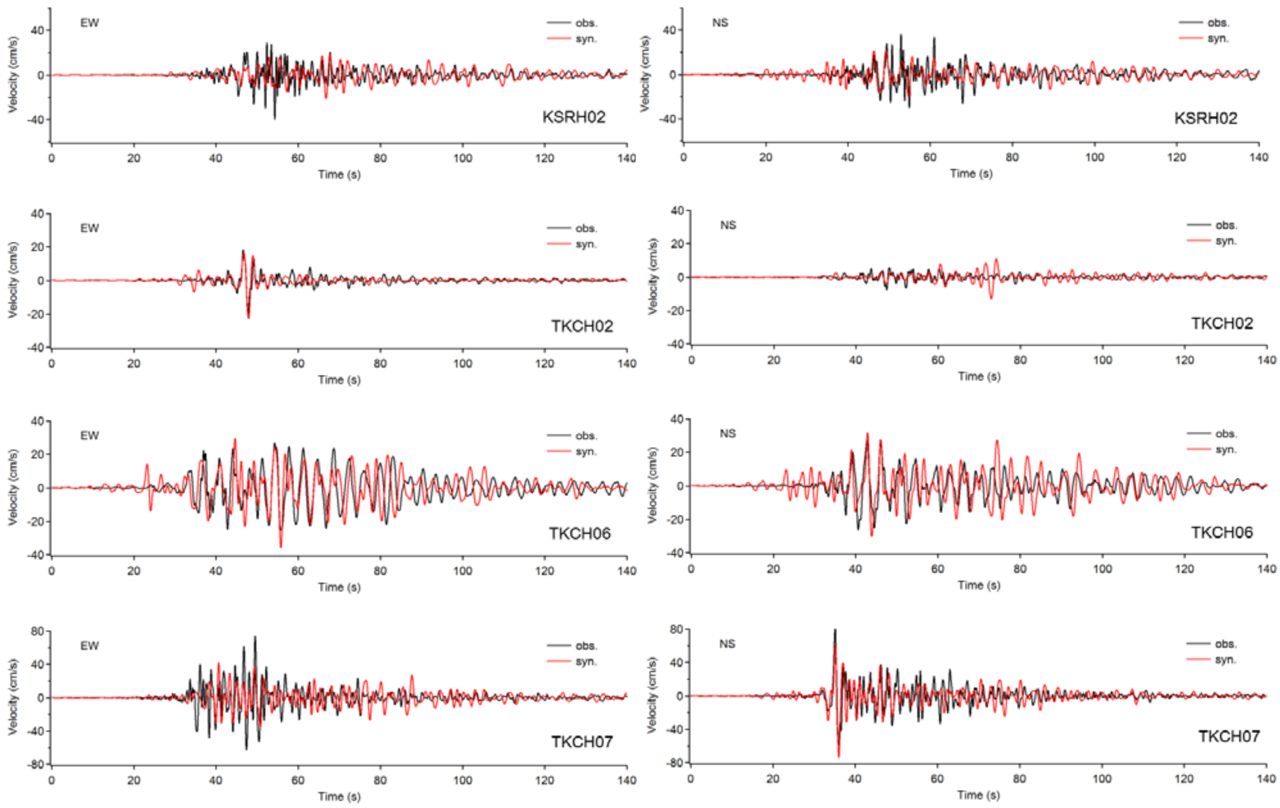

Figure 3.1. Comparison of observed waveforms during the 2003 main shock with synthetic ones at each permanent strong-motion station. The case of better similarity.

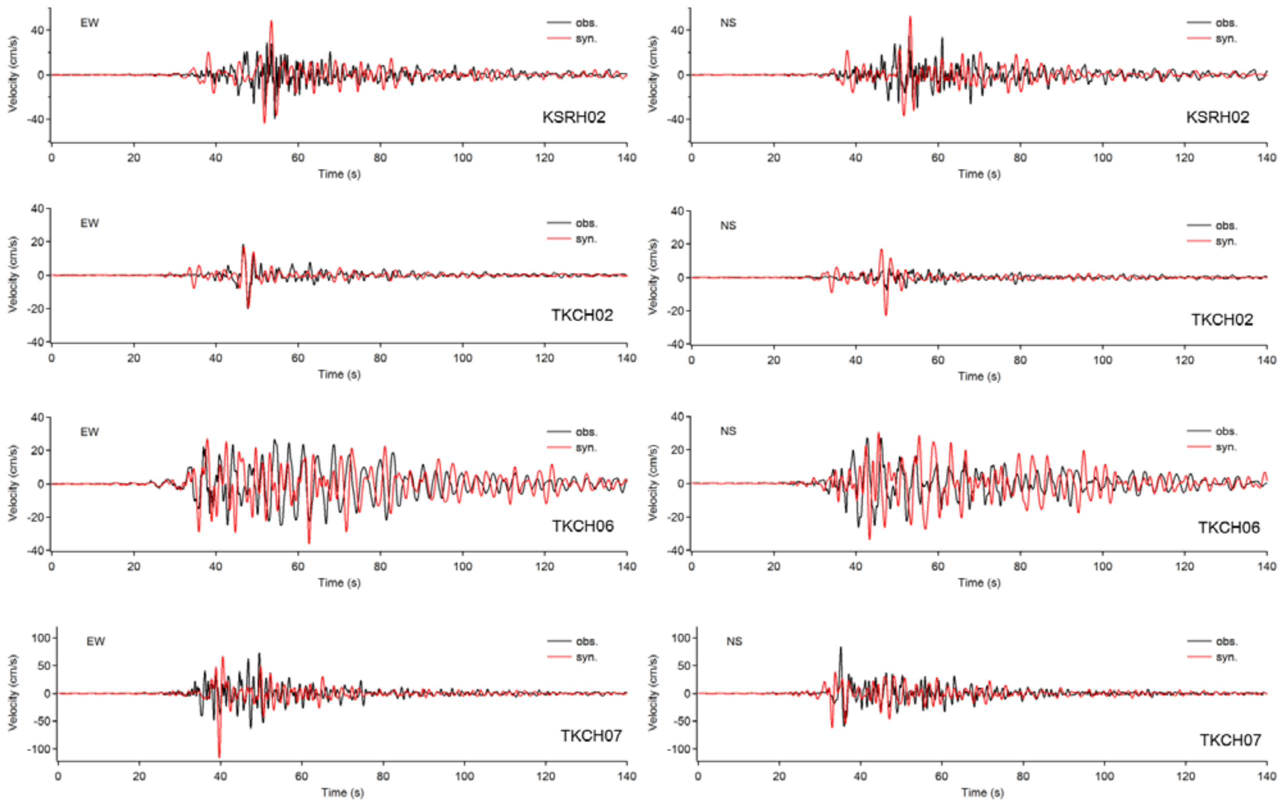

Figure 3.2. Comparison of observed waveforms during the 2003 main shock with synthetic ones at each permanent strong-motion station. The case of worse similarity.

Fig. 3.3 shows how the similarity index between observed and synthetic waveforms vary at each station, according to location of epicentre for small event selected. Here, warm colors represent better similarity and cold colors represent worse similarity. At any station, more or less, the similarity index has variability due to the selection of a small event to evaluate phase characteristics. At TKCH02, TKCH06 and TKCH07, it can be found that the similarity is on the whole better if small events around asperity are selected. At KSRH02, however, the same tendency cannot be found.

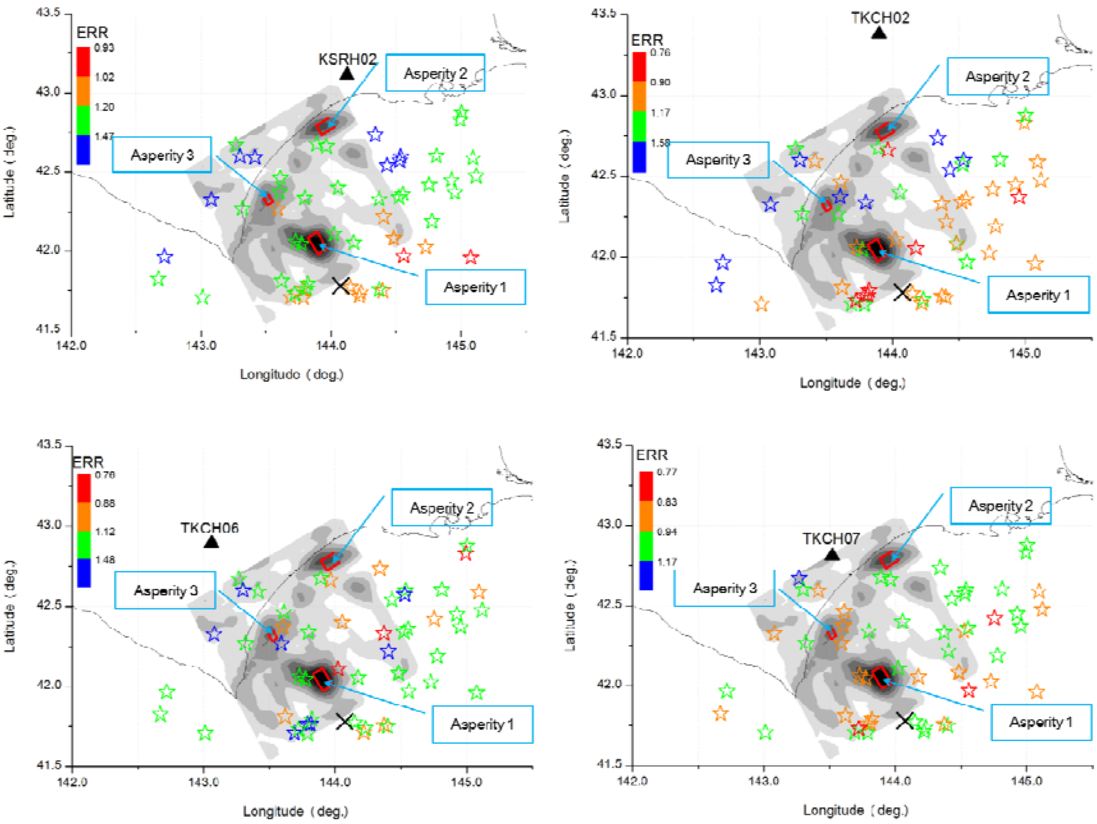

Figure 3.3. Relation between the similarity index of synthetic waveforms and location of epicentre for small events at each permanent strong-motion station.

5. CONCLUSIONS

In this paper, the authors investigated the variability of the predicted ground motion due to the selection of the small event in the strong-motion simulation method based on empirical site amplification factor and phase characteristics. It was confirmed that predicted ground motions vary due to the selection of small event. Also, from a stand point of the similarity between observed and predicted ground motions, when a small event around asperities is selected, the predicted ground motion can reproduce the observed one comparatively better.

AKCNOWLEDGEMENT

We would like to express our gratitude to the National Research Institute for Earth Science and Disaster Prevention (NIED), Japan, for providing important strong-motion data from KiK-net.

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