Effects of Difference of Source Spectrum Modeling for Medium-Sized Earthquake on Synthetic Motions of Empirical Green's Function Method

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SUMMARY:
The empirical Green's function method is one of the ways for predicting strong ground motions. This method superimposes the waves induced by one-size smaller earthquakes than the target earthquake we want to evaluate. In this paper, we investigated the effects caused by the difference between the two kinds of source spectrum modeling, the crack model and the asperity model, for medium-sized earthquakes on the synthetic motions.
The results showed that no obvious difference between the waveforms caused by the crack model and those by the asperity model. But the waveforms depended on the location of the calculation point. On the other hand, the source spectra of the synthetic waves were the same as the theoretical source spectra based on the omega-square model by Brune (1970) in the short-period and the long-period bands. However, the corner frequencies of the source spectra differed with the location of the calculation point. Especially, at the point in the opposite direction of the rupture propagation, the corner frequency of the synthetic motion moved to the longer-period range compared with the omega-square model.

Keywords: Strong Motion Prediction, Empirical Green's Function Method, Source Spectrum

1. INTRODUCTION

1.1. Purpose of the study

The empirical Green's function method is one of the ways for predicting strong ground motions. This method superimposes the waves induced by one-size smaller earthquakes than the target earthquake we want to evaluate. In this method, in case of predicting an M_J 8.0 class earthquake, an M_J 6.5 class earthquake is often used as the smaller earthquake, and its source spectrum is described by the crack model. Here, the M_J is the local magnitude in Japan defined and calculated by Japan Meteorological Agency (JMA) [1]. On the other hand, when simulating the M_J 6.5 class earthquake, which is expressed as a sum of waves induced by an M_J 5.0 class earthquake, its source spectrum is generally described by the asperity model.
According to earthquake records, it is verified that both of the fault models have been observed in the past. That is to say, a proper model can vary for the earthquakes we want to predict. It is important to decide which model we should use when we predict strong ground motions, because many parameters depend on the fault model. Thus, it is necessary to check whether there are any differences attributed to the difference of the source spectrum modeling for medium-sized earthquakes. If some effects are found, we also need to examine them.
Therefore, we investigated the effects caused by this difference of the source spectrum modeling for medium-sized earthquakes on synthetic motions.

1.2. Methodology

To calculate the earthquake ground motions, we used the Green's function method by Dan and Sato (1998)[2]. We synthesized waveforms of the M_J 8.0 class earthquake in the next two steps shown in Figure 1. First, we superimposed waveforms generated from small earthquakes (M_J 5.0 class) into a medium-sized earthquake (M_J 6.5 class) using two source models: the asperity model and the crack model with taking the rupture propagation of the fault plane into account. Next, in the same way, we superimposed the waveforms of the medium-sized earthquake into the large earthquake (M_J 8.0 class) using the asperity model. In this case, we replaced the source spectrum of the middle-sized earthquake described by the asperity model with an equivalent source spectrum of the crack model by setting the same seismic moment (M_0) and short-period level (A).
As shown in Figure 2, we evaluated synthetic motions at 4 points, which are located 150 kilometers away from the center of the fault.
In order to eliminate the characteristics of the source, the path, and the site in the small-earthquake records and obtain the effects of the source modeling only, we used a delta function as the Green's function instead of observational ground motion data. When subfaults are placed regularly on the fault as point sources, an artificial wave interference tends to appear. Accordingly, we arranged the point sources in the subfaults using 21 combinations of random numbers and obtained 21 synthetic waveforms.

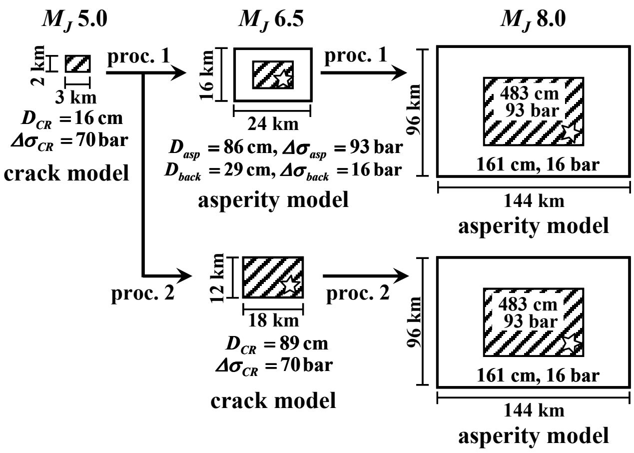

Figure 1. Source models examined in this study

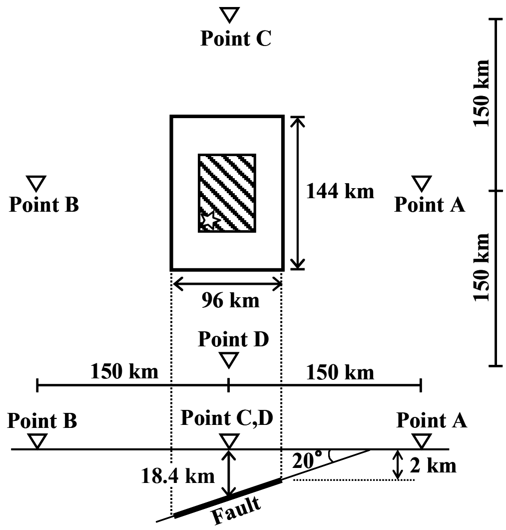

Figure 2. Location of the calculation points

2. SOURCE SPECTRUM

2.1. Asperity model

There are 15 major parameters that describe the asperity model. They are the fault length (L), width (W), area of the fault (S), stress drop ($\Delta\sigma$), average slip on the fault area (D), length of the asperity (L_{asp}), width of the asperity (W_{asp}), area of the asperity (S_{asp}), stress drop of the asperity ($\Delta\sigma_{asp}$), slip on the asperity (D_{asp}), area of the background (S_{back}), effective stress on the back ground (σ_{back}), slip on the background (D_{back}), seismic moment (M_0), and short-period level (A). And they are related by 8 equations as follows[3]:

$$S = LW, \tag{2.1}$$

$$S_{asp} = L_{asp} W_{asp}, \tag{2.2}$$

$$S = S_{asp} + S_{back}, \tag{2.3}$$

$$\Delta\sigma = (7/16)[M_0 / (S/\pi)^{1.5}], \tag{2.4}$$

$$\Delta\sigma S = \Delta\sigma_{asp} S_{asp}, \tag{2.5}$$

$$M_0 = \mu DS, \tag{2.6}$$
$$\mu DS = \mu D_{asp} S_{asp} + \mu D_{back} S_{back}, \tag{2.7}$$
$$A = 4\pi\beta^2 \sqrt{(S_{asp}/\pi)\Delta\sigma^2{}_{asp} + (S_{back}/\pi)\Delta\sigma^2{}_{back}}. \tag{2.8}$$

In this paper, we used the following 7 empirical equations[3), 4)] to set the parameters after assuming JMA magnitude M_J:

$$L = 1.5W, \tag{2.9}$$
$$L_{asp} = 1.5W_{asp}, \tag{2.10}$$
$$S_{asp} = 0.25S, \tag{2.11}$$
$$\sigma_{back} = (D_{back}/W_{back})/(D_{asp}/W_{asp})\Delta\sigma_{asp}, \tag{2.12}$$
$$D_{asp} = 2D, \tag{2.13}$$
$$\log M_0[\text{dyne}\cdot\text{cm}] = 1.5M_J + 16.2, \tag{2.14}$$
$$A[\text{dyne}\cdot\text{cm/s}^2] = 2.46\times10^{17}\times(M_0[\text{dyne}\cdot\text{cm}])^{1/3}. \tag{2.15}$$

On the other hand, according to the calculation result by Boatwright (1988)[5)], the source spectrum of the asperity model has two corner frequencies shown below:

$$f_{casp} = [\sqrt{7/\pi}/4][\beta/\sqrt{(S_{asp}/\pi)}], \tag{2.16}$$
$$f_c = [\sqrt{7/\pi}/4][\beta/\sqrt{(S/\pi)}]. \tag{2.17}$$

These two corner frequencies are related to the area of the asperity S_{asp} and fault area S. And they are based on equation (2.23) that describes a corner frequency of the crack model.
Figure 3(a) shows the source spectra of the asperity models for M_J 5.0, M_J 6.5, and M_J 8.0.

2.2. Crack model

There are 7 major parameters that describe the crack model. They are the fault length (L_{CR}), width (W_{CR}), area of the fault (S_{CR}), stress drop ($\Delta\sigma_{CR}$), average slip on the fault area (D_{CR}), seismic moment (M_{0CR}), and short-period level (A_{CR}). These parameters are related by 4 equations as follows[3)]:

$$S_{CR} = L_{CR}W_{CR}, \tag{2.18}$$
$$\Delta\sigma_{CR} = (7/16)[M_{0CR}/(S_{CR}/\pi)^{1.5}], \tag{2.19}$$
$$M_{0CR} = \mu D_{CR} S_{CR}, \tag{2.20}$$
$$A_{CR} = 4\pi\beta^2\sqrt{(S_{CR}/\pi)}\Delta\sigma_{CR}. \tag{2.21}$$

Like the asperity model, we used equations (2.14) and (2.15) and the following assumption formula (2.22) to set the parameters after setting JMA magnitude M_J:

$$L_{CR} = 1.5W_{CR}. \tag{2.22}$$

According to Brune (1970)[6)], the source spectrum of the crack model has a corner frequency described below:

$$f_{cCR} = [\sqrt{7/\pi}/4][\beta/\sqrt{(S_{CR}/\pi)}. \tag{2.23}$$

Figure 3(b) shows the source spectra of the crack models for M_J 5.0, M_J 6.5, and M_J 8.0. Figure 3(a) and Figure 3(b) show that the source spectra of the crack models are the same as those of the asperity models in the low-frequency band and the high-frequency band because we set the same seismic moment M_0 and the same short-period level A for the crack models as those for the asperity models.

But near the corner frequencies of the crack models (f_{cCR}), the values of the source spectra are slightly larger than those of the asperity models.

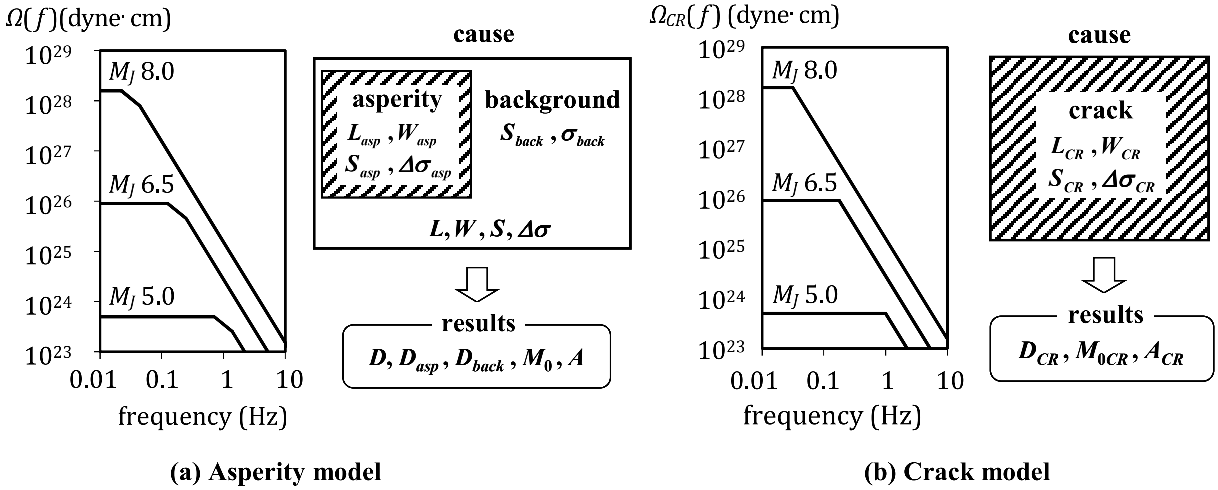

Figure 3. Source spectra of the asperity models and the crack models

In this study, we aim to investigate the effects caused by this difference of the source spectrum modeling for medium-sized earthquakes on the results of the ground motion prediction.

3. RESULTS OF WAVEFORM SYNTHESIS

3.1. Comparison of synthetic waveforms

Figure 4 shows the root mean square of the acceleration time histories of the 21 synthetic waveforms at Points B and C. The synthetic waves of the M_J 8.0 class earthquake are generated by using the M_J 6.5 earthquakes as elements.

As shown in Figure 4, the waveform calculated at Point C has a short duration but large amplitude. On the other side, while the waveform calculated at Point B has a long duration, its amplitude is small. This difference was caused by the rupture directivity effects.

And, when we focus on the peak ground accelerations, the maximum values of the waveforms generated from the crack model are slightly larger than the synthetic results of the asperity model. This is true for both of points B and C. It seems that there are two reasons for this difference in the maximum values. The first one is the propagating length of the rupture on the faults. As shown in Figure 1, the area of the asperity (S_{asp}) is smaller than that of the crack (S_{CR}). Then the propagating length of the rupture on the fault of the crack model is longer than that of the asperity model. The second is the shortest distance between the calculation points and the crack or the asperity area. Because the distance between the fault and the calculation point in the crack model is shorter than that in the asperity model, the waves arrived with less attenuation. However, compared to the effects of the rupture directivity, these effects of the difference of the distance have much smaller impact on the results.

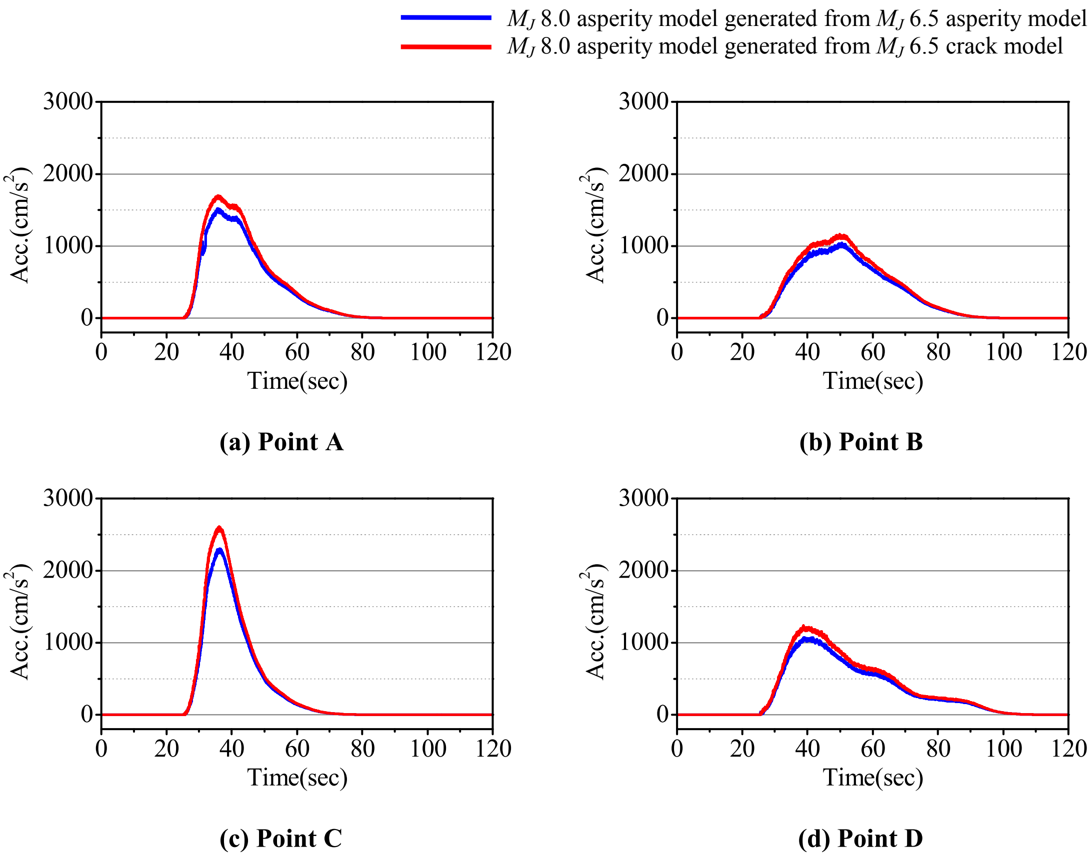

Figure 4. Root mean square of the accelerations of the 21 synthetic waveforms

3.2. Comparison of synthetic ratios

We defined the synthetic ratio as an average of the quotients obtained by dividing each Fourier spectrum of the 21 synthetic waveforms by that of the element earthquake waveform. Figure 5 shows the ratios of the Fourier spectra and those of the source spectra in Figure 3. The gray lines in the figure are the ratios of the source spectra of the small earthquakes shown in Figure 3 to the source spectra of the large earthquakes.

As shown in the figure, in the short-period range (less than 1.0 sec.) and long-period range (more than 30 sec.), the synthetic ratios of the asperity model and those of the crack model match well. The results also correspond with the ratio expected by the omega-square model. But comparing the ratio of the source spectra and the results of the synthetic calculation, we confirmed that the corner frequency moves to the longer period in the middle-period range except Point C, because of the rupture directivity effect. As Point C is in a forward direction, its result agrees with the ratio of the omega-square model. In contrast, since Point B is in the opposite direction, its corner frequency became lower.

In this study, we set 4 calculation points, and none of the synthetic ratios obtained at these points were more than the ratios based on the omega-square model.

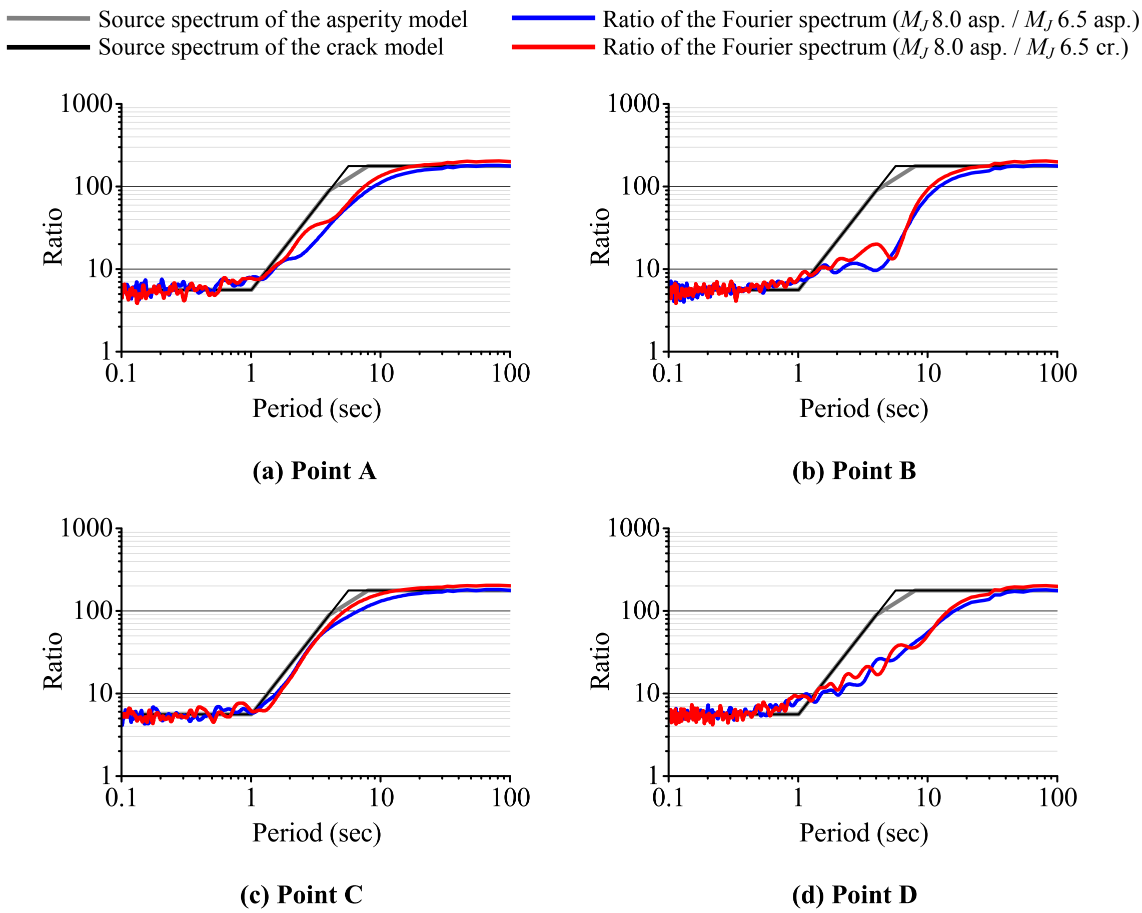

Figure 5. Ratios of the Fourier spectra and the source spectra

4. CONCLUSIONS

In this paper, we investigated the effects caused by the difference of the two source spectrum modeling, the asperity model and the crack model, for medium-sized earthquakes on the synthetic motions. To get clear results about the difference of the source modeling, when synthesizing the waves, we used a delta function as Green's function instead of observational ground motion data.
Our results can be summarized as follows:

1) No obvious difference was found in the peak ground accelerations and the synthetic ratios of the synthesized waveforms by the asperity model and those by the crack model.

2) The corner frequency of the source spectrum depended on the location of the calculation point. Especially, at the point in the opposite direction of the rupture propagation, the corner frequency moved to the longer-period range compared with the omega-square model by Brune (1970) because of the rupture directivity effect.

3) Though we set 4 points for the calculation of the synthesis waveforms, none of the results obtained at these points exceeded the ratios based on the omega-square model.

ACKNOWLEDGEMENT
The contents of this paper are a part of the results studied in the Research Group on Earthquake Ground Motion by Tokyo University of Science, Nikken Sekkei Ltd., Shimizu Corporation, and Ohsaki Research Institute, Inc.

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