EFFECTS OF DETAIL SPATIAL VARIATION OF SLIP AMPLITUDE ON THE GROUND MOTIONS

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ABSTRACT :

We have investigated the effects of detail spatial variation of slip amplitude on the fault plane on ground motions. We calculated ground motions for three different source models; i) Asperity model with rectangular asperity (Model 1), ii) Asperity model with no assumption for the shape of asperity (Model 2), and iii) Model with detail spatial variation of slip amplitude on the fault plane (Model 3). The calculated waveforms show little differences among these three models. On the other hand, the spectrum amplitudes from model 3 show large differences, *i.e.,* peak value of response spectrum amplitude is large and its width of peak spectrum amplitude is wide compared to those from model 1 and 2. Because all of the models might reproduce the peak frequency of directivity pulses from the asperity, these differences come from the way of modeling of slip amplitude, *i.e.*, whether the detail spatial variation of slip amplitude has been incorporated into modeling source for ground motion calculations or not. So far, because we did not compare the calculated waveforms with the observed data, we could not speculate that which model is preferable for the ground motion prediction. Developing the method for modeling source equivalent to the source model for the previous events with variable slip distribution and incorporating more detail variation of slip on the fault plane into modeling source looks very useful for the ground motion prediction for future event.

KEYWORDS: Ground Motion Prediction, Homogeneous Slip Distribution, Asperity, Correlated Random Source Parameter, Heterogeneous Slip Distribution

1. INTRODUCTION

The source model that is widely used for the ground motion prediction in Japan is the asperity model. This model (The Headquarters for Earthquake Research Promotion, 2007) partitions the fault plane into two parts, the asperity which produces ground motions with larger amplitudes, and the background. The main objective of this model is to reproduce the directivity pulse for period of 1~2 sec from large crustal event (its magnitude is around 7) recorded in the near-field and to incorporate the investigation of active faults into setting fault model for the ground motion prediction. But, because this model simply partitions the fault plane into two parts, reproducing the directivity pulse by using theoretical method is very difficult in period range of ≦1 sec. Thus, when the broadband ground motions are calculated by using the hybrid method (Hartzell *et al.,* 2005), the long period ground motions by using theoretical method and the short period ground motions by using the stochastic or empirical method sometimes show differences in amplitudes around the matching period that connects two ground motions. On the other hand, the source model that gives the detail spatial variation of distribution for slip amplitude on the fault plane has been recently proposed to develop the ground motion prediction by using theoretical method in short period range, up to around 0.3 sec (Liu *et al.,* 2006). The expansion of period range of ground motions by theoretical method to the shorter period might lead to the smooth connection between the long period ground motion and the short period ground motions around matching period.

In this study, we have investigated the effects of detail spatial variation of slip amplitude on the fault plane on the calculated ground motions. In order to estimate these effects, we have produced three different source models. The basic idea for each model is explained in the following and its concept is shown in Figure 1(A).

The first one is added to detail spatial variation of slip amplitude on the fault plane (Model 3 in Figure 1(A)). This model also assumes the spatial correlations between slip amplitude and rupture velocity, or risetime. The second one (Model 2 in Figure 1(A)) is based on the first model but partitions the fault plane into two parts, asperity and background based on the definition given in Somerville *et al*. (1999). An asperity is defined as the fault elements whose slip is 1.5 or more times larger than the average slip over the fault plain (Somerville *et al*., 1999). However, no assumption about the shape of asperity is used. The last one (Model 1 in Figure 1(A)) is the conventional asperity model which is usually used as the characterized source model for ground motion prediction. Even though this model also separates the fault plane into two parts, asperity and background based on the same definition of the asperity (Somerville *et al.*, 1999), this model assumes that shape of the asperity is rectangular. We have compared the calculated waveforms and response spectrum amplitude for these three different source models. Based on these comparisons, we have investigated the effects of detail variation of spatial variation of slip amplitude on the fault plane on ground motions.

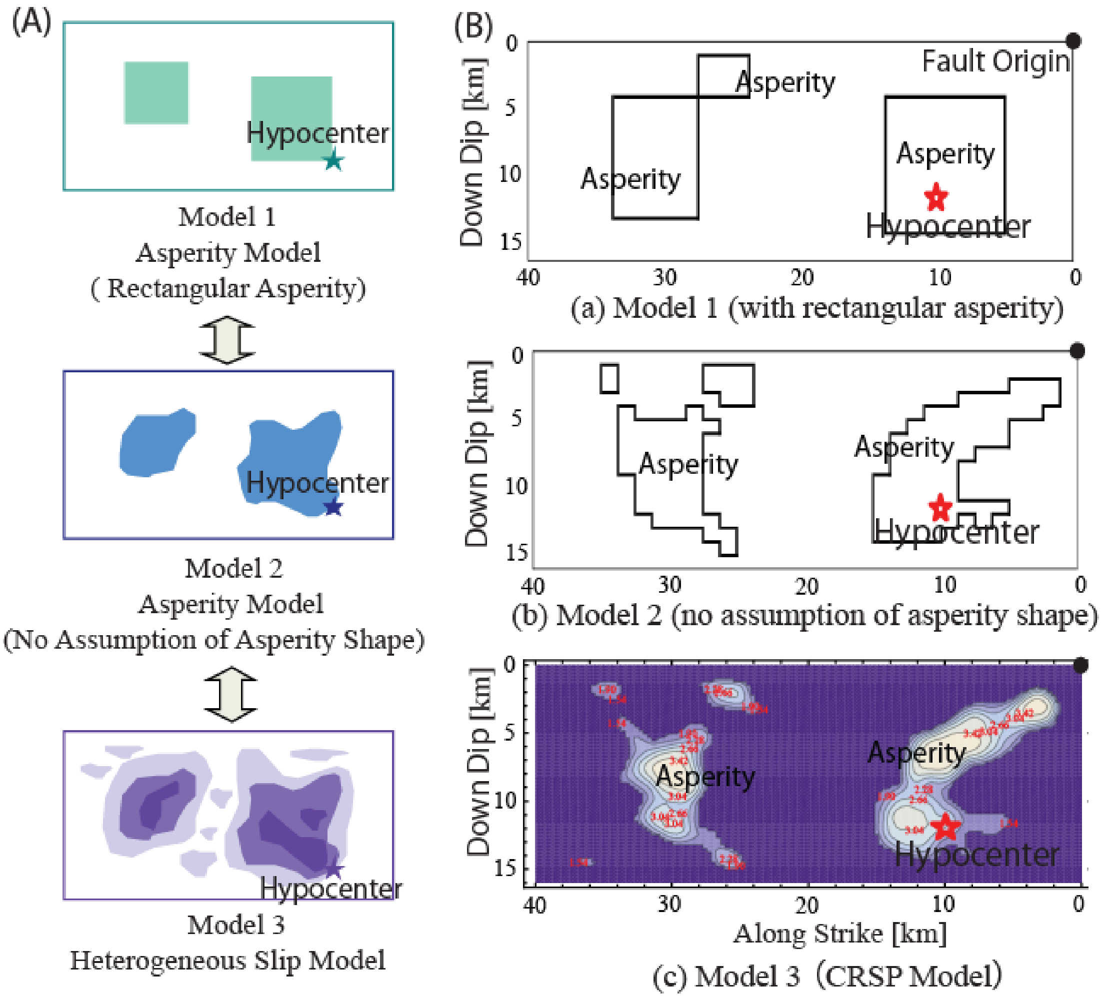

Figure 1 Concept of the modeling source (slip distribution) (A) and the source model used for the scenario event used for this study (B)

2. METHOD

We show the concept of basic idea for modeling source and sample procedure to produce three different source models in Figure 1(1). As mentioned in the previous section, the asperity model (characterized source model) simply separates into two parts, asperity and background (Figure 1(1) Model 1). On the other hand, the distribution of slip amplitude of the real earthquake is usually heterogeneous (Figure 1(1) Model 3). As the distribution of slip amplitude is getting simplified from Model 3 to Model1, the detail variation of slip amplitude on the fault plane is not reflected properly especially on short wavelength range. These effects are more obvious to the shorter period ground motions than those from asperity (*e.g.* directivity pulse).

In this study, we have produced the source model with detail spatial variation of slip amplitude on the fault plane (Model 3 in Figure 1(2)) by using Correlated Random Source Parameters method (Liu *et al.*, 2006, hear after CRSP model). Model 1 and Model 2 in Figure 1(2) have been made basically based on the distribution of slip amplitude by Model 3. The detail procedure to produce Model 1 and 2 from Model 3 is the following.

We set the vertical fault plane (40 km (along strike) x 16 km (along down-dip)) for a strike-slip scenario event. The basic fault parameters for this event are tabulated in Table1. The hypocenter is set to 16 deep from the ground (12 km deep from the upper edge of the fault plane) showing in Figure 2(a). The scenario event is pure- right-lateral strike slip event and its magnitude is 6.8. We first made the slip amplitude of CRSP model for it. (Figure 1(2) Model 3) The procedure to produce this model consists in generating a large number of random slip spatial distributions and then selecting several samples that mimics the idealized geometrical distribution of slip amplitude. The idealized distribution of slip amplitude is assumed to have two asperities locating parallel each other. Then we produced Model 2 in Figure 1(2) whose seismic moment and surface of asperity are equivalent to Model 3 based on the procedure to separate the fault plane into asperity whose slip is 1.5 or more times larger than the average slip over the fault plain and background, and set source parameters for each region proposed by Somerville *et al.* (1999). No shape of asperity is assumed, but the slip amplitudes inside the asperity and background are set to be uniform for this Model 2. Model 1 showing in Figure 1(2) has been made based on Model 2. This model is assumed to have rectangular asperity. The ratio of asperity to the total fault plane is 24 %. The rupture velocity V_R for both Model 1 and 2 is set to V_R = 0.8 V_S (constant, Vs: shear wave velocity of the source area) for whole fault plane.

Table 1 Fault parameter for the scenario event

Fault Length	40 [km]
Fault Width	16 [km]
Depth (Hypocenter)	20 [km] from ground (Showing in Figure 2)
Seismic Moment (Mo)	2.28e+23 [dyn cm] (Mw 6.8)
Average Slip	1.08 [m]
Stress Drop (Δσ)	34.0 [bar]
Dip Angle	90° (Pure Strike Slip)
Rake Angle	0°

The ground motions have been calculated at 12 sites close to the fault showing in Figure 2(b). We used the simple 1D structure and its material parameters for each layer (P-wave velocity: Vp, quality factor for P and S waves: Qp and Qs) are listed in Table 2. We calculate the ground motions for these tree models by using frequency –wave number method (Hisada 1994, 1995) and discuss the difference between them.

Table 2 1D velocity structure used for the calculation

Layer Number	Vp [m/s]	Vs [m/s]	Density [g/cm³]	Qp	Qs	Layer Depth [km]	Top Depth [km]
1	1700	400	1.75	40	20	0.08	0
2	1850	500	1.85	50.0	25.0	0.12	0.08
3	2200	700	2.1	70.0	35.0	0.25	0.20
4	2500	1100	2.3	110.0	55.0	0.55	0.45
5	4500	2600	2.4	400.0	200.0	1.50	1.00
6	6000	3500	2.7	800.0	400.0	17.50	2.50
7	6700	3900	2.8	1000.0	500.0	∞	20.00

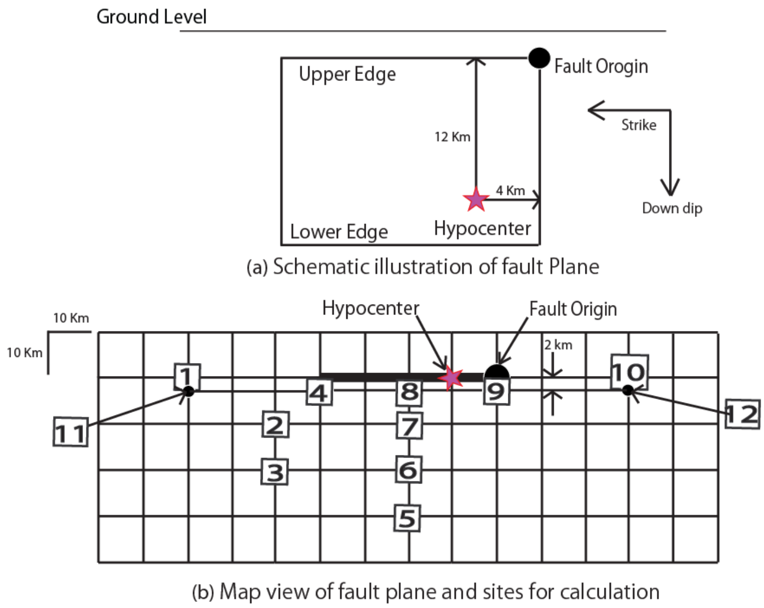

Figure 2 Schematic illustration of fault plane for the scenario event (a) and site geometry for this calculation with respect to the fault plane (b).

3. RESULTS

Among 12 target sites, we pick site 7 and 8 close to the fault plane (Figure 2) and show the results of calculated ground motions for three models in Figure 3.

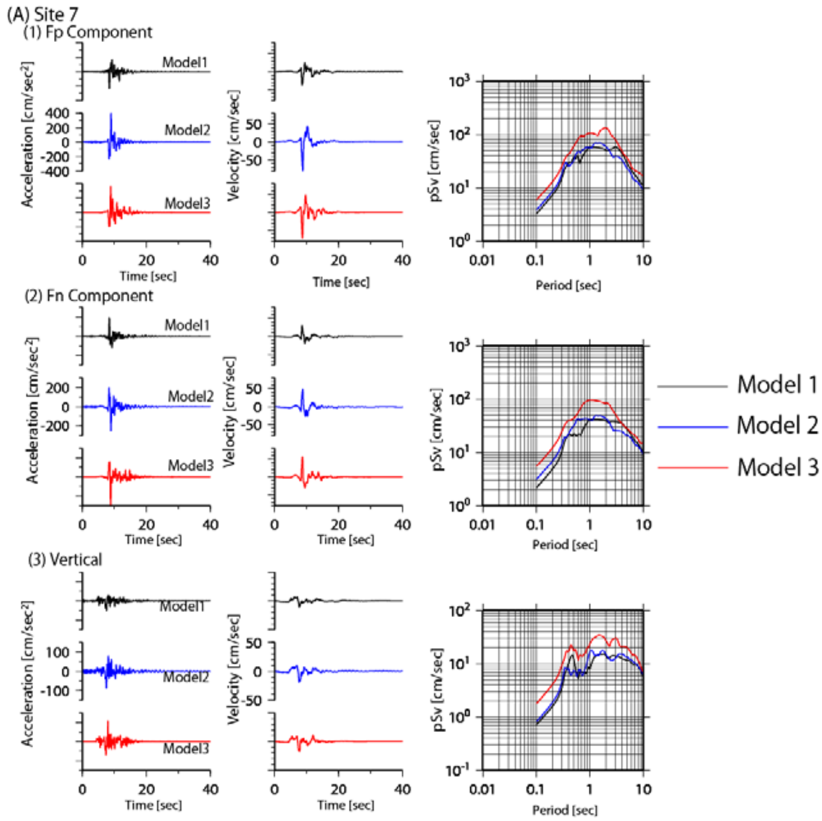

Figure 3A Calculated ground motions (acceleration, velocity and pseudo velocity response spectra at site 7 from three models.

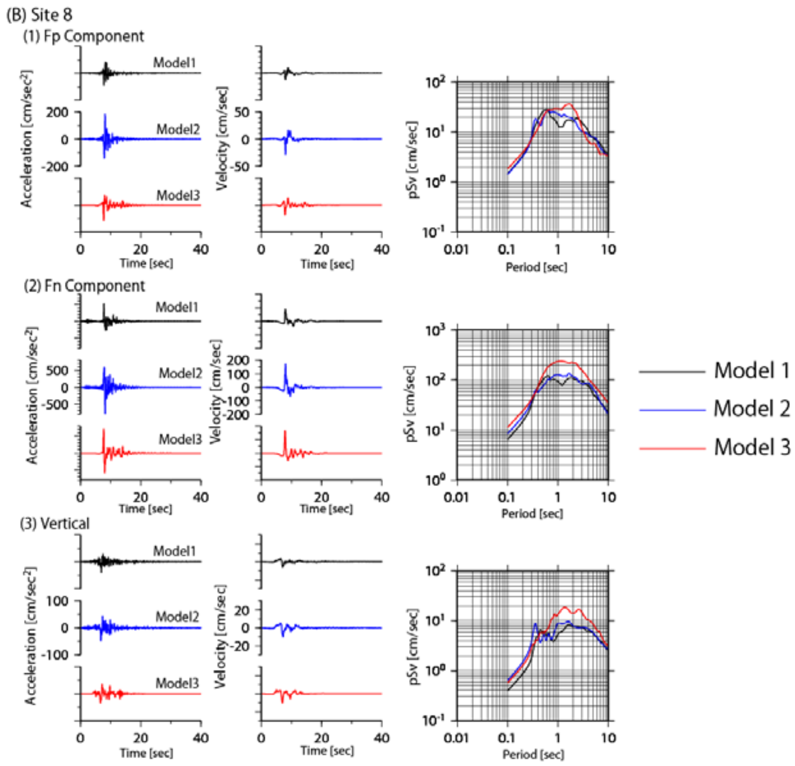

Figure 3B Calculated ground motions (acceleration, velocity and pseudo velocity response spectra at site 8(B) from three models.

Both fault normal and fault parallel components have apparent directivity pulse with large amplitude for all three models. The calculated waveforms (acceleration and velocity) show little differences among these three models. However, the amplitude of pseudo-velocity response spectrum of Model 3 are different from those of Model 1 and 2 especially in the period range of 1～3 sec. The peak amplitude values from Model 3 are much larger than those from Model 1 and 2, and the width of peak amplitude are wide. The amplitude response spectra between from Model 1 and from Model 2 show little difference (those peak amplitude are almost same and those shape of the amplitude are very similar). This similarity may come from the way of modeling that both models have the homogeneous slip distribution even though different asperity shape. The difference of spectra from these three models (especially between Model 1, Model 2 and Model 3) is discussed in the following chapter.

4. DISCUSSION AND SUMMARY

We show the Fourier amplitude spectrum for the fault normal components at sites 7 and 8 in Figure 4(a). We also show the cross section of the velocity model including the fault plane in Figure 4(b). The source model for the scenario event has three asperities and we name each of them based on each size (Figure 4(b)).

The Fourier amplitude spectrum from Model 1 (black line) agrees well with the one from Model 2 (blue line) for almost entire frequency range. However, the spectrum from Model 3 is different from those from other two models around the range of 0.3～1 Hz . In the range of frequency lower than frequency F1 (around 0.3 Hz, corresponding to the black arrow in Figure 4 (a)), all three models produce almost the same Fourier amplitude spectrum. Thus, the peak of amplitude spectrum around the frequency F1 look coming from the asperity on the fault plane. The rupture time of asperity 1 (around 3 sec) also supports that the peak frequency F1 comes from the asperity 1. However, the amplitude spectrum from Model 1 and 2 show the trough higher than frequency F1. On the other hand, the trough of amplitude spectrum from Model 3 higher than frequency F1 has not been seen (Red lines in Figure 4(a)). This difference comes from the way of modeling slip amplitude on the fault plane. Model 1 and 2 ignore the heterogeneity of spatial variation of slip on the fault plane, and

Model 3 builds the heterogeneity into slip amplitude on the fault plane even inside the asperity. This may be the reason that the spectra from Model 1 and 2 do not have the energy to fill the trough. This difference indicates that though partitioning the fault plane into asperity and background is useful to reproduce the directivity pulses coming from asperity such as the conventional characterized source (asperity) model, it might ignore the effects of detail spatial variation (complexity) of slip amplitude on the fault plane on the calculated ground motions.

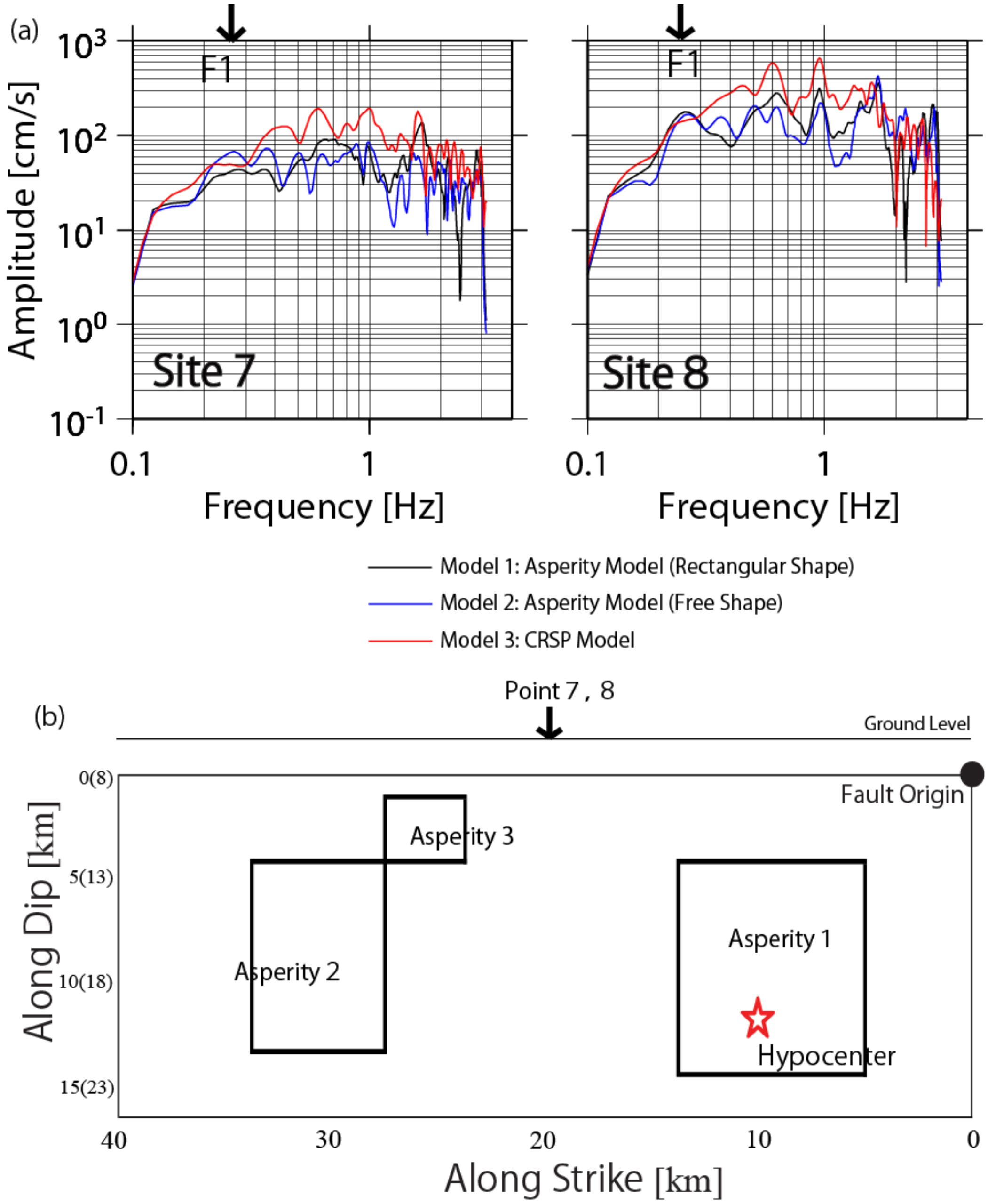

Figure 4 Fourier amplitude spectrum of fault normal component at site 7 and 8 (Figure 2(b)) (a) and schematic view of the model including the fault surface (b). The values on the left hand side of the fault plane denote the depth from the surface.

Model 1 and 2 assumes the constant rupture velocity for the entire fault plane. On the contrary, Model 3 changes the rupture velocities depending on the slip heterogeneities on the fault plane. Recent studies (*e.g.*, Hartzell *et al.*, 2005, Liu *et al.*, 2006) reported the positive correlation between slip amplitude and rupture velocity on the fault plane. We show the spatial distribution of rupture velocity and rise time for this model in

Appendix. As already mentioned, the region with large rupture velocity (small rupture time) agrees with the region with large slip amplitude (around the asperity).

In this study, we compared the ground motions from three different source models for the scenario event. Because we did not compare them with the observed data, we could not speculate that which model is preferable to model the "Real" event. The next step is to develop the method for modeling source that is equivalent to the source model with variable slip amplitude from previous events and to incorporate more detail variation of slip amplitude on the fault plane into modeling source. The comparison of the calculated waveforms with the observed data for a given conditions looks very useful for the ground motion prediction for future events.

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Appendix

In this section, we show the distributions of rupture velocity (rupture time = [distance from hypocenter to each point on the fault plane] / [rupture velocity]) and rise time by using the method by CRSP model in Figure A. Liu *et al.*, (2006) considers the spatial correlation between slip amplitude and rupture velocity, and slip amplitude and rise time. The correlation coefficients are 0.3 for slip amplitude and rupture velocity and 0.6 for slip amplitude and rise time, respectively. Because dynamic modeling of complex rupture process showed that the areas of large slip correlate with fast rupture velocity, the spatial correlation is assumed.

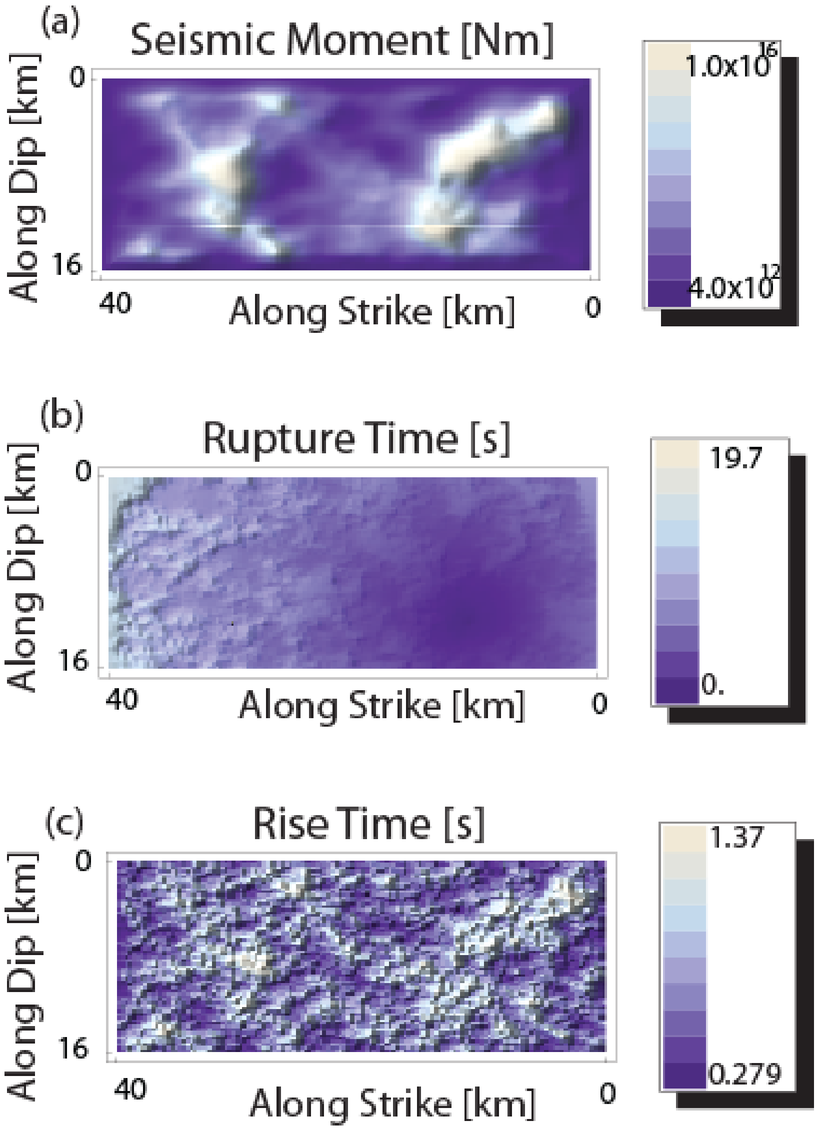

Figure A Spatial variation of seismic moment (a), rupture time (b), and rise time (c) produced by the CRSP model (Liu *et al.*, 2006)