

# **CONTROLLING FACTORS OF STRONG GROUND MOTION PREDICTION FOR SCENARIO EARTHQUAKES**

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## SUMMARY

High probability of future earthquake occurrence on active faults in the western Biwa lake area in Kansai region, Japan, are presented by the nation-level committee on the long-term evaluation. Seismic hazard assessment based on the proper prediction of strong ground motion is the central issue to disaster mitigation for urban area. We simulate ground motions from Mw6.5 class scenario earthquakes making the best use of the strong motion networks such as K-NET and KiK-net as an empirical Green's function databank. The source modeling is carried out by following the recipe of strong ground motion prediction proposed by Irikura and Miyake [1] or Irikura et al. [2]. We set up heterogeneous fault model consisting of two asperities inside the total rupture area, utilizing the empirical relationship of source parameters by Somerville et al. [3]. The length and width of the fault plane are assumed from the surface trace of the active faults and width of the seismogenic zone, respectively. The rupture starting point is supposed from the branching, bending, and jog of the active fault traces (e.g., Nakata et al. [4]). We simulate acceleration and velocity waveforms of the scenario earthquakes by the empirical Green's function method using Mw4.8 event. Peak ground acceleration and velocities from simulated motions are compared with those of the empirical relations. Our ground motion prediction indicates the following facts: The deeper focal depth and larger asperity size broaden the distribution of seismic intensity. The larger stress drop and shorter rise time on asperities increase the seismic intensity. Furthermore the contour pattern of seismic intensity is impacted by the site amplification at the target station and the rupture directivity generated from the asperity. It strongly suggests the importance of ground motion prediction with rupture scenarios.

## **INTRODUCTION**

Since the 1995 Kobe earthquake, Japanese government has started nation-wide evaluation of active faults probability, and strong ground motion prediction for specific source region from active faults or subduction zones. They categorized the Biwako-Seigan active faults as a group of highest probability of earthquake occurrence. The faults locate the western Biwa lake area in Kansai region, Japan. We have conducted strong motion simulation for the northern part of the Biwako-Seigan faults as a hypothetical earthquake source. Source model for the scenario earthquake was constructed as a characterized source

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model based on the recipe of strong motion prediction (Irikura and Miyake [1], Irikura *et al.* [2]). We calculate ground motions using the empirical Green's function method, where the records of small event occurred near the source area is adopted as an empirical Green's function. Peak ground accelerations and velocities of simulated motions are compared with empirical relations. We discuss the importance of the rupture directivity and site effects of deep sediment.

## **CHARACTERIZED SOURCE MODEL FOR GROUND MOTION PREDICTION**

Recent waveform inversion analyses have revealed that heterogeneous slip distribution consists of asperities with large slip and background slip area with less slip. The strong motion characteristics are well correlated to the asperities rather than the background slip area. Somerville *et al.* [3] shows the combined asperity area as well as the total rupture area is proportional to the seismic moment less than the 1992 Landers earthquake. The inversion analyses for the 1999 Kocaeli, Turkey (Mw 7.4) earthquake also support the self-similar scalings of Somerville *et al.* [3]. However when we combine the rupture area compiled by Wells and Coppersimith [5] for larger earthquakes than Mw 7.5, the self-similar scaling of seismic moment and rupture area seems to start bending like the *L*-model (e.g., Scholz [6]). Irikura and Miyake [1](Fig. 1(a)) and Hanks and Bakun [7] pointed out the bending scaling of Mo-S. However even apart from the self-similar scaling, the ratio between asperities and total rupture area showing a constant value (= 0.22) for a moment magnitude range of 5.5 to 7.6 (Fig. 1(b)).

These scaling ideas are a basis for constructing the characterized source model for ground motion prediction. Irikura and Miyake [1] explain the procedure then called it as a recipe. The recipe categorizes seismic moment and fault area as outer fault parameters, area and stress drop of asperities as inner fault parameters, We here introduce the latest recipe by Irikura *et al.* [2] based on the multiple-asperity source model.



Fig. 1(a). Empirical relationship between seismic moment and total rupture area for inland crustal earthquakes. Thick broken and thin solid lines show the relation obtained by Irikura and Miyake [1] and Somerville *et al.* [3], respectively. Shadow ranges  $\pm \sigma$  (standard deviations). Thin solid lines show a factor of 2 and 1/2 for the average.



Fig. 1(b). Empirical relationship between total rupture area and combined area of asperities (thick broken line) for inland crustal earthquakes (Irikura and Miyake [1]). Shadow ranges  $\pm \sigma$  (standard deviations). Thin solid lines show a factor of 2 and 1/2 for the average.

## **Procedure to Construct Fault Parameters**

**Outer Fault Parameters** 

(1) Rupture area S is given, where L is a length of specific fault and W width of the fault

(2) Average stress drop over the fault  $\Delta \sigma_c$  is assumed from the empirical relationship of  $M_0$ -S (e.g.,

Somerville et al. [3]; Irikura and Miyake [1]).

(3) Seismic moment  $M_0$  is estimated assuming the circular-crack model (Eshelby [8]).

#### Inner Fault Parameters

(4) Combined area of asperities  $S_a$  is estimated based on the empirical relationship of  $S_a/S$  (e.g., Somerville *et al.* [3]; Fig. 1(b)).

(5) Stress drop on the asperities  $\Delta \sigma_a$  is estimated assuming the multiple-asperity source model (Das and Kostrov [9]; Boatwright [10]).

(6) Number of asperities N is determined from the information of fault segment.

(7) Average slip of asperities  $D_{ai}$  from the relationship obtained empirically or dynamically.

Extra Fault Parameters

(8) Direction of rupture propagation

(9) Rupture initiation and termination

The width of seismogenic zone  $W_{max}$  are detected 18 km from the seismicity of the microearthquakes in Fig. 2. Consequently fault width W is calculated using  $W = W_{max}/\sin\theta$ . The branching and bending of the active fault traces (e.g., Nakara *et al.* [4]) provide the extra fault parameters. We estimated the rupture direction from the north to south. The recipe created the source parameters of the characterized source model in Table. 1. Fig. 3 displays the assumed fault planes and asperity locations of the scenario earthquake for the Biwako-Seigan faults.



(b)



Fig. 2. Seismicity of the microearthquakes in the Biwako-Seigan area. (a) Map view of seismicity. (b) Cross section of the hypocenters of events in the rectangular area in (a). Hypocenters were determined by the Research Center of Earthquake Prediction, DPRI, Kyoto University in a period of April 1995 to August 2001.

	Sanami Fault	Aibano Fault	Kamidera Fault	References
Fault Length: L	6 km	8 km	5 km	from active fault trace
Fault Width: W	21 km	21 km	21 km	$W_{max}$ : seismogenic zone
$(W = W_{max} / \sin \theta)$	$(\theta = 60^{\circ})$	$(\theta = 60^{\circ})$	$(\theta = 60^{\circ})$	$\theta$ : dip angle
Strike Direction	N190E	N175E	N225E	mainly north to south
				from active fault trace
Rupture Area: S	$399 \text{ km}^2$ ( = 19 km length with 21 km width)			
Average Stress Drop: $\Delta \sigma_c$	2.3 MPa			Somerville <i>et al</i> . [3]
Total Seismic Moment: $M_0$	$M_0 = 7.6 \text{ x } 10^{16} \text{ Nm} (M_w = 6.5)$			
Asperity Area: $S_a$	89 km <sup>2</sup>			Somerville <i>et al.</i> [3]
Area of Each Asperities	16 km <sup>2</sup>	64 km <sup>2</sup>	9 km <sup>2</sup>	
	(4 km x 4 km)	(8 km x 8 km)	(3 km x 3 km)	
Stress Drop on Asperities:	16-18 MPa	16-18 MPa	16-18 MPa	
$\Delta\sigma_a$				
Rise Time	0.4 sec	0.8 sec	0.3 sec	Miyake <i>et al.</i> [11]
Ave. S-wave Velocity: $V_s$	3.4 km/s			
Rupture Velocity: $V_r$	$3.1 \text{ km/s} (= 0.9 V_s)$			

Table 1 Assumed fault parameters for the scenario earthquake for the north part of the Biwako-Seigan faults.



Fig. 3. Assumed characterized model source of the hypothetical event of the north part of the Biwako-Seigan faults. From the north to south, Sanami, Aibano, and Kamidera faults are shown. Thick lines show the traces of the target active faults. Big stars indicate rupture starting points and shadow areas show asperities. The epicenter of the event for the empirical Green function is shown as a small star.

## **Procedure of Broadband Ground Motion Calculation**

The hybrid method (Irikura and Kamae [12]; Kamae *et al.* [13]) is one of the choices for broadband ground motion simulation, where 0.1-10 Hz focuses on the cause of the disaster for the buildings and structures together with large acceleration and velocity. Theoretical and stochastic calculation are applied for long-period and short-period motions, respectively, then combined both with a matching filter.

The empirical Green's function method has convinced of successful simulation as long as the small event records with scaling laws for the fault dimension and source spectra (e.g., Iirkura [14]; Kamae and Irikura [15]; Miyake *et al.* [12]). Dense networks of K-NET or KiK-net increase the simulation points, and make the empirical Green's function method a suitable tool for ground motion simulation of the scenario earthquake. We apply the empirical Green's function technique using the element recoded shown in Fig. 3.

# **GROUND MOTION PREDICTION AND EVALUATION**

We performed the ground motion prediction in a frequency range of 0.2 to 10 Hz. The Signal-Noise level of the small earthquake determines the lower limit of the calculation. Miyake *et al.* [12] confirmed that the large slip-velocity corresponds to the large slip area, and the waveform contributions to acceleration and velocity only form the asperities region are highly dominant for the above frequency range. We aim to evaluate acceleration, velocity, and seismic intensity in this article.

Fig. 4 displays acceleration and velocity at near-fault region (upper 3 traces) and stations close to the Biwa lake (lower 3 traces). The station KISYMD shows long duration due to the thick sediment. The waveform characteristics of the station KISYMD are similar to the waveforms at Osaka basin during the 1995 Kobe earthquake. The predicted seismic intensities are shown in Fig. 5. The rupture propagation from the north to south causes the large seismic intensity (6-) of the southern part of the source region. The stations close to the Biwa lake reaches to the seismic intensity 6+ or 7 due to the site effects of thick sediment. The empirical Green's function method reproduces the individual site effects information for a wide frequency range.

The comparison of the simulated and attenuation relationship for PGA and PGV are shown in Fig. 6. The attenuation is for the hard-rock site by Si and Midorikawa [16] used as a standard relationship of Japanese earthquakes. Some station colored red and blue circles exceeds the empirical relationship, where the red ones are stations of forward directions of the rupture, and the blue ones stations on the thick sediments. We consider that the cause of the significant large PGA and PGV at station SIG007 is surface waves excited by the wave propagation though the thick sediment strengthened together with the effects of forward rupture directivity. For realistic application, non-linear site effects during the strong shaking or liquefaction may reduce the ground motion amplitude.



Fig. 4. Examples of simulated ground accelerations and velocities at stations located on near-fault and sediment sites. Station locations are shown in Fig. 3.



Fig. 6. Comparisons between simulated peak horizontal acceleration and velocities together with the empirical relation for the hard soil sites of Mw6.5 event by Si and Midorikawa [16]. Solid line and dashed lines show the average and standard deviations for the attenuation relation. Red and blue color circles indicate data of stations in the forward directivity area and in the basin, respectively.

#### CONCLUSION

We have conducted strong motion simulation during a hypothetical active fault earthquake for the northern part of the Biwako-Seigan faults. We used the characterized source model for ground motion generation, where the slip and stress drop are characterized from the heterogeneous slip distributions obtained by the recent waveform inversions.

Rupture pattern and location of asperities is the central importance of earthquake scenarios. We referred the idea of Nakata *et al.* [4] to estimate the rupture direction from the branch and bending of active fault traces. We locate the asperities corresponding to the fault segment, following the results of the 1994 Northridge or 1995 Kobe earthquakes. The relationship between shallow/deep asperity position and surface/sub-surface earthquake is open to future discussion. The effective stress on the asperities of the Biwako-Seigan faults, assumed to be equal to stress drop on the asperities, is estimated 16-18 MPa. This value locates between 10 and 25 MPa obtained as stress drop on characterized asperities by dynamic simulations of recent crustal earthquakes (e.g, Iwata *et al.* [17]). Better constraint of such stress parameters promotes the accuracy of ground motion prediction.

Finally our ground motion prediction indicates the following facts: The deeper focal depth and larger asperity size broaden the distribution of seismic intensity. The larger stress drop and shorter rise time on asperities increase the seismic intensity. Furthermore the contour pattern of seismic intensity is impacted by the site amplification at the target station and the rupture directivity generated from the asperity. It strongly suggests the importance of ground motion prediction with rupture scenarios.

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