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A RANDOM SOURCE MODEL FOR STRONG GROUND MOTION PREDICTION

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SUMMARY

For strong ground motion prediction for a site near active fault, a random source model is presented in this paper. Firstly, the relationships between earthquake moment magnitude and rupture area, length, width, and average slip, are listed respectively for three slip types and three moment magnitude intervals from statistical analysis. A finite fault model for the future earthquake on the fault with a given moment magnitude can be built by these global parameters, and then will be divided into many sub-sources by grids, for the variable dislocation on the fault. Secondly, the relationships between earthquake moment magnitude and length, width, slip of maximum asperity, relative coordinate values of the maximum asperity center, size and slip and the other asperities, are derived respectively for three slip types also by statistical data. The dislocation(s) of the asperity(s) then from these local parameters are assigned into the corresponding grids as the deterministic part. The k square model is adopted for the random part. The final dislocation distribution can be worked out by superpose those of the two parts and normalized by the constraint that the total moment in all sub-sources must be the same of the moment of the earthquake, i.e. the product of the area of the fault, the shear modulus and average slip on the whole fault which estimated at the first step. To illustrate the model of this paper, 10 source models are generated for an earthquake with a magnitude 6.7 on dip slip fault.

INTRODUCTION

Finite fault model (FFM) is currently adopted in strong ground motion simulation to describe near-fault rupture directivity effect and hanging wall effect which strongly influence the distribution of ground motion amplitudes on rock sites in the near fault region (Tao and Anderson, 2002). It incorporates the fact that ground motion at a site near the fault is affected mainly from the nearby, local and finite portion of the rupture plane, and the effects of more distant parts of the fault are less important. In the model, the faulting plane is divided into many sub-sources, and the specified dislocation energy is assigned to each one of them, as point source. This model allows a realistic inhomogeneous distribution of the dislocation on the rupture surface.

The most difficult problem for the modeling is how to estimate all the necessary input parameters in FFM before the future earthquake, especially those of energy distribution. In order to randomize the uncertainty,

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Herrero and Bernard (1994) presented a k square model in which displacement spectrum decreases with a rate of k^{-2} when wave number is larger than a given corner wave number k_c. Zeng *et al* (1994) developed a composite source model with power-law distribution of random-sized asperities. In this way, the key point is to constrain potentially all the parameters involved by physical phenomena. Somerville *et al* (1999) suggested that the relations between the size and number of asperities with earthquake moment could be used to constrain simulated slip distribution so that the distribution follows k^{-2} spectral decreasing. Mai and Beroza (2001) analyzed the dependence of the measured relative length a_x, a_z and fractal dimension D with source parameters by means of the results of 44 inversed FFMs of 24 earthquakes, and linked the source parameters on randomness with those on deterministic.

In general, FFMs inversed from the records of occurred earthquakes mainly on long period ground motions, such as velocities and/or displacements of strong ground motions, and velocities of far field ground motions. In long period range, the deterministic part of ground motion is predominant, and the waveform can be simulated from source model and the crust structure. However, in the short period range, the random part is predominant, the waveform cannot be simulated only from the same information.

In this paper, a random source model for strong ground motion prediction from a given earthquake, i.e. Maximum Considered Earthquake MCE for an engineering site, is introduced. As a FFM, its parameters can be divided into two groups, global and local. Four sets of relations are given for the global parameters, and each set consists of relationships for three slip types and three moment magnitude intervals. Another four sets of relations are given for the deterministic part of local parameters. The k square model is adopted for the random part.

GLOBAL PARAMETERS

The geometrical characteristics of FFM are obtained from geological and geophysical investigations of the region. Geometry is specified by the fault location, size, and orientation (strike and dip). In some cases, the fault length can be estimated from geological mapping, fault width can be estimated from regional thickness of the seismogenic zone which generally shown by the regional seismicity distribution in depth, however the resulted values are often the maximum value, not corresponding to the MCE. The size and average slip of the earthquake FFM, characterized by its magnitude or earthquake moment, can be directly estimated from scaling laws. Sometimes the average slip can be checked from the remains displacements in regional paleoseismological investigation.

Wang and Tao (2003) presented 4 sets of semi-empirical relationships between earthquake moment magnitude and rupture area, length, width, and average slip, respectively, from data of 149 historical earthquakes in database of Wells and Coppersmith (1994) and additional 9 events occurred after 1993, as in the following tables.

Table 1 Relation for predicting rupture area S

M_W<6.5	6.5¡ÜM_W<7.0	7.0¡ÜM_W
$\lg S = M_W - 4.0$	$\lg S = M_W - 4.05$	$\lg S = M_W - 4.2$

Table 2 Relation for predicting rupture length L

	M_W<6.5	6.5¡ÜM_W<7.0	7.0¡ÜM_W
All	$\lg L = 0.5M_W - 1.9$	$\lg L = 0.5M_W - 1.85$	$\lg L = 0.5M_W - 1.55$
DS	$\lg L = 0.5M_W - 1.95$	$\lg L = 0.5M_W - 1.9$	
SS	$\lg L = 0.5M_W - 1.9$	$\lg L = 0.5M_W - 1.75$	$\lg L = 0.5M_W - 1.55$

For a strong earthquake with magnitude 6.7, like Northridge event, one can predicts the size of the source FFM as 28×16 km^2, from the dip slip type in table 1 and table 2 respectively. The L and W are for the size along the strike and dip directions respectively, the same hereinafter. The rupture width can also be estimated from table 3, thus the W will be 14 km. The authors prefer the former result, since the deviations of the relationships in the first two tables are less. A more important parameter, the depth from the ground surface to the upper edge of FFM, must be studied more carefully from the regional study. It is usually several kilometers from the statistical data.

Table 3 Relation for predicting rupture width W

	M_W<6.5	6.5¡ÜM_W<7.0	7.0¡ÜM_W<7.5	7.5¡ÜM_W
All	$\lg W = 0.5M_W - 2.0$	$\lg W = 0.5M_W - 2.2$	$\lg W = 0.5M_W - 2.3$	$\lg W = 1.3$
DS	$\lg W = 0.5M_W - 2.1$	$\lg W = 0.5M_W - 2.2$	$\lg W = 0.5M_W - 2.3$	
SS	$\lg W = 0.5M_W - 2.0$	$\lg W = 0.5M_W - 2.1$	$\lg W = 0.5M_W - 2.3$	$\lg W = 1.2$

The average slip can be estimated from table 4. The stress drop is considered as a global parameter and can be estimated from regional seismological study, even though it was considered varying on the rupture surface and/or varying with magnitude.

Table 4 Relation for predicting average slip $\overline{D}$

	M_W<6.5	6.5¡ÜM_W<7.0	7.0¡ÜM_W
All	$\lg \overline{D} = 0.5M_W - 1.45$	$\lg \overline{D} = 0.5M_W - 1.35$	$\lg \overline{D} = 0.5M_W - 1.15$
DS	$\lg \overline{D} = 0.5M_W - 1.45$	$\lg \overline{D} = 0.5M_W - 1.35$	$\lg \overline{D} = 0.5M_W - 1.15$
SS	$\lg \overline{D} = 0.5M_W - 1.45$	$\lg \overline{D} = 0.5M_W - 1.35$	$\lg \overline{D} = 0.5M_W - 1.25$

LOCAL PARAMETERS

Detailed studies of the spatial distribution of slip on the fault plane for earthquakes in tectonically active regions, derived from strong motion recordings and other data, have shown that the slip distribution is highly variable (e.g. Miyakoshi *et al*, 2000; Iwata *et al*, 2001). The number, size, and distribution of asperities in slip (dislocation, energy) can be specified on regular grids. For convenience of FFT in the k square model, a FFM may consist $2^m \times 2^n$ elements. The local parameters that describe the slip heterogeneity or roughness on the fault plane and the rupture process are further divided into two groups, deterministic and random. The deterministic parameters can be estimated from self-similarity. Wang and Tao (2004) developed 4 sets relationships for the size, location and slip of asperity from inverted data of 29 earthquakes. Firstly, the size of the maximum asperity can be taken as 0.21-0.22S, for single asperity case and three fault types. For multiple asperity case, area of the maximum asperity S_{am} and the other asperities S_{ao} can be estimated from the following table.

Table 5 Relation for predicting size of the maximum asperity, S_a and S_{ao}

	S_{am}	S_{ao}
All	0.14S	0.08S
DS	0.15S	0.06S
SS	0.12S	0.10S

For the above FFM case, two asperities are considered, the large one with an area of 0.15S, and the other one with 0.06S. The length and width of the maximum asperity can be estimated from table 6.

Table 6 Relation for predicting length and width of the maximum asperity, L_a and W_a

	L_a		W_a	
	Single Asp.	Multiple Asp.	Single Asp.	Multiple Asp.
All	0.46L	0.27L	0.43W	0.35-0.54W
DS		0.36-0.49L		0.35-0.50W
SS	0.55L	0.22L	0.50W	0.59W

For the example case, one can predict the maximum asperity as 10.2×6.5 km^2, and 27 km^2 for the other one. The number of fault elements covered by this maximum asperity, can be estimated by its size and of fault elements. The location of the maximum asperity is defined by two relative coordinate values X_{am} and Y_{am}, which can be estimated from table 7. For the example, they are 8.3 and 8.0 km from the up – left corner of the FFM respectively. One can layout the maximum asperity element on FFM, and also other asperity element(s) by the similar way.

Table 7 Relation for predicting relative coordinate values of the maximum asperity center, X_{am} and Y_{am}

	X_{am}		Y_{am}	
	Single Asp.	Multiple Asp.	Single Asp.	Multiple Asp.
All	0.49L	0.21-0.50L	0.43-0.56W	0.35-0.53W
DS		0.30-0.49L		0.35-0.50W
SS	0.46L	0.19-0.50L	0.33-0.56W	0.53W

The average slip D_{am} on the maximum asperity and D_{ao} on other asperity(s) in multiple asperity case or the average slip D_a in single asperity case, can be estimated from the following table. For example, 219cm and 191cm are estimated for the two asperities.

Table 8 Relation for predicting average slip on asperity(s), D_{am}, D_{ao} and D_a

	D_{am}	D_{ao}	D_a
All	$2.29\overline{D}$	$1.95\overline{D}$	$2.19\overline{D}$
DS	$2.19\overline{D}$	$1.91\overline{D}$	$2.14\overline{D}$
SS	$2.46\overline{D}$	$2.04\overline{D}$	$2.19\overline{D}$

The slip values then are assigned to each fault element as weighting factor according to the asperity layout on FFM. Furthermore, the total energy or dislocation of the earthquake from the moment magnitude and/or size of the FFM is assigned to each element by these factors.

The parameters of k square model for the random group are the corner wave numbers along strike and dip directions respectively, K_{cx} and K_{cy}, in the following equation.

$$D(k_x, k_y) = \frac{\overline{D}}{\sqrt{1 + \left(\left(\frac{k_x}{K_{cx}} \right)^2 + \left(\frac{k_y}{K_{cy}} \right)^2 \right)^2}} e^{i\phi(k_x, k_y)} \qquad (1)$$

Somerville, Irikula *et al* (1999) suggested that they can be estimated by $\log K_{cx} = 1.72 - 0.5 M_W$ and $\log K_{cy} = 1.93 - 0.5 M_W$.

The dislocation in each grid can be obtained by superposing the values of the two parts. Finally, they must be normalized to assure the total moment in all sub-sources must be the same of the moment of the earthquake, i.e. the product of the area of the fault, the shear modulus and average slip on the whole fault which estimated at the first step.

Ten source models are generated by the process suggested above, as shown in figure1, in order to illustrate the adaptability of the model developed in this paper.

RUPTURE PROCESS

The start point of rupture must be selected from detail investigation of the fault, and its relative coordinate values X_s and Y_s can also be estimated from the relationship in the following table.

Table 9 Relation for predicting relative coordinate values X_s and Y_s of the rupture start point

	X_s	Y_s
All	0.42L	0.42-0.58W
DS	0.43L	0.42-0.81W
SS	0.42L	0.48-0.58W

For the above example, the values of X_s and Y_s can be obtained as 12 and 13 km from the up – left corner of the FFM.

The rupture process is governed by a constant rupture velocity, which can be taken as depth independent at a value of 0.8 times the shear wave velocity generally at the half depth of the FFM in regional crust. The crack in a FFM element is triggered when the rupture reaches its center. A random component, especially needed when the elements are on regular grids, can be added to the rupture velocity. There can be one or multiple rupture start point(s) in source model.

Rules have been established to combine the contributions of the fault elements. In general, the mathematical basis is the representation theorem, which shows how motion at a site is related to slip on the fault. However, the calculation of the Green function is complicated, the analytical formula have been derived just for horizontal layered media, and the number of the layers is limited. Some researchers, including the authors and their co-workers, are working on a Numerical Green Function method. Since the limitation of the fault element size, strong ground motion can only be predicted by this method at long period range of frequency less than 1 Hz. For short period range, the simplest method, the random synthesis procedure can be adopted.

CONCLUSIONS

A random source model for strong ground motion prediction is introduced in this paper. It takes a general form similar with the widely adopted FFM. The global parameters are derived from the geological and geophysical investigation directly and some regional empirical relationships. Four sets of semi-empirical relationships are suggested. The local parameters consist of two groups, the deterministic are also estimated by four sets of empirical relationships, and the random part is described by k square model mainly from Somerville, Irikula *et al* (1999), in which the parameters can be estimated by another two empirical relationships. The final dislocation distribution can be worked out by superposing those of the two parts and normalized to assure that the total moment in all sub-sources must be the same of the moment of the given earthquake. Ten source models for a given earthquake are generated to show the adaptability of the approach presented in this paper.

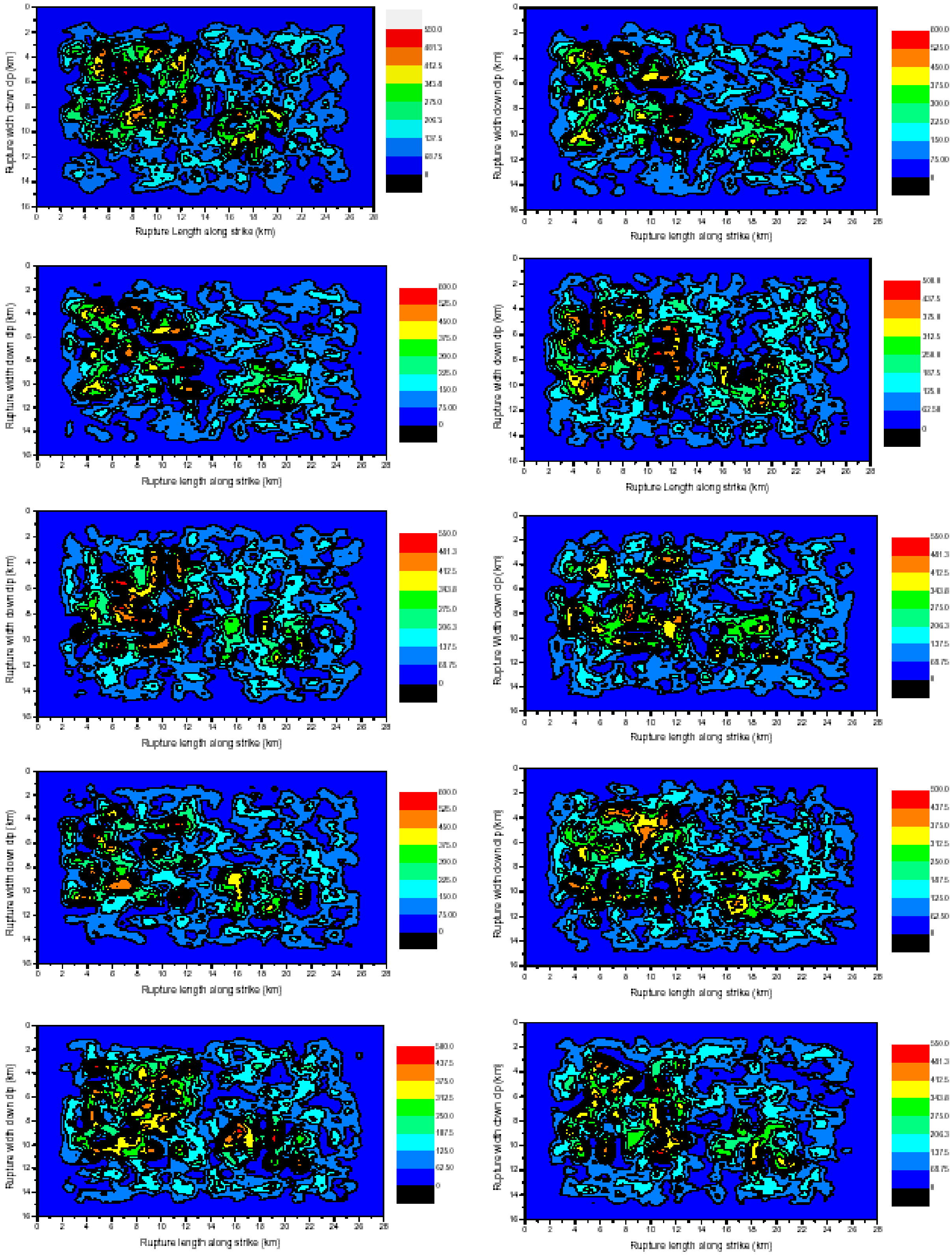

Fig.1 Ten generated source models for a given earthquake

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