AN DYNAMIC CORNER FREQUENCY BASED SOURCE SPECTRAL MODEL

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ABSTRACT :

A source spectral model for stochastic synthesis of near-field ground motion was presented in this paper. It is compared with the famous source spectral model (ω^2) by Brune and the source spectral model with double corner frequencies by Atkinson in different magnitudes. The result shows that the source spectrum by this paper is very close to Brune's for small magnitude and is close to Atkinson's for large magnitude. Afterwards, the source spectral model is combined with the dynamic corner frequency to eliminate the effect of the sub-fault size on the high frequency radiating energy. The improved source spectral model was verified finally from the comparing the ground motion synthesized with the records at three rock sites in Northridge earthquake, 1994.

KEYWORDS: Source spectral model; Dynamic corner frequency; Stochastic synthesis

1. INTRODUCTION

Stochastic finite-fault modeling is a very useful tool for the prediction of high frequency ground motion near the epicenters of large earthquakes (Hartzell, 1978; Irikura, 1983; Somerville *et al.*, 1991; Zeng *et al.*, 1994; Beresnev and Atkinson, 1998). In this method, a large fault is divided into many subfaults and each subfault is considered as a small point source. Ground motions of subfaults are calculated by the stochastic point-source method (Boore, 1983; Anderson, 1984; Atkinson, 2000) in which the Fourier spectrum acceleration of a point-source is calculated by

$$FA(M_0, f, R) = S_A(M_0, f)\cdot G(R)\cdot D(R, f)\cdot A(f)\cdot P(f)\cdot I(f) \tag{1.1}$$

where $FA(M_0, f, R)$ is the Fourier amplitude spectrum of ground motion at a site with distance R, $S(M_0, f)$ is the source spectrum, $G(R)$ accounts for the geometrical attenuation along the distance, $D(R, f)$ represents the energy dissipation attenuation, $A(f)$ is near surface amplification factor and could be estimated by a transfer function of regional crust velocity gradient, $P(f)$ is a high-cut filter, $I(f)$ accounts the relation between the acceleration spectrum and displacement spectrum. After inverse Fourier transform, ground motions of all subfaults are summed with a time lag in the time domain to obtain the ground motion acceleration:

$$a(t) = \sum_{i=1}^{N_L}\sum_{j=1}^{N_W} a_{ij}\left(t - \Delta t_{ij}\right) \tag{1.2}$$

2. SOURCE SPECTRAL MODEL

The most famous source spectral model is the ω^2 model (Aki, 1967; Brune, 1970; Boore 1983) in which the acceleration source spectrum is defined to be:

$$S_A(f) = \frac{CM_0 (2\pi f)^2}{\left[1 + \left(f / f_0\right)^2\right]} \tag{2.1}$$

Where, C is a coefficient independent on frequency, f_0 is corner frequency, M_0 is the seismic moment. In this paper, an improved source spectral model is adopted (Masuda, 1982) with parameters depending on the statistical analysis of the strong motion recordings (Wang and Tao, 2001):

$$S(M_0, f) = \frac{M_0}{[1 + (\frac{f}{f_0})^a]^b} \tag{2.2}$$

The coefficients *a* and *b* are magnitude dependent, as follows:

$$a = 3.05 - 3.33M$$
$$b = \frac{2.0}{a} \tag{2.3}$$

The source spectra compared with those from other two famous models are shown for magnitude 4, 5, 6 and 7 respectively from the bottom to the top in Figure 1. One can observe from Figure 1 that the source spectrum by this paper is very close to Brune's for small magnitude and is close to Atkinson's for large magnitude.

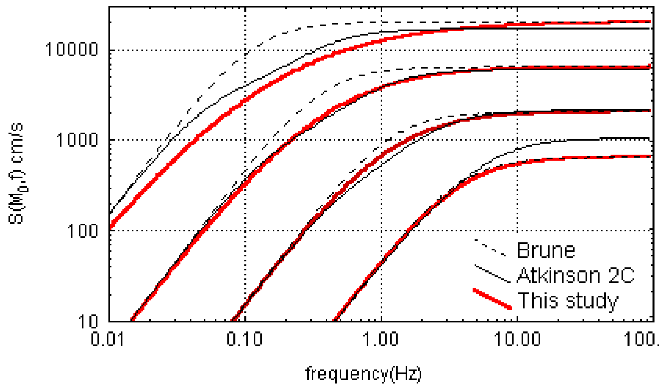

Figure1 Source spectra

3. DYNAMIC CORNER FREQUENCY

It has been a problem that stochastic finite-fault modeling is subfault size dependent (Joyner and Boore, 1986; Beresnev and Atkinson, 1998). The acceleration source spectrum of the subfault in this method is as follows:

$$A(f) = Cm_0 (2\pi f)^2 \Big/ \left[1 + \left(f / f_0\right)^2\right] \tag{3.1}$$

where m_0 is seismic moment of subfault and is defined by

$$m_0 = \Delta\sigma \cdot \Delta l^3 \tag{3.2}$$

f_0 is the corner frequency and is given by

$$f_0 = \frac{yz\beta}{\pi\Delta l} \tag{3.3}$$

Then, the horizontal asymptote of high-frequency radiated energy in this method can be expressed by

$$E_a(f) = C(\Delta\sigma M_0)^{1/2}\left(\frac{yz\beta}{\pi}\right)^2 \Delta l^{-1/2} \tag{3.4}$$

One can easily found from Eqn.3.4 that the high-frequency radiated energy is inversely proportional to the square root of subfault size. Taking the Northridge earthquake, 1994 as an example, one can found this effect on simulated ground motion directly. First, following Wang's work (2004), we worked out a finite fault model with length of 28 km and width of 16 km for the Northridge earthquake, as shown in Figure 2.

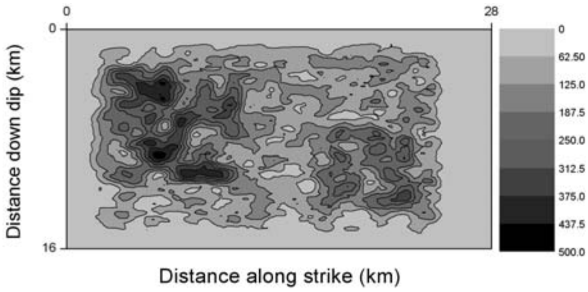

Figure 2 Finite fault model used in the simulation

We use the stochastic finite-fault simulation code FINSIM presented by Beresnev and Atkinson (1998). All the other parameters used in the simulation were kept the same and shown in Table3.1. Simulations are performed for different subfault sizes of 1km and 4km. Figure 3 shows the ground motion accelerations at the station LV3 for different subfault sizes. As we can see, as subfault size increases, the amplitude of acceleration in high frequency decreases and that in low-frequency increases. This is a conceptual disadvantage of the stochastic finite-fault modeling.

Table 3.1 Model Parameters needed by FINSIM

Parameter	**Parameter value**	**Parameter**	**Parameter value**
Fault orientation	strike 122 °, dip 40 °	Kappa	0.03
Fault depth (km)	5	Crustal shear-wave velocity (km/sec)	3.7
$Q(f)$	$333 f^{0.74}$	Crustal density (g/cm^3)	2.8
Distance-dependent duration	$T_0 + 0.1R$	Stress factor	1.6
Windowing function	Saragoni-Hart	Stress drop (bars)	50
Geometric spreading	$1/R$ $(R \le 70km)$ $1/R^0$ $(70km < R < 130km)$ $1/R^{0.5}$ $(R \le 130km)$	Local amplification	Western North America generic rock site (Boore and Joyner, 1997)

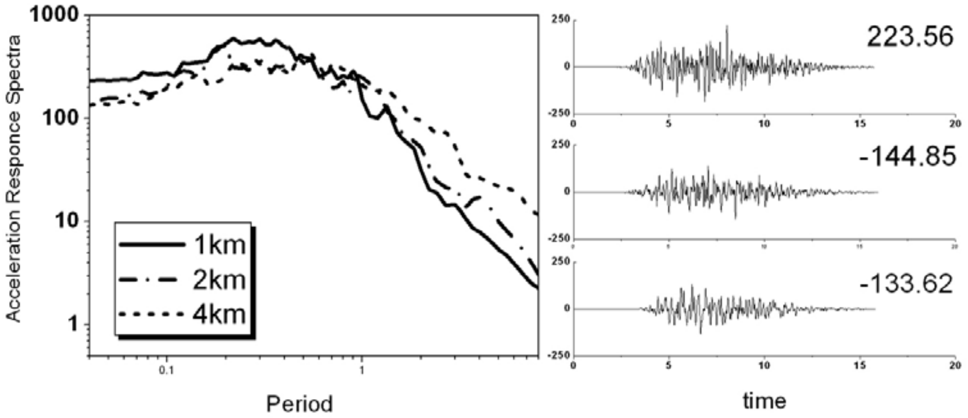

Figure 3 Ground motion accelerations by FINSIM with the subfault sizes of 1, 2 and 4 km.

To solve this problem, we improved the source spectral model based on the concept of dynamic corner frequency (Motazedian and Atkinson, 2005). In Motazedian and Atkinson's work, the ruptured area is treated as time dependent. It begins with zero and up to the entire fault area after all subfaults triggered. At any moment of rupture, the corner frequency is inversely proportional to the rupture area hence is time dependent too. Based on the similar idea, we decided to connect corner frequency with rupture area by means of exponents *a* and *b* in Eqn.2.2. Eqn.2.3 describes the relation between exponents *a*, *b* and moment magnitude. According to Wang (2004), the moment magnitude has the following relation with the rupture area:

$$\log S = M_W - 4.05 \tag{3.5}$$

Substitute Eqn.3.5into Eqn.2.3, we finally describe *a* and *b* as follows:

$$\begin{cases} a = -0.33\log S + 1.34 \\ b = 2.0/a \end{cases} \tag{3.6}$$

Finally, we also use the Northridge earthquake as example to test the superior of our improvement. All the other parameters used in the simulation were also those shown in Table3.1. Ground motions on station LV3 with subfault size of 1, 2 and 4 km were worked out and shown in Figure 4 Afterwards, the simulated ground motions were compared with the observed seismograph and shown in Figure 5. Easy to see from Figure 4 and Figure 5 that ground motions with different subfault sizes are very closed to each other and to the observed one in short period range (T < 2sec).

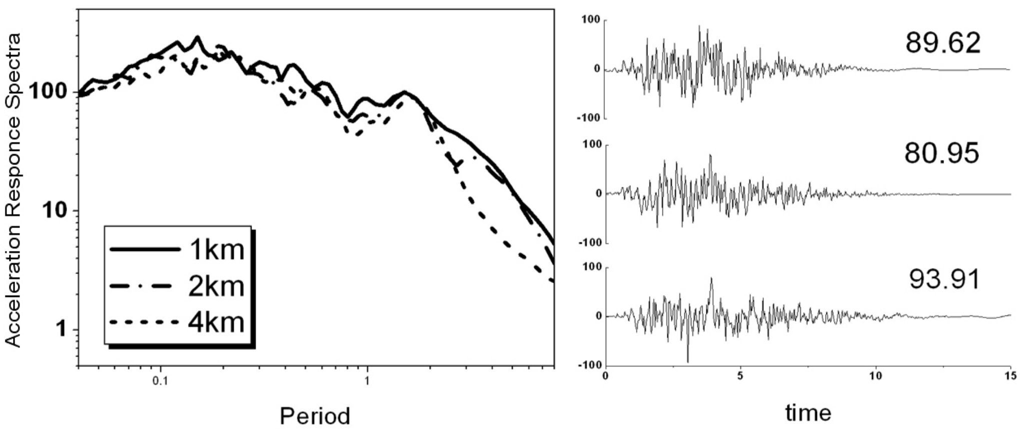

Figure 4 Ground motion accelerations by this article with the subfault sizes of 1, 2 and 4 km.

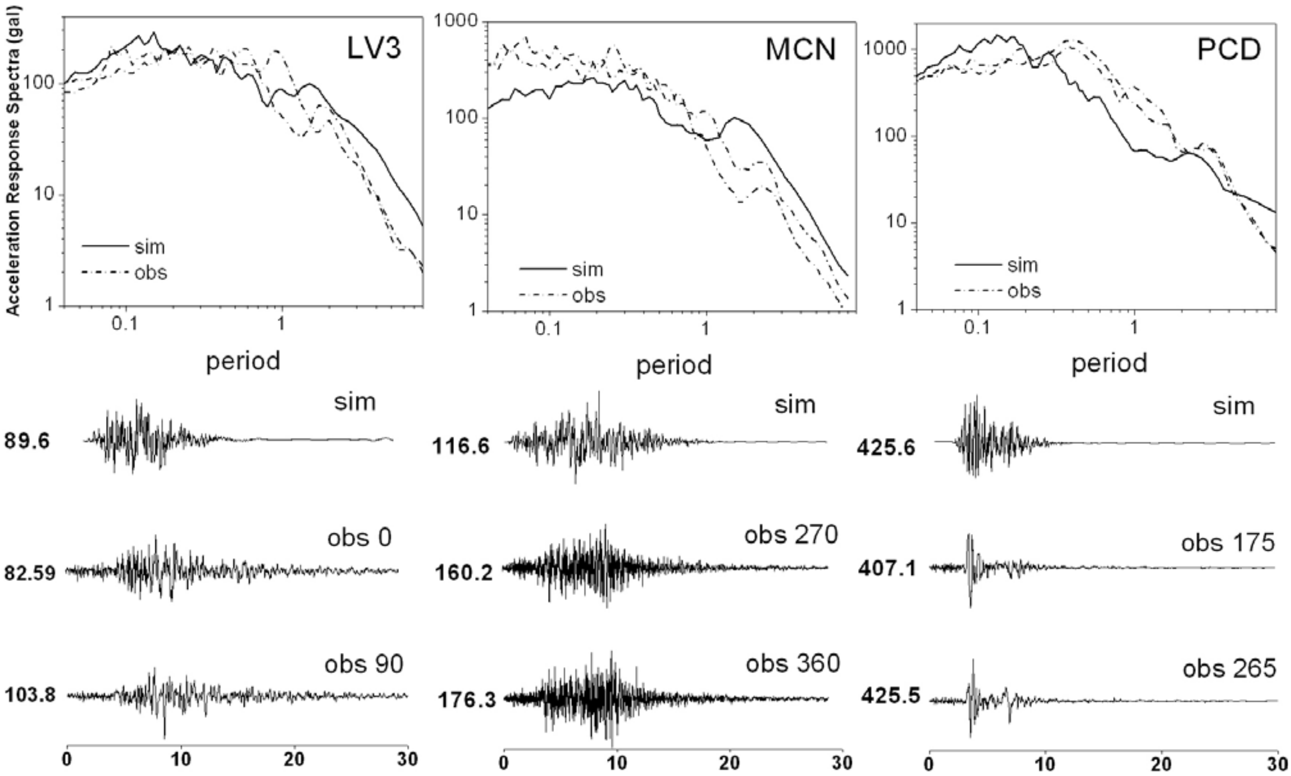

Figure 5 Simulated and observed ground motion on three stations

CONCLUSION

In this article, a source spectral model for stochastic synthesis of near-field ground motion was presented first and compared with two famous source spectral models by Brune and by Atkinson in different magnitudes. The result shows that the source spectrum by this article is close to Brune's and Atkinson's for small and large magnitude respectively. Afterwards, this source spectral model is improved based on dynamic corner frequency to eliminate the effect of the sub-fault size on the simulated ground motions. The improved source spectral model was verified finally by comparing the simulated ground motion with the records at three rock sites in Northridge earthquake, 1994.

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