SMiRT–12 / K. Kussmaul (Editor)

MK01/2

CONSIDERATION OF THE STOCHASTIC DISLOCATION PROCESS IN THE GEOPHYSICAL GROUND MOTION MODEL

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1 Introduction

A large number of ground motion models have been proposed for the seismic design of a nuclear power plant. However none of them fully and satisfactorily simulates high-frequency waves. Since consideration of high-frequency waves is particularly important for the seismic design of a rigid structure, the geophysical ground motion model with the stochastic dislocation process is proposed for simulating high-frequency waves in this study.

Recent studies of earthquake source mechanisms have shown importance of the nonuniform dislocation process due to heterogeneity on a fault plane for generating high-frequency waves. Since mechanisms of high-frequency wave generation are not well understood, a stochastic formulation is employed for representing details of the nonuniform dislocation process. However, a deterministic formulation is used for gross features of the rupture process. In the stochastic dislocation process, the dislocation velocity is assumed to be not constant but randomly distributed in time and space. Local variations in the dislocation process due to the fault heterogeneity are employed. In order to specify the heterogeneity on a fault plane, an entire fault is divided into small segments. Each segment is assigned the different dislocation process, slip velocity and seismic moment release. In particular geometrical variations in fracture surfaces are considered based on observations on topography of natural rock surfaces for generating high-frequency waves.

2 Stochastic Dislocation Process

2.1 Stochastic dislocation process in time

For the coherent rupture process of a fault the dislocation velocity is given by a simple box-car function, while for the incoherent rupture process the dislocation process is random function as shown in Figure 1. Koyama (1985) assumed that the dislocation process is given by the random impact of particles in Brownian motion. When considering incoherent rupture process, the height of the pulses is assumed to be random and the duration of each pulse τ is assumed to be exponentially distributed according to $\exp(-\lambda\tau)$ where λ is the rate of pulse occurrences.

Following Boore and Joyner (1978) integration, the finite dislocation filter for the stochastic dislocation process in time is found to be

$$Ft(\omega)=\left(\frac{\sin^2(\omega To/2)}{(\omega To/2)^2}+\frac{2\sigma^2}{To^2a^2}\,\frac{\lambda To}{\omega^2+\lambda^2}\right)^{1/2} \quad (1)$$

The first term in equation (1) corresponds to the smooth rupture process with a smooth dislocation velocity in time. The second term describes the random rupture process with random dislocation velocity . The patch density λ To (i.e.; the number of patches along the fault plane) and σ (i.e.; the fluctuation in the velocity) are govern the high frequency.

In order to examine the sensitivity of source spectrum to the random dislocation velocity in time, parametric studies are performed. Figure 3 shows changes in the amplitude of the normalized source spectra depending on the coefficient of variation of dislocation velocity. A comparison of these figures shows that the amplitude of the spectra in the higher frequency range increases as the the coefficient of variation increases. The results indicate that the stochastic dislocation process in time generates more high-frequency waves than the uniform dislocation.

2.2 Stochastic Dislocation Process in Space

The source spectrum of the stochastic dislocation process in space is developed by a weighted sum of the source spectrum for trigonometrically distorted faults as follows

$$F_L(\omega)=\Sigma\, \alpha_i F_{iL}(\omega) \qquad (2)$$

where α i is the probability that the wave length of the distorted fault is equal to λ km. The schematic representation of the randomly distorted fault is shown in Figure 2. The probability α i is determined by the power spectrum of natural rock surfaces. (Brown and Schulz 1985, Okubo and Aki 1987) The source spectrum for the trigonometrically distorted fault plane is given by Miyatake (1985)

$$F_{iL}(\omega)=a_{io}\frac{\sin\frac{\omega\Phi_O}{2}L}{\frac{\omega\Phi_O}{2}L}+\frac{a_{il}}{2}\left\{\frac{\sin\frac{k_i+\omega\Phi}{2}L}{\frac{k_i+\omega\Phi}{2}L}+\frac{\sin\frac{k_i-\omega\Phi}{2}L}{\frac{k_i-\omega\Phi}{2}L}\right\}+\frac{a_{i2}}{4}\left\{\frac{\sin\frac{2k_i+\omega\Phi}{2}L}{\frac{2k_i+\omega\Phi}{2}L}+\frac{\sin\frac{2k_i-\omega\Phi}{2}L}{\frac{2k_i-\omega\Phi}{2}L}+\frac{\sin\frac{\omega\Phi}{2}L}{\frac{\omega\Phi}{2}L}\right\} \qquad (3)$$

and

$$a_{i0} = \cos 2\theta_0 \quad a_{i1} = (4\pi\,\Delta h_i / \lambda_i \sin(2\theta_0) \quad a_{i2} = (-8\pi^2\,\Delta h_i / \lambda_i)^2 \cos(2\theta_0) \qquad (4)$$

$$\Phi=\frac{1}{V_r}-\frac{\cos\theta_O}{\beta} \quad k_i=2\pi/\lambda_i \quad h_i(\xi)=\Delta h_i \sin(2\pi\xi/\lambda_i) \qquad (5)$$

In order to examine the sensitivity of the source spectrum to the random dislocation velocity in space, parametric studies are performed. Figure 4 shows changes in the amplitude of the normalized source spectra depending on the distortion of the fault plane. A comparison of these figures shows that the amplitude of the spectra in the higher frequency range increases as the wave length of the distortion is shorter. The result indicates that the spacial variation of the fault plane generates more high-frequency waves.

Then the complete form of the stochastic dislocation process in time and space is obtain by combining equation 1 and 2.

$$F(\omega)=F_t(\omega)F_L(\omega) \qquad (6)$$

3. Ground Motion Simulation Model

In an area of predicting earthquake ground motions, several techniques have been used to simulate ground motions which consider the fault rupture mechanisms and the propagation of various seismic waves from the source to the site. However, few of these methods have been utilized in engineering practice. It is recognized that no one method fits all geologic or tectonic regimes and each method has advantages in some particular situations. In this paper we adopt the normal mode method to simulate the site specific ground motion.

The normal mode method is composed of two steps : (a) computation of the normal modes representing the free oscillations of the earth and (b) site response analysis by weighted

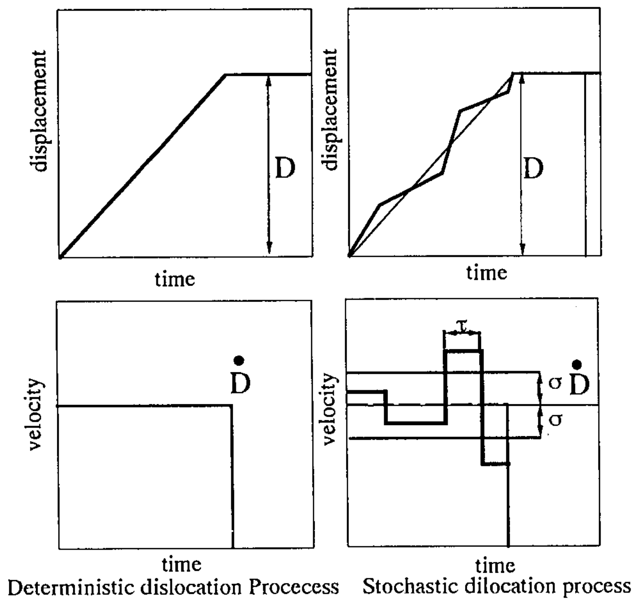


Figure 1 Stochastic dislocaton Process in time

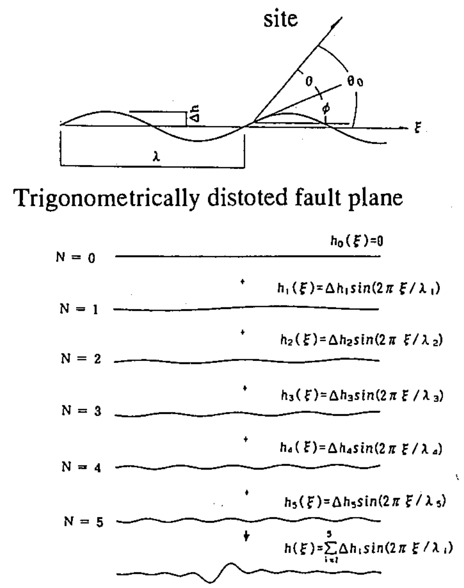


Figure 2 Stochastic dislocaton Process in space

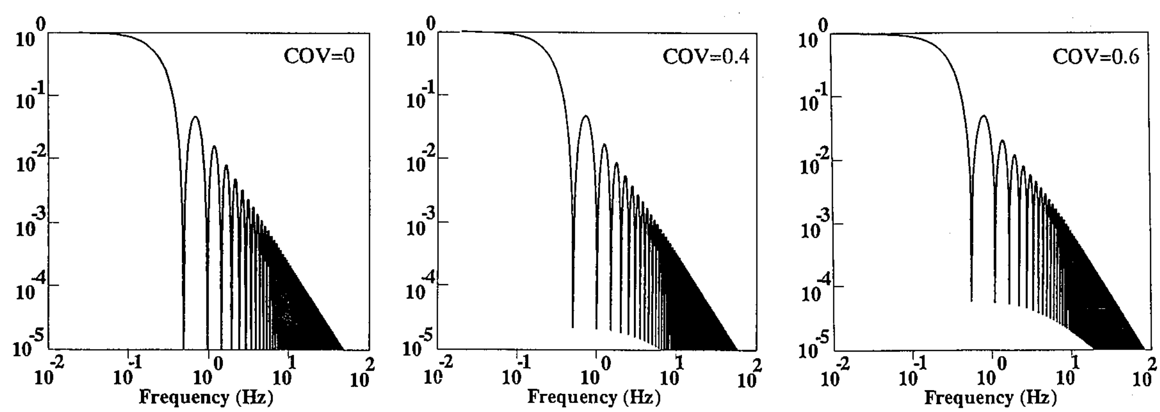


Figure 3 Normalized spectra with the stochastic dislocation process in time

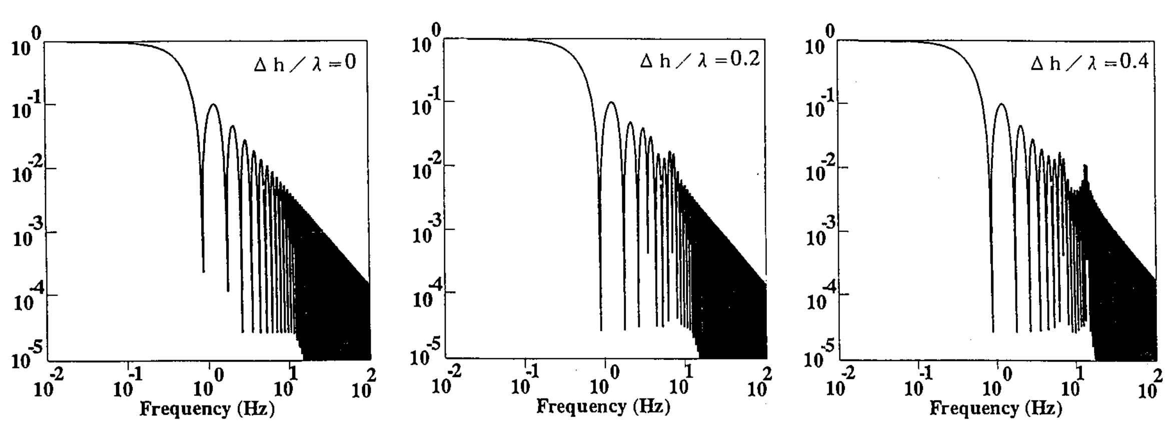


Figure 4 Normalized spectra with the stochastic dislocation process in space

superposition of these modes. In order to compute the normal modes, the earth is assumed to be an elastic spherical body whose free oscillations are described by the elementary equation of free vibrations. The eigenvalues and eigenfunctions that describe the normal modes of vibration of the earth are solution of the homogeneous differential equation of a motion. Two independent modes are identified : the toroidal modes corresponding to a twisting motion of the earth (SH waves) and spheroidal modes corresponding to distorting motions of the earth (P.SV waves). In computing the eigenvalues and eigenfunctions, the sphere is considered to be radially heterogeneous and laterally homogeneous. The excitation function for computing the response motion at a site is modeled as a double couple force. The rupture at a finite fault is modeled as a moving source. Then the response of the ground motion at a site $u(\omega)$ is expressed by a series of filters

$$u(\omega) = S(\omega)\cdot F(\omega)\cdot X(\omega)\cdot Q(\omega)\cdot L(\omega) \qquad (7)$$

where $S(\omega)$ is the Fourier transform of the source time function. $F(\omega)$ represents the dislocation process along the source and is given by the equation 6. $X(\omega)$ represents the wave propagation effect. $Q(\omega)$ is the attenuation effect form the source to the site and $L(\omega)$ is the local soil filter

4. Application of the Model

4.1 Introduction

In order to investigation the applicability of the model, the ground motions from the October 17, 1989 Loma Prieta earthquake, April 4, 1968 Borrego Mountain earthquake and the September 19, 1985 Mexico earthquake are simulated. The same source mechanisms as the events are used to simulate the ground motions. The results are compared with the observed records to demonstrate the effectiveness of the model.

4.2 Simulation of the October 17 1989 Loma Prieta earthquake

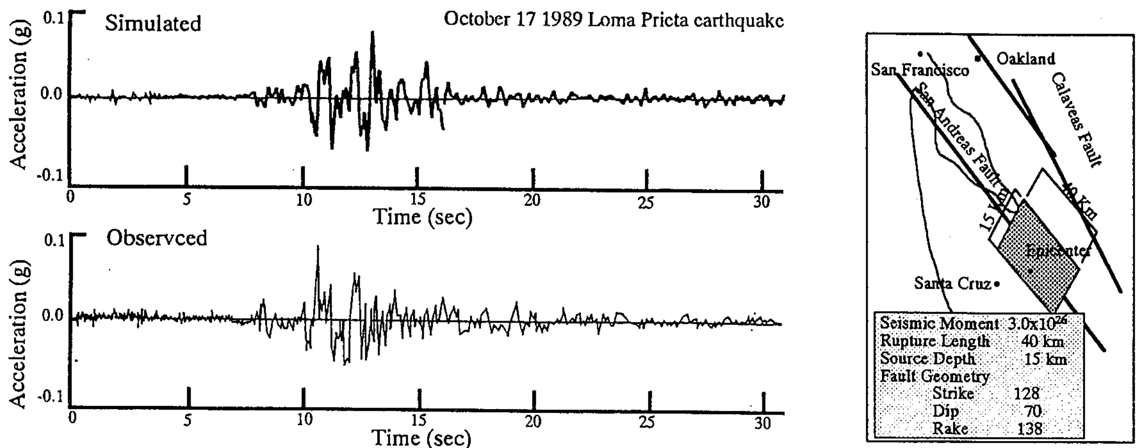
The Loma Prieta earthquake of October 17. 1989 (Ms=7.1) occurred in a segment of the San Andreas fault northeast of Santa Cruz, California. The epicenter was located 16km northeast of Santa Cruz and 30km south of San Jose. The main rupture started at a depth of 15km and the total rupture length is 40km. In order to examine the applicability of the model, the strong ground motions of the Loma Prieta earthquake are simulated. The rupture is assumed to start at the center of the fault plane and is propagated in both directions at a speed of 2.5km/sec. The fault plane is divided into 8 asperities. The asperity length and the rise time are assumed to be 5km and 2.5sec respectively, following the study by Choy and Boartwright (1990). The source parameters used for simulation are shown in Figure 5(a). Figure 5(a) also shows the simulated time history of the strong ground acceleration at the rock site from 20km of the source together with the observed record at Corralitos Eureca Canyon Rd.

4.3 Simulation of the April 4, 1968 Borrego Mountain Earthquake

The Borrego Mountain earthquake of April 4, 1968 had a local Richter magnitude of 6.4. The earthquake occurred on the Covote Creek fault which is the part of the South San Andreas fault. Figure 5(b) shows the epicenter of the Borrego Mountain earthquake and the El Centro recording station where is located 60km from the epicenter. The source mechanisms of this event have been studied in great detail by Heaton and Helmberger (1977). Based on the study the source parameters of the event are determined as shown in Figure 5(b). The ground motion at the El Centro station is simulated to compare the observed motion with the simulated motion. Figure 5(c) shows the time history of the acceleration ground motion together with the observed record at El Centro recording station.

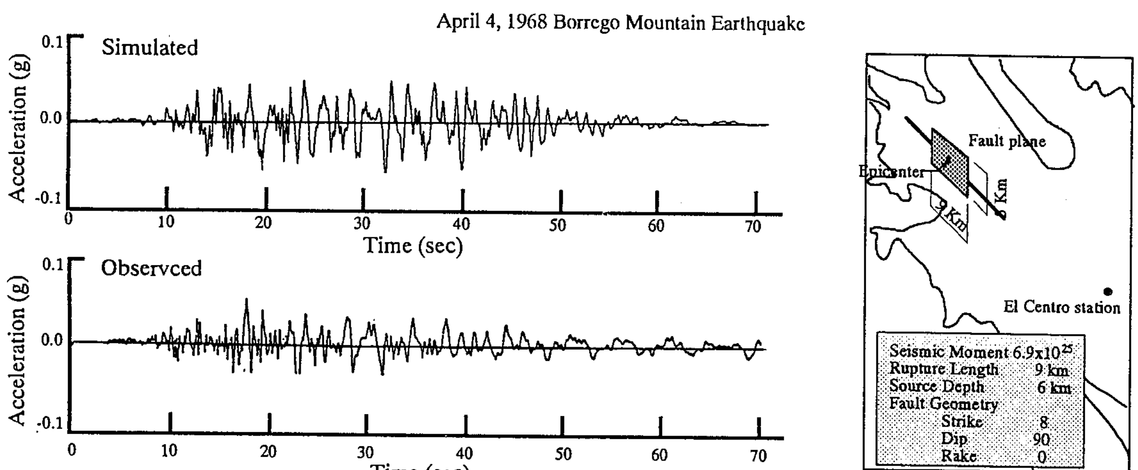
4.4 Simulation of the September 19, 1985 Mexico Earthquake

The strong ground motion of the September 19, 1985 earthquake were characterized by the long duration of ground motions, the relatively long predominant period of ground motion and high amplitude of ground motion at great distances from the epicenter of the event. The source parameters of that event were analyzed from an array of strong motion accelerographs. Based on



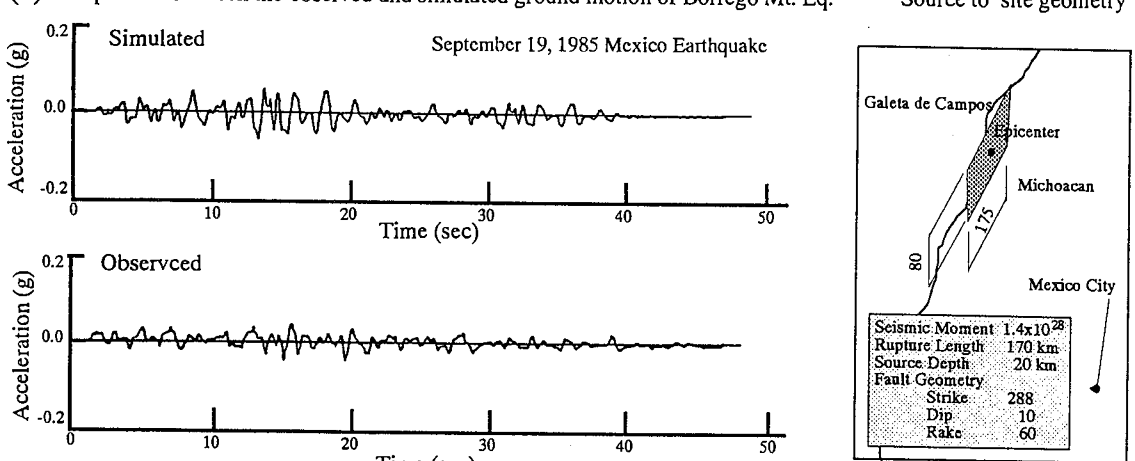
(a) Comparison between the observed and simulated ground motion of Loma Prieta Eq.

Source to site geometry



(b) Comparison between the observed and simulated ground motion of Borrego Mt. Eq.

Source to site geometry



(c) Comparison between the observed and simulated ground motion of Mexco Eq.

Source to site geometry

Figure 5. Simulation of ground motions by the stochastic dislocation model

this information, the source parameters used for simulation are shown in Figure 5(c).From the analysis of short-period records, (Houston, 1985) it is found that three strong pulses were released during the rupture process.The first pulse was small and second to the forth pulses are relatively large. The second pulse was released about 80km south-east of the first pulse location. The third pulse was released near the first pulse location. It is estimated that 40% of the total energy was released by the first strong pulse, 40% by the second pulse, and 20% by the third pulse (Houston, 1985). Anderson et al. (1985) estimated the predominant patch length of the rupture zone as 4km using the source spectrum of the event. Based on this information, the fault plane is divided into fourteen segments and each segment is subdivided into five patches. The rupture is assumed to have started at the epicenter and to have propagated in both direction. The time history of the strong motion acceleration together with the observed record at UNAM are shown in Figure 5(c).

5.Conclusions

Base on the simulation of the ground motions, it is found that the geophysical ground motion model with the stochastic dislocation process represents considerable improvement over existing deterministic ground motion models with the smooth dislocation process. Therefore, the proposed model can be used to estimate the design ground motion for rigid structures at a nuclear power plant site.

Acknowledgments

I extend my sincere gratitude to Professor Anne S. Kiremidjian for suggesting the use of the normal mode method for simulating ground motions.

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