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On Seismic Source Spectra from Complex Earthquakes

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Summary

Within the context of the stochastic modeling approach for ground motion prediction, the most important aspect is the seismic source model. The specific barrier model is a physically realistic source model that enables prediction of both far-field and near-source ground motion. It is a special case of a variable-size subevent earthquake source model, since it assumes identical size subevents distributed without overlap on a fault plane. In this study, the effects of variable-size subevents on the far-field seismic source spectrum are investigated.

Introduction

The stochastic modeling approach, which utilizes a seismological model to describe the spectral amplitudes of the ground motion and their scaling with earthquake size, is arguably the only viable method for prediction of ground motions in Eastern North America. The most important aspect of the seismological model is the source model, which quantifies the spectral seismic radiation from the source. The specific barrier model, proposed and developed by Papageorgiou and Aki (1983a, 1983b), is a physically realistic source model that enables prediction of both far-field and near-source ground motion. It is a special case of a variable-size subevent earthquake source model, since it assumes identical subevent sizes distributed without overlap on a fault plane. In this study, the effects of variable-size subevents on the far-field seismic source spectrum are investigated.

Framework

Consider a complex seismic source that is represented by an aggregate of N circular sub-sources (subevents). It is assumed that subevent j has a random radius R_j and ruptures at a random time instant t_j. Subevent sizes and rupture times are statistically independent of one another. In addition, it is assumed that:

1. The seismic spectral radiation of each subevent has the same functional form $S\ (\omega, R_j)$
2. Subevent sizes follow the same probability distribution defined in the range $[R_a; R_b]$
3. Rupture times for all subevents follow the same probability distribution, which is defined in the interval $[0; T]$ (T = total rupture time of the main event).

Joyner and Boore (1986) derived a simple analytical expression for the seismic radiation from a complex seismic source based on the above assumptions, except that they considered subevents of equal size. This expression was adopted by Papageorgiou (1988) in deriving the source spectrum for the specific barrier model, which exhibits two characteristic frequencies, f_1 and f_2. Corner frequency f_1 is controlled by the duration of rupture of the entire fault and is related to a measure of the stress drop over the entire fault referred to as the "global" stress drop, $\Delta\sigma_G$. Corner frequency f_2 is controlled by the duration of rupture of individual subevents, on which a "local" stress drop $\Delta\sigma_L$ occurs. The "global" and "local" stress drops are key parameters of the model because they have been found to be stable for a given tectonic region.

In this study, the work of Joyner and Boore (1986) and Papageorgiou (1988) was extended by considering variable subevent sizes whose distribution follows uniform and fractal (Frankel 1991, Zeng et al., 1994) distributions. The corresponding analytical expressions for the far-field seismic radiation of the complex earthquake were derived. Although the analytical expressions greatly facilitate the calculations, they are lengthy and will not be presented here.

The deterministic variables of the complex seismic source spectrum are the seismic moment of the main event (M_0) and the "global" and "local" stress drops. These parameters are used to estimate the areal extent of the main event, represented by the radius R_m of a circular fault. In addition, the type and range of the size distribution are specified beforehand.

Example

Figure 1 shows an example of the effects of different distributions of subevent size on the source acceleration spectrum of a M_w = 5.8 earthquake having "global" and "local" stress drops equal to 60 bar and 320 bar, respectively.

The top right diagram of Figure 1 shows a single-size and three fractal (D = 2) probability density functions of subevent size. Lower limits of the fractal density functions are equal to 0.10, 0.25 and 0.40 R_m, and the upper limit is equal to 0.50 R_m for all distributions.

Source acceleration spectra for these subevent size distributions are shown in the left diagram of Figure 1. Notice how the different distribution types and the corresponding ranges affect the spectral shape at intermediate and high frequencies.

Realizations of the abovementioned distributions of subevents on the fault plane are shown in the bottom right diagram of Figure 1. The numbers at the lower left corners indicate the number of subevents needed for each size distribution. These realizations were generated following the procedure proposed by Zeng et al., (1994).

The solid density function denoted by an arrow at R = 0.23 R_m is the Dirac delta function. The corresponding source spectrum and areal distribution of subevents are exactly equal to those of the specific barrier model (Papageorgiou 1988) because the ratio of total subevent area to the area of the main event has been set equal to $\pi/4$.

In all cases, the total seismic moment of the subevents is close to or equal to the seismic moment for the M_w = 5.8 event. It should be noted that only the specific barrier model (blue or solid lines) specifies unambiguously how the subevents (i.e., the seismic moment) are distributed on the fault plane. In all the other cases shown in Figure 1, subevents have been manually arranged on the fault plane for illustration purposes.

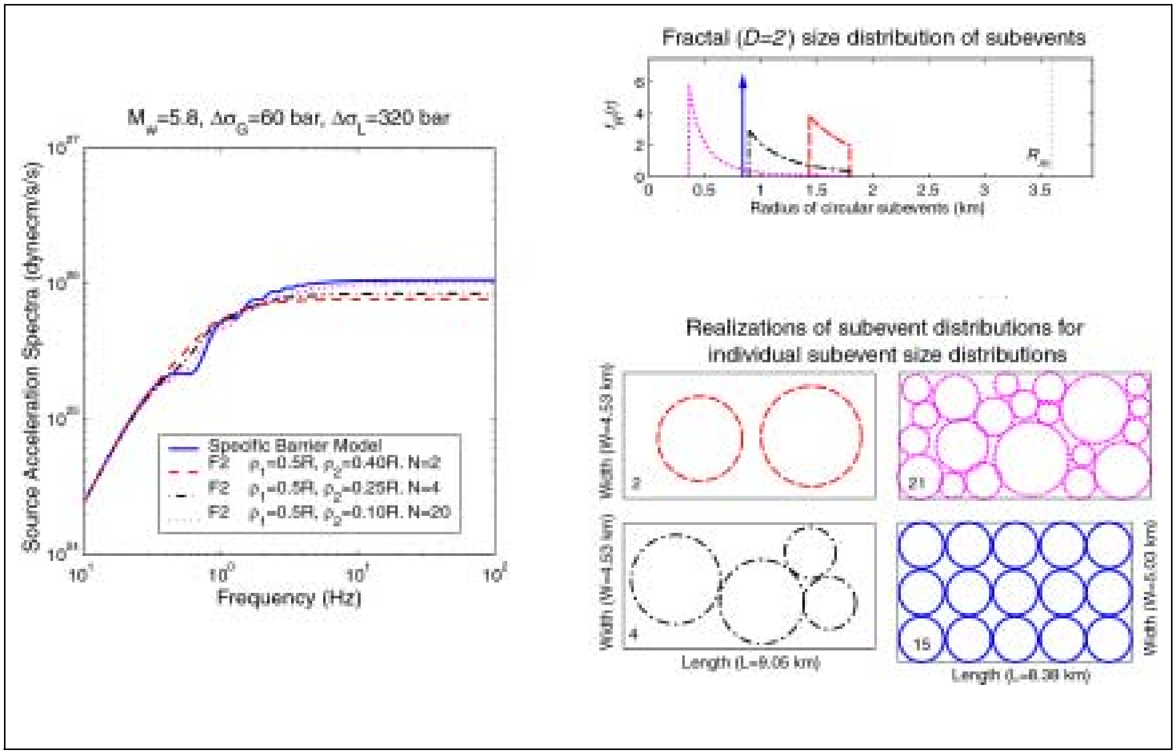

Figure 1. (top right) Four probability density functions of subevent size. The solid arrow denotes a Delta-function at R = 0.23 R_m and corresponds to the specific barrier model. The other density functions are fractal (D = 2) with an upper limit equal to 0.50 R_m and different lower limits. (bottom right) Realizations of the subevent size distributions for a Mw = 5.8 event with $\Delta\sigma_G$ = 60 and $\Delta\sigma_L$ = 320 bars. (left) The corresponding source acceleration spectra.

Main Conclusions

Seismic spectral shapes based on equal- and variable-size subevent distributions are self-similar.

When the width of the size density function approaches zero around a specific subevent size *R*, the seismic spectrum becomes equal to that of the specific barrier model if $(R_m / R)^2 = \pi/4$.

The number of subevents needed to achieve the moment condition is a function of the lower and upper limits of the size distribution and of the ratio of "global" and "local" stress drops.

The larger the number of subevents, the more pronounced the "oscillations" of the spectral shape between the two corner frequencies.

The high-frequency level of source acceleration spectra is a function of lower and upper limits of the size distribution, the ratio of "global" and "local" stress drops, the first corner frequency and the total seismic moment.

The shape of the seismic spectrum is not affected dramatically by the type or range of the size distribution of subevents.

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