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Stochastic Finite-Fault Modeling of Ground Motions from the 1994 Northridge, California, Earthquake. II. Widespread Nonlinear Response at Soil Sites

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Abstract On average, soil sites behaved nonlinearly during the *M* 6.7 1994 Northridge, California, earthquake. This conclusion follows from an analysis that combines elements of two independent lines of investigation. First, we apply the stochastic finite-fault simulation method, calibrated with 28 rock-site recordings of the Northridge mainshock, to the simulation of the input motions to the soil sites that recorded this event. The calibrated model has a near-zero average bias in reproducing ground motions at rock sites in the frequency range from 0.1 to 12.5 Hz.

The soil sites selected are those where there is colocation of strong-motion accelerographs and temporary instruments from the Northridge aftershock observation network. At these sites, weak-motion amplification functions based on numerous aftershock records have been empirically determined, in three separate investigations reported in the literature. These empirical weak-motion amplification factors can be applied to the simulated input rock motions, at each soil site, to determine the expected motions during the mainshock (i.e., neglecting nonlinearity). These expected motions can then be compared to the actual recordings during the mainshock.

This analysis shows that the recorded strong-motion spectra are significantly overestimated if weak-motion amplifications are used. The null hypothesis, stating that the inferred differences between weak- and strong-motion amplifications are statistically insignificant, is rejected with 95% confidence in the frequency range from approximately 2.2 to 10 Hz. On average, the difference between weak- and strong-motion amplifications is a factor of 2. Nonlinear response at those soil stations for which the input peak acceleration exceeded 150 to 200 cm/sec^2 contributes most to this observed average difference. These findings suggest a significant nonlinear response at soil stations in the Los Angeles urban area during the Northridge mainshock. The effect is consistent with the increase in damping of shear waves at high levels of strain, which is well known from geotechnical studies of soil properties.

Introduction

In a companion article (Beresnev and Atkinson, 1998b), we applied the stochastic finite-fault radiation simulation technique (Beresnev and Atkinson, 1997, 1998a) to model strong-motion acceleration data from the *M* 6.7 1994 Northridge, California, mainshock. The method was calibrated against the data recorded at 28 free-field rock sites, at hypocentral distances of up to 94 km, in the Los Angeles urban area. The calibration essentially consists of determining the best value for the radiation-strength factor, which is the only free parameter used in the simulations; all other parameters are determined from known source geometry and regional physical properties. The calibrated method provides an accurate simulation of the spectral content of ground motions on average. The ratio of simulated to observed Fourier spectrum, averaged over all 28 sites, is indistinguishable from unity with 95% confidence in the frequency band from 0.1 to 12.5 Hz. The average ratio fluctuates about unity, with maximum excursions of no more than a factor of 1.35 at nearly all frequencies (Beresnev and Atkinson, 1998b, Fig. 5). There is also no systematic bias in individual-station prediction as a function of hypocentral distance, suggesting that the adopted attenuation model is unbiased over the distance range of the observations (Beresnev and Atkinson, 1998b, Fig. 6).

In this article, we apply the calibrated mainshock simulation model to the soil site recordings of the Northridge earthquake, obtained within the same distance range as the rock sites used in the calibration. The simulation of soil sites