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Simulation of Ground Motion in the Los Angeles Basin

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Progress Report

This year we have improved our ground motion modeling by taking into consideration the effect of heterogeneous fault zone on high frequency waves. We modeled the nonlinear soil response to the site-specific ground motion simulation of the Northridge earthquake. We also investigated the effect of basin response using a simplified ray-theoretical approach. The results are summarized below.

Motivated by the fact that we do not observe any distinct radiation pattern and wave polarization at high frequency, we introduced an effective high frequency source radiation term. This source radiation consists of energy contributions from an angular cross section centered at the direction from the source to receiver in order to simulate high frequency wave reflection and scattering at the fault zone. The total source radiation then equals

$$\alpha\text{*effective-source-radiation} + (1- \alpha)\text{*double-couple-source-radiation},$$

where α is a continuos function of frequency. It equals 1 above a high frequency threshold and tapers to 0 at low frequency since this reflection and scattering at the source zone has less an effect at lower frequencies. The results were validated with the Northridge strong motion observations. Figure 1 compares the results of this improved method and that of regression prediction (Abrahamson and Silva, 1997) to the observed PGA and SA at 3 second. Our synthetics predict the trends of the observed ground motion parameters better than the regression. The figures also show the standard errors of prediction from the improved composite source model and from the Abrahamson and Silva's regression. The scatter in the data is caused by the local site and basin response effects which are not modeled in the current context of high frequency simulation.

On the nonlinear site response modeling, we used the composite source model combined with local site effects estimated from weak motion data to simulate site-specific strong motion. We computed those strong motions at 15 sediment sites which recorded the Northridge earthquakes. Among those simulations, we have taken into consideration the nonlinear site response using the EPRI (1993) nonlinear soil model. Figure 2 shows the ratios of strong to weak motion site amplifications obtained by Su et al. (1999) as a function of frequency averaged over 15 sediment stations. Those site amplifications were referenced to the rock station LA00. The green shaded zone represent ± one standard error of the mean. The average ratio from this figure suggests that the average site deamplification during earthquake strong motion is about 59% or more. Following the same procedure, we calculated the same average ratio of strong (nonlinear) to weak (linear) motion synthetic site response over those 15 sites. The result (cyan shaded lines) is plotted in the same figure for comparison. The results indicate that the model agrees with observation in the frequency range from 1.5 to 10 Hz. However, they diverge at frequencies below 1.5 Hz and above 10 Hz. Above 10 Hz, the nonlinear model shows a rapid increase in amplitudes up to a factor of two of the linear response, an artifact of the nonlinear stress-strain relation, which produces a sudden change in shear modulus as the shear strain reverses. At low frequencies the observed ratios show a clear trend of convergence to unity. However, it is still significantly different from unity within the frequency range of 0.5 to 1.5 Hz. In contrast, the averaged synthetic ratios essentially equal unity within the same frequency range.

In order to confirm that those low frequency estimates are real, we carefully examined the data to be certain that signals are significantly above noises. In addition, our site estimation references to the rock site at LA00 so that the effect of sources from mainshock and aftershocks is minimized. Our result of the observed nonlinearity presented at all frequencies we studied is consistent with the result by Field et al (1997) who referenced their site amplifications to the average of that over several rock sites. Recent work by Cultrera et al. (1998) on the site responses at the Jensen filtration plant shows that the weak motion records of aftershocks within two minutes of the mainshock exhibit a deamplification comparable to that of the mainshock, indicating that the nonlinear shear modulus reduction that occurred during strong shaking may not have recovered as quickly as the current engineering model predicts. In another borehole nonlinearity study, Aguirre and Irikura (1997) found a gradual recovery of the shear wave velocity after the Kobe earthquake. Thus the longer period and relatively lower amplitude motion would be influenced by the same nonlinear deamplification as the high frequency waves. As a consequence, the observed ground motion suffers greater amplitude reduction at low frequency than model prediction based on lab experiments.

On modeling the basin effect on ground motion, we have studied basin response using a simple ray-theoretical approach. In this method, we use the Gaussian Beam method to sum up contributions to the seismogram from multiple reverberations of rays within the basin assuming a constant beam width for each ray as it propagates. In our numerical validations, we compared the solution with that of the finite difference and analytical methods (Trifunac, 1971) and found satisfactory agreements. The method captures well the resonance effect of the basin to the wave propagation and provides better physical understanding of the wave propagation in the basin. Using this simplified method we simulated the basin response of the South San Francisco Bay using the USGS model (Brocher, 1998). The input motion uses strong ground motions from Morgan Hill and Loma Prieta earthquakes as well as synthetic seismograms from a scenario earthquake on the Hayward fault. In general we found a strong frequency dependence of basin response as a function of basin depth and distance to the edge of the basin. It is apparent that wave reverberation and low shear wave velocity in the basin are the primary cause of basin amplification. However at high frequency attenuation gradually dominates amplification as basin depth of the site increases. At low frequency, amplification dominates over attenuation and the responses increase as the basin depth increases. The average responses across the basin show a remarkable linear relationship with the wave incident angles (Figure 3). The average amplitude decreases as the incident angle increases and it appears to be independent of frequency. This is unexpected from some beliefs that waves with near-horizontal incident angle tend to be trapped more easily in the basin than those waves with near-vertical incident angle. In fact, waves with near-horizontal incident angle will be much more easily reflected off the basin compared to waves with near-vertical incident angle.

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Zeng, Y. (1999). A simple ray-theoretical approach to evaluate basin response, in preparation.

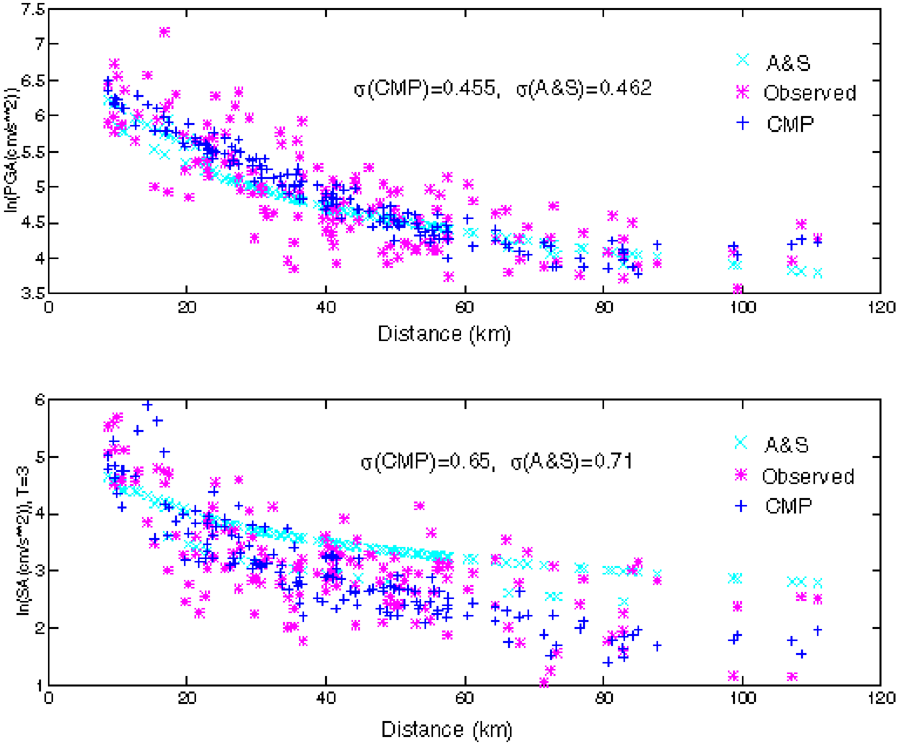

Figure 1. Comparison between observed and predicted peak ground motion parameters for the Northridge earthquake, 1994. The upper panel is for the peak ground acceleration and the low panel is for the spectra acceleration with 5% damping at 3 second period.

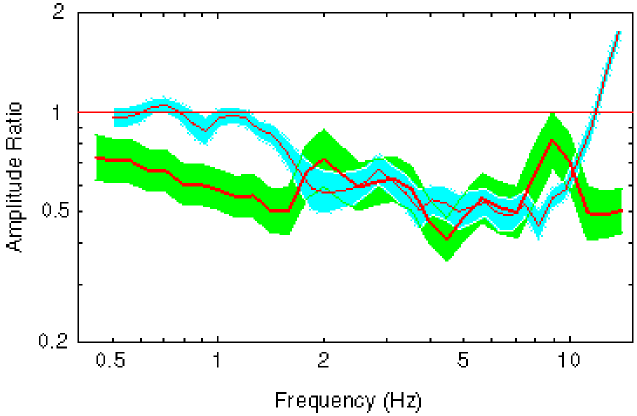

Figure 2. Ratios of strong to weak motion site responses versus frequency averaged over 15 sedimentsites. The thick line (with green shading) is for observation and the thin line (with cyan shading) is for synthetics. The shaded zones represent ± one standard error of the mean.

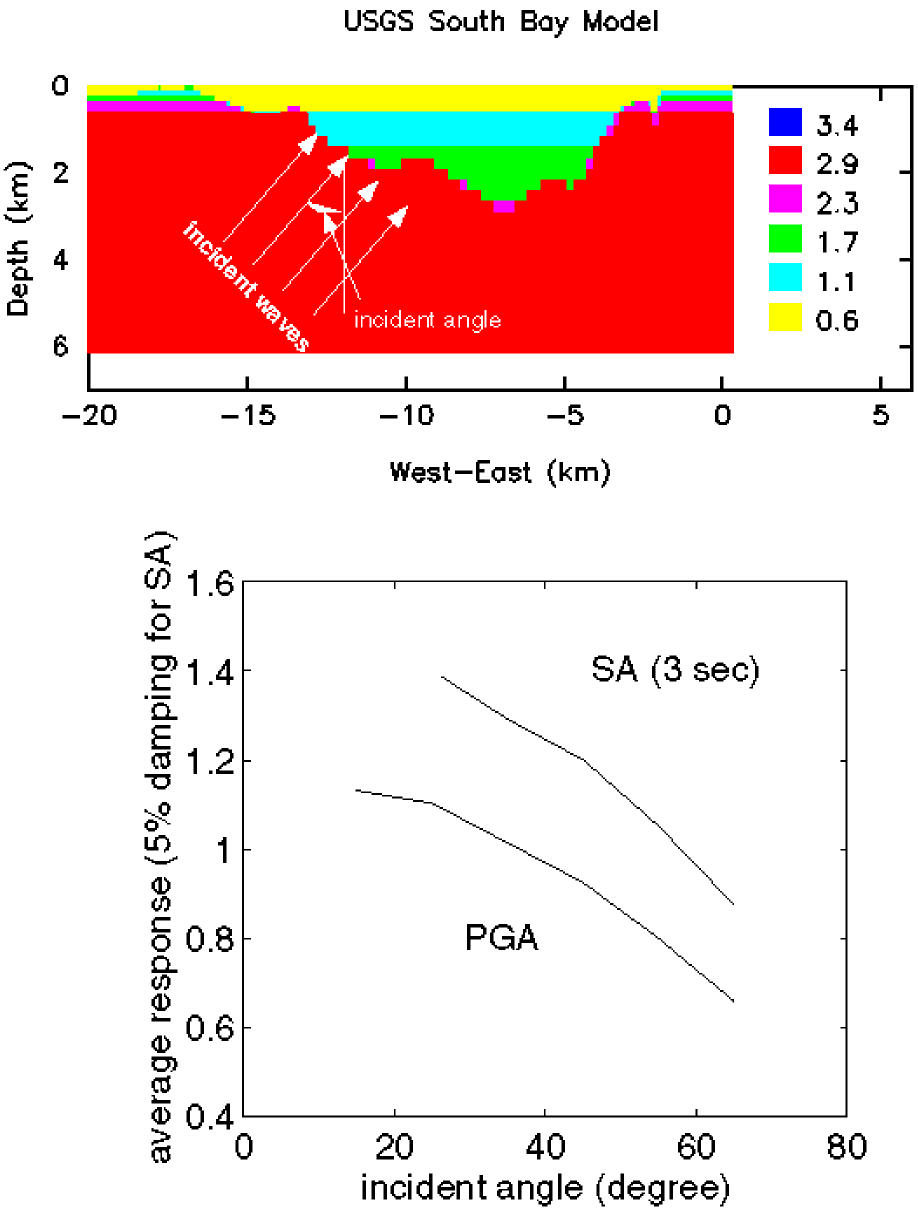

Figure 3. The top panel shows the basin model. The bottom panel shows the average basin response as a function of the incident angle.