1-D Rock Ground Motion Simulation to the SCEC/PEER NGA Initiative

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Progress Report

For the year 2003, Zeng, Anderson and Su have been funded under the SCEC Earthquake Engineering Implementation Interface program to participate in the PEER/SCEC/USGS initiative of the Next Generation Attenuation (NGA) project. Our research task is to carry out 1-D ground motion simulation on rock sites under the NGA working committee's guidelines. This 1-D broadband ground motion simulation on rock will complement the existing observation on magnitude, distance, and frequency range. Our objective is to provide a synthetic database generated using validated ground motion simulation procedures. This database will serve for the purpose of providing guidance to the selection of functional forms used in developing the NGA relations and to constrain the extrapolation of NGA relations outside the range of empirical data.

In order to further quantify the degree to which our ground motion simulation procedure is capable of representing the real ground motion, we have carried out additional validation exercise as the first step before we compute suites of 1-D rock motion simulations for given scenario earthquakes. Much of the groundwork for the development of the composite source model for broadband ground motion prediction has been accomplished through our previous SCEC and PEER research funds. In the current validation exercise, our emphasis is to systematically document the fixed and free model parameters and the corresponding probability distributions for free parameters, and to quantify the resulting data fit in terms of biases and standard errors.

Over the past years, we have focused efforts to develop and improve a numerical simulation procedure to compute synthetic strong motion seismogram using a composite source model (Zeng et al., 1994). The method has been successful in generating realistic strong motion seismograms. The realism is demonstrated by comparing synthetic strong motions with observations from the recent California earthquakes at Landers, Loma Prieta (Su et al., 1994a,b) and Northridge (Zeng and Anderson, 1996; Anderson and Yu, 1996; Su et al., 1998), earthquakes in the eastern US (Ni et al., 1999) and earthquakes in Guerrero, Mexico (Yu, 1994; Zeng et al., 1994; Johnson, 1999), Turkey (Anderson et al., 1997) and India (Khattri et al, 1994; Zeng et al, 1995). We also tested its ability to predict the rupture directivity effect from the Imperial Valley, Loma Prieta, Landers, Northridge and Kobe earthquakes (Zeng and Anderson, 2000).
The composite source model assumes a large earthquake is a superposition of smaller subevents that all break during the earthquake rupture processes. The number and radius of the subevents follow the Guttenberg and Richter frequency-magnitude relation given in form of a power law distribution of radii, $N(r) \sim r^{-p}$ where p is the fractal dimension. Given the source parameters of a large earthquake, we can numerically generate the subevents following the power law relation. We then place these events within the fault plane and allow them to overlap. The random nature of the heterogeneities on a complex fault is achieved by distributing the subevents randomly on the fault plane. Rupture propagates from the hypocenter, and each subevent radiates a displacement pulse of a rupture crack when the rupture front reaches the subevent. Once the source has been specified, we can propagate the motion generated at the source to the site using layered crustal model (Luco and Apsel, 1983) or 3-D inhomogeneity structure using finite difference method.

In this validation exercise, a minimum set of 168 2-component recordings was selected from six relatively well-recorded M>6.5 earthquakes. Among them, 14 are from the 1971 Imperial Valley earthquake, 52 from the 1989 Loma Prieta earthquake, 23 from the 1992 Landers earthquake, 36 from the 1994 Northridge earthquake, 22 from the 1995 Kobe earthquake, and 21 from the 1999 Kocaeli earthquake. Source models of those earthquakes are obtained from our previous SCEC and PEER funded research (Zeng and

Anderson, 2000; Zeng, 2002). Based on those source models, we used the composite source simulation procedure to calculate the synthetic ground motions at all the selected stations.

Figure 1 plots the misfit between the observation and synthetic prediction for the horizontal components for the Northridge earthquake. The misfit is quantified in terms of biases (upper panel) and standard errors (lower panel) over a broad frequency range. The middle line in the upper panel of Figure 1 shows the biases versus frequencies with the 90% confidence level envelopes of the biases. The comparison between synthetics and observations suggests that the composite source model has provided an unbiased broadband kinematic description of the earthquake source rupture. To examine the trend of the fit over distance range, we have computed the synthetic ground motions of the Northridge earthquake at 150 strong motion stations. Figure 2 shows the result in comparison with the observed and regression prediction (Abrahamson and Silva, 1997) for PGA and SA at 3 second. The synthetic simulations clearly predict the trends of attenuation of the observed ground motion parameters over distance. The values plotted at the upper right corner of the figures are the standard errors of the prediction from the composite source model and from Abrahamson and Silva's regression respectively. At long period, our synthetic procedure outperformed the regression prediction in terms of both standard errors and distance attenuation rate. Scatters in the data are caused mainly by local site and basin responses.

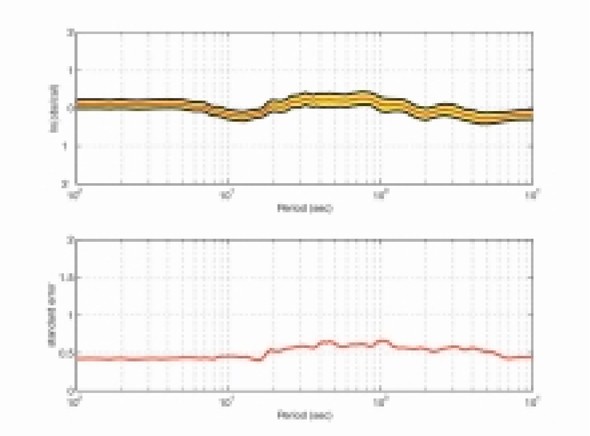

Figure 1. Misfit between the observed and synthetic seismograms for the Northridge earthquake. The upper panel shows the biases (red) and its 90% confidence limits (black) for the horizontal components. The lower panel shows the standard errors.

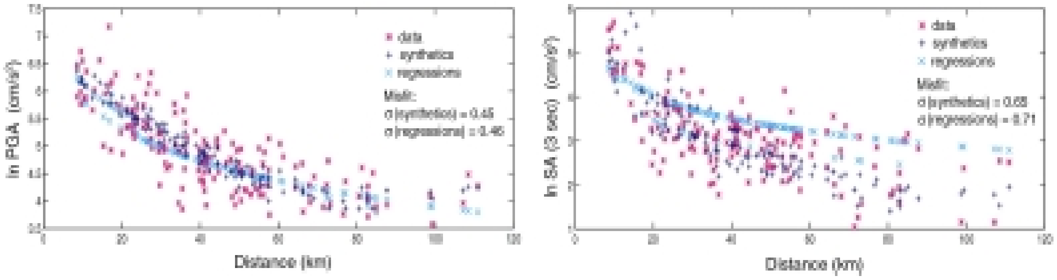

Figure 2. Comparison between observed and predicted peak ground motion parameters for the 1994 Northridge earthquake. The left panel is for the peak ground acceleration and the right panel is for the spectra acceleration with 5% damping at 3 second period.

Figure 3 to Figure 7 plot the same misfits as that of Figure 1 but for the Imperial Valley, Loma Prieta, Landers, Kobe, and Kocaeli earthquakes, respectively. In general, we find the simulations are unbiased and the standard errors for all the events are about 0.5 in average across the validation period range. Given those earthquake magnitudes, the results also demonstrate that our ground motion simulation procedure is unbiased for the magnitude range from 6.5 to 7.3.

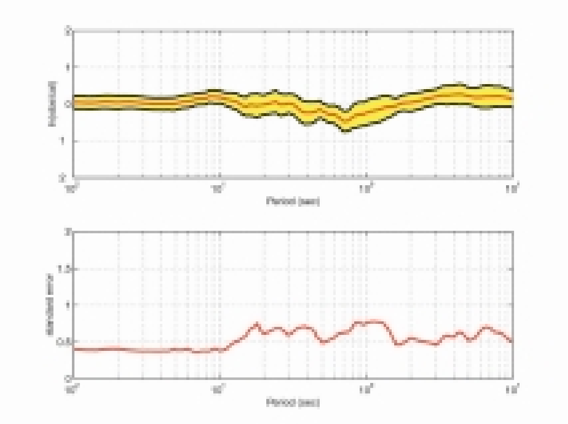

Figure 3. Same as Figure 1 but for the Imperial Valley earthquake.

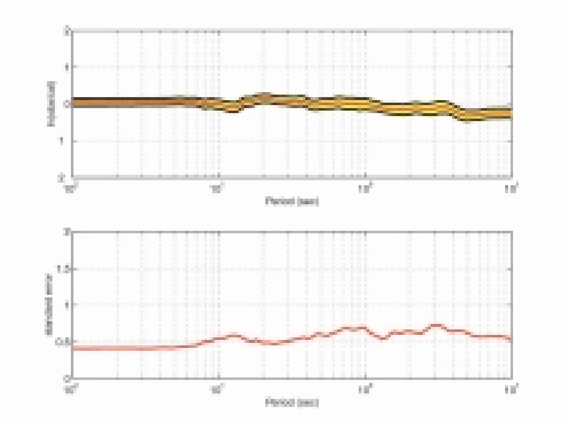

Figure 4. Same as Figure 1 but for the Loma Prieta earthquake.

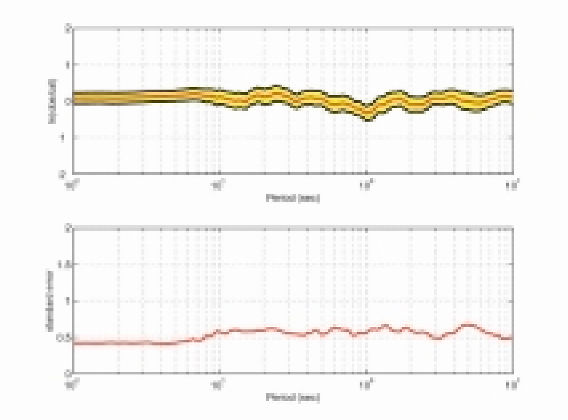

Figure 5. Same as Figure 1 but for the Landers earthquake.

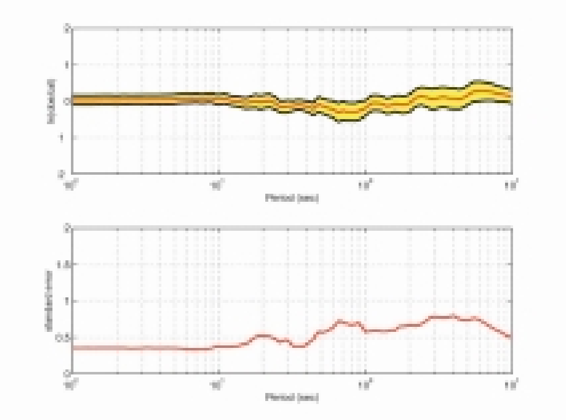

Figure 6. Same as Figure 1 but for the Kobe earthquake.

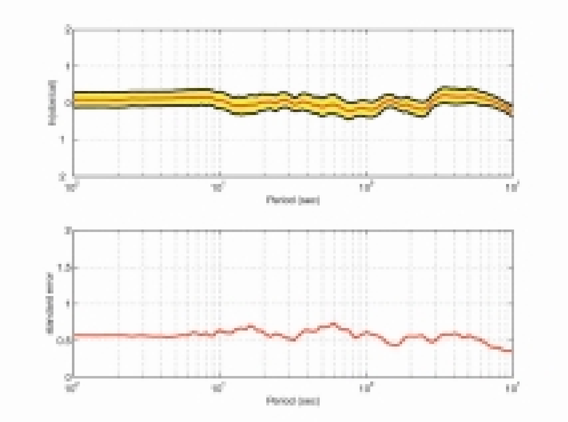

Figure 7. Same as Figure 1 but for the Kocaeli earthquake.

With the confidence provided by the above validations, we have started our next step of scenario ground motion simulations. Issues needed to be address in this simulations are scaling of magnitude from 7 to 8.5, distance from 0 to 10 km and from 70 to 200 km, and period from 3 to 10 seconds. Additional scaling parameters also need to be addressed are directivity, static stress-drop, depth of asperity, and Hanging wall/foot wall effects. The Draft plan for 1-D rock motion simulations includes 10 strike-slip scenarios and 12 reverse-slip scenarios. The asperity ratio of the fault geometry is set to 2:1 for strike slip and 1:1 for reverse events.

Figure 8 show the results of one of the strike-slip scenario ground motion simulations of magnitude 6.5 plotted versus distances. Points in the figures are for PGA and SA with 5% damping for 1, 3 and 10 second periods. We have computed 20 realization at each station with a shallow asperity and a deep asperity composite source model and with rupture initiated at 10 selected hypocenter locations. We found the effect of shallow and deep asperities is small. The scatters in the synthetics are caused by rupture directivity effect. Obviously this effect increases as period increases.

One issue in the distance attenuation is the critical Moho reflection. For peak ground acceleration, we found the effect is negligible. At 1 second period, it creates a shoulder in the ground motion attenuation at distance between 60-100 km. At 3 second period, the shoulder moves to 100-140 km. For 10 second, it moves to 100-200 km. Our interpolation is that the Moho reflection affect the attenuation around 1 second period. For 10 second period, it is the surface waves that start to dominate over body waves. For 3 second period, it is a mix effect of Moho reflection and surface wave generation.

In Figure 8, we have also plotted Abrahamson and Silva's regression curves for PGA, and SA at 1 and 3 second periods over the same distance range as the scenario simulations, respectively. We found there is a factor of 1.5 to 2.5 amplitude shifts between the average scenario ground motion simulations and Abrahamson and Silva's regression predictions depending on the period of the response spectrum. The shift is expected since the S-wave velocity at the top layer is 1.8 km/sec versus the S-wave velocity of 0.7 km/sec or so for the actual B/C boundary of the NEHRP site classification for the upper 30 meters. The differences in attenuation rate between Abrahamson and Silva's regression prediction and our simulation increase with period. We found this difference is consistent with our previous Northridge study showing in Figure 2.

We are now on the process of simulating scenario ground motions at other magnitudes of several strike and reverse-slip fault configurations. Our final result will be submitted to the NGA-E modelers in the data format described in the draft plan for 1-D rock motion simulation.

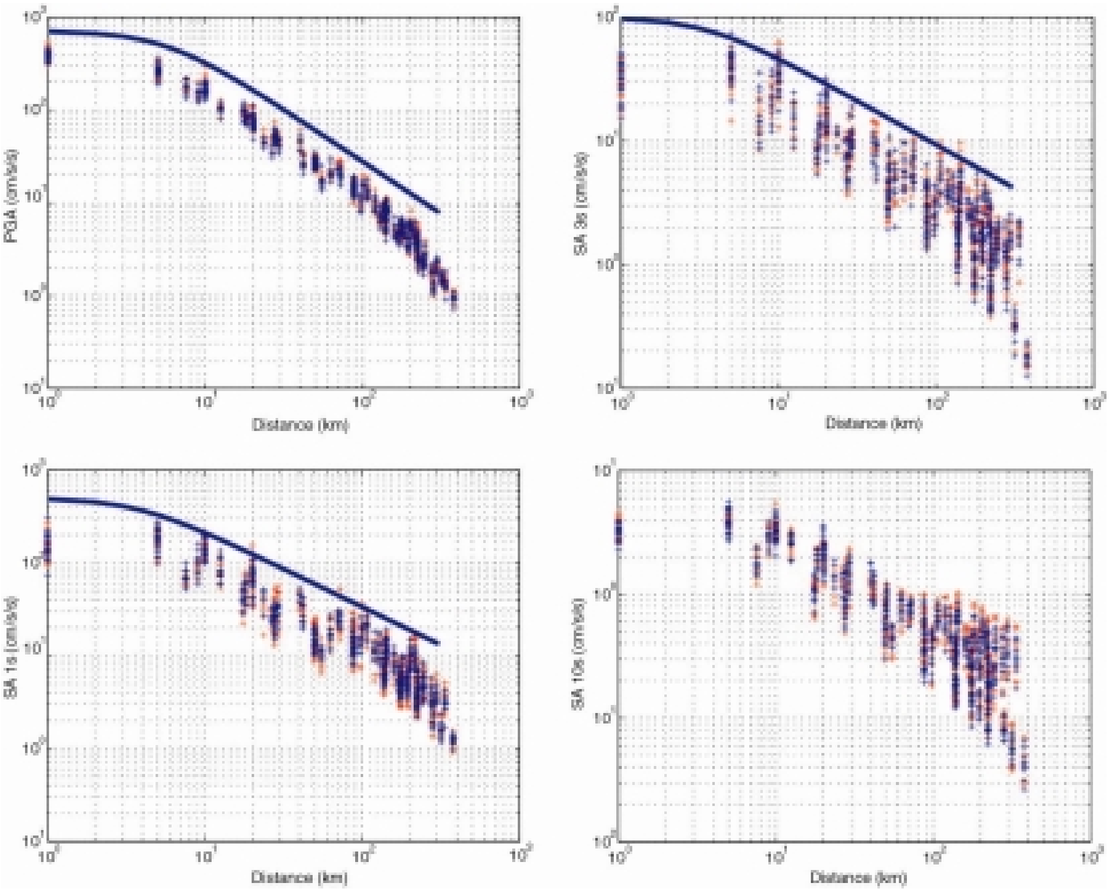

Figure 8. Peak spectral accelerations versus closest distance to the fault for the synthetic ground motion simulation with 5% damping at 0.01, 1, 3 and 10 second periods. Red and blue points are for shallow and deep asperity source models, respectively. The blue curves at 0.01, 1 and 3 second period are from Abrahamson and Silva’s regression predictions over the same distance ranges.

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