Final Project Summary— PEER Lifelines Program

Project Title—**ID Number**	*Validation of 1-D Numerical Simulation Procedures*—**1C02b**		
Start/End Dates	05/01/00 – 11/30/01	Budget/ Funding Source	$49,992 / PG&E/CEC
Project Leader (boldface) and Other Team Members	**Somerville (URS Corporation)**		

1. Project goals and objectives

The objective of this project is to validate procedures for numerically calculating ground motions generated during moderate and larger earthquakes. A set of target earthquakes was chosen to compare the ground motion simulation procedures against. The data were essentially limited to rock sites. The primary goal of this work was to establish the adequacy of the simulation procedures, so that they can then be used to assist in the extrapolation of existing ground motion data (e.g., to very near fault distances) within the NGA (Next Generation Attenuation) program.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

The simulation methodologies analyzed in this project are being used in the NGA program to help guid the development of new ground motion attenuation models. These models will have broad application for engineering purposes throughout the Western US.

3. Brief description of the accomplishments of the project

We have validated our ground motion simulation procedure against a target set of earthquake data. The simulation procedure performs well across a broad frequency band (0.1-10 Hz), and captures many of the important features of strong ground motions, including directivity effects, basin effects, footwall / hanging wall effects, and shallow vs buried rupture effects.

4. Describe any instances where you are aware that your results have been used in industry

Our ground motion simulation procedure is currently being used in the NGA program. In addition, the methodology is being applied by the URS group within engineering projects where broadband ground motion time histories are required for specific scenario earthquake situations.

5. Methodology employed

We present a methodology for generating broadband (0 - 10 Hz) ground motion time histories for moderate and larger crustal earthquakes. Our hybrid technique combines a stochastic approach at high frequencies with a deterministic approach at low frequencies. The broadband response is obtained by summing the separate responses in the time domain using matched filters centered at 1 Hz. We use a kinematic description of fault rupture, incorporating spatial heterogeneity in slip, rupture velocity and rise time by discretizing an extended finite-fault into a number of smaller subfaults. The stochastic approach sums the response for each subfault assuming a random phase, an omega-squared source spectrum and generic ray-path Green's functions. Gross impedance effects are incorporated using quarter wavelength theory to bring the response to a reference baserock velocity level. The deterministic approach sums the response for many point sources distributed across each subfault. Wave propagation at frequencies below 1 Hz is modeled using a 3D viscoelastic finite difference algorithm with the minimum shear wave velocity set between 600 and 1000 m/s, depending on the scope and complexity of the velocity structure. To account for site-specific geologic conditions, short- and mid-period empirical amplification factors provided by Borcherdt [1994] are used to develop frequency-dependent non-linear site response functions. The amplification functions are applied to the stochastic and deterministic responses separately since these may have different (computational) reference site velocities. We note that although the amplification factors are strictly defined for response spectra, we have applied them to the Fourier amplitude spectra of our simulated time histories. This process appears to be justified because the amplification functions vary slowly with frequency and the method

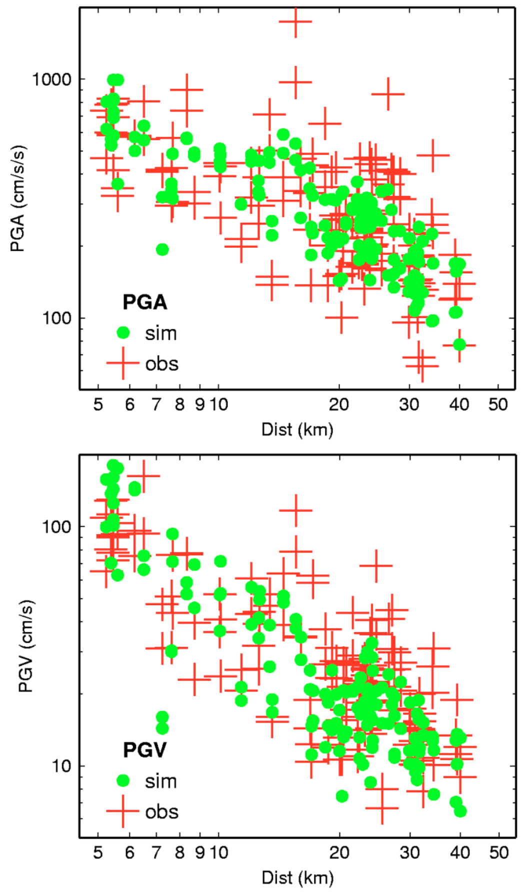

Figure 1. Observed (red crosses) and simulated (green circles) peak ground acceleration (top) and peak ground velocity (bottom) plotted as a function of closest distance to fault rupture at 69 sites for the Northridge earthquake. PGA and PGV values are measured from the observed and simulated time histories.

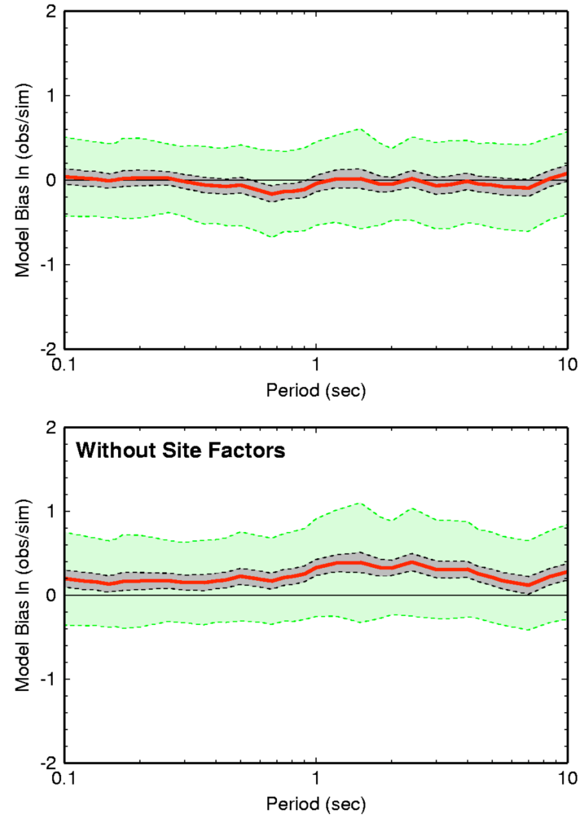

Figure 2. (Top) Spectral acceleration goodness-of-fit computed for the average of both horizontal components for the Northridge earthquake. Red line plots mean model bias averaged over 69 sites. Gray shading denotes 90% confidence interval of the mean and green shading denotes interval of one standard deviation. (Bottom) Same as top except simulation does not incorporate site-specific amplification factors.

produces favorable comparisons with observations. We demonstrate the applicability of the technique by modeling the broadband strong ground motion recordings from the 1989 Loma Prieta and 1994 Northridge earthquakes.

6. Other related work conducted within and/or outside PEER

The ground motion simulation procedure described here results from the efforts of an ongoing process to better understand the physics of earthquake rupture and seismic wave propagation. Specifically, the PIs are actively involved in projects conducted by the Southern California Earthquake Center to develop and test more robust methodologies of earthquake rupture, wave propagation and site response.

7. Recommendations for the future work: what do you think should be done next?

Continued testing of the methodology is certainly warranted. In particular, the transition between the deterministic and stochastic methodologies should be pushed to higher frequencies (currently at 1 Hz). This requires a better understanding of earthquake rupture processes and geologic structure at much shorter length scales than is current available.

8. Author(s), Title, and Date for the final report for this project

Paul Somerville, Robert Graves, and Nancy Collins "Validation of 1D Numerical Simulation Procedures", 2004.