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3D Ground Motion Simulation in Basins

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1. OVERVIEW

This project is a coordinated, multi-institutional investigation of earthquake ground motion in complex, 3D geological structures, using numerical simulations. The objectives are:

- Validate the simulation methods
- Apply them to gain an improved scientific understanding of ground motion generation.
- Foster the integration of simulation methods and results into engineering applications.

The project has the following connections to related activities:

- PEER is a full partner in the project, and provides financial support
- Project is SCEC contribution to PEER-Lifelines/SCEC/USGS Next Generation Attenuation (NGA) project
- Project is a testbed for the SCEC Community Modeling Environment (CME).

The most important accomplishments during the past year are detailed below.

2. VERIFICATION OF ANELASTIC CODES

We completed a comprehensive testing program to verify the mathematical and numerical formulations of 5 different 3D wave propagation codes. Four of the codes are finite difference (FD), and one is finite element (FE). The verification effort has now documented solutions to 10 benchmark problems:

- Simple sources with simple earth models: test problems UHS.1, UHS.2, LOH.1, LOH.2, LOH.3, and LOH.2
- Simple sources with complex earth models: test problems SC2.1, and SC2.2.
- Northridge earthquake model, SCEC Community Velocity Model (CVM).

These benchmarks have become standard tests of 3D codes, and have been provided to numerous investigators outside the SCEC community for that purpose. In addition, a European Union-funded project to develop IT infrastructure for seismology plans to use the SCEC benchmarks as the basis for certifying codes for their project (Heiner Igel, personal communication).

Besides verifying the codes, these test problems provided essential guidelines on (i) the level of grid refinement and (ii) minimum S velocity threshold necessary to resolve the target spectral range (0-0.5 Hz) of the scenario studies described below.

Figure 1 indicates the level of agreement attained among 5 codes, for the simulation experiment based upon the Wald et al. (1996) Northridge earthquake model, embedded in the SCEC CVM. Both elastic and anelastic (with very low Q) tests are shown. At relatively near distances, the 5 solutions are indistinguishable for both tests. At the largest distances, response spectra (2 to 10 sec) are computed with standard deviation (among codes) less than 10% for the elastic case, less than a few 10's of percent for the anelastic case. The greater variation for the anelastic case is largely attributable to variations in the way different codes approximate the absorption band.

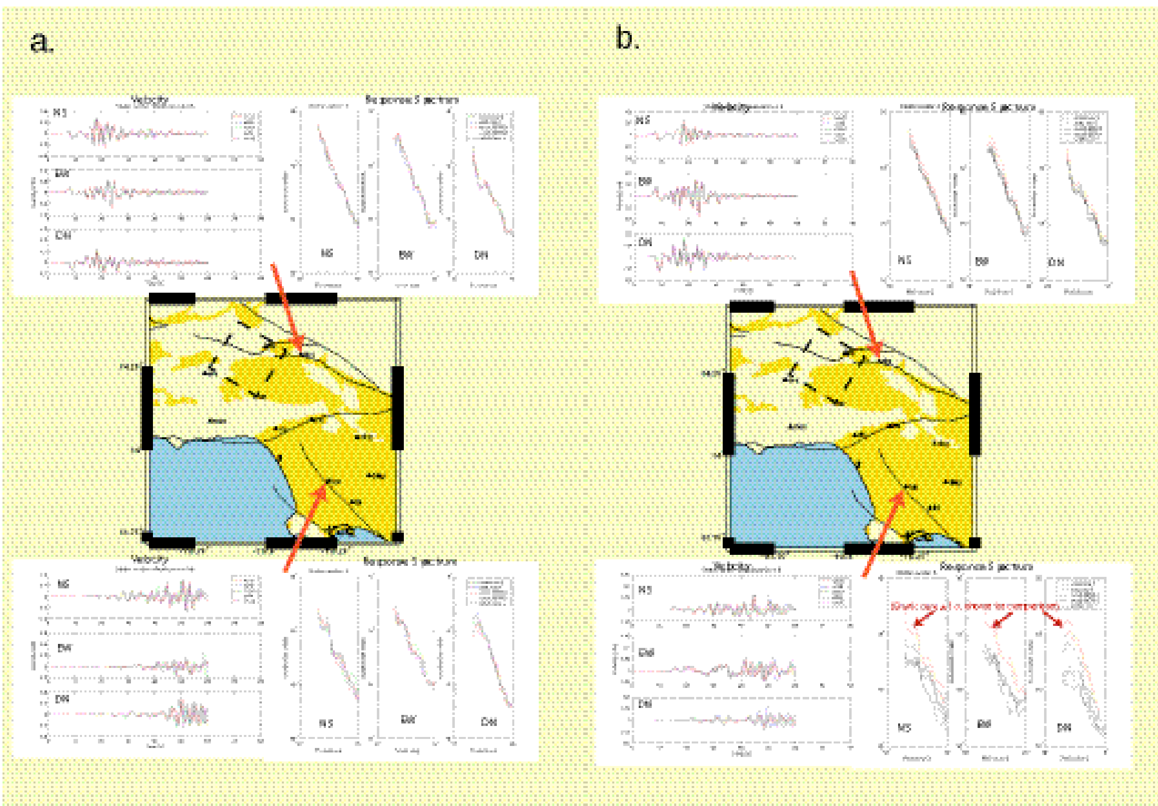

Figure 1. Comparison of elastic (a) and anelastic (b) solutions for Northridge test. Time histories and acceleration response spectra (2-10 sec) are shown.

3. TESTING WITH TRINET DATA FOR SMALL EVENTS

We modeled ground motion from the Mw 4.2 2001 West Hollywood and Mw 4.0 2001 Compton earthquakes at several sites that recorded the earthquakes. These events are sufficiently small that the source complexity is negligible in the 0-0.5 Hz band. Figure 2 compares recorded (black traces) with synthetic velocity seismograms (colored traces) calculated using the SCEC CVM and the Q model of Olsen et al. (2003). Simulations with the SCEC model achieve good absolute amplitudes and shapes of first arrivals, model some secondary arrivals well, and predict durations well. The two small events simulations suggest higher Q values in the Los Angeles basin than do the Northridge earthquake simulations. This discrepancy could be attributable to path differences between events or nonlinearities in the Northridge event, and deserves further study.

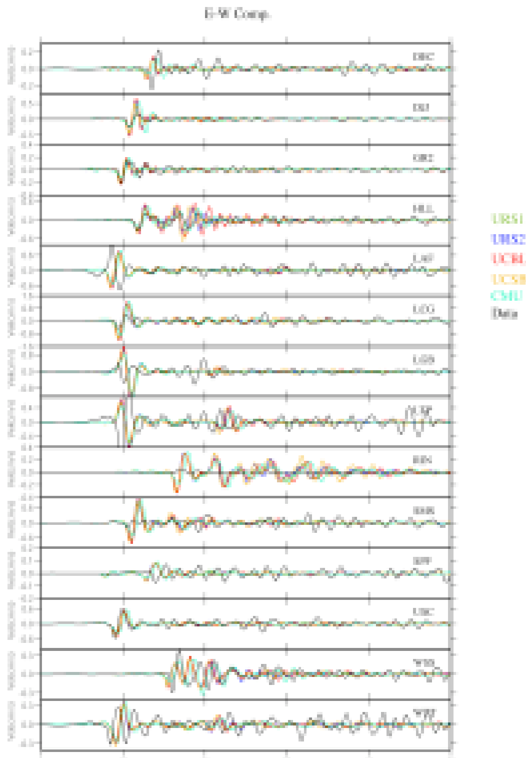

Fig 2. Comparison of recorded (black) and simulated (colors) velocity (E comp) for Compton event

4. EARTHQUAKE SCENARIO SIMULATIONS

A suite of 70 earthquake scenarios was designed and simulated. The objectives were to create a library of synthetic ground motions for the L.A. region for use in engineering studies, to carry out statistical studies of the synthetic motions, and to provide a scientific basis for guiding the NGA-E project in how to modify attenuation relationships to account for basin effects. Simulated ground motion was calculated for 10 faults from the SCEC Community Fault Model (CFM), shown in Figure 3. For each fault, simulations were done for all 6 combinations of 3 different slip models and 2 different hypocenters. This suite of scenario simulations for the L.A. region is an order of magnitude larger than we previously available from SCEC 3D studies (e.g., SCEC Phase III scenarios). In addition, each simulation in the suite has a factor of 2 higher resolution in spatial scale than previous SCEC efforts. These advances were possible because the calculation work load was distributed among 5 researchers, using verified codes (so that results are comparable among codes), and in most cases using parallel processing.

Figure 4 shows the output grid for the simulations. There are 1600 sites at which full 3-component velocity time histories were saved for each simulation, resulting in a synthetic data set of nearly 300,000 time histories. Ten of the cases were repeated with a second code, to provide a cross-check to prevent errors from making it into the synthetic database (as a result of model setup errors, station mislocation, etc). Figure 5 shows the level of agreement achieved between a FD and FE solution for the same scenario, in a

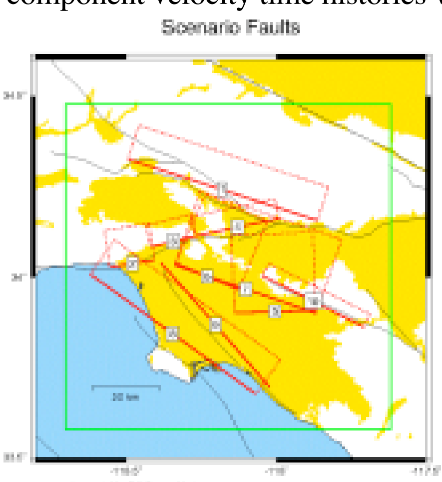

Fig 3. Map of the 10 faults for which the 60 scenarios were computed.

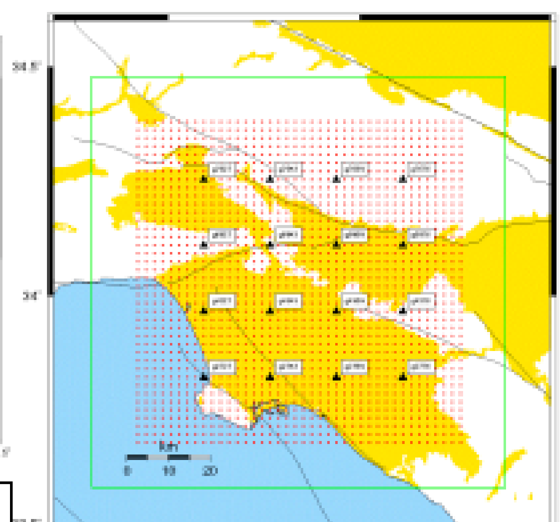

Fig 4. Output grid.

representative cross-check example. Figure 6 shows examples of response spectra maps for one of the 60 simulations, illustrating the strong basin amplifications predicted by the SCEC CVM. Both basin depth and basin edge effects are apparent here (note that the common scale for all periods in this plot partially obscures the long-period basin effects, which are nonetheless large—see Fig 7 below). Comprehensive analysis of the 60 scenarios to extract engineering information and scientific insight will be a large and challenging task. It is desirable to separate and quantify directivity, style-of-faulting, hangingwall/footwall, and frequency-dependent basin amplification effects, relate them to source and basin geometry, and summarize the results in a form of practical engineering applicability.

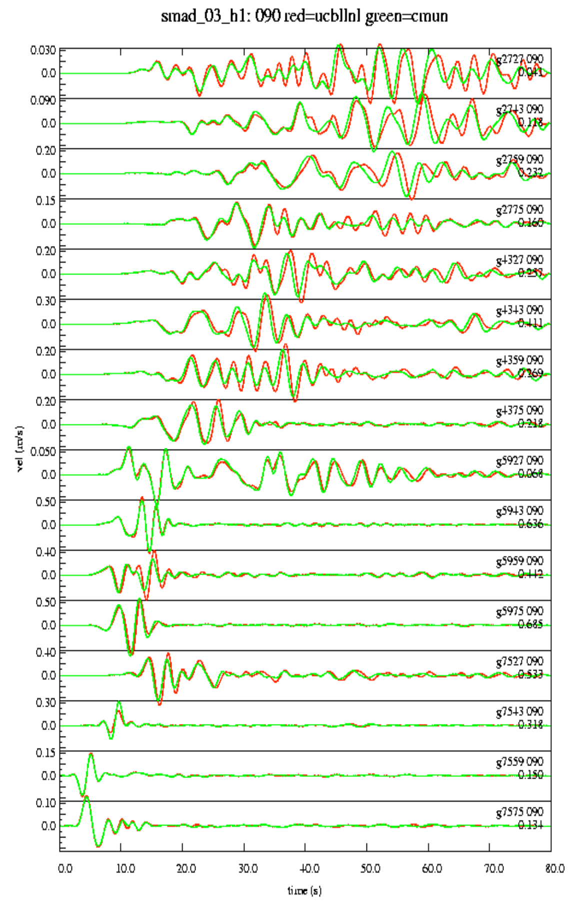

Fig 5. Cross-check simulation example, comparing FE and FD solutions for one of the Sierra Madre fault scenarios.

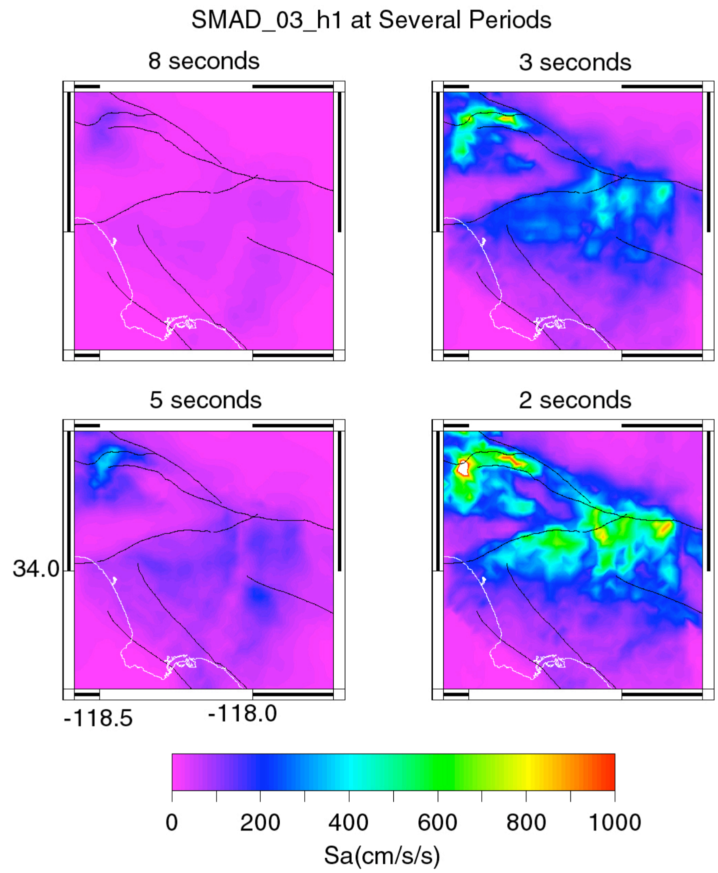

Fig 6. Acceleration spectral response at 4 periods for one of the Sierra Madre fault scenarios.

Figure 7 shows a preliminary separation of synthetic response spectral data by basin depth, for just one of the 60 scenarios. The basin depth (as represented by the 2.5 km S velocity isosurface) is clearly predictive of amplification effects, and there is some suggestion that longer periods (5 sec and greater) are amplified in proportion to depth, while shorter periods are sensitive only to the first few km of sediment depth. This is only a preliminary suggestion from the synthetics for a few cases, and the suggestion is further tempered by the fact that in a single scenario, directivity and basin effects are not easily separated. Definitive results will have to await detailed analysis of the full synthetic data set.

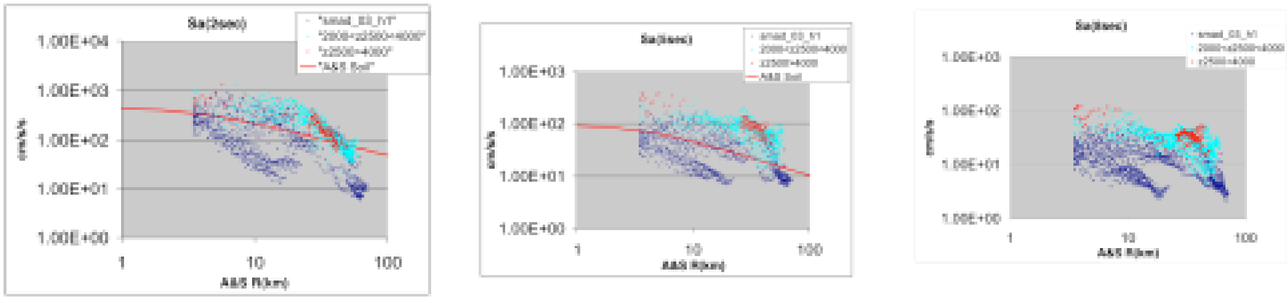

Fig 7. Spectra acceleration for one scenario, versus source distance (Abrahamson-Silva definition). Red line shows the A-S soil regression line. Color segregate the synthetic data by depth to the 2.5 km isosurface ("z2500").

5. ONLINE RESOURCES

- Synthetic intensity-measure database. For each scenario, there is a file available on the web containing the following information for each of the 1600 sites: latitude and longitude, 2 measures of source-to-site distance, and acceleration response spectra for each of the 3 components. This data set provides the basis for engineering analysis of the simulation suite.

- Synthetic ground motion time history database. All 288,000 synthetic seismograms are being collected in a digital library, in collaboration with the SCEC CME project. These synthetics will be associated with metadata documenting the simulations. A prototype metadata scheme has been developed, and will be refined as part of the effort to achive the synthetics.

- SCEC benchmark website. The SCEC benchmark tests descriptions are available on the web.

6. INTERACTION WITH RELATED PROGRAMS

- PEER Lifelines. The PEER Lifelines (PEER-LL) program is a partner with SCEC in this project. That program has provided $175,000 in matching funding over the past year to support the modeling effort. In addition, the project team makes regularly quarterly presentations to the PEER-LL leadership group, receiving regular feedback and guidance for enhancing the engineering impact of the research.

- SCEC Community Modeling Environment. The project serves as a testbed for digital library, grid computing, parallel code performance, code interoperability, and large-scale visualization. The project team has play key roles in development of metadata standards for synthetic data, as well as development of standards for exchange of velocity model and source model descriptions.

- PEER-LL/SCEC/USGS NGA program. Our project is one of SCEC's main contributions to the NGA program. It has been structured to have significant impact on the current phase, NGA-E (empirical). This is being accomplished by balancing progress on the scientific basis of basin ground motion excitation with timely delivery of engineering guidance on basin correction terms for use in new attenuation relations.