Validation of Ground Motion Simulations for Engineering Applications

Annual report, 2007 Project #07069

PI: Jack Baker, Stanford University

Introduction

Adoption of ground motion simulations for rupture-to-rafters analyses depends not only upon the quality of the science underlying the models, but also on empirical validation of ground motion parameters relevant to engineering analyses. This work compares statistical properties of simulated and recorded ground motions, with a focus on properties that are known to affect the response of structures. Comparisons may be difficult due to a lack of recorded data, but the procedures are useful when feasible. Example results are presented for Puente Hills broadband simulations at 648 sites in the Los Angeles region. The simulations were produced by Rob Graves (2006). Figure 1 shows spectral acceleration values at 1 second from an example simulation.

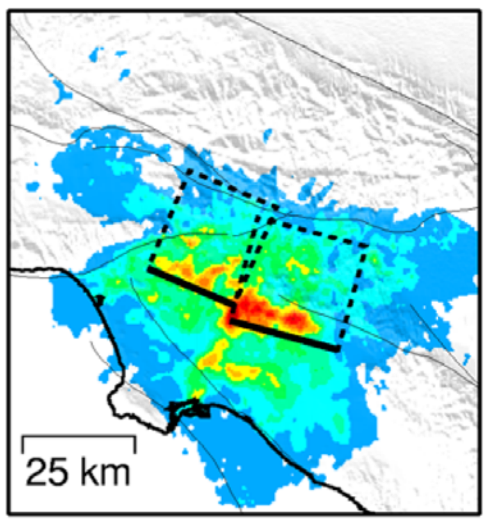

Figure 1: Example spectral acceleration values from the Puente Hills broadband simulations (from Graves and Somerville, 2006)

Elastic response spectra

The elastic response spectrum is important because it often serves as the link between seismic hazard analysis and structural response calculation. Mean spectra are important, but standard deviations and correlations also affect structural response. The figures below show example findings from this project. Figure 2 shows example response spectra from recorded and simulated ground motions having similar magnitudes and distances. (In this and other figures, predictions from ground motion prediction models are also shown for comparison.) The spectra look reasonably similar, except at short periods where the simulations appear to be lower in amplitude and have less record-to-record variability.

Figure 3 shows the means and standard deviations of residuals from ground motion prediction models, for recorded and simulated ground motions with magnitude > 6.5 and V_{s30} > 300 m/s. This figure supports the observations from Figure 2, but confirms them by using a larger set of ground motions. The simulations show reasonable agreement with empirical observations at periods longer than one second, and less good agreement at shorter periods. Figure 4 shows correlations of spectral values at multiple periods; these correlations illustrate the “bumpiness” of the spectra, a factor known to affect response of nonlinear and multi-degree-of-freedom structures (Baker and Cornell 2006). The simulations appear to have a correlation structure that is not in close agreement with comparable empirical models.

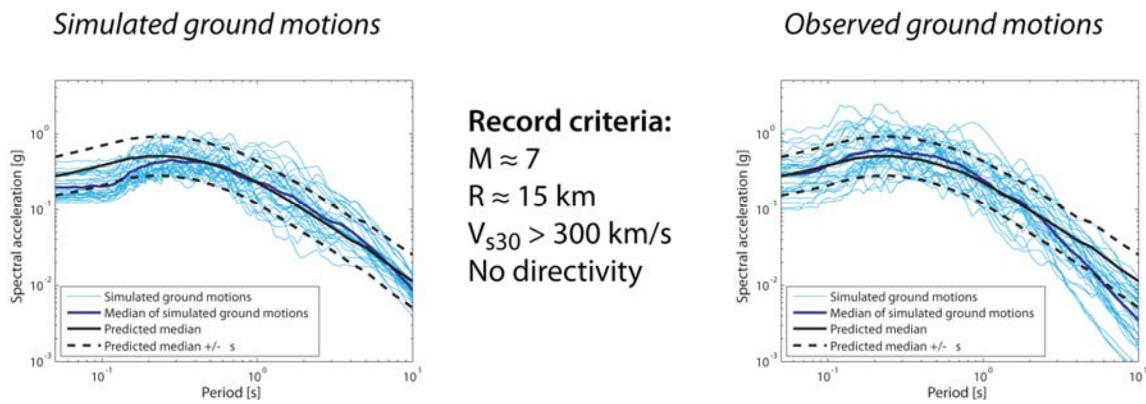

Figure 2: Example response spectra from recorded and simulated ground motions having similar magnitudes and distances.

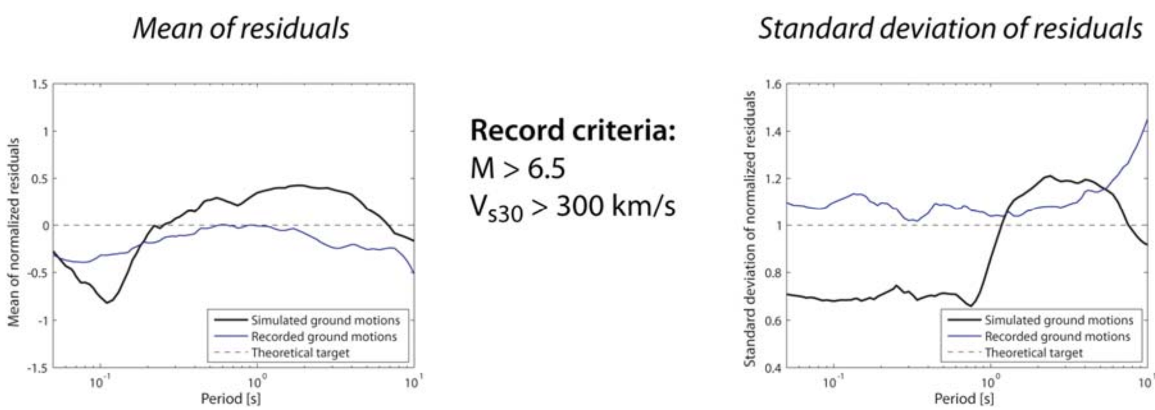

Figure 3: Means and standard deviations of residuals from ground motion prediction models, from recorded and simulated ground motions with magnitude > 6.5 and V_{s30} > 300 m/s.

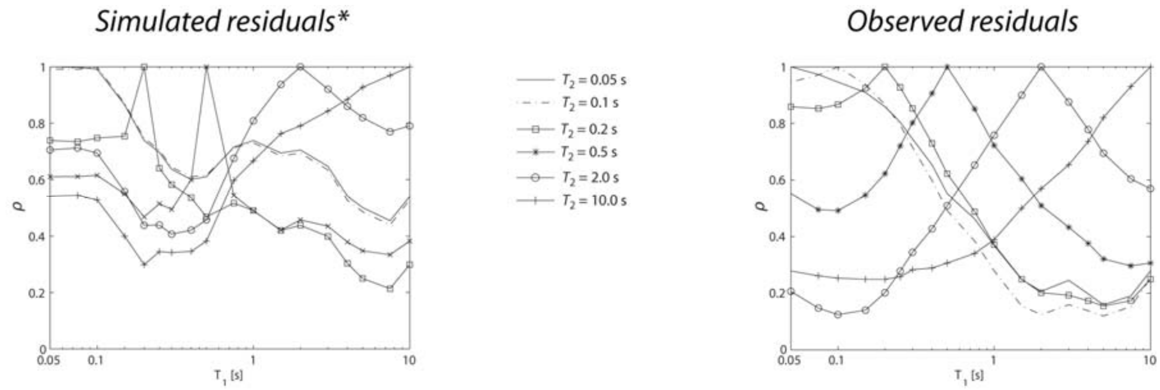

Figure 4: Correlations of residuals at multiple periods, from recorded and simulated ground motions magnitude > 6.5 and V_{s30} > 300 m/s.

Nonlinear response spectra

Real structures are expected to behave nonlinearly in strong ground shaking, so the inelastic response spectrum (which measures peak responses of nonlinear oscillators) provides a proxy for the effect of ground motions on nonlinear structures. Assuming that elastic response spectra of the simulated motions appear reasonable, a simple way to study inelastic spectra is to consider the ratio of inelastic to elastic response, as shown below in Figure 5. Calculated response ratios are shown for both simulated and observed ground motions, plotted versus the expected level of nonlinearity (R).

R measures the ratio between the expected linear response and the yield displacement of the simple oscillator. Other researchers first compute the linear response for each record, but here with use the expected response predicted based on magnitude, distance, etc., because when considering future ground motions in hazard analysis, the true linear response cannot be known a priori. The use of expected response is thus a valuable practical approach (Tothong and Cornell 2006). Response ratios are shown below for suites of simulated and recorded ground motions, and their geometric-mean responses are compared to the predictive model of Tothong and Cornell (2006).

Both the elastic and inelastic response ratios agree well with comparable recorded ground motions at periods larger than 1 second. At shorter periods, the variability of the simulated elastic spectra is lower than the observed spectra and the inelastic response ratios of the simulations appear to be too high. The large inelastic response ratios may be due to differences in the mean elastic spectra, which could affect softening nonlinear oscillators.

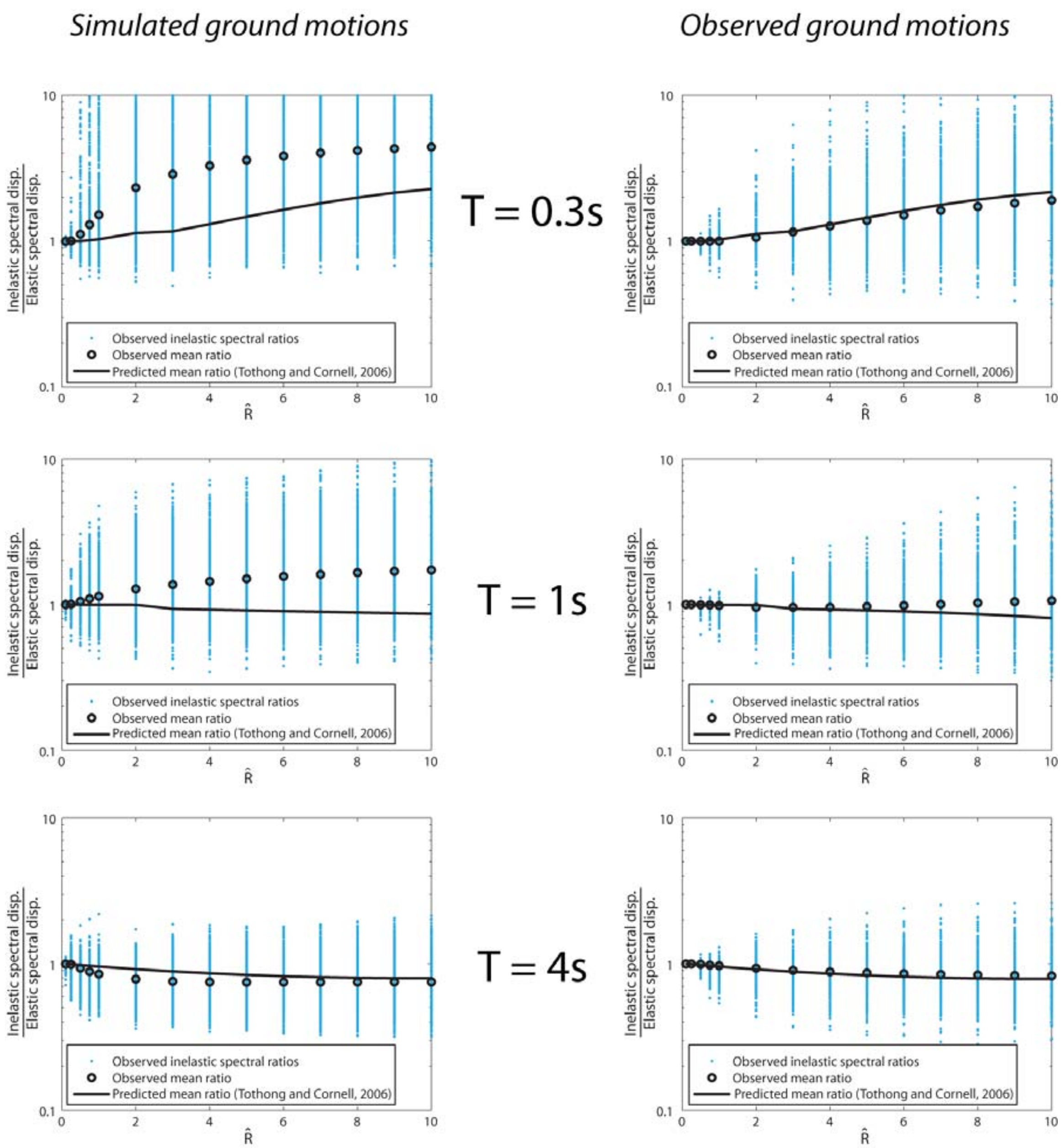

Figure 5: Inelastic response spectra, from recorded and simulated ground motions having magnitude > 6.5 and V_{s30} > 300 m/s.

A tentative list of important ground motion properties, and conclusions to date

To facilitate general validation of simulated ground motions, the following list describes ground motion properties relevant to the engineering community. Preliminary observations relating to the specific simulations studied here are also noted.

Mean values of response spectra

- *Motivation*: capture mean structural response
- *Observations*: simulations appear reasonable at stiff soil sites and periods longer than 0.2s

Standard deviations of response spectra

- *Motivation*: capture structural response variability, and enable physics-based PSHA
- *Observations*: simulations appear reasonable at periods longer than 1s

Correlations of response spectral values at multiple periods

- *Motivation*: measure the "bumpiness" of the spectra, which affects response of nonlinear and multi-degree-of-freedom structures (Tothong and Cornell 2007)
- *Observations*: simulations are consistent with observations (except at soft-soil sites)

Nonlinear response spectral ratios

- *Motivation*: measure a proxy for behavior of nonlinear structures
- *Observations*: simulations appear reasonable at longer periods

Other observations

- The apparent soft-soil discrepancies require further investigation. At present, the simulations on soft soil sites do not appear to be appropriate for engineering use.
- Strong directivity effects in the simulations require more study. This is needed for validation, and the simulations may also help refine directivity-prediction models.

These results will aid engineers in understanding whether ground motion simulations can supplement or improve upon empirical ground motions, as well as provide feedback to those developing simulation models.

Anticipated publications

This data will continue to be valuable to the PI for several future projects. In the short term, the observed directivity effects (mentioned in the previous section) will be studied in more detail. Once findings in this area are finalized, it will be combined with the above material to create a journal article for publication. Other work on this project relating to spatial correlations of ground motion intensity (not reported above, but presented at the 2007 SCEC annual meeting) will be included in a future journal publication as well.

Acknowledgements

Many thanks are due to Rob Graves for providing the ground motion simulations and answering questions regarding the data. Thanks to Polsak Tothong for guidance regarding inelastic spectral ratios and validation tests.

References

Baker J.W. and Cornell C.A., 2006. Correlation of response spectral values for multi-component ground motions, *Bulletin of the Seismological Society of America*, **96** (1), 215-227.

Graves R. and Somerville P.G., 2006. Broadband ground motion simulations for scenario ruptures of the puente hills fault, in *8th National Conference on Earthquake Engineering, San Francisco, California*, 10 pp.

Tothong P. and Cornell C.A., 2006. An empirical ground-motion attenuation relation for inelastic spectral displacement, *Bulletin of the Seismological Society of America*, **96** (6), 2146-2164.

Tothong P. and Cornell C.A., 2007. *Probabilistic seismic demand analysis using advanced ground motion intensity measures, attenuation relationships, and near-fault effects*, Pacific Earthquake Engineering Research Center, University of California at Berkeley, PEER 2006-10, Berkeley, California, 205 pp.