Validation of SCEC Seismogram Simulations

SCEC Workshop on “Use of SCEC Simulations for Building Response Analysis”

Presentation prepared by:

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“Validation”

- Comparison with data from past earthquakes (or empirical models from such data) …

- to validate simulation methods (not the simulated seismograms for past earthquakes) …

- for simulation of not-yet-recorded and/or site-specific seismograms (e.g. for repeat of 1906 San Francisco earthquake) …

- for an application of interest (e.g. building response analysis).
Comparisons with Data

- Seismograms, e.g.

- Response spectra

- Other proxies for building response

- Building response analysis results, e.g.
What validation methodologies should the TAG use?

- Most workshop participants agreed that the TAG should start by validating against recorded ground motions from past earthquakes (e.g. the 1994 Northridge earthquake).
- It was proposed at the workshop that the TAG start with the approximately 8 magnitude 6.5 and larger earthquakes that have been recorded in California. Via collaboration with international colleagues, this list could be expanded to include, among others, the Kobe, Izmit, Chi-Chi, Totori, and Darfield earthquakes.

- A majority of workshop participants felt that the TAG should start by using elastic and inelastic response spectra for validation. A broad range of spectral frequencies, from 0.1 to 10 Hz, were of interest to workshop participants. Inelastic response spectra that account for degradation beyond that of bilinear single-degree-of-freedom oscillators were of interest as well. Other relatively simple goodness-of-fit measures, such as Arias duration, were also suggested.

- Some workshop participants, however, felt that the TAG should not wait to validate simulations for the response of at least a few multi-degree-of-freedom nonlinear building (and possibly site response) models. Such validation exercises may identify additional important metrics for validation (e.g. story drift correlations), and how/whether they relate to elastic and inelastic spectra.

- Whatever the goodness-of-fit measure, its spatial distribution should likely be mapped, as discussed by a few of the presenters at the workshop.
Validation of ground motion simulations through simple proxies for the response of engineered systems

Lynne S. Burks* and Jack W. Baker

Abstract

We propose a list of simple parameters that act as proxies for the response of more complicated engineered systems, and can therefore be studied to validate new methods of ground motion simulation for engineering applications. The primary list of parameters includes correlation of spectral acceleration across periods, ratio of maximum to median spectral acceleration across all horizontal orientations, and the ratio of inelastic to elastic displacement, all of which have reliable empirical models against which simulations can be compared. We also describe several secondary parameters, such as directivity pulse periods and structural collapse capacity, that do not have robust empirical models but are important for engineering analysis. We then demonstrate the application of these parameters to example simulations from the SCEC Broadband Platform validation exercise computed using a variety of methods, including stochastic finite fault (EXSIM), Graves-Pitarka hybrid broadband (GP), and composite source model (CSM). In general, each simulation method matches empirical models for some parameters and not others, indicating that engineers need to carefully validate all parameters relevant to their application before using ground motion simulations.

Online Material: Matlab functions to compute simple proxies and tables of ground motion recordings and simulations used for example calculation. <http://www.stanford.edu/~bakerjw/e-supp/Burks_Baker_(2013)_Metrics,_BSSA-esupp.html>
Correlation of $S_a$ Across Periods

Figure 16: Correlation of $\rho$ for recordings and simulations of the 1989 Loma Prieta earthquake shown with an empirical model for shallow crustal earthquakes (Baker and Jayaram, 2008) and results from subduction zone earthquakes (Al Atik, 2011) at (a) $T_2 = 0.2$ s, (b) $T_2 = 0.8$ s, (c) $T_2 = 1.2$ s, and (d) $T_2 = 3$ s.
Ratio of Maximum to Median $S_a$

(-across all horizontal orientations-)

Figure 17: Ratio of $S_{a_{RotD100}}$ to $S_{a_{RotD50}}$ from empirical models and the median ratio from recordings and simulations of the 1989 Loma Prieta earthquake.
Figure 19: Inelastic to elastic displacement ratio, $S_{di}/S_{de}$, for recordings and simulations of the 1989 Loma Prieta earthquake as a function of $\hat{R}$ at (a) $T = 0.8$ s and (b) $T = 1.6$ s.
Figure 21: Inelastic to elastic displacement ratio, $S_{di}/S_{de}$, for PEER records and matched simulations as a function of $\hat{R}$ at (a) $T = 0.3$ s, (b) $T = 0.8$ s, and (c) $T = 3.0$ s.
Figure 22: Histogram of pulse period, $T_p$, in the East-West direction for the Hayward and San Andreas scenario simulations compared to two empirical models.
Figure 24: Histogram of pulse periods in the North-South direction from the 1994 Northridge earthquake of (a) CSM simulations and (b) EXSIM simulations compared to recordings.
Validation of Simulated Earthquake Ground Motions Based on Evolution of Intensity and Frequency Content

by Sanaz Rezaeian, Peng Zhong, Stephen Hartzell, and Farzin Zareian

Abstract  Simulated earthquake ground motions can be used in many recent engineering applications that require time series as input excitations. However, applicability and validation of simulations are subjects of debate in the seismological and engineering communities. We propose a validation methodology at the waveform level and directly based on characteristics that are expected to influence most structural and geotechnical response parameters. In particular, three time-dependent validation metrics are used to evaluate the evolving intensity, frequency, and bandwidth of a waveform. These validation metrics capture nonstationarities in intensity and frequency content of waveforms, making them ideal to address nonlinear response of structural systems. A two-component error factor is proposed to quantify the average and shape differences between these validation metrics for a simulated and recorded ground-motion pair. Because these metrics are directly related to the waveform characteristics, they provide easily interpretable feedback to seismologists for modifying their ground-motion simulation models. To further simplify the use and interpretation of these metrics for engineers, it is shown how six scalar key parameters, including duration, intensity, and predominant frequency, can be extracted from the validation metrics. The proposed validation methodology is a step forward in paving the road for utilization of simulated ground motions in engineering practice and is demonstrated using examples of recorded and simulated ground motions from the 1994 Northridge, California, earthquake.

Southern California Earthquake Center (SCEC) Workshop on “Use of SCEC Seismogram Simulations for Building Response Analysis”

“Validation of SCEC Seismogram Simulations,” N. Luco (USGS) et al

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Physically Parameterized Prediction Equations for Significant Duration in Active Crustal Regions

Kioumars Afshari, a) S.M.EERI, and Jonathan P. Stewart b) M.EERI

We develop prediction equations for the median and standard deviation of the significant duration of earthquake ground motions from shallow crustal earthquakes in active tectonic regions. We consider significant duration parameters for 5-75%, 5-95%, and 20-80% of the normalized Arias intensity. The equations were derived from a global database with $M_{3.0-7.9}$ events. We find significant noise effects on duration parameters that compel us to exclude some records that had been used previously to develop models for amplitude parameters. Our equations include an $M$-dependent source duration term that also depends on focal mechanism. At small $M$, the data suggest approximately $M$-independent source durations that are close to 1 sec. The increase of source durations with $M$ is slower over the range ~5 to 7.2-7.4 than for larger magnitudes. We adopt an additive path term with breaks in distance scaling at 10 and 50 km. We include site terms that increase duration for decreasing $V_S$ at 30 and increasing basin depth. Our aleatory variability model captures decreasing between- and within-event standard deviation terms with increasing $M$. 

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Figure 1. Normalized Arias intensity and illustration of three significant duration parameters $D_{5-75}$, $D_{5-95}$, and $D_{20-80}$ for an example record.
Categorization of Validation Parameters

- **Spectral from Baker et al**
  1) Correlation of $Sa$ across periods
  2) Ratio of maximum to median $Sa$
  3) Ratio of inelastic to elastic $Sd$

- **Time-domain from Rezaeian et al**
  4) Evolution of intensity
  5) Evolution of predominant frequency
  6) Evolution of bandwidth

- **Scalar from Rezaeian et al**
  7) $I_a$ (Arias Intensity)
  8) $D_{5-95}$ (Duration)
  9) $I_a \div D_{5-95}$
  10) $\omega_{mid}$
  11) $\omega'$
  12) $\zeta$
## Validation Parameters on BBP

**Time evolution of intensity, frequency, & bandwidth**
(Rezaeian et al, 2015)

- Duration (Afshari & Stewart, 2016)

- Max+Median Horizontal Spectral Acceleration
(Burks & Baker, 2014)

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Conclusions

- Several validation parameters that are proxies for building response have been identified and utilized to compare simulations and recordings.

- Comparison results have, informally to date, served as both feedback on simulation methods and demonstrations of their “validity”.

- Consensus “gauntlets” of validation parameters for building response analysis, and for other applications, are still needed.