Use of SCEC Seismogram Simulations for Building Response Analysis

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Early Years of the GMSV TAG

• Proposed by Tom Jordan during 2010 Annual Meeting and mentioned in 2011 SCEC Collaboration Plan (RfP).

• No consensus on testing/rating methodologies, so …

• convened 2011 Planning Workshop for recommendations, …

• requested recommended proposals in 2012-2016 (SCEC4) Collaboration Plans, and …

• convened Coordination Workshops (2012-2013) and Web Conferences (2013-2016).
1 Objective

2 Agenda & Presentations

3 Participants

4 Summary of Outcomes

4.1 What ground motion simulations and/or simulation models should the SCEC GMSV TAG validate?

4.2 What validation methodologies should the TAG use?

4.3 For what engineering application should the TAG validate the simulations?

4.4 Should the TAG prioritize the archiving and distribution of simulations?

4.5 Where/how should the validation methodologies used by the TAG be implemented?

4.6 How should the TAG be organized, at least initially? In other words, how should the TAG operate?

5 Recommendations
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.
2012-2014 GMSV TAG Projects

Past Projects (& SCEC Reports)

- 2014 - "Use and validation of simulated earthquakes for the nonlinear performance-assessment of tall buildings considering spectral shape and duration" (G. Deierlein, Stanford; T. Lin, Marquette)
- 2014 - "Validation of simulated ground motions based on evolution of intensity and frequency content" (F. Zareian, UC-Irvine; S. Rezaeian, USGS)
- 2014 - "Methodology for validating median values and aleatory variability of broadband platform ground motion simulations" (J. Bayless, A. Skarlatoudis, & P. Somerville, URS)
- 2014 - "Empirical evaluation of the variance associated with multiple ruptures of a single fault" (J. Anderson, UNR)

2013-15 – Comparisons of nonlinear response of multi-degree-of-freedom building models to simulated and recorded ground motions (F. Zareian, UCI; I. Iervolino, Naples Federico II)

2013-2015 – Validation of simulated ground motions relative to seismic geotechnical engineering demand parameters (J. Stewart, UCLA)

2013-2015 – Validation for engineering analysis using simple and robust ground motion parameters (J. Baker, Stanford)
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 vector 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.
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 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 $V_{330}$ and increasing basin depth. Our aleatory variability model captures decreasing between- and within-event standard deviation terms with increasing $M$. 
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>
Validation Parameters

Inelastic Spectral Displacement
Elastic Spectral Displacement

Correlation of $S_a$'s

Evolution of Frequency,
Predominant Frequency,
& Rate of Change of
Frequency with Time

Maximum Horizontal Spectral Acceleration
Median Spectral Acceleration

Evolution of Intensity,
Arias Intensity, Significant Duration,
& Arias Intensity / Significant Duration

Inelastic Spectral Displacement
Elastic Spectral Displacement

Evolution of Bandwidth

Correlation of $S_a$'s

SCEC GMSV TAG Web Conference

“A Multi-PI Project on Demonstrations of the Efficacy of the BBP Validation Gauntlets ...,” N. Luco (USGS) et al
October 30, 2017
**2015 GMSV TAG Project**

**Title:** Implementation of GMSV Gauntlets on the SCEC Broadband Platform

**Co-PIs:** Luco & Rezaeian (USGS), Goulet (SCEC), Skarlatoudis & Bayless (AECOM), Maechling & Silva (SCEC)

**Tasks:**
1. Selection of ground motion parameters with corresponding empirical ground motion models
2. Implementation & verification
3. Development of simulated-vs.-recorded and simulated-vs.-modeled comparison figures
4. Dissemination workshop with modelers
2015 GMSV TAG Project

2016 Southern California Earthquake Center (SCEC) Annual Meeting – International Workshop on GMSV

“The SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG),” N. Luco (USGS) September 11, 2016

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

Duration (Afshari & Stewart, 2016)

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

Title: Demonstrations of the Efficacy of the BBP Validation Gauntlets for Building Response Analysis Simulations (a.k.a., Validation of Validation Guantlets)

Co-PIs: Luco & Rezaeian (USGS), Deierlein & Bijelic (Stanford), Zareian (UC-Irvine), Lin (Marquette), Silva & Maechling (SCEC)

Workshop on the Use of SCEC Seismogram Simulations for Building Response Analysis

Conveners: Sanaz Rezaeian and Nicolas Luco
Dates: February 16, 2018 (10:00 - 16:30)
Location: SCEC Boardroom, USC, Los Angeles

SUMMARY: Computer simulations of earthquake ground motion seismograms (e.g., time series of ground acceleration) are among the various products of the Southern California Earthquake Center (SCEC) and other earthquake scientists. For earthquake engineering and other applications, such seismogram simulations can be used to complement data recorded in past earthquakes. Convened by a subgroup of the SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG), this workshop will connect scientists who perform seismogram simulations with engineers who might use them. The discussion will be focused mostly on the use of SCEC Broadband Platform seismogram simulations for building response analysis by structural engineers.

Presentation slides may be downloaded by clicking the links following the title. PLEASE NOTE: Files are the author’s property. They may contain unpublished or preliminary information and should only be used while viewing the talk.

FRIDAY, FEBRUARY 16, 2018
1. The science and software of SCEC seismogram simulations (*Rob Graves & Christine Goulet*)

2. Validation of SCEC seismogram simulations (*Nico Luco & Farzin Zareian*)

3. Demonstrations of the use and validation of SCEC seismogram simulations for building response analysis (*Greg Deierlein & Ting Lin*)

4. Access to SCEC seismogram simulations (*Phil Maechling & Fabio Silva*)
3. Demonstrations of Use

Archetype Buildings

20-story RC frame
- **Archetype ID**: 1020 (FEMA P695)
- **Modeling**: Cyclic hinge model for beams and columns in the lateral frame + leaning system (gravity frame)
- **Period**: $T_1 = 2.6$ sec, $T_2 = 0.9$ sec

42-story RC frame
- **Archetype ID**: simplified from TBI building 1C (H1 direction)
- **Modeling**: force-based fiber element for shear wall + leaning system (gravity frame)
- **Period**: $T_1 = 4.2$ sec, $T_2 = 1.0$ sec

Ref: PEER TBI (2011).
4. Access

Demonstration Broadband Platform (BBP) Ground Motion (GM) Sets for Tall Building Response Analyses – SCEC 2/16/2018 Workshop

Pl’s: G. Deierlein, T. Lin
Students: K. Zhang, W-Y Yen, N. Bijelic

GM Database: SCEC BBP 17.3 (GP sim. by R. Graves)

<table>
<thead>
<tr>
<th>Seismic Source</th>
<th>No. of GM’s</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern San Andreas (M 8.0)</td>
<td>1152</td>
<td>8029-RIN</td>
</tr>
<tr>
<td>Hayward (M 7.0)</td>
<td>576</td>
<td>8029-RIN</td>
</tr>
<tr>
<td>Elysian Park (M 6.6)</td>
<td>704</td>
<td>LADT</td>
</tr>
<tr>
<td>Southern San Andreas (M 7.9)</td>
<td>352</td>
<td>LADT/S688</td>
</tr>
<tr>
<td>San Jacinto (M 7.8)</td>
<td>1408</td>
<td>S688</td>
</tr>
</tbody>
</table>

GM Selection: per ASCE 7-16 spectra*
- 11 GM’s
- Mean Sa>=target response spectra over 0.2-1.5T₁
- Consistent M, R, & mechanism; site condition etc.

• Buildings:
  - 20-story RC frame, $T_1 \sim 3$ sec
  - 42-story RC shear wall, $T_1 \sim 5$ sec

• Sites:
  - San Francisco Downtown (8029-RIN: 37.786 N, 122.391 W, Vs30 = 873 m/s)
  - Los Angeles Downtown (LADT: 34.052 N, 118.257 W, Vs30 = 390 m/s)
  - San Bernardino (S688: 34.104 N, 117.288 W, Vs30 = 280 m/s)

• Intensity Levels:
  - 10% in 50 years “DBE”
  - 2% in 50 years “MCE”


SFDT (8029-RIN) scenario simulations (courtesy of N. Luco, S. Rezaeian, R. Graves, C. Goulet, F. Silva, & P. Maechling)
Other 2015-2016 GMSV TAG Projects

Current Projects [edit]

- 2016 - Demonstrations of the Efficacy of the BBP Validation Gauntlets for Building Response Analysis Simulations (N. Luco & S. Rezaeian, USGS; G. Deierlein & N. Bijelic, Stanford; F. Zareian, UC Irvine; T. Lin, Marquette; F. Silva & P. Maechling, SCEC)
- 2016 - International Workshop on Ground Motion Simulation Validation (S. Rezaeian & N. Luco, USGS; B. Bradley, U-Canterbury; I. Iervolino, Naples Federico II)
- 2016 - Quantification of acceptable ranges of GMSV Gauntlets for validation of simulated ground motion for engineering practice (F. Zareian, UC-Irvine)
- 2016 - A Vs30-based site response module for modifying ground motion time-series on reference site conditions (D. Asimaki, Caltech)
- 2016 - Modeling and implementation of a stochastic geotechnical layer for physics-based ground motion simulations (D. Asimaki, Caltech; R. Taborda, U-Memphis; A. Yong, USGS)
- 2016 - Incorporation of Local Site Effects in Broadband Simulations of Ground Motions: Case Study of the Wildlife Liquefaction Array in Southern California (R. Motamed, UN-Reno; J. Anderson, UN-Reno)
- 2016 - Broadband ground motion simulations for the Canterbury earthquakes with nonlinear effective-stress modeling of surficial soils (B. Bradley, U-Canterbury)
- 2016 - Surface Topography Effects in Three-Dimensional Physics-Based Deterministic Ground Motion Simulations in Southern California (J. Bielak, CMU; R. Taborda, U-Memphis; D. Restrepo, EAFIT)
- 2016 - Next Generation SDSU BBP Module Validation (K. Olsen, SDSU)
- 2016 - An Examination of the Correlations Between Different Goodness-of-Fit Metrics Based on a Large Dataset of Ground Motion Simulation Validations (R. Taborda, U-Memphis)
- 2016 - Inter-Period Correlations of SCEC Broadband Platform Fourier Amplitudes and Response Spectra (J. Bayless, AECOM; A. Skarlatoudis, AECOM; P. Somerville, AECOM; F. Silva, SCEC)

Past Projects (& SCEC Reports) [edit]

- 2015 - Utilization and validation of CyberShake ground motions for the nonlinear performance-assessment of tall buildings (G. Deierlein, Stanford; T. Lin, Marquette)
- 2013-15 - Comparisons of nonlinear response of multi-degree-of-freedom building models to simulated and recorded ground motions (F. Zareian, UCI; I. Iervolino, Naples Federico II)
- 2015 - Toward a Framework for Ground Motion Simulation Validation using Attenuation Relationships. Part 1: Calibration Between NGA-West2 Predictions, Physics-Based Synthetics, and Data (R. Taborda, Memphis)
- 2015 - Implementation and validation of the newly developed rupture model generator at SCEC broadband platform (S.G. Song, KIGAM; L. Dalguer, swissnuclear)
- 2015 - Broadband ground motion simulations for the Canterbury earthquakes with nonlinear effective-stress modeling of surficial soil (B. Bradley, Canterbury)
- 2012-15 - Validation of simulated ground motions relative to seismic geotechnical engineering demand parameters (J. Stewart, UCLA)
- 2015 - Impact of Uncertainty in Magnitude-Area Scaling Relations on BBP Broadband Simulations (A. Skarlatoudis, J. Bayless, & P. Somerville, URS; P. Maechling, SCEC)
- 2015 - Realistic velocity, Q, and scattering models consistent with high frequencies of strong ground motions in California modeled using the composite source model (J. Anderson, UNR)
- 2015 - Including Scattering in the UCSB Broadband Modelling Method (R. Ampuero, UCSB)
Summary

- In SCEC4, most of the SCEC GMSV TAG projects focused on building response analysis and its proxies.

- These projects resulted in publications by, e.g., Zareian/Rezaeian et al, Baker et al, & Deierlein/Lin et al.

- Also resulted in (rough) implementation of the proxies on the SCEC Broadband Platform.

- At the end of SCEC4, began to interact (workshop) with practitioners of building response analysis.