An Overview of Ground Motion
Seismogram Simulation & Validation

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SCEC GMSV Workshop on Use of SCEC Simulations
February 16, 2018
University of Southern California, Los Angeles, CA
Outline

- Motivation for Using Simulations
  - Missing or limited data
  - Site/Region specific ground motions

- Simulation of Ground Motions
  - Deterministic “physics-based”
  - Stochastic (source-based & site-based)
  - Hybrid

- Ground Motion Simulation Validation (GMSV)
  - History of GMSV TAG
  - Validation approaches (using data / models based on data)
  - Outcomes and future direction
Motivation

In seismic design and analysis, development of design ground motions is a crucial step.

- **Lower levels of intensity**
  
  *Expected structural behavior:* Linear  
  
  *Approach:* Response spectrum analysis  
  
  *Requires:* Ground motion spectral values (ground motion prediction equations exist)  
  
  **Spectral Ordinate = GMPE (Magnitude, Distance, Site, etc.)**

- **Higher levels of intensity**
  
  *Expected structural behavior:* Nonlinear  
  
  *Approach:* Response history analysis  
  
  *Requires:* Ground motion time-series (difficulties and controversies exist)  
  
  **Recorded?  Scaled/Modified?  Simulated?**
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  Can result in unrealistic ground motions, e.g., increases energy content without changing duration or frequency content!
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  If “validated”, a better alternative! (also used in development of GMPEs)
Motivation

ASCE 7 procedures permit the use of simulated ground motions. However, rigorous validation needed for engineers to gain confidence in simulations

**ASCE 7-16, 16.2.2. (Nonlinear Response History Analysis):**

“A suite of not less than 11 ground motions shall be selected for each target spectrum. ... Where the required number of recorded ground motions is not available, it shall be permitted to supplement the available records with simulated ground motions. Ground motion simulations shall be consistent with the magnitudes, source characteristics, fault distances, and site conditions controlling the target spectrum.”
Motivation

Simulated ground motions can be useful when:

- **Missing or limited recorded data:**
  - No data for large M at close distance
  - Few moderate M events
  
- Need site/region specific motions
  Represent local directivity effects, basin effect, etc. as opposed to using
  - SoCal data used in NorCal
  - WUS data used in CEUS

PEER NGA-West2 Database
Bozorgnia et al., 2014, Earthquake Spectra
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Earthquakes with M>6.0 since 1950
Usgs.gov
Motivation

Simulated ground motions can be useful in many engineering applications:

- **Structural Analysis**
  - Response-history analysis
    - missing or limited data
    - site/region specific
  - Stochastic dynamic analysis (random vibration)
    - stochastic process used as input

- **Hazard Analysis**
  - Probabilistic seismic hazard analysis (PSHA)
    - when GMPEs not reliable (e.g., long periods or basins, ex., Cybershake)
  - GMPE development, where recordings are scarce
    - missing or limited data (e.g., NGA-East, soil amplifications in WUS)

Focus of today’s workshop.
Ground Motion Simulation

Many simulation models exist. Some are implemented by SCEC. All simulations must model three elements: Source, Path, and Site

Simulation Approaches:

- **Source-based**
  
  Explicitly describe the fault rupture process at the source, propagation path of seismic waves, and effects of local site conditions to generate motions at the site.

- **Site-based**
  
  Describe characteristics of the ground motion as observed at the site, controlled by source, path, and site characteristics. Implicitly account for source, path and site.
**Ground Motion Simulation**

**Simulation Models:**

**Deterministic “physics-based” models (source-based)**

- Source model, e.g., kinematic or dynamic rupture model
- Material model, e.g., seismic velocity model
- Wave propagation equation: analytical for 1D, numerical for 3D

**Example source model:**

**Example velocity model:**

+ Q model (anelastic attenuation)
+ Correction for near-surface soil effects
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Stochastic source-based models
- Ground motion = Source(p1) × Path(p2) × Site(p3)

Parameters p1, p2, p3: moment, stress drop, corner frequency, kappa, Q, rupture velocity, ...

Examples: Boore (1983,…,2003,…,2009), EXSIM, SMSIM

Most improvements focus on enhancing the source spectrum (point source, finite fault)
Fault discretized into many subfaults (similar to deterministic), ground motion for each is a band-limited Gaussian white-noise with finite duration, and delayed based on a rupture velocity
Ground Motion Simulation

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Stochastic site-based models
- Ground motion = Stochastic Process Fitted to Records (pi)
- pi = fun(F, M, R, Vs30)

Example site-based model:

\[ \hat{z}(t) = q(t, \alpha) \]
**Ground Motion Simulation**

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- Computationally intensive
- More reliable at low frequencies (long T)
  - Need info on source & material
- Simpler to generate
- More accurate at high frequencies
  - Most cannot represent nonstationary frequency
Ground Motion Simulation

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Stochastic site-based models
- Ground motion = Stochastic Process Fitted to Records (pi)
- pi = fun(F, M, R, Vs30)
- Accurate at high and low frequencies
- Discontinuities at the “splicing” frequency
- Advantages/disadvantages of both methods

Hybrid models
- Deterministic at long T + Stochastic at short T
- Advantages/disadvantages of both methods

SCEC GMSV Workshop on Use of SCEC Simulations, 2/16/2018
Ground Motion Simulation

Resources for more detail:
Two chapters in 2015 Encyclopedia of Earthquake Engineering

More on SCEC Simulations at 10:45-11:45
Robert Graves & Christine Goulet
“The science and software of SCEC seismogram simulations”
Validation of Simulations

Developers of ground motion simulations validate their own simulations by looking at:
- Model Components (e.g., velocity model)
- Waveforms & Spectral Values

In two way:
- Comparisons to data
- Comparisons to GMPEs (other models based on data)

But these validations:
- Are not done in a uniform way (e.g., Fourier spectra vs. response spectra)
- Don’t consider structural responses or engineering applications

e.g., SCEC Broadband Platform Validation Project (BPVP) for PSA

Sun et al., 2015, BSSA
Validation of Simulations

SCEC Broadband Platform Validation Project (BPVP):

**Short term goal:** supplement data for development of GMPEs and ground motion hazard models (SWUS, NGA-East)

**Long term goal:** develop acceptance of simulations for engineering application

- Five methods from BroadBand platform validated for PSA
- Systematic independent validation against
  - past recorded events (Part A)
  - GMPEs scenario events for which GMPEs are well constrained by data (Part B)
- Transparency of input parameters; code run by independent third party
- Multiple rounds of validation/improvements over ~ 2 years
- Review and evaluation by an independent panel
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SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG) was established in 2010.
Validation of Simulations

SCEC GMSV TAG Objectives:

- Develop and implement testing/rating methodologies via collaboration between ground motion modelers and engineering users.

- Focused on validation for use in “engineering applications,” such as …
  - development of Ground Motion Prediction Equations (GMPE’s), BPVP focused on elastic SDoF
  - Probabilistic Seismic Hazard Analysis (PSHA)
  - structural Nonlinear Response History Analysis (NRHA) of buildings
  - geotechnical Site Response Analysis (SRA)
Validation of Simulations

SCEC GMSV TAG Objectives:

*Not* focused on …

- verification (comparison against theoretical predictions, as opposed to observations)
- comparisons of seismograms, as opposed to …
  - elastic response spectra
  - inelastic response spectra
  - response of geotechnical systems
  - multi-degree-of-freedom building response
  - other “engineering metrics”
- validation of individual simulated ground motions
Validation of Simulations

2010-2014: Projects were individual or joint proposals by independent PIs …, but coordinated by GMSV TAG via annual meetings and monthly web-conferences.

<table>
<thead>
<tr>
<th>Testing Methods</th>
<th>Historical Earthquakes</th>
<th>Empirical Models</th>
<th>Similar Spectra</th>
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<td>GMSV done for three kinds of responses:</td>
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<td>SDoF / Simple Proxies</td>
<td>MDoF</td>
<td>Geotech</td>
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<td>Rezaeian et al. (2014)</td>
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<td>Rathje et al. (2013)</td>
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Many more related projects (also outside SCEC) not listed here.
2015 & 2016: Additional multi-PI collaborative projects that builds on the knowledge from previous GMSV TAG projects by implementing GMSV parameters on the SCEC BBP.

**Study #1** – Baker et al.
**Study #2** – Rezaeian et al.
**Study #3** – Stewart et al.

2015 Multi-PI Project:
Implementing GMSV Parameters/Gauntlets on SCEC BBP

2016 Multi-PI Project:
Validating the **Validation Gauntlets** for Engineering Applications

Coordination with other groups:
Broadband Platform Validation Project (BPVP)
Utilization of Ground Motion Simulations (UGMS): using CyberShake
International groups: New Zealand, Italy,…
Outcome and Future Direction

In SCEC 4 (2010-2016):
- Initiate feedback loop with model developers (through individual PI interactions)
- Implemented validation parameters/gauntlets on the SCEC BBP (through multi-PI projects)
- Simulated ground motions for large M events (through multi-PI projects)
- Achieved more confidence in using simulations for hazard (through BPVP, etc.) and structural analysis (starting with this workshop)

In SCEC 5 (initiated Nov 2017):
- Validations related to GMPEs, but in standard deviation & spatial correlations
- Validations for utilization of simulations in specific engineering applications: e.g., tall-building design, site-specific analysis, etc (TBD @ SCEC Annual Mtg.)

More on Validation after lunch at 12:30-13:30
Nicolas Luco / Farzin Zareian
“Validation of SCEC seismogram simulations”