Summary Of A Large Scale Validation Project Using The SCEC Broadband Ground Motion Simulation Platform

Christine Goulet

SRL Special Focus on BBP Validation

- Published Jan. 2015
  - Built on work from SWUS and NGA-East
  - Nine papers
    - Intro
    - BBP software and implementation
    - Validation exercise design
    - Evaluation of results
    - Updated methodologies:
      - EXSIM
      - Graves and Pitarka (GP)
      - SDSU
      - UCSB
      - Composite Source Model (CSM)
What is the validation objective?

- Proof that the method works!
  - Past work showed that some methods could reproduce past events very closely
  - Such validations may require a lot of “tuning” and sometimes used inverted sources (circularity)
  - These are useful, but not sufficient in building confidence in the models
- Proof that the method will work again in the future!
  - Could the model could be used for events that haven’t occurred yet?
  - We want to validate for “forward simulations”...
Users and objectives

Validation driven by need of seismic hazard projects to supplement recorded datasets

- South-Western U.S. utilities (SWUS)
- PEER NGA-East project (new CENA hazard model)
- PEER NGA-West projects

Quantitative validation for forward simulations in engineering problems

- Short term goal: supplement recorded data for development of ground motion models (GMMs=GMPEs) and hazard analyses
- Long term goal: develop acceptance of simulations for engineering design

Key focus: 5% damped elastic “average” PSA ($f=0.1\text{-}100$ Hz)

*Other metrics being explored now... duration, frequency content, etc.*
Key lessons learned – past validations

Need more transparency, repeatability, independence from the modeler.
- Need to validate against many events, aggregate results
- Need clear documentation of fixed and optimized parameters from modelers for each region
- Need source description that is consistent between methods, or that can be adapted with rules
- Use unique crustal structure \((V, Q)\) for all models
- Consider multiple kinematic source realizations with fixed (Part A) and randomized (Part B) hypocenter location
- Handle site response outside of the simulations (correct data to reference Vs empirical site factors)
- Make all validation metrics computation and plots in uniform units/format – implement post-processing pipeline on BBP
- Need to tie-in to specific code version
- Have an independent operator run the code
Key elements for (empirical) ground-motion model (GMM) development

- Times series and frequency content (FAS) are “reasonable”
  - Visual inspection

PSA evaluation – using 50 source realizations

- PART A: validation against recorded events
  - Evaluation of bias \([\ln(\text{data})/\ln(\text{model})]\) using various approaches
  - Check that attenuation rate is consistent with observations
  - 13 events completed, ~40 stations/event

- PART B: validation against existing GMMs in ranges where they are well constrained by data
  - PSA fits current state of knowledge in a broad sense, within a wide acceptance range
## Simulation Methods and Modelers

<table>
<thead>
<tr>
<th>Method Name(s)</th>
<th>Method type – Finite fault models</th>
<th>Contact(s) and Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Source Model (CSM)</td>
<td>Broadband deterministic</td>
<td>J. Anderson (UNR)</td>
</tr>
<tr>
<td>UCSB</td>
<td></td>
<td>R. Archuleta, J. Crempien (UCSB)</td>
</tr>
<tr>
<td>EXSIM</td>
<td>Stochastic Brune spectrum</td>
<td>K. Assatourians, G. Atkinson (UWO)</td>
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<tr>
<td>Graves and Pitarka</td>
<td>Hybrid: deterministic LF and stochastic HF</td>
<td>R. Graves (USGS)</td>
</tr>
<tr>
<td>SDSU (BB Toolbox)</td>
<td></td>
<td>K. Olsen (SDSU)</td>
</tr>
</tbody>
</table>
## Selection of events and stations

- Large dataset (25 EQs)
- Many regions & tectonic environments
- Span wide magnitude range (Mw 4.6 to 7.62)
- Variety of mechanisms
- Well-recorded (16 EQs with > 40 records within 200 km)
- Select large subset of stations (~40) that are consistent with mean and standard deviation PSa of the full dataset.

<table>
<thead>
<tr>
<th>Region</th>
<th>Event Name</th>
<th>Year</th>
<th>Mw</th>
<th># Records &lt; 200 km</th>
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<tbody>
<tr>
<td>WUS</td>
<td>Loma Prieta</td>
<td>1989</td>
<td>6.94</td>
<td>59</td>
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<tr>
<td>WUS</td>
<td>Northridge</td>
<td>1994</td>
<td>6.73</td>
<td>124</td>
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<td>WUS</td>
<td>Landers</td>
<td>1992</td>
<td>7.22</td>
<td>69</td>
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<td>WUS</td>
<td>Whittier Narrows</td>
<td>1987</td>
<td>5.89</td>
<td>95</td>
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<td>WUS</td>
<td>North Palm Springs</td>
<td>1986</td>
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<td>32</td>
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<td>JAPAN</td>
<td>Tottori</td>
<td>2000</td>
<td>6.59</td>
<td>171</td>
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<tr>
<td>JAPAN</td>
<td>Niigata</td>
<td>2004</td>
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<td>246</td>
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<tr>
<td>WUS</td>
<td>Alum Rock</td>
<td>2007</td>
<td>5.45</td>
<td>40</td>
</tr>
<tr>
<td>WUS</td>
<td>Chino Hills</td>
<td>2008</td>
<td>5.39</td>
<td>40</td>
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<tr>
<td>CENA</td>
<td>Saguenay</td>
<td>1988</td>
<td>5.81</td>
<td>11</td>
</tr>
<tr>
<td>CENA</td>
<td>Riviere-du-Loup</td>
<td>2005</td>
<td>4.60</td>
<td>21</td>
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<tr>
<td>CENA</td>
<td>Mineral, VA</td>
<td>2011</td>
<td>5.68</td>
<td>10</td>
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<tr>
<td>WUS</td>
<td>El Mayor Cucapah</td>
<td>2010</td>
<td>7.20</td>
<td>134</td>
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<tr>
<td>WUS</td>
<td>Hector Mine</td>
<td>1999</td>
<td>7.13</td>
<td>103</td>
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<tr>
<td>WUS</td>
<td>Big Bear</td>
<td>1992</td>
<td>6.46</td>
<td>42</td>
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<tr>
<td>WUS</td>
<td>Parkfield</td>
<td>2004</td>
<td>6.50</td>
<td>78</td>
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<tr>
<td>WUS</td>
<td>Coalinga</td>
<td>1983</td>
<td>6.36</td>
<td>27</td>
</tr>
<tr>
<td>WUS</td>
<td>San Simeon</td>
<td>2003</td>
<td>6.50</td>
<td>21</td>
</tr>
<tr>
<td>JAPAN</td>
<td>Chuetsu-Oki</td>
<td>2007</td>
<td>6.80</td>
<td>286</td>
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<tr>
<td>JAPAN</td>
<td>Iwate</td>
<td>2008</td>
<td>6.90</td>
<td>186</td>
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<tr>
<td>TURKEY</td>
<td>Kocaeli</td>
<td>1999</td>
<td>7.51</td>
<td>14</td>
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<tr>
<td>TAIWAN</td>
<td>Chi-Chi</td>
<td>1999</td>
<td>7.62</td>
<td>257</td>
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<tr>
<td>ITALY</td>
<td>L’ Aquila</td>
<td>2009</td>
<td>6.30</td>
<td>40</td>
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<tr>
<td>NEW ZEALAND</td>
<td>Christchurch</td>
<td>2011</td>
<td>6.20</td>
<td>26</td>
</tr>
<tr>
<td>NEW ZEALAND</td>
<td>Darfield</td>
<td>2010</td>
<td>7.00</td>
<td>24</td>
</tr>
</tbody>
</table>
Evaluation products

- Qualitative evaluation of velocity time series and Husid plot based on Arias intensity

**RECORDED**
$V_{s30} = 822 \text{ m/s}$

**SIMULATED**
$V_{s30} = 863 \text{ m/s}$
Evaluation products

PSa for station 2001-SCE, NR vs 10000034

NR, N/S

NR, E/W

NR, rotd50

Period (s)

Period (s)
Evaluation products

- Bias as goodness-of-fit measure for PSA and PGA
  - Average GOF with T for all stations within an event
Evaluation products

- Goodness-of-fit measures for PSa and PGA
  - Average GOF with T for all stations within an event
  - Average GOF for all realizations (all stations)
Evaluation products

- Goodness-of-fit measures for PSa and PGA
  - Average GOF with $T$ for all stations within an event
  - Average GOF for all realizations (all stations)
  - Average GOF with distance (all realizations)

Part A (comparison with recordings)
Evaluation products

- Goodness-of-fit measures for PSA and PGA
  - Average GOF with T for all stations within an event
  - Average GOF for all realizations (all stations)
  - Average GOF with distance (all realizations)
  - Map of GOF (all realizations)
Evaluation products

- GOF plots also developed for
  - NGA-West1 (2008) GMPEs
  - SMSIM

*Allows to see trends/event terms*
1. Comparison of PSA GOF for each event
   Mean bias
   Mean absolute bias
   - Failure threshold is $\ln(2)=0.69$
   - Thresholds of 0.5 and 0.35 were considered as passing criteria

Combined metric: mean and mean absolute bias
   - Used alone
   - Used with GMPEs

3. Evaluation of attenuation bias
   - Distance dependence slope of zero within 95% confidence interval
### Part A, GOF Validation Threshold = 0.50

---

Unacceptable Threshold = 0.70

-0.50 ≤ highlighted green values ≤ 0.50
(highlighted red values < -0.70 or > 0.70)

<table>
<thead>
<tr>
<th>Event (Mw, Mech.)</th>
<th>UCSB</th>
<th>EXSIM</th>
<th>G&amp;P</th>
<th>SDSU</th>
<th>GMPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chino Hills (5.39, ROBL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum Rock (5.45, SS)</td>
<td>-1.04</td>
<td>1.04</td>
<td>-0.94</td>
<td>0.94</td>
<td>-0.65</td>
</tr>
<tr>
<td>Whittier Narrows (5.89, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Palm Springs (6.12, ROBL)</td>
<td>0.19</td>
<td>0.30</td>
<td>0.38</td>
<td>0.38</td>
<td>0.11</td>
</tr>
<tr>
<td>Tottori (6.59, SS)</td>
<td>-0.18</td>
<td>0.21</td>
<td>-1.18</td>
<td>1.18</td>
<td>0.10</td>
</tr>
<tr>
<td>Niigata (6.65, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northridge (6.73, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loma Prieta (6.94, ROBL)</td>
<td>0.16</td>
<td>0.38</td>
<td>0.19</td>
<td>0.38</td>
<td>0.05</td>
</tr>
<tr>
<td>Landers (7.22, SS)</td>
<td>1.16</td>
<td>1.16</td>
<td>0.73</td>
<td>0.73</td>
<td>0.91</td>
</tr>
<tr>
<td>Riviere-du-Loup (4.6 REV)</td>
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<tr>
<td>Mineral (5.68 REV)</td>
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<td></td>
</tr>
<tr>
<td>Saguenay (5.81 REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average CA</td>
<td>0.37</td>
<td>0.52</td>
<td>0.11</td>
<td>0.55</td>
<td>0.04</td>
</tr>
<tr>
<td>Average CENA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average ALL</td>
<td>0.28</td>
<td>0.47</td>
<td>-0.08</td>
<td>0.64</td>
<td>0.05</td>
</tr>
<tr>
<td>Event [Min, Max</td>
<td>0.01 to 0.1 s</td>
<td>0.1 to 1 s</td>
<td>1 to 3 s</td>
<td>More than 3 s</td>
<td></td>
</tr>
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<td>-------------</td>
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<td></td>
</tr>
<tr>
<td>M7.0 to 7.9</td>
<td>1.38 ± 0.33</td>
<td>0.67 ± 0.37</td>
<td>0.67 ± 0.37</td>
<td>0.67 ± 0.37</td>
<td></td>
</tr>
<tr>
<td>M7.0 to 7.9</td>
<td>1.38 ± 0.33</td>
<td>0.67 ± 0.37</td>
<td>0.67 ± 0.37</td>
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<td>1.38 ± 0.33</td>
<td>0.67 ± 0.37</td>
<td>0.67 ± 0.37</td>
<td>0.67 ± 0.37</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The table above represents earthquake rupture dynamics codes workshop data.
Combined Metric Comparison with GMPEs

\[
CGOF_{\text{Normalized}} = \frac{CGOF_{\text{sims}}}{CGOF_{\text{GMPE}}}
\]
### CGOF Normalized

**Part A, GOF Validation Thresholds**

<table>
<thead>
<tr>
<th>Event (Rev, Mech)</th>
<th>0-5 km</th>
<th>5-20 km</th>
<th>20-70 km</th>
<th>70-200 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chino Hills (5.39, RDB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alum Rock (5.4, SS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whittier Narrows (5.85, RE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Palm Springs (6.12, ROB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetlin (5.9, SS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northridge (6.73, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loma Prieta (6.84, ROB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landers (7.22, SS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riceville-Duquesne (6.6, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral (6.88, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sagamore (6.81, REV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Combined Metric Performance**

<table>
<thead>
<tr>
<th>Event (Rev, Mech)</th>
<th>0-5 km</th>
<th>5-20 km</th>
<th>20-70 km</th>
<th>70-200 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average CA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average CENA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average ALL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Weights**

- 0-5 km:
  - 0.39
  - 0.38
  - 0.50
- 5-20 km:
  - 0.58
  - 0.58
  - 0.55
- 20-70 km:
  - 1.18
  - 1.15
  - 1.19
- 70-200 km:
  - 1.47
  - 1.48
  - 1.51

**MFR**

- 0.22
- 0.78
- 0.33
- 0.30
Attenuation Bias

Fit a line through distance binned GOF values

\[
\ln \left( \frac{S_{a_{obs}}}{S_{a_{syn}}} \right) = a + b \cdot \ln(R)
\]

Determine whether slope \( b=0 \) lies within 95% confidence interval

Figure 1. Best fit line (green), and 95% confidence regions (red-dashed) for the 0.1 to 1 s period bin. GOF values from Table 3.1.2 are shown for event and distance bin. A) CSM; B) UCSB; C) EXSIM, D) G&P, E) SDSU, and F) GMPE. Y-axis is mean bias in natural log units. Values are for each distance bin plotted with respect to the natural log of the central distance of each bin. Data are weighted by the number of stations and discrete periods in each distance bin.
Part B – Design and Evaluation criteria

- Scenarios from NGA-West1&2 well constrained by data at 20 and 50 km Rrup
  - M5.5 REV
  - M6.2 SS
  - M6.6 SS & REV
- 50 realizations of the source, WITH randomized hypocenter location for each
- Simulations for two velocity models: NorCal and SoCal
Summary of Simulated Events

Part B: 4 scenarios

* Part B: 4 scenarios

Rupture Dynamics Codes Workshop
Capturing the uncertainty

- In scenario definitions
  - M and geometry
Capturing the uncertainty

- In input parameters
  - Perform sensitivities due to assumptions and parameter values
  - Develop appropriate parameter space to sample in forward simulations
Application to dynamic codes simulations - considerations

- Define a few initial scenarios and define what bounds a problem:
  - What is “fixed” in the validation: M or moment? fault length? Initial stress level? How?
  - What velocity structure, upper Vs? Path properties to be specified?
  - How many realizations? Start with initial set of validation for tuned (optimized) simulations?

- Start thinking in terms of “rules”
  - Define input parameters, default values and ranges
  - Think how parameters can be set in a general sense from basic scenario definition
  - Rules will most likely be regional in nature

- Think about what uncertainties can be explored
  - Trade-off with computing resources?

- Define initial set of evaluation metrics; borrow what already exists and expand as needed
Thank you!
Validation Gauntlet Development

- 1. Define application and key ground-motion parameters
- 2. Implement validation parameters on appropriate platform, generate plots and ASCII output
- 3. Form an evaluation panel; evaluate the ground-motion parameters
- 4. Develop the gauntlet (evaluation panel activity, performed outside the platform)
- 5. Implement the gauntlet on the platform so it provides fast feedback to model developers
Evaluation

- Review panel
  - Douglas Dreger (Chair), UC Berkeley
  - Gregory Beroza, Stanford
  - Steven Day, SDSU
  - Christine Goulet, UC Berkeley
  - Thomas Jordan, USC
  - Paul Spudich, USGS
  - Jonathan Stewart, UCLA

- Input for review
  - Modeler’s documentation and self-assessment
  - BBP results (parts A and B)
    - Part A: criteria based on binned GOF according to M (event), R, T
    - Part B: simple pass-fail