Verification and Validation of Regional-Scale Ground Motion Models and Simulations

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Operational Validation

» Level of agreement between synthetics and actual data
» Comparison of simulations with observations

Implementation Verification

» Correctness of the implementation of a simulation scheme
» Comparison of simulations with exact or alternative solutions
Operational Validation

» Level of agreement between synthetics and actual data
» Comparison of simulations with observations

Implementation Verification

» Correctness of the implementation of a simulation scheme
» Comparison of simulations with exact or alternative solutions

R. Taborda (2008)
Legacy of the ShakeOut verification exercise

- 3 codes
- 0.5 Hz
- 500 m/s

Bielak et al. (GJI, 2010)
Qualitative verification

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Qualitative verification

Bielak et al. (GJI, 2010)
Quantitative comparisons
Goodness-of-fit (GOF) metrics

Cross Correlation  Arias Intensity  Energy Integral  Duration
PGA  PGV  PGD
Fourier Spectrum  Response Spectrum

8 – 10 Excellent
6 – 8 Good
4 – 6 Fair
0 – 4 Poor

» Wiggle-by-wiggle
  › Kristekova et al. (2006, 2008)
» Signal metrics
  › Anderson (2004)
» Others
2008 Mw 5.4 Chino Hills earthquake verification and validation

» 4 Hz
» 200 m/s
» 300+ observations
Verification at higher frequencies

Taborda et al. (SCEC, 2016)
Validation: time series and energy integral

Data

Synthetics

Taborda and Bielak (BSSA, 2013)
Validation: Fourier spectra

Taborda and Bielak (BSSA, 2013)
GOF maps (components of motion)

Taborda and Bielak (BSSA, 2013)
GOF maps (frequency bands)

Taborda and Bielak (BSSA, 2013)
Influence of seismic velocity models

Taborda and Bielak (BSSA, 2014)
Influence of seismic velocity models

Taborda et al. (GJI, 2016)
Influence of seismic velocity models on synthetics

Taborda and Bielak (BSSA, 2014)
Influence of seismic velocity models on validation results

Taborda and Bielak (BSSA, 2014)
Validation in terms of attenuation

Taborda and Bielak (BSSA, 2014)
Validation as a means to evaluate velocity models

» 30 earthquakes
» 4 velocity models
» 1 Hz
» 200 m/s

The caveat…

» Small-to-moderate magnitude events

Taborda et al. (GJI, 2016)
Taborda et al. (GJI, 2016)
Synthesized results from validation

Taborda et al. (GJI, 2016)
All that can be considered and how it matters

» Velocity model
» Minimum Vs
» Numerical resolution
» Attenuation model
» Source model
» Source uncertainty

<table>
<thead>
<tr>
<th>Sim. ID</th>
<th>CVM-S</th>
<th>$V_{S\text{min}}$</th>
<th>Pts. per wavelength</th>
<th>$\alpha$ in $Q_s = \alpha V_s$</th>
<th>$\lambda$ in $\mathcal{Q}(f) = \mathcal{Q}_0 f^\lambda$</th>
<th>Source</th>
<th>Magnitude</th>
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<td>4</td>
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(a) This corresponds to the attenuation model BKT2, which is frequency independent.
(b) This corresponds to the attenuation model BKT3, which can be frequency dependent if $\lambda \neq 0$. Taborda et al. (WCEE, 2017)
Various possible combinations (CVM here)

Taborda et al. (WCEE, 2017)
Various possible combinations (CVM, Attenuation, Source, ...)

Taborda et al. (WCEE, 2017)
(Preliminary) concluding remarks

» Velocity model  Matters a lot – perhaps the most.

» Minimum Vs  Matters provided the resolution of the model and that of the simulation are worth the computational effort.

» Numerical resolution  Matters a lot for verification, but it does not matter that much for validation. (I know this is blasphemy for some — I will explain.)

» Attenuation model  Matters significantly, especially for far field analysis and higher frequencies.

» Source model  Matters more than one would think of. Even for small earthquakes. Even at some distance (low vs high frequencies, near vs far field.)

» Source uncertainty  Can make a significant difference.
Some other aspects of interest

» Workflows for automated work and combination of methods
» Focus on measures that matter most
» Influence of the urban environment
» Nonlinear site-effects
» Topography
Combination of 3 SCEC Software Platforms (BBP, UCVM, High-F) across multiple HPC systems including TITAN at OLCF and other DOE (Mira) and NSF (Blue Waters) systems.
Integrating 1D BBP and 3D Simulations

### Original Workflow
- **Input Parameters**
  - Fault geometry selected stations
- **BBP Simulation**
  - 1D velocity model
  - ~ 50 realizations
- **Validation**
  - Comparison with data

### Modified Workflow
- **Input Parameters**
  - Fault geometry selected stations
- **BBP Simulation**
  - 1D velocity model
  - ~ 50 realizations
- **Validation**
  - Comparison with data
- **Rupture Selection**
  - Identify the source model that led to the best fit
- **Hercules Simulation**
  - 3D velocity model
  - Low frequency $f < 1$ Hz
- **Corresponding BBP Simulation**
  - High frequency $f > 1$ Hz
- **New Validation**
  - Comparison with data

### 1D Models Comparison
- **BBP**
- **BBP + Hercules**

### 3D Improvement
- **1D BBP**
- **BBP + 3D Hercules**

Taborda et al. (SCEC, 2014)
Alternatives to reduce validation post-processing

» C8: Response spectra

» C4: Energy

Khoshnevis and Taborda (BSSA, 2018)
Attempts to understand effects of urban environments

Taborda and Isbiliroglu (USGS, 2018)
Concluding remarks

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- Source uncertainty: Can make a significant difference.
- Nonlinear soil: Matter a lot. Mostly local. But it may impact regional response to an extent we do not fully understand for now.
- Topography: We know it matters but cannot fully characterize it for synthesis at regional scale just yet.
- Site-city interaction: We do not fully understand yet.
## Concluding remarks

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Under optimal conditions…

![Graphs showing velocity, energy, Fourier amplitude, and Sa for different earthquake distances and magnitudes. The graphs compare data and synthetics with labels for each series.](image)

Taborda and Bielak (BSSA, 2013)
Some suggestions

» Inversions: For better velocity models, thus other information.

» Energy losses: Anelasticity and nonlinearities of engineering interest.

» Variability: Anything that increases it matters at higher frequency (e.g., topography).

» Uncertainty: Simulations / workflows that can carry forward information about uncertainty.

» Workflows: In the form of automated simulations that can be repeated systematically.
Thank you

The people behind…

The agencies and programs that made it possible…