SCEC Broadband Platform Simulations for the PEER NGA-East Project

Jeff Bayless
[AECOM]

Christine Goulet
[PEER, UC Berkeley]

Justin Hollenback
[PEER, UC Berkeley]

(I) Background

NGA-East is a multi-disciplinary research project coordinated by the Pacific Earthquake Engineering Research center (PEER). The objective of NGA-East is to develop a new ground motion characterization (GMC) model for the Central and Eastern North-American (CENA) region. Because the NGA-East ground motion database is essentially limited to events less than **M**6, the empirical ground motion model development has been supported with physics-based broadband ground motion simulations. To that effect, a large validation exercise was completed for four methodologies implemented on the Southern California Earthquake Center (SCEC) Broadband Ground Motion Simulation Platform (BBP) (Goulet et al., 2015). Through the validation process, the methodologies were further improved and deemed ready to be used for the development of magnitude scaling relations for ground motions. This poster provides a summary of the simulations performed to develop magnitude scaling relations and extrapolate the PEER model beyond the range of empirical data.

The SCEC BBP is an important resource for researchers and practitioners who wish to use strong ground motion simulations. The BBP allows a user to generate ground motions for earthquake scenarios using a variety of physics-based simulation methods, with components including earthquake rupture description and generation, low- and high-frequency wave propagation, and options for non-linear site effects. We perform simulations with version v14.10 of the BBP, for a set of forward scenarios, in order to assess how the simulations scale with magnitude in Fourier amplitude spectrum (FAS) and pseudo-spectral acceleration (PSA) space; and to assess how the simulations extrapolate to large **M**.

(II) Objectives

- Perform simulations using the SCEC BBP (as updated for the CENA), for scenarios ranging from **M**5.0 to **M**8.0 with recording stations at varying distances.
- Calculate ratios (in FAS and PSA space) for each scenario relative to its **M**5.0 equivalent, in order to assess how the simulations scale with magnitude.
- Develop a **M**-scaling model with frequency- and distance-dependent scaling coefficients.
- Extend the PEER FAS empirical model (in terms of magnitude, distance and frequency coverage) using the scaling relations from the finite fault (FF) simulations.

(1) Introduction

Before simulation methodologies are used for forward simulations (simulating events that have not been observed), they need to be validated. This work builds on a recent large-scale validation exercise completed in 2014. The validation exercise, including the process, methodologies and their evaluation is documented in detail in a series of nine papers (Focus Issue of the Seismological Research Letters journal, Volume 86, Issue 1).

After multiple rounds of validation in 2013 and 2014, four methods were considered (all from Table 1 except for CSM) for use in NGA-East. All four passed the validation criteria to the extent that they could be used for *relative scaling* of ground motions, meaning the methods are deemed adequate for developing magnitude scaling of ground motions, but that it is not recommended to use the absolute values of the ground motions directly. The NGA-East Project further evaluated the methodologies by initiating forward simulations and examining their properties. NGA-East retained EXSIM, GP and SD as methodologies to use in the project.

Table 1. Simulation Methods

Method name	Short-hand identifier(s)	Latest Reference
Composite Source Model	CSM	Anderson [2015]
EXSIM	EXSIM, EX	Atkinson and Assatourians [2015]
Graves and Pitarka	GP	Grave and Pitarka [2015]
San Diego State University	SDSU, SD	Olsen and Takedatsu [2015]
University of California Santa Barbara	UCSB, SB	Crempien and Archuleta [2015]

(2) Setup of Forward Simulations

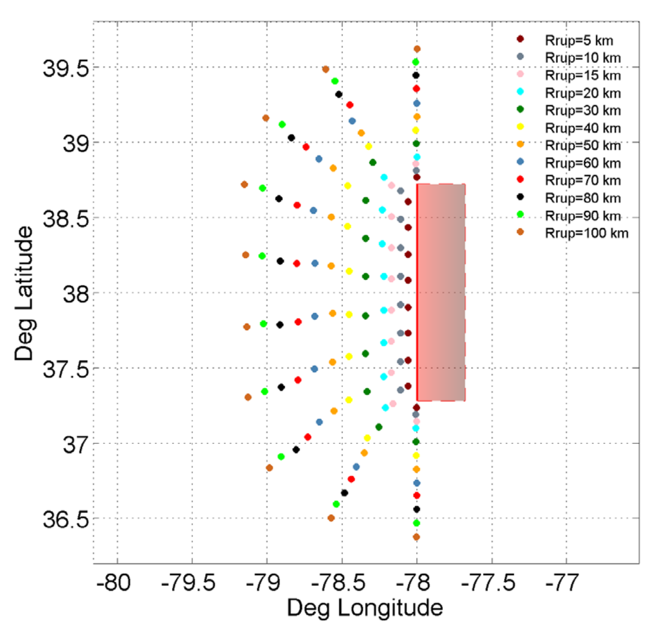
The earthquake scenarios and station layouts were defined to capture the effect of **M**-scaling relative to **M**5.0, for a range of distances.

- Velocity model for all simulations:
  Mineral, Virginia (top velocity = 1 km/s)
- 16 source realizations of each scenario
  Random hypocenter placement (away from fault plane edges)
- Style of Faulting:
  Reverse only (strike = 0°; dip = 45°; average rake = 90°)
- Magnitudes:
  M = 5.0, 5.5, 6.5, 7.5, 8.0
- Depth to top of rupture plane (Z_{tor})
  Z_{tor} = 0, 5, 10 km
- Fault Dimensions (Table 2)
  Determined with the Stable Continent Region (SCR) relations of Leonard (2010).

Table 2.Parameters of Simulation Scenarios

M	Length (km)	Width (km)	Area (km²)	Z_{tor} (km)
5.0	2.5	2.5	6.25	0, 5, 10
5.5	5.0	4.0	20	0, 5, 10
6.5	20	10	200	0, 5, 10
7.5	80	25	2000	0, 5, 10
8.0	160	40	6400	0,5

- For each scenario, stations are located in constant R_{rup} "rings"
  All stations are on the foot wall.
  A total of 10 stations on each ring, equally spaced.
- 12 R_{rup} rings at: 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100 km



Example Fault/Station Layout, **M**8.0, Z_{tor}=0 km case

(3) Results of FF Simulations

- 4 simulation methods (Table 1)
- 14 scenarios (Table 2)
- 16 source realizations of each scenario
- 210 simulation stations per scenario
- 2 horizontal components

≈ 375,000 simulated time series!

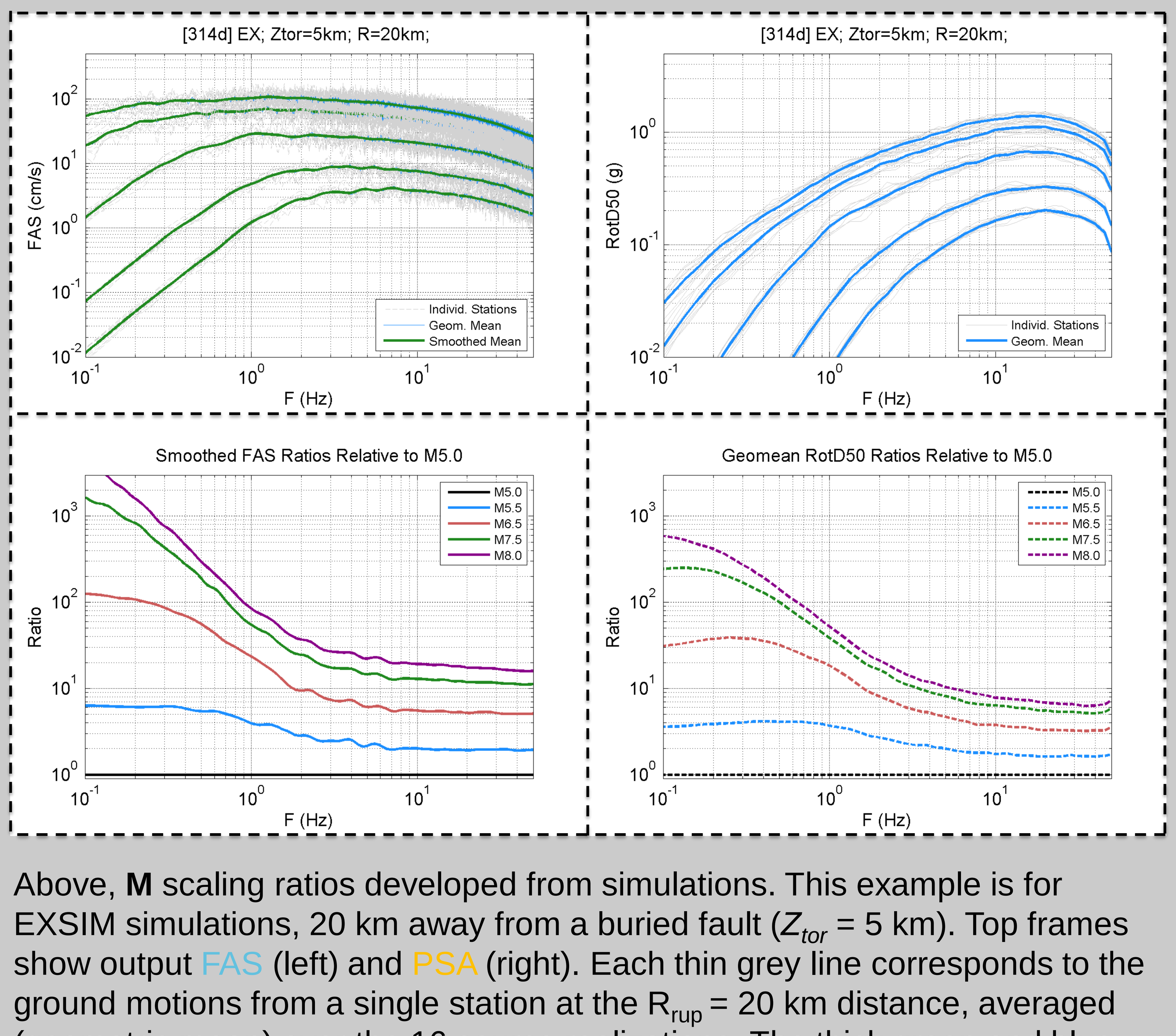
The SCEC BBP produces digital time series and RotD50 response spectra in ASCII format for each simulation.

(4) Processing of Results

The procedure for data processing is summarized in Table 3.

Table 3. Data Processing Steps

Step #	Fourier Amplitude Spectra (FAS)	Pseudo-Spectral Acceleration (PSA)
1	Compute the FAS of each simulated time series using Dave Boore's package TSPP_v4.8.	Start with the RotD50 obtained from each pair of horizontal simulated time series, as computed in the BBP workflow. This is denoted PSA.
2	Average (geometric mean) of FAS at each station over 16 realizations; FASi	Average (geometric mean) of PSA at each station over 16 realizations; PSA_i
3	Average (geometric mean) of FASi at each Rrup band (j); FAS_j Note that there are 12 Rrup distances: 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100 km	Average (geometric mean) of PSA_i at each Rrup band (j); PSA_j
4	Smooth FAS_j using Konno & Ohmachi (1998)	No smoothing is applied.
5	Repeat for Magnitudes 5.0, 5.5, 6.5, 7.5, 8.0	Repeat for Magnitudes 5.0, 5.5, 6.5, 7.5, 8.0
6	Calculate FAS Ratios relative to M 5.0 scenario (Equation 1).	Calculate PSA Ratios relative to M 5.0 scenario
7	Repeat steps 2-6 for each Z_{tor} case (Z_{tor} = 0, 5, 10 km) and simulation method.	Repeat steps 2-6 for each Z_{tor} case (Z_{tor} = 0, 5, 10 km) and simulation method.



Above, **M** scaling ratios developed from simulations. This example is for EXSIM simulations, 20 km away from a buried fault (Z_{tor} = 5 km). Top frames show output FAS (left) and PSA (right). Each thin grey line corresponds to the ground motions from a single station at the R_{rup} = 20 km distance, averaged (geometric mean) over the 16 source realizations. The thick green and blue lines show the smoothed mean ground motions for each **M**5.0, 5.5, 6.5, 7.5 and 8.0 scenarios. Bottom frames show computed ratios for FAS (left) and PSA (right), relative to the **M**5.0 scenario.

(5) M-Scaling Model

Simulation results were provided to NGA-East GMPE developers. One GMPE (PEER model) is based on FAS while the other ones are based on PSA. We focus the discussion on the computations for the PEER FAS-based model (see **Poster #43 by J. Hollenback, N. Kuehn, and C. Goulet** on Wednesday, April 22nd).

The NGA-East PEER GMPE approach consists of the following general steps:

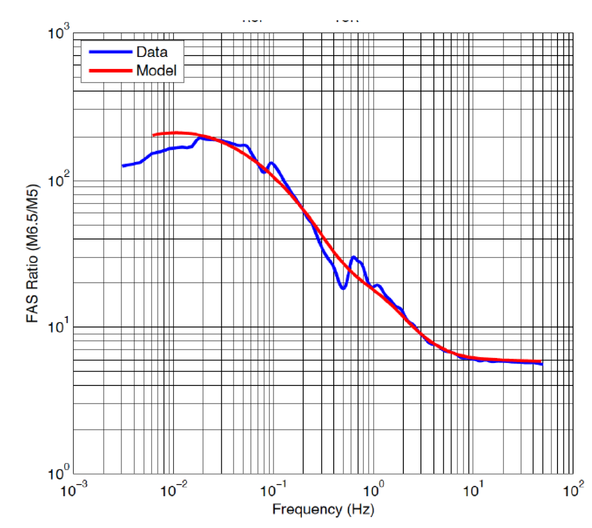
1. Perform an empirical regression on FAS of acceleration in ranges for which the recorded data is reliable,
2. Extend the empirical model (in terms of magnitude, distance and frequency coverage) using a combination of point-source stochastic model and FF simulations,
3. Develop an empirically-calibrated RVT-duration model, and
4. Compute Ground Motion Models for a wide range of magnitude and distances using RVT.

This poster describes the implementation of step (2) above – the extension of the empirical model for large **M** from 0.07 to 10 Hz. By defining the FAS Ratios developed from the simulations as:

$$\alpha\left(f, \mathbf{M}=m, R_{RUP}, Z_{TOR}\right)_{sim} = \frac{FAS\left(f, \mathbf{M}=m, R_{RUP}, Z_{TOR}\right)}{FAS\left(f, \mathbf{M}=5, R_{RUP}, Z_{TOR}\right)} \quad \text{(Eq. 1)}$$

A predictive model was developed for these ratios (independently for both FAS and PSA) using the form:

$$\ln(\alpha) = a_0 + a_1(\mathbf{M}-\mathbf{5}) + a_2(\mathbf{M}-\mathbf{5})^2 + a_3\ln(R_{RUP}) + a_4\mathbf{M} * \ln(R_{RUP}) + a_5 Z_{TOR} \quad \text{(Eq. 2)}$$

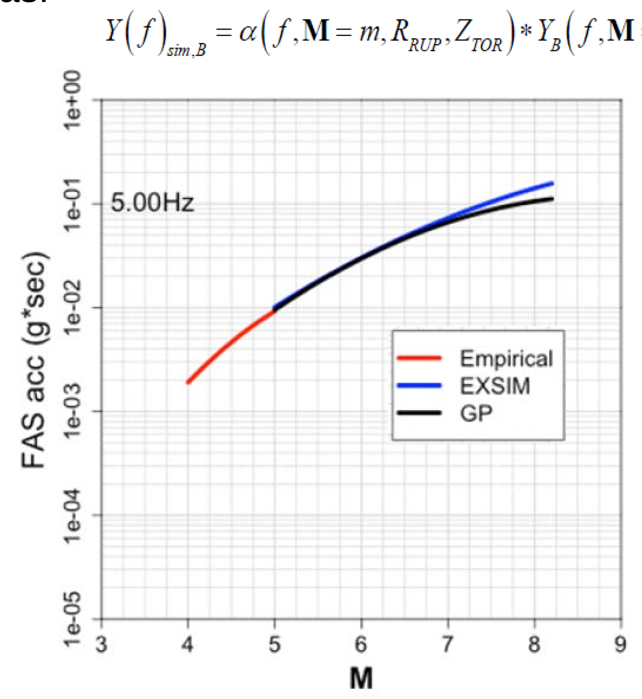


M-scaling ratios from simulations (blue line) compared with the predictive model of the ratios.

This example is for GP simulations, R_{rup} = 80 km, **M**6.5, Z_{tor} = 5 km.

The coefficients of Equation 2 were shared with the NGA-East GMPE modelers. For the PEER model, the median prediction of FAS at frequency *f* extrapolated to **M**>5 for a given simulation method is defined as:

$$Y\left(f\right)_{sim\_B} = \alpha\left(f, \mathbf{M}=m, R_{RUP}, Z_{TOR}\right) * Y_B\left(f, \mathbf{M}=5, Z_{HYP}, R_{RUP}, V_{S30}\right) \quad \text{(Eq. 3)}$$



Empirical magnitude scaling model (red), extrapolated to large magnitude, with the simulation based extrapolations (blue and black) using Equation 3.

This example is for R_{rup} = 10 km, at *f* = 5.0 Hz.

Additionally, the PEER empirical model for FAS was extended from 0.6 to 0.01 Hz, and from 10 to 400 Hz using seismological theory, and corrected to reference site conditions (see Poster #43). Two alternative ground motion models were developed, each reflecting epistemic differences in magnitude scaling from independent FF simulation methodologies EXSIM and GP. A description of the complete PEER NGA-East median ground motion model for CENA can be found on the PEER website (Report PEER 2015/04).

(6) Acknowledgements

We would like to thank the SCEC IT team – specifically Fabio Silva and Phil Maechling. Also thanks to the entire BBP Validation team for ongoing collaboration, including Rob Graves, Kim Olsen, Ralph Archuleta and Karen Assatourians.