Overview of Candidate Media GMMs and Discussion of Model Evaluation

Robert Graves
for the TI Team

http://peer.berkeley.edu/ngaeast/

General Background

- Evaluation framework for assessing candidate models to include in the construction of final Ground Motion Models (GMMs)
- Total of 30 models evaluated for consideration (EPRI + NGA-East)
- Ultimately, 19 GMMs utilized for model development
- *Note: Exclusion of a model (or portion of a model) in the current phase should not be taken to mean the model/approach is not valid*

2

General Background (cont.)

- All NGA-East candidate GMMs are published in the PEER report regardless of whether or not they are included in the final model development
- Results presented here represent TI-Team decisions based on many analyses and discussions
- For model evaluation purposes-
  - Median ground motion levels
  - "CENA-consistent" geometric spreading and Q
  - Site condition: Vs=3000 m/s
  - Kappa = 0.006 s

Primary Screening Criteria (TI-Team)

Do not include GMMs/GMPEs that:

- have been superseded by newer models (as per modelers)
- are more than 10 years old, unless lead developer(s) can provide a compelling reason for their inclusion as candidate models
- can't cover or be reasonably extrapolated to the **M**4-8.2, R0-1200 km ranges
- can't cover or be reasonably interpolated to cover the required range of frequencies (0.1 to 100 Hz plus PGA)
- are not based on applicable data or for which the data is too uncertain to be diagnostic
- have **M**, R and/or freq. scaling that appears unphysical or is inconsistent with the applicable data

Legacy Median Candidate GMPEs

- EPRI Review Project (10 individual models)

Cluster	Model Type	Models
1	Single Corner Brune Source	Silva et al (2002) - SC-CS-Sat* Silva et al (2002) - SC-VS* Toro et al (1997) Frankel et al (1996) * Treated as one model for calculation of weights
2	Complex/Empirical Source $\sim R^{-1}$ Geometrical spreading < 70 km	Silva et al (2002) DC – Sat A08'
3	Complex/Empirical Source $\sim R^{-1.3}$ Geometrical spreading < 70 km	AB06' PZT11
4	Finite Source /Green's Function	Somerville et al. (2001); slightly different models for rifted and non-rifted

5

Legacy Median Candidate GMPEs

EPRI Review Project GMMs

Model	Name and year	Included	Comments
A08p	Atkinson (2008, 2011)	No	Superseded
AB06p	Atkinson and Boore (2006, 2011)	No	Superseded
FEL	Frankel (1996)	No	Superseded
PZT	Pezeshk, Zandieh and Tavakoli (2011)	No	Superseded
SDCS	Silva et al. (2003), double corner	No	Superseded
SEL01NR	Somerville et al (2001), non-rift	No	Expired, poor fit below M5, limited period range
SEL01R	Somerville et al (2001), rift	No	Expired, poor fit below M5, limited period range
SSCCSS	Silva et al. (2003), single corner constant stress	No	Superseded
SSCVS	Silva et al. (2003), single corner variable stress	No	Superseded
TEL	Toro et al. (1997), middle continent	No	Superseded

- Will perform comparison checks with final GMMs

6

“NGA-East” Candidate Models

Approach	Constraints	Extrapolation	Title (Authorship), chapter number in PEER [2015]	Short name(s)
Point-Source (PS) Stochastic (FAS-based)	PS model, published GS & Q models, NGA-East database	PS model	2. Point-Source Stochastic-Method Simulations of Ground Motions for the PEER NGA-East Project (D.M. Boore)	B_a04 B_ab14 B_ab95 B_bca10d B_bs11 B_sgd02
	PS model, broadband inversion of NGA-East database	PS model	3. Development of Hard Rock Ground-Motion Models for Region 2 of Central and Eastern North America (R.B. Darragh, N.A. Abrahamson, W.J. Silva, and N. Gregor)	1CCSP 1CVSP 2CCSP 2CVSP
PS Referenced Empirical	PS model used to develop generic WUS GMM, hybrid empirical adjustment	Generic GMM adjusted to CENA data	4. Regionally-Adjustable Generic Ground-Motion Prediction Equation based on Equivalent Point-Source Simulations: Application to Central and Eastern North America (E. Yenier and G.M. Atkinson)	YA15
Hybrid Empirical (FAS- and PSA-based)	Published sets of CENA and WUS PS models	WUS host region	5. Ground-Motion Prediction Equations for Eastern North America using a Hybrid Empirical Method (S. Pezeshk, A. Zandieh, K.W. Campbell, and B. Tavakoli)	PZCT15_M1SS PZCT15_M2ES
Finite-Fault Simulations (PSA-based)	FF model, NGA-East database	FF model	6. Ground-Motion Predictions for Eastern North American Earthquakes Using Hybrid Broadband Seismograms from Finite-Fault Simulations with Constant Stress-Drop Scaling (A. Frankel)	Frankel
			7. Hybrid Empirical Ground-Motion Model for Central and Eastern North America using Hybrid Broadband Simulations and NGA-West2 GMPEs (A. Shahjouei and S. Pezeshk)	SP15
Traditional Empirical (PSA-based)	NGA-East database	Intensity	8. Empirical Ground-Motion Prediction Equations for Eastern North America (M.N. Al Noman and C.H. Cramer)	ANC15
		Imposed spectral shape	9. Ground-Motion Prediction Equations for the Central and Eastern United States (V. Graizer)	Graizer
Referenced Empirical (PSA-based)	NGA-East database	GMM host region (WUS)	10. Referenced Empirical Ground-Motion Model for Eastern North America (B. Hassani and G.M. Atkinson)	HA15
FAS-RVT-PSA Empirical	NGA-East database	PS and FF models for scaling, global GMs for extrapolation of duration model	11. PEER NGA-East Median Ground-Motion Models (J. Hollenback, N. Kuehn, C.A. Goulet and N.A. Abrahamson)	PEER_GP PEER_EX

7 PEER

NGA-East SMSIM Model Suite

- SMSIM: consistent underlying approach for PS stochastic simulations
- Generate (6) ground motion tables using SMSIM with different models for geometric spreading (GS) and Q

Model	GS and Q Model
B_a04	Based on GS/Q from Atkinson 2004
B_a95	Based on GS/Q from Atkinson 1995
B_ab14	Based on GS/Q from Atkinson and Boore 2014
B_bca10d	Based on GS/Q from Boore, Campbell and Atkinson 2010, model d
B_bs11	Based on GS/Q from Boatwright and Seekins (2011)
B_sgd02	Based on GS/Q from Silva, Gregor and Darragh (2002)

8 PEER

NGA-East SMSIM Suite GS & Q Models

Model and Reference	Geometric Spreading G(R)	What is "R"?[1]	Attenuation exp(-p*f*R/Qb)	Applicable Range[2]
B_ab95 Atkinson and Boore [1995]	$G(R) = \begin{cases} R^{-1}, & R \le 70\text{ km} \\ C_0 R^{0}, & 70\text{ km} < R \le 130\text{ km} \\ C_1 R^{-0.5}, & R > 130\text{ km} \end{cases}$ $C_0 = (1/70)$, $C_1 = (130^{0.5}/70)$	$R = R_{hyp}$	$Q(f) = 680f^{0.36}$ $b = 3.8$ km/s	$4.0 \le \mathbf{M} \le 7.25$ $10 \le R \le 500$ km $0.5 \le f \le 20$ Hz
B_sgd02 Silva et al. [2002]	$G(R) = \begin{cases} R^{-(a+b(\mathbf{M}-6.5))}, & R \le 80\text{ km} \\ C_0 R^{-0.5(a+b(\mathbf{M}-6.5))}, & R > 80\text{ km} \end{cases}$ $a = 1.0296$, $b = -0.0422$, $C_0 = 80^{-0.5(a+b(\mathbf{M}-6.5))}$	$R = R_{hyp}$	$Q(f) = 351f^{0.84}$ $b = 3.52$ km/s	$4.5 \le \mathbf{M} \le 8.5$ $1 \le R \le 400$ km $0.1 \le f \le 100$ Hz
B_a04 Atkinson [2004]	$G(R) = \begin{cases} R^{-1.3}, & R \le 70\text{ km} \\ C_0 R^{0.2}, & 70\text{ km} < R \le 140\text{ km} \\ C_1 R^{-0.5}, & R > 140\text{ km} \end{cases}$ $C_0 = (70^{-0.2}/70^{1.3})$, $C_1 = C_0(140^{0.5}/140^{-0.2})$	$R = R_{hyp}$	$Q(f) = \max(1000, 893f^{0.32})$ $b = 3.7$ km/s	$4.4 \le \mathbf{M} \le 6.8$ $10 \le R \le 800$ km $0.05 \le f \le 20$ Hz
B_bca10d Boore et al. [2010]	$G(R) = R^{-1}$ all R	$R = R_{PS}$	$Q(f) = 2850$ $b = 3.7$ km/s	$4.4 \le \mathbf{M} \le 6.8$ $10 \le R \le 800$ km $0.05 \le f \le 20$ Hz
B_bs11 Boatwright and Seekins [2011]	$G(R) = \begin{cases} R^{-1}, & R \le 50\text{ km} \\ C_0 R^{-0.5}, & R > 50\text{ km} \end{cases}$ $C_0 = (50^{0.5}/50)$	$R = R_{hyp}$	$Q(f) = 410f^{0.5}$ $b = 3.5$ km/s	$4.4 \le \mathbf{M} \le 5.0$ $23 \le R \le 602$ km $0.2 \le f \le 20$ Hz
B_ab14 Atkinson and Boore [2014]	$G(R) = \begin{cases} 10^{T_c C_{LF}} R^{-1.3}, & R \le 50\text{ km} \\ C_0 R^{-0.5}, & R > 50\text{ km} \end{cases}$ $T_c = \begin{cases} 1, & f \le 1Hz \\ 1 - 1.429\log_{10}(f), & 1\text{Hz} < f < 5Hz \\ 0, & f \ge 5Hz \end{cases}$ $C_{LF} = \begin{cases} 0.2\cos\left[\frac{\pi}{2}\left(\frac{R-h}{1-h}\right)\right], & R \le h \\ 0.2\cos\left[\frac{\pi}{2}\left(\frac{R-h}{50-h}\right)\right], & h < R < 50\text{ km} \end{cases}$ h = focal depth (km), $C_0 = (50^{0.5}/50^{1.3})$	$R = R_{PS}$	$Q(f) = 525f^{0.45}$ $b = 3.7$ km/s	$3.5 \le \mathbf{M} \le 6$ $10 \le R \le 500$ km $0.2 \le f \le 20$ Hz

[1] R_{hyp} = hypocentral distance; R_{PS} = effective point source distance
$R_{PS} = [R_{hyp}^2 + h_{FF}^2]^{1/2}$, $\log_{10}(h_{FF}) = -0.405 + 0.235\mathbf{M}$ (Yenier and Atkinson, 2015)
[2] When applicable range not explicitly stated in paper it was inferred from data comparisons.

9

Screening Process

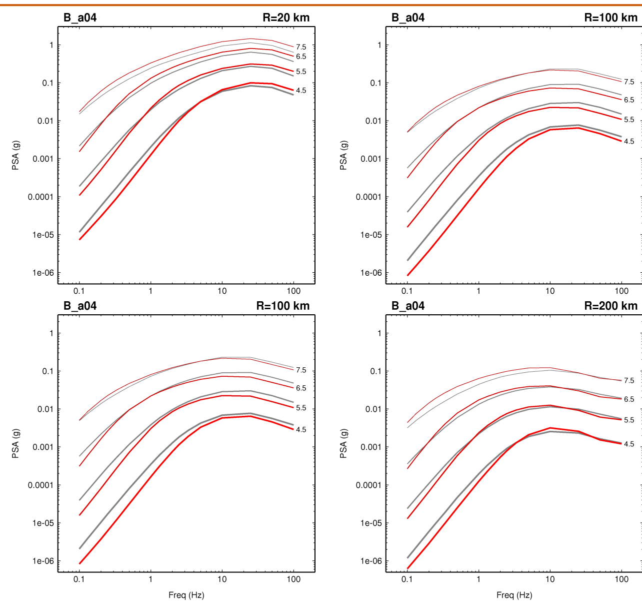
- Compute and tabulate model predictions for
  - **M**4.5, 5.5, 6.5, 7.5
  - R=20 km, 50 km, 100 km, 200 km
  - 0.1 Hz ≤ f ≤ 100 Hz
- At a minimum, models need to exhibit appropriate behavior across this subset of key magnitudes and distances.
- Higher level of importance was given to the spectral shape than to the absolute level of the response.
- Features seen in the spectra need to behave in a physically consistent and defendable manner => ***different*** does not automatically mean ***inappropriate***
- Throughout the model building process, behavior of seed GMMs was continually checked to ensure results are appropriate, understandable, and defendable.

10

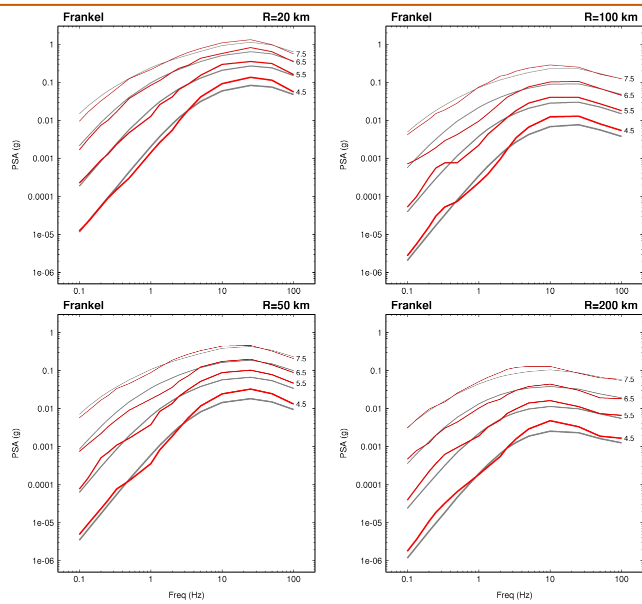
Comparison Plots

- Compare 5% damped PSA for each individual GMM (red curves in following) to that determined by averaging over the 20 candidate models (grey curves in following)
- ***Note:*** *The average curves have no special meaning in and of themselves. They are simply included to provide a smooth, common reference for which to compare each of the individual GMMs.*
- Identify systematic features (i.e. across range of **M** and R) and evaluate appropriateness of the GMM as a function of frequency
- Some examples …

B_a04

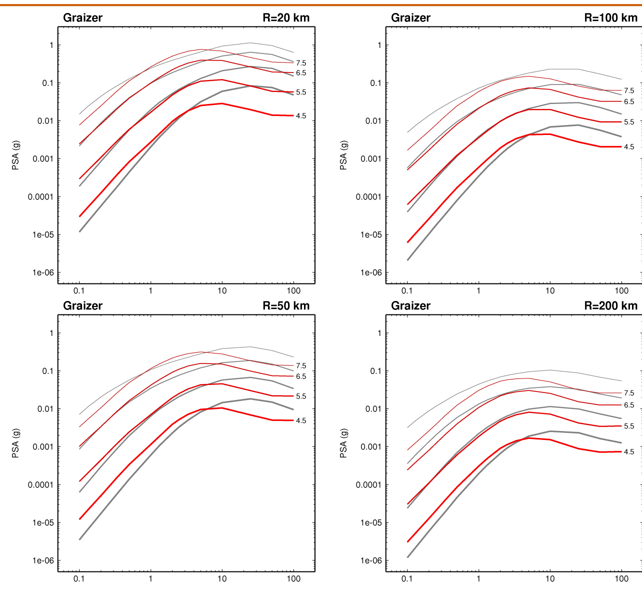


Frankel



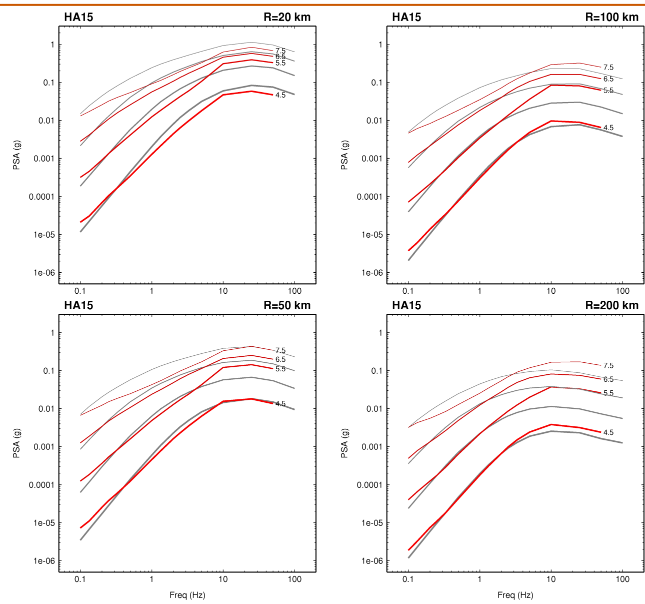
13

Graizer



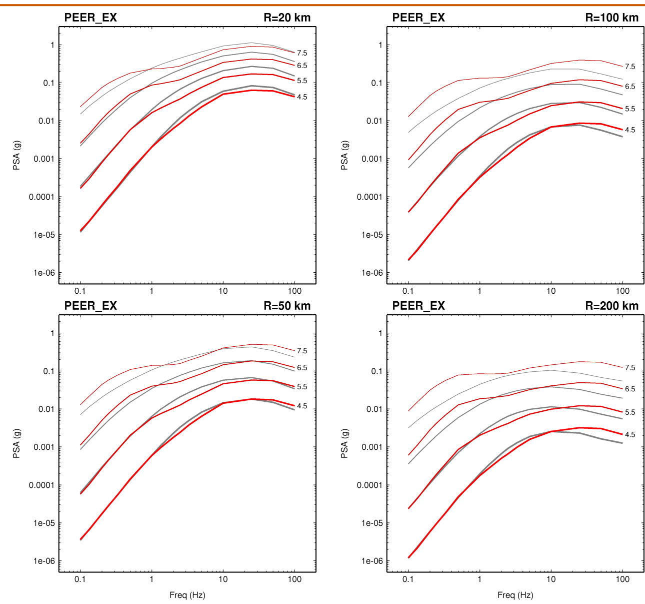
14

HA15



HA15
R=20 km
HA15
R=100 km
HA15
R=50 km
HA15
R=200 km
PSA (g)
Freq (Hz)
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
0.1
1
10
100
7.5
6.5
5.5
4.5

PEER_EX



PEER_EX
R=20 km
PEER_EX
R=100 km
PEER_EX
R=50 km
PEER_EX
R=200 km
PSA (g)
Freq (Hz)
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
0.1
1
10
100
7.5
6.5
5.5
4.5

NGA-East (2015) GMMs Summary

Model	Comments
B_a04	Use as is.
B_a95	Use as is.
B_ab14	Use as is.
B_bca10d	Use as is.
B_bs11	Use as is.
B_sgd02	Use as is.
DASG 1CCSP	Possible bias of low-frequency (f < 1Hz) spectra particularly for larger magnitudes (**M**>6), similar to that seen for WUS SC models. Developers recommend only using f > 1 Hz.
DASG 1CVSP	Possible bias of low-frequency (f < 1Hz) spectra particularly for larger magnitudes (**M**>6), similar to that seen for WUS SC models. Developers recommend only using f > 1 Hz.
DASG 2CVSP	Use as is.
DASG 2CCSP	Use as is.
YA15	Relative drop in response around 50 Hz (not considered an issue by TI-Team). Use as is.
PZCT15_M1SS	Use as is.
PZCT15_M2ES	Use as is.
Frankel	Rough spectral shape due to limited simulations (not considered an issue by TI-Team). Use as is.
SP15	Use as is.
ANC15	Possible bias in magnitude scaling at low-frequencies due to use of intensity data. Fixed h term doesn't extrapolate well with magnitude. Developers recommend not including this model as a seed model.
Graizer	Spectral peak occurs around 3-5 Hz for all magnitudes and distances, much lower than expected for CENA site conditions of Vs=3000 m/s and kappa=0.006 s. Recommend using only 0.2 < f < 5 Hz.
HA15	Magnitude scaling exhibits features inherent to the reference model (BSSA14), cannot be ruled out for CENA with present set of observations. Use as is.
PEER_EX	Magnitude scaling at low-frequency suggests possible bias. Developers recommend only using f > 2 Hz.
PEER_GP	Use as is.

Summary

- Initially considered 30 GMMs as candidates for developing final models
- Established criteria for omitting models:
  - superseded by newer models (as per modelers)
  - more than 10 years old, unless lead developer(s) can provide a compelling reason for their inclusion as candidate models
  - have **M**, R and/or freq. scaling that isn't reasonable
  - can't cover or be reasonably extrapolated to the **M**4-8.2, R0-1200 km ranges
  - can't cover or be reasonably interpolated to cover the range of frequencies (0.1 to 100 Hz plus PGA)
  - not based on applicable data or for which the data is too uncertain to be diagnostic

Summary (cont.)

- EPRI Review Project models (10) not included as most are superseded; will back-check against final models
- Data residuals not used as strict criterion for model selection given **M**, R and f limitations and uncertainties in site response characterization
- However, residuals were used as consistency check (Workshop 3B presentation)
- Based on TI-Team evaluations, 19 of 20 NGA-East GMMs included as seed models in development process
- Most models used "as is", four models used only for limited frequency ranges (all **M** and R)