An Updated Central and Eastern United States Ground-Motion Model

Lawrence Salomone
Pinnacle Specialty Group, Inc.

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Project Description

**Project Goals:**
- Review and, if necessary, update the EPRI (2004, 2006) Ground-Motion Model (GMM)
- Obtain Participatory Peer Review Panel (PPRP) and Nuclear Regulatory Commission (NRC) acceptance of the Updated Ground-Motion Model (GMM)

**Approach**
- Use enhanced SSHAC Level 2 assessment process with PPRP review of technical process and findings and NRC review of the SSHAC Level 2 Report

**Schedule**
- SSHAC Level 2 Study - March 8, 2012 to May 31, 2013 (15 months)
- NRC Review - June 3, 2013 to August 30, 2013 (3 months)
- Total Duration – March 8, 2012 to August 30, 2013 (18 months)
Questions Addressed by Project

• Is the EPRI (2004, 2006) Ground – Motion Model (GMM) based on data, models and methods compiled and evaluated from 2002 to 2004 consistent with current (2012) data, models and methods?

• Should the EPRI (2004, 2006) GMM be updated before using it to calculate GMRS at existing nuclear power plants in response to the NRC RFI 50.54(f) letter dated March 12, 2012?

• Does the preponderance of evidence obtained from Phase 1 require that Phase 2 be completed to assess the seismic hazard differences obtained when using the old and updated EPRI (2004, 2006) GMM?
# EPRI (2004) Ground-Motion Model Grouped By Cluster

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Model Type</th>
<th>Models$^1$</th>
</tr>
</thead>
</table>
| 1       | Single-Corner Stochastic      | Hwang and Huo (1997)  
Silva et al. (2002) – SC-CS  
Silva et al. (2002) – SC-CS-Sat  
Silva et al. (2002) – SC-VS  
Toro et al. (1997)  
Frankel et al. (1996) |
| 2       | Double-Corner Stochastic      | Atkinson and Boore (1995)  
Silva et al. (2002) DC  
Silva et al. (2002) – DC-Sat |
| 3       | Hybrid                        | Abrahamson and Silva (2002)  
Atkinson (2001) and Sadigh et al. (1997)  
Campbell (2003) |
| 4       | Finite-Source /Green’s Function | Somerville et al. (2001) |

$^1$ SC = single-corner; DC = double-corner; CS = constant stress; VS = variable stress; Sat = saturation.
EPRI (2004) Regionalization
Basis for Updating EPRI (2004, 2006) GMM

- Ground motion experts, who developed seven (7) of the thirteen (13) ground motion prediction equations (GMPEs) used in the EPRI (2004, 2006) GMM, recommended that their GMPEs be replaced with newer models developed during the last ten (10) years.

- There are three new GMPEs developed by ground motion experts during the past ten (10) years which should be evaluated and possibly integrated into an update of the EPRI (2004, 2006) GMM.

- A new ground motion database for the Central and Eastern North America (CENA) is now available with nearly 28,000 earthquake recordings. Eighty percent (80%) of the earthquake records are from earthquakes that occurred after the development of the EPRI (2004, 2006) GMM in 2004.

- Comparisons to the database indicate that the EPRI (2004, 2006) GMM overpredicts ground motions at some magnitude-distance-frequency ranges that are important in PSHAs for nuclear power plants.
# Updated EPRI (2004, 2006) Clusters and Models

## Updated EPRI (2004, 2006) GMM Clusters and Models

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Model Types and Cluster Weights (repeated large-magnitude earthquake sources/area earthquake sources)</th>
<th>Models</th>
</tr>
</thead>
</table>
| 1       | Single-Corner Brune Source (0.15/0.185)                                                        | Silva et al. (2002) – SC-CS-Sat<sup>1</sup>  
Toro et al. (1997)  
Frankel et al. (1996) |        |
| 2       | Complex/Empirical Source ~R<sup>-1</sup> Geometrical spreading (0.31/0.383)                     | Silva et al. (2002) – DC-Sat  
Atkinson (2008) with 2011 modifications (A08<sup>1</sup>) |        |
| 3       | Complex/Empirical Source ~R<sup>-1.3</sup> Geometrical spreading (0.35/0.432)                  | Atkinson-Boore (2006) with 2011 modifications (AB06<sup>1</sup>)  
Pezeshk et al. (2011) |        |
| 4       | Finite-Source /Green’s Function (0.19/0)                                                     | Somerville et al. (2001); slightly different models for rifted and nonrifted (not used for distributed seismicity sources with large contribution from M < 6) |        |

SC = single-corner; DC = double-corner; CS = constant stress; VS = variable stress; Sat = saturation.

<sup>1</sup> Treated as one model for calculation of weights.
Study Area and Test Sites
Seismotectonic Zones Developed in CEUS SSC Study
Comparison of Aleatory Variability Model Developed by Atkinson et al. (2012) with the model developed from this study.
Stability of Aleatory Variability Models

- The aleatory variability models used in EPRI (2006) and in the update are based on statistical estimates. As such, they are subject to fluctuation as data sets change and associated models evolve.

- Differences between preliminary and final aleatory estimates from NGA-West 2 are generally smaller than differences between preliminary and final aleatory estimates from NGA-West 1.

- Assessments based on preliminary NGA-West 2 estimates represent appropriate levels of aleatory variability:
  - Differences between preliminary and final aleatory estimates from NGA-West 2 are within statistical uncertainty in estimates.
  - The assessments are based on total observed aleatory variability; they are conservative when used in a ground motion estimation framework that incorporates additional site response uncertainty and variability.

- Single-station sigma concept, in which the component of site-specific variability in site response is removed from aleatory variability, may prove to be a more stable approach for developing aleatory variability models for PSHA.
Rationale for Gulf Region Florida Boundary in Updated EPRI GMM

- Updated EPRI GMM based on structural framework of EPRI (2004, 2006) GMM
  - Mid-Continent Region
  - Gulf Region
- EPRI (2004) regionalization did not provide basis for Florida Gulf Region boundary
- There are two possible mechanisms for the observed low amplitudes of Lg in the Gulf region:
  - Lg phase blockage due to thinning/disruption of the crustal waveguide. It has been shown that structural boundaries that involve thinning of the crustal waveguide are particularly disruptive of Lg.
  - Anelastic attenuation caused by thick, low-velocity, low-Q sediments.
- The Gulf region defined in the CEUS SSC 2012 study delineates the region of the southern United States that has experienced crustal extension and thinning. This region closely corresponds to the northern and eastern margins of the Gulf of Mexico structural basin, which underwent extensional tectonics in the Mesozoic.
GMRS at Chattanooga Test Site

Spectral frequency, Hz

Spectral acceleration, g

27% Peak Reduction at 25 HZ

Chattanooga Orig.

Chattanooga Update
GMRS at Savannah Test Site

14% Peak Reduction at 25 Hz

Spectral acceleration, g

Spectral frequency, Hz

Savannah Orig.

Savannah Update
GMRS at Manchester Test Site

21% Peak Reduction at 25 HZ
GMRS at Central Illinois Test Site

26% Peak Reduction at 25 HZ
GMRS at Topeka Test Site

- Spectral frequency, Hz
- Spectral acceleration, g

26% Peak Reduction at 25 Hz
GMRS at Jackson Test Site

33% Peak Reduction at 25 HZ
GMRS at Houston Test Site

18% Peak Reduction at 25 Hz
Comparison of Ground-Motion Response Spectra

GMRS at 7 Test Sites

Spectral acceleration, g

Spectral frequency, Hz

Chattanooga Orig.
Chattanooga Update
Savannah Orig.
Savannah Update
Manchester Orig.
Manchester Update
Central Illinois Orig.
Central Illinois Update
Topeka Orig.
Topeka Update
Jackson Orig.
Jackson Update
Houston Orig.
Houston Update
Concluding Remarks

• An updated EPRI GMM has been developed to calculate ground motion response spectra (GMRS) at sites of existing nuclear power plant sites

• The Updated EPRI (2004, 2006) GMM was developed using the same structural framework as EPRI (2004) but using current ground-motion prediction equations (GMPEs) and considering a new NGA-East ground-motion database, 80% of which was obtained after EPRI (2004)

• The center, body and range (CBR) of views of the larger technical community have been captured and represented in the Updated EPRI GMM

• There is an important decrease in ground motion at rock at all frequencies except peak ground acceleration (PGA) for the test sites in the Midcontinent Region and Gulf Region when the Updated EPRI GMM (2013) is used with the CEUS SSC Model (2012)

• PPRP (4/5/13) and NRC (8/30/13) of the Updated EPRI GMM have been obtained

• The value of the updated GMM has been enhanced through the participation of recognized seismologists and ground motion experts from industry, government and academia and productive cooperation from the Pacific Earthquake Engineering Research Center (PEER), members of the NGA-East Project and the United States Geological Survey (USGS)

• NGA-East Project PPRP requested that the NGA-East GMM results be compared to the EPRI (2004, 2006) GMM and the EPRI (2013) GMM results using the CEUS SSC source model in its report for the July 14-16, 2014 Workshop.