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Authors

Ramos-Sepulveda, Maria E
Parker, Grace A
Li, Meibei
et al.

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Performance of NGA-East GMMs and Site Amplification Models Relative to CENA Ground Motions

M.E. Ramos-Sepulveda[1], G.A. Parker[2], M. Li[3], O. Ilhan[4], Y.M.A. Hashash[5], E.M. Rathje[6], J.P. Stewart[7]

ABSTRACT

We investigate bias in ground motions predicted for Central and Eastern North America (CENA) using ground motion models (GMMs) combined with site amplification models developed in the NGA-East project. Bias is anticipated because of de-coupled procedures used in the development of the GMMs and site amplification models. The NGA-East GMMs were mainly calibrated by adjusting CENA data to a reference site condition using a site amplification model appropriate for active tectonic regions. Hence, these GMMs are likely biased relative to the CENA reference site condition (3000 m/sec shear wave velocity). Moreover, the NGA-East site amplification model recommended for hazard applications contains a simulation-based term for amplification between the reference condition and time-averaged shear wave velocity V_{S30}=760 m/sec, which is uncertain and has not been calibrated against data from sites with that reference condition. Using the NGA-East dataset, we apply mixed-effects residual analysis and identify that period-dependent bias in 5% damped response spectral acceleration is present across a wide frequency range, but is strongest (i.e., overestimating by a factor of 2) at short oscillator periods <0.2 sec. Ongoing work to remedy this bias consists of expanding the NGA-East dataset with more recent recordings and enhanced metadata, particularly regarding site conditions.

Introduction

In the 2018 U.S. Geological Survey (USGS) National Seismic Hazard Maps [1], ground motions for Central and Eastern North America (CENA) are modeled using ground motion models (GMMs) and site amplification models developed as a part of the NGA-East Project [2–4]. These models were developed by different teams of investigators and under different organizational frameworks, where 17 of them are adjusted seed GMMs developed by independent modelers [5] and, the remining 17 are updated NGA-East for USGS GMMs developed by an integrator team [6].

The updated NGA-East for USGS GMMs [2,3] describe magnitude- and distance-dependent median ground motions, aleatory variability, and epistemic uncertainty of response spectral ordinates for periods between 0.01-10 sec. These models apply for a reference site condition of V_S = 3000 m/sec and site decay parameter (κ_0) of 0.006 sec [7]. The model development was conducted as a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 project

[1] Graduate Student, Dept. Civil & Env. Engin., Univ. California, Los Angeles, CA 90095 (email: mariaramos1@g.ucla.edu)
[2] U.S. Geological Survey, Mendenhall Fellow, Moffett Field, CA 94035
[3] Graduate Student, Dept. Civil, Architectural, & Environ. Engin., Univ. Texas, Austin, TX 78712
[4] Instructor Dr., Ankara Yildirim Beyazit University, Turkey
[5] William J. and Elaine F. Hall Endowed Prof., Dept. Civil & Environ. Engin., Univ Illinois, Urbana-Champaign, IL 61801
[6] Janet S. Cockrell Centennial Prof., Dept. Civil, Environ., & Architectural Engin., Univ. Texas, Austin, TX 78712
[7] Prof., Dept. Civil & Environ. Engin., Univ. California, Los Angeles, CA 90095

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[8,9], which is a formal process involving extensive review.

Because of the hard-rock reference site condition of V_S =3000 m/sec adopted for NGA-East, adjustments were required of recorded ground motions, all of which are from sites with softer-than-reference site conditions (V_{S30} ~150 to 2000 m/sec). Since site-adjusted ground motions were required before model development could begin, the adjustments occurred relatively early in the project. In most cases, these adjustments were made using V_{S30}-based site amplification models for active tectonic regions [Ref 10 or similar]. The adjusted ground motions were used in GMM development as a constraint on scaling relations (with distance and magnitude), but also to set constant terms in the models. The GMM developers realized that the V_{S30}-scaling models could be in error. They performed mixed effects and Bayesian regression techniques in which residuals were analyzed, but without the development of updated V_{S30}-scaling relations for CENA. Ultimately, the use of active region models was necessary given project timing; they were considered to be the best available site amplification models at that time.

This paper addresses potential bias when the resultant NGA-East GMMs are applied in combination with the NGA-East site amplification model. We investigate whether bias exists using a mixed-effects residual analysis with NGA-East data for 5% damped response spectral acceleration. We also describe ongoing research to further examine the bias using an expanded database, and to propose potential solutions.

NGA-East Model Components

The independently developed site amplification model for CENA that was developed for the USGS maps and similar applications [4,11] drew heavily upon research products from the NGA-East Geotechnical Working Group (GWG) [12–14]. The GWG site amplification model development was subject to extensive expert input and review but occurred outside of the SSHAC process.

The GWG site amplification models are intended to represent site amplification relative to V_S = 3000 m/sec, not amplification relative to the NGA-East GMMs. The model has linear and nonlinear components:

$$F_S = F_{lin} + F_{nl} \tag{1}$$

The linear component of the model has two components:

$$F_{lin} = F_V + F_{760} \tag{2}$$

where F_V describes the scaling of ground motion with V_{S30} relative to V_{S30}=760 m/sec and F_{760} describes the amplification of ground motions for 760 m/sec sites relative to 3000 m/sec sites. Two components are used because they were derived using different procedures. F_V is empirically constrained from NGA-East data [12], while F_{760} is derived from ground response simulations. This two-tier approach was required because it was not possible to empirically derive site amplification relative to 3000 m/sec conditions.

Figure 1 shows the F_{760} models for *impedance* and *gradient* conditions, reflecting different geologic conditions in CENA for sites with V_{S30}~760 m/sec. The models have large uncertainties at short periods (< 0.2 sec), which are mainly related to parametric uncertainty in κ_0. The models in Figure 1 cannot be readily calibrated, because there is no NGA-East data at the 3000 m/sec site condition.

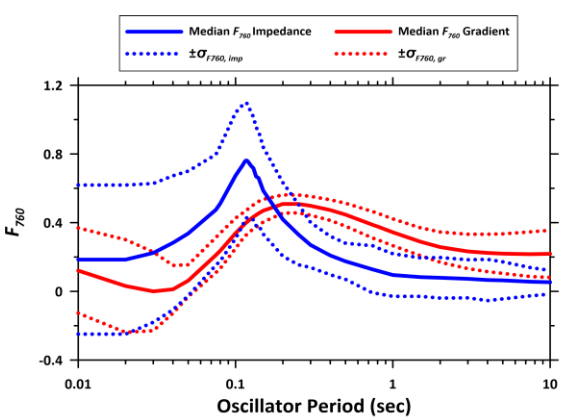

Figure 1. Period-dependent amplification at sites with V_{S30} = 760 m/sec (impedance, gradient profiles) [4]

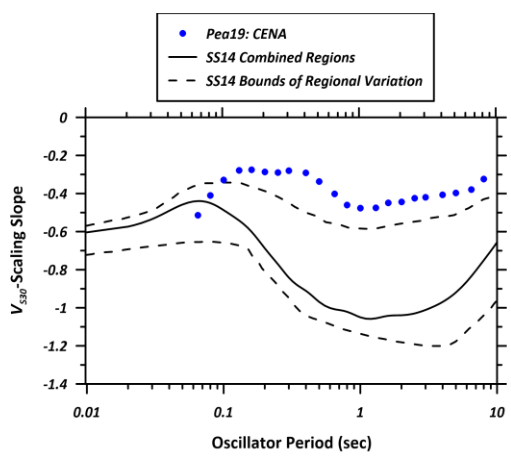

Figure 2. Slopes of V_{S30}-scaling models for CENA [4] and active tectonic regions [10]

Figure 2 compares the scaling of site response with V_{S30} (i.e., the slope in the F_V term, Eq. 2) for CENA and active tectonic regions. An important distinction between the models is the weaker V_{S30} scaling in CENA (i.e., smaller slope in absolute value terms), which means that V_{S30} has less predictive power in CENA than in active regions. This may be a consequence of large impedance contrasts producing site resonances related to variably thick sediments deposited over hard rock [15–17].

Residuals Analysis to Assess Bias

We assess the performance of the combined NGA-East GMMs [2,3] and linear site amplification model [4] using the NGA-East dataset [18]. Residuals of data relative to the combined model were computed as

$$R_{ij} = ln(Y_{ij}) - \left[\mu_{ln}\left(\mathbf{M}_i, (R_{rup})_{ij}, V_S = 3000\right) + F_{lin}(V_{S30})\right] \quad (3)$$

where Y_{ij} are recorded ground motion spectral accelerations for event i and station j, μ_{ln} is the natural log mean from NGA-East GMMs, which have a V_S=3000 m/sec reference site condition, $\mathbf{M}_i$ is moment magnitude for event i, $(R_{rup})_{ij}$ is rupture distance for event i and station j, and F_{lin} is from Eq. (2). The GMMs used for residuals analysis was the "Mean Model" as described in [3]. The subset of the NGA-East dataset used for these analyses were from events with $\mathbf{M}$>4, R_{rup}=0-300 km, and as least 3 recordings per event .

Total residuals were partitioned into between-event and within-event components using mixed-effects regression using the lmer operator in R [19],

$$R_{ij} = c_k + \eta_{E,i} + \delta W_{ij} \quad (4)$$

where c_k represents model bias, $\eta_{E,i}$ is the event term for event i, and δW_{ij} is the within-event residual. Figure 3 plots the model bias c_k as a function of oscillator period (T). The results show that non-zero bias is present over a wide period range, but is most appreciable for T < 0.2 s.

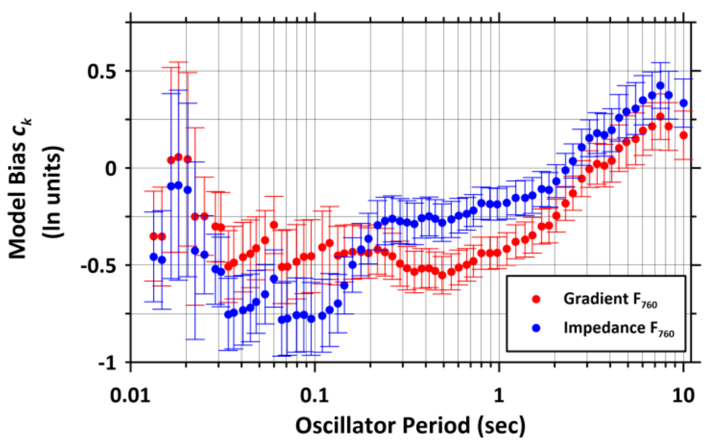

Figure 3. Bias with standard error bars of NGA-East mean model [2,3] with linear site response model [4] using NGA-East data [18]. The effect of the two versions of the F_{760} model were tested independently.

Discussion and Conclusions

In the NGA-East project, the GMMs and site amplification models were developed independently and thus have a potential for bias. When the two models are combined and analyzed against NGA-East data, we observe an overall, period dependent model bias, with negative bias at short oscillator periods, and increasing positive large model bias at long periods (Figure 3). Two specific features of the NGA-East GMMs and site amplification model are most likely causes of the bias: (1) the GMM constant terms, which may have been influenced by site corrections applied in the model development and (2) the F_{760} models which carries significant parametric uncertainty in κ_0. If the constant terms are ultimately found to be in error (which for now is only a working hypothesis), the physical meaning of that error would be that the GMM's reference condition departs from the intended target of 3000 m/sec. Ongoing work seeks to further evaluate the bias and identify procedures by which it can be removed while maintaining an appropriate degree of epistemic uncertainty in the GMMs. That work involves expanding the NGA-East database, improving site metadata, and performing updated ground response simulations for the 760 m/sec reference condition in consideration of newer V_S profiles and improved analysis protocols [18].

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References

[1] Petersen MD, Moschetti MP, Rezaeian S, Mcnamara D. The 2018 Update of the US National Seismic Hazard Model : Overview of Model and Implications. Earthq Spectra 2020;36:5–41. https://doi.org/10.1177/8755293019878199.

[2] Goulet C, Bozorgnia Y, Abrahamson N, Kuehn N, Al Atik L, Youngs R, et al. Pacific Earthquake Engineering Central and Eastern North America Ground-Motion Characterization NGA-East Final Report. vol. PEER Repor. 2018.

[3] Goulet CA, Bozorgnia Y, Kuehn N, Al Atik L, Youngs RR, Graves RW, et al. NGA-East Ground-Motion Characterization model part I : Summary of products and model development. Earthq Spectra 2021;37:1231–82. https://doi.org/10.1177/87552930211018723.

[4] Stewart JP, Parker GA, Atkinson GM, Boore DM, Hashash YMA, Silva WJ. Ergodic Site Amplification Model for Central and Eastern North America. Earthq Spectra 2020;36:42–68. https://doi.org/10.1177/8755293019878185.

[5] Pacific Earthquake Engineering NGA-East : Adjustments to Median Ground-Motion Models for Central and Eastern North America. Pacific Earthq Eng Res Cent 2015.

[6] Goulet CA, Bozorgnia Y, Kuehn N. Pacific Earthquake Engineering NGA-East Ground-Motion Models for the. Pacific Earthq Eng Reseach Cent 2017.

[7] Hashash YMA, Kottke AR, Stewart JP, Campbell KW, Kim B, Moss C, et al. Reference Rock Site Condition for Central and Eastern North America. Bull Seismol Soc Am 2014;104:684–701. https://doi.org/10.1785/0120130132.

[8] Budnitz RJ, Apostolakis G, Boore DM, Cluff LS, Coppersmith KJ, Cornell CA, et al. Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts. vol. NUREG/CR-6. 1997.

[9] NRC. Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies. Off Nucl Regul Res 2012;NUREG-2117.

[10] Seyhan E, Stewart JP. Semi-Empirical Nonlinear Site Amplification from NGA-West2 Data and Simulations. Earthq Spectra 2014;30:1241–56. https://doi.org/10.1193/063013EQS181M.

[11] Hashash YMA, Ilhan O, Harmon JA, Parker GA, Stewart JP, Rathje EM, et al. Nonlinear Site Amplification Model for Ergodic Seismic Hazard Analysis in Central and Eastern North America. Earthq Spectra 2020;36:69–86. https://doi.org/10.1177/8755293019878193.

[12] Parker GA, Stewart JP, Hashash YMA, Rathje EM, Campbell KW, Silva WJ. Empirical Linear Seismic Site Amplification in Central and Eastern North America. Earthq Spectra 2019;35:849–81. https://doi.org/10.1193/083117EQS170M.

[13] Harmon J, Hashash YMA, Stewart JP, Rathje EM, Campbell KW, Silva WJ, et al. Site Amplification Functions for Central and Eastern North America – Part II: Modular Simulation-Based Models. Earthq Spectra 2019;35:815–47. https://doi.org/10.1193/091117EQS179M.

[14] Harmon J, Hashash YMA, Stewart JP, Rathje EM, Campbell KW, Silva WJ, et al. Site Amplification Functions for Central and Eastern North America – Part I: Simulation Data Set Development. Earthq Spectra 2019;35:787–814. https://doi.org/10.1193/091017EQS178M.

[15] Hassani B, Atkinson GM. Site-Effects Model for Central and Eastern North America Based on Peak Frequency. Bull Seismol Soc Am 2016;106:2197–213. https://doi.org/10.1785/0120160049.

[16] Hassani B, Atkinson GM. Site-Effects Model for Central and Eastern North America Based on Peak Frequency and Average Shear-Wave Velocity. Bull Seismol Soc Am 2018;108:338–50. https://doi.org/10.1785/0120170061.

[17] Pratt TL, Schleicher LS. Characterizing Ground-Motion Amplification by Extensive Flat-Lying Sediments : The Seismic Response of the Eastern U.S. Atlantic Coastal Plain Strata. Bull Seismol Soc Am 2021;111:1795–823. https://doi.org/10.1785/0120200328.

[18] Goulet CA, Kishida T, Ancheta TD, Cramer CH, Darragh RB, Silva WJ, et al. PEER NGA-East database. Earthq Spectra 2021;37:1331–53. https://doi.org/10.1177/87552930211015695.

[19] RCoreTeam. R: A Language and Environment for Statistical Computing. vol. ISBN 3-900. 2019.