Title

Findings from a decade of ground motion simulation validation research and a path forward

Authors

Rezaeian, Sanaz
Stewart, Jonathan
Luco, Nico
et al.

Publication Date

2024-07-01

Peer reviewed

FINDINGS FROM A DECADE OF GROUND MOTION SIMULATION VALIDATION RESEARCH AND A PATH FORWARD

S. Rezaeian[1], J.P. Stewart[2], N. Luco[3], and C.A. Goulet[4]

[1] U.S. Geological Survey, Golden, CO, U.S.A., srezaeian@usgs.gov

[2] University of California, Los Angeles, CA, U.S.A.

[3] U.S. Geological Survey, Golden, CO, U.S.A.

[4] U.S. Geological Survey, Pasadena, CA, U.S.A.

1. Abstract

Simulated ground motions can advance seismic hazard assessments and structural response analyses, particularly for conditions with limited recorded ground motions such as large magnitude earthquakes at short source-to-site distances. Rigorous validation of simulated ground motions is required before hazard analysts, practicing engineers, or regulatory bodies can be confident in their use. A decade ago, validation exercises were mainly limited to comparisons of simulated-to-observed waveforms and median values of spectral accelerations for selected earthquakes. The Southern California Earthquake Center (SCEC) Ground Motion Simulation Validation (GMSV) group was formed to increase coordination between simulation modelers and research engineers with the aim of devising and applying more effective methods for simulation validation.

In this presentation, we summarize what has been learned in over a decade of GMSV activities. We categorize different validation methods according to their approach and the metrics considered. Two general validation approaches are to compare validation metrics from simulations to those from historical records or to those from semi-empirical models. Validation metrics consist of ground motion characteristics and structural responses. We discuss example validation studies that have been impactful in the past decade and suggest future research directions. Key lessons learned are that validation is application-specific, our outreach and dissemination need improvement, and much validation-related research remains unexplored.

This presentation is a summary of our recently accepted paper, Rezaeian et al. (In Press), referenced below.

2. Proposed categorization of GMSV methods

Table 1 summarizes prior research by connecting validation approaches (columns) to validation metrics (rows). Examples of prior studies are provided in each of the cells; we have attempted to capture notable citations for diverse application regions but make no claim of capturing all applicable published works. Our intent in presenting Table 1 is to organize prior research on simulation validation in a systematic manner. In Rezaeian et al. (In Press), we categorize validation metrics into two main groups of ground motion characteristics and structural responses. Bradley et al. (2017) also discuss and categorize validation of simulations in a similar manner by considering ground motion and structural response characteristics, but with a focus on spatial extent (i.e., broad regions to site-specific). Their findings are presented in a matrix form whereby different validation metrics (waveforms to structural responses) are judged to be suitable for practice in problems having different spatial extents. Alternative categorization of validation metrics that may involve validation applications have been suggested in the past but are not considered in this article.

Table 1: Categorizing GMSV methods by validation approaches and validation metrics and example publications.

			Validation Approach: Compare to …	
			A. Historical Records	**B. Semi-Empirical Models**
Validation Metric	**Ground Motion Characteristics**	**a) Waveforms**	Graves and Pitarka (2010) Irikura and Miyake (2011)	Rezaeian and Der Kiureghian (2010) Yamamoto and Baker (2013)
		b) Response Spectral Intensity Measures (IMs) and Peak Parameters*	Dreger et al. (2015) Goulet et al. (2015) Chen and Baker (2019) Lee et al. (2020, 2022)	Star et al. (2011) Seyhan et al. (2013) Burks and Baker (2014) Dreger et al. (2015) Goulet et al. (2015) Pitarka et al. (2017, 2020) Nweke et al. (2022)
		c) Other Intensity Measures (IMs)**	Rezaeian et al. (2015) Luco et al. (2016) Bayless and Abrahamson (2018) Wong et al. (2019) Song et al. (2021)	Anderson (2004) Smerzini and Villani (2012) Paolucci et al. (2015) Burks and Baker (2014) Luco et al. (2016) Afshari and Stewart (2016)
	Structural Responses***	**d) Idealized Structural Models**	Bazzurro et al. (2004) Iervolino et al. (2010) Olsen and Mayhew (2010) Galasso et al. (2012) Galasso et al. (2013) Galasso et al. (2018)	Tothong and Cornell (2006) Burks and Baker (2014)
		e) More Realistic Structural Models	Galasso et al. (2013) Zhong (2016) Burks et al. (2019) Zhong et al. (2020) Fayaz et al. (2021)	Munjy et al. (2022)

*Includes median, dispersion, and correlation of response spectral IMs (e.g., spectral acceleration, Sa) and peak parameters (e.g., peak ground acceleration, PGA).
**Includes IMs other than response spectral and peak parameters. These could be scalar (e.g., duration, Fourier amplitude), goodness-of-fit (combination of scalars), or evolutionary (time-varying) parameters.
***Includes engineering demand parameters (EDPs) from structural analyses and decision variables (DVs) such as failure probabilities.

3. References

Afshari K and Stewart JP (2016) Physically parameterized prediction equations for significant duration in active crustal regions. Earthquake Spectra 32(4): 2057-2081. doi:10.1193/063015EQS106M

Anderson J (2004) Quantitative measure of the goodness-of-fit of synthetic seismograms. Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, Paper No. 243, 14 pp.

Bayless J and Abrahamson NA (2018) Evaluation of the inter-period correlation of ground motion simulations. Bulletin of the Seismological Society of America 108(6): 3413–3430. doi:10.1785/0120190077

Bazzurro P, Sjoberg B and Luco N (2004) Post-elastic response of structures to synthetic ground motions. Report for Pacific Earthquake Engineering Research (PEER) Center Lifelines Program Project, pp. 65–112.

Bradley BA, Pettinga D, Baker JW and Fraser J (2017) Guidance on the utilization of earthquake-induced ground motion simulations in engineering practice. Earthquake Spectra 33(3): 809–835. doi:10.1193/120216eqs219ep

Burks LS and Baker JW (2014) Validation of ground-motion simulations through simple proxies for the response of engineered systems. Bulletin of the Seismological Society of America 104(4): 1930–1946. doi:10.1785/0120130276

Chen Y and Baker JW (2019) Spatial correlations in CyberShake physics-based ground-motion simulations. Bulletin of the Seismological Society of America 109(6): 2447–2458. doi:10.1785/0120190065

Dreger DS, Beroza GC, Day SM, Goulet CA, Jordan TH, Spudich PA and Stewart JP (2015) Validation of the SCEC Broadband Platform V14.3 simulation methods using pseudospectral acceleration data. Seismological Research Letters 86(1): 39–47. doi:10.1785/0220140118

Fayaz J, Azar A, Dabaghi M and Zareian F (2021) Methodology for validation of simulated ground motions for seismic response assessment: application to CyberShake source-based ground motions. Bulletin of the Seismological Society of America 111(1): 226–241. doi:10.1785/0120200240

Galasso C, Zareian F, Iervolino I and Graves RW (2012) Validation of ground motion simulations for historical events using SDOF systems. Bulletin of the Seismological Society of America, 102(6), 2727–2740. doi:10.1785/0120120018

Galasso C, Zhong P, Zareian F, Iervolino I and Graves RW (2013) Validation of ground-motion simulations for historical events using MDoF systems. Earthquake Engineering & Structural Dynamics 42(9): 1395–1412. doi:10.1002/eqe.2278

Galasso C, Kaviani P, Tsioulou A and Zareian F (2018) Validation of ground motion simulations for historical events using skewed bridges. Journal of Earthquake Engineering 24(10): 1652–1674. doi:10.1080/13632469.2018.1483277

Graves RW and Pitarka A (2010) Broadband ground-motion simulation using a hybrid approach. Bulletin of the Seismological Society of America 100(5A): 2095–2123. doi:10.1785/0120100057

Iervolino I, De Luca F and Cosenza E (2010) Spectral shape-based assessment of SDOF nonlinear response to real, adjusted and artificial accelerograms. Engineering Structures 32(9): 2776–2792. doi:10.1016/j.engstruct.2010.04.047

Irikura K and Miyake H (2011) Recipe for predicting strong ground motion from crustal earthquake scenarios. Pure and Applied Geophysics 168: 85–104. doi:10.1007/s00024-010-0150-9

Lee RL, Bradley BA, Stafford PJ, Graves RW, and Rodriguez-Marek A (2020) Hybrid broadband ground motion simulation validation of small magnitude earthquakes in Canterbury, New Zealand. Earthquake Spectra 36(2): 673–699. doi:10.1177/8755293019891718

Lee RL, Bradley BA, Stafford PJ, Graves RW and Rodriguez-Marek A (2022) Hybrid broadband ground-motion simulation validation of small magnitude active shallow crustal earthquakes in New Zealand. Earthquake Spectra 38(4): 2548–2579. doi:10.1177/87552930221109297

Luco N, Rezaeian S, Goulet C, Skarlatoudis A, Bayless J, Silva F and Maechling P (2016) Implementation of Ground Motion Simulation Validation (GMSV) Gauntlets on the Broadband Platform. Southern California Earthquake Center (SCEC) Report #15136, 14 pp.

Munjy H, Habchi R and Zareian F (2022) Validation of simulated earthquake ground motions for displacement response of building and bridge structures based on intensity and frequency content parameters. ASCE Journal of Structural Engineering 148(1). doi:10.1061/(ASCE)ST.1943-541X.0003212

Nweke CC, Stewart JP, Graves RW, Goulet CA and Brandenberg SJ (2022) Validating predicted site response in sedimentary basins from 3D ground motion simulations. Earthquake Spectra 38(3): 2135–2161. doi:10.1177/87552930211073159

Olsen KB and Mayhew JE (2010) Goodness-of-fit criteria for broadband synthetic seismograms, with application to the 2008 Mw 5.4 Chino Hills, California, Earthquake. Seismological Research Letters 81(5): 715–723. doi:10.1785/gssrl.81.5.715

Paolucci R, Mazzieri I and Smerzini C (2015) Anatomy of strong ground motion: near-source records and three-dimensional physics-based numerical simulations of the Mw 6.0 2012 May 29 Po Plain earthquake, Italy. Geophysical Journal International 203(3): 2001–2020. doi:10.1093/gji/ggv405

Pitarka A, Graves R, and Irikura K et al. (2017) Performance of Irikura recipe rupture model generator in earthquake ground motion simulations with Graves and Pitarka hybrid approach. Pure and Applied Geophysics 174: 3537–3555. doi:10.1007/s00024-017-1504-3

Pitarka A, Graves R, Irikura K, Miyakoshi K and Rodgers A (2020) Kinematic rupture modeling of ground motion from the M7 Kumamoto, Japan earthquake. Pure and Applied Geophysics 177: 2199–2221. doi:10.1007/s00024-019-02220-5

Rezaeian S and Der Kiureghian A (2010) Simulation of synthetic ground motions for specified earthquake and site characteristics. Earthquake Engineering & Structural Dynamics 39(10): 1155–1180. doi:10.1002/eqe.997

Rezaeian S, Zhong P, Hartzell S and Zareian F (2015) Validation of simulated earthquake ground motions based on evolution of intensity and frequency content. Bulletin of the Seismological Society of America 105(6): 3036–3049. doi:10.1785/0120140210

Rezaeian S, Stewart JP, Luco N, and Goulet CA (In Press) Findings from a Decade of Ground Motion Simulation Validation Research and a Path Forward. Earthquake Spectra.

Wang N, Takedatsu R, Olsen KB and Day SM (2019) Broadband ground-motion simulation with interfrequency correlations. Bulletin of the Seismological Society of America 109(6): 2437–2446. doi:10.1785/0120190136

Yamamoto Y and Baker JW (2013) Stochastic model for earthquake ground motion using wavelet packets. Bulletin of the Seismological Society of America 103(6): 3044–3056. doi:10.1785/0120120312

Zhong P (2016) Ground motion simulation validation for building design and response assessment. Ph.D. Dissertation, University of California, Irvine, 180 pp.

Zhong K, Ling T, Deierlein GG, Graves RW, Silva F and Luco N (2020) Tall building performance-based seismic design using SCEC Broadband Platform site-specific ground motion simulations. Earthquake Engineering & Structural Dynamics 50(1): 81–98. doi:10.1002/eqe.3364

Seyhan, E, JP Stewart and RW Graves (2013) Calibration of a semi-stochastic procedure for simulating high-frequency ground motions. Earthquake Spectra 29(4), 1495–1519. doi:10.1193/122211EQS312M

Smerzini C and Villani M (2012) Broadband numerical simulations in complex near-field geological configurations: The Case of the 2009 Mw 6.3 L'Aquila Earthquake. Bulletin of the Seismological Society of America 102(6): 2436–2451. doi:10.1785/0120120002

Song SG, Causse M and Bayless J (2021) Sensitivity analysis of the interfrequency correlation of synthetic ground motions to pseudodynamic source models. Seismological Research Letters 92(1): 301–313. doi:10.1785/0220200181

Star LM, Stewart JP and Graves RW (2011) Comparison of ground motions from hybrid simulations to NGA prediction equations. Earthquake Spectra 27(2): 331–350. doi:10.1193/1.3583644

Tothong P and Cornell CA (2006) An empirical ground-motion attenuation relation for inelastic spectral displacement. Bulletin of the Seismological Society of America 96(6): 2146–2164. doi:10.1785/0120060018