# Findings from a decase of Ground Motion Simulation Validation (GMSV) research and a path forward

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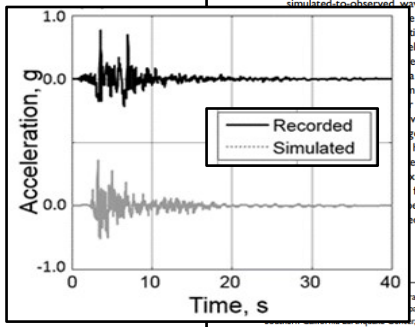



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Advancements in Physics-Based Simulations - Research Paper

EARTHQUAKE SPECTRA

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

Earthquake Spectra
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Abstract

Simulated ground motions have the potential to 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. However, rigorous validation of simulated ground motions is needed for hazard analysts, practicing engineers, or regulatory bodies to 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 ...e Southern California Earthquake Center (SCEC) Ground ...tion (GMSV) group was formed to increase coordination ...lers and research engineers with the aim of devising and ...ethods for simulation validation. Here, we summarize what ...a decade of GMSV activities, principally reflecting the views ...mmunity but also extending our findings and suggestions for ... United States and worldwide simulation validation efforts. ...validation methods according to their approach and the ...general approaches are to compare validation metrics from ...historical records or to those from semi-empirical models. ...egorized into ground motion characteristics and structural ...xample validation studies that have been impactful in the ... future research directions. Key lessons learned are that ...ecific, our outreach and dissemination need improvement, ...d research remains unexplored.

...l Center, U.S. Geological Survey, Denver, CO, U ...artment, University of California, Los Angeles, C ..., University of Southern California, Los Angeles, CA, USA

SCEC

USGS
science for a changing world

# A Synthesis Paper

We acknowledge the invaluable participation and continued interactions of the group members, particularly appreciating the efforts of **Thomas Jordan, Jack Baker, Gregory Deierlein, Farzin Zareian, Carmine Galasso, Paul Somerville, Andreas Skarlatoudis, Jeff Bayless, Nenad Bijelic, Ting Lin, Kuanshi Zhong, Jawad Fayaz, Peng Zhong, Huda Riadh Munjy, Luis Dalguer, Iunio Iervolino, Kioumars Afshari, Brendon Bradley, Caroline Holden, Leonardo Ramirez Guzman, Marco Stupazzini, Seok Goo, Jongwon Lee, John Vidale,** and **Brianna Birkel**. Special thanks go to SCEC simulation modelers and practicing engineers who have attended our workshops and provided feedback and advice to this group, including but not limited to **Robert Graves, Kim Olsen, Ralph Archuleta, Philip Maechling, Fabio Silva, Scott Callaghan, C.B. Crouse, and Farzad Naeim**. Noteworthy to mention are participants of a Special Interest Group session we held at the 2022 Seismological Society of America (SSA) annual meeting in Bellevue, WA, to obtain feedback from the community on publishing the present paper. Early reviews from **Jeff Bayless, Kim Olsen, Morgan Moschetti**, and **Kyle Withers** helped us to further improve this manuscript. Technical reviews from **Roberto Paolucci, Arben Pitarka**, and **Brendon Bradley** were much appreciated and resulted in improving this synthesis paper.

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[2]Civil & Environmental Engineering Department, University of California, Los Angeles, C
[3]Southern California Earthquake Center, University of Southern California, Los Angeles, CA, USA

SCEC

# SCEC GMSV Group:

- **A group established in 2011 by SCEC with the objective to:** … develop and implement, via collaboration between ground motion modelers and engineering users, testing and rating methodologies for the use of ground motion simulations in engineering applications.

- **In early years (2012-2016):**… most of the GMSV projects were independently funded and done by individual PIs, coordinated under the umbrella of the TAG. The TAG organized workshops/events led to larger projects and coordination efforts (e.g., BBP validation project, SEISM project, international workshop). The TAG also coordinated with other SCEC groups (e.g., UGMS)

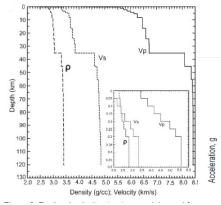
- **In later year (2015-2022):** … also focused on collaborative multi-PI projects to build on the knowledge from previous projects and to start communicating w/ practicing engineers (e.g., validation metrics implemented on BBP, scenario siml.)

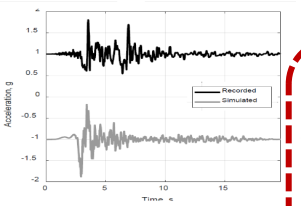
- **2022-2024:** Coordination continues through organized sessions (12NCEE, COSMOS, WCEE24, …)

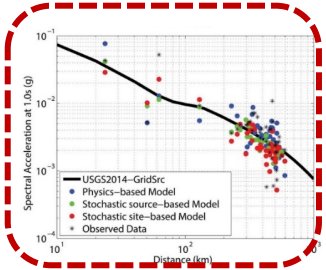
# What is Validation?

Simulations can be validated by comparisons to *"data from past earthquakes"* or to *"empirical models"* based on such data. This can be done at various levels:

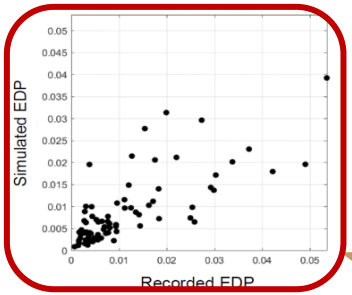
- Model Components (e.g., velocity model)
- Seismograms
- Response Spectra (Sa)
- Proxies beyond Sa for building response (e.g., Duration, max/median-direction Sa, RZZ, …)
- Building response analysis results




Group's Focus




Increasingly application-specific

# One Constant Feedback:

… that our group has received over the past few years in workshops and reviews of our multi-PI proposals

*Example from the SCEC SPC for Award #21144,*

"The Science Planning Committee (SPC) believes this is a critical activity for SCEC, facilitating broader impacts of earthquake science research. The group has been very active, but urgently requires publications that document lessons and recommendations. Specifically, the SPC asks the group to include recommendations on multiple subjects including plans for future GMSV-related projects, and their engineering perspective on how a next-generation SCEC research center can set up effective collaborations with civil engineering groups in the future. The SRL paper should be a top priority."

# Validation Methods

Table 1 categorizes methods and lists example publications

- A “validation method” is defined by a “validation metric” (rows) and a “validation approach” (columns)
- It is acknowledged that other categorizations have been suggested and are possible
- Bradley et al. (2017) → focus on spatial extent
- Future: “Validation Application” → Gauntlets

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

# Validation Examples & Research Needs

- Waveforms:
  Qualitative approaches not very useful for engineering applications, still very valuable for GM modelers

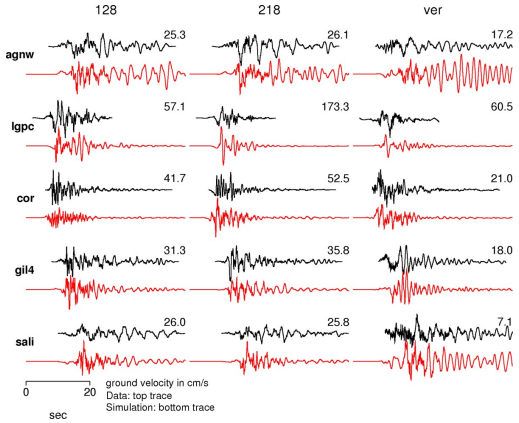



*Figure from Graves & Pitarka (2010)*

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# Validation Examples & Research Needs

- Response Spectral IMs (medians, sigmas, correlations):

  e.g., Correlations

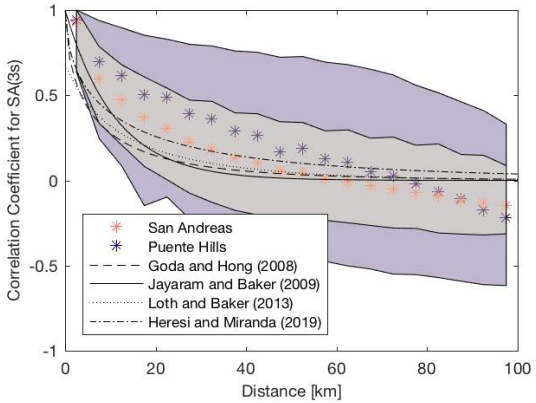


*Figure from Chen & Baker (2019)*

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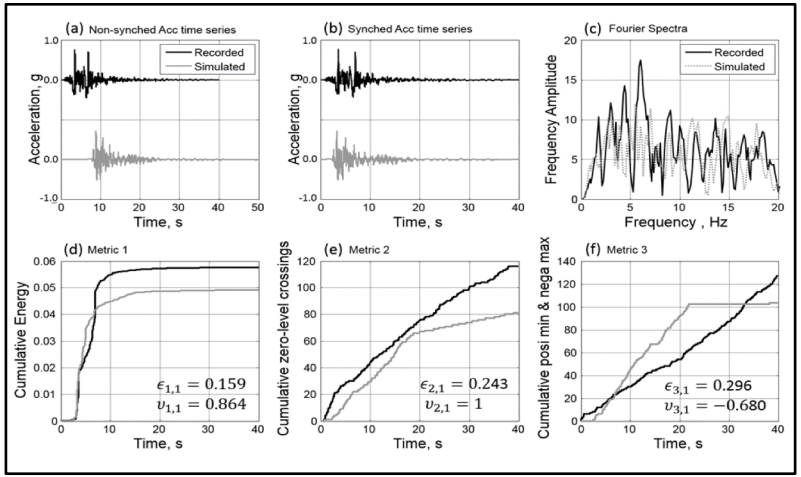
# Validation Examples & Research Needs

- Other IMs (information beyond Sa): scalars, combos, evolutionary

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# Validation Examples & Research Needs

- Idealized/Simple Structural Systems:
  e.g., Inelastic SDoF oscillators: Sdi/Sde

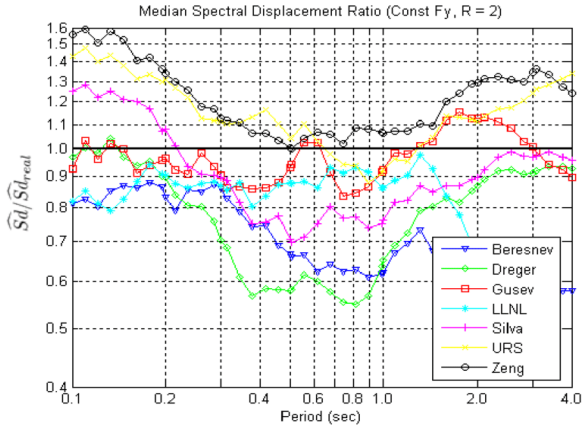


*Figure from Bazzurro et al. (2004)*

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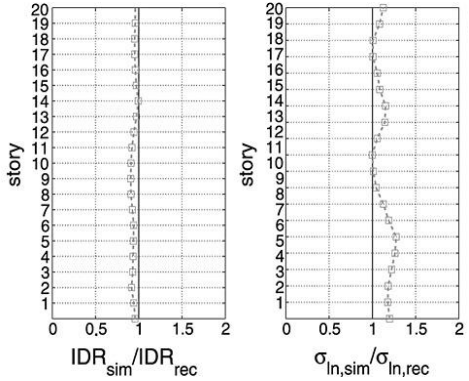
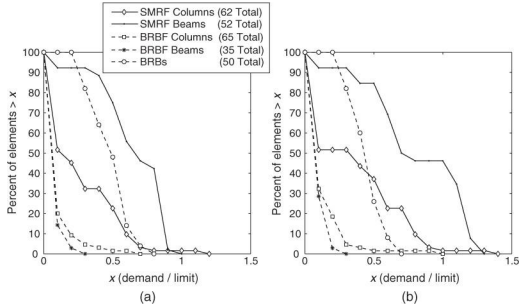
# Validation Examples & Research Needs

- Responses of Realistic Structural Models:




*Galasso et al. (2013)*




*Burks et al. (2019)*

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# Outreach, Dissemination, and Utilization

Validation is useful when it 1) provides guidance for engineers on what simulation methods are suitable for application now, or 2) informs ground motion modelers how to improve their methods for future.

**Past Decade -** The GMSV group has helped to improve development of simulation methods and validation metrics for engineering applications through multi-PI projects, workshops and focus-group meetings, and coordination with other SCEC groups (e.g., UGMS).

**Path Forward -** Despite all the above efforts, simulations are still not commonly used in engineering practice. Key needs to further the utilization of simulations:

- continued validation research
- improved means of communication to share knowledge on simulations (guidelines)
- comprehensive and documented simulation databases (COSMOS?)

# Summary

High-Level Lessons Learned:

1. Validation is **application-specific**
2. Much **research remains** regarding validation & utilization of simulations
3. Our **outreach and communication** must be improved

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