# 2019 SCEC Annual Report
# Award #19173

**Project Title:** SCEC Ground Motion Simulation Validation (GMSV) Guidelines on Utilization of Simulations for Engineering Building Response Applications

**Principal Investigator:** Ting Lin, Texas Tech University (ting.lin@ttu.edu)

**Co-Principal Investigators:**

Sanaz Rezaeian, U.S. Geological Survey

Nicolas Luco, U.S. Geological Survey

Gregory G. Deierlein, Stanford University

Jack W. Baker, Stanford University

Farzin Zareian, University of California, Irvine

**Key Contributors:**

Jon Stewart, University of California, Los Angeles (EEII/GMSV)

Christine Goulet, SCEC

Rob Graves, U.S. Geological Survey (Simulation)

Phil Maechling, SCEC (IT)

C.B. Crouse, AECOM (UGMS)

Jon Heintz, ATC

Practicing engineer experts

SCEC Seismology and IT/CS/Special Projects Teams

GMSV Workshop Participants

**Proposal Category:** Integration and Theory

**SCEC5 Science Priorities:** 4d, 4b, 4c (GM, EEII, CS)

## Abstract

This project provides guidelines on the utilization of simulated earthquake ground motion time series for engineering building response applications based on research conducted in the Southern California Earthquake Center (SCEC) Ground Motion Simulation Validation (GMSV) Technical Activity Group. The emphasis here is on how to use simulated motions for building response studies once a target response spectrum is developed. The recent validation of ground motion simulations, especially for complex system response and site-specific spatial extent, provides the basis towards utilization. This work connects SCEC and other ground motion simulations to practical applications for code-based and performance-based engineering analyses of building responses. To illustrate the appropriateness of simulations for the intended usage, engineering application examples are demonstrated with documented SCEC data products. With this backdrop, we show what simulations are most useful for, what they can and cannot do, with best practices to encourage broader utilization of simulated motions in the engineering community.

## Intellectual Merit

As stated in the SCEC5 Science Plan Basic Question of Earthquake Science Q4, *realistic physics-based predictions of strong ground motions are among the highest long-term priorities of SCEC*. This research connects SCEC 1D and 3D ground motion simulations – specifically *BBP* and *CyberShake* – to practical applications for (a) *code-based* and (b) *performance-based* engineering analyses of building responses. The outcome directly addresses one of the two action items from the GMSV Planning Workshop in August 2018, as follows:

"*Develop a white paper to describe how to use simulated motions for building response studies once a target response spectrum (e.g. UHS or CMS) is developed by some other process. The paper will include best practices, as we now understand them, and identify limitations to the methodology*."

## Broader Impacts

This work is an extension of our previous GMSV research with systematic evaluation of analysis outcomes to provide engineering recommendations, via a committee with representatives from research and practicing engineers, alongside seismology and IT experts. We envision this collaboration - incorporating participant research and stakeholder input - to have a high impact in translating SCEC science research to engineering practice, contributing to future GMSV effort.

## Background

The SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG) focuses on developing, testing and rating methodologies for simulated ground motions to be used in engineering applications. In the SCEC GMSV Planning Workshop between ground motion modelers and engineering users (see Appendix for 8/24/2018 workshop participant list) https://www.scec.org/workshops/2018/gmsv-aug, a key outcome includes action items to address GMSV related to building response. This project outlines the related work to *provide GMSV guidelines for broader utilization of SCEC simulations in the engineering community with respect to building response applications*, based on SCEC GMSV research to date and feedback from practicing engineers.

Ground motion simulation validation (SCEC-based), along with ground motion selection and modification (originally led by PEER GMSM), has received international attention in research and practice. Bradley et al. (2017) described a guidance framework on the utilization of simulations in earthquake engineering practice with an example New Zealand application. Iervolino et al. (2018) investigated seismic reliability of a range of code-conforming Italian buildings in Milan, Naples, and L'Aquila, corresponding to low-, mid- and high- seismic hazard. At SCEC, individual GMSV research projects have examined building responses subjected to simulated and recorded motions (e.g., Goulet et al., 2011; Jayaram and Shome, 2012; Galasso et al., 2013). To integrate research results into SCEC product, a multi-PI project implemented GMSV "gauntlets" (Burks and Baker, 2014; Rezaeian et al., 2015; Afshari and Stewart, 2016) on the Broadband Platform (BBP) (Dreger et al., 2015; Goulet et al., 2015). Another multi-PI collaborative project took a step further to demonstrate the efficacy of validation gauntlets for building response analysis applications (e.g., Bijelic et al., 2018), resulting in a workshop (see Appendix for 2/16/2018 workshop participant list) https://www.scec.org/workshops/2018/gmsv that reached out to practicing engineers who became interested in SCEC simulations. To further workshop-generated interest, systematic evaluation of SCEC GMSV research on building applications to date is valuable to build momentum and encourage early adoption of SCEC simulations among U.S. engineers. This also fills in Bradley et al. (2017)'s ground motion validation matrix especially addressing complex system (MDOF) response and site-specific spatial extent considered in validation.

**Benefits of Simulated Ground Motions**

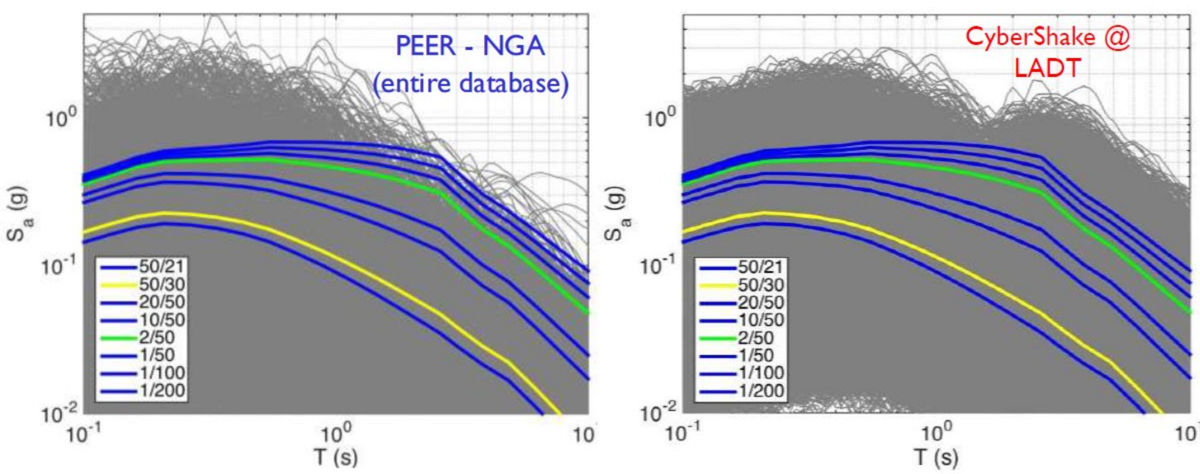


**Figure 1.** Comparison of recorded (PEER-NGA) and simulated (CyberShake Study 15.12) response spectra. Target response spectra are superimposed, with example Conditional Mean Spectra (CMS) from 50% in 21 years to 1% in 200 years probability of exceedance.

What is the added value in earthquake simulations to engineering practice and applied research for nonlinear response history analyses? From a ground motion *database* point of view, Figure 1 illustrates that response spectra generated from the CyberShake (Graves et al., 2011) Project (Study 15.12) at the Los Angeles Downtown (LADT) site alone have much larger coverage at various hazard levels than those of the entire PEER NGA database (Ancheta et al., 2014). Earthquake ground motion simulations are particularly useful for large magnitude, close distance earthquake events (e.g., BBP 17.3) where recordings are limited. Simulations are also important from a *physics-based* perspective to reflect site-specific non-ergodic conditions such as sedimentary basins (e.g., Thompson and Wald, 2016; Moschetti et al., 2018) that may not be fully captured in traditional ground motion prediction equations (GMPEs in e.g., Bozorgnia et al., 2014). A large number of ground motions such as those from BBP and CyberShake also facilitate investigation of the relationship between ground motion parameters (e.g., Luco and Cornell, 2007) and structural response.

**Summary of the Work Done**

To connect SCEC and other ground motion simulations to practical applications for code-based and performance-based engineering (e.g., Deierlein et al., 2003) analyses of building responses, we formed a committee to (1) review prior SCEC GMSV research, (2) vet through engineering practice, (3) convene an in-person meeting to identify gaps and develop consensus, and (4) provide recommendations in the form of a position paper to translate SCEC ground motion simulations and GMSV research into engineering practice.

**Task 1: Review prior SCEC GMSV research**

SCEC GMSV has been active with a spectrum of projects spanning the research domain from waveforms, intensity measures, to building response applications. GMSV projects, including individual and multi-PI collaborative projects, are documented for SCEC4 (led by Nico Luco and Sanaz Rezaeian) https://collaborate.scec.org/gmsv/Main_Page and SCEC5 (led by Sanaz Rezaeian and Jon Stewart) https://sites.google.com/view/scec5-gmsv-tag/home. From the survey questions in the February 2018 workshop with a range of stakeholders including ground motion modelers and engineering users, the top areas of interest based on collective ranking of importance were:

- What are some examples of using and validating SCEC seismograms simulations for building response analysis? Are they just for research, or for practice as well?
- How are seismogram simulations validated? What features (derived parameters) of the seismograms are used for validation? What are the challenges in validating simulations against recorded data? How are the simulated motions vetted for scientific research vs. engineering applications?

To bring research to practice, we aggregated results, observations, and recommendations in a language relevant to the engineering community, specifically for building response applications. This formed the basis of the vetting materials provided to Task 2, the process outlined in Task 3, and a position paper described in Task 4.

**Task 2: Vet through engineering practice**

To demonstrate SCEC seismogram simulations for tall building response analyses, BBP 17.3 simulations (Figure 2) were generated by Rob Graves based on hazard deaggregation by Nico Luco, site selection by Sanaz Rezaeian, and surrogates described by Christine Goulet. These simulations were then processed and distributed by Fabio Silva and Phil Maechling from the SCEC IT team. Representative ground motions were selected by Greg Deierlein, Ting Lin, and PhD students Kuanshi Zhong and Wen-Yi Yen per ASCE 7-16 building code criteria to match target spectra for example buildings (covering different first-mode periods of vibration with higher-mode effects) and sites (in urban areas, including San Francisco and Los Angeles downtown, a CyberShake site) for intensity levels of interest in engineering design.

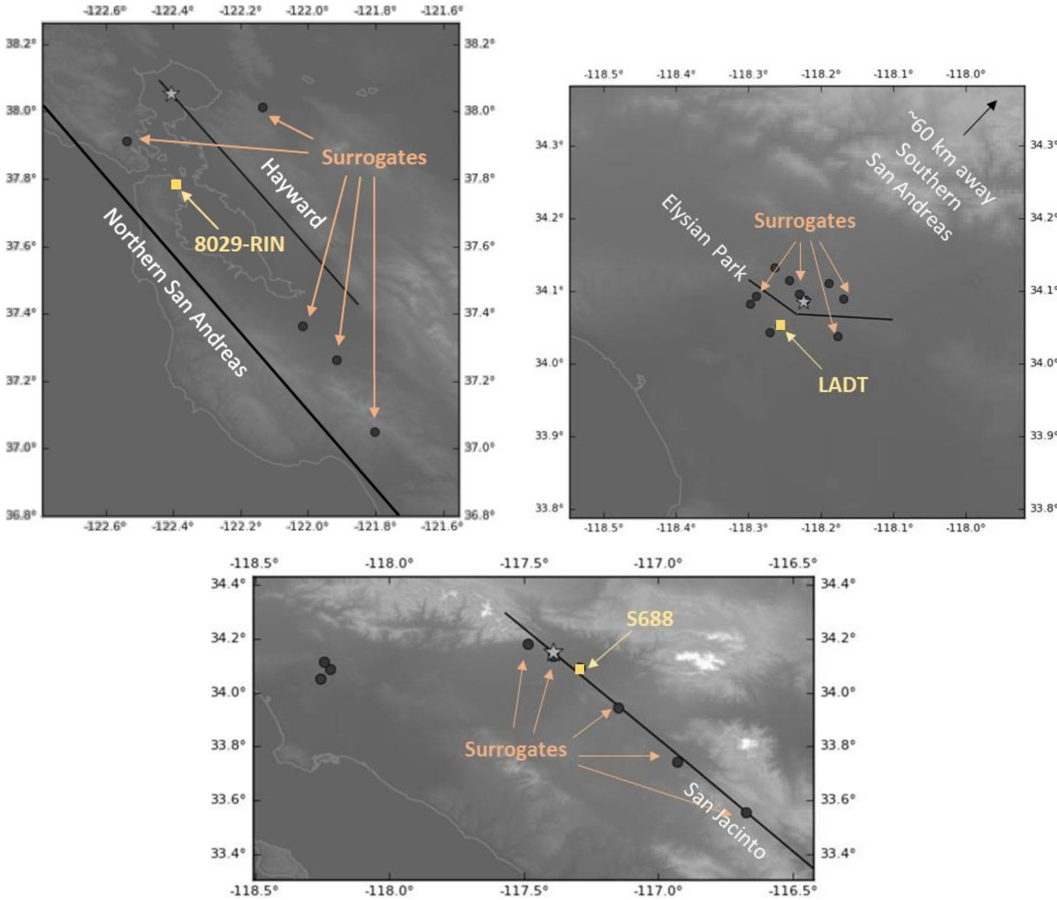


**Figure 2.** Illustrative BBP 17.3 scenario simulations for three benchmark sites of (a) San Francisco Downtown, SFDT (8029-RIN); (b) Los Angeles Downtown (LADT, CyberShake site); and (c) San Bernardino (S688, CyberShake site), illustrating surrogate stations aligned with major contributing fault systems of Northern San Andreas (M 8.0), Hayward (M 7.0), Elysian Park (M 6.6), San Jacinto (M 7.8), and Southern San Andreas (M 7.9) in Northern and Southern California for tall building response applications (Courtesy of Nicolas Luco, Sanaz Rezaeian, Robert W. Graves, Christine Goulet, Fabio Silva, Philip J. Maechling, Kuanshi Zhong, Wen-Yi Yen, Gregory G. Deierlein, and Ting Lin).

Besides examples with additional structures investigated and validated by Munjy and Zareian (2020), performance-based engineering (e.g., collapse fragility application) was also of interest to design firms and engineering organizations. For instance, the SCEC Utilization of Ground Motion Simulations (UGMS) Committee led by C.B. Crouse were interested in structural responses, besides hazard maps and target spectra, under recorded vs. simulated CyberShake motions. Representative engineering examples utilizing SCEC BBP and CyberShake simulations (e.g., Zhong et al., 2020; Bijelic et al., 2018, 2019a, 2019b, 2020) promoted state-of-the-art, user-friendly engineering resources and applications.

This project by the conveners of the February 2018 workshop built on our previous research and continue to engage stakeholders. We carefully examined SCEC simulations and building applications from years of GMSV research by various PIs, via regular web conferences to formulate recommendations through an iterative process.  To vet through engineering practice, we interacted with the Structural Engineers Association of California (SEAOC) and the Applied Technology Council (ATC) for independent evaluation.

**Task 3: Convene an in-person meeting to identify gaps and develop consensus**

To further understand what engineers need and ensure what we deliver meet their expectations, we convened an in-person meeting at SCEC in December 2019 (via Award #19181) to show what we had done and sought feedback. This meeting involved the PI and Co-PIs in this project, along with Jon Stewart as an EEII/GMSV representative, Christine Goulet as a SCEC representative, Rob Graves as a simulation representative, and Phil Maechling as an IT representative. Practicing engineering experts, including C.B. Crouse from AECOM and Jon Heintz from ATC, were invited to the meeting, alongside additional experts from practice nominated by the committee (see Appendix for 12/6/2019 workshop participant list). We jointly identified gaps on utilizing SCEC simulations for engineering building response applications.

**Task 4: Provide recommendations to translate SCEC simulations and GMSV research into engineering practice**

We incorporated group discussion results to prepare recommendations. The findings and related work were shared at the National Earthquake Conference (e.g., Luco, 2020). The final deliverable would be a position paper (Lin et al., 2020a) with guidelines and recommendations (see example list below) in the journal, *Earthquake Spectra*. This paper describes what simulations are most useful for, what they can and cannot do, with best practices to guide engineering applications. We also worked towards citable SCEC data, recognizing contributions from SCEC Seismology and IT/CS/Special Projects teams by individuals like Rob Graves, Kim Olsen, Christine Goulet, Phil Maechling, Scott Callaghan, Fabio Silva, Silvia Mazzoni, Edric Pauk, and Kevin Milner. We provided additional engineering application examples at the $17^{th}$ World Conference on Earthquake Engineering (Lin et al., 2020b) with documented SCEC data product to encourage broader utilization of simulated motions in the engineering community.

**Guidelines and Recommendations**

- The ground motion simulations should be produced for seismic environments similar to the analysis situation of interest.
- The general algorithm used to produce the simulations should be vetted for the specific engineering application of interest.
- The ground motions should contain realistic energy at all frequencies where the structural model might be excited.
- If ground motion duration or other metric is a critical aspect of the response, then it should be incorporated into the simulations.
- If multiple components of shaking are to be input to the structural model, multi-component ground motion simulations are needed.
- If simulated ground motions are being considered because of a site-specific issue (e.g., basin effects) not well characterized by recorded ground motions, the simulation algorithm and input models should be selected to incorporate these effects.
- Nonlinear site response analysis is desirable for sites where high nonlinearity is expected and consideration of near-surface geotechnical layer is important.

**Data and Resources**

The ground motion simulations discussed in this project can be accessed via SCECpedia, SCEC community's collaborative wiki site, for BBP (https://scec.usc.edu/scecpedia/Broadband_Platform) and CyberShake (https://scec.usc.edu/scecpedia/CyberShake) with relevant documentation including ruptures considered, computational domain, and verification. Additional access to BBP 17.3 is available via SCEC Ground Motion Simulations and Engineering Applications Workshop (https://www.scec.org/workshops/2018/gms-engineering) and Data Depot of DesignSafe (https://www.designsafe-ci.org/data), NHERI's web-based research platform.

**Appendix: Related Workshop Participant Lists**

| | 2/16/2018 | 8/24/2018 | 12/6/2019 |
|---|---|---|---|
| Pedro Arduino (UW) | | 1* | |
| Domniki Asimaki (Caltech) | | 1* | |
| Brad Aagaard (USGS) | 1* | | |
| Ralph Archuleta | 1* | | |
| Bob Bachman (R.E. Bachman) | 1 | | |
| Nenad Bijelic (Stanford) | 1 | | |
| Yousef Bozorgnia (UCLA) | | 1 | |
| Philip Caldwell (BSSC) | | 1* | |
| C.B. Crouse (AECOM) | 1 | 1* | 1 |
| Gregory Deierlein (Stanford) | 1 | 1 | 1 |
| Andrew Dinsick (GeoPentech) | | | 1 |
| John Egan (SAGE) | 1* | | |
| Geoffrey Ely (Temblor) | 1 | | |
| Josh Gebelein (SEAOSC) | 1 | 1* | |
| Farid Ghahari (UCLA) | | 1 | |
| Ramin Golesorkhi (Langan) | 1 | | |
| Christine Goulet (USC) | 1 | 1 | 1 |
| Robert Graves (USGS) | 1 | 1 | 1 |
| Jon Heintz (ATC) | | 1 | 1 |
| Ken Hudnut (USGS) | 1 | | |
| Marty Hudson (Wood) | 1 | 1 | 1 |
| Tran Huynh (USC) | | | 1 |
| Saiful Islam (Saiful Bouquet St. Eng.) | | | 1 |
| Ifa Kashefi (LA City) | | | 1 |
| Albert Kottke (PG&E) | | 1* | |
| Jongwon Lee (Arup) | 1 | 1 | 1 |
| Marshall Lew (Amec Foster Wheeler) | 1 | | |
| Ting Lin (Texas Tech University) | 1 | 1 | 1 |
| Doug Lindquist (Hart Crowser, Inc) | 1 | | |

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|---|---|---|---|
| Nico Luco (USGS) | 1 | 1 | 1 |
| Philip Maechling (USC) | 1 | | 1 |
| Silvia Mazzoni (UC Berkeley) | 1* | | |
| Mike Mehrain (MNI, Inc) | | | 1 |
| Kevin Milner (SCEC/USC) | | 1 | |
| Morgan Moschetti (USGS) | 1 | 1 | |
| Farzad Naeim (Farzad Naeim, Inc) | 1* | 1* | 1* |
| Chukwuebuka Nweke (UCLA) | 1* | | |
| Edric Pauk (SCEC) | | 1 | 1 |
| Kim Olsen (SDSU) | 1 | | |
| Sanaz Rezaeian (USGS) | 1 | 1 | 1 |
| Anoosh Shamsabadi (HSRA) | | 1 | |
| Jon Stewart (UCLA) | 1 | 1 | 1 |
| Ali Sumer (OSHPD-FDD) | 1* | 1 | 1* |
| Ricardo Taborda (U Memphis) | 1 | | |
| Ertugrul Taciroglu (UCLA) | | 1 | |
| John Vidale (USC) | 1 | | |
| Katie Wooddell (PG&E) | | 1 | |
| Wen-Yi Yen (Stanford) | 1 | | |
| Kuanshi Zhong (Stanford) | 1 | | |
| Farzin Zareian (UC Irvine) | 1 | 1 | 1 |

1: In-Person Participation; 1*: Remote Participation.

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