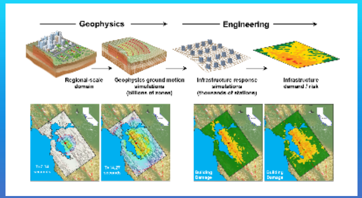

PEER International Pacific Rim Forum
June 16-17, 2021

Guidelines on Utilization of Simulated Ground Motions for Engineering Building Response Applications

Presented on behalf of task committee:
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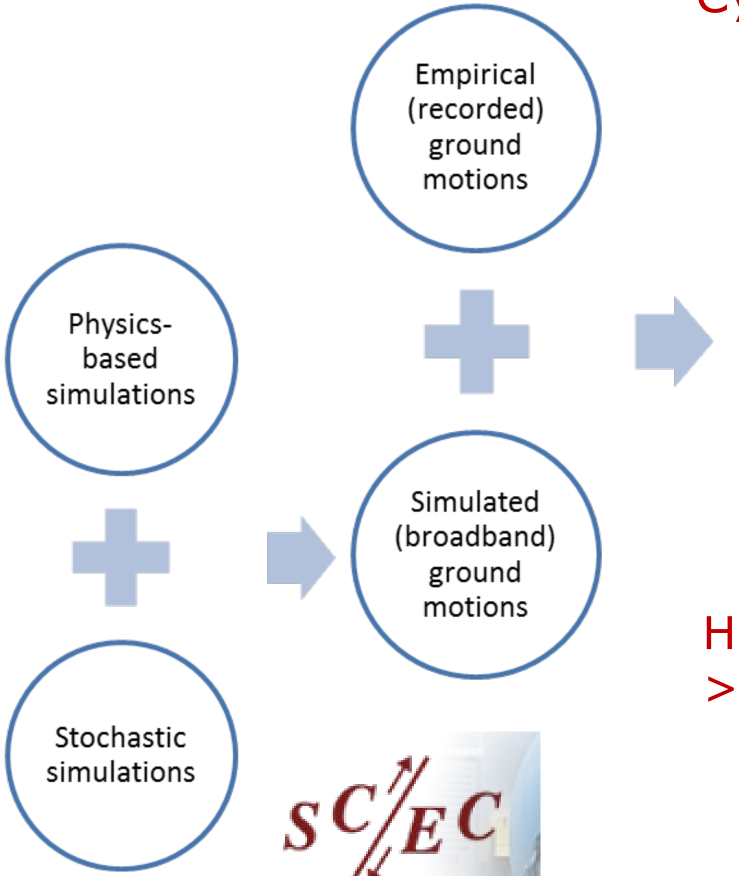
June 17, 2021

PEER

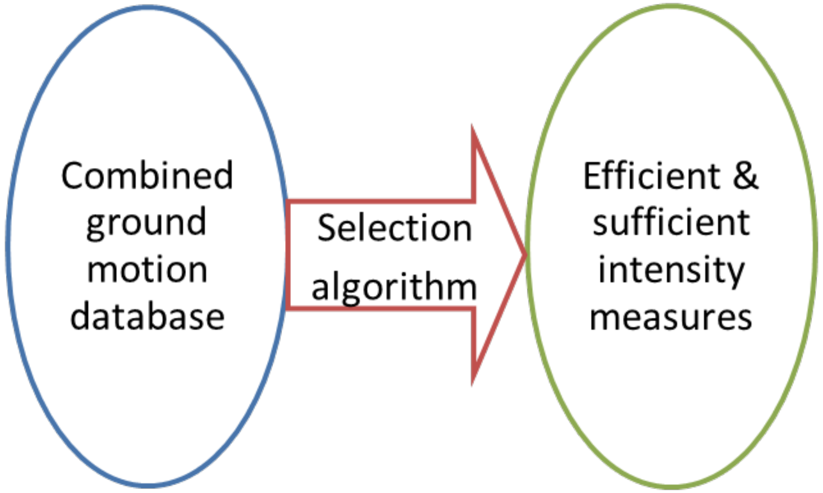
Curiosity – where it all began (2012)

- NorCal probabilistic seismic hazard analysis (PSHA) + performance-based earthquake engineering (PBEE) PhD
- SoCal “Rupture to Rafters” challenge
- Southern California Earthquake Center (SCEC) geophysics + computer science inspiration
- Probabilistic + physics-based?
- “Guinea pig” of CyberShake?
- Strength of one field to solve a tough problem of another: Long T simulations for tall buildings in the Pacific Rim!

Integrating Structural Engineering, Geophysics, and High Performance Computing (HPC)



CyberShake: Physics-based Probabilistic Seismic Hazard Analysis



HPC: 200,000 supercomputing hours a year
>2,000,000 nonlinear response history analyses to date

SCEC #13161, 14186, 14228, 15113, 16110, 16139, 19173

TG-BCS130008, 140006

EQ Song

Like a small fault
In the basin
Sending big waves
Into motion
Like how a single go
Can make *discovery* open

Research Team & Acknowledgments

- This research is supported by the Southern California Earthquake Center (SCEC Award #19173). SCEC is funded by National Science Foundation (NSF) Cooperative Agreement EAR-1600087 & U.S. Geological Survey (USGS) Cooperative Agreement G17AC00047.
- PI: Ting Lin; Co-PIs: Sanaz Rezaeian, Nicolas Luco, Gregory G. Deierlein, Jack W. Baker, Farzin Zareian; PhD Students: Nenad Bijelić, Kuanshi Zhong.
- We acknowledge Jon Stewart, Christine Goulet, Robert W. Graves, Philip J. Maechling, C. B. Crouse, Jon Heintz, Fabio Silva, Scott Callaghan, Kevin Milner, Silvia Mazzoni, Edric Pauk, Tran T. Huynh, SCEC Seismology and IT/CS/Special Projects teams, and GMSV workshop participants for their valuable contributions.

Introduction

- Selection of ground motion time series as inputs to structural response history analysis is an increasingly common practice, particularly for performance-based assessments of tall buildings and other special structures. The selection of such motions is guided by standards and reference documents, e.g., ASCE 7-16 (2016), FEMA P-58 (2018), PEER TBI (2017), and LATBSDC (2018), using target response spectra such as uniform-hazard, risk-targeted (Luco et al. 2007), or conditional spectra (CS, Lin et al. 2013).
- As the availability of recorded motions with matching properties is limited, the procedures for selection allow for modifications (amplitude scaling or spectral matching) of the time series, which potentially introduce bias in the results of structural response analyses (e.g., Luco and Bazzurro 2007, Seifried and Baker 2016).
- Furthermore, the available recorded motions are from only a few geographic areas that do not necessarily correspond to a site of interest.
- With the increasing availability and refinement of simulated ground motions (e.g., Mai and Beroza 2003, Graves and Pitarka 2016, Taborda et al. 2014), such simulations are now a viable option for ground motion selection in a greater set of circumstances.
- Accordingly, the ASCE 7-16 standard explicitly permits the use of simulated ground motions, and other documents at least leave open this option.

Motivation

What is the added value in earthquake simulations to engineering practice and applied research for nonlinear response history analyses?

- Earthquake ground motion simulations are particularly useful for large magnitude, close distance earthquake events (e.g., BBP 17.3) where recordings are limited.

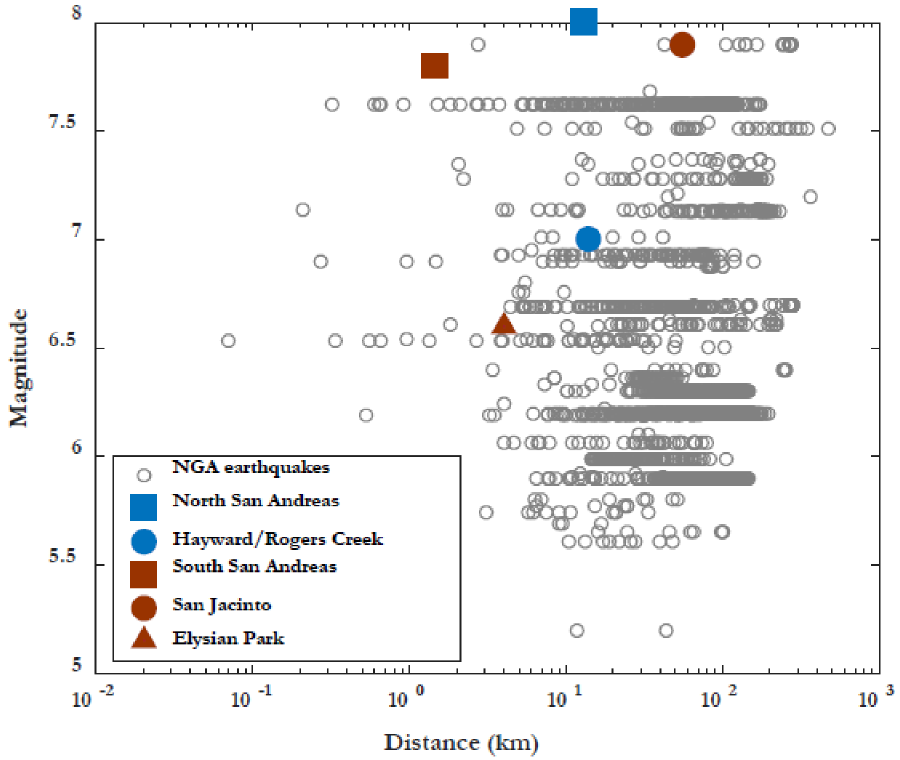


Figure 1. BBP 17.3 simulated earthquakes magnitude-distance scatter plot.

SCEC CyberShake Study 15.12

- From a ground motion **database** point of view, Figure 2 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).

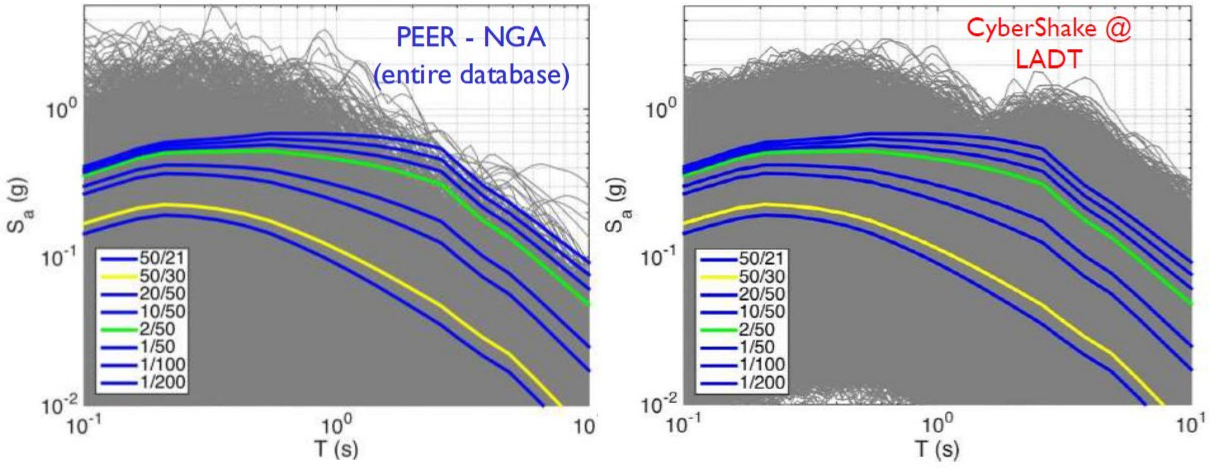


Figure 2: Comparison of recorded (PEER-NGA) and simulated (**CyberShake Study 15.12**) response spectra. Target response spectra are superimposed, with example Conditional Mean Spectra (CMS) from 50% in 21 years to 1% in 200 years probability of exceedance.

Simulation

- Both Broadband Platform (Maechling et al. 2015) 17.3 and CyberShake (Graves et al. 2011) 15.12 simulations are the results of interactions between ground motion modelers and engineering users, i.e., earthquake scenario simulated and broadband component added based on engineering analysis needs, as part of the SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group.
- Ground motion simulations are often generated for site-specific spatial extent. Here we illustrate sites in urban areas (See Figure 3), including San Francisco downtown (SFDT, labeled as 8029-RIN) and Los Angeles downtown (LADT) where many tall buildings are located, along with representative sites located in the Los Angeles basin, e.g., San Bernardino (S688), as part of the SCEC CyberShake project.

SCEC BBP 17.3 scenario simulations

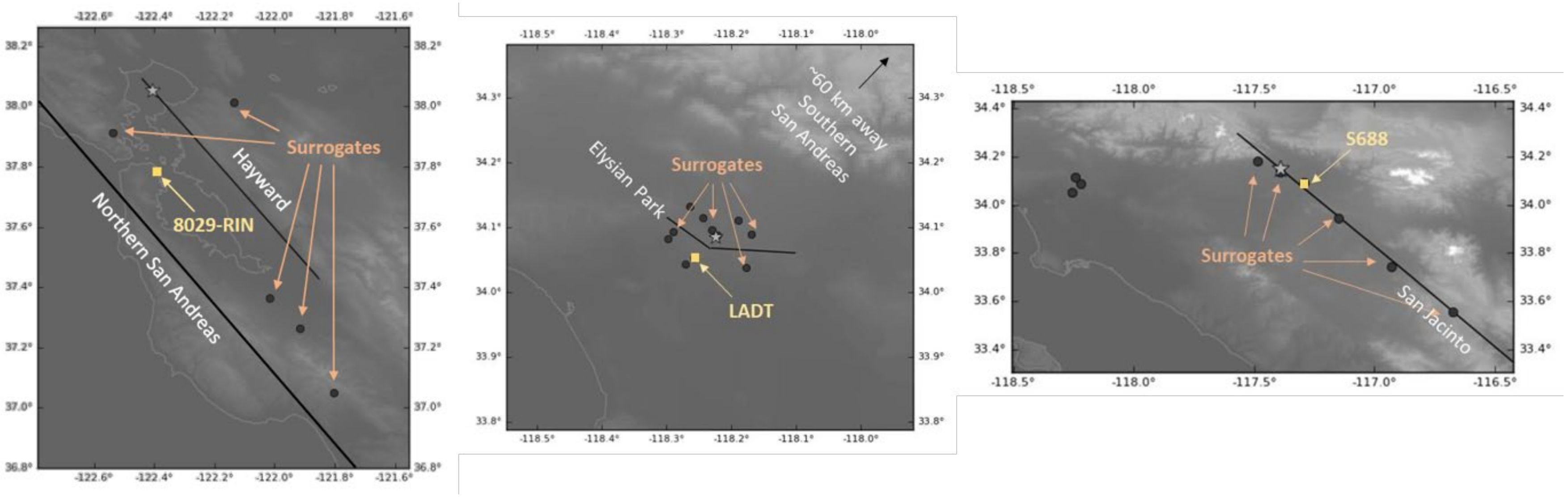


Figure 3: BBP 17.3 scenario simulations for three benchmark sites of (a) San Francisco Downtown, SFDT (8029-RIN); (b) Los Angeles Downtown (LADT, CyberShake site); and (c) San Bernardino (S688, CyberShake site), illustrating major contributing fault systems of Northern San Andreas (M 8.0), Hayward (M 7.0), Elysian Park (M 6.6), San Jacinto (M 7.8), and Southern San Andreas (M 7.9) 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).

Validation

- 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).
- While BBP simulations require some degree of scaling (e.g., Galasso et al. 2013, GMSV 2019), CyberShake enables use of unscaled site-specific simulations.
- Sidestepping intensity measures, Bijelić et al. (2019a) conduct direct analysis using CyberShake 15.12 simulated motions (around 2 million nonlinear response history analyses) and hazard curve vs. conventional approach using NGA recorded motions and USGS hazard curve. To explore where simulated motions provide unique advantages over recorded motions for performance-based engineering, Bijelić et al. (2019b) focus on basin effect characterization in seismic hazard and risk assessments of tall buildings, while Bijelić et al. (2020) use machine learning algorithms for collapse prediction.

Utilization

- 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.
- Following Bijelić et al. (2019a), Baker et al. (2021) focus on CyberShake 15.12 ground motion selection for engineering analysis while Fayaz et al. (2021) extend structural applications from tall buildings to ordinary bridges.
- Zhong et al. (2021) perform nonlinear response history analyses of two tall buildings at three sites, which indicate that similar structural responses are obtained under simulated and recorded motions per ASCE 7 procedure or if selected and scaled to the same target CS and duration intensity measures. The benefit of BBP 17.3 (and simulations such as CyberShake) to avoid large scaling factors is apparent at high intensity levels.

Code-based applications

- For building code application, we select ground motions per ASCE 7-16 (ASCE 2016) building code criteria (including causal features such as magnitude, distance, and mechanism) to match target spectra calculated using USGS design tool (USGS 2018), resulting in eleven ground motions for each building, site, and intensity combination.
- BBP simulations are more consistent with governing hazard, including a better match with target duration.

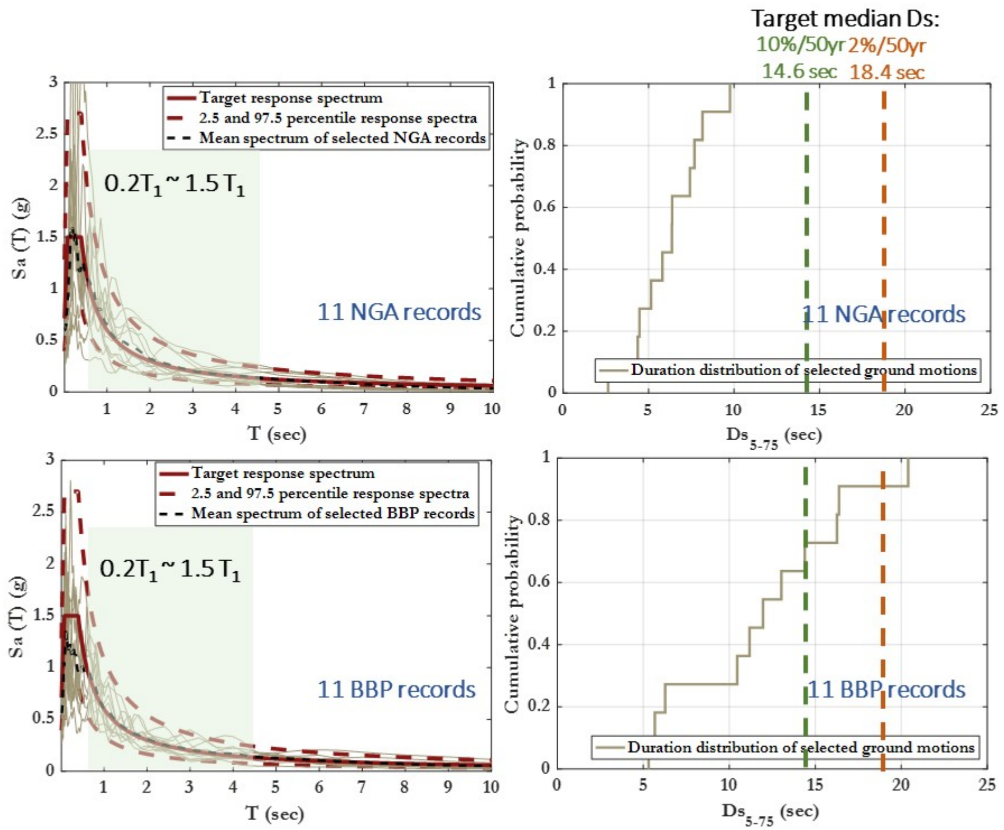


Figure 4: Response spectra and significant durations of ground motion selected from recorded (NGA) and simulated (BBP 17.3) to match ASCE (2016) code spectrum for San Francisco Downtown, SFDT

Performance-based engineering

- For risk-based assessment (NIST 2011), we select one hundred ground motions for each building, site, and intensity combination.
- For sites with multiple contributing earthquake sources, ground motion selection based on source-specific Conditional Spectra (Lin et al., 2013) is more desirable (e.g., LADT).
- BBP and CyberShake motions match GMPE targets well except for basin and near-fault sites.

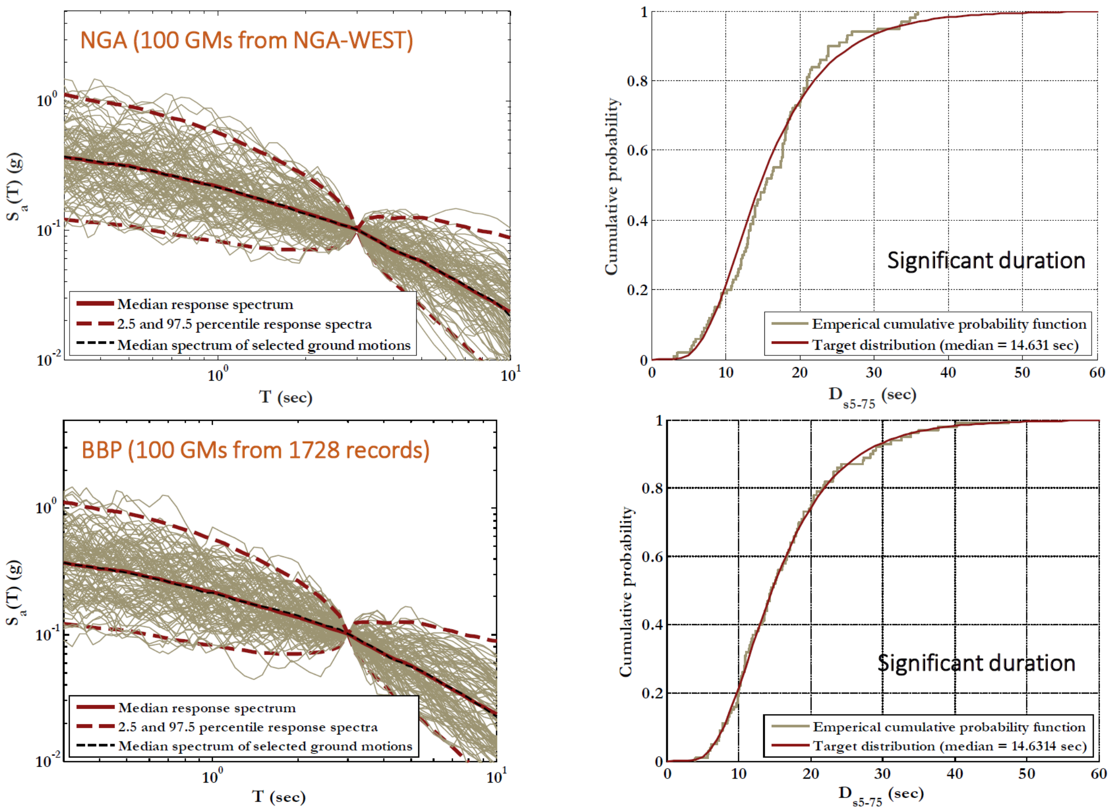


Figure 5: Ground motion selection to match recorded (NGA) and simulated (BBP 17.3) conditional spectra and significance durations (Afshari and Stewart 2016) for San Francisco Downtown, SFDT, T = 3s, 10% in 50 years

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.
- Site-specific (e.g., basin) effects not well characterized by recorded ground motions should be incorporated in the simulation algorithm and input models.
- 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), Natural Hazards Engineering Research Infrastructure, NHERI's web-based research platform.

Additional References on BBP & CyberShake

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Perseverance (2021)

EQ Sci + Eng Song

Introduction
Motivation
Simulation
Validation
Utilization
Recommendations

Keep doing the next right things!

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