# Technical Report on SCEC Award # 16110

# Demonstrations of the Efficacy of the BBP Validation Gauntlets for Building Response Analysis Applications

## PIs:

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### Objective:

This project furthers the use of simulated ground motions by engineers by demonstrating their use for two specific engineering applications, by "validating the validation gauntlets" that are implemented on the SCEC Broadband Platform (BBP) through their use in the two engineering applications, and by merging/simplifying the gauntlets based on the project results. In addition to demonstrating agreement between validation gauntlet results and comparisons of building responses to simulated and recorded ground motions, a workshop is planned to provide descriptions of the simulation models and validation gauntlets in terms that resonate with the intended engineering audience.

### Summary of the work done:

To directly demonstrate that the newly-implemented validation tests on the BBP identify ground motion simulations that are robust (i.e., that they reliably identify where differences between simulated and recorded ground motions may lead to significant differences in building responses), we proposed the following four tasks:

Task 1 – Process latest BBP simulations through newly-implemented validation gauntlets

Task 2 – Compare building responses to simulated ground motions from Task 1 against their recorded counterparts

Task 3 – Demonstrate correlation between results of validation gauntlets and comparisons of building responses

Task 4 – Convene a workshop with building response engineers and ground motion modelers

### *Modifications to the Tasks:*

The tasks evolved over time. Task 1 was extended to include two types of simulations: Type A simulations for historical events, and Type B forward-simulations for scenario events. As a result, due to the additional simulations and the slight change of direction to the objective, Task 4 was modified to convert the proposed workshop for engineers to an in-person working meeting for the PIs. This meeting was held at SCEC in February 2017. The workshop with engineers was proposed to be held during SCEC5; this change was submitted in a proposal for continuation of the GMSV TAG.

To coordinate activities related to the various tasks, the PIs have been meeting periodically (online or in person) over the course of the project and a wiki page has been set up, where more details can be found: https://scec.usc.edu/it/BBP_Validation_Gauntlets_for_Building_Response_Analysis_Applications

### *Group Meetings:*

- *March 16, 2017 (All Tasks)*
- *February 23, 2017 (All Tasks)*
  - Set up a Google Drive Folder
- *February 7, 2017 (All Tasks)*
  - Action items and decision points (Google Doc)
- *January 23, 2017 (Task 1)*
  - Wiki for this particular meeting created
- *December 16 2016 (Task 1)*
  - Disaggregations for 3 demonstration sites
  - List of California BBP stations
- *November 23, 2016 (Task 2)*
  - Proposed Next Steps
- *August 19, 2016 (Tasks 2 and 3)*
  - RZZ Scalar Metrics for Previous Stanford/Marquette BBP Study of Ground Motion Sets
  - SCEC BBP Target Scenario Gauntlet Idea
  - Example spectra for Northridge
- *July 29, 2016 (related to Task 2)*
  - Previous Stanford/Marquette BBP Study and 2016 “Gauntlet” Project Plan

## Task 1 – Process latest BBP simulations through newly-implemented validation gauntlets

A collection of seismogram processing methods that calculate several ground motion parameters used in engineering analysis of strong ground motion data has been added into the SCEC Broadband Platform (BBP). Standalone software implementations of these ground motion processing codes were developed by GMSV scientists and engineers and then provided to the SCEC software development group, who integrated these methods into a March 2017 release of the SCEC Broadband Platform (BBP) called BBP v17.3. Working in close collaboration with scientists and engineers, the SCEC software development group has verifiedthese software implementations within the BBP. This new release of the BBP makes it possible to assemble BBP ground motion processing methods into one, or more, application-specific validation gauntlets that can be used to evaluate the suitability of ground motion simulation methods for use in engineering applications.

The Broadband Platform processing system supports the comparison and evaluation of alternative ground motion simulation methods by ensuring that the same seismogram processing methods are used to calculate ground motion parameters for each simulation method. The BBP v17.3 release now contains software methods for calculating the following ground motion parameters from ground motion time series produced by any of the BBP simulation methods: (1) RotD100, (2) RotD100/RotD50 Ratio, (3) Anderson 2004 metrics, (4) Frequency Amplitude Spectrum (FAS), (5) Evolution of Intensity, (6) Evolution of Predominant Frequency, (7) Evolution of Bandwidth, (8) Arias Intensity (IA), (9) Significant Duration (D5_95), (10) Ratio of Arias Intensity to Duration (IA/D5_95), (11) Predominant Frequency (w_mid), (12) Rate of Change of Frequency (w'), and (13) Bandwidth (Z).

As part of the BBP v17.3 software release process, the newly integrated ground motion processing methods were used to calculate ground motion parameters for the Part A (historic) and Part B (scenario) earthquakes. These simulations serve as regression tests for the BBP, since these simulations have been run for all BBP releases in the last four years. When preparing future releases of the BBP, we expect that some of these newly added processing methods could be added to this regression test suite in order to better quantify improvements of the simulation methods.

The GMSV group then defined a set of three California earthquakes, likely to generate strong ground motions in urban areas. For these earthquakes, we calculated the full complement of ground motion parameters using the newly implemented methods. While two of these simulations involved scenario earthquakes, for which no observed ground motions are available, the Northridge earthquake was also used as a part of this study, which enabled the GMSV group to compare the newly available parameters for both simulated and observed ground motion data for the event.

### *List of Completed Simulations:*

- ***Part-A Events:***

The following simulations were done as part of the BBP 16.5.0 release and are currently available. Part A rupture variations may differ by slip distribution.

| Event | Mw | Variations | Site Response | Methods |
|---|---|---|---|---|
| Alum Rock | 5.45 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Chino Hills | 5.39 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Landers | 7.22 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Loma Prieta | 6.94 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Mineral | 5.68 | 50 | No | ExSim, GP, SDSU, UCSB |
| Niigata | 6.65 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| North Palm Springs | 6.12 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Northridge | 6.73 | 50 | No / Yes for GP* | ExSim, GP, SDSU, Song, UCSB |
| Riviere-du-Loup | 4.6 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Saguenay | 5.81 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Tottori | 6.59 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| Whittier Narrows | 5.89 | 50 | No | ExSim, GP, SDSU, Song, UCSB |

Note: Northridge was calculated both with and without site response (only for the GP method), using the GP 2014 version of the site response module and removing the correction coefficients applied to the observation data files.

- ***Part-B Scenarios:***

Part-B rupture variations may differ by hypocenter location and by slip distribution.

| Event | Region | Distance (km) | Variations | Site Response | Methods |
|---|---|---|---|---|---|
| 5.5 Reverse | LABasin, Northern California | 20, 50 | 50 | No | ExSim, GP, SDSU, Song, UCSB |

| | | | | | |
|---|---|---|---|---|---|
| 6.2 Strike-Slip | LABasin, Northern California | 20, 50 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| 6.6 Reverse | LABasin, Northern California | 20, 50 | 50 | No | ExSim, GP, SDSU, Song, UCSB |
| 6.6 Strike-Slip | LABasin, Northern California | 20, 50 | 50 | No | ExSim, GP, SDSU, Song, UCSB |

### *List of Ground Motion Parameters on BBP for Validation & Corresponding Implemented GMPEs:*

- **Time-Dependent Parameters:**

| |
|---|
| Evolution of Intensity |
| Evolution of Predominant Frequency |
| Evolution of Bandwidth |

- **Scalar Parameters:**

| **Parameter** | **GMPE** |
|---|---|
| Ratio of inelastic to elastic displacement | Baker et al. GMPE |
| Correlation of spectral acceleration across periods | Baker et al. GMPE |
| Ratio of maximum to median response across orientations | Baker et al. GMPE |
| Arias Intensity, Ia | Rezaeian et al. GMPE |
| Significant Duration, D5_95 | Rezaeian et al. GMPE<br>+ Stewart & Afshari GMPE |
| Ratio of Arias Intensity to Duration, Ia/D5_95 | NA |
| Predominant Frequency, w_mid | Rezaeian et al. GMPE |
| Rate of Change of Frequency, w' | Rezaeian et al. GMPE |

| | |
|---|---|
| Bandwidth, z (to be implemented in future) | Rezaeian et al. GMPE |
| Mean Period (to be implemented in future) | Rathje et al. 1998 |

### Task 2 – Compare building responses to simulated ground motions from Task 1 against their recorded counterparts

The goal of this task is to determine earthquake-induced demand parameters in several archetype buildings under simulated and recorded motions, which will provide the basis for further validating the use of simulated ground motions for two engineering applications. The demand parameters will be determined using nonlinear dynamic analyses of the buildings under comparable pairs or suites of simulated and recorded motions.

To cover a range of representative ground motions for engineering application demonstration, the following sites, hazard levels, and structural periods were considered:

***Sites:***

1. Los Angeles Downtown (LADT, 34.052 N, 118.257 W)
2. San Bernardino (S688, 34.104 N, 117.288 W)
3. San Francisco (8029-RIN, 37.786 N, 122.391 W)

***Intensity Measure (IM) Levels:***

1. 10% in 50 years (Design-Based Earthquake)
2. 2 % in 50 years (Maximum Considered Earthquake)
3. 2 % in 200 years

***Structural Periods:***

1. 20-story reinforced concrete frame, T1 ~ 3 sec
2. 43-story reinforced concrete shear wall, T1 ~ 5 sec
3. 2-story steel moment frame, T1 ~ 1 sec

The demonstration sites include both Southern California (1 and 2) and Northern California (3), with additional CyberShake simulations available in Southern California (LADT and S688). Seismic hazard deaggregation was performed for three IM levels covering a period range from 1 to 5 seconds, in order to identify the main contributing earthquake faults. The ruptures were then defined and additional sites selected as part of Task 1 BBP Part B scenarios, which focused on larger intensity events in urban areas that would be of interest to engineering applications.

A number of reinforced concrete and steel buildings with heights ranging from 2 to 43 stories were analyzed with simulated and recorded motions as inputs. Demand parameters that were evaluated include (1) peak story drift ratios, (2) peak floor accelerations, and (3) structural collapse capacity.

The 2-story building is a Special Moment Resisting Frame (SMRF) with bay width (centerline dimension between columns) of 20 feet. The height of the first story is 15 feet, and the height of all the other stories is 13 feet. The building is designed assuming a uniform dead load of 100 psf, a perimeter load of 25 psf to represent the cladding, live load of 50 psf on all floors except the roof, where 20 psf is assumed. Seismic load was assumed per ASCE 7-05 (2006) with R = 8, and site class D conditions under the seismic design category $D_{max}$. The 2-story SMRF has a fundamental period of 0.91 seconds with base shear coefficient of 0.11.

*The illustrative **Engineering Applications** are:*

1. ASCE 7-16 Nonlinear Response History Analysis
2. FEMA P-58 Collapse Fragility Analysis

In the first of these two engineering applications, we demonstrate how simulated and recorded ground motions will result in similar building response parameters used for structural design. This ground motion simulation validation method evaluates the similarities between building response obtained from suites of simulated and recorded ground motions conditioned using the code-based ground motion selection and scaling of ASEC/SEI 7-16. The engineering demand parameter of interest is the maximum interstory drift ratio. The difference between the demands from simulated and recorded motions will be compared using Student's t-test for respective engineering demand parameter distributions. Preliminary results show that the structural behavior resulting from recorded ground motions and simulated ground motions are statistically significantly different. The sets of simulated ground motions overestimate the response compared to the recorded motions. The difference stems from the fact that ground motion simulation models are more likely to generate pulse-like ground motions, which tend to create larger displacement of building response. The higher number of pulse-like motions in the population of simulated motions results in a larger number of pulse-like motions in the selected sets, and therefore, imposes higher seismic demands on structures compared to sets derived from natural recordings.

For both applications, target vector IMs were computed considering spectral shape (via the Conditional Spectra) and conditional significant duration (Afshari and Stewart, 2016). 100 recorded ground motions were selected from the PEER NGA database and scaled to match the target IMs for each IM level at each site. Engineering Application 1 corresponds to IM Level 2, whereas Engineering Application 2 covers IM Levels 1 to 3. Multiple Stripe Analyses were performed to determine collapse fragility. In addition, ground motions were resampled for ASCE 7-16 application with sets of 11, instead of 100, motions. A similar procedure was used for selection of counterpart CyberShake motions in Los Angeles and San Bernardino for nonlinear dynamic structural analyses of the 20- and 43-story tall buildings. The processing of BBP motions from Task 1 is currently underway for additional studies. Structural analysis results will be compared under recorded, BBP, and CyberShake (if applicable) motions; observed differences, if any, will be traced back to gauntlet parameters.

## Task 3 – Demonstrate correlation between results of validation gauntlets and comparisons of building responses

This part of our research aims at developing an understanding of the ways in which validation parameters affect engineering demand parameters (EDPs). This information can assist ground motion modelers with required information to efficiently update their models for future simulations. Preliminary results show that building response is highly correlated with Arias Intensity. The effect of predominant frequency ($\omega_{mid}$) on EDP is determined by the natural frequency of the structure; a ground motion with $\omega_{mid}$ close to natural frequency of the building elevates its response. Along with this, duration only shows its effect on inelastic response at short periods. Conditioned on the same Arias Intensity, ground motions with short duration tend to have large amplitude, which may cause large structural displacements.

## Task 4 – Convene a workshop with building response engineers and ground motion modelers

This workshop was originally proposed as Task 4, but with SCEC4 ending in January 2017 and expansion of simulations in Task 1, the other tasks were not completed in time to hold the workshop in SCEC4. Instead, a proposal has been submitted by Rezaeian and Stewart to hold this workshop during SCEC5 as part of the GMSV TAG efforts.

This workshop is primarily aimed at communicating with potential engineering users of BBP simulations – including engineers from the SCEC Utilization of Ground Motion Simulations (UGMS) Committee, from the Building Seismic Safety Council (BSSC) Project '17 on Development of Next-Generation Seismic Design Maps, and from the 2015 SCEC Site Effects Workshop. Ground motion modelers will also be invited to the workshop, but its primary aim is to educate engineers on the latest developments in ground motion simulation and validation, and to demonstrate to all that the validation gauntlets that have been implemented on the SCEC Broadband Platform effectively identify ground motion simulations that are "valid" for building response analysis. To maximize the benefits of this workshop, ahead of time the participants will be provided with background papers on the latest BBP simulations and a summary of the validation efforts, including the results of Tasks 2 & 3. Workshop participants will discuss the BBP simulation models – keeping in mind the engineering audience – the BBP software, the validation gauntlets, the building response results generated in Task 2, and correlations between the gauntlet results and building response comparisons in Task 3. The workshop will also provide informed feedback to ground motion modelers for updating/enhancing their ground motion simulation models. In addition to the BBP, this feedback can inform other ground motion simulation methodologies in the Community Modeling Environment, potentially including modeling of site effects and high-F. The workshop will affect future development of ground motion simulation validation gauntlets in the GMSV TAG, including any validations for the UGMS Committee, as the advances made in this BBP validation exercise are forwarded into CyberShake simulations.

A preliminary agenda was put together by the group during our March 2017 in-person meeting:

| *Time* | *Title* | *Leader* |
|---|---|---|
| ~5 minutes | Welcome | Tom Jordan |
| ~15 minutes + 5 minutes of Q&A | Intro to Ground Motion Simulation & Validation<br>● Motivation<br>● Types and sources of ground motion simulations<br>● Approaches to and limitations of validation | Sanaz Rezaeian |
| ~20 minutes + 10 minutes of Q&A | Intro to SCEC Broadband Platform (BBP) Simulations<br>● Purpose, framework<br>● Primary products, including recent large scenarios<br>● Validation for GMM/GMPE development | Christine Goulet |
| ~15 minutes + 10 minutes of Q&A | Intro to SCEC CyberShake Project Simulations<br>● Purpose, framework<br>● Primary products<br>● Validation (to date) for hazard mapping | Rob Graves |
| ~20 minutes + 10 minutes of Q&A | Intro to SCEC Ground Motion Simulation Validation (GMSV) Group<br>● Purpose, framework<br>● Validation for building response analysis applications | Nico Luco |
| ~15 minutes | *Break* | |
| ~45 minutes + 30 minutes of Q&A | Demo: Use of BBP Simulations for *ASCE 7-16* Nonlinear Response History Procedure (NRHP)<br>● Brief overview of *ASCE 7-16* NRHP | Farzin Zareian & Ting Lin |

| | | |
|---|---|---|
| | ● Using simulations from past earthquakes for validation?<br>● Using simulations from past and scenario earthquakes | |
| ~60 minutes | *Lunch* | |
| ~45 minutes + 30 minutes of Q&A | Demo: Use of BBP Simulations for *FEMA P-58* Collapse Fragility Analysis (CFA)<br>● Brief overview of FEMA P-58 CFA<br>● Using simulations from past earthquakes for validation?<br>● Using simulations from past and scenario earthquakes | Greg Deierlein & Ting Lin |
| ~15 minutes | *Break* | |
| ~15 minutes + 15 minutes of Q&A | Access to BBP Simulations from Preceding Demos and Future<br>● Show how to get the simulations that were used in the demonstrations of *ASCE 7-16* and *FEMA P-58*<br>● Walk through files | Fabio Silva |
| ~20 minutes + 20 minutes of Q&A | Validation of Future BBP Simulations<br>● E.g. adding new distance ranges (sites), Vs30's | Phil Maechling |
| ~10 minutes + 10 minutes of Q&A | Summary of Workshop | TBD |

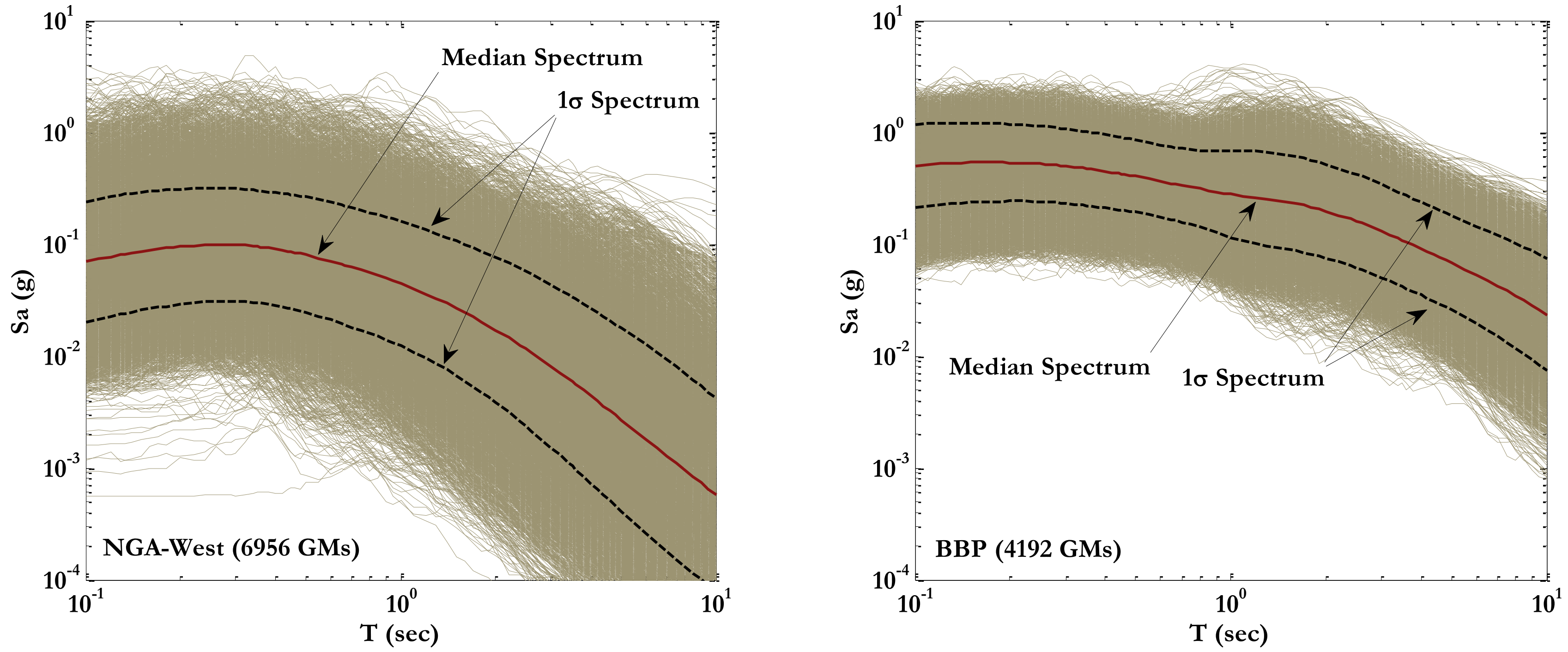

Figure 1: Psuedo acceleration response spectra for horizontal ground motion recordings from, on the left, the NGA-West database of the Pacific Earthquake Engineering Research (PEER) Center (http://ngawest2.berkeley.edu/) and, on the right, the SCEC Broadband Platform (BBP) simulations run as part of this project. The BBP simulations provide ground motions for the sparsely observed large magnitudes, close source-to-site distances, and hence high response spectra of engineering interest. Courtesy of Kuanshi Zhong, Ph.D. Student in Structural Engineering, John A. Blume Earthquake Engineering Center, Stanford University.