2014 SCEC Project #14228

Title: "Use and validation of simulated earthquakes for the nonlinear performance-assessment of tall buildings considering spectral shape and duration"

Principal Investigator: Dr. Gregory Deierlein, Stanford University (ggd@stanford.edu)

Project Co-PI: Dr. Ting Lin, Marquette University

Graduate PhD Student: Nenad Bijelić, Stanford University

ABSTRACT

To investigate how reliably physics-based simulations capture ground motion features that significantly affect structural response, we examined the nonlinear dynamic response of a 20-story moment frame building under simulated and recorded motions at different shaking intensities up to the onset of collapse. Initially, we compared the building response under sets of recorded and simulation ground motions, where the motions in each set are selected to have comparable spectral shape and significant duration. Recorded ground motions were selected and scaled from the PEER NGA database. Simulated motions were selected and scaled from the GP, SDSU and EXSIM datasets of the SCEC Broadband-Platform validation study. A fourth set of simulated ground motions was selected *without scaling* from the SCEC CyberShake database. Overall, the structural demand parameters were similar from the recorded and simulated ground motions, indicating that when ground motions have comparable elastic spectra and durations, the differences in response are statistically insignificant. The analyses do, however, highlight potential problems with using simulated motions to assess structures whose fundamental period is close to the splicing period (T~ 2 sec) used in hybrid broadband simulations. In the second part of the study, we examined the use of the SCEC CyberShake hazard characterization and ground motions as a replacement alternative to conventional seismic hazard and ground motion selection and scaling. This CyberShake comparison is ongoing, but results to date indicate that the structural response data are comparable when the underlying hazard curve is similar for the CyberShake and conventional approaches. Conversely, the results demonstrate the potential benefits of using simulated Cybershake motions in situations where the physics-based simulations capture unique geologic features that are not represented well by conventional seismic hazard analysis based on empirical Ground Motion Prediction Equations.

Performance assessment using BBP ground motions – similar spectra validation

To complement the SCEC Broadband-Platform (BBP) validation effort that focused on validation of individual spectral acceleration values [1], we have examined structural response of an archetype 20-story building [2] under sets of simulated ground motions generated in BBP runs 13.5 and 13.6. In particular, ground motions generated using the GP [3], SDSU [4] and EXSIM [5] methods were used; all recorded ground motions were obtained from the NGA database. To develop comparable sets of simulated and recorded motions, the ground motions are selected using a generalized conditional intensity measure (GCIM) target, consisting of conditional spectral shape (CS) and 5-75% significant duration (Ds). A hypothetical scenario event with M = 6.95 and R = 39.7km was used to generate the GCIM target (Figure 1c). These values of M and R are within the validation range of [1] and correspond to 50% in 30 years (50/30) hazard at a site in San Jose [6], which is chosen to be consistent with the design basis for the archetype building. Spectra for other return periods at this same site are superimposed on all available spectra from the entire NGA database (Figure 1a) and the GP simulated set (Figure 1b), showing how the 50/30 spectra (blue line, second from lowest spectra) is close to the average of these sets. On the other hand, the 2/50 and higher spectra are at the upper limits of ground motion spectra available from these ground motion sets.

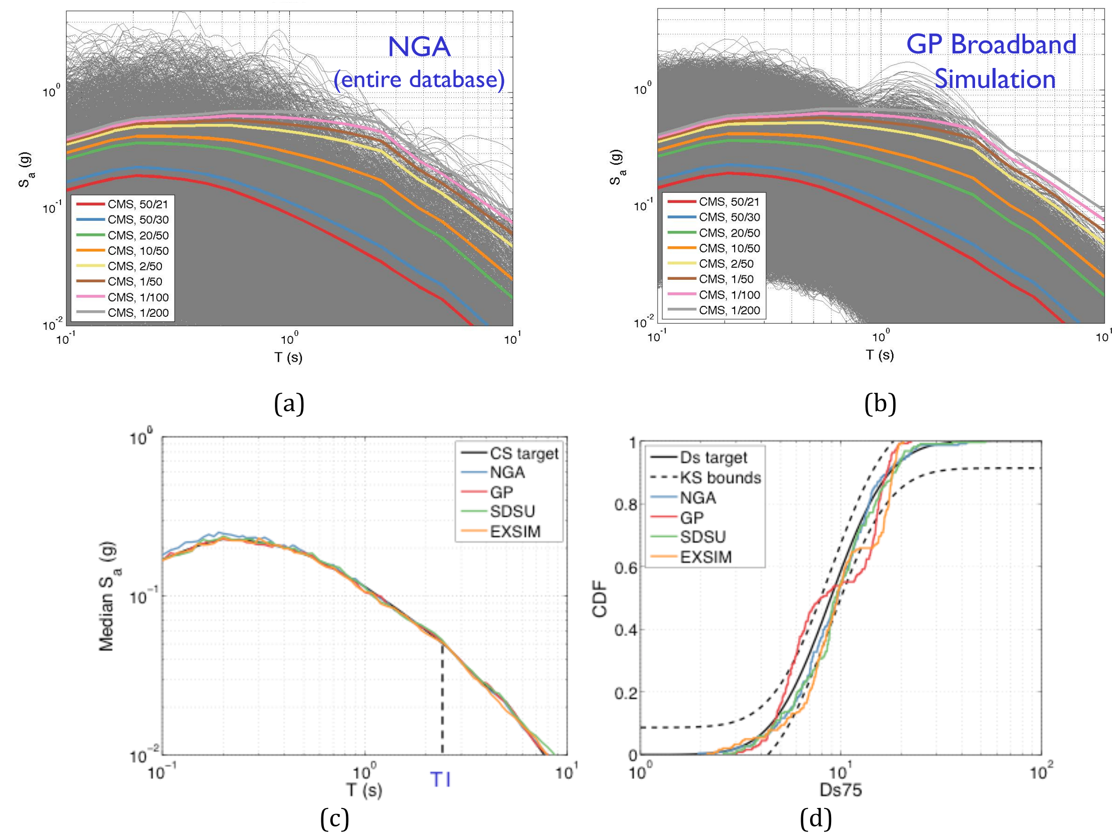


Figure 1. Match of NGA and BBP ground motions sets with the GCIM target: (a) all spectra from NGA database of recorded motions versus the target spectra for San Jose Site, (b) spectra from GP Broadband database of simulated motions to the target spectra for San Jose Site, (c) exponential of the logarithmic mean spectra for selected NGA and three BBP ground motion sets for 50% in 30 yr hazard, (b) significant duration (Ds 5-75%) for selected NGA and three BBP ground motion sets for 50% in 30 yr hazard. Each set initially consisted of 250 ground motions; pulse-like ground motions were then excluded from the selection, resulting in the following number of ground motions for each set: NGA 223, SDSU 219, GP 247, EXSIM 243. The undamental period of the 20-story archetype building (T1 = 2.6s) is used as the conditioning period.

The four ground motion sets were scaled at increasing intensities (up to a maximum scale factor of 14) to investigate the range of structural response, from linear all the way up to the onset of collapse. The structural response is modeled analyses using OpenSees with a model that captures strength and stiffness degradation. Statistical distributions of peak story drift ratios (SDR) and peak floor accelerations (PFA) are compare via hypothesis testing to investigate whether there are systematic biases in computed responses under simulated versus recorded ground motions. Two types of hypothesis tests were used: the t-test and the (non-parametric) ranksum test. The t-test was complemented by the ranksum test to relax the assumptions on the underlying distributions of response parameters and to allow for consideration of collapse cases. These analyses yield following observations (referring to data in Figure 2):

- No significant differences between peak SDRs are found when the response of the structure is in the linear range (SDR < 0.1), corresponding to hazard intensities of about 10% in 50 years or scaling factor ~4 (Figure 2a). Differences in peak SDR respond of up to 20% are observed at higher intensities (drifts up to about 0.03 in Figure 2b), but are still about within the 5% significance statistical rejection bounds.

- The SDSU and GP ground motions yield essentially same collapse response as obtained using NGA motions (Figure 2c); on the other hand, EXSIM motions seem to underestimate collapse response at higher intensities resulting in ~15% larger median collapse capacity.
- Peak SDR exceedance curves (Figure 2d), determined by integrating response with the hazard curve for the San Jose Site, show that all sets yield fairly similar responses, with largest difference in rates being about 20-30%, still within the 5% rejection region.
- Distributions of PFAs obtained using GP and SDSU methods are not significantly different from results obtained using recorded ground motions. However, PFAs obtained using EXSIM sets are significantly small that those from the other sets, reasons for which we are continuing to study.

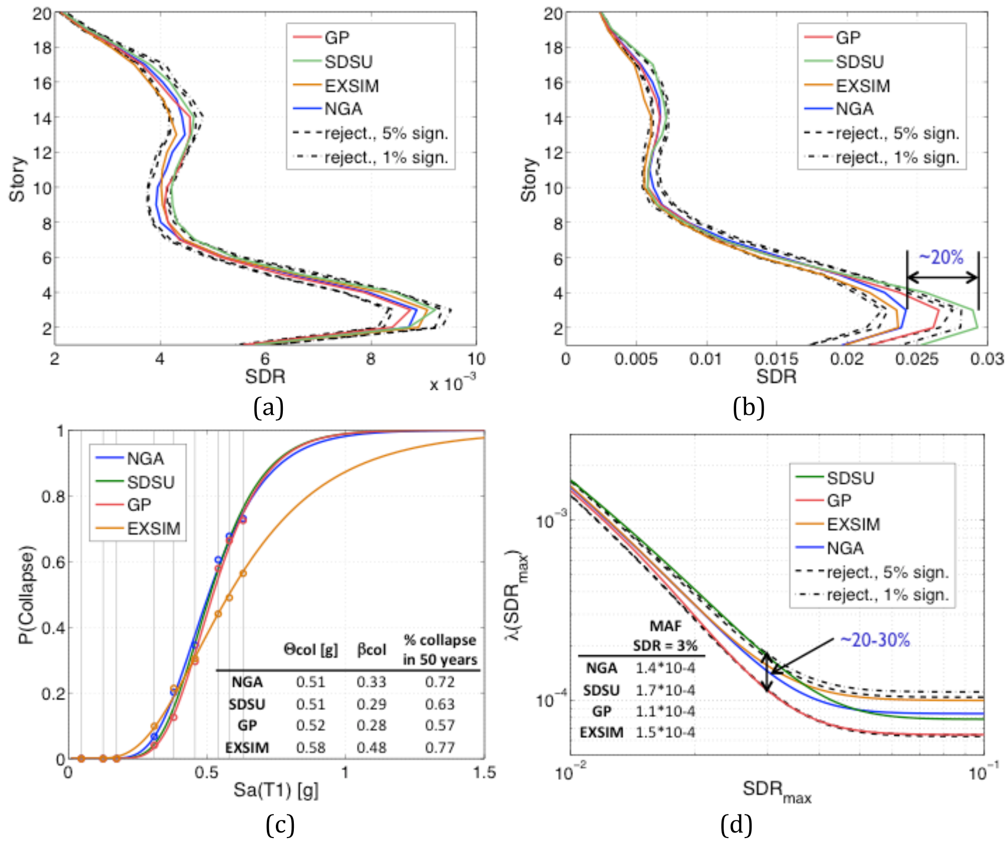


Figure 2. Results of NGA and BBP comparisons (a) Median SDRs at 10/50 yr intensity (50/30 yr sets scaled 3.7 times); (b) median SDRs at 1/100 yr intensity (50/30 yr sets scaled 9.7 times); (c) collapse fragilities; (d) drift exceedance curves of peak SDR, based on USGS hazard curve for San Jose Site.

Performance assessment using unscaled CyberShake ground motions

To further investigate how simulated ground motions can be used in design, in the second portion of our study we focused on comparing structural responses obtained using scaled recorded motions and *unscaled* simulated motions. Here we used broadband seismograms for the LA downtown site generated as part of the CyberShake project (study 13.2, siteID: LADT, runID = 831, ERF_ID = 35). Specific aspects of the study were to (a) contrast ground motions and responses selected with similar spectral intensities, and (b) contrast performance assessments obtained using conventional approaches (i.e. using PSHA/GMPE IM targets and recorded motions) versus complete reliance on CyberShake data for hazard characterization and ground motions.

For the similar spectral intensity validation, we selected CyberShake ground motions that had the same spectral intensity at specific as those with GCIM targets, obtained from PSHA for the LA downtown site. As seen in Figure 3a, for a conditioning period of T=2s there are large differences between spectral shapes of CyberShake motions and the corresponding CS targets, presumably because the conditioning period is close to the splicing period in the CyberShake simulations. On the other hand, for the conditioning period of T=3s (Figure 3b), spectra of CyberShake motions agree well with the long period portion of the CS target, although there are still significant differences for periods less than T=3s. Similar observations were made at other intensities, although the differences are less for lower intensities. Further comparisons between the CyberShake motions and hazard analysis indicate that the significant durations of the simulated motions are longer than the corresponding ground motion duration targets, e.g., median durations of simulated motions are up to 50% longer. As the CS and Ds targets are very dependent on the input assumptions (e.g. deaggregation parameters and GMPEs used) and we are looking further into reasons for these differences. Hence, these comparisons should not be interpreted as an indication of problems with the simulations, but rather as an illustration of the differences that can arise through alternative ways of describing ground motion hazards. It will be interesting to see how these observations change with the forthcoming 1Hz CyberShake motions and with further refinements to the simulations.

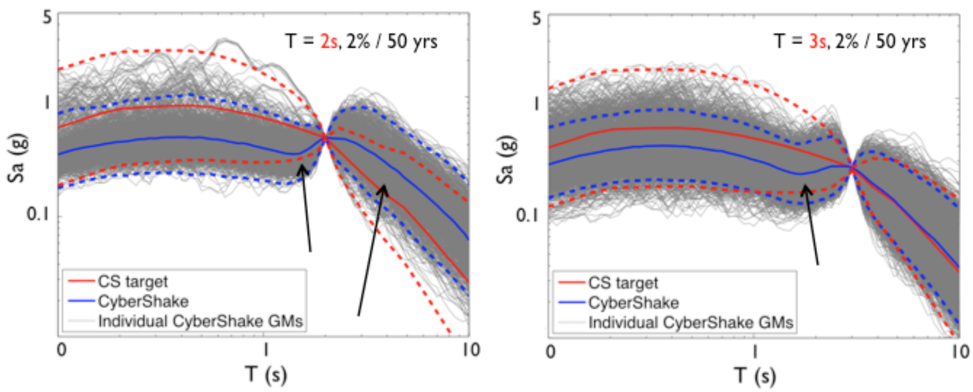


Figure 3. Comparison of CyberShake ground motions, selected to have comparable spectra intensity at the conditioning period of a conditional spectra with a 2/50 yr hazard for the LA downtown site. Conditional targets based on mean deaggragation from USGS. GMPE used: Campbell-Bozorgnia, 2008 [7]; e correlations: Baker-Jayaram, 2008 [8].

We performed structural analyses using unscaled CyberShake motions (selected to match the Sa target at T=3s) and scaled recorded motions (selected to match the CS and Ds targets, T=3s) at intensities ranging from 50% in 21 year hazards up to ~3.5 times the MCE hazard. The analysis yielded results that are similar to those from the previous BBP study, where responses to simulated and recorded motions are similar to the extent to which spectral shapes and durations of input motions are similar. For example, Figure 4a shows that median drifts at lower stories are slightly smaller for simulated motions with comparatively larger differences in higher stories. This can be attributed to higher mode effects and the difference in spectral shapes between simulated and recorded motions in the lower period range (as seen in Figure 3b). Referring to Figure 4b, the collapse fragilities based on unscaled CyberShake and scaled recorded motions are essentially the same, tending to confirm that collapse response is driven by elongated first-mode response.

Physics-based simulations, such as CyberShake, have the potential to comprehensively evaluate site-specific hazard and ground motions as an alternative to conventional approaches that rely on empirical GMPEs and scaling of recorded motions. For the LA downtown site, comparative analyses were conducted where both the seismic hazard curve and ground motions where determined from CyberShake. As shown in Figure 5a, results of such analyses indicate that building drift exceedance rates determined using the CyberSkake data are about twice those determined by conventional

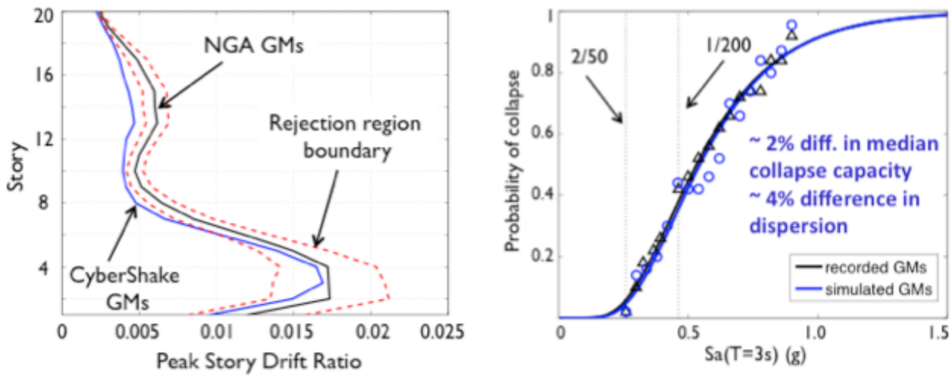
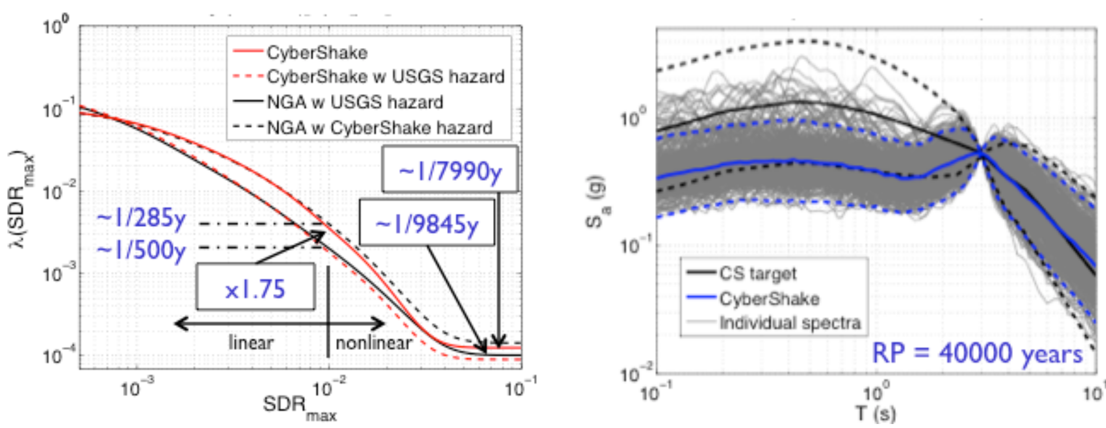


Figure 4. Structural response to unscaled CyberShake motions and scaled recorded motions: (a) median SDRs at 2% in 50 years intensity; (b) collapse fragility curves.

hazard analysis, and the collapse rates are on the order of 20% higher (Figure 5a). These differences are attributable to differences in hazard curves as well as the spectral shapes of ground motions. In particular, in the linear response range, the differences are primarily due to the hazard curves. This was confirmed from analyses that combined the ground motions from Cyberhake with the PSHA-based hazard curve and vice versa, as shown by the dashed lines in Figure 5a. On the other hand, drift exceedance curves in the nonlinear range suggest that spectral shapes of CyberShake motions are more peaked than the CS targets used in conventional approach (Figure 5b). Although the observed differences in drift exceedance and collapse performance are not too large, investigations are underway to examine whether there are instances where simulated motions could provide insight about structural response that is not captured when using recorded ground motions.



(a) (b)

Figure 5. Comparison of performance assessment obtained using site-specific data as opposed to conventional approach: (a) peak SDR exceedance curves; (b) CS targets and CyberShake ground motions for return period (RP) of 40,000 years.

Acknowledgements

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