Selection of CyberShake Time Series for Engineering Building Code Analyses

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Abstract

This report evaluates the application of CyberShake ground motions to high-rise building design in the Los Angeles region. We compare simulated ground motions against past earthquake records and empirical models. First, we considered two selected sites in the Los Angeles region with different underlying soil conditions and selected comparable suites of ground motion records from CyberShake and the NGA-West2 database according to the ASCE 7-16 requirements. We evaluated their corresponding ground motion characteristics including intensity measures, deaggregation, polarization and durations. Major observations include 1) Selected ground motions from CyberShake and NGA-West2 share similar features, in terms of intensity measures and polarization; 2) When selecting records from CyberShake, it is easy to specify magnitudes, distances and faults to match the hazard deaggregation; 3) CyberShake durations on soil are consistent with empirical models, whereas durations on rock are shorter. This inconsistency may be due to limited recorded earthquakes. 4) Occasional excessive polarization in ground motion is produced by the San Andreas fault. Those records are usually excluded after the ground motion selection.

Selected results are presented below. The results provide further insights regarding the value of physics-based ground motion simulations for engineering use.

1 Introduction

Ground motion records are used as input for seismic structural analysis and design. Past earthquakes have served as the main data source for ground motion selection, but the use of simulated ground motion records is also permitted by ASCE7-16. In the past few years, simulation models have been developed using different methodologies, including stochastic (Graves and Pitarka, 2004; Mai et al., 2010) and hybrid (Boore, 2003; Pousse et al., 2006) approaches. Compared to recorded ground motions, simulations provide data for infrequent situations such as large magnitude events and ground motions observed on rock sites, close-to-rupture sites, and sites with low seismicity. However, validation is necessary to ensure

that these simulation outputs are accurate and suitable for seismic engineering analysis and design.

There have been various validations of ground motion simulation conducted with different focuses and methodologies. Studies have been done to compare simulated ground motions with recordings from real earthquakes. Researchers have evaluated one or more ground motion characteristics, such as intensity measures (Aagaard et al., 2008; Dreger et al., 2015; Burks and Baker, 2014), duration parameters (Hartzell et al., 1999; Afshari and Stewart, 2016) and frequency content (Rezaeian et al., 2015). Others have evaluated simulated ground motions by comparing the dynamic responses of single-degree-of-freedom structures or multiple-degree-of-freedom structures (Bazzurro et al., 2004; Iervolino et al., 2010; Galasso et al., 2012, 2013; Jayaram and Shome, 2012). In particular, Bijelic et al. (2014) and Bijelic et al. (2017) have conducted evaluation considering nonlinear dynamic responses of high-rise buildings subjected to recorded and simulated ground motions. More recent research also includes ground motion prediction equations in the validation process (Frankel, 2009; Star et al., 2011). Past validation studies have considered various simulation sources, including SCEC Broadband Platform (BBP) (Bijelic et al. 2014; Burks and Baker, 2014; Burks et al., 2015; Dreger et al., 2015; Afshari and Stewart, 2016), ShakeOut (Star et al., 2011) and simulation scenarios (Aagaard et al., 2008; Galasso et al., 2012, 2013; Jayaram and Shome, 2012). CyberShake, an example of hybrid broadband simulations, is a physics-based seismic hazard model developed by Southern California Earthquake Center. Bijelic et al. (2017) validated CyberShake ground motions for nonlinear performance of tall buildings in the Los Angeles region. Besides this, limited evaluations have been done using CyberShake with a focus on its application for tall buildings analysis and design following the code selection process.

This study aims to evaluate the suitability of simulated ground motions produced by CyberShake for engineering use in high-rise building design in the Los Angeles region. In this project, we validated simulated ground motions against past earthquake records and empirical models. In particular, we compared ground motion records for two sites with different underlying soil conditions according to ASCE 7-16 requirements. We analyzed and compared several ground motion metrics, including intensity measures, deaggregation, duration and polarization among CyberShake, NGA-West2 and some empirical models. Our evaluation process consists of four parts: 1) ground motion selection from CyberShake and NGA-West2 according to ASCE 7-16 requirements, 2) comparison of deaggregation and polarization of the selected ground motions between the two sources, 3) duration validation between CyberShake and empirical models, and 4) analysis of polarization effect generated by CyberShake.

2   Data Sources

We selected simulated ground motion records from CyberShake and recorded ground motions from the NGA-West2 database. CyberShake is a physics-based seismic hazard model, part of the Southern California Earthquake Center Community Modeling Environment (Graves et al., 2011), and has conducted ground motion simulations in California since 2009. For this project, we selected ground motions from the latest available simulation (Study 15.4),
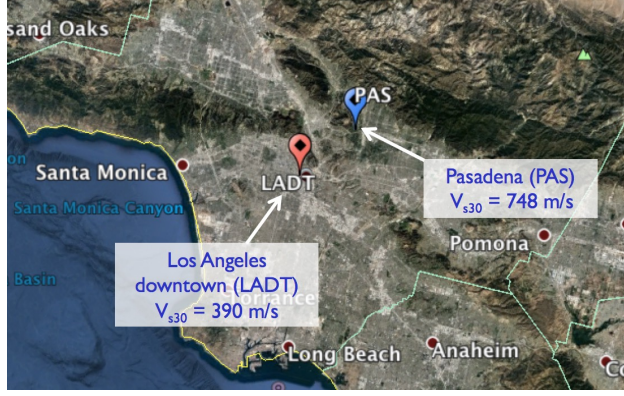
Figure 1: Locations of two selected sites: Los Angeles downtown (LADT) and Pasadena (PAS)

which was conducted for more than 300 sites with 5km spacing in southern California and considered all ruptures within 200km from each site. For a given site, there are around 7,000 ruptures and 415,000 earthquake events identified. This implies that around 415,000 simulated ground motion records are available for a given site. The simulation uses the Graves and Pitarka (2014) rupture generator to describe slip distributions and hypocenter locations for each rupture. Graves and Pitarka (2014) introduce a hybrid broadband ground motion simulation methodology, which includes a deterministic approach at frequencies below 1 Hz and a stochastic approach at frequencies above 1 Hz. The NGA-West2 database provides ground motion records from shallow crustal earthquakes worldwide, including 333 global events with magnitudes greater than 5.0 and 266 events in California with magnitudes between 3.0 and 5.45. The NGA-West2 database consists of 21,336 ground motion records, with magnitudes between 3.0 and 7.9, site-rupture distances between 0.05km and 1533km, and Vs30s between 94m/s and 2100m/s (Ancheta et al., 2014).

3   Ground motion selection

We chose two sites with different soil conditions for analysis: Los Angeles downtown (LADT) with a latitude of 34.05204, longitude of -118.25713, and Vs30 of 390m/s; and Pasadena (PAS) with a latitude of 34.148426, longitude of -118.17119, and Vs30 of 748m/s. Their locations are illustrated in Figure 1.

We first defined the target spectra for the two sites. According to ASCE 7-16 building code requirements, we used a site-specific uniform hazard spectrum with a return period of 2,475 years and a risk coefficient factor of 0.9 to determine the target spectrum for a given site. We selected 11 records from CyberShake and the NGA-West2 databases respectively to match the target spectrum from periods between 1s and 7.5s. The 11 records have the minimum errors among all available records. Each error is defined as

$$Error_{selected} = \sum_{j} (ln(Sa_{selected}(T_j)) - ln(Sa_{targ}(T_j)))^2 \qquad (1)$$

where $Sa_{selected}(T_j)$ is the peak response of the selected record at period T_j, and $Sa_{targ}(T_j)$

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is the target spectrum at the same period.

During selection, we restricted magnitudes and distances according to the hazard deaggregation results, which reveal the contributions of different magnitude-distance pairs to the seismic hazard at a site for a given shaking period. Figure **??** (a), (b), (d), and (e) are deaggregation results generated using the USGS 2014 hazard analysis, at shaking periods of 1s and 5s, with a return period of 2,475 years. The deaggregation results for the two sites are similar, with a major contribution from earthquakes that are within 20 km from the site and have magnitudes from 6.5 to 8. The deaggregation result changes with shaking periods. Earthquakes at longer distances (>40km) and with larger magnitudes contribute more to the hazard at longer periods (5s). For these two sites, they are mainly events from the San Andreas fault. According to the deaggregation results, when selecting records from the NGA-West2 database, we constrained the range of Vs30 as ±150m/s of the value in CyberShake, the range of magnitude as 6 to 10, and the range of site-rupture distance as 0km to 60km. When selecting records from CyberShake, we took two ground motion records generated from the San Andreas fault to include for the high seismic hazard from the San Andreas fault. We allowed a maximum scale factor of 4 in the NGA-West2 selection, but no scaling in the CyberShake selection. Figure 2 summarizes the response spectra of the 11 selected records, in comparison to the target spectrum.

4   Conclusions

This study evaluates CyberShake ground motions for engineering application in tall building design. An engineering practice-oriented process is introduced to validate simulated ground motions against records in the NGA-West2 database, as well as empirical models. We validate CyberShake by studying four properties: intensity measures, deaggregation, duration parameters and polarization effect.

We selected ground motions satisfying ASCE 7-16 requirements from CyberShake and NGA-West2. Two sites, Los Angeles downtown (LADT) and Pasadena (PAS), with different underlying soil conditions were considered. The target spectrum was computed using a site specific uniform hazard spectrum with a return period of 2,475 years and a risk coefficient factor of 0.9. Eleven ground motion records were identified to match the target spectrum at periods between 1s and 7.5s.

We validated CyberShake durations against three empirical models, Afshari and Stewart (2016), Bommer et al. (2009) and Abrahamson and Silva (1996). Some similar patterns are observed for all sources: 1) for a given distance, larger magnitudes result in longer durations; 2) sites with longer distances undergo longer shaking durations; 3) durations observed on soil condition are consistently longer than those on rock. Overall, results from CyberShake at the soil site (LADT) match well with empirical models for magnitudes less than 7.5. For the rock site (PAS), most CyberShake durations are shorter than the outputs from empirical models. The inconsistency can be partly due to the limited recorded earthquakes with large magnitudes, as well as limited records on rock sites.

In conclusion, we analyzed a number of ground motion metrics to provide further insights regarding the value of physics-based ground motion simulations for engineering use. Results suggest that ground motions from CyberShake and the NGA-West2 database share impor-
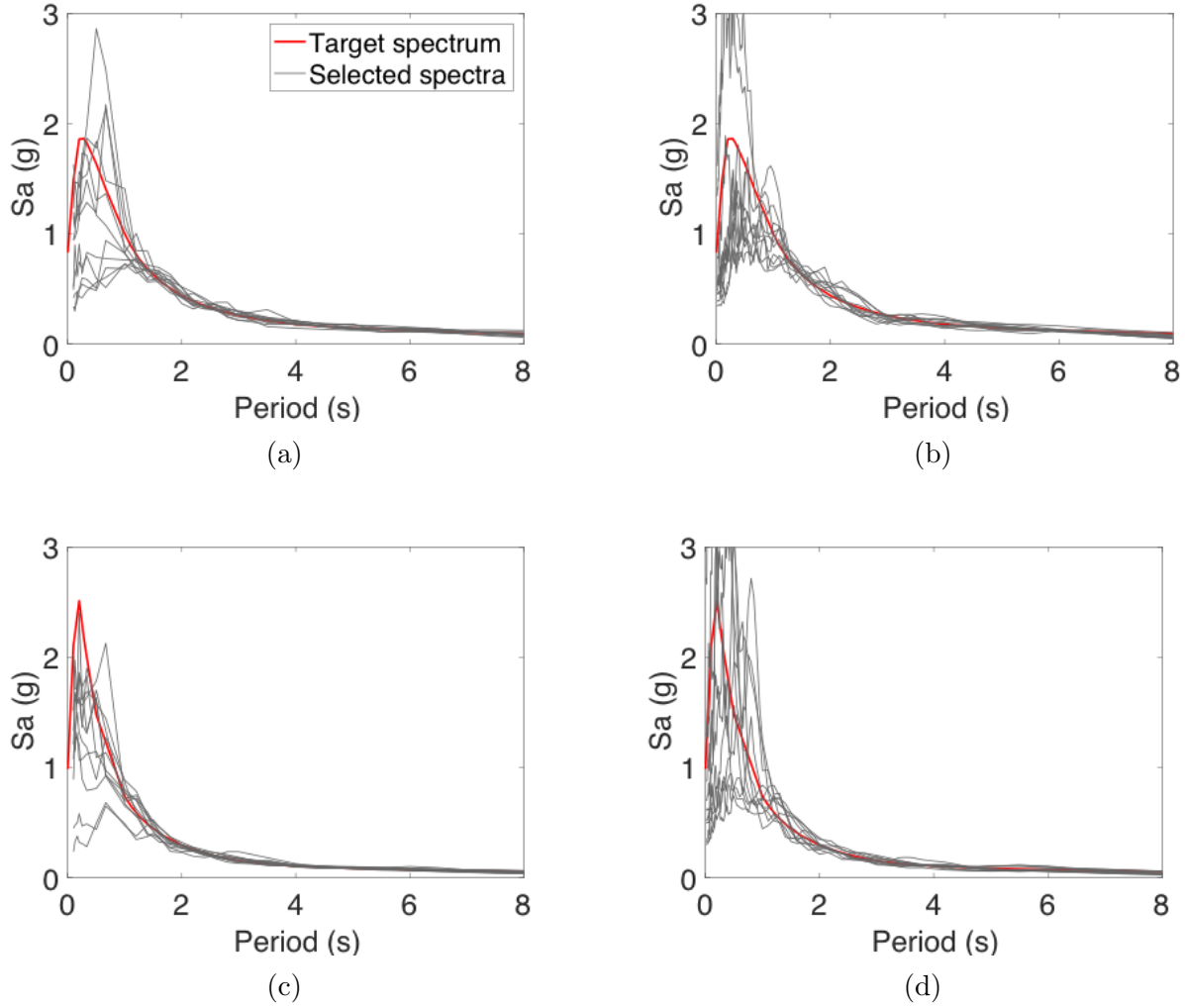
Figure 2: Comparison of target spectrum and selected response spectra from (a) CyberShake for LADT, (b) NGA-West2 for LADT, (c) CyberShake for PAS, (d) NGA-West2 for PAS

tant features in terms of intensity measures, deaggregation and polarization. We observed the overestimation of polarization produced by the San Andreas fault, but those records can be excluded after ground motion selection. This study serves as a preliminary validation of CyberShake, from which we conclude that CyberShake ground motions are suitable for engineering practice.

Additional details from the study are forthcoming in an in-preparation journal article aimed at engineering audiences.