Selection of Time Series in Support of the Committee for Utilization of Ground Motion Simulations

PI: Jack W. Baker Co-PI: Sanaz Rezaeian

Graduate Researcher: Ganyu Teng

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1 Introduction

Numerical 'physics-based' simulations of ground motions are an increasingly important resource for engineers, and play a role in both ground motion hazard analysis and response history analysis. One advantage of simulations versus recorded ground motion data is the essentially infinite amount of data that can be produced, for a wide range of rupture and site characteristics. Conversely, the massive amount of potential data can make it difficult for a structural design team to locate appropriate time series for use in analysis quickly. Considering these circumstances, this report documents a subset of time series selected from the CyberShake platform. A small number of time series (i.e., 320 two-component ground motions) were selected from rupture scenarios of interest for engineering analysis in Southern California, and were screened to have suitable response spectra and vetted to omit time series with unusual or problematic characteristics. This report describes the objectives of the project, and documents the process used to select the time series.

CyberShake is a Southern California Earthquake Center (SCEC) high-performance computing platform producing ground motions for all earthquake sources in the Los Angeles region (Graves et al., 2011). Earthquake ruptures are described kinematically, with slip amplitude, direction and timing across the fault specified based on models calibrated from inversions of past earthquake sources and dynamic rupture simulations (Graves and Pitarka, 2015). The resulting seismic waves are propagated through a three-dimensional velocity model that incorporates the effects of sedimentary basins and other features in the crust. Because these simulations reflect the physical processes associated with earthquake rupture and wave propagation, they and other similar approaches are often referred to as 'physics-based.' The version 15.12 CyberShake simulations used here include stochastic high-frequency energy in addition to the deterministic low-frequency simulations, and thus have realistic ground motion amplitudes at all frequencies of interest for engineering analysis. At each of 336 sites in the Los Angeles region, more than 400,000 ground motions are available, representing multiple rupture realizations from each on-fault ruptures within 200 km of each site, as defined in the Uniform California Earthquake Rupture Forecast, Version 2 (Field et al., 2009). Simulations from this platform have been used previously for ground motion hazard (Crouse and Jordan, 2016) and engineering analysis (Bijelić et al., 2019b,a; Teng and Baker, 2019).

Ground motion simulations can be used for several purposes in engineering analyses (Bradley et al., 2017). They can provide an indication of the ground shaking amplitude resulting from future earthquakes–a metric needed for seismic hazard analysis. And because simulations can be produced from circumstances with limited empirical data from ground motion recordings, they can supplement predictions from empirically calibrated ground motion models typically used for hazard analysis (Goulet et al., 2015; Dreger et al., 2015). Hazard analysis is the original primary application of the CyberShake platform (Graves et al., 2011; Jordan and Callaghan, 2018).

Additionally, given a hazard analysis and target spectrum, simulated ground motion time series can be used as inputs to a response history analysis (e.g., ASCE, 2016; Moehle et al., 2017; LATBSDC, 2008). To date, engineering analysis studies have found the CyberShake ground motions having desired response spectra generally have realistic features of engineering interest, but found that basin effects may in some cases produce larger structural demands than comparable recordings with no basin effects (Bijelić et al., 2019b). This motivates our desire to provide time series from this platform for engineers needing to consider such effects.

When performing ground motion selection for this effort, we took the perspective of an engineering consultant looking to utilize ground motions in a design or assessment project in the Los Angeles area. In projects requiring time series for response history analysis, a site-specific spectrum (or spectra) will be utilized, and that spectrum will differ from any standard spectrum that could be developed for this project (e.g. ASCE, 2016; Moehle et al., 2017; LATBSDC, 2008). So it is not possible to specify a spectrum for this project Further, the projects could take place at a number of locations, so we cannot consider only a single location here. For these reasons, we determined that it would be best to select ground motions with a range of spectral amplitudes and shapes, rather than tightly match any specific spectrum. These consultants will be used to using relatively straightforward interfaces to access existing libraries of recorded ground motions, and may find the SQL-based interface to the unabridged CyberShake database to be onerous to learn. Additionally, some pre-screening and pre-vetting of the selected ground motions will add value to an engineering consultant who may not have prior experience reviewing ground motion simulations, and who may need to justify the quality of the motions to a peer review panel and other members of the project team. The process described below was developed with these considerations in mind.

2 Ground Motion Selection Approach

The process used to select the ground motions consisted of the following steps, which are described in the following subsections

1. Specify candidate locations and site conditions for disaggregation of hazard.
2. Determine earthquake scenarios (i.e., magnitudes and distances) of interest based on largest contributors to hazard, using disaggregation calculations.
3. Generate target response spectra from the distributions of spectral values predicted from a ground motion model, for each scenario.
4. Search the CyberShake database to find time series that match the target response spectra, magnitude and distance values of interest.
5. Review the identified time series.
6. Produce documentation.

2.1 Candidate Locations and Site Conditions

We considered 53 locations in the Los Angeles region. For each location, two site conditions were considered, as quantified by average shear wave velocity values over the top 30m of the site of $V_{S,30} = 365$ and 760 m/s.

2.2 Disaggregation Calculations

For each of the aforementioned candidate locations and site conditions, we performed disaggregations at four spectral periods: 0.2, 1, 2, and 5 seconds. The disaggregations are from the most recent USGS National Seismic Hazard Model (Petersen et al., 2019), at probabilistic (risk-targeted) spectral acceleration values derived for the 2020 NEHRP Recommended Seismic Provisions (reference). Each disaggregation results in a list of fault sources that contribute significantly to the total hazard, with respective mean earthquake magnitudes and mean source-to-site distances.

The magnitude and distance values for all locations, periods, and site conditions are shown in Figure 1. As expected, the MCE-R amplitudes for all cases are resulting from large magnitude ruptures at small distances. In contrast, the magnitude and distance values of the NGA-West2 ground motions are also shown in Figure 1, indicating that the large majority of available recordings are from smaller-magnitude and larger-distance conditions, and thus motivating the collection of the data described herein.

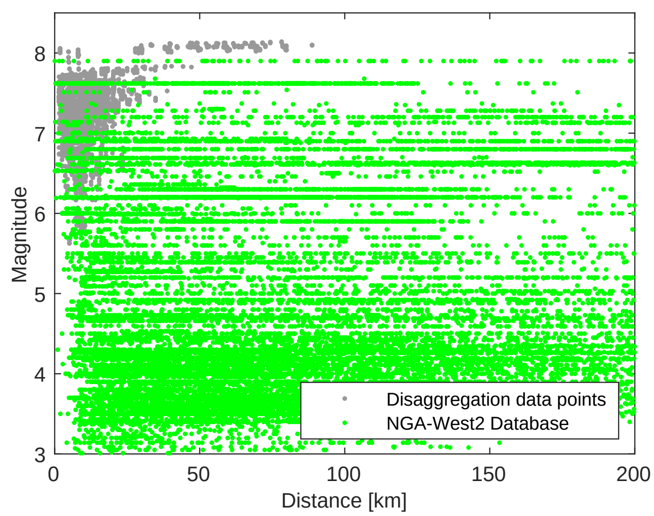

Figure 1: Comparison of disaggregation targets and NGA-West2 database (Ancheta et al., 2014).

To understand some patterns in the results, Figure 2 shows disaggregation results for particular site conditions and spectral periods. Additionally because each point in the figure has a different percent contribution to hazard, an estimated probability density function was also computed for the data, using a kernel smoothed estimate of the total contributions associated with each magnitude and distance value. Contours of the resulting estimates are also shown in the figure.

2.3 Target Scenario Selection

We then focused on rupture scenarios that appear frequently in disaggregation, and where few recordings are available (i.e., we did not worry about small-magnitude scenarios because they are already available in recorded ground motion databases). Figure 3 shows the selected target scenarios.

The CyberShake database was then filtered to identify ground motions that matched the target scenario conditions, within some bounds ($M \pm 0.15$, $R \pm 5$ km, $V_{S,30} \pm 20$ m/s). Figure 3 shows the bounds of the selection criteria, around each of the four scenarios, and Table 1 shows the number of available CyberShake time series for each scenario.

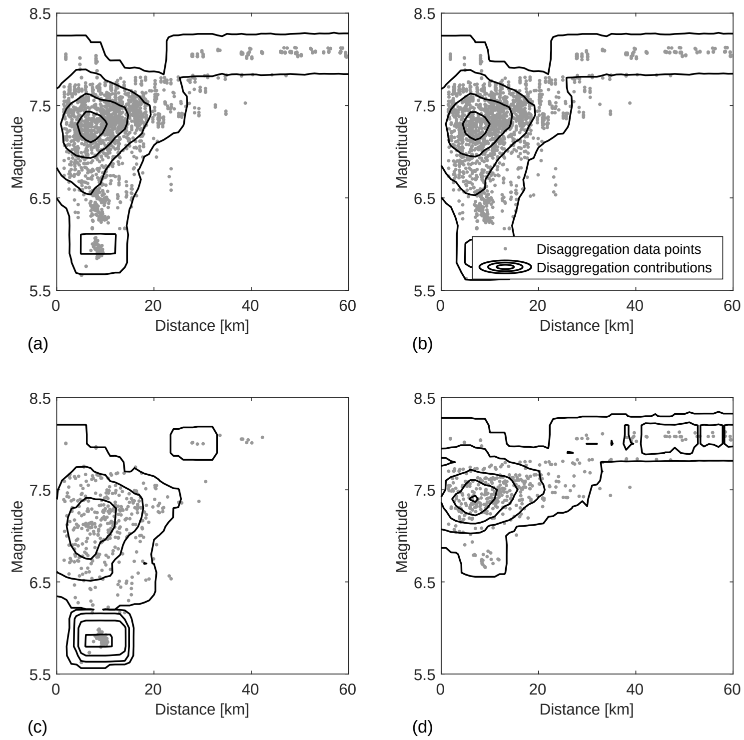

Figure 2: Disaggregation values for subsets of cases. (a) $V_{S,30}$ = 760 m/s, all periods. (b) $V_{S,30}$ = 365 m/s, all periods. (c) $V_{S,30}$ = 365 m/s, T =0.2s. (d) $V_{S,30}$ = 365 m/s, T =5.0s.

2.4 Generate Target Response Spectra

Simply constraining the rupture and site characteristics for ground motion selection still leaves millions of available candidate time series (Table 1). Typical engineering ground motion selection would further narrow the pool of candidate time series by choosing ground motions whose spectra match the site-specific target spectrum. But since no target spectrum is available in this exercise, we proceeded by sampling general response spectra consistent with the scenario rupture conditions. That is, for each magnitude, distance and site condition, we sampled a response spectrum (with variability and period-to-period correlation) using the predictive model of Chiou and Youngs (2014). Forty spectra were sampled for each scenario, and for each sample the CyberShake time series with best match to the sample was selected. This ensures that only CyberShake ground motions with 'reasonable' amplitudes were selected (per an empirical model prediction) and ensures that the selected motions have amplitudes of engineering interest. This approach has been used previously by the PI for selection of reference sets of recorded ground motions (Baker et al., 2011). Further documentation of this approach will be provided in an in-development publication.

2.5 Review of Results

Several stages of review were undertaken, and are still underway. The approach, methodology and draft results were presented several times to the SCEC Ground Motion Simulation Validation (GMSV) Technical Activitiy Group (TAG). These presentations produced valuable comments on what metrics to include in the results, and how to document process. Further review is underway,

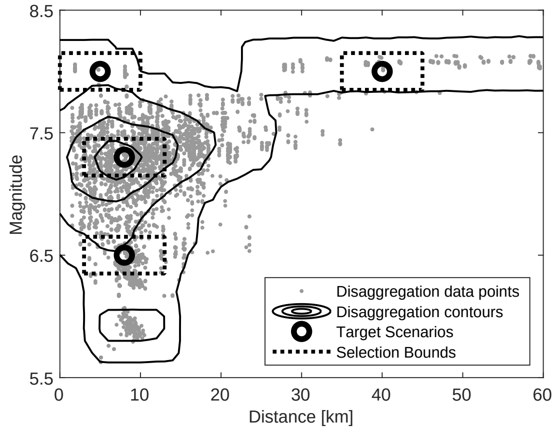

Figure 3: Disaggregation values for all cases, plus target scenarios.

Table 1: Number of site-rupture pairs and number of ground motions available for each considered rupture scenario.

Magnitude	Distance (km)	V_{S30} (m/s)	# of site-rupture pairs	# of ground motions
8	5	760	5,553	2,075,381
8	5	365	2,444	904,177
8	40	760	2,031	725,068
8	40	365	890	311,188
7.3	8	760	4,847	511,899
7.3	8	365	2,166	233,708
6.5	8	760	1,904	33,487
6.5	8	365	943	16,445

and will be utilized when finalizing the results to include.

2.6 Documentation and Repository

A data repository with DOI will be prepared to archive these data. Conversations are underway with SCEC IT personel to establish this repository. The repository will contain numerical data of the time series, response spectra and metadata. Additionally, a report will provide plots of response spectra and time series (acceleration, velocity, displacement) for each ground motion component. The following metadata fields will be provided for each ground motion: Station name and ID, Site $V_{S,30}$ (average shear wave velocity in the top 30m), Shortest distance to the rupture, Earthquake Source Name, Magnitude, An indicator of the presence of a velocity pulse, and the period of that pulse if it is present (Shahi and Baker, 2014), 5-75% significant duration, Hypocenter Latitude, Hypocenter Longitude, Hypocenter Depth, 5%-damped RotD50 response spectra at 30 periods between 0.1 and 10 seconds, Time series file names.

The ground motion data are also loaded into a ground motion selection software repository at `https://github.com/bakerjw/CS_Selection`, so that the ground motions can easily be searched using the same approach as is available for searching libraries of recorded ground motions (Baker and Lee, 2018).

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