DEVELOPMENT OF NEW GROUND-MOTION MAPS FOR LOS ANGELES BASED ON 3-D NUMERICAL SIMULATIONS AND NGA WEST2 EQUATIONS

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Abstract

The Utilization of Ground Motion Simulation (UGMS) committee of the Southern California Earthquake Center (SCEC) is currently developing risk-targeted Maximum Considered Earthquake (MCE_R) maps for possible inclusion as an amendment to the ASCE 7-16 edition of the Los Angeles City Building Code (LACBC). These maps are scheduled for release in 2017. The maps will be based on 3-D numerical ground-motion simulations and ground motions computed using the empirical ground-motion prediction equations (GMPEs) from the Pacific Earthquake Engineering Research (PEER) Center NGA West2 project. A web-based lookup tool, similar to the USGS lookup tool, will be posted so users can obtain the MCE_R response spectrum for a specified latitude and longitude and for a specified site class or 30-m average shear-wave velocity, V_{s30}. The acceleration ordinates of the MCE_R response spectrum will be provided at multiple natural periods in the 0 to 10-sec band; values of S_{DS} and S_{D1}, per the requirements in Section 21.4 of ASCE 7-16, will also be listed.

Introduction

The ultimate goal of the UGMS committee, since its establishment by the SCEC in the spring of 2013, has been to develop improved long-period response spectral acceleration maps for the Los Angeles region for inclusion in the 2020 NEHRP Seismic Provisions, ASCE 7-22 standard, and LACBC. In the interim, MCE_R maps are currently being developed for possible inclusion as an amendment to the ASCE 7-16 edition of the LACBC.

The 20-member UGMS committee consists of seismologists, geotechnical engineers, and structural engineers, mostly from California. This mix of technical disciplines was considered essential if the maps were to be accepted by the structural engineers of southern California and local building officials. Various calculations leading to the production of the MCE_R maps are performed by SCEC technical staff under the direction of the UGMS committee.

The work of the UGMS committee is being coordinated with (1) the SCEC Ground Motion Simulation Validation Technical Activity Group (GMSV-TAG), (2) other SCEC projects, such as CyberShake and the Uniform California Earthquake Rupture Forecast (UCERF) model of earthquake recurrence, and (3) the USGS national seismic hazard mapping project.

Background and Motivation for Improved Long Period Ground Motion Maps

Section 11.4 in the current ASCE 7-10 (and forthcoming ASCE 7-16) standard specifies a general procedure for developing MCE_R response spectral accelerations at intermediate and long periods. These long period accelerations depend on two parameters, S_{M1} and T_L, where S_{M1} is the MCE_R response spectral acceleration at 1-sec period that accounts for the effect of the local site geology through the site coefficient, F_v, and T_L is the period that defines the transition in the MCE_R spectrum from constant spectral velocity to constant spectral displacement.

The T_L parameter was introduced in the ASCE 7-05 standard to provide a more realistic estimate of the response spectrum at long periods. The values of T_L vary from 4 sec to 16 sec depending on location in the US. During its development, deficiencies in the T_L concept were recognized, but a better representation of the long period motions was not possible at the time because the existing GMPEs did not extend to long periods.

The subsequent NGA West and NGA West2 projects, culminating in 2008 and 2013, produced GMPEs for computing response spectra to 10-sec period from shallow crustal earthquakes in the western US. Although these GMPEs were derived from an extensive world-wide ground-motion database, relatively few truly strong ground motion records in this database were from earthquakes in the Los Angeles area, where the effects of the complex 3-D basin structures were known to have significant influences on long period motions. Furthermore, the earthquakes on the local faults contributing to the MCE_R motions in Los Angeles have not occurred during the last several decades when the region was populated with arrays of strong motion instruments.

The available ground motion data for southern California did suggest a correlation between long period ground motions and basin depth. Thus, NGA West, NGA West2, and a few previous generation GMPEs incorporated a basin depth term to model the effect of the basins. However, this parameterization ignores the 3-D effect, as well as the location and orientation of the fault rupture with respect to the basins. Recognizing this deficiency in the empirical GMPEs, SCEC launched a program to simulate ground motions numerically using a physics-based 3-D fault-rupture and wave-propagation model of Southern California. The computations were done with the CyberShake platform that utilized supercomputers to generate millions of simulations covering the range of potential moderate to large magnitude earthquakes on Southern California faults included in the UCERF models the USGS has used to develop the MCE_R ground-motion maps for the region.

The potential feasibility of using CyberShake to develop long period ground motion maps was demonstrated by SCEC (Graves et al., 2010; Wang and Jordan, 2014), and it eventually led to the formation of the SCEC UGMS committee.

MCE_R Response Spectra Generated by UGMS for Southern California

MCE_R response spectra were computed separately for the NGA West2 GMPEs and CyberShake to obtain indications of the differences in these spectra at sites outside and within the region's basins. The GMPE-based MCE_R response spectra were computed by substituting the appropriate values of the basin-depth terms, $Z_{1.0}$ and $Z_{2.5}$ (the depths to the tops of the layers with shear-wave velocities of 1.0 km/sec and 2.5 km/sec), and the V_{s30} value from Wills and Clahan (2006), into the Abrahamson et al. (2014), Boore et al. (2014), Campbell and Bozorgnia (2014), and Chiou and Youngs (2014) GMPEs and conducting the seismic hazard analyses according to the procedures in Chapter 21 of the ASCE 7-10 standard.

The MCE_R response spectra were initially computed at 14 sites in southern California (Figure 1); however, the spectra at four of these sites (PAS, CCP, LADT, and COO) in the Los Angeles area illustrate the general trends observed at other sites. The PAS site (old seismological laboratory of the California Institute of Technology) is a rock site; the CCP (Century City Plaza) and LADT (downtown Los Angeles) sites are near the edge of the Los Angeles basin; and, the COO (Compton) site is in the deep part of the Los Angeles basin. The MCE_R response spectra at these four sites are shown on log-log plots in Figure 2, where the vertical axis is 5% damped pseudovelocity, PSV, selected to better illustrate the differences between the NGA West2 and CyberShake MCE_R response spectra, and the horizontal axis is natural period, T. The CyberShake-based response spectra at the three basin sites are greater than the GMPE-based response spectra at the longer periods; this difference is greatest for the COO site, where the CyberShake-based response spectra are ~50% greater than the GMPE-based response spectra at a natural period T = 5 sec, and ~100% greater for T = 7 – 10 sec.

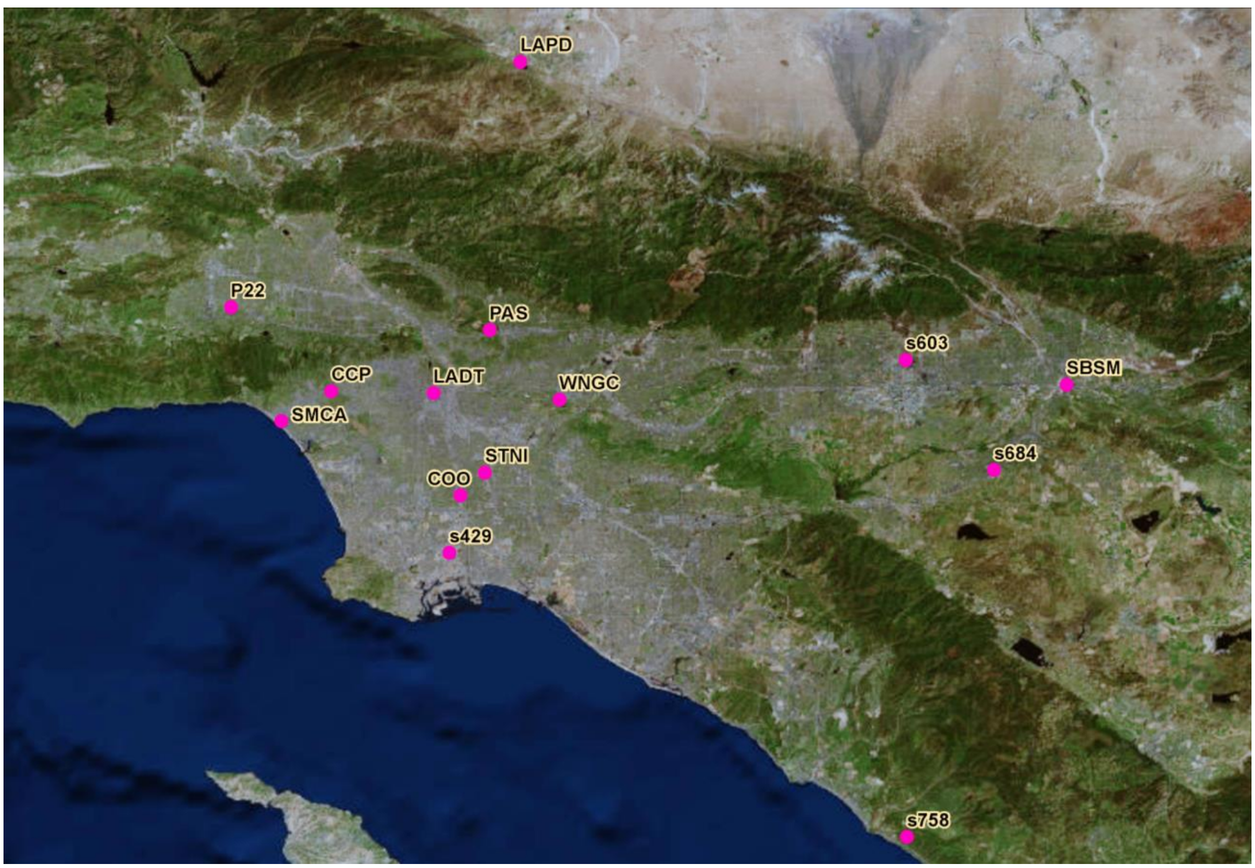

Figure 1. Location of 14 of the CyberShake sites.

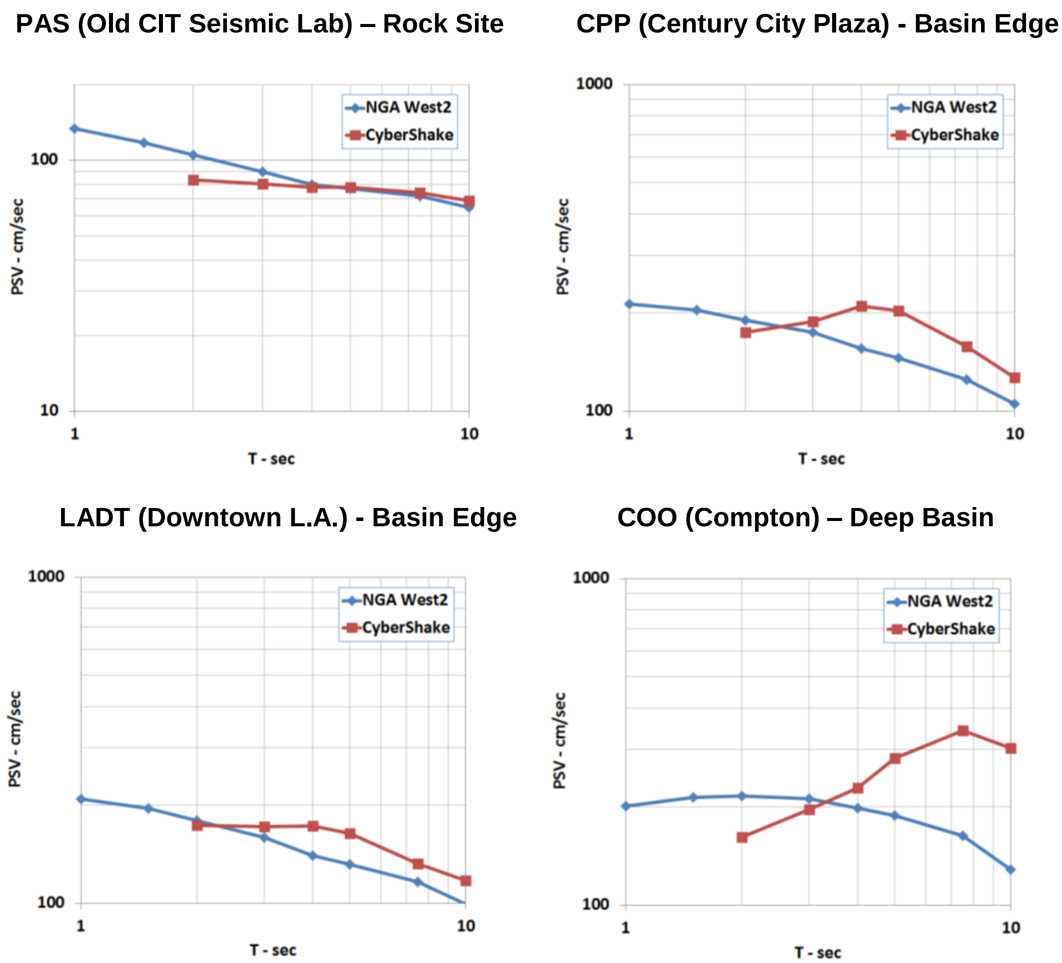

Figure 2. PSV MCE$_R$ response spectra at PAS, CCP, LADT, and COO sites.

Based on MCE$_R$ response spectra computed at these four sites and 59 other sites in southern California, the UGMS committee developed an approach to combine the MCE$_R$ response spectra from the NGA West2 GMPEs with the MCE$_R$ response spectra from CyberShake. The approach is illustrated in the logic tree shown in Figure 3. The final MCE$_R$ response spectra are the weighted geometric average of the MCE$_R$ response spectra from the NGA West2 GMPEs and from the CyberShake simulations; the weights assigned to each vary depending on the natural period, T, with the MCE$_R$ response spectra from the NGA West2 GMPEs receiving all the weight for $T \leq 1.0$ sec. As T increases, the weights for the MCE$_R$ response spectra from the NGA West2 equations decrease, and the weights for the CyberShake MCE$_R$ response spectra increase; for $T \geq 5.0$ sec, the weights are equal. An additional requirement, namely that these "averaged" MCE$_R$ response spectra cannot be less than the MCE$_R$ response spectra from NGA West2 equations, was imposed to account for the underestimation of the CyberShake MCE$_R$ response spectra at $T < \sim 2$ sec, due to the size of the mesh representing the 3-D velocity structure for southern California; this requirement also resulted in smoother MCE$_R$ response spectra.

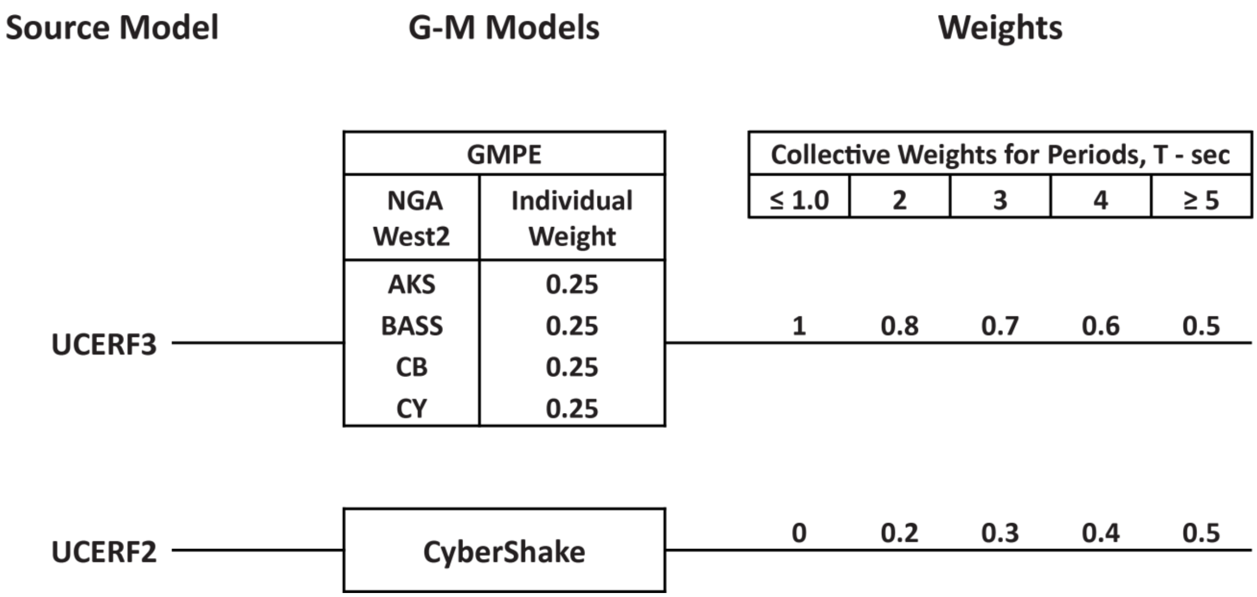

Figure 3. Logic tree illustrating the weights applied to NGA West2 and CyberShake. UCERF is Uniform California Earthquake Rupture Forecast recurrence model. UCERF2 was developed in 2008; this model was updated to UCERF3 in 2014.

The resulting MCE_R response spectra for the LADT and COO sites are shown in Figures 4 and 5, respectively; these spectra are labeled "Site-Specific". In each figure the left-hand plot is log (PSV) versus log T, and the right-hand plot is linear S_a versus linear T, where S_a is the response spectral acceleration, $S_a = (2\pi/T)$ PSV. Also in the left-hand plot is the ASCE 7-16 MCE_R response spectrum constructed from the S_{MS} and S_{M1} values, which were derived from the 2014 USGS map values of S_S and S_1 for the sites and the applicable site coefficients, F_a and F_v, in the ASCE 7-16 standard. The LADT and COO sites were Site Class C and Site Class D, respectively; and, T_L = 8 sec for both sites.

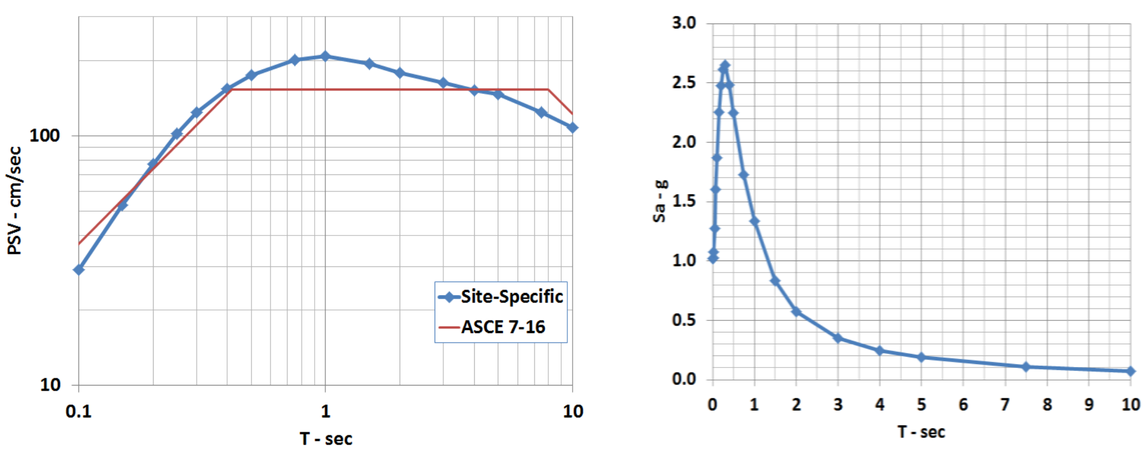

Figure 4. PSV and S_a MCE_R response spectra for LADT site. The ASCE 7-16 MCE_R response spectrum is only plotted on the PSV figure to more clearly illustrate differences with the site-specific MCE_R response spectrum.

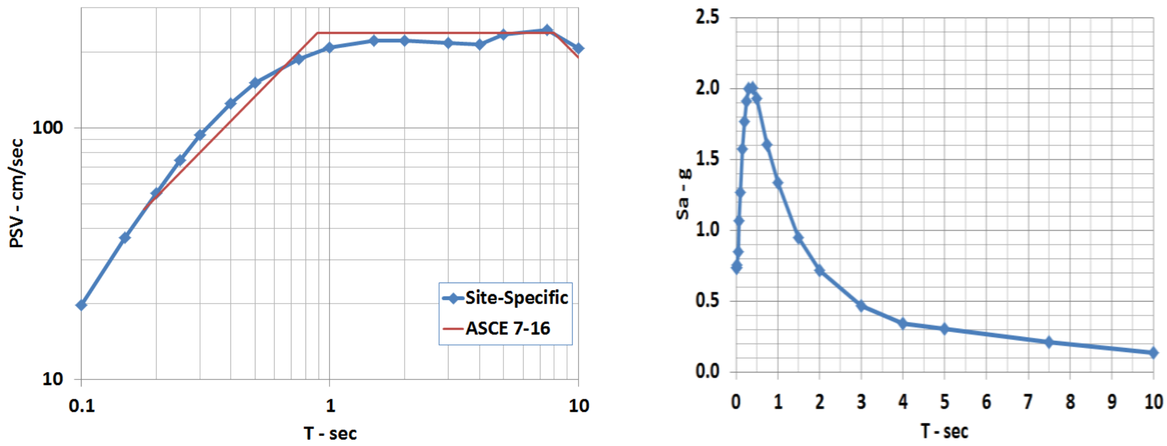

Figure 5. PSV and S_a MCE_R response spectra for COO site.

The parameters to construct the MCE_R response spectra in Figures 4 and 5 were as follows:

LADT: S_{MS} = 2.367, S_{M1} = 0.983; V_{s30} = 390 m/sec, $Z_{1.0}$ = 0.31 km, $Z_{2.5}$ = 2.08 km

COO: S_{MS} = 1.709, S_{M1} = 1.525; V_{s30} = 280 m/sec, $Z_{1.0}$ = 0.73 km, $Z_{2.5}$ = 4.28 km.

Web-Based Lookup Tool

A web-based lookup tool, similar to the USGS lookup tool, is currently being developed by SCEC under the UGMS direction. This tool will enable users to obtain the MCE_R response spectrum for a specified latitude and longitude and for a specified site class or Vs30. If either of these local geologic parameters is not known, the tool will automatically select a default value of V_{s30} from Wills and Clahan (2006). The output will consist of a table of acceleration ordinates of the MCE_R response spectrum at multiple natural periods in the 0 to 10-sec band; a plot of the spectrum will also be included. Values of S_{DS} and S_{D1}, per the requirements in Section 21.4 of ASCE 7-16, will also be listed. The UGMS also plans to include links to other information, such as source and magnitude-distance deaggregation data, and the GMPE-based and CyberShake-based MCE_R response spectra, before the averaging.

Acknowledgements

The work done by Scott Callaghan, Kevin Milner, and Philip Maechling of SCEC to compute the MCE_R response spectra and prepare the CyberShake MCE_R web site with these and other data related to the calculations, is greatly appreciated, as well as the contributions of the UGMS committee members and corresponding members.

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