SCEC 2020 Science Plan Award – Final Report

Project Title: High-resolution ground motion in the LA basin from the 2019 Ridgecrest earthquake sequence: observations and simulations
Principal Investigator: Monica Kohler
Institution: California Institute of Technology
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Abstract

The objective of this project was to study ground-motion response in urban Los Angeles during the 2019 M7.1 and M6.4 Ridgecrest earthquakes using recordings from multiple regional seismic networks, as well as a subset of 350 stations from the much denser Community Seismic Network. We examined the observed response spectral (pseudo) accelerations for a selection of periods of engineering significance (1, 3, 6 and 8 s). Significant ground-motion amplification is present and reproducible between the two events. For the longer periods, coherent spectral acceleration patterns are visible throughout the Los Angeles Basin, while for the shorter periods, the motions are less spatially coherent. However, coherence is still observable at smaller length scales due to the high spatial density of the measurements. Examining possible correlations of the computed response spectral accelerations with basement depth and Vs30, we find the correlations to be stronger for the longer periods. We also tested the performance of two methods for estimating ground motions for the largest event of the Ridgecrest earthquake sequence, namely 3D finite-difference simulations and ground motion prediction equations. For the simulations, we were interested in the performance of the two SCEC 3D Community Velocity Models (CVM-S and CVM-H). For the ground motion prediction equations, we considered four of the 2014 Next Generation Attenuation-West2 Project equations. For some cases, the methods match the observations reasonably well; however, neither approach was able to reproduce the specific locations of the maximum response spectral accelerations, or match the details of the observed amplification patterns.

Intellectual Merit

This project integrated data and data analysis products in ways that contributed to understanding how strong ground motions depend on the complexities of subsurface Earth structure. The focus of this project was analysis of ground shaking and spectral response of the Los Angeles basin during the M6.4 and M7.1 2019 Ridgecrest, CA earthquakes. The goals were to i) analyze the observed ground motions and response spectra at seismic stations from multiple networks, ii) compare observations with simulated ground motions at the same locations, iii) examine the regions that experienced the largest shaking, and iv) discover the geological sources of large-amplitude shaking. Our results were focused on uppermost crustal material heterogeneities as a source of low-frequency amplification, and discrepancies between data and simulations. The wave periods examined in this project had associated depth sensitivities that extend several km into the uppermost crust, well below the geotechnical layer.

Response spectra were computed for the Ridgecrest earthquake ground motions to examine spatial scales and the range of numerically predicted amplification variations across the basin. Project analysis included about 200 Southern California Seismic Network (SCSN) + California Strong Motion Instrumentation Program (CSMIP) stations and 350 Community Seismic Network (CSN) stations within the greater Los Angeles area. Observed data used were acceleration time history records from ground level stations only. Spectral accelerations were computed for periods between 1 and 10 s. The geographical directions associated with the maximum combined response spectral displacements or accelerations were also computed. The overall earthquake data quality for all three networks for both events was high with good site-to-site coherence for neighboring stations in similar geological settings. The performance of the CSN MEMS-based sensors during the earthquake shaking was on par with the SCSN and CSMIP sensors

We constructed assessments of the geographical variability of ground motions in the Los Angeles region during the two largest events of the 2019 Ridgecrest earthquake sequence. These are in the form of spectral acceleration maps for four periods of engineering significance (periods equal to 1, 3, 6, and 8 s). Figure 1 shows the results for 6-s spectral accelerations using2% damping. For the longer periods, coherent spectral acceleration patterns are present throughout the Los Angeles Basin, while for shorter periods, the dense CSN instrumentation allows us to see the increased spatial complexity and the smaller length scale pockets of spectral acceleration amplification. Basement depths and Vs30 are parameters commonly used to predict the ground response. Examining the correlation of the observed ground motions with depth-to-basement, Z1.0, Z2.5, and Vs30, we find the correlation to be stronger for the longer periods. The lack of strong correlation at shorter periods suggests that other factors are influencing the response beyond what is captured considering the above parameters alone. The poor correlation of the Vs30 parameter is likely related to the precision and spatial aliasing of the proxy-based Vs30 estimates. We concluded that possible complicating factors could be the complex geologic structure within the basin, which includes lateral contrasts due to folding and faulting, as well as the variability in shallow geologic deposits connected with current and ancient watershed systems.

Using the data collected from the M7.1 mainshock, we also examined the performance of four NGA-West2 Ground Motion Prediction Equations (GMPEs). These equations explicitly consider the Vs30 of a specific site, as well as sediment thickness, which is parameterized as depth-to-shear-wave velocity of 1.0 km/s (Z1.0) or 2.5 km/s (Z2.5). Vs30 for each site was calculated using linear interpolation of the grid values, and the Z1.0 and Z2.5 values were obtained from the CVM-H model. Using Z1.0 and Z2.5 from the CVM-S model yields similar GMPE predictions. For specific cases, the agreement between the observations and the model predictions is good but there is room for improvement. The GMPEs suffer from underpredictions for the longer periods, but generally perform better at the shorter periods. However, it is often the case that a GMPE performing well for one period does a poor job at a different period. For 3-s period, the GMPEs perform better than ground motion simulations, while for the longer periods (6 s and 8 s), the simulations perform better than the GMPEs. While both simulations and GMPE estimates often reproduced the general amplitudes and trends of the ground-motion response, they had trouble capturing the finer-scale spatial variations of the observed response, as well as matching the specific locations of the maximum amplifications. This stresses the need for caution and further validation when employing these methods. As with the simulated ground motions, the GMPEs miss locations where the observed RotD50 maxima occur (e.g., the San Fernando Valley and west Los Angeles, for the longer periods).

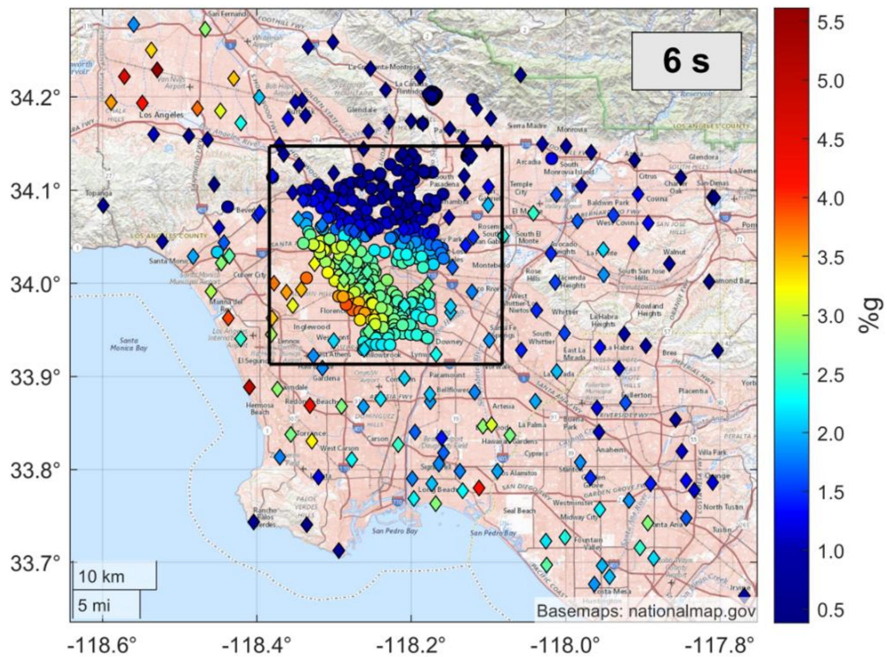

Figure 1. Pseudo-spectral accelerations with 2% damping computed for greater Los Angeles for 2019 M7.1 Ridgecrest earthquake. Circles: CSN stations, Diamonds: SCSN & CSMIP stations. Figure is from Filippitzis et al., "Site response in urban Los Angeles from the 2019 Ridgecrest earthquake sequence," *Earthquake Spectra*, in press, 2021.

In recent years there is a growing effort to expand upon site-specific seismic hazard analysis, with documents such the Alternative Analysis & Design Procedure guidelines published by the Los Angeles Tall Building Seismic Design Council, and projects such as SCEC's Committee for Utilization of Ground Motions Simulations. Our analysis, including the validation of the numerical simulations, are of direct relevance to existing and future building code development. High-rise response in Los Angeles must meet the requirements in ASCE 7-16 and the Alternative Analysis & Design Procedure document published by the Los Angeles Tall Building Seismic Design Council. This document requires that ground motions be developed from site-specific seismic hazard analysis. The majority of site-specific PSHA and DSHA analyses incorporate basin effects by assigning values of basin depth parameters, Z1.0 and Z2.5, and Vs30 in the empirical ground-motion models; in addition, these initiatives consider the results of 3-D numerical models (e.g., CyberShake). The results from our project will bring attention to the potential shortcomings of the currently used site parameters (Z1.0, Z2.5, and Vs30) and the CVMs. The refinement of these parameters and 3D seismic velocity models, in light of new dense seismic data, is essential and will benefit existing guidelines and projects. We are disseminating the results in traditional formats (a publication, academic seminars, and scientific meeting presentations), as well as in presentations to non-academic groups consisting of earthquake and structural engineers. We expect these activities, including the communication outreach component, to continue over the next couple of years.

This project resulted in a publication that is currently in press: Filippitzis, F., M. D. Kohler, T. H. Heaton, R. W. Graves, R. W. Clayton, R. G. Guy, J. J. Bunn, K. M. Chandy, "Site response in urban Los Angeles from the 2019 Ridgecrest earthquake sequence," *Earthquake Spectra*, in press, 2021.

Broader Impacts

This grant funded Caltech graduate student Filippos Filippitzis to work on the project described above. This project made up a significant part of his recently completed PhD thesis. The project also involved a direct collaboration with USGS seismologist Rob Graves who was responsible for computing the simulated ground motions and goodness-of-fit metrics for the Ridgecrest earthquakes, and who was a central part of the interpretation component of all results.

Some of the data used in this project are from a relatively new, dense, low-cost network of seismic sensors (Community Seismic Network: CSN), many of which are installed at Los Angeles Unified School District campuses. The hardware-software architecture of the CSN has the potential to lead to city-wide resilience through its unique design and scalability. CSN's Cloud-based telemetry and communication design will impact the rapidly developing field of dense environmental sensor arrays. The data analyzed in this project highlights how CSN has the potential to change the way civil structures are instrumented and the manner in which these types of data products are disseminated to other domain experts and to the public at-large. Although the analyzed data are from Los Angeles area schools, these results show how the system is easily adaptable to other areas such as San Francisco or Seattle because it only relies on existing in-place technology – the Internet and the cloud. The system can also be expanded to other infrastructure such as hospitals, water and waste-water facilities, gas infrastructure, and electric networks. Such a system will benefit the population in general, as well as benefit post-event response and recovery planning, utilities, government agencies, and financial institutions, among others.

All data used in this project are publicly available via csn.caltech.edu, scedc.caltech.edu, and strongmotioncenter.org.