Spectral Scaling Transfer Function Method for Scenario Ground Motion Simulation with Application to the 2019 Ridgecrest Earthquake Sequence

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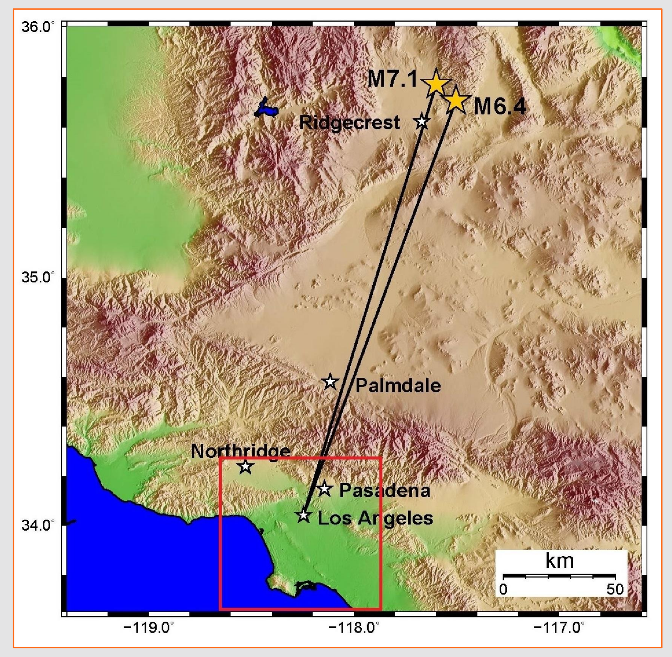
Motivation

During the July 2019 Ridgecrest earthquake sequence, long-period ground motions were felt throughout the Los Angeles region. Mid-rise and high-rise structures swayed for at least two minutes after the initial shear waves reached the base of the buildings.

The earthquake sequence resulted in no damage for buildings in Los Angeles, but it provided a useful dataset for testing a new spectral scaling method to simulate ground motions for scenario large-magnitude earthquakes when smaller-magnitude earthquake data are available from the same source region.

Recent studies investigating the observed ground motions and spectral accelerations in the urban Los Angeles as a result of the Ridgecrest earthquakes (Kohler et al. 2020; Filippitzis et al. 2021) illustrate the difficulties that both 3D simulations and GMPEs encounter when predicting the ground motions and further motivate the analysis of the expected ground motions from a scenario M7.6 Ridgecrest earthquake.



Area under consideration (red box) in relation to the M7.1 & M6.4 epicenters

The Spectral Scaling Transfer Function Method

We present a transfer function-based method for simulating ground motions for scenario large-magnitude earthquakes when a smaller-magnitude earthquake from the same source region has been recorded.

The method is based on Aki's theory of universal similarity of earthquake radiation, in which the Fourier amplitude spectra of far-field radiated body waves can be approximated as a truncated power law with frequency, and far-field body-wave displacements scale as the moment rate function together with constants that account for radiation pattern and geometric spreading.

Based on Aki's f^{-2}scaling law (Aki 1967), the assumed transfer function is a simplified version of the standard spectral scaling model (Brune 1970).

$$|\tilde{u}_i(f)| \sim \frac{P_i}{1+\left(f/f_{c_i}\right)^2}$$

where $\tilde{u}_i(f)$ is Fourier Transform of the radiated seismic waves for the i^{th} earthquake with spectral decay f^{-2}, f_{c_i} is the corner frequency that describes the rupture dimension, and P_i is the potency.

Our scaling procedure refers to an application of a transfer function and is simple in that it reduces the depiction of the source spectrum to only one parameter, the magnitude (Heaton & Hartzell 1989).

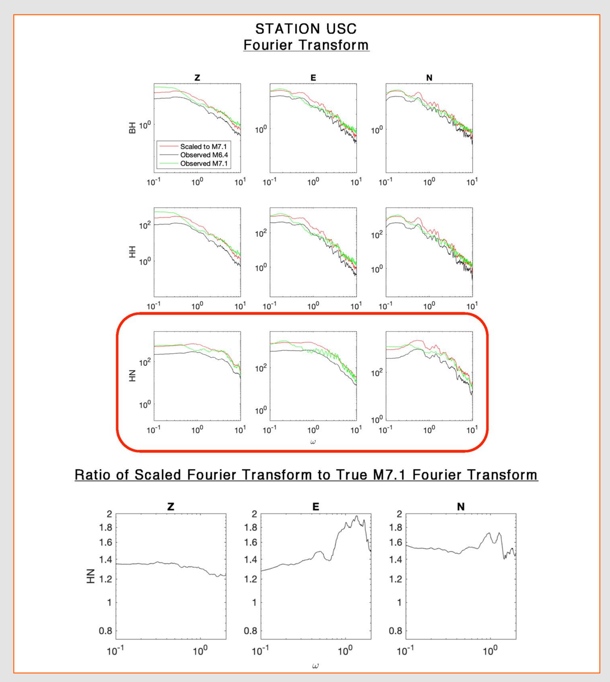
For the low frequency limit, one gets:

$$\lim_{f\to\infty} \frac{|\tilde{u}_2(f)|}{|\tilde{u}_1(f)|} \approx 10^{1/2(M_2-M_1)}$$

while for the high frequency limit:

$$\lim_{f\to 0} \frac{|\tilde{u}_2(f)|}{|\tilde{u}_1(f)|} \approx 10^{3/2(M_2-M_1)}$$

where $\tilde{u}_1(f)$ and $\tilde{u}_2(f)$ are the spectra of earthquakes with moment magnitudes M_1 and M_2.

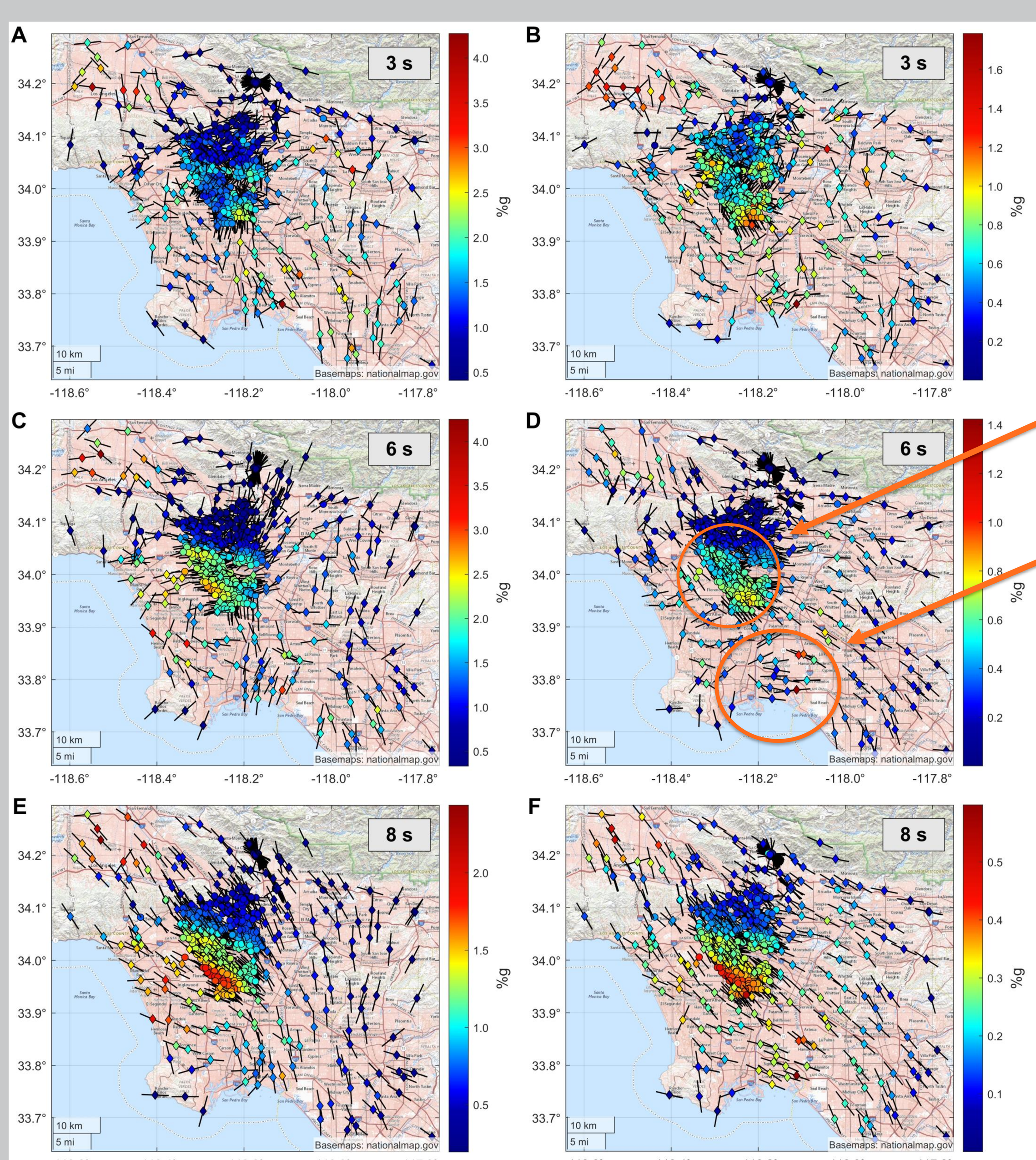


Observed and simulated Ridgecrest earthquake sequence ground motions are used to validate the transfer function method. Spectra comparisons, and ratio of spectra for station USC.

The Ridgecrest 2019 Earthquakes

The Ridgecrest sequence consisted of a M6.4 foreshock that occurred on July 4, 2019, the M7.1 mainshock on July 6, 2019, and several foreshocks and aftershocks with magnitude greater than 5. Here we use data from the two largest events of the sequence (M7.1 and M6.4), as well as from a M5.4 foreshock that occurred on July 5, 2019.

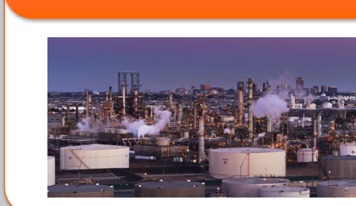
The data is collected from three different networks: CSN (circle markers), SCSN and CSMIP (diamond markers), which all together result in a total of about **550 stations**.



Spectral acceleration maps. Left column: M7.1 Event. Right column: M6.4 Event. Damping ratio ζ=5%. (A-B) T=3s. (C-D) T=6s. (E-F) T=8s. markers: CSN stations, markers: SCSN & CSMIP stations. Note varying scales.

Downtown LA and other LA areas are home to high-rise buildings having long first periods

Oil refinery area fluid containers are found to have long first periods due to fluid sloshing

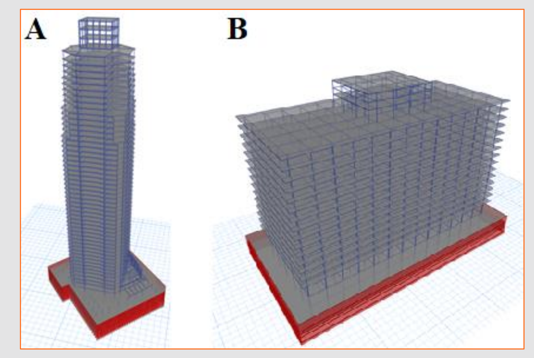


The 1st period (due to sloshing) of a circular tank with 25m radius and 20m height is about 8 s.

We found that:

- The long period motion was amplified in the deeper parts of the LA basin by a factor of 5 relative to the bedrock site values.
- For the longer periods, coherent patterns are present throughout the basin.
- For the shorter periods the motions are less spatially coherent, indicating a high level of scattering in the kilometer scale
- Regional networks lack the necessary station density to show the smaller length scale patterns revealed by the dense CSN instrumentation.

High-Rise And Mid-Rise Application

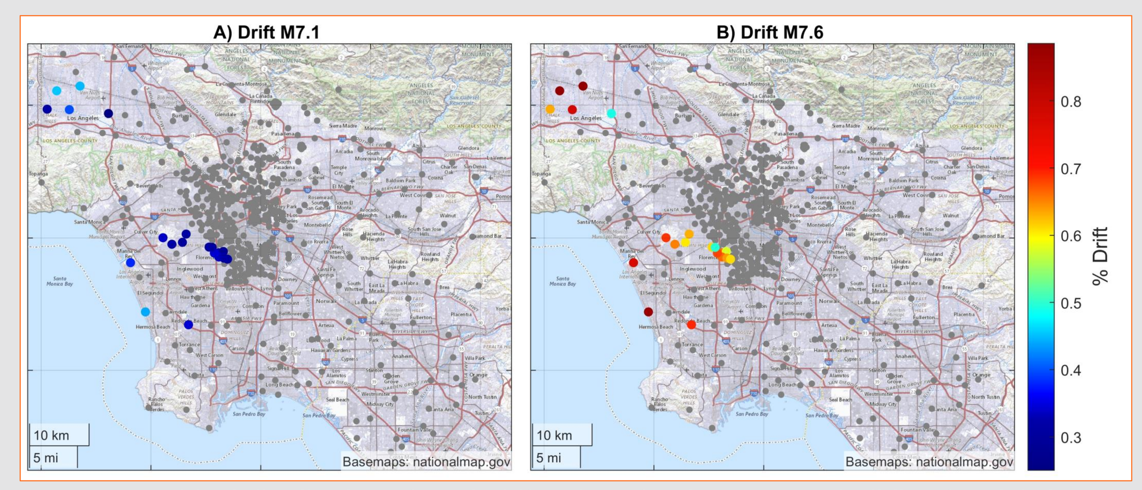


ETABS models of the instrumented: (A) 52-story, and (B) 15-story buildings

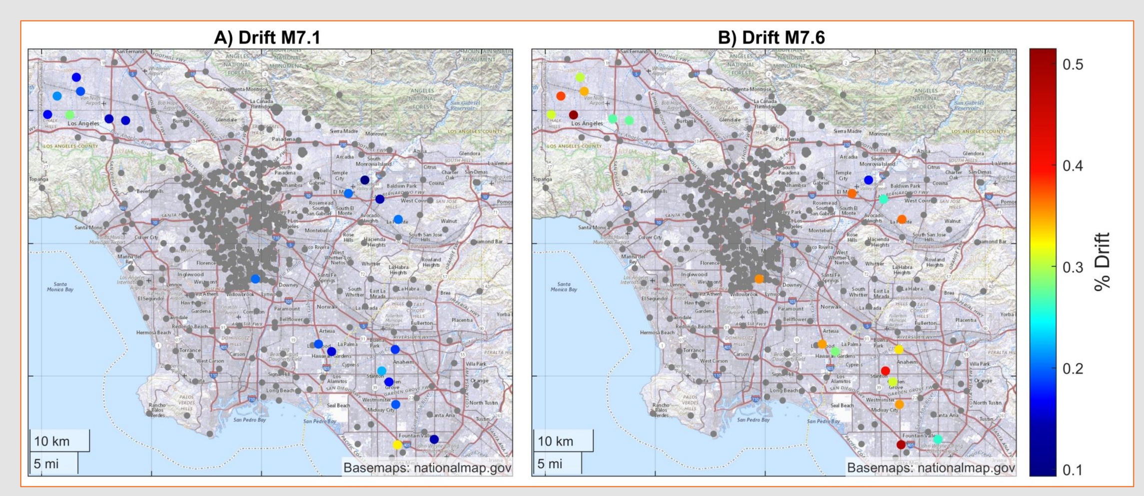
We perform linear dynamic analysis using observed and simulated ground motions.

We utilize finite-element models for two building located in downtown Los Angeles: a 52-story high-rise and 15-story mid-rise.

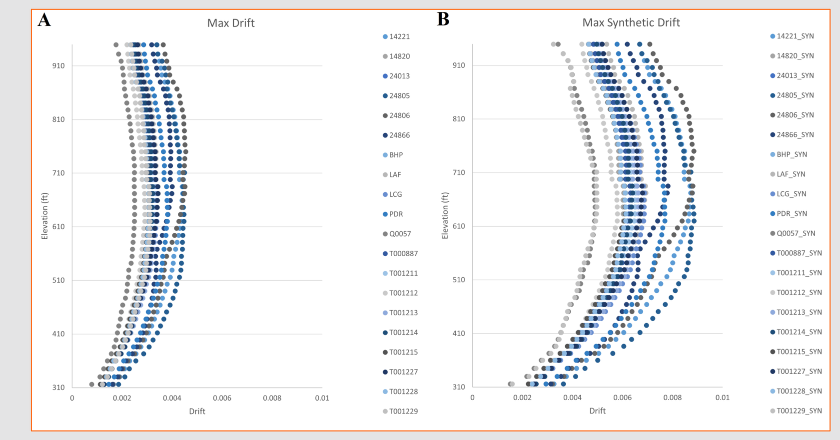
The geographical variations in the predicted inter-story drift, story-level shears and story-level moments for the two buildings are examined, for the observed M7.1 Ridgecrest earthquake, and for a scenario M7.6 Ridgecrest-like earthquake simulated using our spectral scaling method.



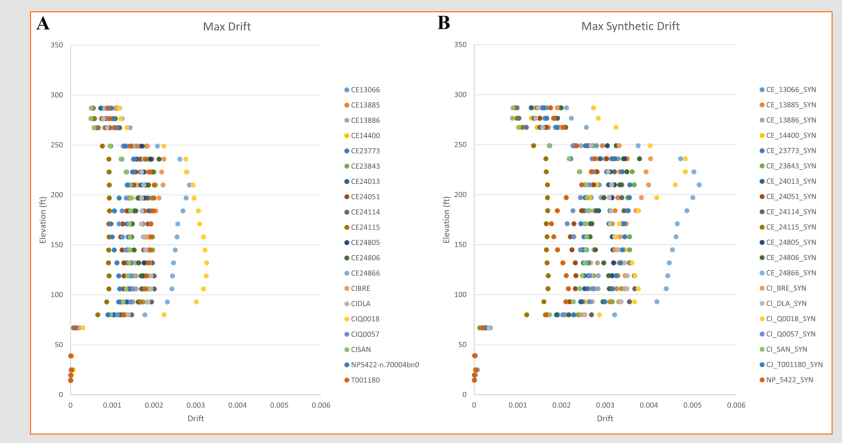
Geographical distribution of peak drift values for the 52-story building for: (A) the observed M7.1 earthquake, and (B) the scenario (scaled) M7.6 earthquake.



Geographical distribution of peak drift values for the 15-story building for: (A) the observed M7.1 earthquake, and (B) the scenario (scaled) M7.6 earthquake.



Maximum inter-story drift for the 52-story building for: (A) the observed M7.1 earthquake, and (B) the scenario (scaled) M7.6 earthquake



Maximum inter-story drift for the 15-story building for: (A) the observed M7.1 earthquake, and (B) the scenario (scaled) M7.6 earthquake.

We further map the maximum values of the computed inter-story drift. These values indicate geographic locations that may be most vulnerable to future large-magnitude, long-period earthquake ground motions for a scenario M7.6 earthquake in the same source region.

We find that:

- Relative to the M7.1 earthquake, the M7.6 scenario earthquake will produce peak elastic inter-story drifts that are 2 times larger for the 15-story (at around the 6th floor) and 2.7 times larger for the 52-story (at around the 30th floor).
- For each building, the maximum levels of drift associated with the scenario M7.6 event would likely lead to damage and yielding in the structures' lateral system components. The effect is more pronounced in the high-rise building, suggesting that the Ridgecrest event is relatively richer in low-frequency content such that the scaling procedure has a larger effect on amplifying low-frequency energy.
- As has been observed in previous studies, deterministic ground motion modeling underpredicts the maximum ground motions and, thus, maximum drift values, for the maximum 6-s PSA locations (Kohler et al. 2020; Filippitzis et al. 2021).

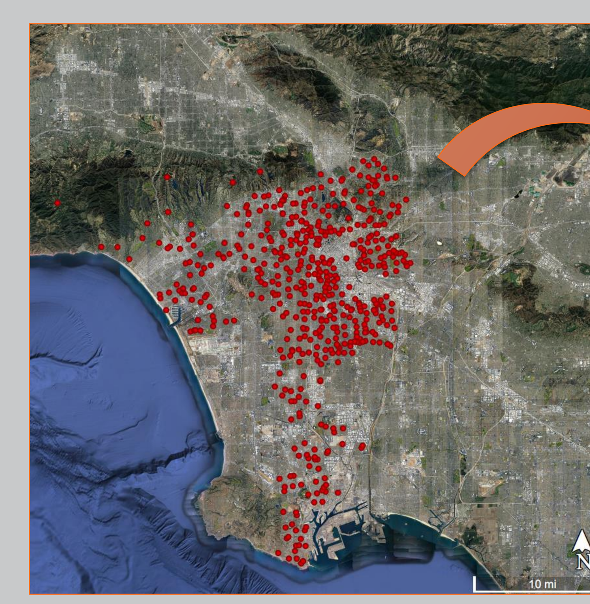
The Community Seismic Network (CSN)

The *Community Seismic Network (CSN)* is a permanent, Cloud-based, strong-motion network, located in LA.

Key features:

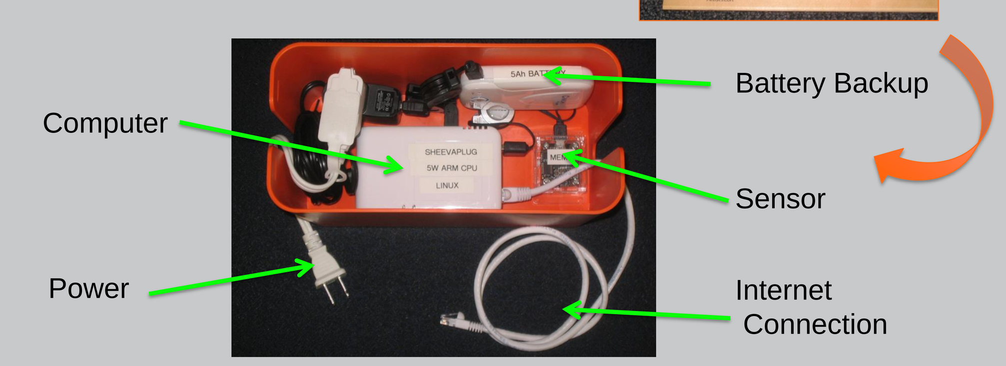
- Over 700 deployed active stations
- Recording continuous acceleration time series 24/7
- Real-time access to the data & event detection
- Inexpensive three-component MEMS accelerometers, ability to detect low-magnitude events in southern California. Up to par with state-of-the-art accelerometers.
- Distributed on-board computing
- Next-generation Cloud computing
- Highly scalable, due to the use of commercial parts and cloud computing. Fast and easy deployment.

For more information visit:
http://csn.caltech.edu
Contact email: *ffilippi@caltech.edu*



CSN - LA Unified School District Deployment

Deployed CSN Box



Acknowledgements

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