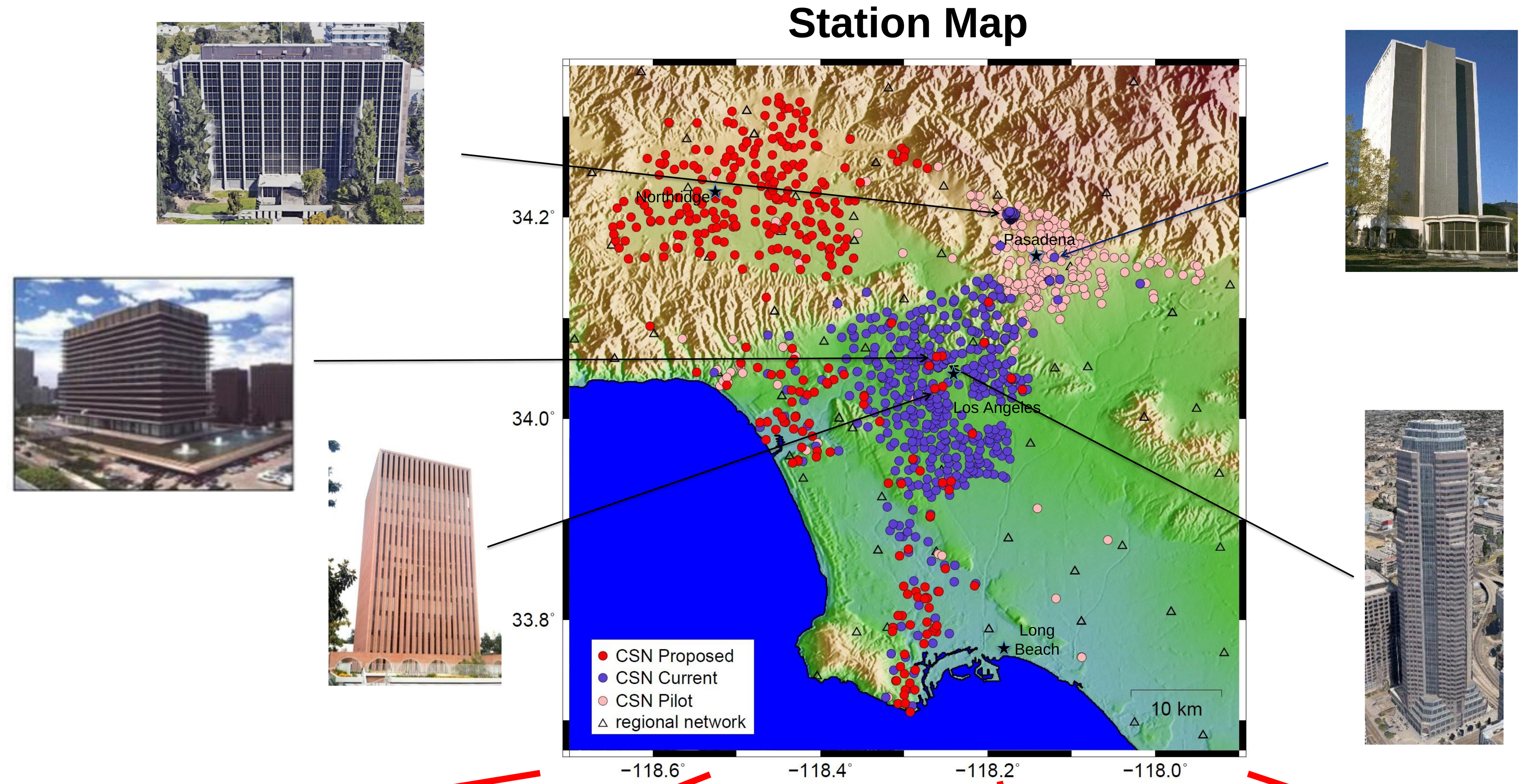
The Community Seismic Network: Applications and Expansion to 1200 Stations

M. Kohler[1]; R. Clayton[1]; Y. Bozorgnia[2]; E. Taciroglu[2]; R. Guy[2]

[1]Caltech, [2]UCLA

The Community Seismic Network (CSN) is a permanent, strong-motion sensor network that records and archives continuous waveform data. Earthquake, wind, and ambient vibration data are used in studies of basin velocity structure, geotechnical layer characterization, structural damage detection methods and real-time assessment, and soft-story building analysis. CSN incorporates computing in the cloud, at the edge, and on devices to map ground motion intensity and building damage probability due to earthquakes. It currently consists of 800 stations, half of which are located on Los Angeles Unified School District (LAUSD) campuses. With recent support provided by the Hilton Foundation and a new partnership with the California Geological Survey (CGS), an additional 500 stations will be deployed at additional LAUSD campuses over the next year. When completed, the network will consist of 1200 triaxial stations located at 0.5 km station spacing at the ground level, and on every floor of several high-rises. The partnership with CGS is for evaluation of deploying additional stations across the State of California to fill in geographical gaps in seismic instrumentation as a long-term collaboration.

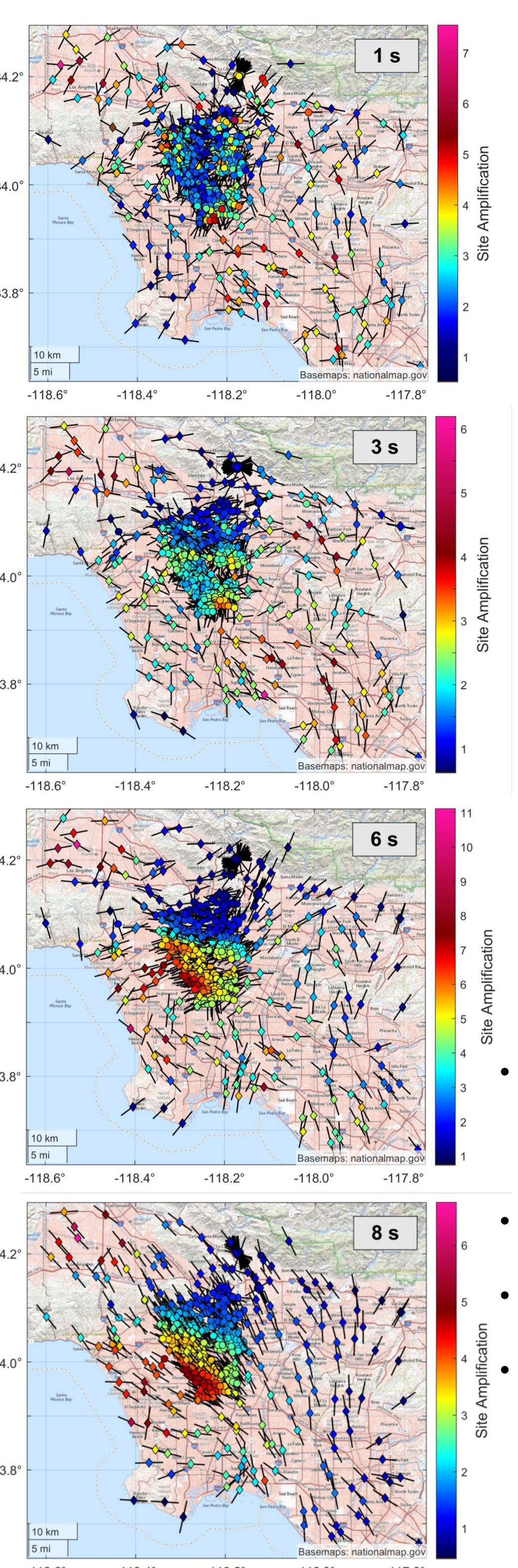
Station Map



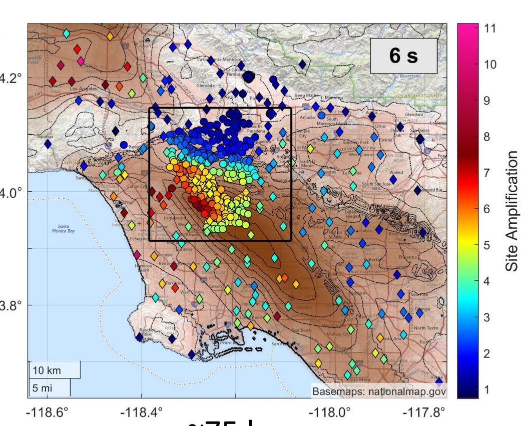
- Continuous acceleration waveforms 50 sps, ±2g.
- School campuses, office buildings, civic buildings, homes, NASA-JPL campus
- Internet/ethernet for majority. Wifi and cell modem for a few pilot stations
- Single-board quad core computer, SD card, USB power supply
- MEMS triaxial sensor at every site
- NTP time

Geotechnical/LAUSD/JPL

M7.1 2019 Ridgecrest spectral acceleration site amplifications and associated maximum directions. Circles: CSN. Diamonds: CISN

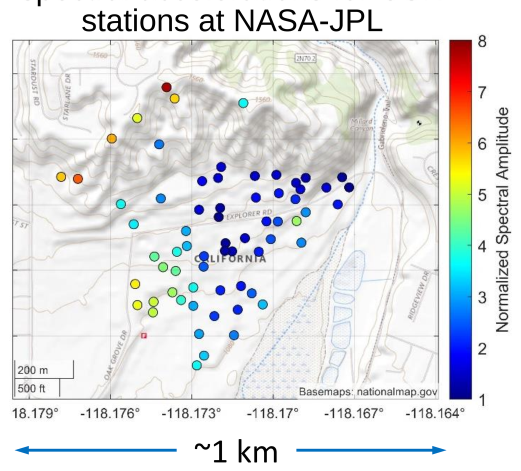


M7.1 2019 Ridgecrest 6-s spectral acceleration site amplifications over contoured CVM-H depth-to-basement. Circles: CSN. Diamonds: CISN



~75 km

M7.1 2019 Ridgecrest 2.6 Hz spectral accelerations for CSN stations at NASA-JPL

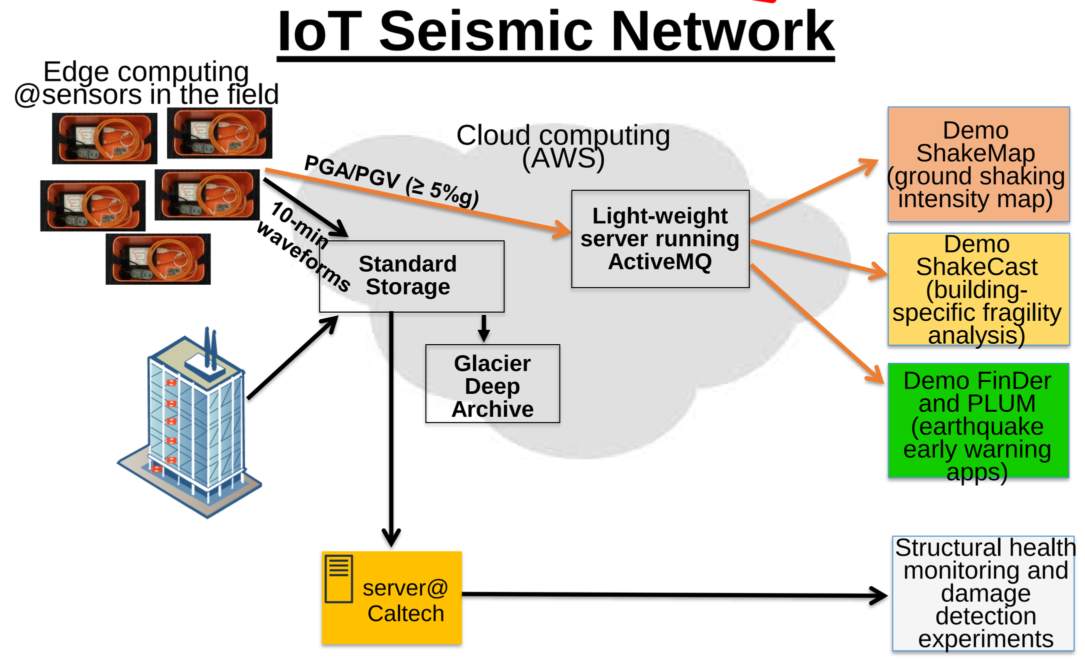


~1 km

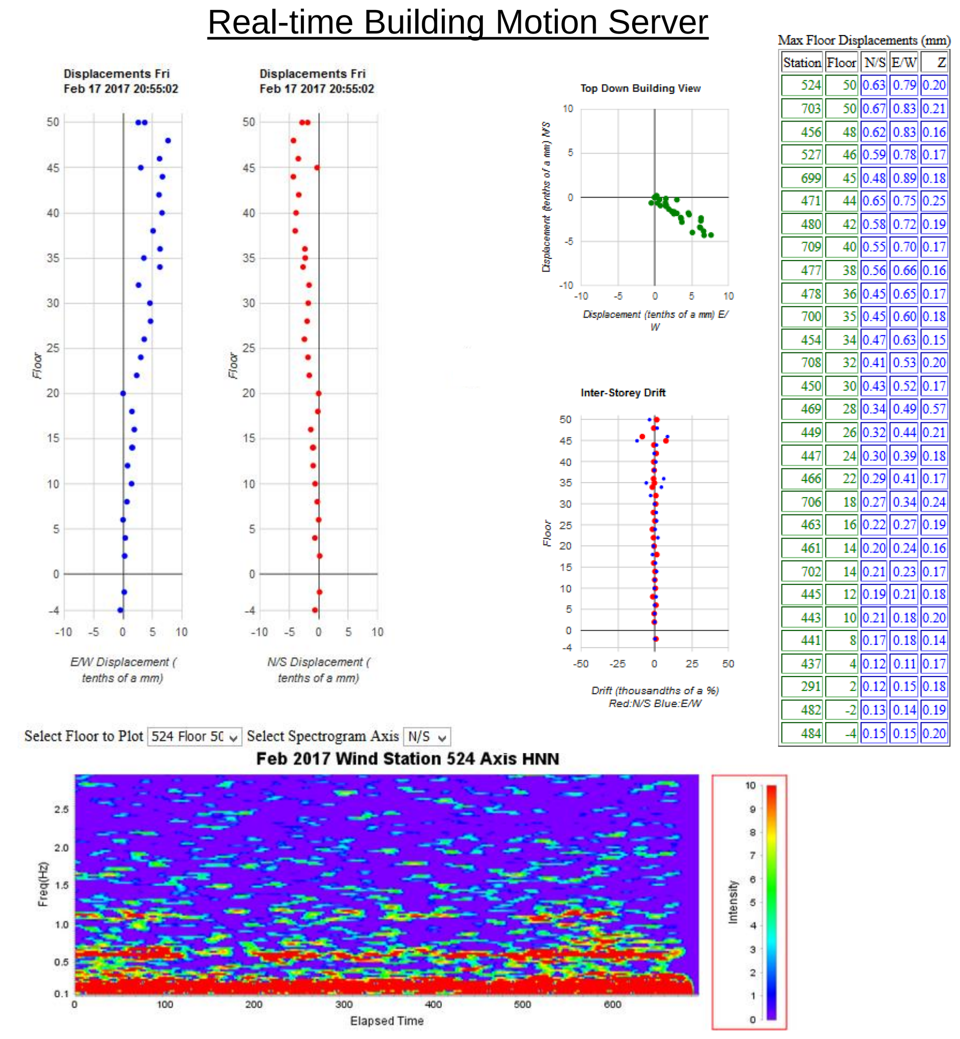
- Long-period amplification occurred both in and far outside the central LA basin and basin edges (4 times larger than downtown LA)
- LA basin geometrical complexity not fully captured in 3D Vs models
- 3D short-period amplification occurred on top of foothills
- Maximum directions indicate shear wave energy interacting with basin boundaries and becoming trapped, producing Rayleigh and Love waves affected by refraction at high-to-low velocity interfaces, i.e., bedrock to sedimentary basin.

- Filippitzis et al., *Ground motions in urban Los Angeles from the 2019 Ridgecrest earthquake sequence*, Earthquake Spectra, 2021.
- Kohler et al., *2019 Ridgecrest earthquake reveals areas of Los Angeles that amplify shaking of high-rises*, SRL, 2020

IoT Seismic Network



Real-time Building Motion Server

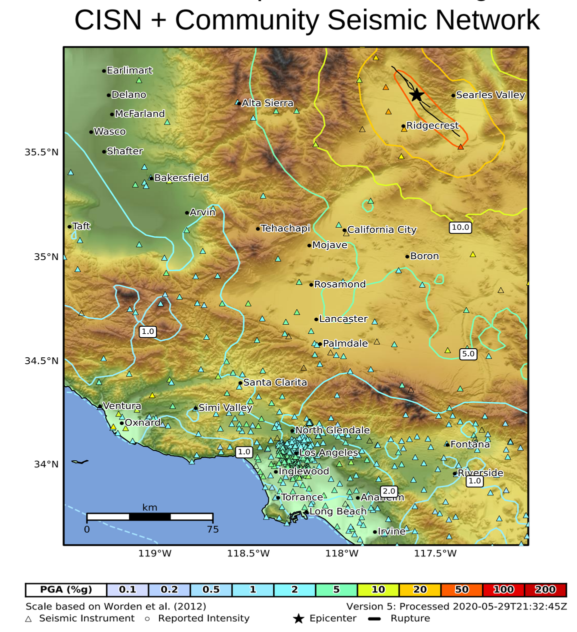


- Device, edge, and cloud computing for PGA, PGV, full waveform data streams.
- Subsets of continuous waveforms streamed into customized real-time structural health monitoring software running at edge ("Building Motion Server")
- Building Motion Server modified for GPU-accelerated Cuda cores

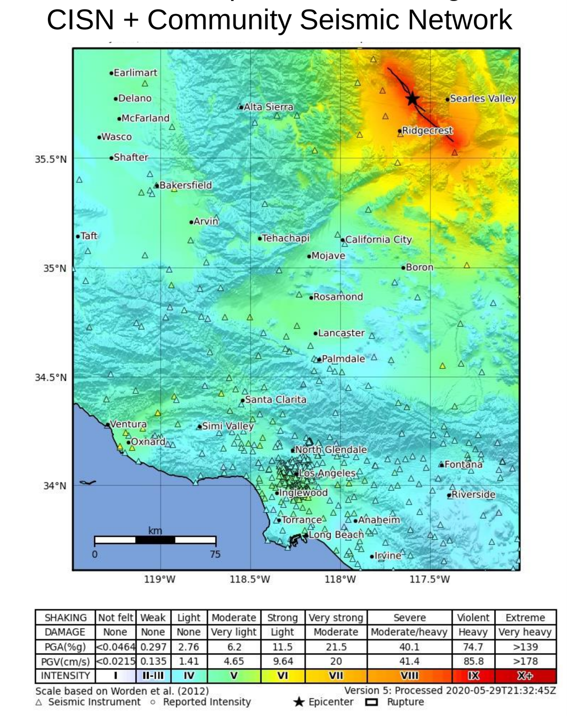
- Clayton et al. *CSN/LAUSD network: A dense accelerometer network in Los Angeles schools*, SRL, 2020
- Kohler et al., *Community Seismic Network and localized earthquake situational awareness*, 11NCEE conference proceedings, 2018

ShakeMap

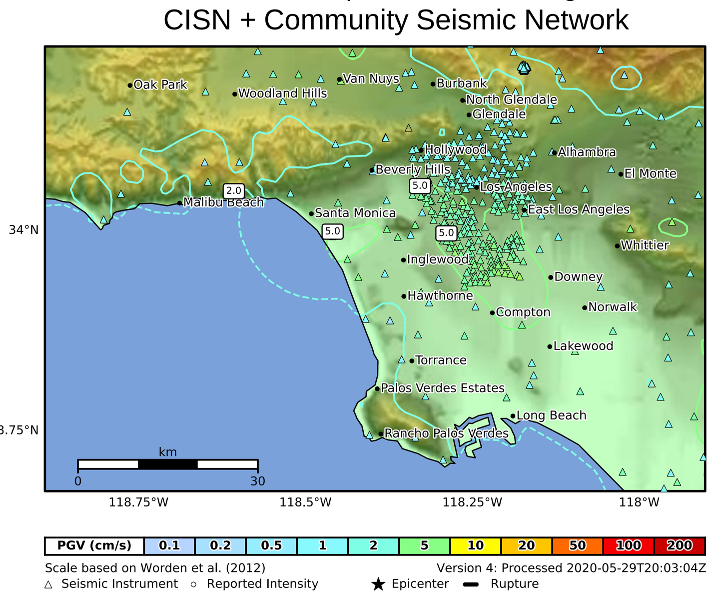
Peak Ground Acceleration
USGS ShakeMap: 2019 M7.1 Ridgecrest
CISN + Community Seismic Network



Macroseismic Intensity
USGS ShakeMap: 2019 M7.1 Ridgecrest
CISN + Community Seismic Network



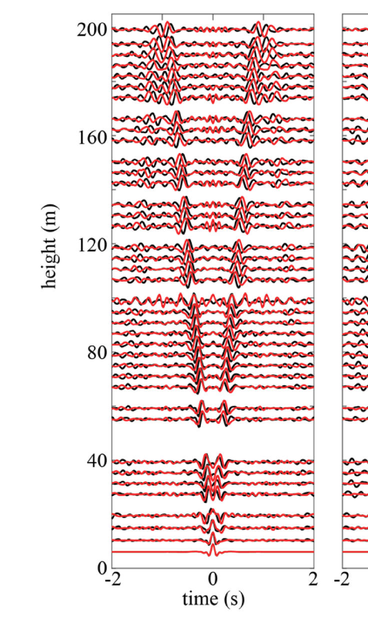
Peak Ground Velocity
USGS ShakeMap: 2019 M7.1 Ridgecrest
CISN + Community Seismic Network



- PGA and PGV values inserted into AQMS database. Associator determines if they meet association criteria
- PGA ≥ 0.5% g, and real-time PGV based on PGA threshold, computed at device
- Compute PGA, PGV, +DYFI ShakeMaps on local test server
- Uncertainty values are computed and assigned for weighting in interpolation, analogous to Did-You-Feel-It procedure

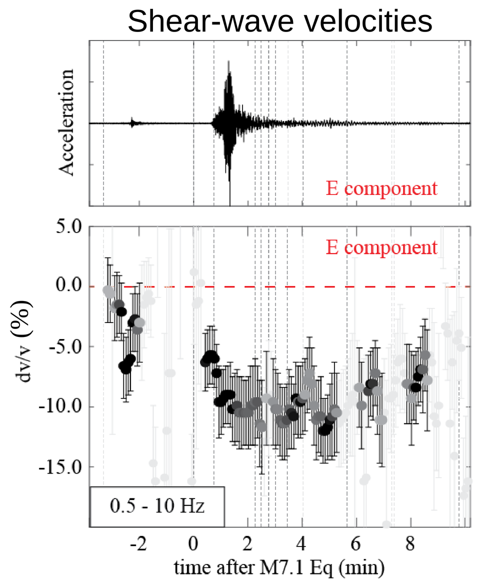
- Kohler, Wald, Thompson, Worden, Clayton, Bunn, Filippitzis, Heaton, Guy, Chandy, *An automated procedure for producing USGS ShakeMap parametric input from non-traditional seismic networks with application to the Community Seismic Network*, AGU, 2020

Structural Health Monitoring



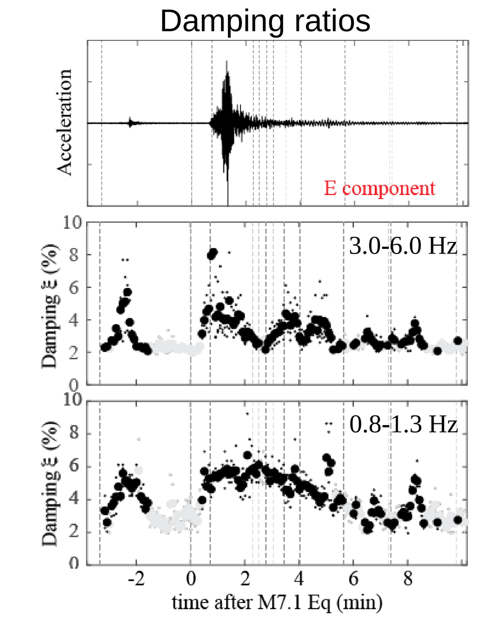
Impulse Response Functions (IRFs) with respect to Floor 2 in 52-story steel moment and brace frame in downtown Los Angeles from ambient vibration data (black traces), and 20-second window during M7.1 Ridgecrest earthquake (red traces) for bldg-EW (Left) and bldg-NS (Right) components from CSN sensors

Shear-wave velocities



Variations in Vs from coda wave interferometry IRFs in bldg-EW direction from M7.1 Ridgecrest mainshock by applying stretching technique. Grayscale: cross correlation value 0-1. Red dashed line: 225 m/s average from ambient vibration data. Vertical dashed lines show M>4.5 foreshock and aftershock times. Bldg-NS direction shows similar results.
- Up to ~12% Vs drop during main shock shaking
- M>4.5 foreshocks and aftershocks: up to ~6% Vs drop, prolonging the velocity drop time duration

Damping ratios



Variations in damping ratios in two frequency bands from coda wave interferometry IRFs in bldg-EW direction. IRF amplitude envelope decays are measured relative to ambient vibrations. Vertical dashed lines show M>4.5 foreshock and aftershock times. Bldg-NS is similar.
- Higher-mode frequencies dominate damping changes
- Foreshocks and aftershocks produce nearly as large damping ratio changes (increases) as main shock.

- G. Prieto and M. Kohler, *Time-varying shear-wave velocities and damping ratios in a high-rise during earthquakes from coda wave interferometry*, AGU, 2021; manu. in prep)

Acknowledgements

We would like to acknowledge support for this project from the **Conrad N. Hilton Foundation**, **Computers and Structures, Inc.**, **Nvidia Corporation**, **Caltech** and **UCLA**.

For more information about the Community Seismic Network, including access to earthquake datasets and publication pdfs, see **csn.caltech.edu**.