Hazard-to-Risk: High-Performance Computing Simulations of Large Earthquake Ground Motions and Structural Risk

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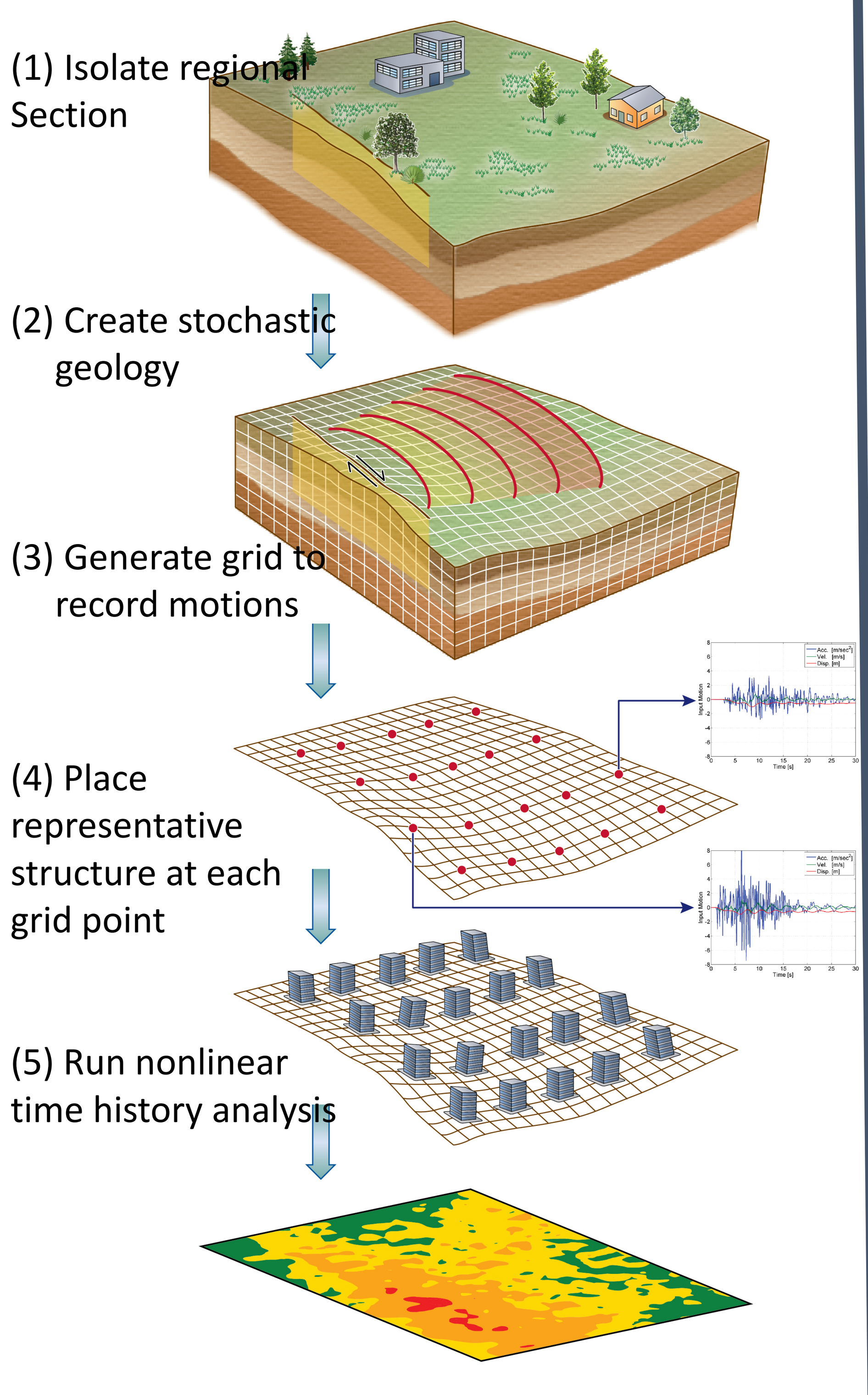
Project Overview

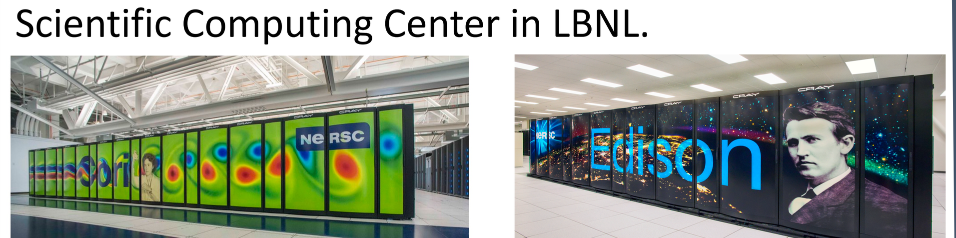
This project is developing and implementing an advanced simulation environment that will exploit emerging Exascale level computing and establish a coupled assessment of earthquake hazard (ground motions) and earthquake risk (structural demands).

Current geophysics simulations at the regional level typically only resolve ground motions at 1-2 Hz frequency content due to existing computational platform limitations. A key objective of this project is to develop ground motion estimates on the order of 5-10 Hz to cover the dynamic response regime of interest for engineered infrastructure. The model evaluated here is an idealized basin/rock system including realistic, complex earthquake fault rupture and a stochastic representation of geology at fine scale. This is a 100km x 50km x 30km regional scale model supporting simulations up to 5Hz.

Computational Workflow

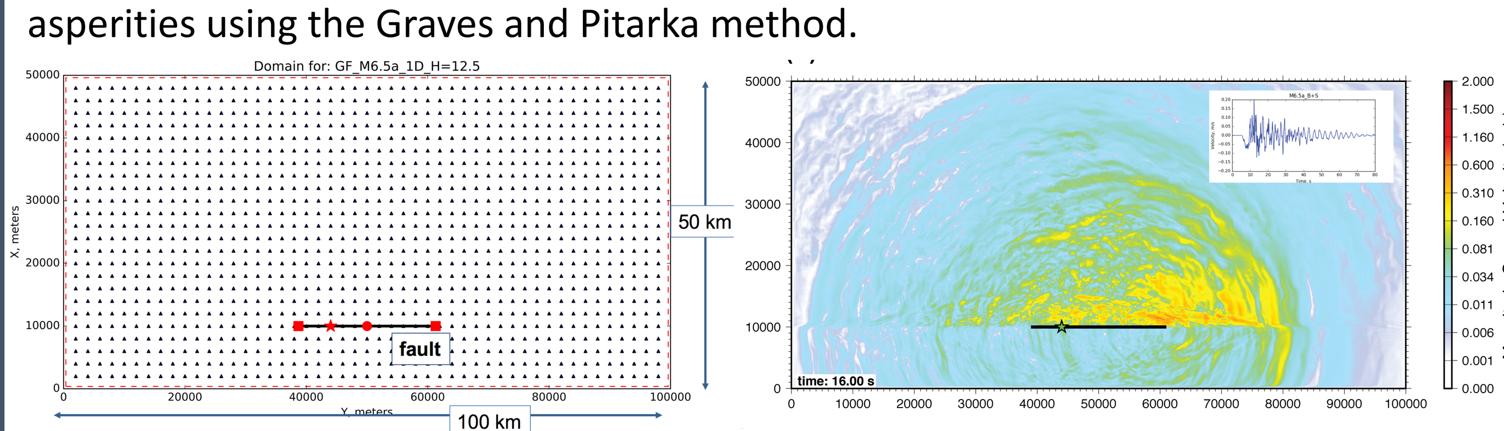


Ground motion simulations were performed on Quartz at LLNL and structural response simulations were performed at the National Energy Research Scientific Computing Center in LBNL.

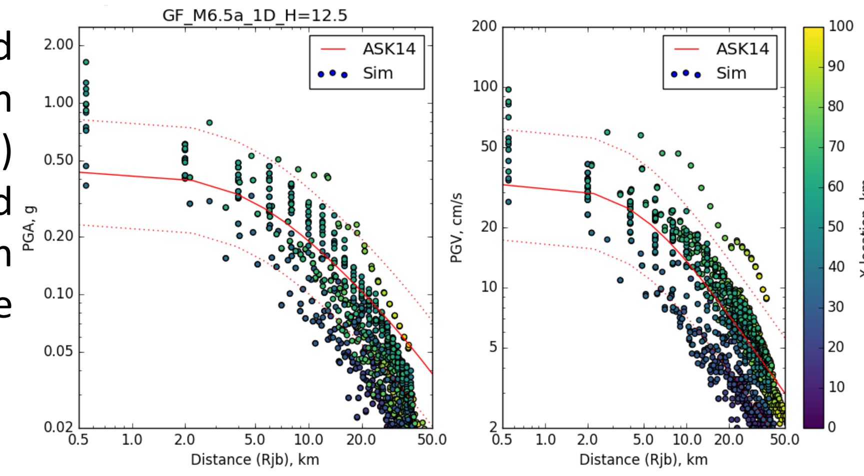


Regional Scale Hazard Simulations

Using SW4, a fourth order finite difference program for seismic wave propagation, ground motions for M6.5 and M7.0 are modeled. The fault rupture process represents a detailed rupture scenario accounting for fault surface roughness and asperities using the Graves and Pitarka method.

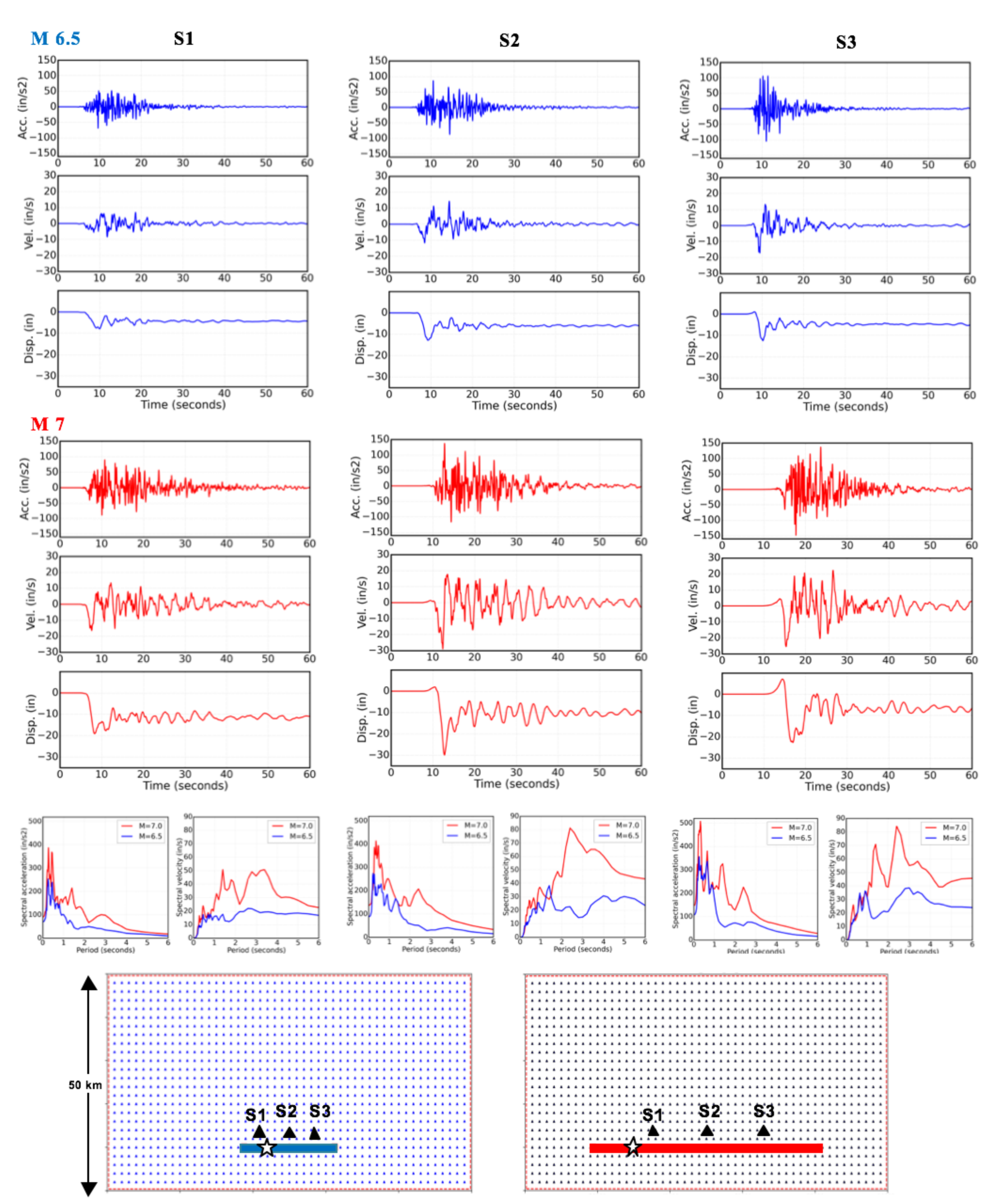


To validate these simulated ground motions, the Ground Motion Intensity Measurements (GMIMs) from the simulations are compared against Ground Motion Prediction Equations (GMPEs) which are based on empirical data.



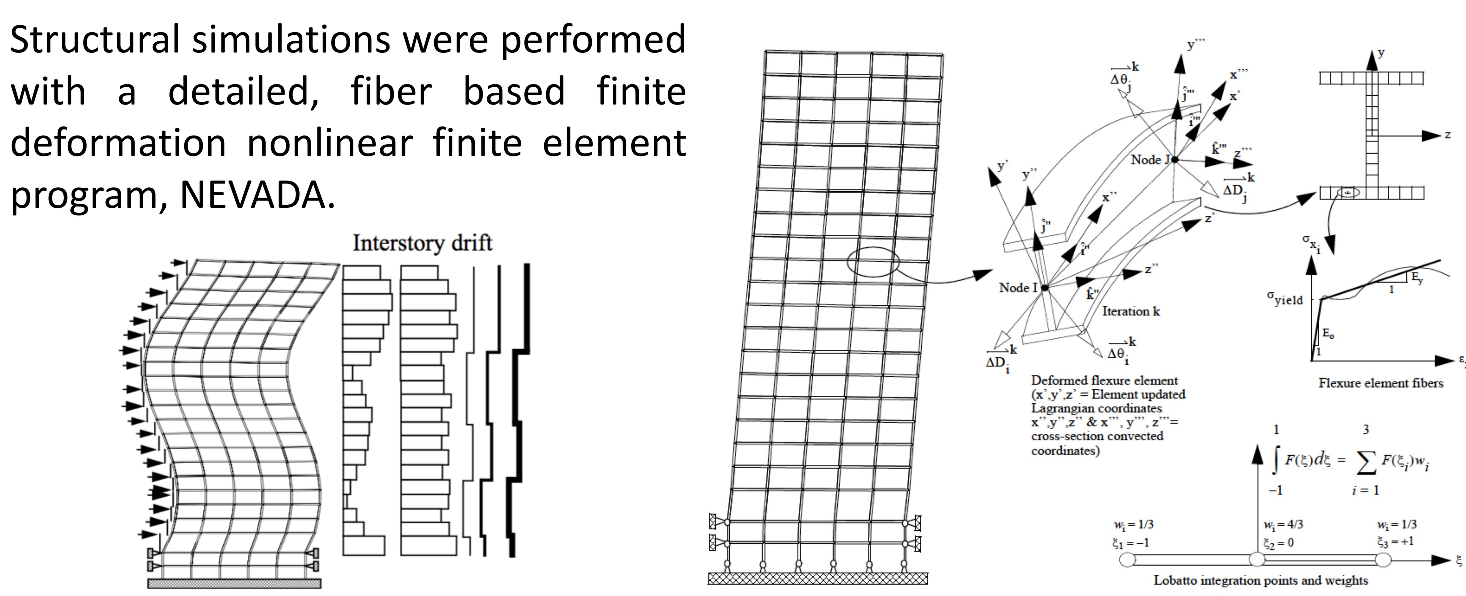
Simulated Strong Ground Motion (0-4 Hz)

Figure on the right shows three representative synthetic seismograms (S1, S2, S3) and corresponding acceleration and velocity spectra from M6.5 and M7.0 earthquake events. The first seismogram (S1) closest to the hypocenter exhibits the lowest amplitude for all three parameters (acceleration, velocity, and displacement). Whereas the second (S2) and third (S3) seismograms, both located in the direction of forward rupture directivity and relatively close to the hypocenter, consistently show higher values of ground motion parameters.



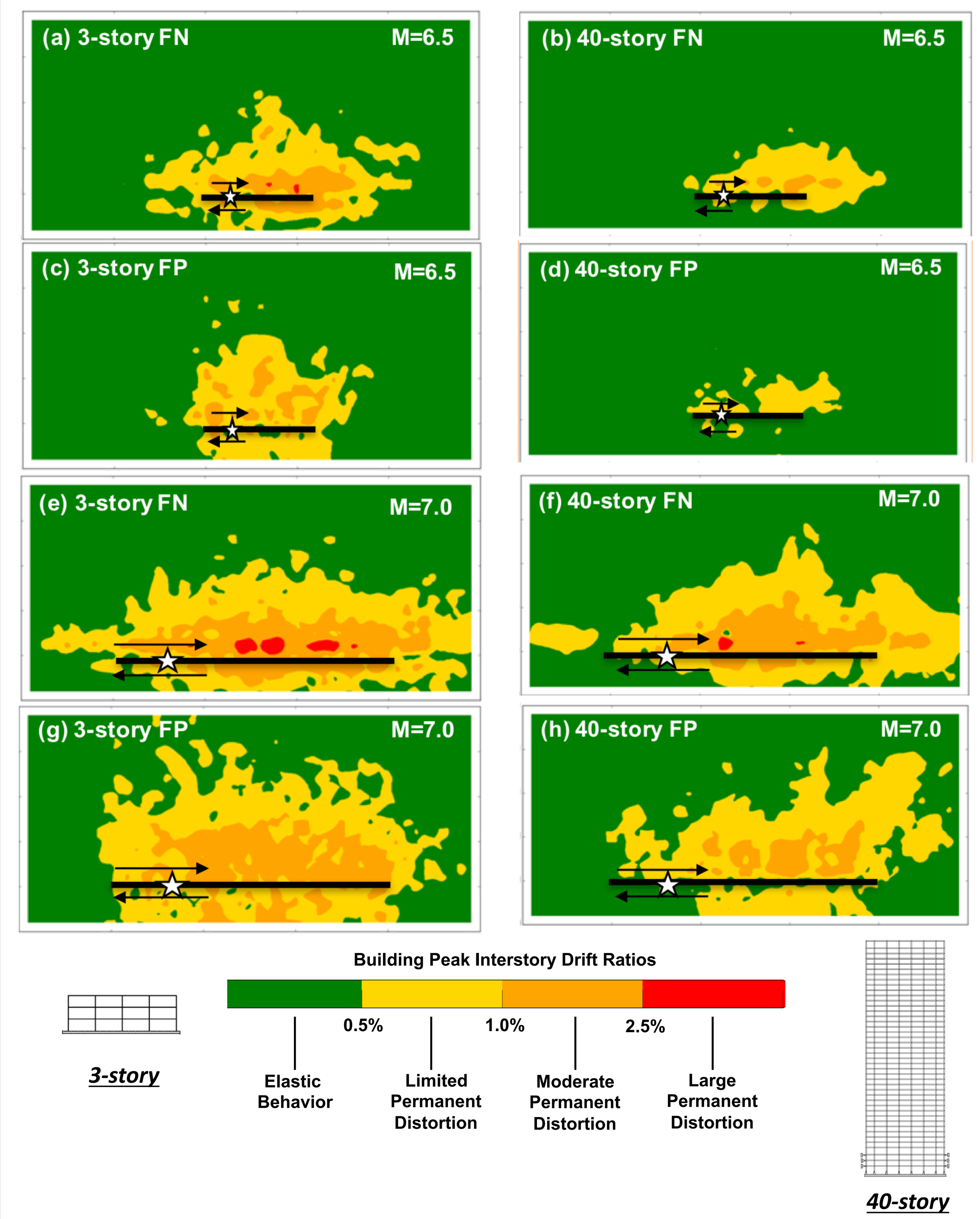
Structural Response Simulations

Structural simulations were performed with a detailed, fiber based finite deformation nonlinear finite element program, NEVADA.

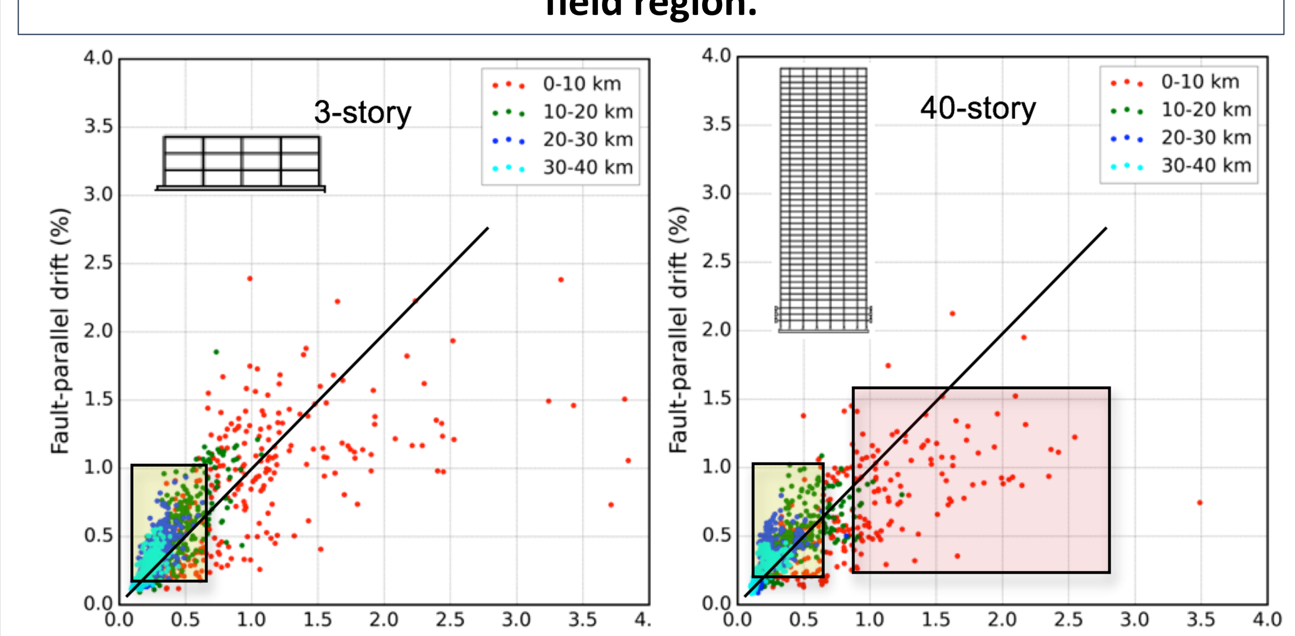


Regional Scale Risk Simulations

Building peak interstory drift contour plots for 3- and 40-story buildings for M6.5 (a - d) and M7.0 (e - h) events. Color bar and corresponding contours represent the interstory drift limits per ASCE/SEI 43-05



Fault normal component contributes to higher risk in the near-fault while fault parallel component contributes to higher risk in the far-field region.

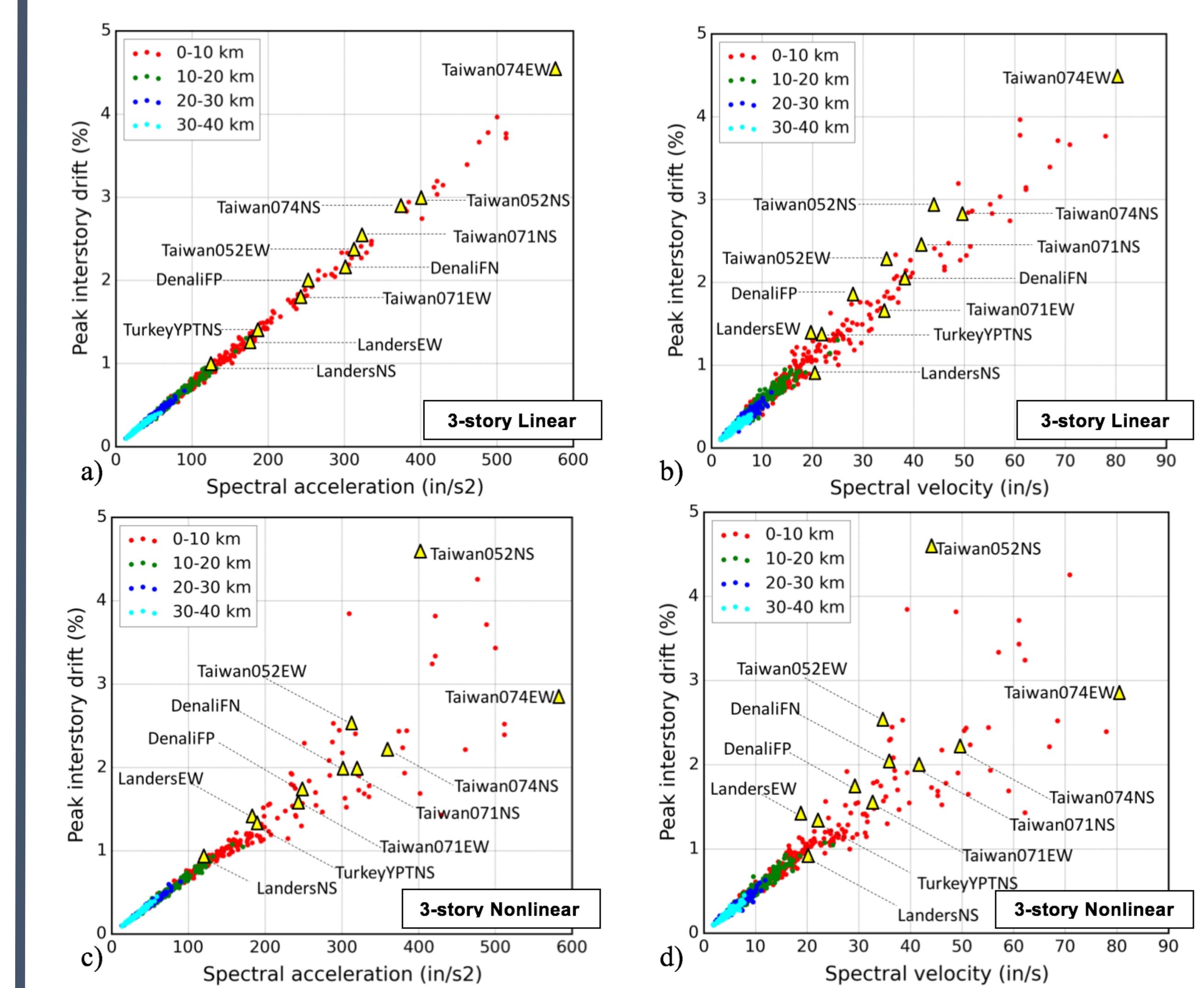


Summary

In this project full-broadband (0-5 Hz) simulated ground motion data were employed to quantify seismic risk for representative building structures on a regional scale. A total of 9,600 nonlinear structural dynamic simulations were performed and analyzed to study the risk variation on a 100 km x 50 km domain for two events (M6.5 and M7). Much work needs to be done to validate the realism of end-to-end, high-performance simulations that span all the way from fault rupture to structural response, but the early results from work underway are very encouraging.

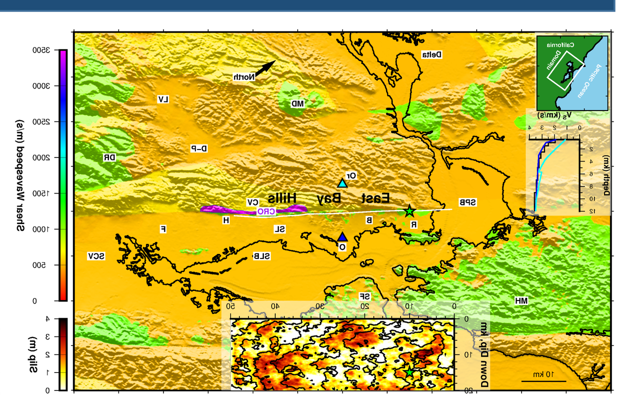
Damage Correlations with Spectral Parameters

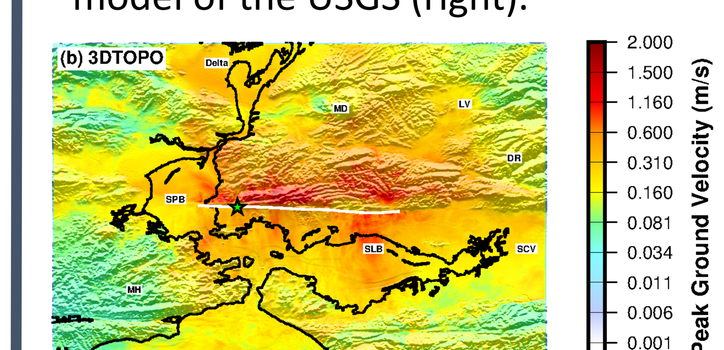
Correlation of peak interstory drift with spectral acceleration (a-c) and spectral velocity (b-d) at the fundamental modal period (0.91s) of a 3-story building for M7.0 event (FN component). Nonlinear results show higher variability especially in the near-fault region.



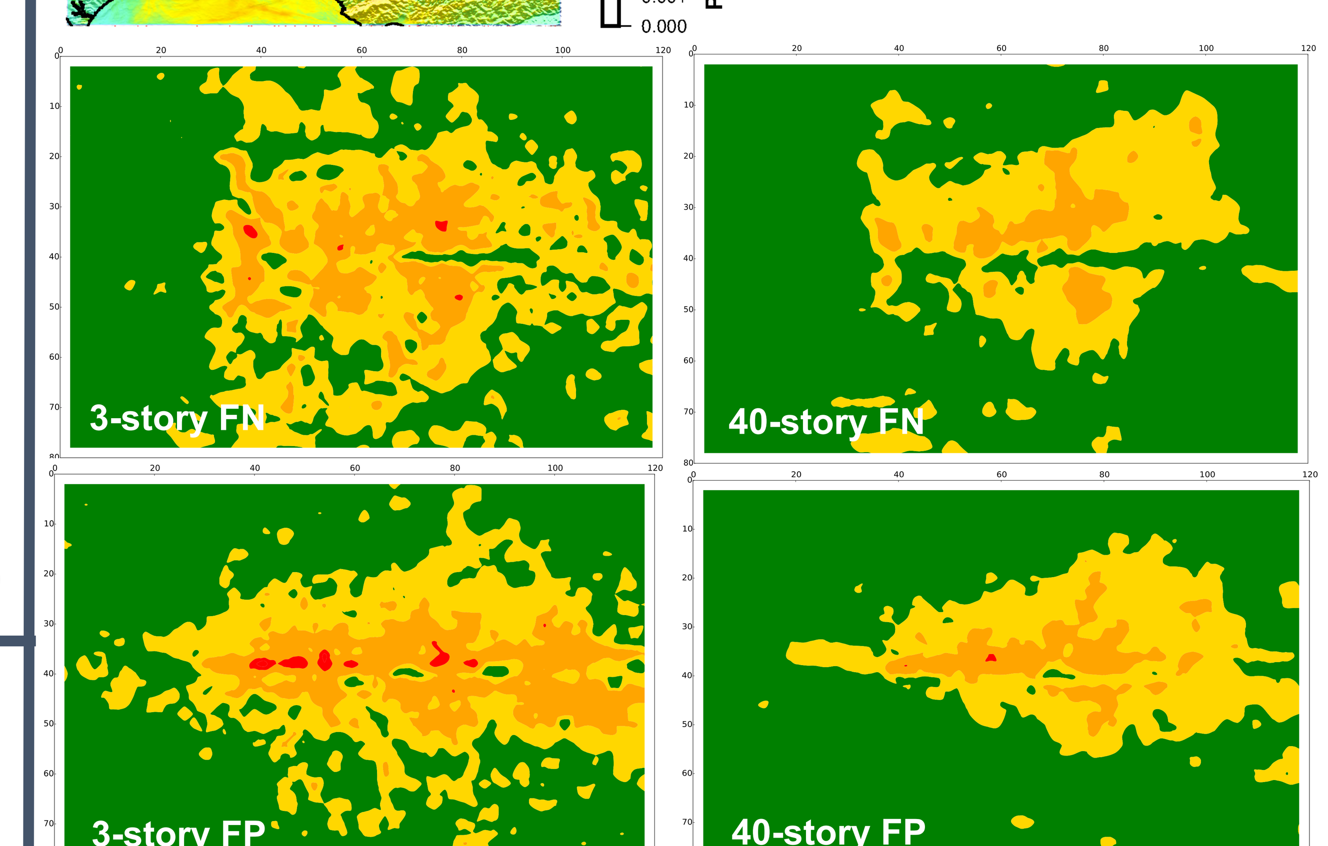
Hayward M7.0 Scenario

We simulated ground motions for an M7.0 earthquake on the Hayward Fault, in the eastern San Francisco Bay Area using the 3D model of the USGS (right).





Peak Ground Velocities (left) are large, particularly east of the fault.



Acknowledgements

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