High Performance Multidisciplinary Simulations for Regional Scale Seismic Hazard and Risk Assessments

- Transforming earthquake assessments

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ECP
EXASCALE COMPUTING PROJECT

BERKELEY LAB

UNIVERSITY OF CALIFORNIA

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Presentation topics

- **Physics-based earthquake hazard and risk assessment**
- **Necessity and application of advanced computer simulations in seismic risk analysis**
- **Regional scale ground motion and risk simulations**
- **New insights for engineering applications**

Transforming earthquake assessments from empiricism to physics simulations

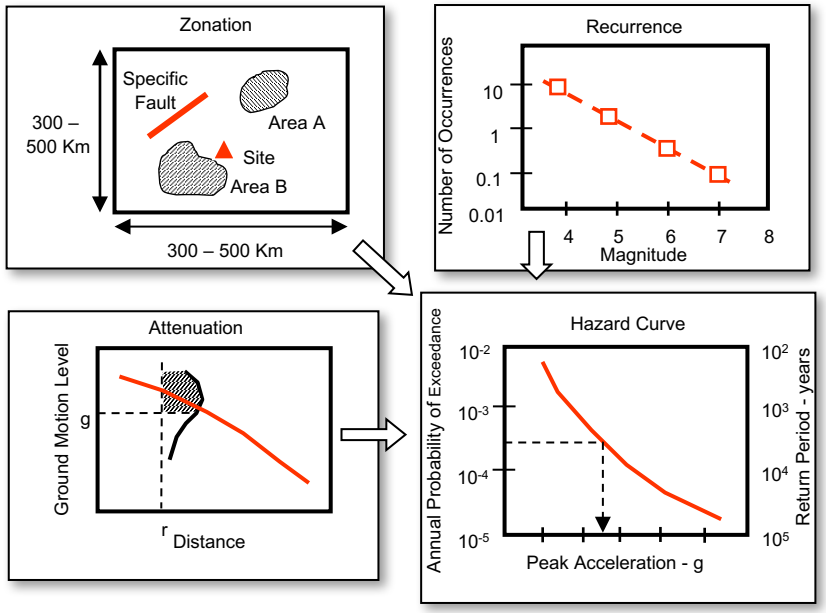
Historical (1960s - now)
Empirically based

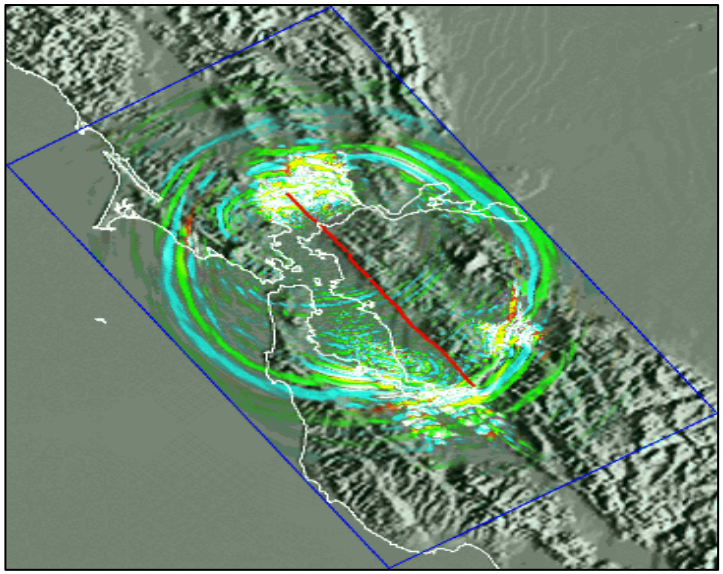
Probabilistic Seismic Hazard

Realistic simulations can both increase understanding and reduce uncertainties

Future (now - forward)
Simulation (physics) based

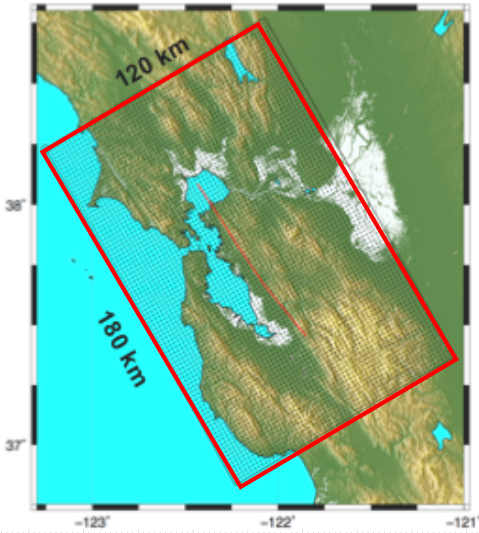
Simulation Based Hazard & Risk

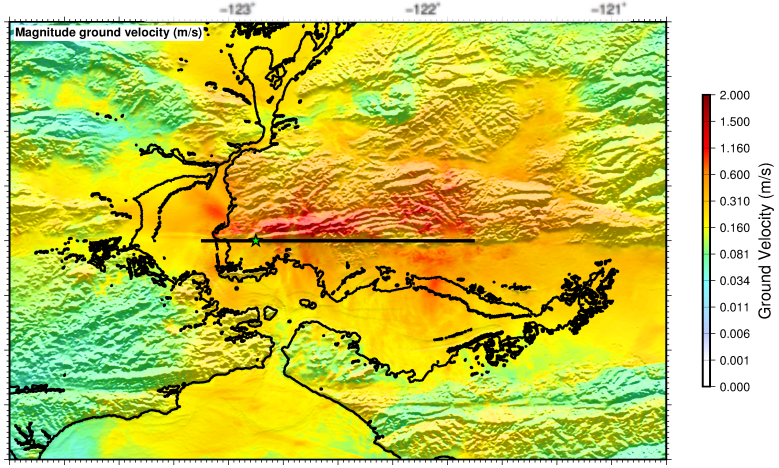




Advanced computational capabilities will allow us to address two important problems

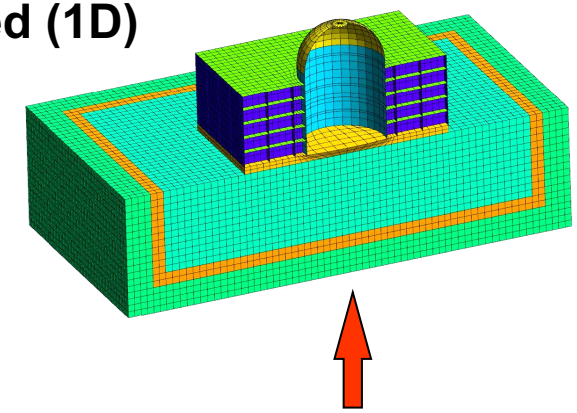
What is the regional-scale distribution of earthquake hazard and risk?



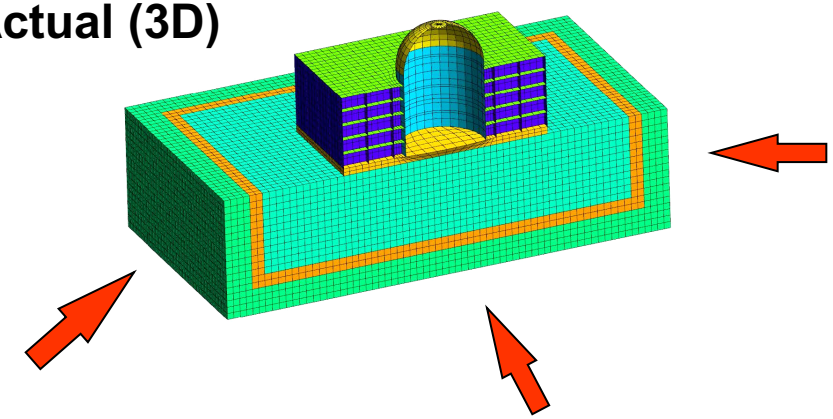


For critical facilities, what does the incident earthquake motion actually look like?

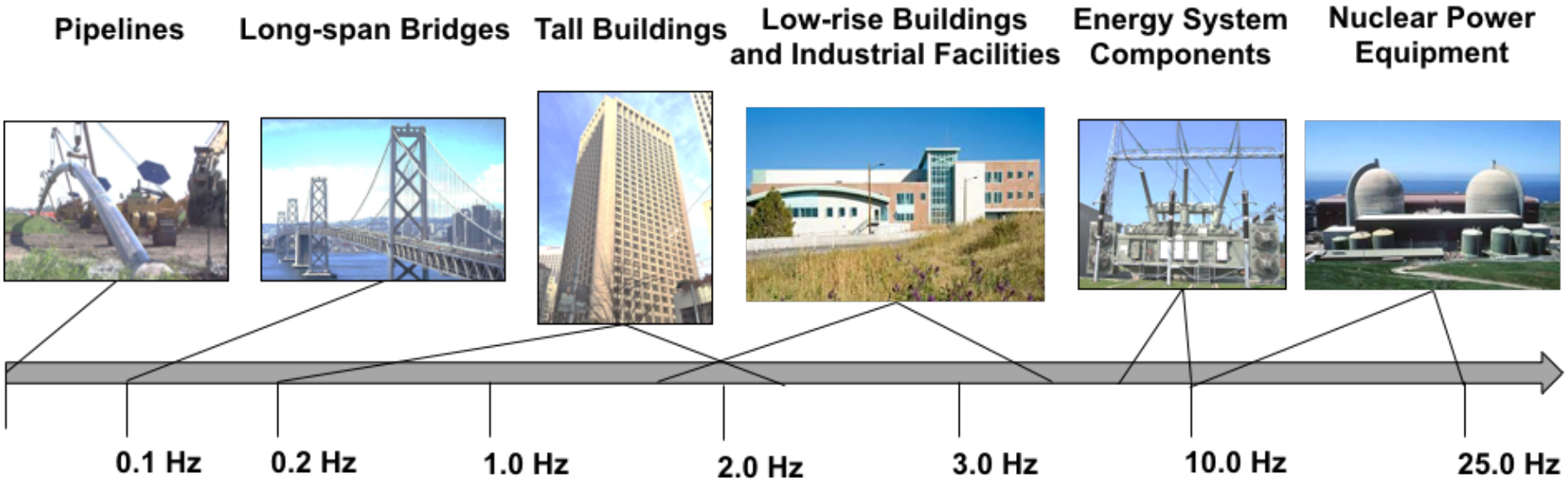
Assumed (1D)



Actual (3D)



Geophysics simulations *must* be advanced to frequencies of engineering interest



Frequency resolution of ground motion simulations as limited by compute capabilities

Larger, faster forward simulations →

Frequency resolution of ground motions simulations as limited by geologic/geotechnical material models

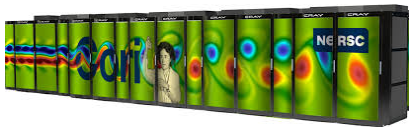
Advanced geologic characterization →

Historically 1-2Hz

Exascale objective ~5 - 10Hz

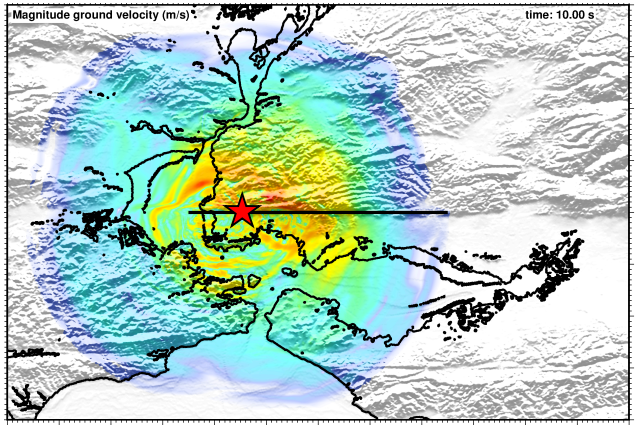
We have completed workflow for coupling geophysics and engineering simulations

Earthquake hazard



2048 nodes or
130,000 cores

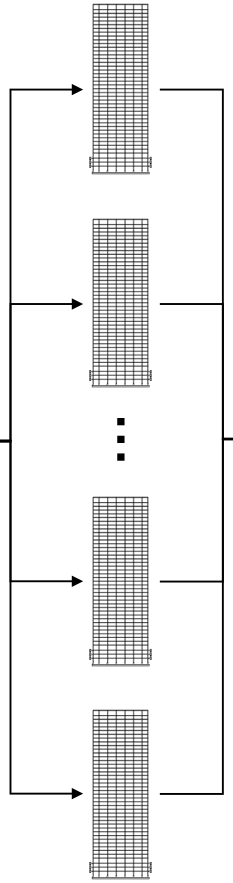
Surface motions from regional geophysics simulation



Rupture hypocenter

SW4

~ 2000 nonlinear building response history simulations

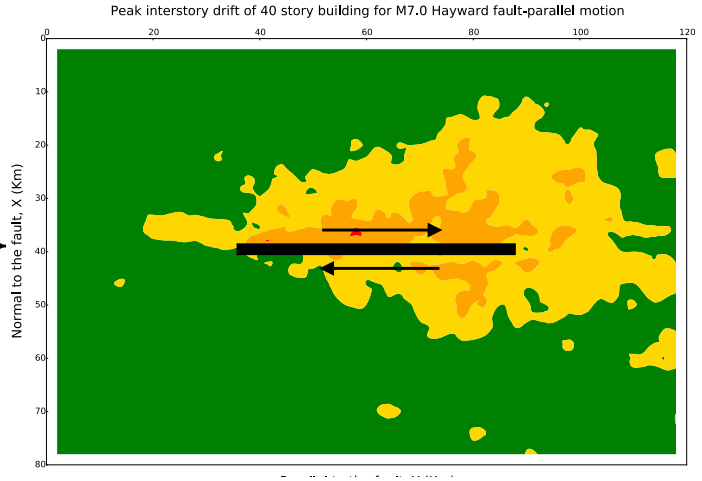


NEVADA

Earthquake risk

50
nodes

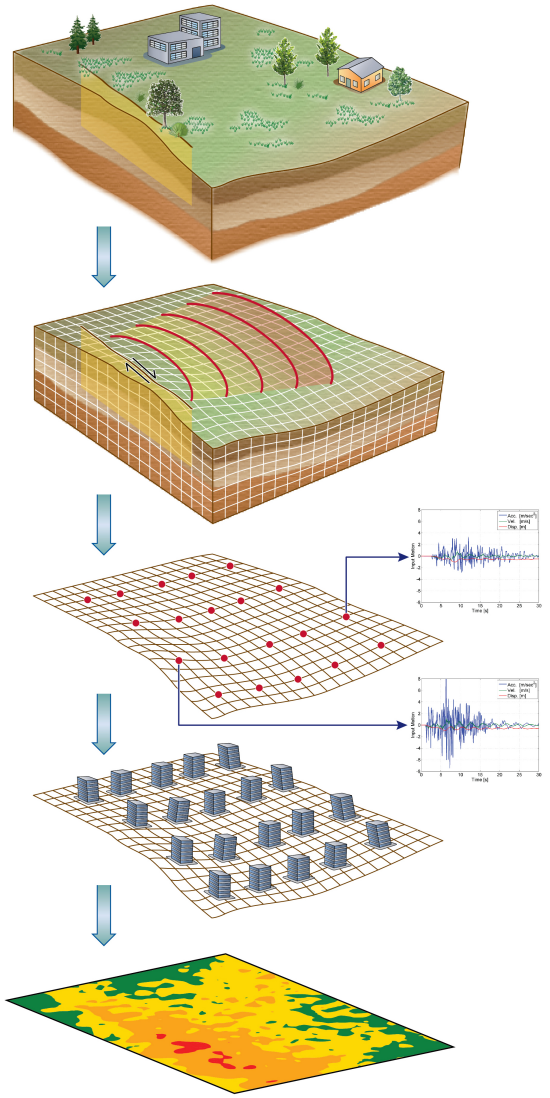
Distribution of building peak interstory drift



0.5% **1.0%** **2.5%**

Elastic Behavior | **Limited Permanent Distortion** | **Moderate Permanent Distortion** | **Large Permanent Distortion**

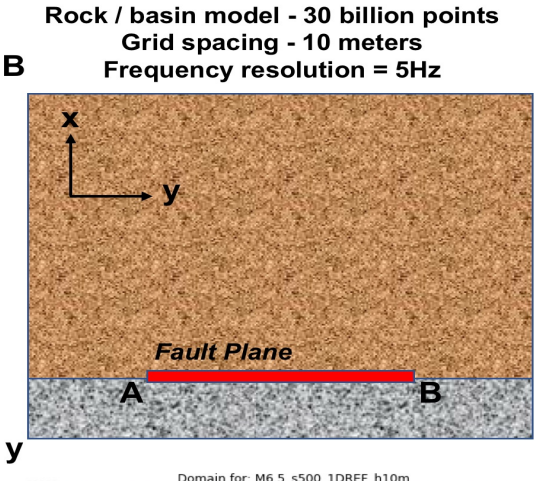
A unique feature of our approach is a close coupling of earthquake hazard and risk

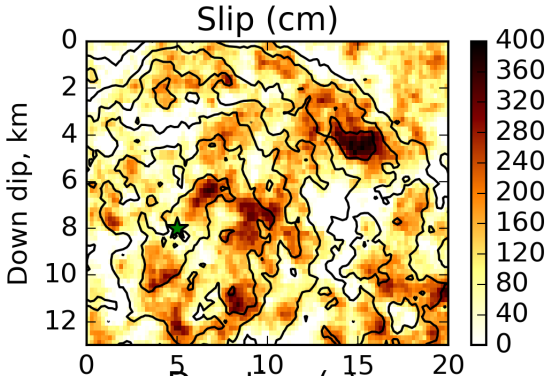


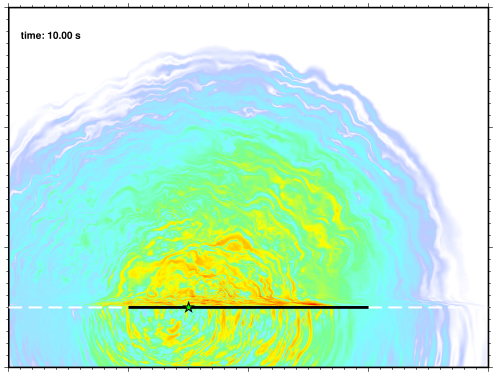
Earthquake Hazard

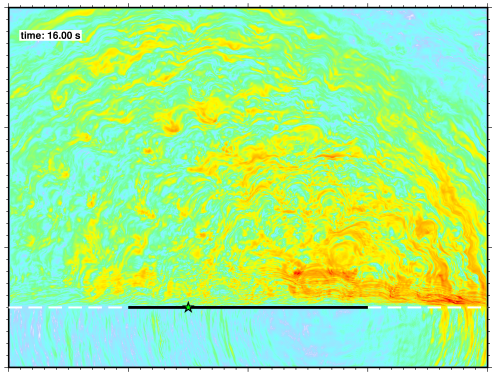
Earthquake Risk

SW4 **– 4th order finite difference geophysics code for wave propagation**

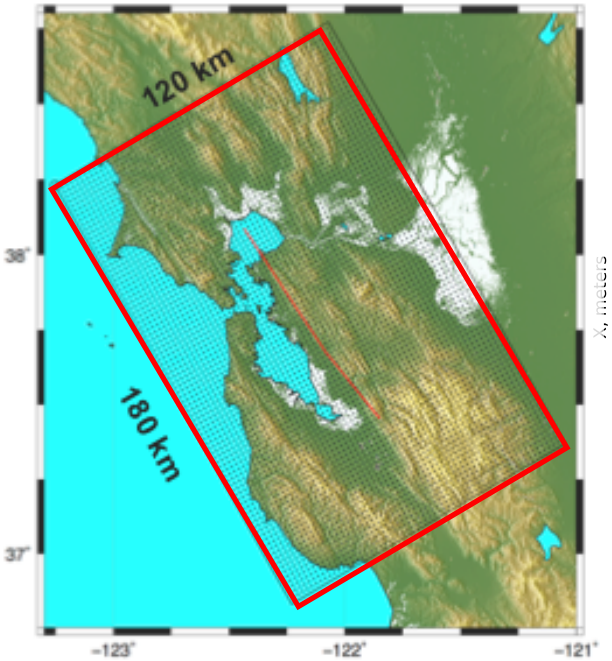


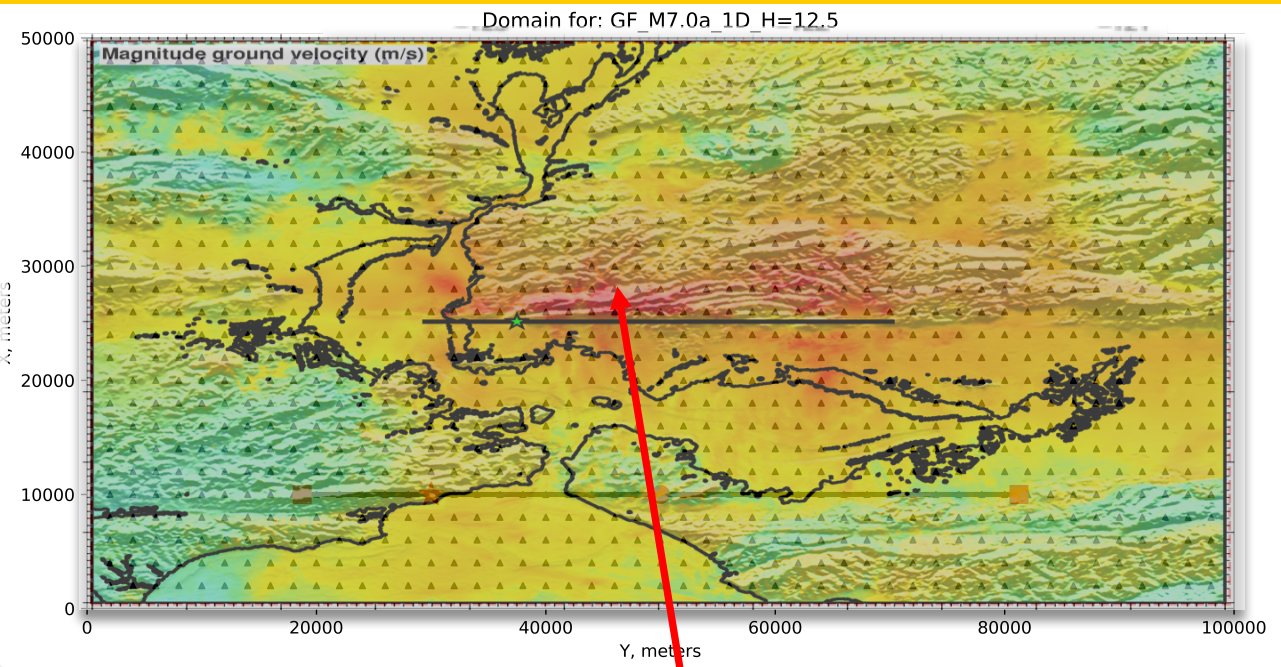


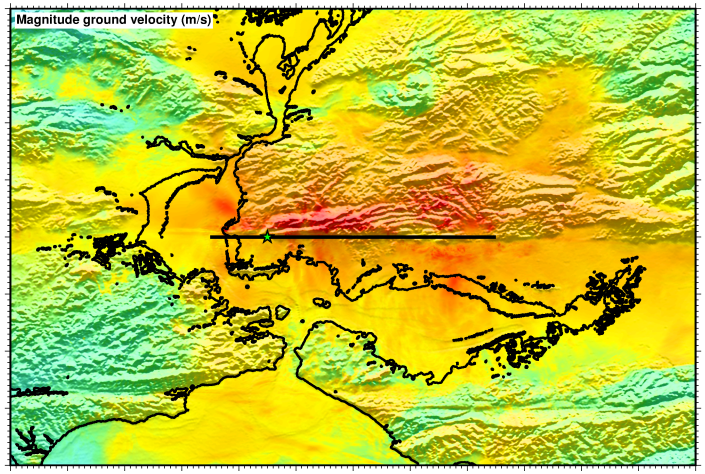


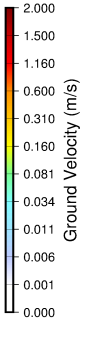


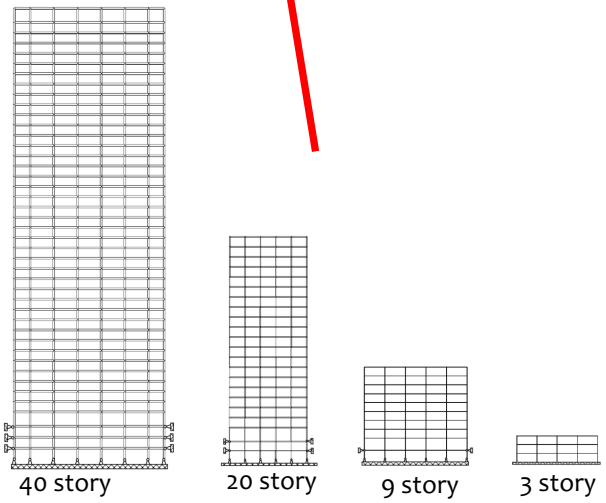
Linking ground motions to structural response





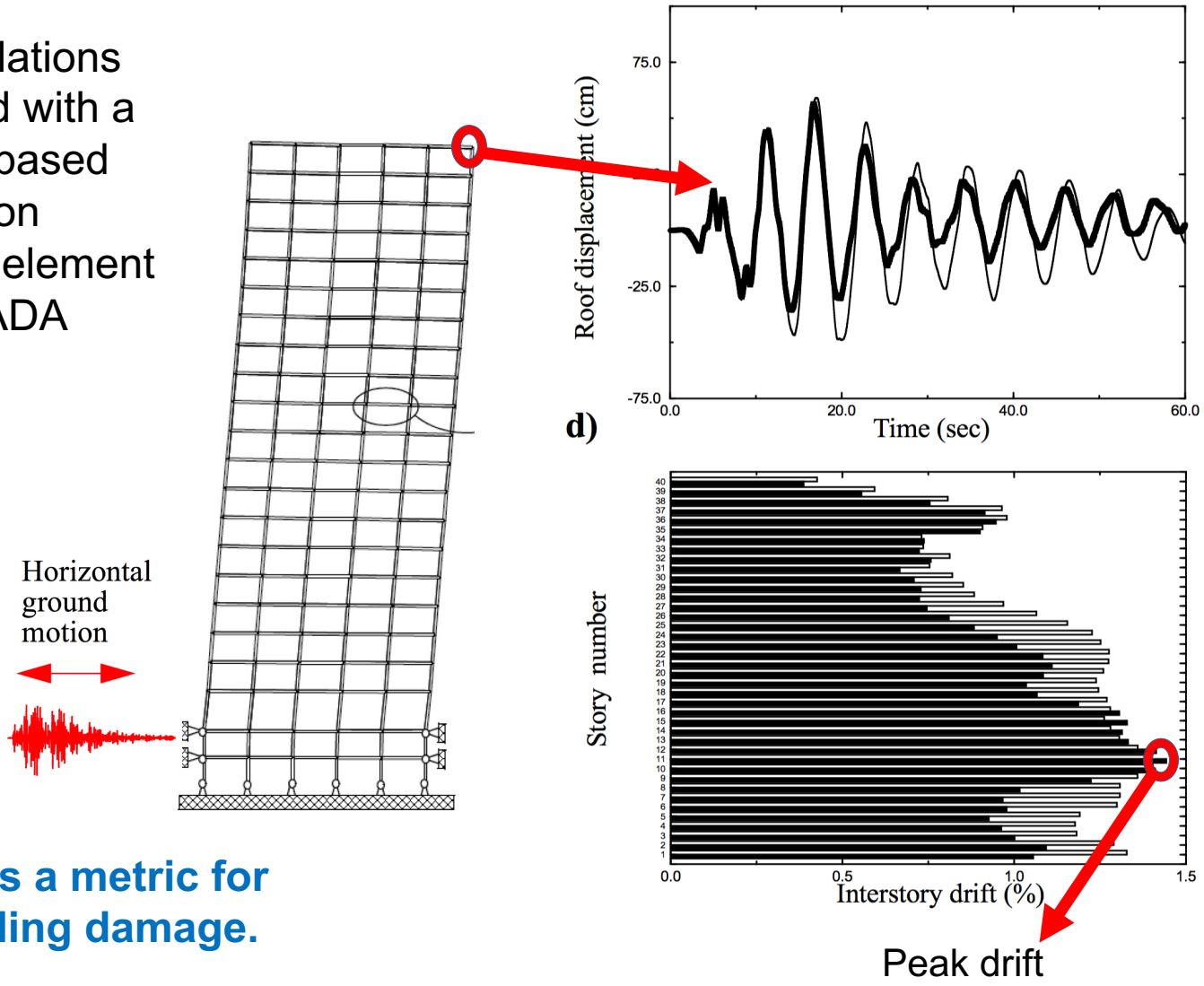






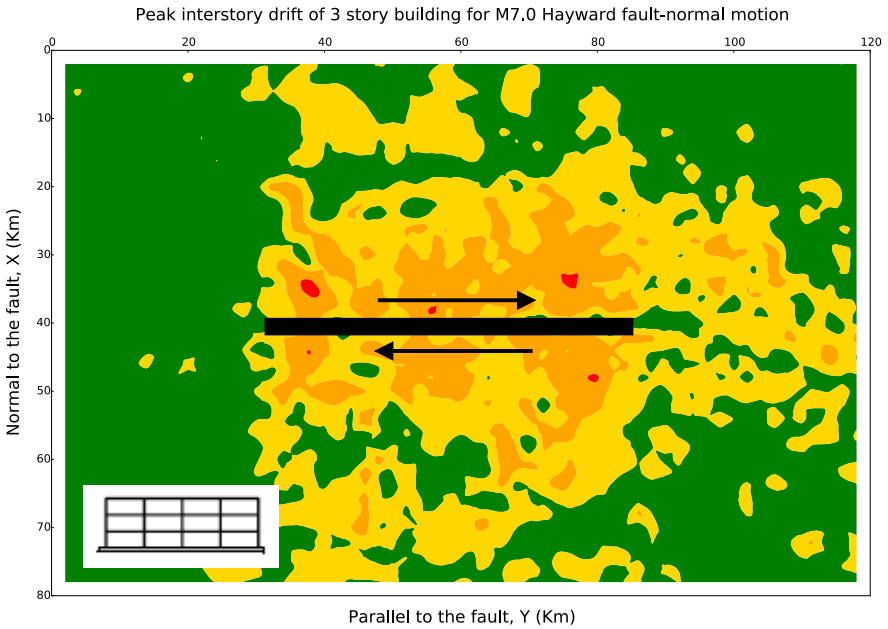
Building damage potentials are evaluated in terms of peak interstory drift

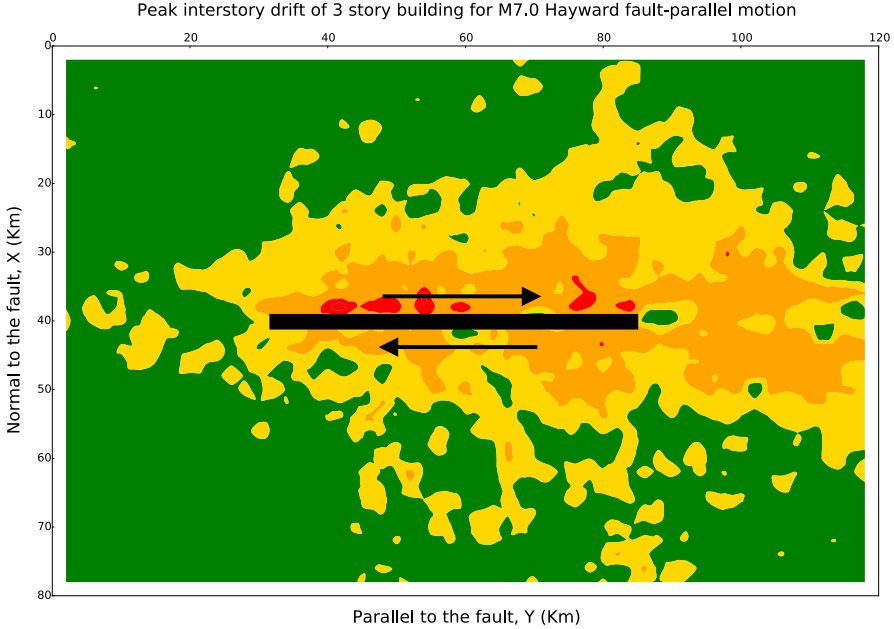
Structural simulations were performed with a detailed , fiber based finite deformation nonlinear finite element program, NEVADA



Interstory drift is a metric for evaluating building damage.

We have completed our first regional scale demonstration of both hazard and risk





Building Peak Interstory Drift Ratios

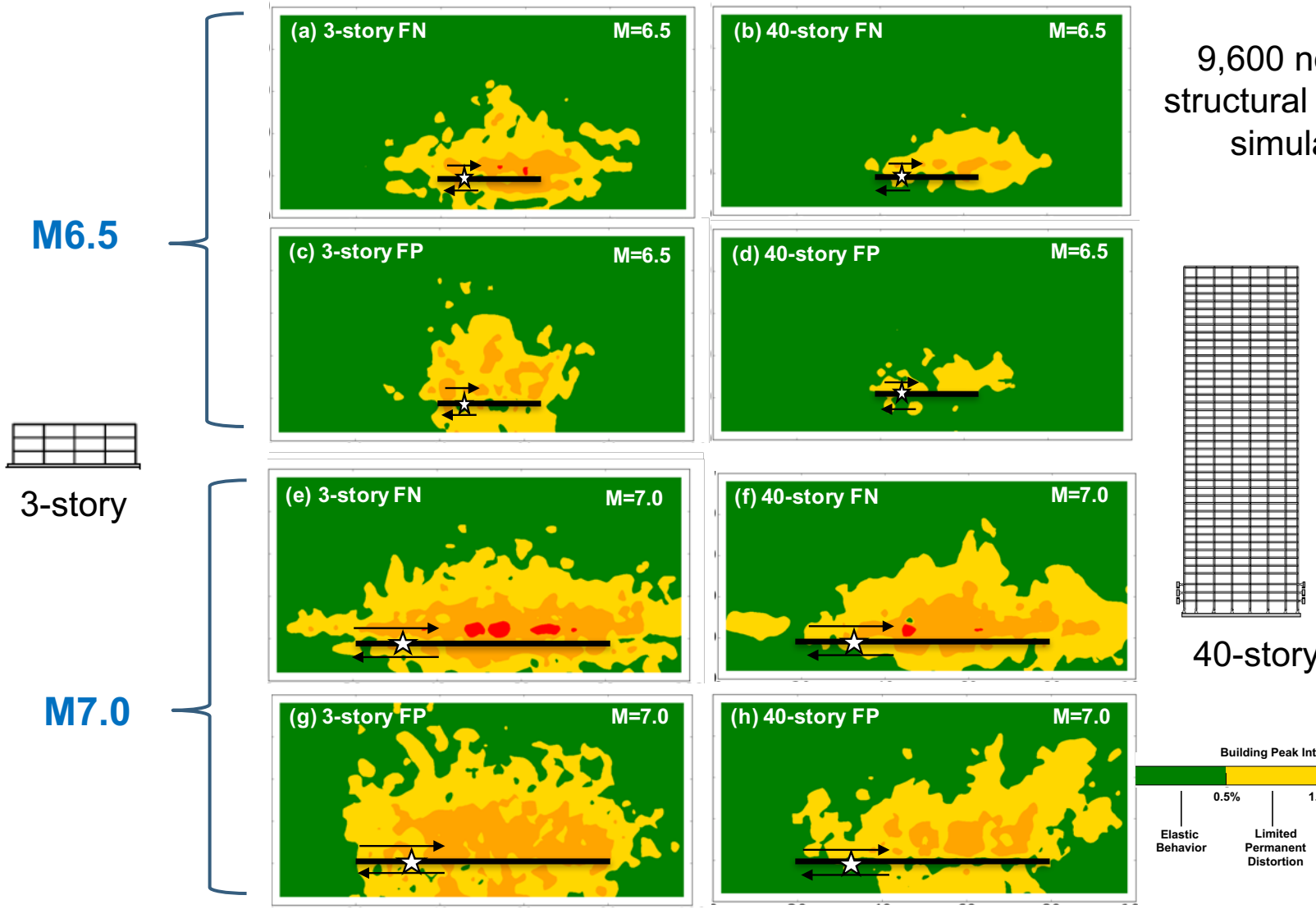
0.5% | 1.0% | 2.5%

Elastic Behavior | **Limited Permanent Distortion** | **Moderate Permanent Distortion** | **Large Permanent Distortion**

DOE standard 1020 limit states

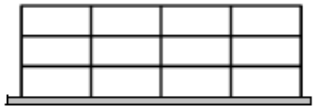
Toward Exascale Earthquake Ground Motion Simulations for Near-Fault Engineering Analysis
Johansen et al. - Computing in Science & Engineering, 2017

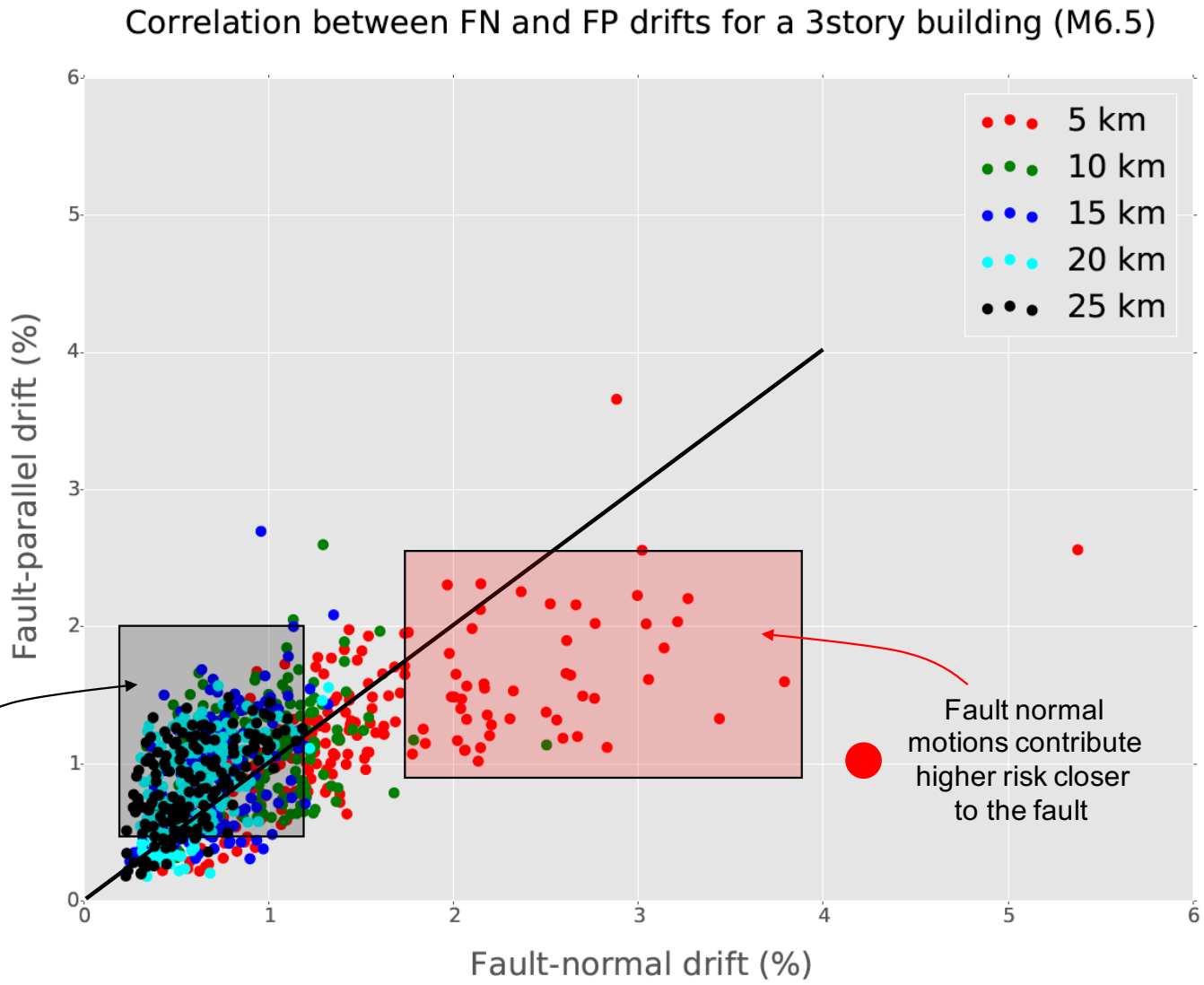
We calculated risks for 3- and 40-story buildings for two events (M6.5 and M7.0)



We are already gaining new insight into infrastructure risk

M=6.5 earthquake
3 story steel frame

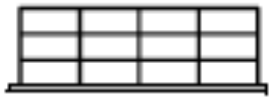




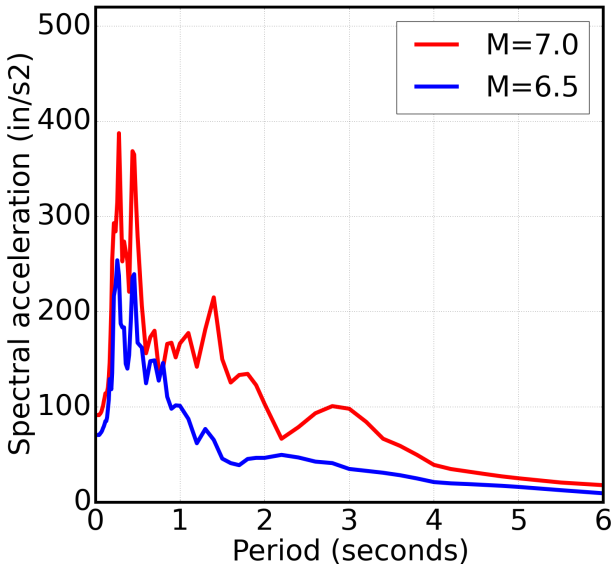
Fault parallel motions contribute higher risk at distance from the fault

Fault normal motions contribute higher risk closer to the fault

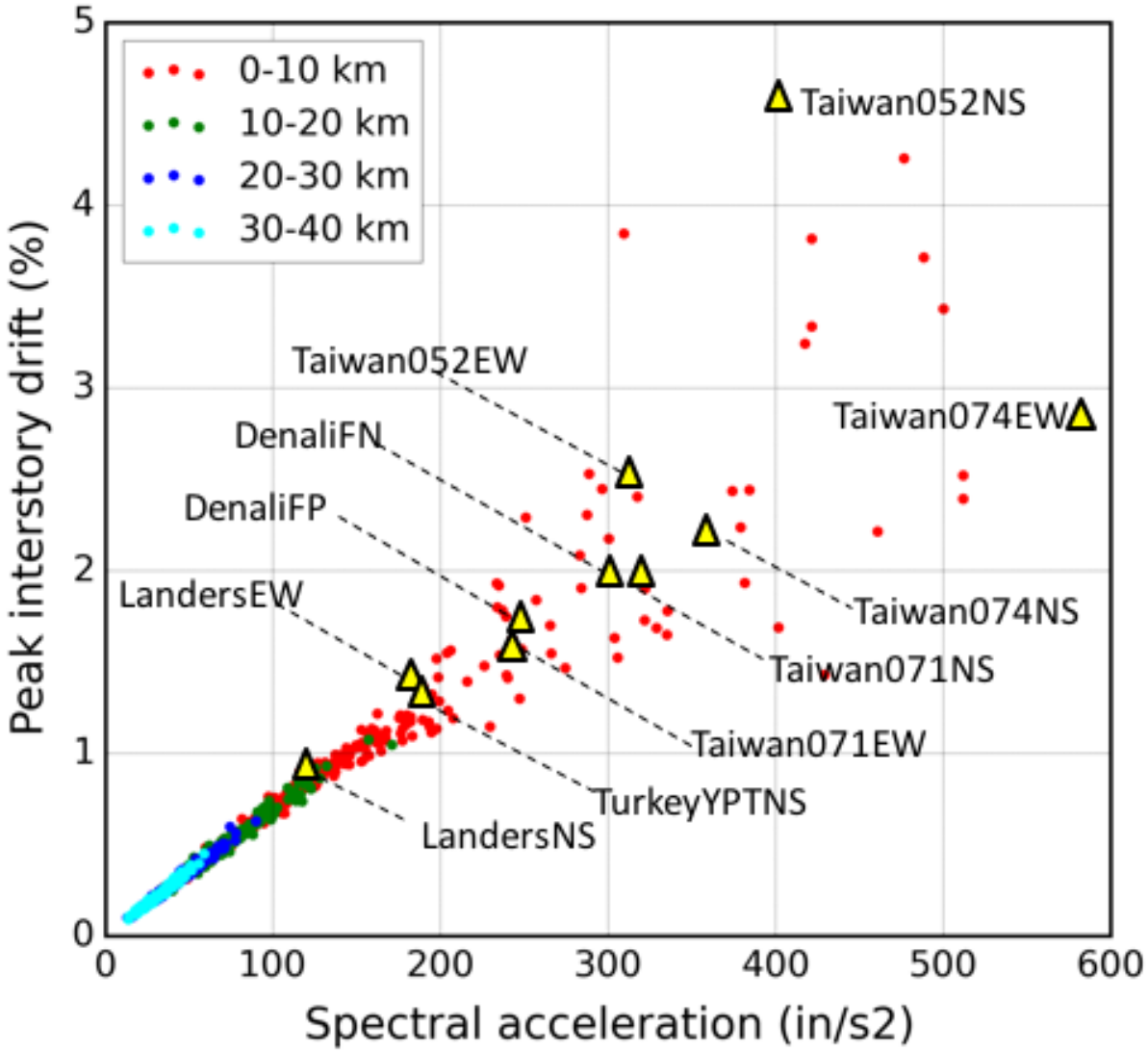
Our simulated structural risk agrees with observed records



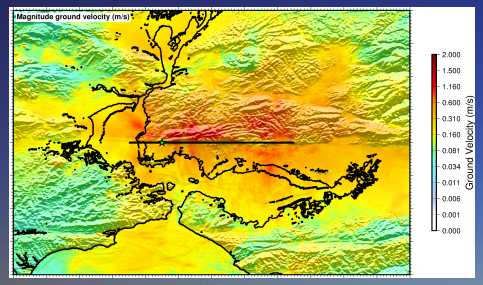
3-story
Natural period = 0.91 s



Higher variability in the near-fault region poses a design challenge for engineers.



Developing an operational strategy for fusing unprecedented simulations and data



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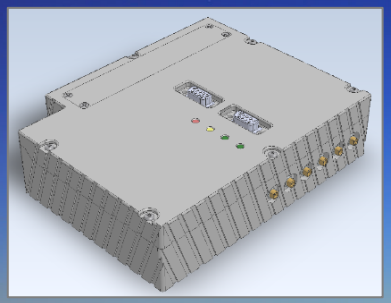

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Energy infrastructure risk

BERKELEY LAB

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A multidisciplinary team is essential – a National Lab scale problem

Computational Science / Math

Anders Petersson

Hans Johansen

Structural / Soil Mechanics

David McCallen

Mamun Miah

Seismology

Artie Rodgers

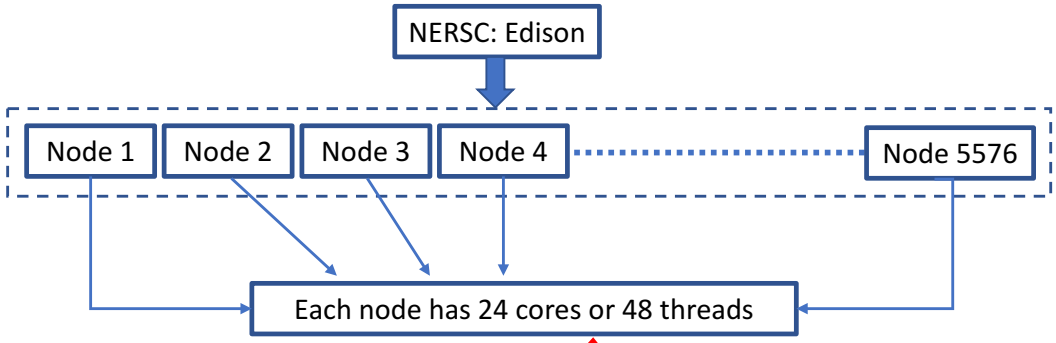
Boris Jeremic

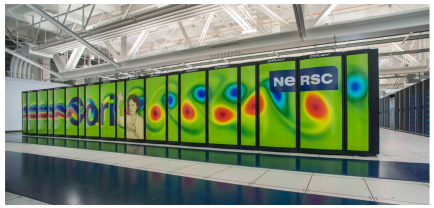
Kurt Nihei

Norm Abrahamson

Thank You!

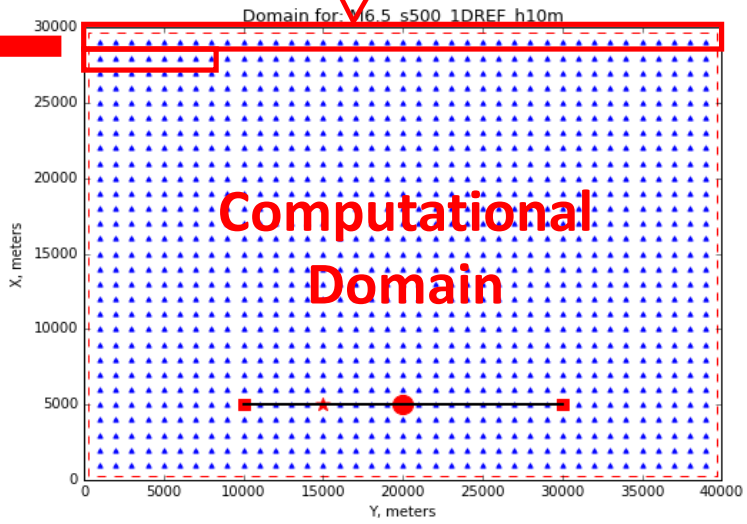
Supercomputing on NERSC





1 run per thread
48 runs per node

48 building locations



Total number of building locations = 39x29 = 1131
Node requirement = 1131/48 = 24
1 additional node is required for TaskFarmer
Total nodes = 24+1 = 25

Note: TaskFarmer script distributes 1 building run in each thread