The EQSIM Computational Framework for Fault-to-Structure Earthquake Simulations
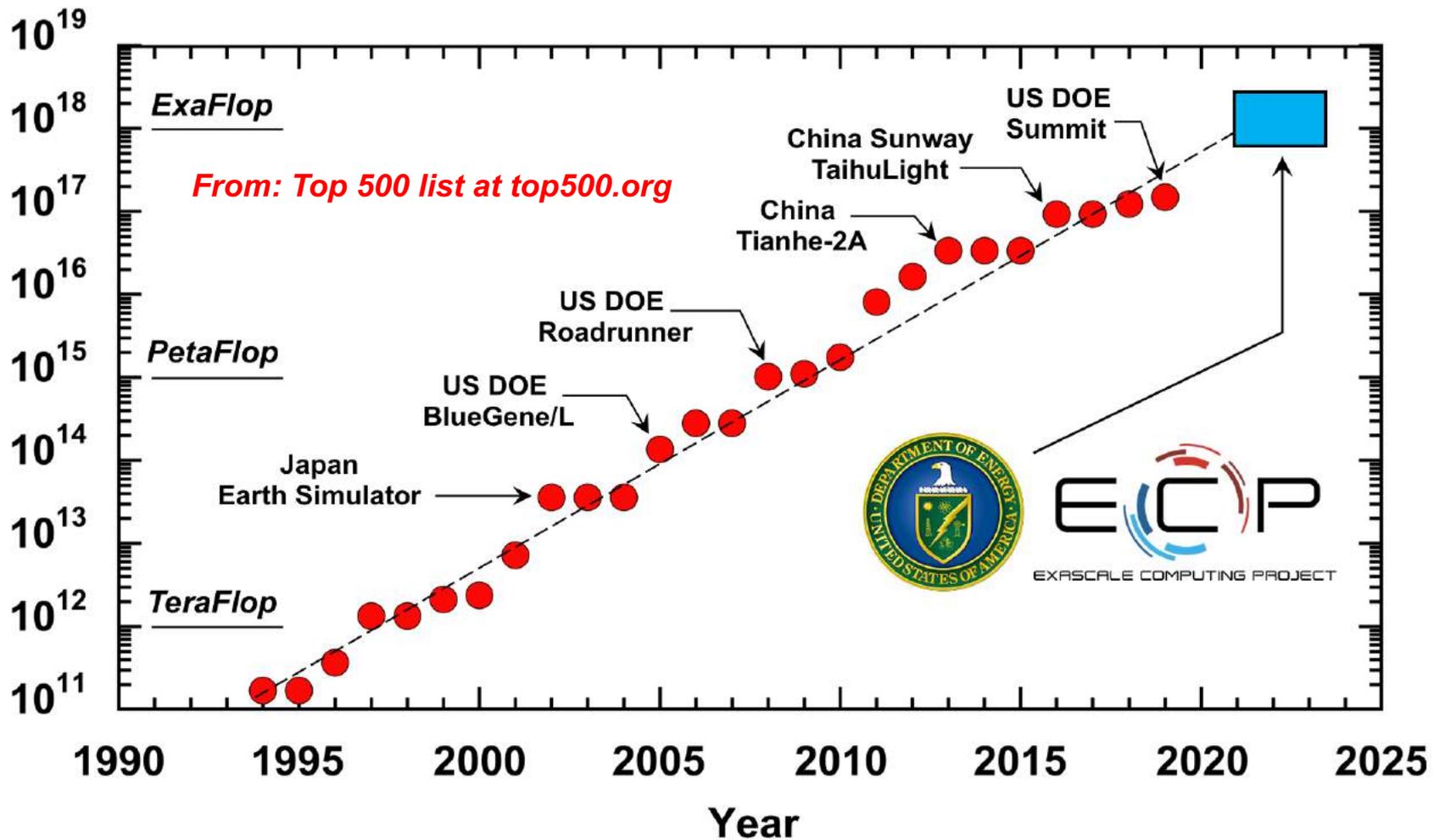
DOE/NRC NPH Workshop 2020

David McCallen
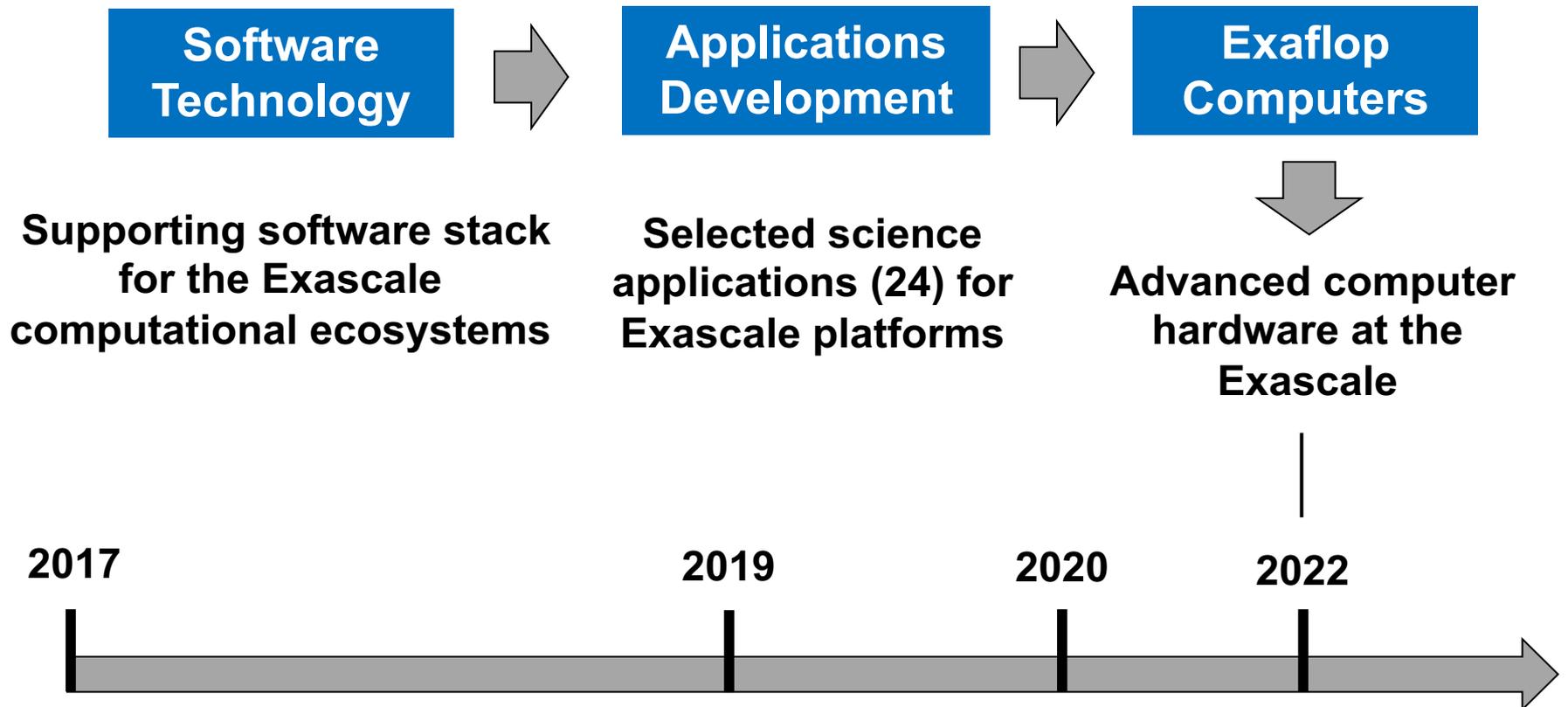**Lawrence Berkeley National Laboratory**
& University of Nevada, Reno

The success of HPC - a continuous march "up and to the right"

The DOE Exascale Computing Project (ECP) is preparing to exploit a billion-billion FLOPS

Three components…

Software Technology		Applications Development		Exaflop Computers

Supporting software stack for the Exascale computational ecosystems

Selected science applications (24) for Exascale platforms

Advanced computer hardware at the Exascale

2017 **2019** **2020** **2022**

EarthQuake SIMulation (EQSIM) framework - fault-to-structure regional simulations

Geophysics → Engineering →

Regional-scale domain → Geophysics ground motion simulations (billions of zones) → Infrastructure response simulations (thousands of stations) → Infrastructure demand / risk
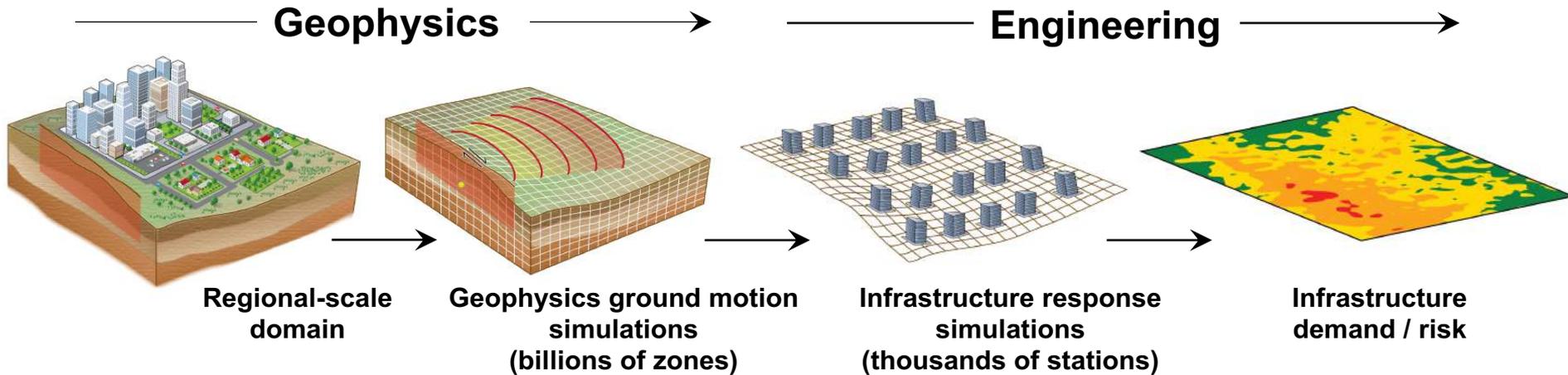
Key issues that will be explored through simulations…

- **How do earthquake ground motions actually vary across a region and how does this impact risk to infrastructure?**

- **How do complex (realistic) incident ground motion waveforms actually interact with a particular facility?**

Our project team spans engineering, seismology, math/computer science

Structural/Geotechnical Mechanics

David McCallen

Mamun Miah

Maryam Tabbakhha

Applied Math / Numerical Methods

Anders Petersson

Bjorn Sjogreen

Computer Science

Houjun Tang
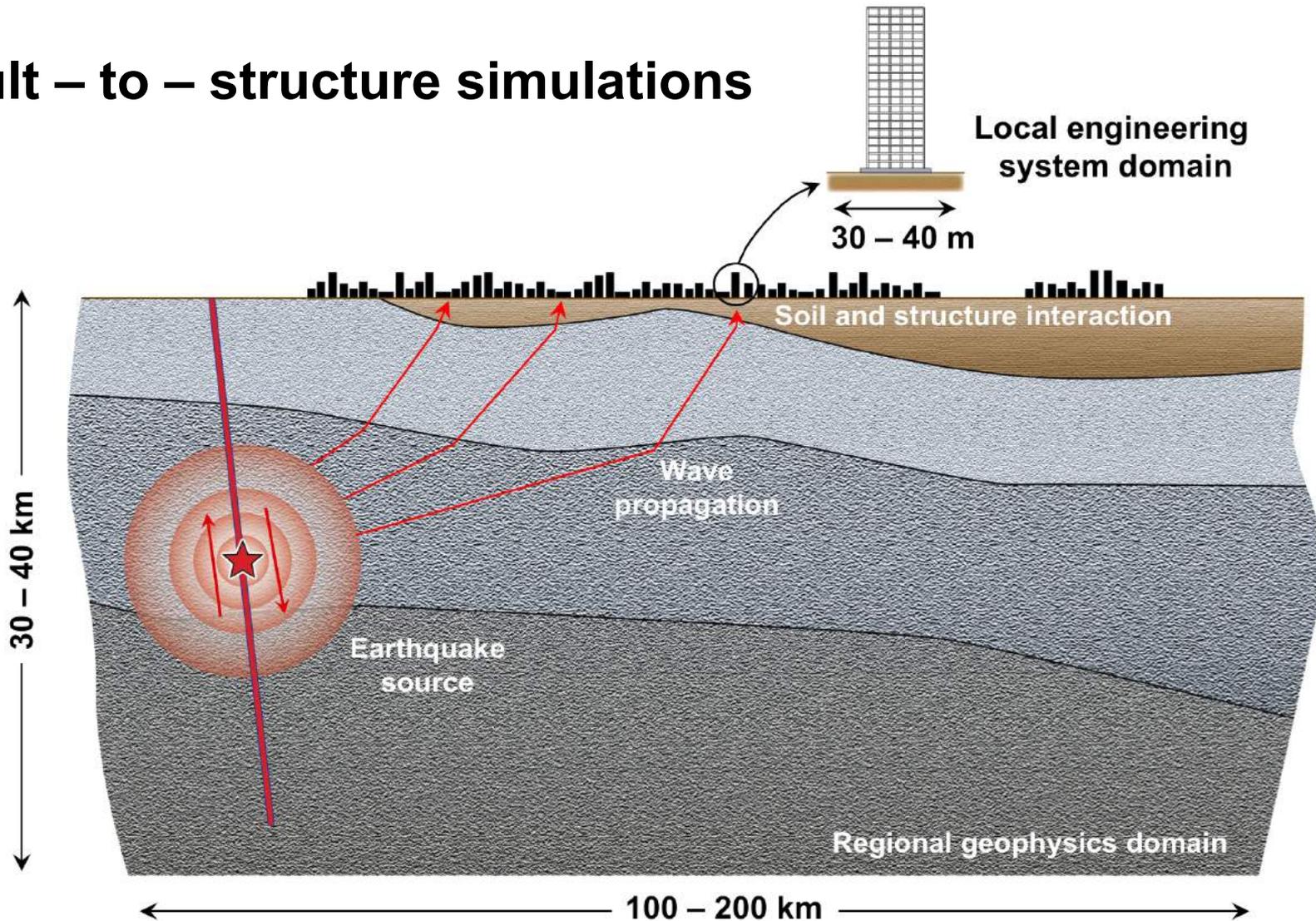
Ramesh Pankajakshan

Seismology / Geophysics

Arben Pitarka

Arthur Rodgers

Ana Aguiar Moya

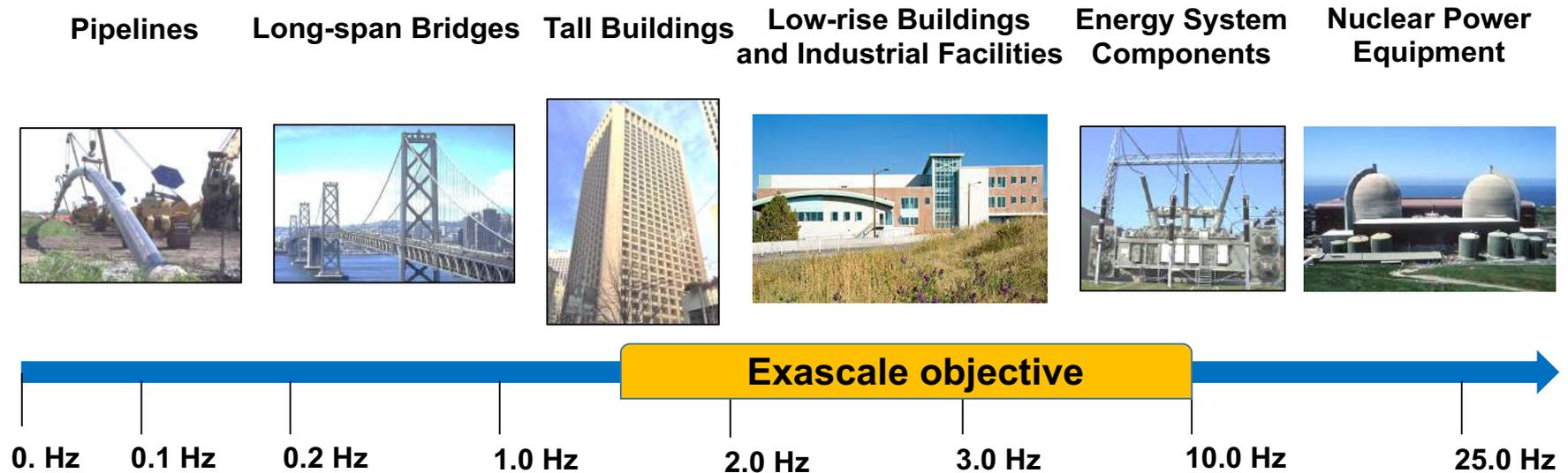# This is a complex, multi-scale scientific and engineering problem

Fault – to – structure simulations

We couple an explicit finite difference code with implicit structure/soil codes

Semi - stochastic kinematic fault rupture model

Surface topography scattering

Spatially correlated stochastic fine-scale geology

Adaptive curvilinear grid near surface

Adaptive Cartesian grid at depth

Super grid dissipative boundary

Viscoelastic rheological model provides quality factors for material attenuation

SW4
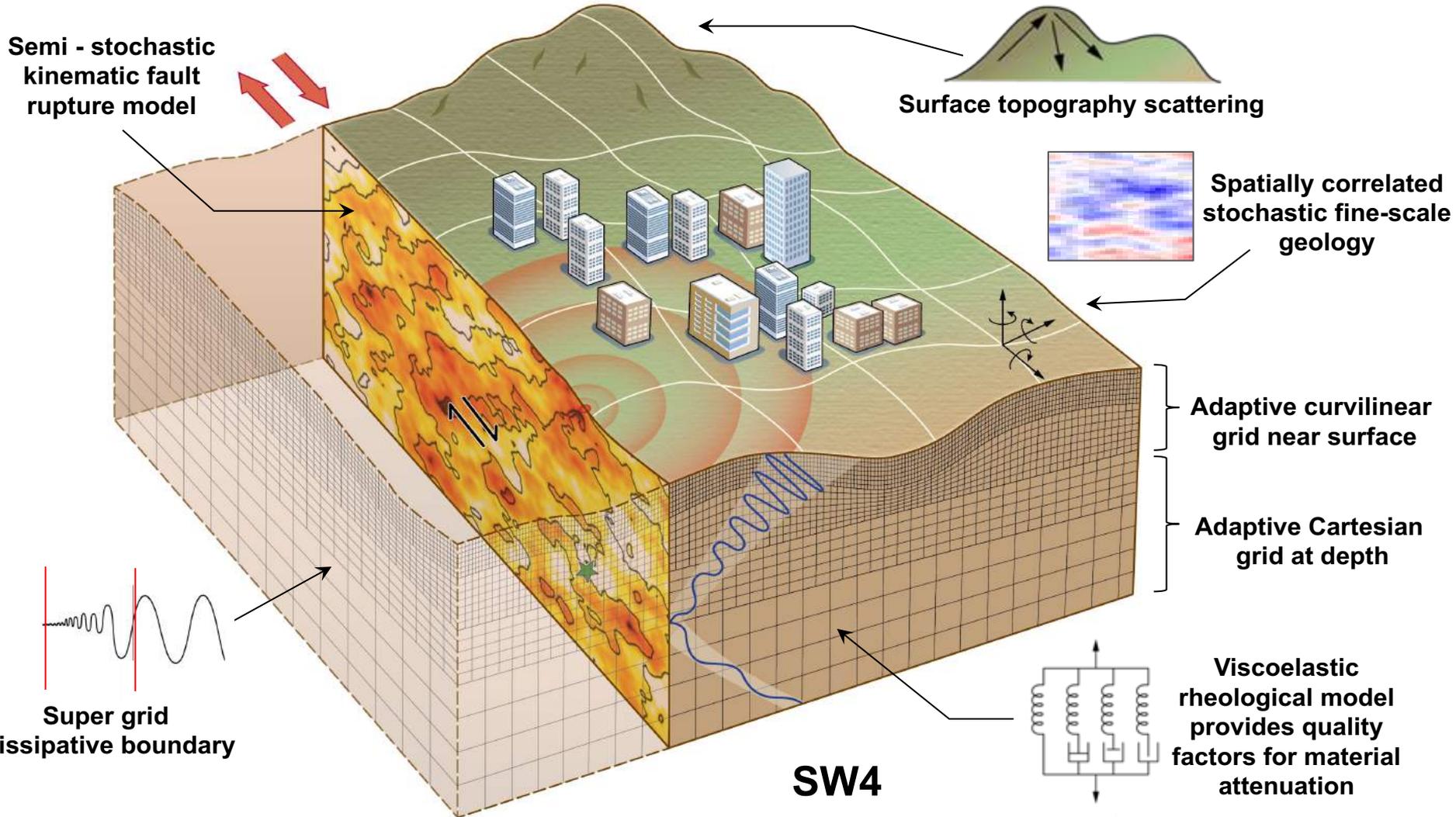
Our Exascale challenge - regional simulations at "engineering" frequencies

| Pipelines | Long-span Bridges | Tall Buildings | Low-rise Buildings and Industrial Facilities | Energy System Components | Nuclear Power Equipment |

Exascale objective

0. Hz   0.1 Hz   0.2 Hz   1.0 Hz   2.0 Hz   3.0 Hz   10.0 Hz   25.0 Hz

Necessary capabilities to do this…

Run much larger models much faster

- Very large models at higher frequency
- Many realizations to account for uncertainties (e.g. fault rupture)

Represent fine-scale geology

- Waveform data inversion to improve geologic models
- Stochastic geology

Specifying our Exascale goals

San Francisco Bay Area (SFBA) regional model

Regional-scale model (SFBA)
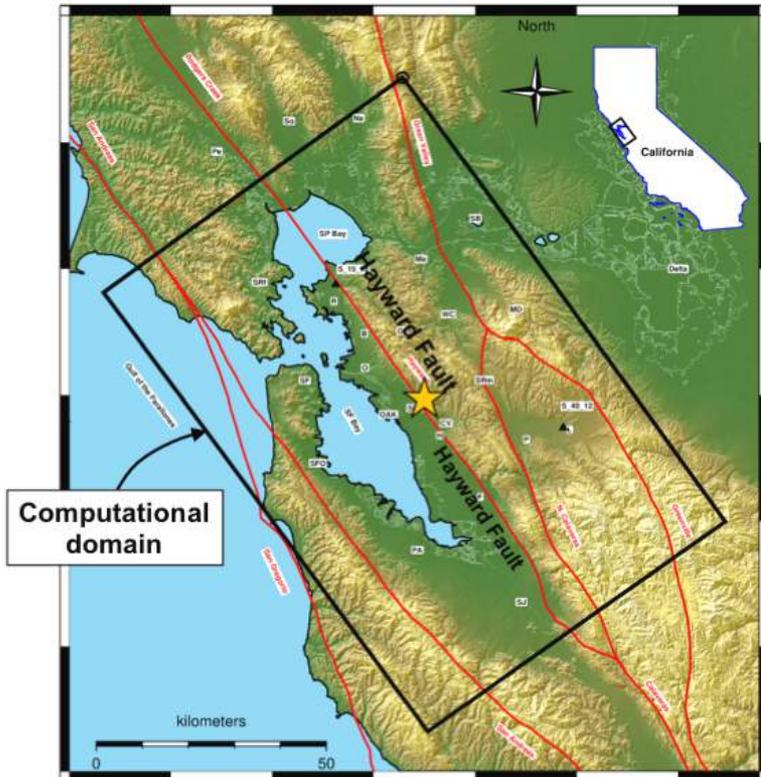
Application ground motion simulation performance goals
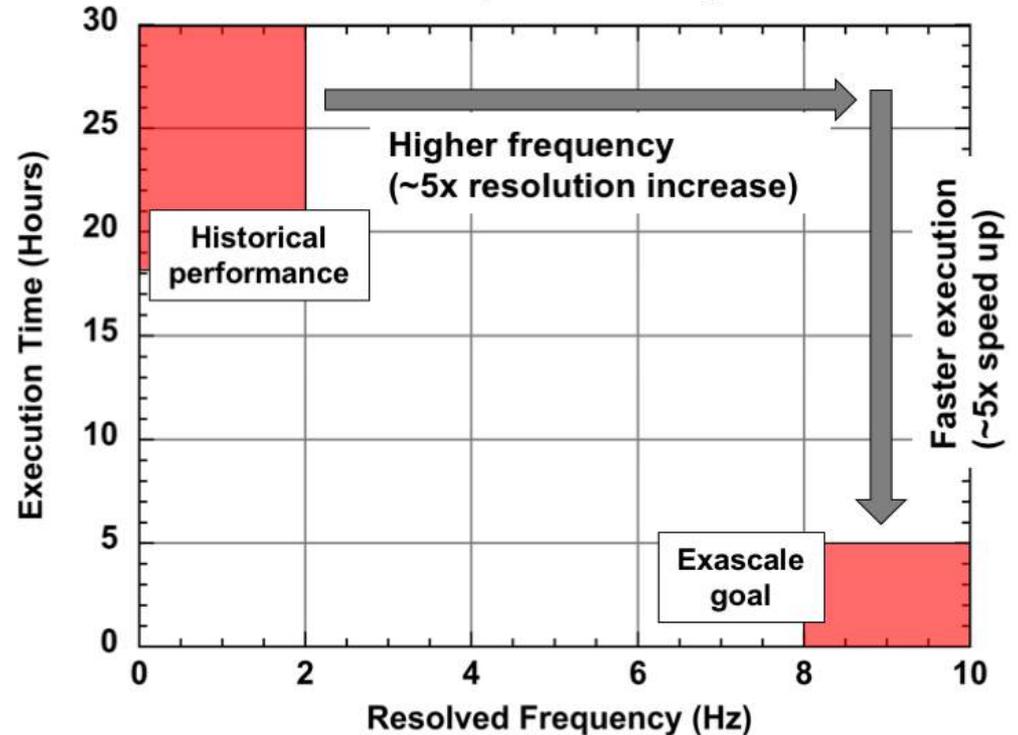
$$FOM = \frac{(Freq)^4}{Wall\ Clock\ Time \times 7.6} \left[\frac{500}{Vsmin}\right]^4$$

Computer science - efficient distribution of work at ~200 billion grid points is essential

Pencil domain "i"

Pencil domain "k"

Pencil domain "n"

Node "n"

Node "k"

Node "i"
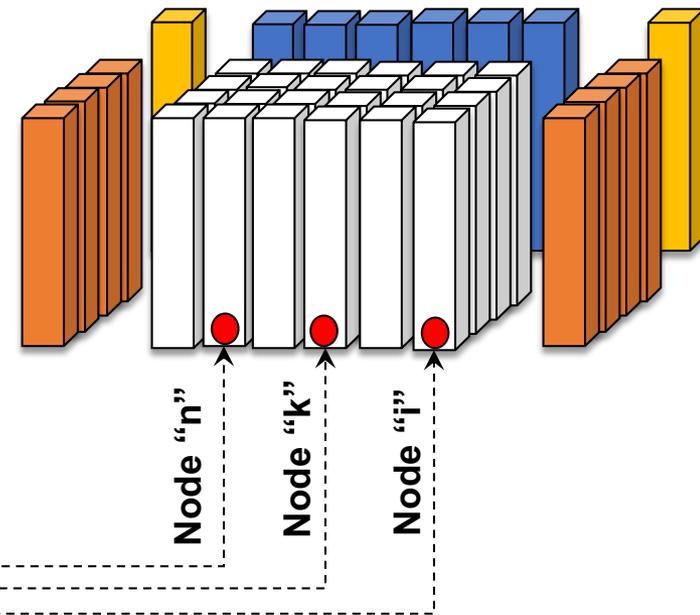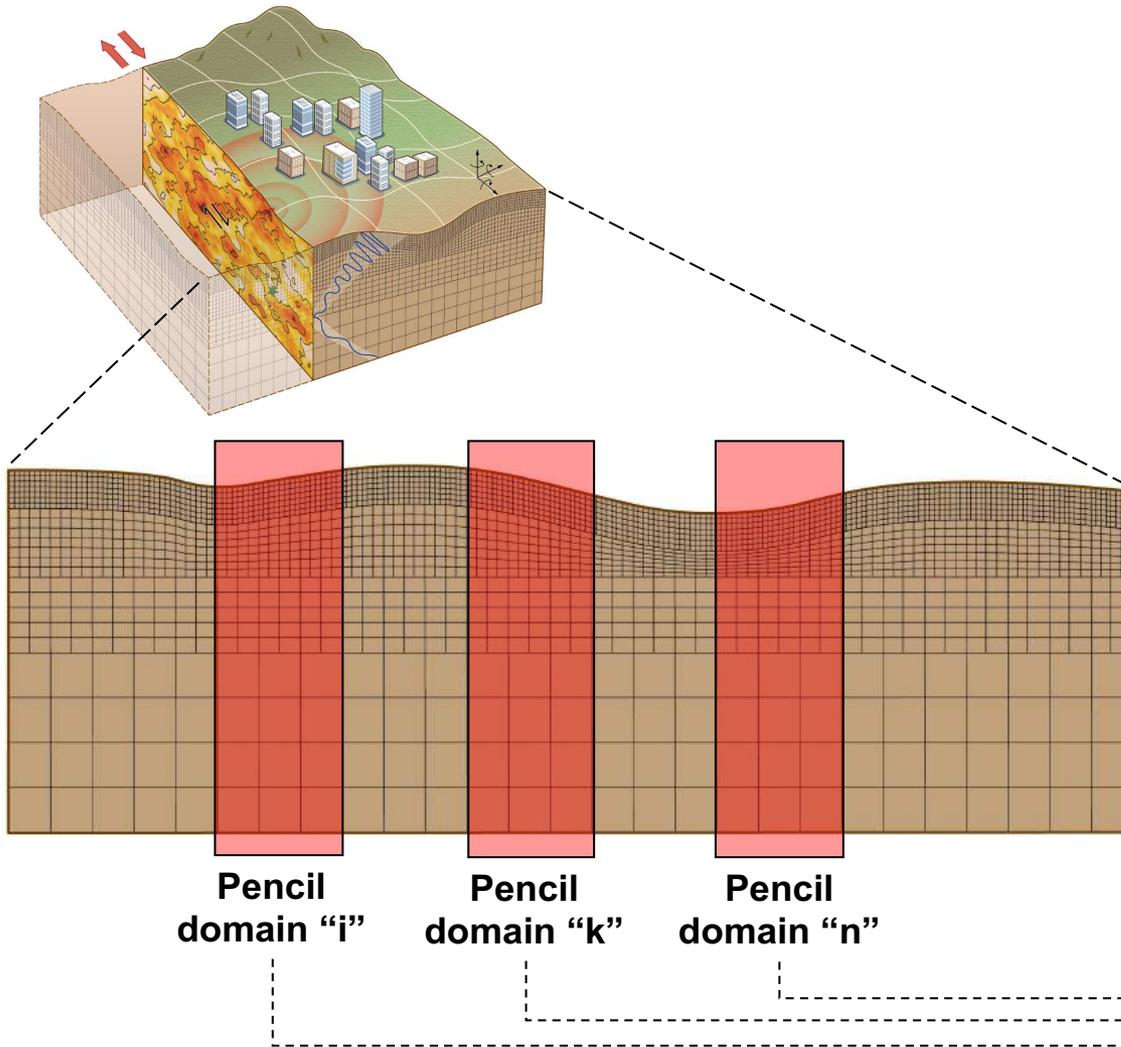
We have already achieved high performance on advanced platforms (FOM = 189)
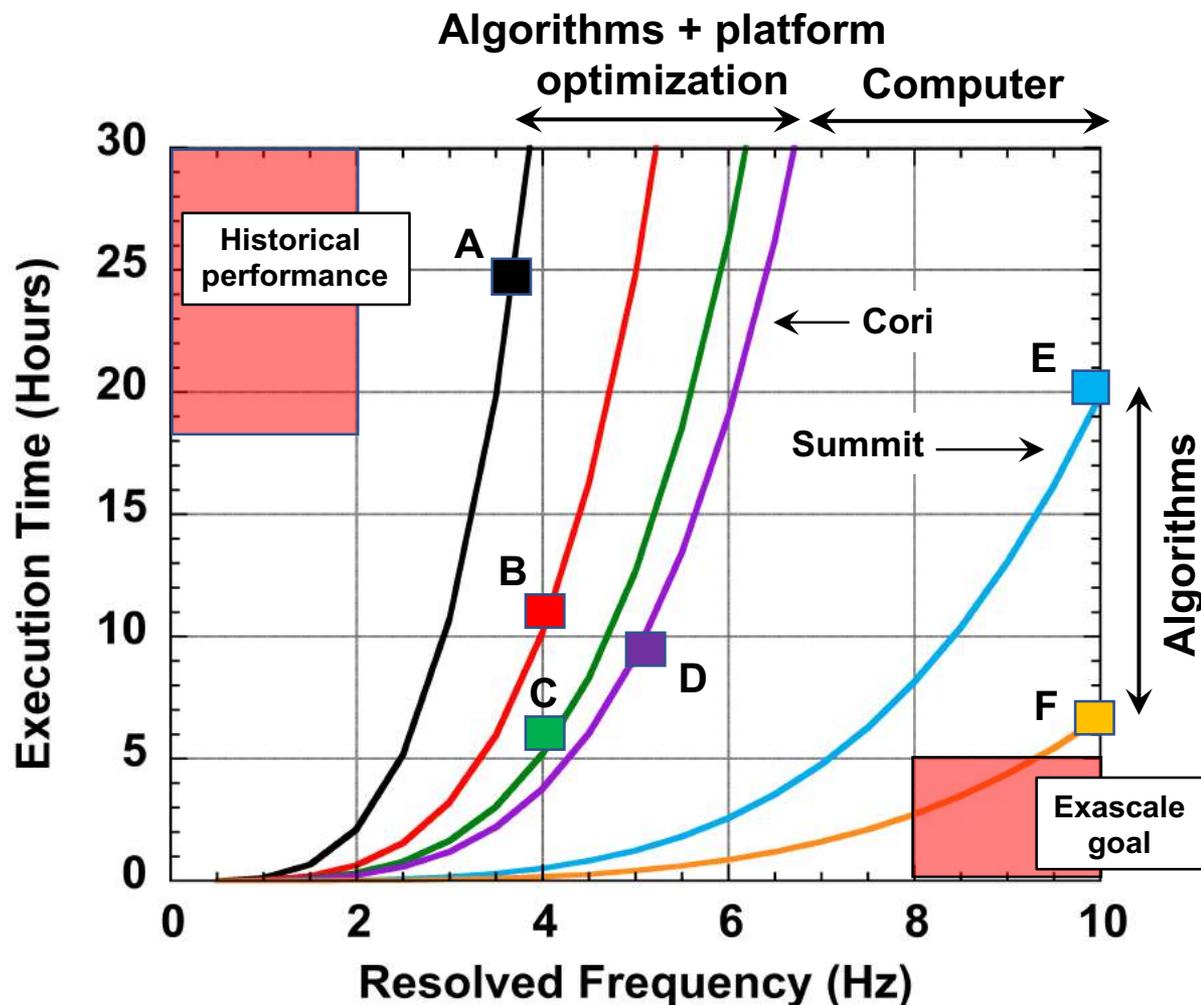
San Francisco Bay Area simulations to 10Hz on the Summit computer
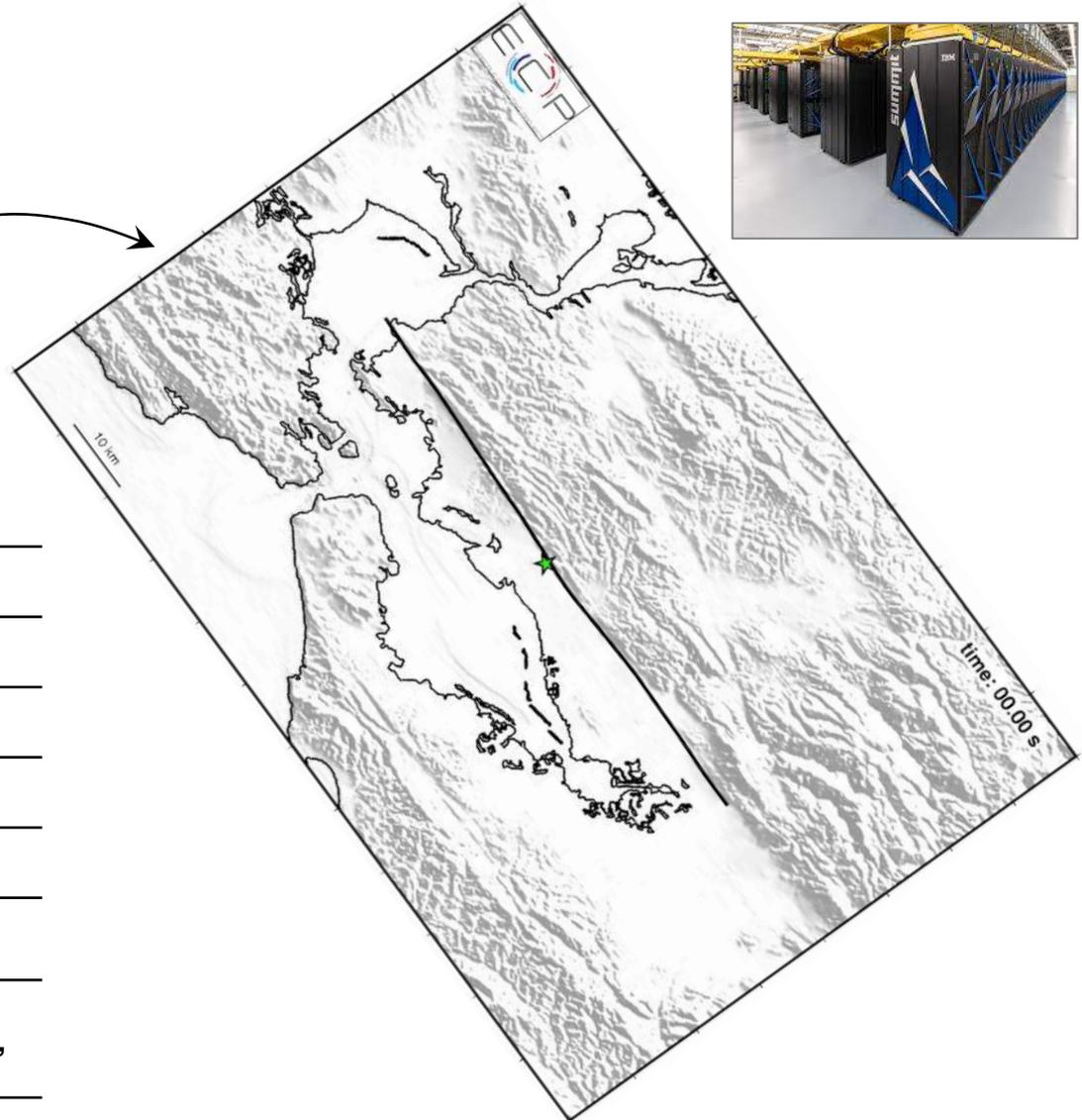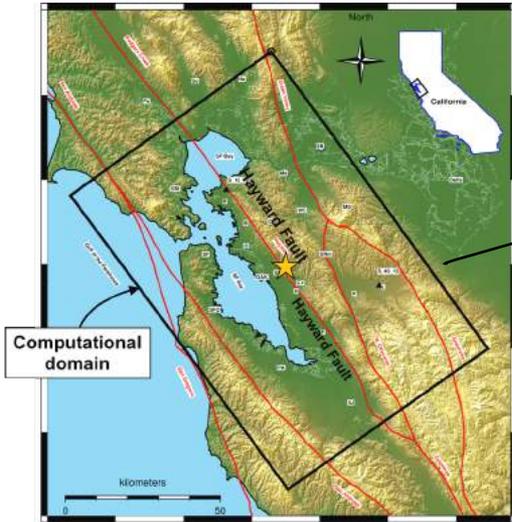
Frequency Resolved	10 Hz
Vs$_{min}$	**500 m/s**
Number of Grid Points	63 Billion
Smallest Cell Size	6.25 m
Platform	SUMMIT (ORNL)
Number of Nodes	1024
Wall Clock Time	6 hours, 58 minutes,

Coupling geophysics and engineering models

a) **Weak Coupling**
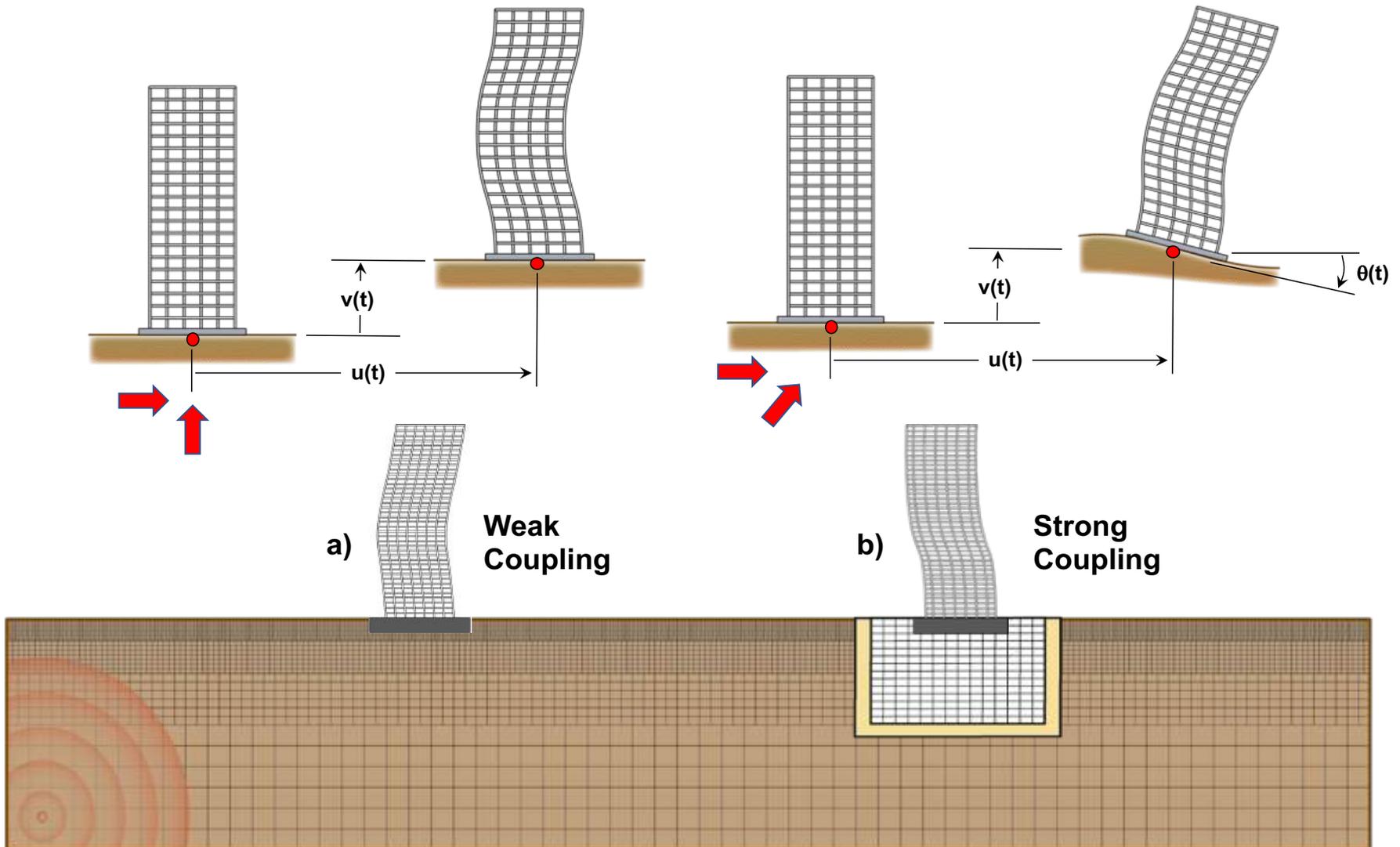
b) **Strong Coupling**

Strong coupling via DRM

Soil island

DRM boundary
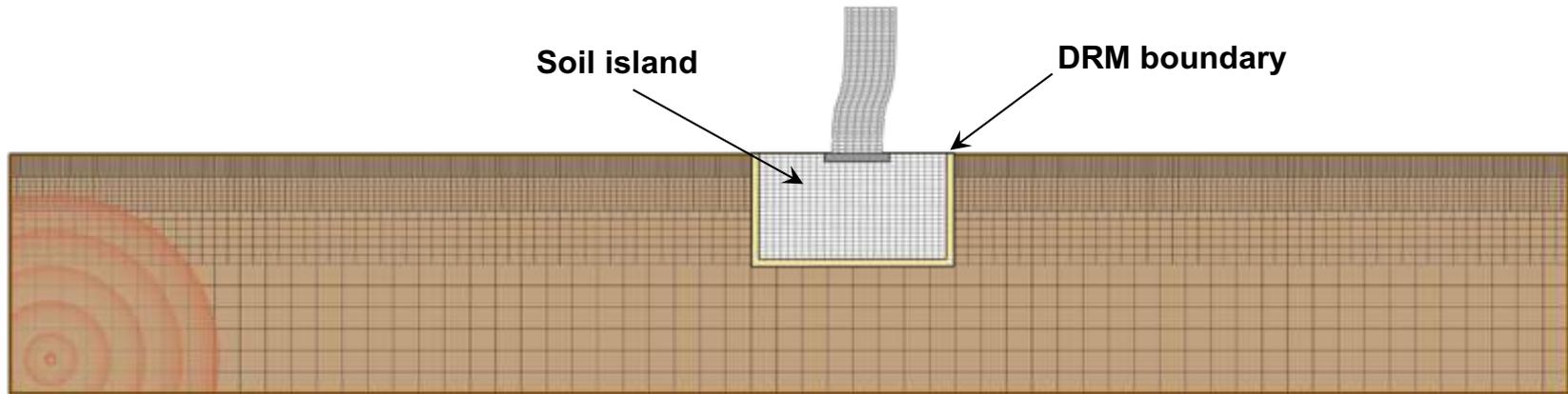
Step 2 – Soil island / structure simulation

Damping layer

DRM boundary motions

Step 1 – SW4 wave propagation solution
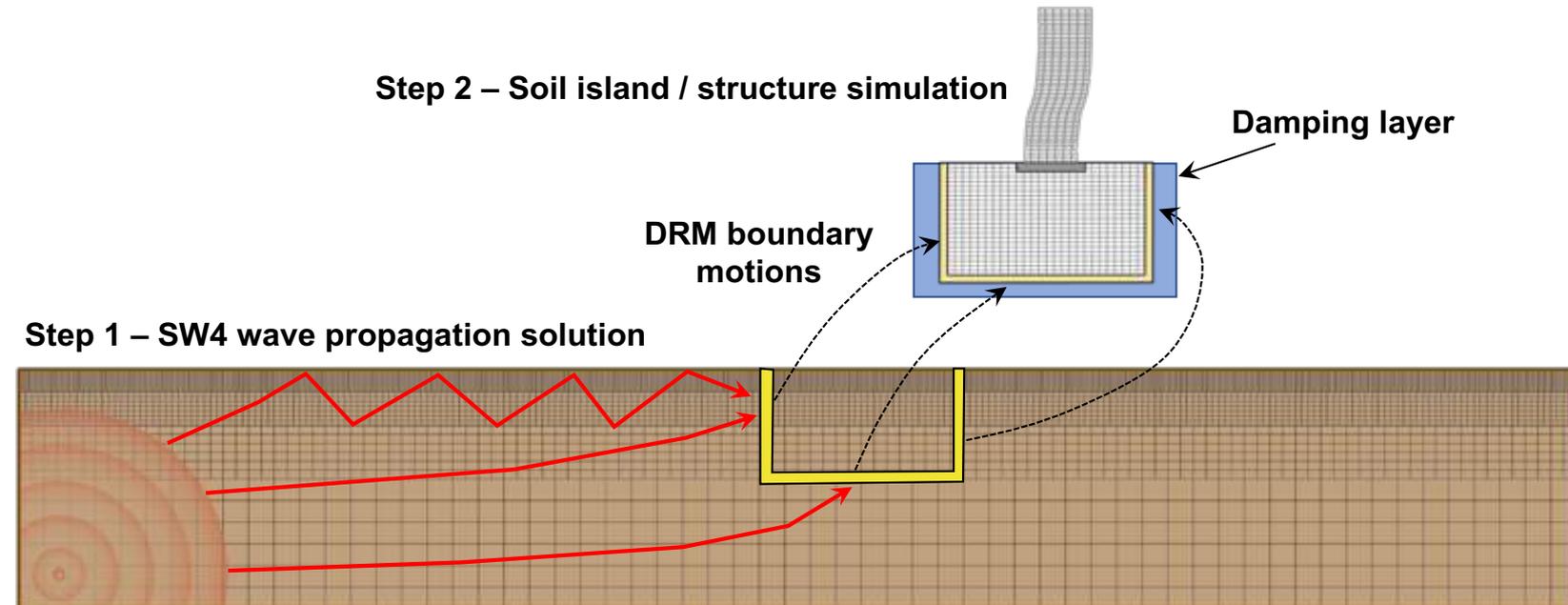
Coupling geophysics and engineering models
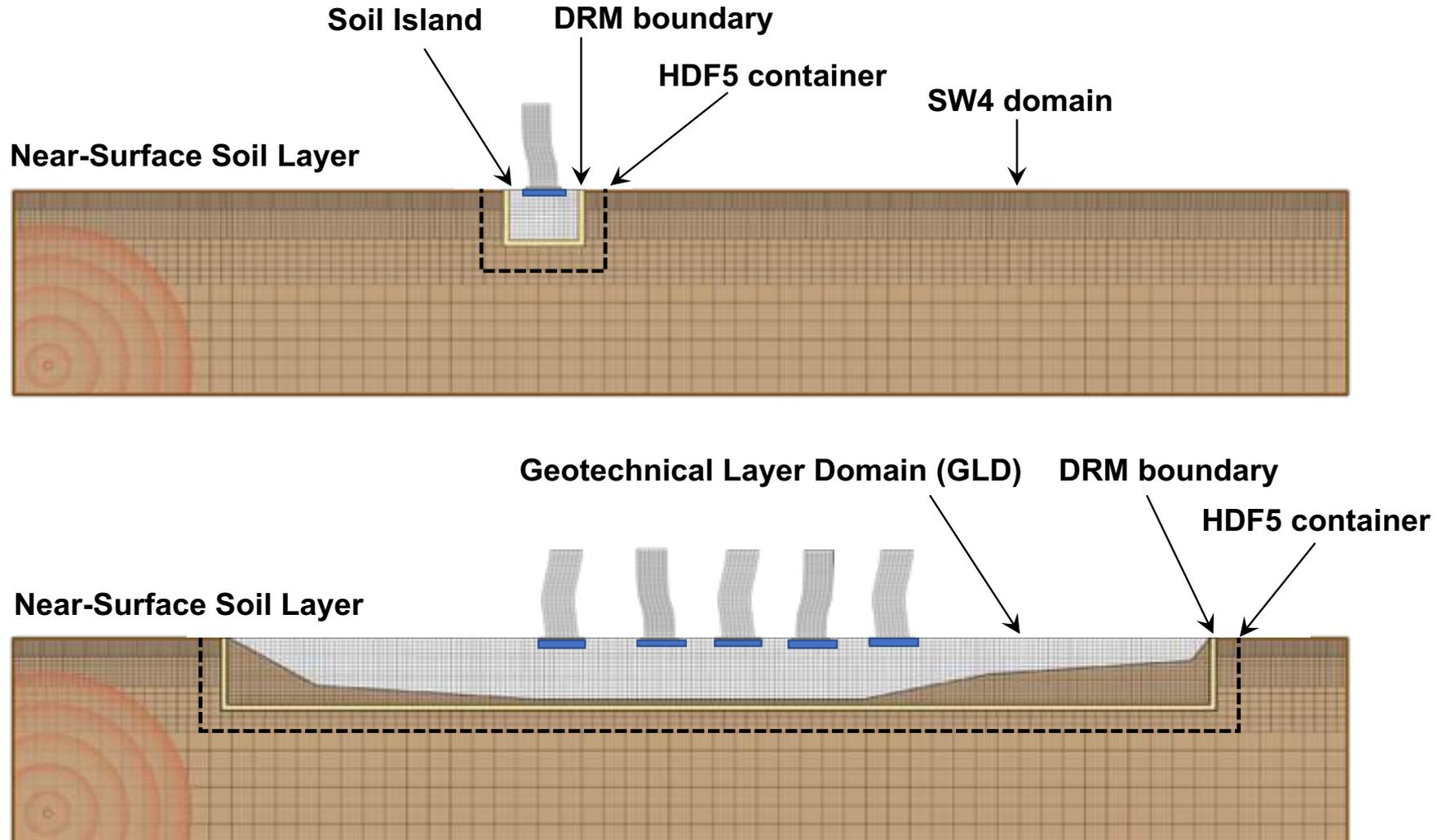
The coupling of geophysics and engineering models has been comprehensively tested

SW4 motions

OpenSees / ESSI soil island motions
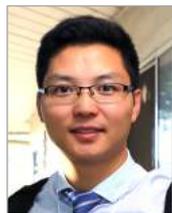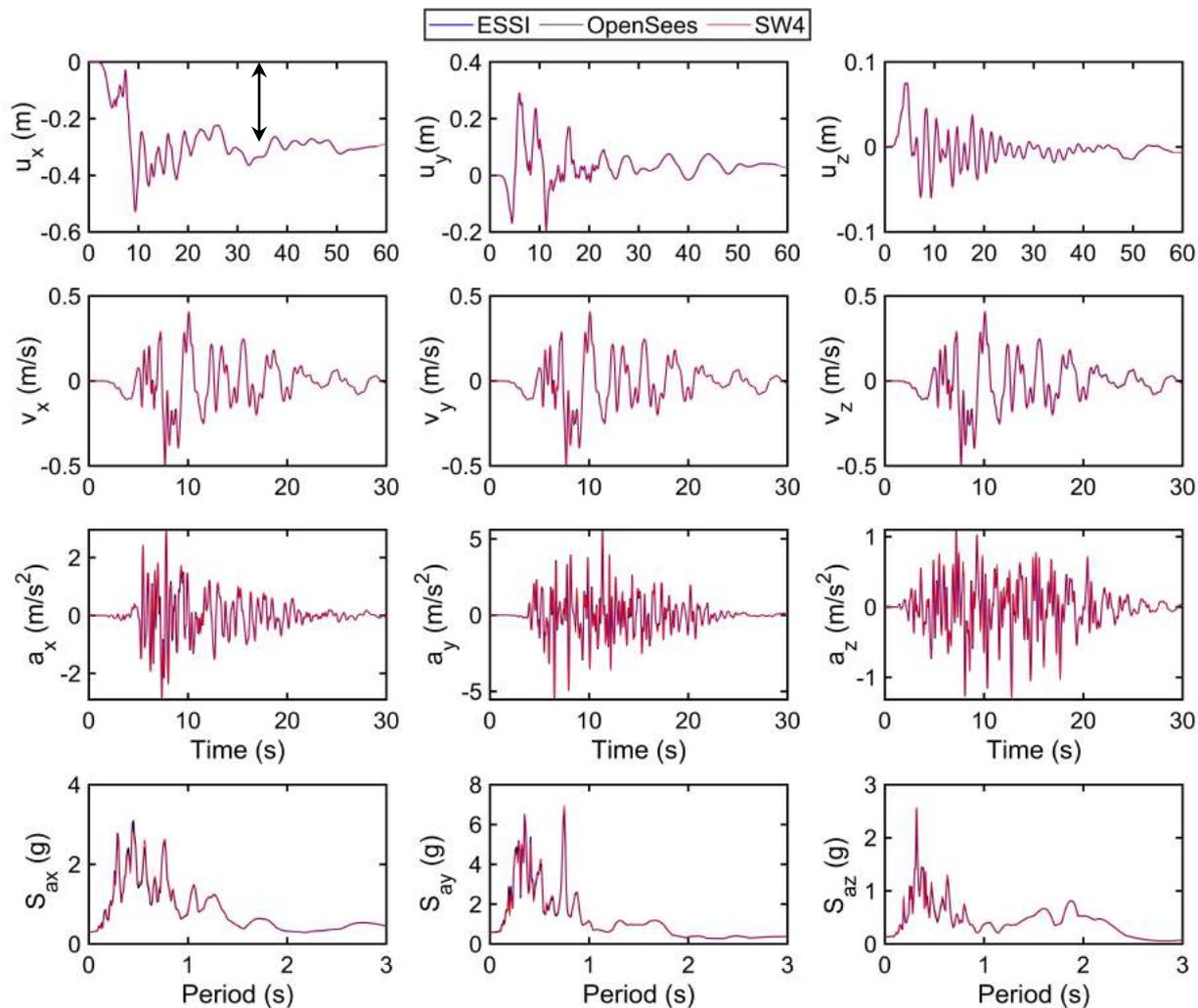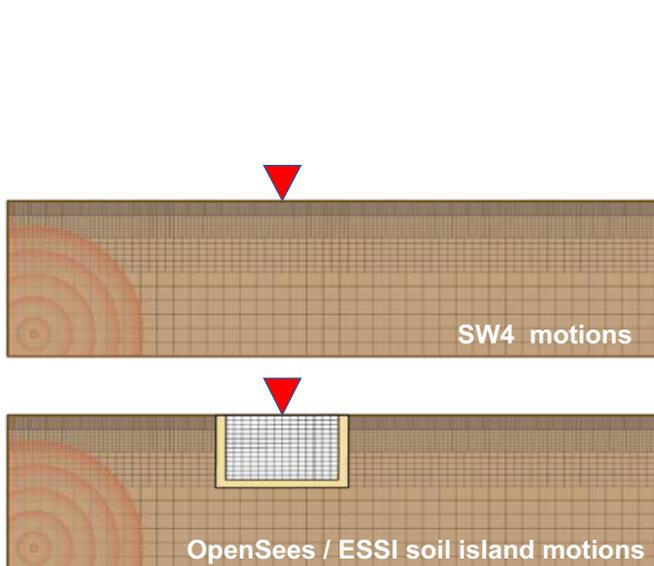
Suiwen Wu   Eric Eckert   Junfei Huang

Basin

25 seconds

ASCE 43-05 Limit States

| 0 | 0.5% | 1.0% | | 2.5% | 3.5% |

1 Km   5 Km   10 Km   20 Km
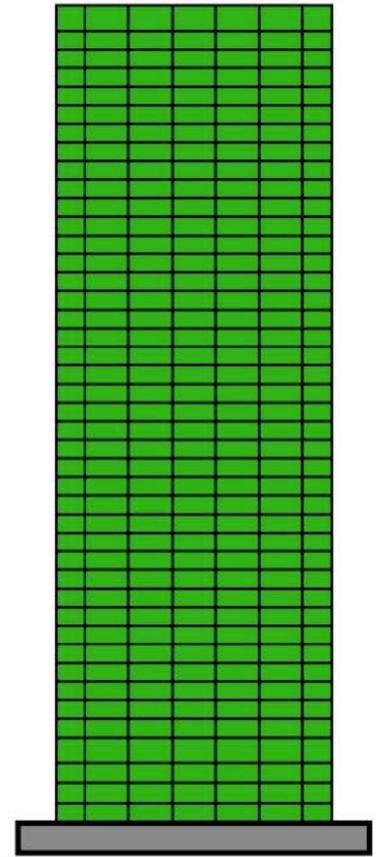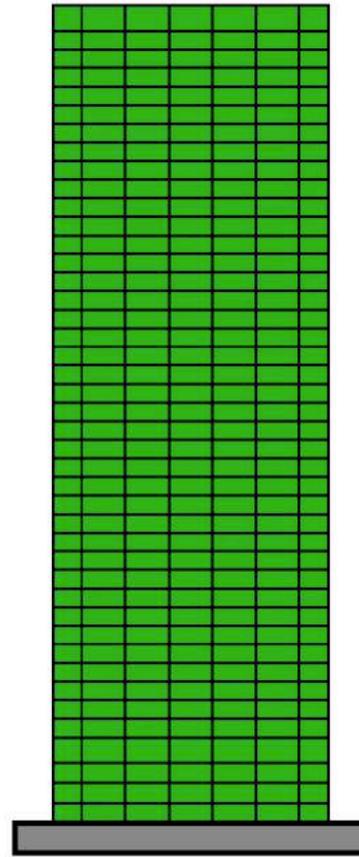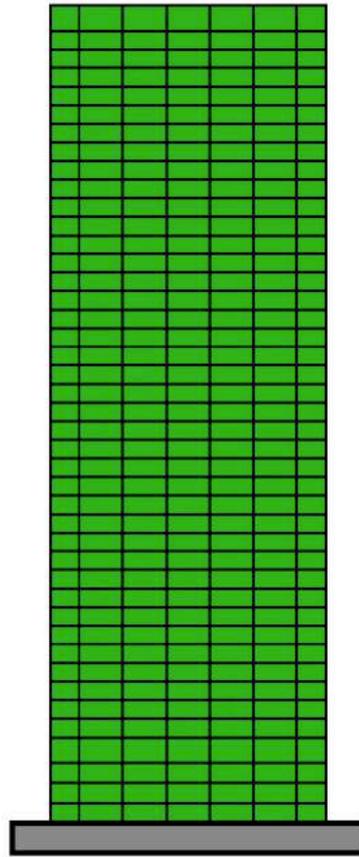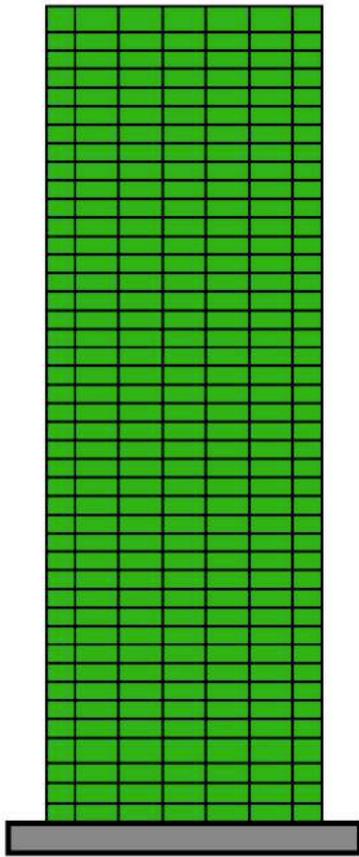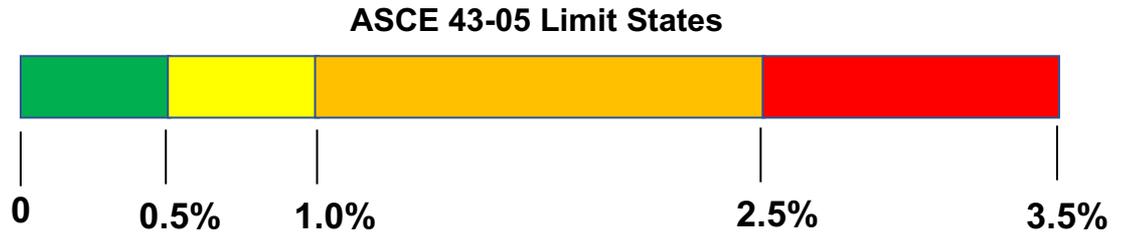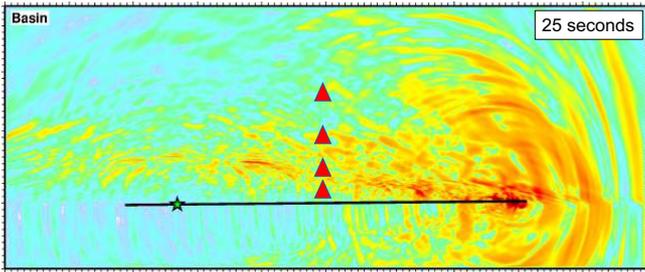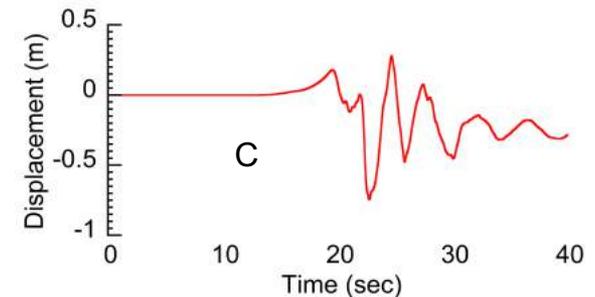
Near-field building response

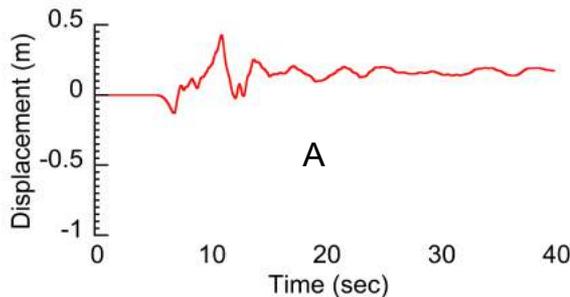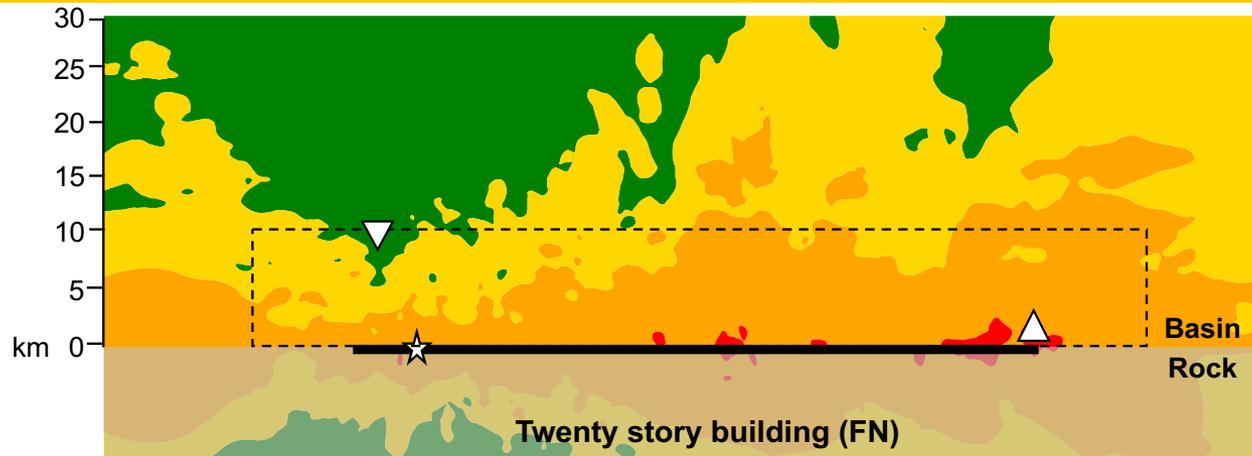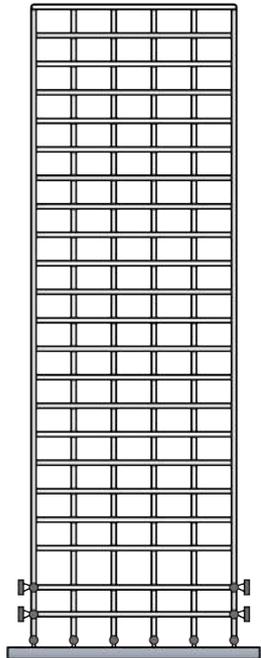**Twenty story steel moment frame (OpenSees)**
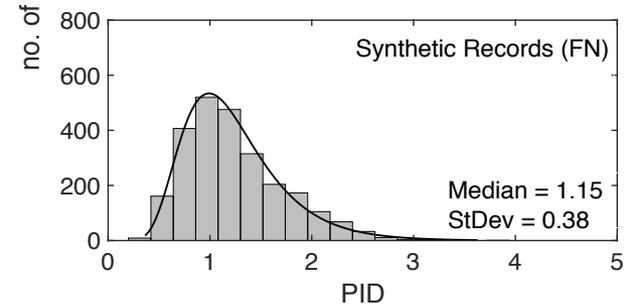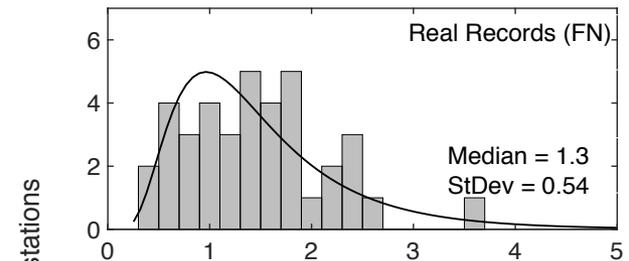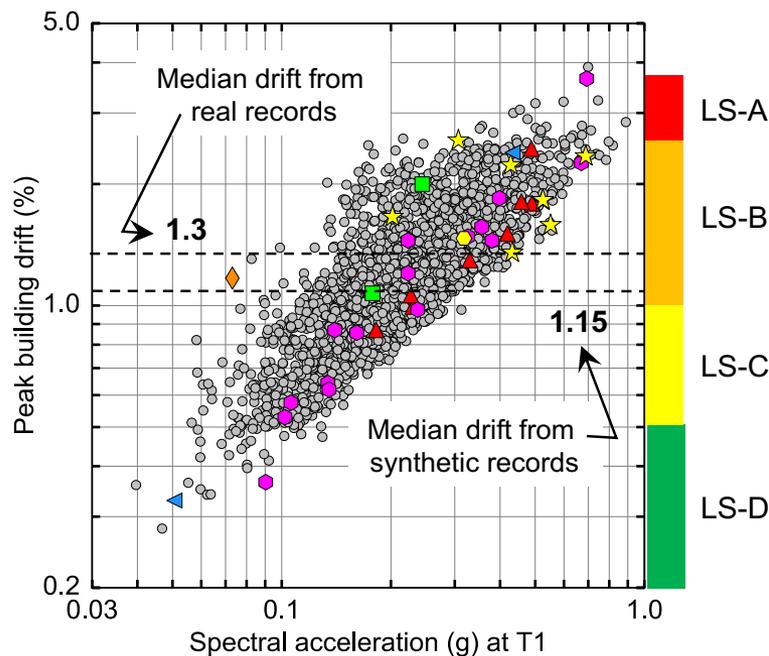
2 Km from fault
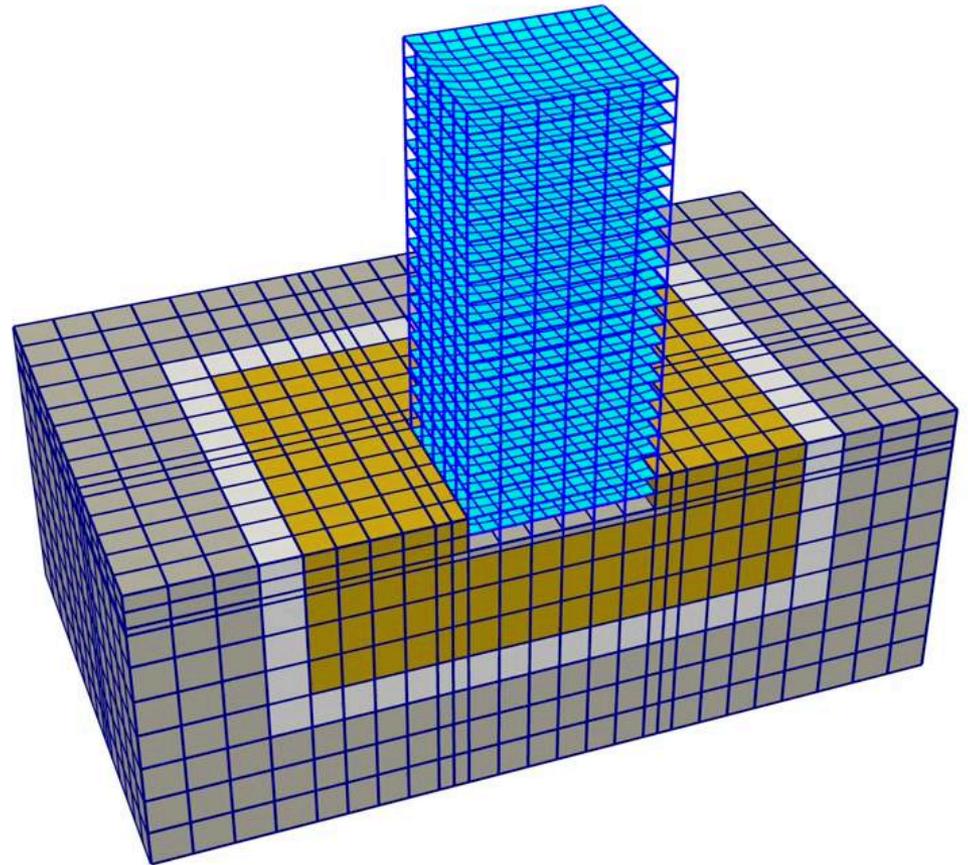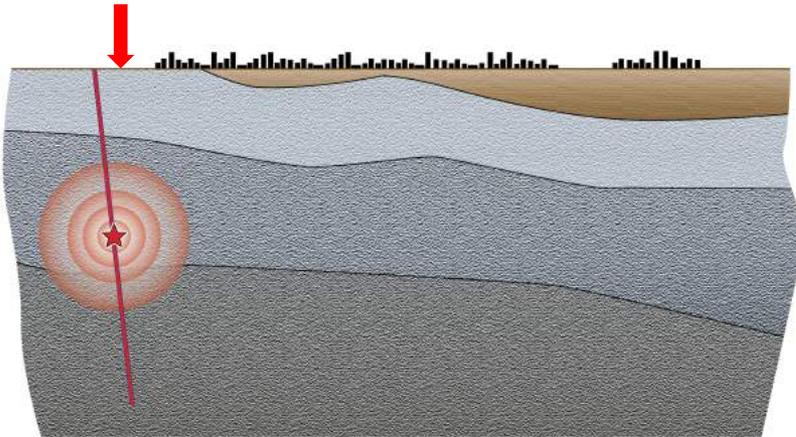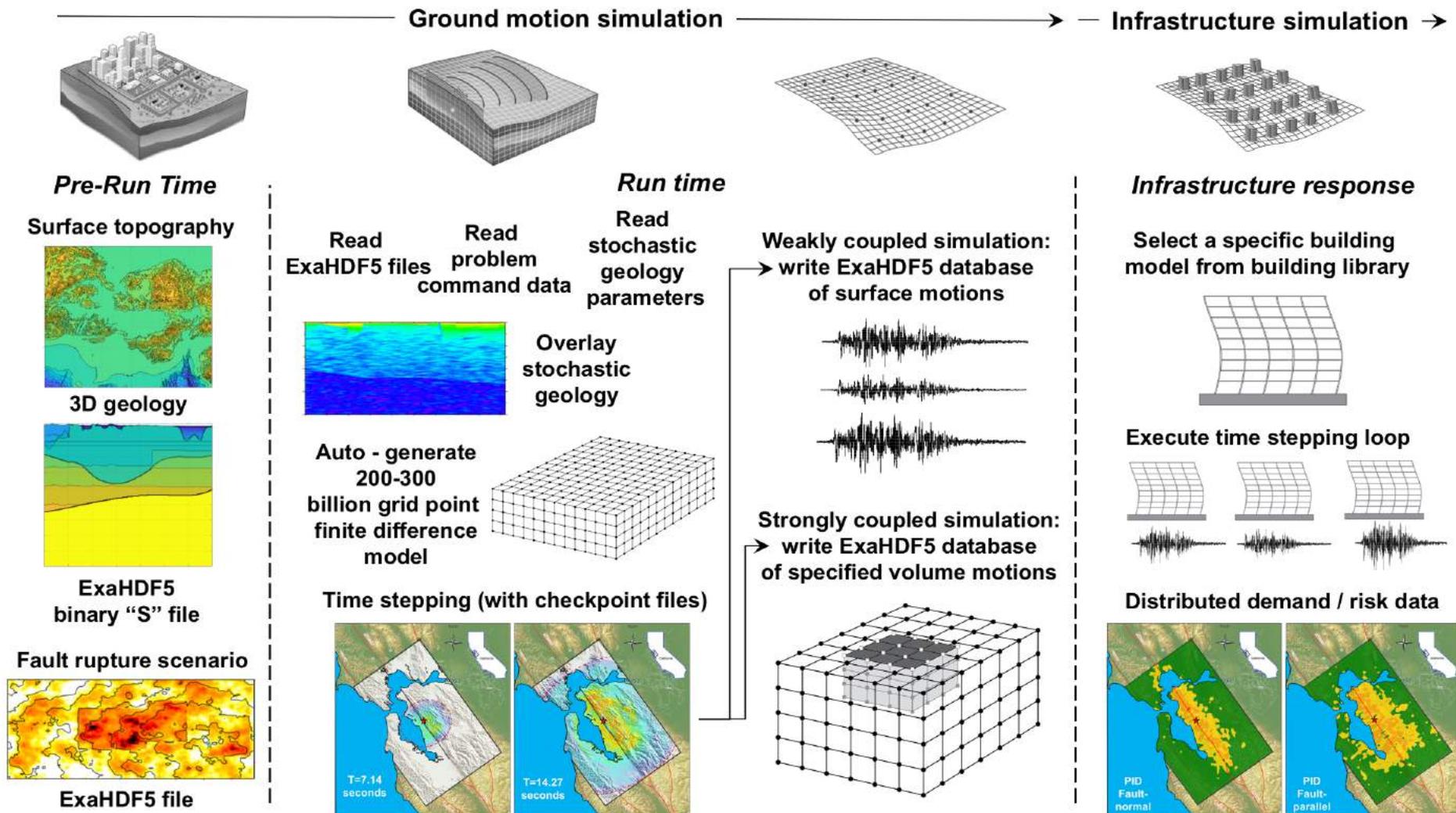
Scrutinizing the simulation model results
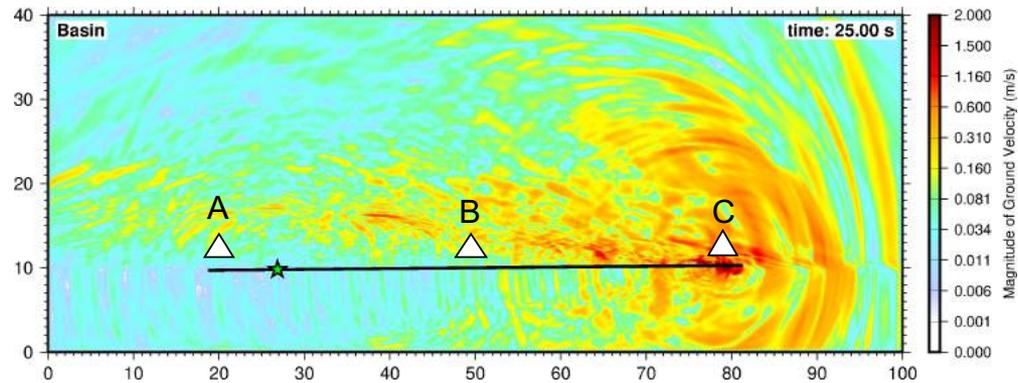
Ground Displacements (FP)
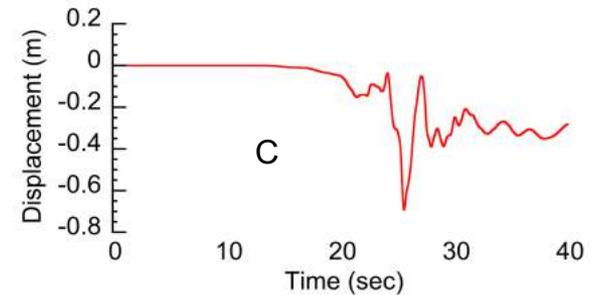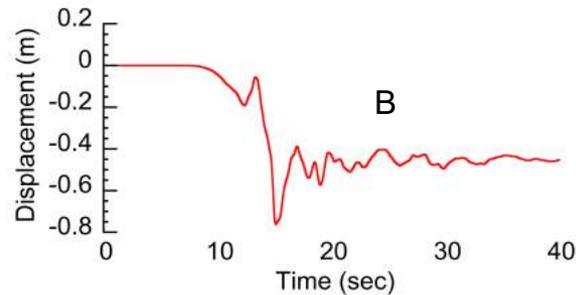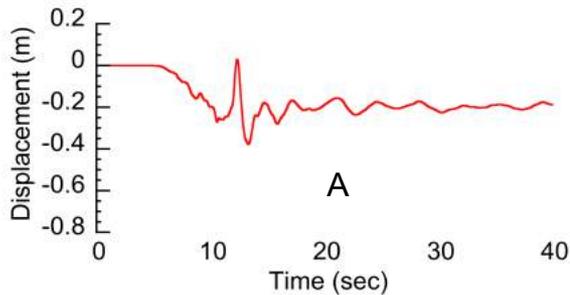
Ground Displacements (FN)

Scrutinizing the simulation model results

Twenty story building (FN)

Min/Max PID

▽ 0.28%

△ 3.20%

Basin
Rock
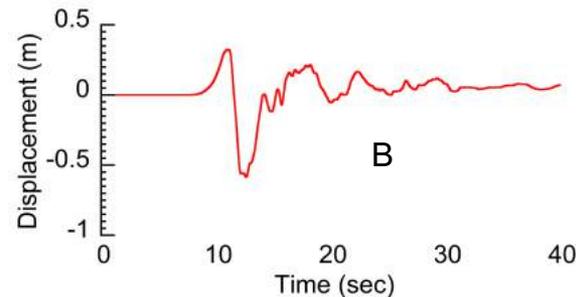
All these capabilities must be wrapped into an effective end-to-end workflow
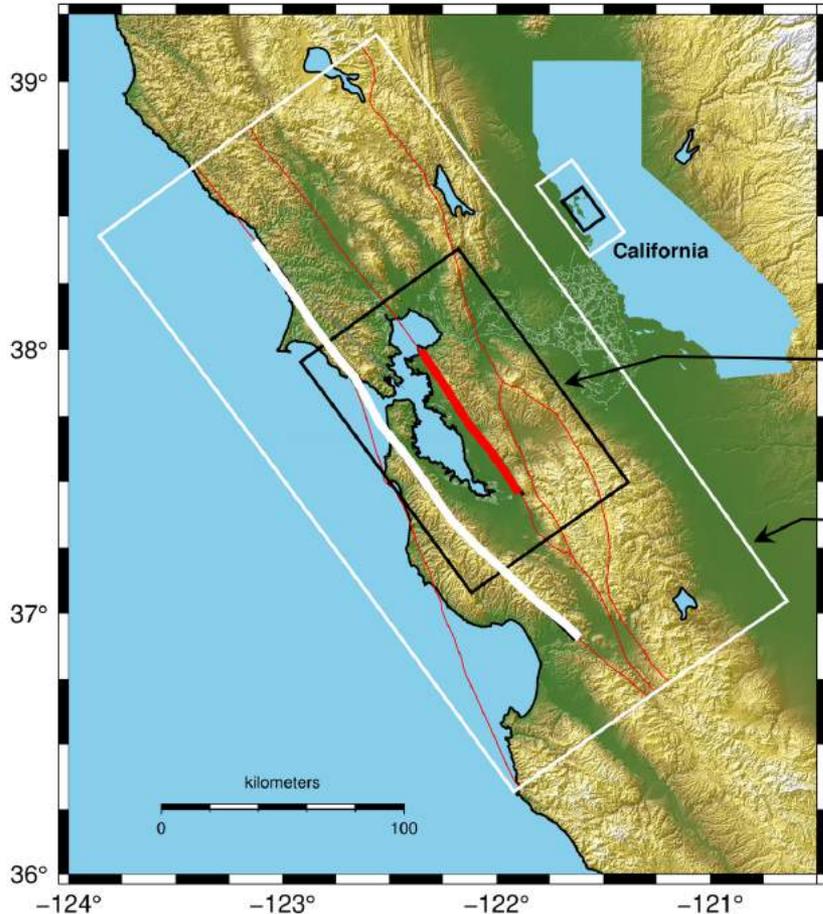
Computational domain for M=7 Hayward fault event (63B grid points)

Computational domain for M=7.5 San Andreas fault event (220B grid points)

First Exascale Platforms

Aurora

Frontier