# Advancements in High Performance Computing and Opportunities for Applications to Earthquake Hazard and Risk

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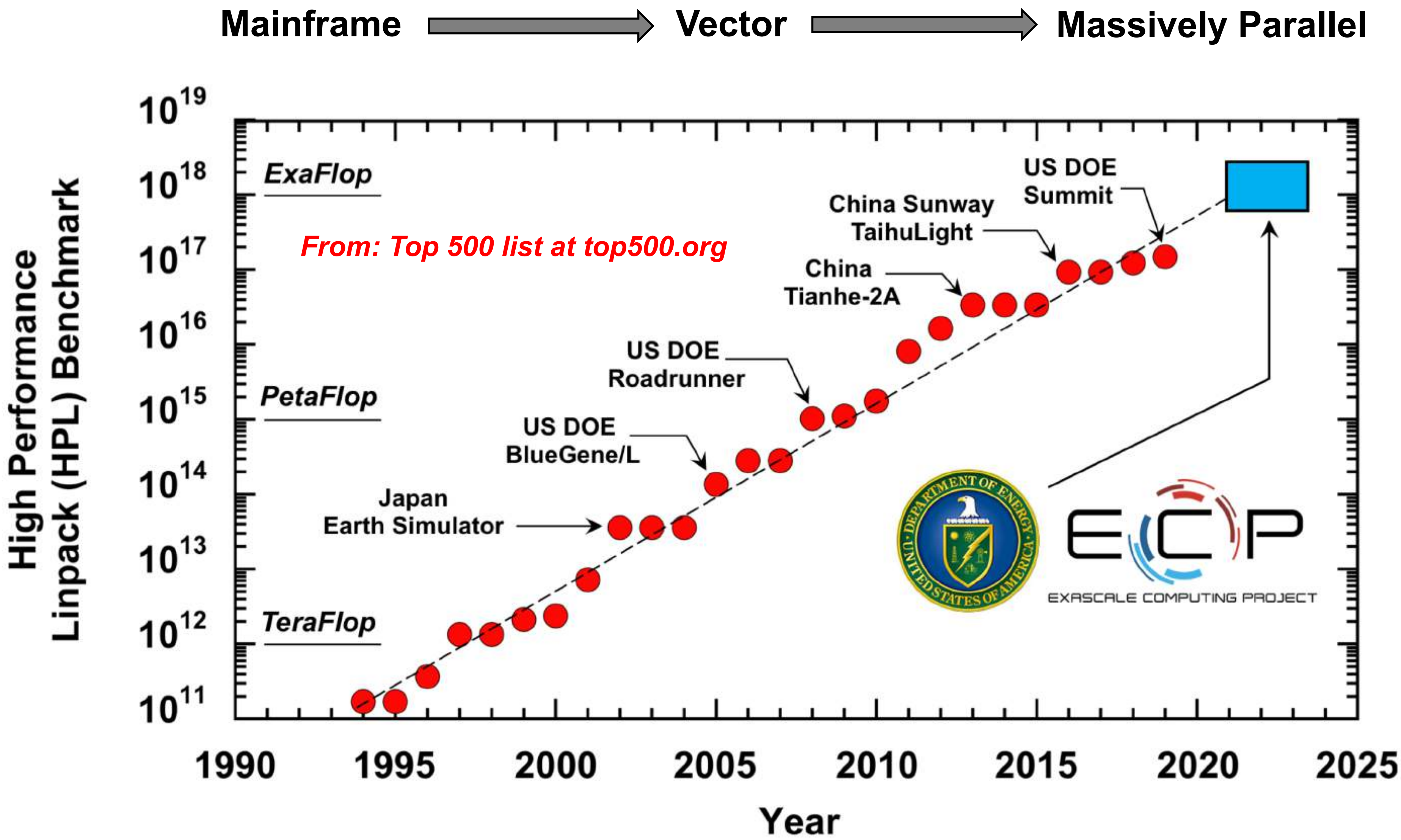
BERKELEY LAB

EXASCALE COMPUTING PROJECT

# 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

*"US Plans $1.8 Billion Spend on DOE Exascale Supercomputing"*

## Three components…

**Software Technology** → **Applications Development** → **Exaflop Computers**

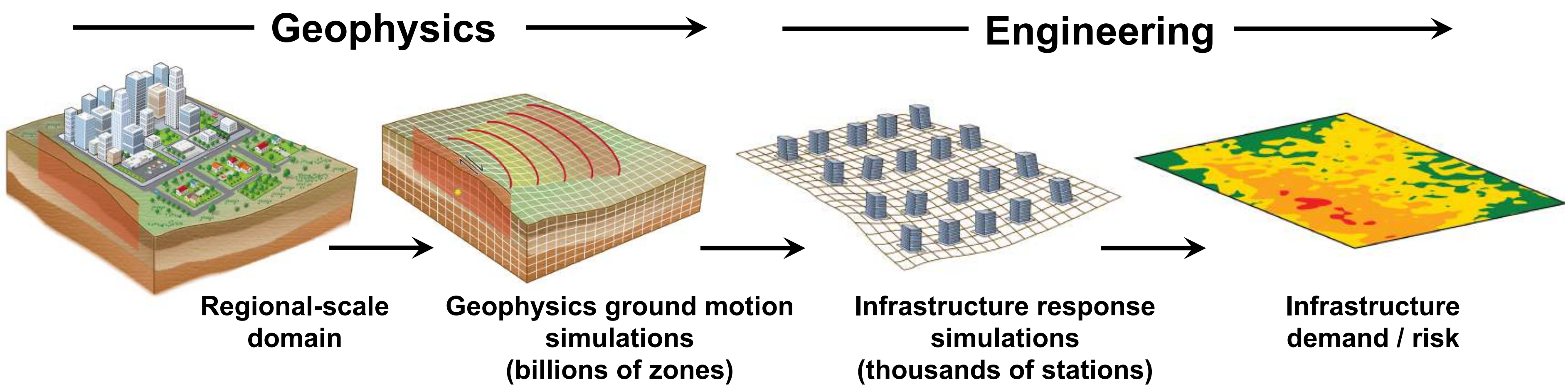
**Software Technology:** Supporting software stack for the Exascale computational ecosystems

**Applications Development:** Selected science applications (24) for Exascale platforms

**Exaflop Computers:** Advanced computer hardware at the Exascale

2017 — 2019 — 2020 — 2022

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




**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 Mechanics

David McCallen

Mamun Miah

Floriana Petrone

## Applied Math / Numerical Methods

Anders Petersson

Bjorn Sjogreen

## Seismology / Geophysics

Arben Pitarka

Arthur Rodgers

## Computer Science

Houjun Tang

Ramesh Pankajakshan

# Our Exascale challenge - regional simulations at “engineering” frequencies

Pipelines

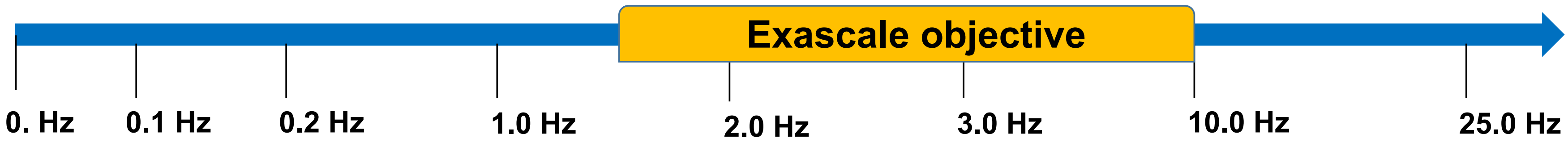
Long-span Bridges

Tall Buildings

Low-rise Buildings and Industrial Facilities

Energy System Components

Nuclear Power Equipment




## 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)

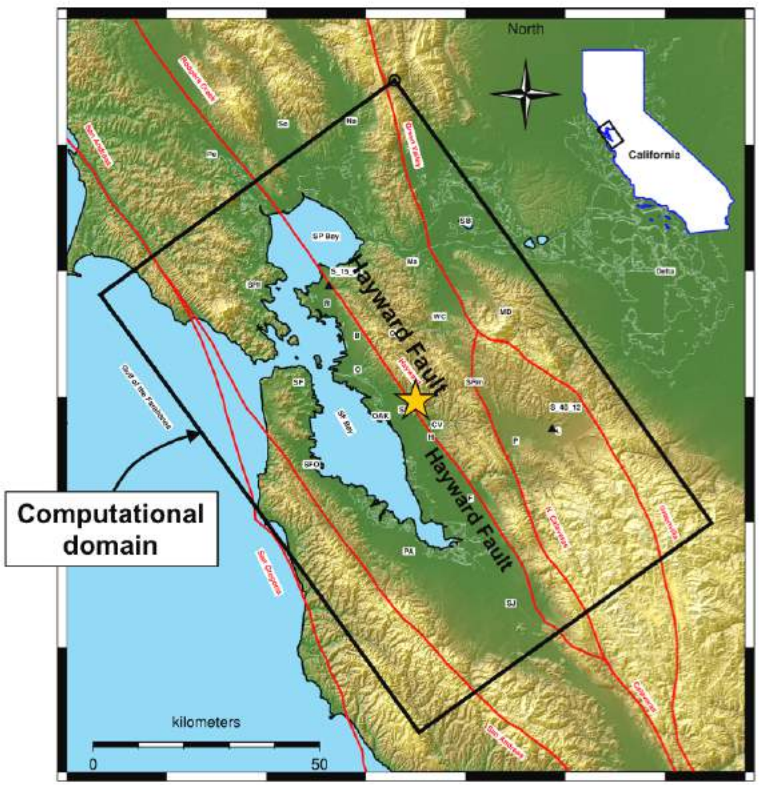
### Represent fine-scale geology

- Waveform data inversion to improve geologic models
- Stochastic geology

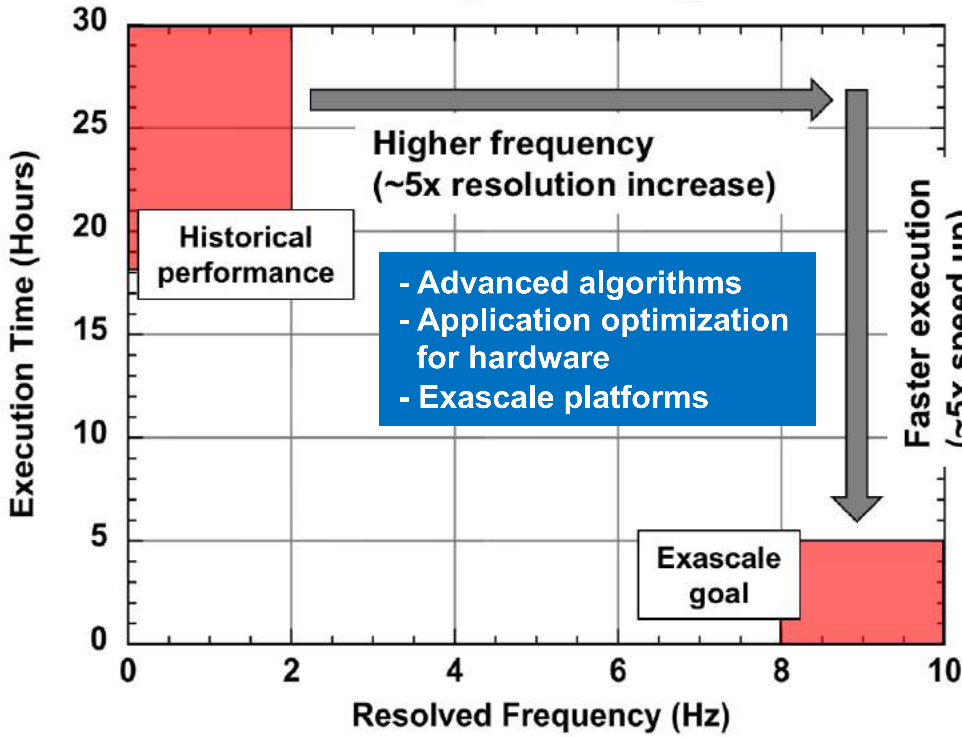
# Establishing our Exascale challenge problem definition and tracking progress

## Fast, high-resolution forward ground motion simulations are at the core of our developments

Regional-scale model (SFBA)



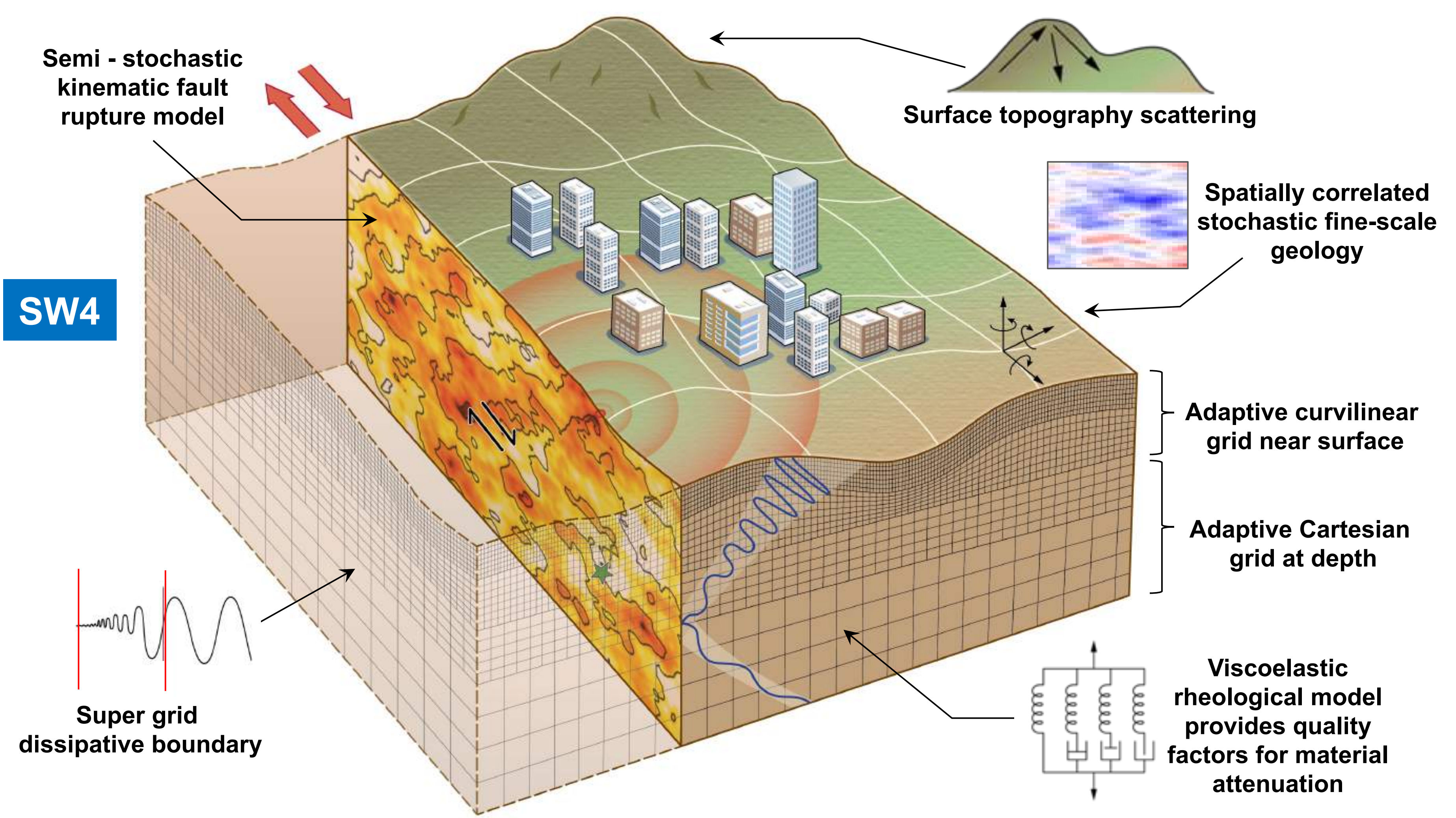

Application ground motion simulation performance goals




"Engineering" frequencies

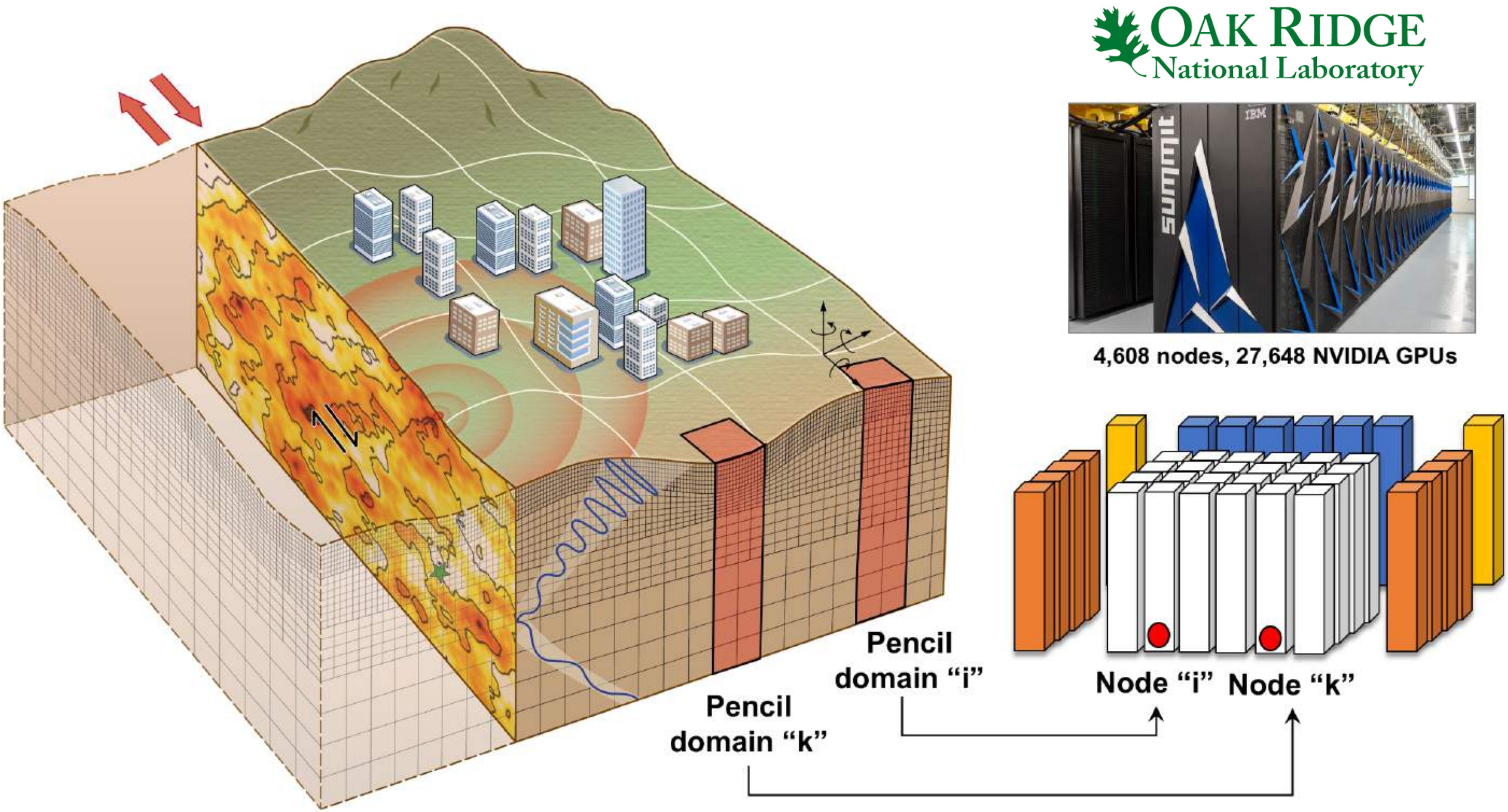
# Advanced algorithms for massively parallel ground motion simulations (SW4)

## Improved physics, computational efficiency at 300 billion grid points



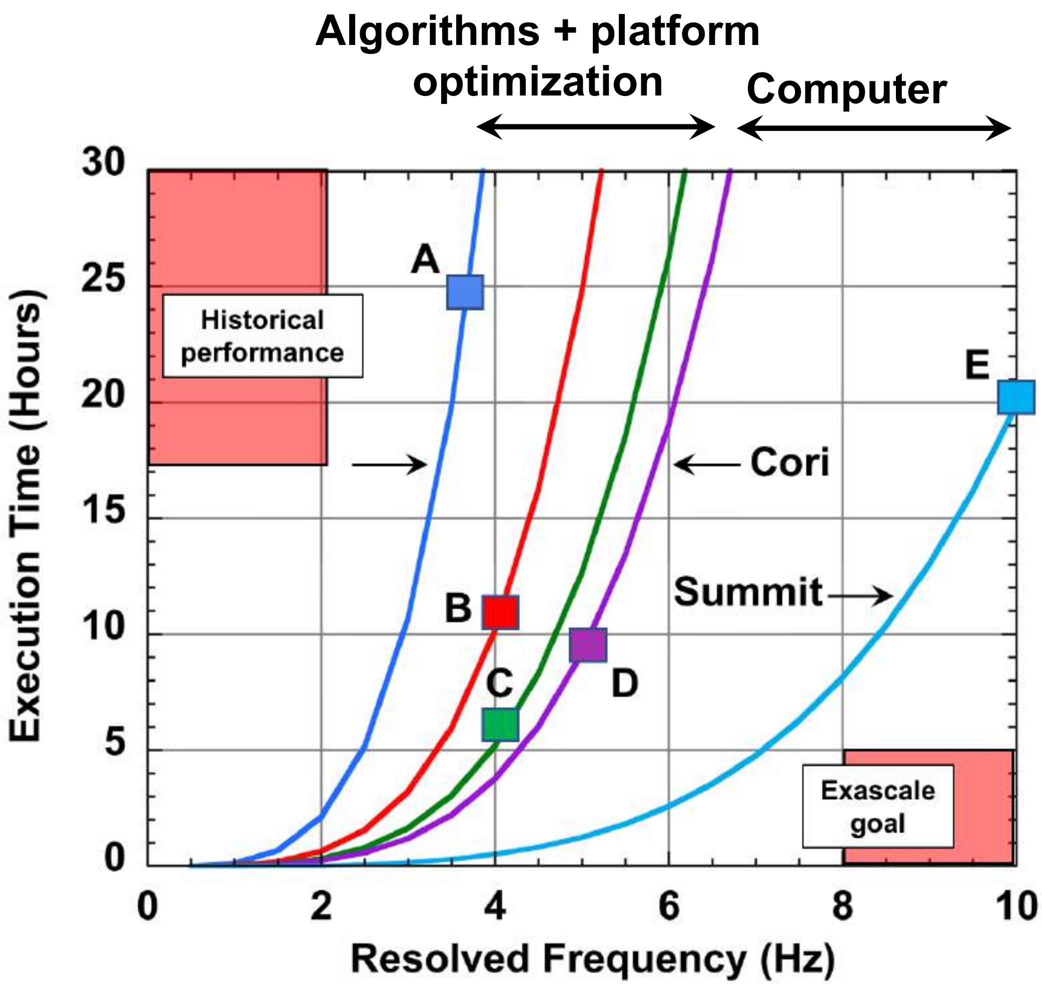
# Computer science contributions – distribution of work on massively parallel platforms

**Getting prepared to exploit the world's fastest scientific platforms**




4,608 nodes, 27,648 NVIDIA GPUs

# We have already achieved high performance on advanced platforms (FOM = 66.2)

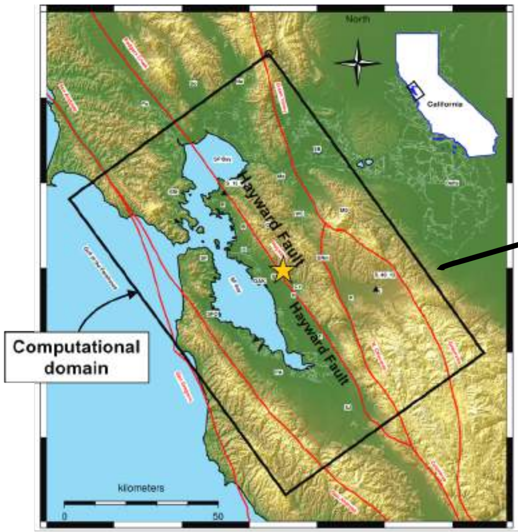


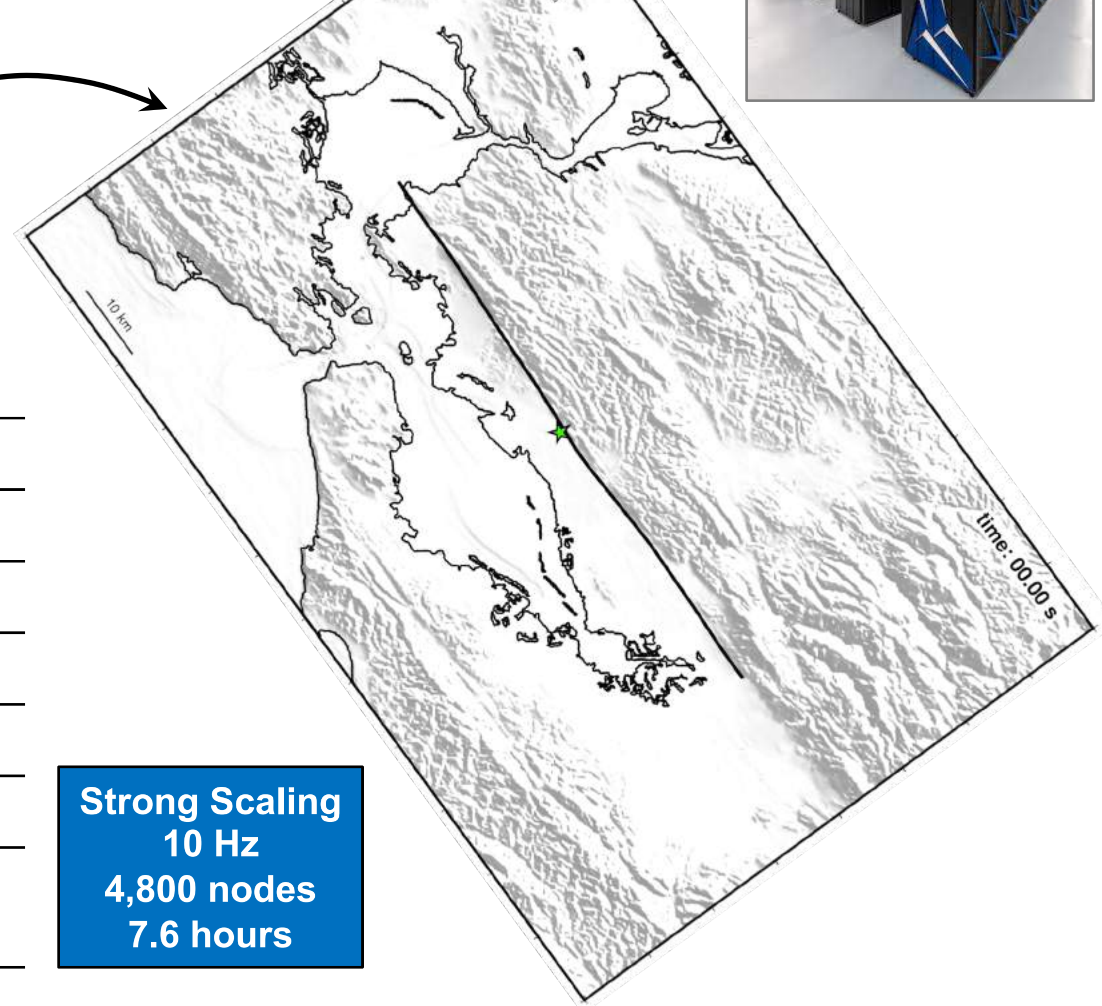


30PF


200PF

# San Francisco Bay Area simulations to 10Hz on the world's #1 computer



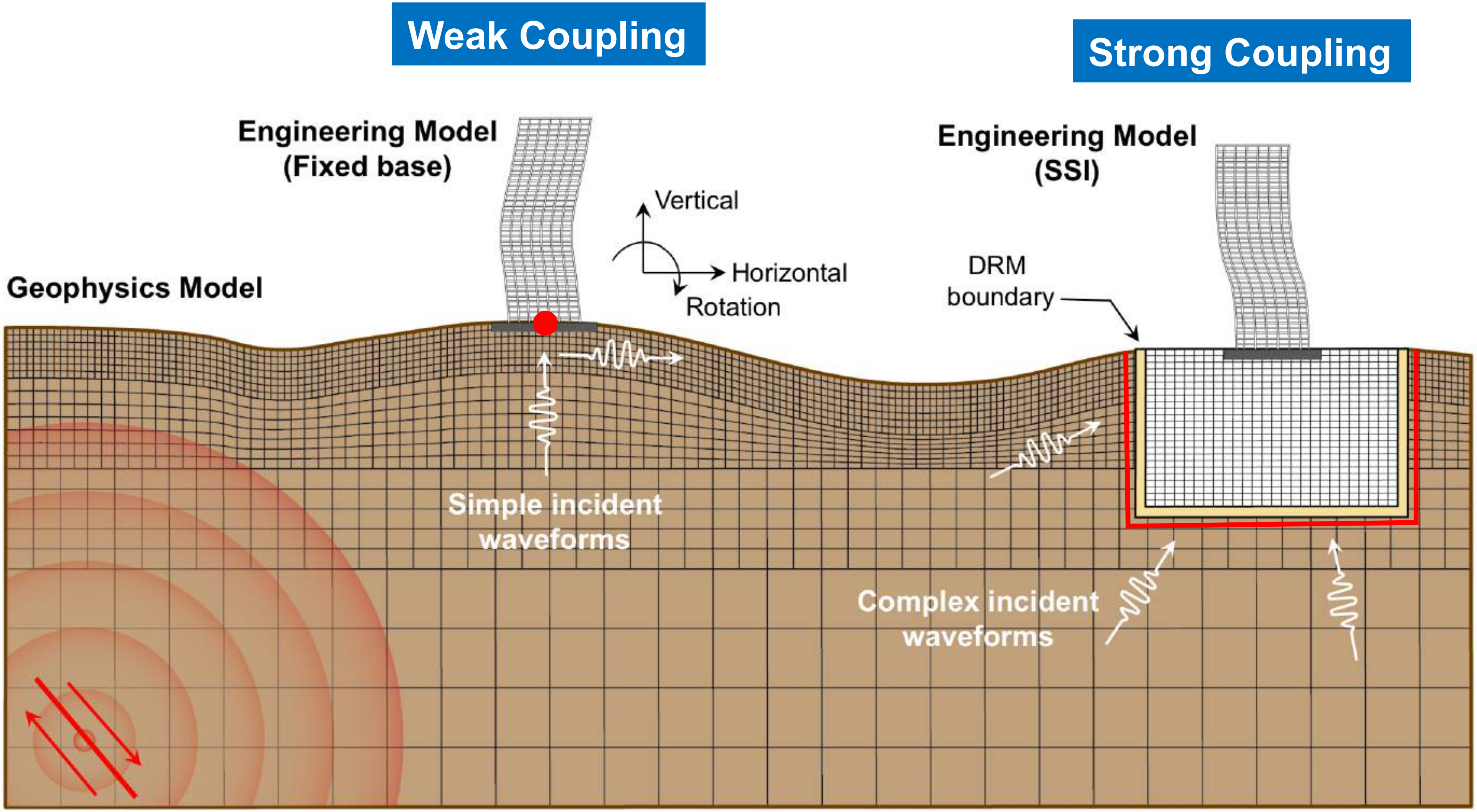





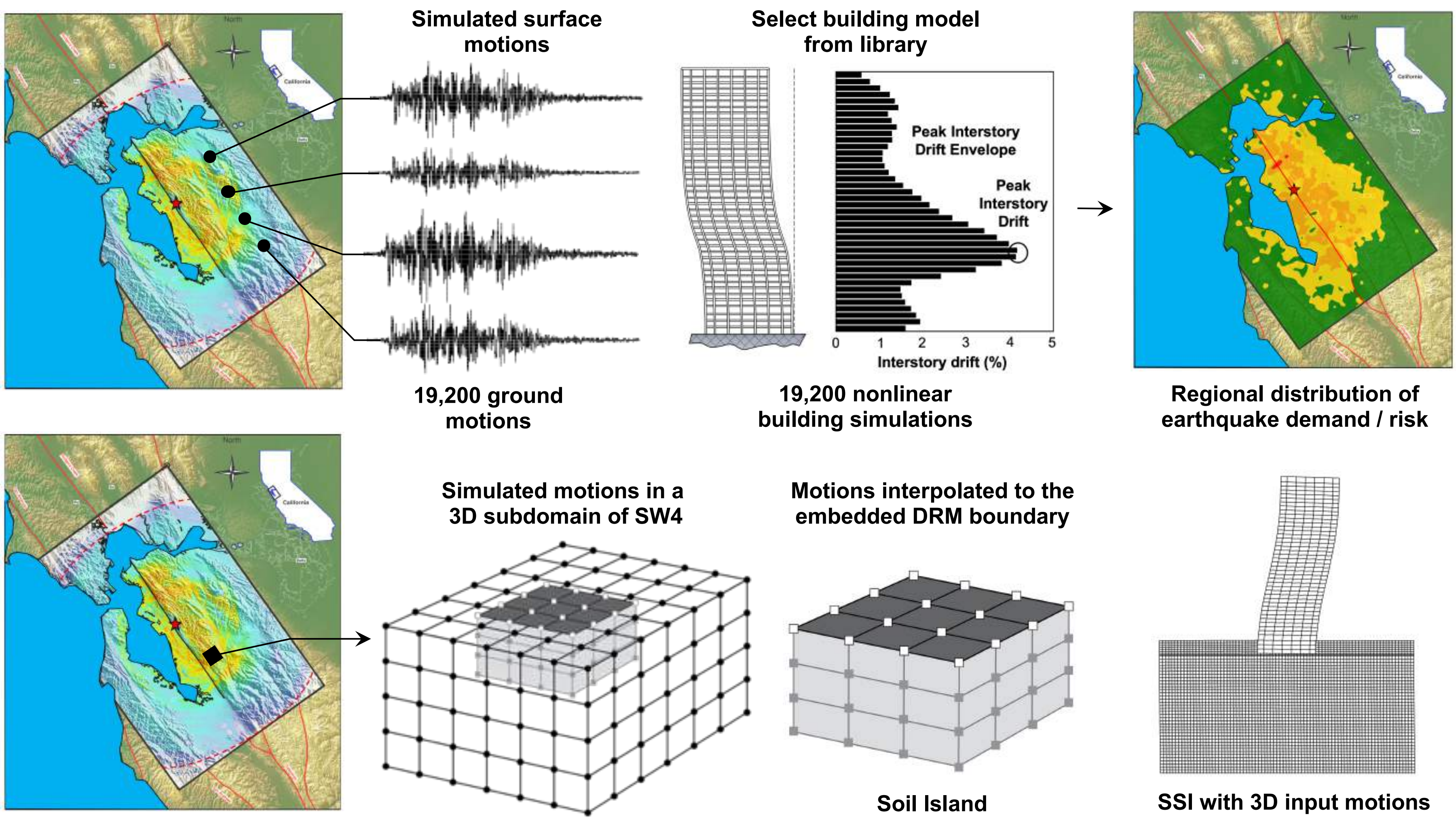
| | |
|---|---|
| Frequency Resolved | 10 Hz |
| $Vs_{min}$ | 500 m/s |
| Number of Grid Points | 203 Billion |
| Smallest Cell Size | 6.25 m |
| Platform | SUMMIT (ORNL) |
| Number of Nodes | 1200 |
| Wall Clock Time | 19 hours, 52 minutes, one check point file |

**Strong Scaling**
**10 Hz**
**4,800 nodes**
**7.6 hours**

# Coupling geophysics and engineering models

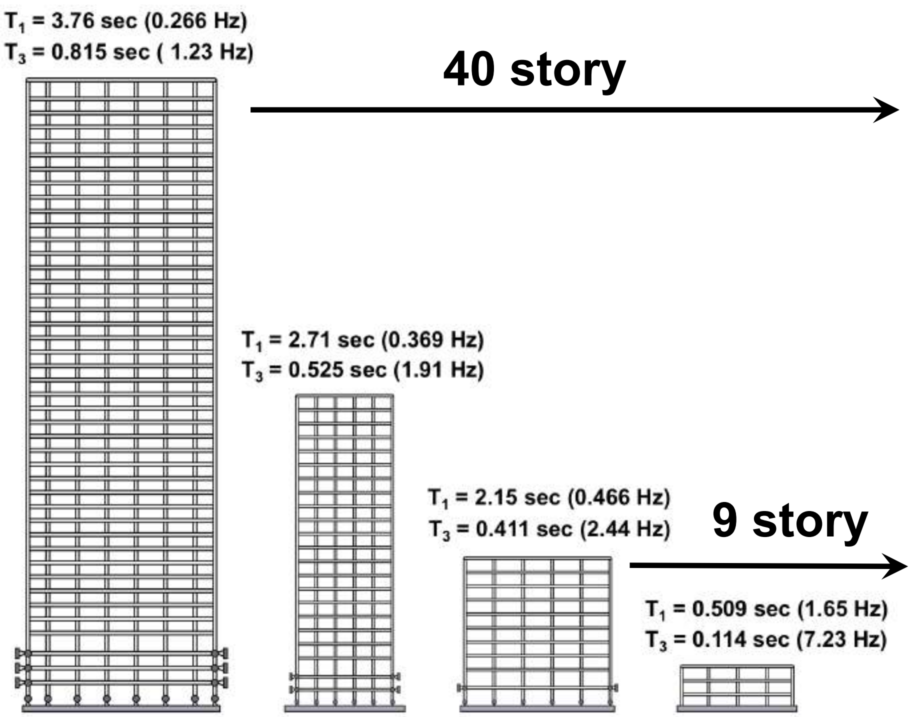


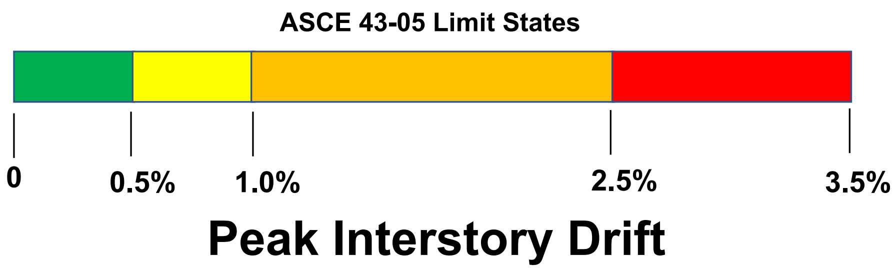
# This spawns two alternate workflows

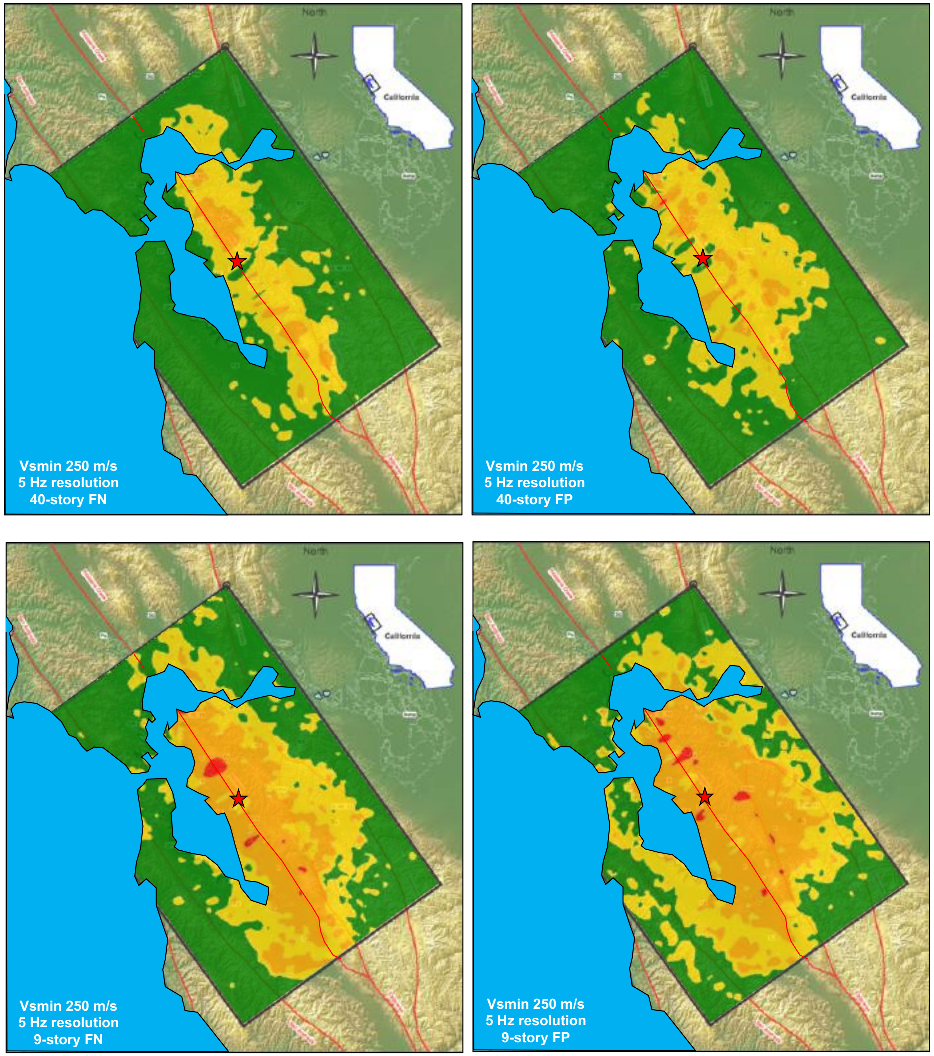


# We are now executing weakly coupled 5 Hz simulations routinely – M7 Hayward fault EQ

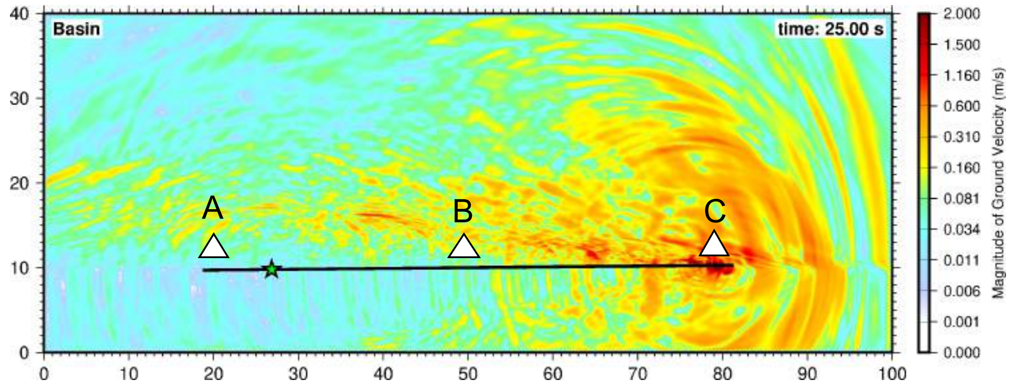
## Infrastructure Library



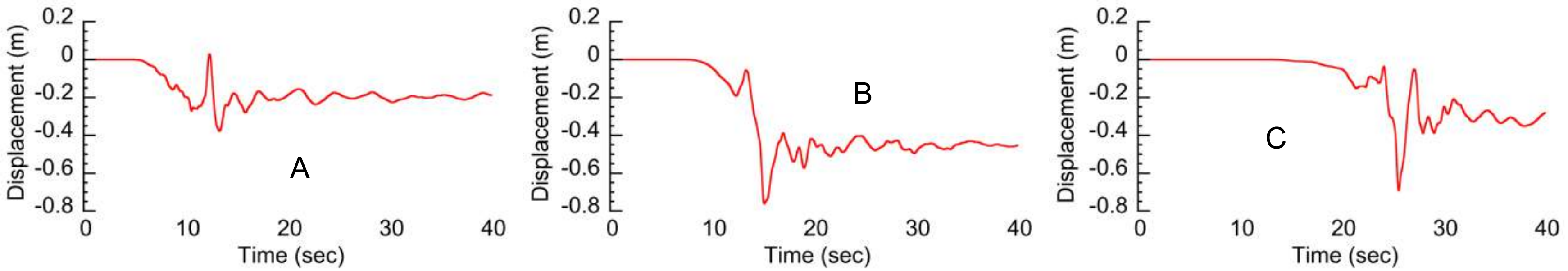



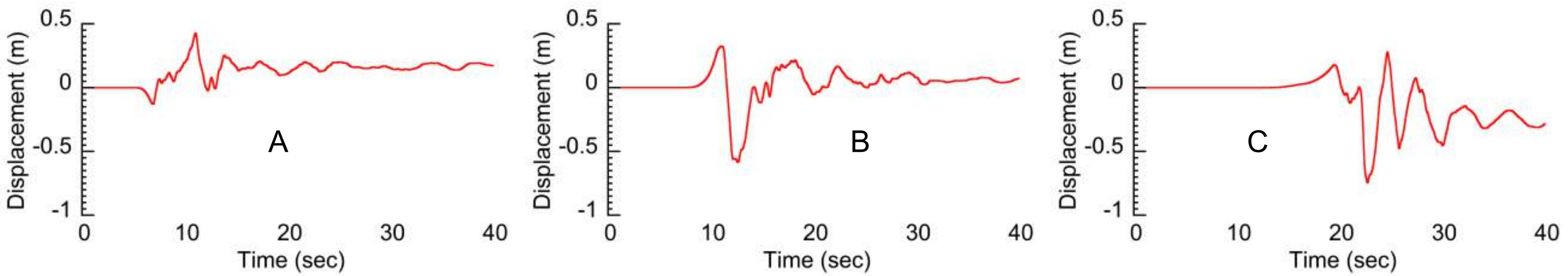
# Scrutinizing the simulation model results



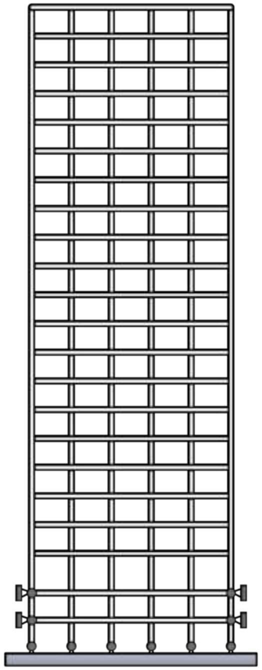

**Ground Displacements (FP)**

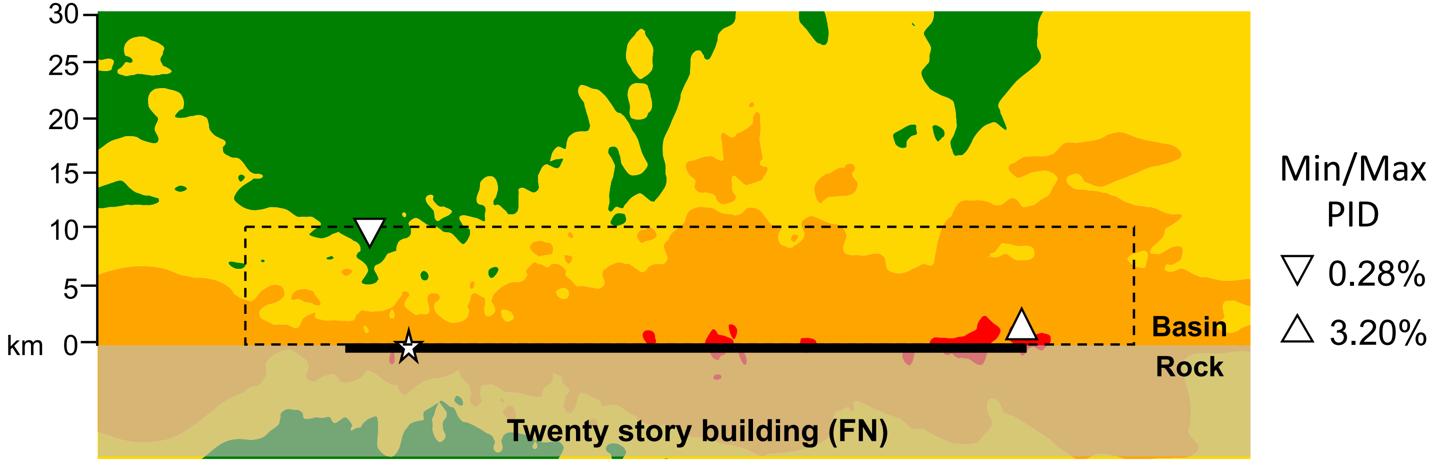


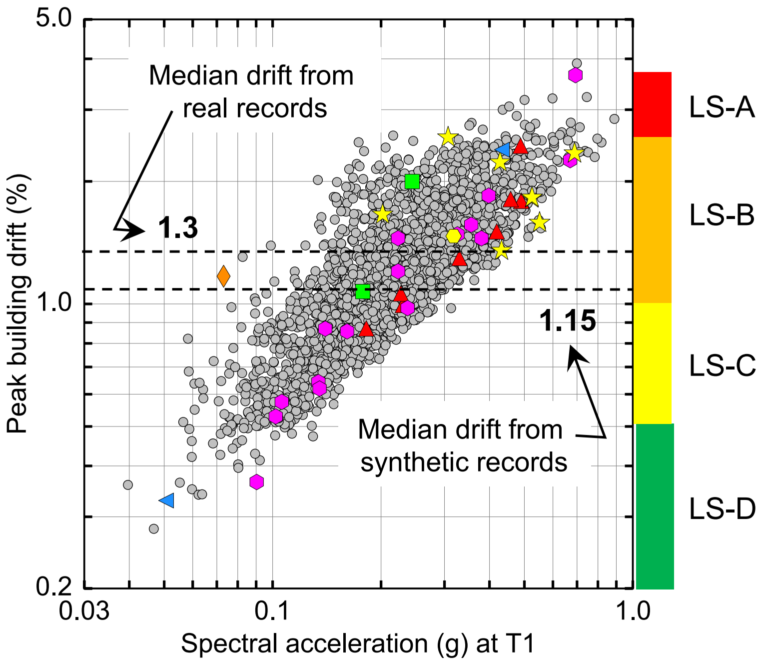

**Ground Displacements (FN)**

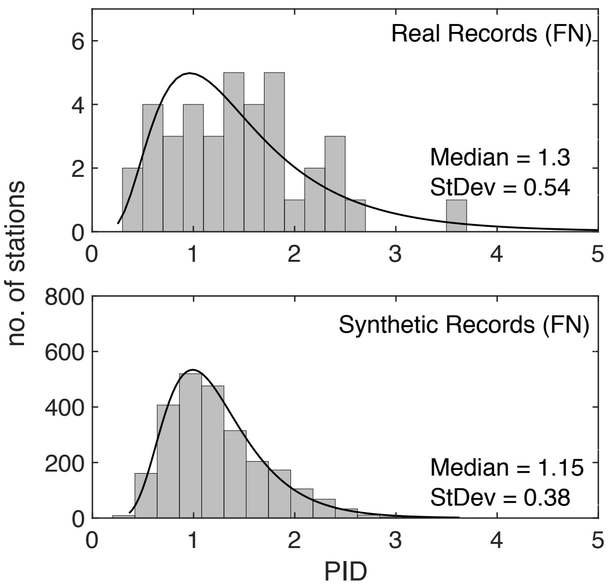


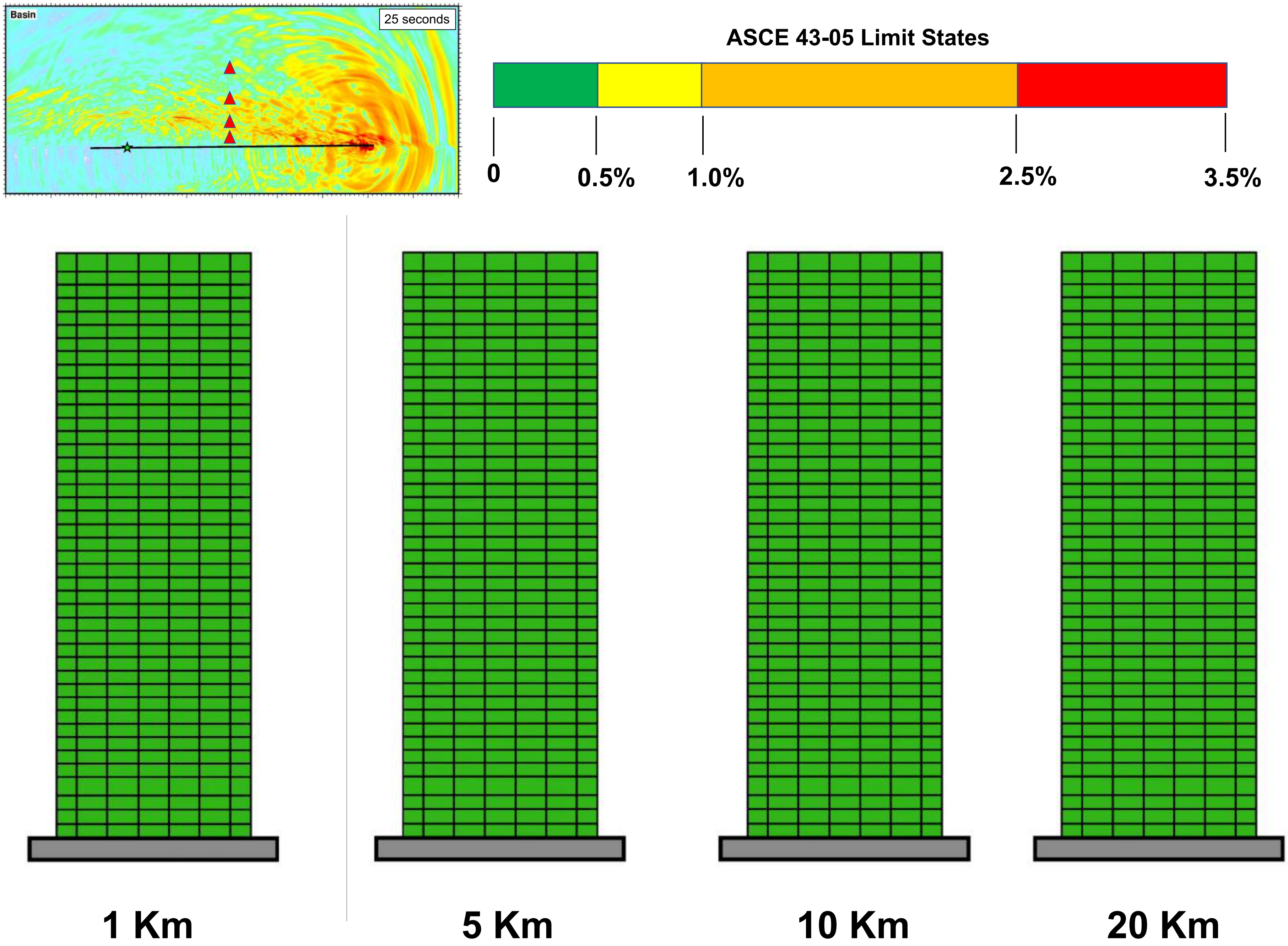
# Scrutinizing the simulation model results

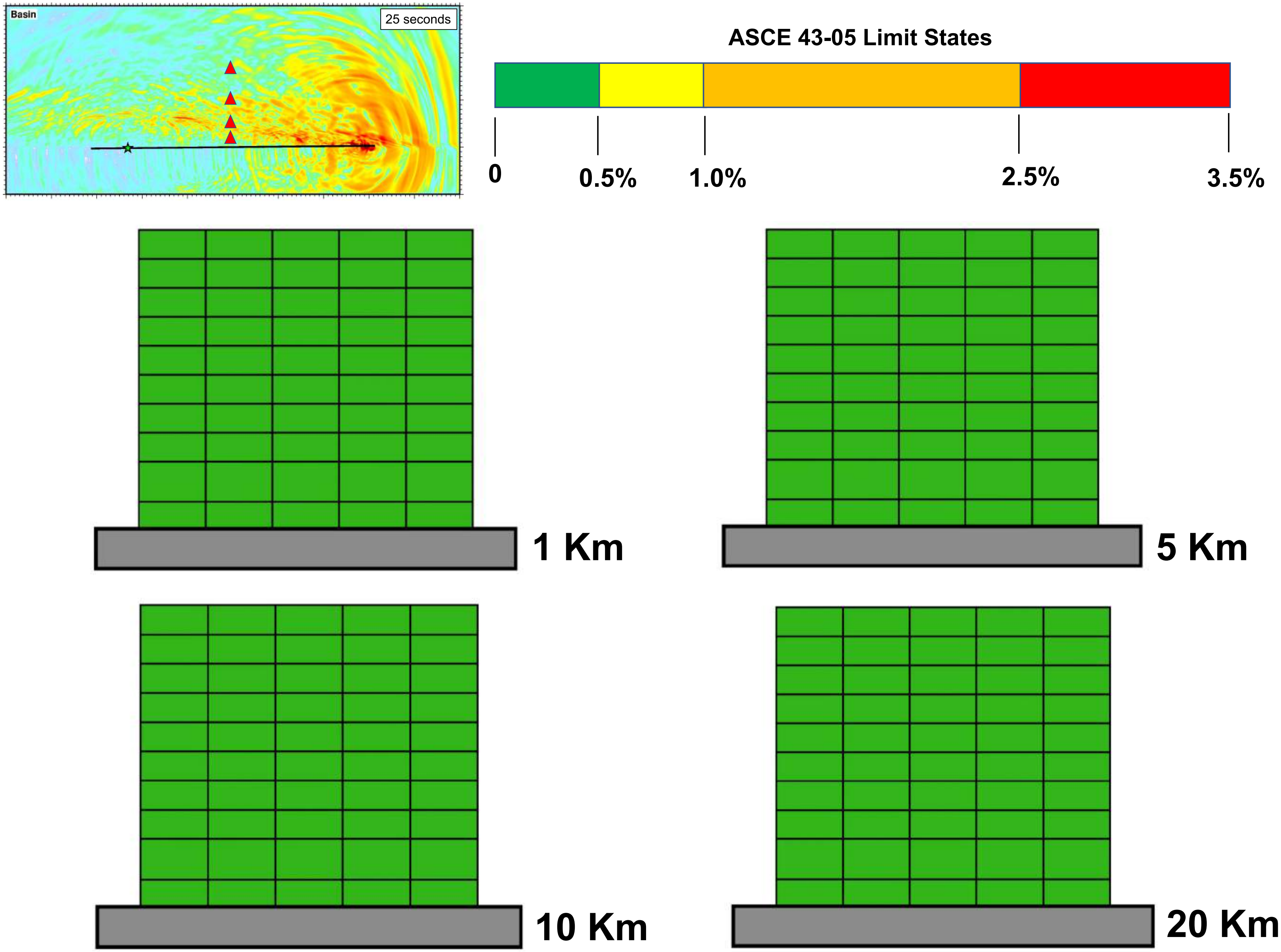




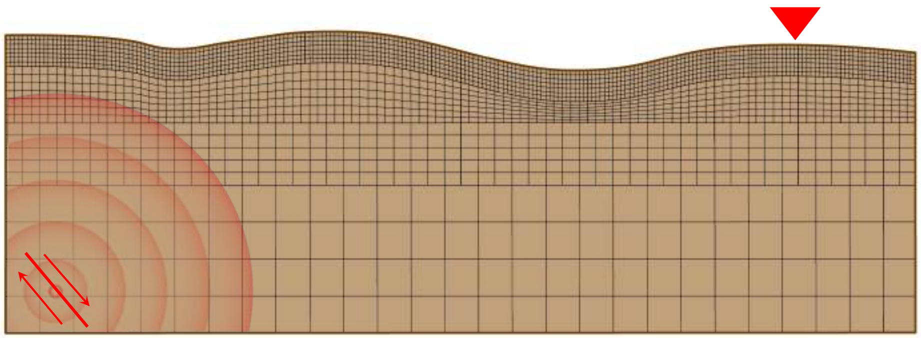




Basin
25 seconds
ASCE 43-05 Limit States
0
0.5%
1.0%
2.5%
3.5%
1 Km
5 Km
10 Km
20 Km

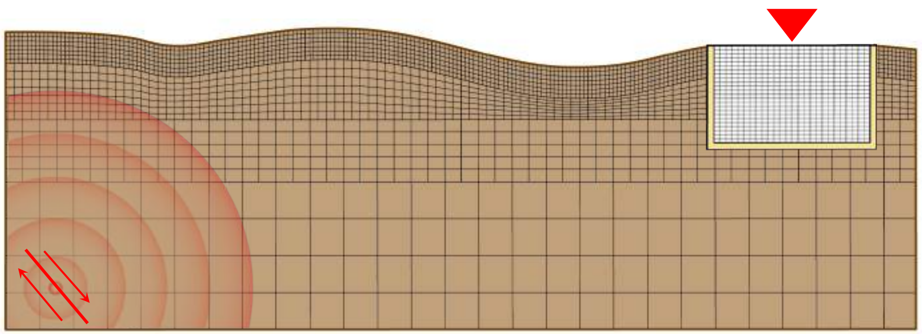

Basin
25 seconds
ASCE 43-05 Limit States
0
0.5%
1.0%
2.5%
3.5%
1 Km
5 Km
10 Km
20 Km

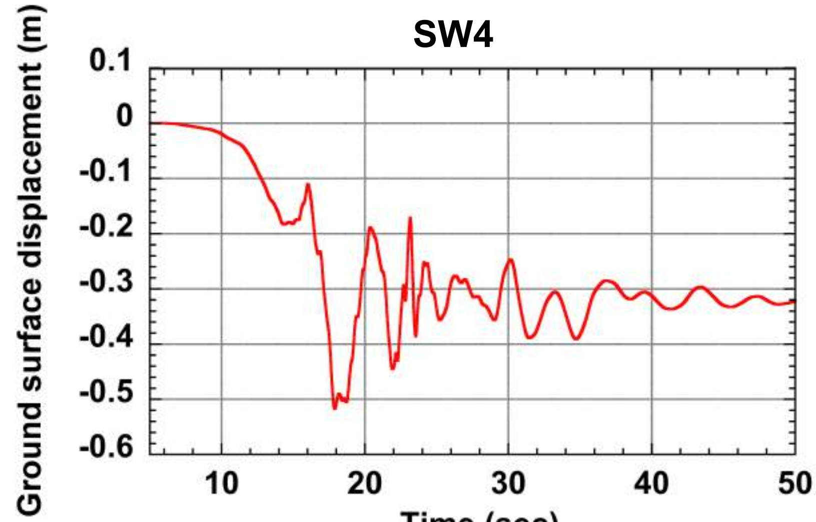
# Testing the Domain Reduction Method (DRM) for near-fault motions

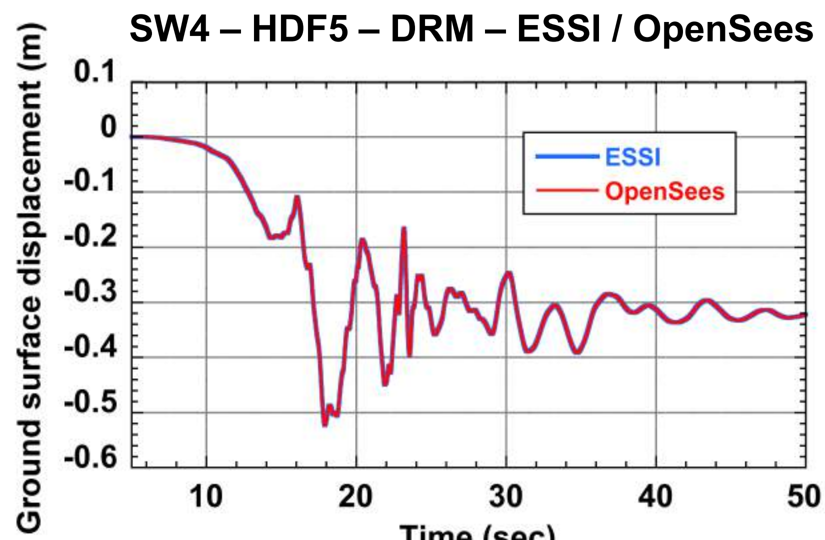
**SW4**

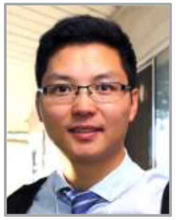


**SW4 – HDF5 – DRM – ESSI / OpenSees**



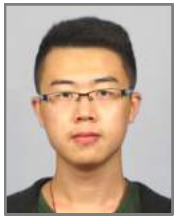


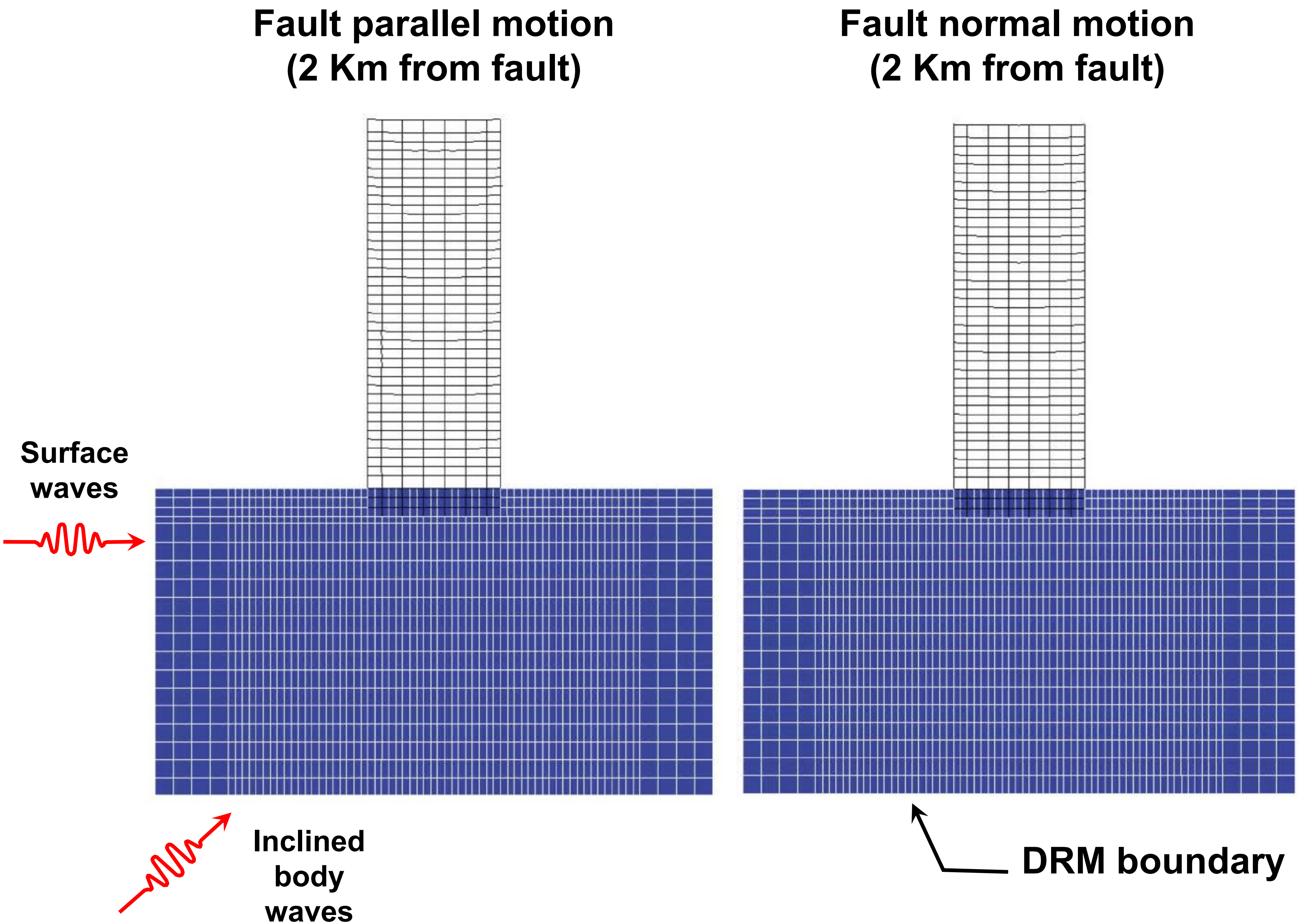



Suiwen Wu

Eric Eckert

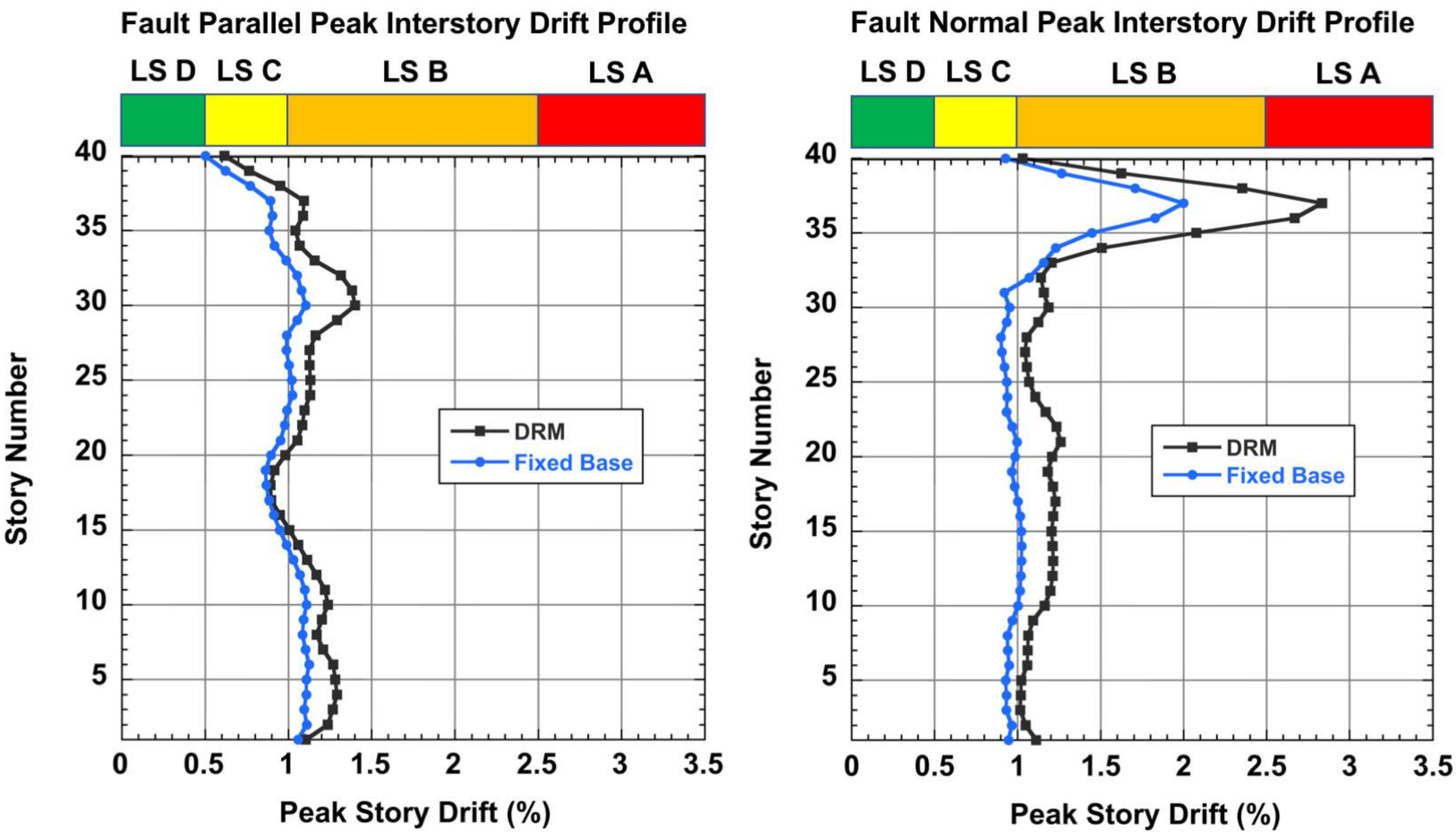


Junfei Huang

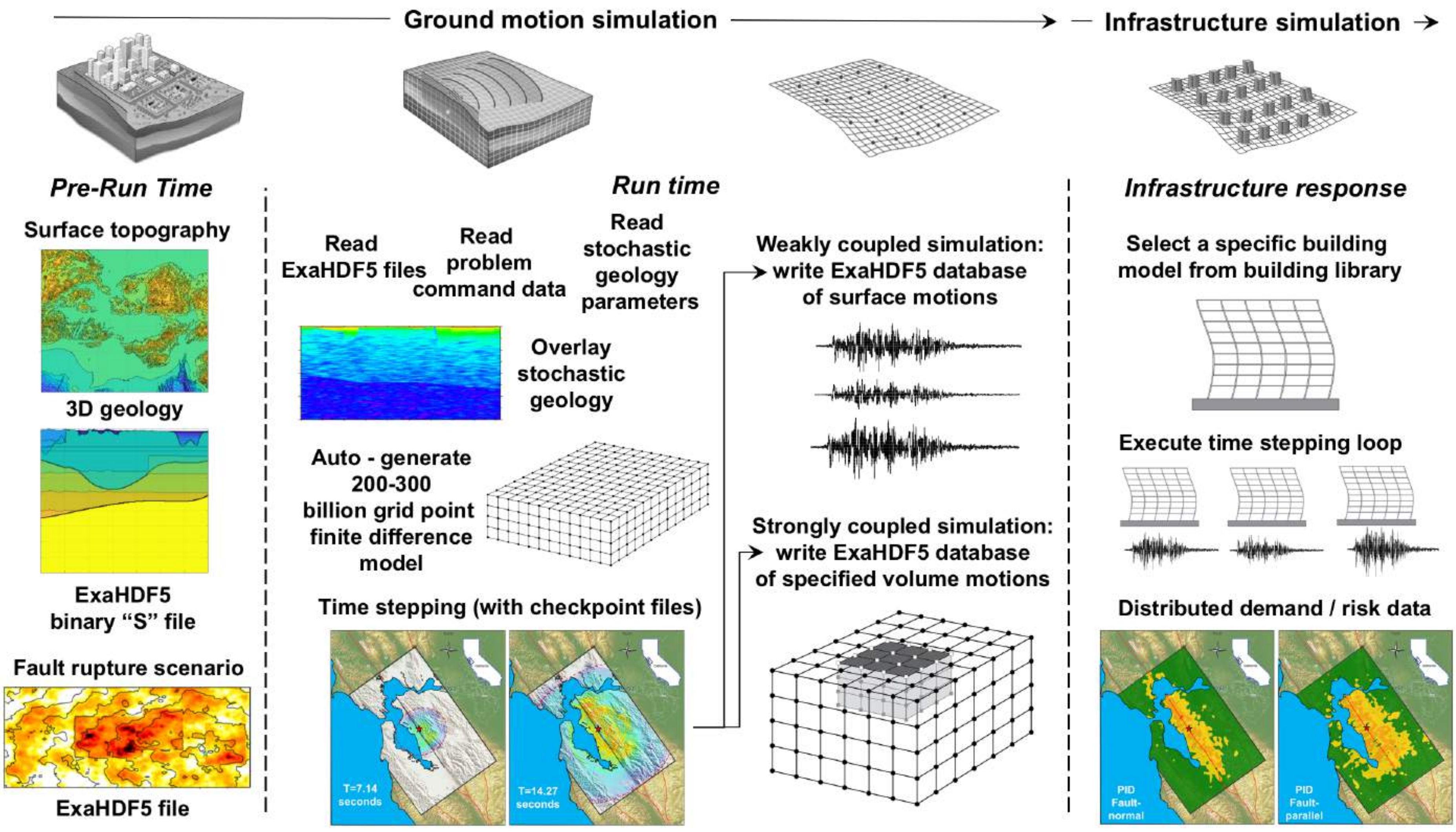


Fault parallel motion
(2 Km from fault)
Fault normal motion
(2 Km from fault)
Surface
waves
Inclined
body
waves
DRM boundary

# We can now investigate the effects of 3D incident waves, ground rotations and SSI



# All these capabilities must be wrapped into an effective end-to-end workflow



# EQSIM “end game” – a compute framework for earthquake hazard and risk simulations