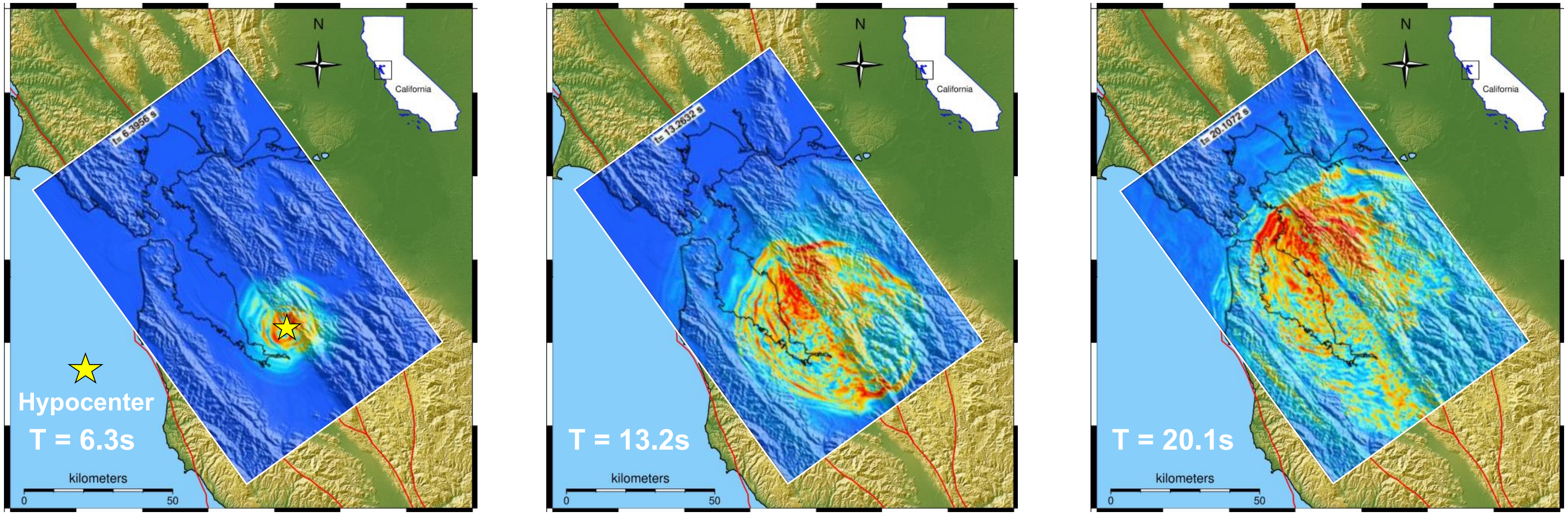


A Regional-Scale Simulated Ground Motion Database (SGDB) for Earthquake Engineering Applications

D. McCallen, R. Nakata, H. Tang, M. Miah
Lawrence Berkeley National Lab

A. Pitarka
Lawrence Livermore National Lab

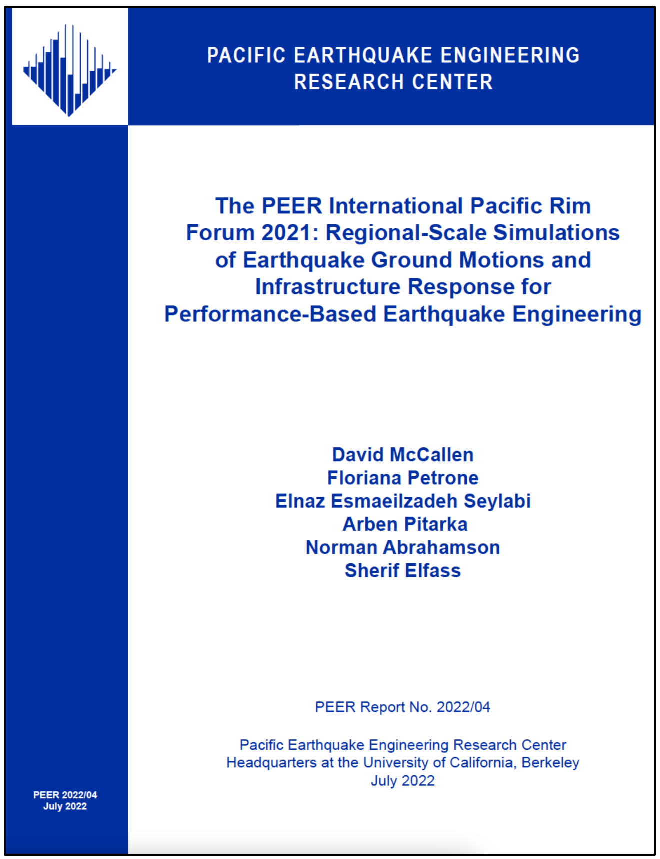
K. Mosalam, S. Gunay, G. Vargas, C. Perez, A. Kasalanati,
PEER Center, UC Berkeley

F. Petrone
University of Nevada/LBNL

BERKELEY LAB
PEER
EQSIM
U.S. DEPARTMENT OF ENERGY
Office of Cybersecurity, Energy Security, and Emergency Response

Community input at PEER-LBNL workshops has helped guide our direction towards a SGDB

PEER Pacific Rim Forum
June 2021


PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

The PEER International Pacific Rim Forum 2021: Regional-Scale Simulations of Earthquake Ground Motions and Infrastructure Response for Performance-Based Earthquake Engineering

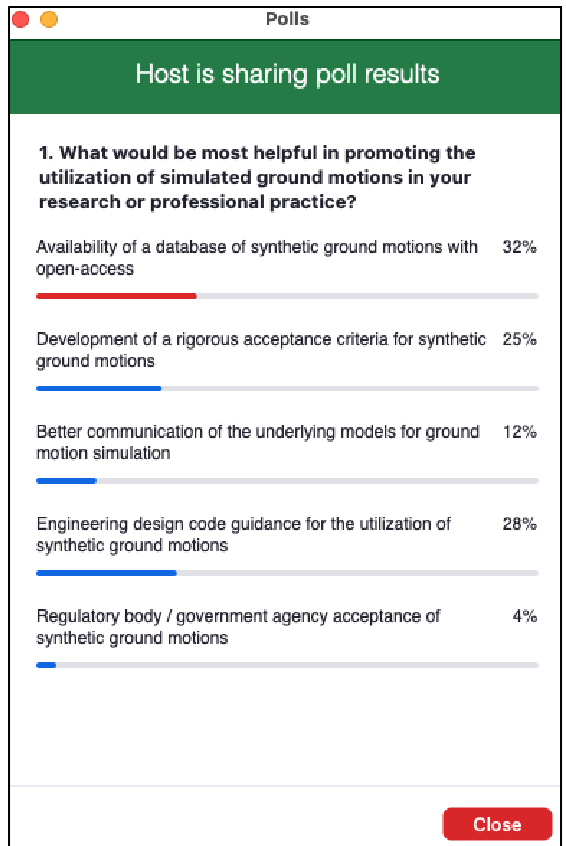
David McCallen
Floriana Petrone
Elnaz Esmaeilzadeh Seylabi
Arben Pitarka
Norman Abrahamson
Sherif Elfass

PEER Report No. 2022/04

Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley
July 2022

PEER 2022/04
July 2022

261 International Participants
41 International Speakers


Polls

Host is sharing poll results

1. What would be most helpful in promoting the utilization of simulated ground motions in your research or professional practice?

Availability of a database of synthetic ground motions with open-access	32%
Development of a rigorous acceptance criteria for synthetic ground motions	25%
Better communication of the underlying models for ground motion simulation	12%
Engineering design code guidance for the utilization of synthetic ground motions	28%
Regulatory body / government agency acceptance of synthetic ground motions	4%

Close

Attendees recommended priorities

Availability of a database of synthetic motions with *open-access*

Assessment and acceptance criteria for synthetic motions

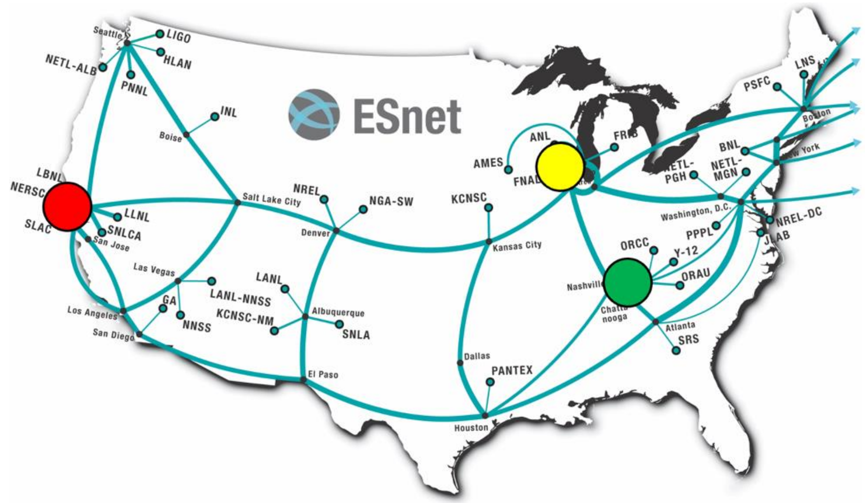
An effective and operationally efficient user interface

Why *now* is the time – the recent major advances in scientific computing capabilities

The new exascale computing ecosystem

ESnet
ENERGY SCIENCES NETWORK

A fiber optic network with multiple 400 Gbits/s channels



ESnet 24/7 operations

Perlmutter (completed 2022)
Lawrence Berkeley National Lab
National Energy Research Scientific Computing Center (NERSC)
1536 GPU accelerated nodes
4 NVIDIA A100 GPUs / node
71 PetaFlops
Top500.org #8

Frontier (completed 2023)
Oak Ridge National Lab
Oak Ridge Leadership Computing Facility (OLCF)
9402 GPU accelerated nodes
4 AMD MI250X GPUs / node
1.194 ExaFlops
Top500.org #1

Aurora (scheduled 2024)
Argonne National Lab
Argonne Leadership Computing Facility (ALCF)
10,624 GPU accelerated nodes
6 Intel Max GPUs / node
Projected ~ 2 ExaFlops
Undergoing final assembly

DOE successfully completed the world's first exaflop ($1x10^{18}$ Flop) GPU-accelerated computer

Advanced hardware

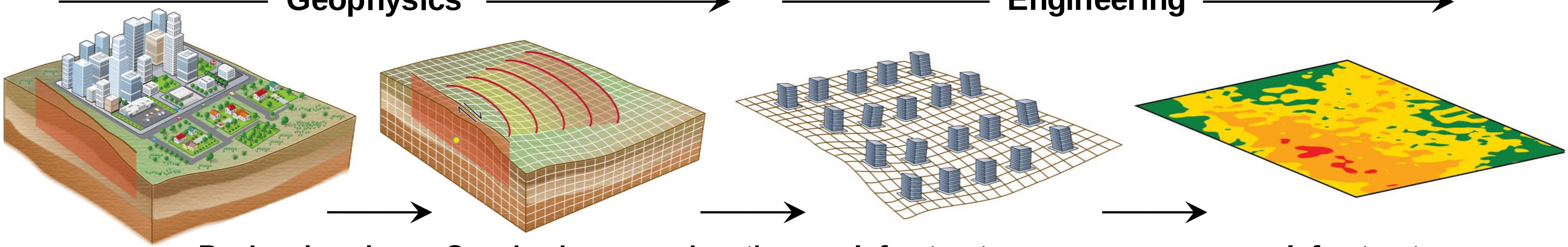
ECP
EXASCALE COMPUTING PROJECT

Frontier
1.194 exaflops
~9,400 compute nodes
(Completed July 2023)

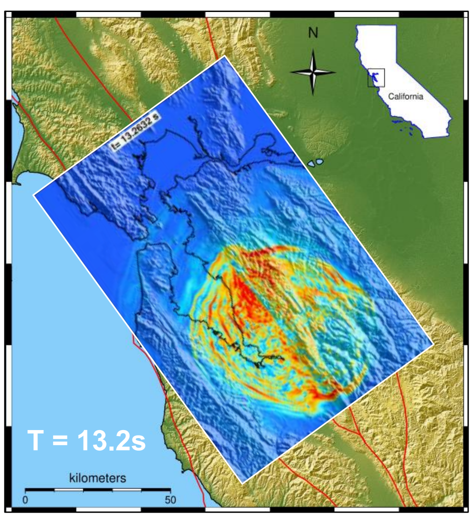
The EarthQuake SIMulation (EQSIM) framework was designed for this computational ecosystem

Advanced software — **Multidisciplinary Fault-to-Structure Simulations**

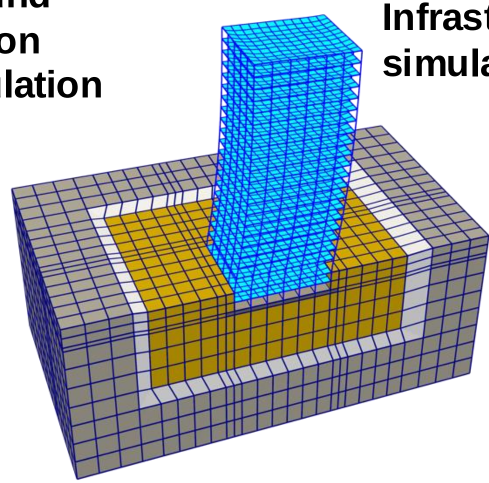
Geophysics → Engineering →



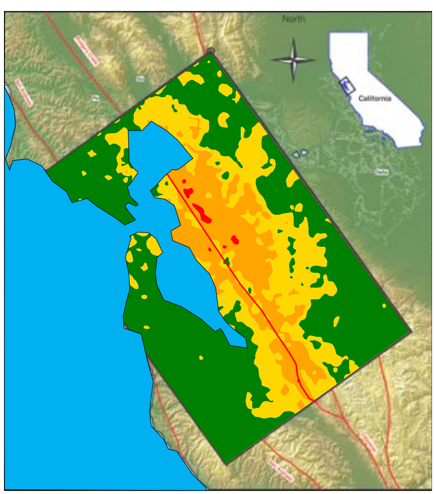
Regional-scale domain → Geophysics ground motion simulations (billions of zones) → Infrastructure response simulations (thousands of stations) → Infrastructure demand / risk



Ground motion simulation



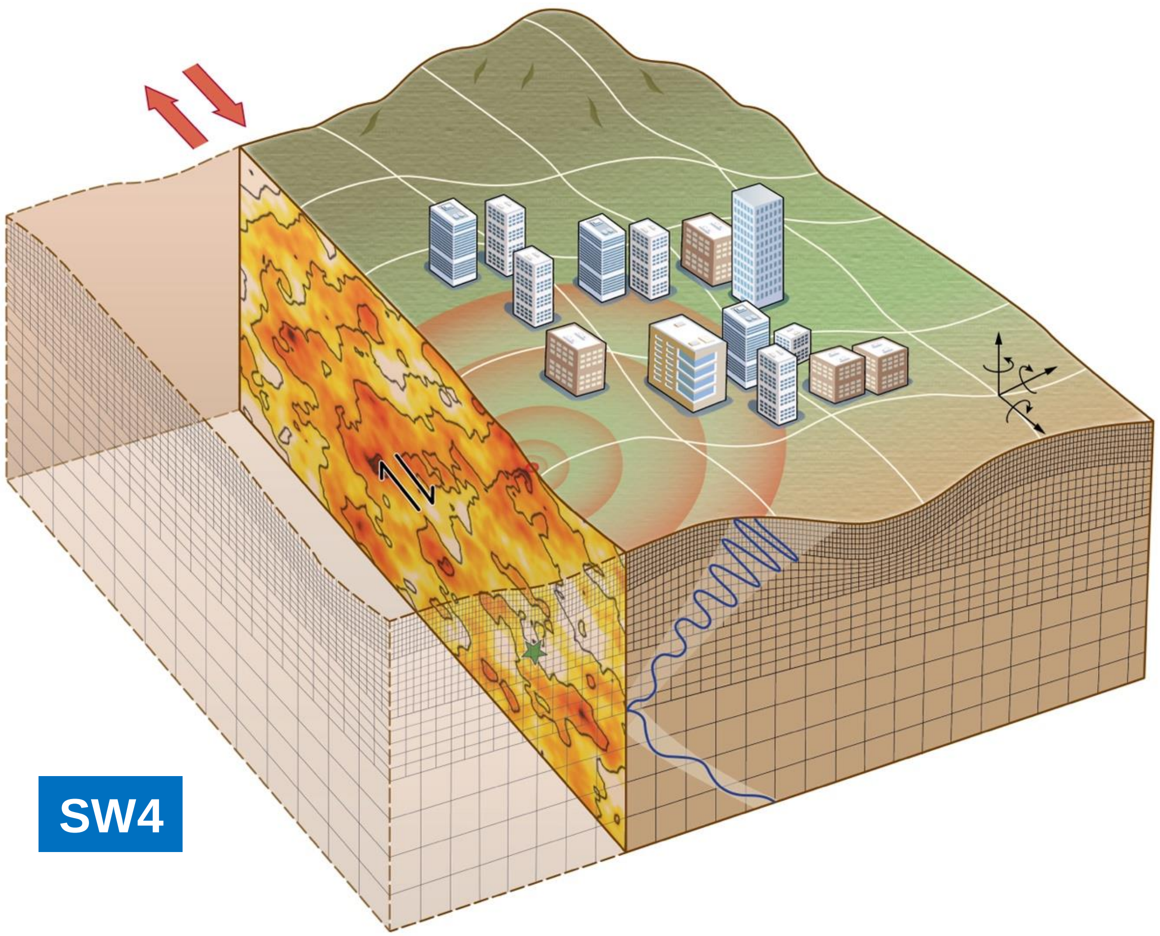
Infrastructure simulations



Regional risk

Over 6 years many advancements were made to the SW4 geophysics wave propagation code

SW4 – Fourth order in space and time



ST dependencies RAJA, ExaIO (HDF5), ALPINE (ZFP)

Algorithms

- Mesh refinement in Cartesian and curvilinear grids

IO and workflow

- Transition to HDF5-based IO (from SW4 homebrew)
- Utilization of ZFP for data compression

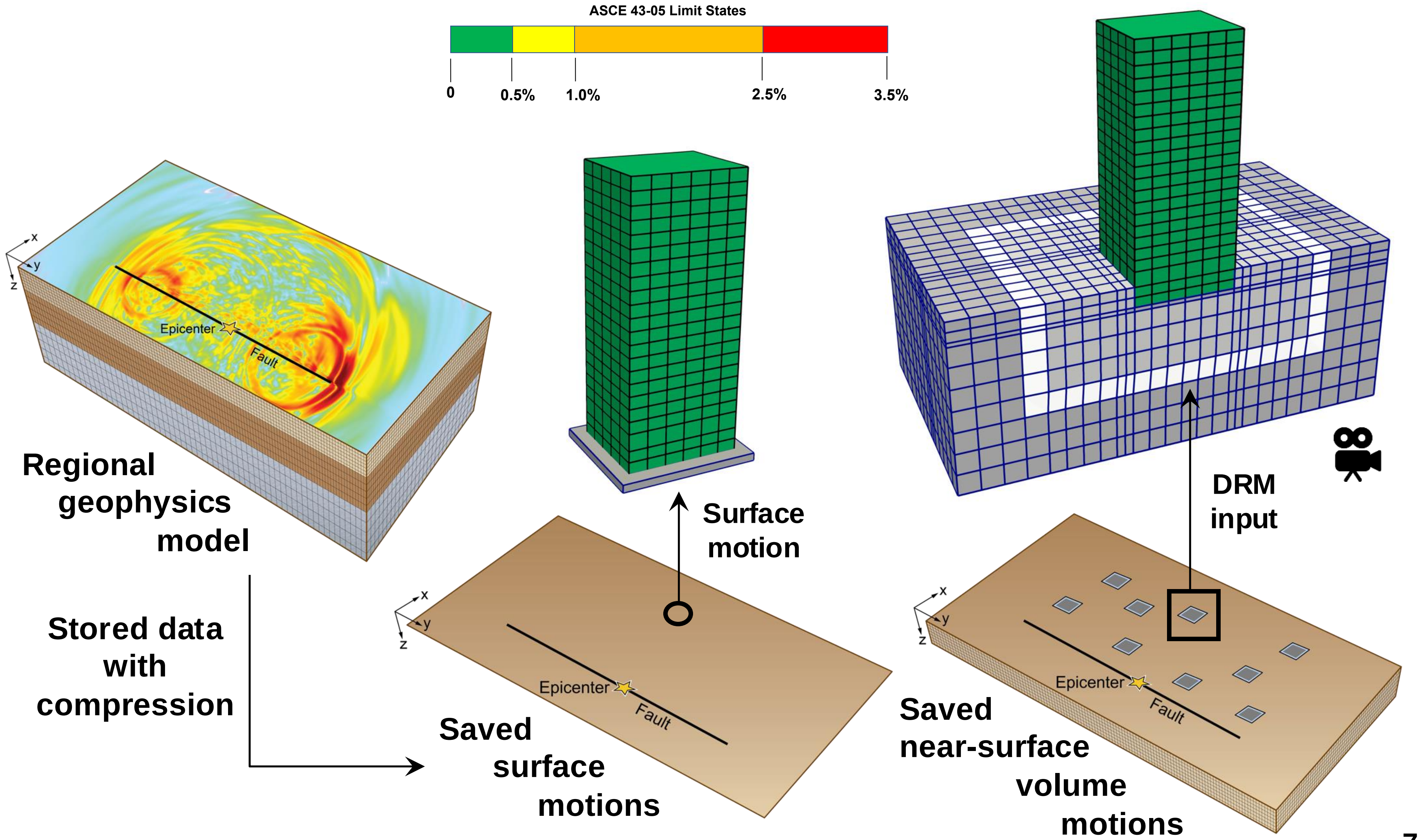
Readiness for GPU-based platforms

- Implementation of RAJA libraries

Enhanced physics models

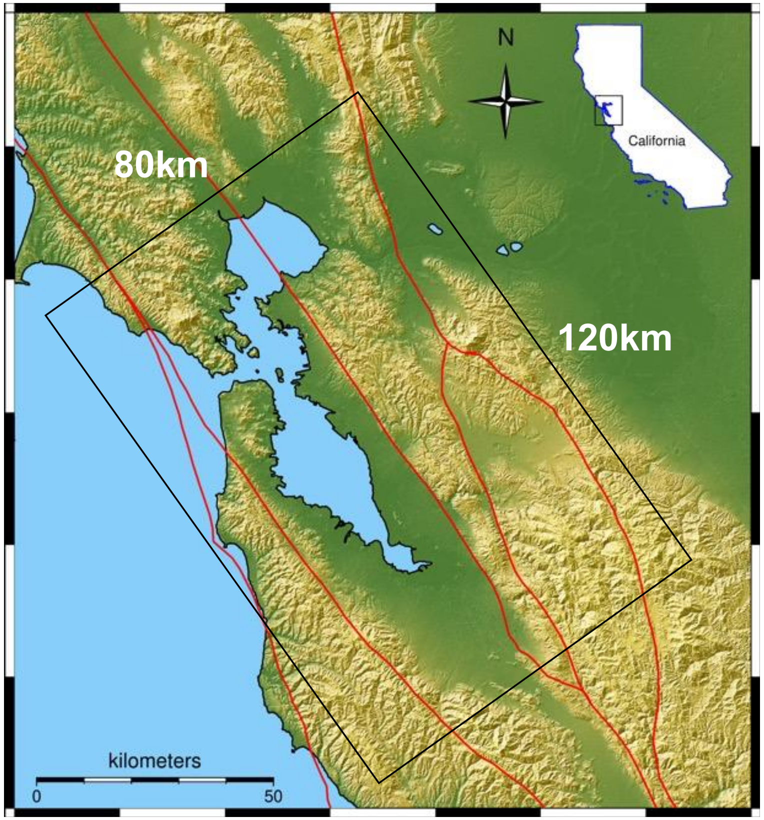
- Enhancements to the Graves - Pitarka rupture model workflow

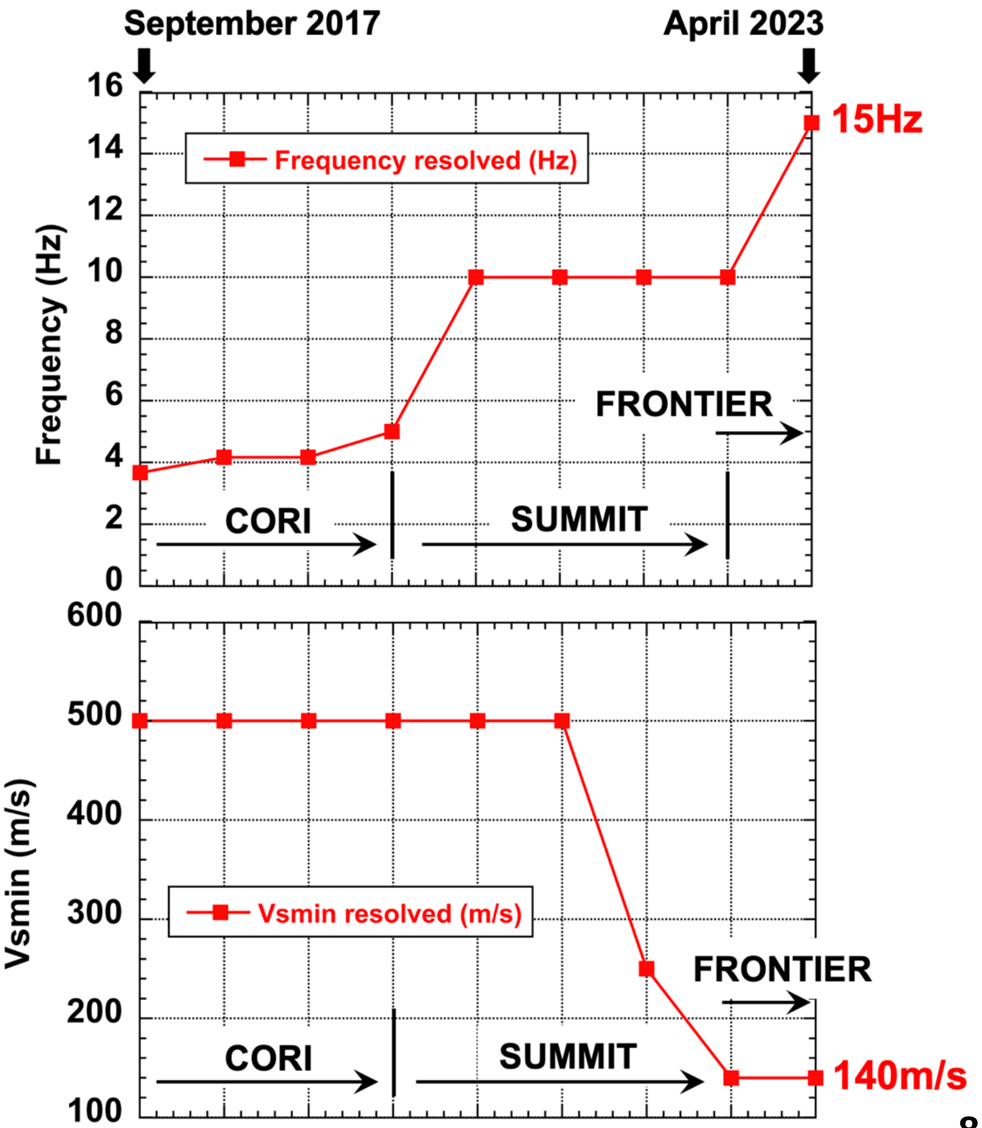
The EQSIM workflow has both fixed base and DRM options fully implemented



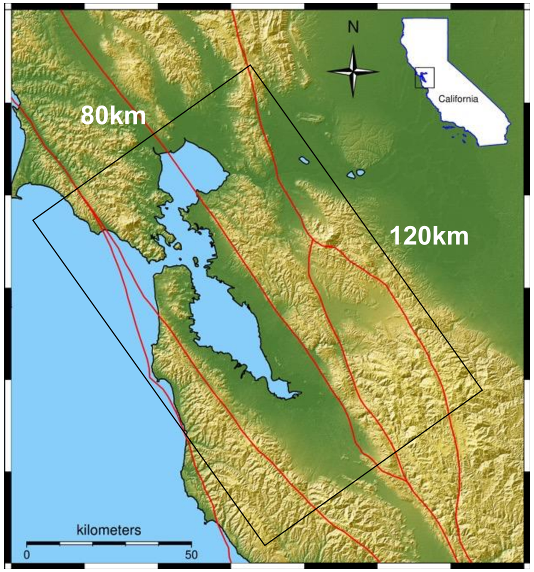
On DOE GPU systems EQSIM has pushed the computational edge of simulation fidelity

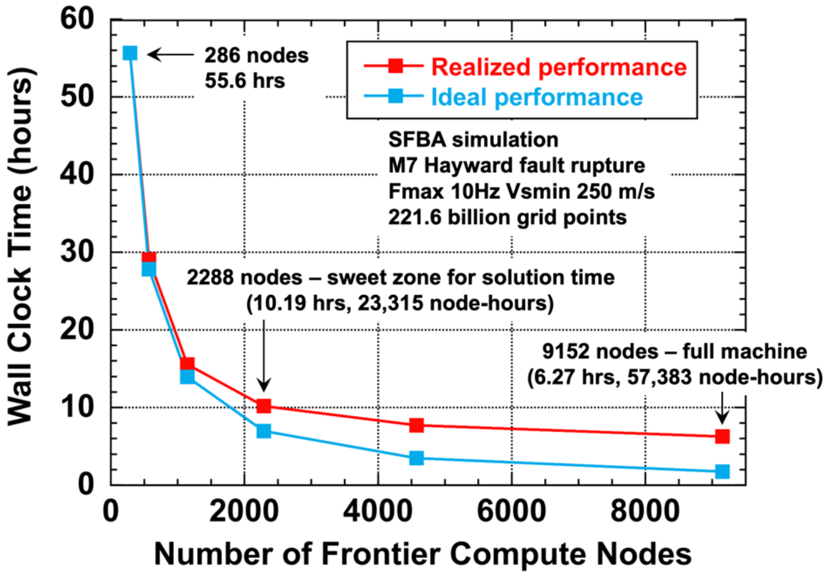
San Francisco Bay regional model





On DOE GPU systems EQSIM has pushed the computational edge of simulation speed





Model	# Frontier nodes	Wall clock time (hrs)
Fmax 5 Hz Vsmin 250 m/s	512	3.8
	3072	1.8
Fmax 10 Hz Vsmin 250 m/s	286	66.5
	9152	6.27
Fmax 15 Hz Vsmin 140 m/s	1800	122
	9152	29.2

Activity 1 - development of regional-scale simulated earthquake ground motions

Engineering

D. McCallen

Berkeley Lab

F. Petrone

Univ. Nevada & Berkeley Lab

M. Miah

Berkeley Lab

Seismology

A. Pitarka

Livermore Lab

R. Nikata

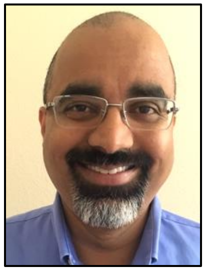
Berkeley Lab

Computer Science

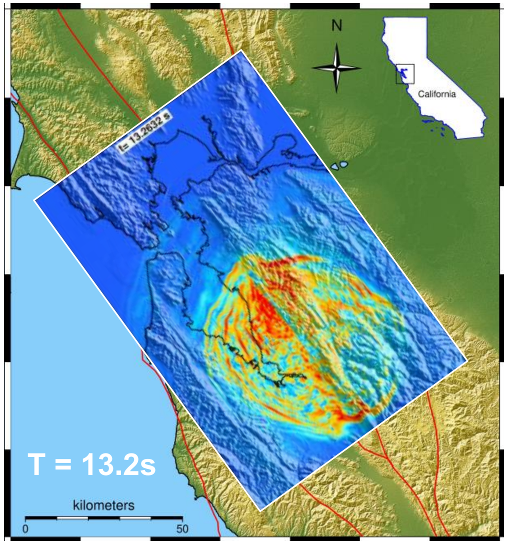
H. Tang

Berkeley Lab

R. Pankajakshan



Livermore Lab



E. Taciroglu

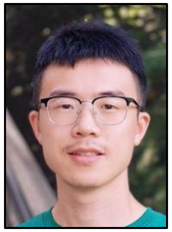
UCLA Civil Engineering

Current postdoctoral scholars and PhD students

Kostantinos Tsalouchidis

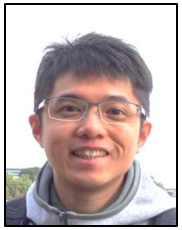
LBNL

Junfei Huang



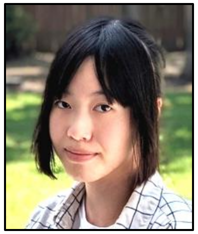
UNR

Clifford Yen



UCLA

Flora Xia



CALTECH

BERKELEY LAB

UCLA Samueli School of Engineering

Activity 2 - development of the interactive open access simulated ground motion database

K. Mosalam

PEER Director & UC Berkeley

S. Gunay

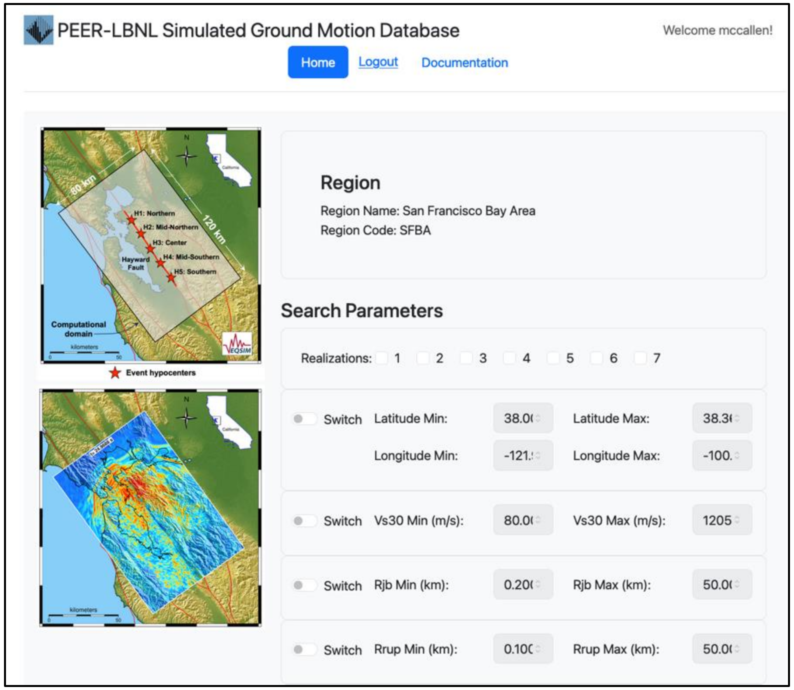
G. Vargas

A. Kasalanati

PhD Student

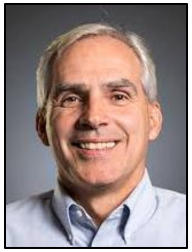
Claudio Perez

UCB



Beta users

P. Arduino



T. Opabola

S. Muin

M. Esteghamati

I. Kim

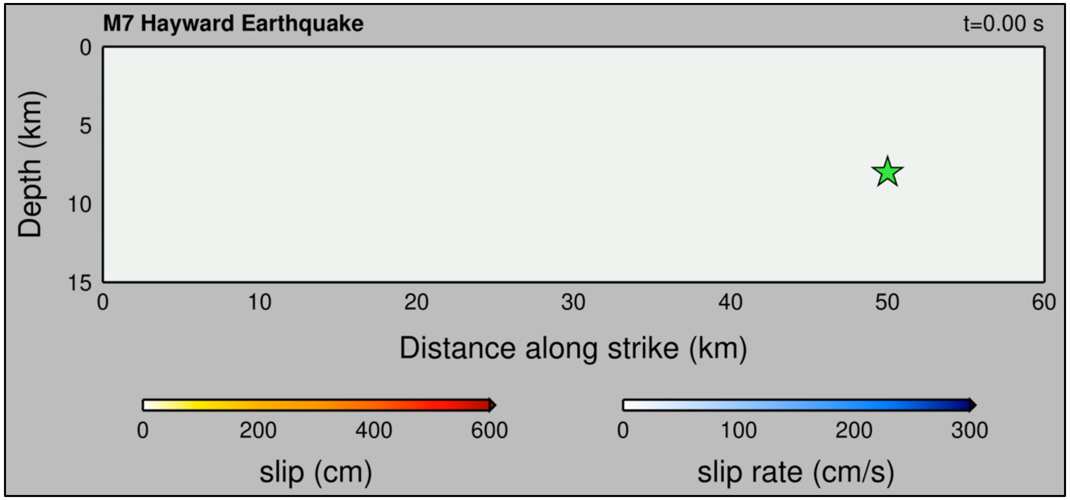
M. Kenawy

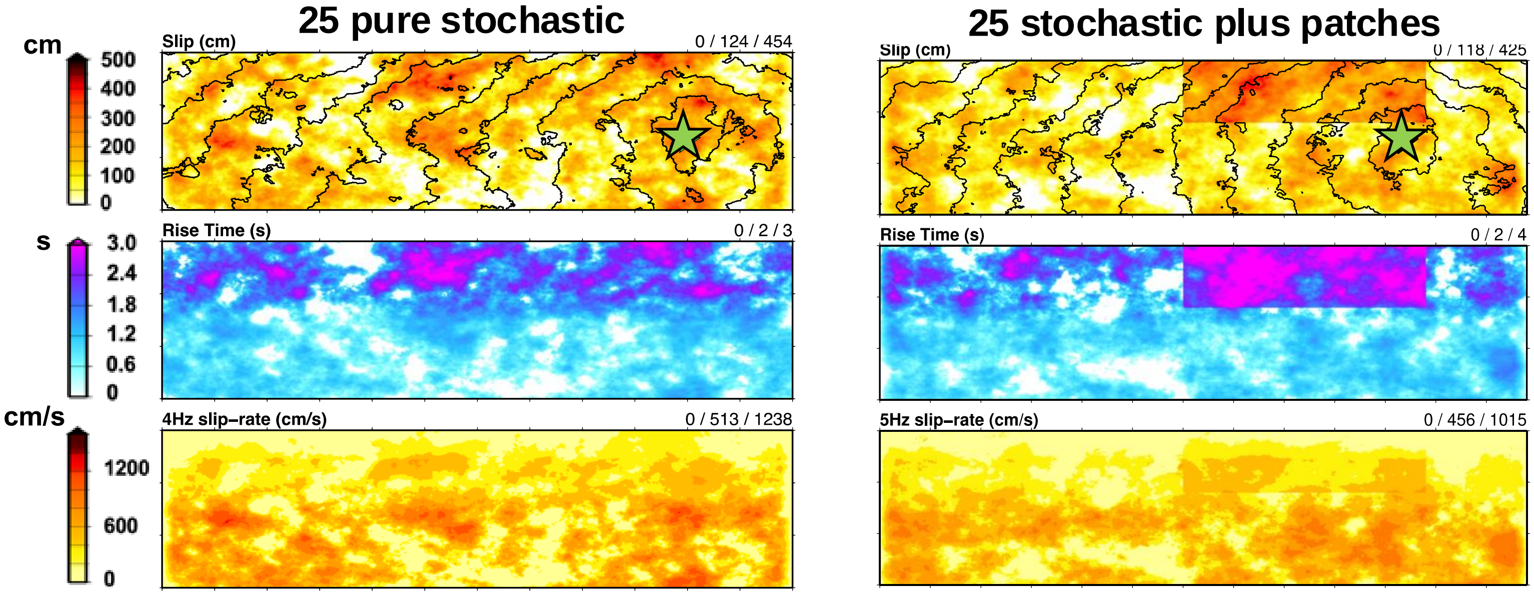
PEER

Berkeley Engineering

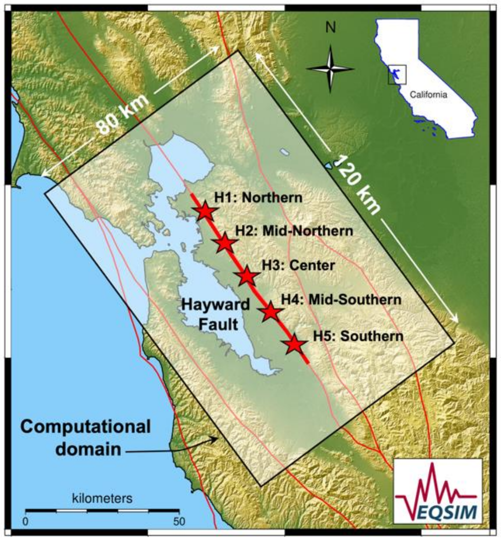
Hayward fault M7 events are characterized using the Graves-Pitarka kinematic rupture model

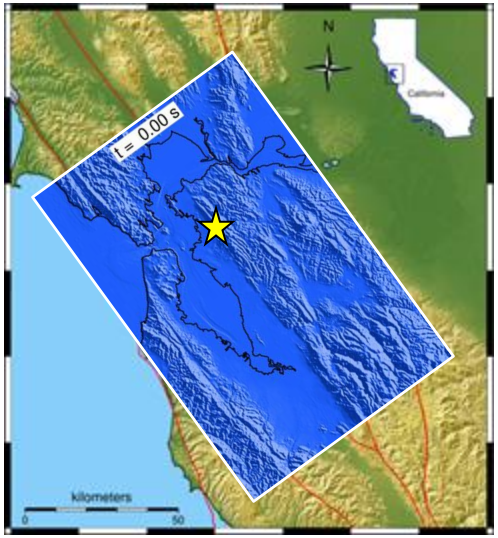
Graves-Pitarka kinematic rupture model

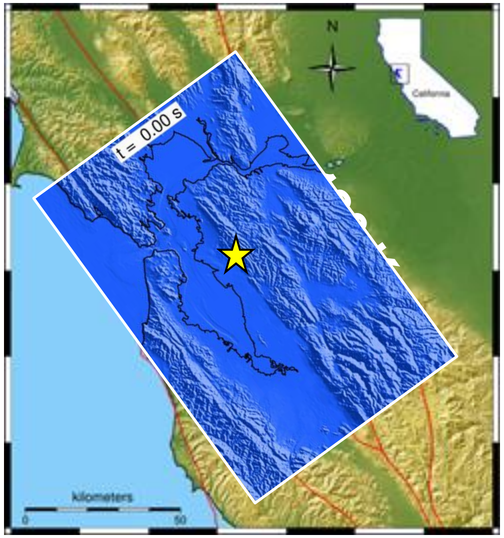


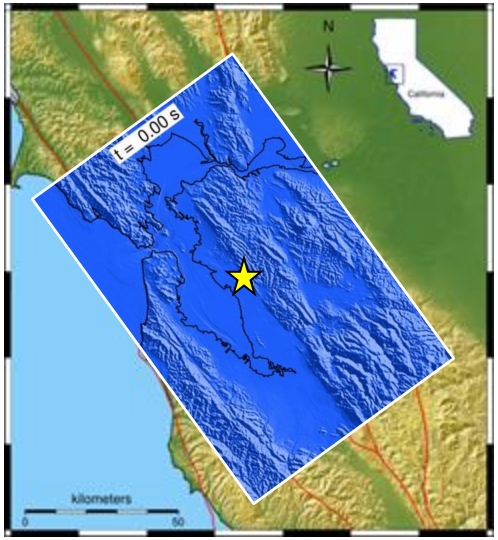


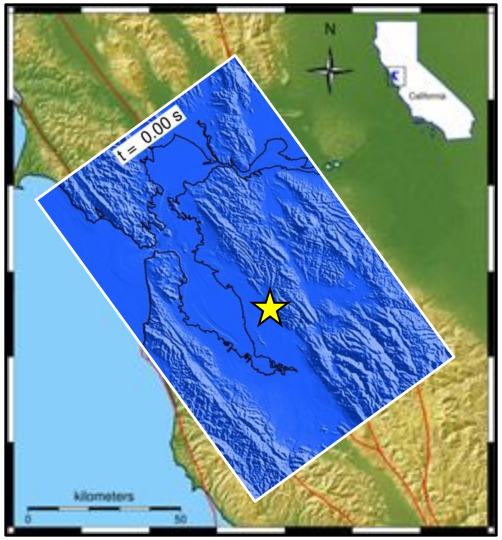
For the simulated motion database, we are completing 50 Hayward fault rupture realizations

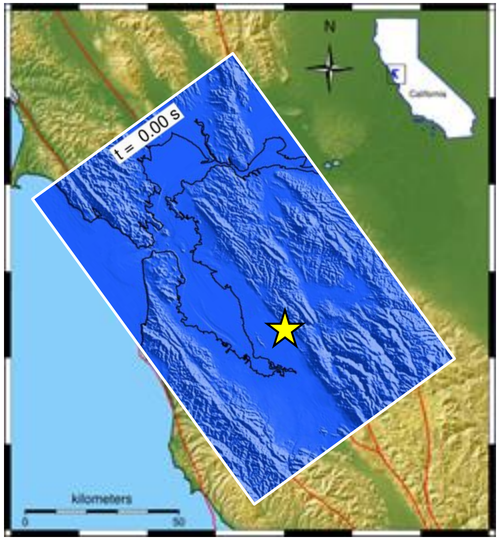






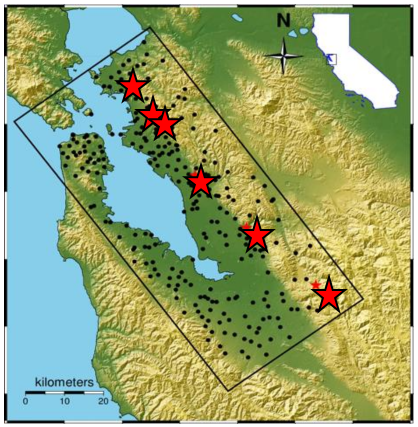




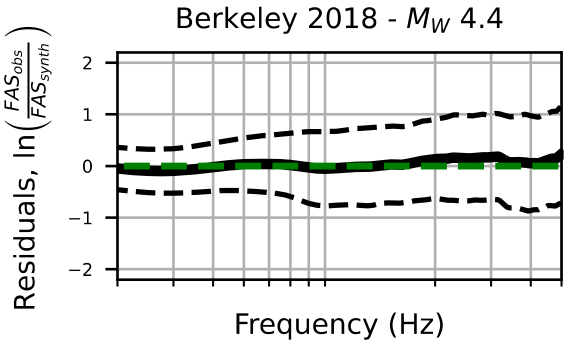


We test our simulated motions in multiple ways

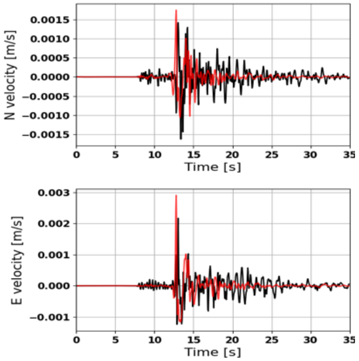
1) Testing the EQSIM Bay Area model – 7 small Hayward fault event simulations



Spectral comparisons

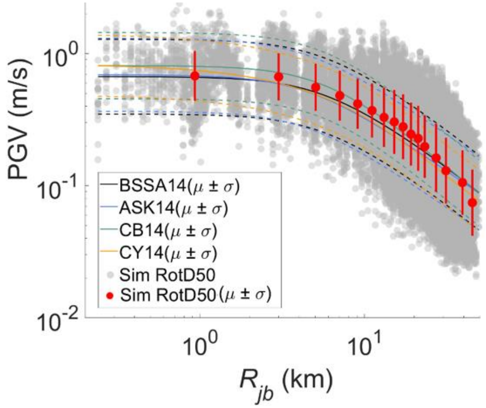


Comparison to measured ground motion waveforms

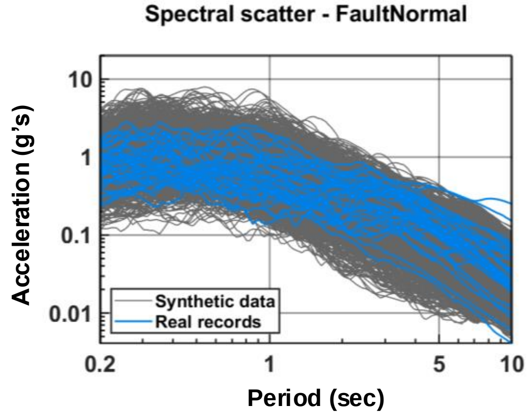


2) Evaluating the simulated large events - 50 M7 Hayward fault realizations

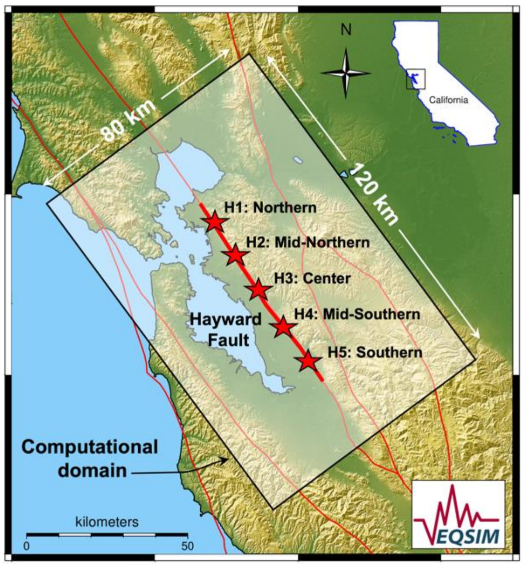
Comparison to existing empirical GMP equations



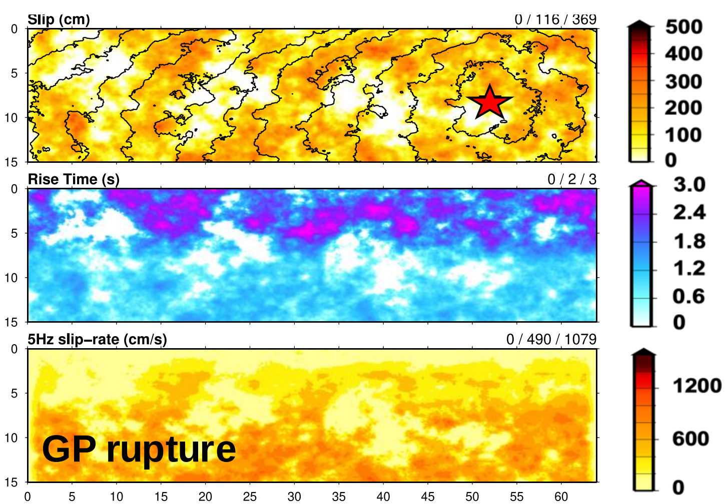
Comparison to existing commensurate ground motion data (near-fault sites < 10 km)



We analyze and critique every individual rupture realization prior to acceptance

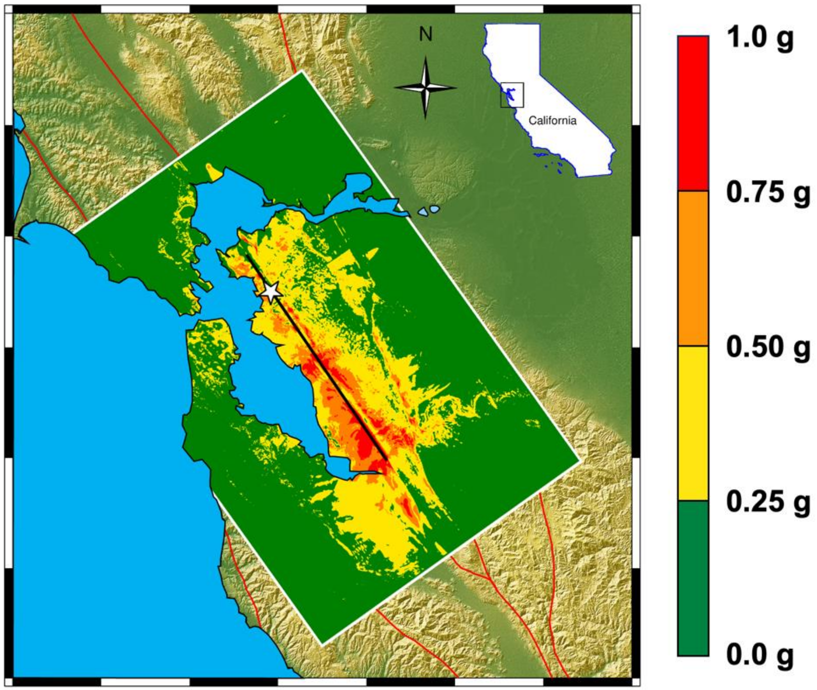


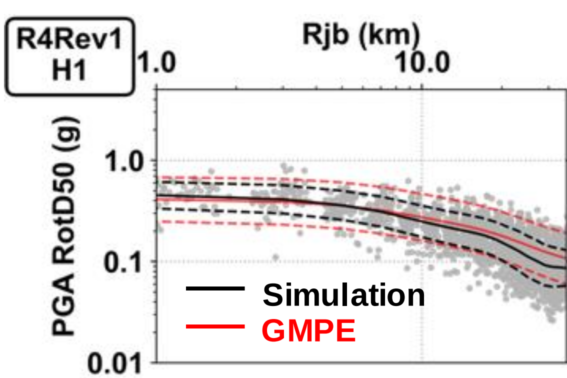
Event Hypocenter Locations

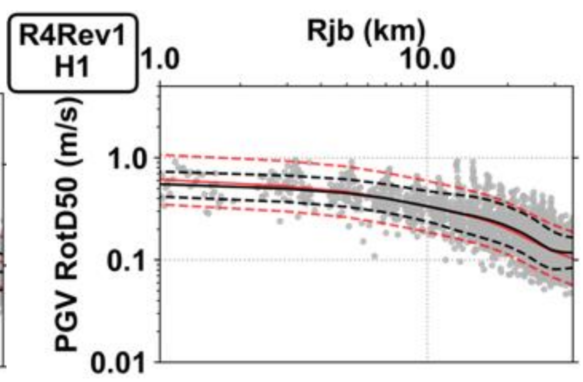


Northern hypocenter →

Hypocenter H1, Realization #4







Testing and analysis of SFBA simulations are being documented

In press for Earthquake SPECTRA

Earthquake Spectra
XX(X):1–33

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DOI: 10.1177/ToBeAssigned
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Performance Evaluation of the USGS Velocity Model for the San Francisco Bay Area

Camilo Pinilla-Ramos[1], Arben Pitarka[2], David McCallen[1] and Rie Nakata[1]

Abstract

In this study, we evaluated the performance of the United States Geological Survey (USGS) velocity model developed for the San Francisco Bay Area (SFBA), version 21.1. The evaluation was performed through high-resolution three-dimensional physics-based ground motion simulations of seven small-magnitude earthquakes (ranging from magnitude 3.8 to 4.4) that occurred on the eastern side of the San Francisco Bay. The simulations were performed in the frequency range from 0 to 5 Hz with a minimum shear wave velocity of 250 m/s, which allowed the capture of wave propagation effects of the near-surface soft materials that characterize local basins. Based on the direct comparison of Fourier amplitude spectra between recorded and simulated

[1]Lawrence National Berkeley Laboratory, Berkeley, California// [2]Lawrence National Livermore Laboratory, Livermore, California

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Research Paper

EERI EARTHQUAKE SPECTRA

Earthquake Spectra
1–25

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Ground-motions site and event specificity: Insights from assessing a suite of simulated ground motions in the San Francisco Bay Area

Floriana Petrone[1], Arsam Taslimi[1], Majid Mohammadi Nia[1], David McCallen[2], and Arben Pitarka[3]

Abstract

This article presents the results of a research that is part of a larger collaborative effort between the Lawrence Berkeley National Laboratory and the Pacific Earthquake Engineering Research Center, funded by the US Department of Energy Office of Cybersecurity, Energy Security and Emergency Response. The main objective of this study is to assess a suite of near and far-field simulated ground motions obtained from 20 realizations of an M7 Hayward Fault earthquake in the San Francisco Bay Area, California USA, and inform the selection of rupture simulation parameters leading to strong motions. To this aim, comparisons are conducted with NGA-W2 and directivity ground-motion models and a selected population of records. An archetypal steel moment-resisting frame is utilized to assess infrastructure response distributions. The analyses carried out for each simulated event and subdomain with consistent properties in terms of shallow shear-wave velocity proved to be instrumental for better interpreting the differences between simulated motions and empirical models. The main reasons identified for variances between simulations and empirical relationships included (1) directivity effects fully captured by the simulations across the full breadth of rupture models; (2) site vicinity to ruptures that incorporate large-slip patches, particularly if these are in the forward-directivity direction; and (3) presence of geologic structures that can "trap" seismic waves and produce ground motions with large amplitude and long signal duration. The analyses carried out in this work provide a path for interpreting ground-motion site and event specificity obtained from a suite of physics-based simulations, differing only in the rupture model characterization, to inform the selection of simulation scenarios for site-specific engineering analyses

[1]University of Nevada, Reno, Reno, NV, USA
[2]Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[3]Lawrence Livermore National Laboratory, Livermore, CA, USA

Corresponding author:
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Email: florianapetrone@unr.edu[AQ: 1][AQ: 2][AQ: 3]

In preparation

Separation of frequency-dependent ground motion directivity from path and site effects using deterministic 5Hz simulations of M7 earthquakes on the Hayward fault

Rie Nakata[1], Arben Pitarka[2], David McCallen[1], Camilo Pinella Ramos[1,3]

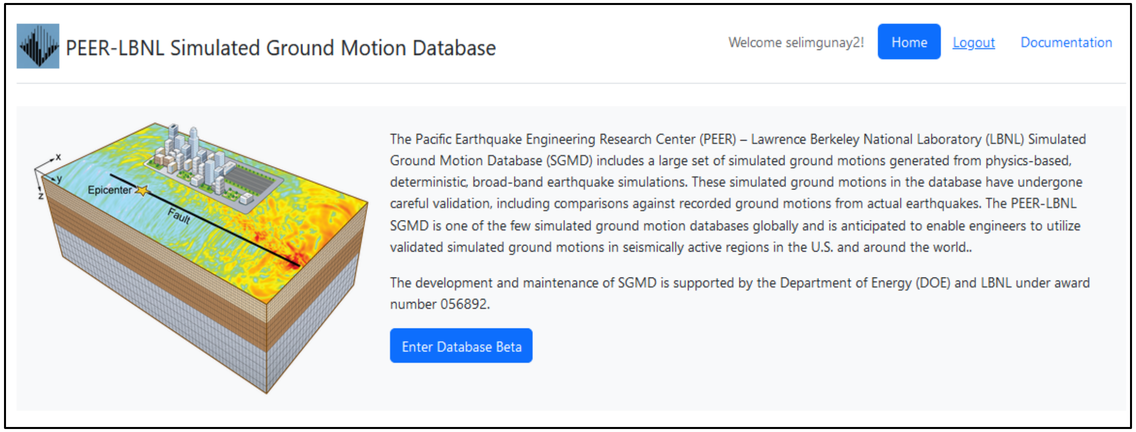
[1]Lawrence Berkeley National Laboratory
[2]Lawrence Livermore National Laboratory
[3]University of Southern California

Abstract

Large earthquakes occur along major active faults, potentially causing devastating damages to infrastructures and claiming a large number of casualties. The active Hayward fault in the San Francisco Bay Area (SFBA), Northern California is a part of the San Andreas Fault system and situates within one of the most densely populated metropolitan area. Near-fault motions amplified by the directivity of rupture propagation is a prominent risk. We perform 25 scenario M7 Hayward-fault earthquakes using five hypocenter locations and analyze the directivity effects. The ensemble average of the 25 scenarios exhibit that the discrepancies in wave propagation effects within the deep basins and across the Hayward fault. Source directivity effects in spectra acceleration, peak ground acceleration and peak ground velocity are isolated by subtracting those value averaged point-wise over 25 scenarios. We demonstrate that this approach is more effective than subtracting empirical ground motion predictions, in which propagation effects such as deep basin effects evident in simulation results are not well captured by the empirical GMMs. The extracted amplifications are mostly symmetric across the fault suggesting that the amplification factor is not significantly affected by the structural effects. The amplification decays quickly and is prominent in the fault parallel component at high frequencies. Amplification factors increase at low frequencies, and affect wide areas in both fault parallel and fault normal components.

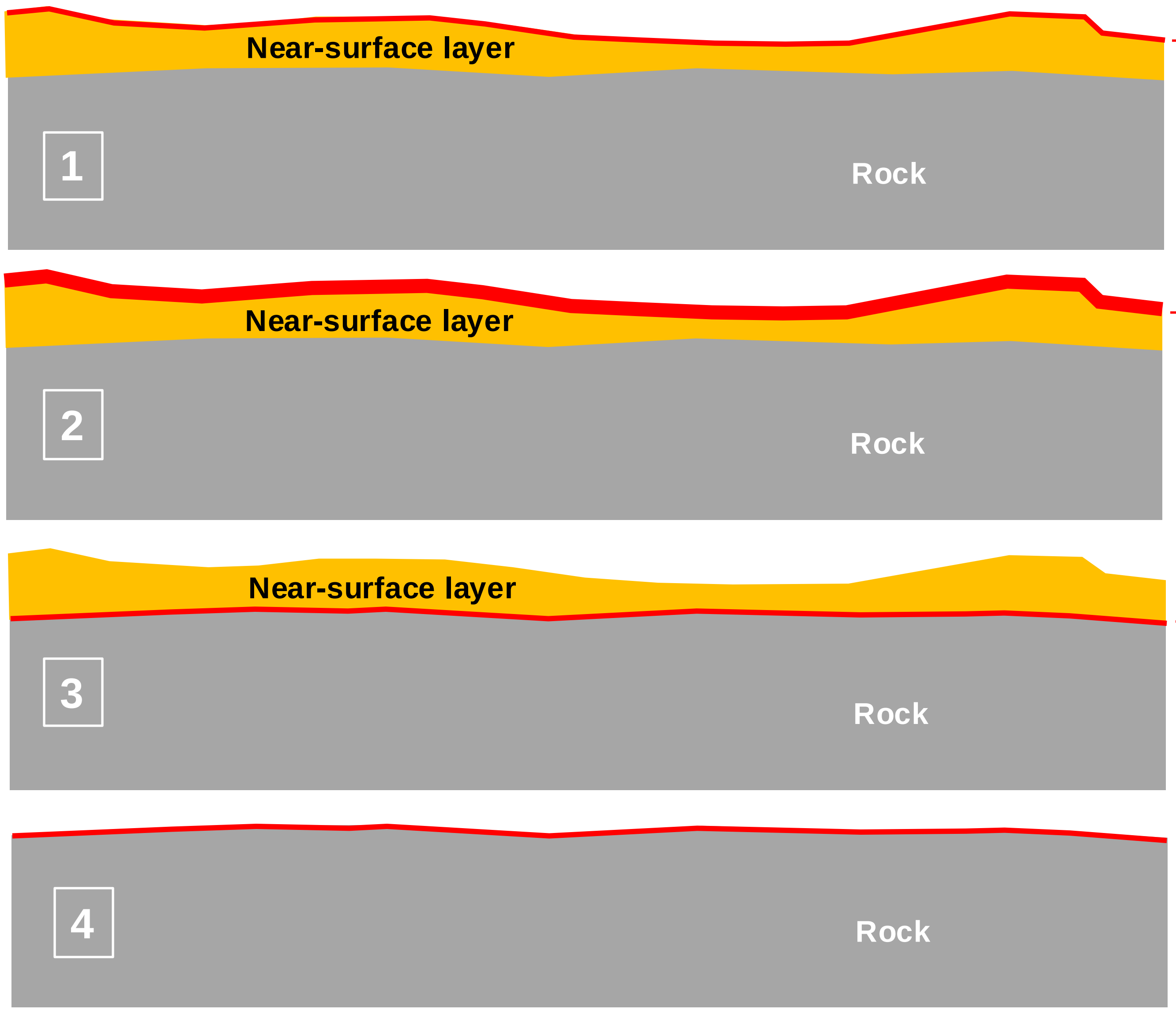
Immediate steps ahead to complete the first regional application in the SF Bay Area

- Complete creation and testing of PEER interactive user software for browsing and downloading simulated ground motions



- Finalize 50 rupture scenarios and acceptance testing
- Provide open access to the set of beta users and obtain early feedback
- Identify any key software utility tools that can help process simulated motions (e.g. RSPmatch)

The SGDB could support multiple engineering use cases depending on the degree of user *pull*



Ground surface motions
- fixed base structural response

Near surface volume motions
- DRM utilization for SSI and/or nonlinear soil response

In-column motions
- 1D site response

Outcrop motions
- 1D site response

Applying a similar approach, Southern California model generation and testing is underway

Chino Hills M5.4, 2008