EQSIM – A High Performance Computational Framework for Fault-to-Structure Simulations on Massively Parallel Computer Platforms

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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

Exascale objective

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
Computer science contributions – distribution of work on massively parallel platforms

Getting prepared to exploit the world’s fastest scientific platforms

OAK RIDGE National Laboratory

4,608 nodes, 27,648 NVIDIA GPUs

Pencil domain “k”
Pencil domain “i”

Node “i” Node “k”
San Francisco Bay Area simulations to 10Hz on the world’s #1 computer

- Frequency Resolved: 10 Hz
- $V_{s_{\text{min}}}$: 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

A. Rodgers (LLNL)
Coupling geophysics and engineering models

Weak Coupling

Engineering Model (Fixed base)

Geophysics Model

Simple incident waveforms

Vertical
Horizontal Rotation

Strong Coupling

Engineering Model (SSI)

DRM boundary

Complex incident waveforms
This spawns two alternate workflows

19,200 ground motions
Simulated motions

19,200 nonlinear building simulations
Select building model from library

SSI with 3D input motions
Simulated motions in a 3D subdomain of SW4

Regional distribution of earthquake demand / risk

Motions interpolated to the embedded DRM boundary

Soil Island

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We are now executing weakly coupled 5 Hz simulations routinely – M7 Hayward fault EQ
Scrubtinizing the simulation model results
ASCE 43-05 Limit States

- 0%
- 0.5%
- 1.0%
- 2.5%
- 3.5%

Basin

25 seconds

1 Km 5 Km 10 Km 20 Km
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.
EQSIM “end game” – a compute framework for earthquake hazard and risk simulations

Earthquake rupture scenario  
- Multiple fault rupture realizations  
- Multiple geologic characterizations  
- “N” fast, high frequency simulations

Earthquake rupture scenario e.g. M=7 Hayward Fault

Realization 1  
Realization 2  
Realization 3  
Realization N
Thanks!

Questions?