

High Fidelity Modeling and Simulation of Earthquake Soil Structure Interaction Effects for Infrastructure Objects

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Outline

Introduction
Motivation

Modeling and Simulation
Seismic Motions
Seismic Energy Dissipation

Summary

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Motivation

Motivation

- ▶ Improve safety and economy of infrastructure objects
- ▶ Improve numerical modeling and simulation for infrastructure objects
- ▶ Modeling and simulation quality assurance, verification & validation
- ▶ Select sophistication level for numerical modeling and simulation (MS) to analyze earthquake soil structure interaction (ESSI) effects
- ▶ Practical numerical modeling and simulation system, MS-ESSI

Uncertainties

- ▶ Modeling uncertainty, introduced by simplifying assumptions, need for capability to perform lower and higher level of sophistication modeling and simulation
- ▶ Parametric uncertainty, propagation of uncertainty in material K^{ep} and loads $F(t)$, through:
 $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$, resulting in PDFs and CDFs for σ_{ij} , ϵ_{ij} , u_i , \dot{u}_i , \ddot{u}_i
- ▶ Le doute n'est pas un état bien agréable, mais l'assurance est un état ridicule. (Voltaire)

High Performance Computing (HPC) for MS-ESSI

High sophistication models usually require significant computational resources

- ▶ Fine grained HPC
 - ▶ Programming techniques, Templates, Metaprograms
 - ▶ Data arrangement for Small Linear Algebra optimization
- ▶ Course grained HPC
 - ▶ Plastic Domain Decomposition method for inelasticity
 - ▶ Variable capability CPUs
 - ▶ Variable performance networks
 - ▶ Workstations, clusters, national and commercial supercomputers (EDISON, CORI, AWS...)

Seismic Motions

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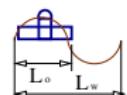
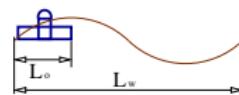
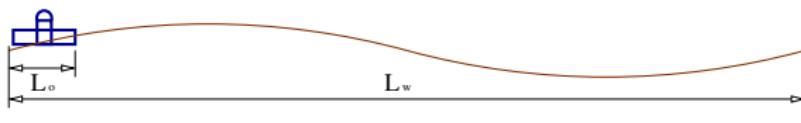
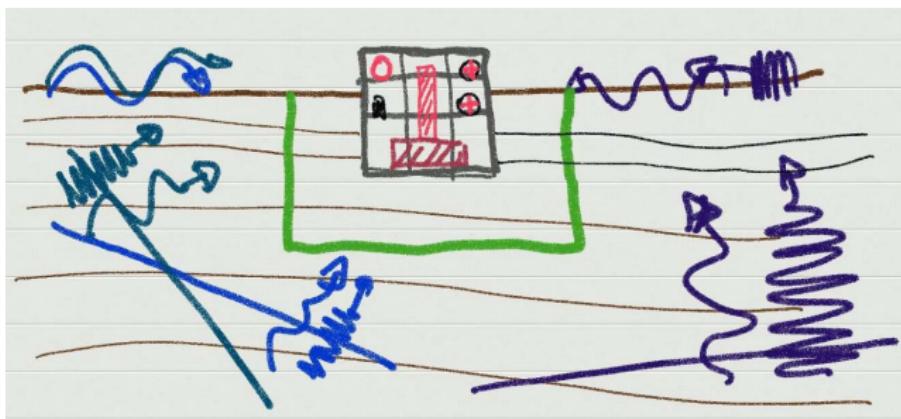
Stress Test Motions and Regional Scale Motions

- ▶ Stress test motions, analytic solutions, plane wave, layered medium, Thomson and Haskel, '50s
 - ▶ 3D - 6C
 - ▶ 3D - 3×1 C
 - ▶ 3D - 1C
 - ▶ 1D - 1C
- ▶ Free field regional scale seismic motions using SW4, Rodgers, Pitarka and Petersson, '10s
- ▶ Knowledge of geology and the site is important

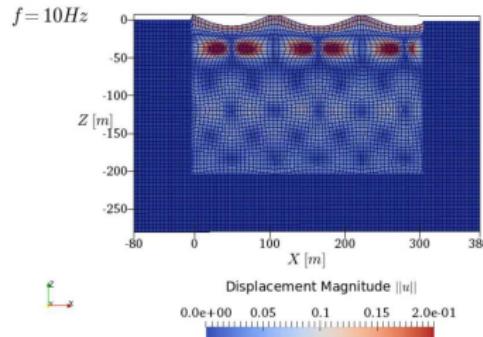
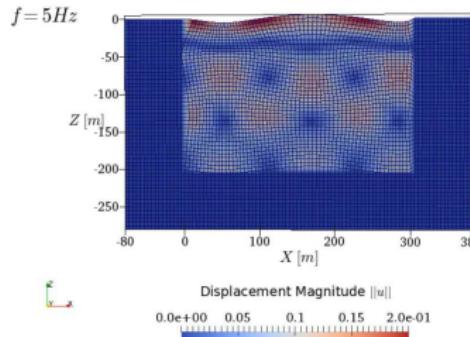
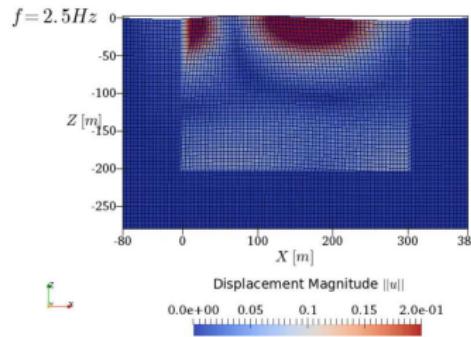
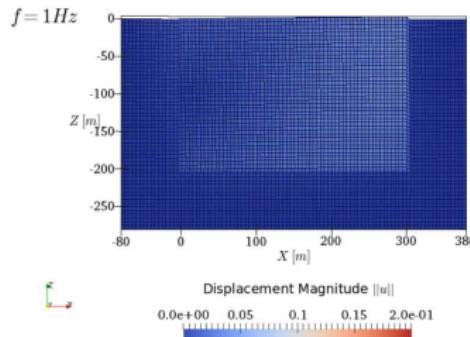
Seismic Motions

Stress Test Motions

- ▶ Variation in inclination, frequency, energy and duration
- ▶ Try to "break" the system, shake-out strong and weak links



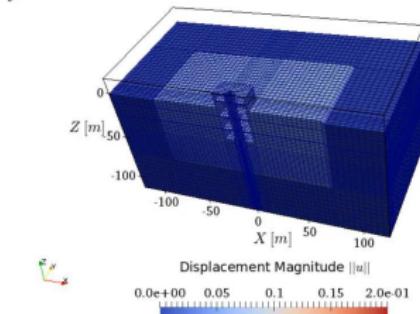
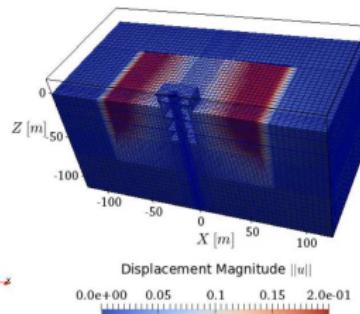
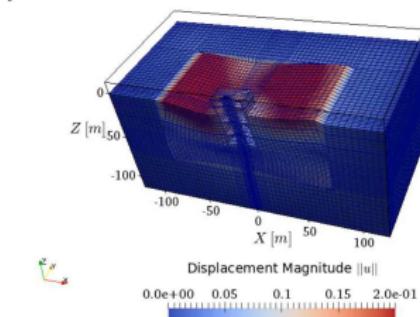
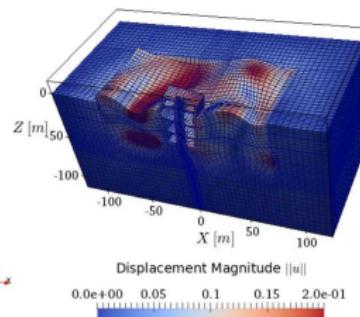
Seismic Motions

Free Field, Variation in Input Frequency, $\theta = 60^\circ$ 

(MP4)



Seismic Motions

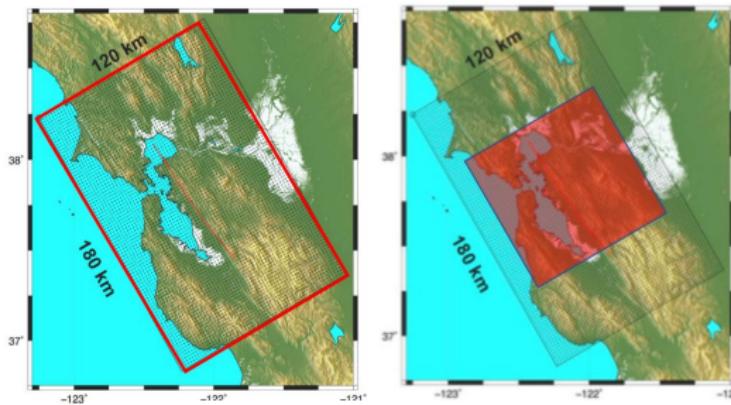
SMR ESSI, Variation in Input Frequency, $\theta = 60^\circ$ $f = 1\text{Hz}$  $f = 2.5\text{Hz}$  $f = 5\text{Hz}$  $f = 10\text{Hz}$ 

(MP4)

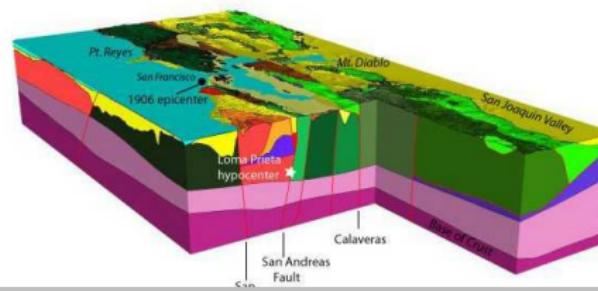


Seismic Motions

Regional Geophysical Models



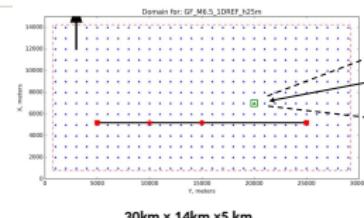
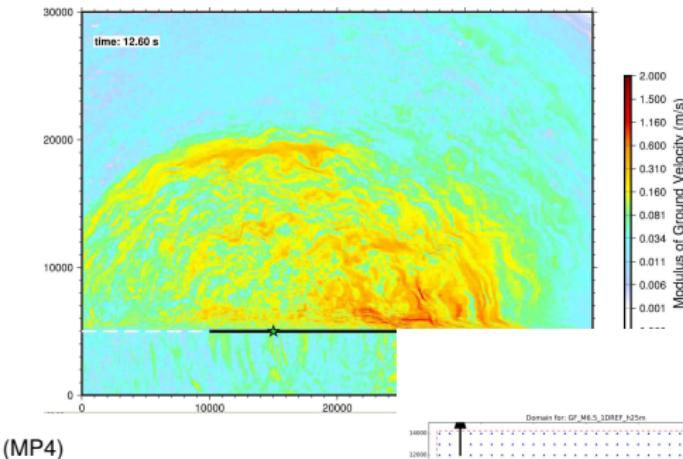
Rodgers et al
LBNL, LBNL



USGS

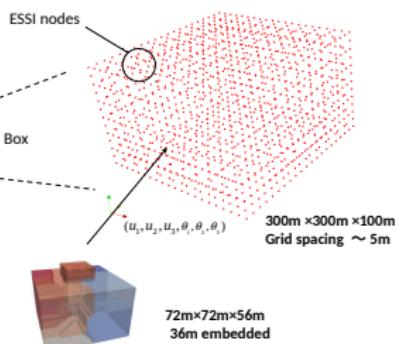
Seismic Motions

Free Field Motions for MS-ESSI



SW42ESSI

Use DRM (Bielak et al.)
to excite ESSI model



Seismic Energy Dissipation

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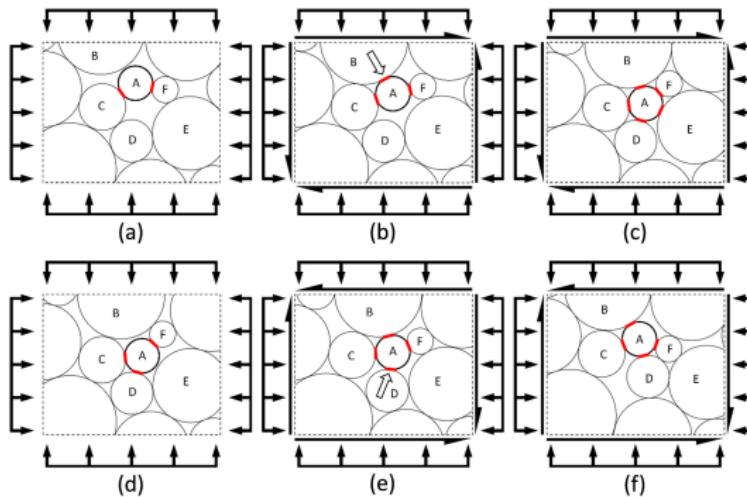
Flow of Seismic Energy

- ▶ Seismic energy input into the ESSI system
- ▶ Seismic energy dissipation outside of ESSI system
 - ▶ Wave reflections
 - ▶ Structural oscillations, wave radiation
- ▶ Seismic energy dissipation within ESSI system
 - ▶ Viscous effects (soil, fluid containers...)
 - ▶ Inelastic effects (soil, concrete, contacts, dissipators...)
- ▶ Numerical energy dissipation and production

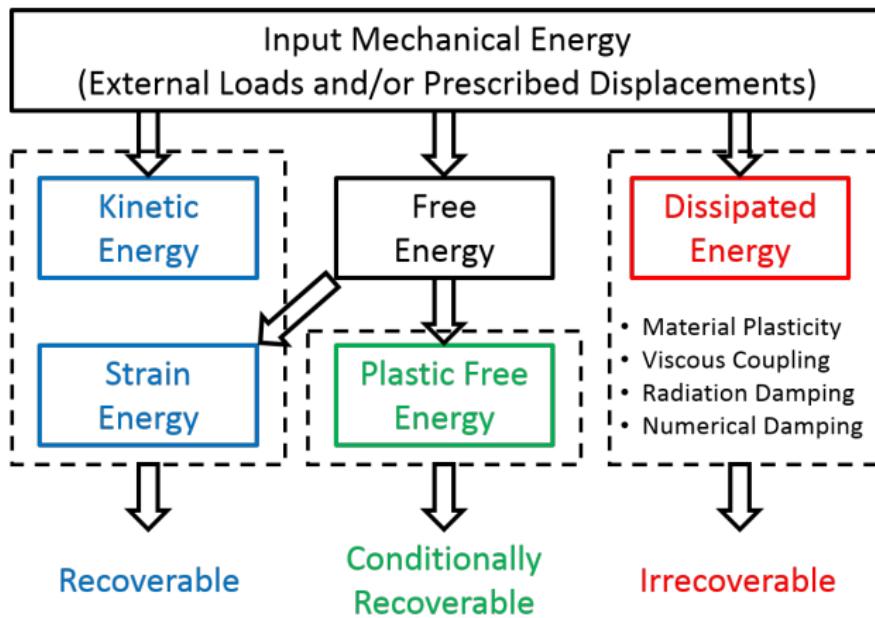
Seismic Energy Dissipation

Plastic Free Energy

- ▶ Multi-scale effect of particle interlocking/rearrangement
- ▶ Strain energy on particle level



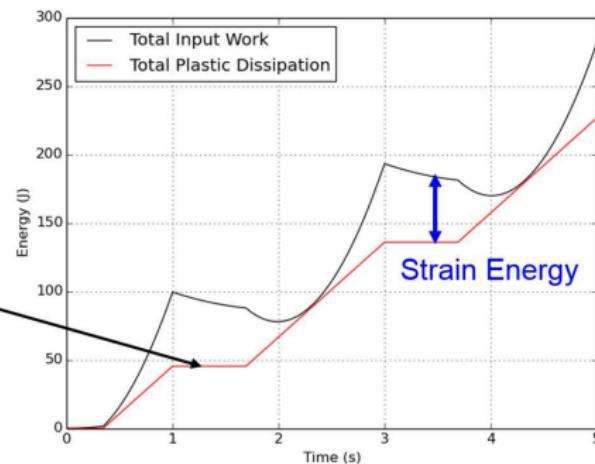
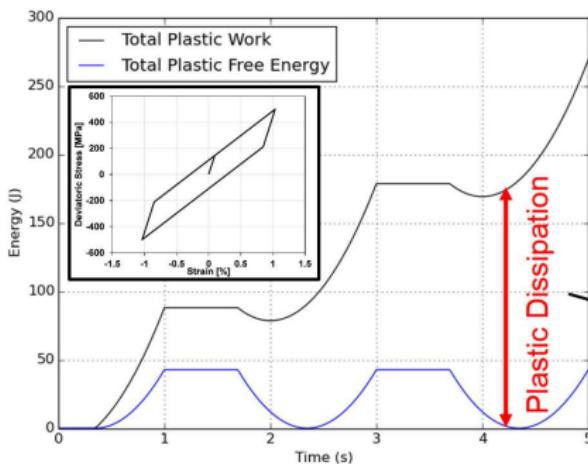
Energy Transformation in Elastic-Plastic Material



Seismic Energy Dissipation

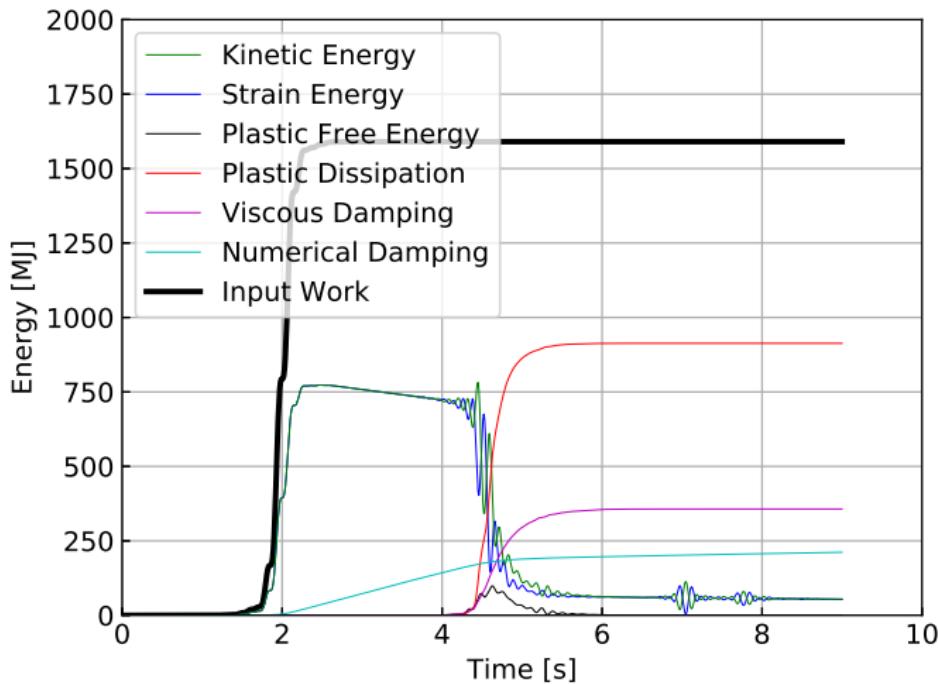
Energy Dissipation from Inelasticity

- ▶ Plastic work is **NOT** plastic dissipation
- ▶ Plastic work = Plastic Dissipation + Plastic Free Energy



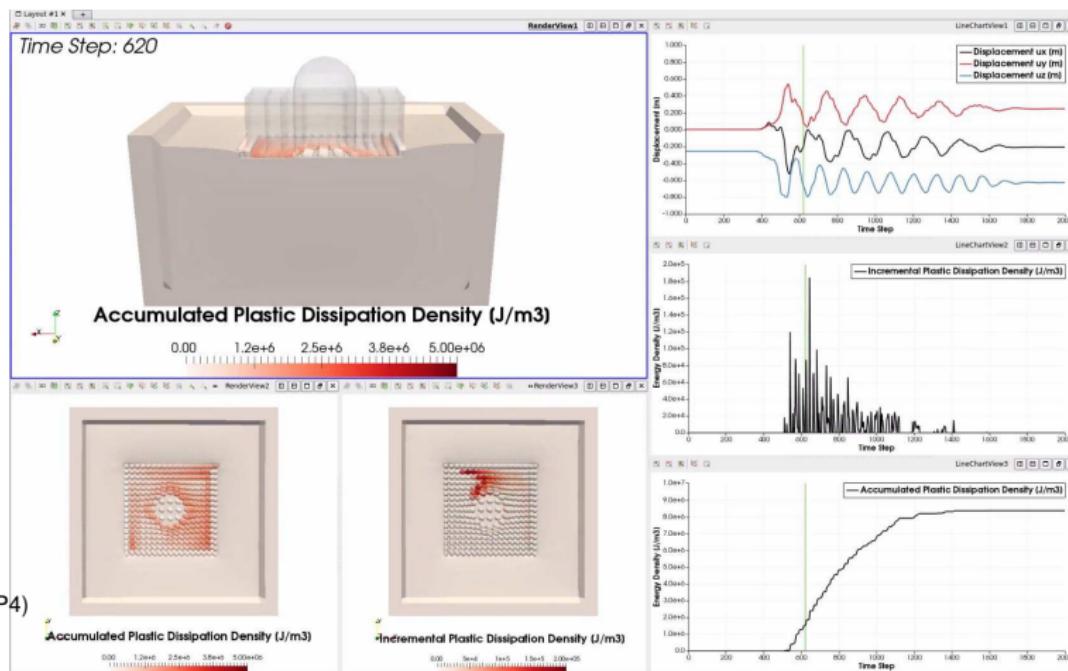
Seismic Energy Dissipation

Energy Dissipation Control



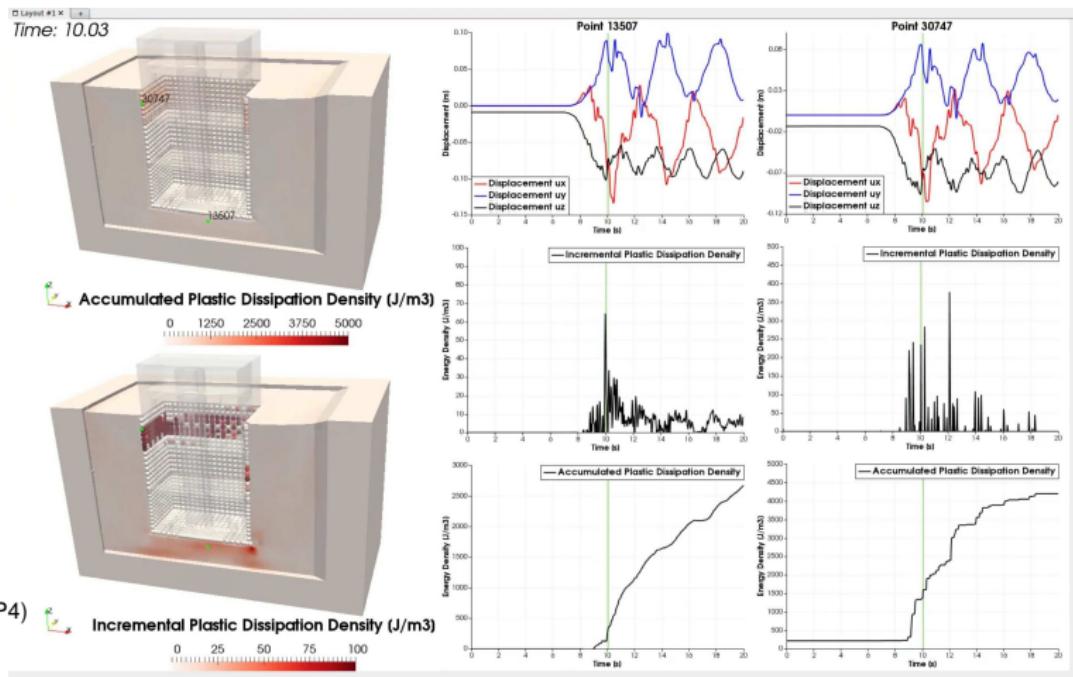
Seismic Energy Dissipation

Energy Dissipation for a NPP



Seismic Energy Dissipation

Energy Dissipation for a SMR



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- ▶ Seismic wave fields, stress test motions, 3C/6C, $3 \times 1C$ and 1C, and regional scale free field models for ESSI behavior
- ▶ Inelastic ESSI behavior and energy dissipation for soil, contact and structure
- ▶ MS-ESSI Simulator: <http://ms-essi.info>
- ▶ Funding from and collaboration with the US-DOE, US-NRC, CNSC-CCSN, US-NSF and UN-IAEA is greatly appreciated

US-DOE: ESSI of Nuclear Installations

The MS-ESSI Simulator: <http://ms-essi.info>

High Quality Validation test (UNR/UCD/LBNL)

