

# 3D Nonlinear Earthquake Soil Structure Interactions for Nuclear Installations

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# Outline

Introduction

Modeling and Simulation  
Seismic Motions  
Inelasticity

Summary

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Modeling and Simulation

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# Motivation

- ▶ Improve safety and economy of infrastructure objects
- ▶ Improve numerical modeling and simulation for infrastructure objects
- ▶ Quality assurance, verification & validation
- ▶ Selected level of sophistication numerical models to analyze earthquake soil structure interaction (ESSI)
- ▶ Modeling uncertainties, seismic motions: 1C, 3C, 6C; Inelasticity vs Elasticity; etc.)
- ▶ Parametric uncertainty,  $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$
- ▶ Practical numerical modeling and simulation system, MS-ESSI Simulator → <http://ms-essi.info>

# Flow of Seismic Energy

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

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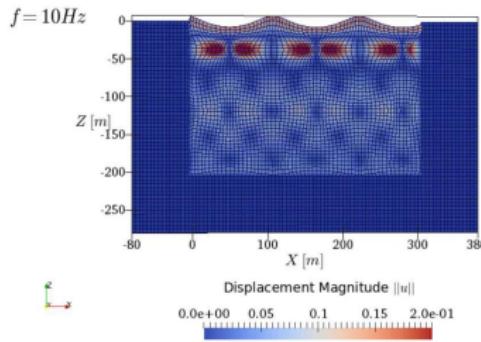
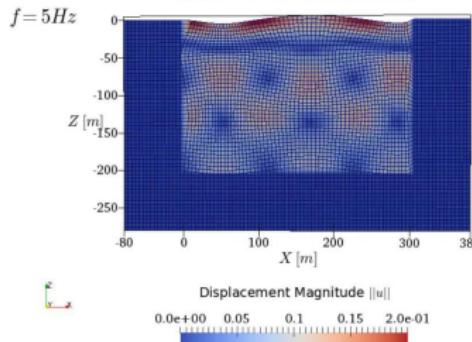
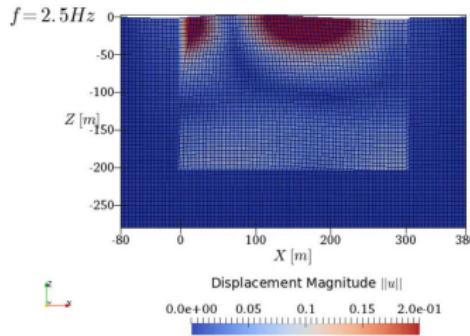
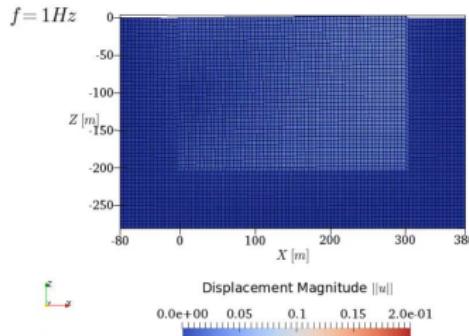
## Seismic Motions

# Seismic Motions

- ▶ Classical motions: 1C or  $3 \times 1C$
- ▶ Stress test motions
  - ▶ 3D - 6C, Thomson, Haskell solution for plane harmonic waves in layered media
  - ▶ 3D -  $3 \times 1C$
  - ▶ 3D - 1C
  - ▶ 1D - 1C
- ▶ Regional scale, site specific seismic motions, 6C, using SW4 program, courtesy of Dr. Rodgers, Dr. Pitarka and Dr. Petersson (LLNL)
- ▶ Knowledge of geology is important!

## Seismic Motions

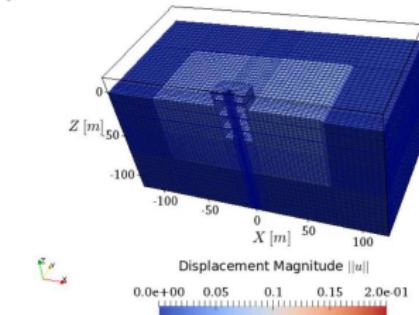
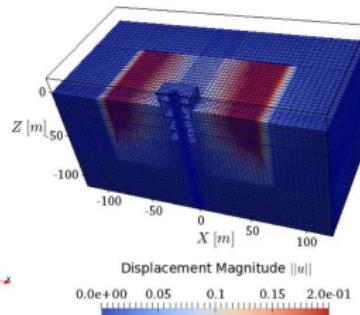
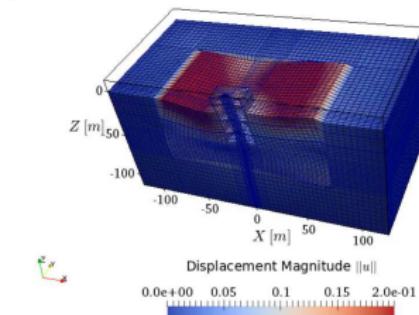
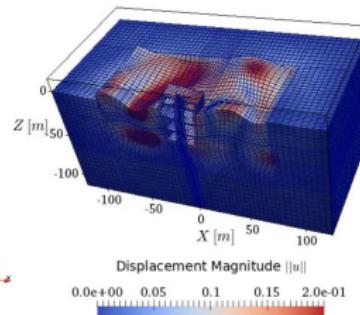
# Free Field, Variation in Input Frequency, $\theta = 60^\circ$



(MP4)



## Seismic Motions

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

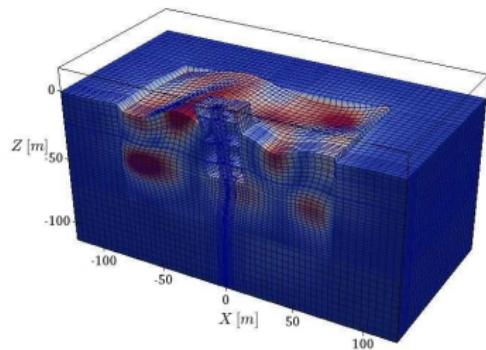
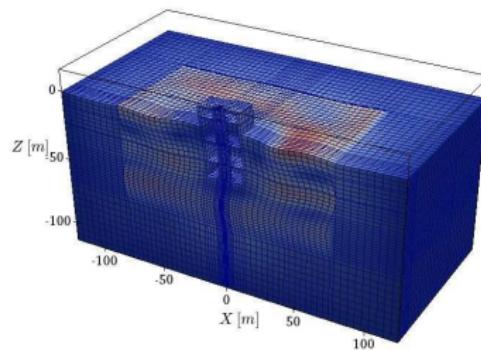
(MP4)



## Seismic Motions

ESSI, 3C vs  $3 \times 1C$ 

3C

 $3 \times 1C$ 

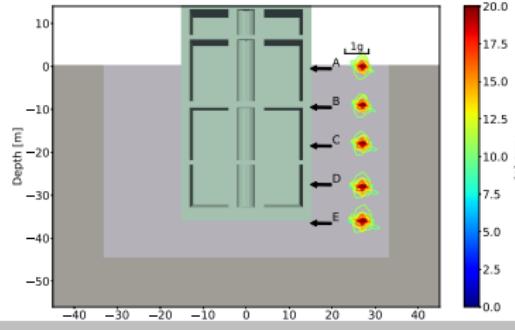
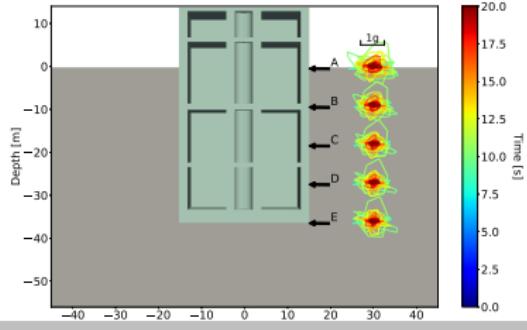
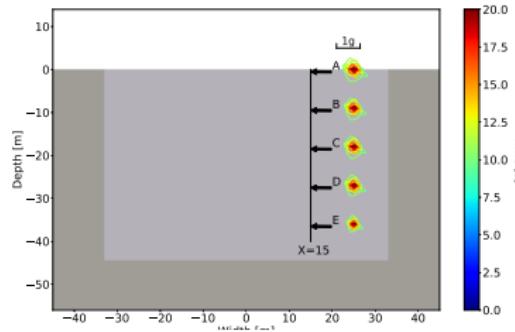
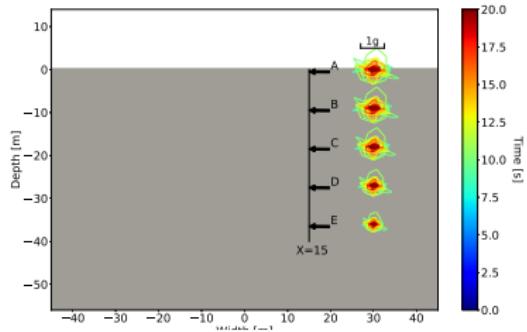
(MP4)

# Inelastic Modeling

- ▶ Soil elastic-plastic
  - ▶ Dry, single phase
  - ▶ Unsaturated (partially saturated)
  - ▶ Fully saturated
- ▶ Contact, inelastic, soil/rock – foundation
  - ▶ Dry, single phase, normal/axial (hard and soft, gap open/close), friction/shear (inelastic)
  - ▶ Fully saturated, suction and excess pressure (dynamic buoyant force)
- ▶ Structural inelasticity/damage
  - ▶ Nonlinear/inelastic fiber beam (concrete, steel)
  - ▶ Nonlinear/inelastic wall/membrane element (concrete, steel)

## Inelasticity

## Accelerations Along Depth

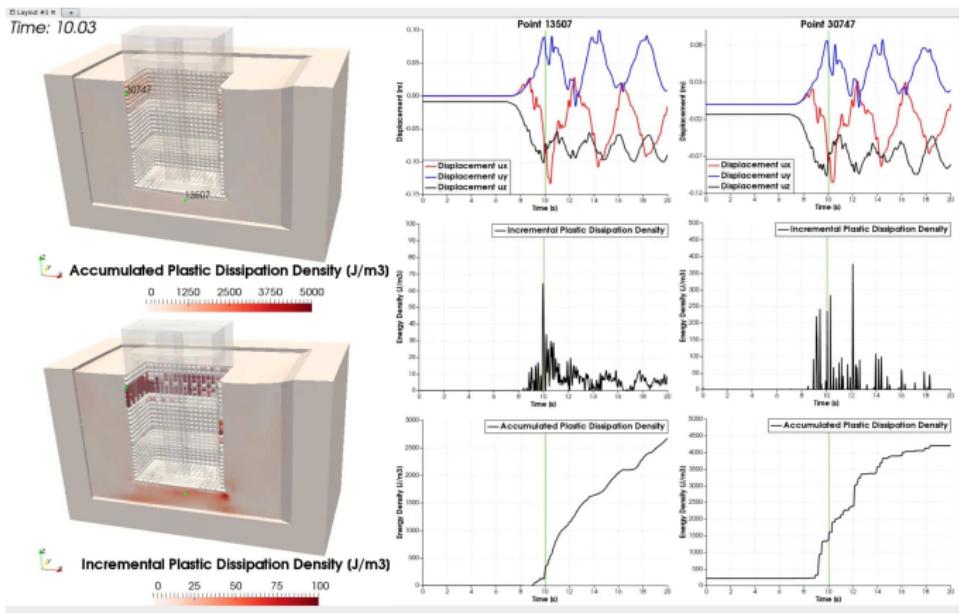


Nonlinear  
site  
effects

Nonlinear  
ESSI  
effects

## Inelasticity

# Seismic Energy Dissipation



(MP4)

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- ▶ Select level of sophistication, quality assured, modeling and simulation
- ▶ Seismic wave fields: 1C,  $3 \times 1C$ , 3C/6C
- ▶ Inelastic ESSI behavior: soil, contact and structure
- ▶ Numerical modeling and simulation used to predict and inform, rather than (force) fit
- ▶ MS-ESSI Simulator, docs, examples, executables:
  - ▶ <http://ms-essi.info>
  - ▶ <http://aws.amazon.com>
- ▶ 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)

