ESSI Simulator Program, Current Status

N. Tafazzoli, F. Pisanò, J. A. Abbel M., B. Kamrani,
C.-G. Jeong, B. Aldridge, R. Roche, A. Kammerer, and

B. Jeremić,

Professor, University of California, Davis, CA
Faculty Scientist, Lawrence Berkeley National Laboratory, Berkeley, CA

SMiRT 22
San Francisco, August 2013

Outline

The Problem

- Modeling and simulation of a realistic nonlinear seismic response of Nuclear Power Plants
- 3D, inclined seismic motions consisting of body and surface waves
- Inelastic (elastic, damage, plastic) behavior of materials and components: soil, rock, contacts, seismic isolators, concrete, steel, etc.
- Full coupling of pore fluids (in soil and rock and contacts) with soil/rock skeleton
- Uncertainty in seismic sources, path, soil/rock and structural response

Proposed Solution

- **Physics based modeling and simulation** (reduce **modeling uncertainty**) of seismic behavior of soil-structure systems (NPP structures, components and systems)
- Development and use of **high fidelity** time domain, nonlinear numerical models, in **deterministic** and **probabilistic** spaces
- Accurate following of the **flow of seismic energy** (input and dissipation) within soil-structure NPP system

High Fidelity Modeling of Energy Flow

- Energy influx, body and surface waves, 3D, inclined
- Mechanical dissipation outside of SSI domain:
  - Radiation of reflected waves
  - Radiation of oscillating SSI system
- Mechanical dissipation inside SSI domain:
  - Plasticity of soil/rock subdomain
  - Plasticity of foundation – soil/rock interface
  - Viscous coupling of porous solid with pore fluid (air, water)
  - Plasticity/damage of the structure
  - Viscous coupling of structure/foundation with fluids
- Numerical energy dissipation/production

Outline

ESSI Project

- Development of the ESSI Simulator System for Hi-Fi modeling and simulation of non-linear earthquake soil/rock structure interaction problems:
  - **ESSI-Program** is a 3D, nonlinear, time domain, high performance, parallel finite element program specifically developed for high fidelity modeling and simulation of Earthquake Soil/Rock Structure Interaction problems for NPPs
  - **ESSI-Computer**
  - **ESSI-Notes**
- A UCD/LBNL project with funding from and collaboration with the US-NRC, CNSC, US-NSF, US-DOE, LLNL, INL, AREVA NP GmbH, Shimizu Corp. etc.

Outline

Pisanò Elastic Plastic Material Model

- 3D incremental elastic-plastic material model that can be calibrated from G/G_{max} and damping curve data
- Elasticity: linear or nonlinear
- Yield surface, Drucker-Prager cone, collapsed (limit analysis, vanishing elastic regions) to cylinder (von Mises), with conical bounding surface
- Plastic flow and rotational kinematic hardening, similar to Manzari-Dafalias model (1997)
- Yield (loading-unloading) condition established using stress projection

Pisanò Model: Calibration for G/G_{max} and Damping

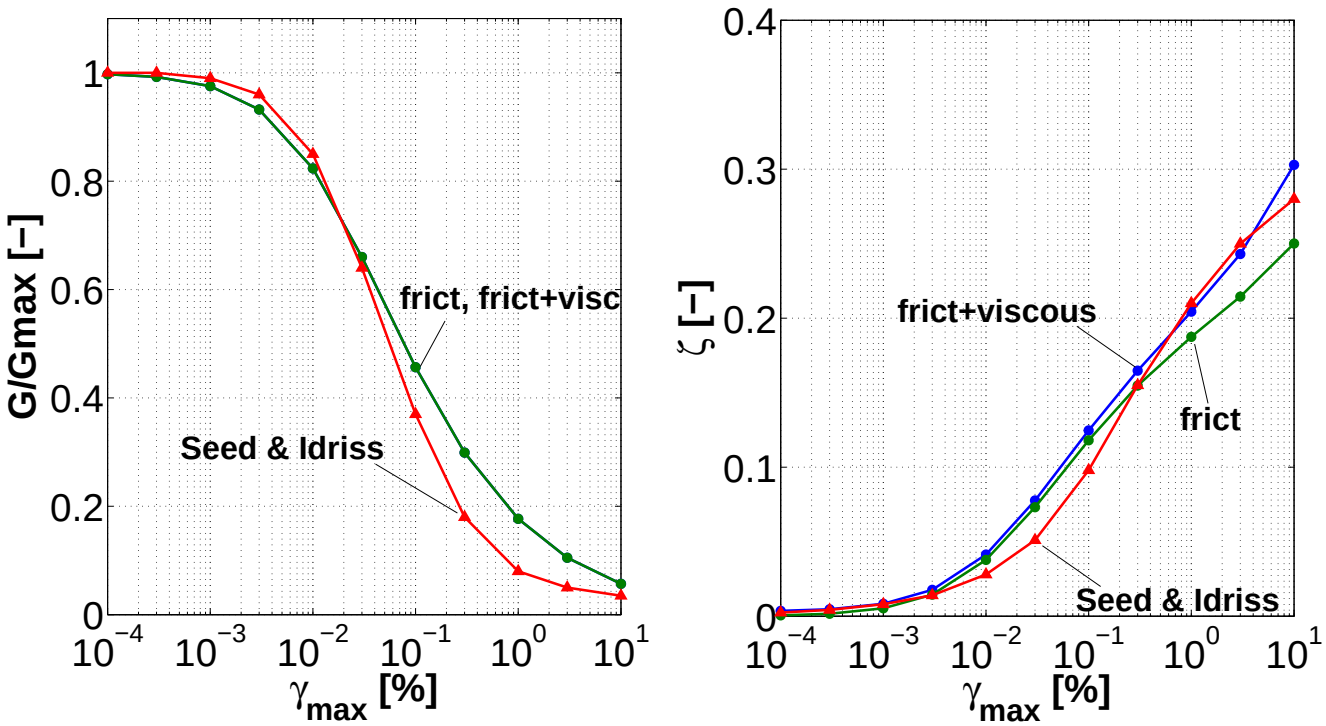
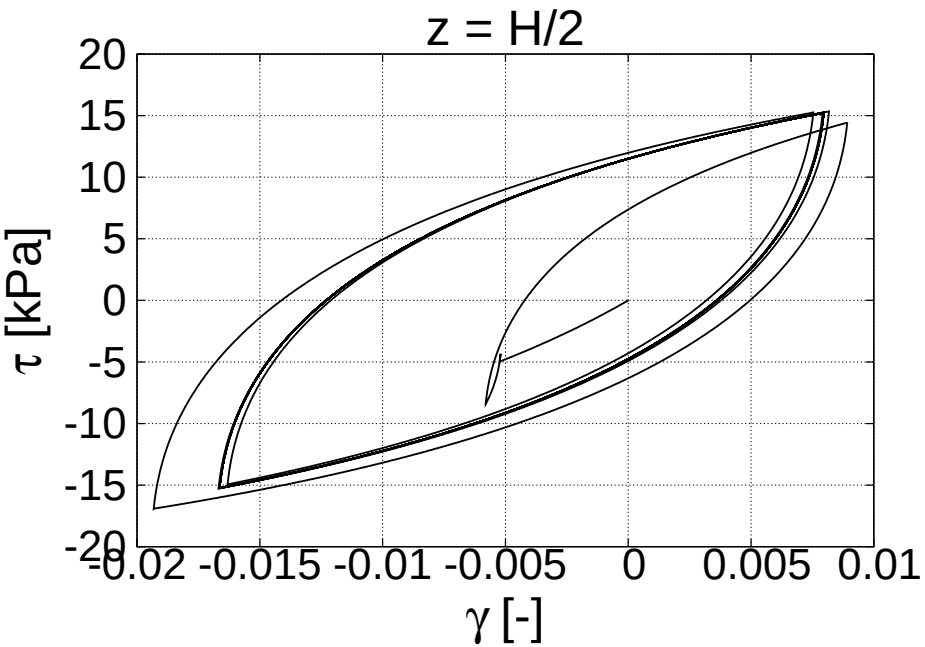


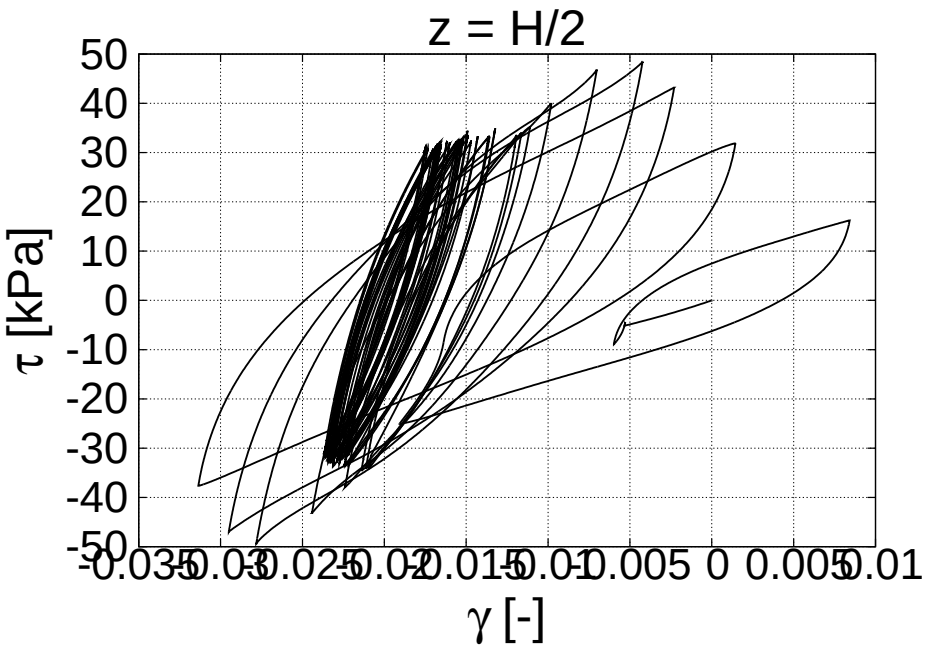
Figure: Comparison between experimental and simulated G/G_{max} and damping curves (p_0=100 kPa, T=2π s, ζ = 0.003, G_{max} = 4 MPa, ν=0.25, M=1.2, k_d=ξ=0, h=G_{max}/(15p_0), m=1)

Soil Volume Response

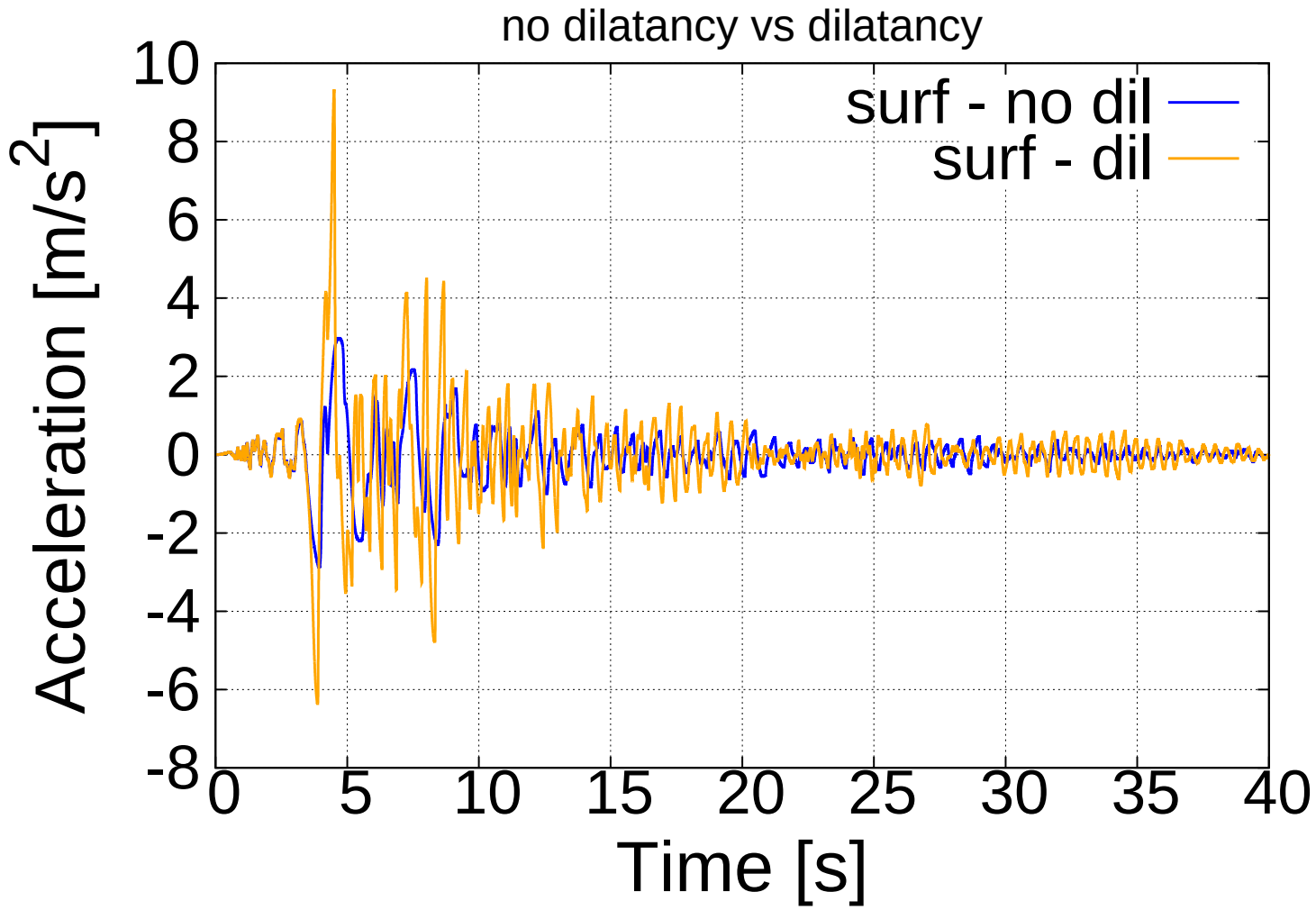
- Soil behavior is very much a function of volumetric response
- Dilative soils: increase volume due to shearing
- Compressive soils: decrease volume due to shearing
- Modulus reduction and damping curves do not provide volumetric data
- Soil volume change will affect response due to volume constraints

No Volume Change and Dilative Soil

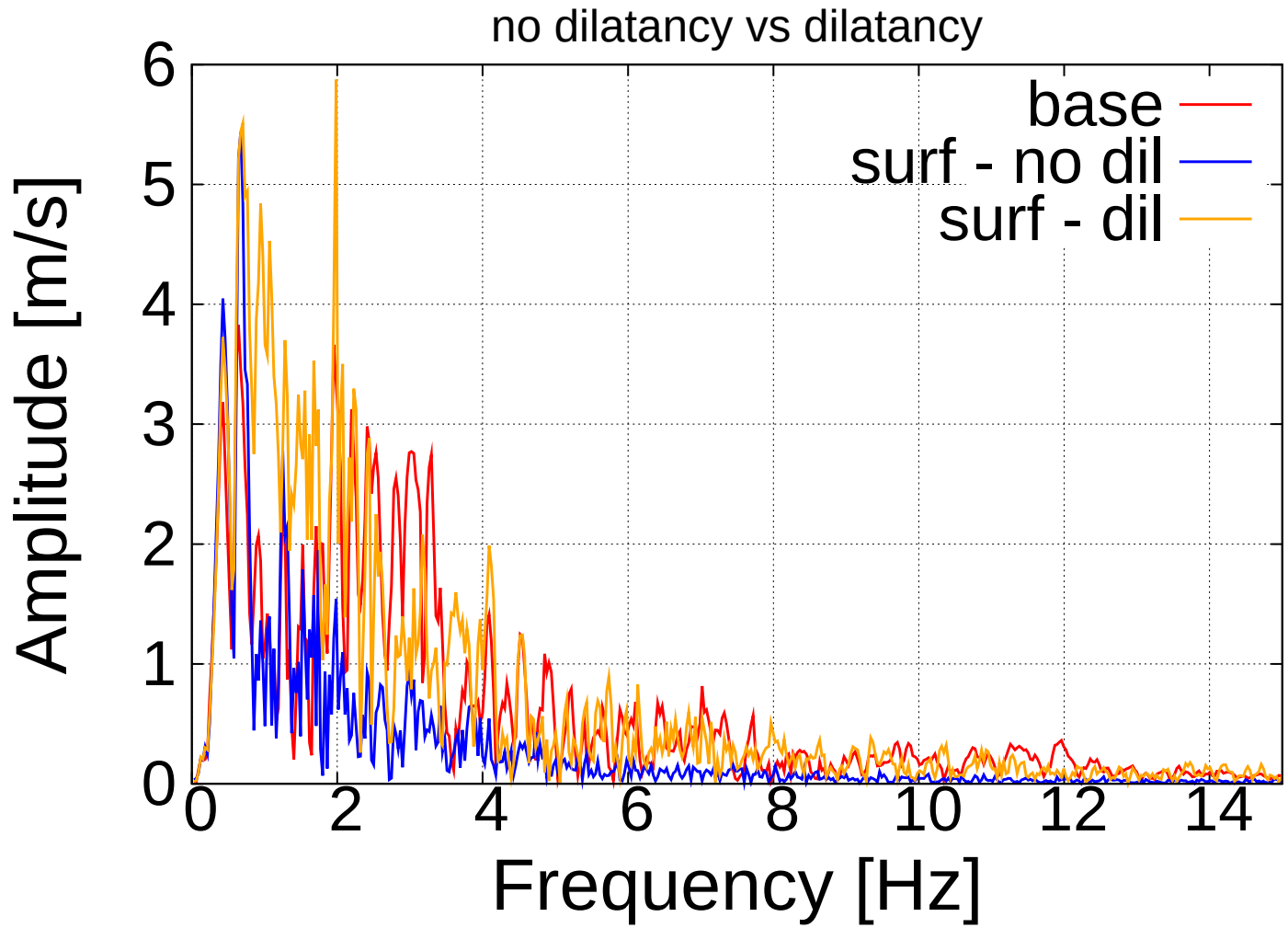




Northridge, No Volume Change and Dilative Soils



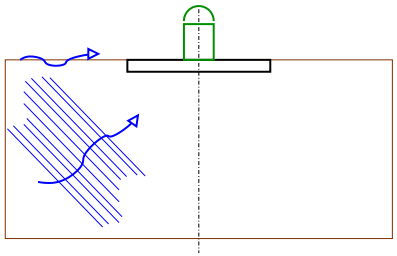
Northridge, No Volume Change and Dilative Soils

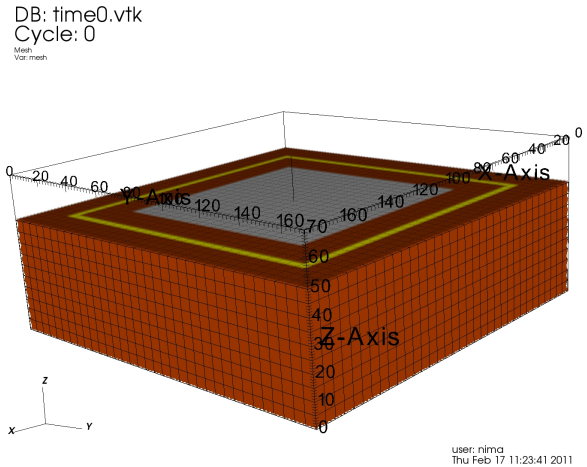


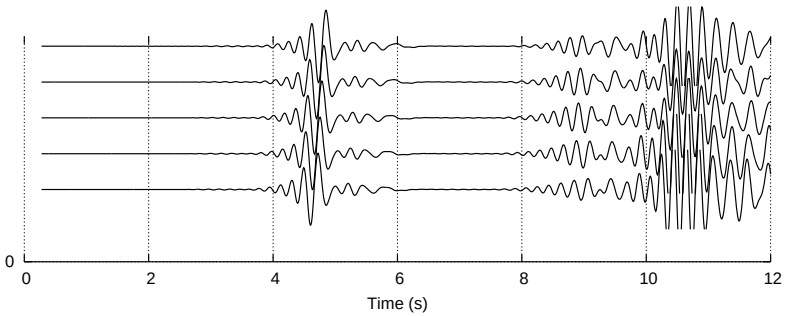
Outline

Nuclear Power Plant with Base Slip

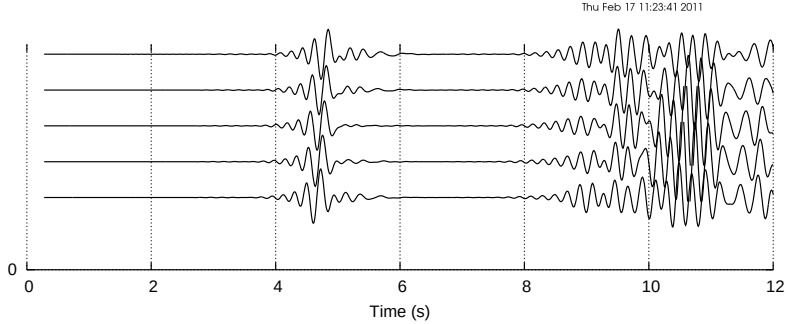
- Low friction zone between concrete foundation and soil/rock
- Inclined, 3D, body and surface, seismic wave field (wavelets: Ricker, Ormsby; real seismic, etc.)





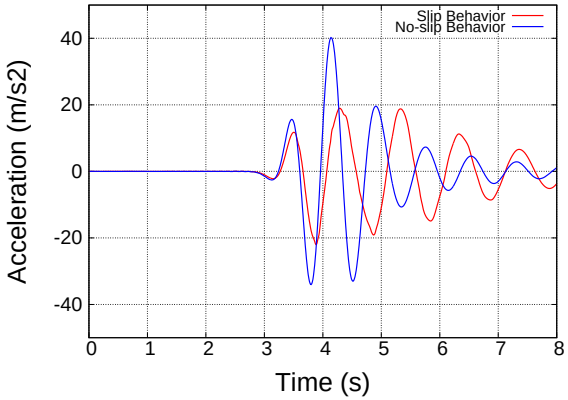


horizontal

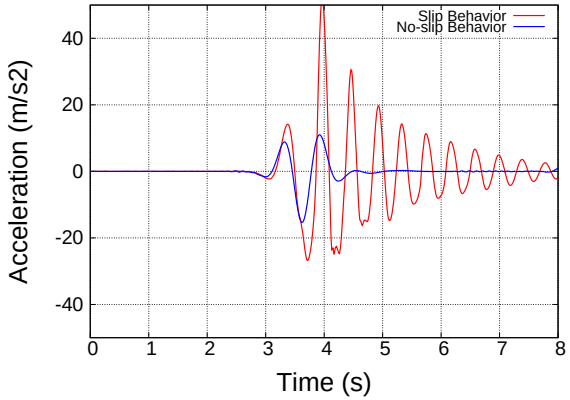


vertical

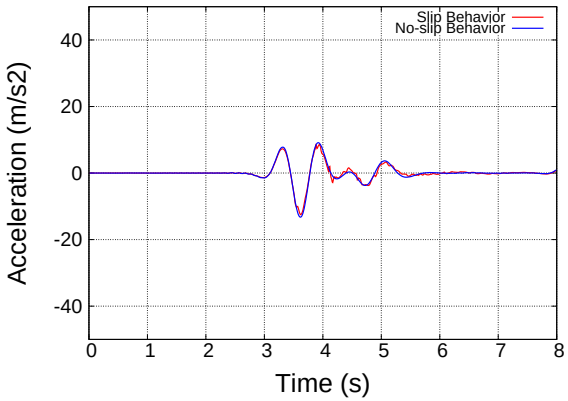
Acc. Response for a Full 3D (at 45°) Ricker Wavelet



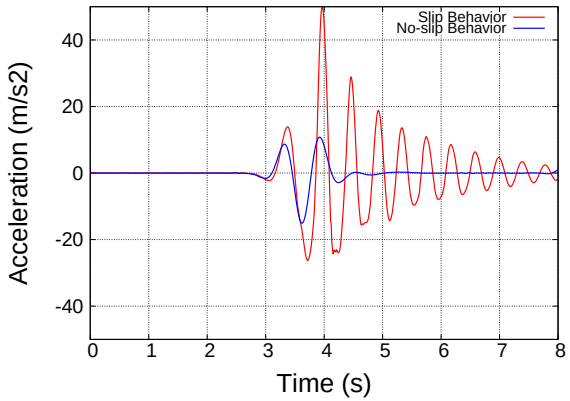
top X



top Z

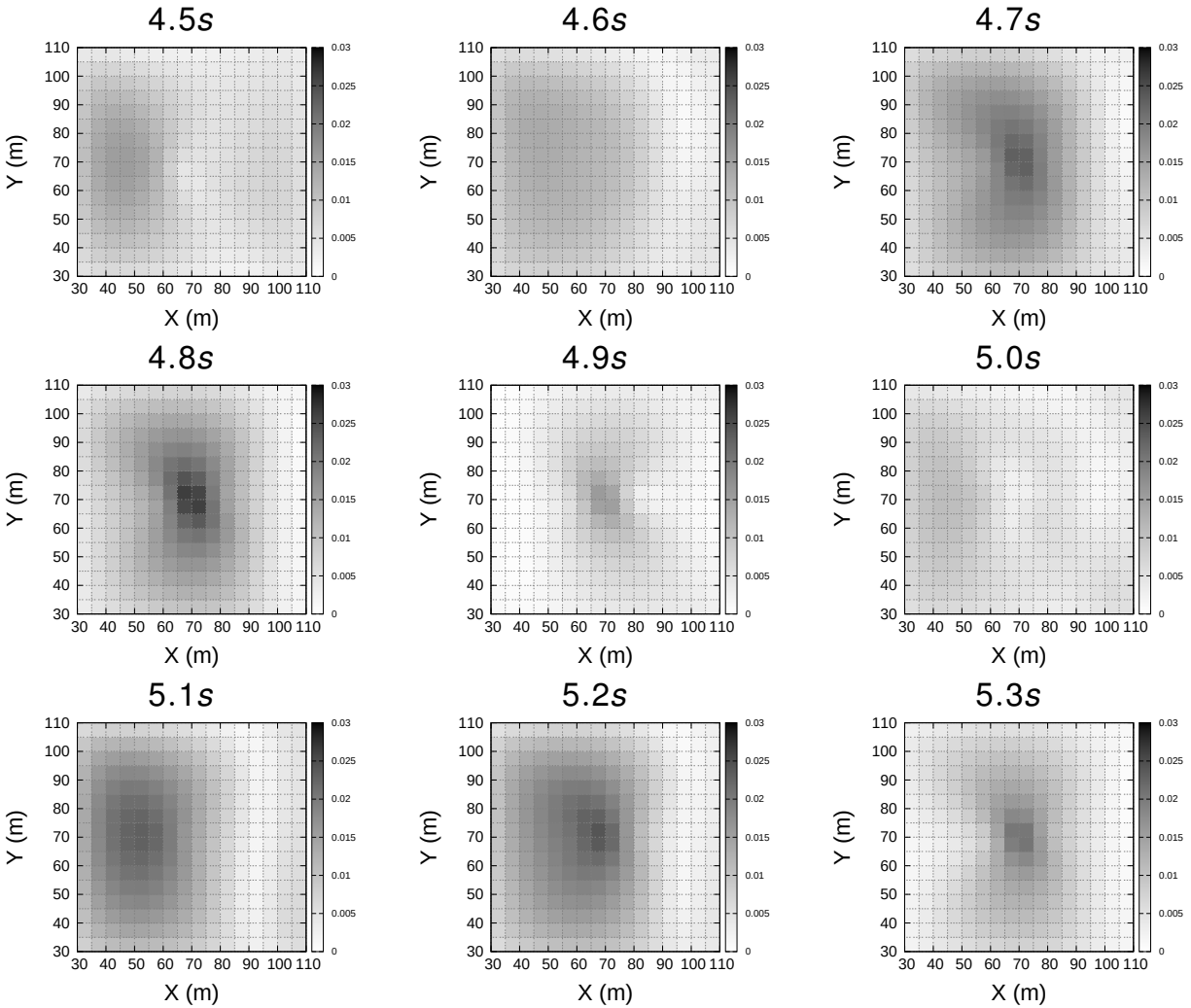


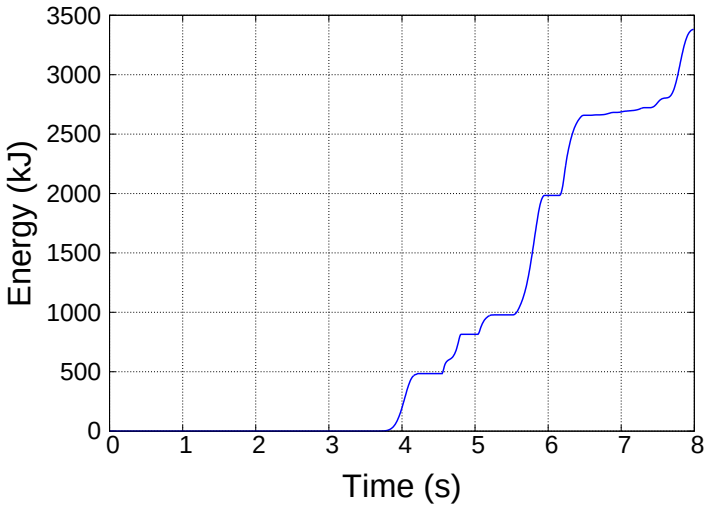
bottom X



bottom Z

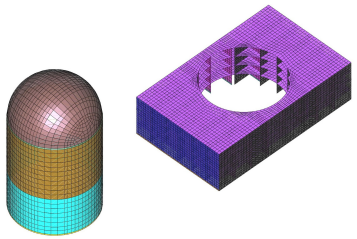
Slipping Response and Energy Dissipated (45° Ricker)

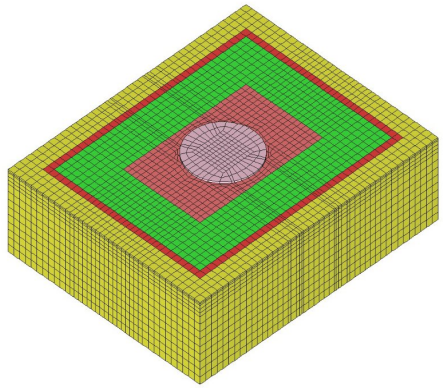


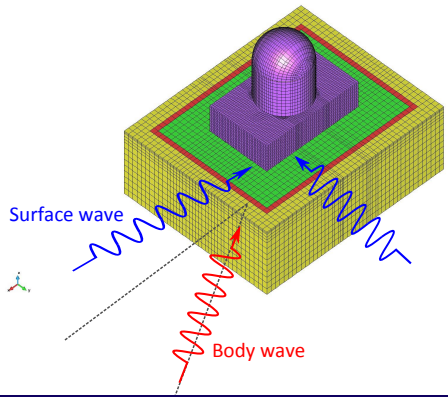


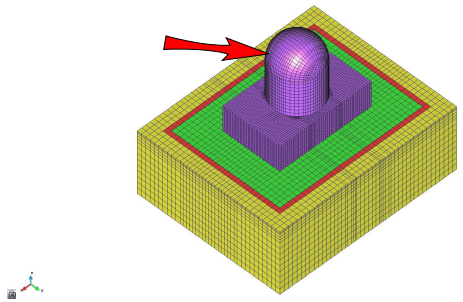
Current NPP Model(s)

- Inclined seismic waves
- Foundation slip/no-slip
- Dynamics of impact
- Isolators, dissipators
- Piles and pile groups
- Uncorrelated (incoherent) motions
- Saturated dense vs loose soil with buoyant forces









Summary

- Nonlinear Earthquake Soil/Rock Structure Interaction (ESSI) plays a decisive role in seismic performance of NPPs
- Nonlinear ESSI modeling and simulations has to be performed using high fidelity modeling and simulation tools
- High fidelity ESSI modeling and simulation tools require extensive verification and validation
- Risk informed decision making can/should only be done using such high fidelity modeling and simulation
- **ESSI Simulator Program** (system), is one such tool that is used for modeling, simulations, design and regulatory decision making
- Education and training of users (regulators, designers, owners/applicants) proves essential

Acknowledgement

- Funding from and collaboration with the US-NRC, CNSC, US-NSF, US-DOE, LLNL, INL, and collaboration with AREVA NP GmbH, Shimizu Corp., etc. is greatly appreciated,

- Collaborators, students: Mr. Abell, Mr. Jeong, Mr. Aldridge. Mr. Kamranimoghadam, Dr. Tafazzoli, Dr. Pisanò, Dr. Martinelli, Dr. Preisig, Dr. Chang, Prof. Sett (U. Bufallo), Prof. Taiebat (U. British Columbia), Prof. Yang (U. Alaska)