ESSI Simulator Program, Current Status

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Outline

Motivation

ESSI Simulator System

Modeling and Applications
  Pisanò Model, $G/G_{max}$ and Damping Curves
  Contact Base Isolation

Current Work

Summary
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
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Summary
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**

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Summary
Pisanò Elastic Plastic Material Model

- 3D incremental elastic-plastic material model that can be calibrated from $G/G_{\text{max}}$ 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 $G/G_{\text{max}}$ and Damping

Figure: Comparison between experimental and simulated $G/G_{\text{max}}$ and damping curves ($p_0=100$ kPa, $T=2\pi$ s, $\zeta = 0.003$, $G_{\text{max}} = 4$ MPa, $\nu=0.25$, $M=1.2$, $k_d=\xi=0$, $h=G_{\text{max}}/(15p_0)$, $m=1$)
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

\[ \tau \text{ [kPa]} \]

\[ \gamma \text{ [-]} \]

\[ z = \frac{H}{2} \]

\[ \tau \text{ [kPa]} \]

\[ \gamma \text{ [-]} \]
Northridge, No Volume Change and Dilative Soils

![Graph showing acceleration vs time for no dilatancy and dilatancy cases.](image-url)
Northridge, No Volume Change and Dilative Soils

![Graph showing amplitude vs frequency for different conditions: base, surf - no dil, surf - dil.](image-url)
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Summary
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.)
Acc. Response for a Full 3D (at 45°) Ricker Wavelet

Contact Base Isolation

Jeremić

ESSI Simulator Program, Current Status
Slipping Response and Energy Dissipated (45° Ricker)

ESSI Simulator System

Modeling and Applications

Current Work

Summary

Contact Base Isolation

 Jeremić

ESSI Simulator Program, Current Status
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
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