Modeling and Simulation of Earthquake Soil Structure Interaction for Nuclear Installations

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Outline

Introduction
  Motivation

Modeling and Simulation
  MS-ESSI/Real-ESSI Simulator System
  Illustrative Examples

Summary
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Improve modeling and simulation for infrastructure objects

Use of numerical models to analyze statics and dynamics of soil/rock-structure systems

Reduction of modeling uncertainty

Desired level of sophistication (high ↔ low) analysis

Follow the flow, input and dissipation, of seismic energy,

Practical system for modeling and simulation of Earthquakes, Soils, Structures and their Interaction,

Real-ESSI/MS-ESSI:

http://ms-essi.info/   http://real-essi.info/
Predictive Capabilities

- Prediction under Uncertainty: use of computational model to predict the state of SSI system under conditions for which the computational model has not been validated.

- Verification: provides evidence that the model is solved correctly. Mathematics issue.

- Validation: provides evidence that the correct model is solved. Physics issue.

- Modeling and parametric uncertainties are always present, need to be addressed

- Goal: Predict and Inform rather than (force) Fit
# Outline

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Real-ESSI/MS-ESSI
MS-ESSI / Real-ESSI

- A system for time domain, nonlinear/inelastic, deterministic or probabilistic, modeling and simulation of
  - statics and dynamics of soil,
  - statics and dynamics of rock,
  - statics and dynamics of structures,
  - statics of soil-structure systems, and
  - dynamics of earthquake-soil-structure system interaction.

- Design, linear elastic, load combinations, dimensioning
- Assessment, nonlinear/inelastic, safety margins
MS-ESSI / Real-ESSI Modeling Features

► Solid elements, dry, saturated, elastic, inelastic
► Structural elements, beams, shells, elastic, inelastic
► Contact elements, dry, coupled/saturated,
► Super element, stiffness and mass matrices
► Material models, soil, concrete, steel...
► Seismic input, 1C and 3C, deterministic or probabilistic
► Energy dissipation calculations
► Solid/Structure – Fluid interaction, full coupling
► All Modeling Features listed at http://ms-essi.info/
MS-ESSI / Real-ESSI Simulation Features

- Static loading stages
- Dynamic loading stages
- Restart, simulation tree
- Solution advancement methods/algorithms, on global and constitutive levels, with and without enforcing equilibrium
- High Performance Computing
  - Fine grained, template mataprograms, small matrix library
  - Coarse grained, distributed memory parallel
- All Simulation Features are listed at http://ms-essi.info/
MS-ESSI / Real-ESSI Model Development

- Pre-Processing, gmsh/gmESSI, translation (SASSI...)
- Choose level of sophistication, reduce modeling uncertainty
- Model developed in phases
- Verify model components
- Build confidence in inelastic modeling
MS-ESSI / Real-ESSI Modeling Phases
MS-ESSI / Real-ESSI Results Post Processing

- All output is saved (stress, strain, displacements, energy...)
- Time histories, scripts to plot or extract in preferred format
- 3D visualization, Paraview with pvESSI plugin
MS-ESSI / Real-ESSI Verification

- Implementation verification
- Solution verification for each component
  - Finite elements
  - Constitutive algorithms
  - Solution advancement, static and dynamic
- Error quantification for ranges of modeling parameters
- Automatic verification, a 13 hour process on multiple CPUs
MS-ESSI / Real-ESSI Validation

- Validation partially done, need for high quality data
- Validation, UNR soil box tests in the near future
  - Soil testing, range of strains, confinements, stress paths
  - Contact testing, axial, shear, soil-concrete, formed, poured
  - Wave propagation through soil, equivalent elastic and inelastic, 1C and 2C, dilatancy influence
- Inelastic structural behavior for beams, walls, plates, shells, use of already published high quality test data
- ESSI tests for a complete simplified SSI systems
MS-ESSI / Real-ESSI Training and Education

- Short Courses:
  - Online short course this fall/winter
  - Professional practice
  - Examples available in lecture notes, and documentation
  - MS-ESSI system, with examples on Amazon Web Services (AWS)

- Full lecture notes (2600+ pages) available online

- Up to date information on Real-ESSI/MS-ESSI at:
  http://ms-essi.info/ and http://real-essi.info/
MS-ESSI / Real-ESSI Core Functionality

- Introduction to inelastic/nonlinear analysis for practicing engineers
- Use of prescribed/required (low, medium, high) fidelity numerical models to analyze ESSI behavior
- Set of suggested modeling and simulation parameters
- Investigate sensitivity of response to model sophistication
- Investigate sensitivity of response to model parameters
MS-ESSI / Real-ESSI Core Functionality Components

- Structural elements: Truss, Beam, Shell, Super-Element
- Soil, solids: elastic, $G/G_{max}$
- Contacts: Bonded, Frictional, Gap open/close
- Loads: Static, Dynamic (earthquake, 1C or $3 \times 1C$), Restart
- Simulation: Explicit no-equilibrium, Implicit equilibrium,
- Core Functionality Application programs: APPS
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Seismic Motions

- Variation in inclination, frequency, energy, duration...
- Deterministic and Probabilistic
- Stress test the soil-structure system
Free Field, Variation in Input Frequency, $\theta = 60^\circ$
SMR ESSI, Variation in Input Frequency, $\theta = 60^\circ$
SMR ESSI, 3C vs 3×1C

(OGV)

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Free Field vs ESSI - Different Frequencies

Acceleration response - Surface center point A

(a) \( f = 1\text{Hz} \quad \theta = 60^\circ \)

(b) \( f = 5\text{Hz} \quad \theta = 60^\circ \)

(c) \( f = 10\text{Hz} \quad \theta = 60^\circ \)
SMR, Inelastic Response, Energy Dissipation

(MP4)
Wall, Regular and ASR Concrete

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Real-ESSI/MS-ESSI
Solid/Structure – Fluid Interaction

(MP4)

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Real-ESSI/MS-ESSI
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Summary

- Numerical modeling to predict and inform, rather than fit
- Inelastic/nonlinear analysis done in phases
- Education and Training is the key!

- **Real-ESSI/MS-ESSI Simulator System:**
  - [ms-essi.info](http://ms-essi.info/)
  - [real-essi.info](http://real-essi.info/)