

Earthquake Soil Structure Interaction Modeling and Simulation

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Outline

Motivation

Real ESSI Modeling and Simulation

Challenges

Motivation

- ▶ Improve seismic design of soil structure systems
- ▶ **Earthquake Soil Structure Interaction (ESSI)** in time and space, plays a major role in successes and failures
- ▶ Accurate following and directing (!) the flow of seismic energy in ESSI system to optimize for
 - ▶ Safety and
 - ▶ Economy
- ▶ Development of high fidelity numerical modeling and simulation tools to analyze realistic ESSI behavior:
Real ESSI simulator (aka: Стварно Лако, Muy Fácil, Molto Facile, 真简单, 本当に簡単, Πραγματικά Εύχολο, آسان واقعی, Très Facile, Вистински Лесно)

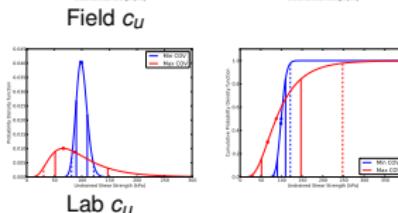
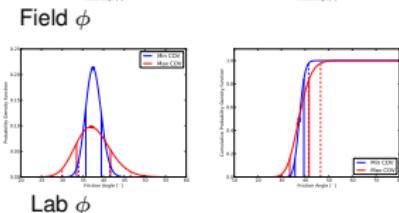
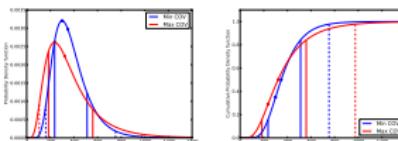
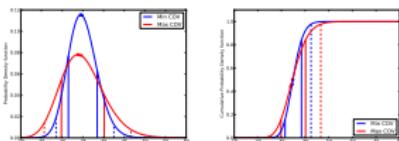
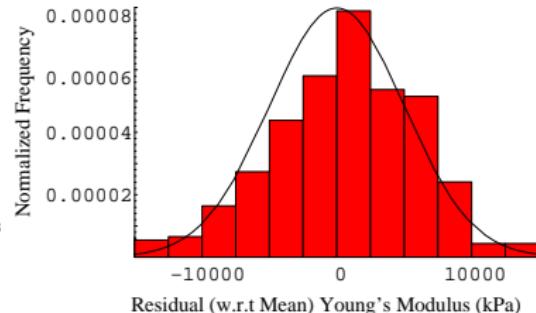
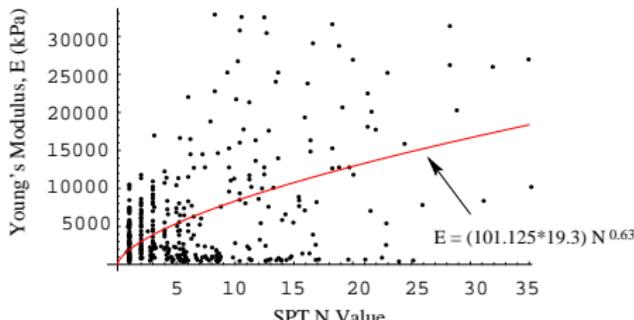
Predictive Capabilities

- ▶ Verification provides evidence that the model is solved correctly. Mathematics issue.
- ▶ Validation provides evidence that the correct model is solved. Physics issue.
- ▶ Prediction under Uncertainty (!): use of computational model to foretell the state of a physical system under consideration under conditions for which the computational model has not been validated.
- ▶ Predictive capabilities with low Kolmogorov Complexity
- ▶ Modeling and simulation goal
 - ▶ Inform, not fit
 - ▶ Predict, not diagnose

Reduction of Modeling Uncertainty

- ▶ Simplified modeling: Features (important ?) are neglected (6D ground motions, inelasticity)
- ▶ Modeling Uncertainty: unrealistic and unnecessary modeling simplifications
- ▶ Modeling simplifications are justifiable if one or two level higher sophistication model shows that features being simplified out are not important

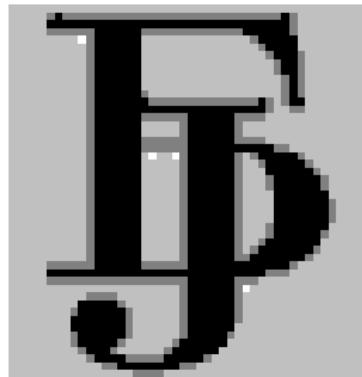
Uncertain Material and Loads



Real ESSI Modeling and Simulation Issues

- ▶ Seismic Motions: 6D, inclined, body and surface seismic waves (translations, rotations); Incoherency
- ▶ Inelastic material: soil, rock, concrete, steel; Contacts, foundation-soil, dry, saturated slip-gap; Nonlinear buoyant forces; Isolators, Dissipators
- ▶ Uncertain material and loading (above)
- ▶ Verification and Validation ⇒ Predictions
- ▶ High Fidelity Models ⇒ High Performance Computing
- ▶ Education

6D Seismic Motions and ESSI



large scale seismic field



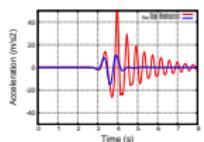
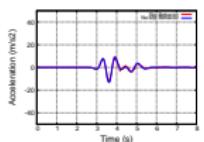
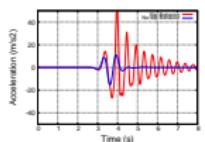
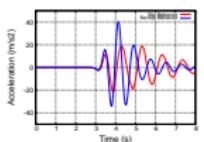
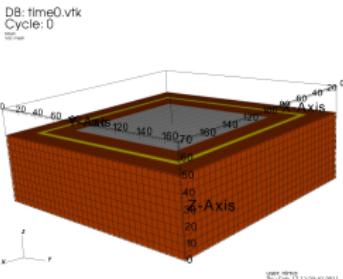
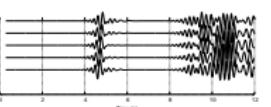
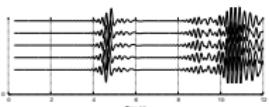
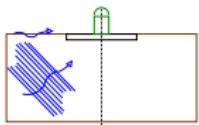
Free Field at location



ESSI for an NPP

Modeling and Simulation Issues

Inelastic Contact, Base Slip and Gap

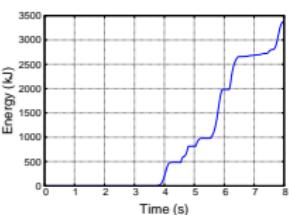
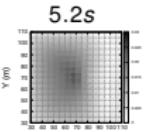
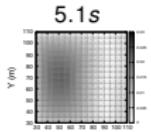
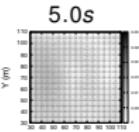
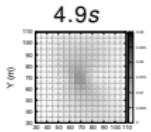
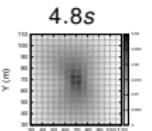
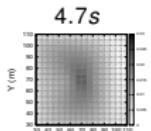
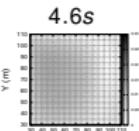
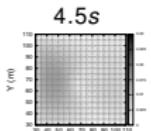


top X

top Z

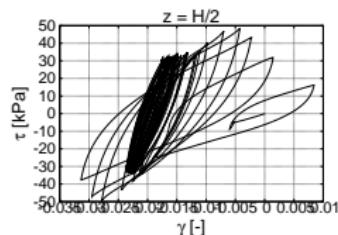
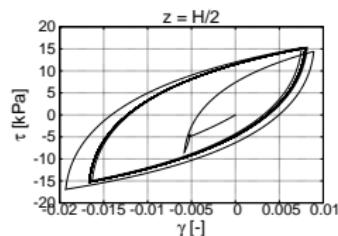
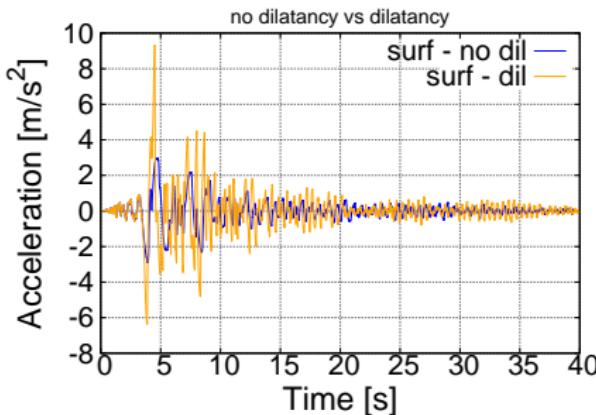
bottom X

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1D Wave (?!), No Volume Change and Dilative Soil

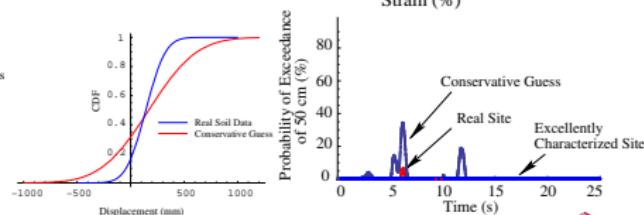
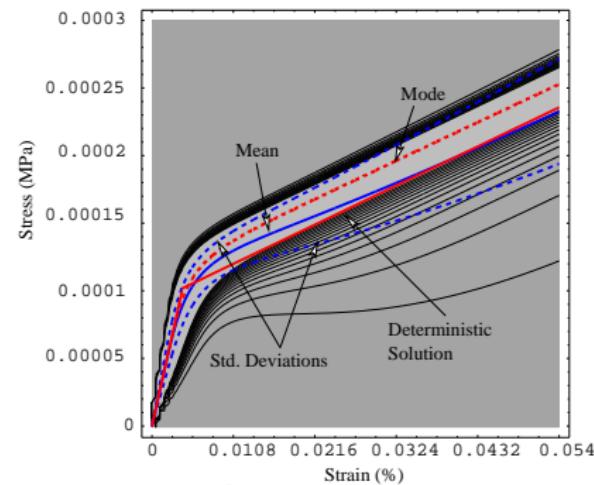
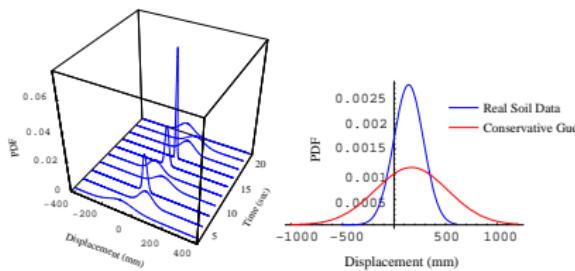
- ▶ Lack of soil volume change data for regular G/G_{max} and damping testing
- ▶ Significant influence on Seismic motion propagation



Modeling and Simulation Issues

Uncertain Inelastic Wave Propagation

- ▶ Probabilistic Elasto-Plasticity
- ▶ Stochastic Elastic-Plastic Finite Element Method



Challenges

- ▶ Most technical challenges are actively worked on (US-NRC, US-NSF, US-DOE, CNSC projects) and results are already available (6D motions, inelasticity, uncertainty, verification, validation, &c.)
- ▶ Validation needs more work (new US-DOE project!)
- ▶ Change state of practice
- ▶ Change state of research
- ▶ Education (designers, regulators, owners, &c.) is essential

Acknowledgement

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