Advancement in Earthquake Soil Structure Interaction (ESSI) Modeling and Simulation

Boris Jeremić

University of California, Davis
Lawrence Berkeley National Laboratory, Berkeley

A University of California Pacific Rim Forum
The Earthquake Resilience of Nuclear Facilities
Berkeley, CA. January 2017

Outline

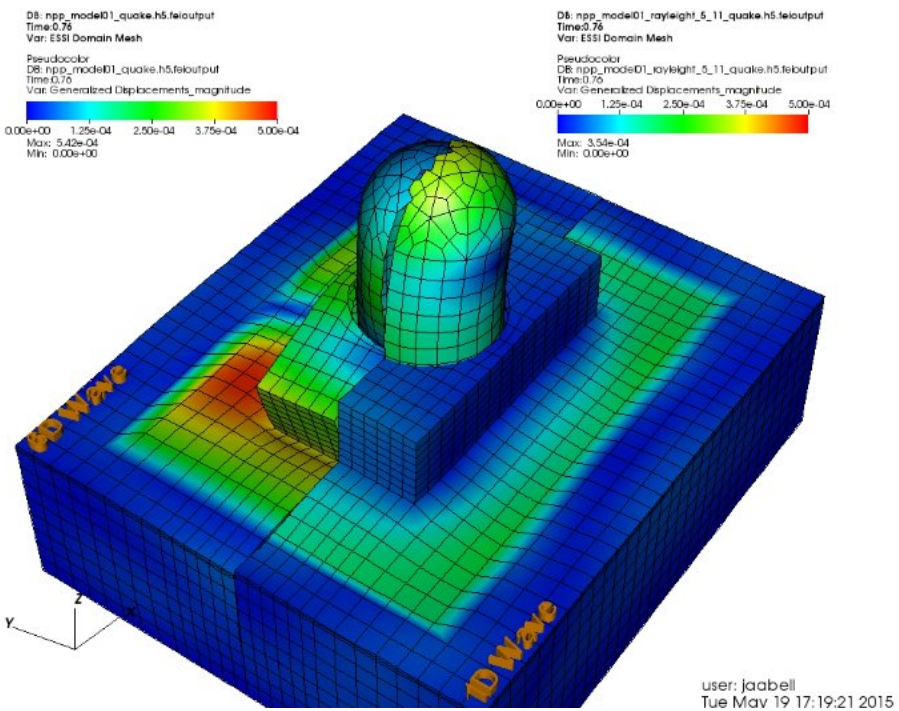
Motivation

- Improve seismic design of soil structure systems
- Earthquake Soil Structure Interaction (ESSI) in time and space, plays a decisive role in successes and failures
- Accurate following and directing (!) the flow of seismic energy in ESSI system to optimize for Safety and Economy
- Verification and Validation for Numerical Predictions
- Modeling and Parametric Uncertainties
- High fidelity numerical modeling and simulation tool to analyze realistic ESSI behavior: The **Real ESSI** Simulator
- DOE Project with Dr. McCallen and Dr. Buckle

Modeling Uncertainty

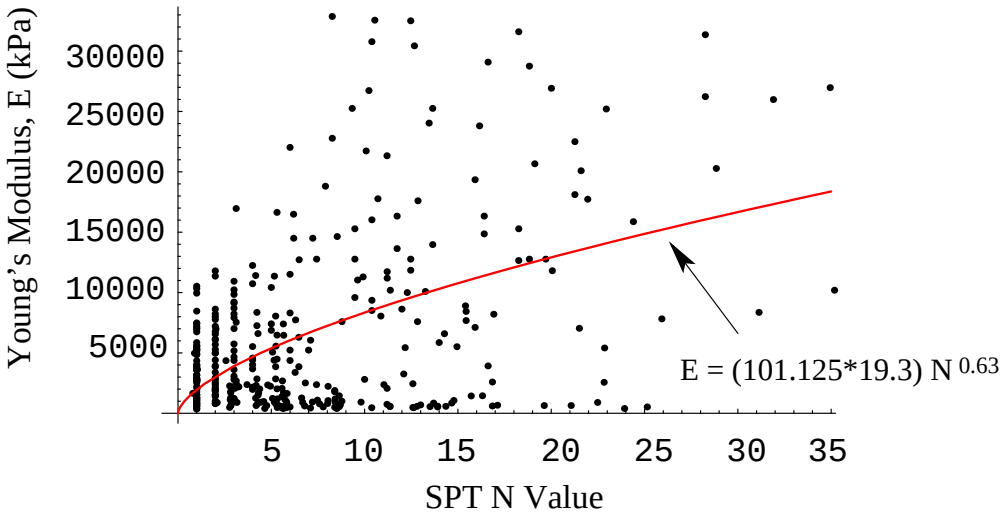
Modeling simplifications (unrealistic?) for important features

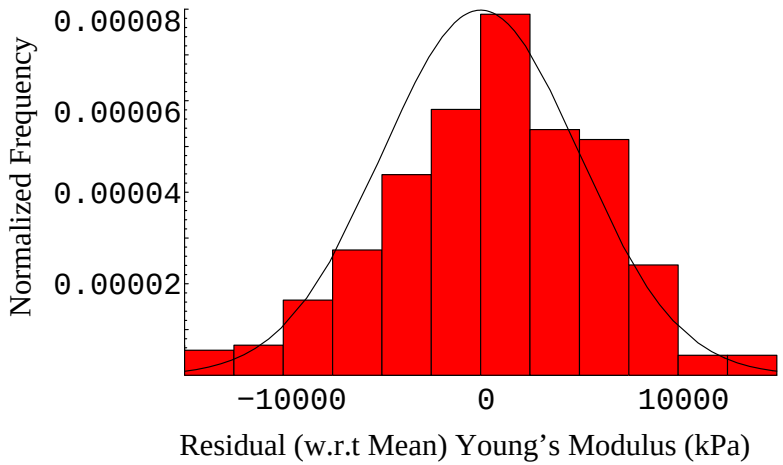
- Inelastic material: soil, rock, concrete, steel; Contacts, dry, saturated slip–gap; Nonlinear buoyant forces; Isolators, Dissipators
- Seismic Motions: 6D, inclined, body and surface waves



Parametric Uncertainty

Uncertain loads and material (shown uncertain elastic stiffness)





Predictive Capabilities

- Verification: provides evidence that the model is solved correctly. Mathematics issue. Well developed (for the Real ESSI Simulator).
- Validation: provides evidence that the correct model is solved. Physics issue. Work in progress, US-DOE project.
- Prediction: 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.
- Goal is to predict and inform, rather than fit!

Outline

Seismic Energy Input and Dissipation

- Seismic energy input, through a closed boundary
- Mechanical dissipation outside of SSI domain:
  - reflected wave radiation
  - SSI system oscillation radiation
- Mechanical dissipation/conversion inside SSI domain:
  - plasticity of soil and rock
  - plasticity/damage of structure/foundation
  - plasticity of contact (foundation – soil) zone
  - viscous coupling in soils and structure
- Numerical energy dissipation/production

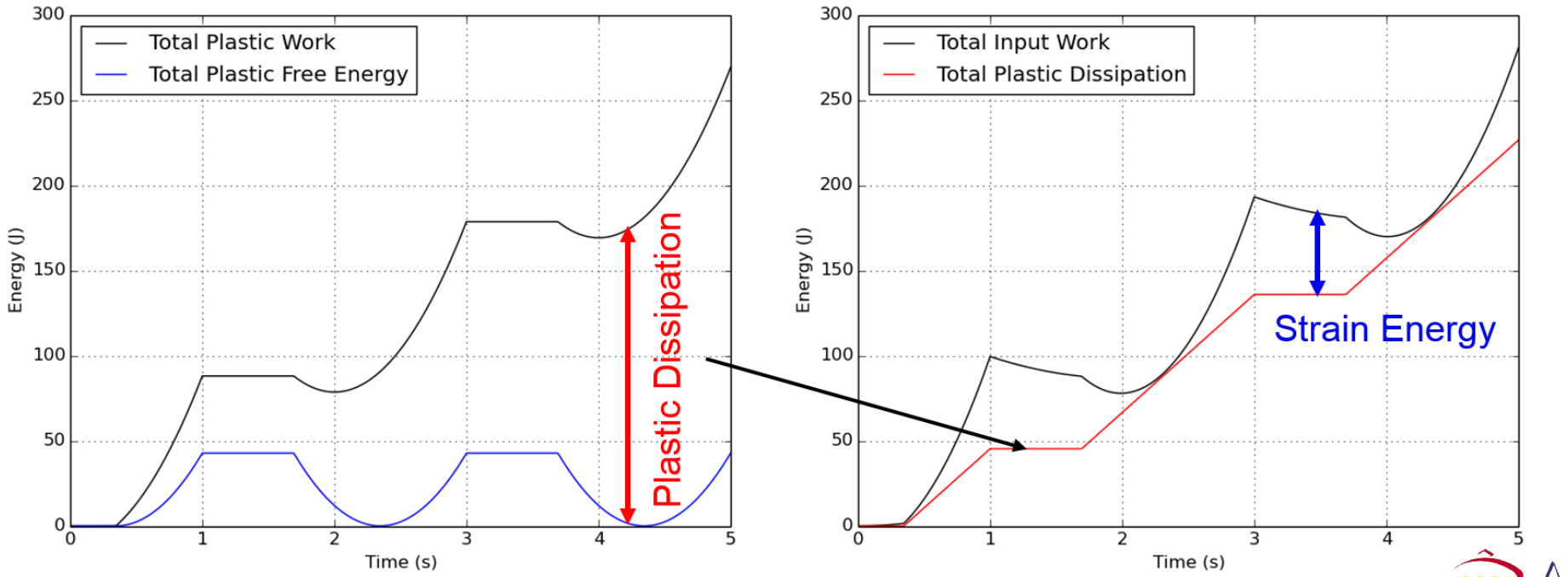
Material Energy Dissipation

- Free Energy
  - Based on the second law of thermodynamics
  - Decomposed into elastic and plastic components
- Plastic Free Energy
  - Particle rearrangement of granular/molecular assembly
  - Related to material internal variables (back stress etc.)
- Energy Dissipation due to Plasticity
  - Incremental dissipation should be nonnegative

Energy Dissipation on Material Level

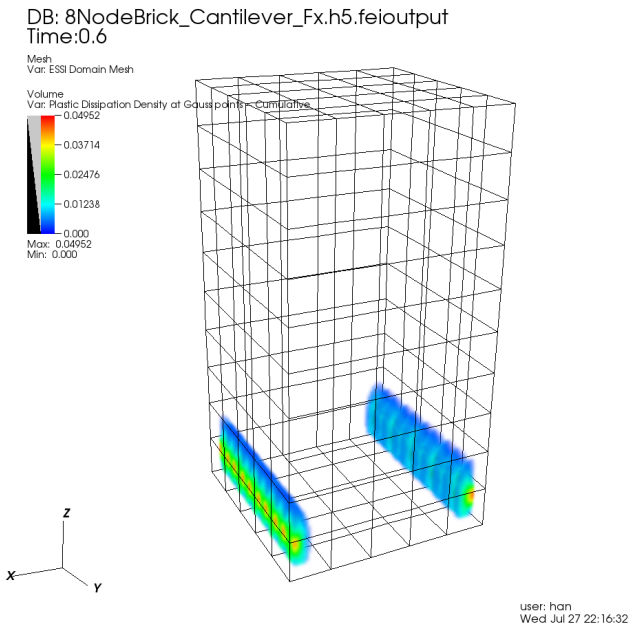
Single elasto-plastic element under cyclic shear loading

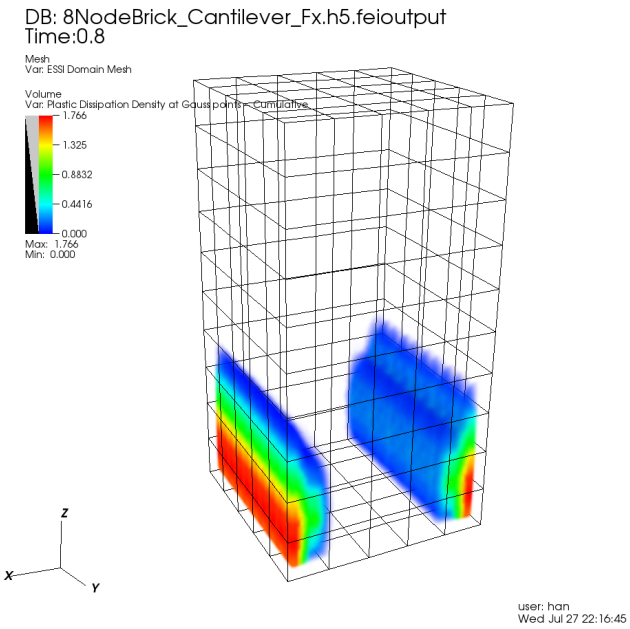
- Significant difference between plastic work and dissipation
- Plastic work can decrease, however, dissipation always increases

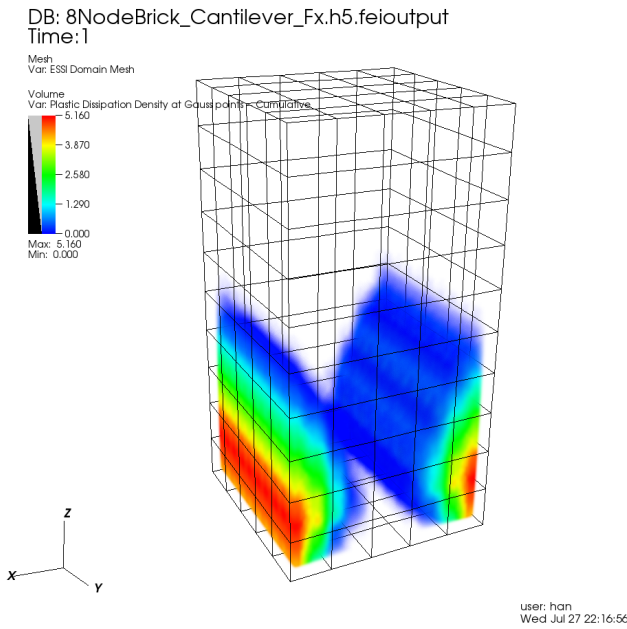


Evolution of Energy Dissipation

Short cantilever under shear/bending loading

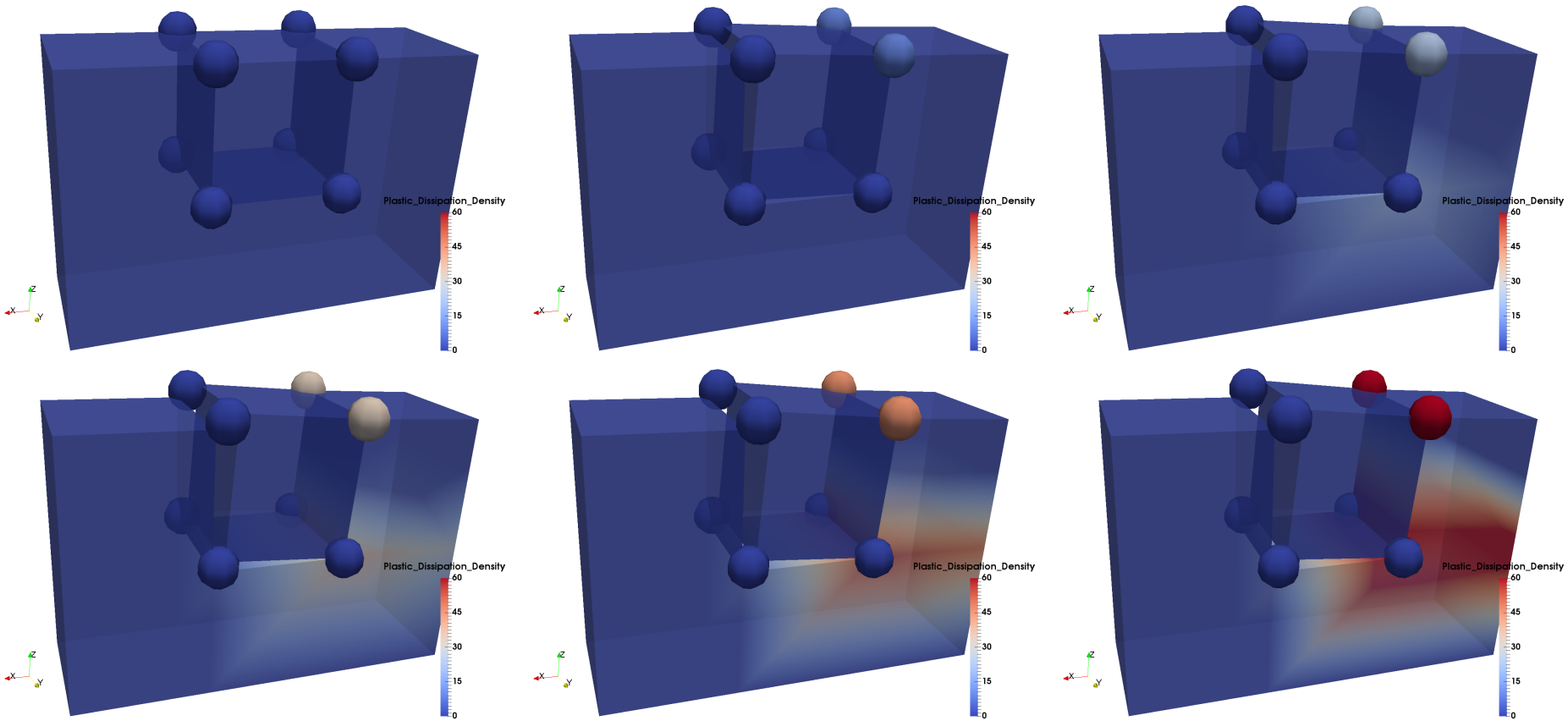




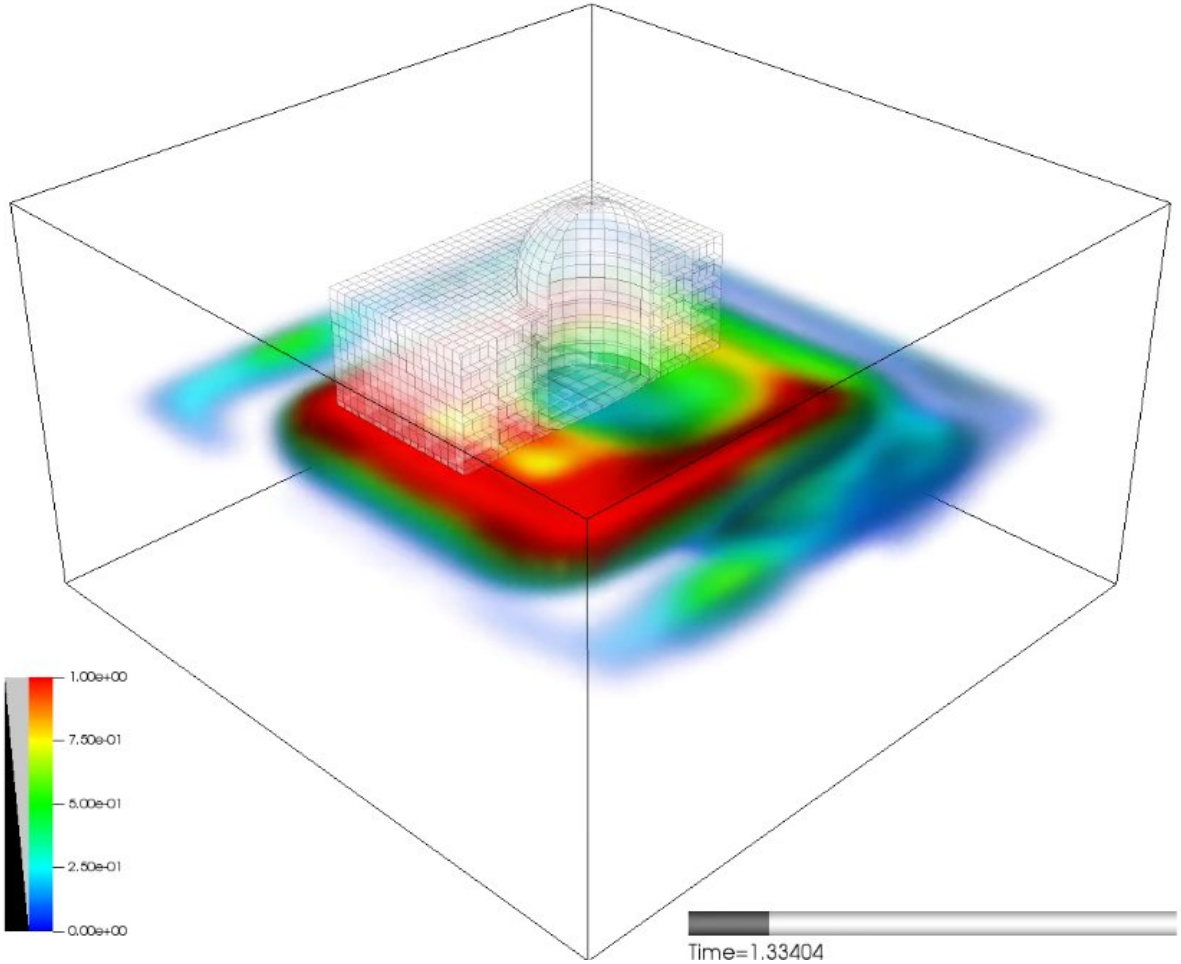


Energy Dissipation in Contact Zone

Elasto-plastic brick elements coupled with contact elements.



Seismic Energy Dissipation under an NPP

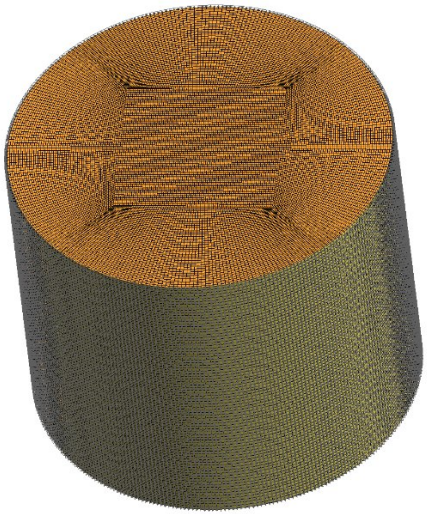


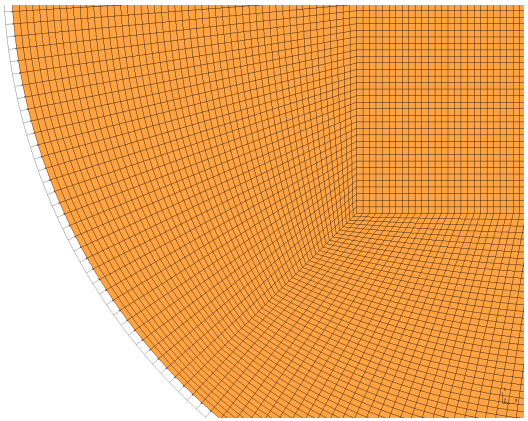
(animations above)

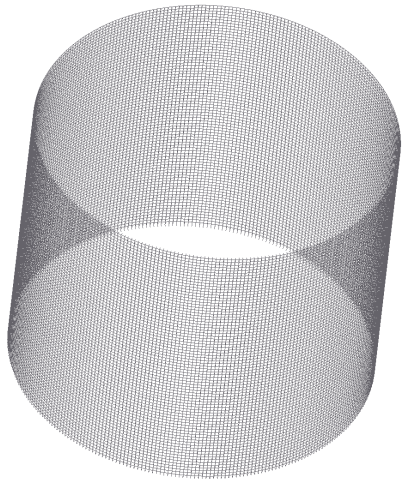
Outline

UNR Experimental Setup Modeling

- Detailed models of UNR test setup
- Different levels of modeling sophistication

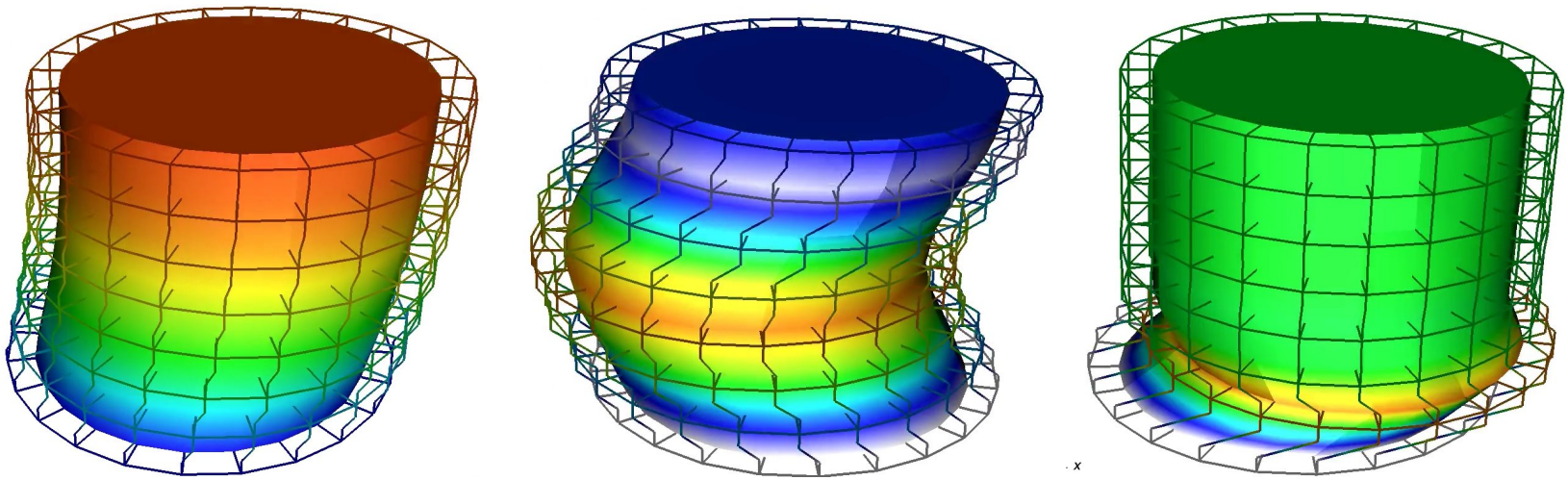






UNR Experimental Setup, Model

- Gain better understanding of behavior
- Guide design
- Validation experiments



Summary

- Modeling and Parametric uncertainties
- Change state of practice (and research)
- 5 Year U.S. DOE Project
  - Development of advanced computational tools and validation test data for earthquake response of nuclear facilities
  - Enhance understanding of the expected levels of damage, and margins against failure, for critical facilities subjected to earthquake ground motions
- Education is the key to successful use of realistic nonlinear Earthquake Soil Structure Interaction modeling and simulation

Acknowledgement

- Collaboration with and funding from the US-DOE (current), IAEA, US-NRC, US-NSF, CNSC, LLNL, INL, AREVA NP GmbH, and Shimizu Corp. is greatly appreciated,
- Collaborators: Mr. Feng, Mr. Lacour, Ms. Behbehani, Mr. Han, Mr, Sinha, Mr. Wang, Dr. Abell, Mr. Watanabe, Mr. Chao, Dr. Tafazzoli, Dr. Sett, Dr. McCallen, Dr. Buckle, Dr. McKenna, Dr. Pisanò,