Advancement in Earthquake Soil Structure Interaction Modeling and Simulation

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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

Outline

Seismic Energy Input and Dissipation

- Seismic energy input, through a closed boundary (DRM)
- Mechanical dissipation outside of SSI domain:
  - reflected wave radiation
  - SSI system oscillation radiation
- Mechanical dissipation/conversion inside SSI domain:
  - plasticity of soil subdomains
  - plasticity/damage of the parts of structure/foundation
  - viscous coupling of in soils and structure
  - potential $\leftrightarrow$ kinetic energy
- Numerical energy dissipation/production

Energy Parameters

- Kinetic Energy Density:

$$dE_K(x,t) = \rho(x)\, v_i(x,t)\, dv_i(x,t)$$

- Strain Energy Density:

$$dE_S(x,t) = \sigma_{ij}(x,t)\, d\epsilon_{ij}(x,t)$$

- Plastic Work Density:

$$dW_P(x,t) = \sigma_{ij}(x,t)\, d\epsilon^{pl}_{ij}(x,t)$$

Plastic Free Energy and Dissipation

- Free Energy
  - Based on the second law of thermodynamics
  - Decomposed into elastic and plastic components
- Plastic Free Energy
  - From particle rearrangement of granular assembly
  - Related to material internal variables (back stress etc.)
  - Decomposed into isotropic and kinematic components

$$d\Psi_{pl}^{iso} = \frac{1}{\kappa_1} k \, dk; \quad d\Psi_{pl}^{kin} = \frac{1}{a_1} \alpha_{ij} \, d\alpha_{ij}$$

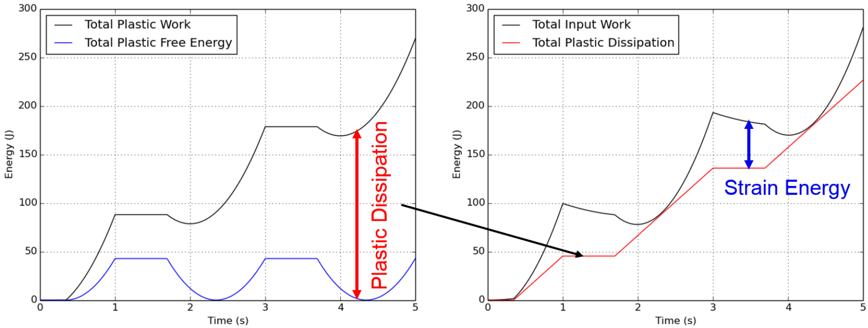
- Energy Dissipation due to Plasticity
  - Incremental dissipation should always be nonnegative

$$dD_P = dW_P - d\Psi_{pl} = \sigma_{ij} \, d\epsilon_{ij}^{pl} - d\Psi_{pl} \geq 0$$

Energy Dissipation on Material Level

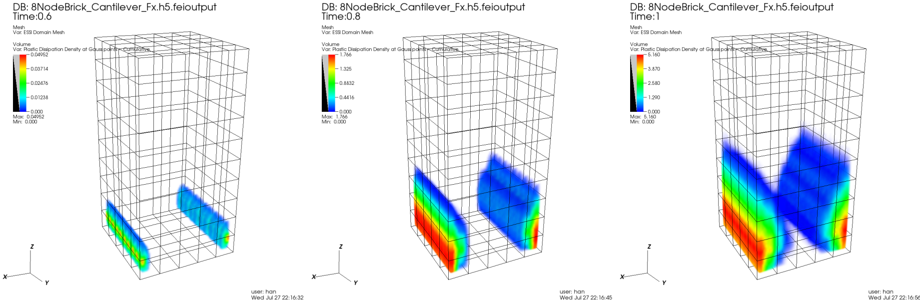
Single elasto-plastic element under cyclic shear loading

- Significant difference between plastic work and dissipation
- Plastic work can drop but dissipation always increases



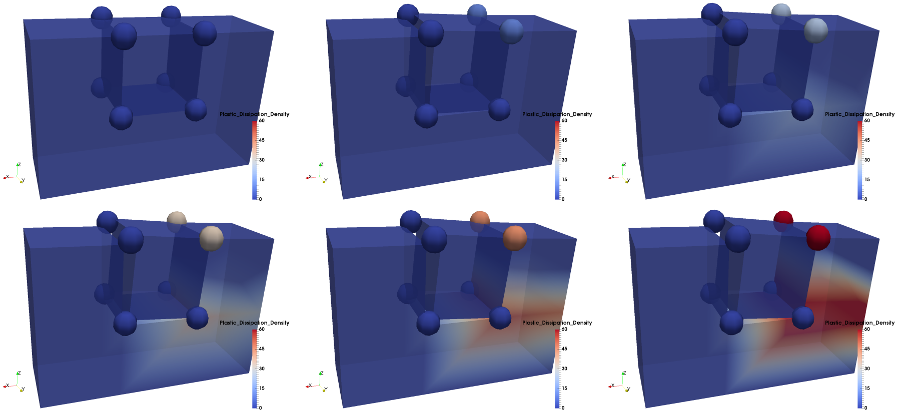
Evolution of Energy Dissipation

Short cantilever under shear loading

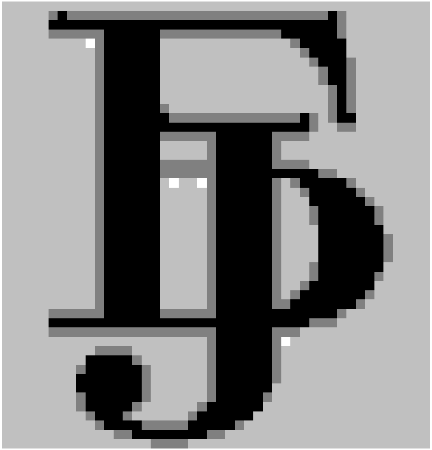


Energy Dissipation in Contact Zone

Elasto-plastic brick elements coupled with contact elements.



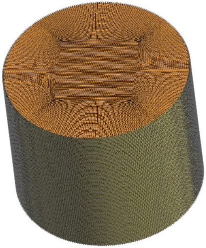
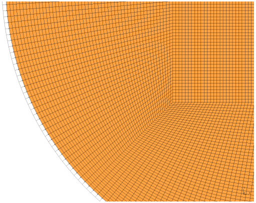
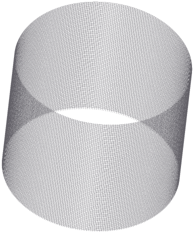
Seismic Energy Dissipation under an NPP



Outline

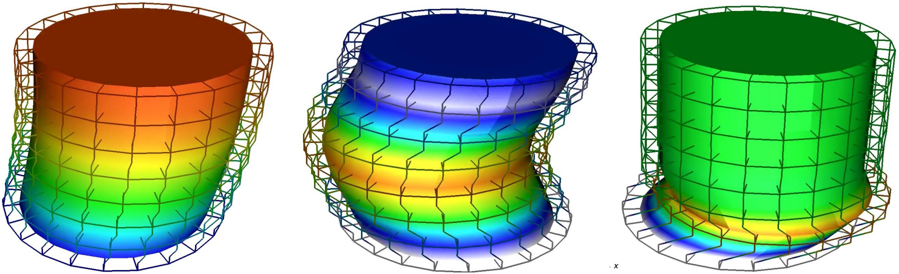
UNR Experimental Setup Modeling

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

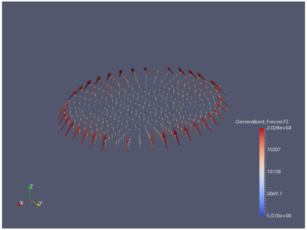
UNR Experimental Setup, Model

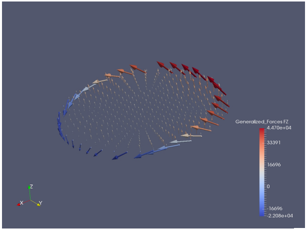
- Gain better understanding of behavior
- Guide design
- Validation experiments



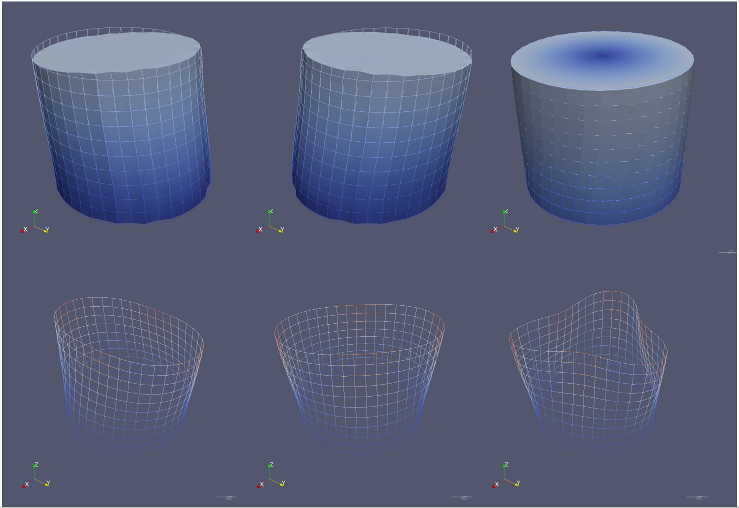
UNR Experiments, Design and Validation

- Detailed, parametric analysis for the effects of
  - Wall friction
  - Soil inelastic response
  - Cylinder rocking modes
  - Cylinder wobbling modes
- Models for validation of a free field response
- Models for validation of SSI with attention to contact
- Models for high frequency wave tomography

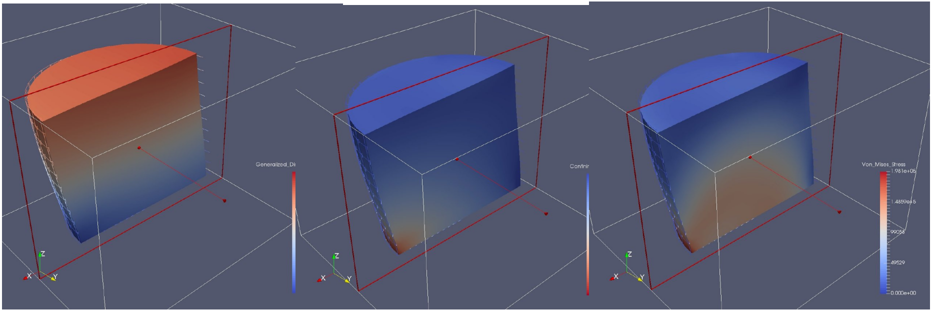




UNR Setup Analysis, Eigen Modes



UNR Setup Analysis, Static Pushover



Ux, p, q

Summary

- Modeling and Parametric uncertainties
- Goal is to predict and inform, not fit or diagnose
- 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