

Non-linear Soil-Structure Interaction: Benefits and Issues

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Motivation

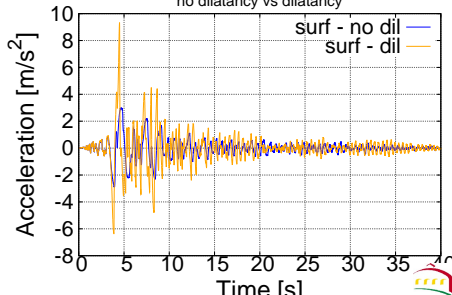
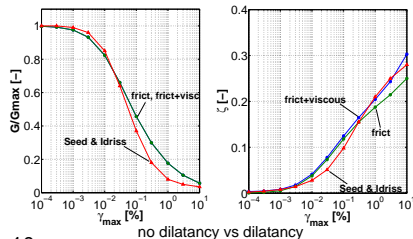
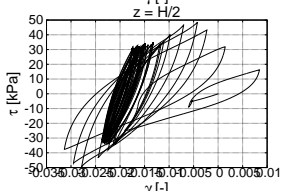
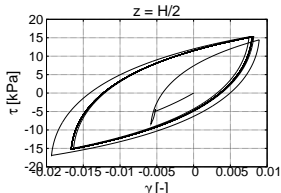
- ▶ Seismic response of Nuclear Power Plants is controlled by the nonlinear dynamic interaction of three components:
 - ▶ Earthquake
 - ▶ Soil/Rock
 - ▶ Structure
- ▶ Nonlinear Earthquake Soil Structure Interaction (ESSI) in time and space, plays a decisive role in successes and failures
- ▶ Follow and direct the flow of seismic energy and its dissipation in ESSI system to optimize for safety and economy
- ▶ High fidelity numerical modeling and simulation to analyze realistic ESSI behavior

Realistic, Nonlinear ESSI Issues

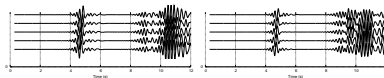
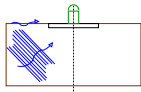
- ▶ Nonlinear/inelastic behavior
 - ▶ Nonlinear, inelastic soil/rock (saturated or dry)
 - ▶ Nonlinear, inelastic contact (saturated or dry)
 - ▶ Nonlinear, inelastic structures, systems and components
 - ▶ Nonlinear buoyant forces
- ▶ Full 3D (6D) Earthquake motions
 - ▶ Body waves (P, SV, SH)
 - ▶ Surface waves (Rayleigh, Love, &c.)
- ▶ Uncertain material and loads
- ▶ Verification and validation for accurate numerical simulations

Elastic-Plastic Soil, Dense/Loose, Volume Change

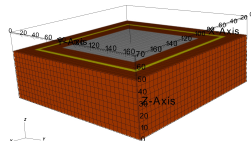
- ▶ G/G_{max} and damping data lacks volume change info
- ▶ Influences seismic motion



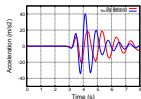
Inelastic Contact, Base Slip and Gap



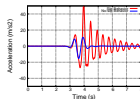
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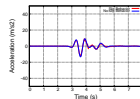
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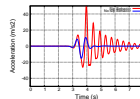
top X



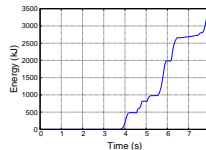
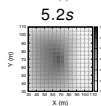
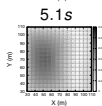
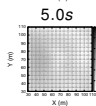
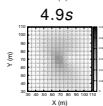
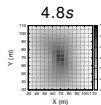
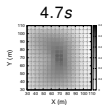
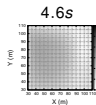
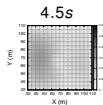
top Z



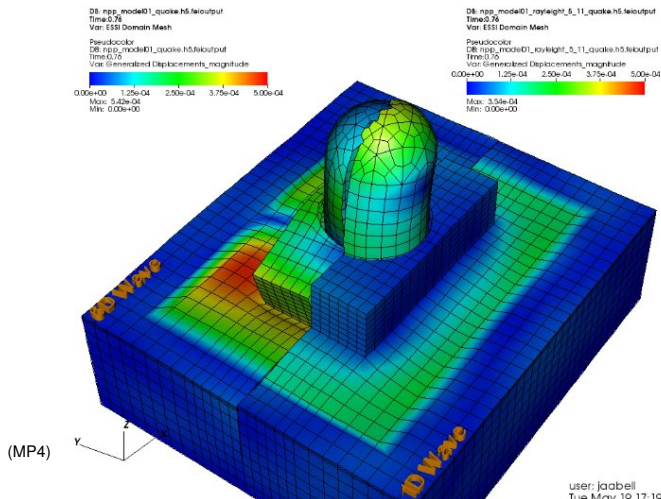
bottom X



bottom Z

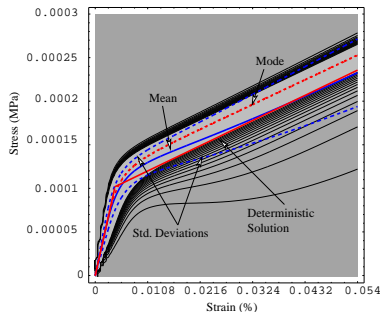
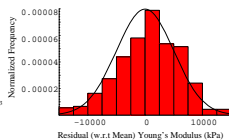
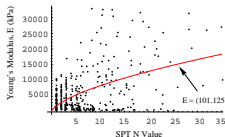


6D vs 1D: Real ESSI Response

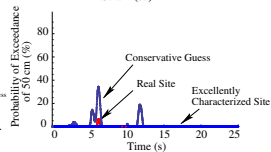
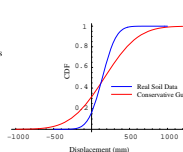
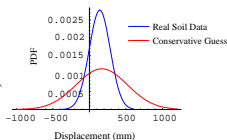
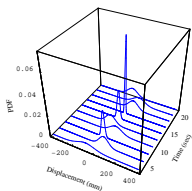


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Uncertain Material and Loads, Wave Propagation



- Probabilistic Elasto-Plasticity
- Stochastic Elastic-Plastic FEM



Predictive Capabilities

- ▶ Verification: evidence that the model is solved correctly
- ▶ Validation: evidence that the correct model is solved
- ▶ Reduce modeling uncertainty
- ▶ Higher sophistication models (one or two levels) to demonstrate adequacy of modeling simplifications
- ▶ Sensitivity studies to demonstrate importance of parameters
- ▶ Real ESSI Simulator goal: predict and inform, and not fit
- ▶ New U.S. DOE project: "A Modern Computational Framework for the Nonlinear Seismic Analysis of Nuclear Facilities and Systems" that will further enhance the Real ESSI Simulator (develop validation tests, education, training, and distribution)

Concluding Remarks

- ▶ Real ESSI modeling and simulation
 - ▶ nonlinear, inelastic behavior (deterministic and probabilistic)
 - ▶ 3D (6D) ground motions (deterministic and probabilistic)
- ▶ Verification (not benchmarking) and validation for proper prediction
- ▶ Benefits of nonlinear, realistic ESSI
 - ▶ Seismic energy dissipation
 - ▶ Reduction of modeling uncertainty
- ▶ Education of designers, regulators, owners, &c. is essential!
- ▶ Funding from and collaboration with the US-NRC, CNSC/CCSN, US-DOE, US-NSF, Shimizu Corp., and AREVA NP GmbH is greatly appreciated,