

Nonlinear effects in Earthquake Soil Structure Interaction of Nuclear Power Plants

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Outline

Introduction

Modeling and Simulations

Summary

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Motivation

Improve seismic modeling and simulation for infrastructure objects

Use of high fidelity numerical models to analyze seismic behavior of soil structure nuclear facilities

Reduction of modeling uncertainty, ability to perform high(er) level of sophistication modeling and simulation

Accurately follow the flow of seismic energy in a soil structure system

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Introduction

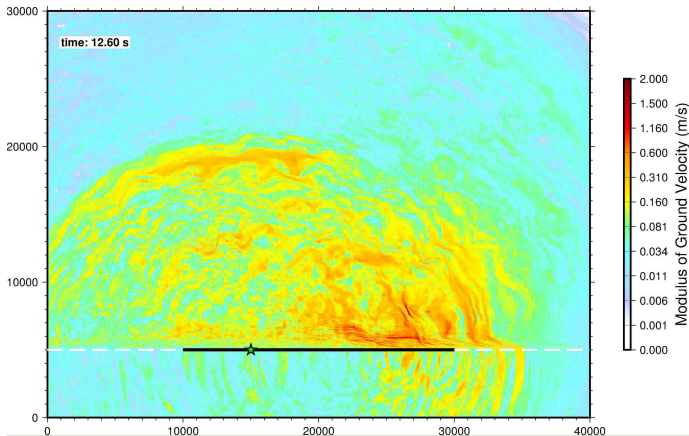
Modeling and Simulations

Summary

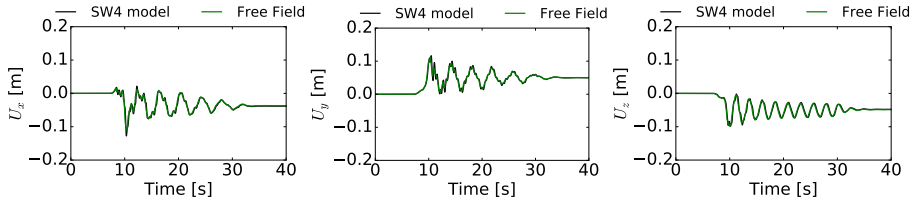
Development of Seismic Motions

- ▶ 1D and/or 2D and or $3 \times 1D$ and/or 3D (6D) motions can be used
- ▶ 3D motions from regional scale modeling
- ▶ Knowledge of geology (deep and shallow) needed
- ▶ Using SW4 (LLNL): Dr. Rodgers, Dr. Pitarka and Dr. Petersson

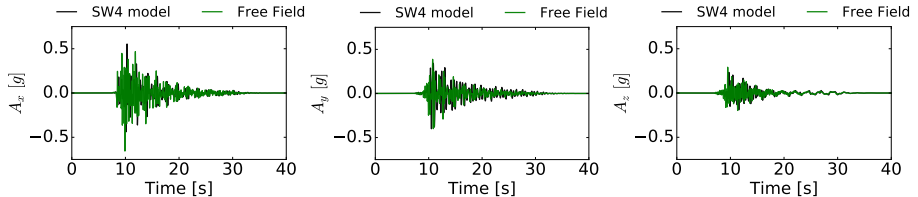
Regional Model Motions (Rodgers et al LLNL)



Free Field Verification

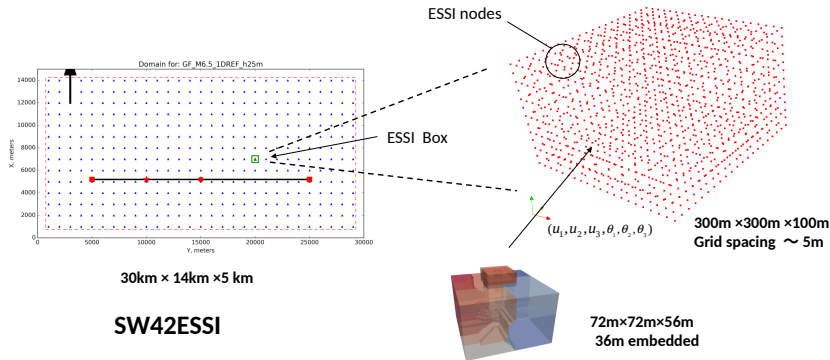


(a) Relative Displacement

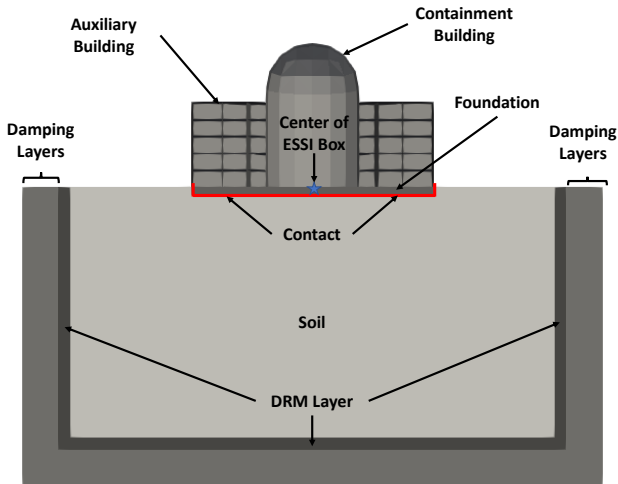


(b) Acceleration

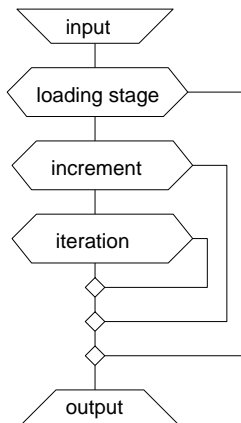
Seismic Motions: SW4 to Real ESSI



NPP Model

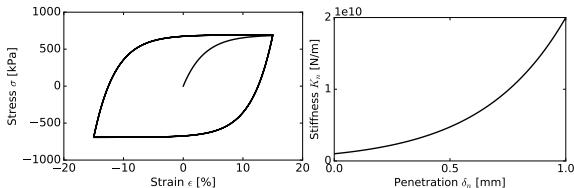


Inelastic/Nonlinear Analysis

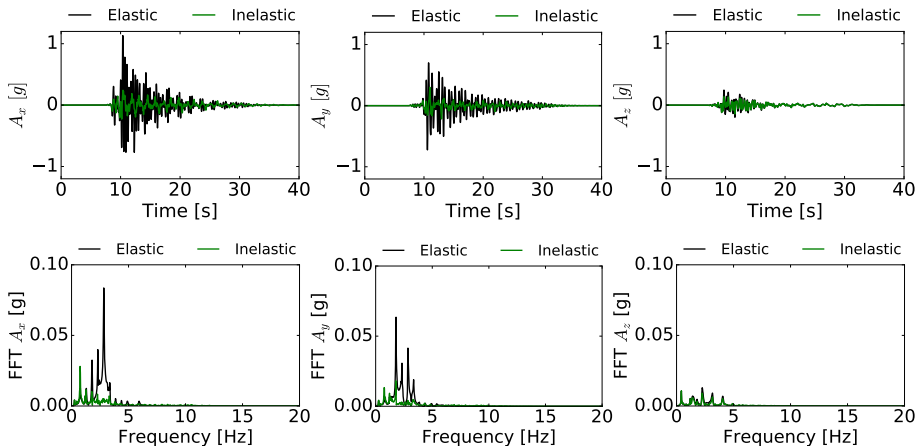


Inelastic Soil and Inelastic Contact

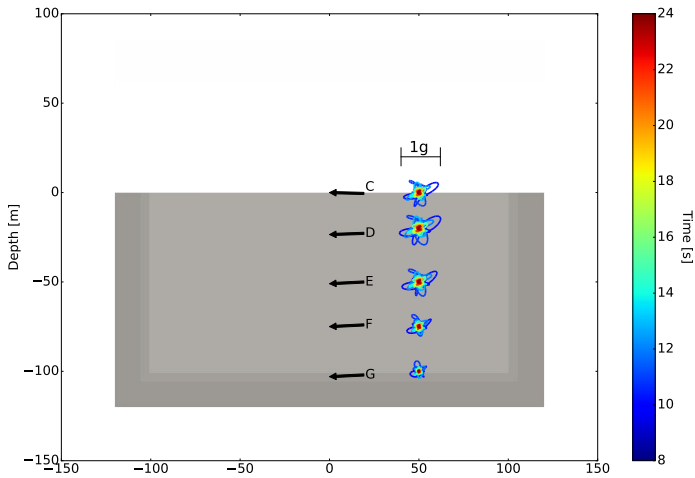
- ▶ Shear velocity of soil $V_s = 500m/s$
- ▶ Undrained shear strength (Dickenson 1994)
 $V_s[m/s] = 23(S_u[kPa])^{0.475}$
- ▶ For $V_s = 500m/s$ Undrained Strength $S_u = 650kPa$ and Young's Modulus of $E = 1.3GPa$
- ▶ von Mises, Armstrong Frederick kinematic hardening ($S_u = 650kPa$ at $\gamma = 0.01\%$; $h_a = 30MPa$, $c_r = 25$)
- ▶ Soft contact (concrete-soil), gapping and nonlinear shear



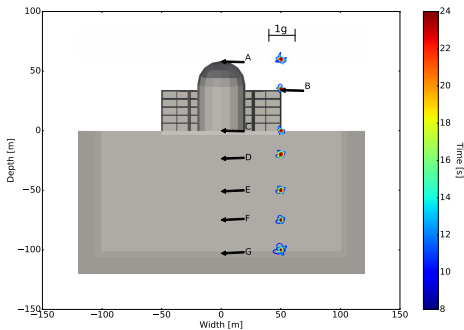
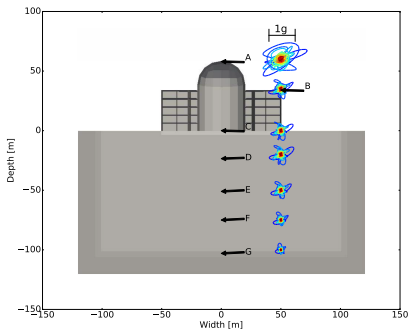
Acc. Response, Top of Containment Building



Acceleration Traces, Free Field

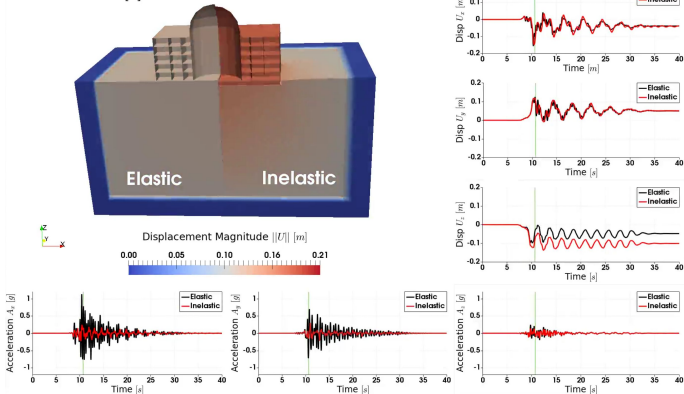


Acceleration Traces, Elastic vs Inelastic

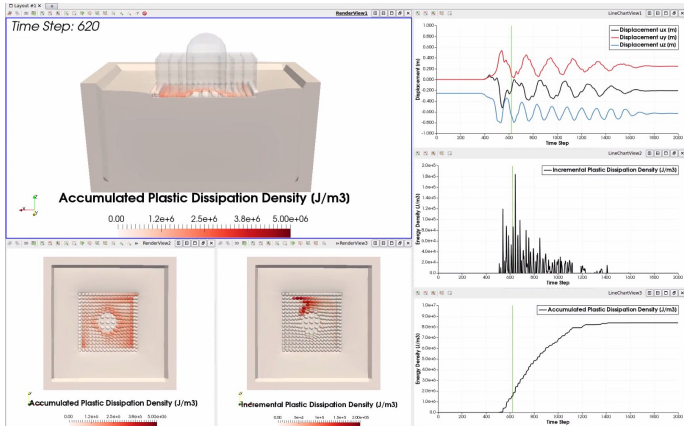


Elastic and Inelastic Response: Differences

Time: 10.67 [s]



Energy Dissipation in Large-Scale Model (NPP)



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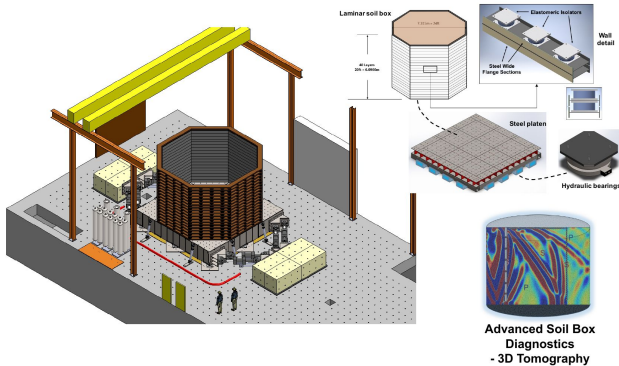
Summary

US-DOE Project for ESSI of Nuclear Facilities

The Real ESSI Simulator System (UCD/LBNL)

Modeling from seismic source to NPP (LLNL/UCD/LBNL)

High Quality Validation test (UNR/UCD/LBNL)



Summary

- ▶ Reduction of demand due to inelastic effects
- ▶ The Real ESSI Simulator system used for all the model development, modeling/simulations and post-processing
- ▶ The Real ESSI Simulator system documentation and information about different availability/use options is at <http://real-essi.info>
- ▶ Nonlinear/Inelastic Earthquake Soil Structure Interaction (ESSI) short course offered this fall in San Francisco, more info at <http://real-essi.info>
- ▶ Funding from and collaboration with the US-DOE, US-NRC, US-NSF, CNSC-CCSN, UN-IAEA, and Shimizu Corp. is greatly appreciated,