Wavelet Based Synthetic Earthquake Sources for Path and Soil Structure Interaction Modeling: Stress Testing of Nuclear Power Plants

Boris Jeremić, José Antonio Abell and Sumeet Kumar Sinha

University of California, Davis, CA, USA
Lawrence Berkeley National Laboratory, Berkeley, CA, USA

BestPSHANI, IAEA
Vienna, Austria, November 2015

Outline

Motivation

Stress Test Ground Motions

Summary

Outline

Motivation

Stress Test Ground Motions

Summary

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
- Reduce modeling uncertainty and propagate parametric uncertainty, develop models and simulations that predict and inform rather than (force) fit
- Development of high fidelity numerical models and simulations to analyze realistic ESSI behavior

High Fidelity ESSI Behavior

- Realistic ESSI modeling and simulation issues
  - Three dimensional (3D, or actually 6D) seismic motion fields
  - Inelastic (elastic-plastic, nonlinear (!)) behavior of materials (soil, rock, concrete, steel, &c.), contacts (slip, gap), isolators / dissipators, buoyant pressures, &c.
  - Prediction through (extensive) Verification and Validation

Realistic ESSI: What Seismic Motions to Use?

- 1D motions, state of practice and research (!?)
- 3D motions, really 3 $\times$ 1D, also state of practice and (most) research (!?)
- 6D motions, realistic motions (!): body (P, SH, SV) and surface waves (Rayleigh, Love, &c.)
- Detailed knowledge of geology (!):
  - Spatial resolution of features for required wave lengths
  - Inelastic behavior of materials (deep and shallow)

Local Site Motion Fields

Local site will affect motions:

- Local geology can (will) amplify some and de-amplify (or remove completely) motion components/features, (6D, frequencies, magnitude, &c.)
- Inelastic material (soil/rock) can (will) amplify and de-amplify motion components/features (6D, frequencies, magnitude, &c.)

Proposal: Additional Motion Fields

- In addition to developing realistic surface motions using large scale source to site simulations (as seen in a number of presentations here),
- Develop near field seismic motion fields, in high resolution, with simple point/line sources, to stress-test / shake-out soil-structure system

Outline

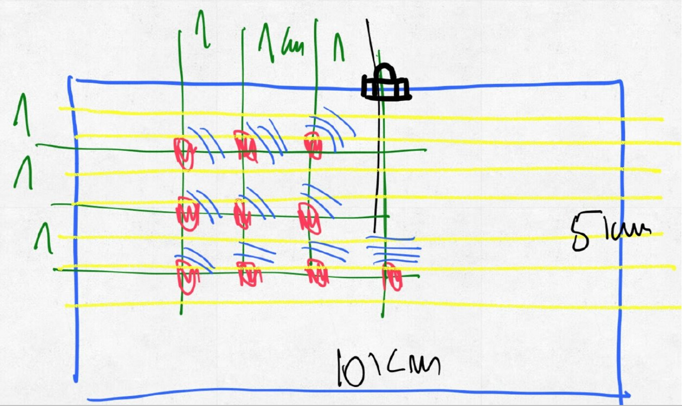
Motivation

Stress Test Ground Motions

Summary

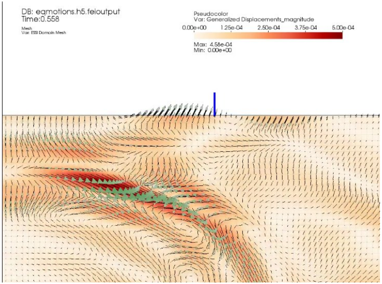
Stress Testing NPP SSI Systems

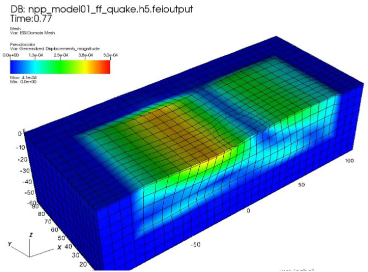
- Excite NPP SSI system with different waves, energies and durations
- Try to "break" the system, shake-out strong and weak links



Stress Test Motions

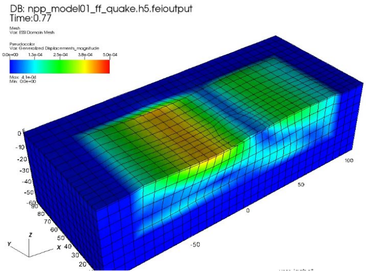
- Develop free field models with sources within
- Sources are simple, point (mostly), line and surface
- Sources will send both P and S waves
- Variation in strike and dip
- Simulation programs, Real ESSI Simulator and SW4

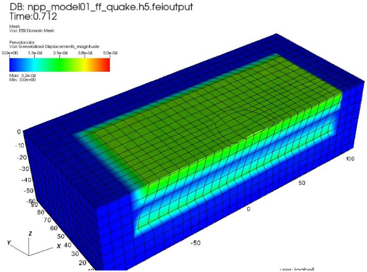




Stress Test Motions, 6D vs 1D

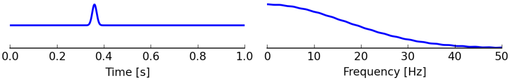
- Danger of picking one component of motions for 1D or 3$\times$1D (it is done all the time!)
- Excellent (forced) fit, but not a prediction and information is lost (remember, goal is to predict and inform and not fit)



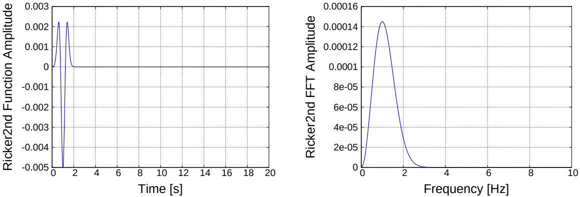


Stress Test Source Signals

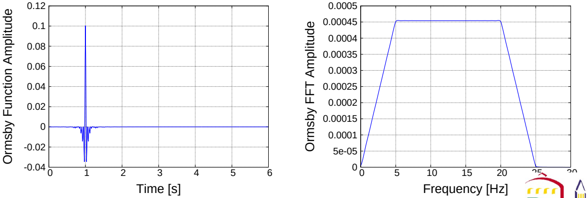
- Gauss



- Ricker (1st, 2nd)

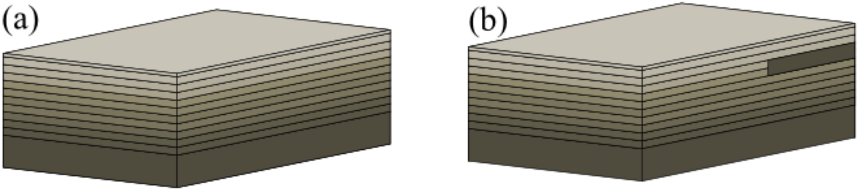


- Ormsby



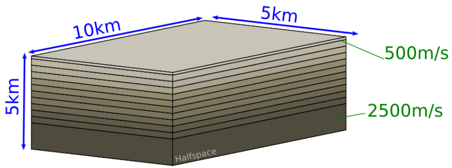
Layered and Dyke/Sill Models

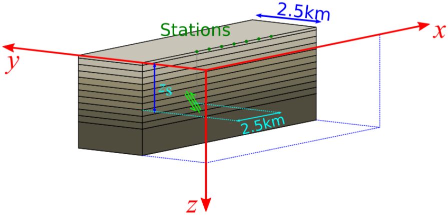
- Uniform soil/rock, to show surface waves
- Horizontally layered geology (a), to show bending/refraction and more surface waves
- Dyke/Sill intrusion within layered geology (b), to show effects of local geology on free field motions



Variable Sources

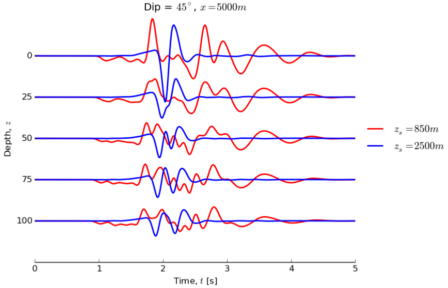
- Source locations matrix (point sources)
- Source strike and dip variation (here only dip)
- Magnitude variations
- Range of frequencies

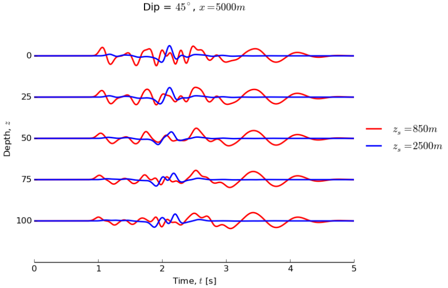




Layered System, Variable Source Depth

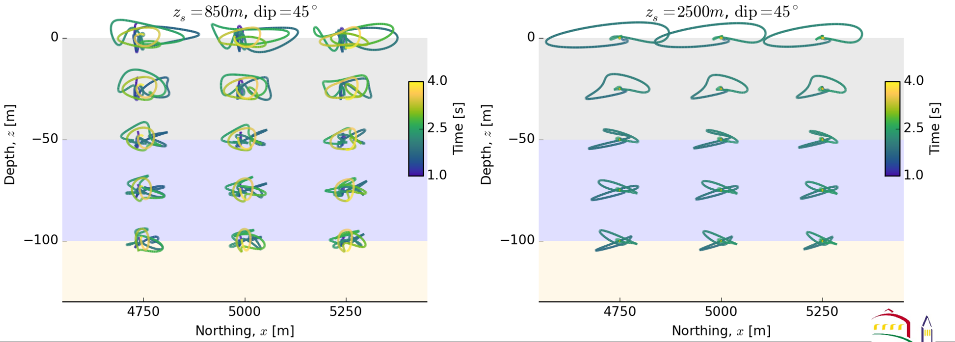
- Epicenter is 2500m away from the location of interest
- Source depth 850m (softer layers) and 2500m (hard rock)
- Different wave propagation path to the point of interest
- Surface waves quite pronounced



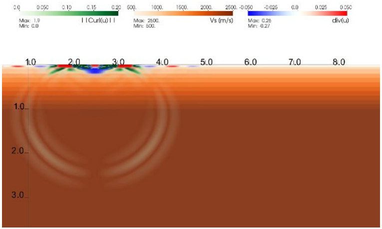


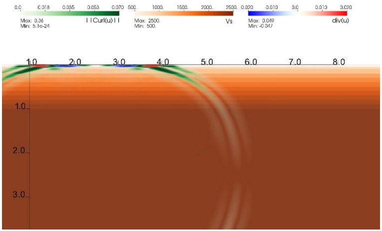
Layered System, Displacement Traces

- Surface waves present
- Layered geology did not filter out surface waves
- Mildly incoherent motions



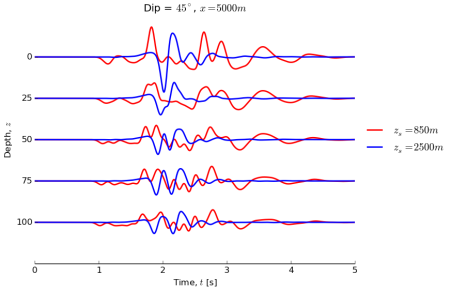
Layered System, Variable Source Depth





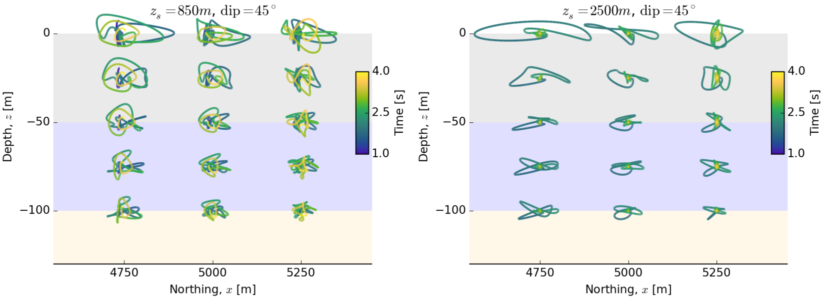
Dyke/Sill Intrusion, Variable Source Depth

- Lower amplitudes than with layered only model!
- Difference in body and surface wave arrivals
- Surface waves present

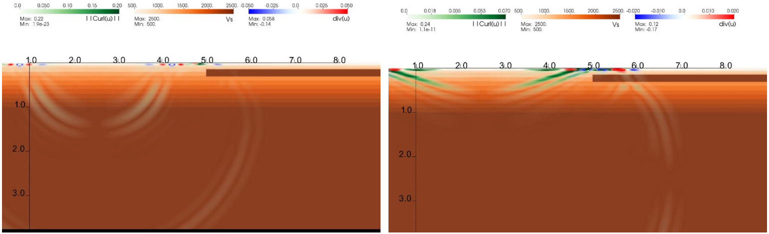


Dyke/Sill Intrusion, Variable Source Depth

- Incoherent motion field
- Note incoherence is in 2D (and really in 3D, it is reduced, for this model)

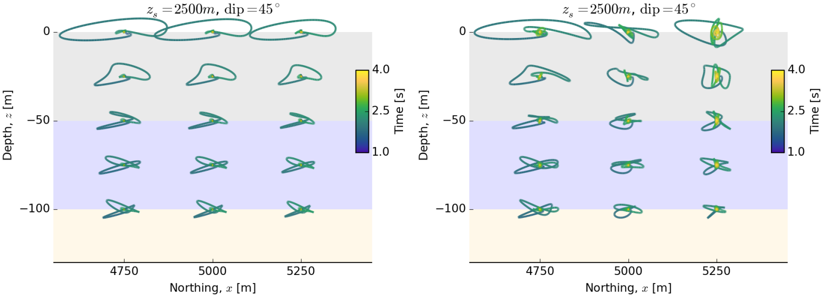


Dyke/Sill Intrusion, Variable Source Depth



Dyke/Sill as Seismic Energy Sink

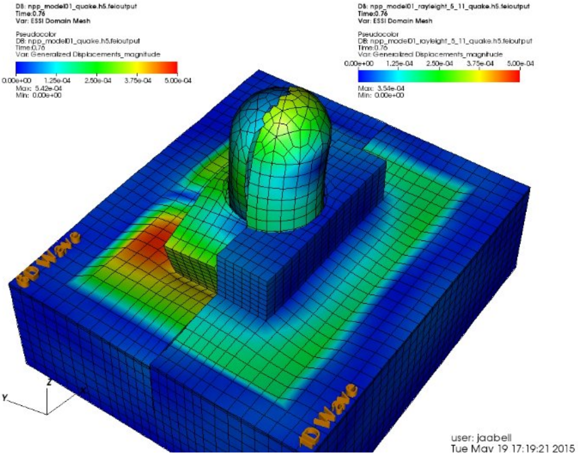
- Dyke/Sill (right Fig), made of stiff rock, is an energy sink, as well as energy reflector
- Variable wave lengths behave differently, depending on dyke/sill geometry and location



Importance of Realistic Seismic Motion Fields

- Developed synthetic (!) free field motions need to excite a number of (all!) possible responses from a nuclear facility
- Knowledge of detailed geology is needed, geometry and material properties, including inelasticity of shallow layers
- Reduction of modeling uncertainty
- Direct use for Realistic ESSI simulations

6D vs 1D NPP ESSI Response Comparison



Outline

Motivation

Stress Test Ground Motions

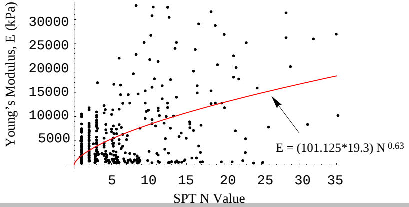
Summary

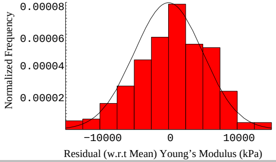
Concluding Remarks

- 6D motions are important
- Need for high resolution motion fields
- In addition to realistic geophysics models for motions (field), need for stress-test, shake-out motions to find weak and strong links of a soil structure systems (nuclear facilities)
- Simple source functions, focus on creating a range of motions at the location
- Geologic features (global and local) and inelastic material behavior needs to be characterized as they will (significantly) change/affect motions

Needs, Current and Future Developments

- Useful for Real ESSI analysis if large scale geophysical models can focus on local site specific features that are needed for realistic ESSI analysis
- Education will prove essential
- Inelastic/nonlinear FEM modeling is available for both geophysics and ESSI simulations
- Stochastic Elastic-Plastic FEM methodology in development, all in Real ESSI Simulator





Acknowledgement

- Funding from and/or collaboration with the US-NRC, US-DOE, US-NSF, CNSC, AREVA NP GmbH, and Shimizu Corp. is greatly appreciated,
- Collaborators: Prof. Yang, Dr. Cheng, Dr. Jie, Dr. Tafazzoli, Prof. Pisanò, Mr. Watanabe, Mr. Vlaski, Mr. Orbović, Dr. McCallen, Dr. Budnitz, Dr. Kammerer, and UCD students: Mr. Abell, Mr. Feng, Mr. Sinha, Mr. Luo, Mr. Lacour, Mr. Yang, Ms. Behbehani