A Modern Computational Framework for Nonlinear Seismic Analysis of Nuclear Facilities and Systems

LBNL Department of Energy Research Program

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MOTIVATION FOR ADVANCED METHODS

Nuclear facilities are a unique element of infrastructure that can impact many facets of a community's resiliency. They not only serve as commercial power generating plants, but also as nuclear materials and nuclear science facilities for agencies such as the US Department of Energy (DOE).

Nuclear facilities are typically characterized by a relatively low aspect ratio (modest height and significant width) and a substantial mass and significant embedment. These facilities present a complex interaction between a structural system and surrounding soil especially during seismic events.

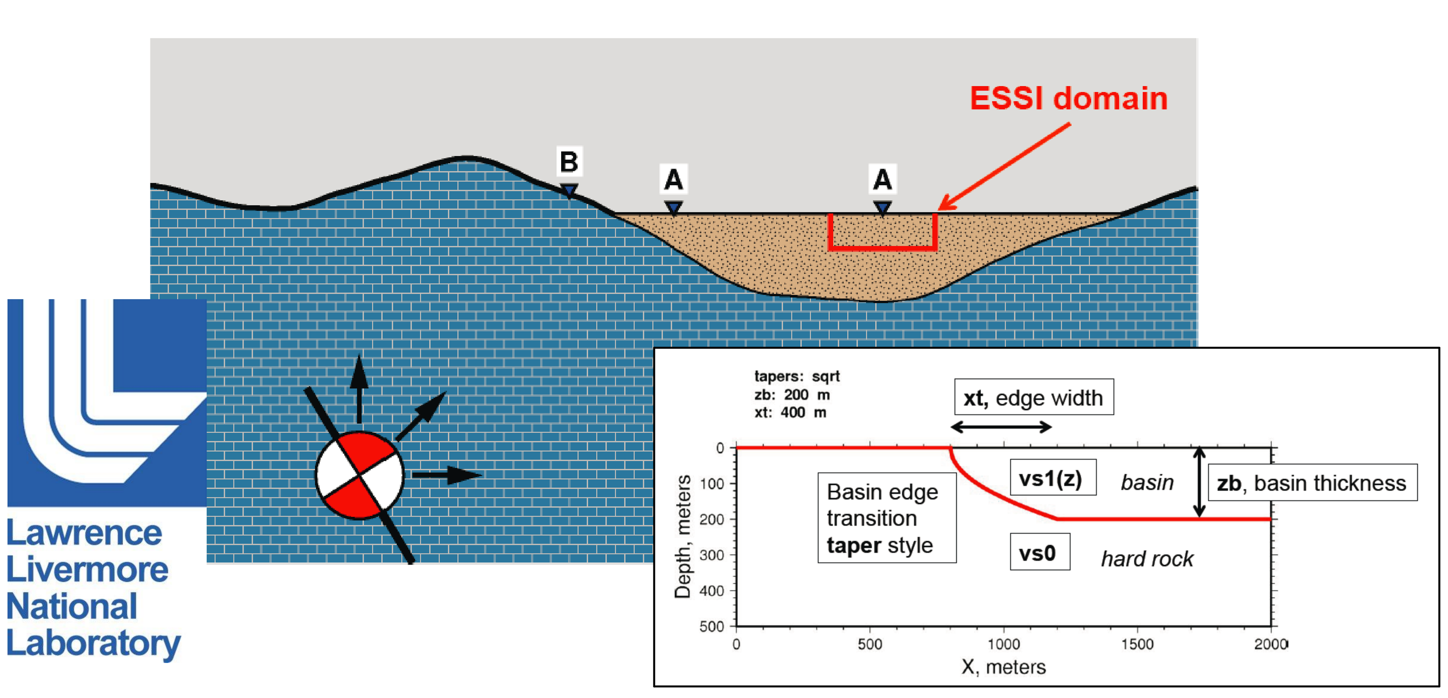
Traditional methods of analyzing the soil structure interaction (SSI) of nuclear facilities utilized software first developed at UC Berkeley in the 1970s. However, due to the computational limitations of that era, studies used simplified idealizations with superstructure characterization limited to linear elastic behavior. Over the past several decades, computation capabilities have increased allowing representation of more complex phenomena.

PROJECT OVERVIEW

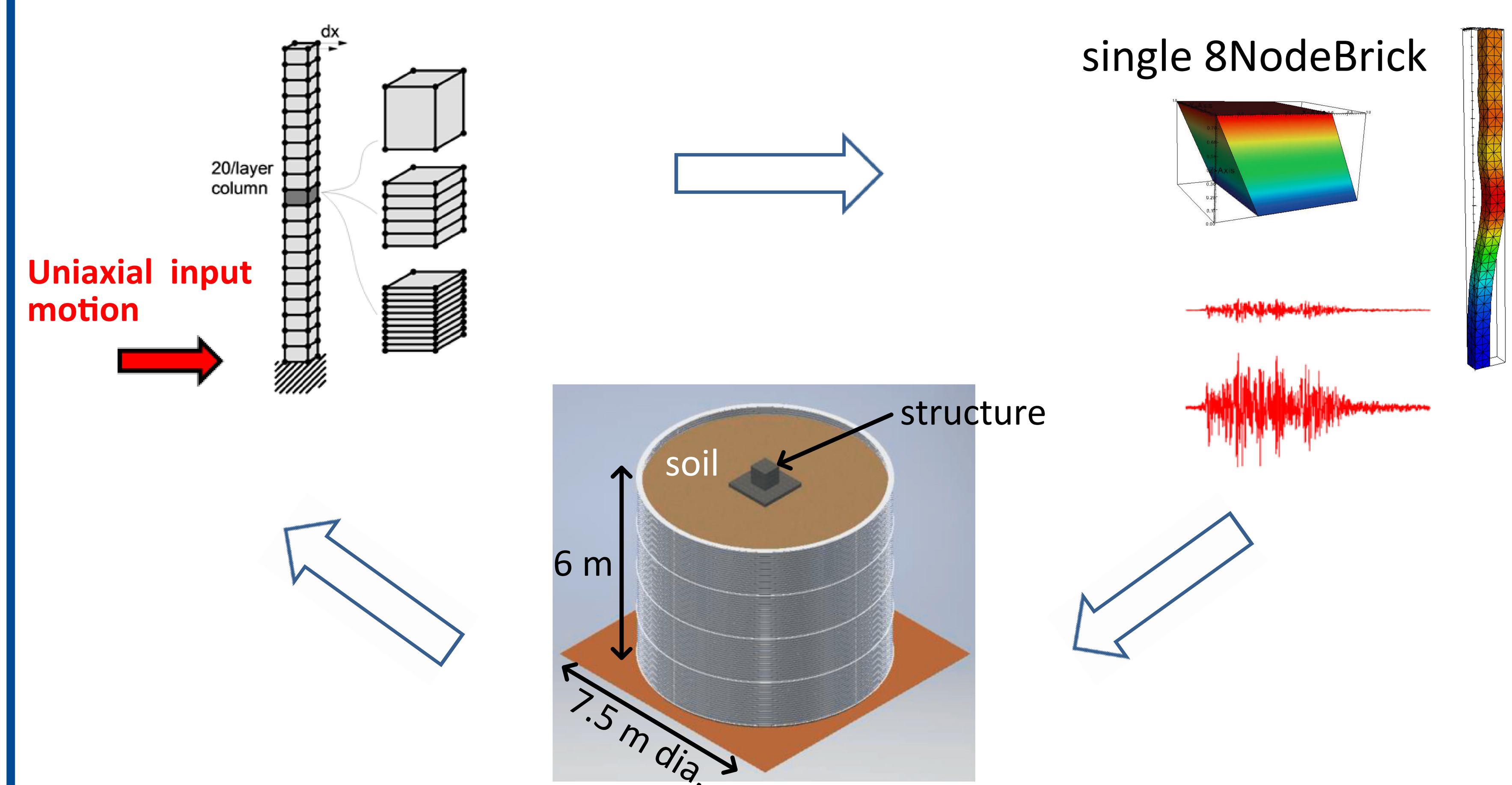
The project focuses on developing a modernized, computationally efficient, verified and validated tool set for the nonlinear analysis of nuclear facilities. This will evolve the current linear elastic point design methodologies to a performance-based design approach addressing the risk-informed, performance goals required for critical facilities such as these. To do so this involves the development of a nonlinear time-domain finite element code for the SSI analysis to conduct parametric studies and eventually validation through comparison to scaled experimental work on a large-scale laminar soil box and shake table.

PROJECT ORGANIZATION

LBNL & UC Davis	UNR	LLNL
Development of a state-of-the-art nonlinear, time-domain finite element code for the analysis of soil-structure systems	Design and fabrication of scaled experimental soil box and shake table with required instrumentation	Parametric study to provide true characteristics of incident earthquake waveforms and the variance form the classical assumption of vertically propagating shear waves



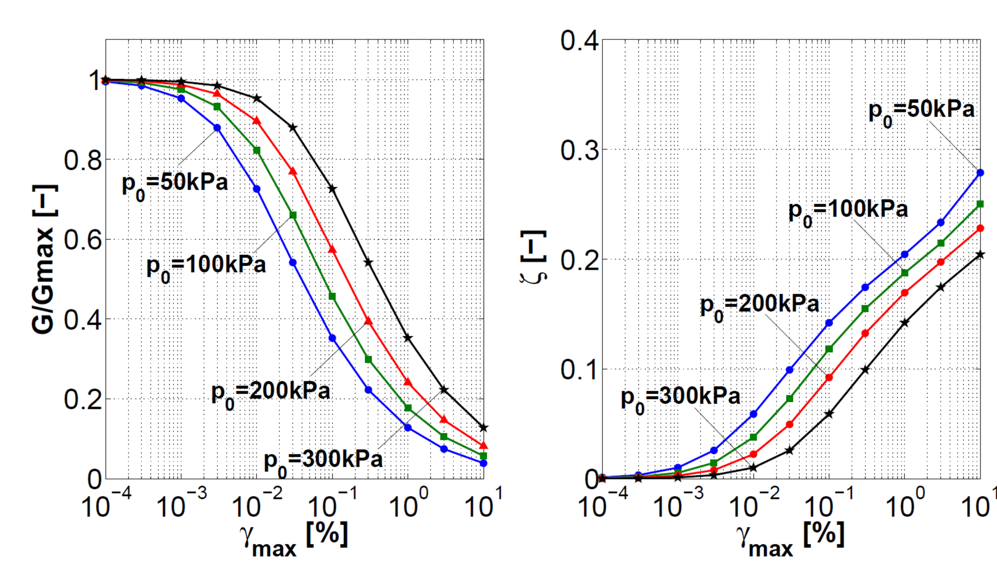
SOIL BOX DESIGN



NUMERICAL MODEL

SOIL MODELING (Pisanò)

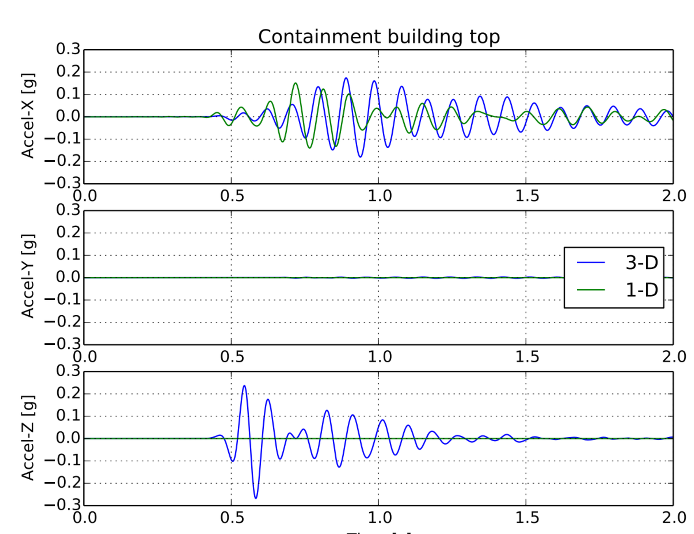
- **incremental 3D** visco-elastic-plastic model
- constitutive relationship based on two parallel resisting/dissipative mechanisms: **purely frictional** (elastic-plastic) and **viscous**
- **pressure - dependent** stable behavior (G/Gmax, ζ) over a **wide strain range**
- properties defined by **a few parameters** calibrated based on standard experimental data

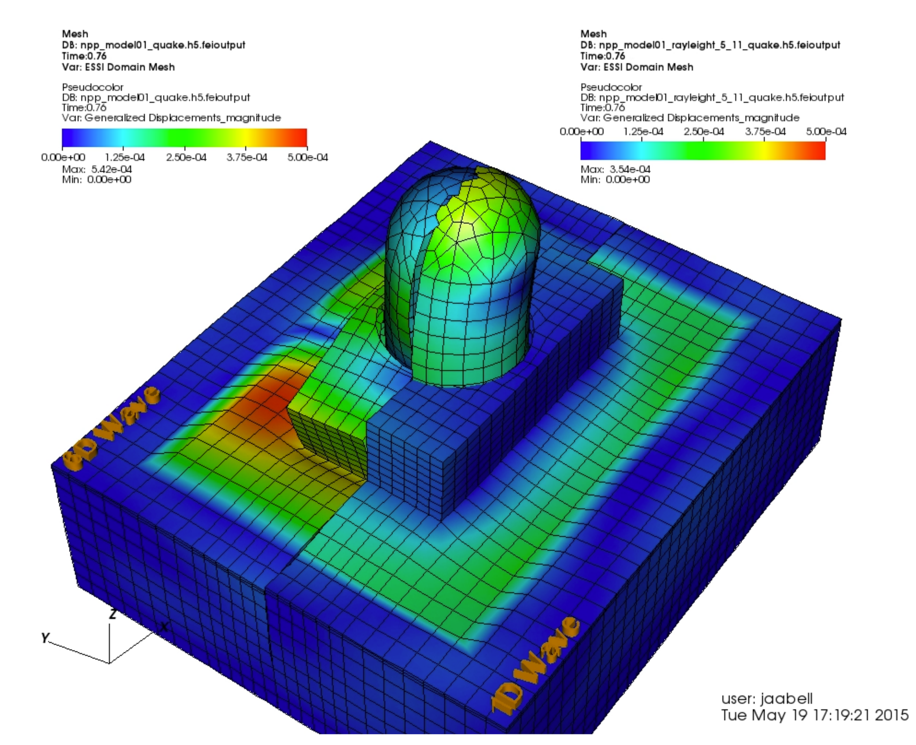


F. Pisanò, B. Jeremic (2014). "Simulating stiffness degradation and damping in soils via a simple visco-elastic-plastic model", Soil Dynamics and Earthquake Engineering, 63, 98-109

WAVE MODELING (6D)

- **1D vs 6D**
- include **P, S** and **surface waves**





CONCLUDING REMARKS

These preliminary steps are creating a strong analytical foundation for the development of more complex models.

Results show sensitivity to element definition, boundary conditions and loading stages. Understanding these details allow for comparison of Real ESSI models against other programs such as LS DYNA and DEEPSOIL.

The work on soil modeling will proceed to expand to 2D and full 3D modeling exploring the effects of soil boundaries, bi-directional horizontal ground motions, and mesh refinement. Ultimately, with the completion of the large-scale laminar soil box, experimental validation of scaled superstructures will be conducted.

ACKNOWLEDGEMENTS

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