

Advances in Application of Nonlinear SSI in the Nuclear Industry

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Purpose

- Discuss current state of NonLinear Soil-Structure Interaction (NLSSI) in the nuclear industry
- Present ongoing Research and Development (R&D) at INL related to:
 - Developing an acceptable NLSSI methodology
 - Application of NLSSI to seismic PRA
 - Advanced framework for multi-hazard scenario's

Current Status of NLSSI in Nuclear Industry

- NonLinear Soil-Structure Interaction seismic analysis routinely performed in commercial non-nuclear industry
- Application in nuclear industry is limited
- Barriers include:
 - Lack of acceptance in ASCE – 4
 - Perceived (or real) limitations of time domain software to perform NLSSI
 - Lack of NLSSI methodology
- Path to overcoming barriers
 - Soon to be released ASCE 4-15 has non-mandatory Appendix B titled “Nonlinear Time Domain Soil-Structure Interaction Analysis”
 - INL has developed methodology for performing NLSSI analysis
 - Commercial/open source software suppliers are adding additional numerical capability to handle NLSSI

What is the Need?

	KK 2007	Fukushima 2011	North Anna 2011
Design Value (g)	0.20	0.26 (Original) 0.45 (Update)	0.18
Recorded Value (g)	0.32	0.56	0.26

- Uncertainty associated with seismic hazard
- NLSSI needed to capture nonlinear behavior during larger earthquakes
 - Gapping and Sliding
 - Material Nonlinearity
 - Implementation into SPRA

All Exceeded Design Basis Earthquake

Managing Uncertainties is a desirable goal

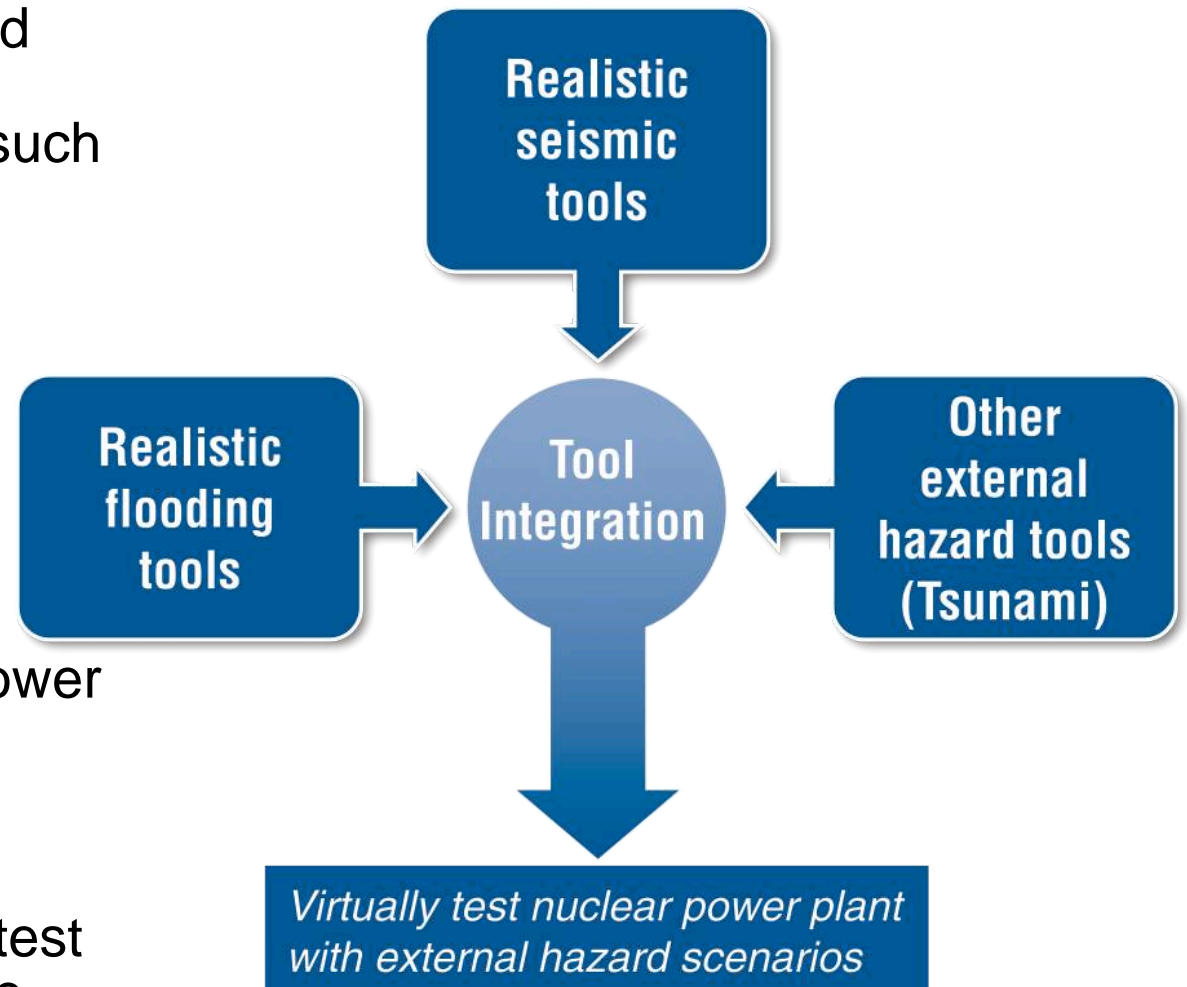
INL External Hazards R&D

Short to Medium Term Goal

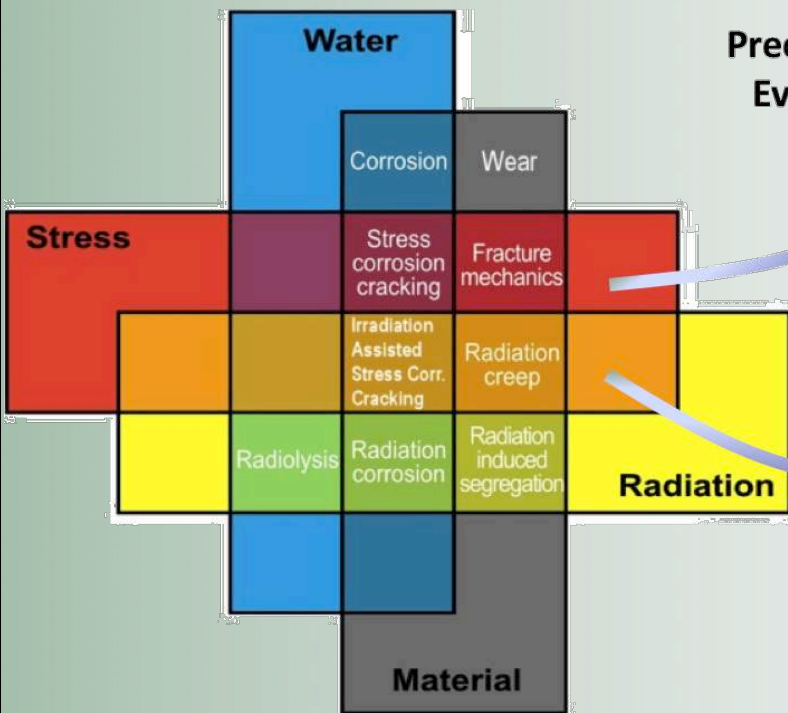
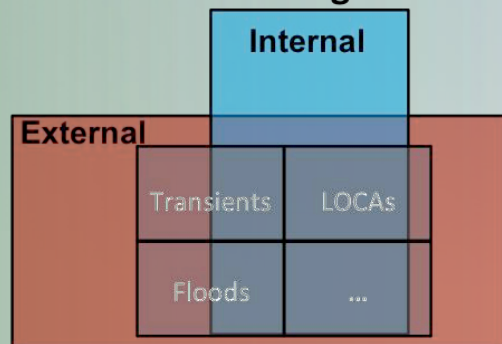
- Provide DOE and Industry with robust analytical methods to evaluate a range of seismic ground motions at critical infrastructure and nuclear facilities and implement protective measures such as seismic isolation (SI).
- The goal is to manage seismic risk at nuclear facilities through cost effective analytical approaches and technologies

Long Term Goal

- Evaluate the performance of virtual nuclear power plants and nuclear facilities to a wide range of external hazards including multiple event scenarios.
- This allows nuclear facility owners to virtually test external hazards before the actual facilities are tested with actual hazards.
- Owners can then anticipate potential issues and resolve them



Possible Initiating Events



Possible Material Degradations

Risk-Informed Margin Evaluation

Precursor Events

Impacts to Plant Operation (Load)

Ability of the Plant Safety Barriers to Respond to Impacts (Capacity)

Possible Impacts to Plant Economics & Reliability & Safety

RISMC Toolkit

Domain Knowledge (failure models, operational data, etc.)

RAVEN (Controller and Scenarios)

RELAP-7 (T-H)

Grizzly (Aging Effects)

Peacock (Graphical Interface)

Bison (Fuel Performance)

MAMMOTH (Fuel Physics)

External Events

Flood

Seismic

Accident Sequences

Containment Behavior

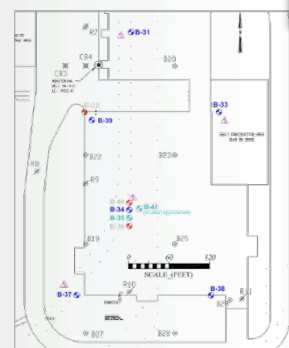
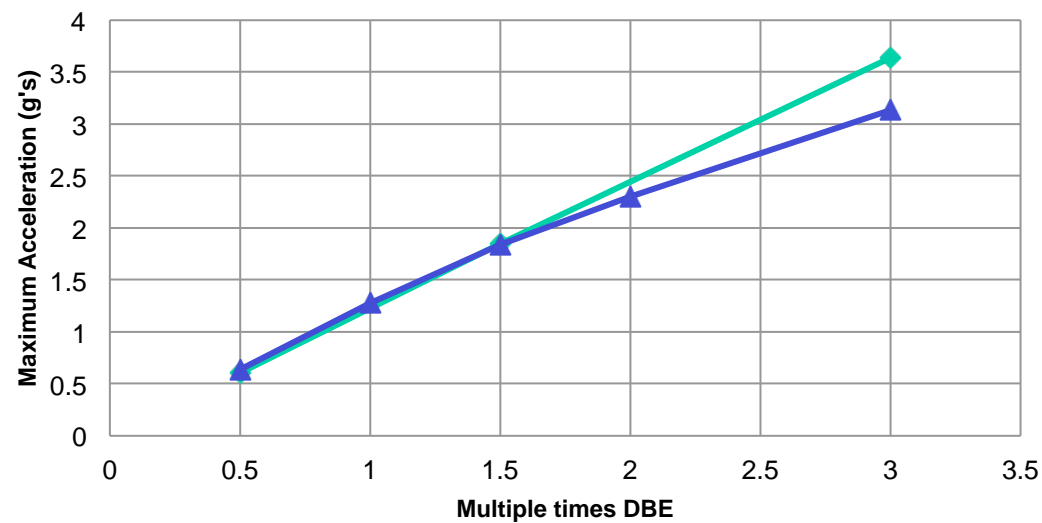


FIGURE 1
SITE PLAN

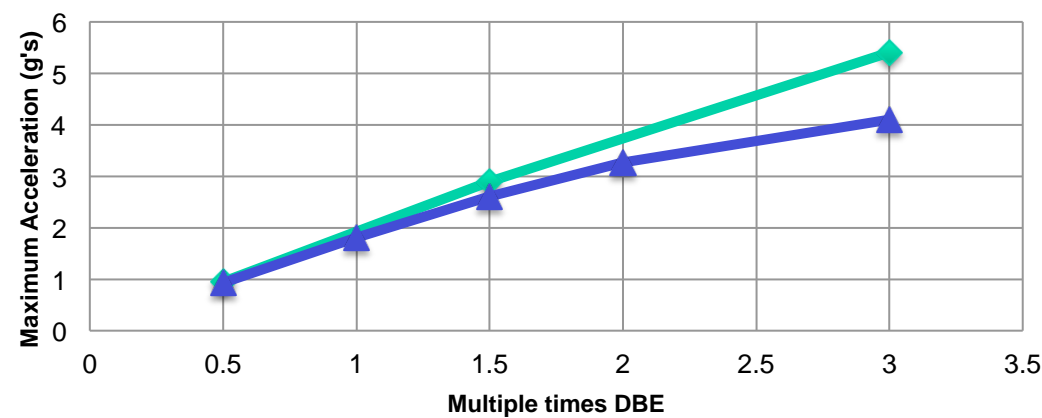
MOOSE (Solver Framework)

Linear SSI vs. NLSSI Results

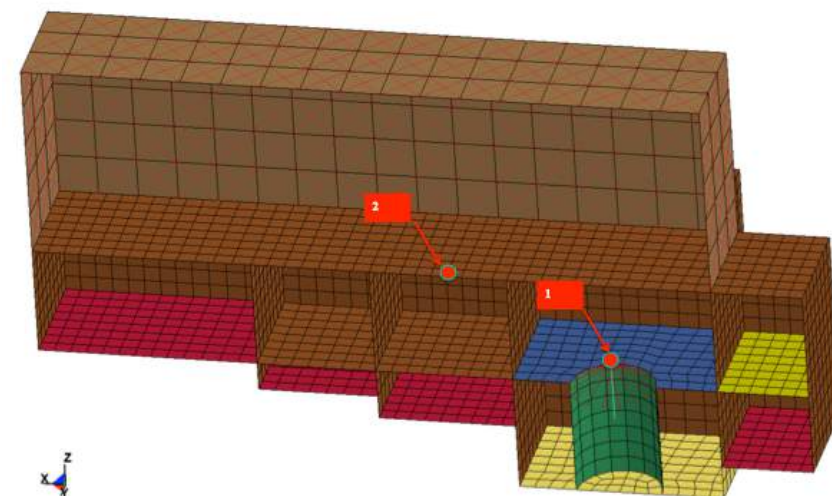
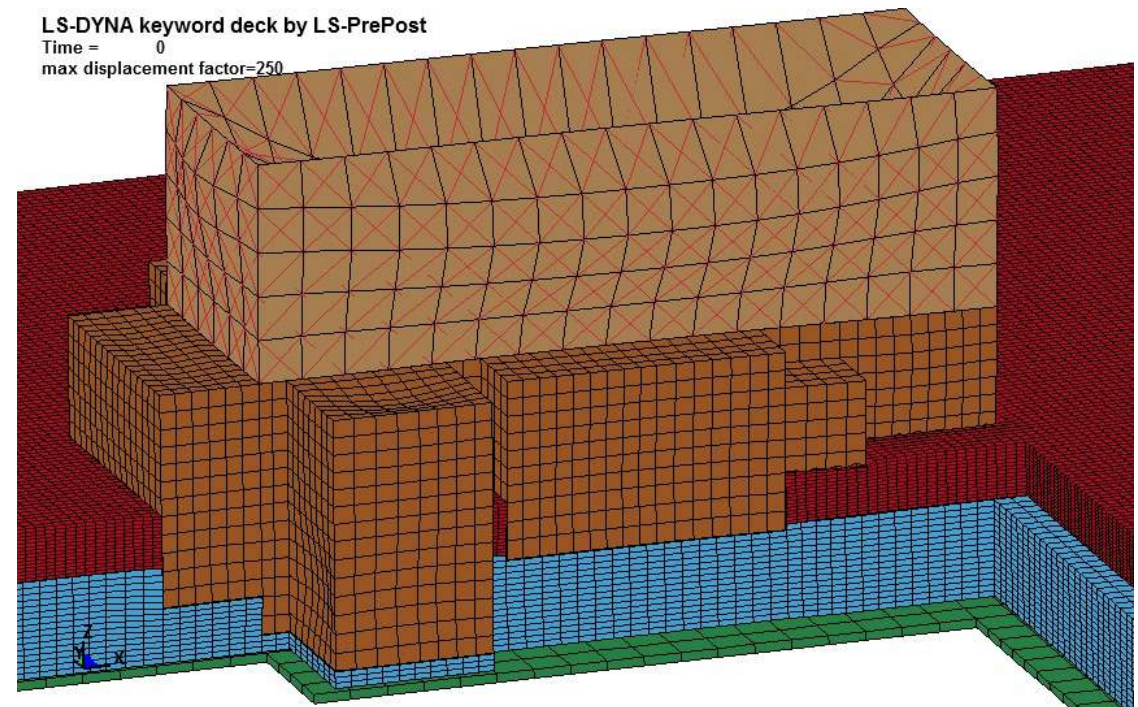
Is the assumption that ground motion scales linearly with ground motion valid?



◆ Projected Location 1 Response at Site A Linear
▲ Projected Location 1 Response at Site A NLSSI



◆ Projected Location 2 Response at Site A Linear
▲ Projected Location 2 Response at Site A NLSSI



Nonlinear Soil-Structure Interaction Animation

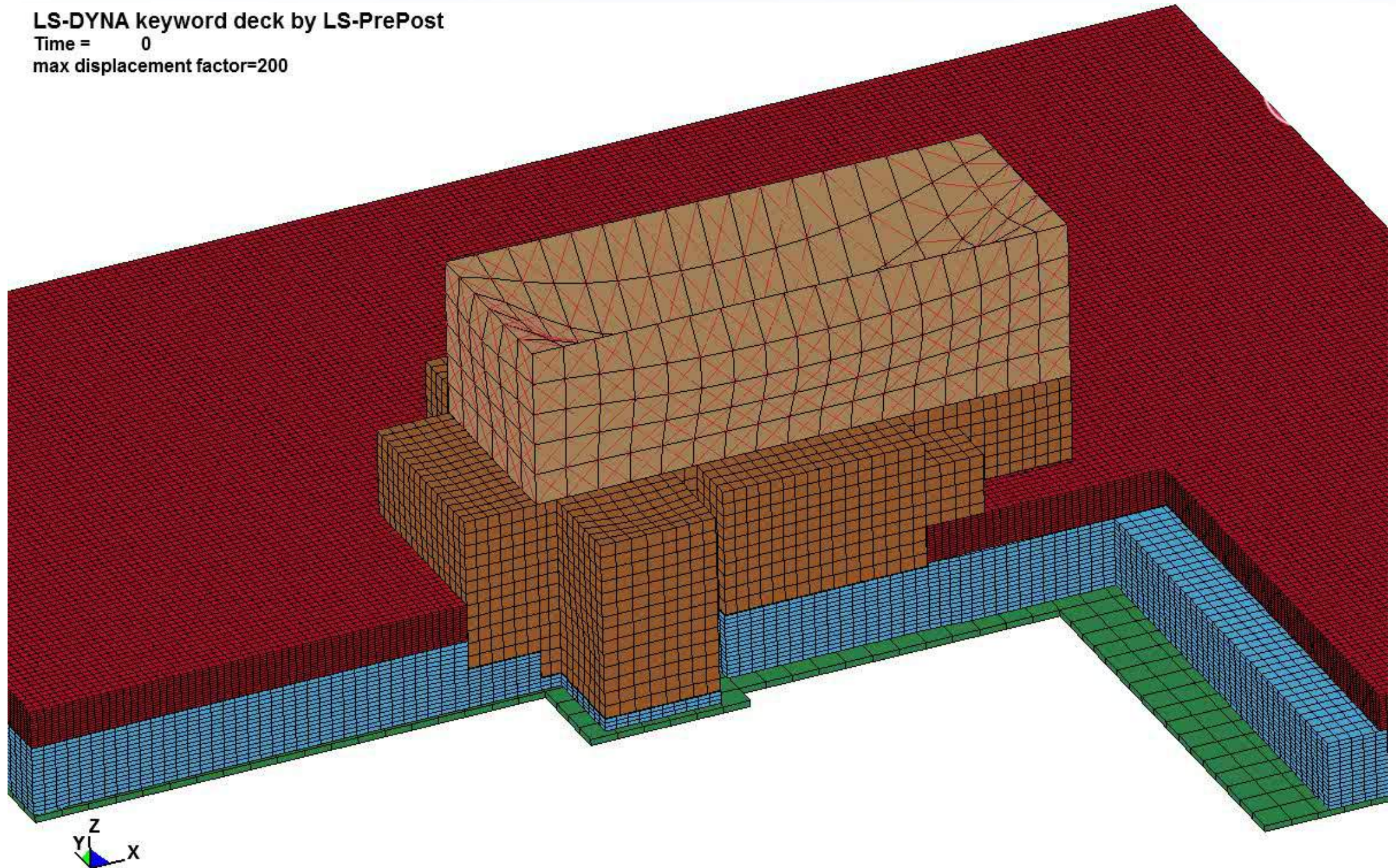
- Number of Elements: 704,000
- Number of CPUs: 1
- Computer Run Time to Produce 40 Seconds of Results: 20 hours

Nonlinear Soil-Structure Interaction Animation

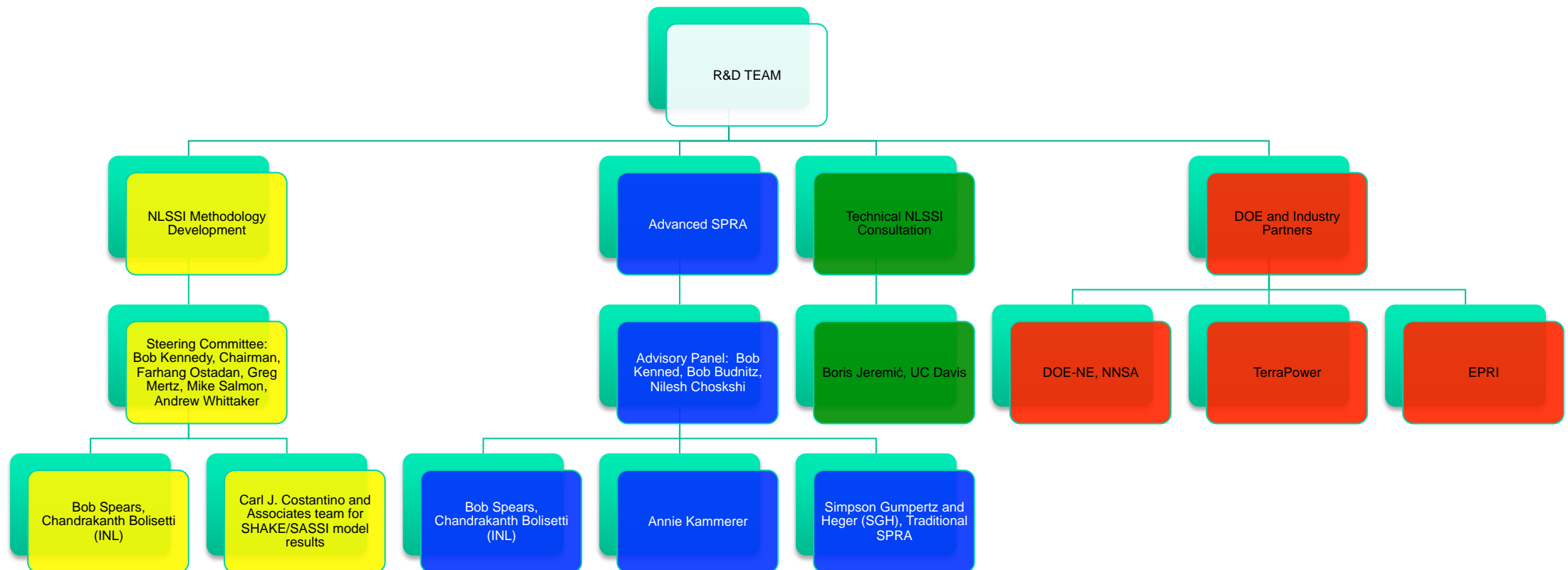
LS-DYNA keyword deck by LS-PrePost

Time = 0

max displacement factor=200



R&D Team



Conclusion

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