Seismic Research and Development

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Purpose of Presentation

- Provide an overview of collaborative INL seismic research and development activities

VISION
Verified and Validated advanced external hazard analysis tools and methods implemented in a comprehensive, risk-informed framework that provides best estimate nuclear facility and NPP response and economically ensures plant safety during and after beyond design basis events.
## Research and Development Process for Delivering External Hazard Analysis Methods and Tools

<table>
<thead>
<tr>
<th>METHODS</th>
<th>TOOLS (Numerical Software)</th>
<th>DATA</th>
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<tbody>
<tr>
<td>Development of code based criteria and approaches for using advanced tools.</td>
<td>Software development to support code based criteria. Numerical approaches for analyzing design and beyond design basis events.</td>
<td>Perform experimental tests (gather data) to validate the methods and tools. Gather data from actual earthquakes to validate site response analysis and infer dynamic soil properties.</td>
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External Hazard Methods and Tool Development

- Tools developed on a common framework, MOOSE
- Couple together multiple capabilities
- Quantify external hazard risk
- Provide the basis for making economically safe decisions
<table>
<thead>
<tr>
<th>Advisory Committee</th>
<th>Team Members</th>
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<tbody>
<tr>
<td>Bob Kennedy</td>
<td>Chandu Bolisetti (INL)</td>
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<tr>
<td>Farhang Ostadan</td>
<td>Swetha Veeraraghavan (INL, post doc)</td>
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<td>Greg Mertz</td>
<td>Bob Spears (INL)</td>
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<td>Mike Salmon</td>
<td>Will Hoffman</td>
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<td>Andrew Whittaker</td>
<td>Efe Kurt (INL, post doc June 2016)</td>
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<tr>
<td>Bob Budnitz</td>
<td>Justin Coleman (INL)</td>
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Tools Applied to Nuclear Facilities

- Tool kit used to design nuclear facilities for design and beyond design earthquakes
- Used for:
  - Existing nuclear facilities and nuclear power plants
  - Deeply embedded advanced reactors
- For existing nuclear facilities need to quantify material aging
- Need economics tool to assess potential benefit of seismic isolation
Need for Advanced Seismic Methods and Tools

- Quantify response of NPPs and Nuclear Facilities for:
  - Effect of embedment (deeply embedded structures)
  - Non-vertically propagating waves
  - Gapping, sliding, and uplift and large soil strains during medium to large earthquakes
  - Seismic isolation
- Methods need to be implemented in codes and standards
  - Appendix B of ASCE 4

From: Darendeli (2001)
• Running nuclear structure models at various sites at various embedment depths and comparing with SASSI to determine:
  – What process should be followed when using NonLinear Soil-Structure Interaction (NLSSI)
  – What nonlinearities change ISRS
  – Assessing usability of current gapping, sliding, uplift models
  – Assessing usability of current nonlinear soil models
  – How large does the NLSSI soil box need to be

East-West – x-direction
North-South – y-direction
Vertical – z-direction
Tool Development, Mastodon

- Mastodon is a nonlinear soil-structure interaction finite element analysis tool
- Mastodon code development includes
  - Newmark Time Integration
  - Point source energy release calculations
  - Domain Reduction Method (DRM)
  - Dynamic Porous Media Flow (u-P-U)
  - Multi-Yield Hysteretic Soil Model (Soil-HYS)
  - Lysmer Boundaries
  - Rayleigh Damping
  - Ability to coupling with other physics
- **Current development work**
  - Gapping, sliding, and uplift element for cyclic shaking
  - Stochastic finite elements
  - Web-based verification and user Manuals
  - Low strain frequency independent damping viscous damping
  - **Verification** of new capabilities
  - Beta version of Mastodon
  - Automating capability to minimize user error
Validation of Mastodon

- Data gathered will be made publically available
- Two specific activities ongoing:
  1. Validation of 1D site response using geotechnical laminar box (GLB)
  2. Development of small scale laboratory for gapping, sliding, and uplift studies
    - Used to inform numerical constitutive models
    - Data used to develop larger system scale tests
Validation of Mastodon

GLB

• “Simple” 1D input
• Simple sine waves in undrained sand
• Five series of tests from low (linear soil response) to higher amplitude
• Data from test used to benchmark and validate linear and nonlinear site response numerical codes
• Provides data that will be used to characterize shear wave passage in a controlled environment

Gapping Sliding Uplift

• Small-Scale Structural Dynamics Laboratory
  • Allows numerical code developers to define and run experiments
• Physical testing of new ideas
• Collecting independent data
• Integrating the observations and measured data into numerical analysis
• Producing reliable and useful information for the science community and public
• Investigation of the Soil-Structure Interface Behavior:
  • Different soil types and conditions
  • Different material, geometry, and surface roughness for the structural model
  • Different loading conditions; monotonic, cyclic, and shake table
  • Comparison with the available constitutive relations for the best estimate
• State-of-the-art instrumentation
Questions

• Seismic research team at INL developing verified and validated multi-hazard methods and tools for quantifying risk at nuclear facilities and NPPs.
• Methods and Tools used to economically ensure nuclear facility safety
• Used for:
  – Existing nuclear facilities and nuclear power plants
  – Deeply embedded advanced reactors
INL Seismic R&D Mission and Vision

VISION

Verified and Validated advanced external hazard analysis tools and methods implemented in a comprehensive, risk-informed framework that provides best estimate nuclear facility and NPP response and economically ensures plant safety during and after beyond design basis events.

- Manage seismic risk at nuclear facilities and nuclear power plants (NPPs) through cost effective analytical approaches and technologies
- Reduce uncertainty and quantify the safety margins at existing and new nuclear facilities and NPPs.

Short Term Goal

- Integrate R&D efforts and expertise to create a useable seismic soil-structure interaction (SSI) methodology deployable in codes and standards
- Manage seismic risk at nuclear facilities through cost-effective, verified and validated analytical methods and tools
- Develop and deploy technologies and approaches for seismic risk management technologies, such as seismic isolation (SI)

Medium - 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.
- Allows nuclear facility owners to virtually test nuclear facilities with external hazards before the actual facilities are tested with actual hazards.
- Owners can then anticipate potential issues and effectively invest their money
Action Justin and Anthony, explore the possibility of placing a stiff soil column in the box

- Bob and Greg had a concern that with a stiff soil column a full wavelength would not be formed. For instance if a 1000 ft/s soil column was placed in the box and we wanted to pass a frequency of 25 Hz then one wavelength is about 40 ft (longer than the box). (Action Justin, Anthony, and Greg work on defining a reasonable test)

- More discussion at 2:00 pm