Civil and Structural Engineering Gaps in Small Modular Reactor Designs

Boris Jeremić (UCD/LBNL)
with
Justin Coleman (INL) and Andrew Whittaker (UB)

ASME 2014 SMR Symposium

Outline

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SMR: Civil Structural Economic Opportunities

- SMRs present the opportunity to make investments in nuclear power more affordable
- To capitalize on this economic potential SMR vendors need to:
  - provide a design that is economically more affordable (per kilowatt hour) by:
    - Maximizing the modularity
    - Minimizing regulatory risk by using standardizing approaches for modular construction, seismic isolation, and seismic analysis

SMR: Regulatory Challenges Related to Standardization

- Ideally vendors would have standardized methods to use in the licensing process:
  - Modular construction
  - Seismic isolation of Structure, Systems, and Components (SSCs)
  - Seismic analysis methods
- Standardized methods would minimize NRC questions during the licensing process

SMR: Need for Appropriate Tools and Methods

- Seismic Analysis and Design to meet Performance Goals
  - Analysis must be accurate, reducing modeling uncertainty
  - Design must be consistent with codes and standards
  - Produce designs that are conservative with respect to the Earthquake Hazard
- Seismic Probabilistic Risk Assessment
  - Want accurate (or best estimate) core damage frequency numbers

SMR: Seismic Challenges (from US-NRC)

US-NRC DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER iPWR DESIGN; (deeply embedded structures)

- Effect of deep embedment on the relative significance of kinematic interaction
- The extent to which non-vertically propagating shear waves may be more important for deeply embedded structures than for those with shallow embedment depth
- The impact of deep embedment on the accuracy of side wall impedance functions calculated with standard methods
- The effect of nonlinear behavior (e.g., separation of structure and soil, and soil material properties) on wall pressure and SSI calculations;
- The variation of V/H (vertical to horizontal) spectral ratios on ground motion over the depth of the facility.

SMR: Challenges for Design

- Seismic performance goals for SMRs
- Earthquake Soil Structure Interaction analysis of deeply embedded structures
- Modeling of fluid-structure interaction
- Seismic isolation of SMR components and systems
- Modular SC construction of SMR components and systems
- Uncertainty in material behavior, earthquake loads, &c. (advanced seismic probabilistic risk assessment for SMRs)
- Modeling uncertainty
- Protection of SMRs from man made hazard (aircraft impact, &c.)
- Regulatory guidance for the civil/structural design of SMRs

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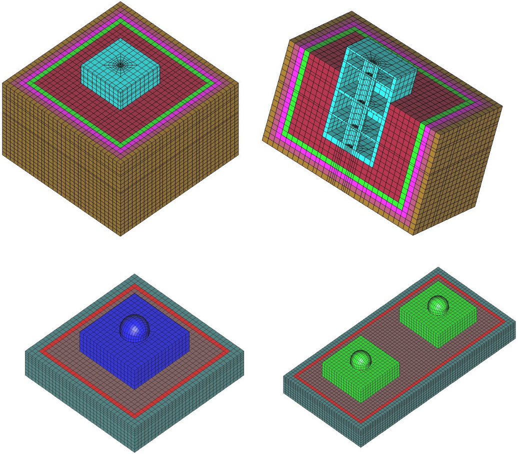
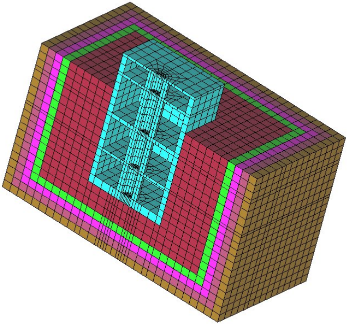
High Fidelity Modeling and Simulation

Some soil-structure features of SMR are similar with LWRs

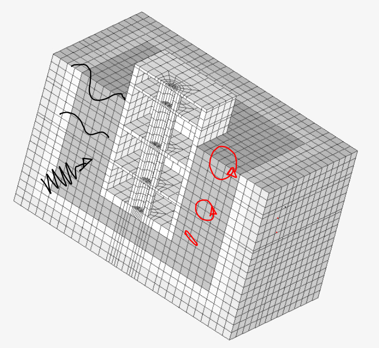


Earthquake Soil Structure Interaction (ESSI)



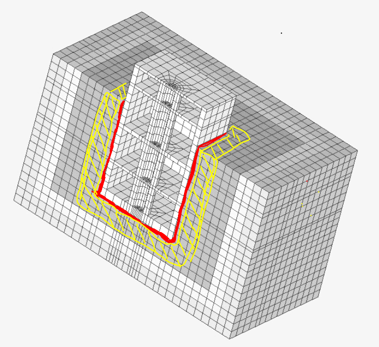
- A number of ESSI modeling and simulation issues that control the seismic response
- Detrimental and Beneficial ESSI effects
- Seismic energy propagation and dissipation

ESSI: Seismic Body and Surface Waves



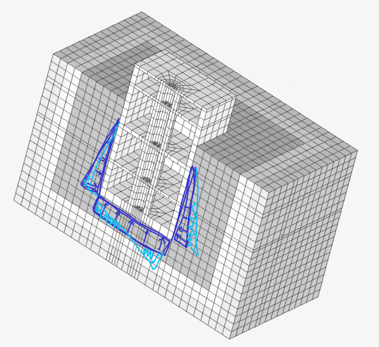
- Seismic surface waves carry most seismic energy
- SMR bottom: body waves; SMR top: surface waves
- Incoherent seismic motions

ESSI: Nonlinear Contact and Soil/Rock Zones



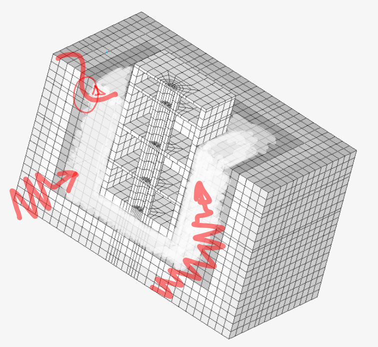
- Seismic energy dissipated at the contact
- Seismic energy dissipated within adjacent soil/rock zones
- Passive (complete) structural isolation (beneficial)

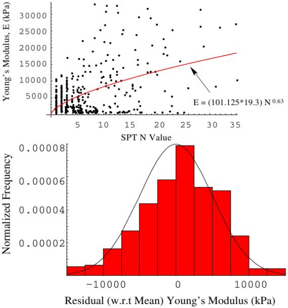
ESSI: Fluid Structure Interaction



- SMR below water table,
- Saturated soil (liquefaction, densification/stiffening)
- Buoyant forces (dynamically changing)

ESSI: Uncertain Material and Uncertain Loads





- Inherently uncertain material response
- Inherently uncertain (seismic) loading
- Full probabilistic modeling and simulations is desired

Modeling Uncertainty

- Goal: reduction of modeling uncertainty
- Modeling Uncertainty: introduced with unnecessary modeling simplification
- Modeling Uncertainty: introduced with unrealistic modeling simplification
- Use of results obtained using models with (high) modeling uncertainty for design is questionable

Verification and Validation

- Verification provides evidence that the model is solved correctly. Mathematics issue.
- Validation provides evidence that the correct model is solved. Physics issue.
- Prediction: use of computational model to foretell the state of a physical system under consideration under conditions for which the computational model has not been validated.
- Goal: physics based predictive capabilities with low modeling uncertainty
- High fidelity, hierarchical, predictive capabilities, aim for higher modeling sophistication then needed

Seismic Isolation

- Goal: reduction of seismic demand
- Active: using engineered devices for SSCs
- Passive: relying on surrounding soil and contact zone

Modular, Standardized Design and Construction

For an efficient (safety and economy) SMR:

- High fidelity modeling and simulation of standardized modules and a complete SMR
- Design of standardized modules
- Construction of standardized modules that assemble into a complete, efficient SMR

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Closing Thoughts

- SMRs present significant opportunities to make investment in nuclear power more affordable
- Design challenges can be successfully overcome by relying on high fidelity modeling and simulation
- Use of full nonlinear, time domain, deterministic and probabilistic modeling and simulation methods/tools (for example: NRC ESSI Simulator) can help emphasize many benefits SMR soil-structure system feature!
- Standardized, modular approach to modeling, design and construction of SMRs for enhanced safety and economy