NRC RIC 2022

March 10, 2022

Development of a Soil-Structure-Interaction Framework in Support to Enhance Regulatory Oversight for SMRs

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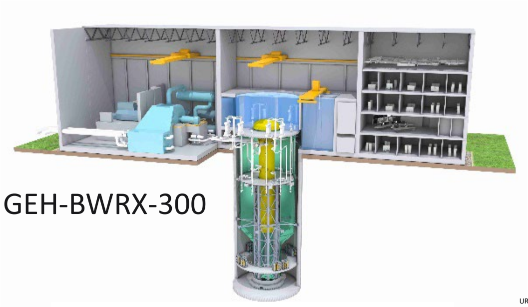
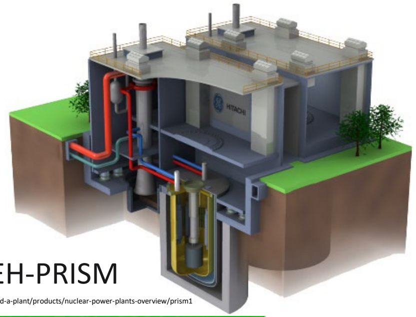
Introduction: Attributes of SMR designs

- Most small modular reactor (SMR) designs that are currently under development place critical compartments, such as the reactor and containment structures, or the entire structure below ground level
- Placing critical compartments below ground level serves as a safety measure from: (i) natural and man-made external hazards, (ii) environmental exposure of contaminants in an accident event, and (iii) conduct heat away from the reactor in the event of a coolant failure



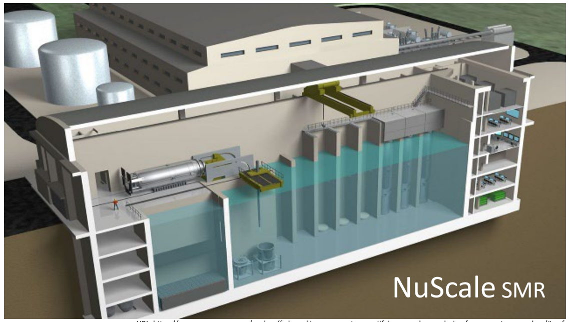
GEH-BWRX-300

URL :https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/bwrx-300



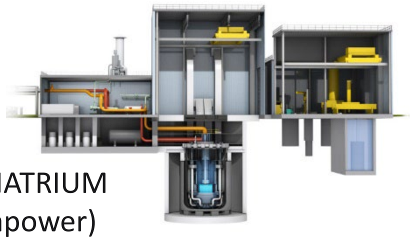
GEH-PRISM

URL :https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/prism1



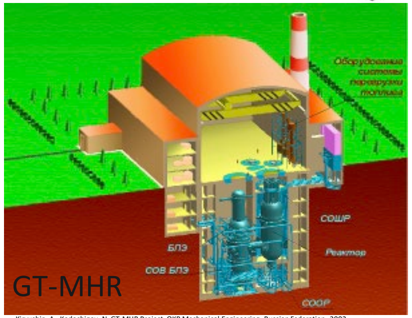
NuScale SMR

URL: https://www.power-eng.com/nuclear/feds-seeking-comment-on-certifying-nuscale-smr-design-for-u-s-next-gen-nuclear/#gref



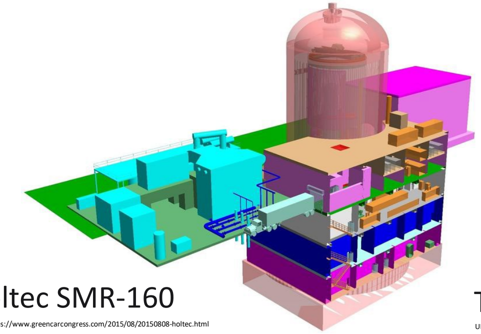
GEH-NATRIUM (Terrapower)

URL : https://natriumpower.com



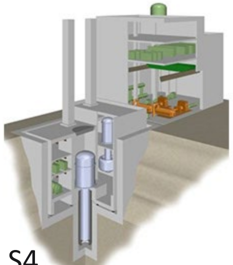
GT-MHR

Kiryushin, A., Kodochigov, N. GT-MHR Project, OKB Mechanical Engineering, Russian Federation, 2002



Holtec SMR-160

URL : https://www.greencarcongress.com/2015/08/20150808-holtec.html



Toshiba S4

URL : https://www.toshiba-energy.com/en/nuclearenergy/rd/safety-reactor.htm

Introduction: Research Motivation

- Partially or fully burying large compartments will change the dynamic response of structure compared with surface footings and increase the importance of modeling soil-structure interface behavior (e.g., gapping and sliding between structure and soil)
- Most tools for evaluating SSI effects have been developed and validated for structures located at or near the ground surface
- There is a <u>lack of large-scale experimental data</u> for validation of nonlinear contact/interface behavior of embedded structures
- Validation is needed to provide confidence in results from numerical simulations of partially-buried SMRs

- **This study seeks to fill this gap through large-scale experiments and advanced numerical simulations**

Project Objective and Research Need

- **Primary Objective:**
  - Develop a framework to analyze and evaluate the seismic response of new generation SMR designs while accounting for nonlinear soil-structure-interaction and their unique designs
- **Research Need:**
  - Conduct large-scale experimental evaluations to investigate and characterize the SSI behavior of partially-buried structures
  - Develop experimentally-validated numerical modeling methodologies for evaluating SMRs and other nuclear facilities

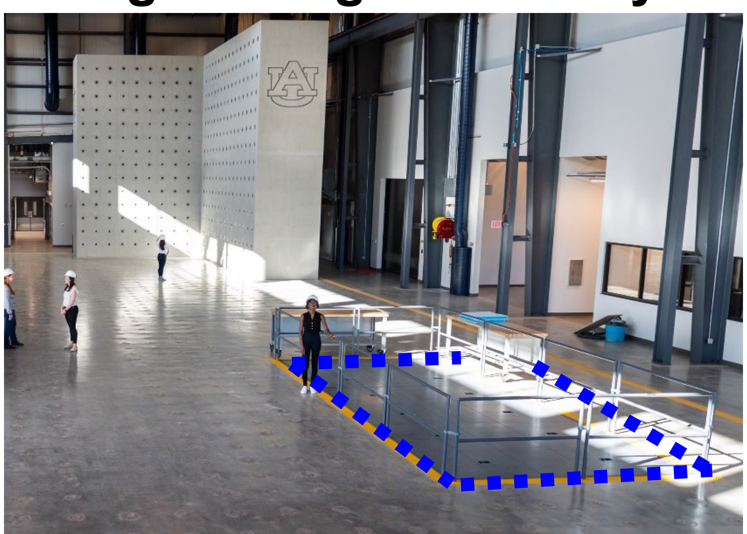
Project Tasks

- The project will consist of three major phases
  - Phase 1: Large-scale testing of caissons
    - Conduct large-scale SSI experiments to generate reliable experimental data
  - Phase 2: Development of experimentally validated FE models
    - Develop and validate numerical models against experimental data obtained in this research and other relevant tests using nonlinear time-domain modeling tools
  - Phase 3: Validating modeling approach against actual field data
    - Perform comparative studies using the developed FE modeling methodology to capture the response of seismic response recordings of NPP structures

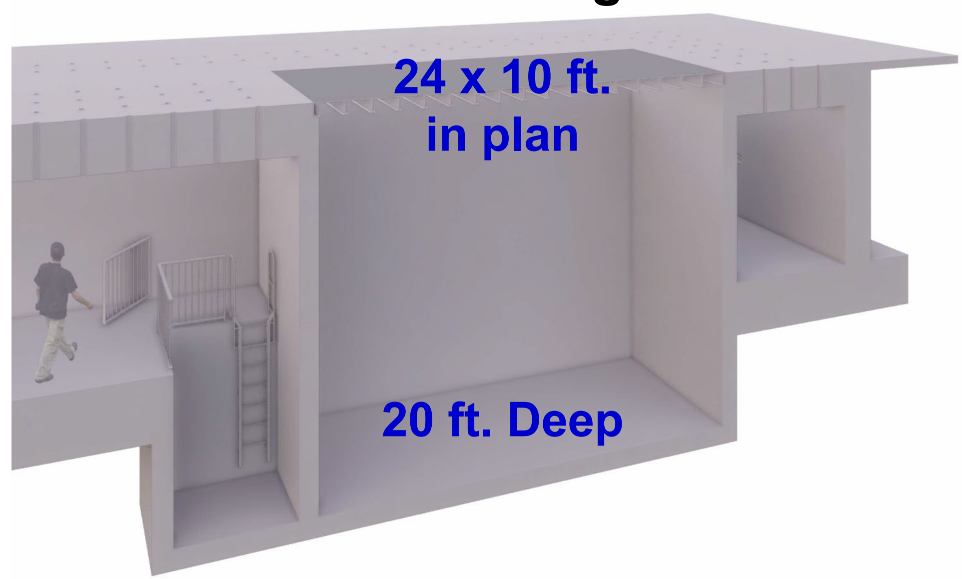
Phase 1: Large-scale testing

- Conduct large-scale SSI experiments to generate reliable experimental data that captures:
  - Physical properties controlling the system response
  - Field representative interfaces
  - Realistic length scales
  - Various effective stress levels

Advanced Structural Engineering Laboratory

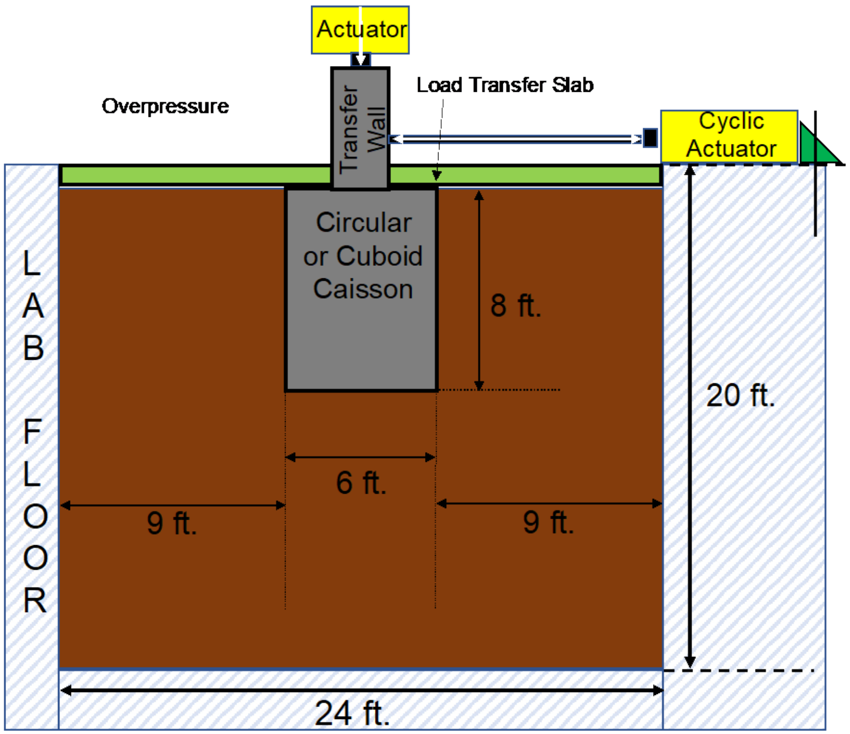


Geotechnical Testing Chamber



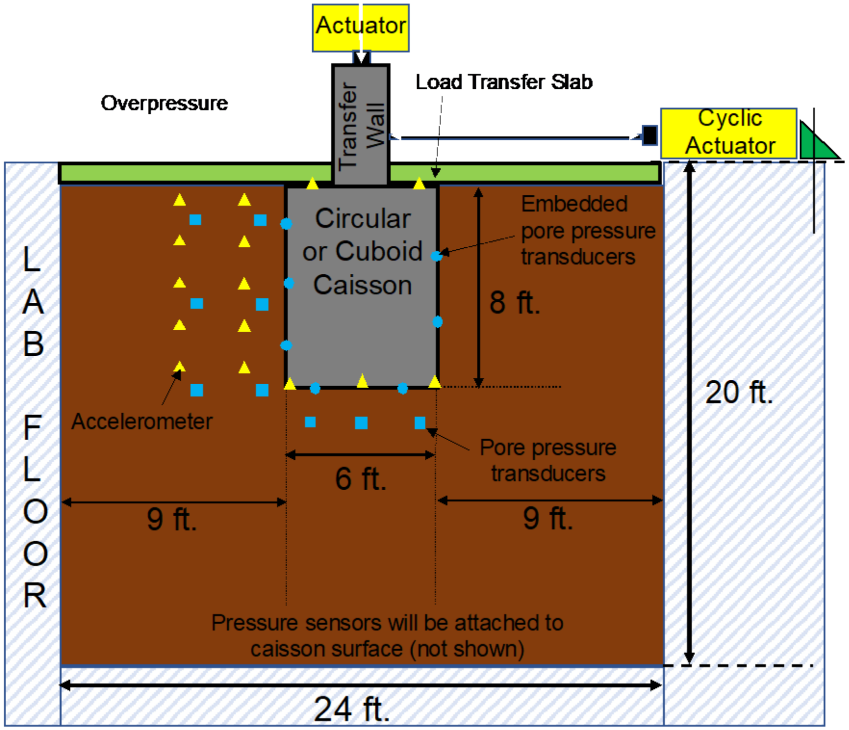
Phase 1: Large-scale testing

- Conduct large-scale SSI experiments to investigate and characterize interface and soil properties
- Testing parameters:
  - Specimen properties
    - Caisson shape
    - Caisson surface material
    - Caisson burial depth
  - Soil properties
    - Soil density
    - Soil saturation level
  - Horizontal loading type
    - Quasi-static cyclic
    - Hormonic vibrations
    - Ground motions expected in the US
  - Vertical over-pressurization level



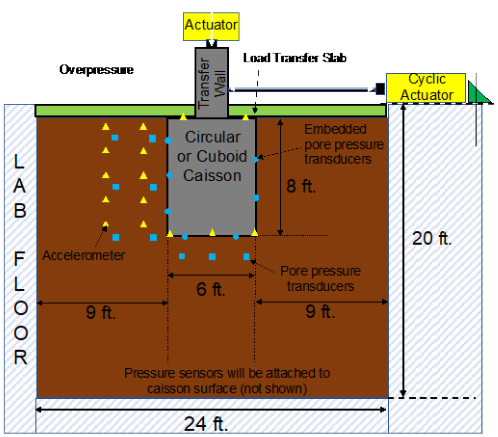
Phase 1: Large-scale testing

- Conduct large-scale SSI experiments to investigate and characterize interface and soil properties
- Testing measurements:
  - Hysteresis responses of caisson (e.g., force vs. displacement and moment vs. rocking angle)
  - Dynamic soil capacity measurement for combined loading
  - Surface pressures at interfaces and formation of gaps
  - Transient and permanent vertical settlements
  - Pore water pressure at interfaces
  - Post-test particle size distribution at interfaces for evaluating crushing

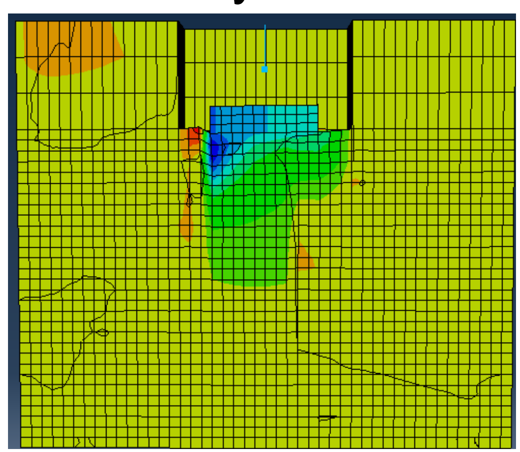


Phase 2: Development of FE models

- Develop and validate benchmark numerical models in nonlinear time-domain FE software (e.g., Abaqus, LS-Dyna, MASTODON) against experimental data
  - Validation of nonlinear constitute material models
    - Backbone curves, pressure sensitivity parameters, dilation constants, cut-off pressure
  - Characterize pressure-dependent interfacial properties
    - Normal direction properties (gapping, rocking)
    - Tangential direction (sticking, sliding, friction)
  - Sensitivity studies on boundary conditions used in model

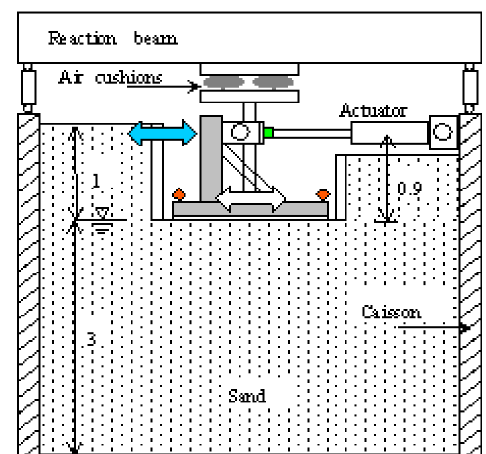


SSI Testing to be conducted in this Research



Representative FEA result

From D. Datta, et al. Investigation of interface nonlinearity on SSI analyses," SMiRT-24, 2017

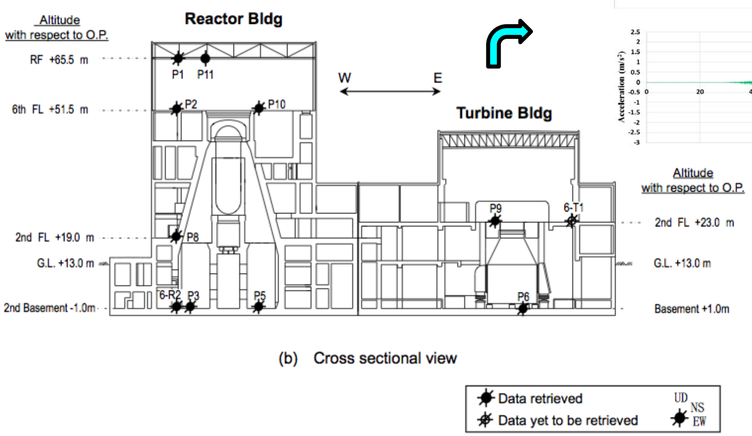


Similar SSI Testing conducted in the past

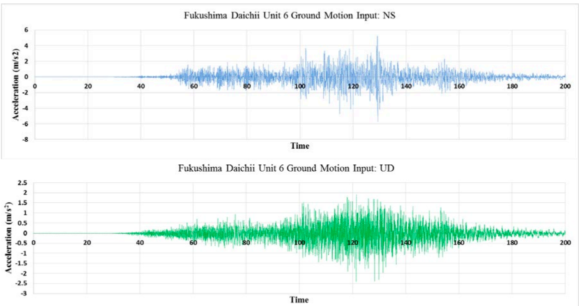
From P. Negro, Large-scale geotechnical experiments on soil-found. interaction, TRISEE, 1998.

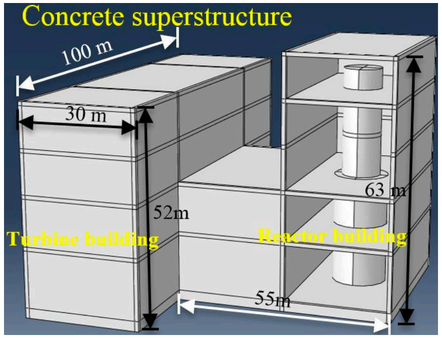
Phase 3: Validating modeling approach

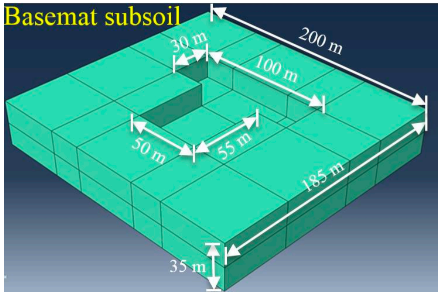
- Perform comparative studies against real field data.
  - Conducting an exploratory study to validate the applicability of the modeling approach for implementation on full scale safety-related nuclear structures,
    - Modeling of the Fukushima Daiichi NPP using the site soil profile and ground motion data measured near the NPP
  - Conducting comparative studies against the 'industry-standard' frequency-domain linear analyses.



(b) Cross sectional view







Figures from D. Datta, et al. Investigation of interface nonlinearity on SSI analyses," SMiRT-24, 2017

Project Timeline

Tasks	FY22				FY23				FY24			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Phase 1: Large-scale testing of caissons												
Phase 2: Development of experimentally validated FE models												
Phase 3: Validating modeling approach against field data												

AUBURN UNIVERSITY

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Thank you for the opportunity to present our project

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