
# Staff Presentation to the ACRS Sub-Committee

**GEH Licensing Topical Report**
**BWRX-300 Advanced Civil Construction and Design Approach**
**(NEDO–33914, Revision 1)**

**MARCH 18, 2022**

# Topical Report Review Chronology

- GEH submitted licensing topical report (LTR) NEDO–33914, Revision 0, "BWRX-300 Advanced Civil Construction and Design Approach," on January 20, 2021
- NRC issued requests for additional information (RAIs) 9849 and 9859 on July 19 and July 30, 2021, respectively
- GEH provided responses to RAI 9849 on August 19, 2021, and RAI 9859 on September 13 and November 4, 2021. The NRC staff found the responses acceptable.
- GEH issued LTR Revision 1 on November 18, 2021, that incorporated the RAI responses
- NRC issued the advanced safety evaluation on February 15, 2022

# NRC Staff

**Reviewers:**

- Amitava Ghosh, Ph.D., Geotechnical Engineer, Presenter, NRR/DEX/ESEB
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# Agenda

- Introduction
- Difference Between Traditional Light Water Reactor and GEH BWRX-300
- Regulatory Bases
- NRC Staff Major Reviewed Topics
- Other Reviewed Topics
- NRC Staff Review Strategy
- Rock Fracture Network/FIA Model/Limitation & Condition (L&C) #1
- Stability of Reactor Shaft/L&C #2
- Soil-Structure Interaction Modeling/L&C #3
- Strain-Compatible Subgrade Dynamic Properties/L&C #4
- Nonlinear Soil-Structure Interaction Analysis/L&C #5
- Staff Conclusions

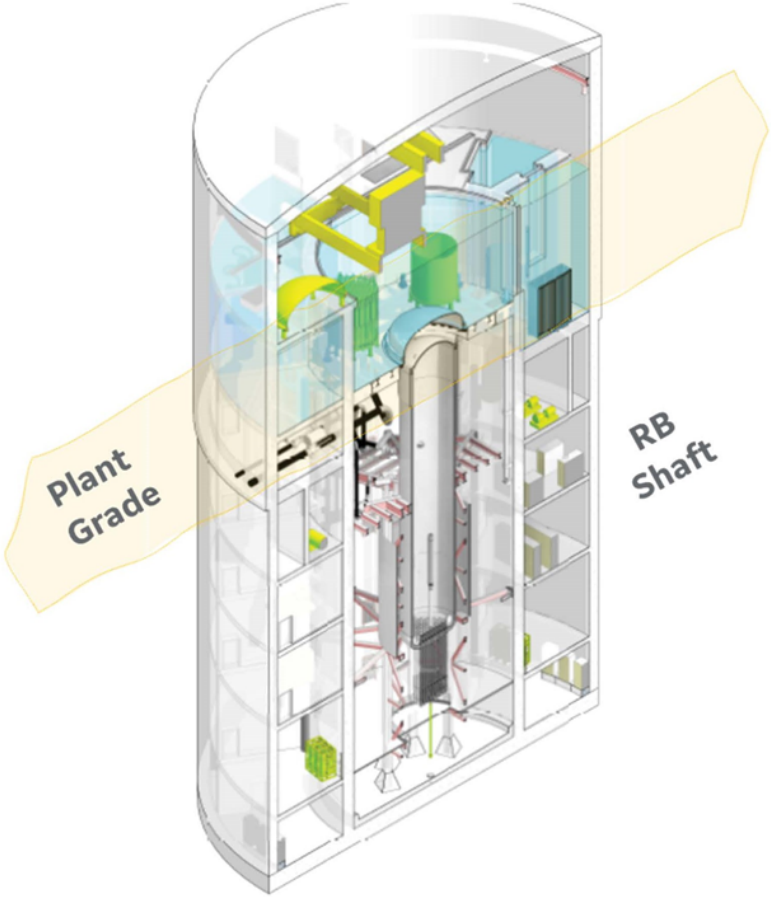
# Difference Between Traditional Light Water Reactor and GEH BWRX-300

- GEH BWRX-300 will be deeply embedded in a vertical shaft
- Posses some unique issues
  - Reactor may be in only soil layers, only rock layers, or rock overlain by soil
  - Rock mass has fractures; joints, bedding planes, faults, cavities (karst features): fracture network
  - In-situ stress field
  - Water table
  - Response to Safe Shutdown earthquake (SSE)

**From: Cao, et al. 2016. An Experimental and Numerical Study on Mechanical Behavior of Ubiquitous-Joint Brittle Rock-Like Specimens Under Uniaxial Compression. Rock Mechanics and Rock Engineering.**

# GEH BWRX-300 Reactor

- RB is placed in a vertical right-cylinder shaft and located below-grade to mitigate effects of possible external events, including aircraft crashes, adverse weather, flooding, fires, and earthquakes




**LTR Figure 1-3**

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# Regulatory Bases

- Defining Subsurface Conditions
  - 10 CFR 100.20(c)(1): the Commission consider physical characteristics of the site
  - 10 CFR 100.23: sets forth the principal geologic and seismic considerations that guide the Commission in its evaluation of the suitability of a proposed site and adequacy of the design bases established in consideration of the geologic and seismic characteristics of the proposed site, such that, there is a reasonable assurance that a nuclear power plant can be constructed and operated at the proposed site without undue risk to the health and safety of the public

- Development of Site Design Parameters
  - 10 CFR Part 50, Appendix A, General Design Criteria 2: Design bases for protection against natural phenomena

# NRC Staff Review

- LTR proposes approaches at conceptual level to deal with technical issues
  - Rock fracture network (LTR Section 3.1.3 and others)
  - Stability of reactor shaft (LTR Section 5.1.2 and others)
  - Foundation Interface Analysis (FIA) model (including parameter estimation) (LTR Section 4)
  - Soil-Structure Interaction (SSI) modeling (including parameter estimation of equivalent linear elastic materials) (LTR Section 5.1.2)
  - Strain-compatible dynamic properties (LTR Section 5.2.4)
  - Nonlinear SSI analysis (sensitivity) (LTR Section 5.3.11)

# Other Reviewed Topics in LTR

- Design Earth Pressure Load Validation (LTR Section 5.1.3) including Probabilistic Earth Pressure Analyses (LTR Section 5.1.4)
- Development of Ground Motion Acceleration Time Histories (LTR Section 5.2.3)
- Effects of Non-Vertically Propagating Seismic Waves (LTR Section 5.3.3)
- Approaches for Meeting DC/COL ISG-017 Guidance (LTR Section 5.3.4)
- Modeling of Structure-Soil-Structure Interaction Effects (LTR Section 5.3.7)
- Soil Separation Effects (LTR Section 5.3.9)
- Groundwater Variation Effects (LTR Section 5.3.10)
- II/I interaction effects (LTR Section 6)

# NRC Staff Review Strategy

- Staff review emphasized on
  - Whether the proposed approach is appropriate?
  - Has the proposed approach been used before in similar circumstances elsewhere, especially in nuclear applications?
  - Has proposed approach any limitations?
  - Have all parameter values necessary to use the approach be determined using appropriate test method(s)?
  - Does the proposed approach have any inherent assumption that needs to be verified?

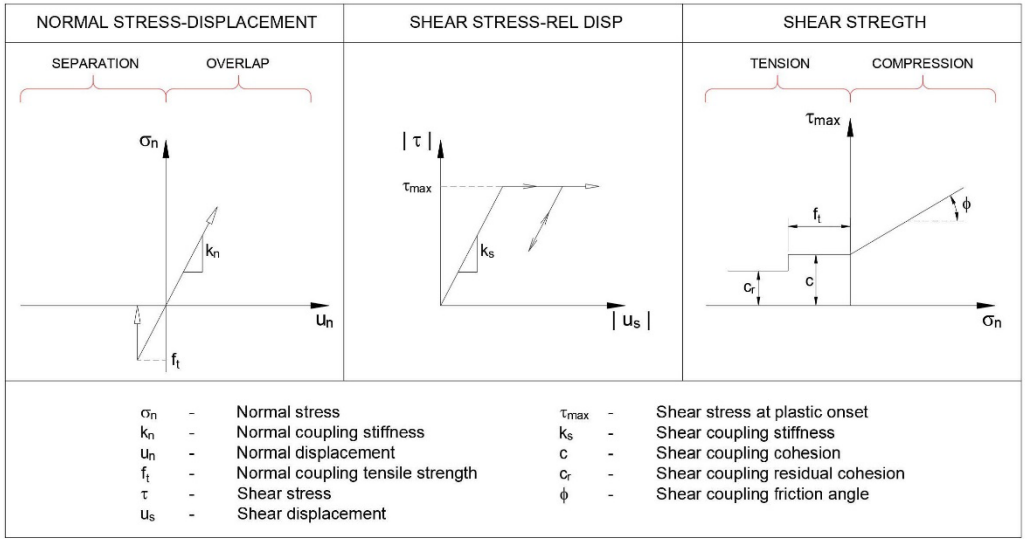
# Rock Fracture Network

- Fractures control the response of a rock mass
- Fracture network:
  - Dip angle
  - Dip direction
  - Fracture spacing
  - Number of fracture sets
- Staff will review rock fracture network characterization (LTR Section 3) in a site-specific license application

**From: Cao, et al. 2016. An Experimental and Numerical Study on Mechanical Behavior of Ubiquitous-Joint Brittle Rock-Like Specimens Under Uniaxial Compression. Rock mechanics and Rock Engineering.**

# Foundation Interface Analysis (FIA) Model (LTR Section 4)

- Response of the interface in normal (perpendicular) direction
- Response of the interface in shear (along) direction
- Shear strength of the interface
- Normal strength = 0
- Model will have rock/soil-structure, rock-rock (joints, bedding planes, etc.), rock-soil interfaces
- Simulation at different stages: pre-excavation through start-up and operation

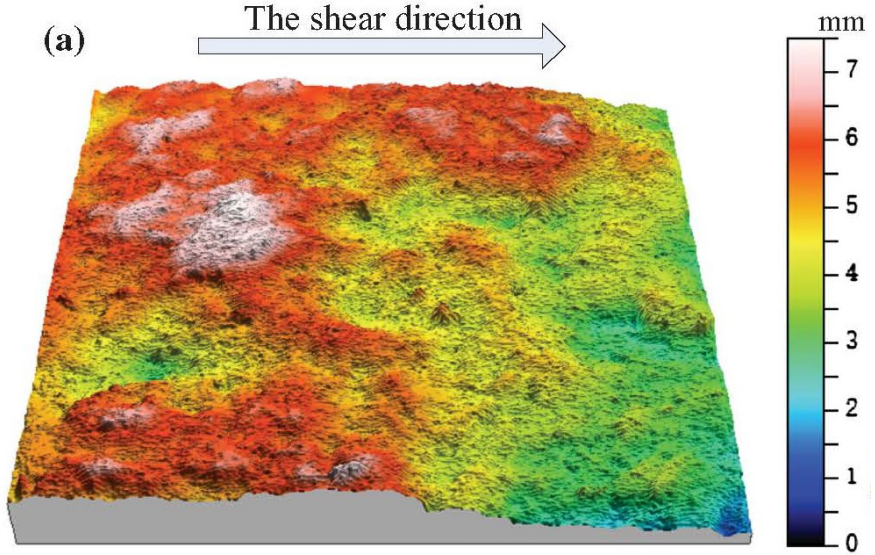



**LTR Figure 4-2**

# FIA Model Parameter Estimation

- Direct Shear Test in Laboratory
  - Natural rock joint samples collected in site investigation
  - Large sample size

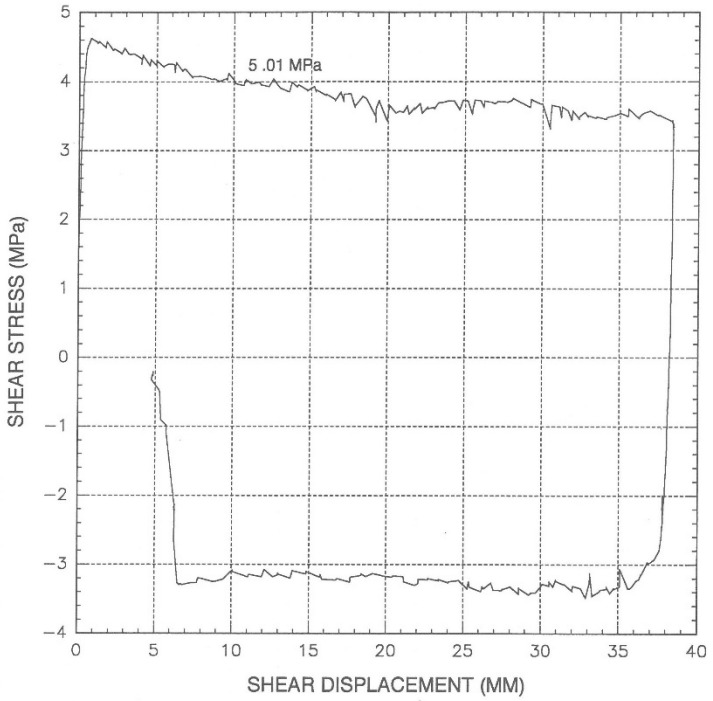
- Sample rock joint surface

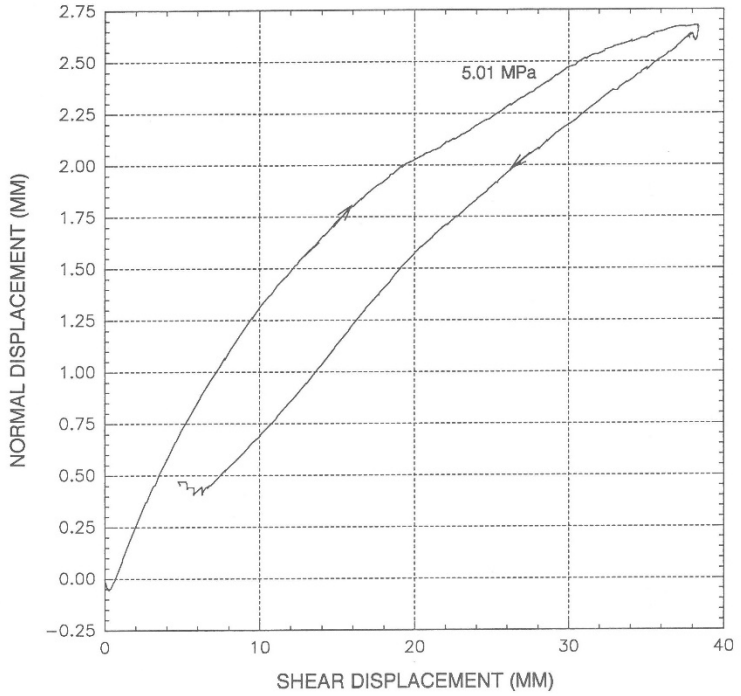



**From: Fan, et al. 2019. Geotechnical and Geological Engineering. Experimental and Numerical Study on the Damage Evolution of Random Rock Joint Surface During Direct Shear Under CNL Condition.**

# Direct Shear Test of Rock Joint

- Shear Test vs. Shear Displacement
- Normal Displacement vs. Shear Displacement




**From: NUREG/CR-6178**

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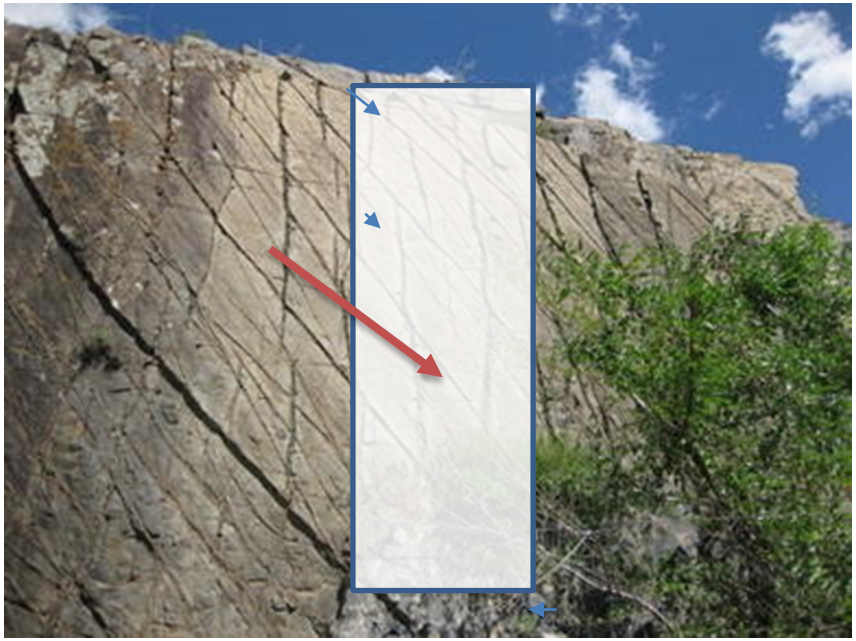
# Limitation & Condition (L&C) #1: Interface Characteristics Testing

- Large size samples collected at a site should be tested in the laboratory to have an acceptable estimate of the measured fracture (e.g., rock-rock, rock-soil) and interface (e.g., rock/soil-structure) strength and deformation parameters for a nuclear power plant (Response to RAI 02.05.04-2)

- Staff will review the sizes of the samples and their testing at the laboratory to estimate the properties of the discontinuities and interfaces in a site-specific license application with a BWRX-300 SMR

# Stability of Reactor Shaft

- Stability of Embedded Reactor: Unstable rock mass without any permanent support systems is not acceptable
- Unstable blocks in surrounding region
  - Key block theory (Goodman and Shi, 1985)
  - Numerical simulation e.g., FIA model (LTR Section 4.0)
  - Results verified by instrumentation installed (LTR Section 3.3)



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# L&C #2: Stable Excavation

- A stable shaft excavation would have no unstable blocks in its surrounding that may slide into the excavation
- A self-supported (even with some temporary reinforcement) excavation would be needed to place the RB and to estimate the earth pressure loads to be considered in the generic design of the RB structure
- Staff will review method(s) used to identify the unstable rock blocks and to assess the earth pressure imparted on the RB shaft for determining whether the subgrade is acceptable for siting the reactor in a site-specific application
- Any temporary reinforcement or mitigation measures used to stabilize the surrounding materials would be reviewed by the staff

# Soil-Structure Interaction (SSI) Modeling

- Interaction of embedded RB structure with surrounding media important for integrity of the RB structure

- Simplified assumptions to enable efficient calculation of stress demand on the RB using the System for Analysis of Soil-Structure Interaction (SASSI) computer code
  - Subgrade material continuous
  - Subgrade material isotropic and linear elastic
  - No nonlinearities at soil-structure interface
  - Static lateral pressure from weight of self-supported rock neglected (Stable Excavation)

- SSI Analysis: following ASCE/SEI 4-16

# Isotropic, Linear Elastic, Continuous Subgrade Media

- Soil: Elastic modulus $E_{st}$ from Cone Penetration Test (CPT), Standard Penetration Test (SPT), Pressuremeter
- Rock: $E_{st}$ function of Intact Rock Modulus, Rock Fracture Network, other properties
  - Rock Mass Classification Schemes: Rock Mass Rating (RMR), Geological Strength Index (GSI), others
  - Each incorporates rock fracture information
  - Groups different rock masses into a few classes
  - Experience from past projects used to assign properties of each class
  - Empirical correlation with rock mass modulus (or, stiffness) $E_{st}$
  - Rock mass idealized as an isotropic medium

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# L&C #3: Isotropic and Homogeneous Rock Mass

- Rock mass classification systems inherently assume isotropic and homogeneous rock mass
- A jointed (or a fractured) rock mass is assumed to contain a sufficient number of fracture sets so that its deformational behavior may be assumed to be isotropic and homogeneous
- Staff will review whether the fracture sets at the selected site would make the rock mass behavior isotropic and homogeneous in any future site-specific licensing application

# Strain-Compatible Subgrade Dynamic Properties

- Properties used as input for SSI analysis to be consistent with soil/rock properties used in generation of input motion
- RG 1.208 and NUREG/CR-6728
  - Control motions based on a generic rock site may not result in strain-compatible properties
- GEH has proposed an approach to develop Hazard Consistent Strain-Compatible Properties (HCSCP) consistent with observed strong ground motion parameters
- Assumed strain-compatible properties approximately lognormally distributed, consistent with observed strong ground motion parameters

# L&C # 4: Site Specific Application of the HCSCP

- Approach is reasonable
- It will be the first ever application to a nuclear reactor project
- During review of future licensing applications, staff will audit the HCSCP approach

# Nonlinear Soil-Structure Interaction (SSI) Analysis

- Nonlinear Seismic Soil-Structure Interaction Analysis (LTR Section 5.3.11)
  - May be important for sites with high seismicity and/or with highly nonlinear subgrade materials
  - Separation and/or sliding at soil-structure interface
  - Nonlinearity at rock fractures
  - Sensitivity Nonlinear SSI analysis following ASCE/SEI 4-16, Appendix B
- Nonlinear SSI analysis is complex

# L&C # 5: Nonlinear SSI Analysis

- NRC staff plans to review the characterization and modeling of the nonlinear behavior of the materials surrounding the reactor in any future licensing application utilizing a nonlinear SSI analysis approach

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# Staff Conclusions

- Staff finds that the approaches proposed to characterize the surrounding media (soil and/or rock) reasonable
- Staff finds that the approaches proposed to develop site design parameters reasonable
- Staff placed five Limitations & Conditions to have a more in-depth review the background information, relevant design/site information, characterization of the surrounding media, and development of site design parameters associated with them