NRC Staff Questions for the November 8, 2023, Public Meeting with SMR, LLC (A Holtec International Company) to Discuss the SMR-160 Update of Its Soil-Structure Interaction Methodology

Note: The following questions were sent to SMR, LLC (Holtec) on November 6, 2023. Additionally, on August 14, 2023, the NRC staff provided responses to SMR (Holtec) for questions SMR (Holtec) asked regarding its Seismic Methodology:

> 8-14-23 - Email to A. Brenner, SMR, LLC (Holtec) re: NRC Staff response to Questions re: Seismic Methodology (Project 99902049)(ML23226A138)

1. Boulanger and Beaty (2016) provide a checklist for the review of seismic deformation analyses of embankment dams. Twelve aspects for a review and associated questions are provided, some of which may be applicable to SSI analyses for nuclear facilities. The twelve aspects are: 1) Seismic Failure Modes and Important Behaviors, 2) Validation Record for the Numerical Model Procedure, 3) Site Characterization Basis for Material Parameters, 4) Calibration and Evaluation of the Constitutive Model, 5) Numerical Modeling Procedures, 6) Input Ground Motions, 7) Initial Static Stress Conditions, 8) Dynamic Response, 9) Post-Shaking Deformations, 10) Parametric Analyses, 11) Uncertainties and Limitations, 12) Reasonableness of Conclusions. Has SMR (Holtec) considered these aspects in its SSI analyses?

2. Given the substantial significance of the soil behavior surrounding the structure, what will you do to verify that the constitutive model properties and analytical soil behavior are consistent with site specific soil behavior? What plans do you have for soil testing or are soil testing results available to demonstrate that the soil constitutive model and chosen model parameters used result in behavior consistent with site soils?

3. How will you consider uncertainty in soil behavior and constitutive model behavior in your analyses?

4. What studies will be completed to evaluate the sensitivity of the structure, system, and component loading/response to variability/uncertainty in the constitutive model and model parameters?

5. The white paper only indicates using the EPRI modulus reduction and damping curves to describe the nonlinear behavior of the soil. Have you considered modulus reduction and damping curves measured using soil samples from the site? What is the basis for the decision to not use modulus reduction and damping curves obtained from site specific soil and other generic curves for soil testing?

6. I understand that *MAT_232 is a linear hysteretic soil model. Are the shear modulus and damping values used to define the model behavior determined from equivalent linear site response analyses for an appropriate loading/strain level?

7. Will you use anything in addition to modulus reduction and damping curves to calibrate the *MAT_079 parameters?

8. Can you provide reasons for some differences in SHAKE2000 and LS-DYNA results. For example, in Figure 8, there is a large spectral acceleration spike in the LS-DYNA results compared to the SHAKE2000 results. What is the reason for the much larger LS-DYNA spectral acceleration between 2 and 3 Hz.

9. How will soil behavior/response in the SSI analyses be used to assess reasonableness of the SSI results?

10. It is not clear whether the FEM model shown in Figure 2 can produce results for overturning, sliding and flotation checks under load combinations as provided per Section 3.8.5 in NUREG-0800.

11. The White Paper discusses nonlinear soil models in detail; however, it does not provide sufficient details on the proposed nonlinear time-domain SSI analysis methodology and corresponding results. Will there be additional preapplication interactions, a future White Paper or Topical Report that provides descriptions and evaluations of some key elements of the proposed methodology including, but not limited to, the following:
    - Modeling of structure-soil interface including gapping and sliding.
    - Soil boundaries – location and type of the lower boundary; location and type of lateral boundaries; handling of radiation damping and description of transmitting boundaries if used.
    - Element size – sufficiently refined finite elements; soil discretization ensuring frequency transmission up to the cutoff frequency.
    - Boundary motion input – compatibility of soil boundary input motions with the design ground motion specified at the control point; treatment of non-vertically propagating waves if considered.
    - Solution scheme and time step – integration time step ensuring stability and accuracy of the solution.
    - Fluid effects (if applicable) – modeling of the fluid and the fluid-structure or fluid-structure-soil interaction effects.
    - Probabilistic SSI analysis (if applicable) - analysis parameters treated as random variables, sampling method used, the number of simulations and statistical properties evaluated, discussion of treatment of uncertainties.

12. The proposed nonlinear SSI analysis methodology is a first-of-a-kind application to new reactor license application. NUREG-0800, SRP criteria generally deal with linear elastic analysis, and SRP Section 3.7.2 also states that “the staff conducts a detailed review of all inelastic/nonlinear analyses.” Therefore, the staff believes that additional information and evaluations beyond the usual scope of linear analysis should be included in the paper for staff’s detailed review of the proposed methodology, such as the following:
    - Verification and validation of the models and methods, including benchmarking against the established solutions (e.g., SASSI frequency-domain linear elastic solutions; theoretical/closed-form solutions, experimental data) to demonstrate reasonableness of the proposed methodology.

- Uncertainty and sensitivity analysis for the models, material properties, input ground motions, and other key parameters involved.
- An independent peer review by those with appropriate geotechnical and structural engineering experience to support reliability and accuracy of the results.

13. Discuss the implications of nonlinear SSI analysis on seismic risk assessment of SSCs in the context of risk-informed performance-based design.

14. In Section 2, Background, it is stated that the “SSI analysis method is adept at explicitly capturing geometric nonlinearity at the interfaces connecting deeply embedded seismic Category I structures with the surrounding soil.” However, in Section 4, SMR SSI Model Development, there is no mention of a contact element available in LS-DYNA used in this Finite Element (FE) model, shown in Figures 2 through 5. It is also not clear whether the results shown in Figure 23 include the geometric nonlinearity of the interface.

15. Figure 1 shows a zone of soil that exhibits nonlinearity. It is not clear how the nonlinear response of the soil was accounted for in the FE model. Is it through the soil shear stress–shear strain hysteretic loop (e.g., as shown in Figures 20 and 21) or the material model itself in nonlinear.

16. Clarify whether the soil layer represented by different color elements corresponds to the layers given in Table 1.

17. Clarify whether the labeling of RAB (north end) and RAB (south end) is correct in Figure 4.

18. Although two LS-DYNA soil material models (*MAT_232 and *MAT_079) were discussed in Section 5, Benchmarking of Soil Models, *MAT_079 element was not discussed later. Confirm whether this material model will also be used in the analysis and discuss the scenarios where one would be preferred over the other. Are there any differences between the responses from these two material models observed?

19. What is Set 1 earthquake in Figure 7?

20. Please define what is meant by mild or moderate seismic events. It is not clear why the seismic response of the concrete structures will be conducted for only mild and moderate seismic events.

21. Section 6, Verification of Time Domain Analysis Method, mentions of surface-to-surface contact model used in the analysis. However, the desired contact behavior (e.g., only sliding, sliding with separation, etc.) or the specific contact model of LS-DYNA used was not mentioned. Please clarify.

22. It is not clear in Section 6, Verification of Time Domain Analysis Method, what is meant by the revised LS-DYNA model. Please clarify what would be the new model and why would it be necessary.

23. In Section 4, SMR SSI Development, it is stated that the “Solid” elements of the LS-DYNA were used to model soil, concrete, and water in the annular reservoir and in the spent fuel pool through a simple fluid material model which has no shear capacity. It is not clear whether the selected solid element with fluid characteristics can simulate water “sloshing” when subjected to a dynamic (seismic) motion. Please clarify. In addition, please discuss the interaction of the element with “Fluid” material model with the “Solid” element.

References

Boulanger, R.W. and Beaty, M.H. (2016). “Seismic Deformation Analyses of Embankment Dams: A Reviewer’s Checklist,” USSD 2016 Annual Meeting and Conference