TOPIC #1: Seismic Hazard (SPID Sections 2.1, 2.2, and 2.3)

Robinson Nuclear Power Plant (RNPP) evaluated seismically induced liquefaction hazards at the HB Robinson plant area in Section 3.1.5 of the SPRA submittal report (ML19346E204, non-public) and addressed three major areas in their evaluations: (i) liquefaction triggering and site wide continuity of liquefaction, (ii) liquefaction induced settlement; and (iii) liquefaction induced lateral spreading. In order to complete SPRA Review Checklist Topic #1, staff requests response to the following clarification questions with regards to the methodology and conclusions associated with each of these evaluations.

A) For evaluation of liquefaction triggering and site-wide continuity of liquefaction, the SPRA submittal report refers to References [40], [41], and [42]. In Section 3.1.5 of the SPRA submittal report, RNPP concluded that "While liquefaction could potentially occur at a single exploration, not every sample in the exploration may indicate liquefaction triggering, and in adjacent explorations, liquefaction triggering may not be indicated at the same elevations. As shown in [42], there is not an indication at any of the four hazard levels of a liquefiable soil layer that is continuous across the protected area." Regarding this conclusion, please address the following questions.

1) Sections 3.3.1 and 3.3.2 of Reference [40] state that the cyclic stress ratio (CSR) was computed using estimates of maximum shear stress (τ_{max}) directly from site response analyses. Section 4.3.3 of the liquefaction sensitivity analysis (Reference [41]) acknowledges that using estimates of τ_{max} from site response analyses to compute CSR leads to an unconservative bias in the resulting factor of safety against liquefaction (FS_L). Section 4.3.3 also shows that for a single boring at a single level of hazard the "factor of safety is increased by about 10-14% on average" with respect to values of FS_L computed using the semi-empirical method proposed by Boulanger and Idriss (2012) to estimate τ_{max}. Despite this unconservativism, the decision in Section 6.0 is to use site-specific estimates of τ_{max} to compute CSR.

   a. How does this decision to use τ_{max} directly from site response analyses affect the continuity of a liquefiable layer [42], settlement [43], and lateral spreading [46], which are dependent on FS_L computed using Boulanger and Idriss (2012)?

2) Regarding the evaluation of continuity of a liquefiable soil layer, Section 6.2 of Reference [42] states that "for purposes of this calculation, site-wide liquefaction is taken to be present if a stratigraphic layer is present that is continuous across the site and within which the liquefaction triggering factor of safety for the evaluated explorations is consistently equal to or less than 1.00."

   a. Please clarify the definition of a layer that is "continuous." For example, must the stratigraphic layer be present in all boreholes, a high percentage, or some other qualitative/quantitative measurement? Must the stratigraphic layer be of a minimum thickness?

   b. Was the uncertainty in the evaluated continuity (or lack thereof) of potentially liquefiable soils considered? If so, how was this uncertainty characterized (e.g., given the horizontal spacing between boreholes and the vertical spacing between samples or standard penetration tests within the boreholes)?

B) For evaluation of settlement due to liquefaction, the SPRA submittal report refers to Reference [43]. The settlements computed as described in Reference [43] contributed to the seismic fragilities as discussed in Section 4 and summarized in Table 5.4-2 and Table 5.5-2 of the SPRA submittal report. Based on the information provided in the settlement evaluations as referenced, staff requests clarification to the following questions:

1) As stated in Section 6.1 of Reference [43], the equation used to compute settlement is a function of corrected SPT blow-count ($N_{1,60cs}$) and FS_L. This equation is based on the method proposed by Ishihara and Yoshimine (1992), slightly modified by Yoshimine et al. (2006) and Idriss and Boulanger (2008). According to Ishihara and Yoshimine (1992), FS_L is defined by laboratory tests where $FS_L = 1.0$ is associated with initial liquefaction, which in Yoshimine and Ishihara (1992) is interpreted as the point where the soil in the lab test reaches a threshold strain (e.g., 2.5% single-amplitude axial strain in triaxial tests or 3.5% single-amplitude shear strain in simple shear tests). In the methodology described in Section 6.1 of Reference [43], FS_L is computed as cyclic resistance ratio (CRR) divided by CSR where CRR is computed using the Boulanger and Idriss (2012) equation with randomized values of the error, $\varepsilon_{ln(CRR)}$ (mean = 0, standard deviation = 0.13).

    a. Is the FS_L inherent in the Ishihara and Yoshimine (1992) method compatible with the FS_L computed using randomized values of CRR as described in Section 6.1 of Reference [43]?

2) As stated in Section 6.1.2.3 of Reference [43], $N_{1,60cs}$ was computed using an equation for the overburden correction factor (C_N) that was given by Youd et al. (2001). This is not the same equation for C_N that is given by Idriss and Boulanger (2008, 2010) and Boulanger and Idriss (2012).

    a. What effect does Youd et al. (2001) C_N have on $N_{1,60cs}$? Are the $N_{1,60cs}$ values computed with this C_N compatible with the Boulanger and Idriss (2012) equation for CRR = $f(N_{1,60cs})$?

3) Estimates of FS_L are often modified to correct for overburden stress. In the Boulanger and Idriss (2012) method, FS_L is multiplied by the overburden correction factor, K_σ. As discussed in Section 6.1.2.7 of Reference [43], the FS_L computations ignored the upper limit on K_σ recommended by Idriss and Boulanger (2008, 2010). Ignoring this upper limit could increase the values of FS_L, particularly for shallow soils with medium to high values of $N_{1,60cs}$.

    a. Please clarify why the upper limit on K_σ was not included. If possible, describe the impact of excluding the upper limit on K_σ with regards to settlement.

4) The failure of the Deepwell Pump D (SF-WP-DPW-PMP-D-SETTLE, Table 5.5.-2, SPRA submittal) is caused by liquefaction-induced settlement.

    a. Please provide calculation RNP-C/FLEX-0053 “Seismic Fragility Evaluation of the Deep Well Pump D Piping for the Effects of Liquefaction-Induced Soil

Settlement" to review the methodology used in estimating the fragility of the Deep Well Pump D.

C) For evaluation of lateral spreading (or lateral displacement) due to liquefaction, the SPRA submittal report refers to Reference [46]. The results of the lateral spreading analysis were used to evaluate fragility estimates as described in Section 4 of the SPRA submittal report. Based on the information provided in lateral spreading evaluations as referenced, staff requests clarification to the following questions:

1) As stated in Section 4.5 of Reference [45], "because lateral spreading can only occur when there is a continuous liquefying layer… the probability of a continuous layer occurring becomes one of the most important factors for LD [lateral displacement] accumulation. Calculation 4150-GEO-023 (AMEC, 2016a) determined those probabilities."

   a. Please provide "Calculation 4150-GEO-023" (AMEC, 2016a) so that the staff can review the methodology used in these calculations and the results.

2) As stated in Section 4.3 of Reference [46], "The occurrences of continuous layer of liquefying soils were evaluated in Calc 4150-GEO-023 (AMEC, 2016a) and the results are used in this calculation. If a continuous layer occurred, a value of 1 was assigned for that layer; if a continuous layer did not occur, a value of 0 was assigned."

   a. What probability of a continuous layer indicates that "a continuous layer occurred?" For example, is the presence of a continuous layer associated with a threshold probability (e.g., 50%)?

   b. Please explain why the discrete values of 0 and 1 were selected. Why not multiply by a continuous variable between 0 and 1 (e.g., the probability of a continuous liquefying layer)?

D) Questions about FLEX Area

1) Section 14 of Reference [16] says that the liquefaction evaluation at the location of the FLEX storage building was performed similarly to the evaluation of the main plant area. Table 14-2 shows the values of FS_L with depth for the borings in the area around the FLEX storage building, but it is not clear to the staff whether settlement or lateral spreading were evaluated.

   a. Clarify whether settlement and lateral spreading calculations were performed using the SPT blow counts from the boreholes around the FLEX area. If they were, what were the results of these calculations? The staff believes that these answers may be contained in the reference document 4150-GEO-031, "Flex Building Liquefaction Potential at Flex-C GMRS." If so, please post the document for review:

2) Please clarify whether liquefaction triggering, settlement, and lateral spreading were evaluated for the FLEX deployment path and at the location of FLEX staging areas? If so, what were the findings? Or post appropriate reference(s) that contain this information.

TOPIC #15: Documentation of the Seismic PRA (SPID Section 6.8) and,
TOPIC #12: Selection of Dominant Risk Contributors that Require Fragility Analysis Using the Separation of Variables Methodology (SPID Section 6.4.1)

Staff reviewed the information on evaluation of fragility of Lake Robinson Dam presented by RNPP in the SPRA submittal; Station calculation for the Seismically Induced Liquefaction Fragility Evaluation of Robinson Dam (Reference 67); and Responses to Focused Scope Peer Review Findings and Resolutions, F&O 2-1 provided in Table A-2 of the SPRA submittal. In order to complete SPRA Review Checklist Topic #12 and 15, staff requests response to the following clarification questions with regards to the methodology and conclusions.

1) The Robinson Dam seismic fragility is evaluated in Reference 67, where it is concluded ~~[[CEII]]~~ in Section 3 (Results and Conclusions) that the median capacity of the dam is **[[ ]]** ~~[[CEII]]~~ The document also presented fragility data in Table 1 and the fragility curve in Figure 1. Staff finds that the evaluated fragility in Reference 67 (Table 1) and fragility data for ~~[[CEII]]~~ **[[ ]]** presented in the SPRA ~~[[CEII]]~~ submittal (Tables 5.4-2 and 5.5-2) are not same. The conditional failure probabilities are observed to be substantially different. Clarify which fragility data was used in the plant logic model. If the data as presented in Tables 5.4-2 and 5.5.-2 were used, provide basis for the fragility.

2) RNPP used the PM4SAND constitutive model for the **[[** ~~[[CEII]]~~ **]]**. Section 5.2 ~~[[CEII]]~~ of Appendix B [Reference 67] recognizes that there are other analytical models, which "may produce different results" while PM4SAND is "well vetted" in the academic field and industrial practices. Staff requests reference to any publication(s) in support of PM4SAND as a stable, reliable, and realistic model for seismic embankment NDA.

3) The geotechnical input parameters and the constitutive models used for dynamic simulation of the Robinson dam are presented in Table 1 of Appendix B [Reference 67]. Staff requests information on the geotechnical characterization and evaluation of Upstream Dam Fill (USFL) demonstrating that the material is not liquefiable and that the values for all the geotechnical parameters are justified.

4) Appendix B, Section 5.2.1 [Reference 67] states that the "contraction rate parameter is set to default value (h_{po} =0.4) as recommended by Boulanger and Ziotopoulou (2017)." Staff could not verify this statement in Boulanger and Ziotopoulou (2017), instead the authors in the PM4SAND manual (Boulanger and Ziotopoulou, 2017) and in other publications strongly recommends that the h_{po} should be calibrated using single element models for each $(N_1)_{60}$ values by "matching the CRR values from direct simple shear (DSS) simulations with the $CRR_{M=7.5}$ values that were computed using the SPT-based liquefaction triggering correlation." Further, any change in the default values of the

secondary parameters (e.g. default values for maximum and minimum void ratio was not used in this model) will require calibration of h_{po}. Staff requests technical basis for using a single value of h_{po} for all $(N_1)_{60}$ or present results of a sensitivity analysis, either performed by the modeler or in the open literature, showing that the deformation of a dam in NDA with PM4SAND is not sensitive to h_{po} within the range of $(N_1)_{60}$ used in this simulation.

5) In response to F&O 2-1, the disposition referred to Reference 67 for post-earthquake deformation estimate. As stated in Section 5.6, Appendix B of Reference 67, please clarify how the deformation at the end of the duration of the shaking is considered as post-earthquake deformation. It is known that post-seismic displacement is associated with volumetric compaction and any associated shear deformation once the excess pore pressure from seismic shaking dissipates and requires post-seismic stability evaluation or post-seismic deformation estimate. From the excess pore pressure ratio plots presented in Appendix B [Reference 67], it appears that in most cases the **[[** **]]**; hence, understanding on expected range of post-seismic deformation is essential. [[CEII]] [[CEII]]

6) Appendix B [Reference 67] provided a good description of the modeling approach including the probabilistic simulation process for developing fragility of the Robinson Dam. Although NDAs are increasingly used in the industry to evaluate seismic performance of embankment dams, the multi-step modeling approach and use of recently developed liquefaction constitutive models makes the modeling process complex. Staff is requesting a high-level description on the testing or verification approach and the criteria used to develop confidence in each step of the modeling process. Staff is not requesting any Quality Assurance documentations on Verification and Validation.

References within SPRA Submittal

[16] Station calculation for the Final Seismic Analysis [RNP-C/FLEX-007, Rev 007].

[40] Station calculation for the Liquefaction Analysis for Robinson Plant [Amec Foster Wheeler, 4150-GEO-015, Rev 0].

[41] Station calculation for the Liquefaction Sensitivity Analysis for Robinson Plant [Amec Foster Wheeler, 4150-GEO-016, Rev 2].

[42] Station calculation for the Site-Wide Liquefaction Evaluation Plant [Amec Foster Wheeler, 4150-GEO-018].

[43] Station calculation for the Liquefaction Settlement Calculation [RNP-C/FLEX-0031, Rev 001]

[46]. Station calculation for the Probability of Lateral Displacement of Continuous Liquefaction Layer [RNP-C/FLEX-0049, Rev 000]

[67] Station calculation for the Seismically Induced Liquefaction Fragility Evaluation of Robinson Dam [RNP-C/FLEX-0060, Rev 001].

General References

Boulanger, R.W., and Idriss, I.M. (2014). "CPT and SPT based liquefaction triggering procedures," Report No. UCD/CGM-14/01, University of California, Davis.

Boulanger, R.W., and Idriss, I.M. (2012). "Probabilistic standard penetration test-based liquefaction-triggering procedure," *J. Geotechnical and Geoenvironmental Eng.*, 130(10): 1185-1195.

Boulanger and Ziotopoulou (2017). "PM4SAND (Version 3.1): A sand plasticity model for earthquake engineering applications." Report Number UCD/CGM-17/01. Center for Geotechnical Modeling, University of California Davis, California.

Idriss, I.M., and Boulanger, R.W. (2008). *Soil Liquefaction During Earthquakes.* Earthquake Engineering Research Institute (EERI), Monograph MNO-12.

Idriss, I.M., and Boulanger, R.W. (2010). "SPT-based liquefaction triggering procedures," Report No. UCD/CGM-10/02, University of California, Davis.

Ishihara, K., and Yoshimine, M. (1992). "Evaluation of settlements in sand deposits following liquefaction during earthquakes," *Soils and Foundations* 32(1): 173–88.

Yoshimine, M., Nishizaki, H., Amano, K., and Hosono, Y. (2006). "Flow deformation of liquefied sand under constant shear load and its application to analysis of flow slide in infinite slope," *Soil Dynamics and Earthquake Eng*. 26: 253–264.

Youd, T. L., Idriss, I. M., Andrus, R. D., Arango, I., Castro, G, Christian, J. T., Dobry, R., Finn, W. D. L., Harder Jr., L. F., Hynes, M. E., Ishihara, K., Koester, J. P., Liao, S. S. C., Marcuson III, W. F., Martin, G. R., Mitchell, J. K., Moriwaki, Y., Power, M. S., Robertson, P. K., Seed, R. B., and Stokoe II, K. H. (2001). "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils", *J. Geotechnical and Geoenvironmental Eng*., ASCE, 127(10): 817-833.