NRC RAI Letter No. PTN-RAI-LTR-040

SRP Section: 02.05.04 - Stability of Subsurface Materials and Foundations

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS1)

NRC RAI Number: 02.05.04-12 (eRAI 6006)

Section 2.5.4.5.2 “Extent of Excavations, Fills, and Slopes”, states that the TPNPP Units 6 and 7 nuclear islands will be founded directly on a 20 ft thick lean-concrete layer above a competent rock stratum (Key Largo Formation). In accordance with NUREG-0800, Standard Review Plan, Chapter 2.5.4, "Stability of Subsurface Materials and Foundations," please address the following:

a. Define “Lean Concrete” and clarify if CLSM is used. Also specify which ACI standard(s) will be followed.

b. Given the load path, how is the potential for cracking of the lean concrete evaluated? Also discuss your plan to control thermal cracking of the fill materials.

c. Describe the load transfer mechanism between the base of the NI structures and the lean fill concrete as well as the load transfer between the lean concrete and the surrounding supporting soils.

d. Your chemical tests of soil and rock indicated that that the chemistry of soil and rock is considered to be aggressive towards cementitious materials. Please provide test results on groundwater chemistry including pH, chlorides, and sulfates. Evaluate the potential aging effects and address the concrete durability for lean concrete backfill and subfoundation due to aggressive soil and groundwater conditions. Also provide a description on how potential settlement and differential settlement due to erosion of cement from porous lean concrete backfill will be addressed.

FPL RESPONSE:

a. Define “Lean Concrete” and clarify if CLSM is used. Also specify which ACI standard(s) will be followed.

Lean concrete is unreinforced concrete with a smaller ratio of cement to aggregate than structural concrete. It is used for filling and not structural duties. In the remainder of the response, the term “lean concrete fill” will be shortened to “concrete fill”. The American Concrete Institute (ACI) standard that will be followed is ACI 207, “Guide to Mass Concrete” prepared by ACI Committee 207 (FSAR Subsection 2.5.4 Reference 281). Controlled Low Strength Material (CLSM) will not be used for fill beneath the nuclear island.

b. Given the load path, how is the potential for cracking of the lean concrete evaluated? Also discuss your plan to control thermal cracking of the fill materials.

FSAR Subsection 2.5.4.12 indicates the concrete fill will have an estimated compressive strength of 1500 psi. The design bearing capacity of this strength of concrete is over 100 ksf. According to the AP 1000 Design Control Document, the maximum applied bearing pressure (from the Reactor Building) is 8.9 ksf, less than 9 percent of the bearing capacity of the concrete. Thus, cracking of the concrete due to loading/overstressing is not expected.

FSAR Reference 281 defines mass concrete as “any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking”. The approximately 19-foot thick layer of concrete fill qualifies as mass concrete. As such, FSAR Reference 281 guidelines for preventing thermal cracking in concrete will be followed in preparing a thermal control plan during the detailed design. A thermal control plan can include some or all of the following elements:

- Use a well-graded aggregate and Type I and/or Type II cement in the concrete mix.
- The low strength of the concrete fill will require relatively less cement and thus reduce the level of the heat of hydration found in stronger mixes. To reduce the heat of hydration further, use Portland cement substitutes such as Class F flyash to replace a portion of the cement. Flyash has a slower pozzolanic reaction than cement, and thus less heat of hydration. Uncontrolled heat of hydration is the cause of thermal cracking and thus minimizing the heat of hydration will greatly reduce the possibility of thermal cracking.
- Even with the heat of hydration in the design mix minimized, it may still require the concrete fill to be placed in relatively thin lifts to avoid cracking. Typically, maximum thickness of each concrete fill lift is set at around 3 feet.
- When another lift is required on top of an existing lift, the new lift will be poured only after the underlying lift has enough time to properly cool down.
- Concrete design and placement will be tailored to minimize the maximum temperature inside the concrete pour and to minimize the maximum temperature difference between the hottest spot and the surface of the concrete pour. The exposed surfaces will be insulated as required to limit the temperature differential in the concrete mass to 20°C maximum. This will necessitate that thermocouples be embedded within and on the concrete mass; effective monitoring of the thermocouples should eliminate the potential for thermal cracking. Concrete placement temperature will be controlled as necessary by the use of ice, chilled water, shading aggregate piles, spraying coarse aggregate for evaporative cooling, and scheduling placements to take advantage of coolest temperatures (such as at night).

c. Describe the load transfer mechanism between the base of the NI structures and the lean fill concrete as well as the load transfer between the lean concrete and the surrounding supporting soils.

The rock beneath the concrete fill (i.e., the Key Largo Formation) has the same compressive strength as the concrete fill (1,500 psi) and the rock beneath the Key Largo Formation (i.e., the Fort Thompson Formation) has a slightly higher strength of 2,000 psi (FSAR Table 2.5.4-209). Thus, during vertical load transfer from the foundation to the concrete fill and from the concrete fill to the underlying rock, stress levels will remain low in these materials and well within the elastic range. Consequently, there will be elastic stress distribution. A stress distribution below the foundation can be conservatively taken as no steeper than 2V:1H, but most likely closer to 1V:1H.

For transfer of lateral loading, FSAR Table 2.5.4-209 shows coefficient of friction against sliding between mass concrete and the Key Largo Formation to be 0.7. This coefficient value applies to resistance to sliding of the concrete fill bearing on the Key Largo Formation. The 0.7 value also applies to the resistance to sliding of the base of the concrete foundation mat of the nuclear island bearing on the mudmat and the mudmat bearing on the concrete fill. The mudmat provides a working surface for the construction of the concrete foundation mat; the mudmat has a minimum thickness of 12 inches of un-reinforced concrete. As noted in FSAR Subsection 3.8.5.1, a sheet type HDPE waterproofing material will be used for both the horizontal and vertical surfaces under Seismic Category I structures. The material will be qualified by test, with commercial grade dedication and laboratory testing, to achieve a minimum coefficient of friction against sliding of 0.55, as shown in FSAR Subsection 3.8.5.1 (provided in COLA Revision 3). This waterproof membrane is sandwiched within the mudmat.

Because of the low seismic forces (and hence lateral loading) at the Turkey Point site, the friction between the foundation and the mudmat, the friction within the mudmat (waterproofing material), the friction between the mudmat and the concrete fill, and the friction between the concrete fill and the underlying rock will be sufficient to prevent any sliding movement. Thus the surrounding structural backfill and in-situ soils and rock will not be required to resist lateral loading from the building.

d. Your chemical tests of soil and rock indicated that that the chemistry of soil and rock is considered to be aggressive towards cementitious materials. Please provide test results on groundwater chemistry including pH, chlorides, and sulfates. Evaluate the potential aging effects and address the concrete durability for lean concrete backfill and subfoundation due to aggressive soil and groundwater conditions. Also provide a description on how potential settlement and differential settlement due to erosion of cement from porous lean concrete backfill will be addressed.

The measured values of chemical tests on groundwater samples from observation wells on the site are presented in FSAR Tables 2.4.12-210 (pH) and 2.4.12-211 (chloride and sulfate). The pH values measured from 24 water samples ranged from 6.65 to 7.29, resulting in a median of 7.06, i.e., essentially neutral. The chloride values measured from 24 water samples ranged from 16,300 to 37,500 ppm, resulting in a median value of about 29,000 ppm. The sulfate values measured from 24 water samples ranged from 2,280 to 4,400 ppm, resulting in a median value of about 3,800 ppm, or close to 0.4 percent by weight. This classifies the concrete exposure to sulfate attack as severe, according to the ACI Manual of Concrete Practice, Part 1. FSAR Tables 2.4.12-210 and 2.4.12-211 contain other parameters measured from chemical tests; these are considered inapplicable to the evaluation because they are not corrosion agents.

The approximate plan dimensions of the approximately 19-foot thick mass of concrete fill are 240 feet x 290 feet, including 30-foot width of concrete fill extending beyond the perimeter of the nuclear island. The concrete fill will be placed on top of Key Largo Limestone that will have been extensively grouted to enable dewatering. The concrete fill will be placed against the perimeter concrete diaphragm wall that extends down to El. -60 feet, as shown in FSAR Figure 2.5.4-222 (provided in COLA Revision 3). The majority of the surface of the concrete fill will be covered by the nuclear island, and the remainder will be covered by structural fill. Thus, there will be limited exposure of the concrete fill to aggressive groundwater and soil. On the perimeter, there is a 30-foot wide buffer of concrete fill placed against a concrete diaphragm wall, and on the surface, most of the concrete fill is covered by structures. The only plausible potential for exposure is on the base of the concrete fill. One (of several) potential solutions to this situation would be to make the first lift of concrete fill from sulfate resisting cement. The high chloride content that can cause steel corrosion is not of concern, since the concrete is unreinforced.

Based on the conditions described above and the potential solution for combating the effects of high sulfate content, there are little or no mechanisms that could cause erosion of cement from the concrete fill, and thus there will be no impact on total or differential settlement.

This response is PLANT SPECIFIC.

References:

None

ASSOCIATED COLA REVISIONS:

The second paragraph of FSAR Subsection 2.5.4.5.1 will be revised in a future FSAR revision as follows:

The deepest excavation is **to** approximately El. -35 feet. Structural fill is placed around but not below the power block structures extending to as deep as El. -14 feet. Lean concrete fill is placed between **the bottom of the mudmat that is below** El. -14 feet and the bottom of the excavation. **Lean concrete is unreinforced concrete with a smaller ratio of cement to aggregate than structural concrete. It is used for filling and not structural duties.** The final grade is shown on Figure 2.5.4-201. The grade in profile is shown in Figure 2.5.4-221.

The third paragraph of FSAR Subsection 2.5.4.5.1.2 will be revised in a future FSAR revision as follows:

Structural fill consisting of excavated fill material is placed around but not below any nuclear island structure. Replacement material below the nuclear islands consists of lean concrete fill. The selection of lean concrete mix design is made at project detailed design. The compressive strength of 1.5 ksi is estimated for lean concrete fill. **The approximately 19-foot thick layer of lean concrete fill qualifies as mass concrete. As such, Reference 281 guidelines for preventing thermal cracking in concrete will be followed in preparing a thermal control plan during the detailed design. A thermal control plan can include some or all of the following elements:**

- **Use a well-graded aggregate and Type I and/or Type II cement in the concrete mix.**

- **The low strength of the lean concrete fill will require relatively less cement and thus reduce the level of the heat of hydration found in stronger mixes. To reduce the heat of hydration further, use Portland cement substitutes such as Class F flyash to replace a portion of the cement. Flyash has a slower pozzolanic reaction than cement, and thus less heat of hydration. Uncontrolled heat of hydration is the cause of thermal cracking and thus minimizing the heat of hydration will greatly reduce the possibility of thermal cracking.**
- **Even with the heat of hydration in the design mix minimized, it may still require the lean concrete fill to be placed in relatively thin lifts to avoid cracking. Typically, maximum thickness of each lean concrete fill lift is set at around 3 feet.**
- **When another lift is required on top of an existing lift, the new lift will be poured only after the underlying lift has enough time to properly cool down.**

Concrete design and placement will be tailored to minimize the maximum temperature inside the concrete pour and to minimize the maximum temperature difference between the hottest spot and the surface of the concrete pour. The exposed surfaces will be insulated as required to limit the temperature differential in the concrete mass to 20°C maximum. This will necessitate that thermocouples be embedded within and on the concrete mass; effective monitoring of the thermocouples should eliminate the potential for thermal cracking. Concrete placement temperature will be controlled as necessary by the use of ice, chilled water, shading aggregate piles, spraying coarse aggregate for evaporative cooling, and scheduling placements to take advantage of coolest temperatures (such as at night).

ASSOCIATED ENCLOSURES:

None