PMTurkeyCOLPEm Resource

From:	Comar, Manny
Sent:	Wednesday, October 03, 2012 7:53 AM
To:	TurkeyCOL Resource
Subject:	FW: DRAFT RAI Responses FPL Turkey Point 6 & 7 for eRAIs 6006 & 6184 Stability of Subsurface Materials and Foundations
Attachments:	Draft Revised Response for NRC RAI Letter No. 040, RAI 02.05.04-1 (eRAI 6006).pdf; Draft Revised Response for NRC RAI Letter No. 040, RAI 02.05.04-25 (eRAI 6184).pdf

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From: Franzone, Steve [mailto:Steve.Franzone@fpl.com]
Sent: Saturday, September 29, 2012 9:04 AM
To: Comar, Manny
Cc: Burski, Raymond; Maher, William; Franzone, Steve
Subject: DRAFT RAI Responses FPL Turkey Point 6 & 7 for eRAIs 6006 & 6184 Stability of Subsurface Materials and Foundations

Manny,

To support a future public meeting, FPL is providing draft revised responses for eRAIs 6006 & 6184 (RAI questions 02.05.04-1, 02.05.04-25) in the attached files.

If you have any questions, please contact me.
Thanks
Steve Franzone
NNP Licensing Manager - COLA
"Three Rules of Work: Out of clutter find simplicity; From discord find harmony; In the middle of difficulty lies opportunity." Albert Einstein
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Draft Revised Response for NRC RAI Letter No. 040, RAI 02.05.04-25 (eRAI 6184).pdf	290903	

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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: 02.05.04-1 (eRAI 6006)

FSAR Section 2.5.4.1.2.1 presents a discussion on dissolution activity in the limestone formation, including potential cavities at depths. Among the data sets used to assess the potential existence of cavities is the microgravity data presented in Figures 2.5.4-224 through 231 which provide insights into the existence of potential cavities in at the site. Based on the analysis of gravity data analyses, this section concludes that there are no large cavities underneath the site. In accordance with NUREG-0800, Standard Review Plan, Chapter 2.5.4, "Stability of Subsurface Materials and Foundations," and Regulatory Guide (RG) 1.132, "Site Investigations for Foundations of Nuclear Power Plants" please provide additional discussion on the adequacy of the assumptions used in the microgravity data analyses. Since only profile measurements were made and large gaps remain between profiles throughout the site area, please justify your assumption that no large cavities exist throughout the site. Also, please provide additional references and data sources used to reach this conclusion.

FPL RESPONSE:

FPL has reached its conclusions that the likelihood for encountering extensive dissolution beneath the power block is small based on the integration of geological/geotechnical data collected during the subsurface investigation program as well as the use of three concurrent geophysical surveys (microgravity, seismic refraction, and multi-channel analysis of surface waves). The seismic refraction and multi-channel analysis of surface waves (MASW) data are helpful in removing the effects of the overlying less dense muck in the interpretation of the microgravity survey data. As shown in FSAR Figure 2.5.4-227 and Figure 1, the MASW survey data also indicate that the muck is thicker above surficial solution features (vegetated depressions) that appear to be floored by continuous Key Largo limestone.

The geotechnical subsurface investigation program comprised 64 borings in the power block area and 24 borings outside the power block. FSAR Subsections 2.5.4.1.1, 2.5.4.1.2.1, 2.5.1.2.2, and 2.5.1.2.4 describe the locations and number of borings, the relatively small number of rod drops, and the vertical extents of those rod drops. Figure 2 shows the locations of all boreholes and identifies those boreholes with documented rod drops. Table 1 identifies the rod drop depth, the rod drop length and the stratigraphic unit in which the rod drop occurred. Boring logs (FSAR Reference 2.5.1-708) indicate the:

- 3-foot drop in B-805 occurred within the Miami Limestone.
- 2-foot drop in B-637 occurred within the Miami Limestone.
- Rod drops in borings B-738, B-811 and B-814 occurred in sandy zones within the Fort Thompson Formation.
- 1-foot drop in B-714 occurred at the base of the Fort Thompson Formation immediately before penetrating the sands of the Tamiami Formation.

No rod drops occurred within the nuclear island footprint of either Unit 6 or Unit 7. Boring B-714 is located within the footprint of the Unit 7 Annex Building and this rod drop might have been due to the process of drilling from the hard limestone of the Fort Thompson Formation into the underlying silty sand of the Tamiami Formation.

The subsurface investigation and testing program and the aerial photo analysis and geologic reconnaissance, described in FSAR Subsection 2.5.3.8.2.1, produced the data used to support the conclusion that the likelihood for encountering extensive dissolution beneath the power block is small. FPL did not rely on offsite data or publications, as the extent or absence of karst is generally site-specific and a function of mineralogy, lithology, groundwater elevation, groundwater gradient, and geochemistry.

The assumptions used in the microgravity data analysis include assuming that a spherical, water-filled cavity would have a sufficient density contrast with the surrounding limestone to produce a microgravity anomaly. The density contrast is based on laboratory test and published data summarized in the FSAR Subsection 2.5.4.4.5.4 and on experience conducting similar geophysical surveys in south Florida. A spherical cavity was used in the analysis as the most conservative approach since it represents the most compact form of “missing mass,” and therefore produces the smallest gravity anomaly for a given cavity diameter. Other geometric distributions of a cavity, having the same diameter as the sphere, would produce a significantly larger gravity anomaly. The detectability of the anomaly varies with cavity size, depth, and location with respect to the survey line.

To further reduce any uncertainties in the resolution and interpretation of microgravity data with depth, and away from geophysical survey lines and boreholes, FPL proposes a commitment to conduct a microgravity survey on the base of the nuclear island (NI) excavation. The current excavation concept is to grout the excavation as part of the dewatering program. FSAR Subsection 2.5.4.5.4 describes the dewatering and excavation methods. The installation of a grout plug, approximately 25 feet thick, to prevent vertical seepage is described in FSAR Subsection 2.5.4.6.2 and, in more detail, in ER Subsection 3.9.1.7. The grout plug will be constructed from elevation -35 feet NAVD 88 to elevation -60 feet NAVD 88 by first drilling from the ground surface and then grouting. Vertical boreholes will be drilled in a grid pattern and grouted in an iterative process, which is estimated to consist of four rounds of drilling and grouting, prior to excavation. The grouting procedure described in ER Subsection 3.9.1.7 is expected to fill voids that may exist beneath the nuclear island excavation to an elevation of -60 feet NAVD 88. It is anticipated that the density of the grout will be similar to that of the foundation limestone and that the proposed microgravity survey will be designed to detect density anomalies below the grout plug that represent potential solution features with a diameter of 25 feet or greater if spherical and 12 feet or greater if cylindrical. Preliminary estimates indicate that a hypothetical solution feature with an approximate diameter of 30 feet at a depth immediately below El. -60 feet NAVD 88 will have a negligible effect on the stability of the nuclear island foundation, i.e., negligible effect on bearing capacity, settlement, or resistance to sliding. Such a cavity would cause an increase in stress levels in the vicinity of the cavity due to stress redistribution. However, the stresses from the design loading on the nuclear island at that depth are comparatively low (less than 50 psi) so that the effects are insignificant in the limestone of the Fort Thompson Formation with an average unconfined compressive strength of 2,000 psi (FSAR Table 2.5.4-209).

Table 1. Rod Drops at the Turkey Point Units 6 & 7 Area

Boring ID	From	To	Rod Drop	Stratigraphic Unit
	(Depth, FT)		(Length, FT)	
B-637	28.6	30.6	2	Miami Limestone
B-714	112	113	1	Fort Thompson Formation
B-738	71.9	74.5	2.6	Fort Thompson Formation
B-805	27	30	3	Miami Limestone
B-811	61.3	65.3	4	Fort Thompson Formation
B-814	87.6	88.1	0.5	Fort Thompson Formation

Note: No rod drops in the Nuclear Islands. B-714 is located in the Annex Building footprint in Unit 7.
Source: Reference 2.5.1-708

Figure 1. Line 10 Geophysical Data

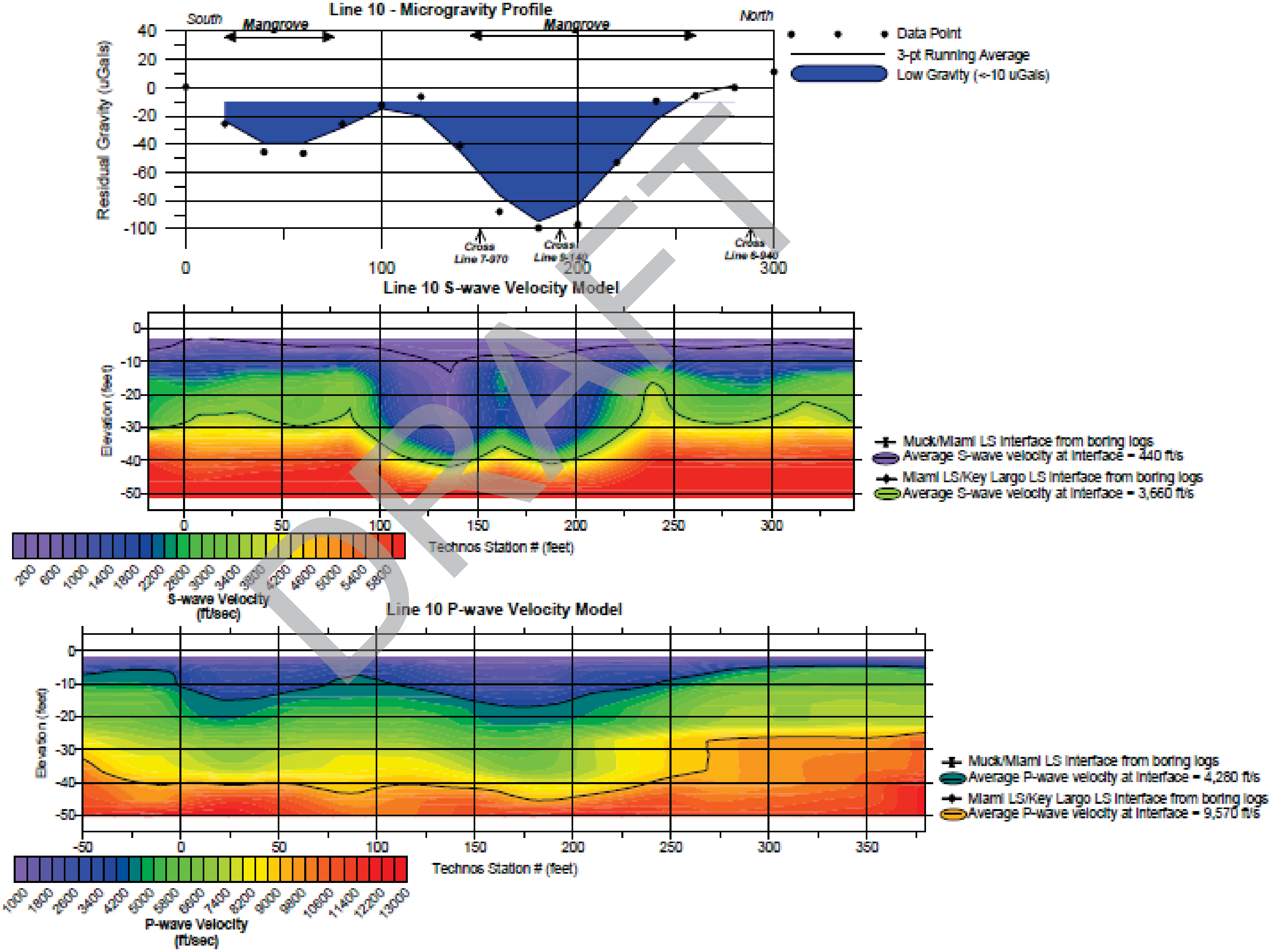
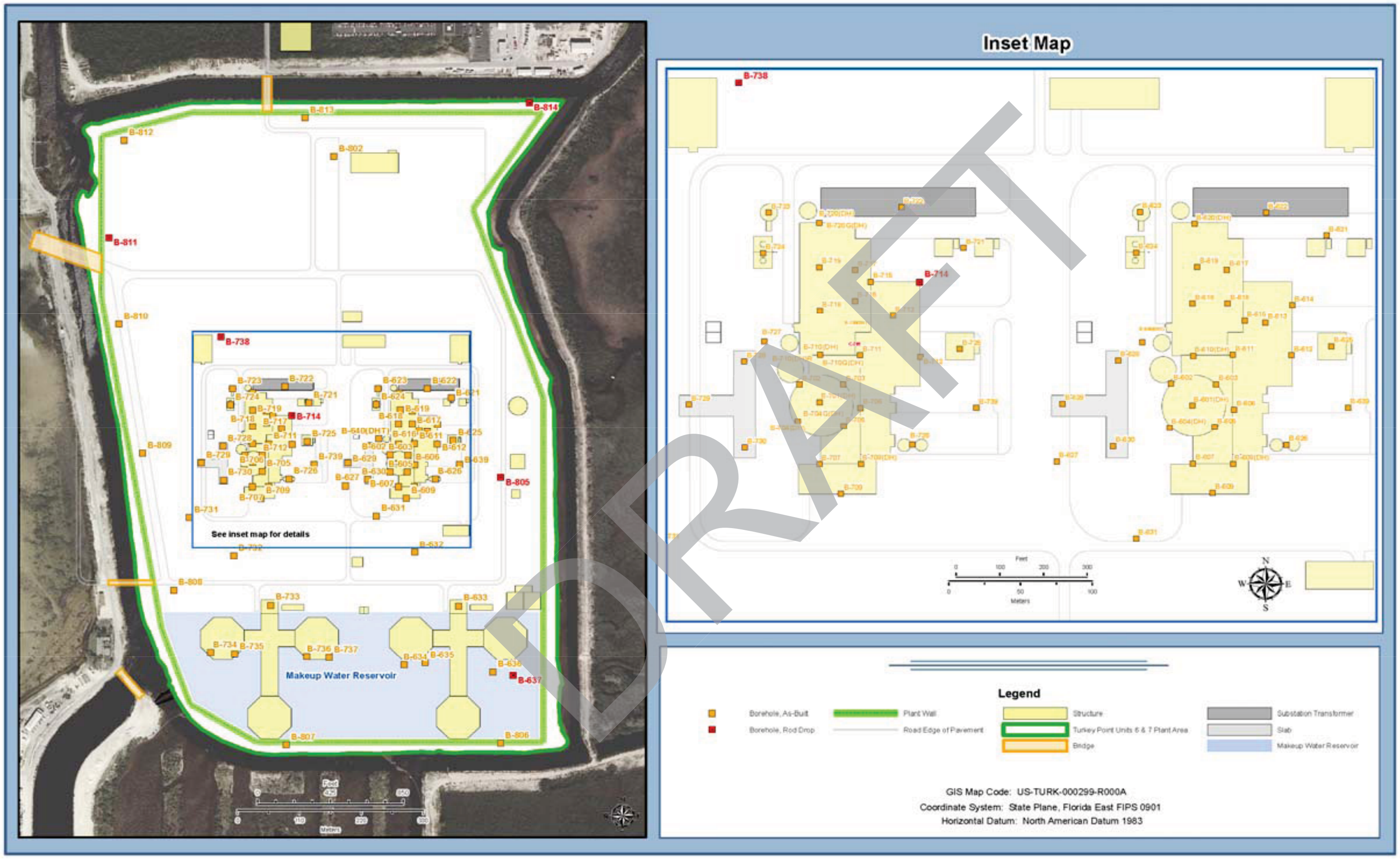


Figure 2. Locations of Borings with Rod Drops at Turkey Point Units 6 & 7



Source: FSAR Reference 2.5.1-708

This Response is Site Specific

ASSOCIATED COLA REVISIONS:

The following text in FSAR Subsection 2.5.1.2.4, Site Geologic Hazards, ninth and eleventh paragraphs, will be revised in a future revision of the COLA.

Ninth paragraph:

Despite the presence of the aforementioned upper and lower secondary porosity zones, the number and magnitude of rod drops that occurred during drilling were negligible~~, as described in Subsection 2.5.4.1.2.1~~. **Boring logs (Reference 708) indicate the:**

- **3-foot drop in B-805 occurred within the Miami Limestone.**
- **2-foot drop in B-637 occurred within the Miami Limestone.**
- **Rod drops in borings B-738, B-811 and B-814 occurred in sandy zones within the Fort Thompson Formation.**
- **1-foot drop in B-714 occurred at the base of the Fort Thompson Formation immediately before penetrating the sands of the Tamiami Formation.**

No rod drops occurred within the nuclear island footprint of either Unit 6 or Unit 7. Boring B-714 is located within the footprint of the Unit 7 Annex Building and this rod drop might have been due to the process of drilling from the hard limestone of the Fort Thompson Formation into the underlying silty sand of the Tamiami Formation (Table 2.5.1-208, Figure 2.5.1-350).

Cavities observed during rock core operations were relatively small. The overall data collected during the Units 6 & 7 subsurface investigations are consistent with a communication with the FGS, which indicates that dissolution present in the site area is generally considered to be micro-karst with numerous small cavities. **This information is consistent with Cunningham (References 404 and 723) investigations in the Biscayne Aquifer in southeastern Florida.**

Eleventh paragraph:

An integrated geophysical survey focused on the Units 6 & 7 power block area and the small surface depressions identified within the site is discussed in Subsection 2.5.4.4.5. Based on **an integrated interpretation of the boring data (Subsection 2.5.4.1.2.1) and the integrated site geophysical survey** ~~all of the site characterization~~ data ~~collected from the site~~, there is no **apparent** evidence for sinkhole hazards or for the potential of surface collapse due to the presence of large underground openings. **The multi-channel analysis of surface waves (MASW) data indicate that the vegetated depressions at the site are underlain by continuous Key Largo Formation (Figures 2.5.4-227 and 241). These two figures show MASW data along survey lines 9 and 10 that intersect at a prominent vegetated depression. Within the limits of survey resolution, the microgravity data do not indicate the presence of large subsurface voids. To address uncertainties in the resolution of the geophysical data away from survey lines and at depth beneath the foundation, a microgravity survey will be conducted at the base of the Unit 6 and Unit 7 nuclear island excavations (Subsection 2.5.4.4.5.5).**

The following text in FSAR Subsection 2.5.3.8.2.1, Potential Sources of Non-Tectonic, Geologic Deformation, fifth paragraph, last sentence will be revised in a future revision of the COLA.

Based upon available **borehole and geophysical** data, there is minimal hazard posed by sinkholes and no evidence for potential surface collapse due to the presence of large underground openings.

The following text in FSAR Subsection 2.5.3.8.3, Summary of Potential Deformation at the Site, will be revised in a future revision of the COLA.

There is no evidence of potential tectonic faulting or tectonic deformation at the site. The only potential non-tectonic, geologic hazard at the site is surficial limestone dissolution. No **apparent** indicators of collapse or settlement problems exist at the site, and the geotechnical investigation found no evidence for subsurface dissolution features that would cause such problems. This conclusion is **partly** confirmed by the results of an integrated geophysical investigation focused on identification of subsurface dissolution features at the site (Subsection 2.5.4.4.5). No human-related deformation hazard exists at the site. **To address uncertainties in the resolution of the geophysical data away from survey lines and at depth beneath the foundation, a microgravity survey will be conducted at the base of the Unit 6 and Unit 7 nuclear island excavations (Subsection 2.5.4.4.5.5).**

The following text in FSAR Subsection 2.5.4.1.2.1, third paragraph, will be revised in a future revision of the COLA.

Small dissolution features are present in limestone drill core samples collected during the subsurface investigation at the site and described in Reference 257. They occur in the form of vugs and moldic secondary porosity, particularly in the Miami and Key Largo ~~L~~limestones. During the site subsurface investigation, six-rod drops, indicating the potential presence of voids, were noted during approximately 9000 feet of rock coring **(Table 2.5.1-208 and Figure 2.5.1-350)**. Two of the rod drops (B-637 and B-805) occurred within the Miami Limestone, which will be removed from beneath the nuclear island during construction. These two rod drops had magnitudes of 2 and 3 feet. One rod drop (B-714) occurred at the base of the Fort Thompson Formation immediately before penetrating the sands of the Tamiami Formation and had a magnitude of 1 foot. The remaining three rod drops (B-738, B-811, and B-814) occurred within sandy zones of the Fort Thompson Formation in the elevation range of –62.7 to –79.1. These three rod drops, which are all located outside the nuclear island footprint, had magnitudes ranging from 0.5 to 4 feet. **While** ~~C~~caliper and acoustic logs from the 10 boreholes where downhole geophysical data were obtained do not indicate the presence of **large** voids**, they do support the interpretation of two preferential secondary porosity flow zones**. A more detailed discussion of the site geologic hazards is presented in Subsection 2.5.1.2.4. A description of the results of a geophysical survey using microgravity, seismic refraction, and multichannel analysis of surface waves methods to investigate the potential for solution features beneath the site is provided in Subsection 2.5.4.4.5.

The following text in FSAR Subsection 2.5.4.4.5.5 Conclusions re-titled “Summary and Commitment” will be revised in a future revision of the COLA.

2.5.4.4.5.5 ~~Conclusions~~ **Summary and Commitment**

Based on geophysical site characterization data, there is no **apparent** indication that sinkhole hazards exist at the site. There is also no **apparent** evidence for the presence of underground openings within the survey area that could result in surface collapse. Large low gravity anomalies with magnitudes less than –30 µGals are only detected outside the power block areas, primarily in areas associated with surface depressions containing vegetation. Once the effects of variations in muck thickness are removed from the residual gravity data, all the remaining low gravity anomalies can be explained by density variations within the Miami Limestone. **The results of the drilling program and borehole geophysical data (Subsections 2.5.1.2.4 and 2.5.4.1.2.1) indicate the existence of two preferential secondary porosity flow zones. The extent of rod drops in six of the 88 borings (approximately 9,000 feet of rock cores) integrated with the field geophysical data supports the interpretation that large voids are absent beneath the footprints of the Units 6 & 7 nuclear islands.**

However, considering the uncertainties related to resolution in the geophysical data at depth and away from survey lines, a microgravity survey will be performed on the excavation surface to detect the presence, or verify the absence of potential water-filled dissolution features beneath the power block. The microgravity survey will be designed to detect 25-foot diameter spherical voids and cylindrical voids as small as 12-feet in diameter at the base of the 25-foot thick grout plug at an elevation of approximately -60 feet NAVD 88. If present, microgravity anomalies may be further investigated by drilling and sampling to determine their origin.

Table 2.5.1-208 will be added to FSAR Subsection 2.5.1 in a future COLA revision:

Table 2.5.1-208. Rod Drops at the Turkey Point Units 6 & 7 Area

Boring ID	From	To	Rod Drop	Stratigraphic Unit
	(Depth, FT)		(Length, FT)	
B-637	28.6	30.6	2	Miami Limestone
B-714	112	113	1	Fort Thompson Formation
B-738	71.9	74.5	2.6	Fort Thompson Formation
B-805	27	30	3	Miami Limestone
B-811	61.3	65.3	4	Fort Thompson Formation
B-814	87.6	88.1	0.5	Fort Thompson Formation

Note: No rod drops in the Nuclear Islands. B-714 is located in the Annex Building footprint in Unit 7.
Source: Reference 2.5.1-708

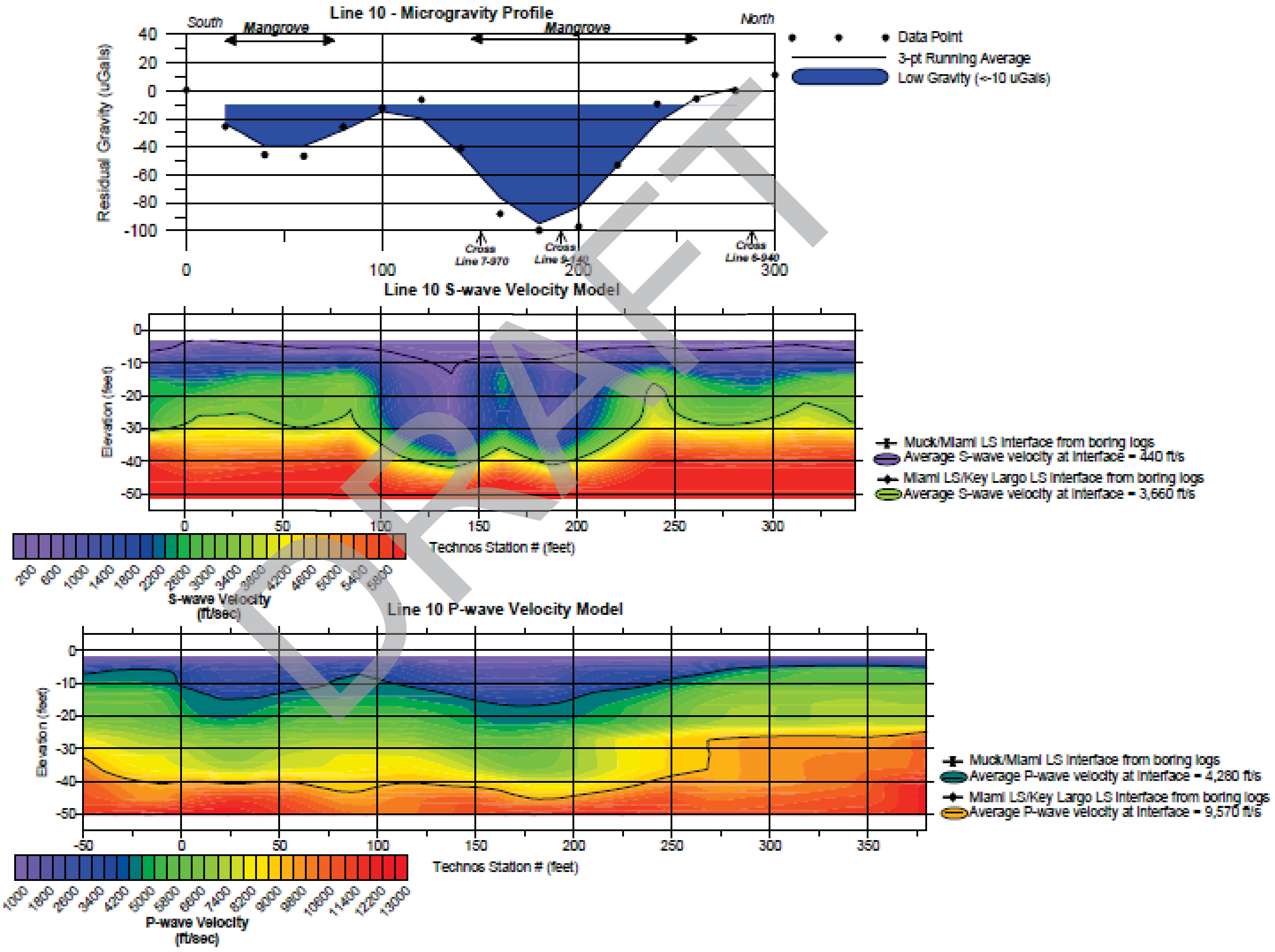
Figure 2.5.1-350 will be added to FSAR Subsection 2.5.1 in a future COLA revision:

Figure 2.5.1-350. Locations of Borings with Rod Drops at the Turkey Point Units 6 & 7

Source Reference 2.5.1-708

Figure 2.5.4-241 will be added to FSAR Subsection 2.5.4 in a future COLA revision:

Figure 2.5.4-241. Line 10 Geophysical Data



References:

None

ASSOCIATED ENCLOSURES:

None

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: 02.05.04-25 (eRAI 6184)

FSAR Section 2.5.4.2.1.3.4 states that the core recovery and the rock quality designation (RQD) for the limestone layers are very inconsistent. Also, according to FSAR Section 2.5.4.2.3, Laboratory strength tests were performed on intact rock core samples from the Key Largo and Fort Thompson formations. However, no further discussion is presented in the FSAR about the characteristics of the rock mass for these formations. In order to better understand how the foundation bearing rock mass was characterized and in accordance with 10 CFR 100.23 (d) (4) and NUREG-0800, Standard Review Plan, Chapter 2.5.4, "Stability of Subsurface Materials and Foundations,"

a) Please discuss how various geologic parameters such as voids and discontinuities (joints, faults, or bedding planes) influenced the overall rock mass behavior and thus, the rock mass classification.

b) Please describe how the deformation modulus, compressive strength, and shear strength parameters for rock mass were accounted for in the foundation stability analysis (settlement, bearing capacity).

FPL RESPONSE:

The response is provided in four parts - part 1 describes rock mass classification systems; part 2 describes empirical methods correlating rock mass classification values to rock mass properties; part 3 discusses the application of the RQD, RMR and Q classification systems at the FPL site and their use in determining rock mass properties; and part 4 provides an account of the rock mass properties at the FPL site for foundation stability analyses.

1. Rock Mass Classification Systems

Numerous rock mass classification systems have been developed over the past 100 years for various applications. The United States Army Corp of Engineers (USACE) Engineering Manual (EM) 1110-1-2908 on Engineering Design – Rock Foundations (Reference 1) describes six classification systems that have been used extensively. These include: Terzaghi's Rock Load Height Classification; Lauffer's Classification; Deere's Rock Quality Designation (RQD); Rock Structure Rating (RSR) Concept; Geomechanics or Rock Mass Rating (RMR) System; and the Q-System. ASTM D5878-08 (Reference 2) describes eight classification systems and their applications and these include the RMR; RSR; Q System; Unified Rock Classification System (URCS); Rock Material Field Classification System (RMFCS); New Austrian Tunneling Method (NATM); Coal Mine Roof Rating (CMRR); and Japanese Rock Mass Classification Systems. Most of these classification systems were primarily developed to assess stability and support estimates of underground excavations, but over the years the application has expanded to use in slope and foundation design. Reference 1 describes three of the classification systems as applicable to work on rock foundations. These include the RQD, Geomechanics or RMR System and the Q System. The following is a brief discussion of each of these classification systems.

Rock Quality Designation (RQD)

The Rock Quality Designation (RQD) is defined as the "percentage of intact core pieces longer than 4 inches (100 mm) in the total length of core" (Hoek et al, Reference 3). Only intact lengths of core broken by natural joints or discontinuities are considered, breaks caused by drilling etc. are ignored. Originally developed by Deere et al. (Reference 4) to provide a quantitative estimate of rock mass quality from rock core, the RQD value is presented as a percentage which correlates to rock quality. For example, an RQD between 0 and 25% represents "very poor" quality rock while values of between 90 and 100% represent "excellent" quality rock. The procedure for determining RQD is presented in ASTM D6032-08 (Reference 5). The RQD value is intended to represent the rock mass quality in-situ and is a major component to the RMR and Q classification systems.

Geomechanics or RMR Classification.

The Geomechanics Classification or RMR system, first published by Bieniawski in the mid 1970's and updated in 1989 as described in Hoek et al (Reference 3) was originally developed as a design tool for tunnels. Six parameters are used to classify the rock mass using this system:

- Uniaxial compressive strength of the rock material
- RQD
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation of discontinuities

The first five parameters are assigned a number or rating and addition of the five ratings gives the RMR value. This RMR value is then adjusted to account for the orientation of the discontinuities on a structure-specific basis. The RMR value provides an indication of the rock mass class, from very poor to very good. A RMR rating of less than 21 is class "V" and described as "very poor" rock. Conversely, a RMR rating of between 81 and 100 is rock class "I" and described as "very good" rock. The RMR is then used to predict tunnel stand-up time and support. The RMR system is based upon case histories from civil engineering projects and has evolved over the years, along with the parameter ratings, as more case studies have become available (Reference 3).

Rock Tunneling Quality Index, Q

Barton et al. (Reference 6) originally developed the rock Tunneling Quality Index (Q) or Q or NGI (Norwegian Geotechnical Institute) classification system for tunnel design work. Again, six parameters are used to define the Q index:

- RQD
- J_n is the joint set number
- J_r is the joint roughness number
- J_a is the joint alteration number
- J_w is the joint water reduction factor
- SRF is the stress reduction factor

The parameters are classified and assigned a value and the Q value is then calculated from the following equation:

$$Q = RQD/J_n \times J_r/J_a \times J_w/SRF \qquad \text{(Eqn. 1)}$$

The Q value is then used in a design chart to estimate the support required for a specific tunnel span or height. Like the RMR system, the Q system was originally developed from well documented case studies but unlike the RMR system its parameters have remained relatively constant since its inception in 1974 (Milne et al., Reference 7).

2. Empirical methods correlating rock mass classification values to rock mass properties.

Elastic Modulus or Modulus of Deformation

Reference 1 presents a number of empirical methods to obtain the in-situ elastic modulus from rock mass classification values or indices. The first empirical method is a correlation with RQD.

$$E_d = \{(0.0231)(RQD) - 1.32\} \times E_{t50} \qquad \text{(Eqn. 2)}$$

Where:

E_d = in-situ modulus of deformation
E_{t50} = laboratory tangent modulus at 50 percent of the unconfined compressive strength.
For RQD values > ~ 60%.

The second empirical method is a correlation with RMR values. Serafim and Pereira developed the following correlation, which covers the entire RMR range (Reference 8):

$$E_d = 10^{(RMR-10)/40} \qquad \text{(Eqn. 3)}$$

Where:

E_d = in-situ modulus of deformation (in GPa).

Bieniawski (Reference 9) (Eqn. 4) also proposes an RMR correlation:

$$E_{MASS} = 2 \times RMR - 100 \qquad \text{(Eqn. 4)}$$

Where:

E_{MASS} is the elastic modulus of the rock mass (in GPa).
For RMR > 50.

The third set of empirical methods are correlations with Q values that Barton proposed in 1983 (Reference 1):

E_d (mean) = 25 x log Q (Eqn. 5)

E_d (min) = 10 x log Q (Eqn. 6)

E_d (max) = 40 x log Q (Eqn. 7)

Where:

E_d (mean) = mean value of in-situ modulus of deformation (GPa)
E_d (min) = minimum value or lower bound value of in-situ modulus of deformation (GPa)
E_d (max) = maximum value or upper bound value of in-situ modulus of deformation (GPa)

Strength

Reference 1 presents information on the selection of design shear strength parameters and the most applicable tests to determine the shear strength of rock, plus a discussion of rock failure characteristics. Correlations between rock mass classification system values and shear strength are not presented.

Hoek and Brown (Reference 10) developed the following correlation between RMR values and the Hoek-Brown strength parameters, m and s:

For undisturbed rock:

$m = m_i \exp\{(RMR-100)/28\}$ (Eqn. 8)

$s = \exp\{(RMR-100)/9\}$ (Eqn. 9)

For disturbed rock:

$m = m_i \exp\{(RMR-100)/14\}$ (Eqn. 10)

$s = \exp\{(RMR-100)/6\}$ (Eqn. 11)

Where:

m and s = factors for a specific rock type used in the Hoek-Brown criterion.

m_i = Hoek-Brown constant for intact rock pieces.

Hoek (Reference 11) contains more information on the Hoek-Brown criterion for rock masses.

3. The application of RQD, RMR, and Q classification systems to characterize the rock at the FPL site and their use in determining rock mass properties.

RQD Classification System

The RQD classification system was used to classify rock core recovered from borings drilled at the FPL site. Upon retrieval of the core, RQD values were calculated for the Key Largo Limestone, the Fort Thompson and Arcadia formations. The RQD values for these lithologies are in FSAR Table 2.5.4-206. Recommended average best-fit RQD values are in FSAR Table 2.5.4-209.

An empirical correlation between RQD and the in-situ elastic modulus is presented in Eqn. 2. However, review of the input parameters required in the equation and the assumptions upon which the equation is based indicate that this correlation is not applicable at the FPL site. First, as described in Reference 1, the equation shows that the relationship is invalid for RQD values less than approximately 60%. Second, the equation was developed from data that indicated considerable variation between the in-situ modulus of elasticity and the laboratory tangent modulus. As shown in FSAR Table 2.5.4-206, average RQD values for the Fort Thompson and Arcadia formations are 40% and 57%, respectively, rendering the equation invalid for these formations. The average RQD value for the Key Largo Limestone is 65%, and thus the equation is valid. However, due to difficulties encountered during testing, only two laboratory tests to determine the elastic modulus could be performed successfully. Both samples were obtained from around 50 feet depth at the boundary between the Key Largo and Fort Thompson Limestone Formations. The results of the laboratory test to determine the in-situ elastic modulus and the difficulties encountered are discussed in more detail in the response to RAI 2.5.4-6. Because of this small amount of testing, the elastic modulus was determined from evaluations based on in-situ shear wave velocity (Vs) measurements, as described in part 4 of this response. The use of the tangent modulus to determine the in-situ elastic modulus is questionable. Hoek et al. (Reference 12) contend that the tangent modulus is probably not related to the properties of the rock mass but rather is associated with the closing of gaps in the near surface rock and the mechanical components of the loading system.

RMR and Q Classification Systems

The RMR and Q classification systems are not considered appropriate methods by which to characterize the rock at the FPL site. The RMR and Q classification systems are primarily applicable to jointed rocks, and as described in FSAR Section 2.5.1.2.3 “no systematic jointing patterns were identified within the bedrock underlying the FPL site”. FSAR Section 2.5.1.2.2, describes the Key Largo Limestone as a “coralline limestone characterized by the presence of vuggy porosity”. The Fort Thompson Formation is described as a “sandy limestone with zones of uncemented sand interbeds, some vugs, and zones of moldic porosity” and the Arcadia Formation is described as consisting of “carbonate rock ranging from packstone to wackestone to a mudstone, with a few isolated lenses of sand”. The most frequently used input parameters of the RMR and Q classification systems, as described in part 1 of this response, pertain to joints or discontinuities. For this reason, it is generally considered that these systems work best in blocky ground where the degree of jointing is often the most important input parameter.

As the RMR and Q classification systems were not utilized at the site, the empirical correlations relating RMR and Q values to in-situ elastic modulus values presented in Equations 3 through 7 are not applied here. Similarly, the empirical correlation between RMR values and the Hoek-Brown strength parameters m and s presented in Equations 8 through 11 are not applied.

4. Accounting for rock mass properties at the FPL site for foundation stability analyses.

The strength and deformation characteristics of the Key Largo Limestone, Fort Thompson, and Arcadia formations at the FPL site were determined from laboratory tests and in-situ shear wave velocity (V_s) measurements. The unconfined compressive strength (U) of the various rock lithologies were determined from laboratory unconfined compressive strength tests performed on 31 samples of the Key Largo Limestone, 46 samples of the Fort Thompson Formation and 3 samples of the Arcadia Formation. The recommended unconfined compressive strength values are in FSAR Table 2.5.4-209 and a discussion on how they were developed is provided in detail in response to RAI 2.5.4-18. The deformation characteristics, elastic (E) and shear (G) modulus, were determined from evaluations based on in-situ shear wave velocity (V_s) measurements. Laboratory tests to determine the in-situ elastic modulus were attempted, however, given the difficulties encountered only two tests were performed successfully. A discussion on this, the results of the two tests and the development of the elastic and shear modulus using the in-situ shear wave velocity (V_s) are in the response to RAI 2.5.4-6.

The recommended elastic and shear modulus are in FSAR Table 2.5.4-209.

The strength and deformation properties determined for the limestone formations at the FPL site and used in the foundation stability analyses are considered to reasonably represent the in-situ rock or rock mass at the site. While comparisons of these properties with properties derived from empirical correlations provided in part 2 of this response might have been useful from a research or comparison perspective, the RQD correlation is not considered reliable and the RMR and Q classification systems were not considered applicable methods by which to characterize the rock mass at the site.

In terms of using rock mass classification systems to determine rock mass properties, it is important to remember that empirically derived rock mass properties are estimates only. As described in Reference 1, “empirical correlations between the modulus of deformation and rock mass classification systems are helpful in establishing likely ranges of values and provide approximate values for preliminary design”. The use of rock mass classification systems has expanded over the years and while they provide guidance in the early stages of design, consideration should always be given to the limitations of the systems and the basis upon which they were originally developed. In providing their “ten commandments” for using RMR and Q, Barton and Bieniawski (Reference 13) agree that the classification systems should be applied “in the letter and spirit for which they are developed”. In conclusion, since the rock mass deformation characteristics were derived from in-situ shear wave velocity (V_s) data, and these data are considered to reflect the various geologic features in the rock mass such as voids and discontinuities, estimates of elastic modulus values were not derived from the empirical correlations relating RMR and Q classification systems (originally developed as design tools to estimate support for underground openings).

This response is PLANT SPECIFIC.

References:

1. USACE EM 1110-1-2908, “Engineering Design – Rock Foundations,” *Rock Mass Characterization,*” Chapter 4, November 30, 1994
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7. Milne, D., Hadjigeorgiou, J., Pakalnis, R., “Rock Mass characterization for Underground Hard Rock Mines.” *Tunneling and Underground Space Technology*, Vol. 13, No.4, pp. 383-391, 1998.
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10. Hoek, E., and Brown, E. T., “The Hoek-Brown failure criterion – a 1988 update”. *Rock Engineering for Underground Excavations: Proceedings of the 15th Canadian Rock Mechanics Symposium*, pp. 31-38. Toronto, Department of Civil Engineering, University of Toronto, 1988.
11. Hoek, E, “Rock mass properties,” Course notes, *Practical Rock Engineering* Chapter 11. Available at http://www.rocscience.com/education/hoeks_corner, 2007.
12. Hoek, E. and Diederichs, M. S., “Empirical estimation of rock mass modulus,” *International Journal of Rock Mechanics & Mining Sciences,* Vol. 43, p. 203-215, 2006.
13. Barton, N., and Bieniawski, Z. T., “RMR and Q - Setting records,” Tunnels and Tunnelling International, February 2008.

ASSOCIATED COLA REVISIONS:

The following changes will be made in a future COLA revision

FSAR Subsection 2.5.4.2.1.3.4 will be revised as follows:

2.5.4.2.1.3.4 Rock Recovery and RQD

Numerous rock mass classification systems have been developed over the past 100 years for various applications. The United States Army Corp of Engineers (USACE) Engineering Manual (EM) 1110-1-2908 on Engineering Design – Rock Foundations (1994) describes six classification systems that have been used extensively. These include: Terzaghi's Rock Load Height Classification; Lauffer's Classification; Deere's Rock Quality Designation (RQD); Rock Structure Rating (RSR) Concept; Geomechanics or Rock Mass Rating (RMR) System; and the Q-System. ASTM D5878-08 (2008) describes eight classification systems and their applications and these include the RMR; RSR; Q System; Unified Rock Classification System (URCS); Rock Material Field Classification System (RMFCS); New Austrian Tunneling Method (NATM); Coal Mine Roof Rating (CMRR); and Japanese Rock Mass Classification Systems. USACE EM 1110-1-2908 (1994) describes three of the classification systems as applicable to work on rock foundations. These include the RQD, Geomechanics or RMR System and the Q System. At the site, the RQD value is used to quantitatively estimate the rock mass quality. The RQD value is calculated from the drill core logs and presented as a percentage which correlates to rock quality, as described below.

FSAR Subsection 2.5.4.13 References will be revised as follows:

283. ASTM D5878-08, "Standard Guides for Using Rock-Mass Classification Systems for Engineering Purposes," ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 2008.

284. ACE EM 1110-1-2908, "Engineering Design – Rock Foundations," *Rock Mass Characterization,"* Chapter 4, November 30, 1994.

ASSOCIATED ENCLOSURES:

None