PMTurkeyCOLPEm Resource

From: Comar, Manny
Sent: Thursday, October 30, 2014 9:06 AM
To: TurkeyCOL Resource
Subject: FW: FPL Letter L-2014-286 Signed 10-03-2014: NRC RAI Letter No. 044 (eRAI 6184) Voluntary Revised Response
Attachments: L-2014-286 Signed 10-06-2014 - Voluntary Revised Response to NRC RAI Letter No. 044 (eRAI 6184).pdf

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From: Burski, Raymond [mailto:RAYMOND.BURSKI@fpl.com]
Sent: Friday, October 03, 2014 3:48 PM
To: Williamson, Alicia; Maher, William; Comar, Manny; Hoeg, Tim; Terry, Tomeka; McCree, Victor
Subject: FPL Letter L-2014-286 Signed 10-03-2014: NRC RAI Letter No. 044 (eRAI 6184) Voluntary Revised Response

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

Re: Florida Power & Light Company
Proposed Turkey Point Units 6 and 7
Docket Nos. 52-040 and 52-041
Voluntary Revised Response to NRC Request for Additional Information Letter No. 044 (eRAI 6184) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations

References:

1. NRC Letter to FPL dated December 2, 2011, Request for Additional Information Letter No.044 Related to SRP Section 02.05.04 – Stability of Subsurface Materials and Foundations for the Turkey Point Nuclear Plant Units 6 and 7 Combined License Application
2. FPL Letter L-2011-559 to NRC dated December 19, 2011, Schedule for Response to NRC Request for Additional Information Letter No. 044 (eRAI 6184) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations (ML11356A067)
3. FPL Letter L-2012-026 to NRC dated January 19, 2012, Response to NRC Request for Additional Information Letter No. 044 (eRAI 6184) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations (ML12023A072)
4. FPL Letter L-2014-111 to NRC dated April 29, 2014, Revised Response to NRC Request for Additional Information Letter No. 040 (eRAI 6006) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations
5. FPL Letter L-2014-152 to NRC dated June 18, 2014, Submittal of Part 2, Chapter 2, Section 2.5

FPL and NRC Staff have been engaged in interactions concerning the information provided in References 1 through 5.

As a result of these interactions Florida Power & Light Company (FPL) is providing, as attachments to this letter, a revised response for the Nuclear Regulatory Commission's (NRC) Request for Additional Information (RAI) RAI 02.05.04-25. The attachment identifies changes that will be made in a future revision of the Turkey Point Units 6 and 7 Combined License Application (if applicable). This revised RAI response provides the current version of the response and associated COLA change in order to facilitate the NRC Staff's review. This revision reflects changes provided in earlier revisions of the RAI response.

Ray Burski
NNP Licensing Engineer
Turkey Point Units 6&7 COLA Project
New Nuclear Projects
Florida Power & Light Company
700 Universe Blvd
Juno Beach, FL 33408

(O) 561-694-4496
(C) 504-909-6436

Hearing Identifier: TurkeyPoint_COL_Public
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Sent Date: 10/30/2014 9:06:08 AM
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From: Comar, Manny

Created By: Manny.Comar@nrc.gov

Recipients:
"TurkeyCOL Resource" <TurkeyCOL.Resource@nrc.gov>
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L-2014-286
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October 3, 2014

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

Re: Florida Power & Light Company
Proposed Turkey Point Units 6 and 7
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Voluntary Revised Response to NRC Request for Additional Information Letter No. 044 (eRAI 6184) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations

References:

1. NRC Letter to FPL dated December 2, 2011, Request for Additional Information Letter No.044 Related to SRP Section 02.05.04 – Stability of Subsurface Materials and Foundations for the Turkey Point Nuclear Plant Units 6 and 7 Combined License Application
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3. FPL Letter L-2012-026 to NRC dated January 19, 2012, Response to NRC Request for Additional Information Letter No. 044 (eRAI 6184) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations (ML12023A072)
4. FPL Letter L-2014-111 to NRC dated April 29, 2014, Revised Response to NRC Request for Additional Information Letter No. 040 (eRAI 6006) – Standard Review Plan Section 02.05.04 – Stability of Subsurface Materials and Foundations
5. FPL Letter L-2014-152 to NRC dated June 18, 2014, Submittal of Part 2, Chapter 2, Section 2.5

FPL and NRC Staff have been engaged in interactions concerning the information provided in References 1 through 5.

As a result of these interactions Florida Power & Light Company (FPL) is providing, as attachments to this letter, a revised response for the Nuclear Regulatory Commission's (NRC) Request for Additional Information (RAI) RAI 02.05.04-25. The attachment identifies changes that will be made in a future revision of the Turkey Point Units 6 and 7 Combined

License Application (if applicable). This revised RAI response provides the current version of the response and associated COLA change in order to facilitate the NRC Staff's review. This revision reflects changes provided in earlier revisions of the RAI response.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on October 3, 2014.

Sincerely,

William Maher
Senior Licensing Director – New Nuclear Projects

WDM/RFB

Attachment: FPL Revised Response to NRC RAI No. 02.05.04-25 (eRAI 6184)

cc:
PTN 6 & 7 Project Manager, AP1000 Projects Branch 1, USNRC DNRL/NRO
Regional Administrator, Region II, USNRC
Senior Resident Inspector, USNRC, Turkey Point Plant 3 & 4

NRC RAI Letter No. PTN-RAI-LTR-044

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 characterize 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:

Part a)

The Miami Limestone, the Key Largo Limestone, the Fort Thompson Formation, and the Arcadia Formation are all limestone with varying degrees of hardness and local void characteristics. This results in variability of the core recovery and rock quality designation (RQD) measurements as well as small variances in laboratory test results of unconfined compressive strength (UCS). All variances of RQD are considered in the rock mass analysis which includes any interpreted void space. The data considered in this response includes all the data collected during initial and supplemental site investigations. The scope of the supplemental site investigation is provided in the revised response to RAI 02.05.04-3.

Fracturing and jointing at Turkey Point Units 6 & 7, where observed, is very widely spaced except under the vegetated depressions and drainages where the Miami Limestone, Key Largo Limestone, and Fort Thompson formations are slightly to moderately fractured as observed within the inclined borings of the supplemental investigation (Reference 1).

As part of the supplemental investigation, three inclined borings (R-6-1a, R-6-1a-A, and R-7-4) are drilled in areas that were anticipated to be slightly to moderately fractured (in vegetated depressions and across drainages). The borings are inclined to increase the lateral extent of the investigation and evaluate fracture density beneath depressions and drainages. Of the 48 observed fractures with measured dips in the inclined borings, only two fractures have a relative dip greater than 65 degrees, which is near vertical (80 degrees to 90 degrees) in the corrected orientation. Fractures with this orientation would be difficult to capture in the vertical borings. However, it is worth noting that these are the least frequent fractures. The predominant fracture dip is between 30 degrees and 60 degrees, thus, most fractures would also be observable in vertical borings. Outside of depressions and drainages, fractures in general are less frequent and almost all are described as totally healed.

Results from the site investigations show that interpreted tool drops (due to voids and/or voids filled with soft sediments) are also found more often under the vegetated depressions and drainages. In the three inclined borings, a total of 15.2 feet of tool drops are observed, in a total of 356.4 feet cored, for only 4.3 percent of the total cored. Individual drops in the inclined borings range from 0.3 feet to 2.5 feet.

Outside the vegetated depressions and drainages (in vertical borings), a total of 20.1 feet of interpreted tool drops are observed, in a total of 7918.4 feet cored, for a 0.3 percent of the total cored in 68 borings. Individual drops in the vertical borings range from 0.4 feet to 4 feet (1.5 feet max within the Unit 6 and 7 building footprints). A detailed discussion of interpreted tool drops and subsurface fractures and voids is provided in the revised response to RAI 02.05.04-1.

The maximum length of interpreted tool drop (due to voids and/or voids filled with soft sediments) is limited to 1.5 feet within the Unit 6 and 7 building footprints, and the frequency of encountering an interpreted tool drop is less than 0.5 percent site-wide. These statistics are based on the drilling conducted during both the initial and supplemental site investigations. Since voids, voids filled with soft sediments, and any zones of abundant small-scale voids impact the RQD, and thus, the rock mass classification, their effect on rock mass properties is inherently considered in the calculations of settlement and bearing capacity. Void size and frequency is discussed in detail in the revised response to RAI 02.05.04-1.

Therefore, the Turkey Point Units 6 & 7 site is classified into two rock mass categories, FD1 and FD4, based on fracture density. Using Reference 2, fracture density FD1 is described as very slightly fractured and FD4 is described as slightly to moderately fractured.

All geologic parameters from the field and the lab are taken into account when classifying the rock masses. The rock mass rating (RMR) system and the Geologic Strength Index (GSI) produce single values to characterize each rock mass at depth from the available information. The resulting classifications are then statistically summarized to represent local variances using standard deviation and coefficient of variance. These two systems are chosen over other classification systems due to their high frequency of use and research as well as applicability to calculation of other rock properties such as shear strength parameters and deformation modulus.

Both GSI and RMR, in addition to UCS, are used directly in empirical calculations of deformation modulus and shear strength parameters. Shear strength parameters are used in the calculation of bearing capacity while rock mass deformation modulus is implemented in the calculation of expected settlement of the underlying strata.

Rock Mass Classification

Rock mass classification systems are specifically developed to estimate properties of the bearing strata as a whole, from characteristics of individual rock cores, core samples, and boring logs. The RMR system accounts for five categories that describe a rock mass and outline ratings for each parameter (Reference 3). The five parameters are:

1. Strength of intact rock
2. RQD
3. Spacing of discontinuities
4. Condition of discontinuities
5. Groundwater condition

An additional rating adjustment for orientation of discontinuities is applied after calculating the sum of the five main ratings. This adjustment is subtracted according to the potential disadvantage of joint set strike and dip to the specific application, for example, tunnels, foundations, or slopes (Reference 3).

The first two of the five main ratings are directly determined from laboratory and field data. Strength of intact rock is measured in the laboratory from UCS tests on core samples, and RQD is measured in the field according to lengths of intact rock in a given core run. Discontinuity characterization and groundwater condition are interpreted using boring logs from the initial and supplemental site investigations (References 1 and 4).

Laboratory measurements of UCS are summarized in revised FSAR Table 2.5.4-207 and revised FSAR Figure 2.5.4-217 in the revised response to RAI 02.05.04-4.

Field measurements of RQD and recovery lengths are summarized in revised FSAR Table 2.5.4-206, revised in this response. Recovery and RQD values by core run range from 0 percent to 100 percent in all rock layers except the Arcadia Formation where the minimum measured recovery is 18 percent. Average recovery, by layer, ranges from 67 percent to 86 percent and average RQD, by layer, ranges from 37 percent to 67 percent. Revised FSAR Figure 2.5.4-215 (Sheet 1), revised in this response, presents the scatter of RQD values in all rock layers. Revised FSAR Figure 2.5.4-215 (Sheet 2), also revised in this response, presents the scatter of RQD values in rock layers above El. −150 feet. On Sheet 2, RQD values appear more consistent within layers and a distinction is observed at approximate El. −55 feet between the generally higher RQD values of the Key Largo Limestone and the generally lower RQD values of the Fort Thompson Formation.

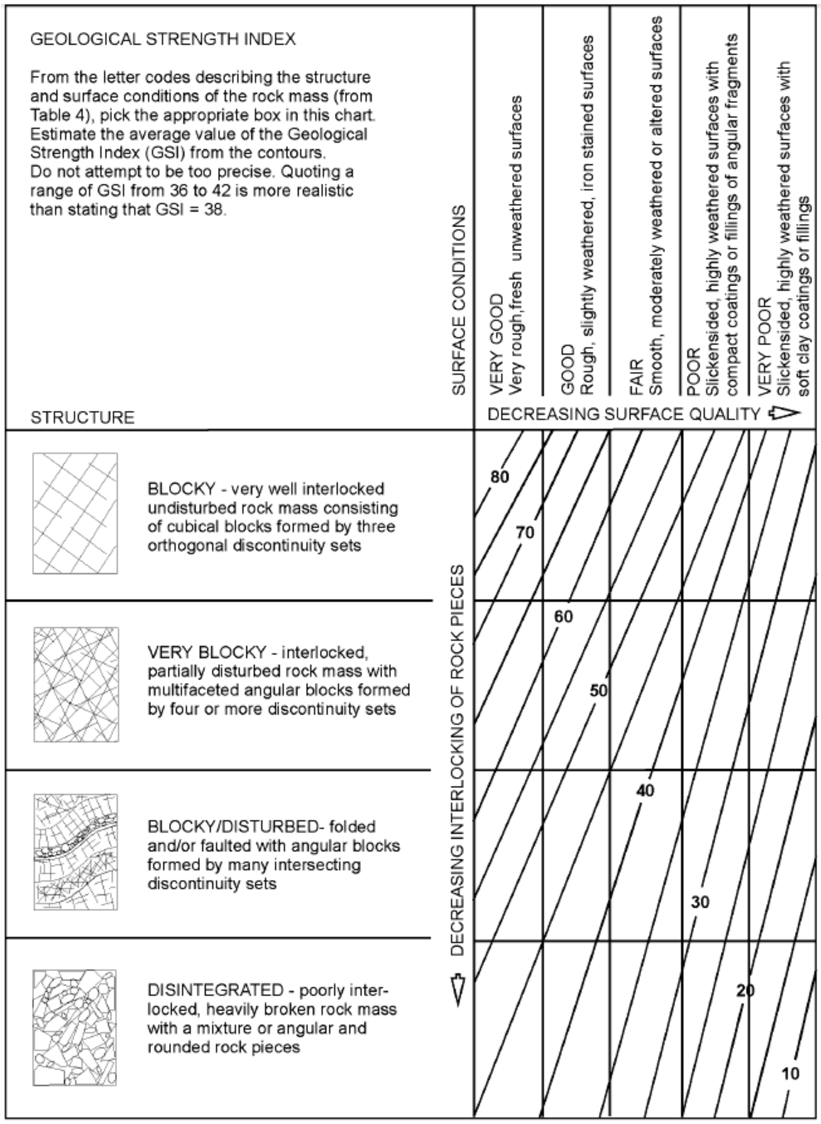
The variability of RQD is accounted for in RMR classification by rating each core run separately then statistically summarizing the core run RMR ratings by layer. This allows every RQD value to be included in the RMR classification. The other four RMR parameters are rated according to layer instead of core run.

The boring logs (References 1 and 4) present information used for discontinuity characterization (spacing, condition, and orientation) and groundwater condition. Descriptions of joints and fractures include openness, infill thickness, infill strength, wall roughness, and wall weathering. The discontinuity spacing observed in the inclined borings is assumed to be the worst case for evaluation of RMR since the lateral spacing cannot be determined from a limited number of borings. The groundwater condition is determined by water level measurement and drilling notes, indicated on the boring logs, and verified through laboratory moisture content values.

Another way of classifying a rock mass is graphically using the GSI system and the discontinuity characterization from the boring logs. GSI specifically accounts for the structure of the rock mass (spacing of discontinuities) on one axis and the joint surface conditions (condition of discontinuities) on the other (Figure 1).

Both GSI and RMR take geologic parameters such as voids and discontinuities into account and can be incorporated into empirical estimates of deformation modulus and shear strength parameters. Deformation modulus and shear strength parameters are used in further calculation of foundation stability.

Figure 1 Geologic Strength Index



Source: Reference 5

Part b)

Foundation Stability Analysis

Bearing capacity analysis utilizes shear strength parameters, c’ and φ', strata unit weights and geometry of the foundation configuration. Shear strength parameters are developed based on rock mass classification and compressive strength to be used in the bearing capacity analysis.

Rock mass deformation modulus is critical for determination of expected settlement and deformation of the underlying strata. Settlement analysis calculates vertical strain using rock and soil stiffness, Poisson's ratio, and effective stresses based on foundation geometry, foundation loading, and the weight of the soil column.

Recommended values for shear strength parameters are presented in revised FSAR Table 2.5.4-209.

The rock mass modulus is considered as one of the sources for determining the stiffness of the rock formations. Results of P-S Suspension tests, unconfined compressive strength tests with stress-strain measurements, and pressuremeter tests are also used to determine the rock stiffness. The details of this assessment are provided in the revised response to RAI 02.05.04-6. The values calculated from this response include only the rock mass modulus obtained from rock mass classification.

Calculation of Shear Strength Parameters

Mohr-Coulomb failure parameters, φ' and c', define the shear strength of a rock mass and are calculated using laboratory UCS test results, overburden stress characterization, and material parameters. This is achieved using the Generalized Hoek-Brown Criterion (Reference 6) as expressed by Equation 1:

$$\sigma'_1 = \sigma'_3 + \sigma_{ci}\left(m_b \frac{\sigma'_3}{\sigma_{ci}} + s\right)^a \qquad \text{Equation 1}$$

Where,

σ'_1 and σ'_3 = major and minor effective stresses, respectively,
σ_{ci} = uniaxial compressive strength, reported from UCS testing, and
m_b, s and a = material properties given by Equations 2, 3, and 4.

$$m_b = m_i \exp\left(\frac{GSI-100}{28-14D}\right) \qquad \text{Equation 2}$$

$$s = \exp\left(\frac{GSI-100}{9-3D}\right) \qquad \text{Equation 3}$$

$$a = \frac{1}{2} + \frac{1}{6}\left(exp\frac{-GSI}{15} - exp\frac{-20}{3}\right) \qquad \text{Equation 4}$$

Where,

m_i = material property for intact rock,
GSI = geologic strength index, and
D = disturbance factor according to method of excavation.

The Mohr-Coulomb failure parameters φ' and c' are subsequently found using these material parameters and Equations 5 and 6:

$$\varphi' = \arcsin\left(\frac{6am_b(s+m_b\sigma'_{3n})^{a-1}}{2(1+a)(2+a)+6am_b(s+m_b\sigma'_{3n})^{a-1}}\right)$$ Equation 5

$$c' = \frac{\sigma_{ci}[(1+2a)s+(1-a)m_b\sigma'_{3n}](s+m_b\sigma'_{3n})^{a-1}}{(1+a)(2+a)\sqrt{1+(6am_b(s+m_b\sigma'_{3n})^{a-1})/((1+a)(2+a))}}$$ Equation 6

Where,

a, s, m_b, and σ_{ci} = material properties defined previously, and
σ'_{3n} is given by Equation 7:

$$\sigma'_{3n} = \sigma'_{3max}/\sigma_{ci}$$ Equation 7

The upper limit of confining stress (σ'_{3max}), for which the Hoek-Brown criterion is calculated, is determined according to the geotechnical application. The global rock mass strength, as estimated by Mohr-Coulomb relationships, is denoted as σ'_{cm}. For the case of slope design these two parameters are defined as in Equations 8 and 9:

$$\frac{\sigma'_{3max}}{\sigma'_{cm}} = 0.72\left(\frac{\sigma'_{cm}}{\sigma_0}\right)^{-0.91}$$ Equation 8

$$\sigma'_{cm} = \sigma_{ci}\frac{[m_b+4s-a(m_b-8s)](m_b/4+s)^{a-1}}{2(1+a)(2+a)}$$ Equation 9

Where,

a, s, m_b, and σ_{ci} = material properties defined previously, and
σ_0 = vertical stress from overburden, including effects of ground water.

Rock Mass Modulus

Rock mass deformation modulus (E_{rm}) can be calculated from either RMR or GSI depending on the methodology. The methodologies presented in Equations 10, 11, and 12 all include laboratory UCS results in the calculation of intact elastic modulus. An overall rock mass modulus is determined as the average of Equations 10, 11, and 12, and is included in the evaluation of rock stiffness discussed in the revised response to RAI 02.05.04-6.

Hoek and Diederichs (Reference 7) utilize GSI (Equation 10):

$$E_{rm} = E_i\left(0.02 + \frac{1-D/2}{1+e^{\left(\frac{60+15D-GSI}{11}\right)}}\right)$$ Equation 10

Sonmez et al., (Reference 8) use RMR (Equation 11):

$$E_{rm} = E_i * 10^{\frac{(RMR-100)(100-RMR)}{4000e^{(-RMR/100)}}} \quad \text{Equation 11}$$

Nicholson and Bieniawski (Reference 9) use RMR as given in Equation 12. The reduction factor in parentheses is calculated in percent and is therefore divided by 100:

$$E_{rm} = E_i\left(0.0028 * RMR^2 + 0.9e^{\left(\frac{RMR}{22.82}\right)}\right)/100 \quad \text{Equation 12}$$

Where,

E_{rm} is rock mass modulus,
E_i is intact elastic modulus, UCS times modulus ratio, MR (Reference 7),
D is the disturbance factor as used in calculation of φ' and c',
RMR is the rock mass rating, and
GSI is the geologic strength index.

FD4/FD1 Zone Boundaries

Shear strength parameters and rock mass modulus are derived for two separate rock masses at the Turkey Point Units 6 & 7 site: the FD1 zone (very slightly fractured) and the FD4 zone (slightly to moderately fractured). The interpreted FD4 zone exists beneath the vegetated depressions and drainages (Figure 3). Not all core runs under vegetated depressions and drainages are characterized as FD4, but this is considered as the worst case fracture density under the investigated depression and drainage footprints. In inclined borings, any local zones higher than FD4 are limited in lateral extent and are spaced widely between zones.

Three inclined borings intersect the interpreted FD4 zone: R-6-1a, R-6-1a-A, and R-7-4 (Figure 3). Inclined borings R-6-1a and R-6-1a-A both intersect the most prominent vegetated drainage near Unit 6. Inclined borehole R-7-4 intersects the most prominent vegetated depression near Unit 7. All three borings encounter a higher density of fractures than borings outside of vegetated wet areas in the initial and supplemental site investigations (References 4 and 1, respectively).

In both inclined borings at Unit 6, measured depths (MD) are noted at the widest zones of higher fracture density. Knowing the inclination of the borings is 15 degrees from vertical, the width of the more densely fractured zone encountered by borings R-6-1a and R-6-1a-A is calculated as 8 feet and 9 feet wide, respectively (Figure 2). At the surface, the vegetated drainage is around 10 feet wide according to aerial imagery (Figure 3). Therefore, it can be assumed that the FD4 zones are within the extents of vegetation under wet areas.

Beneath the vegetated depression to the west of Unit 7, core samples from borehole R-7-4 show evidence of fracturing throughout the Key Largo Limestone and the Fort Thompson formations (Figure 2). In the Miami and Key Largo Limestone, from ground surface to 44 feet (MD), staining observed on fracture walls is dark brown. Below 44 feet (MD), what is observed on the walls of the discontinuities is calcite recrystallization with the rock maintaining similar fracture density. The change in the characteristics of the coating of joints is interpreted as possible evidence of a transition between surface water infiltration inhibiting calcite recrystallization above 44 feet (MD) and groundwater flow promoting calcite recrystallization below. Therefore, since the rock maintains similar fracture density despite the change in discontinuity condition, it is assumed that the FD4 zones extend from the Miami Limestone through the Fort Thompson Formation.

Other zones of fracturing between FD1 and FD4 are possible in areas where there is no evident sign of permanent vegetation and drainage; however, only healed vertical fractures (R-6-1b, R-7-1, B-620), one healed near horizontal fracture (R-6-2) and one area with an open horizontal and 60 degree fracture (R-7-2) have been described at the site outside of the vegetated areas (References 1 and 4). Likely fractured zones are indicated in Figure 3. The interpreted locations of these possible fracture zones are further discussed in the revised response to RAI 02.05.04-1.

Figure 2 Cross-sections of Inclined Borings Including Notes on Fracture Density (FD)

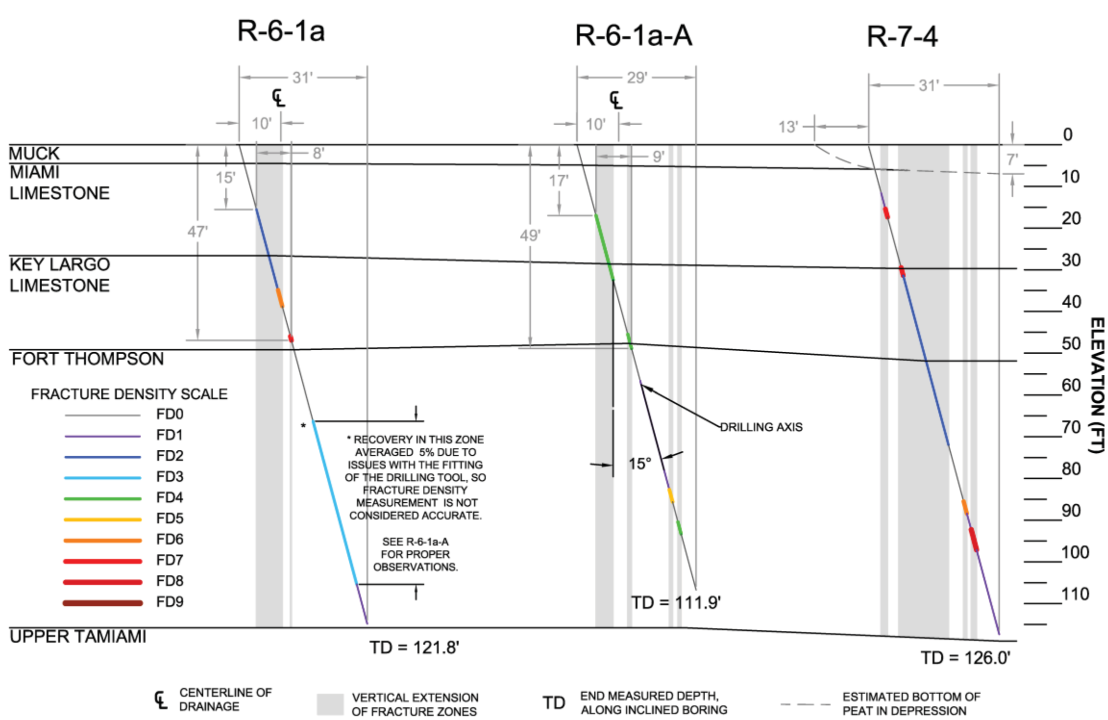
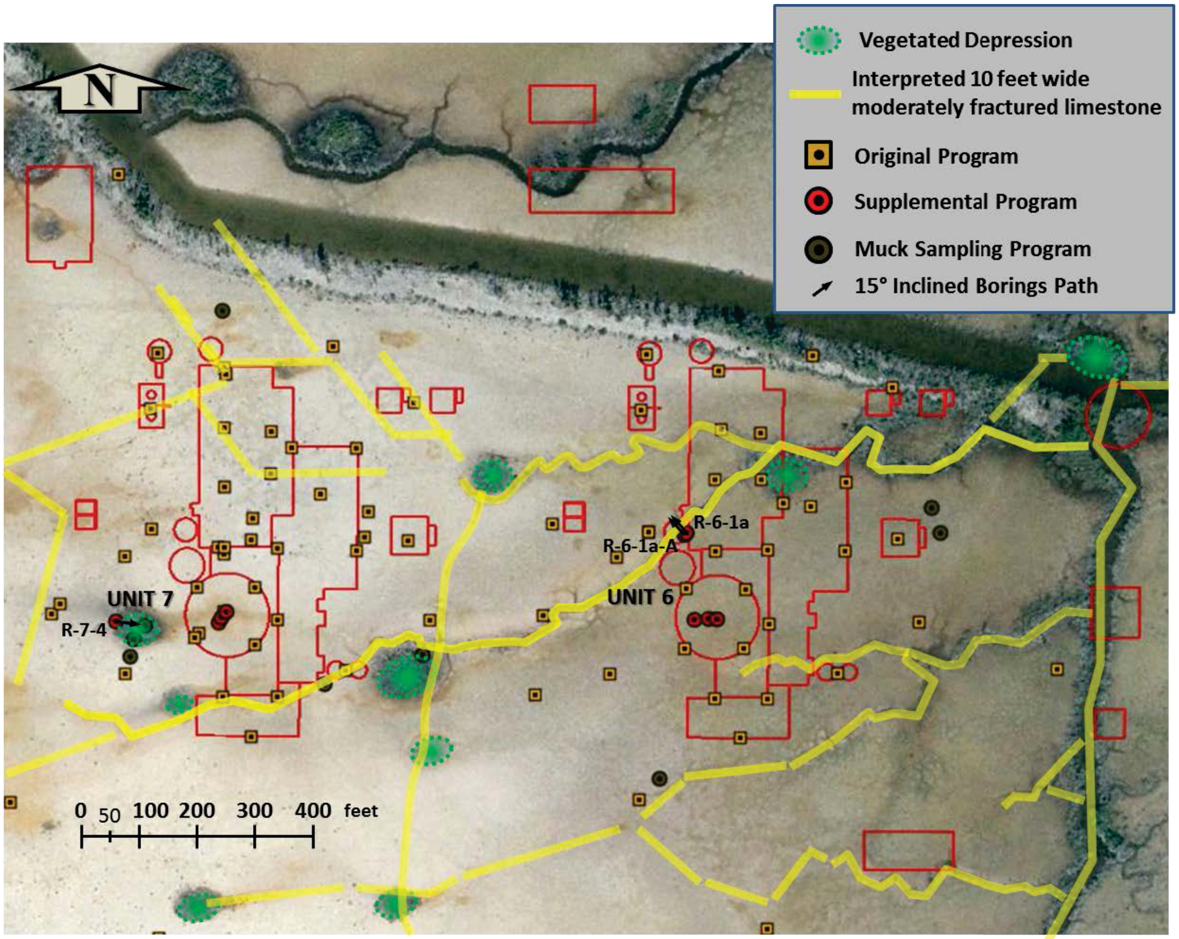


Figure 3 Estimated Location of FD4 Zones[1]



Google earth image 1/30/2005 U.S. Geological Survey

(1) Arrows on inclined borings point in direction of drilling.

This response is PLANT SPECIFIC.

References:

1. Paul C. Rizzo Associates, Inc., *Supplemental Field Investigation Data Report, Turkey Point Nuclear Power Plant Units 6 & 7*, Revision 2, RIZZO, Pittsburgh, Pennsylvania, April 15, 2014.

2. U.S. Department of the Interior Bureau of Reclamation, *Engineering Geology Field Manual*, pg. 97, 2001.

3. USACE, *Rock Foundations*, Engineering Manual (USACE) EM 1110-1-2908, US Army Corps of Engineers, 1994.

4. MACTEC Engineering and Consulting, Inc., *Final Data Report – Geotechnical Exploration and Testing – Turkey Point COL Project, Florida City, Florida,* Volume 1, Appendix B, pp. 84−64, MACTEC, Raleigh, North Carolina, October 6, 2008.

5. Hoek, E. and E.T. Brown, *Practical Estimates of Rock Mass Strength*, International Journal of Rock Mechanics and Mining Sciences, Vol. 34, No. 8, pages 1165-1186, Table 5, 1997.

6. Hoek, E., C. Carranza-Torres, and B. Corkum, *Generalized Hoek-Brown Failure Criterion - 2002 Edition*, 5th North American Rock Mechanics, 2002.

7. Hoek, E. and M.S. Diederichs, *Empirical Estimation of Rock Mass Modulus*, International Journal of Rock Mechanics & Mining Sciences, Volume 43, pp. 203−215, 2006.

8. Sonmez H., C Gokceoglu, H.A. Nefeslioglu, and A. Kayabasi, *Estimation of Rock Modulus: For Intact Rocks with an Artificial Neural Network and for Rock Masses with a New Empirical Equation*, International Journal of Rock Mechanics and Mining Science, Volume 43, p. 231, 2006.

9. Nicholson, G.A. and Z.T. Bieniawski, *A Nonlinear Deformation Modulus Based on rock Mass Classification*, International Journal of Mining and Geological Engineering, Volume 8, pp. 189-190, 1990.

ASSOCIATED COLA REVISIONS:

New text will be added after the last paragraph of Subsection 2.5.4.2.1.1 in a future revision as follows:

2.5.4.2.1.1 Summary of Soil and Rock Strata

Shear strength parameters and rock mass modulus are derived for two separate rock masses at the Turkey Point site: the FD1 zone (very slightly fractured) and the FD4 zone (slightly to moderately fractured) (Reference 216).

Other zones of fracturing between FD1 and FD4 are possible in areas where there is no evident sign of permanent vegetation and drainage; however, only healed vertical fractures (R-6-1b, R-7-1, B-620), one healed near horizontal fracture (R-6-2) and one area with an open horizontal fracture and a 60 degree fracture (R-7-2) are described at the site outside of the vegetated areas. The estimated locations of likely fractured zones are indicated in Figure 2.5.4-254.

Three inclined borings intersect the interpreted FD4 zone, which covers significantly less area, and exists beneath the vegetated depressions and drainages (Figures 2.5.4-254 and 2.5.4-255). Not all core runs under vegetated depressions and drainages are characterized as fracture density FD4, but this is considered as the worst-case fracture density under the investigated depression and drainage footprints.

As part of the supplemental investigation, three inclined borings (R-6-1a, R-6-1a-A, and R-7-4) are drilled in areas anticipated to be slightly to moderately fractured (in vegetated depressions and across drainages). The borings are inclined to increase the lateral extent of the investigation and to evaluate fracture density beneath

depressions and drainages. Of the 48 observed fractures with measured dips in the inclined borings, only two fractures have a relative dip greater than 65 degrees, which is near vertical (80 degrees to 90 degrees) in the corrected orientation. Fractures with this orientation would be difficult to capture in the vertical borings. However, it is worth noting that these are the least frequent fractures. The predominant fracture dip is between 30 degrees and 60 degrees, thus, most fractures would also be observable in vertical borings. Outside of depressions and drainages, fractures in general are less frequent and almost all are described as totally healed.

Beneath the vegetated depression to the west of Unit 7, core samples from boring R-7-4 show evidence of fracturing throughout the Key Largo Limestone and the Fort Thompson formations. In the Miami and Key Largo Limestone, from ground surface to 44 feet (MD), staining observed on fracture walls is dark brown. Below 44 feet (MD), what is observed on the walls of the discontinuities is calcite recrystallization with the rock maintaining similar fracture density. The change in the characteristics of the coating of joints is interpreted as possible evidence of a transition between surface water infiltration inhibiting calcite recrystallization above 44 feet (MD) and groundwater flow promoting calcite recrystallization below. However, because there is no change in fracture density it is assumed that the interpreted FD4 zones extend from the Miami Limestone through the Fort Thompson Formation.

Text will be added after the last paragraph of Subsection 2.5.4.2.1.2.2 in a future revision as follows:

Miami Limestone is expected to be more densely fractured beneath vegetated depressions and drainages as described in Subsection 2.5.4.2.1.1 and presented in Figures 2.5.4-254 and 2.5.4-255.

Text will be added after the last paragraph of Subsection 2.5.4.2.1.2.3 in a future revision as follows:

Key Largo Limestone is expected to be more densely fractured beneath vegetated depressions and drainages as described in Subsection 2.5.4.2.1.1 and presented in Figures 2.5.4-254 and 2.5.4-255.

Text will be added after the last paragraph of Subsection 2.5.4.2.1.2.4 in a future revision as follows:

2.5.4.2.1.2.4 Stratum 4 (Fort Thompson Formation)

The Fort Thompson Formation is expected to be more densely fractured beneath vegetated depressions and drainages as described in Subsection 2.5.4.2.1.1 and presented in Figures 2.5.4-254 and 2.5.4-255.

Subsection 2.5.4.2.1.3.4 will be revised in a future revision as follows:

2.5.4.2.1.3.4 Rock Recovery and RQD

Rock is sampled using HQ3 and PQ3 core barrel equipment. The rock quality designation (RQD) is calculated based on the core runs sampled. In addition to recovery, the RQD provides an index of rock strength for general characterization of a rock mass. As shown on Figure 2.5.4-215, the rock RQD is very inconsistent. In general rock quality appears to be at its maximum in the ~~range from approximately El. –45 to El. –60 feet~~**Key Largo Limestone**. A summary of recovery and RQD for the three rock strata cored is presented in Table 2.5.4-206.

Subsection 2.5.4.2.1.3.20 will be added in a future revision as follows:

2.5.4.2.1.3.20 Rock Mass Classification

Rock mass classification systems are specifically developed to estimate properties of the bearing strata as a whole from characteristics of individual rock cores, core samples, and boring logs. The rock mass rating (RMR) system accounts for five categories that describe a rock mass and outline ratings for each parameter (Reference 303). The five parameters are:

1. **Strength of intact rock**
2. **RQD**
3. **Spacing of discontinuities**
4. **Condition of discontinuities**
5. **Groundwater condition**

An additional rating adjustment for orientation of discontinuities is applied after calculating the sum of the five main ratings. This adjustment is subtracted according to the potential disadvantage of joint set strike and dip to the specific application, such as tunnels, foundations, or slopes (Reference 303).

The first two of the five main ratings are directly determined from laboratory and field data. Strength of intact rock is measured in the laboratory from unconfined compression strength (UCS) tests on core samples, and RQD is measured in the field according to lengths of intact rock in a given core run. Discontinuity characterization and groundwater condition are interpreted using boring logs from the initial and supplemental site investigations (References 257 and 290).

Laboratory measurements of UCS are summarized in Table 2.5.4-207 and Figure 2.5.4-217.

Field measurements of RQD and recovery lengths are summarized in Table 2.5.4-206. Recovery and RQD values by core run range from 0 percent to 100 percent in all rock layers except the Arcadia Formation where the minimum measured recovery is 18 percent. Average recovery by layer ranges from 67 percent to 86 percent and

average RQD by layer ranges from 37 percent to 67 percent. Figure 2.5.4-215 (Sheet 1) presents the scatter of RQD values in all rock layers. Figure 2.5.4-215 (Sheet 2) presents the scatter of RQD values in rock layers above El. −150 feet. On Sheet 2, RQD values appear more consistent within layers and a distinction is observed at approximate El. -55 feet between the generally higher RQD values of the Key Largo Limestone and the generally lower RQD values of the Fort Thompson Formation.

The variability of RQD is accounted for in RMR classification by rating each core run separately then statistically summarizing the core run RMR ratings by layer. This allows every RQD value to be included in the RMR classification. The other four RMR parameters are rated according to layer instead of core run.

The boring logs (References 257 and 290) present information used for discontinuity characterization (spacing, condition, and orientation) and groundwater condition. Descriptions of joints and fractures include openness, infill thickness, infill strength, wall roughness, and wall weathering. The discontinuity spacing is assumed to be the worst case for evaluation of RMR since the lateral spacing cannot be determined from a limited number of borings. The groundwater condition is determined by water level measurement and drilling notes, indicated on the boring logs, and verified through laboratory moisture content values.

Another way of classifying a rock mass is graphically using the Geologic Strength Index (GSI) system and the discontinuity characterization from the boring logs. GSI specifically accounts for the structure of the rock mass (spacing of discontinuities) on one axis and the joint surface conditions (condition of discontinuities) on the other.

Subsection 2.5.4.2.1.3.21 will be added in a future revision as follows:

2.5.4.2.1.3.21 Shear Strength of Rock

Mohr-Coulomb failure parameters, φ' and c', define the shear strength of a rock mass and are calculated using laboratory UCS test results, overburden stress characterization and material parameters. This is achieved using the Generalized Hoek-Brown criterion (Reference 305).

A new reference will be added FSAR Subsection 2.5.4.13 in a future revision:

305. Hoek, E., C. Carranza-Torres, and B. Corkum, *Generalized Hoek-Brown Failure Criterion − 2002 Edition*, 5th North American Rock Mechanics, 2002.

FSAR Table 2.5.4-206 will be replaced in a future revision as follows:

Table 2.5.4-206
Summary of Recovery and RQD Values for Rock Strata

Stratum	Description of Value	Recovery (%)	RQD (%)	No. of Samples	
				Recovery	RQD
Miami	Minimum	0	0	78	78
	Maximum	100	100		
	Average	67	37		
Key Largo	Minimum	0	0	437	437
	Maximum	100	100		
	Average	86	67		
Fort Thompson	Minimum	0	0	1189	1189
	Maximum	100	100		
	Average	67	39		
Arcadia	Minimum	18	0	34	34
	Maximum	100	100		
	Average	82	57		

Data from References 257 **and 290**

FSAR Table 2.5.4-209 will be revised in a future revision as follows: *(Note: The values in red are changed by this response; the entire table will be updated in COLA Rev 6 to include changes in other associated RAIs)*

Table 2.5.4-209 (Sheet 1 of 2)
Summary of Recommended Geotechnical Engineering Parameters

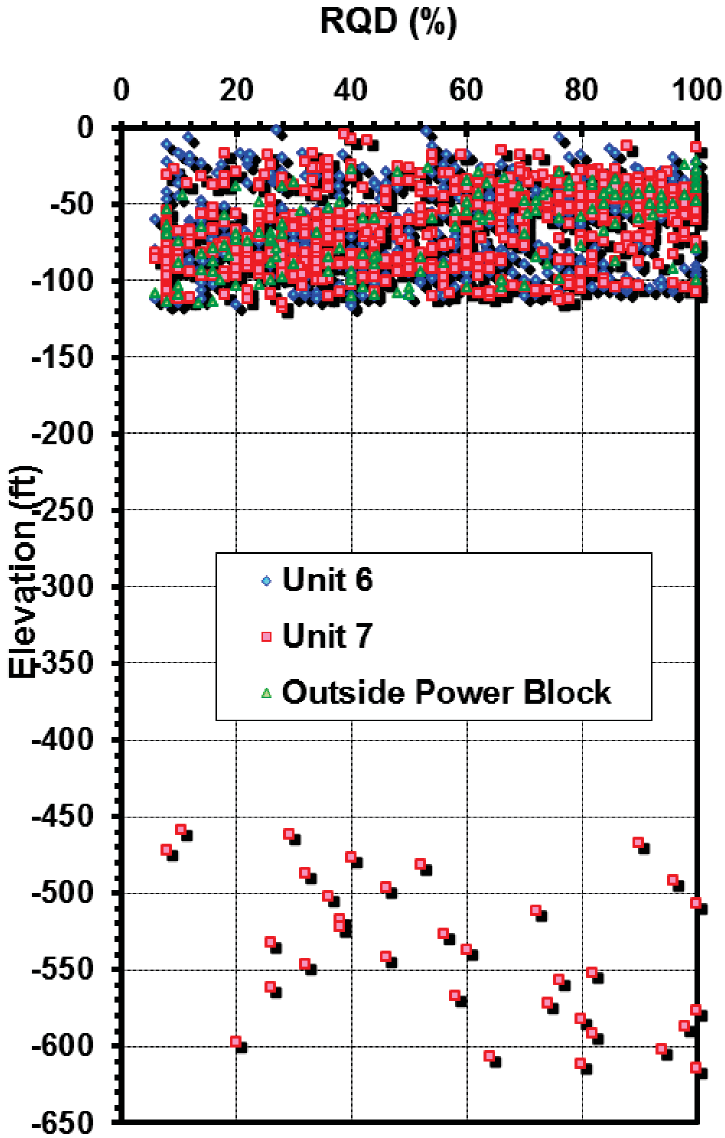
Stratum(a)	1(a)	2	3	4	5	6	7	8	Fill
Description	**Muck**	**Miami**	**Key Largo**	**Ft. Thompson**	**Upper Tamiami**	**Lower Tamiami**	**Peace River**	**Arcadia**	**—**
Elevation of top of layer (ft)	–1.2	–4.5	–26.7	–49.4	–115.1	–159.0	–215.2	–452.1	—
USCS symbol	ML, MH	GM, GP-GM, SM, SW-SM, SW, SP-SM	Limestone	Limestone	SM, SP-SM	ML	SM	Limestone	—
Total unit weight, γ (pcf)	80	125	136	139	120	120	120	130	130
Natural water content, w, (%)	>80	—	—	—	—	30	—	—	33
Fines content (%)	>60	18	—	—	28	62	16	—	15
Atterberg limits									
Liquid limit, LL	—	—	—	—	—	24	—	—	—
Plastic limit, PL	—	—	—	—	—	20	—	—	—
Plasticity index, PI	—	—	—	—	—	4	—	—	—
SPT N60-value (blows/ft)	~0	20	—	—	40	32	75	—	30
Undrained properties									
Undrained shear strength, su (ksf)	—	—	—	—	—	4.0	—	—	—
Internal friction angle, φ, (deg)	—	—	—	—	—	—	—	—	—
Drained properties									
Effective cohesion, c′ (ksf)	—	**6.2 (FD1) 2.0 (FD4)**	**22.5 (FD1) 6.8 (FD4)**	**22.4 (FD1) 8.8 (FD4)**	0	1.7	0	—	—
Effective friction angle, φ′ (deg)	—	**56**	**55 (FD1) 56 (FD4)**	**52**	35	20	40	—	33
Average Rock core recovery (%)	—	~~—~~ **67**	~~83 to 96~~ **86**	~~41 to 98~~ **67**	—	—	—	~~63 to 100~~ **82**	—
Average RQD (%)	—	~~—~~ **37**	~~54 to 81~~ **67**	~~16 to 91~~ **39**	—	—	—	~~32 to 90~~ **57**	—
Unconfined compressive strength, U (psi)	—	200	1,500	2,000	—	—	—	100	—
Elastic modulus (high strain), EH	—	630 ksi	2,600 ksi	1,500 ksi	1,500 ksf	2,500 ksf	2,700 ksf	980 ksi	1,100 ksf
Elastic modulus (low strain), EL	—	950 ksi	2,600 ksi	1,500 ksi	19,700 ksf	25,750 ksf	27,400 ksf	980 ksi	9,100 ksf
Shear modulus (high strain), GH	—	230 ksi	1,000 ksi	550 ksi	550 ksf	900 ksf	1,000 ksf	360 ksi	420 ksf
Shear modulus (low strain), GL	—	350 ksi	1,000 ksi	550 ksi	7,300 ksf	9,500 ksf	10,150 ksf	360 ksi	3,500 ksf
Shear wave velocity, Vs, (ft/sec)	—	3,600	5,800	4,250	1,400	1,600	1,650	3,600	860
Compression wave velocity, Vc, (ft/sec)	—	8,000	11,000	8,700	2,900	3,300	3,450	7,850	1,600
Coefficient of sliding	—	0.6	0.7	0.7	0.4	0.3	—	—	0.5
Poisson's ratio, *v′*	—	0.37	0.31	0.34	0.35	0.35	0.35	0.36	0.3
Static earth pressure coefficients									
Active, Ka	—	0.3	—	—	0.27	0.5	—	—	0.3
At-rest, Ko	—	0.5	—	—	0.5	0.66	—	—	0.5

Table 2.5.4-209 (Sheet 2 of 2)
Summary of Recommended Geotechnical Engineering Parameters

[a] Properties of Stratum 1 (muck) are not provided as this stratum was removed prior to construction.
The values tabulated for use as design guideline only. Refer to specific boring logs, CPT logs, and laboratory test results for appropriate modifications at specific design locations.
USCS = Unified Soil Classification System (ML = silt; MH = silt of high plasticity; GM = silty gravel; GP = poorly graded gravel; SM = silty sand; SW = well graded sand; SP = poorly graded sand).

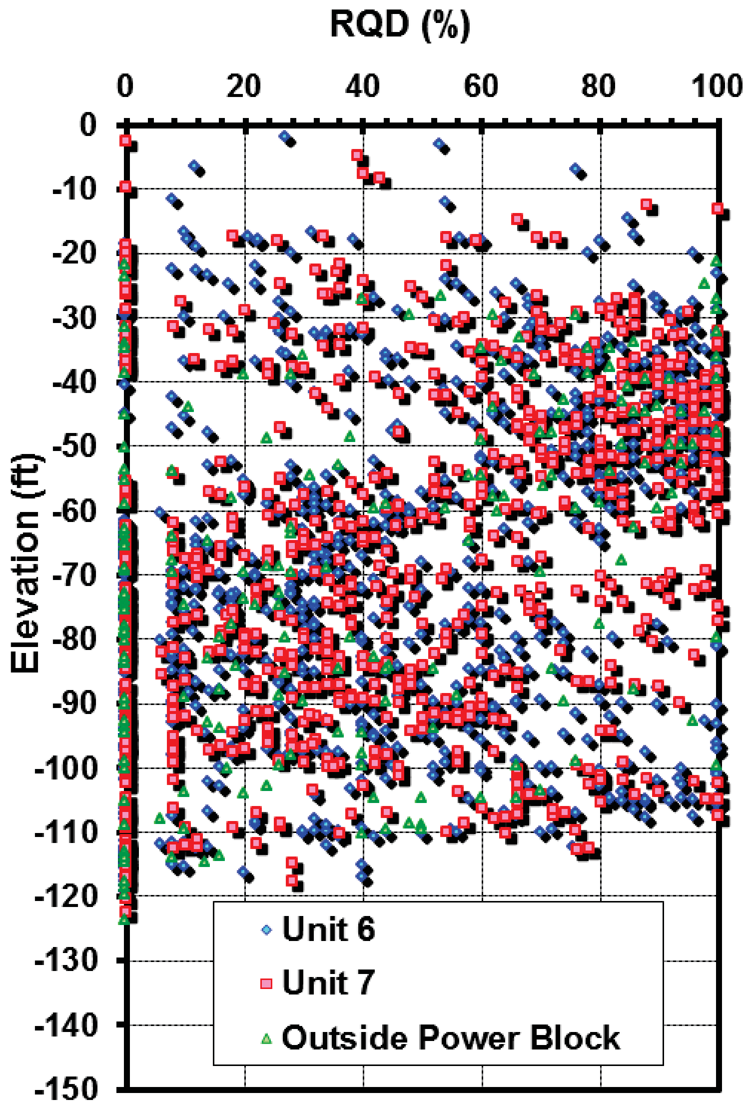
FSAR Figure 2.5.4-215 will be replaced with the following figure in a future revision:

Figure 2.5.4-215 Plot of Rock RQD Data with ~~Depth~~ Elevation
(Sheet 1 of 2)



Data from References 257 and 290

Figure 2.5.4-215 Plot of Rock RQD Data with ~~Depth~~ Elevation (Sheet 2 of 2)



Data from References 257 and 290

The following figures will be added in a future revision:

Figure 2.5.4-254 Estimated Location of Interpreted FD4 (Slightly to Moderately Fractured) Zones

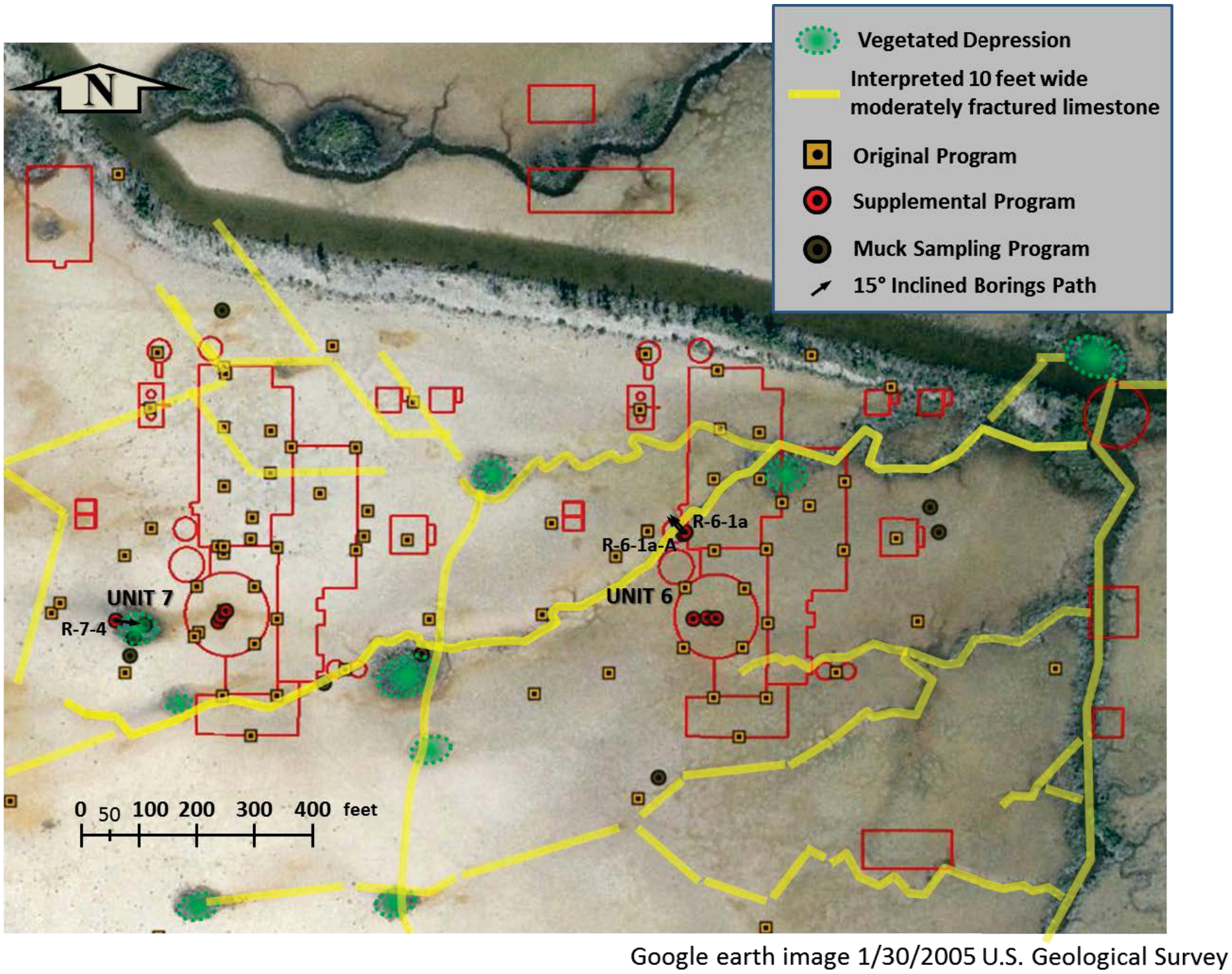
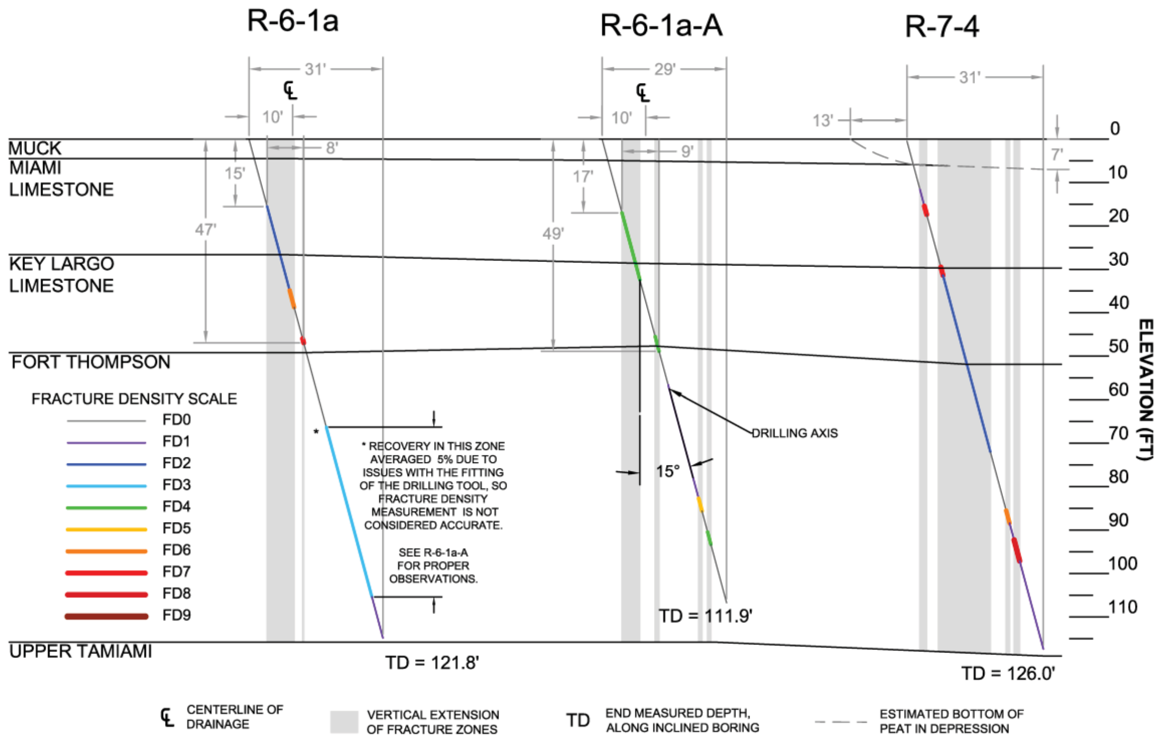


Figure 2.5.4-255 Cross-sections of Inclined Borings Including Notes on Fracture Density (FD)



ASSOCIATED ENCLOSURES:

None