Duke Energy®

Bryan J. Dolan
VP, Nuclear Plant Development

Duke Energy
EC09D/ 526 South Church Street
Charlotte, NC 28201-1006

Mailing Address:
P.O. Box 1006 – EC09D
Charlotte, NC 28201-1006

704-382-0605

Bryan.Dolan@duke-energy.com

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Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Duke Energy Carolinas, LLC
William States Lee III Nuclear Station - Docket Nos. 52-018 and 52-019
AP1000 Combined License Application for the
William States Lee III Nuclear Station Units 1 and 2
Response to Request for Additional Information
(RAI No. 2098)
Ltr# WLG2009.06-01

Reference: Letter from Brian Hughes (NRC) to Peter Hastings (Duke Energy), Request for Additional Information Letter No. 066 Related to SRP 02.05.04 – Stability of Subsurface Materials and Foundations for the William States Lee III Units 1 and 2 Combined License Application, dated March 23, 2009

This letter provides the Duke Energy response to the Nuclear Regulatory Commission's request for additional information (RAI) included in the referenced letter.

The response to the NRC information request described in the referenced letter is addressed in a separate enclosure, which also identifies associated changes, when appropriate, that will be made in a future revision of the Final Safety Analysis Report for the Lee Nuclear Station.

If you have any questions or need any additional information, please contact Peter S. Hastings, Nuclear Plant Development Licensing Manager, at 980-373-7820.

Bryan J. Dolan

Bryan J. Dolan
Vice President
Nuclear Plant Development

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NRO

Enclosure:

1) Duke Energy Response to Request for Additional Information Letter 066, RAI 02.05.04-015

AFFIDAVIT OF BRYAN J. DOLAN

Bryan J. Dolan, being duly sworn, states that he is Vice President, Nuclear Plant Development, Duke Energy Carolinas, LLC, that he is authorized on the part of said Company to sign and file with the U. S. Nuclear Regulatory Commission this supplement to the combined license application for the William States Lee III Nuclear Station and that all the matter and facts set forth herein are true and correct to the best of his knowledge.

Bryan J. Dolan

Bryan J. Dolan

Subscribed and sworn to me on June 2, 2009

Phoebe P. Elliott

Notary Public

My commission expires: June 26, 2011

SEAL

xc (w/o enclosure):

Loren Plisco, Deputy Regional Administrator, Region II
Stephanie Coffin, Branch Chief, DNRL

xc (w/ enclosure):

Brian Hughes, Senior Project Manager, DNRL

Lee Nuclear Station Response to Request for Additional Information (RAI)

RAI Letter No. 066

NRC Technical Review Branch: Geosciences and Geotechnical Engineering Branch 1 (RGS1)

Reference NRC RAI Number(s): RAI 02.05.04-015

NRC RAI:

AP1000 DCD, Revision 17, Table 2.5-1 provides the limits of acceptable settlement without additional evaluation. The table states that the total settlement for the nuclear island foundation mat is 3 inches and the differential settlement across the nuclear island foundation mat is limited to ½ inch in 50 ft. Additionally, Westinghouse response to RAI-TR85-SEB1-36 corrects Table 2.5-1 of Rev 17, to state that the differential settlement between the nuclear island and the turbine building is limited to 3 inches, and the differential settlement between the nuclear island and other buildings is also limited to 3 inches.

In the case of the nuclear island founded on rock and the turbine building and other surrounding buildings founded on shallow foundations supported on fill, please provide estimates of the settlement and differential settlement of the non-safety related structures. Please provide a description of the program/method that you will implement to ensure that the actual settlements and differential settlements of the structures do not exceed the DCD settlement criteria.

Duke Energy Response:

The Lee Nuclear Station nuclear island (NI) structures are founded on fill concrete and/or hard rock. As described in the response to RAI 02.05.04-010 (Reference 1), Duke Energy has chosen to use granular backfill material adjacent to the NI and beneath adjacent structures. The granular backfill material is obtained from a suitable off-site source. The material properties of the granular backfill material will meet or exceed the interface requirements in the AP1000 DCD Subsection 2.5.4.6.2 (Reference 2). Compliance with the AP1000 DCD limits of acceptable settlement, including differential settlement of the non-safety related structures, is accomplished by using granular backfill material adjacent to the NI and beneath adjacent structures. This RAI response provides technical information regarding the engineering properties for granular backfill material beneath Seismic Category II and non-seismic buildings including bearing capacity of the granular backfill material, allowable bearing pressure based on factor of safety, and allowable bearing pressure based on settlement.

Granular Backfill Material Beneath Buildings

The granular backfill material will be obtained from a quarry or suitable alternative, and will be a manufactured material. The Unified Soil Classification System (USCS) classification symbols will be SW to SP (well graded sand to poorly graded sand), or GW to GP (well graded gravel to poorly graded gravel). There are multiple sources capable of producing manufactured materials in sufficient quantity and quality to support the Lee Nuclear Station construction requirements.

The imported granular fill is placed beneath the structures adjacent to the NI (both units), including the Annex Buildings (Seismic Category II portion), Radwaste Buildings, and Turbine Buildings. The granular fill is compacted in thin lifts to a dry density that is at least 96% of the maximum dry density obtained from ASTM D 1557 (modified Proctor). Based on this, the granular fill will be at a relative density of 80% (Lee and Singh (1971 (Reference 3)). Note that relative compaction compared to the modified Proctor maximum dry density will be the controlling requirement for the granular fill. Idriss and Boulanger (2008) (Reference 4) indicate the $(N_1)_{60}$ will be about 29-30 blows/ft if the granular fill is a sand at this relative density; based on Rollins et al. (1998) (Reference 5), the $(N_1)_{60}$ will be about 45 blows/ft if the granular fill is a gravel at this relative density.

Based on empirical information in NAVFAC (1986) (Reference 6), reasonable values would be a saturated unit weight of 136 lb/ft^3 for a typical SW material, 142 lb/ft^3 for a typical GP material, and 150 lb/ft^3 for a typical GW material, all compacted to 96% relative compaction (RC) (modified Proctor). Empirical information in Reference 6 also indicates typical SW material compacted to 80% relative density (96% of modified Proctor maximum dry density) would have an effective stress friction angle of approximately 37 degrees. Typical GP material compacted to 80% relative density (96% of modified Proctor maximum dry density) would have an effective stress friction angle equal to approximately 39 degrees. Typical GW material compacted to 80% relative density (96% of modified Proctor maximum dry density) would have an effective stress friction angle equal to approximately 41 degrees. The effective stress cohesion intercept for these typical materials would be zero.

The preceding engineering properties for typical granular fill materials are summarized in Table 1, attached. An effective stress friction angle equal to 35 degrees is conservatively used for the ultimate bearing capacity calculations in conjunction with the material-specific unit weights.

The allowable bearing pressure and settlement of the foundations to be supported on the granular fill are discussed below.

<u>Bearing Capacity of Granular Fill</u>

For granular fill, bearing capacity is based on Terzaghi's bearing capacity equations modified by Meyerhof and Hansen and provided by Bowles (1996) (Reference 7). The ultimate (gross) bearing capacity of a footing (q_{ult}) supported on homogeneous soils can be estimated by:

$$q_{ult} = cN_c s_c d_c + q'N_q s_q d_q + 0.5\gamma_e BN_\gamma s_\gamma d_\gamma R_b$$

Where:

- c = cohesive shear strength of the soil (zero for granular fill)
- ϕ = friction angle of the soil
- q' = effective overburden pressure at the foundation base
- γ_e = effective unit weight of the soil
- B = foundation width (smallest dimension)
- N_c, N_q, and N_γ = bearing capacity factors (defined in Reference 7)
- s_c, s_q and s_γ = shape factors (defined in Reference 7)
- d_c, d_q and d_γ = depth factors (defined in Reference 7)
- R_b = size limitation factor (defined in Reference 7)

These equations use the effective unit weight of the soil, the width and depth of the foundation, and bearing capacity and shape factors that are a function of the angle of internal friction of the soil. Consequently, each foundation has a different bearing capacity depending on the foundation dimensions. The Radwaste Buildings, Annex Buildings (Seismic Category II portion), and Turbine Buildings all bear on mat foundation areas rather than having their columns and walls supported on individual spread footing foundations. For large foundations, the bearing capacity equations can give very large bearing capacity values, even when a factor of safety of 3.0 is included for the allowable bearing value. In such situations, settlement, discussed later herein, normally governs.

Allowable Bearing Pressure Based on Factor of Safety

Table 2, attached, gives the approximate building dimensions and loading (applied bearing pressure) on the mat foundation. Table 3, attached, gives the estimated allowable safe bearing pressure for the Seismic Category II Annex Building and nonseismic Turbine and Radwaste Buildings based on granular fill soils underlying the structures and a safety factor equal to 3. Because of the irregular shapes of these structures, minimum width dimensions for "B" are considered in the theoretical bearing capacity analyses. The groundwater table is assumed to be at elevation 584 feet in these calculations.

Allowable Bearing Pressure Based on Settlement

For large mat foundations (such as those that support the structures), Peck, Hansen, and Thornburn (1974) (Reference 8) indicate that, based on geotechnical experience, if total foundation settlement is limited to 2 inches, with differential settlement limited to ¾ inch, the performance of the structure should not be impacted. For individual footings that support smaller plant components, the corresponding value of total settlement is 1 inch.

Reference 8 determines the allowable foundation pressures which, if not exceeded, will result in settlements not to exceed 1 inch for smaller footings and not to exceed 2 inches for larger foundation areas (e.g., mat foundations). If the safety factor against exceeding the ultimate bearing capacity as calculated earlier herein is adequate, the maximum applied bearing pressure to cause settlement not to exceed 1 inch or 2 inches according to Reference 8 is;

$q_{allowable\_1\ inch} = 0.11\ (N_1)_{60} \times C_w$ (tsf), and

$q_{allowable\_2\ inches} = 0.22\ (N_1)_{60} \times C_w$ (tsf)

Where:

$$C_w = 0.5 + \frac{0.5 D_w}{D_f + B}$$

Where:

D_w = depth to groundwater measured from the ground surface surrounding the foundation; and

C_w = adjustment factor for depth of the groundwater table (D_w) less than the sum of the foundation depth below the ground surface (D_f) and smallest foundation dimension (B); the minimum value is 0.5; the maximum value is 1.0.

Note: If $D_w \le D_f$, $C_w = 0.5$.

For granular fill composed of sand (SW to SP) with $(N_1)_{60}$ = 29 – 30 blows/ft, the applied pressure would be about 6.5 tsf (13 ksf) for limiting 2 inches settlement of a mat foundation. For granular fill composed of gravelly materials (GW, GP, etc.) with $(N_1)_{60}$ = 45 blows/ft, the corresponding applied pressures for limiting settlement would be about 10 tsf (20 ksf) for 2 inches settlement of a mat foundation.

The buildings all have mat foundations, so the allowable bearing pressure for limiting settlement to 2 inches is applicable. The presence of the water table reduces the allowable bearing pressure. Table 4, attached, provides the allowable bearing pressure for limiting settlement to 2 inches for the potential granular fill types and with groundwater at elevation 584 feet. The available pressures that limit settlement to 2 inches on mat foundations exceed the estimated actual pressures exerted by the Radwaste Building, Annex Building (Seismic Category II portion), and Turbine Building. It is noted that the limiting pressures for 2 inches settlement are for a mat underlain by sand to a depth below the bottom of the foundation equal to the width B (Reference 8). None of the buildings is underlain by such a depth of granular fill (except possibly the Radwaste Building at the northwest corner of the NI for Unit 1). The Turbine Buildings have the least thickness of granular fill below the foundation, which will allow less settlement than implied by simply comparing the applied bearing pressure to the limiting bearing pressure.

The method that will be implemented to ensure that the actual settlement and differential settlement of the structures do not exceed the DCD settlement criteria will be to select and approve the materials actually used for granular fill, and implement field placement and compaction control procedures to create a very dense granular fill capable of supporting the structures without allowing excessive settlement to occur. Fill placement and compaction control procedures will be addressed in construction specifications and drawings. Those construction documents include requirements for suitable fill, sufficient testing to address potential material variations, and in-place density testing frequency (e.g., a minimum of one test per 10,000 square feet of fill placed). They also include requirements for an on-site testing agency for quality control (e.g., gradation, moisture density, placement, and compaction) and requirements to ensure that the fill operations conform to the earthwork specification. The soil testing agency is required to be independent of the earthwork contractor and to have an approved quality program. Sufficient laboratory compaction (modified Proctor) and grain size distribution tests are performed to ensure that variations in the fill material are accounted for. A test fill program is also included for the purposes of determining an optimum size of roller, number of passes, lift thickness, and other relevant data for achievement of the specified compaction.

Based on the above considerations, the settlement of the Radwaste, Annex (Seismic Category II portion), and Turbine Buildings will not exceed 2 inches as supported on the granular fill. Thus, the settlement of these structures will not exceed the DCD settlement criterion of 3 inches differential settlement between them and the NI supported on rock or fill concrete overlying rock (which experiences insignificant settlement). In addition, because the NI structures are founded on fill concrete and/or hard rock, the differential settlement across the NI foundation mat will not exceed the DCD criterion of ½ inch in 50 ft, as already described in FSAR Subsection 2.5.4.10.2.

Duke Energy will submit updates to the FSAR addressing the DCD settlement criterion of 3 inches differential settlement between the NI and Radwaste, Annex (Seismic Category II portion), and Turbine Buildings in conjunction with the other FSAR changes described, and by the date provided, in the response to RAI 02.05.04-010 (Reference 1). These changes to relevant portions of the FSAR to address meeting the DCD differential settlement criteria will be incorporated into a future revision of the Final Safety Analysis Report.

References:

1. Bryan J. Dolan (Duke Energy) to Document Control Desk, U.S. Nuclear Regulatory Commission (NRC), Response to Request for Additional Information (RAI No. 1881), Ltr# WLG2009.05-05, dated May 15, 2009.
2. Westinghouse Electric Company LLC. "AP1000 Design Control Document" (APP-GW-GL-700) Revision 17.
3. Lee, K. L., and Singh, A., 1971. Relative Density and Relative Compaction, Journal of the Soil Mechanics and Foundation Division, Proc. Of the American Society of Civil Engineers, Vol. 97, No. SM7, July, pages 1049 – 1052.
4. Idriss, I. M., and Boulanger, R. W., 2008. Soil Liquefaction during Earthquakes, Monograph MNO 12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.
5. Rollins, K. M., Evans, M., Diehl, N. and Daily, W., 1998. "Shear Modulus and Damping Relationships for Gravels," Journal of Geotechnical and Geoenvironmental Engineering., ASCE, Vol. 124, No. 5, p. 396 – 405.
6. NAVFAC, 1986. Soil Mechanics, design manuals 7.1 and 7.2, Naval Facilities Engineering Command, Alexandria, VA.
7. Bowles, J. E. (1996), Foundation Analysis and Design, 5th Edition, The McGraw-Hill Companies, Inc.
8. Peck, R. B., Hanson, W. E., and Thornburn, T. H., 1974. Foundation Engineering, 2nd Edition, John Wiley and Sons, NY.

Associated Revision to the Lee Nuclear Station Final Safety Analysis Report:

Duke Energy will submit updates to the FSAR implementing the changes described above by the date provided in the response to RAI 02.05.04-010 (Reference 1).

Attachments:

1) Table 1. Estimated Engineering Properties for Typical Granular Fill Materials
2) Table 2. Structure Size and Foundation Applied Bearing Pressure
3) Table 3. Allowable Bearing Pressure Based on Safety Factor
4) Table 4. Allowable Bearing Pressure Based on Limiting Settlement

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 1 to RAI 02.05.04-015

Table 1. Estimated Engineering Properties for Typical Granular Fill Materials

Table 1. Estimated Engineering Properties for Typical Granular Fill Materials

USCS Type	Units	SW	GP	GW
Maximum Dry Density (ASTM D1557)	(lb/ft^3)	124	133.5	146
Compacted Dry Density In-Place (1)	(lb/ft^3)	119	128	140
Saturated Unit Weight In-Place (2)	(lb/ft^3)	136	142	150
Effective Stress Friction Angle (c = 0)	(degrees)	37 (3)	39 (3)	41 (3)
Equivalent $(N_1)_{60}$	(blows/ft)	29 – 30	45	45

(1) 96% relative compaction by modified Proctor (ASTM D1557).

(2) Assume wet unit weight (above water table) is equal to saturated unit weight.

(3) Effective stress friction angle = 35 degrees is conservatively used for ultimate bearing capacity calculations.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 2 to RAI 02.05.04-015

Table 2. Structure Size and Foundation Applied Bearing Pressure

Table 2. Structure Size and Foundation Applied Bearing Pressure

Structure	Seismic Category	Elevation of Base of Foundation (feet)	Depth of Foundation	Width [1]	Length	$q_{applied}$ (ksf)
			D_f (feet)	B (feet)	L (feet)	
Annex Building	SC-II	588	1.5	70	289	2.06
Turbine Building	Non-seismic [3]	586 – 569 [2]	3.5	127	312	1.70
Radwaste Building	Non-seismic	588	1.5	69	178	0.52

(1) Smallest width of building shown.

(2) Higher elevation used.

(3) Final Design of the Turbine Building may designate the portion closest to the NI as SC-II. This would not change the assessments presented in this RAI response.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 3 to RAI 02.05.04-015

Table 3. Allowable Bearing Pressure Based on Safety Factor

Table 3. Allowable Bearing Pressure Based on Safety Factor

Structure	Subsurface	B x L (feet)	Bearing Pressure (ksf)		$q_{applied}$ (ksf)	$q_{safe} > q_{applied}$?
			q_{ult} [(1)]	q_{safe} [(2)]		
SW Sand Granular Fill						
Annex Building	Granular Fill – SW	70 x 289	77.25	25.75	2.06	Yes
Turbine Building	Granular Fill – SW	127 x 312	120.04	40.01	1.70	Yes
Radwaste Building	Granular Fill – SW	69 x 178	72.71	24.24	0.52	Yes
GP Gravel Granular Fill						
Annex Building	Granular Fill – GP	70 x 289	82.74	27.58	2.06	Yes
Turbine Building	Granular Fill – GP	127 x 312	128.82	42.94	1.70	Yes
Radwaste Building	Granular Fill – GP	69 x 178	77.84	25.95	0.52	Yes
GW Gravel Granular Fill						
Annex Building	Granular Fill – GW	70 x 289	90.06	30.02	2.06	Yes
Turbine Building	Granular Fill – GW	127 x 312	140.53	46.84	1.70	Yes
Radwaste Building	Granular Fill – GW	69 x 178	84.68	28.23	0.52	Yes

(1) Groundwater level is assumed to be at elevation 584, or 5.5 feet below the yard surface.

(2) Factor of safety of 3 is used in the analyses.

Lee Nuclear Station Response to Request for Additional Information (RAI)

Attachment 4 to RAI 02.05.04-015

Table 4. Allowable Bearing Pressure Based on Limiting Settlement

Table 4. Allowable Bearing Pressure Based on Limiting Settlement

Structure	Subsurface	q_{allow} (1) (ksf)	$q_{applied}$ (ksf)	$q_{allow} > q_{applied}$?	Anticipated Settlement (inches)
SW Sand Granular Fill					
Annex Building	Granular Fill – SW	7.11	2.06	Yes	< 2
Turbine Building	Granular Fill – SW	6.88	1.70	Yes	< 2
Radwaste Building	Granular Fill – SW	7.11	0.52	Yes	< 2
GP Gravel Granular Fill					
Annex Building	Granular Fill – GP	10.66	2.06	Yes	< 2
Turbine Building	Granular Fill – GP	10.32	1.70	Yes	< 2
Radwaste Building	Granular Fill – GP	10.67	0.52	Yes	< 2
GW Gravel Granular Fill					
Annex Building	Granular Fill – GW	10.66	2.06	Yes	< 2
Turbine Building	Granular Fill – GW	10.32	1.70	Yes	< 2
Radwaste Building	Granular Fill – GW	10.67	0.52	Yes	< 2

(1) For limiting settlement to 2 inches.