Permit No.	Scan Date	DIN
3612-INDUS-2008	**December 17, 2013**	**20298**

RECEIVED
December 17, 2013
Solid Waste Section
Asheville Regional Office

December 16, 2013

North Carolina Department of Environment and Natural Resources
Land Quality Section
1612 Mail Service Center
Raleigh, North Carolina 27699

Attention: Mr. Steven M. McEvoy, P.E.
Steve.mcevoy@ncdenr.gov
State Dam Safety Engineer

Reference: Variance Request Letter
Allen Retired Ash Basin Dam, Gaston County, State Dam ID: GASTO-016
Retired Ash Basin (RAB) – Ash Landfill (Solid Waste Permit No. 36-12)
Duke Energy - Allen Steam Station, Belmont, NC
S&ME Project No. 1356-10-009C, Task 4
North Carolina P.E. Firm License No. F-0176

Dear Mr. McEvoy:

On behalf of Duke Energy, S&ME, Inc. (S&ME) prepared this letter and related information to request a variance to the Certificate of Approval (COA) dated November 30, 2010 for the Allen Retired Ash Basin (RAB) Dam (State Dam ID: GASTO-016) at Duke Energy's Allen Steam Station. We prepared this letter as requested during a conference call on December 3, 2013 between Mr. Steven M. McEvoy with North Carolina Department of Environment and Natural Resources (NCDENR) Land Quality Section, Dams Program, Mr. Larry Frost with NCDENR Solid Waste Section, Mr. Tim Russell and Mr. Sean DeNeale with Duke Energy, and Mr. Jason Reeves and Mr. Kyle Baucom with S&ME.

The COA (provided as Attachment 1) outlines several stipulations related to the landfill construction. These requirements have been met thus far. As explained during the above-mentioned conference call, we are requesting a variance to the compaction moisture criteria outlined in Part 3.a of the COA. Part 3.a of the COA currently states that:

"Waste fill shall be compacted to a minimum of 95 (ninety-five) percent of its standard Proctor (ASTM D698) maximum dry density. Compacted moisture content shall be within 5 (five) percent of optimal moisture content."

The subsequent sections of this letter explain in further detail the background of the project and the rationale for the requested variance.

BACKGROUND

The Allen RAB Ash Landfill is being constructed over a retired ash basin at Duke Energy's Allen Steam Station. Phase 1 construction consists of the construction of Cells 1 and 2. The Cell 1 liner system was constructed, and a "Permit to Operate" (PTO) for Cell 1 (Solid Waste Permit No. 36-12) was issued by NCDENR Solid Waste Section on December 9, 2009.

With the landfill being located behind (up gradient) of the existing RAB dam, the landfill became a part of Dam Safety jurisdiction at the beginning of 2010 with changes in G.S. 143-215.25A(a)(4) of the North Carolina Dam Safety Law of 1967. The Cell 2 liner system construction was ongoing during 2010. On November 30, 2010, Dam Safety issued the COA for the Allen RAB Dam (State Dam ID: GASTO-016). Within the COA, several stipulations were outlined related to the ongoing landfill operations. Part 3 of the COA provided specific quality control placement requirements for material placed in the landfill. These quality control criteria were included in Appendix II of the Operations Plan. On December 8, 2010, the PTO was issued for Phase 1 (Cells 1 and 2). Since then, Phase 1 has been operated in general accordance with the relevant Dam Safety and Solid Waste permit documents.

Another stipulation related to ongoing landfill operations was Part 1 of the COA, which requires the submittal of quarterly reports by the Engineer of Record documenting that the material is being placed in accordance with the quality control requirements and explaining whether the design material strength parameters remain valid. Since the 1st Quarter of 2011, S&ME has submitted the quarterly reports to Dam Safety. It should also be noted that the Engineer of Record transitioned from Kenneth Daly to Jason Reeves during the 2nd Quarter of 2012 as documented in the Landfill Operations Observation and Testing Services quarterly report dated July 6, 2012.

In summary, landfilled material has been placed in accordance with the quality control requirements. In addition, twelve (12) consolidated-undrained (CU) triaxial compression tests (ASTM D 4767) have been performed over the previous three (3) years on representative material (fly ash) compacted to 95 percent of its standard Proctor (ASTM D698) maximum dry density and near optimum moisture content. The test results indicate effective friction angles (Φ') ranging from approximately 29.0 to 32.7 degrees for the ash materials tested between 2011 and 2013 to date.

Slope stability analyses reported in S&ME's Permit to Operate – Modifications Request dated September 3, 2010 indicated that the material tested must exhibit an effective friction angle (Φ') of at least 26 degrees in order to achieve the design safety factors (1.5 for static conditions and 1.0 for pseudo-static conditions) associated with the critical slip surfaces. To date, the ash materials tested for the quarterly reporting have met this minimum effective friction angle criteria.

OPERATIONS MODIFICATION

Since July 2011, landfilled material has generally been placed in Cell 2A, and no material has been placed in Cell 1. Cell 1 was left with the sump area and haul ramp exposed to aid in leachate and stormwater management. The Cell 1 top deck consists of fly ash covered with a dust suppressant in accordance with the Dust Control Plan in the Operations Plan.

Due to the future waste projections, an operating decision was made to temporarily close Cell 1. Temporary closure consists of filling the sump area and haul ramp with waste material, crowning the top deck with waste material, and applying 12 inches of interim soil cover. The temporary closure will minimize infiltration and leachate, thereby treating precipitation in the form of stormwater. Because of the limited waste generation at the plant, bottom ash from the Pond 2 excavation is being placed in conjunction with filling the sump area, haul ramp, and crowning Cell 1. It should be noted that bottom ash material is a permitted waste based on the Operations Plan.

During the initial placement of the bottom ash material, the landfill operator, Charah, had difficulty meeting the moisture criterion stated in Part 3.a of the COA. The material was moisture conditioned with a water truck. However, due to the free-draining characteristics of this material, the in-place moisture contents typically averaged on the order of 10 percent dry of the optimum moisture content. The compaction requirement of 95 percent of its standard Proctor (ASTM D698) maximum dry density was met with the bottom ash being dry of the specified moisture range. The shape of the standard Proctor moisture-density relationships indicates that the moisture content of the bottom ash material at compaction has less influence on its compaction characteristics than typical soil materials, and the behavior is similar to granular materials such as ASTM C33 fine aggregate that do not typically have specified compaction moisture ranges. This characteristic of bottom ash is also described in Part 7.6.2 of ASTM E 2277, “Design and Construction of Coal Ash Structural Fills” (provided as Attachment 2).

With the moisture criteria in the quality control requirements fundamentally being based on achieving the material strength parameters, Duke and S&ME proposed to perform a CU triaxial compression test on representative bottom ash material compacted to 95 percent of its standard Proctor (ASTM D698) maximum dry density and 10 percent dry of the optimum moisture content, which is representative of field conditions. This proposal was also discussed during the conference call on December 3, 2013 between NCDENR, Duke, and S&ME representatives. The standard Proctor moisture-density relationship for sample BA-3 has similar moisture-density characteristics as bottom ash placed in the landfill. The shear strength test results indicate an average effective friction angle (Φ') of approximately 37.9 degrees, which is greater than the necessary 26 degrees to achieve the design safety factors (1.5 for static conditions and 1.0 for pseudo-static conditions) associated with the critical slip surfaces. The laboratory test results are provided as Attachment 3 to this letter.

VARIANCE REQUEST

The results of the field and laboratory testing and literature review indicate that the granular bottom ash materials are relatively insensitive to compaction water content provided that wetting of the bottom ash is sufficient to prevent bulking behavior. The permeability of these materials allow water to drain out through the placement and compaction process. The test data suggests these materials can be placed in a dry state and then compacted into dense particle arrangements to produce the minimum design shear strength properties. Therefore, we recommend a variance be allowed to the moisture criterion stated in Part 3.a. of the COA. The recommended variance is as follows:

"Waste fill shall be compacted to a minimum of 95 percent of its standard Proctor (ASTM D698) maximum dry density. Compacted moisture content shall be within 5 percent of the optimum moisture content. If during placement of granular waste fill the compaction criterion is achieved, but the moisture content criterion cannot be obtained due to the free-draining nature of the materials such that the material is dryer than 5 percent of optimum moisture content, the Engineer shall be contacted for approval prior to the placement of the next successive lift."

CLOSING

We appreciate your cooperation and we believe that the proposed variance request and discussion herein address your interests. Please contact us at your earliest convenience if you have any questions or need additional information.

Respectfully submitted,

S&ME, Inc.

Kyle Baucom, P.E.
Project Engineer

NORTH CAROLINA PROFESSIONAL SEAL 24486 ENGINEER JASON S. REEVES 12-16-13

Jason S. Reeves, P.E.
Senior Project Engineer
Engineer of Record

Attachments: 1: Dam Safety "Certificate of Approval" dated November 30, 2010
2: ASTM E 2277, "Design and Construction of Coal Ash Structural Fills"
3: Bottom Ash Laboratory Test Results

Cc: Larry Frost, NCDENR, Division of Waste Management - Solid Waste Section
Tim Russell, Duke Energy
Sean DeNeale, Duke Energy
Don Scruggs, Duke Energy

ATTACHMENT 1

Dam Safety “Certificate of Approval” dated
November 30, 2010

NCDENR

North Carolina Department of Environment and Natural Resources
Division of Land Resources

James D. Simons, PG, PE
Director and State Geologist

Beverly Eaves Perdue, Governor
Dee Freeman, Secretary

Certificate of Approval

November 30, 2010

CERTIFIED MAIL
RETURN RECEIPT

Duke Energy Corporation
Attn: Mr. B. Henry Taylor, PE, Senior Engineer
Procurement, Construction and EH&S – Environmental Projects
EC11Y P.O. Box 1006
Charlotte, North Carolina 28201-1006

RE: Allen Retired Ash Basin Dam
Approval to Modify
Gaston County
State Dam ID: GASTO-016

Dear Mr. Taylor:

This is in response to your submissions dated and received as follows of plans, specifications and design data for modification of the subject dam in compliance with the Dam Safety Law of 1967.

1. "OPERATIONS PLAN RETIRED ASH BASIN (RAB) – ASH LANDFILL ALLEN STEAM STATION BELMONT, NORTH CAROLINA" document dated March 11, 2008, revised September 3, 2010. This document was received on September 9, 2010.

2. "Permit to Operate – Modifications Request" document dated September 3, 2010. This document was received on September 9, 2010.

3. "Permit to Operate – Modifications Request – Response to NCDENR Comments" document dated November 11, 2010. This document was received on November 12, 2010.

This dam is of high hazard classification. These plans, specifications and design data were prepared under the supervision of Mr. Kenneth R. Daly, PE, with S&ME, Inc.

This letter constitutes approval of the proposal to modify the subject dam according to the plans and specifications received by this Division on September 9, 2010, revised November 12, 2010 with the following stipulations:

1. Project construction shall be supervised by Mr. Kenneth R. Daly, PE. Mr. Kenneth R. Daly, PE shall be responsible for field observation of construction as necessary to ensure compliance with approved plans. Mr. Kenneth R. Daly, PE shall provide a report to this office on March 31, June 30, September 30 and December 31 of each year for the duration of the project beginning in 2011. The report is to be in a format which will certify that material placement to date is in accordance with approved compaction requirements and provide professional opinion as to whether material strength parameters assumed in the structural analyses by S&ME, Inc. dated February 18, 2009 and May 1, 2009 remain valid. This report is to be provided in digital format.

2. During construction, the Division of Land Resources may require such progress reports as are deemed necessary.

3. The Operations Plan shall be revised as follows for quality control of compaction effort on dry placed waste ash material:

    a. Waste fill shall be compacted to a minimum of 95 (ninety-five) percent of its Standard Proctor (ASTM D698) maximum dry density. Compacted moisture content shall be within 5 (five) percent of optimal moisture content.

    b. Cells 1 and 3: At minimum, perform in-place density tests at a frequency of one test per 8,000 cubic yards (or one test per 216,000 square feet of 12-inch thick lift). At minimum, develop one moisture-density relationship (Standard Proctor test – ASTM D698) at a frequency of one test per 50,000 cubic yards of material placed.

    c. Cells 2 and 4: At minimum, perform in-place density tests at a frequency of one test per 2,000 cubic yards (or one test per 54,000 square feet of 12-inch thick lift). At minimum, develop one moisture-density relationship (Standard Proctor test – ASTM D698) at a frequency of one test per 20,000 cubic yards of material placed.

4. In accordance with GS 143-215.29 and NCAC 15A-2K .0203, .0212, .0215, and .0216, within 30 days of completion of the project, Mr. Kenneth R. Daly, PE shall inspect the completed work and upon finding that the work has been done as specified and the dam is safe, shall file with the Division of Land Resources two sets of record drawings and a certificate stating that the work has been completed in accordance with approved plans, specifications and other requirements.

5. Final approval for operation of this dam must be issued by the Division of Land Resources upon project completion.

6. An emergency action plan (EAP) is required for all high hazard dams. It is strongly recommended that the EAP be submitted prior to commencing modifications to address

problems that may arise during construction. Nevertheless, the EAP must be received prior to March 31, 2011 or this approval is void.

7. You must notify Mr. Zahid Khan, Regional Engineer, Land Quality Section, 610 East Center Avenue, Mooresville, North Carolina 28115, (704) 663-1699 ten days before the start of construction.

The Army Corps of Engineers and the Water Quality Section of this Department should be contacted to determine if additional permits are required. Also, the erosion and sediment control program having jurisdiction should be contacted to determine permit requirements. In any case, sediment must be prevented from entering the waters of the state or flowing onto neighboring property.

Construction of the modifications must begin within one year of the date of this letter or this approval is void. For assistance you may contact the Mooresville Regional Office at (704) 663-1699 or a staff member of the Dam Safety Program in the Raleigh Central Office at telephone number (919) 733-4574.

Sincerely,

James D. Simons, PG, PE
Director and State Geologist

JDS/smm

cc: Mr. Kenneth R. Daly, PE, with S&ME, Inc.
Mr. Zahid Khan, Land Quality Regional Engineer
Surface Water Protection Regional Supervisor

File name: GASTO-016_20101130_COAM_Allen Retired Ash Basin Dam.doc

SENDER: *COMPLETE THIS SECTION*	*COMPLETE THIS SECTION ON DELIVERY*
■ Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired. ■ Print your name and address on the reverse so that we can return the card to you. ■ *Attach* this card to the back of the mailpiece, or on the front if space permits.	A. Signature X ☐ Agent ☐ Addressee B. Received by (*Printed Name*) C. Date of Delivery
1. Article Addressed to: Duke Energy Corporation Attn: Mr. B. Henry Taylor, PE Procurement, Construction and EH&S – Environmental Projects EC11Y P.O. Box 1006 Charlotte, North Carolina 28201-1006	D. Is delivery address different from item 1? ☐ Yes If YES, enter delivery address below: ☐ No 3. Service Type ☒ Certified Mail ☐ Express Mail ☐ Registered ☒ Return Receipt for Merchandise ☐ Insured Mail ☐ C.O.D. 4. Restricted Delivery? (*Extra Fee*) ☐ Yes
2. Article Number (*Transfer from service label*)	7008 1300 0000 1130 1788

PS Form 3811, February 2004 Domestic Return Receipt GHSTO-016 102595-02-M-1540

ATTACHMENT 2

ASTM E 2277, “Design and Construction of Coal Ash Structural Fills”

Designation: E2277 – 03

Standard Guide for
Design and Construction of Coal Ash Structural Fills[1]

This standard is issued under the fixed designation E2277; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers procedures for the design and construction of engineered structural fills using coal fly ash, bottom ash, or ponded ash.

1.2 The utilization of coal ash under this guide is a component of a pollution prevention program; Guide E1609 describes pollution prevention activities in more detail. Utilization of coal ash in this manner conserves land, natural resources, and energy.

1.3 This guide applies only to fly ash and bottom ash produced primarily by the combustion of coal.

1.4 The testing, engineering, and construction practices for coal ash fills are similar to generally accepted practices for natural soil fills. Coal ash structural fills should be designed using generally accepted engineering practices.

1.5 Laws and regulations governing the use of coal ash vary by state. The user of this guide has the responsibility to determine and comply with applicable requirements.

1.6 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C150 Specification for Portland Cement
C188 Test Method for Density of Hydraulic Cement
C311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C595/C595M Specification for Blended Hydraulic Cements
D75 Practice for Sampling Aggregates
D420 Guide to Site Characterization for Engineering Design and Construction Purposes
D422 Test Method for Particle-Size Analysis of Soils
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3(600 kN-m/m^3))
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1195 Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
D1196 Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
D1452 Practice for Soil Exploration and Sampling by Auger Borings
D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3(2,700 kN-m/m^3))
D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1883 Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
D2166 Test Method for Unconfined Compressive Strength of Cohesive Soil
D2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D2850 Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils
D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)[3]
D3080 Test Method for Direct Shear Test of Soils Under

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment and is the direct responsibility of Subcommittee E50.03 on Pollution Prevention, Reuse, Recycling, and Environmental Efficiency.

Current edition approved May 10, 2003. Published July 2003. DOI: 10.1520/E2277-03.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

Consolidated Drained Conditions
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3877 Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures
D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
D4429 Test Method for CBR (California Bearing Ratio) of Soils in Place
D4643 Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
D4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating
D4972 Test Method for pH of Soils
D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
D5239 Practice for Characterizing Fly Ash for Use in Soil Stabilization
E1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process
E1528 Practice for Limited Environmental Due Diligence: Transaction Screen Process
E1609 Guide for Development and Implementation of a Pollution Prevention Program[3]
E2201 Terminology for Coal Combustion Products
G51 Test Method for Measuring pH of Soil for Use in Corrosion Testing
G57 Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

2.2 *AASHTO Standards:*[4]
T 288 Determining Minimum Laboratory Soil Resistivity
T 289 Determining pH of Soil for Use in Corrosion Testing
T 290 Determining Water Soluble Sulfate Ion Content in Soil
T 291 Determining Water Soluble Chloride Ion Content in Soil

3. Terminology

3.1 *Definitions*—For definitions related to Coal Combustion Products, see Terminology E2201. For definitions related to geotechnical properties see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *internal erosion*—piping; the progressive removal of soil particles from a mass by percolating water, leading to the development of channels.

4. Significance and Use

4.1 *General*:

4.1.1 Coal ashes are suitable materials for the construction of engineered, structural fills. Coal ashes may be used as: structural fill for building sites and foundations; embankments for highways and railroads, dikes, levees; and in any other application requiring a compacted fill material. Their low unit weight, relatively high shear strength, ease of handling, and compaction all make coal ashes useful as fill material. Coal ashes may be a cost-effective fill material in many areas because they are available in bulk quantities, conserve natural resources, and reduce the expenditures required for the purchase, permits, and operation of a soil borrow pit. Coal ash often can be delivered at near optimum moisture content.

4.1.2 This guide describes the unique design and construction considerations that may apply to structural fills constructed of coal ash. The requirements for specific structural fills may vary due to local site conditions or the intended use of the structural fill, or both.

4.2 *Regulatory Framework*:

4.2.1 *Federal*—The U.S. Environmental Protection Agency (USEPA) has completed a study of coal combustion byproducts for the U.S. Congress and has issued a formal regulatory determination (**1, 2**).[5] USEPA "encourages the utilization of coal combustion by-products and supports State efforts to promote utilization in an environmentally beneficial manner" (**3**). USEPA subsequently ruled that national regulation of most beneficial uses of coal ash, including structural fills, is not warranted (**4**).

4.2.2 *State and Local*—Laws and regulations regarding the use of coal ash vary by state and locality.

4.3 *Economic Benefits*—Coal ash can be a cost-effective fill material. In many areas, it is available in bulk quantities at a reasonable cost. Use of coal ash conserves natural resources and reduces the expenditures for the purchase, permits, and operation of a soil borrow pit.

5. Engineering Properties and Behavior

5.1 *General*—Fly ash and bottom ash exhibit distinct engineering properties and behavior as described below. The engineering properties and behavior of ponded ash may be similar to fly ash or bottom ash, depending on the ratio of each in the ponded ash.

5.2 *Unit Weight*—Many coal ashes have relatively low unit weights. The low unit weight of these materials can be advantageous for some structural fill applications. The lighter weight material will reduce the load on weak layers or zones of soft foundation soils such as poorly consolidated or landslide-prone soils. Additionally, the low unit weight of these materials will reduce transportation costs since less tonnage of material is hauled to fill a given volume.

5.3 *Strength*:

5.3.1 *Shear Strength*—For non-self-cementing fly ash and bottom ash, shear strength is derived primarily from internal friction. Typical values for angles of internal friction for non-self-cementing fly ash are higher than many natural fine-grained soils. These ashes are non-cohesive and although the ash may appear cohesive in a partially saturated state, this effect is completely lost when the material is either completely dried or saturated.

[4] Interim Specifications for Transportation Materials and Methods of Sampling and Testing, Part II, AASHTO, 444 North Capitol St., N.W., Suite 225, Washington, DC 20001.

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

5.3.1.1 Due to its angular shape, the shear strength of bottom ash is typically greater than fly ash and is similar to the shear strength of natural materials of similar gradation. However, friable bottom ash may exhibit lower shear strength than natural materials of similar gradation.

5.3.2 *Compressive Strength*—Self-cementing fly ash experiences a cementing action that increases with time. Because the hydration of dry self-cementing fly ash commences immediately upon exposure to water, higher compressive strengths will be attained when the fly ash is placed and compacted immediately following addition of water. If too much time lapses, the fly ash particles can become cemented in a loose state, reducing the compacted density and strength.

5.4 *Consolidation Characteristics*—Structural fills constructed of fly ash typically exhibit small amounts of time-dependent, post-construction consolidation. This is because excess pore water pressures dissipate relatively rapidly, and thus, most of the embankment settlement or deformation occurs due to elastic deformation of the material, rather than by classical consolidation. Most deformation due to the mass of the fill or structure thereon generally occurs during construction.

5.4.1 Bottom ash is usually a free-draining material that can be compacted into a relatively dense, incompressible mass. For these reasons structural fills constructed of bottom ash also typically exhibit small amounts of time-dependent, post-construction consolidation or deformation, with most deformation occurring during construction.

5.4.2 Self-cementing fly ash typically exhibits minimal post-construction consolidation or deformation due to cementing and solidification of the fly ash.

5.4.3 Some self-cementing fly ash may swell with time. Section 6.3.8 provides guidance on evaluating the swelling potential of self-cementing fly ash.

5.5 *Permeability*—The permeability of non-self-cementing fly ash is similar to values observed for natural silty soils.

5.5.1 Self-cementing fly ash is relatively impermeable, with permeability values similar to natural clays.

5.5.2 Bottom ash is typically as permeable as granular soils of similar gradation.

5.6 *Liquefaction and Frost Heave*—Fine-grained, non-cohesive materials such as fly ash are susceptible to liquefaction and frost heave when saturated. For this reason, fly ash fills are designed to be well drained or are located in areas where they are not subject to saturation or infiltration by surface or ground water. Self-cementing fly ash is not susceptible to liquefaction.

5.6.1 Bottom ash is not typically susceptible to either liquefaction or frost heave. However, some of the finer bottom ash materials may behave quite similarly to fly ash and would require the same consideration for design as fly ash fills.

6. Testing Procedure

6.1 *General*—Testing requirements are determined based on site conditions, knowledge of the coal ash, intended use of the fill, and local requirements.

6.2 *Sampling*—Practice D75 or Test Method C311 as appropriate, and Guide D420 with sample extraction conducted in accordance with Practice D1452, Test Method D1586, or Practice D3550, as appropriate.

6.3 *Physical and Engineering Characteristics*:

6.3.1 *Grain-Size Distribution*—Test Method D422. For fly ash, a substantial portion of the material will be finer than the No. 200 sieve and hydrometer analyses will also be required. Use distilled water in the hydrometer test with a deflocculating agent added to prevent fly ash from forming flocs. Self-cementing fly ash[es] may require use of alcohol or other nonreactive solution in place of the standard solution used. Fly ash often has a relatively uniform particle size and precautions against overloading sieves are warranted. Specimen loss through dusting can also be a problem. Specific gravity may vary with particle size. Specific gravity values used in hydrometer analyses should be appropriate to the portion of the sample being tested.

6.3.2 *Specific Gravity*—Test Method D854. For some fly ash, a significant portion of the particles may have a density less than water and float. Agitation of the slurry may be needed to keep the particles in suspension so that the average specific gravity can be obtained. Alternately for this ash and self-cementing fly ash, Test Method C188, which uses kerosene as the fluid, may be used.

6.3.3 *Water Content*—Test Method D2216. For self-cementing fly ash consider lowering the drying temperature to 140°F (60°C) to avoid driving off the water of hydration.

6.3.4 *Compaction*:

6.3.4.1 *Fly Ash*—Test Method D698 or D1557. For dry self-cementing fly ash, the time interval between wetting and compaction in the laboratory should be similar to that anticipated during construction to account for the influence of the rate of hydration on compaction characteristics.

6.3.4.2 *Bottom Ash*—Test Methods D4253 and D4254 may be used for the determination of maximum and minimum density of coarse-grained bottom ashes that do not exhibit a moisture-density relationship.

6.3.5 *Strength*:

6.3.5.1 *Shear Strength*—Test Method D3080. This test is preferred because it models the drained conditions that typically exist in a structural fill constructed of coal ash. The method is modified in that the shear box is not to be filled with water.

6.3.5.2 *Compressive Strength of Non-Self-Cementing Fly Ash*—Test Method D2850. Compact specimens to the unit weights and water contents required by the project compaction requirements.

6.3.5.3 *Compressive Strength of Self-Cementing Fly Ash*—Test Method D2166. The unconfined compressive strength at various ages is used to evaluate short-term and long-term strength development.

6.3.6 *Hydraulic Conductivity*—Test Method D5084. Hydraulic conductivity is used to estimate the quantity of infiltration for designing underdrains.

6.3.7 *Compressibility*—Test Method D2435. Samples should be prepared at the degree of compaction specified for construction and at the optimum water content determined by the compaction test. This is because fly ash tends to lose surface stability in the field when compacted at water contents greater than the optimum for compaction. Coal ash consolidates rapidly, therefore compressibility typically is not a design concern. Because of the non-cohesive nature of some coal ashes, extra care in sample handling is needed.

6.3.8 *Swelling*—Test Methods D3877, for self-cementing fly ash. Reactions producing the expansive properties may not commence for a period of more than 30 days after initial ash hydration. The test procedures must address this delayed reaction. The procedure should be modified to extend the wetting and drying cycles to a frequency determined by a qualified design engineer.

6.4 *Chemical Characteristics*—Chemical analyses are routinely conducted by many coal ash producers and are communicated to users of this material by means of a Material Safety Data Sheet (MSDS) or some similar communication. For the structural fill designer these results provide information on characteristics that may need to be considered in design, particularly with regard to assessing chemical interaction between fill and other materials or structures. Tests for soluble species may also be required by local regulatory agencies.

6.4.1 *Chemical Composition*—Test Methods C311 is often used to determine the major chemical constituents.

6.4.2 *pH*—Test Method D4972 or Practice D5239. The pH of the coal ash may vary with age, water content, and other conditions.

6.4.3 *Resistivity*—Test Method G57, a field test, is used to measure coal ash resistivity as an indicator of possible corrosion potential for embedded metals. An alternate laboratory procedure is AASHTO Interim Method of Test T 288. Likely field water contents should be considered in assessing test conditions and results. Field water contents in drained coal ash fills are likely to be close to the optimum water content for compaction. AASHTO Interim Methods of Test T 289, T 290, and T 291 provide measurements of the pH, water-soluble sulfate ion content and water-soluble chloride ion content of the coal ash that are useful in evaluating corrosion potential. Test Method G51 is also used to determine the pH of soil for use in corrosion testing.

6.4.4 *Sulfate*—Sulfate content as determined from the coal ash chemical analysis by Test Method C311, or other method is used in a preliminary assessment of the potential for sulfate attack on concrete. As with corrosivity, likely field water conditions and variations in concentrations with time should be considered.

7. Design Considerations

7.1 *General*—The design process and procedures are similar to those normally followed for cohesionless natural soil materials. Cohesion developed by self-cementing fly ash can also be considered in the design of fill slopes and determination of bearing capacity. Refs (**5-9**) provide additional information regarding laboratory testing, design, and construction procedures.

7.1.1 The ultimate end use of the site can present special design considerations. For example, fly ash is not an appropriate medium for septic systems. A thicker soil cover may be appropriate depending on the planned end use of the site. Deed restrictions may be warranted in some instances.

7.2 *Site Characterization*:

7.2.1 *General*—The siting and design of a coal ash structural fill requires the same characterization of site conditions that is typically required of earthwork construction projects of similar size. The geologic and hydrologic conditions at the site must be understood to determine design parameters for the structural fill. In addition, consideration of environmental resources at or near the site is required to avoid or minimize negative environmental consequences. Practices E1527 and E1528 may be applied whenever a real estate transaction is involved.

7.2.2 *Geologic and Hydrologic Investigation*—A subsurface investigation may involve a review of available information about the site, a site reconnaissance by a geologist or engineer, and extraction of soil and rock samples for classification and testing, depending on the size and intended use of the structural fill. Guide D420 provides guidance for conducting subsurface investigations.

7.2.3 *Environmental Resources*—Many sensitive environmental resources such as wetlands, floodplains, rare and endangered species, and cultural resource areas are afforded protection by Federal, state, and local regulations and ordinances. Appropriate action should be taken to comply with the requirements of the regulatory agency having jurisdiction at the structural fill site.

7.3 *Site Preparation and Internal Drainage*—Some structural fills constructed of non-self-cementing fly ash must be well drained because of the sensitivity of the material to the flow of water (that is, piping). Problems such as slope stability, liquefaction, and frost heave that may result from saturation of the fly ash are thus avoided. When necessary, a drainage blanket can be used to provide internal drainage and serve as a capillary barrier. Coal ash should be placed in areas where it is not subject to saturation by surface or ground water to avoid this concern.

7.3.1 *Site Preparation*—Site preparation involves grading and drainage improvements required prior to placement of coal ash. Surface drainage is diverted and controlled. Erosion and sedimentation controls are installed. If needed, wet areas are allowed to drain and dry. Unsuitable materials such as vegetation and topsoil are removed and the subgrade is prepared. Provisions to stockpile any soil needed for final cover are included.

7.3.2 *Site Drainage*—Provisions for positive site drainage are essential if the structural fill is to be reliably maintained in an unsaturated condition. Drainage of seeps and springs encountered during construction should be provided for in design of a site drainage system. A series of perforated pipe drains or aggregate-filled trenches are commonly used for this purpose. These systems are flexible and can be expanded in areal extent as needed to accommodate conditions encountered during construction. Adequate filter protection of drains to ensure long-term, maintenance-free performance should be included. Any provisions needed to control site ground-water levels through collection and drainage should be included in the design.

7.3.3 *Drainage Blanket*—For non-self-cementing fly ash, a drainage blanket of free-draining material may be used. The drainage blanket also serves as a barrier to capillary saturation.

Bottom ash often has a suitable particle size range to serve as a drainage blanket. Sand, gravel, or other aggregate can also be used depending upon the gradation of these materials. Adequate filter protection such as a geotextile between the fill and drainage blanket must be considered and included to ensure satisfactory long-term performance. The drainage blanket should be designed so that the outlets will remain freely drained. Including outlet pipes with rodent screens is one method that is often satisfactory.

7.4 *Surface Cover and Drainage*—Provisions must be made for controlling erosion of coal ash fills. Due to its fine-grained, non-cohesive nature, non-self-cementing fly ash is readily eroded. Unprotected, compacted coal ash is erodible when exposed to surface runoff or high winds. Erosion control is normally accomplished by controlling surface run-on and run-off and by establishing permanent cover with compacted stone, pavement, or soil and vegetation.

7.4.1 *Cover*—Effective cover to control erosion can be either pavement or soil depending upon the final use of the surface. Surface configuration should include provisions for controlled, positive drainage of surface runoff. Minimum slopes to prevent ponding both on surfaces and in drainage ways of approximately 1 to 3 % are desirable so that settlement and minor surface variations can be accommodated.

7.4.2 *Soil Thickness/Vegetation*—The required thickness of soil cover varies and will depend upon site use, climate, and the type of vegetation to be established. The most important consideration is to control wind and water erosion of the surface. On sites where erosion potential is small, 6 in. (150 mm) of cover may provide protection, but 1 ft is probably a practical minimum thickness in most cases. Where erosion potential is greater, or deeper rooted vegetation is planned, greater thicknesses may be warranted. In some cases fly ash/soil blends are used as part of the cover to reduce the need for soil borrow. In these applications, testing of the blend to determine its suitability as a growing medium should be conducted.

7.4.3 *Surface Drainage*—Positive surface drainage is needed to prevent ponding that can lead to erosion problems. Suitable channel linings designed to accommodate storm flows without damage are needed. Slopes on surface areas and in drainage channels should be sufficient to prevent ponding and avoid long-term maintenance problems.

7.5 *Structural Performance*—In order to perform satisfactorily, any fill material must support its own mass, that of the loads to be placed on it, and have acceptable settlement. Each of these aspects is analyzed as part of the design process.

7.5.1 *Slope Stability*—Embankment slopes should be stable and able to stand without slumping or sliding. Stability analyses should consider static, dynamic and seismic loadings, and seepage forces, as appropriate. Desired factors of safety typically range from 1.2 (seismic and dynamic) to 1.5 (static). Stability of exterior slopes, foundation soils and embankment combined, and cover soils should be analyzed.

7.5.2 *Bearing Capacity*—The ability of the fill to support structures bearing on or within the fill can be calculated by conventional procedures used for natural soils.

7.5.2.1 *Footings*—Ultimate bearing capacity analysis is appropriate for footings bearing on compacted coal ash structural fills. The analysis is simplified by the drained, non-cohesive nature of the fill (except for self-cementing fly ash). The relatively low unit weight of coal ash as compared to natural soils should be considered in the analyses. Footings that are wider than the thickness of the fill below the footing or that are located near the edge of slopes are cases that may require special consideration.

7.5.2.2 *Slabs and Pavements*—The ability of the fill to support slabs and pavements to be located on the fill surface can be assessed by standard pavement design procedures and by determining the modulus of subgrade reaction by Test Methods D1195 or D1196, or bearing ratio by Test Methods D1883 or D4429, as appropriate.

7.5.3 *Settlement*—As with any fill material, settlement due to consolidation and compression of the fill and the underlying materials should be considered in design. Settlement may adversely affect project performance if not considered in design. Conventional methods of analysis used with natural soils are appropriate.

7.5.4 *Lateral Earth Pressure*—Conventional methods of analysis of lateral earth pressure can be used for coal ash considering that the material is cohesionless (except for self-cementing fly ash) and has a lower unit weight than many natural soils. For structures that are fixed and unable to yield, earth pressure at rest coefficients of 0.5 are typically used in estimating loads. For most yielding retaining walls, active earth pressures are determined by Rankine's method. Coulomb's method is generally used for walls over 20 ft (6.1 m) in height.

7.6 *Compaction*—Proper and uniform compaction (including control of molding water content) of coal ash placed in the structural fill increases the strength of the material, reduces the compressibility, and produces a relatively uniform structural fill. Coal ash is readily spread and compacted by conventional construction equipment; vibratory compactors operated at or near resonant frequency are particularly effective.

7.6.1 *Fly Ash*—Because it is fine-grained, fly ash exhibits compaction behavior under static compaction similar to natural soils in that compaction is sensitive to molding water content. Most fly ash has a well-defined compaction relationship, that is, for a given static compactive energy, there exists an optimum water content at which compaction of the fly ash will achieve the maximum dry unit weight. Attempting to compact fly ash above the optimum water content results in displacement of the fly ash and limited densification is attained. Using static compaction, the compaction of fly ash with water contents below the optimum water content requires more compactive effort to achieve desired results. However, the compaction of fly ash is not especially sensitive to variations in water content when using vibratory compactors operated at the resonant frequency. Thus, fly ash that is several percent below the optimum water content can be readily compacted using vibratory compactors operated at the resonant frequency. Compaction characteristics of dry self-cementing ash changes rapidly with time after exposure to water. This property is a result of the rapid rate of hydration that produces a cementitious reaction. A reduction in maximum density of more than

30 pounds per cubic foot can occur and must be addressed by the design and compaction procedures.

7.6.2 *Bottom Ash*—Bottom ash is typically free-draining, therefore, unless saturated, the moisture content of this material has little influence on its compaction characteristics. Simply wetting the bottom ash sufficiently to prevent bulking will promote adequate compaction.

7.6.3 *Placement of Coal Ash*—Coal ash should be placed in loose layers of uniform thickness. Each layer should be compacted to the required density because strength is derived from internal friction and this value is dependent on the relative compaction/unit weight of the coal ash. A maximum layer thickness is usually specified to ensure that the required density is achieved through the full depth of the layer. Control of layer thickness is not as important for self-cementing fly ash because additional strength is derived from the cementitious products formed during the hydration process.

7.6.4 *Degree of Compaction*:

7.6.4.1 *Fly Ash*—A typical requirement is that the fill be compacted to a minimum of 95 to 100 % of the maximum dry unit weight, in accordance with Test Method D698, or 90 to 95 % of the maximum dry unit weight in accordance with Test Methods D1557. Similar requirements are usually applied for the subgrade. Either method is acceptable. However, the desired performance of the site in terms of safe slopes and adequate performance of foundations, structures, roadways, and so forth, will dictate the degree of compaction needed.

7.6.4.2 *Bottom Ash*—Granular bottom ash is typically compacted to 70 % relative density, in accordance with Test Method D4254.

7.6.5 *Compaction Specifications*—Compaction specifications may dictate either the construction method to be used or the performance standard to be attained.

7.6.5.1 *Method Specifications*—Method specifications specify the type of compaction equipment, the fill material placement methods, and the number of equipment passes to be used in compaction. Method specifications are based on the results of field compaction tests on trial test strips. The test strips are normally conducted at the construction site using the equipment proposed for use and materials or sources that will supply fill material for the project. Method specifications have the advantage of providing continuous quality control by monitoring the ongoing construction activities. If the material source changes or the material itself changes during construction, then the field testing should be repeated on the new material. Method specifications may also be useful for situations where variations in material properties make determination of the appropriate compaction curve difficult.

7.6.5.2 *Performance Specifications*:

(1) Fly Ash—The compaction criteria are typically expressed as a percentage of the maximum dry unit weight, in accordance with Test Method D698 or D1557 and at molding water contents that do not exceed the optimum water content plus a given percentage and that prevent dusting during placement and compaction. When using static-type compaction, an allowable range of water contents is also usually specified so that the material will be in the range where the required unit weight can be readily achieved. Fly ash has a tendency to be displaced under the mass of the compactor when placed above the optimum water content. Specifications requiring placement over a range of water content less than the optimum water content will control this phenomenon. Experience has shown that vibratory compactors operating at the resonant frequency can achieve the required degree of compaction in a minimum of passes over a wide range of water contents, but not excessively wet, of the optimum water content.

(2) Bottom Ash—Performance specifications for bottom ash typically specify the compaction criteria as a percentage of the relative density in accordance with Test Method D4254, and may require use of vibratory compaction equipment.

7.6.6 *Dust Control*—Dusting does not occur during placement and compaction of coal ash when the molding water content of the coal ash is sufficient to achieve the desired degree of compaction. Coal ash surfaces exposed to the sun and wind can dry out and become susceptible to dusting. Dusting can be controlled by wetting the coal ash, applying a dust suppressant, constructing wind screens or by placing the final soil cover.

7.7 *Protection of Embedded Materials*—When materials are to be embedded in the structural fill, it is prudent during design to assess whether any deleterious reactions are likely to occur. Specifically, the potential for corrosion of pipes, conduits, and other metal structures should be evaluated. Concrete structures such as culverts, footings, and retaining walls should be evaluated for sulfate attack.

7.7.1 *Corrosion Protection*—Low resistivity is commonly used as an indicator of the corrosion potential of soil or aggregates. Field tests with coal ash have shown that additional contributing factors are high or low pH, high soluble sulfate and soluble chlorides, and partially saturated field moisture conditions. It is appropriate to check all of these factors and consider the lifetime and sensitivity of the embedded material. Appropriate test methods are described in 6.4.3. The standards used by the local state transportation agency for evaluating corrosion potential of soil fill may be used as a reference. The criteria in Refs **(10, 11)** may also be applied in lieu of state requirements.

7.7.2 *Sulfate Attack on Concrete*—Sulfate attack on concrete in coal ash fills has received attention because of the sulfate content in some coal ash. The sulfate exposure is considered severe when the water soluble sulfate in soil (or ash) exceeds 0.20 % by weight, or when sulfate in water exceeds 1500 ppm. As with corrosion, other factors such as moisture will be contributing factors. Also as with corrosion, there is a need to assess sensitivity and lifetime of the structure, and the difficulty of replacement or repair. If sulfate exposure is a concern, the use of blended or sulfate-resistant cements such as those described in Specifications C595/C595M and C150, or application of polymer or bituminous coatings may provide protection.

7.8 *Radionuclides*—As with other structural fill materials, certain radioactive elements are known to occur naturally in coal ash. The model standards and techniques for controlling radon in accordance with Ref **(12)** are recommended for new building construction, where needed.

8. Construction

8.1 *General*—Construction procedures for coal ash structural fills are similar to conventional earthwork operations. Routine methods employed with soil fills to control dusting, erosion, and sedimentation are similarly required.

8.2 *Weather Restrictions*—Construction should be suspended during severe weather conditions. Operations may proceed during moderately wet periods by reducing the amount of water added at the plant or job site to compensate for precipitation. Dry coal ash can also be disked into excessively wet coal ash to reduce the water content to an acceptable level. Because fly ash obtained directly from silos or hoppers dissipates heat slowly, it may be placed during cold weather. If frost penetrates the surface a few inches, it can be removed from the surface or recompacted upon thawing and drying.

8.2.1 *Dust Control*—Dust control measures routinely used on earthwork projects are effective in minimizing airborne particulate at coal ash fill sites. Typical controls include avoiding hauling on completed ash surfaces, use of wind breaks, moisture-conditioning of the coal ash, wetting or covering of exposed coal ash surfaces, chemically treating coal ash surfaces and paving, wetting, and covering of high-traffic haul roads with coarse materials.

8.2.2 *Erosion Control*—Coal ash typically does not require additional sedimentation and erosion control measures beyond those normally employed for soil fills in accordance with state and local requirements.

8.3 *Source and Delivery*—Coal ash is typically supplied from sources containing little or no extraneous or deleterious material. Non-self-cementing fly ash and bottom ash are usually hauled in covered dump trucks with tightly sealed tailgates. These coal ashes may be conditioned with water at the plant, if necessary. Self-cementing fly ash is hauled in pneumatic tank trucks and conditioned with water at the project site or may be partially conditioned and hauled in covered dump trucks to the project site. Care should be taken to not overfill the trucks so that spillage does not occur. Adequate measures must be taken to ensure proper water content when using fly ash or bottom ash that has been stored in landfills, ponds, and lagoons. Trucks should be spray-cleaned with water at the plant to reduce spillage and dust during transport. Provisions should be made for cleaning of public roads in the event spillage does occur.

8.4 *On-Site Storage*—Limit on-site storage of coal ash to the minimum quantity required to maintain the construction schedule. For stockpiles, provide sedimentation and erosion controls in accordance with state and local requirements. Self-cementing fly ash that is not partially conditioned should be stored dry in pneumatic tank trucks or in suitably protected storage silos. Precautions normally taken for bulk storage of cement and lime may be required.

8.5 *Site Preparation*—The base of the fill should be stripped of vegetation and organic soils. The subgrade should be compacted to the desired dry unit weight and underdrains installed, when required.

8.6 *Placement and Compaction*—Place coal ash in uniform layers not exceeding the thickness specified. The coal ash must be spread uniformly; otherwise, the compaction equipment will ride on uneven hard spots in the fill, resulting in softer areas between the high spots. Tracking the coal ash with a dozer or truck prior to compaction will facilitate compaction to the required density. Typically, a coal ash fill is compacted with a vibratory or pneumatic-tired roller. Fill should not be placed on saturated or frozen material. If water must be added to obtain optimum water content condition, allow adequate time for the entire lift to equilibrate, yet compact before the surface dries out. Water should be sprayed uniformly.

8.6.1 Most coal ashes can be placed and compacted in a manner very similar to soil and aggregate fill materials. In fact, most coal ashes exhibit very little cohesion and are not as sensitive to variations in moisture content as natural soils.

8.6.1.1 Fly ash is typically placed and compacted in a manner similar to non-cohesive fine-grained soils. Smooth drum vibratory rollers and pneumatic-tired rollers typically compact fly ash most effectively. Although not always, fly ash typically exhibits a measurable moisture-density relationship that can be utilized for compaction quality control. It should be noted that fly ash that exhibits self-cementing properties must be compacted soon after the addition of water.

8.6.1.2 Bottom ash is generally placed and compacted in a manner similar to non-cohesive coarse-grained soils or fine aggregate. Smooth drum vibratory rollers and pneumatic-tired rollers typically are most effective for the compaction of these materials. Bottom ash may or may not exhibit consistent moisture-density relationships.

8.7 *Cover*—Structural fill slopes should be covered with soil and revegetated as soon as practicable following the fill placement operations. Top surfaces should also be covered promptly to reduce infiltration of precipitation and runoff into the fill and to minimize surface erosion.

8.8 *Quality Control*—Quality control programs for coal ash structural fills are similar to quality control programs for earthwork projects. These programs typically include visual observation of coal ash placement operations, supplemented with laboratory and field testing to confirm that the structural fill is constructed as designed. The testing requirements will vary depending on whether a method specification or performance specification is used.

8.8.1 Visual observations are typically made to verify lift thickness, the number of passes of the compactor on each lift, and the behavior of the coal ash under the weight of the compaction equipment. Laboratory compaction tests (Test Methods D698, D1557, D4253 and D4254) are performed to establish baseline data needed to control compaction in the field. Field unit weight and water content tests are conducted regularly on compacted lifts to verify that the required degree of compaction is achieved. Test Methods D1556, D2167, or D2922 may be used to determine the field unit weight. Test Methods D2216, D4643, or D4959 may be used to estimate the water content.

8.8.2 It is prudent to maintain daily job logs documenting site conditions, weather, and work activities. Water content and unit weight tests should be taken as specified by the design engineer and whenever visual observations indicate the desired degree of compaction is possibly not being achieved. As a guide in performance specifications, one test for every 1000 to 2000 cubic yards of fill is suggested.

9. Keywords

9.1 bottom ash; coal ash; embankment; fly ash; pollution prevention; resource conservation; structural fill; utilization

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ATTACHMENT 3

Bottom Ash Laboratory Test Results

Form No. TR-D422-2
Revision No. 0
Revision Date: 02/20/08

Particle Size Analysis of Soils

ASTM D 422

S&ME, Inc. ~ 9751 Southern Pine Boulevard ~ Charlotte, NC 28273

Project #: **1356-10-009C Phase 04** Report Date: 12/16/13
Project Name: Allen RAB Ash LF Phase 1 Operations Test Date(s): 12/9-13/13
Client Name: Duke Energy Address: 526 South Church Street, Charlotte, NC 28202
Boring #: NA Sample #: BA-3 Sample Date: 12/9/13
Location: Pond No.2 Offset: NA Elevation: NA
Sample Description: Gray Black Silty Coarse to Fine Sand (SM)

Pan #:	Beaker #:	**Apparent Relative Density (Assumed)**		**2.200**	
Hydrometer Jar #:					
Pan Tare Weight (grams):		**Moisture Content**		Hygroscopic	Natural
Total Sample Air Dried Wt. + tare wt. (grams):	446.27		Tare #	KK	
Weight of Total Sample Air Dried:	446.27	A	Tare Wt.	16.07	
Weight of Air Dried Hydrometer Sample (g):	100.00	B	Wet Wt. + A	26.46	
Total Sample Oven Dried:	406.15	C	Dry Wt. + A	25.41	
Hydrometer Sample Oven Dried (**W**):	89.89	D	Water Wt. (B-C)	1.05	
% Passing #10:	87.9%	E	Dry Wt. (C-A)	9.34	
Correction Factor a (Table 1):	1.09		% Moisture (100 x D/E)	11.24%	

Sieve	Retained Wt.	Percent Passing	
3.0"	0.0	Pan # (washed)	100.0%
1.5"	0.0		100.0%
1.0"	0.0		100.0%
3/4"	0.0		100.0%
1/2"	0.0		100.0%
3/8"	0.8	Soil Mortar	99.8%
#4	9.8		97.6%
#10	49.29	**100.0%**	87.9%
#20	8.97	90.0%	79.1%
#40	24.79	72.4%	63.6%
#60	37.48	58.3%	51.2%
#100	52.03	42.1%	37.0%
#200	66.74	25.8%	22.6%

Description of Sand & Gravel Particles Rounded ☐ Angular ☒ Hard & Durable ☒ Soft ☐ Weathered & Friable ☒
Stirring Apparatus: A ☒ B ☐ Dispersion Time: 1 min. Sodium Hexametaphosphate: 40 g./ Liter
Balance: *ID No.* 20233 *Cal. Date:* 6/18/2013 Hydrometer: *ID No.* 3901 *Cal. Date:* 3/25/2012
Control Cylinder ☒ **Composite Correction** ☐ **Type:** **151H** ☐ **152H** ☒

Time	Temp.	Hydrometer	Corrections		Hydrometer	Percent Passing		Effective Depth	Table 3	Diameter
			Control Cylinder	Composite Correction		P(-#10) =	P (total) =			D =
T (Min.)	(0.5 °C)	Reading			R	(R x a / W) x 100	P x % Passing #10	L	K	K x ((L/T)^1/2
1	22.0	24.0	4.5		19.50	23.6%	20.8%	13.1	0.01562	0.05653
2	22.0	21.0	4.5		16.50	20.0%	17.6%	13.6	0.01562	0.04071
5	22.0	14.0	4.5		9.50	11.5%	10.1%	14.7	0.01562	0.02681
15	22.0	10.5	4.5		6.00	7.3%	6.4%	15.3	0.01562	0.01578
30	22.0	9.0	4.5		4.50	5.5%	4.8%	15.6	0.01562	0.01125
60	22.0	7.5	4.5		3.00	3.6%	3.2%	15.8	0.01562	0.00802
250	22.0	6.5	4.5		2.00	2.4%	2.1%	16.0	0.01562	0.00395
1440	22.0	5.5	4.5		1.00	1.2%	1.1%	16.1	0.01562	0.00165

References / Comments / Deviations ASTM D422, D 2487, D 4318

Karen Warner		Jason Reeves	Senior Engineer	12-16-13
Technician Name	*Certification #*	*Technical Responsibility*	*Position*	*Date*

Form No. TR-D422-3
Revision No. 0
Revision Date: 02/20/08

Particle Size Analysis of Soils

S&ME

ASTM D422

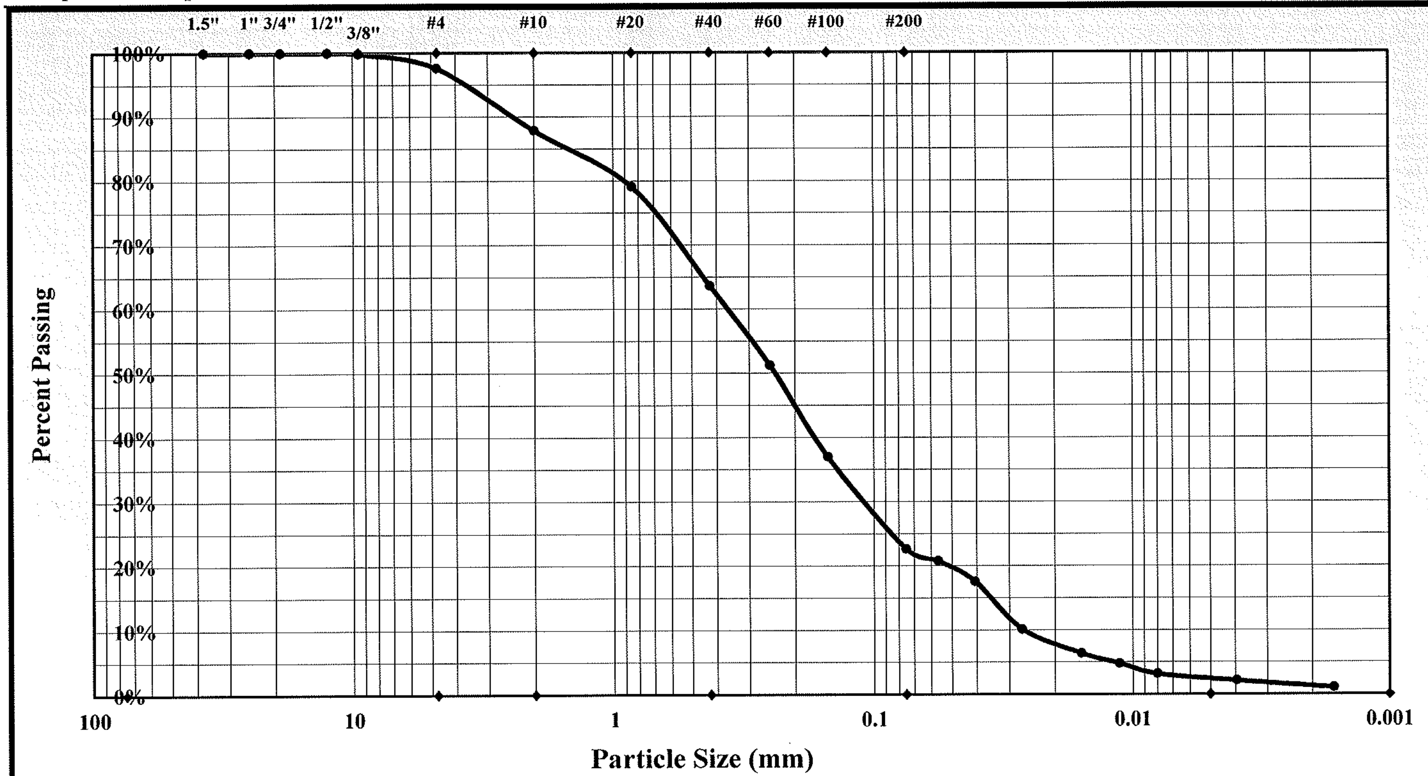
Quality Assurance

S&ME, Inc. ~ 9751 Southern Pine Boulevard ~ Charlotte, NC 28273

S&ME Project #:	1356-10-009C Phase 04	Report Date:	12/16/13
Project Name:	Allen RAB Ash LF Phase 1 Operations	Test Date(s):	12/9-13/13
Client Name:	Duke Energy		
Address:	526 South Church Street, Charlotte, NC 28202		

Boring #:	NA	Sample #:	BA-3	Sample Date:	12/9/13
Location:	Pond No.2	Offset:	NA	Elevation:	NA

Sample Description: Gray Black Silty Coarse to Fine Sand (SM)



Cobbles	< 300 mm (12") and > 75 mm (3")	Fine Sand	< 0.425 mm and > 0.075 mm (#200)
Gravel	< 75 mm and > 4.75 mm (#4)	Silt	< 0.075 and > 0.005 mm
Coarse Sand	< 4.75 mm and >2.00 mm (#10)	Clay	< 0.005 mm
Medium Sand	< 2.00 mm and > 0.425 mm (#40)	Colloids	< 0.001 mm

Maximum Particle Size:	3/8"	Gravel:	2.4%	Silt	20.1%
Silt & Clay (% Passing #200):	22.6%	Total Sand:	75.0%	Clay	2.5%
ent Relative Density (Assumed)	2.200	Moisture Content		Colloids	
Liquid Limit	ND	Plastic Limit	ND	Plastic Index	ND
Coarse Sand:	9.7%	Medium Sand:	24.2%	Fine Sand:	41.0%

Description of Sand and Gravel: Rounded ☐ Angular ☒ Hard & Durable ☒ Soft ☐ Weathered & Friable ☒

Mechanical Stirring Apparatus A Dispersion Period: 1 min. Dispersing Agent: Sodium Hexametaphosphate: 40 g./ Liter

References / Comments / Deviations: ASTM D 4318, D 854, D 2487

Technician Name: [signature] **Date:** 12/16/13

Jason Reeves	[signature]	Senior Engineer	12-16-13
Technical Responsibility	*Signature*	*Position*	*Date*

Form No. TR-D698-1
Revision No. 0
Revision Date: 11/21/07

S&ME

Moisture - Density Relationship

ASTM D558, D698, D1557, AASHTO T99, T180

Quality Assurance

S&ME, Inc. ~ 9751 Southern Pine Boulevard ~ Charlotte, NC 28273

Project #:	**1356-10-009C**	**Phase 04**	Report Date:	12/16/13
Project Name:	Allen RAB Ash LF Phase 1 Operations		Test Date(s)	12/9-10/13
Client Name:	Duke Energy			
Client Address:	526 South Church Street, Charlotte, NC 28202			

Boring #:	NI	Sample #:	BA-3	Sample Date:	12/9/2013
Location:	Pond No.2	Offset:	NI	Depth:	NI

Sample Description: Gray Black Silty Coarse to Fine Sand (SM)

Type and Specification	*S&ME ID #*	*Cal Date:*	*Type and Specification*	*S&ME ID #*	*Cal Date:*
Balance (0.1 g)	22182	6/18/2013	Compaction Mold	20116	2/4/2013
Balance	22182	6/18/2013	Compaction Hammer	27760	7/17/2013
Straightedge	27772	8/20/2013	Oven	22152	10/1/2013
Sieve #4	10939	9/19/2013			

Water Content Water Content requires GP 2 Balance (0.1 gram Readability). Check:
ASTM D2216 ☒ AASHTO T265 ☐ ASTM D4959 ☐ ASTM D4643 ☐

	Water Added:	120	160	200	240	280	
	Tare #:	GH	KO	BE	5E	694	
A. Tare Weight	A.	163.5	164.3	164.4	158.7	158.4	
B. Wet Wt + Tare Wt	B.	1046.8	1041.6	1217.5	1436.0	1471.0	
C. Dry Wt. + Tare Wt.	C.	787.0	774.6	883.1	1019.1	1032.2	
D. Water Weight	B-C	259.8	267.0	334.4	416.9	438.8	
E. Dry Weight	C-A	623.5	610.3	718.7	860.4	873.8	
F. Moisture Content	100*D/E	**41.7%**	**43.7%**	**46.5%**	**48.5%**	**50.2%**	

Compaction Data Requires a GP 5 Balance for ASTM (1 gram or .0022 Lb. readability). Check:
ASTM D558 ☐ ASTM D 698 ☒ ASTM D1557 ☐ AASHTO T99 ☐ AASHTO T180 ☐
Method A ☒ Method B ☐ Method C ☐ Method D (ASTM 1978) ☐ AASHTO Method D ☐

G. Wt of Soil + Mold	G.	5523	5548	5595	5607	5608	
H. Wt. of Mold	H.	4276	4276	4276	4276	4276	
I. Wt. of Soil (g. or lbs.)	G-H	1247	1272	1319	1331	1332	
J. Wt of Soil (Lbs.)	I/453.6 or I	2.749	2.804	2.908	2.934	2.937	
K. Mold Volume Factor	K.	30.02	30.02	30.02	30.02	30.02	
L. Wet Density (PCF)	J*K	82.5	84.2	87.3	88.1	88.2	
M. Dry Density (PCF)	L/(1+F)	**58.2**	**58.6**	**59.6**	**59.3**	**58.7**	

Sieve Size used to separate the Oversize Fraction: #4 Sieve ☒ 3/8 inch Sieve ☐ 3/4 inch Sieve ☐
Mechanical Rammer ☒ Manual Rammer ☐ Moist Preparation ☒ Dry Preparation ☐

References / Comments / Deviations: *ND = Not determined *NI = Information was not provided

Jennifer Olsen	*[signature]*		12/16/13
Technician Name	*Signature*	*Certification Type/No.*	*Date*
Jason Reeves	*[signature]*	Senior Engineer	12-16-13
Technical Responsibility	*Signature*	*Position*	*Date*

Form No. TR-D698-2
Revision No. : 0
Revision Date: 11/21/07

Moisture - Density Report

S&ME
Quality Assurance

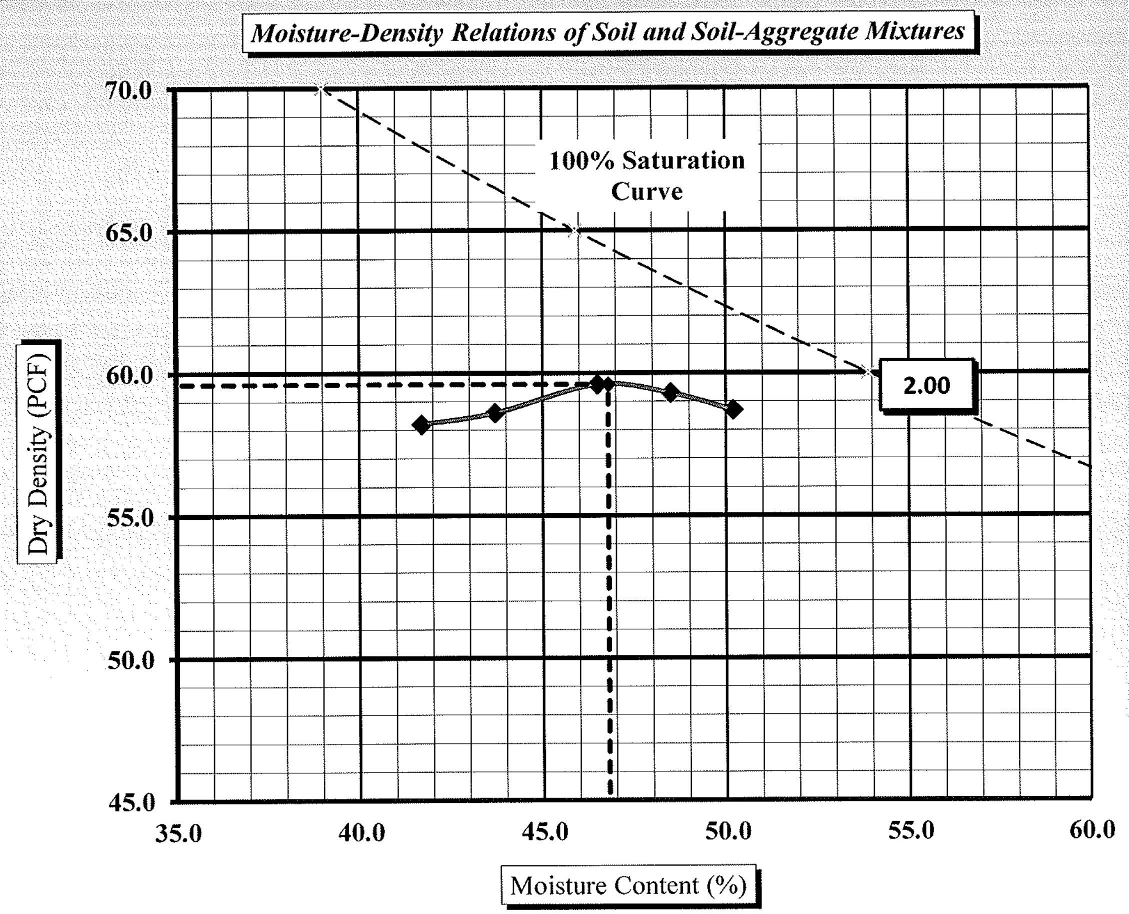
S&ME, Inc. ~ 9751 Southern Pine Boulevard ~ Charlotte, NC 28273

S&ME Project #:	**1356-10-009C**	***Phase 04***	Report Date:	12/16/13
Project Name:	Allen RAB Ash LF Phase 1 Operations		Test Date(s):	12/9-10/13
Client Name:	Duke Energy			
Client Address:	526 South Church Street, Charlotte, NC 28202			

Boring #:	NI	Sample #:	BA-3	Sample Date:	12/9/2013
Location:	Pond No.2	Offset:	NI	Depth:	NI
Sample Description:	Gray Black Silty Coarse to Fine Sand (SM)				

Maximum Dry Density 59.6 PCF. Optimum Moisture Content 46.8%

ASTM D 698 -- Method A



Soil Properties

Natural Moisture Content	**ND**
Specific Gravity of Soil (D854)	**ND**
Liquid Limit	**ND**
Plastic Limit	**ND**
Plastic Index	**ND**

% Passing

3/4"	100.0%
3/8"	99.8%
#4	97.6%
#10	87.9%
#20	79.1%
#40	63.6%
#200	22.6%

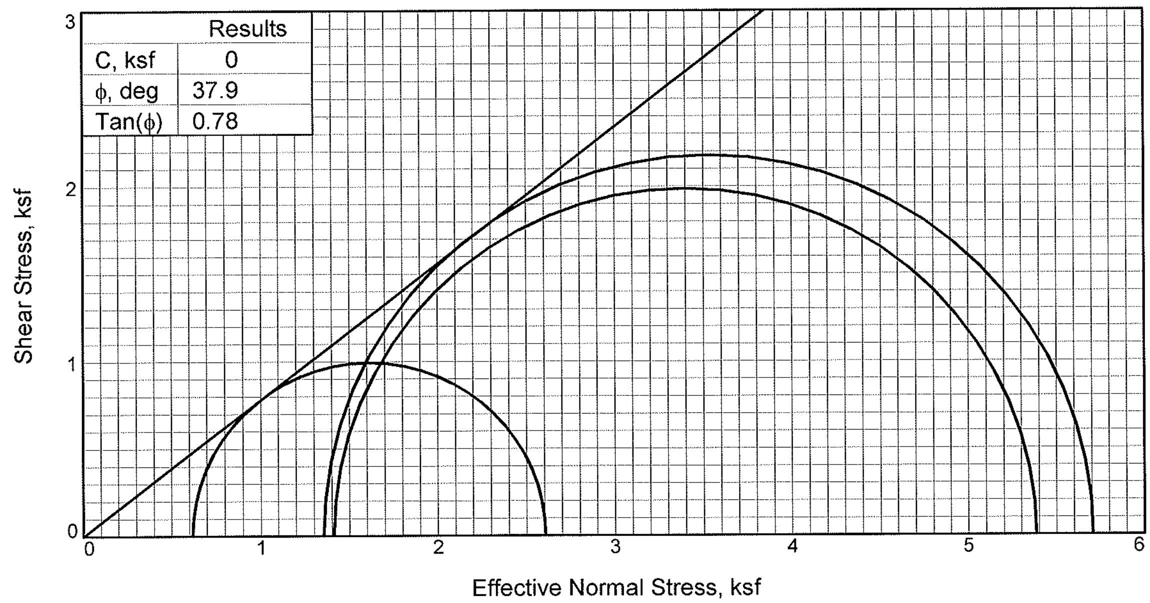
Oversize Fraction

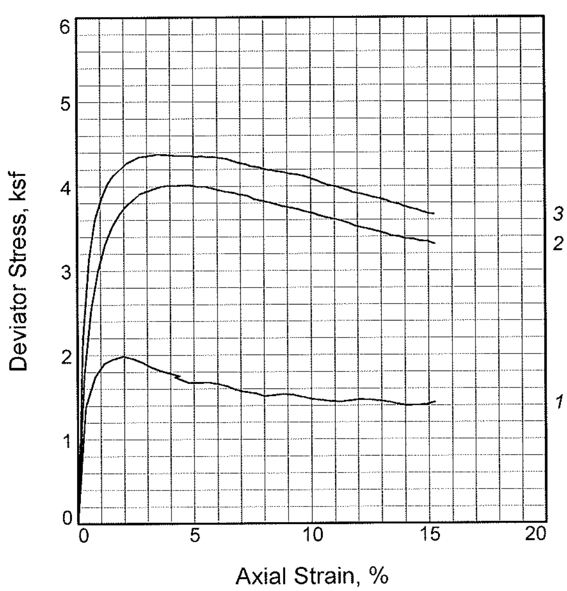
Bulk Gravity
% Moisture
% Oversize
MDD
Opt. MC

Moisture-Density Curve Displayed: Fine Fraction ☒ Corrected for Oversize Fraction (ASTM D 4718) ☐
Sieve Size used to separate the Oversize Fraction: #4 Sieve ☒ 3/8 inch Sieve ☐ 3/4 inch Sieve ☐
Mechanical Rammer ☒ Manual Rammer ☐ Moist Preparation ☒ Dry Preparation ☐

References / Comments / Deviations: ND = Not determined NI = Information was not provided
Technician: Jennifer Olsen *Jennifer Olsen* Date: 12/16/13
ASTM D 2216: Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
ASTM D 698: Laboratory Compaction Characteristics of Soil Using Standard Effort

Jason Reeves	*[signature]*	Senior Engineer	12-16-13
Technical Responsibility	*Signature*	*Position*	*Date*





Sample No.		1	2	3
Initial	Water Content, %	37.9	37.0	37.3
	Dry Density, pcf	56.3	56.7	56.5
	Saturation, %	57.9	57.2	57.5
	Void Ratio	1.4389	1.4238	1.4289
	Diameter, in.	2.853	2.853	2.853
	Height, in.	6.000	6.000	6.000
At Test	Water Content, %	61.3	57.0	58.7
	Dry Density, pcf	58.5	60.9	59.9
	Saturation, %	100.0	100.0	100.0
	Void Ratio	1.3494	1.2544	1.2922
	Diameter, in.	2.818	2.785	2.798
	Height, in.	5.926	5.858	5.886
Strain rate, in./min.		0.012	0.009	0.008
Eff. Cell Pressure, ksf		1.44	2.88	4.32
Fail. Stress, ksf		1.99	3.97	4.35
Total Pore Pr., ksf		12.34	12.99	14.49
Strain, %		2.0	3.3	2.9
Ult. Stress, ksf				
Total Pore Pr., ksf				
Strain, %				
$\bar{\sigma}_1$ Failure, ksf		2.60	5.38	5.71
$\bar{\sigma}_3$ Failure, ksf		0.62	1.41	1.35

Type of Test:
CU with Pore Pressures

Sample Type: Remolded

Description: Gray Black Silty Coarse to Fine Sand (SM)

LL= ND **PI=** ND

Assumed Specific Gravity= 2.2

Remarks: Remolded to 95% MDD at -10% Dry of Optimum

Figure BA-3

Client: Duke Energy

Project: Allen RAB Ash LF Phase 1 Operations

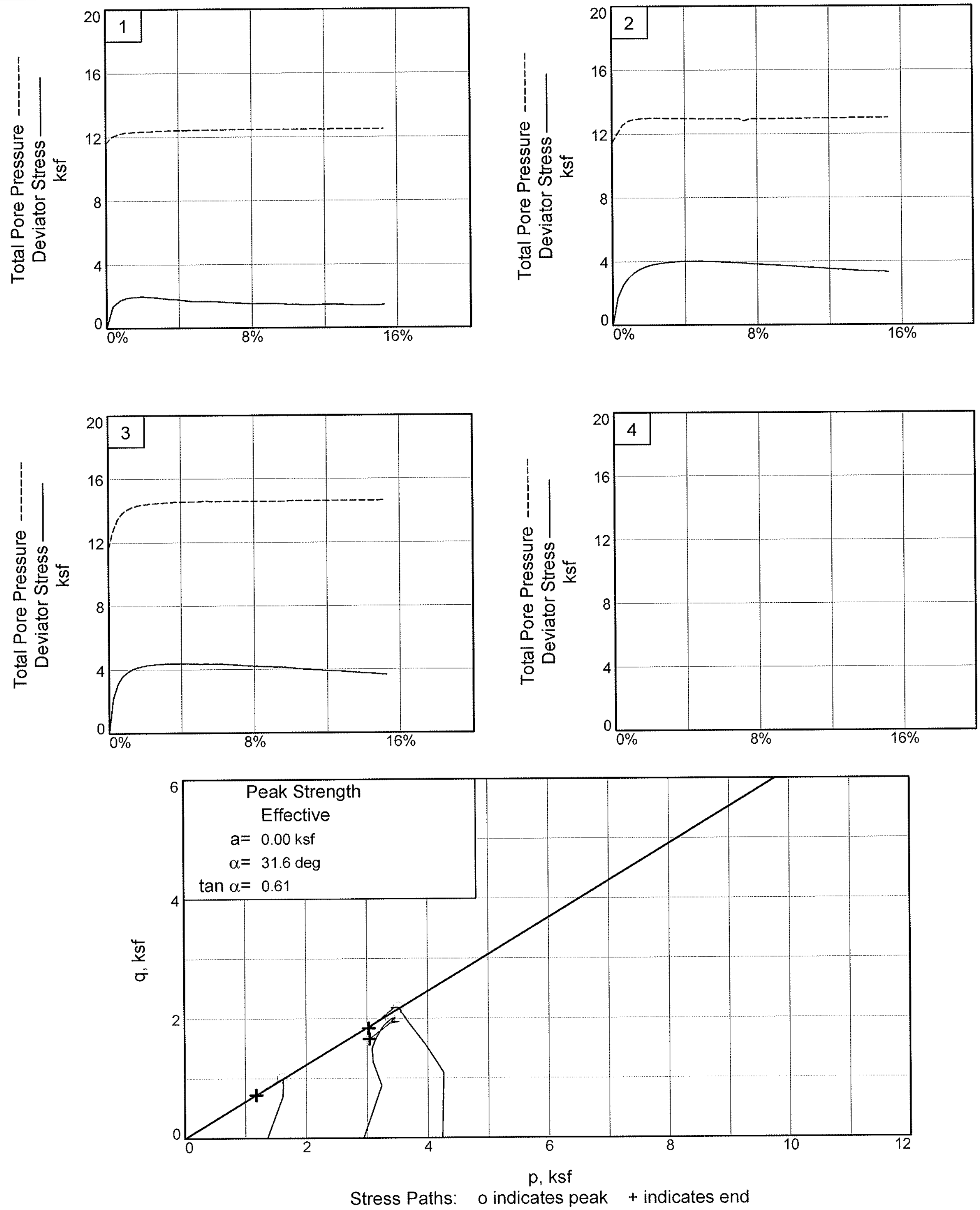
Location: Pond No. 2

Sample Number: BA-3

Proj. No.: 1356-10-009C Phase 04 **Date Sampled:** 12/9/13

TRIAXIAL SHEAR TEST REPORT
S & ME, INC.
Charlotte, North Carolina

Tested By: KMW (signature) **Checked By:** JSR JSR 12-16-13



Client: Duke Energy
Project: Allen RAB Ash LF Phase 1 Operations
Location: Pond No. 2 **Sample Number:** BA-3
Project No.: 1356-10-009C Phase 04 **Figure** BA-3

S & ME, INC.

Tested By: KMW **Checked By:** JSR

TRIAXIAL COMPRESSION TEST

CU with Pore Pressures

12/16/2013
9:56 AM

Date: 12/9/13
Client: Duke Energy
Project: Allen RAB Ash LF Phase 1 Operations
Project No.: 1356-10-009C Phase 04
Location: Pond No. 2
Sample Number: BA-3
Description: Gray Black Silty Coarse to Fine Sand (SM)
Remarks: Remolded to 95% MDD at -10% Dry of Optimum
Type of Sample: Remolded
Assumed Specific Gravity=2.2 **LL=**ND **PL=** **PI=**ND
Test Method: COE uniform strain

Parameters for Specimen No. 1

Specimen Parameter	Initial	Saturated	Consolidated	Final
Moisture content: Moist soil+tare, gms.	277.680			866.030
Moisture content: Dry soil+tare, gms.	229.940			523.570
Moisture content: Tare, gms.	103.940			74.650
Moisture, %	37.9	62.7	61.3	76.3
Moist specimen weight, gms.	781.80			
Diameter, in.	2.853	2.829	2.818	
Area, in.^{2}	6.393	6.286	6.235	
Height, in.	6.000	5.950	5.926	
Net decrease in height, in.		0.050	0.024	
Wet density, pcf	77.6	93.9	94.3	
Dry density, pcf	56.3	57.7	58.5	
Void ratio	1.4389	1.3783	1.3494	
Saturation, %	57.9	100.0	100.0	

Test Readings for Specimen No. 1

Consolidation cell pressure = 90.00 psi (12.96 ksf)
Consolidation back pressure = 80.00 psi (11.52 ksf)
Consolidation effective confining stress = 1.44 ksf
Strain rate, in./min. = 0.012
Fail. Stress = 1.99 ksf **at reading no.** 5

Test Readings for Specimen No. 1

No.	Def. Dial in.	Load Dial	Load lbs.	Strain %	Deviator Stress ksf	Minor Eff. Stress ksf	Major Eff. Stress ksf	1:3 Ratio	Pore Press. psi	P ksf	Q ksf
0	0.0000	14.800	0.0	0.0	0.00	1.35	1.35	1.00	80.60	1.35	0.00
1	0.0210	74.800	60.0	0.4	1.38	0.92	2.30	2.50	83.60	1.61	0.69
2	0.0450	90.800	76.0	0.8	1.74	0.75	2.49	3.33	84.80	1.62	0.87
3	0.0680	98.200	83.4	1.1	1.90	0.66	2.57	3.87	85.40	1.61	0.95
4	0.0920	100.800	86.0	1.6	1.96	0.63	2.59	4.09	85.60	1.61	0.98
5	0.1160	102.500	87.7	2.0	1.99	0.62	2.60	4.21	85.70	1.61	0.99
6	0.1390	101.600	86.8	2.3	1.96	0.60	2.56	4.24	85.80	1.58	0.98
7	0.1630	100.200	85.4	2.8	1.92	0.58	2.49	4.33	86.00	1.54	0.96
8	0.1870	97.800	83.0	3.2	1.86	0.56	2.42	4.31	86.10	1.49	0.93
9	0.2120	96.200	81.4	3.6	1.81	0.55	2.36	4.31	86.20	1.45	0.91
10	0.2600	94.000	79.2	4.4	1.75	0.55	2.30	4.20	86.20	1.42	0.87
11	0.2480	93.200	78.4	4.2	1.73	0.53	2.27	4.26	86.30	1.40	0.87
12	0.2600	92.400	77.6	4.4	1.71	0.53	2.25	4.22	86.30	1.39	0.86
13	0.2840	90.900	76.1	4.8	1.67	0.52	2.19	4.23	86.40	1.36	0.84
14	0.3080	91.200	76.4	5.2	1.67	0.52	2.19	4.23	86.40	1.35	0.84
15	0.3310	91.600	76.8	5.6	1.67	0.50	2.18	4.32	86.50	1.34	0.84
16	0.3540	91.200	76.4	6.0	1.66	0.50	2.16	4.29	86.50	1.33	0.83
17	0.3780	90.300	75.5	6.4	1.63	0.50	2.14	4.24	86.50	1.32	0.82
18	0.4020	88.600	73.8	6.8	1.59	0.49	2.08	4.25	86.60	1.28	0.79
19	0.4270	87.700	72.9	7.2	1.56	0.49	2.05	4.19	86.60	1.27	0.78
20	0.4510	87.300	72.5	7.6	1.55	0.49	2.04	4.16	86.60	1.26	0.77
21	0.4752	86.000	71.2	8.0	1.51	0.49	2.00	4.09	86.60	1.25	0.76
22	0.4990	86.900	72.1	8.4	1.52	0.49	2.01	4.11	86.60	1.25	0.76
23	0.5230	87.800	73.0	8.8	1.54	0.48	2.01	4.23	86.70	1.24	0.77
24	0.5460	87.600	72.8	9.2	1.53	0.48	2.00	4.21	86.70	1.24	0.76
25	0.5710	86.700	71.9	9.6	1.50	0.48	1.98	4.16	86.70	1.23	0.75
26	0.5950	85.800	71.0	10.0	1.48	0.48	1.95	4.10	86.70	1.21	0.74
27	0.6190	85.600	70.8	10.4	1.46	0.48	1.94	4.08	86.70	1.21	0.73
28	0.6430	85.100	70.3	10.9	1.45	0.48	1.92	4.05	86.70	1.20	0.72
29	0.6670	85.200	70.4	11.3	1.44	0.46	1.90	4.13	86.80	1.18	0.72
30	0.6910	86.200	71.4	11.7	1.46	0.46	1.92	4.14	86.78	1.19	0.73
31	0.7150	87.300	72.5	12.1	1.47	0.49	1.96	4.01	86.60	1.23	0.74
32	0.7390	87.400	72.6	12.5	1.47	0.46	1.93	4.18	86.80	1.19	0.73
33	0.7620	87.200	72.4	12.9	1.46	0.46	1.92	4.16	86.80	1.19	0.73
34	0.7870	86.700	71.9	13.3	1.44	0.46	1.90	4.12	86.80	1.18	0.72
35	0.8110	85.700	70.9	13.7	1.41	0.46	1.87	4.07	86.80	1.17	0.71
36	0.8350	85.400	70.6	14.1	1.40	0.46	1.86	4.04	86.80	1.16	0.70
37	0.8590	85.800	71.0	14.5	1.40	0.46	1.86	4.04	86.80	1.16	0.70
38	0.8830	86.500	71.7	14.9	1.41	0.46	1.87	4.06	86.80	1.17	0.70
39	0.9040	88.200	73.4	15.3	1.44	0.46	1.90	4.12	86.80	1.18	0.72

Parameters for Specimen No. 2

Specimen Parameter	Initial	Saturated	Consolidated	Final
Moisture content: Moist soil+tare, gms.	327.090			891.660
Moisture content: Dry soil+tare, gms.	269.040			551.170
Moisture content: Tare, gms.	112.280			84.350
Moisture, %	37.0	61.4	57.0	72.9
Moist specimen weight, gms.	781.80			
Diameter, in.	2.853	2.824	2.785	
Area, in.²	6.393	6.265	6.090	
Height, in.	6.000	5.940	5.858	
Net decrease in height, in.		0.060	0.082	
Wet density, pcf	77.6	94.3	95.7	
Dry density, pcf	56.7	58.4	60.9	
Void ratio	1.4238	1.3515	1.2544	
Saturation, %	57.2	100.0	100.0	

Test Readings for Specimen No. 2

Consolidation cell pressure = 100.00 psi (14.40 ksf)

Consolidation back pressure = 80.00 psi (11.52 ksf)

Consolidation effective confining stress = 2.88 ksf

Strain rate, in./min. = 0.009

Fail. Stress = 3.97 ksf **at reading no.** 11

No.	Def. Dial in.	Load Dial	Load lbs.	Strain %	Deviator Stress ksf	Minor Eff. Stress ksf	Major Eff. Stress ksf	1:3 Ratio	Pore Press. psi	P ksf	Q ksf
0	0.0030	20.200	0.0	0.0	0.00	2.94	2.94	1.00	79.60	2.94	0.00
1	0.0200	94.600	74.4	0.3	1.75	2.36	4.12	1.74	83.60	3.24	0.88
2	0.0380	128.000	107.8	0.6	2.53	1.83	4.36	2.39	87.30	3.10	1.27
3	0.0550	147.800	127.6	0.9	2.99	1.58	4.57	2.89	89.00	3.08	1.50
4	0.0730	161.800	141.6	1.2	3.31	1.48	4.79	3.23	89.70	3.14	1.65
5	0.0910	171.200	151.0	1.5	3.52	1.44	4.96	3.44	90.00	3.20	1.76
6	0.1100	178.300	158.1	1.8	3.67	1.41	5.08	3.60	90.20	3.25	1.83
7	0.1270	183.230	163.0	2.1	3.77	1.40	5.17	3.70	90.30	3.28	1.89
8	0.1450	187.000	166.8	2.4	3.85	1.40	5.25	3.76	90.30	3.32	1.92
9	0.1610	190.200	170.0	2.7	3.91	1.40	5.31	3.80	90.30	3.35	1.96
10	0.1800	192.100	171.9	3.0	3.94	1.41	5.35	3.79	90.20	3.38	1.97
11	0.1980	194.000	173.8	3.3	3.97	1.41	5.38	3.82	90.20	3.40	1.99
12	0.2160	195.800	175.6	3.6	4.00	1.43	5.43	3.81	90.10	3.43	2.00
13	0.2300	196.500	176.3	3.9	4.01	1.43	5.43	3.81	90.10	3.43	2.00
14	0.2510	197.100	176.9	4.2	4.01	1.44	5.45	3.78	90.00	3.44	2.00
15	0.2700	198.000	177.8	4.6	4.01	1.44	5.45	3.79	90.00	3.45	2.01
16	0.2880	198.700	178.5	4.9	4.02	1.45	5.47	3.76	89.90	3.46	2.01
17	0.3050	198.300	178.1	5.2	3.99	1.45	5.45	3.75	89.90	3.45	2.00
18	0.3240	198.900	178.7	5.5	3.99	1.45	5.45	3.75	89.90	3.45	2.00
19	0.3410	198.700	178.5	5.8	3.98	1.45	5.43	3.73	89.90	3.44	1.99
20	0.3590	198.200	178.0	6.1	3.95	1.45	5.41	3.72	89.90	3.43	1.98
21	0.3770	198.000	177.8	6.4	3.94	1.45	5.39	3.71	89.90	3.42	1.97
22	0.3950	198.000	177.8	6.7	3.92	1.45	5.38	3.70	89.90	3.42	1.96
23	0.4130	197.600	177.4	7.0	3.90	1.45	5.36	3.68	89.90	3.40	1.95
24	0.4300	197.600	177.4	7.3	3.89	1.58	5.47	3.46	89.00	3.53	1.94
25	0.4490	196.200	176.0	7.6	3.84	1.45	5.30	3.64	89.90	3.38	1.92
26	0.4670	196.000	175.8	7.9	3.83	1.45	5.28	3.63	89.90	3.37	1.91

Test Readings for Specimen No. 2

No.	Def. Dial in.	Load Dial	Load lbs.	Strain %	Deviator Stress ksf	Minor Eff. Stress ksf	Major Eff. Stress ksf	1:3 Ratio	Pore Press. psi	P ksf	Q ksf
27	0.4840	195.800	175.6	8.2	3.81	1.45	5.27	3.62	89.90	3.36	1.91
28	0.5020	195.200	175.0	8.5	3.79	1.45	5.24	3.60	89.90	3.35	1.89
29	0.5210	194.700	174.5	8.8	3.76	1.45	5.22	3.59	89.90	3.33	1.88
30	0.5390	194.500	174.3	9.1	3.74	1.44	5.18	3.60	90.00	3.31	1.87
31	0.5560	194.200	174.0	9.4	3.73	1.44	5.17	3.59	90.00	3.30	1.86
32	0.5740	193.600	173.4	9.7	3.70	1.44	5.14	3.57	90.00	3.29	1.85
33	0.5920	193.200	173.0	10.1	3.68	1.44	5.12	3.55	90.00	3.28	1.84
34	0.6090	192.300	172.1	10.3	3.65	1.44	5.09	3.53	90.00	3.26	1.82
35	0.6280	192.000	171.8	10.7	3.63	1.43	5.05	3.55	90.10	3.24	1.81
36	0.6460	191.700	171.5	11.0	3.61	1.43	5.04	3.53	90.10	3.23	1.80
37	0.6640	191.300	171.1	11.3	3.59	1.43	5.01	3.52	90.10	3.22	1.79
38	0.6820	190.600	170.4	11.6	3.56	1.43	4.99	3.50	90.10	3.21	1.78
39	0.7000	189.540	169.3	11.9	3.53	1.41	4.94	3.50	90.20	3.17	1.76
40	0.7180	189.100	168.9	12.2	3.51	1.41	4.92	3.48	90.20	3.16	1.75
41	0.7360	188.800	168.6	12.5	3.49	1.41	4.90	3.47	90.20	3.16	1.74
42	0.7540	188.300	168.1	12.8	3.47	1.41	4.88	3.46	90.20	3.14	1.73
43	0.7720	187.700	167.5	13.1	3.44	1.40	4.84	3.46	90.30	3.12	1.72
44	0.7900	186.700	166.5	13.4	3.41	1.40	4.80	3.44	90.30	3.10	1.70
45	0.8070	187.000	166.8	13.7	3.40	1.40	4.80	3.44	90.30	3.10	1.70
46	0.8250	186.300	166.1	14.0	3.38	1.40	4.77	3.42	90.30	3.08	1.69
47	0.8430	186.700	166.5	14.3	3.37	1.38	4.75	3.44	90.40	3.07	1.69
48	0.8620	186.100	165.9	14.7	3.35	1.38	4.73	3.42	90.40	3.06	1.67
49	0.8790	186.400	166.2	15.0	3.34	1.38	4.72	3.42	90.40	3.05	1.67
50	0.8970	185.700	165.5	15.3	3.32	1.38	4.70	3.40	90.40	3.04	1.66

Parameters for Specimen No. 3

Specimen Parameter	Initial	Saturated	Consolidated	Final
Moisture content: Moist soil+tare, gms.	235.360			859.170
Moisture content: Dry soil+tare, gms.	199.870			528.760
Moisture content: Tare, gms.	104.770			74.950
Moisture, %	37.3	62.4	58.7	72.8
Moist specimen weight, gms.	781.80			
Diameter, in.	2.853	2.831	2.798	
Area, in.^{2}	6.393	6.293	6.150	
Height, in.	6.000	5.953	5.886	
Net decrease in height, in.		0.047	0.067	
Wet density, pcf	77.6	94.0	95.1	
Dry density, pcf	56.5	57.9	59.9	
Void ratio	1.4289	1.3721	1.2922	
Saturation, %	57.5	100.0	100.0	

Test Readings for Specimen No. 3

Consolidation cell pressure = 110.00 psi (15.84 ksf)
Consolidation back pressure = 80.00 psi (11.52 ksf)
Consolidation effective confining stress = 4.32 ksf
Strain rate, in./min. = 0.008
Fail. Stress = 4.35 ksf **at reading no.** 11

No.	Def. Dial in.	Load Dial	Load lbs.	Strain %	Deviator Stress ksf	Minor Eff. Stress ksf	Major Eff. Stress ksf	1:3 Ratio	Pore Press. psi	P ksf	Q ksf
0	0.0010	22.700	0.0	0.0	0.00	4.23	4.23	1.00	80.60	4.23	0.00
1	0.0150	116.000	93.3	0.2	2.18	3.17	5.35	1.69	88.00	4.26	1.09
2	0.0310	157.300	134.6	0.5	3.14	2.39	5.53	2.31	93.40	3.96	1.57
3	0.0460	177.500	154.8	0.8	3.60	1.99	5.58	2.81	96.20	3.79	1.80
4	0.0630	189.400	166.7	1.1	3.86	1.76	5.62	3.20	97.80	3.69	1.93
5	0.0790	197.300	174.6	1.3	4.03	1.61	5.65	3.50	98.80	3.63	2.02
6	0.0940	202.200	179.5	1.6	4.14	1.53	5.66	3.71	99.40	3.59	2.07
7	0.1110	206.000	183.3	1.9	4.21	1.45	5.67	3.90	99.90	3.56	2.11
8	0.1250	209.100	186.4	2.1	4.27	1.43	5.70	4.00	100.10	3.56	2.14
9	0.1400	211.000	188.3	2.4	4.30	1.38	5.69	4.11	100.40	3.53	2.15
10	0.1570	213.500	190.8	2.7	4.35	1.37	5.72	4.18	100.50	3.54	2.17
11	0.1730	214.200	191.5	2.9	4.35	1.35	5.71	4.22	100.60	3.53	2.18
12	0.1880	215.300	192.6	3.2	4.37	1.32	5.69	4.30	100.80	3.51	2.18
13	0.2050	216.300	193.6	3.5	4.38	1.31	5.69	4.34	100.90	3.50	2.19
14	0.2200	216.700	194.0	3.7	4.37	1.30	5.67	4.37	101.00	3.48	2.19
15	0.2360	217.000	194.3	4.0	4.37	1.30	5.66	4.37	101.00	3.48	2.18
16	0.2520	217.400	194.7	4.3	4.36	1.30	5.66	4.37	101.00	3.48	2.18
17	0.2680	217.800	195.1	4.5	4.36	1.28	5.64	4.40	101.10	3.46	2.18
18	0.2830	218.300	195.6	4.8	4.36	1.28	5.64	4.40	101.10	3.46	2.18
19	0.3000	218.500	195.8	5.1	4.35	1.27	5.62	4.43	101.20	3.44	2.18
20	0.3150	219.100	196.4	5.3	4.35	1.22	5.58	4.56	101.50	3.40	2.18
21	0.3310	219.400	196.7	5.6	4.35	1.27	5.61	4.43	101.20	3.44	2.17
22	0.3470	219.900	197.2	5.9	4.35	1.27	5.61	4.43	101.20	3.44	2.17
23	0.3630	220.000	197.3	6.2	4.34	1.27	5.60	4.42	101.20	3.44	2.17
24	0.3790	220.000	197.3	6.4	4.32	1.27	5.59	4.41	101.20	3.43	2.16
25	0.3950	219.400	196.7	6.7	4.30	1.27	5.56	4.39	101.20	3.42	2.15
26	0.4100	218.900	196.2	6.9	4.27	1.27	5.54	4.37	101.20	3.40	2.14

Test Readings for Specimen No. 3

No.	Def. Dial in.	Load Dial	Load lbs.	Strain %	Deviator Stress ksf	Minor Eff. Stress ksf	Major Eff. Stress ksf	1:3 Ratio	Pore Press. psi	P ksf	Q ksf
27	0.4260	218.800	196.1	7.2	4.26	1.27	5.53	4.36	101.20	3.40	2.13
28	0.4410	218.200	195.5	7.5	4.24	1.27	5.50	4.34	101.20	3.38	2.12
29	0.4580	218.300	195.6	7.8	4.22	1.25	5.48	4.37	101.30	3.36	2.11
30	0.4750	217.700	195.0	8.1	4.20	1.25	5.45	4.35	101.30	3.35	2.10
31	0.4900	217.800	195.1	8.3	4.19	1.25	5.44	4.34	101.30	3.35	2.09
32	0.5070	217.900	195.2	8.6	4.18	1.25	5.43	4.33	101.30	3.34	2.09
33	0.5220	217.900	195.2	8.9	4.17	1.25	5.42	4.33	101.30	3.34	2.08
34	0.5380	217.500	194.8	9.1	4.15	1.25	5.40	4.31	101.30	3.33	2.07
35	0.5530	217.700	195.0	9.4	4.14	1.25	5.39	4.30	101.30	3.32	2.07
36	0.5690	217.600	194.9	9.7	4.12	1.25	5.38	4.29	101.30	3.31	2.06
37	0.5850	216.900	194.2	9.9	4.10	1.24	5.33	4.31	101.40	3.29	2.05
38	0.6010	216.300	193.6	10.2	4.07	1.24	5.31	4.29	101.40	3.27	2.04
39	0.6170	215.200	192.5	10.5	4.04	1.24	5.27	4.26	101.40	3.26	2.02
40	0.6330	214.600	191.9	10.7	4.01	1.24	5.25	4.24	101.40	3.24	2.01
41	0.6490	214.600	191.9	11.0	4.00	1.24	5.24	4.23	101.40	3.24	2.00
42	0.6650	214.000	191.3	11.3	3.97	1.24	5.21	4.21	101.40	3.23	1.99
43	0.6810	213.700	191.0	11.6	3.96	1.22	5.18	4.23	101.50	3.20	1.98
44	0.6970	212.800	190.1	11.8	3.92	1.21	5.13	4.24	101.60	3.17	1.96
45	0.7120	212.700	190.0	12.1	3.91	1.22	5.14	4.20	101.50	3.18	1.96
46	0.7280	212.300	189.6	12.4	3.89	1.21	5.10	4.22	101.60	3.16	1.95
47	0.7440	211.800	189.1	12.6	3.87	1.21	5.08	4.20	101.60	3.14	1.93
48	0.7600	211.800	189.1	12.9	3.86	1.21	5.07	4.19	101.60	3.14	1.93
49	0.7770	211.300	188.6	13.2	3.83	1.21	5.04	4.17	101.60	3.13	1.92
50	0.7920	210.200	187.5	13.4	3.80	1.21	5.01	4.14	101.60	3.11	1.90
51	0.8090	210.200	187.5	13.7	3.79	1.21	5.00	4.13	101.60	3.10	1.89
52	0.8240	209.200	186.5	14.0	3.76	1.21	4.97	4.11	101.60	3.09	1.88
53	0.8410	208.700	186.0	14.3	3.73	1.21	4.94	4.09	101.60	3.08	1.87
54	0.8560	208.400	185.7	14.5	3.72	1.21	4.93	4.07	101.60	3.07	1.86
55	0.8730	207.600	184.9	14.8	3.69	1.21	4.90	4.05	101.60	3.05	1.84
56	0.8880	207.200	184.5	15.1	3.67	1.20	4.86	4.07	101.70	3.03	1.83
57	0.8990	207.500	184.8	15.3	3.67	1.20	4.86	4.07	101.70	3.03	1.83