Bottom Ash Test Section Evaluation
Erwinville, LA

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ABSTRACT

Bottom ash is a by-product of the energy industry and the residual of burning coal in a kiln firing process. Bottom ash is black and the consistency of coarse sand with gravel clinker traces. The product is used in other states as embankment material, and this project will evaluate the product for use in Louisiana.

Many laboratory tests were conducted to evaluate the properties of the bottom ash material. Those tests included moisture content, standard and modified Proctor, grain size distribution, California Bearing Ratio (CBR), nuclear moisture density, direct shear, pH, and resistivity tests.

A test section was constructed with the bottom ash material. The purpose of the test section was to evaluate the in-situ properties of the material in the field, the construction techniques, and the potential field quality control methods and devices to monitor field construction.

The results of the Dynamic Cone Penetrometer (DCP) and the nuclear moisture density gauge appeared to be the most effective tools in evaluating the material. The DCP results were repeatable and closely matched typical values for sand strength/stiffness. The nuclear gauge proved to be an appropriate tool for construction control.

Implementation of the bottom ash material should provide the Louisiana Department of Transportation and Development (LADOTD) an effective embankment alternative at a low cost. The material also has relatively low density, which could provide another lightweight embankment alternative for soft subsurface soils.

Recommendations include future test sections with field monitoring due to the limited scope of the project. A draft specification has been included for review and approval by the chief engineer.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of Big River Industries, Inc., John River Cartage, and Hernandez Trucking who assisted with the site, material, and equipment necessary to construct the field test section. Their support and assistance helped move this project forward. The authors appreciate the assistance from the geotechnical and pavement groups at Louisiana Transportation Research Center (LTRC). Student workers from Louisiana State University also played an important role in conducting laboratory tests.

IMPLEMENTATION STATEMENT

This study identified the possibility of using bottom ash as a potentially low cost embankment material. Should the material be allowed as an alternative on Louisiana Department of Transportation and Development projects, the Department would benefit through cost savings on materials within the cost effective area. An additional benefit would be the reuse of a waste product, therefore, reducing the amounts stored in landfills.

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INTRODUCTION

Bottom ash is a by-product of the energy industry and the residual of burning coal in the kiln firing process. Bottom ash is black and the consistency of coarse sand with gravel clinker traces. Several suppliers in Louisiana generate the product.

The LADOTD was asked to consider using bottom ash as an alternative source of embankment material since it is available and would reduce the amount entering landfills by recycling the material. Other states (West Virginia, Wisconsin, Indiana, etc.) have successful experiences using bottom ash within their road systems. Specifically, West Virginia used bottom ash material within the embankments and mechanically stabilized earth (MSE) walls of the major intersection improvements to US 35 and Interstate 64 in 2003.

The current LADOTD embankment specifications do not address the use of bottom ash. Due to the lack of use and experience with bottom ash in Louisiana, a test section was proposed to further evaluate the material. The knowledge gained from other states was beneficial, but the Department felt that an independent field evaluation of the product was necessary to gain firsthand knowledge of the material.

OBJECTIVE

The objective of this project is to evaluate bottom ash as an alternative source of embankment material for highway construction in Louisiana, which includes strength, stiffness, and field construction of the material.

SCOPE

The scope of the material evaluation focused on the use of the material as embankment material for highway construction in Louisiana. Other supplemental uses may also apply through similar applications. Basic properties of the bottom ash were validated and characterized in this study through laboratory and in-situ field tests. The tests were primarily designed to evaluate the performance, compaction, construction, and monitoring issues associated with the material.

This evaluation does not address the environmental issues that may be associated with the permitting and regulation of the bottom ash material by the Louisiana Department of Environmental Quality. These items should be addressed and resolved prior to approving this product for use by the LADOTD.

METHODOLOGY & DISCUSSION OF RESULTS

This study was divided into two major parts: Laboratory and Field Testing programs. Many different test methods and testing devices were used to evaluate the bottom ash material. The different testing programs were used to determine and identify not only the properties of the material but also to determine which device (or method) would best evaluate the material in an accurate, precise, and consistent manner.

Laboratory Testing Program

Laboratory testing consisted of various tests conducted to identify the general properties of the bottom ash material and factors that significantly affect the material's performance. The testing also evaluated the material against similar materials commonly used by LADOTD with current LADOTD specifications.

Material

Big River Industries, Inc. supplied the bottom ash material used in the laboratory and field evaluation. The material is generated at the Big Cajun II Power Plant in Pointe Coupee Parish, LA. After the burning process, the bottom ash is collected and pumped via slurry to storage ponds at the site; the material is later stockpiled onsite. The bottom ash is black and the consistency of coarse sand with gravel clinker traces.

Figure 1
Stockpiled bottom ash for test section

Moisture Content

Moisture content samples of the bottom ash material were collected throughout the study process. Moisture contents were calculated on the samples delivered to LTRC at the beginning of the project. Additional moistures were collected during the field and laboratory testing to assist with dry density calculations. The method used to calculate moisture content is DOTD TR 403 (ASTM D 2216). Results ranged from about 9 to 34 percent with the material bleeding water at increased moisture contents.

Particle Size Analysis (Gradation)
Three analyses were performed during the course of the bottom ash evaluation to gauge whether the material was consistent throughout different samples. The method used is detailed in DOTD TR 407 (ASTM D 422). The first analysis was on material received from the supplier. A second analysis was on the bottom ash after it had been compacted in the Proctor mold. This was done to determine if the material's gradation changed due to breakdown of particles during the compaction process. A third analysis was conducted on a field sample to ensure consistency.

As Figure 2 shows, the material changed only slightly after compaction. Also plotted on the figure is the range of non-plastic embankment requirements of LADOTD Section 1003.09(a) for reference. The figure indicates that the bottom ash has a gradation close to the coarse side of the LADOTD specification.

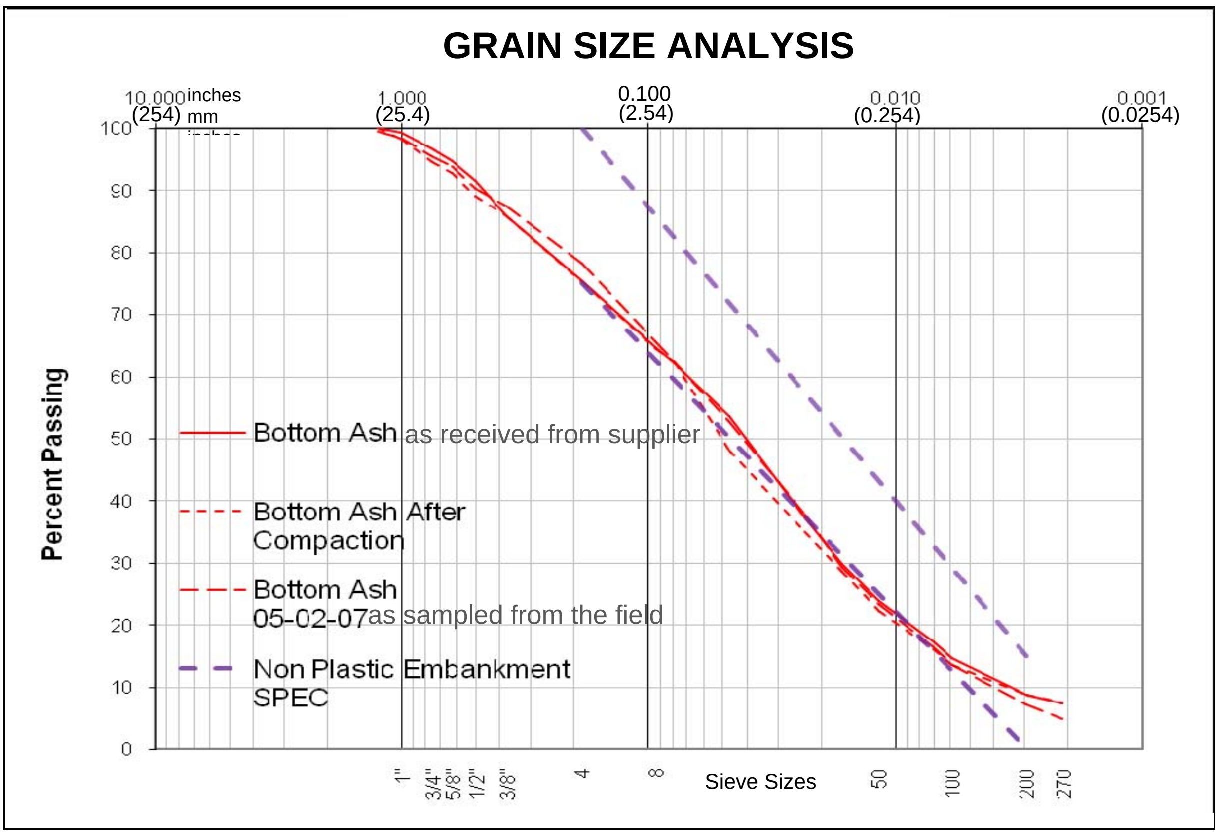

Figure 2
Grain size analyses

Calculations in Figure 3 show the Coefficient of Uniformity, Cu, and the Coefficient of Gradation, Cc, and the criteria needed to classify as “well-graded.” The bottom ash material meets the criteria for well-graded, which is an indicator of a good representation of all particle sizes, and can aid in compaction potential.

D=Diameter in mm at % passing

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.8}{0.1} = 18 \quad >6$$

$$C_c = \frac{(D_{30})^2}{(D60)(D_{10})} = \frac{(0.44)^2}{1.8*0.1} = 1.076 \quad 1<C_c<3$$

Well Graded Criteria

Gravel, C_u >4
Sands, C_u >6
& Gravels & Sands, C_c must be: $1<C_c<3$

Therefore: Well -Graded

Figure 3
Gradation calculations

Classification

The Unified Soil Classification System (USCS) is a standardized system used to group and identify similar soil types, and identify them with a unique standardized identification system, published as ASTM D 2487. According to the USCS, the bottom ash falls into the classification of a SW-SM, a well-graded sand with silt.

The American Association of State Highway and Transportation Officials (AASHTO) system is similar and published as AASHTO M 145. According to this system, the bottom ash classifies as A-2-4 material.

Standard and Modified Proctor Compaction Tests

Standard and modified Proctor compaction tests were conducted on the bottom ash in the laboratory according to LADOTD TR 418 (ASTMs D 698 and D1557, respectively) as shown in Figure 4. The results of the standard Proctor tests indicate that there is no well-defined compaction curve as normally seen in a regular soil. The modified test remained at a nearly constant dry density even though the material continued to accept water. These odd fluctuation results are relatively common for non-plastic (granular) material.

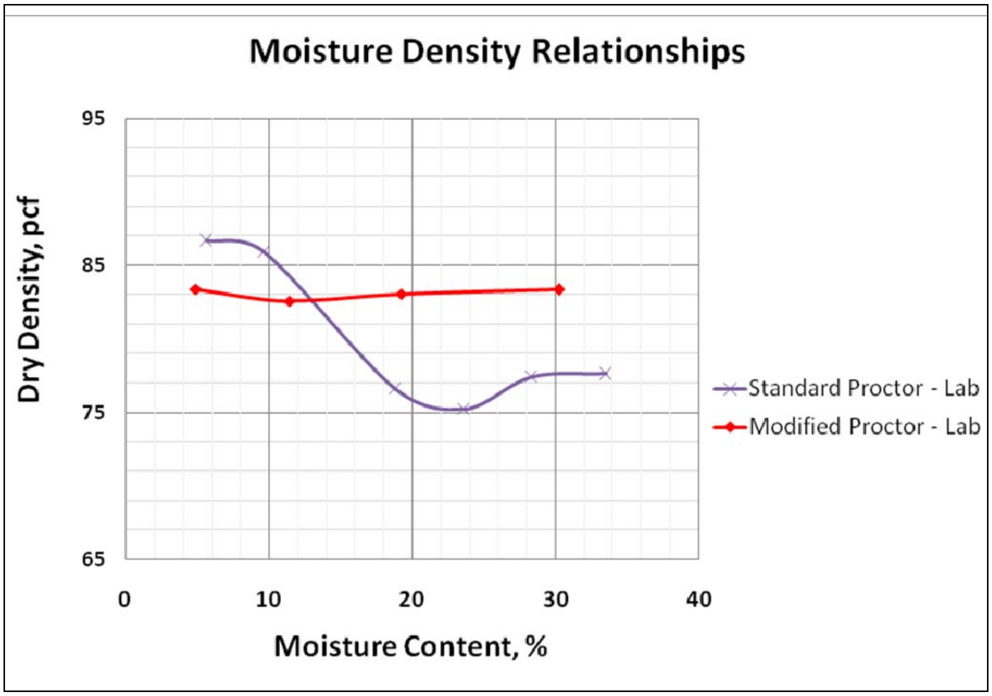

Figure 4
Moisture density proctor plots

Resistivity, pH, and Corrosion Protection

Resistivity is commonly used as an indicator of the corrosion potential of soil or aggregates. Table 1 presents reference values for resistivity and corrosivity. Additional contributing factors to corrosion are extreme pH, high soluble sulfate, 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.

Table 1
Resistivity and corrosion reference values

Reference Values(8)	
Resistivity, OHM-cm	Corrosivity Rating
>20,000	Essentially non-corrosive
10,000 to 20,000	Mildly corrosive
5,000 to 10,000	Moderately Corrosive
3,000 to 5,000	Corrosive
1,000 to 3,000	Highly Corrosive
< 1,000	Extremely Corrosive

The LADOTD Materials Laboratory conducted pH and resistivity tests on the bottom ash material for LTRC (Table 2). These tests indicate the high potential for corrosion of drainage structures. The test methods for pH and resistivity are outlined in DOTD TR 430 and DOTD TR 429, respectively.

Table 2
Bottom ash resistivity and pH results

Sample	Initial Resistivity, OHM-cm	Minimum Resistivity, OHM-cm	pH
Bottom Ash, Bag A	14,000	700	9.3
Bottom Ash, Bag B	25,000	690	9.2

Department of Environmental Quality

On November 5, 2001, the Department of Environmental Quality issued a letter of no objection regarding the handling practices and marketing of fly ash and bottom ash generated from the above referenced facility (see Appendix A). Current permit and regulatory status was not researched as part of this study but should be verified acceptable prior to approval for use within LADOTD.

California Bearing Ratio

CBR is a simple test that is used to obtain an indication of subgrade, subbase, or base course strength in pavement layers. The systematic CBR test procedure is published as ASTM D 1883.

Typical CBR values for sand and sandy soils range from 5 to 40 (Holtz & Kovacs 1981). Table 3 presents the results of CBR tests on the bottom ash material and values for reference. The data in Table 3 indicates that in a confined condition the bottom ash performance is close to that of sand.

Table 3
CBR results

CBR Bottom Ash Results				Reference Values	
CBR Result	Un-Soaked Bottom Ash	2-Day Soak Bottom Ash	4-Day Soak Bottom Ash	Sand	4-Day Soak Mexican Limestone
CBR @ 0.10”	11.3	6.0	13.3	10	20.0
CBR @ 0.20”	11.1	8.3	17.8	—	26.6

Direct Shear Test

Direct shear tests were conducted on the bottom ash material in the LTRC geotechnical laboratory. This test is designed to determine the internal angle of friction (φ) and cohesion (c) of the tested material. The direct shear test is outlined in ASTM D 3080. The test was conducted on both oven dry and saturated material to determine if changes in moisture would affect the strength of the material. The results of the direct shear test, as shown in Figure 5 indicate that c=zero, and φ=45.4° and 47.6° for dry (points 1, 2, and 3) and saturated (points 4, 5, and 6) conditions, respectively. These results are close to those obtained by others (Wisconsin Electrical Power Company, West Virginia DOT, etc.).

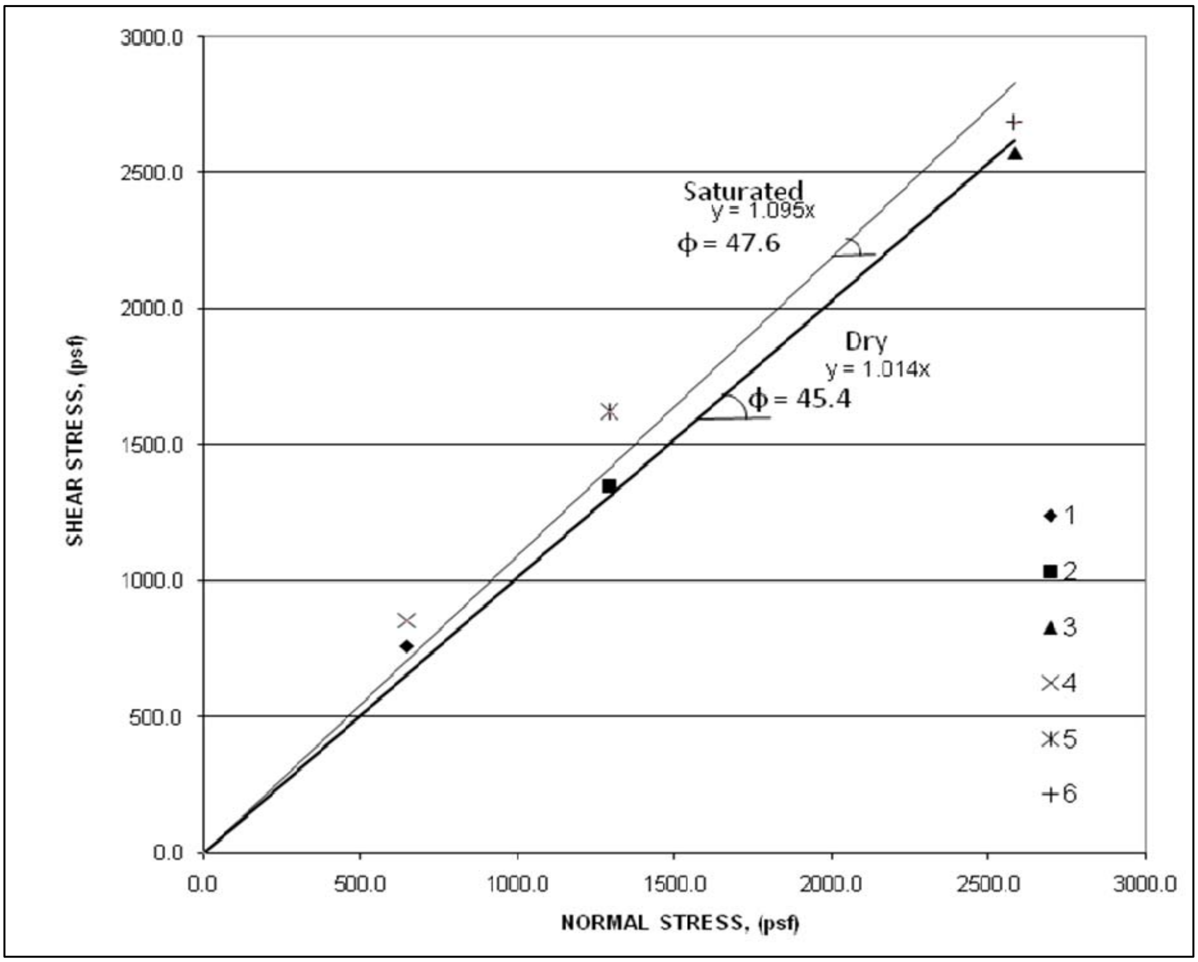

Figure 5
Direct shear results

Field Testing Program

The field-testing program included building a full-scale test section in Erwinville, LA. Testing at the site included several field test instruments and some used currently by the LADOTD. The devices were used to determine properties including density, moisture content, strength, and stiffness of the tested material. The test program sought to get firsthand experience with the material for its constructability and explore any possible problems associated with the construction process. It also sought to determine the best device(s) to measure and assure that bottom ash, if used in an embankment, will be monitored with appropriate quality control device(s).

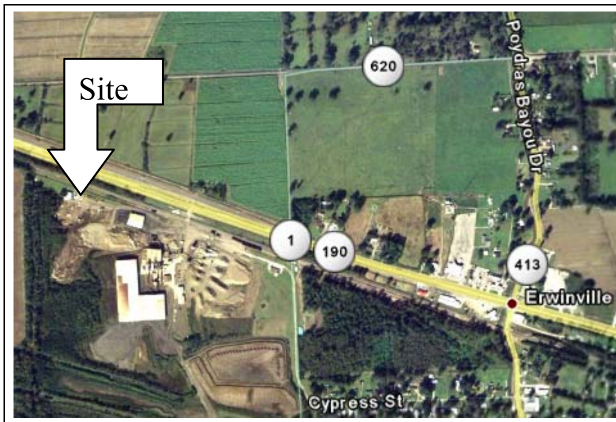

Figure 6
Field test site – Erwinville, LA

On Tuesday, May 01, 2007, the LTRC Geotechnical crew mobilized to the Big River Industries Gravelite Plant, which is located just west of Erwinville, Louisiana and south of US 190. The test section is located at the northwest side of the site in an area once used for truck maintenance operations. The surface soils appeared to be Gravelite compacted under years of truck traffic.

Upon the team's arrival, several stockpiles of bottom ash were stacked on the site, and a lift of the material (the supplier's test section) was spread upon the proposed test site. The existing on-site material was removed so the test section could begin on the Gravelite "natural ground." Several tests were conducted on the natural ground prior to placing the first lift of the bottom ash.

Test Section Plan

The original dimensions of the test section were 150 ft. by 50 ft. with 5 lifts of 12 in. each. Once the first lift placement began, it was determined in the field that a test section 125 ft. long and 50 ft. wide and 4 lifts of 12 in. were enough to serve the testing purpose. A sketch of the test plan profile is included in Figure 7.

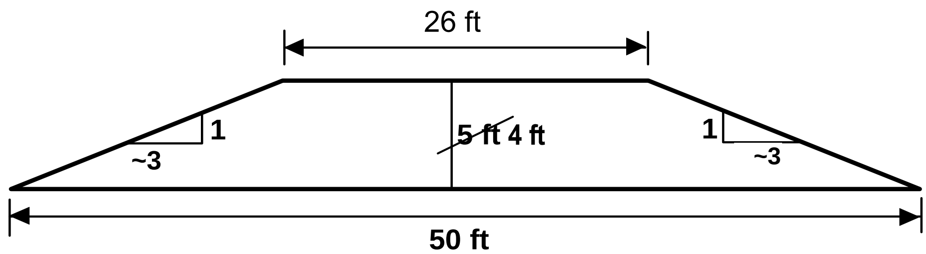

Figure 7
Test section profile

Figure 8
Test area

Placement Begins

Initially the stockpiled materials were moved into position on the test area with a Komatsu WA420, front end-loader, and then spread with a Komatsu D31P dozer to the designated 12 in. thickness (Figure 8). As the stockpiles were depleted, more material was hauled in, stockpiled, or dumped directly on the test area. As the dozer spread the bottom ash material across the test area, a laser level was used to check each lift thickness.

Vibratory Compaction

A Case SV208, vibratory roller was used to compact the bottom ash lifts (Figure 9). The roller crossed the material in the east-west direction, which matched the longer dimension of the test section. A series of tests were performed between passes of the roller, followed by additional tests upon completion of each lift.

Figure 9
Case SV208, vibratory roller

Water Truck

The Big River Gravelite plant supplied a water truck for the test section that held and sprayed non-potable water on each lift. The truck is normally used to spray the plant's raw product and roads throughout the plant for dust control (see Figure 10).

Figure 10
Water truck

During the addition of moisture with the water truck, the driver turned the wheel too sharply for this unbound material. The surface layer shifted, and the water truck began to bog down (see Figure 11). The driver soon realized his error, corrected the wheel angle, and the water truck pulled out of the rut. The same situation would have likely occurred in normal non-plastic embankment (sand).

Figure 11
Water truck driver's wheel cut sharp

GeoGauge Stiffness Tests

The Stiffness GeoGauge device (Figure 12) was introduced for transportation applications by Humboldt Manufacturing Company. The GeoGauge is a nondestructive, portable device that can provide rapid measurements of in-situ stiffness of compacted subgrades, subbases, and base layers at the rate of one test per 90 seconds. The GeoGauge device has a diameter of 11 in., a height of 10 in., weighs about 22 lb., and has an influence depth of about 8 in. It rests on the soil surface via a ring–shaped foot with an outside diameter of 4.5 in. and inside diameter of 3.5 in. It has a shaker that generates a very small dynamic force, F, to vibrate the foot at 25 specific frequencies ranging from 100 to 196 Hz. This produces a very small deflection, δ, which is measured by a geophone sensor within the body of the gauge. The ratio of F/δ represents a measure of stiffness of the material, assuming an elastic behavior. The GeoGauge stiffness (H_{SG}) is determined based on an average of 25 stiffness values determined at 25 different frequencies. It can then be converted to soil elastic modulus (E_G) using the following equation:

Figure 12
Humboldt GeoGauge

$$\mathbf{E_G = H_{SG}} \cdot \frac{(1 - v^2)}{(1.77R)} \qquad (1)$$

where *v* is the soil's Poisson's ratio and *R* is the radius of the GeoGauge foot (2.25 in.).

The GeoGauge device was employed to the site and used to test the elastic modulus of each lift of bottom ash embankment as well as the natural ground. The bottom ash results ranged between 1.68 and 3.32 ksi, and are summarized in Table 3. The results reported as overload indicate deflections outside the device's range, and values in parenthesis indicate the average of test location values. For reference, a typical GeoGauge result on sand is 7.52 ksi (51.9 MPa). The GeoGauge results were lower than sand and the results collected on natural ground, but the results were consistent within the bottom ash results. This illustrates the need to determine specific GeoGauge target values for each unique material.

Table 4
GeoGauge results

Test	No. of Passes	GeoGauge Elastic Modulus (ksi)	
		Location 1	Location 2
Natural Ground	—	3.05, 5.66, 7.21 (5.31)	7.91, 9.81, 8.49 (8.73)
1st 1 ft. Lift	6-Dry	1.95, 2.15 (2.05)	overload
	6-Wet	2.45, 2.48, 2.43 (2.46)	2.10, 2.07, 1.94 (2.04)
2nd 1 ft. Lift	2-Wet	overload	1.68, 1.99 (1.84)
	4-Wet	2.22, 2.14, 2.21 (2.19)	overload
	6-Wet	1.97	2.34, 2.33, 2.56 (2.41)
	8-Wet	2.39, 2.57, 2.72 (2.56)	2.27, 2.37, 2.35 (2.33)
3rd 1 ft. Lift	8-Dry	2.60, 2.78, 2.79 (2.72)	3.19, 3.00, 2.82 (3.01)
	8-Wet	2.91, 2.98, 3.32 (3.07)	2.81, 2.71, 2.77 (2.76)
4th 1 ft. Lift	8-Dry	2.40, 2.36, 2.41 (2.39)	2.28, 2.41, 2.58 (2.42)
	8-Wet	2.34, 2.12, 2.02, (2.16)	2.26, 2.59, 2.46 (2.44)

Light Falling Weight Deflectometer (LFWD) Tests

The LFWD is a portable FWD that has been developed in Germany as an alternative in-situ testing device to the plate load test. The Prima 100 model LFWD was used in this study. It was developed and marketed by Carl Bro Pavement Consultants in Denmark. It weighs 57 lb., and has a 22 lb., falling weight that impacts a spring to produce a load pulse of 15-20 ms.

The Prima 100 has a load range of 0.23-3.37 kips (i.e., up to 9.4 ksf with its 8 in. diameter loading plate) by varying the drop height. It measures both the applied force and center deflection during each test. The center deflection (δ_c) of the loading plate is used to calculate the LFWD elastic modulus (E_{LFWD}) using PC software (see Figure 13). The E_{LFWD} is calculated using the expression of surface loading on elastic half space (Boussinesq elastic half space). This expression is described by equation (2):

$$\mathbf{E_{LFWD}} = \frac{2(1-v^2)\sigma \times R}{\delta_c} \qquad (2)$$

In equation (2), σ is the applied stress, and *R* is the radius of the loading plate.

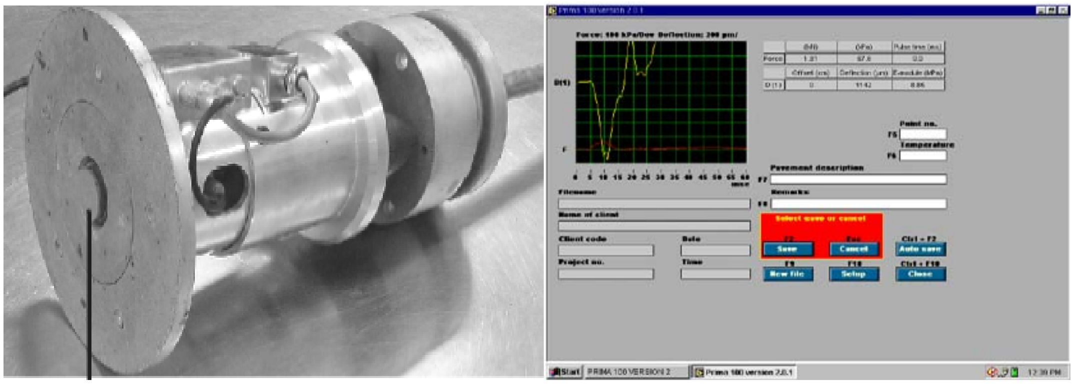

Figure 13
LFWD and software

The LFWD was used to estimate the elastic modulus of each lift of bottom ash embankment and the results are summarized in Table 4 below. It should be noted here that the influence depth of LFWD is about 12 in.

The bottom ash LFWD results ranged between 0.46 ksi to 0.98 ksi and are shown in Table 5. For reference, a typical LFWD result on sand is 3.83 ksi (26.4MPa). As seen with the GeoGauge, the values were less than those recorded on sand. This device was included in the test program to determine if it was an acceptable device to this new product. Based on the results and field experience, it is unlikely that the device would be used to control bottom ash compaction.

Table 5
Light falling weight deflectometer results

Test	No. of Passes	E_{LFWD} (ksi)	
		Location 1	Location 2
1st 1 ft. Lift	6	0.95	0.98
2nd 1 ft. Lift	8	0.68	0.63
3rd 1 ft. Lift	8	0.64	0.58
4th 1 ft. Lift	8	0.46	0.47

Nuclear Moisture Density Gauge

Humboldt's HS-5001EZ Moisture/Density Gauge was used to test the bottom ash material at the site (Figure 13). The nuclear moisture density gauge measures in-situ moisture content and dry density through direct transmission and backscatter modes of a source emission of gamma radiation. The small amounts of radiation are scattered by the soil particles in proportion to the total density of the material. In addition, since hydrogen atoms in water scatter neutrons, this provides a method for moisture determination.

The results of the field tests are presented in Table 6, and the values are plotted on Figure 15. The tests were conducted on different lifts with different amounts of energy induced into the layer through passes of the roller. Most values were above 75 pcf; values less than 75 pcf are flagged with an asterisk in the Table 6.

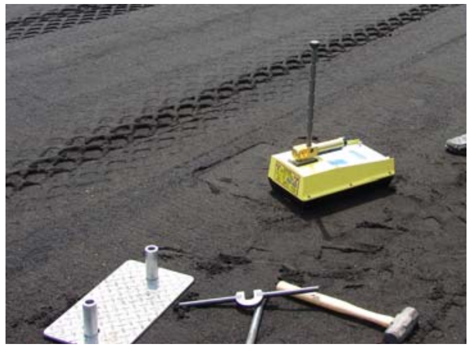

Figure 14
Nuclear moisture density gauge

Table 6
Nuclear moisture density results

Field Nuclear Moisture Density Readings

Ground Surface

Number Passes	Water Truck	Nuclear Gauge Moisture	Nuclear Gauge Density	depth in.
Previous Use, ?	No	13.3	99.7	4
	No	19.0	87.5	2
	No	6.2	95.0	4

Lift # 1

Number Passes	Water Truck	Nuclear Gauge Moisture	Nuclear Gauge Density	depth in.
2	NO	11.2	83.2	12
2	NO	10.7	85.9	12
2	NO	9.7	89.4	12
4	YES	20.0	81.1	12
4	YES	13.9	84.6	12
4	YES	12.9	85.5	12
6	YES	14.0	85.4	12
6	YES	15.0	84.9	6
6	YES	14.6	86.3	6
6	YES	16.2	84.7	10
6	YES	14.4	87.1	12
6	YES	14.6	84.9	12
6	YES	13.7	86.2	6
6	YES	16.5	88.6	6

Lift # 2

Number Passes	Water Truck	Nuclear Gauge Moisture	Nuclear Gauge Density	depth in.
2	YES	17.7	75.0	12
2	YES	21.5	75.4	12
2	YES	16.1	84.3	12
2	YES	17.5	81.9	12
2	YES	21.8	* 73.4	12
2	YES	21.2	* 72.4	6
4	YES	18.5	80.1	12
4	YES	21.0	* 73.6	12
4	YES	21.4	* 70.5	12
4	YES	19.1	* 71.5	12
4	YES	15.7	80.2	12
6	YES	15.2	86.0	12
6	YES	15.6	82.2	12
6	YES	25.6	* 68.3	12
6	YES	20.9	* 71.8	12
6	YES	23.0	* 68.4	12
8	YES	16.5	83.8	12
8	YES	20.2	76.6	12
8	YES	16.6	80.2	12
8	YES	19.8	77.3	12
8	YES	13.5	85.6	12

Lift # 3

Number Passes	Water Truck	Nuclear Gauge Moisture	Nuclear Gauge Density	depth in.
16	YES	18.6	83.2	12
16	YES	14.6	87.9	12
16	YES	18.7	83.2	12
16	YES	14.7	85.0	12

Lift # 4

Number Passes	Water Truck	Nuclear Gauge Moisture	Nuclear Gauge Density	depth in.
16	YES	24.3	* 71.3	12
16	YES	20.3	79.3	12
16	YES	25.9	* 70.3	12
16	YES	21.5	75.8	12
16	YES	22.6	* 70.9	12
16	YES	24.5	* 73.6	12
16	YES	23.1	* 74.3	12
16	YES	29.2	* 69.5	12
16	YES	25.8	* 72.2	12
16	YES	22.8	* 71.2	12

Bottom Ash Statistics Lifts 1 thru 4

Average	18.4	79.3
Min	9.7	68.3
Max	29.2	89.4
STD	4.4	6.4

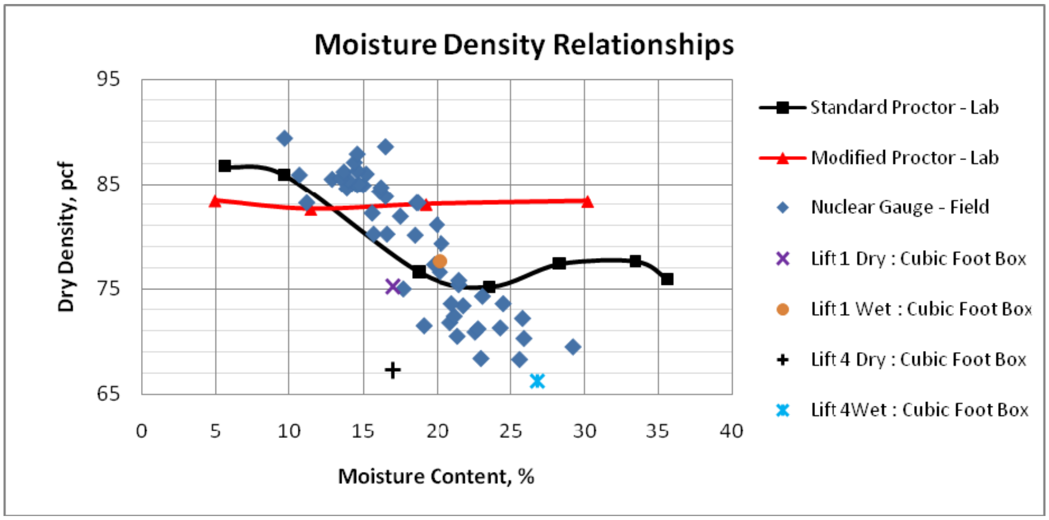

Figure 15
Moisture density plot summary

Box Density

A steel box 3ft. long, 1ft. wide, and 4 in. deep (a cubic foot volume) was used at the site to collect moisture density data. The box was buried in-situ within a layer of bottom ash with material compacted in and around the box by the vibratory roller. Upon completion of the number of passes, the box was removed, scraped flush, and weighed onsite with a balance scale as shown in Figure 16. The box was buried and compacted under different efforts (passes) and moisture contents. Since density equals mass over volume (density=mass/volume), the cubic foot box made for easier calculations with densities in English units of pounds per cubic foot (pcf). Moisture samples were collected so that conversions from wet density to dry density could be determined.

The cubic foot box measurements were compared against field (nuclear) and laboratory (Proctor) moisture density values as shown in Table 7. This was done to verify that the nuclear gauge was functioning properly on the bottom ash material. An additional function of the box was to determine the potential of the box to serve as a quality control and validation device as it did on Interstate 10 and Picardy's lightweight aggregate. The box, though more labor intensive than the nuclear density gauge, also proved to be a suitable method for verifying moisture and density.

Figure 16
Cubic foot box

Table 7
Cubic foot box field moisture density results

Location	Moisture, %	Wet Density, pcf	Dry Density, pcf
Lift 1 Dry	17.0	88.0	75.2
Lift 1 Wet	20.2	93.3	77.6
Lift 4 Dry	17.0	78.7	67.3
Lift 4 Wet	26.8	84.0	66.2

The results of the nuclear and cubic foot box moisture density tests are plotted along with the Proctor moisture density results in Figure 15.

Compaction Effort and Number of Passes

The nuclear gauge results collected at the surface of each lift have been plotted with respect to the lift and number of vibratory roller passes in Figure 17 and Figure 18, respectively. In Figure 17, the results for Lifts 1 and 4 show the largest differences in moisture and density and may reflect the influence of the stiff bottom below (former truck operations area surface). The data points for Lift 2 extend from the bottom to the top of the dataset. Figure 18 shows the variation between all four lifts and the values after set passes. Figure 19 through Figure 22 show the results separately for each individual lift for clarity and contrast to Figure 17.

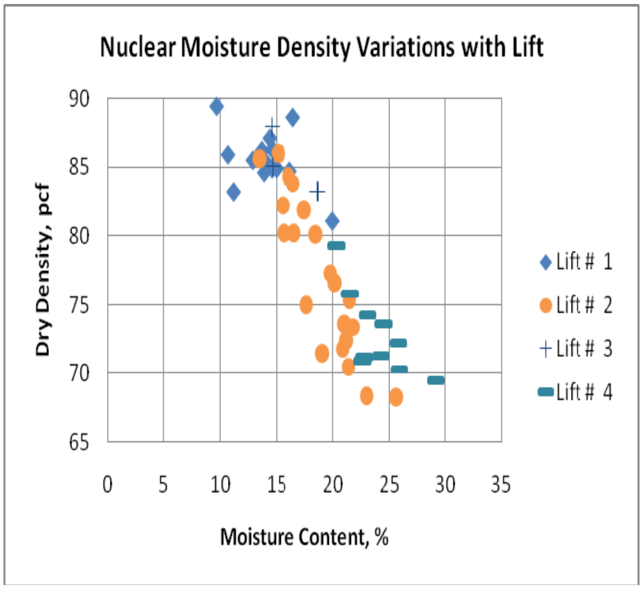

Figure 17
Nuclear moisture density by lift

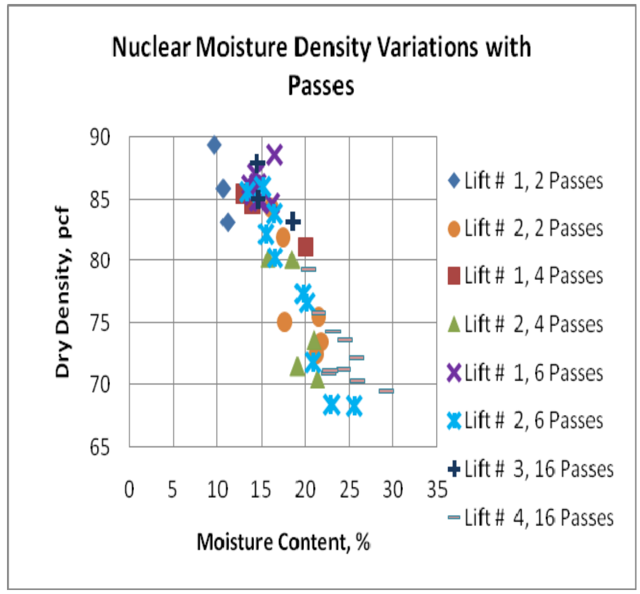

Figure 18
Nuclear moisture density by passes

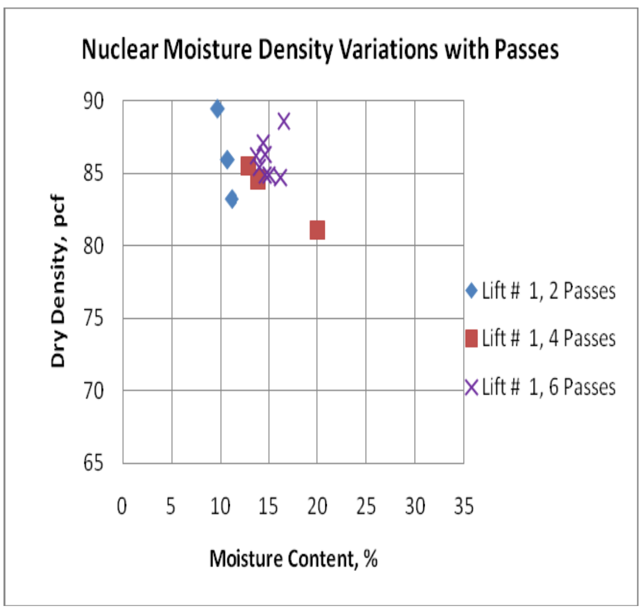

Figure 19
Nuclear moisture density, Lift 1

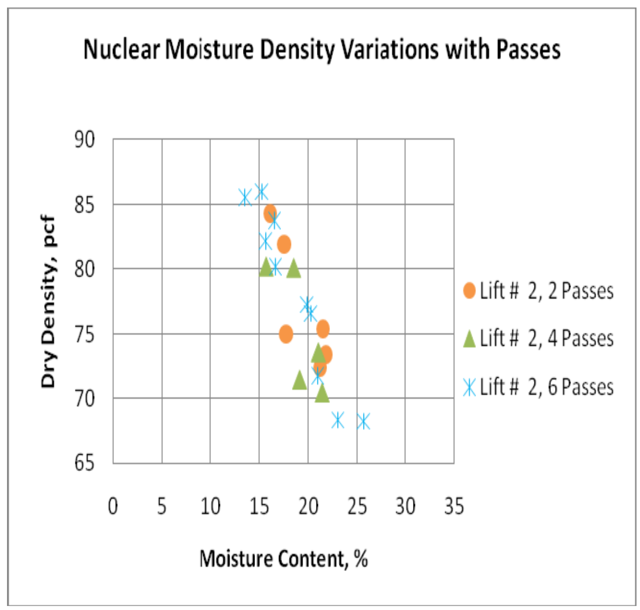

Figure 20
Nuclear moisture density, Lift 2

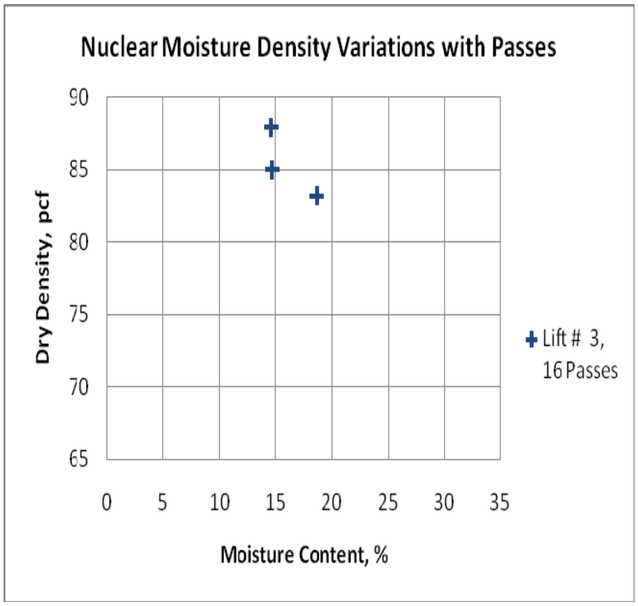

Figure 21
Nuclear moisture density, Lift 3

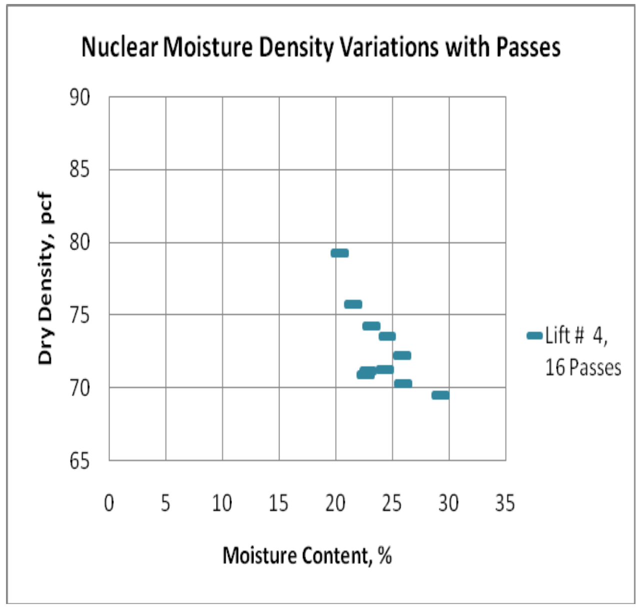

Figure 22
Nuclear moisture density, Lift 4

These charts show that material near 10 percent moisture is more dense than wetter samples, and this dryer material is more likely to be compacted near optimum than at wetter moistures regardless of the number of passes. This mirrors the Proctor compaction data presented earlier in the report.

Dynamic Cone Penetrometer Tests

The DCP is a simple device that advances a 60°, ¾ in. wide cone connected to a ⅝ in.-diameter steel rod with a consistent amount of energy (a 17.67 lb. hammer repeatedly dropped from a height of 22.6 in.); see Figure 23. The DCP test usually extends about 3 ft. down below the tested surface. The penetration of the cone tip varies depending on resistance (stiffness) of tested soil. The stiffer the material, the lower the penetration rate in mm/blow. The DCP data profile is an indication of strength and layer changes.

Figure 23
The DCP

Table 8 presents the results of the DCP tests as the calculated averages in mm/blow for each particular 12 in. lift. The last column represents an average of the tests conducted for each lift. Twelve DCP tests were conducted on the bottom ash test section. The first test (test 1), was started atop the third lift, and continued to the stiff "natural ground" below. Tests 2 through 11 were standard 3 ft. (37.5 in. rod) tests started atop Lift 4. Test 12 used an extension to penetrate deeper into the 4 ft. test section. The surface lift value (46.4) was slightly higher due to disturbance during the coordination of the longer DCP assembly.

Table 8 also shows an increase in stiffness with depth. This is likely due to increased confinement due to the overburden of upper layers. Specifically, the unconfined surface of test 1 (Lift 3) is comparable in stiffness to the unconfined surface of tests 2 through 11 (Lift 4); an increasing trend in strength (reduced mm/blow) can be seen in the lower lifts due to the confinement of the upper lifts. Figure 24 depicts the DCP test data graphically.

Table 8
DCP results, mm/blow

Bottom Ash DCP Results Stiffness, mm/blow													
Test Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	Average
Lift 4		23.6	23.7	27.6	23.6	24.9	26.9	31.1	26.7	27.7	26.9	*46.4*	26.3
Lift 3	21.9	13.3	13.0	15.3	12.7	11.9	11.9	12.1	14.2	11.2	13.5	13.9	13.0
Lift 2	14.5	8.2	8.4	12.0	10.9	8.8	8.2	9.5	9.6	9.6	12.8	13.2	10.1
Lift 1	8.6	6.5	9.8	7.0	9.3	7.8	6.7	8.6	10.0	7.5	7.8	8.3	8.1
Ground												3.9	3.9

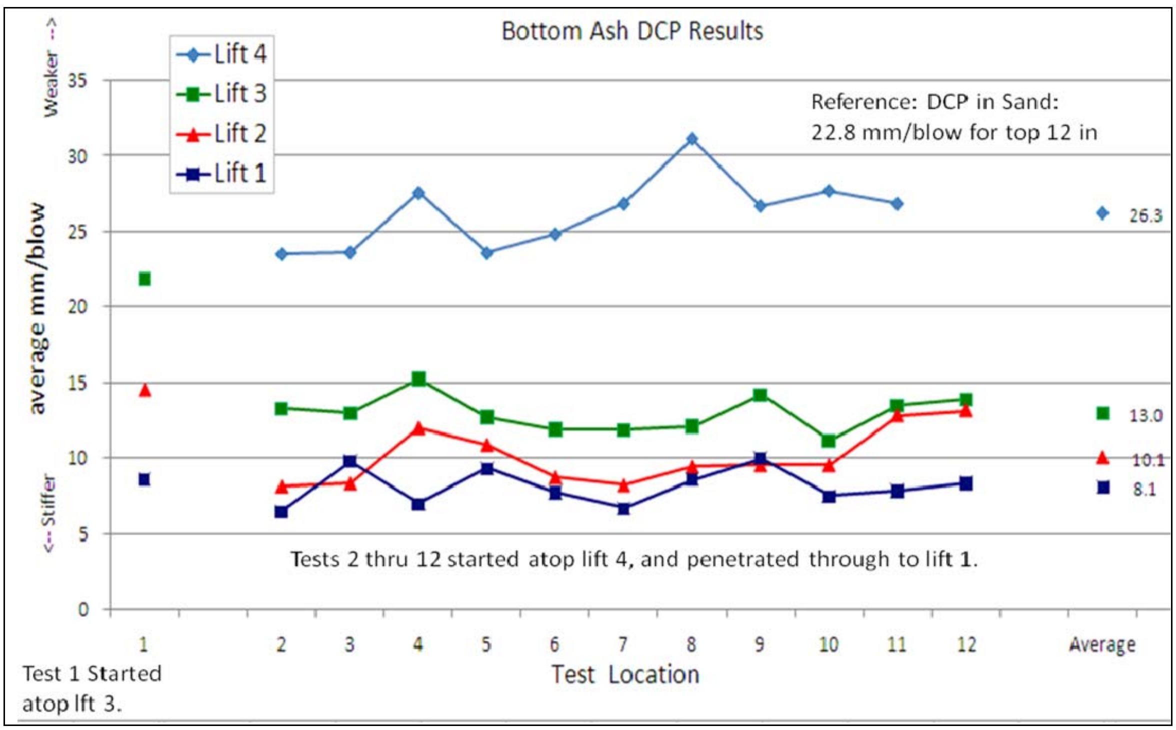

Figure 24
DCP results by Lift

Figure 25 shows the profile with depth of the Dynamic Cone Penetration Index (DCPI) which is defined as the distance traveled in millimeters after each drop of the hammer, thus mm/blow. This figure shows the depth of penetration and the lift thicknesses in relation to the DCPI. The DCPI values get smaller and therefore stronger with depth. This is likely due to the effect of the overlying layers confining the material. The curves as a whole follow the same general trend with weak material (high DCPI values) near the surface and stronger material (lower DCPI values) with increasing depth.

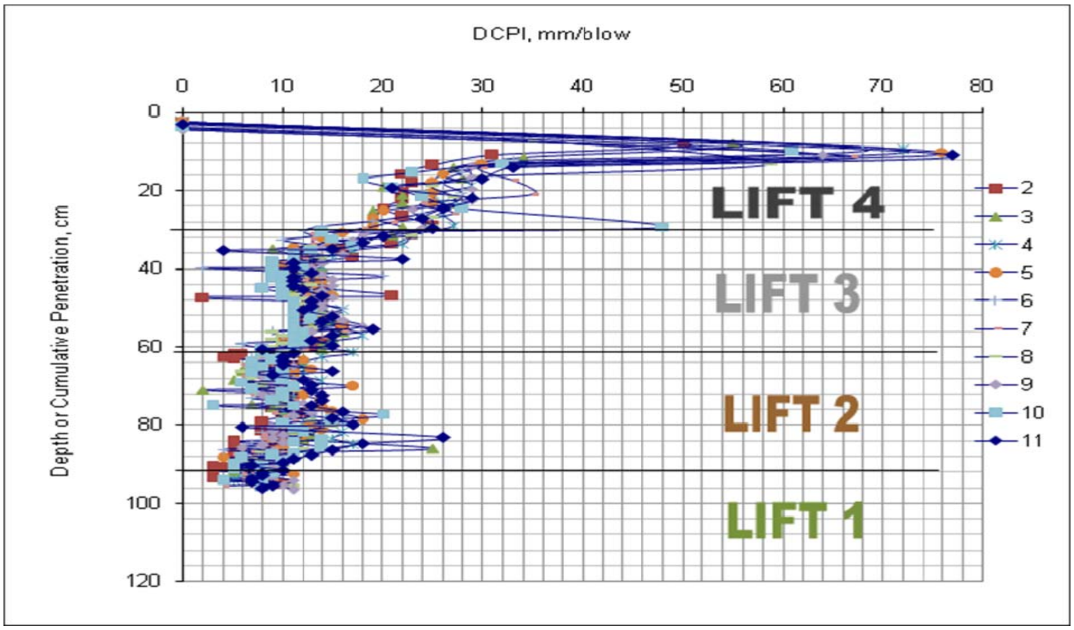

Figure 25
DCP results, showing improvement with depth

Plate Load Test and Pressure Cells

The Plate Load Test (PLT) has been used for many years to determine the bearing capacity of soils and to evaluate the strength/stiffness of pavement systems. The test consists of applying a static load in uniform increments on a circular plate (typically 12 in. diameter) resting on the surface of the layer to be tested and measuring the corresponding deflections. The load is usually transmitted to the plate by a hydraulic jack acting against heavy mobile equipment or reaction frame (Figure 26). The magnitude of each load increment shall be small enough to permit the recording of sufficient number of load-deflection points to produce an accurate load-deflection curve. The test results can be used to determine the elastic modulus of the tested layer using the following equation:

Figure 26
PLT jack

$$E_{PLT} = \frac{P(1-\nu^2)}{2R\delta} \tag{3}$$

where E_{PLT} is the elastic modulus, *P* is the applied load, *R* is the radius of the plate, δ is the deflection of the plate, and *v* is Poisson's ratio.

The results of PLT were used to estimate the initial tangent modulus, $E_{PLT(i)}$, and the reloading elastic modulus ,$E_{PLT(R2)}$). The $E_{PLT(i)}$ modulus was calculated from the initial slope of the load-displacement curve, while $E_{PLT(R2)}$ was determined from the second loading cycle of the test, as shown in Figure 27. The influence depth of the PLT is about 1.5 times the plate diameter (1.5 x 12 = 18 in.).

Pressure cells, roughly 4 in. diameter, were installed at the bottom of Lifts 2, 3, and 4, see Figure 35 in the Appendix. These pressure cells were located beneath the PLT test to measure the increase in pressure due to the applied load and to determine the influence depth of compaction. The pressure cells generate millivolt electrical activity detectable by a computer. This millivolt activity is then converted to loads via predetermined calibration values.

In this study, one PLT test was conducted after completion of the construction of the bottom ash embankment. The test was performed according to ASTM D1195-93. A front-end loader, which weighed about 35 tons (see Appendix Figure 36), was used as a reaction to the PLT, and readings were obtained manually. The load-deformation curve of the PLT is shown in Figure 27. The results showed that the $E_{PLT(i)}$ = 0.57 ksi and the $E_{PLT(R2)}$ = 0.96 ksi for the upper 18 in. (influence depth) of the embankment. For reference typical PLT results on sand are $E_{PLT(i)}$ = 5.1ksi (35.3 MPa) and the $E_{PLT(R2)}$ = 7.25 ksi (50 MPa).

A laptop computer with data acquisition software was connected to the pressure cell hardware and collected the data for analysis, see Appendix Figure 37. Unfortunately, the field data was determined to be invalid upon office analysis. It was therefore not included in this report.

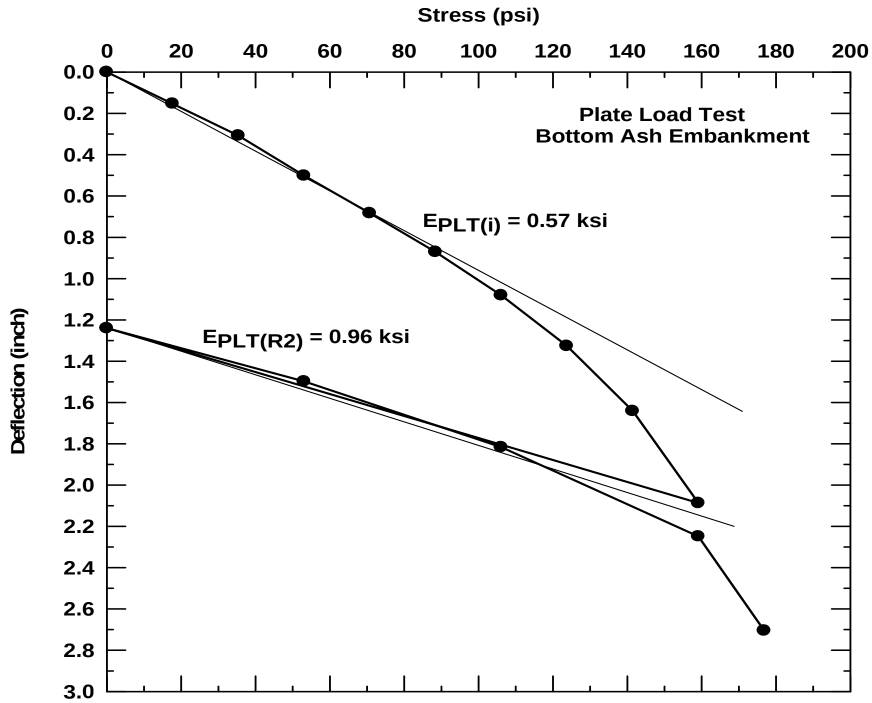

Figure 27
Plate load test results

An inspection was made of the embankment test section roughly two weeks after construction. The site experienced several rain events, including a large downpour on May 3, 2007. Water at the site caused erosion of the edge of the embankment in several locations, see Figure 28. This photograph indicates that the material is susceptible to erosion and needs lateral confinement and erosion protection in the likely form of a soil blanket.

Figure 28
Erosion of test section

CONCLUSIONS

Material and Classification

The material is black and is a residual material from the kiln coal burning process. The material roughly meets the gradation specification for non-plastic embankment material under Section 1003.09 (a). Even though the bottom ash is not sand, according to the USCS, the material classifies as a well-graded sand with silt, SW-SM, and as A-2-4 according to the AASHTO classification system.

The bottom ash is a relatively lightweight material weighing roughly 75 to 85 pcf, and could serve the Department as another source of lightweight material. The lightweight properties were not the main objective of this study, but may be a secondary benefit to the low-cost of this recycled material. The lightweight properties may be advantageous when settlement concerns arise.

Environmental Issues

The pH of the samples tested was acceptable at 9.2. The resistivity, however, was low and may cause corrosion issues, especially on metal pipes. This is a common concern regarding bottom ash and can be addressed by not using the material near metal pipes or simply avoiding metal pipes in the drainage design.

The Louisiana Department of Environmental Quality (DEQ) monitors the generation of the product through a permitted process. Any source generating the material should have approval from DEQ prior to approving their material for use in DOTD projects.

GeoGauge, LFWD, and Plate Load Tests

Compared to reference values for sand, the bottom ash results from the above devices/tests were weaker. The difference is most likely because the sand reference values were from a trench site, where there was confinement of the material. If bottom ash were placed in a similar confined situation, its values would likely be higher due to the additional confinement as evident by the CBR results. Therefore, its confinement is critical to the successful usage of the bottom ash in an embankment.

Dynamic Cone Penetrometer

The DCP appears to be the most appropriate tool for construction control and the evaluation of strength/stiffness of the bottom ash. The nuclear gauge also appears to be a valid tool to measure moisture content and dry density in the field. The loose surface of the material allowed the first few blows of the hammer to penetrate the material; however, as the DCP penetrated deeper into the embankment, the DCP results were more comparable to sand. This is due to the additional confinement and overburden of the upper layers on the lower layers of bottom ash. Typical DCP values on sand are about 10 mm/blow, which match closely with the bottom ash values for the lower lifts. These additional layers increase the weight and confinement of the bottom ash that results in improving stiffness at lower levels indicating that the material would benefit from confinement in the form of a cap.

Direct Shear Test and California Bearing Ratio

The angle of internal friction from the direct shear tests were both above 40°, which is similar to comparable values for sand. The soaked and un-soaked CBR results were in line with typical CBR values for sand and sandy soils (range from 5 to 40).

Erosion Potential

The material is granular and non-plastic in nature with no cohesion to hold the material together. It is therefore more likely to erode and scour under heavy rains and water sources. If the material is to be used in embankments, their slopes need protection against erosion through confinement with a soil blanket or geotextile material.

Moisture and Density

Standard and modified Proctor moisture density tests conducted on the bottom ash material in the LTRC soil laboratory are shown in Figure 4. The results of the standard Proctor indicate a wet peak and a dry peak. The modified Proctor shows a constant density with various moisture contents.

The field nuclear moisture density gauge results are shown atop the Proctor curves on Figure 15. The nuclear gauge is a common field construction control device. The study included the device as part of our matrix both as a control and as a possible field verification tool for the bottom ash material. Additional field moisture density measurements collected with the cubic foot box are also shown on Figure 15. Several trends can be seen this figure. The nuclear gauge results roughly follow a curve of the standard proctor. In addition, the box densities are inline and verify the nuclear moisture density results.

Table 6 summarizes all nuclear gauge readings collected from the field. If one analyzes the results, one will conclude that the majority of samples with dry densities less than 75 pcf also have moistures above 20 percent. Nuclear gauge readings on this table with dry densities less than 75 pcf been noted with star in the table. All but one result of the bottom ash moisture contents collected with the nuclear gauge is above 10 percent. This range of moistures from 10 to 20 percent contains the highest dry densities. It also roughly defines a lower limit of dry density of 75 pcf.

Placement, Compaction, Vibration, and Moisture

There does not appear to be a trend of increasing vibratory roller passes to increasing density. Moisture content appears to be the best correlation to dry density in the field. The results indicate that moisture values between 10 and 20 percent lead to higher dry densities in the field. Therefore, if placed at moisture contents in this range and compacted with a couple of passes of a vibratory roller, the material should reach above 75 pcf.

RECOMMENDATIONS

Based on the findings and conclusions of this limited evaluation, the following specifications have been drafted for review and implementation with the Department. The following draft specifications must be approved by the chief engineer prior to use. In addition, should bottom ash be allowed within department projects, detailed construction monitoring is recommended to verify the conclusions of this report and its limited scope.

Based on the findings of this study and the tests conducted, the material performs well, and more like sand, when placed in a confined condition. This study therefore recommends a 24 in. embankment cap on the bottom ash. In addition, due to the high potential for corrosion, the material should not be placed near metal structures, anchors, or objects. Department of Environmental Quality approval should be received prior to use in state highways.

DRAFT Construction Specifications for Bottom Ash Embankment

ITEM S-XXX, Bottom Ash Embankment
This item consists of building non-plastic embankments using bottom ash, as shown in the plans, in accordance with these special provisions and Section 203 of the *Standard Specifications*.

Section 203 of the 2006 *Standard Specifications* is amended as follows:

Section 203.09 Non plastic Embankment. Heading (e) is added as follows.

(e) Bottom Ash Embankment Construction: Water shall be added or other suitable means shall be taken to prevent dust results from the transporting and placing of dry material. The material shall conform to the following gradation limits or as directed:

Sieve Size	Percent Passing
1 ½ inch (37.5 mm)	**100**
No. 40 mesh sieve (0.42 mm)	**0 - 60**
No. 200 mesh sieve (0.074 mm)	**0 - 15**

The embankment material shall be placed in lifts not exceeding 12 inches (300 mm) in thickness (loose) after establishing a working table as directed. Each lift should be compacted to the dry weight density not being less than 75 lb/ft^3 and field moisture content between 10 and 20% moisture. Field density testing shall be in accordance with Subsection 203.07. The contractor shall furnish and place a plastic soil blanket complying with Subsection 203.10 except the minimum thickness of the soil blanket will be 24 inches (600 mm). Bottom ash shall not be placed within 24 inches of bottom of base course or within 10 feet of metal drainage structures.

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APPENDICES

Appendix A: Department of Environmental Quality Letter, November 5, 2001

BC2 Permits 43

State of Louisiana

Department of Environmental Quality

M.J. "MIKE" FOSTER, JR.
GOVERNOR

J. DALE GIVENS
SECRETARY

November 5, 2001

Mr. Gary Ellender
Manager, Environmental Affairs
Cajun Electric Power Cooperative, Inc.
10719 Airline Highway
Baton Rouge, LA 70816-4213

RE: Big Cajun II Power Plant
AI # 38867
GD-077-0583 / P-0108
Pointe Coupee Parish

Dear Mr. Ellender:

The Department is in receipt of Mr. Andrew J. Harrison Jr.' s letter dated September 26, 2001, on behalf of Big Cajun II Power Plant, requesting a letter of no objection to the handling practices and the marketing fly ash and bottom ash generated from the referenced facility.

As stated in your solid waste permit renewal application which is currently under technical review, you proposed to have an option to sell the fly ash directly from the silos or to store temporarily the material in the Fly Ash Basin for beneficial reuse. Also, you proposed to have another option to remove and sell for beneficial reuse the fly ash and bottom ash from the permitted surface impoundments when the demand for ash exceeds production.

Please be advised that since you have been exercising these options with the department's approval for many years, we have no objection to your proposals.

In addition, we concur with your understanding that according to LAC 33:VII.511.D.2.a, the referenced standard permit shall remain in effect until the administrative authority issues a final decision, since the reapplication of the permit was submitted before the expiration date of the standard permit.

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OFFICE OF ENVIRONMENTAL ASSESSMENT
P.O. BOX 82178 • BATON ROUGE, LOUISIANA 70884-2178 • TELEPHONE (225) 765-0355 • FAX (225) 765-0617
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Mr. Ellender
Page Two

Should you have any questions or comments regarding this matter, please contact Mr. Hoa Van Nguyen of the Technology Division at 225-765-0355 or Ms. Thea Johnson of the Permits Division at 225-765-0217.

Sincerely,

Bliss Higgins
Assistant Secretary

hvn

cc: Mr. Andrew J. Harrison Jr., Jones Walker L.L.P.

Appendix B: Test Section Photographs

Figure 29
Placement of material by front-end loader and haul trucks

Figure 30
Komatsu WA420, front-end loader used to move stockpiled bottom ash

Figure 31
Komatsu D31P, dozer used to spread the bottom ash lifts

Figure 32
Laser level used to measure lifts and lifts prior to compaction

Figure 33
Haul truck and water trucks driving on the lifts with minimal rutting

Figure 34
Before and after vibratory roller

Figure 35
Pressure sensor and wire installation

Figure 36
Plate load reaction vehicle and plate load setup

Figure 37
Data acquisition and test location after plate removal

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