The Use of Bottom Ash in the Design of Dams

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Keywords: Bottom Ash, Dams, Shear Strength, Unit Weight, Compressibility, Permeability, Grain-size

Abstract: The design of dams requires selecting materials that possess engineering properties that allow a structure to perform in a reliable and safe fashion while allowing their construction to be carried out within the economic and time constraints of a project. The selected materials need to exhibit: high shear strength, unit weights that limit the loading on the foundation soils, and compressibility characteristics that minimize total and differential settlement. Permeability and grain-size characteristics of the selected materials determine their location within the cross-section of a dam. Bottom ash, a by-product of burning coal at a power plant, is a material that exhibits high shear strength, low compressibility, and relatively low unit weight. These engineering properties make bottom ash an ideal material in the design and construction of dams. Bottom ash also exhibits a relatively high permeability and a grain-size distribution that allows the design engineer to use it in direct contact with impervious materials and/or toe drains and to meet well established filter and piping criteria. The work presented herein describes the engineering properties of the bottom ashes that led to their selection in the design of the dams that form Horse Ford Creek Fly Ash Reservoir in Kentucky, Muskingum River Plant Upper Reservoir in Ohio, and Tanners Creek Fly Ash Pond in Indiana. These facilities are currently under construction. The bottom ash has proved to be an economical material because it has demonstrated to have good engineering properties and to be available near the project location.

Introduction

Dams and Reservoirs serve to impound water or other materials that are transported to their final deposition by hydraulic means, such as fly ash at coal burning power plants, or coal fines at coal preparation plants. Therefore, the problem of designing a dam becomes twofold: design a structure strong enough to resist hydrostatic and other forces introduced upon it; and preventing the uncontrolled loss of water over, under, through, or around the structure. (1) Dams may be made of earth or masonry materials.

The design of earth dams requires selecting materials that exhibit high shear strength, unit weights that limit the loading on the foundation soils tolerable deformations, and compressibility characteristics that minimize total and differential settlement. Permeability and grain size characteristics of the selected materials determine their location within the cross-section of a dam. The shear strength and compressibility characteristics of clay soils commonly used in the core and cut off keys or earth dams have been well documented, i.e. Jurgenson (2). Selected materials for stability of the embankment have commonly consisted of rock and soils.

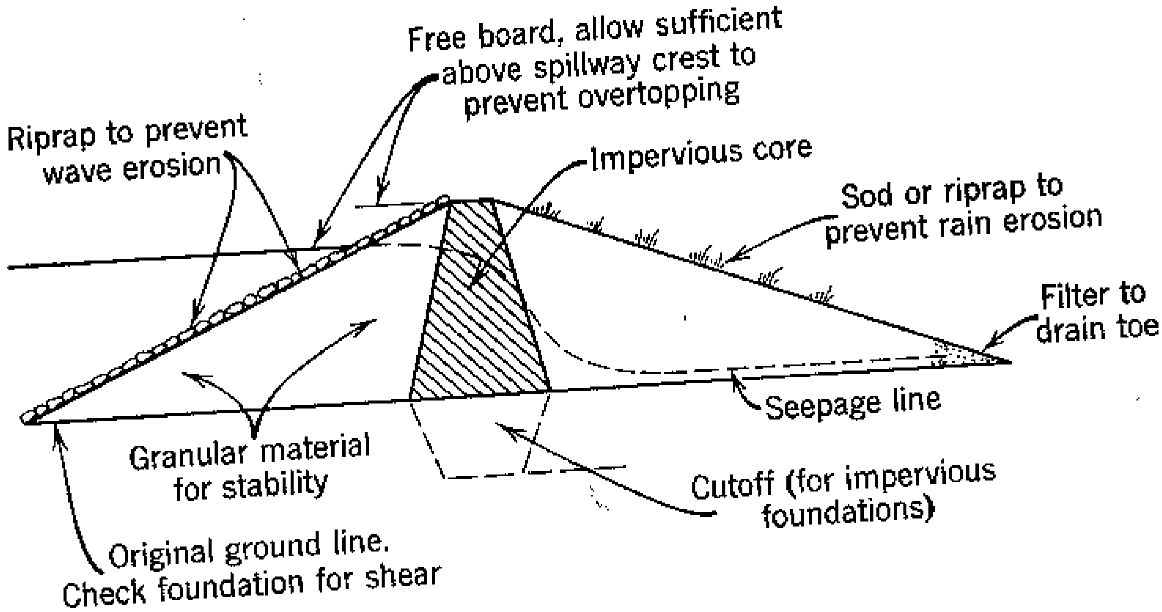

Figure 1. Principal elements of an earth dam. (1)

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In the case of the dams presented in this paper, the selected material for the stability of the embankment consisted of Bottom Ash.

Figure 2. Bottom Ash from the Muskingum River Power Plant

Bottom ash, a by-product of burning coal at a power plant, is a material that develops high shear strength and low compressibility at relatively low unit weights. Bottom ash also exhibits a relatively high permeability and a grain-size distribution that allows it to be used in direct contact behind the impervious core of dams or as in toe-drains.

In the work presented herein, the engineering properties of bottom ash will be expressed as follows:

- The shear strength will be expressed in a similar fashion as that of natural occurring granular soils such as sands and gravels.[3] The shear strength of bottom ash is therefore expressed as $\tau = \sigma_N \tan \varphi$.
- The compressibility will be expressed as the ratio of the applied normal stress, σ_N, to the associated strain, ε, as determined in laboratory test.
- The density as the values of the maximum and minimum dry density determined in the laboratory by means of the ASTM D4254 test methods.
- The permeability as the results of the flexible wall permeameter.
- Grain size distribution will be presented in graphical form and values of D_{85} and D_{15} of typical bottom ash gradations at each site used to illustrate the bottom ash applicability as filter material.

In the following sections, a review of the existing condition at each facility will be presented as well as the engineering properties of the bottom ash at each location that led to its selection as the material for the embankment.

Horseford Creek Fly Ash Reservoir Dam Raising

<u>Existing Conditions and Dam History (4)</u>

The Horseford Creek Dam (also known as the Big Sandy Dam) was constructed to create a pond for storing fly ash from the Big Sandy Plant. It is located just south of Blaine Creek near Louisa, Kentucky, approximately 1.3 miles from the plant.

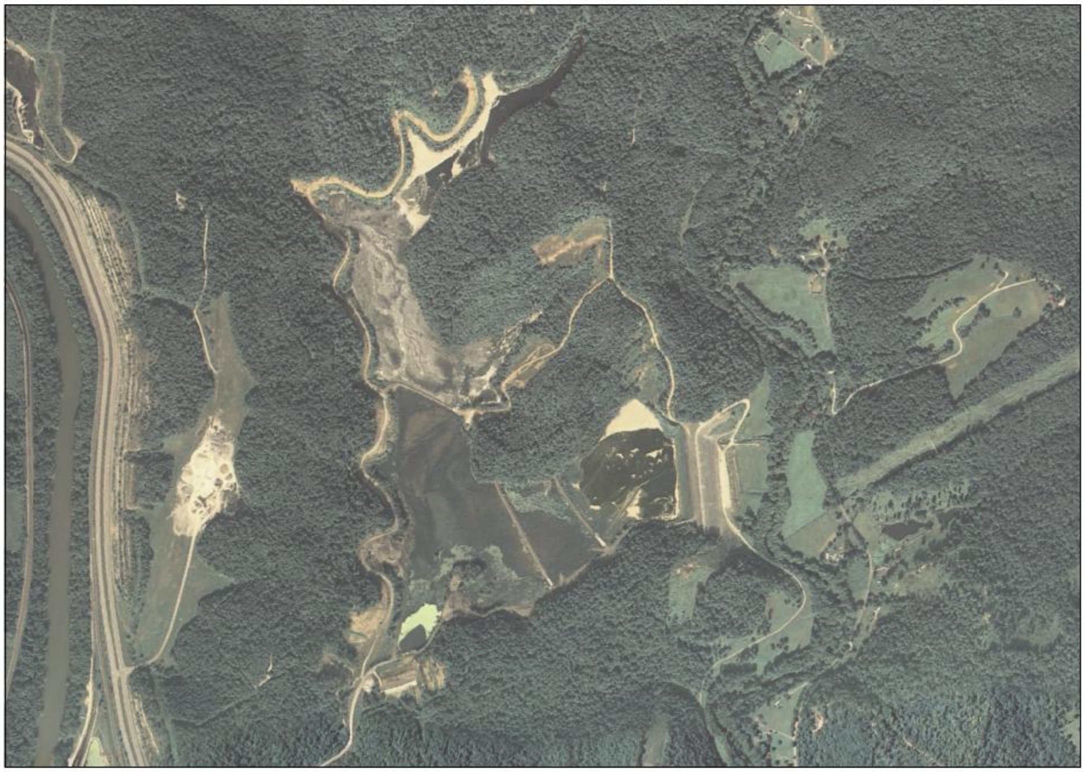


Figure 3. Horseford Creek Dam Raising

Construction of the dam was started late in 1968 and continued into early 1970. In January 1969, when the dam was 70 ft. high (crest el. 598+/-), a 500 ft. long central section of the embankment began spreading in both upstream and downstream directions, Figure 4.

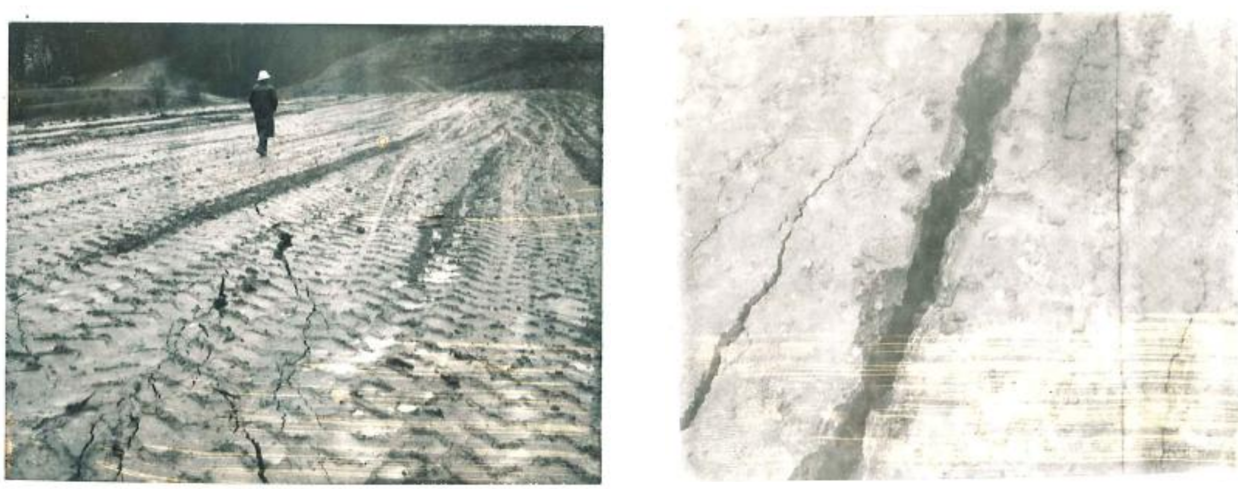


Figure 4. Tension Cracks on the Downstream Embankment of the Dam

The dam was inspected and it was recommended that rock fill berms be constructed without delay on both the upstream and downstream sides of the dam. Additional borings indicate that the deformation possibly was caused by a layer of soft clay beneath the dam and/or by some embankment materials being placed too wet.

By the end of February 1969, the rate of deformation in the central section had decrease substantially and construction was resumed. The embankment was raised by only 9.5 ft. (el. 607.5) before construction was again stopped because of excessive deformations.

In mid-May, the rate of deformation again decreased and construction was resumed. In an effort to control the deformation the operation was modified so that the dam was raised at a rate of only 1.5 feet per week. However, in mid-June deformations started again and construction was halted. The deformations were no longer limited to the central section but now included deformation in both the upstream and downstream berms.

By October 1969, the rate of deformation had subsided and it was possible to resume construction. However, prior to continuing construction of the dam, piezometers were installed in the embankment and foundation materials and both the upstream and downstream berms were enlarged. Construction of the dam was then continued at a very slow rate until the final design crest elevation of 625 was reached in mid-February 1970.

Settlements and horizontal deflections for the central upper portion of the embankment slopes during construction are as follows:

Settlement from Jan. 17 to Aug. 15, 1969:

DS Slope = 14 In.
US Slope = 16 In.

Horizontal Deflection from Jan. 30 to Oct. 6, 1969:

DS Slope = 22 In.
US Slope = 29 In.

Deformation records are not complete as the measurements were started after the initial deformations had occurred and other data were not maintained to the end of construction in January 1970. Thus, the total settlement during construction may have been as much as two feet and the maximum horizontal deflection, which was in upstream direction, may have been as much as three feet.

In April 1976, Casagrande Consultants initiated the site investigation for the second stage dam raising. The American Electric Power Service Corporation developed the designs necessary to raise the crest elevation of the dam to elevation 675. During the second stage construction of the main embankment, an area near the west abutment of the original dam sloughed.

Figure 5. Tension Cracks on an area near the west abutment of the original dam

The vegetation of the downstream slope was stripped immediately and a stabilizing berm (which later became part of the clay core) was constructed utilizing a 24-hour work schedule. The presence of this berm controlled the movement and no significant movement or excessive pore pressures have been recorded since that time.

The dam construction was completed in 1979 without additional delays. A description of the features of the dam subsequent to the completion of the second stage is presented in the following paragraphs.

The crest of the embankment after the second stage raising was approximately 800 foot long and 30 foot wide. The total height of the dam at the maximum section is approximately 135 feet, as measured from the crest of the embankment to the toe of the stabilizing berm. The main section of the embankment has an upstream slope of 1V:2H. The stabilizing berm on the upstream slope has a top width of about 70 feet, and a top elevation at approximate el. 635. The general slope of the downstream face is 1V:2H, but has been broken into several segments by an access road and the stabilizing berm. The stabilizing berm is approximately 190 ft. wide and its top elevation is el. 590. The dam was constructed with a clay core, a chimney drain and a drainage blanket beneath the downstream slope.

The outlet works consist of a reinforced concrete, drop-inlet type spillway located on the left abutment of the dam. The intake is an 85 foot high, vertical, decanting riser structure with concrete stop logs. The stop logs provide a mechanism to raise the overflow weir crest elevation concurrently with the rising (impounded) fly ash elevation. The riser consists of a double weir and operates using both weirs under all normal and flood conditions. In the unlikely event that a stop log should break, a slide gate can be operated to terminate flow through either bay of the riser. The slide gate will prevent fly ash from being discharged without affecting the function of the other cell.

The water discharged over the stoplogs flows through a 30 inch diameter pre-stressed concrete cylinder pipe. The conduit terminates in a riprap lined plunge pool and stilling basin. The emergency spillway, located in a saddle near the southeastern portion of the reservoir, consists of a 50 foot wide channel at el. 671.0.

Proposed Raising (4)

The State 3 Raising consists of: (1) raising the crest of the dam to elevation 711 feet, Figure 6 illustrates the Stage 3 raising of Horseford Creek Dam; (2) constructing a new saddle dam and emergency spillway. The raising of the main dam is being constructed by widening the downstream embankment of the dam over the 1969 downstream berm and adding a maximum of 15 feet of material per year across the entire dam until the proposed elevation is reached. A maximum of 5 feet of material may be placed in a given construction period. A minimum of 3 months should elapse between consecutive construction periods. Bottom ash is being used for the embankment of the dam and clay is used for the core material. (4)

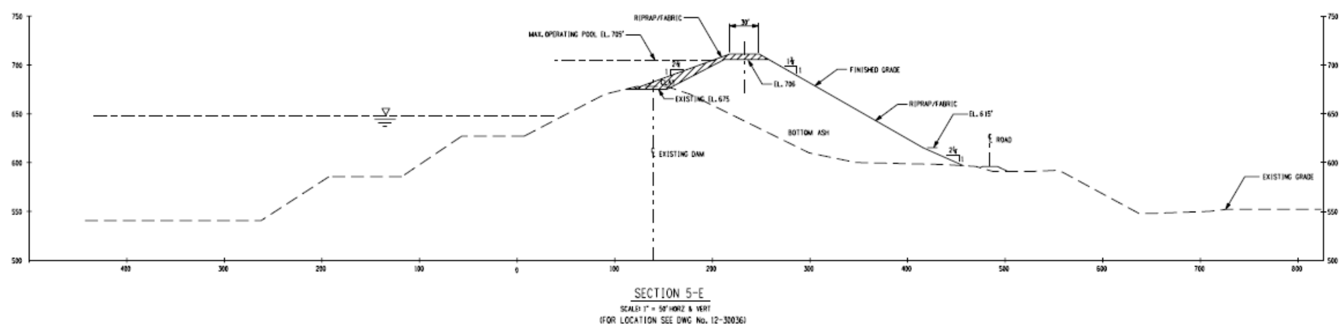


Figure 6. Raising of Horseford Creek Dam

Bottom Ash Engineering Properties

The bottom ash for the raising of Horseford Creek Dam was produced at the Big Sandy Plant.

Shear Strength

The shear strength of the bottom ash for this project was determined in the laboratory by means of triaxial compression consolidated drain tests (CD). All samples were prepared by compacting bottom ash to a relative density of 70% as determined in the laboratory in accordance with ASTM D4254 method. A summary of the shear strength and the associated normal stress is presented in graphical form in Figure 7.

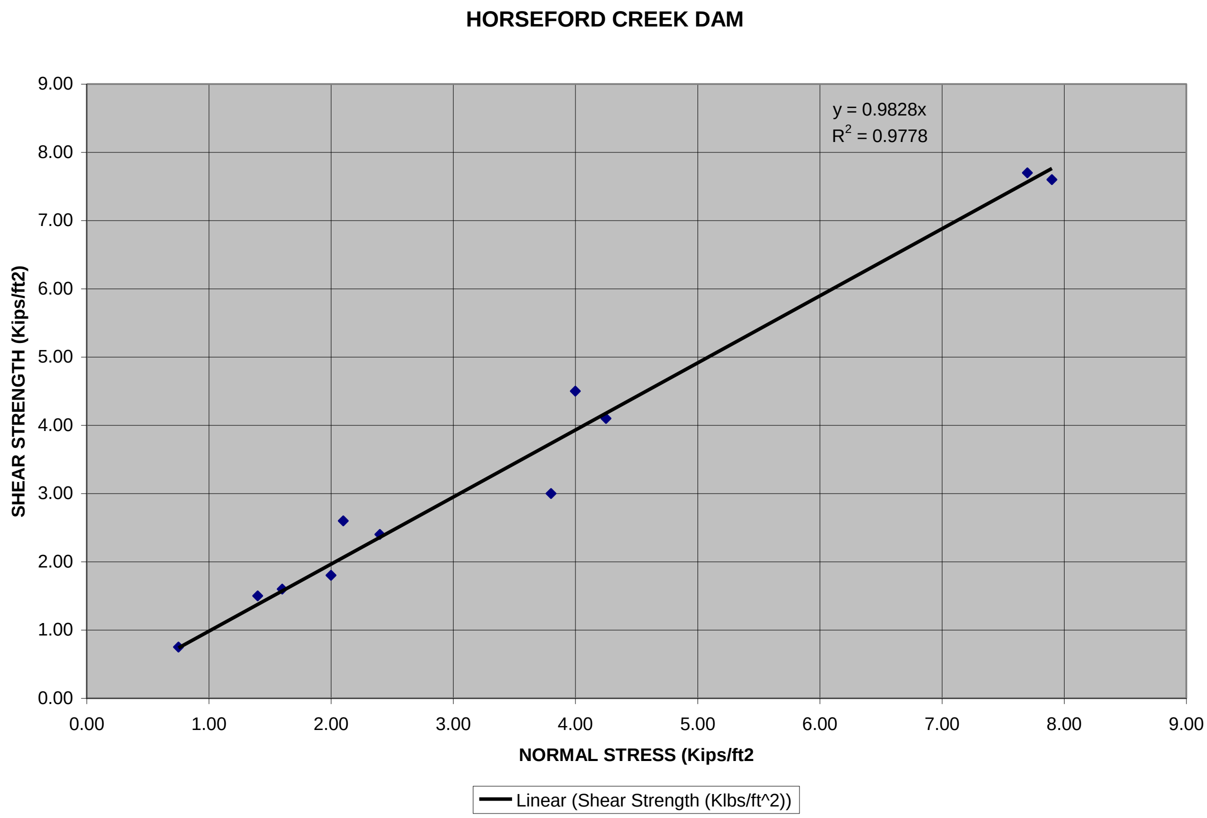


Figure 7. Shear Strength of Big Sandy Plant's Bottom Ash

The line that best fit the test data is also shown on Figure 7. On this basis the shear strength of the bottom ash used at this project may be in the range of $\tau = \sigma_N \tan 38^o$ and $\tau = \sigma_N \tan 51^o$; with the best-fit line providing a value of $\tau = \sigma_N \tan 44^o$.

Compressibility

The compressibility of the bottom ash was evaluated based on the results of the CD tests. The tests were conducted at different level of confining pressure ranging from 580 pounds per square foot (psf) to 2,300 psf. On this basis the ratio (σ_N / ε) of the applied normal stress, σ_N, to the associated strain, ε, range from 13,000,000 psf to 16,400,000 psf. (4)

Permeability

The permeability of the bottom ash from the Big Sandy Plant used in this project was determined in the laboratory. The results show that the coefficient of permeability decreases with increasing percentage of fines. With 2% of particles passing the No. 200 sieve, the coefficient of permeability, k, is about 1.7 x 10^{-1} cm/sec, whereas, with 20% passing the No. 200 sieve, the coefficient of permeability, k, is 1.9 x 10^{-3} cm/sec. (4)

Density

Maximum and minimum dry density determinations were performed in accordance with the ASTM D4254 method. The results of the density tests are shown in Figure 8.

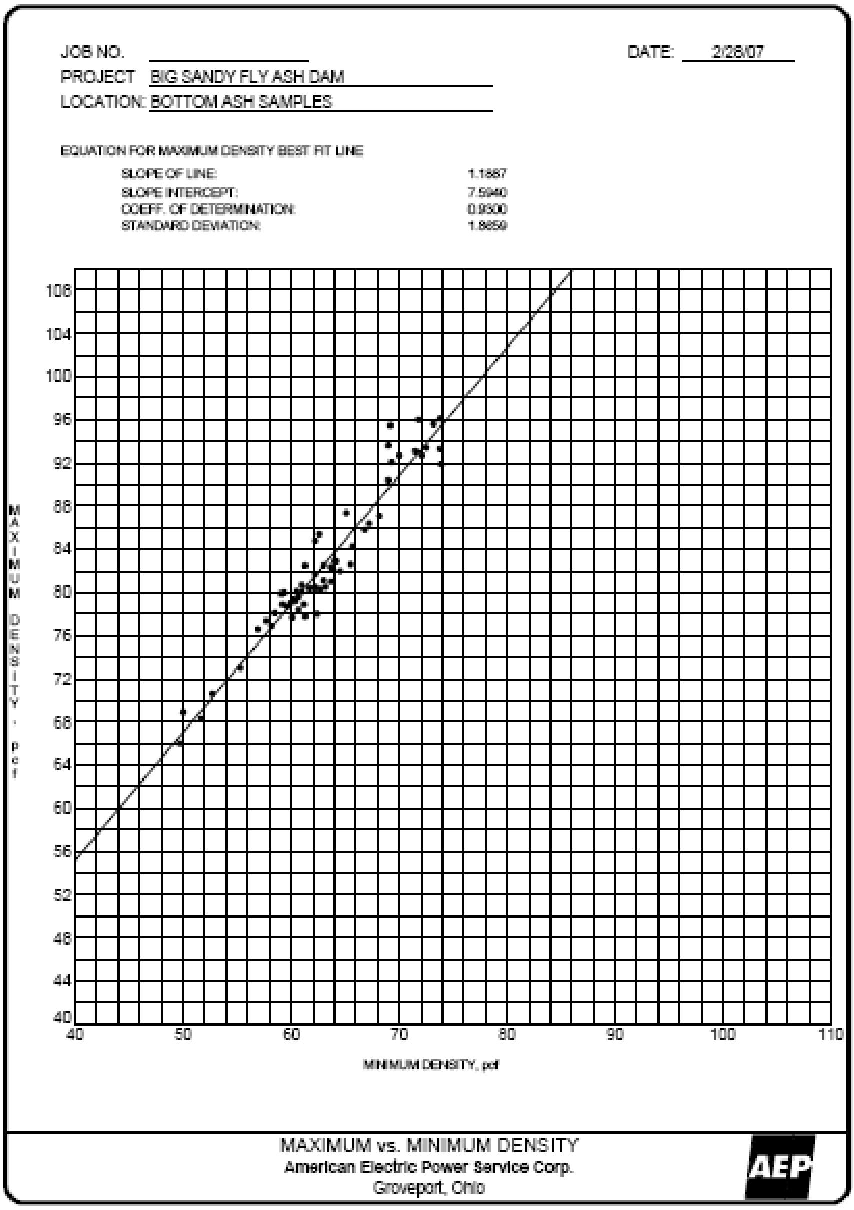
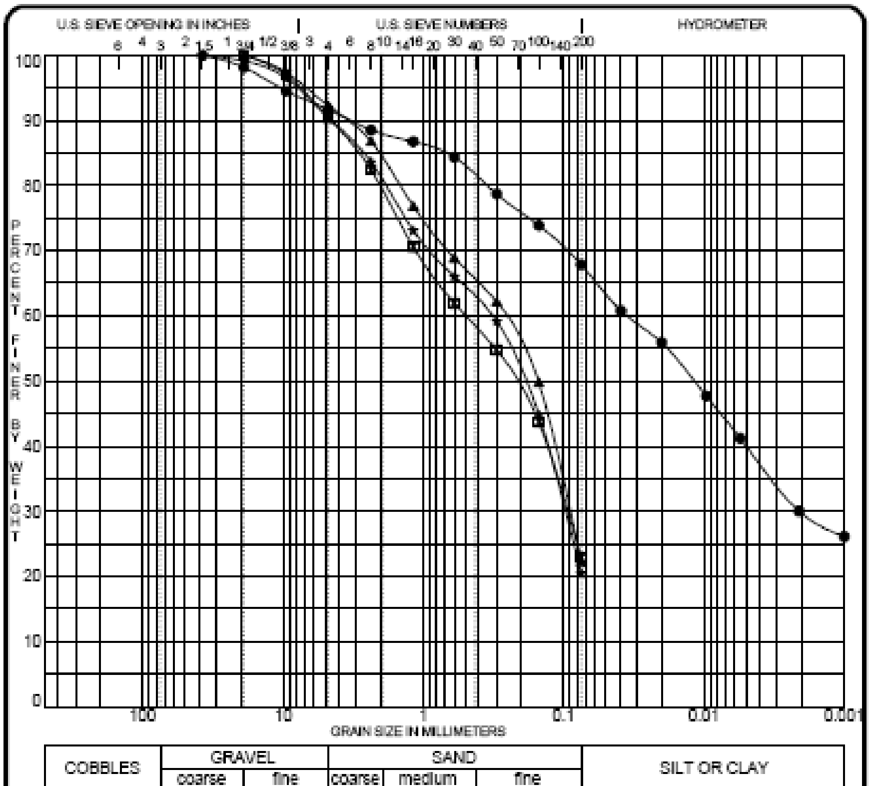


Figure 8. Range of Maximum and Minimum Dry Densities of Big Sandy Plant's Bottom Ash.

The Minimum dry density of the Big Sandy bottom ash ranges from 50 pounds per cubic foot (pcf) to 70 pcf with the Maximum density ranging from 66 pcf to 96 pcf respectively. Average specific gravity of the bottom ash used in this project has been 2.32.

Grain Size Distribution

Many of the problems associated with the use of selected materials immediately behind the impervious zones of an earth-dam stem from the need to satisfy the apparently conflicting requirements of piping and permeability. To comply with the piping requirements in this project, it was decided to verify the relation between the pore holes of the impervious (clay) materials and of the filter material (bottom ash). Typical grain-size distribution analyses of the bottom ash and of the clay for this project are presented in Figure 9.



Specimen Identification		Classification	MC%	LL	PL	PI	Sp.Gr.
● BSTP-3	0.5	CLAY TEST PIT - 0.5'-5.0'		45	22	23	2.74
⊠ S-8635	0.0	BOTTOM ASH DENSITY TEST #1 - AUG 2001					
▲ S-8636	0.0	BOTTOM ASH DENSITY TEST #2 - AUG 2001					
★ S-8637	0.0	BOTTOM ASH DENSITY TEST #3 - AUG 2001					

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Fines	%<.002
● BSTP-3	0.5	37.500	0.035	0.002		8.3	23.8	67.9	29.7
⊠ S-8635	0.0	19.000	0.437	0.095		9.6	67.6	22.9	
▲ S-8636	0.0	19.000	0.266	0.091		7.8	70.0	22.2	
★ S-8637	0.0	37.500	0.325	0.098		9.6	69.9	20.5	

PROJECT BIG SANDY FLY ASH DAM -   JOB NO.   DATE 2/28/07

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Figure 9. Typical Range of Big Sandy Plant's Bottom Ash Gradation.

On the basis of this gradations compliance with piping and permeability requirements were investigated.

Piping criteria: a) the 15% size (D_{15f}) of the filter material is approximately 0.07 millimeters (mm).

The 85% size (D_{85s}) of the protected soil (clay) is 0.6 millimeters. The ratio of D_{15} of a filter to D_{85} of a soil, called the piping ratio, is:

$D_{15f} / D_{85s} = 0.07 / 0.6 = 1.7 < 4$

b) The 15% size (D_{15}) of a filter material should also be at least four or five times the 15% size (D_{15}) of the protected soil.

$D_{15f} / D_{15s} = 0.07 / 0.001 = 70 > 4$

Permeability requirements: it is intended to determine the relation between the permeability of the materials. :

k (filter)/ k (clay core) = $10^{-3}/ 10^{-7} = 10000 \gg 40$

It is therefore concluded that the bottom ash satisfies all requirements to perform as a filter in this project.

Muskingum River Upper Reservoir Dam Raising

Existing Conditions and Dam History (5)

The Upper Reservoir was constructed to create a pond for storing fly ash from the Muskingum River Plant. The reservoir is formed by two high dams, Mill Stone and No Name, a wing dam next to the main dams, and a free board dam across from the main dams as shown on Figure 10. The reservoir is located in Waterford Township, Washington County, Ohio, approximately one mile south from the plant.

Figure 10. Muskingum River Upper Reservoir

The dam was constructed in 1975 to a final settle crest elevation of 825 feet for a total maximum height of 140 feet above the stripped ground surface of No-Name Creek, and approximately 100 feet above Mill Stone Creek.

The cross-section of the dams consists of an upstream shell of boiler slag, a central core of impervious silty clay, a downstream transition zone of bottom ash, and a downstream shell of boiler slag. An impervious backfilled core trench was excavated into rock for the full length of the main embankment. The overburden soils beneath the downstream shell were excavated to the bedrock surface and backfilled with boiler slag. The upstream shell foundation treatment consisted of stripping the topsoil and other organic materials and placing a 5 to 7 feet layer of clay to minimized seepage migration through the rock foundation.

An access embankment to serve as both a project access road and a support for the fly ash slurry lines was constructed of boiler slag over the wing dam. The embankment raised the grade from elevation 810 feet to elevation 825 feet.

The outlet works for the reservoir (principal spillway), is a drop-inlet decanting structure, known as the upper reservoir spillway, located in a saddle to the west of the wing dike. The spillway combined with reservoir surcharge storage has been deemed adequate to pass safely the flood produced by the design storm and therefore, a separate emergency spillway was not provided.

The 30-foot wide crest of the main dam was cambered to allow for expected post-construction settlement of the dam. Slope protection consisted of 1.5 feet of riprap on 1 foot of bedding on the exposed portion of the upstream slope, and similar riprap and bedding treatment on a portion of the downstream slope of the dam near the toe.

A 1500-foot long wing dike (maximum height approximately 30 feet was constructed from the west abutment of the main dam to a low ridge to provide reservoir closure. The wing dike cross-section geometry is similar to that of the main dam, with the exception that a 5-foot deep cutoff trench is provided instead of a core trench that would extend to the rock foundation.

Three low freeboard dikes were constructed in saddles around the reservoir to provide the required freeboard for flood storage and wave action. The freeboard dikes are constructed of impervious material with a crest of 20 feet. Slope protection consists of topsoil and seeding on the upstream and downstream faces of the dikes and boiler slag on the crest of the dike.

Since the completion of the dam construction, the abutments of both Mill Stone Creek and No-Name Creek Dams have exhibited significant amounts of seepage, in some cases inducing instability of the shallow overburden soils.

<u>Proposed Raising (5)</u>

The 842 feet Raising consists of: (1) raising the crest of all dam to elevation 842 feet, (2) extending the existing spillway and, 3) constructing a new emergency spillway. The raising of the main dams is being constructed by widening the downstream embankment of the dam between the 1975 downstream toes and the seepage collection ponds. All known abutment seepage is being directed to the new down stream shell of the dams and controlled through their internal drainage features. Bottom ash is being used for the embankment of all the dams and clay is used for their core material (5). Figure 11 illustrates a typical cross-section of the 842 foot dam raising.

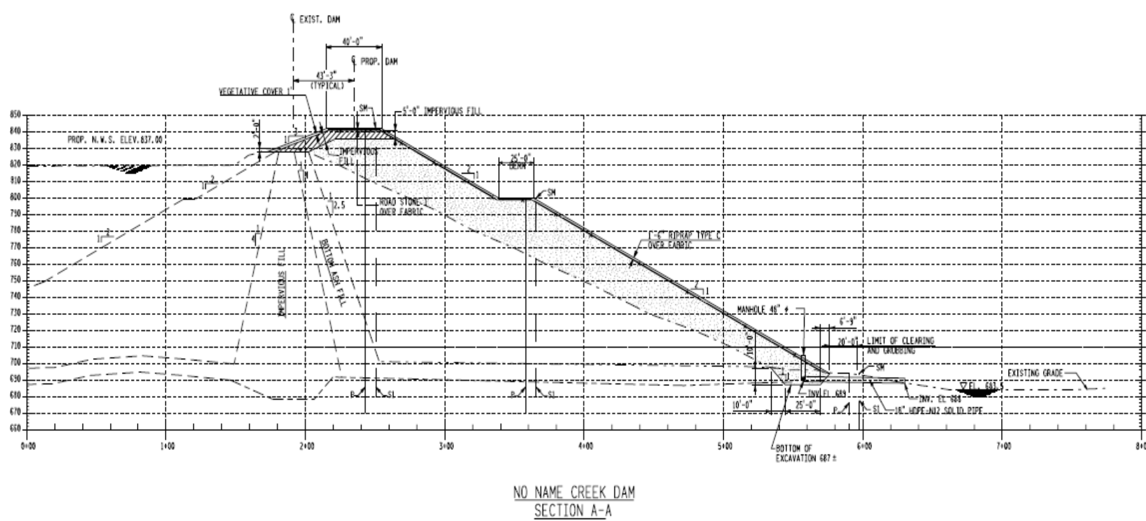


Figure 11. Raising of the Upper Reservoir Dams - Typical Cross-section.

Bottom Ash Engineering Properties

The bottom ash for the Raising of the Upper Reservoir Dams was produced at the Muskingum River Plant.

Shear Strength

The shear strength of the bottom ash for this project was determined in the laboratory by means of tri-axial consolidated drain test. All samples were prepared by compacting bottom ash to a relative density of 70% as determined in the laboratory in accordance with ASTM D4254 method. A summary of the shear strength and the associated normal stress is presented in graphical form in Figure 12.

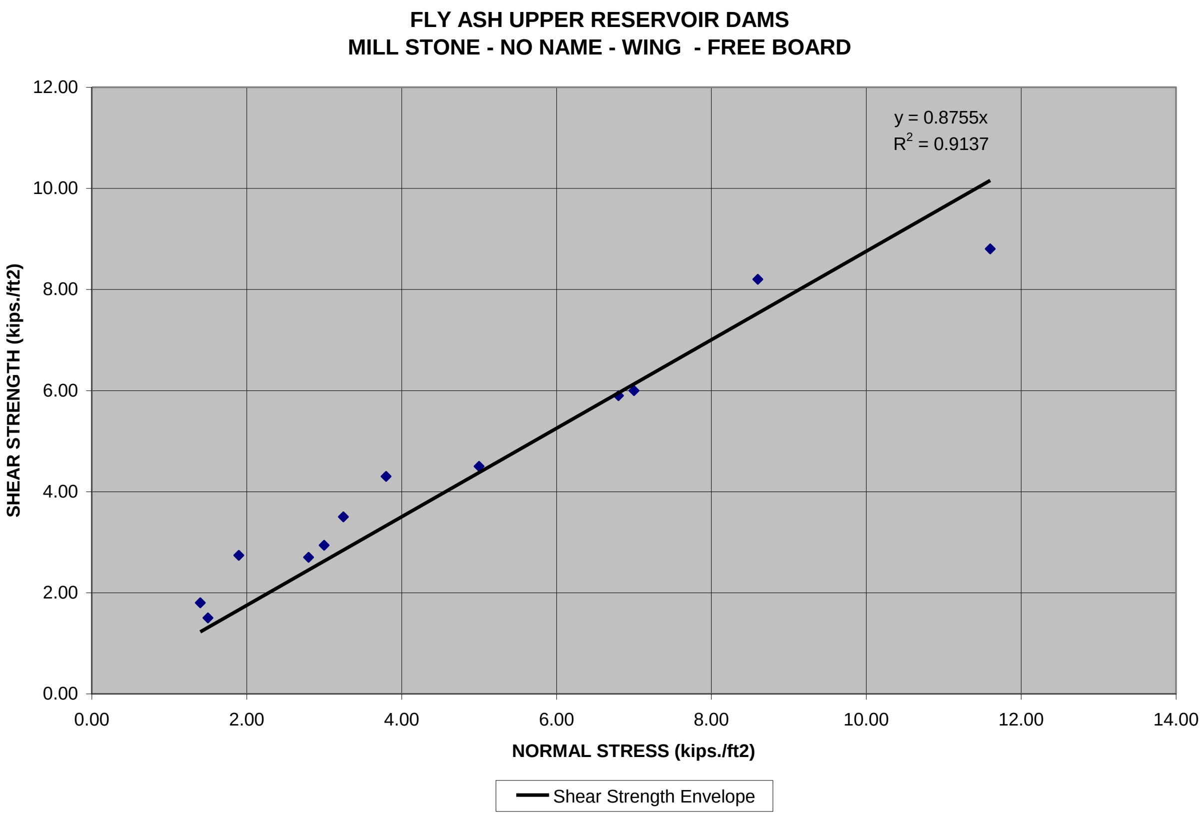


Figure 12. Shear Strength of Muskingum River Plant's Bottom Ash.

The line that best fit the test data is also shown in Figure 12. On this basis the shear strength of the bottom ash used at this project may be in the range of $\tau = \sigma_N \tan 37^o$ and $\tau = \sigma_N \tan 55^o$; with the best-fit line providing a value of $\tau = \sigma_N \tan 41^o$.

Compressibility

The compressibility of the bottom ash was evaluated in the laboratory by conducting odometer tests. The tests were conducted by applying incremental loads up to a load of

16 tons per square foot (tsf). On this basis, the ratio (σ_N / ε) of the applied normal stress, σ_N, to the associated strain, ε, ranges from 17,000,000 psf to 21,100,000 psf. (5)

Permeability

The permeability of the bottom ash from the Muskingum River Plant used in this project was determined in the laboratory. The results show that the coefficient of permeability decreases with increasing percentage of fines. With 10 % of particles passing the No. 200 sieve, the coefficient of permeability, k, is about 1.8×10^{-2} cm/sec, whereas, with 25% passing the No. 200 sieve, the coefficient of permeability, k, is 1.3×10^{-3} cm/sec. (5)

Density

Maximum and minimum density tests were performed in accordance with the ASTM D4254 method. The results of the density tests are shown in Figure 13.

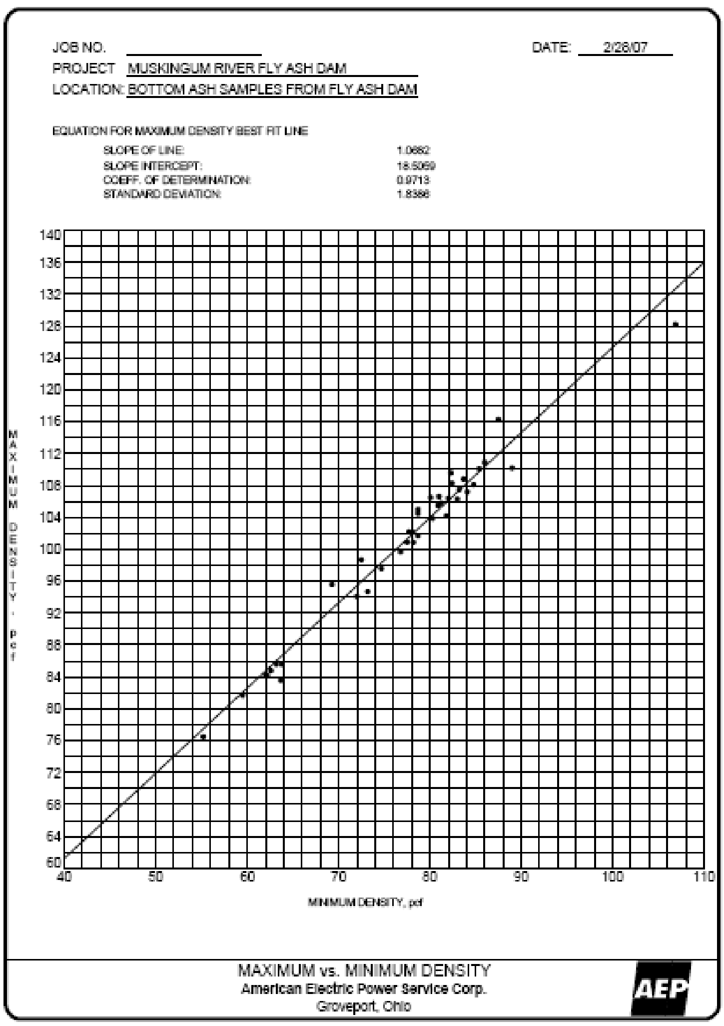
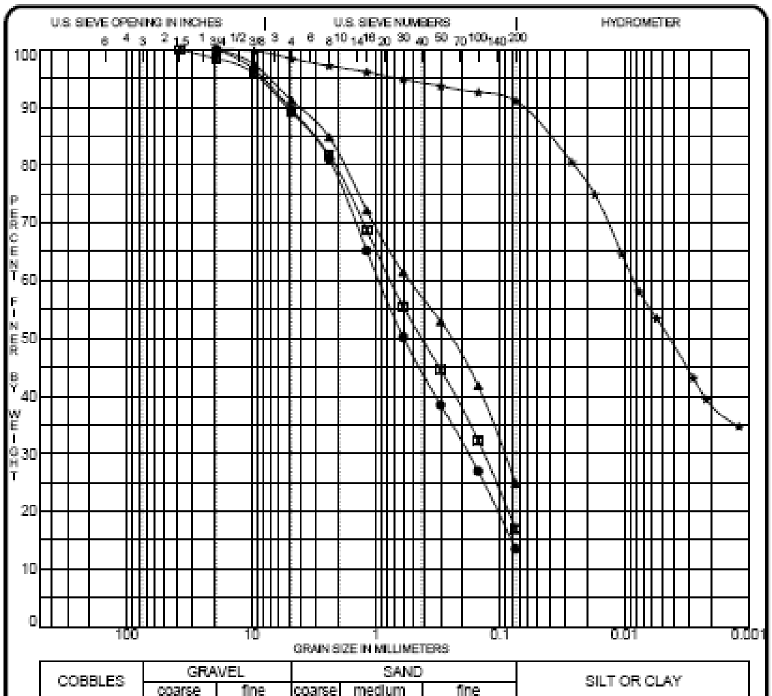


Figure 13. Range of Maximum and Minimum Dry Densities of Muskingum River Plant's Bottom Ash

The Minimum dry density of the Muskingum River bottom ash ranges from 55 pounds per cubic foot (pcf) to 107 pcf with the Maximum density ranging from 76 pcf to 128 pcf respectively. Average specific gravity of the bottom ash used in this project is 2.5.

Grain Size Distribution

Many of the problems associated with the use of selected materials immediately behind the impervious zones of an earth-dam stem from the need to satisfy the apparently conflicting requirements of piping and permeability. To comply with the piping requirements in this project, it was decided to verify the relation between the pore holes of the impervious (clay) materials and of the filter material (bottom ash). Grain-size distribution analyses of the bottom ash are presented in Figure 14.



	Specimen Identification		Classification	MC%	LL	PL	PI	Sp.Gr.	
●	S-S354	0.0	RANDOM SAMPLE COLLECTED DURING CONST.						
⊠	S-S406	0.0	RANDOM BA SAMPLED DURING CONST.						
▲	S-S407	0.0	RANDOM BA SAMPLED DURING CONST.						
★	TP-01	1.0	CLAY BUCKET SAMPLE - 1'-16'	22.9	42	21	21	2.75	

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Fines	%<.002
●	S-S354	0.0	19.000	0.934	0.180		10.4	76.1	13.5	
⊠	S-S406	0.0	37.500	0.756	0.135		10.8	72.2	17.0	
▲	S-S407	0.0	19.000	0.536	0.093		8.8	66.3	24.9	
★	TP-01	1.0	19.000	0.008			1.5	7.3	91.2	38.7

PROJECT MUSKINGUM RIVER FLY ASH DAM - BOTTOM ASH SAMPLES FROM FLY ASH DAM
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Figure 14. Typical Range of Muskingum River Plant’s Bottom Ash Gradation.

On the basis of these gradations compliance with piping and permeability requirements were investigated.

Piping criteria: a) the 15% size (D_{15f}) of the filter material is approximately 0.08 millimeters (mm).

The 85% size (D_{85s}) of the protected soil (clay) is 0.04 millimeters. The ratio of D_{15} of a filter to D_{85} of a soil, called the piping ratio, is:

$D_{15f} / D_{85s} = 0.08 / 0.04 = 2 < 4$

b) The 15% size (D_{15f}) of a filter material should also be at least four or five times the 15% size (D_{15s}) of the protected soil.

$D_{15f} / D_{15s} = 0.08 / 0.001 = 80 > 4$

Permeability requirements; it is intended to determine the relation between the permeability of the materials. :

$k\ (\text{filter}) / k\ (\text{clay core}) = 10^{-3} / 10^{-7} = 10000 >> 40$

It is therefore concluded that the bottom ash satisfies all requirements to perform as a filter in this project.

Tanners Creek Pond 518 feet Dam Raising

Existing Conditions and Dam History (6)

The State I Ash Pond is located along the Ohio River near the community of Aurora, Indiana. The pond serves as a fly ash storage area and consists of four earth dikes surrounding approximately 80 acres at a normal pool elevation of 490 feet, Figure 15.

Prior to any construction, the elevation of the original ground surface of the site varied between elevation 468 feet and elevation 474 feet. The materials used to construct the dikes were excavated from within the existing pond area. The bottom of pond ranges from elevation 452 feet to elevation 462 feet, averaging a design elevation of 458 feet. Top of dike is an elevation 494 feet, with the exception of the dike along the rail road, which rises to elevation 499 feet at each end to facilitate drainage for the re-circulating water piping.

The outside slopes of the existing (or Casagrande) embankment is approximately 2.5:1 (H:V). The inside slopes of Dikes are 2:1 from the bottom of pond to an intermediate upstream bench at elevation 487 feet. The remainder of the inside slopes are 3:1.

During construction, dike embankment fill consisted of a predominately clay and silty clay material. Silty sand to sand with gravel was exposed within the southern portion of the pond's bottom. Some of this granular material was mixed with the embankment clay. Precautions were taken to use as little granular material as possible. Where granular material was exposed within the pond, based upon the elevation of exposure, either at least two feet was undercut and backfilled with clay or at least two feet of clay was placed over the granular soil. This is referred to as the clay blanket. A 20-mil PVC liner was placed over the entire interior of the pond, below top of the dike. Additionally, the tops of the dikes and outside slopes had vegetation established to prevent erosion.

Figure 15. Fly Ash Storage pond – Elevation 518' Dam Raising

Proposed Raising (6)

The proposed raising consists of building three offset upstream dikes and a splitter dike to form a main storage pond at a dike final crest elevation of 518 feet and a permanent clear water pond. Figure16 illustrates the proposed concept.

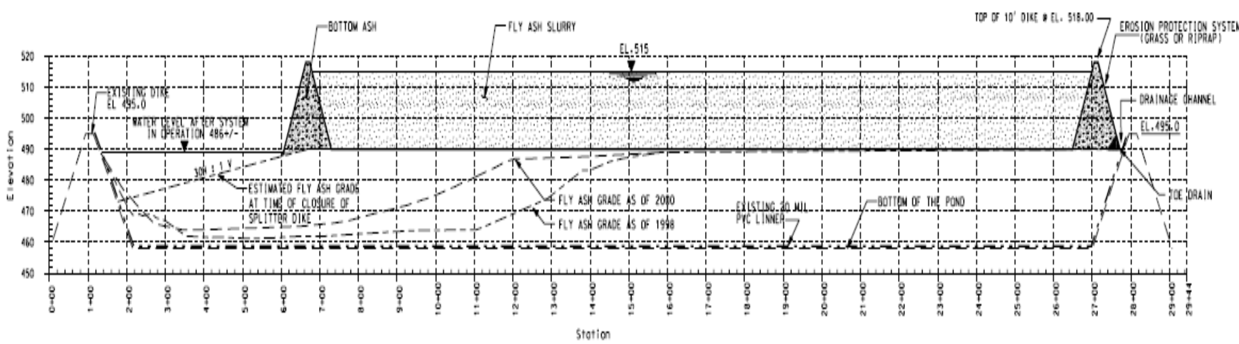


Figure16. Tanners Creek 518 feet Dam raising

The dikes are being constructed over a time period of 6 years depending on the need for fly ash storage and on the availability of bottom ash, the main construction material. The initial phase of the raising was completed when the proposed dikes reached a crest elevation of 497 feet. The remaining of the raising will consist of subsequent phases constructed as the fly ash accumulates, while maintaining a three-foot freeboard from the level of the water in the storage pond to the crest of the dikes.

The dikes are being constructed using bottom ash. The proposed embankment will have a downstream and upstream grade of 3 horizontal to 1 vertical and a 20-foot wide final crest. The new dikes have a toe-drain in the down-stream side of the embankment that allows the release of seepage into a perimeter open channel, or, as in the case of the splitter dike, into the Clearwater pond. The perimeter channel is formed by the PVC-lined upstream slope of the existing facility and the downstream slope of the raised facility. The channel was protected using riprap over geo-textile. Toe drain materials were selected to comply with design requirements for granular filters and drains of embankment dams. Above the riprap covered sections of the down stream slopes, the exterior face of the embankment is covered with soil and a vegetative cover to minimize erosion of the slopes.

The foundation material for the proposed dikes was the already deposited fly ash. Geogrids placed at the base of the embankment are used to maintain the integrity of the dikes while undergoing settlement.

Hydrologic and hydraulic requirements of the proposed facility are met by providing two operating spillways consisting of inclined raiser structures in the main storage pond, and an emergency overflow in the clear water pond. The raisers are capable of controlling the design inflows individually during normal operation of the pond, as well as during the occurrence of the design storm. Their operation will be based upon the need to direct sedimentation patterns within the pond. The raisers were made of coated steel and connected to a high-density polyethylene pipe through the base of the embankment. These materials will provide the flexibility necessary to undergo the anticipated settlement while minimizing the risk of hindering performance. The emergency spillway will be a conventional concrete structure sized to pass the design flow safely

To monitor construction and performance of the proposed raising, it is intended to install slope inclinometers, and surface deformation monuments on the dikes of the existing facility. In addition, settlement plates along the axis of the embankments will be placed at the base of the proposed dikes at several locations including one adjacent to the location of each operating spillway pipe (6).

<u>Bottom Ash Engineering Properties</u>

The bottom ash for the raising of the Tanners Creek Pond Dams was produced at the Tanners Creek Plant.

Shear Strength

The shear strength of the bottom ash for this project was determined in the laboratory by means of tri-axial consolidated drain test. All samples were prepared by compacting bottom ash to a relative density of 70% as determined in the laboratory in accordance with ASTM D4254 method. A summary of the shear strength and the associated normal stress is presented in graphical form in Figure 17.

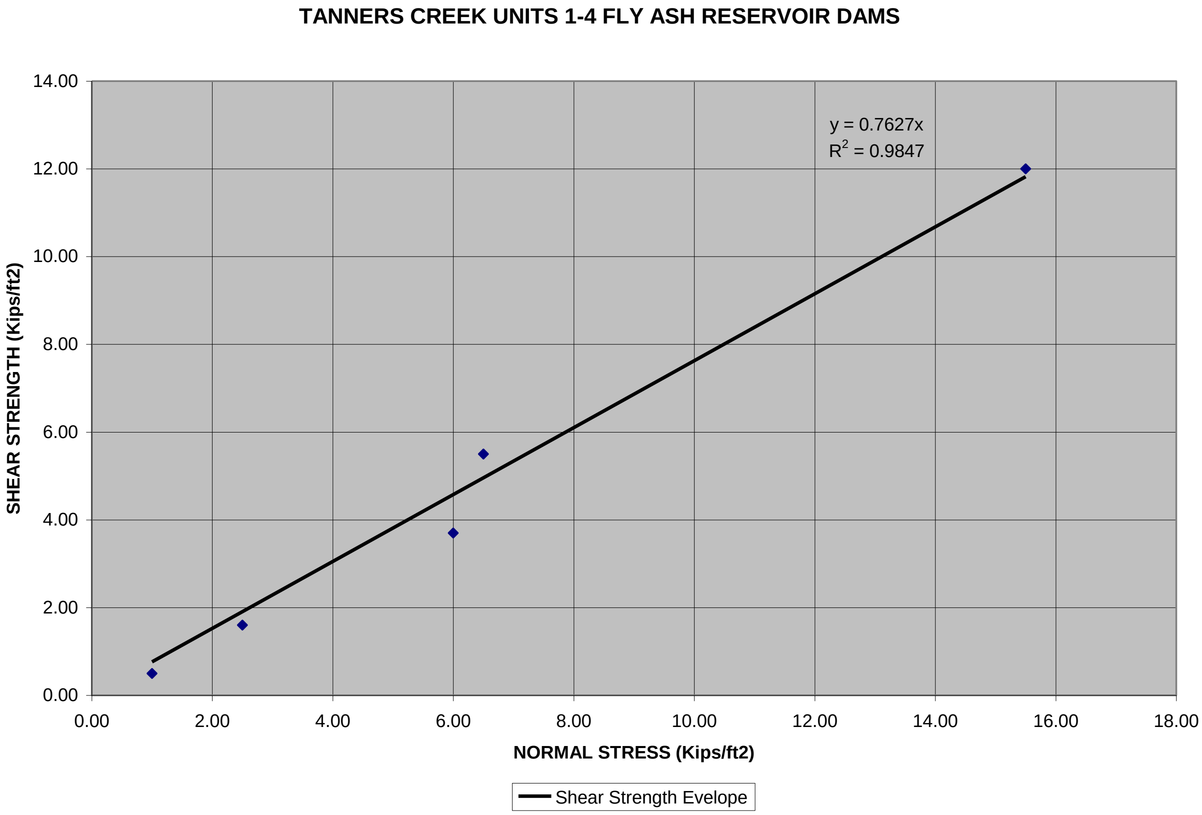


Figure 17. Shear Strength of Tanners Creek Plant's Bottom Ash

The line that best fit the test data is also shown in Figure 16. On this basis the shear strength of the bottom ash used at this project may be in the range of $\tau = \sigma_N \tan 26^o$ and $\tau = \sigma_N \tan 40^o$; with the best-fit line providing a value of $\tau = \sigma_N \tan 37^o$.

Compressibility

The compressibility of the bottom ash was evaluated in the laboratory based on the results of the CD tests. The tests were conducted by applying different confining pressures. On this basis, (σ_N / ε), the ratio of the applied normal stress, σ_N, to the associated strain, ε, ranges from 28,000,000 psf to 28,600,000 psf (6).

Permeability

The permeability of the bottom ash from the Tanners Creek Plant used in this project was determined in the laboratory. The results show that the coefficient of permeability decreases with increasing percentage of fines. With 5 % of particles passing the No. 200 sieve, the coefficient of permeability, k, is about 1.7×10^{-1} cm/sec, whereas, with

21% passing the No. 200 sieve, the coefficient of permeability, k, is 1.4×10^{-3} cm/sec (6).

Density

Maximum and minimum density tests were performed in accordance with the ASTM D4254 method. The results of the density tests are shown in Figure 18.

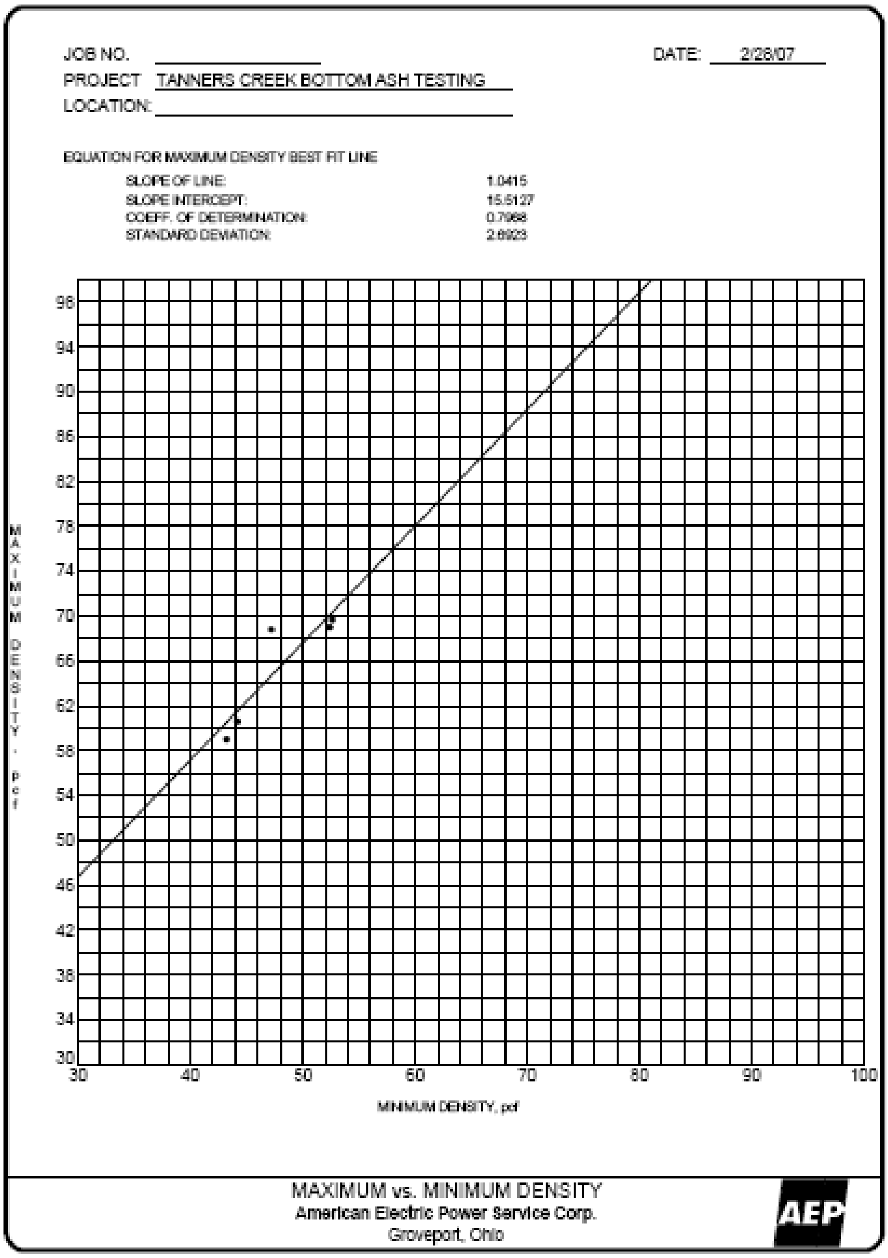
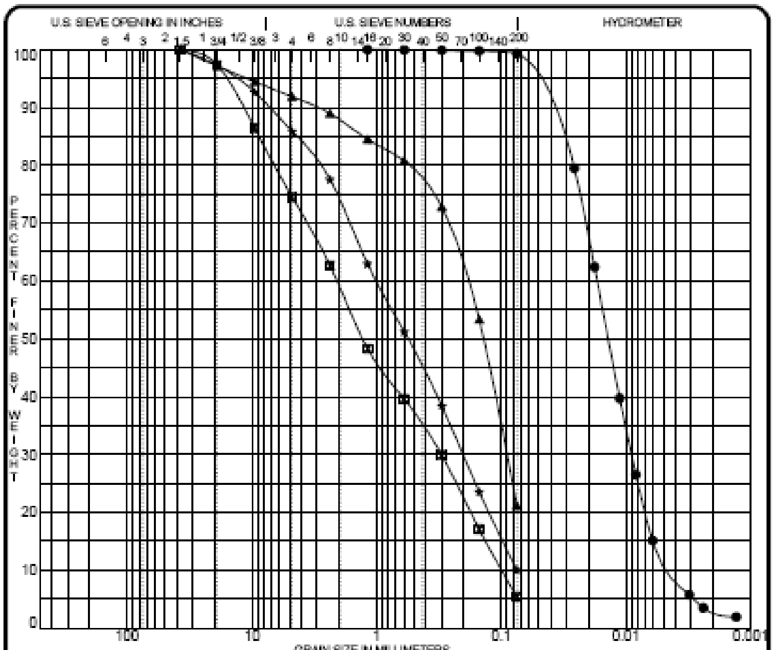


Figure 18. Range of Maximum and Minimum Dry Densities of Tanners Creek Plant's Bottom Ash.

The Minimum dry density of the Tanners Creek bottom ash ranges from 43 pounds per cubic foot (pcf) to 52 pcf with the Maximum density ranging from 59 pcf to 70 pcf respectively. Specific gravity of the bottom ash used in this project has ranged between 2.1 and 2.3

Grain Size Distribution

Many of the problems associated with the use of selected materials immediately behind the impervious zones of an earth-dam stem from the need to satisfy the apparently conflicting requirements of piping and permeability. To comply with the piping requirements in this project, it was decided to verify the relation between the pore holes of the fly ash on the upstream of the embankment and of the filter material (bottom ash). Grain-size distribution analyses of the bottom ash are presented in Figure 19.



Specimen Identification			Classification	MC%	LL	PL	PI	Sp.Gr.
●	FA-105	5.8	BROWN FLY ASH					2.84
⊠	S-8344	0.0	BOTTOM ASH SAMPLES 1-5 - SAMPLED 2/9/00		NP	NP	NP	
▲	S-8351	0.0	UNITS 1,2,3 BOTTOM ASH - SAMPLED 3-23-00		NP	NP	NP	2.24
★	S-9014	0.0	UNITS 1,2,3 BOTTOM ASH					2.12

Specimen Identification			D100	D60	D30	D10	%Gravel	%Sand	%Fines	%<.002
●	FA-105	5.8	1.180	0.017	0.009	0.004	0.0	0.7	99.3	3.0
⊠	S-8344	0.0	37.500	2.075	0.302	0.099	25.5	69.1	5.4	
▲	S-8351	0.0	37.500	0.190	0.091		8.1	70.7	21.1	
★	S-9014	0.0	37.500	0.994	0.203		14.1	75.8	10.0	

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Figure 19. Typical Range of Tanners Creek Plant’s Bottom Ash Gradation.

On the basis of these gradations compliance with piping and permeability requirements were investigated.

Piping criteria; a) the 15% size (D_{15f}) of the filter material is approximately 0.1 millimeters (mm).

The 85% size (D_{85s}) of the protected soil (fly ash) is 0.03 millimeters. The ratio of D_{15} of a filter to D_{85} of a soil, called the piping ratio, is:

$D_{15} / D_{85} = 0.1 / 0.03 = 3.33 < 4$

b) The 15% size (D_{15f}) of a filter material should also be at least four or five times the 15% size (D_{15s}) of the protected soil.

$D_{15f} / D_{15s} = 0.1 / 0.005 = 20 > 4$

Permeability requirements; it is intended to determine the relation between the permeability of the materials. :

k (filter)/ k (fly ash) = $10^{-3} / 10^{-5} = 100 > 40$

It is therefore concluded that the bottom ash will satisfy all requirements to perform as a filter in this project.

Conclusions

Bottom ash produced at the Big Sandy, Muskingum River and Tanners Creek Plants was selected as the material to be used in the embankment for the raising of the dams that form their respective fly ash reservoirs because it offered the following advantages:

- Its high shear strength allowed the use of steep grades on the downstream face of the dam, thus minimizing the volume of material used.
- Its relative low density allowed the raising of the dams to be placed on marginal foundation conditions.
- Its permeability and grain-size allowed its use immediately behind the impervious materials without the need for special filtering layers.
- Its availability near the place of use made it to be the most economical of materials offering similar technical advantages.

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