IN-PLACE SOLIDIFICATION OF COAL TAILINGS FOR EXPRESSWAY SUBGRADE[1]

N. Catherine Bazán-Arias,.[2]; Stanley R. Michalski, Phillip E. Glogowski, and Frank Howard

Abstract. The Mon-Fayette Expressway is one of the largest highway construction projects undertaken in PA in recent years. A 400-foot long segment with ingress and egress ramps was scheduled for construction over an active 10-acre coal tailings (fine coal refuse) disposal impoundment in Washington County, PA. The coal tailings are deposited by a slurry pipeline, are not traversable, and are over 40 feet thick in the central pond portions. The initial approved Expressway plans included construction of a temporary dike, separating the active slurry pond from the highway right-of-way, followed by complete removal of the tailings upstream of the dike. The remaining void would be raised to highway grade with a structural earth and rock fill followed by removal of the temporary dike. A dam would be constructed on the highway embankment slope to isolate the highway and its supporting embankment from the tailings pond.

Howard Concrete Pumping Company, Inc. and GAI Consultants, Inc. proposed an engineering value, cost saving, novel approach to solidify the tailings in-place providing a stable foundation for construction of the highway embankment and the dam. This approach eliminates the temporary dike and off site disposal of the tailings. Key advantages included lower cost and rapid implementation. In January 2000, following an intensive research and development program, the plan was approved by the concerned parties. Work began in June 2000.

Procedures were developed for both shallow and deep mixing that result in a stable mixture of tailings and fly ash/cement grout. A large backhoe equipped with a custom-designed long-reach dipper stick and hydraulically driven mixing device performed shallow mixing. Deep mixing was conducted with a custom-designed three-auger mix panel supported by a Manitowoc crane. Approximately 320,000 cubic yards of coal tailings were stabilized. The project was successfully completed in March 2001 and Expressway construction remained on schedule.

Key words: fine coal refuse, shallow mixing, deep mixing, fly ash, grout, slurry, Mon-Fayette Expressway

---

[1] Paper presented at the 2004 National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Mine Drainage Task Force, April 18-24, 2004. Published by ASMR, 3134 Montavesta Road., Lexington, KY 40502.

[2] N. Catherine Bazán-Arias, Ph.D., is a Staff Engineer-in-Training; Stanley R. Michalski, P.G., is a Senior Staff Geologist, and Phillip E. Glogowski, P.E., is an Engineering Manager, GAI Consultants, Inc., 570 Beatty Road, Monroeville, PA 15146. Frank Howard is President, Howard Concrete Pumping Company, Inc., 701 Millers Run Road, Cuddy, PA 15031.
Proceedings America Society of Mining and Reclamation, 2004 pp 111- 125
DOI: 10.21000/JASMR04010111
https://doi.org/10.21000/JASMR04010111

Introduction

A section over 1,000 feet long of the Mon-Fayette Expressway (MFX) was to be constructed over an active fine coal refuse (FCR) slurry pond, in Washington County, Pennsylvania. Construction included isolating the highway right-of-way from the slurry pond by constructing a temporary dewatering dike and removing the FCR upstream of the dike. The remaining void would then be filled with a structural fill to the highway grade. Uncertainties associated with the plan included: 1) the method for constructing the in-pond separation dike, 2) the dike removal following construction of the highway embankment, 3) the construction of a dam between the highway embankment and the slurry pond, and 4) the tight construction schedule.

In late 1999, Howard Concrete Pumping Company, Inc. (HCP) and GAI Consultants, Inc. (GAI) proposed an alternative technique for: 1) eliminating the construction and preclude the removal of the temporary dewatering dike, 2) avoiding the removal and disposal of the FCR within the expressway embankment footprint, 3) reducing the construction cost of building over the slurry pond and 4) keeping the project on schedule. The objective of the proposed method was to solidify the FCR in-place to obtain a suitable sub-grade for construction of both the expressway embankment and the dam between the expressway and the slurry pond. A cement-fly ash grout/slurry, employing shallow and deep soil mixing was proposed to solidify the FCR. A laboratory program was initiated to determine the feasibility of stabilizing the FCR. Early test data was promising and led to propose a plan for insitu solidification. The concept was eventually accepted and contractual arrangements made to fast track the project.

In June 2000, work began to solidify the in-place FCR in an approximately 10-acre portion of the coal tailings impoundment (Fig. 1). The area treated had to comply with the requirements for a stable foundation for a dam and section 52F2 of the MFX embankment. That is, the strength parameters of the sub-grade generated through in-place solidification had to be equal to or better than those provided by conventional earth fill materials. Quality control and safety procedures had to be strictly followed.

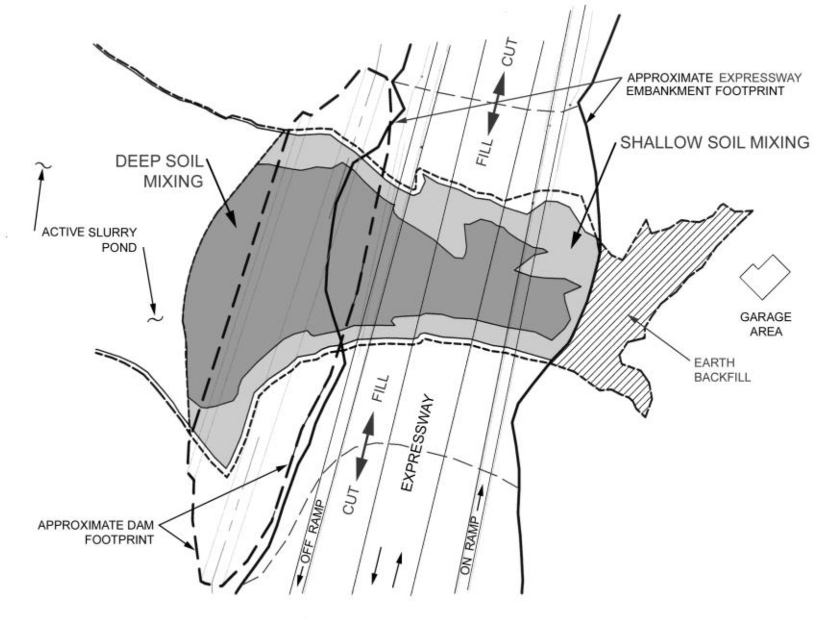

Figure 1. Plan view of project area.

Grout Mix Design

The final laboratory dry grout mix design consisted of Portland cement and Type F fly ash. The blend was selected after combining an engineering review and analysis of the laboratory test results with the economic suitability of the mix. The proportions of as-received components made up one cubic yard of grout mix.

The grout mix was monitored through unconfined compressive strength (UCS) testing, which was performed on the 7-day and 28-day basis for all grout mixes. The earliest curing time in which UCS testing was performed for equipment to operate on the treated material was 5 days. The acceptance criteria was a 100 psi or greater 28-day UCS as determined by American Society for Testing and Materials (ASTM) D 2166 tests conducted on the solidified FCR.

The GAI laboratory consolidated drained shear strength results for the mixture indicated that the eight-day shear strength envelope for solidified FCR exceeded the envelopes previously used for slope stability analyses.

Solidification Process Implementation

Fig. 2 highlights the key work at the site: shallow mixing, deep mixing, grout mix batch plant location, FCR slurry pond, and stabilized surface.

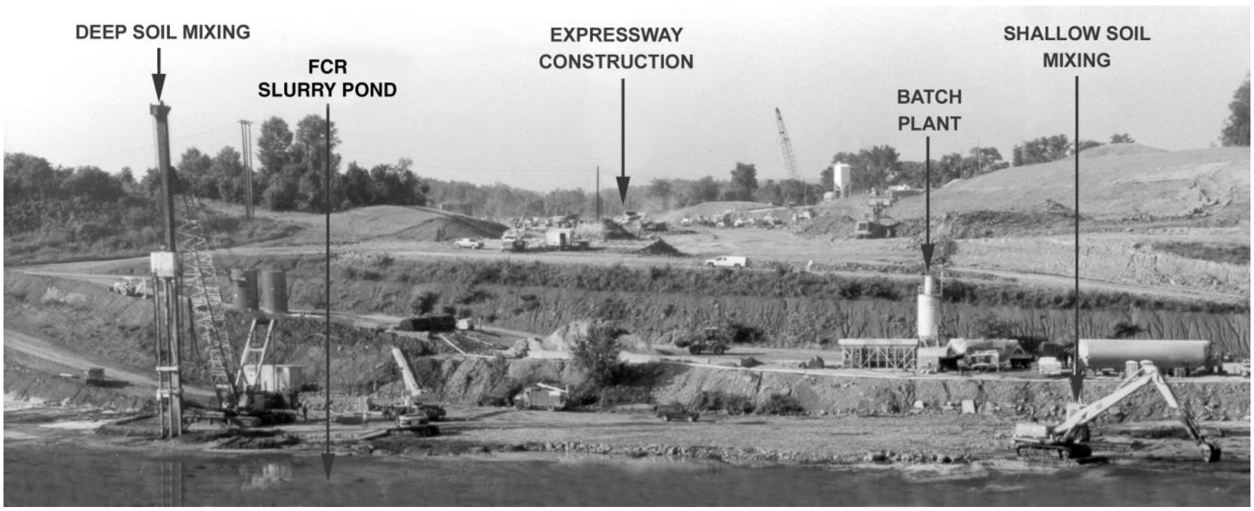

Figure 2. View of the project work area.

In-place mixing took place by working from the edges of the slurry pond and progressing inward working over increasingly deeper FCR. Only during the initial stages of the solidification work was the equipment working from natural ground. A stable platform of solidified FCR to work from was created as the solidification progressed. Prior to the solidification of the blended materials, the uppermost layer was graded to provide a relatively flat working surface once solidified. Crane mats were used during deep mixing operations. Mixing took place below the slurry pond pool elevation and proceeded row-by-row over the length of available surface area. The solidified FCR raised the finished surface above the initial starting elevation as a result of the addition of the grout mix. Since the surface was raised more over the deeper portions of the FCR, a positive slope on the solidified FCR was maintained to drain to the existing slurry pond to prevent water and tailings from encroaching on the completed work area. This required partial placement of the highway embankment fill over the completed work area.

The mixing plan to solidify the FCR in the slurry pond consisted of two phases: Phase 1 was performed from the slurry pond bank where FCR was mixed using a long stick backhoe equipped with a special bucket (shallow mixing). Phase 2 was conducted with deep soil mixing equipment utilizing auger paddles supported by a crane.

The grout mix preparation plant consisted of a volumetric grout mixing plant, grout agitator, positive displacement grout pumps, and flow meters. Flow meters were calibrated at the start of the project and periodically to insure the accurate delivery of the grout mix components. The cement and fly ash were stored on-site in bulk containers and stockpiles. The grout mix was produced at a rate sufficient to supply the shallow and deep mixing operations, and samples were taken and tested to verify the use of correct quantities of materials.

The grout mix was pumped from the preparation plant to the shallow or deep mixing location with positive displacement pumps through four-inch and three-inch diameter pipelines. As specified by Quality Control and Quality Assurance (QC/QA) procedures, the grout mix slurry was monitored continuously to insure that the correct quantity of grout mix was delivered to the FCR, and samples of the treated FCR were taken and tested to verify that the design strength was being met.

The sampler for the deep mixed treated FCR consisted of an I-beam fitted with a plate and a trap door at one end of the plate, forming an open box between the beam, the plate and the trap door. When the beam was lowered to the depth of the desired sample, the treated material flowed through the beam and plate. Then, the beam was raised, reversing direction, and the trap door closed trapping material for sampling. The material was poured from the sampler into a five-gallon bucket and immediately transported to the laboratory.

Phase 1 – Shallow Mixing

In-place mixing was performed starting from the edge of the slurry pond and progressing into the pond, working over increasing depths of solidified FCR. Shallow soil mixing was performed only along the slurry pond edge within the proposed embankment footprint (Figure 1). The shallow mixing began at the western edge of the pond, and was intended to form a stable platform of solidified FCR to operate the deep mixing equipment.

Cement-fly ash shallow soil mixing was performed using a large backhoe (Caterpillar 245 excavator) with a long reach dipper stick and hydraulic driven dynamic mixing head device attached at the end of the dipper stick (Figure 3). Shallow soil mixing for depths of FCR of 10 feet or less was performed as a batch mix in a dimensioned cell of FCR established by conventional surveying practices (Figure 4). The cell size varied based on irregularities of the slurry pond, reach of the backhoe and depth of the FCR. The cell dimension extending into the pond was governed by a maximum depth of 10 feet of FCR or to the maximum reach of the backhoe, whichever occurred first. The volume of FCR within the cell was determined and the required quantity of grout mix was calculated and added into the active cell via the blending and mixing bucket. Upon completion, an adjacent cell was delineated and the process repeated.

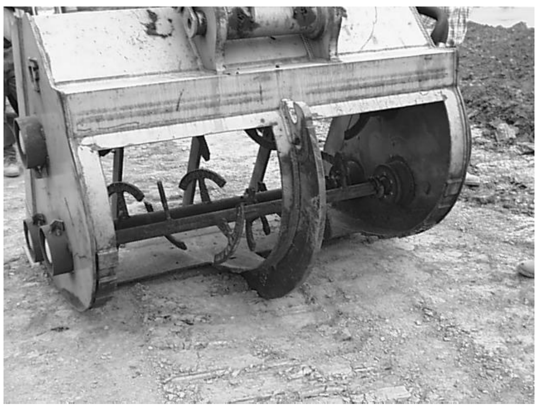

Figure 3. Shallow soil mixing bucket.

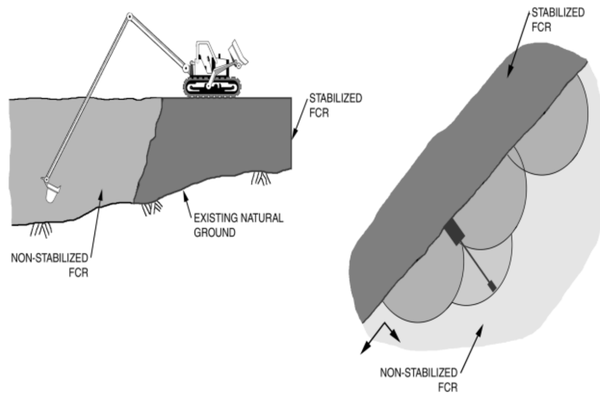

Figure 4. Shallow soil mixing.

The vertical elevation was monitored with a backhoe-mounted computer and bucket level controller normally used in the trenching industry. The operator monitored the quantity of grout delivered to the mixing head attachment on the backhoe using backhoe-mounted direct read-out flow meters. Mixing was accomplished by injecting the grout mix into a custom backhoe bucket equipped with grout injection nozzles and three (3) rotating augers mounted in the bucket (Figure 3). The mixing action of dragging the bucket through FCR provided a uniform blending of the grout mix with the FCR. Shallow soil mixing solidified an estimated 100 percent of the FCR in the 0 to 10-foot shallow mixing depth zone.

Phase 2 – Deep Mixing

In-place deep soil mixing was performed from the working platform utilizing a crane (Fig. 5 and 6). In-place mixing layout and estimated depth for each stroke was predetermined

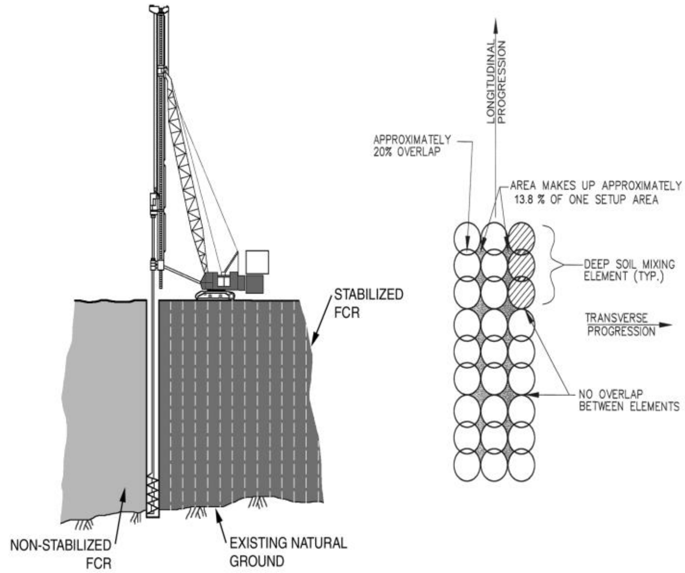

Figure 5. Deep soil mixing augers. Figure 6. Deep soil mixing procedure.

from available mapping information. The base machine operator recorded the depth and grout pumping rate for each stroke. The number of batches delivered for each stroke also was recorded to measure the volume of grout mix used. The grout mix was pumped through the auger shafts and injected from the tip of the two outside auger shafts. The augers consist of both auger flight and mixing paddle sections which broke up the FCR and blended it with the grout mix to produce a homogeneous mass. The mixing action of the augers blended, circulated and kneaded the FCR over the length of the column while mixing it in-place with the grout mix.

One stroke was defined as one pass down and up while injecting slurry with the triple-axis augers. A stroke length was as much as 42 feet (plus or minus) in depth. The auger diameter was 5 feet and the augers were on 3.33-foot centers, creating an overlap. HCP had on site sufficient deep mixing tools to reach to a depth of 60 feet. The work pattern consisted of twin, overlapped columns for each stroke. Each stroke encompasses an area in plan of about 50.3 square feet, including overlap between mixing shafts, and defines one element in a row (Fig. 6).

The proposed rows and elements were located using stakes and conventional survey methods. Based on the lines prepared by the surveyor, field personnel marked the offset locations of each element. A guide line was then used to locate the mixing tool at each element location. Movement of the base machine established preliminary alignment of the mixing head or augers. Locations of the operation were verified with a line transit.

Based on the properties of the FCR, a downward penetration provided adequate mixing. The grout mix injection rate per vertical foot of depth was adjusted to meet the requirements of the mix design. An optimal penetration rate was determined after initial QC/QA tests were evaluated. Deep soil mixing was performed from the existing ground or a working platform of solidified FCR. The penetration rate was set on the controls in the crane operator’s cab. All necessary adjustments were recorded and dated along with the start time, bottom time and completion time of each element.

The electric motor and mixing system had two speeds. The low speed was used at the beginning of each stroke to assure accuracy and control, and also when obstructions or difficult mixing conditions were encountered. The high speed was used for soil mixing during penetration and withdrawal. All adjustments to the RPM and penetration rate were monitored and changes were made to the injection rate of the grout mix in accordance with the mix design.

Penetration into material more resistant than the FCR (natural ground) was determined by the base machine operator. Advancement diminished as the mixing tools passed through the FCR and into native soil. This was accompanied by a sharp increase in amperage as the mixing tools penetrated into material other than FCR and a slow down of penetration rate. The stroke length was determined in advance and if the increase in amperage coincided with the anticipated depth of the stroke, it was considered that the bottom of the FCR had been encountered. No significant penetration into native soil was conducted. The existing FCR surface at the location of each element was determined by the depth of the element.

During the withdrawal of the augers the motor was reversed to achieve additional blending of the grout mix with the FCR. Higher rotational speed was used during withdrawal.

The grout slurry injection rate per vertical foot of element was performed in accordance with the requirements of the design mix. The design quantity of slurry for the length of the stroke was injected during the penetration and bottom mixing. The volume of grout mix injected for each stroke was monitored, verified by calculation and recorded on the Daily Quality Control Report

(DQCR). A copy of the DQCR was provided to the Owner's field inspector with the daily report.

Adjacent deep mixing elements did not overlap and there was un-solidified material between the individual columns. In plan layout, this resulted in approximately 86.2 percent of solidified FCR within any given area of deep soil mixing (Fig. 6). In practice, the solidified columns may slump slightly and could squeeze any untreated material.

The average production rate was about 500 cubic yards per rig-shift. On average, 20 strokes per rig-shift were completed under optimal working conditions. Where mixing was shallowest, it was also the least efficient, having many more location set-ups and moves between strokes. Any obstructions encountered during the mixing operation reduced this production rate.

Shallow and deep soil mixing required approximately 5.25 million gallons of water over the duration of the project. Water was available from a local water company (potable) and was adequate for blending with fly ash and cement. For the production rates described earlier, the specific requirements were approximately 115,000 gallons per day, delivered at 150 gallons (20 cubic feet) per minute per base machine.

Material Sampling and Testing

All grout mix samples were randomly selected as approved by the Engineer. One set of samples was retrieved daily from the mix plant for strength testing, on a random basis according to the Pennsylvania Test Method (PTM) No. 1. Three-day strengths were typically obtained in accordance with ASTM 2166 and used to verify the consistency of plant mixing operations.

A sample of in-place treated FCR material was taken randomly on a daily basis, in accordance with PTM No. 1. The bulk samples were secured by a special tool from the in-place slurry mix at one of three depth locations (bottom, mid-depth, and near top). The slurry mix was molded into cylinders in general accordance with ASTM 4832. Acceptable results were based on the UCS achieving 100 psi in 28 days.

Three-inch diameter by six-inch high molds were used to cast cylinder samples. Clumps or gravel size impurities that did not pass the No. 4 sieve were removed from the wet sample, which was poured into the molds and tapped to remove trapped air pockets and then sealed. The samples were stored on-site in a temperature and moisture controlled environment for 7 to

28 days. Each sample of grout mix and treated FCR material consisted of a minimum of four cylinders. The cylinders were made and cured in accordance with ASTM C 31 procedures.

Strength Testing of Blended Materials The samples were compression tested by HCP's on-site laboratory and all tests were witnessed by the Engineer or a designated representative. Intermediate testing was performed to verify that a minimum strength of 30 psi was achieved before the deep mixing equipment was moved onto the area. Typically, these were 3-day or 7-day strength verifications. However, final acceptance was based on 28-day strengths achieving an UCS of 100 psi.

One 7-day sample and one 28-day sample from each bulk sample secured from a single location was subjected to UCS testing (ASTM 2166). One direct shear test (three-point series) was conducted on reconstituted samples of solidified FCR for every 40,000 cubic yards of FCR mixed. Testing results were submitted with the Daily Quality Control Report.

If the test samples did not meet the specified strength criteria, the Portland cement portion of the design mix was increased and the rate of testing was increased until the desired strength criteria were met.

Ultimate In-Place Testing. The soil mixing treatment areas cured for a minimum of 28 days prior to performing the confirmation borings. Six (6) geotechnical borings were performed to document the in-place quality of the solidified FCR. Cores of the treated FCR were obtained where practical, and subject to UCS tests. The tests were performed to confirm that the material was relatively homogeneous and that the required UCSs were being attained. Acceptable results were based on a 28-day or later UCS equal to or greater than 100 psi. Standard Penetration Tests (SPTs) were used as a guideline to establish, through appropriate correlations, the strength of the material. Additionally, the Engineer selected test pits for excavating within the solidified FCR to obtain a broader perspective of the mixing quality and to retrieve samples.

Three borings were drilled about midway through the project within the dam and MFX embankment footprint. The remaining three borings were drilled toward the end of the project within the dam footprint. Continuous sampling was conducted utilizing double-tube core barrel and/or standard split-spoon sampling procedures (SPT). The samples were handled and stored as per conventional soil sampling procedures. All borehole testing and or test pit excavations were monitored and reviewed by a geotechnical engineer.

Slope Stability

Previously conducted slope stability analyses established that the originally approved plan met the minimum required factors of safety. The soil strength parameters used in these analyses were φ = 33.0º and c = 0.0 for effective stress, and φ = 28.0º and c = 0.0 for post-seismic effective stress design. Direct shear test results of solidified FCR material samples that cured up to 29 days are presented in Table 1, indicating that the solidified FCR material that moist cured for 29 days resulted in angles of internal friction of φ' = > 45º for effective stress design, and φ' > 35.0º for post-seismic effective stress design. The cohesion intercepts were c = 1.38 and c = 0.4 ton per square foot, respectively.

Table 1. Summary of UCS and Direct Shear Test Results for Solidified FCR

	UCS (psi)		Peak Strength		Post-Peak Strength	
Curing Time (days)	Sample 1	Sample 2	Angle of Internal Friction Φ' (deg.)	Cohesion Intercept c' (tsf)	Angle of Internal Friction Φ' (deg.)	Cohesion Intercept c' (tsf)
1	14	12	30.3	0.468	27.5	0.38
2	28	26	30.6	0.586	29.3	0.28
3	-	30	-	-	-	-
4	-	36	-	-	-	-
5	47	-	-	-	-	-
7	63	41	32.4	0.72	32	0.9
8	-	-	33.3	1.116	31.8	0.26
28	106(1)	119(1)	-	-		
29	-	-	54.6	1.384	44	0.12

(1) Extrapolated from 34-day breaks.

Since the angles of internal friction for solidified FCR are greater than those used in the previous analyses, even if the cohesion values are assumed to be c = 0.0, the minimum slope stability factors of safety for solidified FCR would also be greater. Therefore, the previously analyzed, reviewed, and approved slope stability analyses were considered conservative and additional slope stability analyses using the test strength parameters for solidified FCR were not necessary.

Quality Control/Quality Assurance

The actual conduct of the operations to solidify the FCR and responsibility for compliance with the provisions of the MSHA Act 30 CFR were with the general contractor and HCP, both independent entities not connected with the mining company. The general contractor, HCP and their subcontractors were responsible for implementing the construction quality control (QC) requirements in the Technical Specifications for FCR solidification, to regulate and monitor the procedures, equipment, materials, and personnel. In addition, quality assurance (QA) testing was implemented and conducted by the Owner's Project Manager and the Owner's Engineer. The approved specifications for the dam governed the monitoring and testing requirements for the conventional earth fill construction.

All measuring devices were calibrated at the start of the project and verified and/or re-calibrated for every 10,000 cubic yards of grout delivered or as directed by the Owner or its representative.

Material delivery tickets for cement and fly ash were submitted as part of the daily QC report. A daily summary of the quantities of materials used and delivered to the site were provided to the Owner's Project Manager and the Owner's Engineer for submission to the DEP with the construction monitoring reports. Additionally, HCP documented the progress of the solidification program on a daily basis. The QC reports included information on locations, times, dates, penetration depths and various grouting operations.

Safety Procedures

Eight to fifteen men per shift were required to operate the shallow and deep mixing operations. On site operations were conducted in accordance with OSHA, MSHA, and Owner's

Wrap-Up Insurance requirements. Standard equipment safety procedures for heavy construction were followed.

Concluding Remarks

The original plan for constructing the MFX required a temporary dewatering dike to isolate a dam (to expand the storage capacity of the slurry pond) and the MFX embankment areas from the active slurry pond. Upon completing the dewatering dike, the FCR upstream (west) would have been excavated, dewatered by the addition of dry coal combustion products (fly ash), and then placed in a permitted disposal facility. This plan complicated the MFX construction schedule. An additional difficulty was that substantially more FCR occupied the area to be excavated, dewatered and disposed of than reported on the bid documents. Further, the construction and subsequent removal of the dewatering dike could have disrupted on-going FCR recovery dredging operations within the active slurry pond.

Solidification of the FCR eliminated construction and eventual removal of the temporary dewatering dike; and removal, stabilization and disposal of a substantial quantity of FCR. Additionally, the volume of structural (earth) fill that was required to complete the dam was reduced substantially, enabling the general contractor to allocate more preferred borrow materials to the dam construction.

In-place solidification took 10-months to complete (June 2000 to March 2001) which met the construction schedule for the MFX. It avoided the construction and then removal of a temporary dewatering dike which not only contributed to a more efficient approach but more importantly saved construction time and funds. Figure 7 shows an artist's rendition of the finished embankment as compared to Figure 2. Section 52F2 of the MFX was opened to the public on April 2002.

In brief, the in-place solidification of FCR offered significant time and cost savings and it is recommended for projects similar to the MFX.

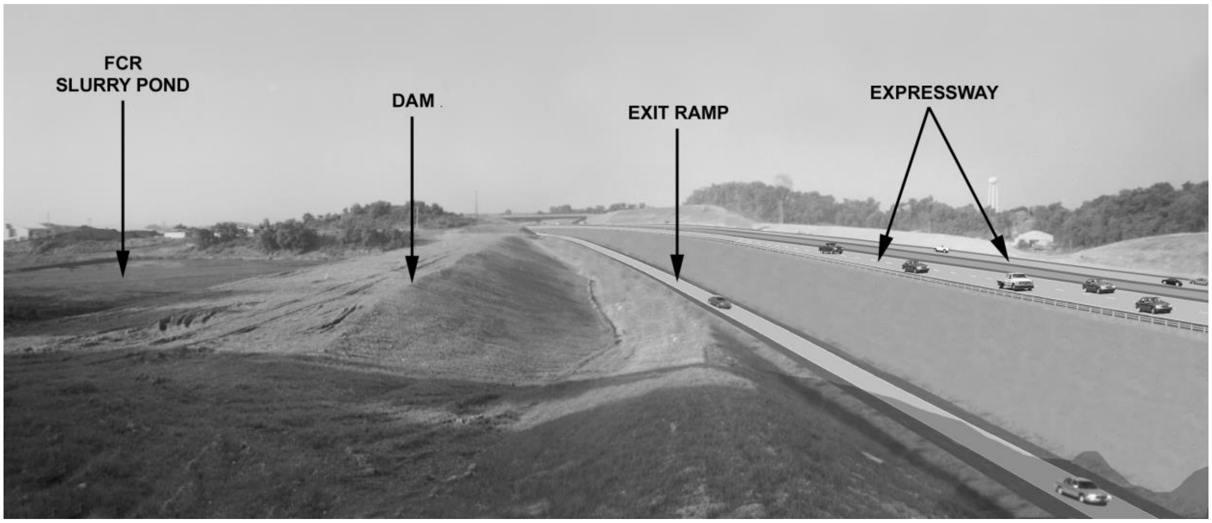

Figure 7. Plan view of project area: artist's rendition of finished MFX.

Literature Cited

American Society of Testing Materials (ASTM). D 2166. Standard test methods for unconfined compressive strength of cohesive soils.

ASTM D 4832. Preparation and testing of controlled low strength material (CLSM) test.

ASTM C 31. Making and curing concrete test specimens in field.

Electric Power Research Institute. April 1992. Fly ash design manual for road and site application. Volume 2: Slurried Placement. Prepared by GAI Consultants, Inc. Monroeville, PA. TR-100472-V2.

Electric Power Research Institute. December 1988. Laboratory testing of fly ash slurry. Prepared by GAI Consultants, Inc. Monroeville, PA. CS-6100.

Gray, T.A., Michalski, S.R., and Parkinson, J.W. 2000. Re-mining coal preparation plant slurry ponds. Tailing Dams 2000 Proceedings. Association of State Dam Safety Officials, Lexington, Kentucky. Las Vegas, Nevada. March 28-30.

Hoffman, D.C.; Briggs, R.W.; Michalski, S.R. January 1979. Management of coal preparation fine wastes without disposal ponds. p. 60. Report Number(s): FE-11270-1; EPA-600/ 7-78-189 Contract Number (DOE): AC01-79ET11270.

Kumar, Sanjeev; Puri, Vijay K.; Das, Braja M; and Devkota, Bimal C. 2001. Geotechnical properties of fly ash and lime – fly ash stabilized coal mine refuse. Electronic Journal of Geotechnical Engineering, Volume 6. Oklahoma State University, Stillwater, Oklahoma.

Michalski, S.R.; Szwed, D.F.; Kay, G.P.; Knott, D.L.; and Newman, F.B. 1995. Closure of pickle liquor sludge bed. p. 16. The Geoenvironment 2000: Characterization, Containment, Remediation and Performance in Environmental Geotechnics. ASCE, New Orleans, Louisiana. February 14-16.

Thomas, M.D.A.; Kettle, R.J.; Morton, J.A. 1987. Short-term durability of cement stabilised minestone. pp. 533-544. Reclamation, Treatment and Utilization of Coal Mining Wastes, A.K.M. Rainbow, Ed. International Symposium on the Reclamation, Treatment and Utilization of Coal Mining Wastes. Nottingham, UK. September 7. http://dx.doi.org/10.1016/b978-0-444-42876-9.50046-4.