Use of Coal Ash in Transportation Structures in Indiana

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Abstract

Indiana Department of Transportation (INDOT) initiated numerous research projects on recyclable and non-hazardous waste products for highway applications including coal combustion by-products, tire shreds, recycled foundry sands, and crushed glass. Research projects to identify the benefits of Coal Combustion By-products and study their engineering properties were funded by INDOT. Based on the research findings, INDOT constructed multiple embankments using coal ash fill materials with an extensive monitoring program. The instrumentations include the horizontal and vertical inclinometers, settlement plates, and monitoring wells. In this paper, four coal ash embankment projects are presented. The total length of the embankment is about 3,280 feet, and the maximum fill height is 25 feet. The maximum dry density of coal ash used in the embankment construction is lighter than the conventional fill materials. Dynamic Cone Penetration (DCP) Test was initiated to perform the compaction control of the coal ash embankment. This paper covers the construction details, experiences gained during and post-construction, long-term monitoring results, and INDOT material and construction specifications listed in Section 203.08.2 and 203.23.1 associated with coal combustion by-products.

Introduction

According to the American Coal Ash Association (2022), 29 and 9 million short tons of fly and bottom ash were produced in the United States in 2019. Sixty-one percent of fly ash and thirty-two percent of bottom ash produced in 2019 were recycled. Table 1 shows the production and use of coal ash in the United States during 2019.

Table 1. Production and Beneficial Use of Coal Ash in the US (ACAA, 2022)

By-product	Production (short tons)	Beneficial Use (short tons)
Fly ash	29,319,239	17,768,235
Bottom ash	9,150,680	2,923,586
Boiler Slag	965,138	697,001
Total	39,435,057	21,388,822

Finding a beneficial way and promoting the use of recycled coal ash will save the disposal cost, and landfill space, which will conserve the natural resources. From many INDOT-funded researches on recycling the coal ash and demonstration projects, a wealth of literature was developed to provide the characteristics of materials, their long-term performance, and specification for the design and construction of coal ash embankment (Kim et al. 2006; Karim et al. 1997; Alleman et al. 1996; Huang 2990; Yoon et al. 2006; Bhat and Lovell 1996). The gradation of fly ash is in the range of typical silty and clayey soils. The bottom ash shows the gradation in the range of sand. The unit weight of coal ashes is generally lighter than the typical embankment fill materials. As shown in Figure 1, the type of fly ash produced in Indiana is mainly Class F except for very few locations.

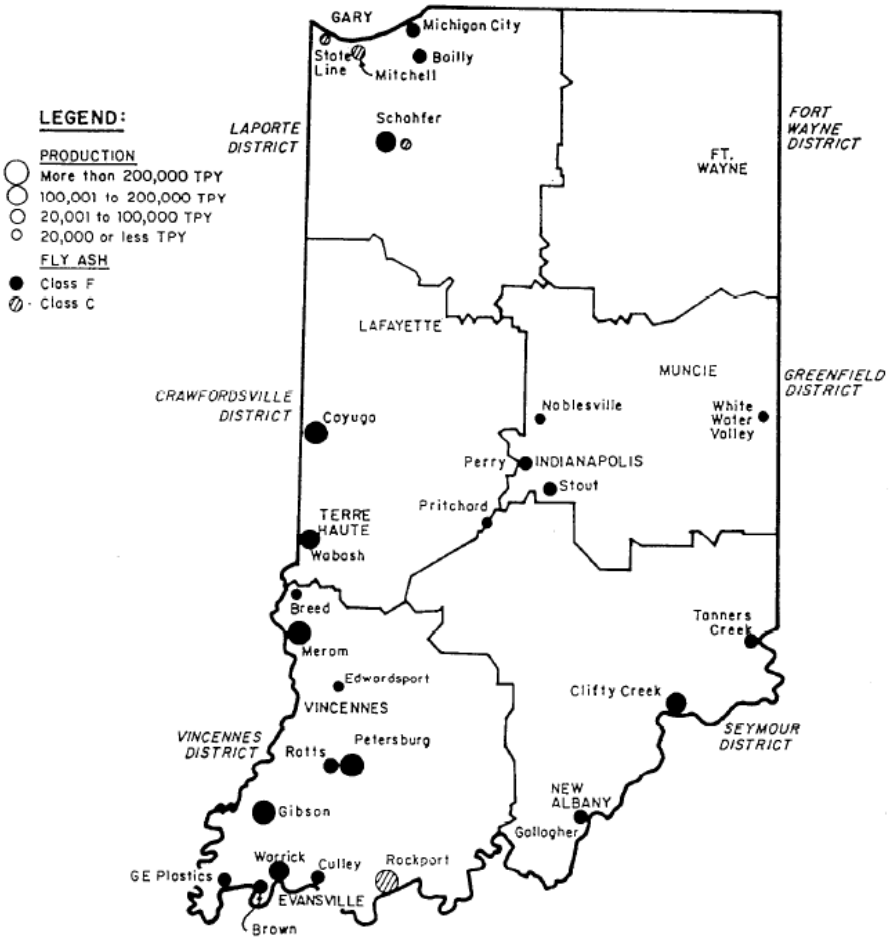

Figure 1. Production of Fly Ash in Indiana (GAI and USIFCAU 1993).

Coal Ash Demonstration Embankment Construction

This paper presents four coal ash embankment projects in Lake County, Marion County, Knox County, and Vigo County. The total length of the embankment is more than 3,280 feet, and the maximum fill height is 25 feet.

US 12 in Lake County

This demonstration project is located in US 12 in Lake County, IN (Figure 2). The length and height of the embankment are 290 feet and 12 feet. The embankment was constructed on sandy foundation soils with a side slope of 2H:1V. The fill material used is the bottom ash with a total quantity of about 5,000 cubic yards. Engineering properties of the bottom ash fill are tabulated in Table 2.

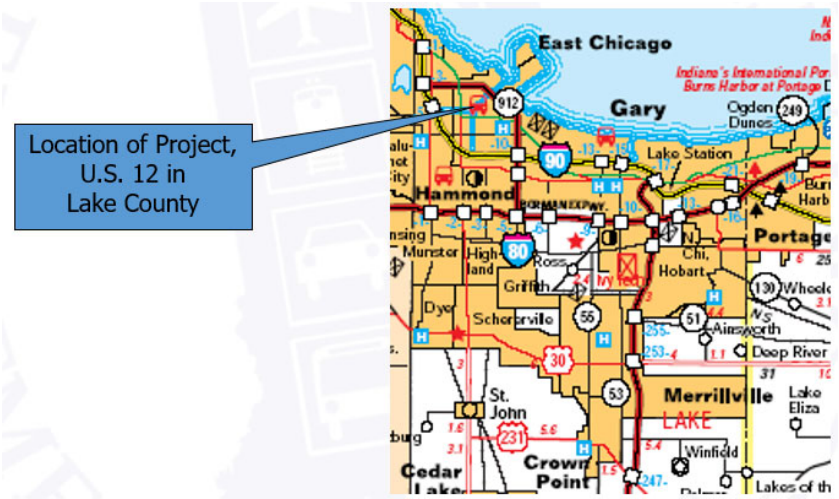

Figure 2. Location of Project (US12 in Lake County)

Table 2. Engineering Properties of Bottom Ash

AASHTO Classification	A-1-a
Passing # 200 Sieve	1%
Maximum Dry Density	92 pcf
Specific Gravity (AASHTO T-100)	2.37 ~ 2.47
Hydraulic Conductivity (AASHTO T-215)	3.3×10^{-3} ft/sec
Friction Angle (AASHTO T-236)	35° to 45°
CBR (AASHTO T-193)	45 ~ 70

The embankment was constructed in a 6-inch lift and each lift was compacted 6 passes with a 10-ton vibratory roller. The embankment construction was successfully completed and performs well with no major maintenance issues (Figure 3).

Figure 3. US12/20 Bottom Ash Embankment in Lake County (Picture taken in 2002).

I-465 in Marion County

This demonstration project is located in I-465 in Lake County, IN (Figure 4). The length and height of the embankment are 1300 feet and 16 feet. The embankment was constructed on cohesive foundation soils with a side slope of 2.5H:1V. The fill material used is a mixture of bottom ash and fly ash with a toral quantity of about 10,000 cubic yards. Engineering properties of the bottom ash fill are tabulated in Table 3.

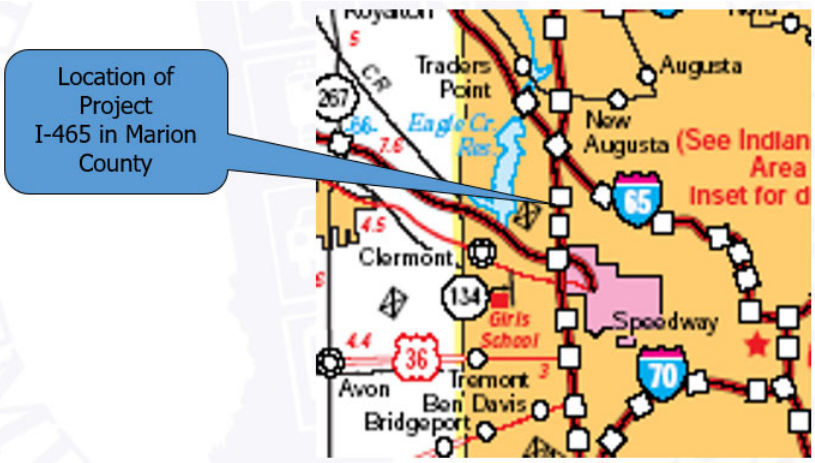

Figure 4. Location of Project (US12 in Lake County)

Table 3. Engineering Properties of Mixture of Bottom Ash and Fly Ash

Passing # 200 Sieve	Less than 20%
Maximum Dry Density	108 pcf
Optimum Moisture Contents (Standard Proctor)	15.7%

The embankment was constructed in a 6-inch lift, and each lift was compacted 5 passes with a static roller. The coal ash embankment was encased with 2 feet of cohesive soil to prevent erosion or runoff infiltration (See Figure 5). The performance of the embankment was monitored using settlement plates for 190 days after construction. The total settlement of the embankment ranges from 1.4 to 2.2 inches. The embankment construction performs well with no significant maintenance issues (Figure 6).

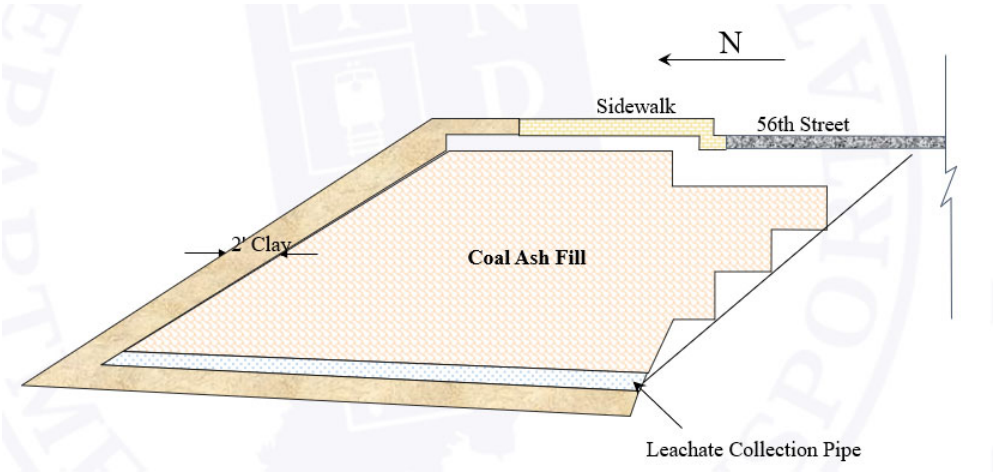

Figure 5. Clay Encasement

Figure 6. Coal Ash Embankment, I-465 at 56th street (Picture taken in 2022).

US 50 in Knox County

This demonstration project is located in US 50 in Knox County, IN (Figure 7). The length and height of the embankment are 2000 feet and less than 8 feet. The embankment was constructed on silty foundation soils with a side slope of 2H:1V. The fill material used is the bottom ash. The engineering properties of the bottom ash are tabulated in Table 4.

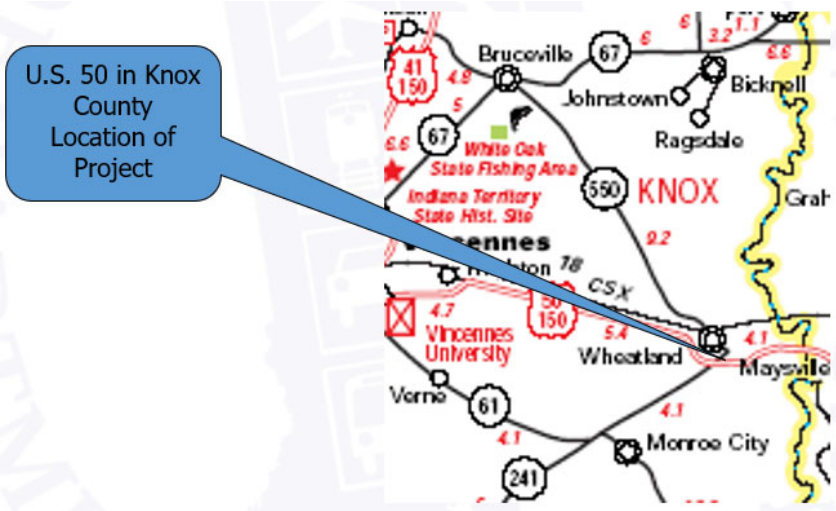

Figure 7. Location of Project (US 50 in Knox County)

Table 4. Engineering Properties of Bottom Ash

Passing # 200 Sieve	Less than 40%
Maximum Dry Density	105 pcf
Optimum Moisture Contents (Standard Proctor)	15%

The embankment was constructed in a 6-inch lift and each lift was compacted 6 to 7 passes with a static roller to meet a minimum 95% of maximum density determined by the standard Proctor test. Two ground water monitoring wells were installed next to the embankment and water quality was monitored for two years. There was no change in water quality. Settlement of the embankment was also monitored. Total settlement measured met the design requirement, and there was no post-construction distress on the embankment and slope as shown in Figure 8.

Figure 8. Post Construction Performance of Coal Ash Embankment

SR 641in Vigo County

This demonstration project is located in SR 641 in Vigo County, IN (Figure 9). The height of the embankment is 20 feet. The embankment was constructed on silty foundation soils with a side slope of 3H:1V. The fill material used is the fly ash, and its engineering properties are tabulated in Table 5. The compaction of fly ash embankment fill was evaluated using the sand cone test, nuclear gage, and Dynamic Cone Penetrator (DCP). The performance of the embankment was monitored using the settlement plates, settlement cells, vertical and horizontal inclinometers, and earth pressure cells. The performance of the embankment was successful as shown in Figure 9. The embankment design, construction requirement and detailed monitoring results are available in the report by Yoon et al. (2006).

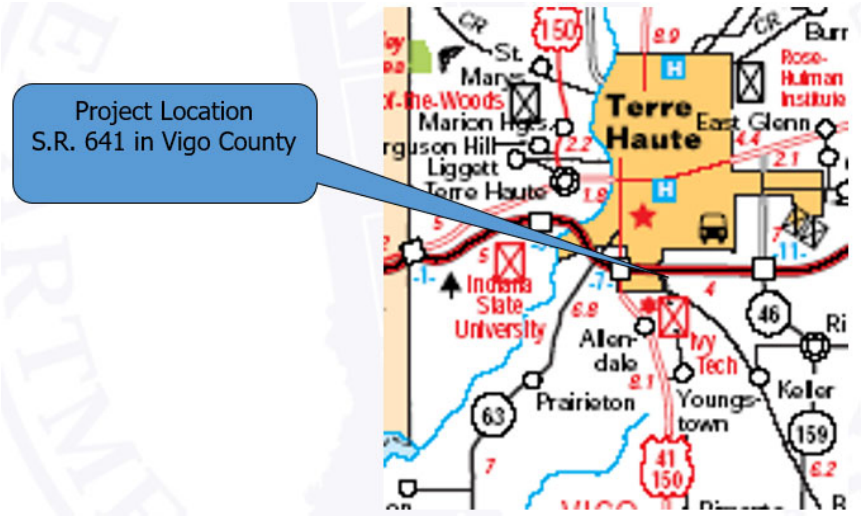

Figure 9. Location of Project (SR 641 in Vigo County)

Table 5. Engineering Properties of Fly Ash

Passing # 200 Sieve	60%
Maximum Target Dry Density	96 pcf
Target Optimum Moisture Contents	19%

Figure 9. Post Construction Performance of Fly Ash Embankment

Material and Construction Specification

Based on the long history of research on the coal ash, experiences gained during and post-construction, long-term monitoring results, INDOT material and construction specifications listed the coal ash as an acceptable embankment fill material. The material requirement and construction details associated with coal combustion by-products are specified in Sections 203.08.2 (Coal Ash) and 203.23.1 (Coal Ash Embankment) (INDOT, 2022).

Coal Ash Material Requirement (Section 203.08.2 – Coal Ash)

Coal ash is defined as either fly ash, bottom ash, or a mixture of both. The fly ash is defined as coal ash with a gradation of 70% or less passing No. 200 (75 μm, 0.0029 inch) sieve. The bottom ash is defined as coal ash with a gradation of 20% or less passing the No. 200 sieve and 10% or less retained on the No. 10 (2.0 mm, 0.0787 inch) sieve. Boron levels of coal ash should be less than 5 ppm by the Indiana Neutral Leachate Testing (INLT) methodology. If coal ash is obtained from a commercial source, the Contractor shall also provide a letter from the source allowing access by the Department personnel for the purpose of inspecting the processes used to produce the coal ash stockpile and for sampling the stockpile for testing by the Department.

Coal Ash Embankment Construction Requirement (203.23.1 - Coal Ash Embankment)

Coal ash should not be mixed with other embankment materials. Coal ash should not be placed in the Mechanically Stabilized Earth Wall (MSEW) backfill, encasement material, subgrade treatment, location directly in contact with permanent metallic construction materials, and environmentally sensitive area as follows:

- Below existing ground.
- Within a 100 ft horizontal distance of a stream, river, lake, reservoir, wetland, karst feature or any protected environmental area.
- Within a 150 ft horizontal distance of a well, spring, pond, or other ground source of water.

Embankment compaction is determined by DCP testing with a minimum blow count of 7 for a 6 in. compacted lift for fly ash and a minimum blow count of 16 for a 12 in. compacted depth of bottom ash consisting of two compacted 6 in. lifts. Lateral underdrains should be installed at the bottom of coal ash embankments. Coal ash shall be encased on all sides with cohesive soil meeting the minimum encasement requirements shown in Table 6.

Table 6. Cohesive Soil Encasement

Total Finished Embankment Height	Encasement thickness (ft)
Less than 10ft	2
10 ft to 20 ft	3
Greater than 20 ft	4

Conclusions

The following summarizes the lessons learned from the long history of INDOT-funded research, construction, and performance monitoring on coal ash embankments:

- INDOT has completed several projects using coal ash.
- INDOT will continue to utilize it in embankment construction.
- The research on these embankment projects has been valuable by helping make coal ash a useful material that would normally be disposed of in landfills or old coal mines.
- The benefits of using coal combustion by-products are reduction of disposal costs, fewer disposal areas, and conservation of natural resources.
- Mechanical and economic advantages relative to conventional materials, such as lightweight fill, are recognized.

References

Alleman, J. E., P. J. Fox, and D. J. DeBattista. Performance Evaluation of Highway Embankment Constructed Using Coal Ash. Publication FHWA/IN/JHRP-96/05. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1996.

American Coal Ash Association (ACAA), Beneficial Use of Coal Combustion Products, https://acaa-usa.org/wp-content/uploads/coal-combustion-products-use/ACAA-Brochure-Web.pdf. Accessed June 14, 2022.

Bhat, S. T., and C. W. Lovell. Use of Coal Combustion Residues and Foundry Sands in Flowable Fill. Publication FHWA/IN/JHRP-96/02. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1996.

GAI Consultants, Inc. and USIFCAU (1993), Use of Coal Combustion By-Products in Highway Construction, Prepared for the General Assembly of Indiana, and the Indiana Department of Transportation in response to House Enrolled Act 1056 and Senate Bill 209.

Huang, W. The Use of Bottom Ash in Highway Embankments, Subgrades, and Subbases. Publication FHWA/IN/JHRP-90/04-1. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1990.

Indiana Department of Transportation, INDOT Standard Specifications 2022.

Karim, A. M., C. W. Lovell, and R. Salgado. Building Embankments of Fly/Bottom Ash Mixtures. Publication FHWA/IN/JTRP-97/01. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1997.

Kim, B., S. Yoon, U. Balunaini, M. Prezzi, and R. Salgado. Determination of Ash Mixture Properties and Construction of Test Embankment - Part A. Publication FHWA/IN/JTRP-2006/24-A. , Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2006.

Yoon, S., U. Balunaini, M. Prezzi, R. Salgado, and N. Z. Siddiki. Determination of Ash Mixture Properties and Construction of Test Embankment - Part B. Publication FHWA/IN/JTRP-2006/24-B. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2006.