BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

| | | |
|---|---|---|
| IN THE MATTER OF: | ) | |
| | ) | AS 2021-001 |
| PETITION OF MIDWEST | ) | |
| GENERATION, LLC FOR AN | ) | |
| ADJUSTED STANDARD FROM | ) | (Adjusted Standard) |
| 845.740(a) AND FINDING OF | ) | |
| INAPPLICABILITY OF PART 845 | ) | |
| (JOLIET 29 STATION) | ) | |

**NOTICE OF FILING**

To: See attached Service List

PLEASE TAKE NOTICE that I have today electronically filed with the Office of the Clerk of the Pollution Control Board Midwest Generation, LLC's Responses to the Illinois EPA's Responses to the Board Questions, a copy of which is herewith served upon you.

Dated: July 22, 2022

MIDWEST GENERATION, LLC

By: ___/s/Kristen L. Gale __________

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**CERTIFICATE OF SERVICE**

The undersigned, an attorney, certifies that a true copy of the foregoing Notice of Filing, and Midwest Generation, LLC's Responses to the Illinois EPA's Responses to the Board Questions was electronically filed on July 22, 2022 with the following:

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and that copies were sent via e-mail on July 22, 2022 to the parties on the service list.

Dated: July 22, 2022 /s/Kristen L. Gale ____________

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**BEFORE THE ILLINOIS POLLUTION CONTROL BOARD**

| | | |
|---|---|---|
| IN THE MATTER OF: | ) | |
| | ) | |
| Midwest Generation, LLC's Petition for | ) | |
| an Adjusted Standard and Finding of | ) | AS 2021-001 |
| Inapplicability from 35 Ill. Adm. | ) | |
| Code 845 (Joliet 29 Station) | ) | |
| | ) | |

**MIDWEST GENERATION LLC'S RESPONSES TO THE**
**ILLINOIS EPA'S RESPONSES TO THE BOARD QUESTIONS**

Respondent Midwest Generation, LLC ("MWG"), by its undersigned counsel, submits its responses to the Illinois Environmental Protection Agency's ("Illinois EPA" or "Agency") answers to the Board Questions for the above captioned matter. MWG does not have follow-up questions to the Agency's Answers.

**Board Question No. 1**
Why is the poz-o-pac liner in Pond 2 more of a concern for groundwater contamination than the poz-o-pac liners in Ponds 1 and 3?

> **Agency's Response:** The poz-o-pac in in Pond 2 is not more of a concern than in Ponds 1 and 3. However, in the Agency Recommendation for Ponds 1 and 3, the Agency focused on the question of applicability due to Ponds 1 and 3 containing a de-minimis quantity of CCR. Therefore, the Agency did not do the same extensive search of records that was done with regard to the instant case, where the adjusted standard is for an alternative to the closure by removal requirements. Closure by removal specifically speaks to removal of CCR, CCR residues, containment system components such as liners, contaminated subsoils, impoundment structures and ancillary equipment.

**MWG's Response to Agency's Response to Board Question 1**:

The CCR used to make poz-o-pac in all three ponds is coal combustion by-product ("CCB") as that term is defined in 3.135 of the Act. 415 ILCS 5/3.135. Section 3.135 states that CCB means coal combustion waste when used "…as a raw ingredient or mineral filler in the manufacture of the following commercial products: …**cementious products**…"[1] 415 ILCS 5/3.135(a)(2)

[1] This appears to be a spelling error in the statute, because "cementious" is not a word in the dictionary. "Cementitious" is defined as "having the properties of cement." Merriam-Webster Dictionary, https://www.merriam-webster.com/dictionary/cementitious (last checked on July 15, 2022)

(emphasis added). Dr. Radlinsky, an expert in cementitious materials, testified that poz-o-pac is a cementitious product. PCB21-1, 6/28/2022 Tr., p. 89:9-11. Accordingly, the CCR in the poz-o-pac is CCB under Section 3.135(a)(2). 415 ILCS 5/3.135(a)(2). Additionally, cementitious products do not have any conditions for the use of CCR. *Id.* Under Section 3.135(a-5), only those uses described in Sections 3.135(a)(3)(A) and (a)(7) through (9) are subject to conditions on the use of CCR, including sampling using test method ASTM D3987-85. 415 ILCS 5/3.135(a-5). And further, as agreed by Illinois EPA, the uses in Section 3.135(a), including use as a cementitious product, do not require Agency review and approval. 415 ILCS 5/31.135(b), PCB21-1, 6/29/2022 Tr. p. 79:7-11, 84:23:1-85-1.

In any case, Mr. Dehlin concluded that the poz-o-pac on Ponds 1 and 3 was in similarly good condition as Pond 2. 6/28/2022 Tr. p. 198:10-19. Mr. Dehlin conducted an exhaustive investigation of the Pond 2 poz-o-pac, including reviewing the preliminary and final construction drawings, pictures from when the pond was relined in 2008, and the construction documents when the HDPE was overlain on the poz-o-pac, including Field Change orders. Agency Ex. G, Attachments 1-11, MWG Ex. 28, Attachments 1-6. In his expert opinion, he determined that the poz-o-pac in Pond 2 was in good condition. 6/28/2022 Tr. pp. 194:8-16, 195:3-11, 197:7-8. Moreover, once the HDPE liner was installed over the poz-o-pac liner, “it’s not subject to the elements.” 6/28/2022 Tr. pp. 196:6-12. The same is true for Ponds 1 and 3, because, as he stated, both were constructed in a substantially similar manner as Pond 2 – earthen embankments, initially lined with poz-o-pac, and both are covered with an HDPE liner. 6/28/2022 Tr. p. 198:1-9; Agency Ex. G, Attachment 10; MWG Ex. 1, ¶¶9, 22.

It is unclear whether the last sentence of the Agency’s answer is addressed to Pond 2, a CCR surface impoundment, or Ponds 1 and 3, which all parties agree are *not* CCR surface impoundments. For sake of clarity, as Mr. Naglosky testified, before the federal CCR regulation (40 C.F.R. Part 257, subpart D) and Illinois CCR regulation were effective, MWG removed the CCR from Pond 1 and cleaned the pond of the CCR, which did not require Illinois EPA's approval. 6/28/2022 Tr. p. 16:21-24, 19:1-6, 20-22. [2] Pond 3 was never used as a CCR surface impoundment. MWG Ex. 1, ¶¶18-21. Because Ponds 1 and 3 are not CCR surface impoundments, the closure by removal requirements of Part 845 do not apply to either pond.

**Board Question No. 2**

Does the poz-o-pac liner pose a threat of CCR groundwater contamination even if the "CCR material" in the liner has been changed in a chemical reaction and physically encapsulated?

> **Agency Response:** Yes. If the poz-o-pac degrades at a later date, then "physically encapsulated" material would be a CCR material left in place. As to chemically changed material, mechanical or chemical weathering processes have the potential to alter the properties of the poz-o-pac.
>
> The FHWA Report Recommendation Exhibit C, Special Considerations and Unresolved Issues states that pozzolanic materials can break down the structure of the poz-o-pac causing geotechnical suitability issues.
>
> Poz-o-pac much like rock and concrete, would need to be crushed to be evaluated for potential contamination. As acceptable methods for testing for metals contamination or leaching are not performed on rock.
>
> If MWG provided chemical analysis and other analytical data demonstrating that the synthetic liner is competent and the subsoils including the poz-o-pac were not contaminated, the Agency would agree that threat of CCR groundwater contamination does not exist.

**MWG's Response to Agency's Response to Board Question 2**

The Agency's answer is premised upon speculation – "*if*" the poz-o-pac degrades. However, there is no evidence that the poz-o-pac in Pond 2 is degraded and there is no evidence that it will degrade. Without any evidence of past or future degradation, the Agency's response is wholly unsupported speculation of some sort of risk which should not prevent the Board from granting the requested Adjusted Standard.

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[2] The Federal CCR Regulation became effective on October 19, 2015 and the Illinois CCR regulation became effective on April 21, 2021. 40 C.F.R. 257.51; 35 Ill. Adm. Code Part 845.

Instead, the totality of the evidence presented by MWG, including the testimony of three experts, demonstrates that the Pond 2 poz-o-pac is in good condition and does not present an adverse risk to groundwater. Dr. Radlinsky, an expert in cementitious products such as poz-o-pac, specifically testified that there was little risk to the groundwater from the poz-o-pac. In response to Mr. Rao's question on whether the poz-o-pac is "nonleachable", Dr. Radlinsky stated that the chemical formed in the chemical reaction, calcium silicate hydrate, "is a water insoluble material." *Id.* p. 84:5-14. He further stated that the USEPA recognizes the beneficial incapsulated use of CCR in concrete materials, such as poz-o-pac, and there is no minimum requirement for monitoring or testing for a potential of a release to the environmental from the encapsulated CCR. *Id.* pp. 85:17-86:3.[3] He ended his response to Mr. Rao's question about the leachability of the poz-o-pac:

> "Quite frankly, you know, there are literally thousands of miles of concrete pavements in the United States and worldwide, concrete with -- you know, pavements with -- made with concrete fly ash, and it's just not a -- they get a lot of rain and otherwise precipitation, a lot of exposure and potential for leaching, and to my knowledge it's just not a concern."
> *Id.*, p. 86:4-11

In fact, the FHWA Report the Agency relies upon further supports Dr. Radlinky's opinion. The FHWA Report states that Illinois has more than 100 projects that used fly ash as a stabilized base and subbase, by far the largest number of projects in the country. Agency Ex. C, p. 1. The projects are state and county roads, and the Agency presented no evidence that it is concerned about potential leaching of any contaminants to groundwater from those projects.

Dr. Radlinsky further stated that in his expert opinion, it is "highly unlikely" that it is possible for a hypothetically cracked poz-o-pac liner to leach material into the groundwater. *Id*. p. 86:18-87:1. He elaborated that the poz-o-pac is now covered by a multicomponent waterproofing system – the HDPE liner – and for water to reach the poz-o-pac, it would first have to flow through

[3] The definition of CCB treats CCR encapsulated in cementitious products similarly. 415 ILCS 5/3.135(a)(2).

the waterproofing system. *Id.* p. 87:1-8. He further stated that there is no evidence of cracking on the poz-o-pac. *Id*. p. 87:10-12. As explained in MWG's Response to the Agency's Answer to Board Question Number 1 (*supra*), Mr. Dehlin's exhaustive investigation showed that the poz-o-pac was in good condition. Dr. Radlinsky also stated that the performance of the poz-o-pac depended on what the material is exposed to, and in this case, the poz-o-pac had not been exposed very often to heavy machinery. *Id.* p. 93:10-94:14. Mr. Naglosky testified that CCR removals from Pond 2 occurred every five to ten years. 6/28/2022 Tr., p. 23:19-24:4. In other words, during the 30 years that the poz-o-pac was the primary liner, large equipment was used at most *six times*. In comparison, Dr. Radlinsky pointed out that poz-o-pac and other cementitious products are used in roads subject to daily exposure to heavy equipment. 6/28/2022 Tr., p. 75:11-17, 79:8-23. Ultimately, based upon the totality of the factors, Dr. Radlinsky concluded that there was not a concern of leaching into the groundwater. *Id.*, p. 88:9-10.

Mr. Maxwell, the expert on groundwater agreed with that conclusion. He evaluated the twelve years of quarterly groundwater monitoring data. Based upon the absence of groundwater contamination after the poz-o-pac has been in the ground for 44 years, he concluded it is not a potential source of contamination. 6/28/2022 Tr. p. 138:2-8.

The Agency also incorrectly claims that the poz-o-pac needs to be tested. First, as explained in MWG's Response to the Agency's Answer to Board Question Number 1 (*supra*), the CCR used to make the poz-o-pac is CCB, and no testing is required of the raw material or the product. 415 ILCS 5/3.135(a)(2). Additionally, both Mr. Dehlin and Mr. Maxwell testified that that there is no need to sample the poz-o-pac because it is in good condition, is not a source of contamination and sampling would require compromising the HDPE liner to obtain the sample. 6/28/2022 Tr. p. 161:21-162:12, 227:17-228:4.

The Agency also egregiously misrepresents the Special Considerations and Unresolved Issues in the FHWA Report. Agency Ex. C. There is no discussion of pozzolanic materials breaking down the structure of the poz-o-pac "causing geotechnical suitability issues" in either section of the report cited by the Agency. In fact, the term "geotechnical" is absent from the entire report. Instead, the report simply states that pozzolanic stabilized base (PSB) materials are subject to shrinkage cracking, but the cracking is "more evident when Portland cement is used in the mix." Portland cement was not used in Pond 2. In sum, the FHWA Report provides no support for the Agency's position that sampling of the poz-o-pac liner should be required.

**Board Question No. 3**

The FHWA Report included in the Agency's February 4, 2022, Recommendation is from 2006, is the Agency aware of any more recent discussion of the poz-o-pac liners or PSB material having problems with structural stability?

> **Agency Response:** The FHWA Report number FHWA-NIH-06-088 was published in 2006 and no modification seems to have been done since then. However, FHWA Report number FHWA-RD-97-148 was last modified on March 8, 2016 (Recommendation, Exhibit C) and provides more detail on poz-o-pac and discusses its use as a pozzolanic stabilized base (PSB) material. The publication in 2006 was the final report and the 2016 was updated information to the 2006 report.

**MWG's Response to Agency's Response to Board Question No. 3**

MWG does not disagree with the publication dates of the two documents. However, Exhibit C of the Agency's Recommendation is one chapter of the FHWA Report number FHWA-RD-97-148. The entire report is entitled "User Guidelines for Waste and Byproduct Materials in Pavement Construction," and has additional discussion of PSB material and its structural stability.[4] Another chapter of FHWA-RD-97-148, entitled "Coal Bottom Ash/Boiler Slab – Stabilized Base" and dated March 8, 2016, has further discussion of the performance of PCB material. The Coal Bottom

[4] The entire report is available here: https://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/index.cfm. (last visited July 17, 2022)

Ash/Boiler Slab – Stabilized Base chapter, attached as MWG Exhibit 39, evaluated a study of the performance of PSB material in roads. The study showed that a lime-stabilized base showed no cracking whereas the cement stabilized base, such as Portland cement, showed cracking after use. Here, the poz-o-pac is a lime-stabilized base, and Portland cement was not used. The Coal Bottom Ash/Boiler Slab – Stabilized Base chapter also references United States roads with similar composition of lime-stabilized bases, and specifically identifies State Rt. 195 in Montgomery County, Illinois as a lime-fly ash base road, further supporting Dr. Radlinsky's statement that fly ash is used nationwide without issue or concern.

**Board Question No. 4**

The Agency's February 2022 Recommendation on page 20 states, "While a geotextile cushion was installed beneath the HDPE liner, there are other factors that may cause damage to the liner. In addition to overburden stress, liners installed in impoundments that are exposed to sunlight and weather conditions suffer degradation that buried HDPE liners do not." Please comment on whether the Agency has conducted any inspection of the existing HDPE liner that indicates any damage to the liner. If not, please explain the rationale for concluding that the HDPE liner system may be damaged or compromised.

> **Agency Response:** The Agency has not conducted an inspection.
> However, the Agency relied on aerial photograph evidence between 2005 and 2020 accessed on or around November 9, 2021 from Google Earth Pro. The aerial photographs reviewed by the Agency showed the white liner material exposed at the top of Pond 2 even when Pond 2 contained water and CCR. The October 2007 and October 2019 Google Earth aerial photographs verified that heavy equipment was used to remove the CCR material. There are large equipment tracks into and out of Pond 2. All aerial photographs reviewed are available on Google Earth as of June 27, 2022.

**MWG's Response to Agency's Response to Board Question No. 4**

Once again, the Agency response provides only speculation. The Agency has not *observed* any damage to the liner in the Google Earth Pro images of the Pond 2 liner on which it relies. Also, the Agency's reference to the October 2007 aerial photos is not relevant. The pond was relined in 2008 with the HDPE liner, so any heavy equipment observed in the Pond before 2008 has no bearing on the current condition of the HDPE liner. In fact, MWG conducts weekly inspections and annual inspections of Pond 2, and the inspections have not found any damage to the liner. *See* Agency Exs. K and L

Mr. Naglosky explained that the heavy machinery does not touch the liner. Instead, there is a 6-inch layer of gravel, a 12-inch layer of sand, and a geotextile layer on the base of the pond, over the HDPE liner. Ex. 1, ¶ 23, 6/28/2022 Tr. p. 18:11-19. Because the CCR on the sides of the pond were flushed off the sides with a hose, the HDPE liner on the sides were not at risk from the equipment. *Id.* Mr. Dehlin also explained that the HDPE liner was protected from risk of punctures because a geotextile was installed on both sides of the liner, and thus it is "highly unlikely that the HDPE liner suffered perforations."[5] 6/29/2022 Tr. p. 11:1-23. In support of his opinion, Mr. Dehlin relied upon Designing with Geosynthetics, which the Geotextile Institute called "the widely used professional/academic book."[6] Designing with Geosynthetics showed that an HDPE liner sandwiched between two geotextile layers has more than double the protection. Ex. 28, p. 6 and Attachment 12.

Further, there is no risk for the HDPE liner to degrade from exposure of the liner. Until 2019, a majority of the liner was under the ash and water. 6/29/2022 Tr. p. 12:18-13:7. Even its exposure for the past three years, is of little risk. The HDPE liner in Pond 2 is white, significantly reducing the risk of UV degradation. 6/29/2022 Tr., p. 13:8-14:9; Ex. 28, Attachments 9 & 10. Because of its color and the presence of two geotextile layers surrounding the liner, Mr. Dehlin concluded that the white HDPE liner in Pond 2 was not compromised by either punctures or UV damage. 6/29/2022 Tr. p. 14:20-24.

**Board Question No. 5**

The Agency states that the cobalt analytical results exceed the GWPS of 0.006 mg/L under Section 845.600 at MW-04 as recently as October 22, 2020." 2-4-22 Rec. at 24. However,

[5] Koerner, R.M. (2005.) Designing with Geosynthetics. 5th Ed, Fig. 5.8.
[6] https://geosynthetic-institute.org/newbook.htm.

in Table 2 of Exhibit 11 and Table 1 of Exhibit O, the cobalt measurement for October 22, 2020, does not appear to be in agreement. Table 2 of Exhibit 11 has cobalt measured as 0.0041 mg/L and Table 1 has the measurement for cobalt as 0.0082 mg/L.

a. Please elaborate on the discrepancy in the data between the two tables.

**Agency Answer:** Table 11 was prepared pursuant to the CCA and included only dissolved metals analytical. Table I of Exhibit O was prepared pursuant to Part 845 and the measurements taken were total metals.

b. Comment on whether the differences are due to different sample results.

**Agency Answer:** Yes, you would see different sample results because dissolved is filtered in the field or laboratory and total is not filtered at either location.

**MWG's Response to Agency's Response to Board Question No. 5:** MWG agrees with the Agency's answers.

**Board Question No. 6**

On pages 13 and 14 of the February 2022 Recommendation, the Agency states that beneficial use of CCR for structural fill, foundation backfill, antiskid material, soil stabilization, pavement, or mine subsidence must meet the following requirements: cannot be mixed with hazardous waste before its use, must be tested using method ASTM D3987-85, cannot exceed the Class I GWQS. Further, CCR must also be used "in an engineered application or combined with cement, sand, or water to produce a controlled strength fill material and covered with 12 inches of soil unless infiltration is prevented by the material itself or other cover material."

a. Please explain why the treated "CCR material" in the post-o-Pac liner does not fit under the definition of "beneficial Use".

**Agency Answer:** The liner may have met the "beneficial use" definition when it was first installed years ago. However, the Agency is concerned with the "contaminated" nature of the parent materials used for the Poz-o-Pac with respect to Closure by Removal, including "contaminated subsoils" according to 35 Ill. Admin. Code 845.740(a) as requested in the adjusted standard proceeding by MWG. The Agency is aware that the liner has been exposed to large equipment that may cause damage to the liner and there is also an issue of exceedances of cobalt that calls into the integrity of the liner.

**MWG's Response to Agency's Response to Board Question No. 6.a.**

The Agency's Response, as repeated previously in its Recommendation, is incorrect. The CCR in the poz-o-pac is not "structural fill, foundation backfill, antiskid material, soil stabilization, pavement, or mine subsidence." The CCR in the poz-o-pac is CCB under Section 3.135(a)(2) because it was used "as a raw material or mineral filler in the manufacture of the…cementious products." 415 ILCS 5/3.135(a)(2). Under Section 3.135(a), analysis of the CCR and the resulting poz-o-pac is not required when using CCR as a raw material in the manufacture of cementious product. 415 ILCS 5/3.135(a)(2), (a-5).

The Agency's speculation about the condition of the poz-o-pac is not supported by the evidence. From 1978 to 2008, the poz-o-pac was rarely exposed to large equipment. At most, large equipment was used on the poz-o-pac six times for the thirty years the poz-o-pac was the primary liner. 6/28/2022 Tr., p. 23:19-24:4. As Dr. Radlinsky stated, poz-o-pac and other cementitious products are used in roads subject to daily exposure to heavy equipment. 6/28/2022 Tr., p. 75:11-17, 79:8-23; *See also* Agency Ex. C, p. 1 (more than 100 projects in Illinois that used fly ash as a stabilized base and subbase) and MWG Ex. 39, attached, FHWA-RD-97-148, "Coal Bottom Ash/Boiler Slab – Stabilized Base," (State Rt. 195 in Montgomery County, Illinois is composed of a lime-fly ash base).

The Agency also incorrectly claims that the subsoils are somehow contaminated. The groundwater data does not support that claim. Not only are there no detections of the most common CCR constituents in the groundwater, there is no evidence that CCR was used in the construction or reconstruction of Pond 2. *See* 6/28/2022 Tr. p. 118:6-20 (the absence of the common CCR indicators shows that there is not a release of CCR); 6/28/2022 Tr. p. 180:4-6, 181:19-22 (no CCR used in the fill in the embankments); 6/28/2022 Tr. p. 201:1-202:5, 208:8-210:13, 220:20-221:5, Ex. 28, Attachment 1 (no CCR used as fill under the HDPE liner); 6/29/2022 Tr. p. 70:6-20 (earthen materials, and not CCR was used as fill during the original construction of Pond 2).

Finally, the Agency's contention that the cobalt detected in one well is somehow connected to the poz-o-pac liner is also devoid of factual support. The MW-4 cobalt detections were due to the release of naturally-occurring cobalt in soil released as a result of road salt in the groundwater. 6/28/2022 Tr. p. 125:20-128:24; Ex. D of MWG Ex. 22 and MWG Ex. 37.

> b. Comment on whether MWG can demonstrate that the use of CCR in poz-o-pac liner is a “beneficial use” outside using the shake test?
>
> **Agency Answer:** MWG could also do a soil analytical, after crushing of the poz-o-pac, to include total recoverable metals with minimum detection limits as defined in 35 Ill. Admin. Code 1100 and limited to constituents found in 35 Ill. Admin. Code 845.600. For each detection of an aforementioned metal, Synthetic Precipitation Leaching Procedure (SPLP) would be analyzed to determine the impact to groundwater and compared to 35 Ill. Admin. Code 845.600 groundwater protection standards.

**<u>MWG’s Response to Agency’s Response to Board Question 6.b.</u>**

As a beneficial use of CCR in the poz-o-pac pursuant to Section 3.135(a)(2), the poz-o-pac is a cementitious product which does not require the application of a shake test. 415 ILCS 5/3.135(a)(2), (a-5); 6/28/2022 Tr., p. 89:9-11. *See also* MWG’s Response to Agency’s Response to Board Question 2.

# EXHIBIT 39

# User Guidelines for Waste and Byproduct Materials in Pavement Construction

[ **Material Description** ] [ **Asphalt Concrete** ] [ **Granular Base** ]

## COAL BOTTOM ASH/BOILER SLAG

## User Guideline

*Stabilized Base*

### INTRODUCTION

Bottom ash and/or boiler slag can be used as either the fine aggregate fraction or, in some cases, as the entire aggregate in either Portland cement or pozzolan-stabilized base and subbase mixtures. A blend of bottom ash and boiler slag may comprise the entire aggregate portion of the mix if both materials are available. If only bottom ash is available, it may be used as the entire source of aggregate, or it may be blended with a coarse aggregate to meet a specified range of gradation. If only boiler slag is available, it must be blended with sand or other well-graded fine aggregate to produce an aggregate with a suitable particle size distribution. If a broader range of particle sizes is specified, further blending with a coarse aggregate may also be necessary.

### PERFORMANCE RECORD

Bottom ash and, in particular, boiler slag have been used as aggregate sources in stabilized base or subbase applications since as far back as 40 years ago. Most of these installations have not been well documented, but their service record is believed to have been from fair to very good.

A recent survey reported that in 1996, 0.6 million metric tons (0.7 million tons) of bottom ash and/or boiler slag (predominantly bottom ash) were used as road base or subbase materials. The category for road base or subbase includes stabilized base or subbase, as well as granular or unbound base or subbase installations. The exact percentage used in stabilized base applications was not reported.

According to a 1992 survey of all state highway and transportation agencies, at least five states indicated that they were currently making use of bottom ash or boiler slag in some type of stabilized base or subbase applications. These states include Arkansas, Kentucky, Mississippi, Texas, and Utah. A sixth state, Wyoming, indicated some use of bottom ash as a granular base, but cited instability of the material as the reason for discontinuing the use of bottom ash. Although the nature of the instability was not explained, it is believed to be due to a lack of cohesion in the base, possibly because of the material becoming too dry.

Bottom ash and boiler slag have been used in the past as an aggregate for stabilized base and subbase mixtures in other states, although not necessarily on state highway projects. These states include, but are not limited to, Georgia, Illinois, Michigan, North Dakota, Ohio, and West Virginia. There are currently no state specifications for the use of bottom ash or boiler slag as an aggregate in stabilized base or subbase mixtures. Table 4-8 presents a listing of pertinent data on some selected applications.

**Table 4-8. Pozzolanic stabilized base general design and construction data.**

| Project (Date) | Type | Constituents | Compressive Strength Data | |
|---|---|---|---|---|
| State Rt. 195[4]<br>Montgomery County,<br>Illinois (1976) | 5.6 km (3.5 mi)<br>250 mm (10 in)<br>Lime-Fly Ash Base Course | Lime - 3%<br>Class F Fly Ash - 32.5%<br>Boiler Slag - 64.5%<br>(minus 4.75 mm (No. 4) sieve) | Lab<br><br>Cores | >6900 kPa<br>(1000 lb/in$^2$)<br>9700 kPa<br>(1400 lb/in$^2$) |
| Route 2[5]<br>Wheeling,<br>West Virginia<br>(1971-1972) | Portland Cement,<br>Boiler Ash,<br>Bottom Ash<br>Base Course | Aggregate<br>Boiler Slag - 54%<br>Bottom Ash - 46% | No data | |

| | | | | |
|---|---|---|---|---|
| | | Portland Cement - 5% (wt of aggregate) | | |
| Route 34[6]<br>Charleston,<br>West Virginia | Portland Cement<br>Bottom Ash | No Data | Cores (2 yr) | >9000 kPa<br>(1300 lb/in$^2$) |
| Rome,<br>Georgia[7]<br>(early 1980's) | 305 mm (12 in)<br>Lime<br>Bottom Ash<br>Base Course | Lime - 6 - 8% | Cores (6 wk) | >4800 kPa<br>(700 lb/in$^2$) |
| Route 22[8]<br>Georgia<br>(1985) | 305 m (1000 ft)<br>216 mm (8-1/2 in)<br>Portland Cement<br>Pond Ash<br>Base Course | No Data | Lab ( 7 day) | 3400 kPa<br>(494 lb/in$^2$) |
| Route 15<br>Stone County<br>Mississippi<br>(1987) | Lime Stabilized Base and<br>Portland Cement Stabilized<br>Base with<br>Class C Pond Ash | Lime - 2 - 7%<br>Cement - 7.5% | 7% Lime Base<br>Cores<br><br>Cement Base<br>Cores | 4500 - 8700<br>kPa<br>(650 - 1260<br>lb/in$^2$)<br>15900 kPa<br>(2300 lb/in$^2$) |

Pozzolan-stabilized base compositions consisting of lime, fly ash, and aggregates (LFA) were originally patented in the early 1950's under the trade name Poz-O-Pac. Some of the first LFA compositions in the Chicago area were mixed in place and used boiler slag as the aggregate. These early mixtures contained an average of 5 percent by weight hydrated lime, 35 percent Class F fly ash, and 60 percent boiler slag. Pavements using such mixtures provided many years of satisfactory service, and cores taken from these pavements have developed compressive strengths well in excess of 6900 kPa (1,000 lb/in$^2$)

Typical of these early boiler slag mixes was a 5.6 km (3.5 mile) service road built from State Route 195 to the Coffeen power station near Coffeen, Illinois, during the mid-1970’s. General design and construction data are presented in Table 4-8. The pavement reportedly performed without distress, even though the roadway was constantly subjected to heavy truck traffic.

The first known large-scale use of a cement stabilized bottom ash base course in the United States was in the relocation of West Virginia Route 2 during the 1971-72 construction season. The aggregate used was a blend of bottom ash and boiler slag from American Electric Power Company’s Mitchell and Kammer plants, respectively. General design and construction data are presented in Table 4-8. The blend was necessary in order to meet the West Virginia Department of Highway gradation specifications for cement-treated base course. The roadway provided excellent service for over 10 years at a substantial reduction in cost compared with the use of conventional aggregates.

Since 1984 several hundred miles of low-volume secondary roads in West Virginia have been reconstructed using cement-stabilized bottom ash. Most of these roads were primarily gravel subbase with traffic ranging from 150 to 1,500 vehicles per day. A typical section, presented in Table 4-8, is Route 34 in Putnam County, near Charleston, where a 150 mm (6 in) thick bottom ash subbase was placed and compacted. Successive 150 mm (6 in) thick lifts of cement-treated bottom ash were placed on top of the subbase.

During the early 1980’s, Georgia Power Company successfully constructed a lime-stabilized bottom ash base with a 38 mm (1-1/2 in) asphalt wearing surface near Rome, Georgia. In 1985, the Georgia Department of Transportation successfully constructed a 305 m (1,000 ft) section of cement stabilized pond ash base on State Route 22.

In 1987, pond ash from subbituminous coal was used to reconstruct approximately 2.4 km (1.5 miles) of State Route 15 in Stone County, Mississippi. The reconstruction involved five different sections, four with lime-stabilized ash and one with cement-stabilized ash. A 1.36 km (0.85 mile) control section of mechanically stabilized sand-clay subbase was also constructed. All sections were mixed in place and had a double bituminous surface treatment as a wearing surface. Stabilized base design data are presented in Table 4-8.

Deflection measurements were taken each year after construction through 1990. The sections with 6 and 7 percent lime and 7.5 percent cement all had much lower deflection readings than the control section and the section with only 2 percent lime. After 3 years of service, the control section and the section with 2 percent lime had no observed cracking, while the cement stabilized section had the most cracking. The shrinkage cracking of cement-stabilized granular materials is a fairly common occurrence, especially in soil-cement mixtures. The cracking in traditional soil-cement mixtures is attributable to the hydration of Portland cement. None of the cracking that was observed was considered structural in nature.

**MATERIAL PROCESSING REQUIREMENTS**

Bottom ash and/or boiler slag are both well-drained materials that can be readily dewatered in 1 or 2 days. Ponded ash reclaimed from a lagoon for use as a base course aggregate should be stockpiled and allowed to drain prior to use. Ponded ash will require a longer dewatering period because it usually includes some fly ash. The higher the percentage of fly ash in the ponded ash, the longer will be the time required for dewatering.

**Crushing or Screening**

Well-graded aggregates normally require less activator or reagent than poorly graded aggregates in order to produce a well-compacted mixture. Bottom ash is generally a more well-graded aggregate than boiler slag, which is normally more uniformly graded between the 4.75 mm (No. 4) and 0.42 mm (No. 40) sieve sizes. Pond ash may be a blend of bottom ash and fly ash, and will vary in gradation, depending on its location in the pond relative to the discharge pipe. Bottom ash may contain some agglomerations or popcorn-like particles. These agglomerations should either be reduced in size by clinker grinders at the power plant or removed by scalping or screening at the 12.7 mm (1/2 in) or 19 mm (3/4 in) screen.

**Blending**

When necessary to achieve a specified gradation, bottom ash or boiler slag may need to be blended with other aggregates. This is normally not necessary with bottom ash, but may be necessary with boiler slag.

**Removal of Deleterious Materials**

Deleterious materials, especially coal pyrites, should be removed at the power plant prior to use of bottom ash or boiler slag as an aggregate. The pyrites oxidize (or weather) over time, causing expansion and possible popouts of individual particles from the matrix. Soluble sulfates also occur in some bottom ashes. Low pH values are often used as an indicator for the presence of sulfates.

**ENGINEERING PROPERTIES**

Some of the engineering properties of bottom ash and/or boiler slag that are of particular interest when used as aggregates in stabilized base or subbase mixtures are gradation, specific gravity and unit weight, durability, and soundness.

*Gradation*: The size limits in Table 4-9 are recommended for cement-treated aggregate base by the Portland Cement Association and are applicable to bottom ash and/or boiler slag use in cement-treated base course mixes.

**Table 4-9. Recommended gradation for cement stabilized base.**

| Sieve Size | Percent Passing |
|---|---|
| 19 mm (3/4 in) | 100 |
| 9.5 mm (3/8 in) | 70-90 |
| 4.75 mm (No. 4) | 55-90 |
| 3.35 mm (No. 8) | 40-70 |
| 1.18 mm (No. 16) | 30-60 |
| 0.075 mm (No. 200) | 0-30 |

*Specific Gravity and Unit Weight*: The specific gravity of bottom ash usually ranges from 2.1 to 2.7, with dry unit weights ranging from 720 to 1600 kg/m$^3$ (45 to 100 lb/ft$^3$). The specific gravity of boiler slag usually ranges from 2.3 to 2.9, with dry unit weights ranging from 960 to 1440 kg/m$^3$ (60 to 90 lb/ft$^3$). With bottom ash, lower specific gravity is usually indicative of the presence of porous, popcorn-like particles, which readily degrade under compaction.

*Durability*: In ASTM C131 (Los Angeles Abrasion) tests, bottom ash has had loss values between 30 and 50 percent. Boiler slag has had loss values between 24 and 48 percent. Most bottom ashes have loss values less than 45 percent, enabling them to meet ASTM requirements for soil-aggregate base and subbase materials.

*Soundness*: The durability of an aggregate for possible use in stabilized bases or subbases can be evaluated by the sodium sulfate soundness test. Bottom ash has had sodium sulfate soundness loss values that normally range from 1.5 to 10.5 percent. Boiler slag has had sodium sulfate soundness loss values of between 1 and 9 percent. The lower the specific gravity, the higher the probable percentage of deleterious material in the ash, which will likely be reflected in a higher value for soundness loss.

**DESIGN CONSIDERATIONS**

**Mix Design**

For pozzolan-stabilized base (PSB) mixtures containing coal fly ash (along with either lime, Portland cement, or kiln dust as an activator), the initial step in determining mix design proportions is to find the optimum fines content. This is done by progressively increasing the percentage of fines and determining the compacted density of each blend. Fly ash alone can be used to represent the total fines. A Proctor mold and standard compaction procedures are used for each blend of bottom ash and/or boiler slag and fines. Fly ash percentages ranging from 25 to 45 percent by dry weight of the total blend are suggested for the initial trial mixes.

At least three different fly ash additions are needed to establish the optimum fines content, which is the percentage of fines that results in the highest compacted dry density. The dry density for each fly ash percentage is then plotted to identify the optimum fines content. An optimum moisture content must then be determined for the selected mix design proportions.

Once the design fly ash percentage and optimum moisture content have been determined, the activator (lime, Portland cement, kiln dust, etc.) percentage must also be established. Trial mixtures using a gradual increase in the activator percentage are recommended. Final mix proportions are selected based on the results of compressive strength and durability testing, using ASTM C593 procedures. The objective is to meet strength and durability criteria with the most economical mix design.

For cement-stabilized bottom ash and/or boiler slag mixtures, the only mix design consideration is a determination of the percentage of Portland cement to be added to the mixture. As with the PSB mixtures, trial mixtures using several increasing percentages of cement will be necessary. Usually between 5 and 12 percent Portland cement will be needed to properly stabilize bottom ash and/or boiler slag for use as a roller-compacted base course. The results of ASTM C593 compressive strength and durability testing should be the basis for selection of final mix proportions.

The compacted unit weight of bottom ash and/or boiler slag mixes is usually considerably lower than the compacted unit weight of stabilized base mixtures containing conventional aggregates. Consequently, a cement content of 10 percent by weight for a base course mix containing bottom ash and/or boiler slag may be the equivalent of a 7 percent by weight cement content for a similar mix containing a normal weight aggregate.

In general, the trial mixture with the lowest percentage of cement (or activator plus fly ash in PSB mixtures) that satisfies both the compressive strength and the durability criteria is considered the most economical mixture. To ensure an adequate factor of safety for field placement, it is recommended that the stabilized base or subbase mixture used in the field have an activator content that is at least 0.5 percent higher (1.0 percent higher if using kiln dust) than that of the most economical mixture.[18]

**Structural Design**

The thickness design of stabilized base or subbase mixtures containing bottom ash or boiler slag can be undertaken using the standard structural equivalency design method for flexible pavements described in the AASHTO Design Guide.[19] This method uses an empirical structural number (SN) that relates pavement layer thickness to performance.

Table 4-10 lists recommended structural coefficient values based on studies of pozzolanic and crushed stone base materials[19] for stabilized base or subbase mixtures. The values are for stabilized base or subbase materials that attain a given range of compressive strength, regardless of the source of aggregate used or the type of reagent(s) in the design mix. These coefficient values are based on the use of $a_1$ = 0.44 (used for a bituminous wearing surface) and a value of $a_3$ = 0.15 (used for a crushed stone base).

**Table 4-10. Recommended structural layer coefficient values for stabilized base and subbase materials.**

| Quality | Compressive Strength, psi (7 days @ 37.7° C) | Recommended Structural Layer Coefficient |
|---|---|---|
| High | Greater than 1,000 | $a_2$ = 0.34 |
| Average | 650 to 1,000 | $a_2$ = 0.28 |
| Low | 400 to 650 | $a_2$ = 0.20 |

The main factors influencing the selection of the structural layer coefficient are the compressive strength and modulus of elasticity of the stabilized base material. The value of compressive strength recommended for determination of the structural layer coefficient is the field design compressive strength, which is the compressive strength developed in the laboratory after 56 days of moist curing at 73° F (23° C).[18] However, other time and temperature curing conditions may be required by various specifying agencies.

When a Portland cement concrete (PCC) roadway surface is to be designed with a stabilized base or subbase, the AASHTO structural design method for rigid pavements can be used.(19)

## CONSTRUCTION PROCEDURES

### Material Handling and Storage

Both bottom ash and boiler slag can be handled and stored using the same methods and equipment that are normally used for handling and storage of conventional aggregates.

### Mixing, Placing, and Compacting

The blending or mixing of bottom ash or boiler slag in stabilized base mixtures can be done either in a mixing plant or in place. Plant mixing is recommended because it provides greater control over the quantities of materials batched and also results in the production of a more uniform mixture. Although mixing in place does not usually result in as accurate a proportioning of mix components as plant mixing, it is probably used more frequently with mixes involving bottom ash or boiler slag and will still produce a satisfactory stabilized base material.

Stabilized base materials should not be placed in layers that are less than 100 mm (4 in) or greater than 200 to 225 mm (8 to 9 in) in compacted thickness. These materials should be spread in loose layers that are approximately 50 mm (2 in) greater in thickness prior to compaction than the desired compacted thickness. The top surface of an underlying layer should be scarified prior to placing the next layer. For granular or coarse graded mixtures, steel-wheeled vibratory rollers are most frequently used for compaction. For more fine-grained mixtures, a vibratory sheepsfoot roller, followed by a pneumatic roller, is often employed.(18)

To develop the design strength of a stabilized base mixture, the material must be well-compacted and must be as close as possible to its optimum moisture content when placed. Plant-mixed materials should be delivered to the job site as soon as possible after mixing and should be compacted within a reasonable time after placement.

When self-cementing fly ashes are used as a cementitious material in stabilized base mixtures, compaction should be accomplished as soon as possible after mixing. Otherwise, delays between placement and compaction of such mixtures may be accompanied by a significant decrease in the strength of the compacted stabilized base material, unless a retarder is used. A commercial retarder, such as gypsum or borax, may be added at the mixing plant in low percentages (approximately 1 percent by weight) without adversely affecting the strength development of the stabilized base material.(18)

### Curing

After placement and compaction, the stabilized base material must be properly cured to protect against drying and to assist in the development of in-place strength. An asphalt emulsion seal coat should be applied to the top surface of the stabilized base or subbase material within 24 hours after placement. The same practice is applicable if a PCC pavement is to be constructed above the stabilized base or subbase material. Placement of asphalt paving over the stabilized base is recommended within 7 days after the base has been installed. Unless an asphalt binder and/or surface course has been placed over the stabilized base material, it is recommended that vehicles should not be permitted to drive over the material until it has achieved an in-place compressive strength of at least 2400 kPa (350 lb/in$^2$).(18)

### Special Considerations

*Cold Weather Construction*: Stabilized base materials containing bottom ash and/or boiler slag that are subjected to freezing and thawing conditions must be able to develop a certain level of cementing action and in-place strength prior to the first freeze-thaw cycle in order to withstand the disruptive forces of such cycles. For northern states, many state transportation agencies have established construction cutoff dates for stabilized base materials. These cutoff dates ordinarily range from September 15 to October 15, depending on the state, or the location within a particular state, as well as the ability of the stabilized base mixture to develop a minimum desired compressive strength within a specified time period.(19)

*Crack Control Techniques*: Stabilized base materials, especially those in which Portland cement is used as the activator, are subject to cracking. The cracks are almost always shrinkage related and are not the result of any structural weakness or defects in the stabilized base material. The cracks also do not appear to be related to the type of aggregate used in the base mix. Unfortunately, shrinkage cracks eventually reflect through the overlying asphalt pavement and must be sealed at the pavement surface to prevent water intrusion and subsequent damage due to freezing and thawing.

One approach to controlling or minimizing reflective cracking associated with shrinkage cracks in stabilized base materials is to saw cut transverse joints in the asphalt surface that extend into the stabilized base material to a depth of 75 mm (3 in) to 100 mm (4 in). Joint spacings of 9 m (30 ft) have been suggested.(18) The joints should all be sealed using a hot poured asphaltic joint sealant.

## UNRESOLVED ISSUES

As noted above, control of shrinkage cracking has been long considered by many state transportation agencies as a prime concern associated with stabilized base mixtures, especially cement-stabilized mixtures. Since most mixtures that include bottom ash and/or boiler slag as the aggregate have been placed on secondary roads, haul roads, and parking lots, as opposed to higher-type highway facilities, the issue of crack control has not been as great a concern to the owners or administrators of these installations. However, additional mix designs with reduced potential for shrinkage cracking need to be developed, especially if these materials are someday to be used on higher-type facilities.

Pyrites must be removed before bottom ash or boiler slag can be used. Soluble sulfates in bottom ash may warrant removal if found in sufficient quatity to be considered detrimental. Improved techniques for timely removal of these detrimental constituents are needed.

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