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JOINT HIGHWAY RESEARCH PROJECT

Executive Summary

FHWA/IN/JHRP-90/4 -2

THE USE OF BOTTOM ASH IN HIGHWAY EMBANKMENTS, SUBGRADES, AND SUBBASES

Wei-Hsing Huang

PURDUE UNIVERSITY

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To: H. L. Michael, Director
Joint Highway Research Project

Feb. 15, 1990

Project: C-36-50I

From: C. W. Lovell and J. E. Lovell
Joint Highway Research Project

File: 6-19-9

Attached is the Final Report of the HPR Part II study titled "The Use of Bottom Ash in Highway Embankments, Subgrades, and Subbases." The report was prepared by Mr. Wei-Hsing Huang, Graduate Research Assistant, under our direction.

A total of eleven Indiana bottom ashes was selected, sampled from ten power plants, and tested extensively to provide information on the properties of Indiana bottom ashes. The results of detailed evaluations show that the properties of bottom ash compare favorably with conventional highway materials, and they would also meet specification requirements set for conventional materials.

The potential environmental effects of bottom ash utilization were evaluated by performing the EP toxicity test and an Indiana leaching method. It was found that bottom ash can be classified as nonhazardous according to the current EPA regulations. Also, bottom ash leachate would meet the requirements for the most restrictive type of waste site specified in the Indiana Administrative Code.

The report is submitted for review, comment and acceptance in fulfillment of the referenced study.

Respectfully submitted,

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16. Abstract

This research assessed those properties of power plant bottom ash likely to affect its use as highway fill or pavement material, based on laboratory investigation conducted on eleven Indiana bottom ashes. Laboratory tests included: chemical analysis, mineralogical study, microscopic examination of ash particles, specific gravity, grain size distribution, sulfate soundness, Los Angeles abrasion, permeability, shear strength, moisture-density relations, degradation under compaction, compressibility, and California bearing ratio.

The various test values and properties were compared to those of representative granular soils or appropriate specifications. These comparisons provide information necessary for judging the suitability of bottom ash in Indiana highway construction.

The potential environmental effects of bottom ash utilization were evaluated by performing leaching tests outlined in the EP toxicity test and an Indiana leaching method. Chemical analysis of the leachates showed that bottom ash is nonhazardous, and its effects on the quality of ground water are minimal.

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by

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Introduction

The growing demand for electricity has resulted in the construction of many coal-fired power plants and as a result the production of power plant ash has continued to increase. For example, in the 10-year period of 1976 to 1986, the annual production of power plant ash for the U.S. increased from 54 to 67 million tons. Disposal of power plant ash not only has become more burdensome to the power industry but also results in a cost ultimately transferred to the power consumer. In the state of Indiana, the trend of increasing ash production by electric utilities is particularly true, because 98 percent of the Indiana electricity is generated from the burning of coal.

In view of the benefits to be gained from the utilization of power plant ash as a construction material, much research and other efforts devoted to exploring productive uses for this material in the construction of highways, buildings, and other structures is justified. In the past, much of the available research has focused on the properties and uses of fly ash. This is understandable because fly ash represents approximately two-thirds of the total ash production. However, other studies [1,2] have indicated that engineering properties of many bottom ashes compare favorably with those of conventional highway construction materials. Unfortunately, an extensive review of the literature reveals that the amount of laboratory and field data on the properties and performance of this material is very limited. In order to develop productive uses of bottom ashes, a substantial data base on their properties is needed.

A potential problem associated with the use of power plant bottom ash is its variability. These variations occur because of differences in: a) the type and origin of coal burned, b) boiler types, c) degree of coal pulverization, d) firing conditions in the furnace, and e) ash handling practices. Even bottom ash produced from a single source can be quite variable depending on the operating conditions and procedures. Therefore, there is a need for a systematic procedure to evaluate locally available bottom ashes for potential construction uses.

The Surface Transportation and Uniform Relocation Assistance Act of 1987 included a strong endorsement of coal ash use in highway construction. Accordingly, the Federal Highway Administration is encouraging large-volume use of coal ash by providing an additional 5 percent Federal-aid match for highway projects that include more than 1,000 tons of coal ash [3]. Since the state of Indiana is one of the eight largest ash-producing states in the United States, the Indiana

Department of Transportation (INDOT) is motivated to use bottom ash in Indiana highway construction.

Experimental Program

Eleven different bottom ashes from ten utility stations were selected for laboratory testing in this study. The ash materials consisted of nine dry bottom ashes, one wet bottom ash, and a source which was a combination of both wet and dry ashes. As the utilization of ash material will be economic only on a regional or local basis, one of the important criteria for the selection was the geographic distribution of the sources. A reasonable geographic balance among the eleven ashes selected for study was accomplished, with three bottom ashes identified as being from northwestern Indiana, four from central Indiana, and 4 from southern Indiana.

In most power plants, bottom ash is transported to a disposal lagoon as a slurry flowing through closed conduits. The closed ash transport and handling systems are seldom equipped with sampling ports at convenient locations. In such cases, bottom ashes were collected as grab specimens from ash deposits at the outlet of sluice pipes. In fact, at power plants where bottom and fly ashes are co-disposed, the ash sampled represented the coarse fraction of the ash in the lagoon.

Most of the power plants were burning Illinois Basin bituminous coals at the time of sampling. Generally, coal was supplied from a major source and was supplemented from various minor sources. Very few plants burned single-source coal.

The experimental program of this study consisted essentially of a laboratory investigation aimed at testing bottom ash samples by standard as well as nonstandard methods. A large number of diverse laboratory measurements were performed to develop an overall profile of the characteristics of each bottom ash. The laboratory testing program was implemented in three phases. The first phase was to conduct a characterization analysis of the ash materials. The second phase consisted of testing the bottom ash materials for their geotechnical properties. The third phase of the testing program was a laboratory evaluation of potential environmental effects of bottom ash utilization. This involved laboratory leaching tests and chemical analysis of the leachates.

Results

The majority of wet bottom ash particles were angular to subangular in shape and had a smooth surface texture. Most of the particles featured fractured faces, which made wet bottom ash much like crushed glass. On the other hand, dry bottom ashes had quite angular particles, and a highly porous surface texture was observed even in fine ash particles. It was also observed that dry bottom ashes were both externally and internally porous, resulting in an irregular particle shape and rough, gritty surface texture. The surfaces of the bottom ash particles were essentially free of dust, but some fly ash particles were observed to be loosely held to the surfaces of larger particles.

Mineralogical analysis revealed that crystalline compounds such as quartz (SiO_2) and hematite (Fe_2O_3) are found in almost all dry bottom ashes. Mullite ($3Al_2O_3 \cdot 2SiO_2$) and magnetite (Fe_3O_4) are also frequently found in dry bottom ash. Pyrite (FeS_2) was identified in two ash samples, one in significant content (Stout) and the other one in a minute amount only (Mitchell).

In general, Indiana bottom ashes are reasonably typical in chemical composition. The principal ash constituents in bottom ash are silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). There are smaller quantities of calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O), sodium oxide (Na_2O), and sulfur trioxide (SO_3), as well as minute traces of other elements.

Dry bottom ash and wet bottom boiler slag have quite different gradation characteristics. Dry bottom ashes exhibited well-graded size distribution ranging from fine gravel to fine sand sizes, whereas the gradation of the wet bottom ash was quite uniform with a majority of the sizes occurring in a narrow range between the No. 8 and No. 30 sieves. Of the 11 bottom ashes studied, ten (10) were classified by USCS as sand and the other one as gravel. The wet bottom ash was found to be poorly graded because of its low coefficient of uniformity. Classification of bottom ashes by the AASHTO system showed that all bottom ashes fall in the A-1 group, with 7 ashes classified as A-1-a and the remaining four as A-1-b.

Comparing the gradations of bottom ash with the specification limits given by the Indiana Department of Transportation showed that most dry bottom ashes would satisfy the gradation specifications for either the 1 in. or 1/2 in. top size materials. The wet bottom ash, being too uniform and coarse, fell outside the gradation specifications for bases and subbases.

The specific gravity of bottom ash were determined by the test methods applicable to aggregates and soils, as well as a gas pycnometer method. The specific gravity of bottom ashes was found to range from 1.9 to 3.4, which is much wider than that for most soils (ranges from 2.5 to 2.8). Generally, the more porous or vesicular an ash appears, the greater the variation in the specific gravity determined by different methods. It was also found that low specific gravities were always accompanied by greater variations in the measurements. Thus, it was concluded that a low specific gravity represents a highly porous or vesicular texture, which is the characteristic of popcornlike particles. Since popcornlike particles are readily degradable under loading or compaction, bottom ash containing a large amount of these particles are judged to be undesirable for engineering purposes. Therefore, the results from the specific gravity tests suggested that the specific gravity of bottom ash may be used as an indicator of the material quality.

The sodium sulfate soundness losses on bottom ashes after five cycles of soaking and drying varied from 1.3 to 10.8 percent. The wet bottom ash had the lowest sulfate soundness loss because of its glassy surface texture and its low porosity. The soundness losses for dry bottom ashes ranged from about 2 to 6 percent except for the ash produced from stoker furnaces. The presence of porous and popcornlike particles had caused a significant increase in the soundness loss of stoker ash. On the basis of the specification limits given by Indiana Department of Transportation [4] all bottom ashes studied would be considered adequate for class A subbase material.

The percent wear values determined by the Los Angeles abrasion test on all bottom ashes were less than 50, except the stoker ash. Some samples had abrasion values greater than 40 but less than 45. Thus, most bottom ashes would meet the specifications given by INDOT for class C subbase, and some ashes are able to meet the specifications for class A subbase [4].

A comparison between the sulfate soundness losses and abrasion values revealed that bottom ashes with high sulfate soundness losses also have high percentage wears under an abrasion test. Since the applicability of the sulfate soundness test on bottom ash material has been previously questioned, the Los Angeles abrasion test may provide a superior measure of the quality of bottom ash as an aggregate.

The measured coefficients of permeability ranged from 0.002 to 0.10 cm/sec for selected bottom ashes. The wet bottom ash displayed the largest value of coefficient of permeability due to its uniform size distribution and absence of fines. Generally, the coefficients of permeability of bottom ash fall in a medium permeability range, and are comparable to those of granular soils with similar gradings.

The calculated C constant in Hazen's equation varied from 0.1 to 0.9 for bottom ash samples. Considering the wide range of coefficient of permeability for soils, the Hazen's equation may be used in estimating the coefficient of permeability for bottom ashes, when testing is not practicable.

The angles of shearing resistance for bottom ash samples in a loose condition were quite large in magnitude, ranging from 35 to 45 degrees. It was found that the angle of shearing resistance for the wet bottom ash falls within the same range as that for conventional soils. The values obtained from dry bottom ashes were higher than those from conventional soils. Therefore, if bottom ash is used as an embankment material, the stability of the embankment can be higher than that for natural granular soils. If it is used in highway subgrades or subbases, the bearing value may be higher than that encountered with a natural sand.

The relationship between dry density and moisture content was determined by the standard Proctor compaction procedures for several bottom ash samples. The resulting moisture-density relations showed that the shapes of the moisture-density curves are typical of those for cohesionless materials. The dry densities obtained were high when the soil was air-dried, and high when the soil was completely saturated, with somewhat lower densities occurring when the soil had intermediate water contents.

The compaction curves showed a slight decrease in density at the highest water contents. Field compaction data reported on free draining materials indicated that field compaction curves do not show such a decrease. Field curves generally exhibit maximum dry density at either an air-dried condition or a "flushed" condition. Sometimes, the air-dried condition may not be practicable for field construction, but it is practicable to maintain the material in a flushed condition during the compaction process. If adequate measures have been taken to protect the underlying layers, close control of the water content will not be necessary, and the flushed condition can be achieved simply by applying an excess of water.

One-dimensional compression tests were performed on bottom ashes in a dense condition. Due to the high permeability of bottom ash, the deformations took place almost immediately. Comparing the stress-strain relationships obtained from several bottom ashes with those from an uniform medium sand it was found that bottom ashes were slightly more compressible than the sand.

The CBR values for bottom ash ranged from 40 to 70. Compared to the typical values for a number of soils and base course materials, bottom ash falls in the categories of "good subbases" and "good gravel bases" on the basis of the CBR values.

In order to evaluate the leaching potential of bottom ash, the Extraction Procedure (EP) toxicity test and an Indiana leaching method were conducted on bottom ash samples. The EP toxicity test is designed by EPA to simulate the leaching a solid waste will undergo in a sanitary landfill [5]. The Indiana leaching method test is specified in the Indiana Administrative Code [6] to classify restricted waste facility.

Results of the EP leachate analyses on bottom ash leachates showed that all concentrations of the regulated analytes in bottom ash leachates were well below the maximum contaminant levels in EP toxicity, in most cases one to three orders of magnitude lower. Therefore, bottom ashes could be characterized by the EP toxicity test as nonhazardous according to current EPA regulations governing solid waste characterization [5].

The salt content of bottom ash leachates was tested by the Indiana leaching method. The concentrations of the regulated analytes were compared with the maximum allowable limits specified in the Indiana Administrative Code (329 IAC 2-9-3) for type IV restricted waste site [6]. In all cases, the concentrations of bottom ash leachates are far below the type IV criteria which are the most restrictive ones in the code.

It was also noted that the leachate from wet bottom ash had lower concentrations of trace metals and salts than the leachates from dry bottom ashes. However, no correlation between the pH value and the leachate concentrations was found. All of the bottom ashes tested had leachates that were slightly alkaline in character. It was reported that ash leachates exhibiting acidic nature are most likely because of the presence of pyrite particles in ash materials.

Pyrites, produced from preparation of coal prior to firing, are known to characteristically exhibit the highest pollution potential. This is because pyrites will react with oxygen and water to form ferrous iron and sulfuric acid. The resulting acidic environment tend to increase the rate of dissolution of heavy metals and possibly produce a contaminated leachate. If pyrites are indiscriminately mixed with ash, leachate generated from the mixture could pose a problem because of the low pH that increases the potential for unacceptable concentrations of trace metals in the leachate.

In this study, leachates from the two ash samples containing pyrites showed very low pH values. Leachate from Stout ash, which contained significant amount of pyrites, had a pH as low as 2.9, as determined by the Indiana leaching method. Although there was only trace amount of pyrites present in Mitchell ash, the pH of the leachate from this ash was 6.0. Because visual identification of pyrite particles in bottom ash is difficult, especially if pyrites are present in a limited amount, the pH measurement may be used to identify bottom ash-pyrite mixtures which are objectionable in terms of environmental concerns.

Economic Evaluation

The economic evaluation of the use of bottom ash focused on two phases:

1. An assessment of economic potential for Indiana bottom ash based largely on the quantities available and their location with respect to potential market areas.

2. A qualitative study of the cost factors that would determine the cost of bottom ash in place for development as a highway construction material.

In 1986, there were 29 utility power plants in the state of Indiana which burned coal as the primary fuel. Of the 29 power plants, 20 were operated by the five utility companies in the state, and 9 were smaller municipal or privately-owned operations. However, coal burning power plants are not spread uniformly throughout the state. There is a high concentration in the extreme southern part. In contrast, northeastern Indiana is essentially without coal-burning power plants.

A comparison of the areas short of aggregate supplies with the distribution of coal-burning power plants in Indiana revealed that the aggregate shortage areas are well covered by power plants. Population and economic growth are generally accompanied by increased construction activities. Since population shifts have been toward the big cities, all major cities in Indiana are expected to continue their growth. Areas that are expected to have the highest rate of population and economic growth in Indiana are the Lake region, Indianapolis, north vicinity of Louisville, Fort Wayne, Evansville, and Terre Haute. Again, almost all of these areas have power plants. Therefore, bottom ash has a great economic potential for use as a highway construction material in these areas.

Conclusions

Current disposal practices suggest that power plant bottom ash is still considered by many power-generating companies as a waste product. If more extensive utilization of the material is expected, bottom ash must be regarded as an useful resource by utility companies. It is strongly desired that power plants exercise closer controls over the production, collection, and stockpiling of the material to provide a product of greater uniformity.

Based on the results of laboratory evaluations of selected Indiana bottom ashes, it is concluded that the properties of bottom ash compare favorably with conventional granular materials, and the majority of the bottom ashes are suitable for various uses in highway construction. It is obvious that utilization of such extensively produced by-products of the power industry as an economic highway material should be encouraged in the immediate future. It is recommended that the Indiana Department of Transportation proceed to schedule the construction of experimental sections of embankment and pavement using bottom ash.

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