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Effective Use of Bottom Ash as a Geotechnical Material

Braja M. Das

Ali A. Selim

Tom W. Pfeifle

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Braja M. Das
Civil Engineering Department
The University of Texas at El Paso
El Paso, Texas

Ali A. Selim
Civil Engineering Department
South Dakota State University
Brookings, South Dakota

Tom W. Pfeifle
McClelland Engineers, Inc.
St. Louis, Missouri

Abstract

Some geotechnical properties of bottom ash produced from the burning of North Dakota lignite in a power plant are presented. These properties include grain size distribution, maximum and minimum void ratios, maximum dry density of compaction and optimum moisture content from standard Proctor tests, angle of friction, one-dimensional compressibility, and coefficient of permeability. The geotechnical properties of this bottom ash, as determined from laboratory tests, appear to be comparable to those generally obtained from poorly graded sands and indicate that bottom ash can be used for such works as backfill of retaining structures, construction of highway embankments, and fill material for grading purposes.

1. INTRODUCTION

With the current problem of obtaining a cheap and reliable source of energy, coal is probably considered to be the best possibility, at least for the near future. Statistics show that the coal reserves in the United States exceed any other energy resource material. It appears that coal can be used for solving our immediate energy problems, provided the waste products such as boiler slag, fly ash, and bottom ash produced by coal-burning power plants can be properly disposed of.

In the last decade or so, a number of investigators have worked on the physical and chemical properties of fly ash and its possible applications as a geotechnical material.

Bottom ash, which is another waste product of coal-burning power plants, is a granular material. This ash, which is insoluble and chemically inert, is not a pollutant. However, limited studies have so far been done to evaluate its properties and possible uses. In most cases, it is removed from the plant site at the owner's expense. This necessitates the acquisition of proper disposal sites and consideration of environmental and aesthetic problems.

Seals, Moulton and Ruth (5) have, in a more recent paper, studied the geotechnical and chemical properties of several bottom ashes produced by burning of bituminous coal. In this paper, the results of some laboratory tests conducted for evaluation of the geotechnical properties of a bottom ash produced from burning of a North Dakota lignite at Big Stone Power Plant are presented. These have been compared with similar properties of sand to determine its possible applicability in such works as backfill of retaining walls, fill material for construction of embankments, etc.

2. ORIGIN OF BOTTOM ASH

Big Stone Power Plant is located in the northeastern corner of South Dakota and is jointly owned by Montana-Dakota Utilities Company, Northwestern Public Service Company, and Otter Tail Power Company. The fuel used in this plant is North Dakota lignite with an annual total of over two million tons obtained from the Knife River Coal Mining Company near Gascoyne, North Dakota. North Dakota lignite has about 42% moisture and contains about 1/2 to 3/4% sulphur as opposed to 3 to 4% for most bituminous coals.

For power production purposes, the lignite is crushed to a size of 1/4 in. or less and then it is fed to cyclone furnaces that fire the boiler.

Each day approximately 140 tons of fly ash and about 360 tons of bottom ash are produced from the plant.

The bottom ash analyzed here was collected from the stock piles of the Big Stone Power Plant. The ash was brought to the laboratory and oven dried at 104° C for about 48 hours before the beginning of various test programs.

3. LABORATORY TEST PROGRAM

The laboratory tests performed included grain size analysis, specific gravity, maximum and minimum void ratios, standard Proctor compaction density, direct and triaxial shear, one-dimensional compression, and permeability. The general procedure, results, and analysis of each of the tests are given below. It needs to be pointed out that many of the physical properties of a bottom ash will depend on the source of coal, type of boiler, and some other minor factors. The intent of this paper is only a qualitative evaluation of the geotechnical properties and assessment of its possible uses.

3.1 GRAIN SIZE ANALYSIS

Dry sieve analysis on a representative sample of bottom ash was made using U.S. sieves No. 4, 10, 20, 40, 60, 100, and 200. The grain size distribution is shown in Fig. 1. The uniformity coefficient and the coefficient of gradation are given as,

$$C_u \text{ (uniformity coefficient)} = \frac{D_{60}}{D_{10}}$$

$$= \frac{1.05 \text{ mm}}{0.46 \text{ mm}} = 2.28 < 6$$

$$C_c \text{ (coefficient of gradation)} = \frac{D_{30}}{D_{60} \times D_{10}}$$

$$= \frac{(0.8 \text{ mm})^2}{1.05 \text{ mm} \times 0.46 \text{ mm}} = 1.32$$

Based on the Unified Soil Classification System, this can be grouped under the category of SP (poorly graded sand--little or no fines) and as A-1-b according to the AASHTO Classification System.

3.2 SPECIFIC GRAVITY OF SOLIDS

Specific gravity of the solids was determined in accordance with the ASTM designation D-584. The average value from a number of tests was found to be 2.81. This value is somewhat higher than those generally obtained for various sands ($\simeq$ 2.65 to 2.7) with little or no fines. Also, it appears to be higher than those obtained by Seals, Moulton and Ruth (5). This comparison is shown in Table 1.

TABLE 1. SPECIFIC GRAVITY OF BOTTOM ASH

Source	Specific gravity	Reference
Fort Martin		
Unit 1	2.35	(5)
Unit 2	2.48	(5)
Kammer	2.72	(5)
Kanawha River	2.28	(5)
Mitchell	2.78	(5)
Muskingham	2.47	(5)
Willow Island	2.61	(5)
Big Stone	2.81	Present study

3.3 MAXIMUM AND MINIMUM VOID RATIOS

In granular materials, the degree of compaction is often expressed in terms of relative

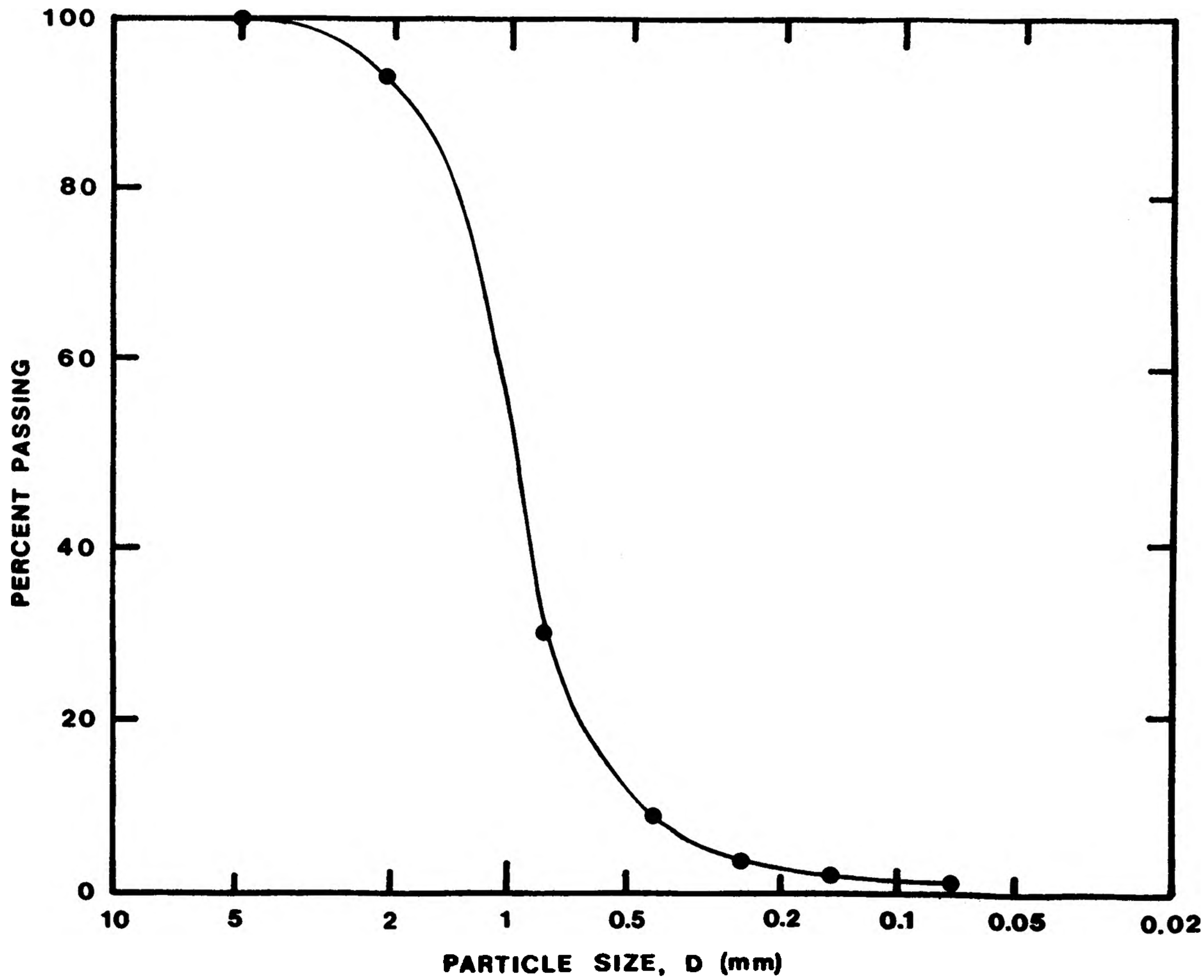

Fig. 1. Grain size distribution

density. For that reason, the maximum and minimum dry unit weights were determined in the laboratory in accordance with ASTM test designation D-2049, and found to be 106 and 86 lb/ft^3, respectively. The dry unit weight can be expressed by the equation,

$$\gamma = \frac{G_s \gamma_w}{1 + e} \tag{1}$$

where,

G_s = specific gravity of solids,

γ_w = unit weight of water

γ = dry unit weight, and

e = void ratio.

The minimum and maximum void ratios which correspond to the maximum and minimum dry unit weights were calculated to be 0.654 and 1.04, respectively. In Fig. 2, the ranges of void ratio encountered in various types of sandy soils have been compared with those found in the case of this bottom ash.

3.4 STANDARD PROCTOR COMPACTION TEST

The results of the standard Proctor compaction tests (ASTM D-698; 5-1/2 lb hammer, 3 layers and 25 blows/layer) conducted on the bottom ash are shown in Fig. 3. The maximum dry density obtained in the laboratory was about 104.4 lb/ft^3 at a moisture content of 20.5%.

3.5 ONE-DIMENSIONAL COMPRESSION

One-dimensional compression tests on the ash were conducted by using the standard laboratory consolidation equipment. Only that portion of the ash which passed No. 10 sieve was used for performing the tests. (Note: 93% of the ash was passing No. 10 U.S. sieve.) The tests were made on several specimen--each

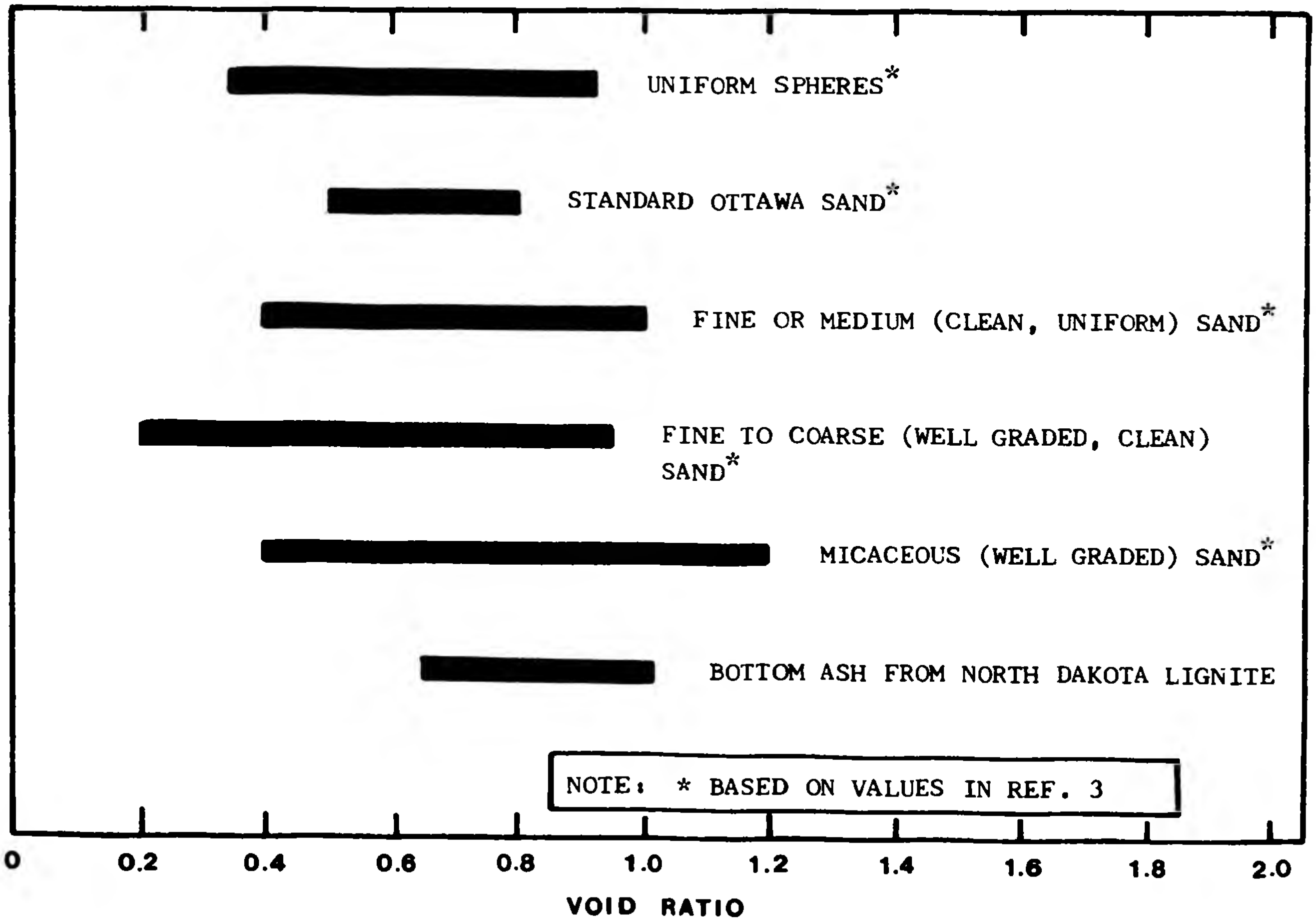

Fig. 2. Comparison of the range of void ratios encountered in the ash with that of various types of sand

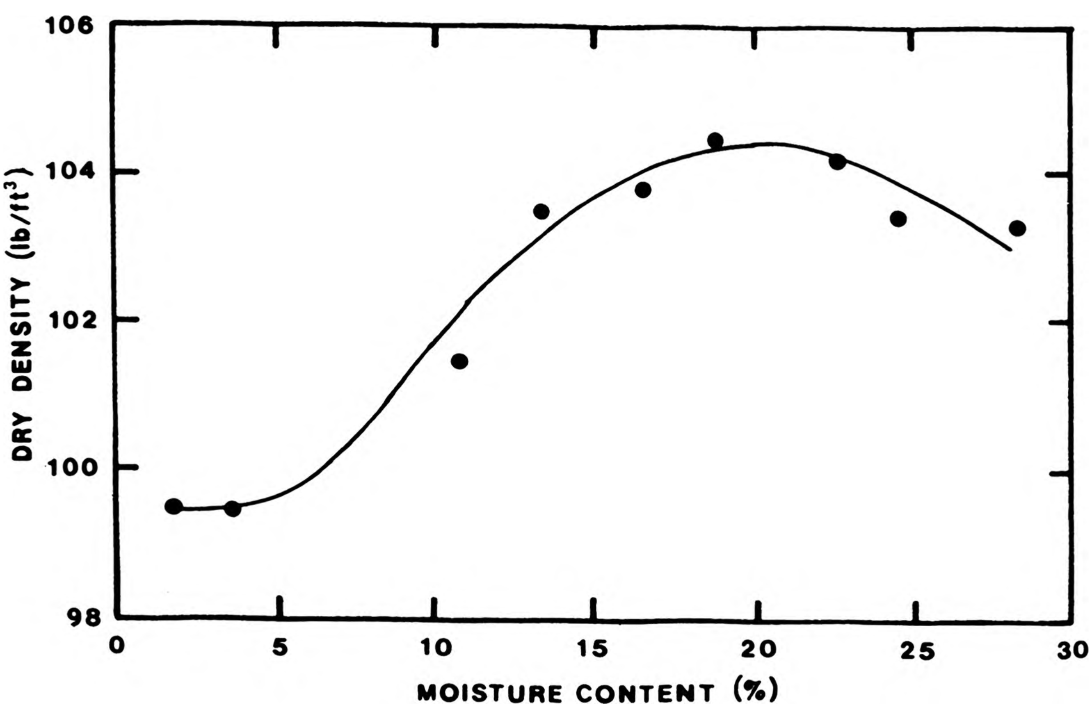

Fig. 3. Moisture-density relation from standard Proctor tests

one being prepared as a different initial relative density. The relative density is defined as,

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \quad (2)$$

where,

e_{max}, e_{min} = maximum and minimum void ratios determined in the laboratory (Sect. 3.3), and

e = void ratio at compaction.

Normal stress on each specimen was increased in steps up to about 170 lb/in^2.

Fig. 4. shows a plot of the axial strain against the corresponding normal stress at relative densities of 0, 26, 51, and 100% The constrained secant modulus is defined as,

$$M = \frac{\Delta\sigma_v}{\Delta\epsilon_v} \quad (3)$$

where,

$\Delta\sigma_v$ = incremental vertical stress, and

$\Delta\epsilon_v$ = incremental vertical strain.

The values of constrained secant modulus calculated from Fig. 4 (from zero stress to the stress level indicated) are given in Fig. 5. At σ_v = 100 lb/in^2, the values of M for relative densities of 0 and 100% are about 3000 lb/in^2 and 9000 lb/in^2, respectively. These values are generally comparable to those obtained for well-graded sandy soil.

3.6 DIRECT AND TRIAXIAL SHEAR TESTS

A number of direct and triaxial shear tests were performed on the minus 10 fraction of ash. Samples for the tests were prepared at various initial relative densities. The angles of shearing resistance obtained from those tests are given in Fig. 6. Based on the limited test results, the angle of friction, ϕ, may be approximated as,

Direct shear test:

$$\phi = 36 + 0.12\, D_r \quad (4)$$

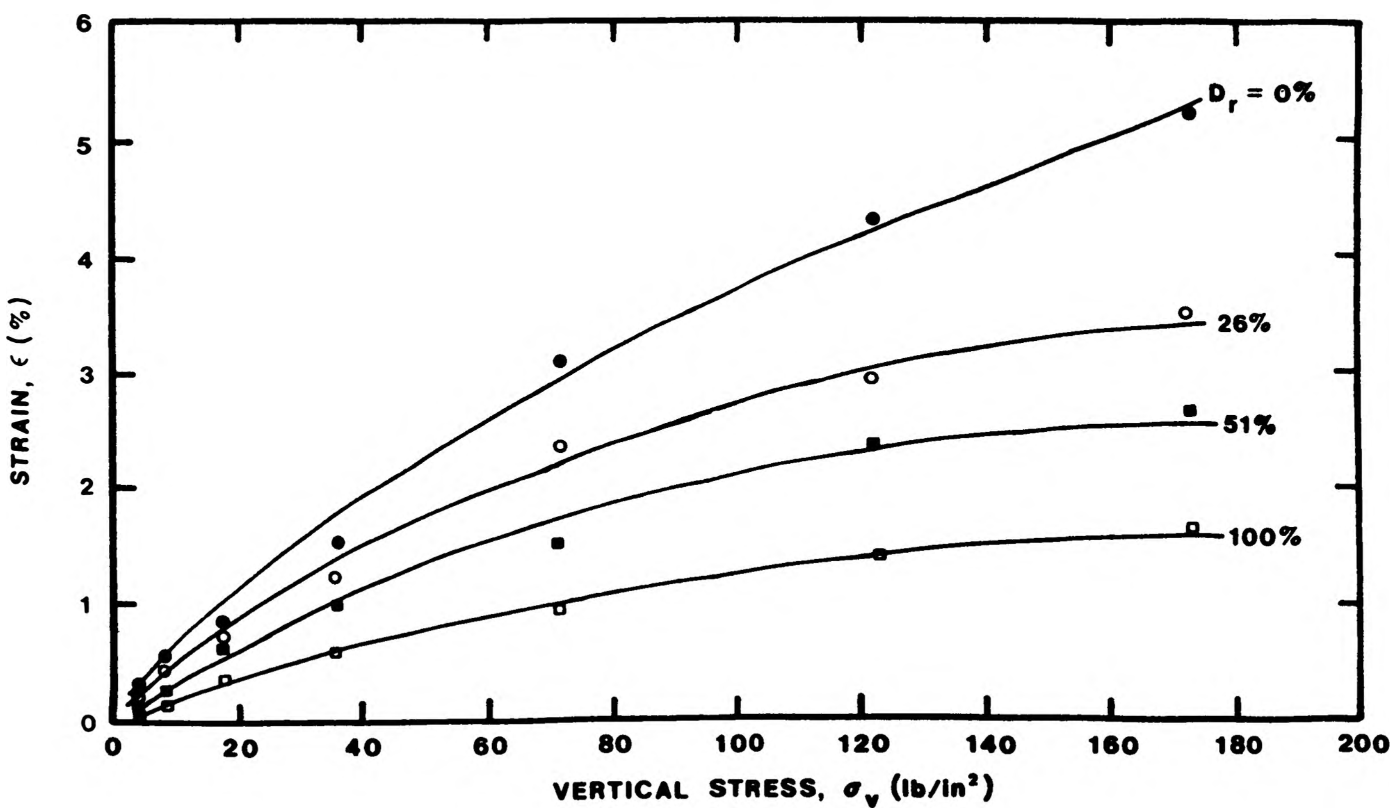

Fig. 4. Plot of axial strain against stress from one-dimensional compression tests

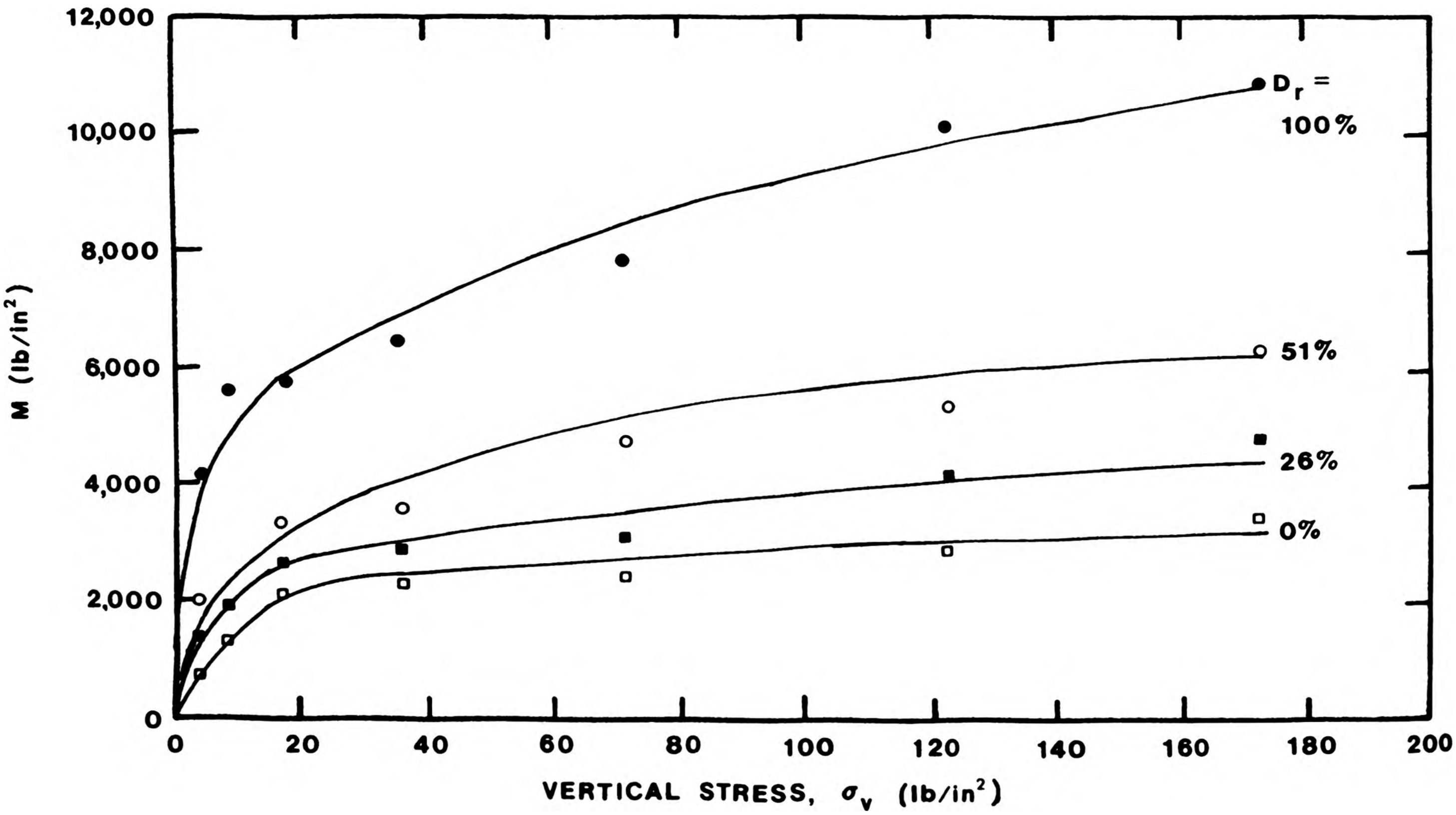

Fig. 5. Constrained secant modulus for zero stress to the stress level shown

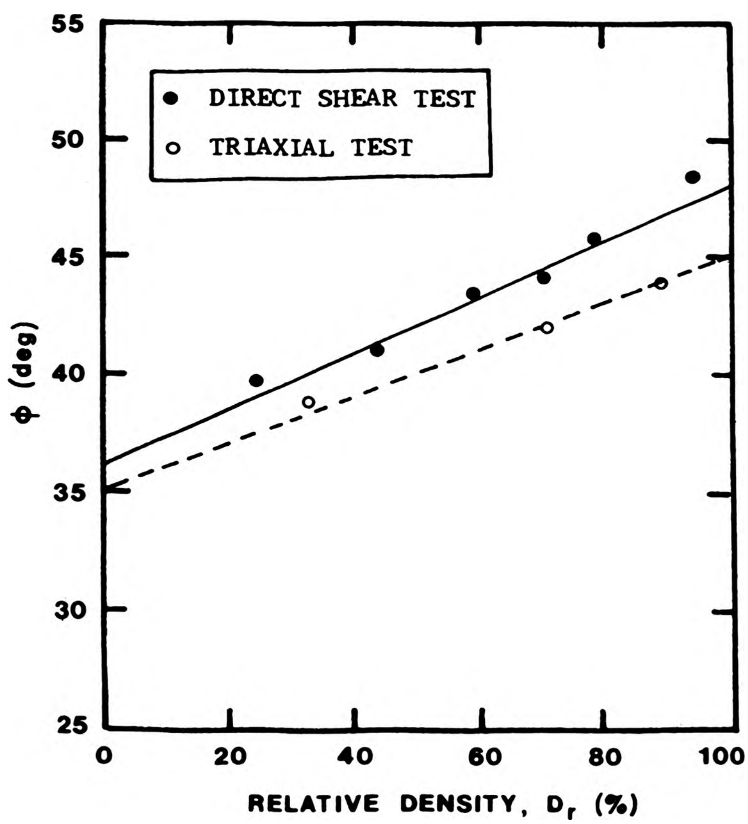

Fig. 6. Variation of angle of friction with relative density

and triaxial shear test:

$$\Phi = 35 + 0.10\ D_r \tag{5}$$

For a given relative density, the slightly smaller value of the friction angle in the triaxial tests, as compared to the direct shear tests, was expected due to the difference in confining stress conditions.

The angle of friction at a given relative density depends on several factors such as size and shape of individual particles. The general range of friction angle encountered in sand as given bv Zeevaert (6) is shown in Fig. 7. The lower and upper limits of this range can be approximated as follows,

For smooth grains:

$$\Phi = 28 + 0.07\ D_r \tag{6}$$

and for angular grains:

$$\Phi = 29 + 0.17\ D_r \tag{7}$$

Based on field observations, Meyerhof (4) has also given similar relations for friction angle of sand in the form,

$$\Phi = 25 + 1.15\ D_r \tag{8}$$

(for sands with more than 5% fine)

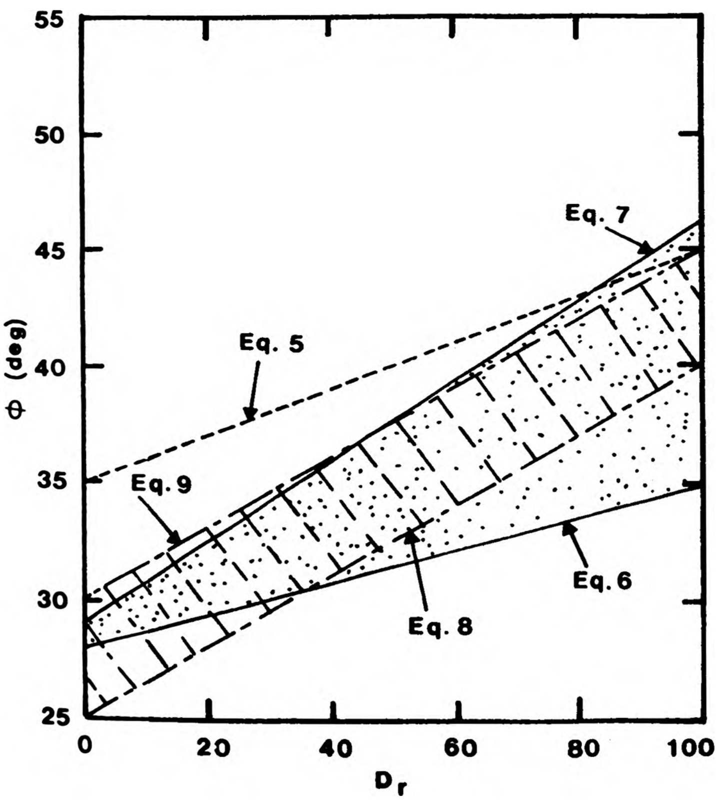

Fig. 7. Comparison of friction angle of the bottom ash with that generally obtained in sand

and

$$\phi = 30 + 0.15\ D_r \tag{9}$$

(for sands with less than 5% fine)

Eqs. (8) and (9) are also shown in Fig. 6. For comparison purposes, Eq. (5) for the bottom ash is also plotted in Fig. 7. It may be seen that, in general, the values of ϕ are higher than those generally encountered in sands. This property of the bottom ash is an advantage, particularly for cases when it is used as a backfill material of retaining structures since the total pressure on a wall of a given height is directly proportional to the active pressure coefficient. With a higher value of ϕ, the active pressure coefficient will be less and thus the total design pressure. Similar advantages could be derived in the higher factor of safety of embankment slopes.

3.7 PERMEABILITY TESTS

Coefficients of permeability, k, of the ash at various void ratios were determined in the laboratory by means of constant head permeability tests. The experimental values are shown in Fig. 8. The range of variation of the coefficient of permeability is from 0.14 cm/sec in the loosest state to about 0.03 cm/sec in the densest state. Table 2 shows the general range of values for the coefficient of permeability for sandy soils along with those determined for the ash. The comparison shows that the drainage quality of the ash is comparable to that of clean sand.

TABLE 2. COMPARISON OF THE TYPICAL VALUES OF THE COEFFICIENT OF PERMEABILITY OF SAND WITH THAT OF THE BOTTOM ASH

Soil type	k (cm/sec)	Reference
Clean sand (coarse)	1-0.01	(2)
Sand (mixture)	0.01-0.005	(2)
Fine sand	0.05-0.001	(2)
Silty sand	0.002-0.0001	(2)
Bottom ash	0.14-0.03	

4. CONCLUSIONS

Some standard and useful laboratory test results on a bottom ash produced by burning of lignite are presented. Based on these test results, the following conclusions can be drawn:

(1) The common geotechnical properties such as grain size, compressibility, and permeability compare reasonably well with those of sandy soils.

(2) The angle of friction of the ash at a given relative density is rather high as compared to that of sand. This is an advantage from the design point of view, if the ash is used for backfill of retaining structures, construction of embankments, etc.

(3) If the bottom ash is not a pollutant, it can be reasonably and economically used in various construction works without treating it as a waste material.

(4) The properties of a bottom ash will vary depending on the source of coal and type of furnace used. Thus, the geotechnical properties for each ash

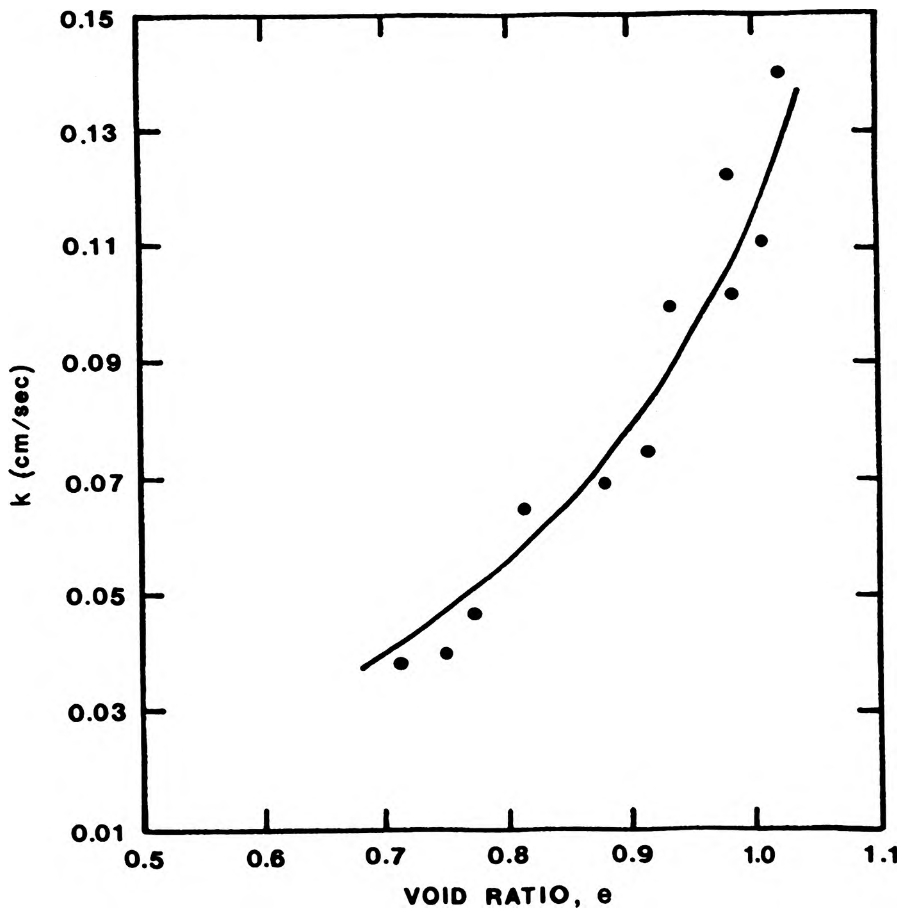

Fig. 8. Variation of k with void ratio

need to be evaluated before possible use.

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BIOGRAPHIES

Braja M. Das received his bachelor's degree in civil engineering from Utkal University, India, in 1963, and his Ph.D. in the area of soil mechanics and foundation engineering from the University of Wisconsin at Madison in 1972. Presently he is a member of the Faculty of Civil Engineering at The University of Texas at El Paso.

Ali A. Selim received his bachelor's degree in civil engineering from Egypt. He was awarded his Ph.D. in civil engineering from the University of Missouri-Rolla in 1976. He is presently an associate professor in the Civil Engineering Department at South Dakota State University, Brookings.

Tom W. Pfeifle received his B.S. degree in civil engineering from South Dakota State University in 1976. He also received his M.S. in the area of soil mechanics and structures from the same school in 1978. He is presently employed as a geotechnical engineer with McClelland Engineers, Inc., St. Louis, Mo.