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Improvement in California Bearing Ratio of Various Soils in Botswana by Fly Ash

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Synopsis

Botswana is a country of about 581730 km^2 in area. Three quarters of which is covered by sands of the Kalahari Desert on the western side of the country. Rapid development has taken place in road construction in Botswana during the past decade. A major problem in providing an adequate road system in this region has been the scarcity of good road construction material compounded by adverse climatic and geological factors.

In the present investigation effort has been made to improve California bearing ration of various types of soils by adding fly ash alone. Soils of various grading, varying from Kalahari sand to clay of high plasticity were collected from different parts of the country. These soils were mixed with different proportions of fly ash. California bearing ratios (C.B.R.) of 4 days soaked samples of all the soil-fly ash admixtures were determined. All the samples were cured in the mould for 7 days before soaking them in water. It was found that C.B.R of all the soils increased with the increase in fly ash proportion as well as with the curing period. The gain in C.B.R. was found to be maximum in sandy soils and minimum in clayey soils with silty soils falling in between. The use of fly ash in stabilizing soils for road construction would provide an economic solution to improve the material for road construction as well as reduce the amount of dumping of fly ash as a waste, which is about 350 tons per day in Botswana.

Introduction

Botswana is a country of about 581730 km^2 in area. Three quarters of which is covered by sands of the Kalahari Desert on the western side of the country. Rapid development has taken place in road construction in Botswana during the past decade. A major problem in providing an adequate road system in this region has been the scarcity of good road construction material compounded by adverse climatic and geological factors. Such a situation results either in importing the materials from a long haul distance or to stabilize these materials with costly additives like cement. This makes the project prohibitively expensive especially in case of a low trafficked road.

In recent years application of fly ash has been considered in road construction with great interest. A successful use of fly ash in soil stabilization not only reduces the cost of the project but it also provides a solution to make use of a material which otherwise would have to be disposed as a waste.

Fly ash is a waste product of coal burning. Globally, thermal power stations produce several million tons of fly ash every day. Most of it is being dumped as waste. Only a few countries are using limited amount of fly ash in the construction of structural fills, bulk fills, flowable material fills, road bases, earth embankments, and compressed soil blocks, while in most of the countries it is being dumped as a waste. The President of the Indian Geotechnical Society, which reads as follows, recently made a nation wide pledge in a News Bulletin[1]:

"Accumulation of fly ash has reached alarmingly high levels requiring immediate attention for its disposal. Geotechnical engineering activity is a primary mechanism of its bulk utilization and disposal. This requires a certain amount of basic and applied research both in field and laboratories. I would urge members to contribute in this emerging area."

In Botswana, the only Power Station at Morupule produces fly ash at a rate of about 350 tons per day. Only about 5% of fly ash is being used by cement industries while more than 95% is being dumped on land as a waste material. In the present investigation effort has been made to stabilize various types of soils by fly ash.

Material Used

Soils

In all six different types of soils varying from non-plastic sands to clays of high plasticity were collected from different locations.

Soil 1 – Kalahari sand:
The Kalahari sand covers almost three quarters of the country's total area. This sand belongs to a family of arid soils. Arid soils are those soils, which are conditioned by an arid climate. The typical characteristics of arid soil strata are:

- Low water content and low water table resulting in them being unsaturated and having relatively large pore water suctions.
- They have a crust, which is rich in salts. This often arises largely from the upward moisture loss at the top of the profile by evaporation. It often results in arid soils, which get cemented or bonded by the precipitation of salts.
- They are often cemented by calcium carbonate to form calcrete.
- These soils are usually sorted and deposited by wind resulting into the formation of poorly graded (single sized) soils having very loose structure.

The Kalahari sand varies in colour:

I. White to buff - these are clean quartz sands
II. Red, brown or purple - depending upon the amount of iron coating

III. Greenish - when the iron oxide has been reduced in stagnant water, and
IV. Grey – when it is mixed with humus.

In the present investigation white Kalahari sand was used.

Soil 2 – Calcrete:.
The calcrete, which exist in Botswana, are the result of pedogenic soil forming process, in which carbonates of calcium (and often magnesium) have accumulated in Kalahari sand. Solution and deposition over time have since given rise to a number of calcareous deposits, all called calcrete, varying from loose calcified sand to massive, hard "rock". The calcrete used was a nodular calcrete, which is found throughout the region (Palapye) around the power station. The grading modulus of this material is fairly high in its natural state, however, with little mechanical effort it breaks down to much smaller size particles. The grading modulus, therefore, could be a misleading parameter for this material to be used for road bases.

Soil 3,4 and 5 – Silty sand (SM) and Silts of intermediate and low plasticity (MI, ML):
These inorganic soils of varying gradation and plasticity were collected from typical sites located within a radius of 40 km around the power station.

Soil 6- Black cotton soil (B.C.S):
This is an expansive soil of high plasticity(CH). It is found in abundance in Francistown, a town located at a distance of about 150 km north of power station. The soil is highly unsuitable as a construction material due its volume change characteristics with the change in water content. However, it was included in the investigation to cover a wide rang of soils with varying plasticity.

Fly ash
Fly ash can be defined as the fine ash that is carried out of the boiler with the flue gases. The fly ash shows some pozzolanic properties, which depends upon its chemical composition. Higher free lime and lower unburnt carbon enhances its pozzolanic property. The fly ash sample used in this investigation is a mixture of grabs samples obtained from Morupule power station. Chemical composition of fly ash (as supplied by Botswana Power Corporation) is shown in Table-1.

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	Na_2O	P_2O_5
Composition %	41.2	33.6	5.08	6.45	3.0	2.31	0.44	0.1	<0.05

Table-1 Chemical composition of fly ash

Soil – Fly ash Mixtures:
The soil – fly ash mixtures were prepared by mixing 4, 8, 16 and 24% of fly ash (by weight) with all the soils respectively. All these mixtures were tested in the laboratory for their index properties, compaction characteristics and California bearing ratios.

Laboratory tests

All the classification tests were performed as per Standard Test Methods TMH1, SABS - 1980, which is also being followed by the Department of Roads in Botswana.

Compaction Test:
The tests were carried out to determine the maximum dry density (MDD) and optimum moisture content (OMC) of soil mixtures at Modified AASHTO compaction effort. The mould used was 152.4 mm in diameter and 152.4 mm high. The samples were compacted in 5 layers by applying 55 blows to each layer with a free fall of 457.2 mm of 5.5 kg weight.

California Bearing Ratio
The samples were prepared at OMC and compacted using Modified AASHTO compaction effort. The samples were then cured for 7 days using gunny bags. The compacted samples in the moulds were wrapped with gunny bags, which were kept wet all the time by sprinkling water at regular intervals. The samples were then soaked in water for 4 days under a surcharge weight of 5.5 kg. At the end of 4 days, the samples were taken out, drained and tested for C.B.R. The rate of penetration of the plunger was kept at 1.27 mm per minute.

Results and Discussions

The results of all the classification tests are tabulated in Table-2. The soils were classified as per B.S. classification.

No.	Soil Type	Liquid limit W_l %	Plastic limit W_p %	Plasticity index I_p	Linear shrinkage %	Specific gravity G_s	Classification
1.	Kalahari sand	NP	NP	NP	0	2.68	SP
2.	Calcrete	28	15	13	6.0	2.73	GS
3.	Silty sand	25	21	4	0	2.70	SM
4.	Silty soil	37	27	10	5.7	2.77	MI
5.	Silty soil	38	26	12	9.64	2.90	ML
6.	Clay	65	27	38	22.9	2.73	CH
7.	Fly ash	NP	NP	NP	0	2.10	ML

Table-2 Properties of Soils and Fly ash

The gradation curves of all the soils and fly ash are shown in Fig.1

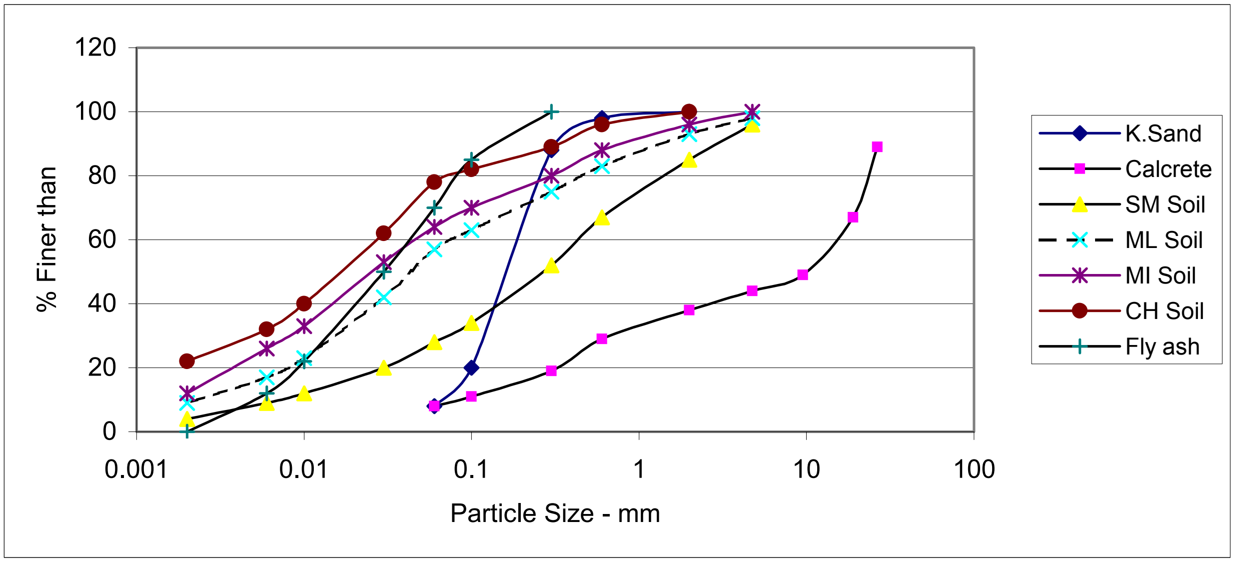

Fig. 1 Gradation curves of all the soils and fly ash

Results of compaction tests on all the soils and their admixtures with fly ash are shown in Table-3.

Fly Ash	K. Sand		Calcrete		SM Soil		ML Soil		MI Soil		CH Soil	
	OMC %	MDD Kg/m^3	OMC %	MDD Kg/m^3	OMC %	MDD Kg/m^3	OMC %	MDD Kg/m^3	OMC %	MDD Kg/m^3	OMC %	MDD Kg/m^3
+0%	5	1765	15.6	1753	9	1936	12	2020	11	1982	20	1544
+4+	5	1740	19	1687	8.8	1920	11.9	2015	11	1960	22	1550
+8%	5	1710	19.9	1670	8.8	1900	11.9	2000	10.8	1940	22.7	1564
+16%	6	1605	23.4	1665	9	1866	11.7	1946	11.5	1904	21.4	1584
+24%	7	1502	17	1662	9	1853	12.3	1926	12	1870	23.5	1508

Table-3 OMC and MDD of all the admixtures

It is noted that while there is hardly any effect of fly ash on OMC, MDD in general decreases with the increase in fly ash proportion. This variation was expected, as the specific gravity of fly ash is relatively lower than that of soils, which decreases the specific gravity of the soil – fly ash admixture. However, black cotton soil was exception to this trend where MDD increased slightly up to 16% of fly ash, and then it decreased. It is in accordance with the findings of Indraratna and Kuganinthira[2], who found that for dispersive clays the MDD first increases and then decreases with the increase in fly ash content.

California Bearing Ratio:

The variation of C.B.R. with fly ash is shown in Fig.2. It is observed that the addition of fly ash increases the C.B.R. of all the soils except for Kalahari sand for which it decreases. The gain is found to be maximum for silty sand and minimum for black cotton soil. In general higher the plasticity index lower is the gain. Two more samples of

Kalahari sand were tested with 28% and 32 % of fly ash. It is interesting to note that C.B.R. of Kalahari sand was found to show a trend of increasing C.B.R. beyond 24%, suggesting that higher amount of fly ash is needed for effective pozzolonic activity in case of a poorly graded inert material such as Kalahari sand.

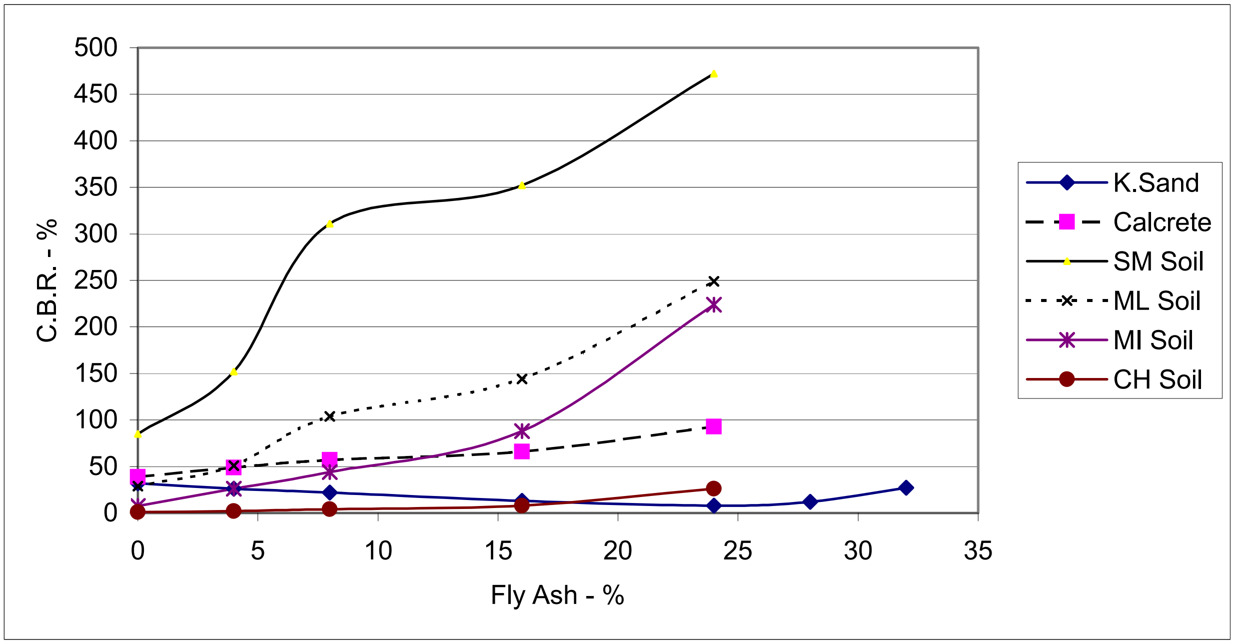

Fig. 2 Variation of C.B.R. with fly ash

For design of roads in Botswana, in terms of C.B.R., the specifications[3] are as follows:

	High Traffic Roads (HTR)	Low Traffic Roads (LTR)
Bases courses	80%	45%
Sub-bases courses	45%	25%

It can be seen from Fig.2 that except for Kalahari sand and black cotton soils all other soils, which were unsuitable for base courses for HTR were suitable after stabilization with fly ash. The amount of fly ash required for improvement varied with soil type. The improvement was primarily due to the pozzolanic activity of fly ash, which depends upon the amount of free lime present. It has been found that if the unburnt carbon is negligible, even a small quantity of free lime present in fly ash can initiate pozzolanic hardening [Koo[4]].

CONCLUSION

1. California bearing ratio of all the soil is increased with the addition of fly ash except for Kalahari sand which first decreases and then increases beyond 16% of fly ash.

2. The increase in California bearing ratio is maximum in silty sand and minimum in black cotton soil.
3. Silty sand, calcrete and silts of low and medium plasticity can be used for base courses by stabilizing with fly ash.

RECOMMENDATION

An effort should be made to use fly ash to stabilize soils for road construction, which would reduce the amount of waste globally. However, since the pozzolanic activity of a fly ash depends upon various factors, samples from each batch of fly ash should be tested in the laboratory before suggesting specifications about the amount of fly ash to be mixed with a soil.

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