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Strengthening Black Cotton Soil with Fly Ash and Moorum: An Investigation of the Role of Subgrade and Subbase Layers

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A B S T R A C T

One of the most effective and economical methods to strengthen clayey soils is addition of stabilizing agents such as fly ash to the soil. In this study, highly plastic clay was stabilized using fly ash. Geotechnical properties such as Atterberg limits, unconfined compressive strength (UCS), and the California bearing ratio (CBR) value of virgin black cotton soil and soil treated with fly ash were evaluated. Soil was stabilized with various proportions of fly ash, i.e., at 0%, 10%, 15%, 20%, and 30%. The UCS of black cotton soil–fly ash mixes is found to be at its maximum at 20% fly ash content and thereafter decreases with further increases in fly ash content. However, in the case of fly ash mixed with soil, the CBR value obtained was less compared with virgin soil. Furthermore, CBR was performed with two-thirds part fly ash soil mixed with one-third part moorum with better results. The maximum CBR value was found to be 5.03% at 20% fly ash content. These results are significant; they prove that we can use fly ash as subgrade material for the reason that in actual conditions, water does not easily enter into the subgrade layer because it is protected by a moorum (subbase) course.

A R T I C L E I N F O

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1. Introduction

Some soils possess low strength and volume change characteristics, and consequently, we cannot use them directly in highways. In India, about 51.8 million hectares of the land area are covered with expansive black cotton soil (Mehta et al., 2013). Black cotton soil has the tendency of undergoing volumetric change due to change in moisture content. This will create instability to the structure resting on it. The properties of the soils may be altered in many ways by, viz., mechanical, thermal, chemical, and other treatments. Modification of soil properties by admixtures is a common stabilization method for such soils. Among various admixtures available, lime, fly ash, and cement are most widely and commonly used for the stabilization of soils. In India, coal is the primary fuel in thermal power plants and other industries, and it produces fly ash as a by-product. Fly ash contains siliceous and aluminous materials and also a certain amount of lime. Fly ash is a nonplastic material, and it reduces the plastic properties of soil. Generally, less than 35% of the total amount of fly ash is utilized worldwide (Lieberman et al., 2014). While use of fly ash is relatively high in the construction sector as bricks and in the production of cement (Scheetz and Earle, 1998; Ahmaruzzaman, 2010), we present here potential use of fly ash for stabilization of soil.

2. Details of the Experiment

This section provides details of the experiments conducted. Section 2.1 notes the test conducted, and section 2.2 provides the details of materials used.

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2.1 Tests conducted

In this study, fly ash was used in subgrade soil with the main aim of improving the engineering properties of the soil. Moorum was used in the subbase. Index properties such as maximum dry density (MDD) and optimum moisture content (OMC) at different percentages of fly ash and soil mixtures, and engineering properties, such as California bearing ratio (CBR) and unconfined compressive strength (UCS), were evaluated for flexible pavements. Specifically, the following tests were conducted for this study:

1. Grain size analysis of soil and moorum.
2. Consistency limits of soil, moorum, and soil–fly ash mixtures (at different percentages).
3. Proctor compaction test for determining MDD and OMC of moorum, soil, and soil–fly ash mix (at different percentages).
4. UCS test for only soil, and soil–fly ash mix.
5. CBR test of moorum and soil, and soil–fly ash mix with two-thirds layer of mix and one-third layer of moorum.

2.2 Materials used

Following are the detai ls of the materials used in the experiment.

2.2.1 Soil

Natural soil was obtained from Kamptee (Nagpur District) in Maharashtra Province of India. The soil was excavated from a depth of 2.0 m from the natural ground level. The soil is dark gray to black with high clay content.

2.2.2 Moorum

Moorum was used in the subbase course. Locally available moorum from the surrounding area of Nagpur, India, was collected and was used for this investigation. Moorum collected from this region is found to have good geotechnical properties.

2.2.3 Fly ash

Fly ash was used with soil in the subgrade layer and was collected from the Koradi power plant, Nagpur, India. Table 1 shows typical characteristics of fly ash found in this region.

3. Results of the Experiments

3.1 Geotechnical properties of soil and moorum

Tests were conducted to determine the particle size, Atterberg limits (plastic and liquid limit), OMC, MDD, UCS, and CBR values.

Table 1
Properties of fly ash in Nagpur region

Property	Value
Color	Gray
Specific gravity	1.90–2.55
Plasticity	Nonplastic
Optimum moisture content (OMC) (%)	38–18
Maximum dry density (MDD) (g/cm^3)	0.9–1.6
Cohesion (kN/m^2)	Negligible
Angle of internal friction	30°–40°
Compression index (c_c)	0.05–0.4
Permeability (cm/s)	8×10^{-6}–7×10^{-4}
Coefficient of uniformity	3.1–10.7

Note: Source: Mehta et al. (2013).

Table 2
Geotechnical properties of soil

Property	Value
Grain size distribution	Gravel 5.6% (particles >4.75 mm in size) Sand 8% (4.75 mm < D > 75 μm) Fines 86% (passing 75 μm)
Liquid limit	66.48%
Plastic limit	29.70%
Plasticity index	36.78%
Free swell	100%
Classification (Indian standard)	CH Clay with high compressibility
Color	Grayish black
Maximum dry density	1.54 g/cm^3
Optimum moisture content	26%
Unconfined compressive strength	7.6 N/cm^2
California bearing ratio	2.1%

These properties are presented in Table 2 and Table 3 for soil and moorum, respectively.

3.2 Soil treated with fly ash

Following are the results for the tests conducted on soil treated with fly ash.

3.2.1 Index properties

The liquid limit and plastic limit of soil, moorum, and fly ash mixed with soil at different percentages were determined as per Indian Standard 2720 (Part V) (Indian Standards Institution [ISI], 1970a). When fly ash was added to soil, the liquid limit characteristics were decreased, and the plastic limit changed slightly. The plasticity index was decreased with different percentage mixes of fly ash, as shown in Table 4. These observations are consistent with the results reported in Yadu et al. (2011), where they used fly ash and rice husk to stabilize black cotton soil.

3.2.2 Maximum dry density and optimum water content

Indian Standard 2720 (Part VII) (ISI, 1974) specifications, was used for conducting the standard proctor test. Results are shown in Table 5. The MDD passed through a minimum at 20% fly ash. The observed MDD behavior is primarily because of the difference in specific gravities of the soil and fly ash and the immediate formation of cemented products by hydration, thereby reducing the density of soil (Takhelmayum et al., 2013).

Table 3
Geotechnical properties of moorum

Property	Value
Grain size distribution	Gravel 19.6% (particles >4.75 mm in size) Sand 60.4% (4.75 mm < D > 75 μm) Fines 20% (passing 75 μm)
Liquid limit	57%
Plastic limit	23%
Plasticity index	34%
Classification (Indian standard)	Clayey sand with fines of high compressibility
Color	Red
Maximum dry density	1.91 g/cm^3
Optimum moisture content	14.99%
California bearing ratio (soaked 4 days)	6.32%

Table 4
Index properties of soil treated with fly ash

No.	Fly ash (%)	Liquid limit (W_l) (%)	Plastic limit (W_p) (%)	Plasticity index (I_p) (%)
1	0	66.48	29.70	36.78
2	10	53.13	25.675	27.45
3	15	52.1	28.13	23.97
4	20	49.3	26.14	23.16
5	25	48.15	30.705	17.445
6	30	46.03	29.735	16.895

3.2.3 Unconfined compressive strength test

The UCS test was conducted as per specifications of Indian Standard 2720 (Part X) (ISI, 1970b). At 0–20% fly ash, the UCS value increased, but beyond 20%, it decreased, as shown in Table 6.

3.2.4 California bearing ratio test (soaked 4 days)

The CBR test was conducted as per specifications of Indian Standard 2720 (Part XVI) (ISI, 1987). Generally, the CBR test is performed on subgrade soil; such tests were performed in this study as pilot tests as shown in Table 6. These results are similar to the study by Mehta et al. (2013), where in soaked condition, the CBR value decreased for fly ash mixed with soil.

In order to simulate field conditions, in which a subgrade layer is overlain by a subbase layer, a 40-mm subbase layer was provided in the CBR mold. The thickness of this layer was one-third the height of the mold. The thickness of the subbase layer was maintained constant for all subsequent tests, i.e., CBR values were determined on top of subbase layers. The change in CBR value is shown in Table 6.

4. Discussion of Results

When fly ash was added to black cotton soil, the liquid limit characteristics decreased and the plastic limit slightly changed. The plasticity index of virgin soil was found to be 36.78%, but with an increase in the amount of fly ash, the plasticity index decreased, and a value of 16.895% was observed at 30% fly ash. When fly ash is mixed with soil, it reduces the clay content, with a subsequent decrease in the plasticity index (Hardaha et al., 2013).

At 0% fly ash, the MDD value was found to be 1.54 g/cm^3. When the amount of fly ash was increased, the MDD value decreased to a minimum MDD value of 1.44 gm/cm^3 at 20% fly ash. The decrease in the maximum dry unit weight with the increase in the percentage of fly ash is primarily a result of the lower specific gravity of the fly ash compared with expansive soil. In the case of shear strength characteristics, the UCS of natural soil was 7.6 N/cm^2, but when treated with fly ash, a maximum UCS value of 18.15 N/cm^2 was obtained at 20% fly ash.

Table 5
Maximum dry density (MDD) and optimum moisture content (OMC) values for different ratios of fly ash

No.	Fly ash (%)	MDD (g/cm^3)	OMC (%)
1	0	1.54	26.21
2	10	1.53	19.34
3	15	1.51	22.10
4	20	1.44	22.57
5	25	1.48	23.10
6	30	1.51	24.10

Table 6
Unconfined compressive strength (UCS) and California bearing ratio (CBR) values for different percentages of fly ash

No.	Fly ash (%)	UCS (N/cm^2)	CBR (%)	
			Soil–fly ash mix	Soil–fly ash with moorum
1	0	7.6	2.10	2.10
2	10	12.16	1.50	2.91
3	15	13.29	1.62	4.12
4	20	18.15	1.71	5.03
5	25	16.67	1.59	4.10
6	30	16.18	1.52	3.01

The CBR test of a fly ash and soil mixture with a moorum layer also yielded a maximum value at 20% fly ash content, but the value (5.03) was approximately three times that without the moorum layer (1.71), perhaps because of loosening of the black cotton soil during the soaking process (Mehta et al., 2013). The present study shows a significant increase in CBR value owing to the addition of fly ash along with moorum as a subbase. This indicates that we can reduce the thickness of the crust of the pavement if we use moorum as a subbase, resulting in significant savings in road construction material.

5. Conclusions

In flexible pavements, generally thickness is decided by the CBR value. Our results are significant because they prove that we can use fly ash as a subgrade material in actual conditions due to the simple reason that water does not easily enter into the subgrade layer, since it is protected by the moorum (subbase) course. Therefore, we can achieve the same strength for pavements with less thickness, resulting in savings in material.

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