Field Studies on the Pulverization of Black Cotton Soil for the Construction of Stabilized Soil Road Bases

H. L. UPPAL, L. R. CHADDA, and P. K. DHAWAN, Central Road Research Institute, New Delhi, India

Stabilization of black cotton soil with lime has been found effective in improving the engineering properties of the soil. Consequently, this has led to the increasing use of lime-stabilized black cotton soil in subbases or bases of road pavement. A properly pulverized soil is, however, a prerequisite for successful stabilization of soil. This paper describes a number of methods that have been tried in the field to achieve an economical and effective pulverization method. It has been shown that an acceptable degree of pulverization can be attained when the soil is handled mechanically at a particular moisture range by using agricultural machinery.

•EXPANSIVE SOILS (1) occur in different parts of the world. One such soil, commonly termed black cotton soil, has similar characteristics and forms one of the major soil groups (2) of India, covering an area of about 500,000 km^2 (Fig. 1). The soil is predominantly montmorillonite (3, 4) having high base exchange capacity. It is characterized by high swelling on wetting and excessive shrinkage on drying. When swelling is restricted, it results in the development of swell pressure (3). On account of these peculiar properties, the black cotton soil presents serious problems in the construction of roads. Even at places where the conditions for the development of swell pressure do not exist, the roads still fail because of poor supporting power of the subgrade in wet condition.

It has been observed that the waviness at the road surface is mostly due to the working up of the soft subgrade soil into the crevices of the stone soling, thereby dislodging the soling stone from its original position. The sinking of the stone soling into the soft subgrade is a continuous process, and no amount of strengthening of the existing pavement at the surface would remedy this defect. It is, therefore, very necessary that a compacted layer of nonexpansive material having low voids be provided to prevent the movement of subgrade soil into the crevices of the stone soling. Such materials that could be considered suitable are light-textured soils, sands, or gravelly soils. In India, sandy soils or sands are not generally found in black cotton soil areas. At places, however, granular material mixed with soil fines, locally called moorum, occurs and a compacted layer of this laid over the subgrade before placing the stone soling has led to satisfactory results.

There are, however, still very large areas where none of these materials occurs and the only alternative is to improve the existing soil for use as a subbase between the subgrade and the stone soling. One of the known effective methods (4, 5) to improve the engineering properties of black cotton soil is the stabilization with lime. To achieve these requirements, it is necessary that the soil, which is generally in the form of hard clods, be brought to a reasonable degree of fineness to facilitate uniform mixing of lime with soil.

Paper sponsored by Committee on Lime and Lime-Fly Ash Stabilization.

Figure 1. Black soil region of India.

Whereas light-textured soils are generally in a friable state when removed from the fields, it is not so in the case of expansive black cotton soil, which is very soft and sticky in the wet condition but very hard in the dry state.

OBJECT OF THE STUDY

The object of the present study, therefore, is to evolve a technique for an effective and economic pulverization of black cotton soil, which is a prerequisite for the uniform mixing of soil with lime and the subsequent development of strength.

Before taking up the field study, it was considered necessary to define the degree of fineness of soil. According to unpublished literature from the British Road Research Laboratory, the degree of fineness, which is also commonly termed as degree of pulverization, is determined from the formula

$$\frac{W_1 - W_2}{W_1 + W_3} \times 100$$

where

W_1 = total weight of the sample,
W_2 = weight of the sample retained on $^3/_{16}$-in. sieve, and
W_3 = weight of the sample passing $^3/_{16}$-in. sieve and retained on No. 8 sieve (British standard sieve or B. S. S.) 2 mm size.

It will appear from this formula that the fineness is not only controlled by the percentage of material passing the $^3/_{16}$-in. sieve but also by the fraction smaller than 2 mm.

For stabilization of light-textured soils with cement, about a 65 percent degree of pulverization (6), according to this formula, is considered suitable; but for hard clods of black cotton soil, such a high degree of pulverization may not be a practical possibility

TABLE 1

EFFECT OF DEGREE OF PULVERIZATION OF SOIL ON THE SOAKED CBR WHEN TREATED WITH 3 PERCENT COMMERCIAL HYDRATED LIME (PURITY 40 PERCENT) AND COMPACTED TO 1.5 gm/cc DENSITY

Sample	Percent Passing			CBR Soaked (percent)	Moisture Absorption (percent)
	1-in. Sieve	3/16-in. Sieve	No. 8 Sieve (B.S.S.)		
1	100.0	0.0	0.0	2.4	27.5
2	100.0	50.0	15.0	14.2	26.3
3	100.0	100.0	30.0	14.3	26.9
4	100.0	100.0	100.0	14.7	25.3

Note: Soil characteristics are liquid limit = 75.3 percent; plasticity index = 34.7 percent; and fraction coarser than No. 200 sieve (U.S. sieve) = 5.0 percent.

(7), 8). It was, therefore, considered necessary to relax the limits of fraction finer than 2 mm from the calculations. Before finally accepting the modification, it was essential to know how the clods of black cotton soil pulverized to particles of varying sizes will affect the resultant strength in saturated condition when the soil is stabilized with lime. Toward this objective, a preliminary laboratory study was carried out with soil samples having varying clod sizes. To achieve a limited increase in strength, trials were made using a low concentration of lime.

In the laboratory trials, the soil having a varying degree of fineness was compacted at optimum moisture with 3 percent commercial lime of known purity. After curing the treated specimens for 10 days, these were tested for soaked CBR. The results obtained are given in Table 1.

It will be observed from the data given in Table 1 that if the soil to start with consists of at least 50 percent passing the 3/16-in. sieve then the strength attained is practically the same, irrespective of the fraction passing the No. 8 sieve (B.S.S.). It may be due to the fact that the process of mixing lime with soil and subsequent compaction may have resulted in further improving the degree of pulverization.

PULVERIZATION BY MANUAL LABOR

It is a common experience that during the rainy season the black cotton soil is sticky and difficult to handle. The field trials on the pulverization of soil by manual labor were, therefore, restricted to the dry season; details are given in the following.

Crowbar and Pickax

The field trials for the pulverization of black cotton soil were carried out on Berasia-Sironj Road near Bhopal (central India) in 1964. After removing the top vegetation, the dry soil crust for a depth of about 8 in. was loosened with crowbars. The soil thus obtained was comprised mostly of 5- to 6-in. clods. These were broken with pickaxes or rammers but the output was very poor, which raised the cost to 20 rupees per 100 cu ft for getting soil of acceptable degree of pulverization, i.e., about 100 percent passing the 1-in. sieve and about 50 percent passing the 3/16-in. sieve. With a view to economizing on cost, an attempt was made to use a country plow drawn by a bullock, instead of digging manually, but this did not work well on account of the soil being dry and hard.

Wetting and Drying of Soil Clods

It has been observed that, when black cotton soil shrinks in the process of drying, high stresses are produced that lead to the disintegration of soil at the surface. Advantage was taken of this phenomenon in the pulverization of the soil. In actual practice, the soil dug from the fields was stacked and water was sprinkled on the clods. In the process of drying, the shrinkage of the soil took place and led to its disintegration

at the surface. The process was frequently repeated to get more and more of the soil fines. It gave satisfactory results as almost 50 percent of the material passing the 3/16-in. sieve could be obtained. This process would, however, require water within economic reach. Besides being slow, such operations will cost about 12 to 15 rupees per 100 cu ft.

PULVERIZATION BY MECHANICAL MEANS

Power Roller

The soil in the dry condition was dug from the adjoining fields, and clods were broken with pickaxes so as to reduce them to a size not bigger than 2 in. The soil clods were spread over a hard subgrade, and a power roller passed over them a number of times with frequent raking of the crushed material. It was found that about 8 passes of the roller and frequent raking of the rolled soil resulted in grading as follows:

Sieve No.	Percent Passing
1½ in.	100.0
1 in.	83.0
⅜ in.	80.0
3/16 in.	60.0

The cost of soil pulverized according to this method worked out to 10 to 12 rupees per 100 cu ft.

Heavy Agricultural Machinery

In the absence of a specially designed plant for the purpose, agricultural machinery available in the country was used. Field trials were, therefore, carried out with the following heavy agricultural machinery normally used for plowing the field and breaking clods (Fig. 2):

1. International Caterpillar tractor, 110 hp;
2. Moldboard plow consisting of 4 plowshares that can plow to about 15 in. in depth;
3. Disc plow consisting of 5 discs 28 in. in diameter with a working width of 10 ft; and
4. Offset notched disc harrow consisting of 18 discs 22 in. in diameter arranged in 2 gangs with a working width of 10 ft.

A field trial was initiated at Sehore (central India) by using this machinery in April 1964 when the ground surface was hard and badly cracked because of a hot, dry summer. To start with, the moldboard plow with a working width of 6 ft was used. This could plow up to a depth of about 15 in., giving clods of varying sizes with a maximum of about 8 in. After the moldboard plow was used, the disc plow was operated on the excavated soil. This reduced the size of the big clods to about 4 in. in the process of slicing. The soil was further subjected to the action of the offset notched disc harrow to improve pulverization. It was observed that, even with 6 passes of the disc harrow, there were still many clods 4 in. in size that resisted pulverization and were therefore removed manually. The sieve analysis of the resultant soil is as follows:

Sieve No.	Percent Passing
1½ in.	100.0
1 in.	81.4
⅜ in.	57.6
3/16 in.	33.5

During this operation, it was observed that those clods that were dry and consequently hard resisted breaking up, whereas slightly wet clods could be pulverized easily. It was, therefore, inferred that the pulverization of black cotton soil with heavy agricultural machinery required the soil to exist within a certain range of

Moldboard plow

Disc plow

Offset notched disc harrow

Pulverized black cotton soil being carried by the laborers

Figure 2. Agricultural machinery.

moisture for effective pulverization. With a view to finding out the range of moisture that would facilitate pulverization, soil samples at various depths of the natural subgrade were taken and subjected to moisture tests. The results are as follows:

Depth, in.	Moisture, Percent
6	7.1
12	15.6
18	18.2

It can be inferred that the clods that could not be pulverized had a moisture content of about 7 percent and those that could be readily pulverized had a moisture content ranging between 15 and 18 percent. It can, therefore, be stated that it will be more economical to pulverize black cotton soil after the rainy season when uniform field moisture conditions are likely to prevail.

Experiments were also made on the pulverization of black cotton soil in a moist state. Before operating the machinery, the moisture distribution to a depth of 2 ft was checked at 3 different stretches on the Sehore-Bilquishganj Road (central India) where the experiments were carried out. The data are given in Table 2.

It will be observed that the moisture throughout the depth is very uniform except at the top where there is a slightly lower moisture content.

The field trials were carred out in December for a length of about 440 yards using the same machinery.

TABLE 2

PERCENTAGE OF MOISTURE IN BLACK COTTON SOIL

Depth, in.	Site 1	Site 2	Site 3
1	14.7	15.1	14.8
6	19.8	19.5	19.8
12	20.4	19.9	20.9
18	20.5	21.6	21.9
24	20.5	22.0	21.9

TABLE 3

SIEVE ANALYSIS OF BLACK COTTON SOIL PULVERIZED IN THE MOIST STATE WITH AGRICULTURAL MACHINERY

Sieve No. (B.S.S.)	Percent Passing		
	2 Passes	4 Passes	6 Passes
1½ in.	100.0	100.0	100.0
1 in.	82.6	88.3	89.6
⅜ in.	70.6	69.9	79.0
5/16 in.	44.8	49.6	55.8
No. 8	29.1	34.3	38.6
No. 36	5.2	6.8	8.2

It was observed that, after the soil had been dug out with the moldboard plow, the disc plow could conveniently cut down the big clods to a smaller size at this moisture. The operation was also smoother as compared to pulverization of the dry soil. The soil thus pulverized was further subjected to the action of the offset notched disc harrow, with a view to determining the minimum number of passes needed to achieve the required degree of pulverization. The soil was tested for sieve analysis after 2, 4, and 6 passes. The results are given in Table 3.

It will appear from the data given in Table 3 that the acceptable limits of pulverization, i.e., 50 percent passing the 5/16-in. sieve, could be achieved with 6 passes of the offset harrow. It will be observed further that insofar as the upper limits are concerned the conditions are just satisfied. It will be found more economical to accept about a 10 percent fraction coarser than 1 in. than to make additional passes of the offset disc harrow to pulverize it further. It will also be noticed that with this type of machinery the moisture for effective degree of pulverization ranges between 15 and 20 percent. The cost of pulverization as worked out by this machinery is 1 rupee per 100 cu ft as given in Table 4.

Light Agricultural Machinery

As heavy agricultural machinery is not easily available at most of the sites, further field trials were carried out using light agricultural machinery, which is readily procurable. The trials were made at Sidhantam in Andhra Pradesh (south India) where the construction of 5½ miles of the right approach road to Vasista Bridge, forming a part of the National Highway, was undertaken.

The light machinery consisted of the following:

1. Tractor, 50 hp;
2. Moldboard plow consisting of 3 plowshares;
3. Disc harrow consisting of 20 saucer-shaped discs 10 in. in diameter; and
4. Offset disc harrow consisting of 10 discs 20 in. in diameter arranged in two gangs.

The operation with this machinery was carried out, as in the case of heavy agricultural machinery, at varying moisture contents. It was found that effective pulverization could be economically achieved when the moisture content of the soil ranges between 10 and 22 percent, as against 15 and 20 percent in the case of the heavy machinery. It was further observed that it required about 6 passes of the disc harrow and about 10 passes of the offset harrow to achieve an acceptable degree of pulverization.

The cost of pulverization worked out to 2 rupees per 100 cu ft of loose soil as given in Table 5.

The higher cost of pulverization with light agricultural machinery as compared to heavy machinery resulted from the fact that the moldboard plow fitted with a light tractor could not plow more than 8 in. deep.

As a result of conducting a number of trials, it was found that, with the light machinery, it was possible to pulverize only about 8,000 cu ft of the soil in 8 hours as against 40,000 cu ft with heavy machinery during the same period. Although heavy

TABLE 4

COST ANALYSIS OF PULVERIZATION OF BLACK COTTON SOIL WITH HEAVY AGRICULTURAL MACHINERY

Item	Amount
Cubic feet of soil pulverized in 8 hours	40,000
Hire charges of the machinery at 45 rupees per hour	360.00
Labor charges, rupees	20.00
Miscellaneous charges such as for tools and repairs, rupees	20.00
Total rupees	400.00
Cost (in rupees) of pulverizing 100 cu ft $= \frac{100 \times 400}{40,000}$	1.00

TABLE 5

COST ANALYSIS OF PULVERIZATION OF BLACK COTTON SOIL WITH LIGHT AGRICULTURAL MACHINERY

Item	Amount
Cubic feet of soil pulverized in 8 hours	8,000
Hire charges of the machinery for 8 hours, rupees	120.00
Labor charges, rupees	20.00
Miscellaneous charges such as for tools and repairs, rupees	20.00
Total rupees	160.00
Cost (in rupees) of pulverizing 100 cu ft $= \frac{160 \times 100}{8,000}$	2.00

machinery is more economical to use, it is not readily available in the market. Therefore, even though the cost of pulverization with light agricultural machinery is slightly more, it is still preferred on account of its easy procurement either from the market or on hire from the agriculturists. The additional cost of pulverization is not likely to have any significant effect on the overall cost of road construction.

ACKNOWLEDGMENT

This paper is published with the permission of the Director of the Central Road Research Institute, New Delhi.

REFERENCES

1. Dudal, R. Dark Clay Soils of Tropical and Subtropical Regions. Soil Science, Vol. 95, No. 4, 1963, pp. 264-270.
2. Raychaudhuri, S. P., et al. Black Soils of India. National Institute of Sciences, India, 1963, 47 pp.
3. Uppal, H. L., and Palit, R. M. A Study of Factors Influencing the Swell Pressure of Clays. Indian Roads Congress, 1961.
4. Uppal, H. L., and Bhatia, H. S. Stabilization of Black Cotton Soil for Use in Road Construction. Indian Roads Congress, Road Research Bull. 5, 1958, pp. 105-154.
5. Mehra, S. R., and Chadda, L. R. Some Laboratory Investigations for Improving Black Cotton Soil in Road Construction. Indian Roads Congress, Road Research Bull. 4, 1957, pp. 51-72.
6. Bruce, A., and Clarkson, J. Highway Design and Construction. International Text Book Co., Scranton, Penn.
7. Pulverization Characteristics of Soils. Soil Cement News, No. 35, p. 4, 1950.
8. Davidson, L. K., et al. Soil Pulverization and Lime Migration in Soil Lime Stabilization. Highway Research Record 92, 1965, pp. 103-126.