International Journal of Science Engineering and Advance Technology (IJSEAT)
ISSN 2321-6905, Vol. 8, Issue 2, February -2020

Stabilization of Lime Treated Black Cotton Soil with Bamboo Fibre

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Abstract: Construction of pavement subgrades for roads and railways on black cotton soil (BC soil) is highly risky on geo-technical grounds because such soil is susceptible to differential settlements, poor shear strength and high compressibility. Chemical stabilization is one of the oldest methods of stabilization of problematic soil. In recent days, it has been investigated that addition of fibers will improve the ductility behavior of the soil there by reducing the development of crack during shrinkage.

This project describes the compaction and strength behavior of Lime treated black cotton soil (BC soil) reinforced with bamboo fibers. The various percentage of lime as 2%, 4%, 6% and 8% was used to find out the optimum value of lime. Bamboo fiber has been randomly included into the lime treated soil at four different percentages of fiber content, i.e. 0.5%, 1% 1.5%, and 2% (by weight of soil). The tests which were carried out are Atterberg's Limits, Modified compaction test, California bearing ratio test and unconfined compression test. The test result indicates that strength properties of optimum combination of BC soil-lime specimens reinforced with bamboo fibers is appreciably better than untreated BC soil. And also the strength of the mixed soil increases with increase in days. And Cyclic Plate Load tests were carried out for the optimum percentage obtained from the above test results and the results were analyzed for the suitability of subgrade under certain loads in a model test tanks under laboratory conditions.

Key words- ductility behavior, cotton, Lime treated black cotton soil

I. Introduction

The soils which show volumetric changes due to changes in their moisture content are referred to as swelling soils. Some partially saturated clayey soils are very sensitive to variations in water content and show excessive volume changes. Such soils, when they increase in volume because of an increase in their water contents, are classified as expansive soils.Problem of expansive soils has appeared as cracking and break-up of pavements, railways, highway embankments, roadways, building foundations, slab on-grade members and, channel and reservoir linings, irrigation systems, water lines, sewer lines. (Gromko, 1974; Wayne et al. 1984; Mowafy et al. 1985; Kehew, 1995)

It is reported that damage to the structures due to expansive soils has been the most costly natural hazard in some countries. In the United States damage caused by expansive clays exceeds the combined average annual damage from floods, hurricanes, earthquakes, and tornadoes (Jones and Holtz, 1973). Documented evidence of the problems associated with expansive clays is worldwide, having occurred in such countries as the United States, China, Australia, India, Canada, and regions in Europe. (Popescu, 1986) It is reasonable that studies on the problem of expansive soils become more important day by day if the durative deficit of world resources and economy is taken into consideration. (Cited in Ipek, 1998) When geotechnical engineers are faced with expansive soils, the engineering properties of those soils may need to be improved to make them suitable for construction. (Muntohar and Hantoro, 2002)

A substantial literature has concluded this severity an extent of damage inflicted by soil deposits of swelling nature, to various structures, throughout the world (Ganapathy, Joneqs and Jones, Abduljauwad, Osama and Ahmed, Zhang). The loss caused due to damaged structures proved the need for more reliable investigation, of such soils and necessary methods to eliminate or reduce the effect of soil volume change. Additives, including lime, fly ash, Portland cement, saw dust and more recently synthetics are available that will lessen these problems when mixed in the proper amounts with problem soils. These additives may be used separately or in combination and each has construction issues related to its performance

REVIEW ON EXPANSIVE SOIL

Expansive soil term is used for the soils that have potential shrinking and swelling property under changing water content. Foundations constructed on expansive soils will be exposed to huge uplift forces due to swelling and these forces will result many structural problems.

Unsaturated expansive clays are a type of soils that, because of their mineralogical composition, usually experience large swelling strains when wetted. If the clay is in a saturated

Revised Manuscript received on January 05th , 2020
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state, large swelling strains are also observed when the soil is unloaded. These soils have also been referred to in the literature as active clays and swelling clays. (Gens and Alonso, 1992)

Swelling clays are found in many parts of the world, particularly in semi-arid areas. In a review of Chen (1988), swelling clays are detected in Australia, Canada, China, Israel, Jordan, Saudi Arabia, India, South Africa, Sudan, Ethiopia, Spain, and the United States. (Wibawa, 2003) This is not to say that such soils do not exist elsewhere, for, indeed, they can be found almost everywhere.

It is obvious that the lightweight structures (damage to a lightweight structure is possible when very little volume expansion takes place in soil) that are designed and built by conventional techniques will be damaged in case of heaving. (Kehew, 1995) But although highway embankments and roadways are generally insensitive to vertical movements, high maintenance costs should be overcome if constructed on expansive soils. (Mowafy et al. 1985) The moisture may come from rain, flooding, leaking water or sewer lines or from reduction in surface evapotranspiration when an area is covered by a building or pavement. As it is mentioned above this problem is due to the mineralogical composition of these soils. Especially soils containing the clay mineral montmorillonite (a smectite) generally exhibit these properties. To understand and overcome these problems, expansive soils should be examined carefully and unsaturated soil mechanics should be taken into consideration.

There are many correlations that are useful for identifying potentially expansive soils. It is also possible to identify them visually. Visual indications may be (Wayne et al., 1984);

1.Wide and deep shrinkage cracks occurring during dry periods,

2.Soil is rock-hard when dry, but very stiff and sticky when wet,

3.Damages on the surrounding structures due to expansion of soil.

Materials And Their Properties

In the following sections, the details of various materials and chemicals used in the laboratory experimentation are reported

Soil And Its Composition

The soil used was a typical black cotton soil collected from Allavaram mandalam near Amalapuram in East Godavari District, Andhra Pradesh State, India. The properties of soil are presented in the Table 4.1. All the tests carried on the soil are as per IS specifications.

Table: Properties of Expansive Soil

S.No	Property	Properties
1.	Grain size distribution	
	Gravel (%)	0
	Sand (%)	2
	Silt (%)	22
	Clay (%)	76
2.	Atterberg limits	
	Liquid limit (%)	87
	Plastic limit (%)	42
	Plasticity index (%)	45
3.	Compaction properties	
	Optimum Moisture Content,(O.M.C) (%)	27.69
	Maximum Dry Density, (M.D.D) (g/cc)	1.44
4.	Specific Gravity (G)	2.68
5.	Soil Classification	CH
6.	Soaked C.B.R (%)	2.0
7.	Free swell (%)	140
9	Cohesion (C) (Kg/cm²)	0.58
10	Angle of internal friction (ø)	2º

The range of chemical constituents of these soils are Silica (48-58%), Alumina (13-22%), Lime (1-8%), Magnesium Oxide (1.8-5%), Ferric Oxide (7.5-15%), Titanium Oxide (0.3-2.2%), Sulphate (0.9-2%), Carbonate (0.5-6.6%) and Organic matter (0.4-3.6%) (Katti, 1979).

Banana Fibre

It is a natural fibre obtained from banana plant. This fibre is obtained mainly from pseudo stem which acts as a strong fibre after dried properly. It is a fibre with appropriate stiffness and good mechanical properties

Properties of Banana Fibre

S.No	Properties	Values
1.	Colour	Light Brown
2.	Average diameter (mm)	0.75
3.	Average length (mm)	15
4.	Average tensile strength (N/mm^2)	11
5.	Fiber Density (g/cc)	0.62

PHOSPHORUS PENTOXIDE

Phosphorus Pentoxide is white coloured sticky powder form which is highly reactive with water and clay particles of soil. It improves the index properties, dry density, and optimum moisture content of soil

Properties of Ferric Chloride

Property	Value
Molar Mass	283.9 g mol^{-1}
Crystal structure	powder
Appearance	white powder
Odor	odorless
Density	2.39 g/cm^3
Melting Point	340 °C (644 °F; 613 K)
Boiling Point	360 °C
Solubility in water	exothermic hydrolysis

Laboratory Experimentation

Different tests were conducted in the laboratory on the expansive soil to study the behaviour of expansive soil, when it is treated with Banana fibre along with Ferric chloride.The following tests were conducted as per IS code of practice

Grain Size Analysis

The weight of soil fraction aggregate retained on each standard sieve is calculated as the percentage of the total weight of the sample taken. The grain size distribution of soils/aggregates is an essential requisitein mterial characterization. Indian standard codes of practice I.S:1498-1970 gives the standard size of various sieves. These sieves are arranged in increasing order from bottom.

Dry sieve analysis is suitable for cohesion less soils and if the soil contains a substantial quantity of fine particles, a wet sieve analysis is required.

WATER CONTENT

The water content is defined as the ratio of the mass of water to the mass of solids. Water content, also known as the moisture content is expressed as percentage and used as decimal in computation.

The water content of a soil is an important parameter that controls its behaviour. It is a quantitative measure of the wetness of a soil mass. The water content of a soil can be determined by many methods of which oven drying method has been adopted here. In this method the soil sample in the container is dried in an oven at a temperature of 110°±5°C for 24 hours.

Water content, $w = M_w/ M_s = (M_2-M_3)/ (M_3-M_1)$

Where, M_1 = mass of container, with lid

M_2 = mass of container, lid and wet soil

M_3 = mass of container, lid and dry soil

FREE SWELL INDEX (FSI)

Free Swell Index (FSI) is a parameter used for the identification of the expansive soil.

For the determination of the free swell index of a soil, 20g of dry soil passing through a 425µ size sieve is taken. One sample of 10g is poured into a 100cc capacity graduated cylinder containing water, and the other sample of 10g is poured into a 100cc capacity graduated cylinder containing kerosene oil.

Both the cylinders are kept undisturbed in a laboratory. After 24 hours, the settled volumes of both the samples are measured.

$$FSI = \frac{\text{Settled soil volume in water} - \text{Settled soil volume in kerosene}}{\text{Settled soil volume in Kerosene}} \times 100$$

Because kerosene is a non-polar liquid, it does not cause any swell of the soil. Table 4.1 gives degree of expansion of a soil depending upon its free swell index as per IS: 2720 (Part III- 1980).

ATTERBERG LIMITS

Liquid Limit

Liquid limit is the moisture content at which 25 blows in standard liquid limit apparatus will just close a groove of standard dimensions cut in the sample by the grooving tool by specified amount. The flow curve is plotted in the log-scale on the x-axis, and the water content in the arithmetic scale on y-axis. The flow curve is straight line drawn on the semi-logarithmic plot, a nearly as possible through three or more plotted points. The moisture content corresponding to 25 blows is read from this curve rounded off to the nearest whole number and is reported as the liquid limit of the soil.

Virgin soil and optimum percentage of BF i.e. (1%) by dry weight are mixed with the soil and the liquid limit were determined as per IS: 2720 (part-5)-1985.

Plastic Limit

Plastic limit is the moisture content at which a soil when rolled into thread of smallest diameter possible, starts crumbling and has a diameter of 3mm.The Plastic limit (w_p) is expressed as a whole number by obtaining the mean of the moisture contents of the plastic limit.

Virgin soil and optimum percentage of BF i.e. (1%) by dry weight is mixed with the soil and the plastic limit were determined as per IS: 2720 (part-6)-1972.

COMPACTION TEST

From the compaction test, the maximum dry density (MDD) and Optimum Moisture Content (OMC) of the soil are found for the selected type and amount of compaction based on the procedure described in Indian standard codes of practice I.S:2720 (Part VIII – 1983).

The weight of mould with moist compacted soil is W gm.

Weight of empty mould = $W_m$gm

Volume of mould = V_m cc

Wet density, $¥_m = \frac{(w-w_m)}{v_m} g/cc$

Let the moisture content be = w %

Then dry density,

$$¥_d = \frac{¥_m}{\left(1+\frac{w}{100}\right)} = \frac{(w-w_m)}{v_m\left(1+\frac{w}{100}\right)} g/cc$$

The compaction test is carried out at different proportion of BF % (0.25%,0.5%,0.75%,1.0% and 2.0%) and corresponding MDD and OMC is figured out from the graph.

- The OMC of the soil indicated the particular moisture content at which the soil should be compacted to achieve maximum dry density. If the compacting effort applied is less, the OMC increases and the value can again be found experimentally or estimated.
- In field compaction, the compacting moisture content is first controlled at OMC and the adequacy of rolling or compaction is controlled by checking the dry density achieved and comparing with the maximum dry density. Thus compaction test results (OMC and maximum dry density) are used in the field control test in the compaction projects.
- Compaction, in general in considered most useful in the preparation of sub grade and other pavement layers and in construction of embankments in order to increase

the stability and to decrease settlement. There is also a soil classification method based on the maximum dry density in the standard (proctor compaction test lower values indicating weaker soil).

STRENGTH TESTS

CBR Test

The CBR is a measure of shearing resistance of the material under controlled density and moisture conditions. The load-penetration curve for each specimen is plotted on natural scale. The load values at 2.5 mm and 5.0 mm are obtained from the load penetration curve to compute CBR values using the following equation.

$$CBR\ (\%) = \frac{\textit{Load carried by soil sample at defined penetration level}}{\textit{Load carried by standard crushed stones at the same penetration level}} \times 100$$

Based on extensive CBR test data collected, empirical design charts were developed by the California State Highway Department, correlating the CBR value and flexible pavement thickness requirement. For various traffic volumes different design thickness curves are available.

The California bearing ratio tests (as per IS: 2720 (part-16)-1979) were conducted on all the combinations listed in table, at the end of the curing period (all the samples were soaked for 4 days).

Samples were prepared by compacting different mixes to the maximum dry density of the soil. The initial moisture content for these samples was maintained at optimum moisture content of the soil. The amount of BF to be added to the amount of water was arrived at based on the optimum moisture content of the natural soil and the BF prepared. This BF was added to the air dry soil and the mixture was thoroughly mixed

Tri-Axial Test

Shear tests are generally carried out on small samples in the laboratory to evaluate the strength properties of the element in the soil mass. The strength parameters, namely the cohesion and angle of shearing resistance are usually found from these tests.

The tri-axial test specimen is subjected to the all-round pressure equal to the lateral pressure, σ_3 and the applied vertical stress or deviator stress σ_d such that the total vertical stress is $\sigma_1 = \sigma_d + \sigma_3$. Mohr stress circles are plotted at normal stress intercepts σ_3 and σ_1 or with diameters equal to deviator stresses. From the Mohr's envelope, the cohesion C and the angle of internal friction φ of the soil can be derived.

- The shear strength parameters C and φ of the materials may be used to find the shearing resistance of the material, using Coulomb's equation.

$$S = C + \sigma \tan\phi$$

- In flexible pavement design, the E value of sub grade soils is to be found from tri-axial test.
- Tri-axial test is used in the design of bituminous mixes.

Samples were prepared by compacting different mixes to the maximum dry density of the soil. The initial moisture content for these samples was maintained at optimum moisture content of the soil. The amount of BF to be added to the amount of water was arrived at based on the optimum moisture content of the natural soil and the BF was prepared. This solution was added to the dry soil and the mixture was thoroughly mixed.

Specific Gravity Test

Specific gravity of solid particles (G) is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water at 4°C.

The specific gravity of solid particles can be determined in a laboratory using a density bottle fitted with a stopper. The mass of bottle, including that of stopper, is taken. About 5-10g of oven dry sample of soil is taken in bottle and weighed. Distilled water is then added to cover the sample. The soil is allowed to soak. More water is added until the bottle is half full. Air entrapped in the soil is expelled by applying a vacuum pressure in vacuum desiccators. More water is added to the bottle to make it full. The stopper is inserted and the mass is taken. The bottle is emptied, washed and then refilled with distilled water. The bottle must be filled to the same mark as in the previous case. The mass of water filled with water is taken.

$$G = (M_2-M_1)/ [(M_2-M_1) - (M_3-M_4)]$$

Where

M_1=Mass of Empty bottle

M_2=Mass of bottle and dry soil

M_3=Mass of bottle, soil and water

M_4=Mass of bottle filled with water

Cyclic Plate Load Test

Plate Load Test is a field test for determining the ultimate load carrying capacity of soil and the maximum settlement under an applied load. The plate load test basically consists of loading a steel plate placed at the foundation level and recording the settlements corresponding to each load increment. The load applied is gradually increased till the plate starts to sink at a rapid rate. The total value of load on the plate in such a stage divided by the area of the steel plate gives the value of the ultimate bearing capacity of soil. The ultimate bearing capacity is divided by suitable factor of safety (which ranges from 2 to 3 to arrive at the value of safe load capacity of soil.

These tests were carried out on flexible pavements systems in a circular steel tank of diameter 60cm as shown in plate 3.10. The loading was done through a circular metal plate of 10cm diameter laid on the model flexible pavement system. The steel tank was placed on the pedestal of the compression testing machine. Two dial gauges of least count 0.01mm were arranged as shown in fig 4.11 for obtaining the deformations. A 5 Ton capacity hydraulic jack was placed on the loading. Cyclic load tests were carried out at OMC state corresponding to tire pressures of 500,560,630,700 and 1000kPa. Each pressure increment was applied until there was no significant change in deformation between the consecutive cycles. The testing was further continued till the occurrence of failure of the model pavement to record the ultimate load for with or without the geo-textile as reinforcement and separator.

Preparation Of Soil Layer For Pavement Sub-Grade

Expansive clay of total thickness 30cms mixed with water at OMC was compacted and laid in layers of 5cms compacted thickness.

Preparation Of Gravel Cushion For Pavement Sub-Grade

On the prepared sub base, three layers of gravel each of 5cm compacted thickness, was laid to a total thickness of 15cm which acts as a binding material.

laboratory test results

In the laboratory, index tests and strength tests were conducted by using different percentages of BF and Phosphorus Pentoxidewith a view to determine the optimum percentage of BF and chemical.

The effect of addition of different proportions of BF with the combination of additives to the expansive soil on the Atterberg`s limits, free swell index and strength properties are discussed in detail in the following sections.

Properties Of Treated And Untreated Expansive Clay

S.No	Descriptions	Untreated Expansive Clay	Treated with Expansive Clay with 1% BF
1.	Atterberg limits Liquid limit (%) Plastic limit (%) Plasticity index (%)	 87 42 45	 82 45.3 36.7
2.	Compaction properties O.M.C (%) MDD(gm/cc)	 27.69 1.44	 45.21 1.33
3.	Specific Gravity (G)	2.68	2.74
4.	Soaked C.B.R (%)	2.0	5.6
5.	Free swell Index (%)	140	92

6.	Cohesion (C) (Kg/cm²)	0.58	0.94
7.	Angle of internal friction (ø)	20	4028’

Free Swell Index

To determine the free swell index of soil as per **IS: 2720 (Part XL) – 1977**. Free swell or differential free swell, also termed as free swell index, and is the increase in volume of soil without any external constraint when subjected to submergence in water.

Free swell index =

$$[V_d - V_k] / V_k \times 100\%$$

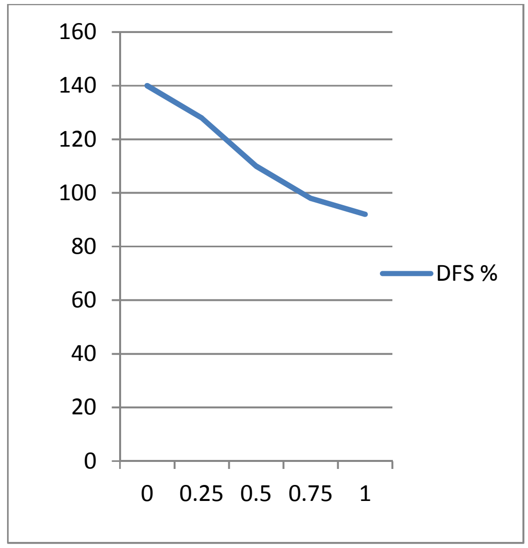
Where,

V_d = volume of soil specimen read from the graduated cylinder containing distilled water.

V_k = volume of soil specimen read from the graduated cylinder containing kerosene.

FreeSwell Index values of expansive clay treated with percentage variation of BF.

Banana Fibre (%)	DFS (%)
0	140
0.25	124
0.5	116
0.75	98
1.0	92



CONCLUSIONS

The following conclusions were drawn based on the laboratory studies carried out on this study.

Optimum percentages of Banana Fibre (BF) and Phosphorus Pentoxide[$FeCl_3$] were observed during the laboratory investigations are summarized and presented in the following table

Optimum percentage of BF and P_2O_5observed during the laboratory investigations

S.No	Additives	Optimum Percentages
1	Banana Fibre (BF)	1%
2	Phosphorus Pentoxide	1%

1. From the laboratory studies, it was observed that the Free Swell Index of the expansive clay has been **decreased** by 34% with the addition of 1% BF when compared with the untreated expansive clay.
2. It was also observed that the Free Swell Index of the expansive clay has been further **decreased** by 17% with addition of Phosphorus Pentoxide to the BF treated expansive clay.

3. From the laboratory studies, it was observed that the liquid limit of the expansive soil has been **decreased** by 6% with the addition of 1% BF when compared with the untreated expansive clay.
4. It was also observed that the liquid limit of the expansive clay has been **decreased** by 8% with the addition of Phosphorus Pentoxide to the 1% BF treated expansive clay.
5. From the laboratory studies, it was observed that the plastic limit of the expansive clay has been **increased** by 8% with the addition of 1% BF when compared with the untreated expansive clay.
6. It was also observed that the plastic limit of the expansive clay has been further **increased** by 2% with the addition of Phosphorus Pentoxide to the 1% BF treated expansive clay.
7. It was observed that the CBR value **increased** by 180% on addition of 1% BF and further improvement was observed that 45% increased when treated with optimum values of Phosphorus Pentoxide when compared with untreated expansive clay.
8. It was observed from the laboratory results that the shear strength parameters of expansive clay are **improved** with the addition of Banana Fibre along with optimum percentages of Ferric Chloride.
9. It was concluded from the laboratory investigation that the CBR values of expansive clay treated with 1% BF + 1% Phosphorus Pentoxide exhibits better results.
10. It was observed from the laboratory Static Plate Load Test results, that the ultimate load carrying capacity of the 1% BF treated expansive clay foundation bed has been **improved** by 82% when compared with the untreated expansive clay foundation bed.
11. It was observed from the laboratory Static Plate Load Test results, that the ultimate load carrying capacity was further **improved** by 175% with 1% BF + 1% P_2O_5 treated expansive clay foundation bed when compared with the untreated expansive clay foundation bed.
12. Hence, from all the above observations, it was concluded that the 1% Phosphorus Pentoxidealong with 1% BF treated expansive clay exhibits better and satisfactory results.

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