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STABILIZATION OF EXPANSIVE SOIL USING ADMIXTURES

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ABSTRACT

Engineers often encounter difficulties when building on or with Black Cotton soil because of its poor engineering performance, which includes high clay content, low strength and an inadequate bearing capacity. The need to find a stabilizing substance was prompted by the poor performance of BC soil. Conventional stabilizers like gravel, sand, cement are depleting and becoming expansive day by day. Therefore, it became imperative to search for alternative stabilizers that are both economical and environmental friendly. Lime, fly ash, and bioenzyme (Terrazyme) have recently shown effectiveness as stabilizing agents. In this paper, soil samples were evaluated using fly ash, lime, and bioenzymes. The results of the Compaction test, Consistency limit, California Bearing Ratio have all been examined and discussed. It has been noted that a notable improvement has occurred to engineering properties of B.C. soil with these stabilizers.

KEYWORDS: Black cotton (B.C.) soil, Bioenzyme, Terrazyme, Lime, Fly ash, Soil Stabilization.

1. INTRODUCTION

Expansive soils or black cotton soil cover over 51.8 million hectares of land in India. When dry, Black cotton soils are extremely hard; yet, when wet, they entirely lose their strength. A global issue, expansive soils challenge civil engineers with a number of difficulties. To enhance the engineering properties of expansive soils, a variety of techniques are modified. The problematic soils are either treated with additives or removed and replaced with material of higher quality. The stabilization of the problematic soils is very important for many of the geotechnical engineering applications such as pavement structures, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines and sewer lines to avoid damage due to settlement of soft soil or to the swelling action of expansive soil.

Black Cotton Soil

Black clays or tropical black earth or black cottons are known to be potentially expansive soils which are "black" or "greyish black" or in their eroded phase "greyish white" heavy loam or clay (usually 50%), with predominant clay mineral of the smectite group, rich in alkali earth elements and the horizons sometimes contain calcium carbonate or magnesium oxide concretions. Many other terms have been applied locally, such as "regur" soils in India, "margalitic" soils in Indonesia, "black turf" in Africa and "tirs" in Morocco. Although there are several names, the term "black cotton soil" is adopted in this paper because of its extensive use in literature. The term "black cotton" is believed to have originated from India where the locations of these soils favour cotton growth. Black cotton soils have been defined differently by different authors, for instance Mohr and Van Baren (1959) proposed the term "margalitic soils" which they defined as "black or greyish black, grey or in the eroded phase greyish-white" heavy loam or clays; which crack when dry and swell when moist.

Problems in Black Cotton Soils

It is a well-known fact that water is the worst enemy of road pavement, particularly in expansive soil areas. Water penetrates into the road pavement from three sides viz. top surface, side berms and from sub grade due to capillary action. Therefore, road specifications in expansive soil areas must take these factors into consideration. The road surfacing must be impervious, side berms paved and sub grade well treated to check capillary rise of water.

- Black Cotton soils absorb water heavily, swell, become soft and lose strength.
- These soils are easily compressible when wet and possesses a tendency to heave during wet condition.
- Black Cotton soils shrink in volume and develop cracks during summer. These properties make them poor foundation soils and earth construction material.
- The stability and performance of the pavements are greatly influenced by the sub grade and embankment as they serve as foundations for pavements.
- The wetting and drying process causes vertical movement in the soil mass which leads to failure of a pavement, in the form of settlement, heavy depression, cracking and unevenness.

Soil Stabilization

Soil stabilization is the process of altering some soil properties by different methods, mechanical or chemical in order to produce an improved soil material which has all the desired engineering properties. Soils are generally stabilized to increase their strength and durability or to prevent erosion and dust formation in soils. The main aim is the creation of a soil material or system that will hold under thedesign use conditions and for the designed life of the engineering project. The properties of soil vary a great deal at different places or in certain cases even at one place; the success of soil stabilization depends on soil testing. Various methods are employed to stabilize soil and the method should be verified in the lab with the soil material before applying it on the field.

Principles of Soil Stabilization include evaluating the soil properties of the area under consideration. Deciding the property of soil which needs to be altered to get the design value and choose the effective and economical method for stabilization, designing the Stabilized soil mix sample and testing it in the lab for intended stability and durability values.

Soil Stabilizing Agent

A. Bio Enzyme

Enzymatic emulsions contain enzymes (protein molecules) that react with soil molecules to form a cementing bond that stabilizes the soil structure and reduces the soil's affinity for water. Categorically speaking, enzymatic emulsions work on a variety of soils as long as a minimum amount of clay particles are present. When applied at low application rates to the surface of the unbound road surface, enzymatic emulsions perform well for dust suppression. They bond soil particles together and so reduce dust generation. At higher application rates, enzymatic emulsions can be used to stabilize soils. Some of the bioenzymes are Renolith, Permazyme, Fujibeton, Terrazyme etc. Mechanism of Stabilization includes in clay water mixture positively charged ions (cat-ions) are present around the clay particles, creating a film of water around the clay particle that remains attached or adsorbed on the clay surface. The adsorbed water or double layer gives clay particles their plasticity. In some cases the clay can swell and the size of double layer increases, but it can be reduced by drying. Therefore, to truly improve the soil properties, it is necessary to permanently reduce the thickness of double layer. Cat-ion exchange processes can accomplish this by utilizing fermentation processes specific micro-organisms can produce stabilizing enzyme in large quantity. These soil-stabilizing enzymes catalyze the reactions between the clay and the organic cat-ions and accelerate the cat-ionic exchange without becoming part of the end product. Terrazyme replaces adsorbed water with organic cations, thus neutralizing the negative charge on a clay particle. The organic cations also reduce the thickness of the electrical double layer. This allows Terrazyme treated soils to be compacted more tightly together. Terrazyme resists being replaced by water, thus reducing the tendency of some clay to swell. Terrazyme promotes the development of cementatious compounds.

B. Fly Ash

Fly ash is a residue of coal combustion that occurs at power generation and incineration plants in many countries. Fly ash can be used to

1. lower the water content of soils,
2. reduce shrink-swell potential,
3. increaseworkability, and
4. increase soil strength and stiffness.

C. Lime

Lime can be obtained in the form of quicklime or hydrated lime. Quicklime is manufactured by calcinations of limestone at high temperatures, which chemically transforms calcium carbonate into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. Lime can be used to stabilize clay soils and sub marginal base materials (i.e., clay-gravel, caliche, etc.). When added to clay soils, lime reacts with water in the soil and reduces the soil's watercontent. The lime also causes ion exchange within the clay, resulting in flocculation of the clay particles. This reaction changes the soil structure and reduces the plasticity of the soil. These changes will increase soil workability and can increase the soil strength and stiffness.

2. LITERATURE REVIEW

Lekha et al.(1) have check the improvements in the properties of Black Cotton (BC) soil with a non-traditional stabilizer. The collected soil samples were treated with a commercially available bio enzyme and the treated soil samples were cured for different curing periods as 0, 7 and 28 days. The engineering properties obtained for different mix proportions of soil and the stabilizer are studied. The results of Consistency limits, FSI, UCS, CBR and Permeability test obtained for different curing periods under soaked and unsoaked conditions have been studied and discussed.

Lim et al. (2) have observed the soil road stabilization technologies for the extremes of dry and wet condition and discussed their positive impacts so as to convince the field engineers to adopt such technologies effectively in Malaysian rural areas. Such roadways designed for low-volume traffic are constructed of local soils containing high percentages of fines and high indices of plasticity.

Vijay Rajoria etal.(3) have shown that stabilization of soil with bio-enzyme is evolutionary technique. Recently researchers used many bio-enzymes available for soil stabilization such as regolith,Permazyme, Terrazama, Fujibeton etc. which had been proven to be very effective and economical in soil stabilization. These bio enzymes satisfy the performance in its economic feasibility and serviceability criteria.

Puente Agarwal etal.(4) in their Study had carried out on the bio-enzyme namely Terrazyme, which had been used in their work to study its effect on the Unconfined Compressive strength of the Black Cotton soil having high clay content, low strength and minimal bearing capacity. Terrazyme eco-friendly stabilizer and proves cost effective in soil stabilization. It had been found that Terrazyme treated Black Cotton soil shows significant increase in Unconfined Compressive strength with longer curing period.

3. MATERIALS AND METHODOLOGY

Materials used in this study are black cotton soil, lime, flyash and bioenzyme. Black cotton soil for present investigation is collected from Shingnapur, Tal-Kopargaon, Dist-Ahmednagar as shown in Figure 1,

Figure 1 Soil Sample of BC Soil.

Commercially available enzyme (Terrazyme) has been used in the present investigation (shown in figure 2). It is purchase from NATURE plus, Inc 55 Rachel Drive Stratford, Chennai. It is available as a concentrated liquid and is to be diluted with water in specified proportion before mixing with the soil.

Figure 2 Bioenzyme. (Terrazyme)

Lime used in the present investigation was obtained from local distributer, Kopargaon, MH, India. Commercially available lime was dry and later sieved through I.S.425 micron sieve was taken for the study. The chemical composition of lime is given in Table1. The fly ash is collected from Thermal Power Plant Eklahare, Tal-Nasik, dist-Nasik.

Table 1 Chemical Analysis of Hydrated Lime.

Chemical Characteristics	Percentage (%)
Silica	4.2
Insoluble matter	5.6
Ferric Oxide	1.7
Alumina	1.4
Calcium Oxide	51.7
Magnesia	0.7
Loss on ignition	30

Table 2 Chemical composition of Fly ash.

Constituent	Percentage Range
Silica (SiO_2)	49-67
Alumina (Al_2O_3)	16-29
Iron Oxide (Fe_2O_3)	4-10
Calcium Oxide (CaO)	1-4
Magnesium Oxide (MgO)	0.2-2
Sulphur (SO_3)	0.1-2
Loss on Ignition	0.5-3

Tests taken on treated soil sample

A. Consistency Limit: This test consists of two test i.e. Liquid limit and plastic limit as explain in detail in below.

a. Liquid Limit Test Procedure:

- The soil sample prepared shall be placed in an evaporating dish, covered, and cured, and then thoroughly mixed with the addition of distilled, dematerialized or tap water by alternately and repeatedly stirring, cutting and kneading with a spatula. If needed, further additions of water shall be made in increments of 1 to 3 ml, each increment of water shall be thoroughly mixed with the soil.

- A sufficient quantity of the soil mixture obtained shall be placed in the cup. Care should be taken to prevent the entrapment of air bubbles within the mass. With the spatula, level the soil and return the excess soil to the evaporating dish.
- The soil in the cup shall be divided equally by a firm stroke of the grooving tool along the diameter through the centre line of the cam follower so that a clean, sharp groove of the proper dimensions will be formed.
- Lift and drop the cup by turning the crank, at the rate of 2 rps, until the two halves of the sample flow together and come in contact at the bottom of the groove along a distance of 12.7 mm. Record the number of blows required to close the groove this distance. A valid test is one in which 15 to 35 blows are required to close the groove.
- A sample of the soil is now taken to determine its moisture content.
- After 24 hours the readings of placed samples in container are taken for moisture content determination.

Figure 3 Liquid Limit Apparatus.

b. Plastic Limit Test Procedure

- Squeeze and roll 8 gm test sample into an ellipsoidal shaped mass. Roll this mass between the fingers or palm of hand and the ground glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling should be between 80 and 90 strokes/min., counting a stroke as one complete motion of the hand forward and back to the starting position again.
- When the diameter of the thread becomes 3 mm, break the thread into six or eight pieces. Squeeze the pieces together between the thumbs and fingers into a uniform mass roughly ellipsoidal in shape, and reroll.

- Continue this alternate rolling to a thread 3 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread.
- When the plastic limit has been reached, a sample of the soil is immediately taken to determine its moisture content.
- After 24 hours the readings of placed samples in container are taken for moisture content determination.

Figure 4 Plastic Limit Apparatus.

B. Compaction Test

- Weigh out four 2200 g samples in separate mixing pans and label 1, 2, 3 and 4.
- Estimate the natural moisture content of the soil.
- Add the amount of water to samples by an equal amount.
- Assemble the 101.6 mm mould with collar and base plate. Place the assembly on the compaction base.
- Take the mixed sample and compact in the mould in five equal layers.
- Compact each layer with 25 blows from the rammer dropping freely from a height of 457 mm. Avoid bouncing the weight off the handle at the top of the stroke when operating the rammer. Distribute the blows uniformly over the surface of the layer being compacted.
- After the specimen has been compacted, remove the collar from the mold and use the straight-edge to trim the compacted soils even with the top.
- Remove the mold from the base plate, remove the compacted specimen and remove the liner.
- Weigh the specimen and record the weight to the nearest gram.

- Slice the sample vertically and remove approximately 100 grams of soil from the central section of the test specimen for moisture content determination. Place the sample in a bin, weight, and oven dry to a constant weight at 110oC.
- Determine the difference between the wet and dry weights and record as weight of moisture for calculation of moisture content.
- Repeat the procedure for compacting and moisture content determinations for each of the four samples.

Figure 5 Compaction Test Apparatus.

C. California Bearing Ratio Test

- There are two types of methods in compacting soil specimen in the CBR moulds as static compaction method and dynamic compaction method.
- The material used in the above two methods shall pass 19 mm sieve for fine grained soil.
- Replace the material retained on 19 mm sieve by an equal amount of material passing 19 mm sieve and retained on 4.75 mm sieve.
- Take representative sample of soil weighing approximately 6 kg and mix thoroughly at OMC.
- Record the empty weight of the mould with base plate, with extension collar removed.
- Replace the extension collar of the mould.
- Insert a spacer disc over the base plate and place a filter paper on the top of the spacer disc.
- Place the mould on a solid base such as a concrete floor or plinth and compact the wet soil in to the mould in five layers of approximately equal mass each layer being given 56 blows with 9 kg hammer equally distributed and dropped from a height of 450 mm above the soil.

- The amount of soil used shall be sufficient to fill the mould, leaving not more than about 6 mm to be struck off when the extension collar is removed.
- Remove the extension collar and carefully level the compacted soil to the top of the mould by means of straight edge.
- Remove the spacer disc by inverting the mould and weigh the mould with compacted soil.
- Place a filter paper between the base plate and the inverted mould.
- Replace the extension collar of the mould.
- Prepare two more specimens in the same procedure as described above.

Figure 6 CBR Testing Machine.

METHODOLOGY

In present paper work had performed in four different stages,

Stage 1: Testing physical properties of untreated black cotton soil:

Physical properties of untreated black cotton soil were tested by using the standard tests like moisture content, Specific gravity, Unconfined Compression test, Standard Proctor Test, Free swell index, Liquid limit, Plastic limit, Coefficient of Permeability, California Bearing Ratio test (CBR) etc. Results of untreated B. C. soil are as shown in Table 3.

Table 3 Result of Untreated B.C. soil.

Sr. No.	Property	BC soil
1	Specific gravity	2.26
2	Grain size distribution (%)	
	a) Gravel	5
	b) Sand	23
	c) Silt	56
	d) Clay	16

3	Consistency limits (%)	
	a) Liquid limit	59.93
	b) Plastic limit	30.18
4	IS Soil Classification	CH
5	Compaction test	
	a) MDD (g/cc)	1.15
	b) OMC (%)	63.63
6	Co-efficient of permeability	$0.83x10^{-7}$
7	Unconfined compression test (KN/m^2)	146
8	Free Swell Index (%)	48
9	California Bearing Ratio test (%)	10.1

Stage 2: Stabilization by using Bio enzyme

In the second stage of work the soil sample was tested with addition of stabilizing agent i.e. Bio enzyme by varying curing period from 0 to 4 weeks and dosages from 0.02 to 0.024 ml/Kg of soil. Then soil was tested for Liquid limit, Plastic limit, Standard Proctor test and California Bearing Ratio test (CBR).

Terrazyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application. In the present work concentration i.e. amount of bioenzyme is calculated as per the manual provided by manufacturer. Procedure of addition of Bioenzyme includes following steps,

1. Lab Preparation = 1 ml of TZ Concentrate + 100 ml water (1:100dilution)
2. Withdraw from the Lab Preparation that ml as from dosages per kg of soil sample and add to the water required to bring sample to within 2 % below Optimum Moisture Content (Lab Application Mixture).
3. Make a "Lab Preparation" by adding 1 ml TZ mixed with 100 ml water (or 5 ml TZ mixed with 5 X 100 ml water). TZ is diluted now 1:100.
4. Mix water required + ml of Lab Application Mixture uniformly with soil sample.

Stage 3: Stabilization by using Lime

In third stage of work the soil sample was tested with addition of stabilizing agent i.e. Lime. Soil stabilization occurs when lime is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates. For the present work lime percentage is varied from 1% to 6%. Then soil is tested for Liquid limit, Plastic limit, Standard Proctor test and California Bearing Ratio test (CBR).

Stage 4: Stabilization by using Fly ash

In fourth stage of work the soil sample was tested with addition of stabilizing agent i.e. Fly ash. Fly ash is air dried and pulverized. Fly ash is waste by product of Thermal power plant. Fly ash by itself has little cementatious value but in the presence of moisture it reacts chemically and forms cementatious compounds and attributes to the improvement of strength and compressibility characteristics of soils. For the present work fly ash percentage is varied from 10% to 50%. Then soil is tested for Liquid limit, Plastic limit, Standard Proctor test and California Bearing Ratio test (CBR).

5. RESULT AND DISCUSSION

A. Test on BC soil with Bioenzyme:-

a. California Bearing Ratio Test: Unsoaked CBR test were conducted on treated soil sample having Bioenzyme dose as below,

Dosage 1:- For 1 kg = 0.020 ml of Enzyme

Dosage 2:- For 1 kg = 0.022 ml of Enzyme

Dosage 3:- For 1 kg = 0.024 ml of Enzyme

Results for the soil samples combine with Bioenzyme are shown in Figure 7,

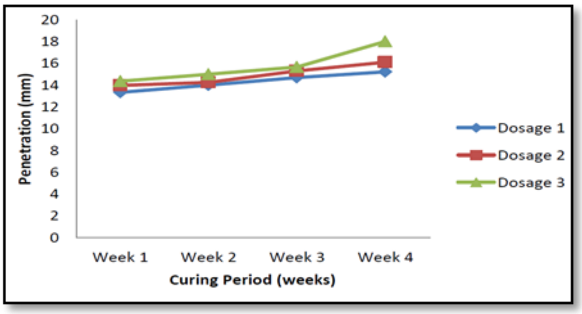

Figure 7 Combine variation of CBR for treated Soil with Different Bioenzyme Dosage.

It is observed from figure 7 that, Unsoaked CBR values increase with the increase in curing period. This is because soil treated with enzyme renders improved density values by reducing the void ratios. This tendency may be due to effective cation exchange process which generally takes longer period in the absence of such stabilizers.

b. Consistency Limit Test: The enzyme treated soil samples consistency limits were tested immediately after the mixing. It shows the variation of consistency limit with different curing period is shown in Figure 8,

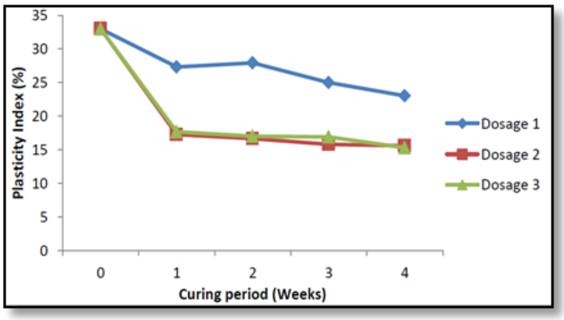

Figure 8 Combine variation of P.I. for treated Soil with Different Bioen1zyme Dosages.

The decrease in liquid limit, plastic limit and plasticity index after 1 to 4 weeks of curing period and also with the amount of dosages is observed from the figure 4.12. Amount of clay content plays a major role in the variation of consistency limits. The mix becomes very stiff after weeks of curing.

c. Compaction Test: The standard compaction test results for variation with 0 to 4 weeks curing period are shown in Figure 9 and Figure 10.

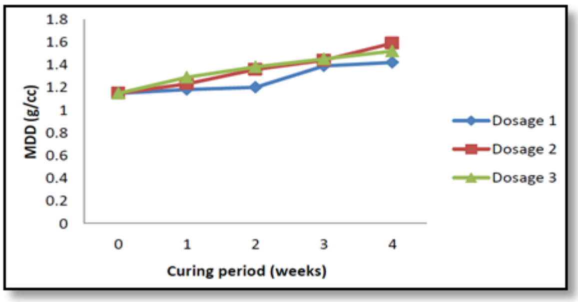

Figure 9 Combine variation of MDD for treated Soil with Different Bioenzyme Dosages.

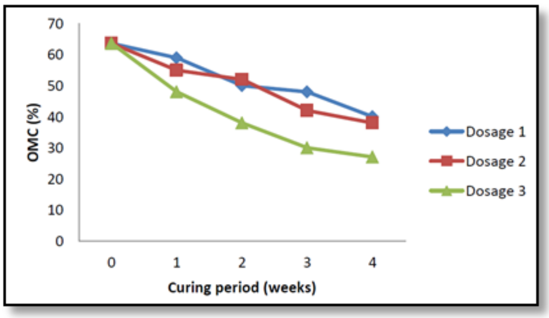

Figure 10 Combine variation of OMC for treated Soil with Different Bioenzyme Dosages.

From figure 9 it is clearly observe that, there is change in MDD of treated soil with increase in curing period as well as dosages concentration. From figure 10, OMC is observed to be decreasing with increase in curing period and dosages concentration. It is due to film of adsorbed water which is greatly reduced for treated soil and these soil particles acquire a tendency to agglomerate.

B. Test on BC soil with Lime:

a. California Bearing Ratio Test: The Unsoaked CBR value of the soil mixed with varying percentage of lime are shown in Figure 11.

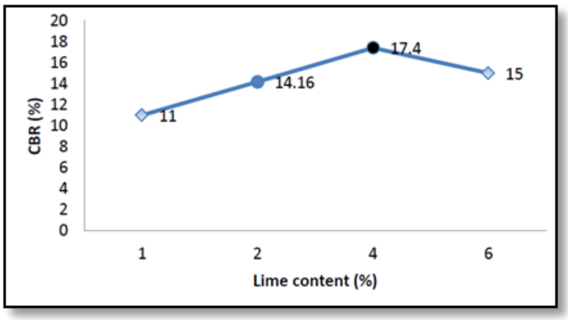

Figure 11 Variation of CBR for treated Soil with Lime.

It is observed from figure 11 that up to 4% there is increase in CBR with increase in lime content and after which it goes on decreasing. The optimum lime content is observed to be at about 4%.

b. Consistency Limit Test: Result of Liquid limit, Plastic limit and Plasticity Index are shown in Figure 12.

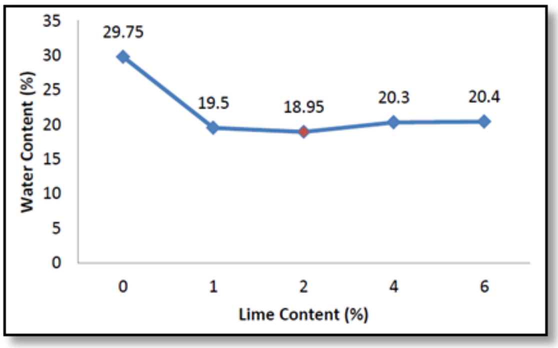

Figure 12 Variation of plasticity index for treated Soil with Lime.

Liquid limit of treated soil is reduced by 10% after lime was added. The liquid limit of the soil decreases with increase in lime content. Although the plastic limit did not change distinctly with increase in lime content, the lowest value was reached at a lime content of about 2% where plasticity index of soil is minimum.

c. Compaction Test: The compaction test results for variation with 0 to 6% of lime content are shown in Figures 13 and 14.

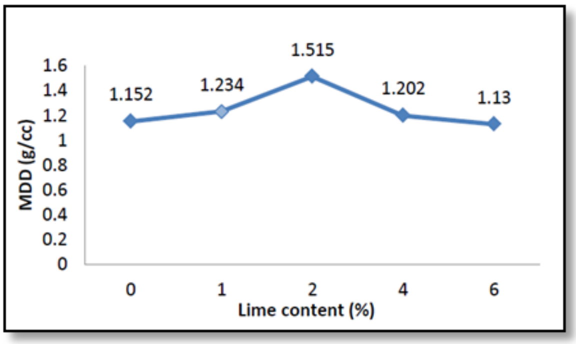

Figure 13 Variation of MDD for treated Soil with Lime.

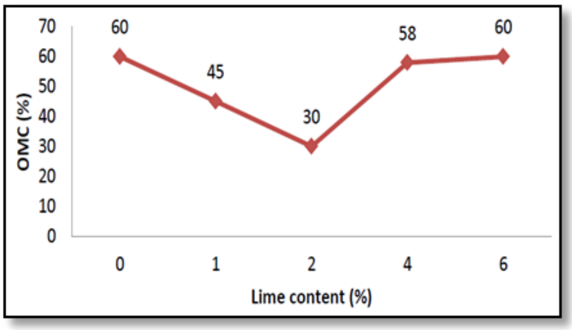

Figure 14 Variation of OMC for treated Soil with Lime.

From figure 13 and 14 it is clearly observe that, there is change in MDD of treated soil which increases up to 2% and then decreases with lime content and results of OMC is observed to be reverse of MDD.

C. Test on BC soil with Fly ash:

a. California Bearing Ratio Test: The result of the Unsoaked CBR values with variation of fly ash are as shown in Figure 15.

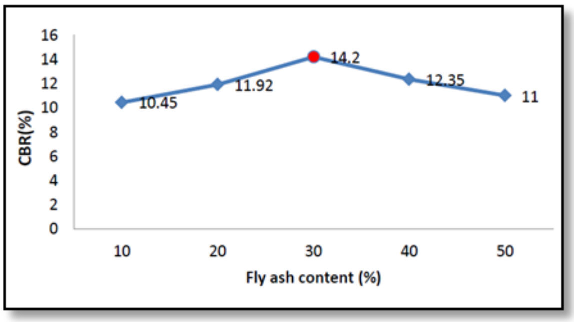

Figure 15 Variation of CBR for treated Soil with Fly ash.

The California bearing ratio (CBR) values of BC soil increases with increase of fly ash content. CBR value becomes maximum at 30% fly ash and then it start to reduce.

b. Consistency Limit Test: The variation of plasticity index on addition of fly ash to the black cotton soil is shown in Figure 16.

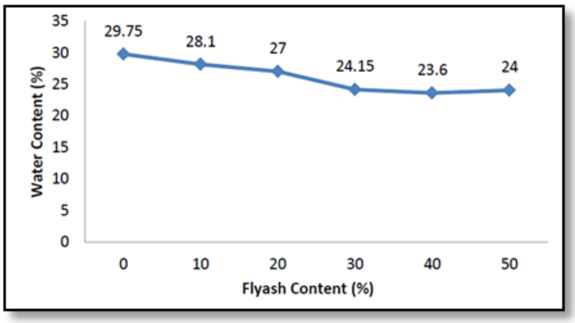

Figure 16 Variation of consistency limit for treated Soil with Fly ash.

Increased addition of fly ash with BC soil, the amount of soil to be flocculated decreases and the finer particles of fly ash may be incorporated in the voids of flocculated soil, thereby decreasing the water held in the pores leading to the decrease in the consistency limit.

c. Compaction Test: The results for compaction test are shown in Figures 17 and 18.

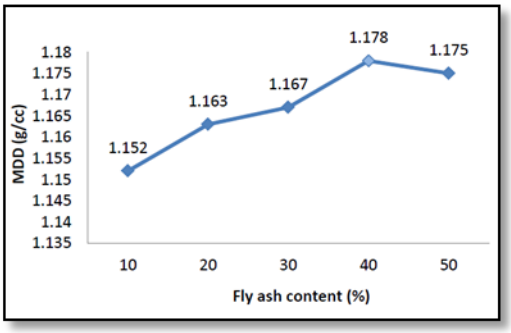

Figure 17 Variation of MDD for treated Soil with Fly ash.

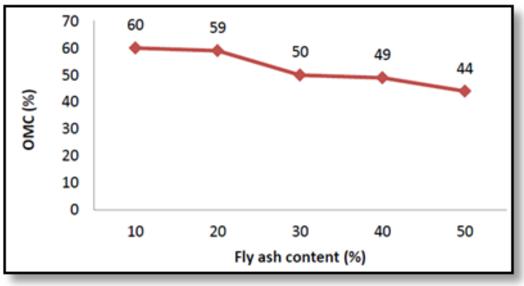

Figure 18 Variation of OMC for treated Soil with Fly ash.

In B.C. soil, MDD increased slightly up to 40% of fly ash, and then it decreased. It is shown that for depressive clays the MDD first increases and then decreases with the increase in fly ash content. OMC of B,C. soil treated with fly ash decreases with the increase in fly ash content.

5. CONCLUSIONS

After performing the entire test on BC soil in laboratory with the addition of different stabilizing agents some of the following conclusions are drawn as below,

1. After addition of bioenzyme, unsoaked CBR values are significantly increase with the increase in curing period and also with increase in amount of dosages.
2. Bioenzyme decreases liquid limit, plastic limit and plasticity index of soil after 1 to 4 weeks of curing period and also with the amount of dosages. The mix becomes very stiff after weeks of curing.
3. As increase in curing period and dosages of bioenzyme, the MDD of treated soil increases and OMC is observed to be decreasing.
4. Unsoaked CBR values gradually increase with the increase in lime addition up to 44.55% for lime content 4% so, the optimum lime content is observed at about 4%.
5. Addition of lime with the soil shows that, Plasticity index decreases with increase in lime content up to 2 %.
6. MDD of treated soil is increases up to 2% and then decreases with lime content and OMC is observed to be reverse of MDD result.
7. The Increase in Unsoaked CBR values with the increasing percentages of fly ash and then decreases after 30%.
8. Plasticity index is decreases with increase in addition of fly ash up to 40%.
9. MDD increased slightly up to 40% of fly ash and then it decreases. OMC of B,C. soil treated with fly ash decreases with the increase in fly ash content.
10. Bioenzyme is best stabilizing agent as compared to lime and fly ash and also has life time sustainability, so it can be used in Expressways and national highways.
11. Lime and Fly ash are cheaper materials and has considerable scope for construction of low cost roads such as Village roads.

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