BLACK COTTON SOIL STABILIZATION BY BIO ENZYMES

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ABSTRACT:

Engineers often face the problem of constructing facilities on or with soils, which do not posses sufficient strength to support the loads imposed upon them either during construction or during the service life of the structure. Vast areas of India consist of Black Cotton Soil which has high clay content, low strength and minimal bearing capacity. The poor engineering performance of such soils has forced Engineers device cost effective and ecofriendly methods for improving the engineering properties of poor soils. As the conventional soil stabilizers like gravel, sand, etc. are depleting and becoming expensive day by day at a very rapid pace, it becomes necessary to look towards for alternative ecofriendly stabilizers as their substitute. Recently many Bio-enzymes have emerged as cost effective stabilizers for soil stabilization. One such bio-enzyme, Terrazyme, has been used in the present work to study its effect on the Unconfined Compressive strength of the Black Cotton soil. It has been found that Terrazyme treated Black Cotton soil shows significant increase in Unconfined Compressive strength with longer curing period. Bio-enzyme is a natural, non toxic, non flammable, non-corrosive liquid enzyme formulation fermented from vegetable extracts that improves the engineering qualities of soil, facilitates higher soil compaction densities and increases stability.

Key words: *Black Cotton Soil, Bio Enzymes, Stabilization Techniques, Fly Ash Comparison's*

INTRODUCTION: Soil is the indispensable element of this nature. It is attached to everyone in one or another way. All the basic amenities of life, whether it is concerned with food, clothes and house, have been fulfilled by the soil .Without the soil it is just next to impossible to think about life on this earth. These soils are residual deposits formed from basalt or trap rocks. Black cotton soils are clays of high plasticity. They contain essentially the clay mineral montmorillonite, which is the most unstable clay mineral, thus the soils have high shrinkage and swelling characteristics. The sharing strength of the soil is extremely low, is highly compressible and has very low bearing capacity. It is very difficult to work with this soil, as do not posses sufficient strength to support the loads imposed upon them either during construction or during the service life of the structure. For better performance of structures built on such soils, the performance characteristics of such soils need to be improved.

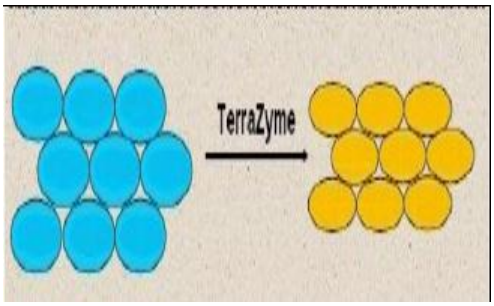
Scope of study : Enzyme catalyze the reactions between the clay and the organic cat-ions and accelerate the cat-ionic exchange process to reduce adsorbed layer thickness. For other types of chemical stabilization, chemicals are mixed with soil, which is difficult to mix thoroughly, but bio-enzyme is easy to use as it can be mixed with water at optimum moisture content and then it is sprayed over soil and compacted. In this study Black cotton soil with varying index properties have been tested for stabilization process and strength of the stabilized soil were evaluated after curing period of 0 days, 14days, 21 days and 28 days for various enzyme dosages 200ml/3m3 , 200ml/2.5m3 , 200ml/2m3 , 200ml/1.5m3 . The tests which were carried out are the California Bearing

Ratio (CBR) test and Unconfined Compressive strength (UCS) test of the soil specimen. The test results indicate that bio-enzyme stabilization improves the strength of BC soil up to great extent, which indicate the bearing capacity and the resistance to deformation increases in stabilized soil. An attempt has been made to study the properties of soil modified with the bio-enzyme , in order to use this technology for low volume roads. Based on laboratory findings, field trials were carried out using bioenzyme in some of roads in India. Moreover, in case of scarcity of granular material, only bio-enzyme stabilized surface with thin bituminous surfacing also can fulfil the pavement design requirement. Adopting the IRC method based on soil CBR, the pavement design thickness on stabilized soil also reduces 25 to 40 percent.

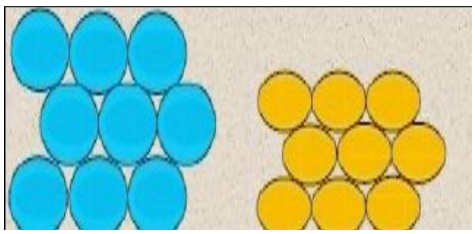
Enzymes and its terminology

Terrazyme, a Bio-Enzymatic Soil Stabilizer : TerraZyme is a natural, non-toxic, non-corrosive and noninflammable liquid, produced by formulating vegetable extracts. Organic enzymes come in liquid form. They are perfectly soluble in water, brown in color with smell of molasses. Their aroma has no effect. Neither gloves nor masks are required during handling. TerraZyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application. TerraZyme when added to water and mixed with soil alters the engineering properties depending upon the type of the soil and dosage of enzyme. These enzymes are liquid additives, which act on the soil to reduce the voids between soil particles and minimize absorbed water in the soil for maximum compaction.

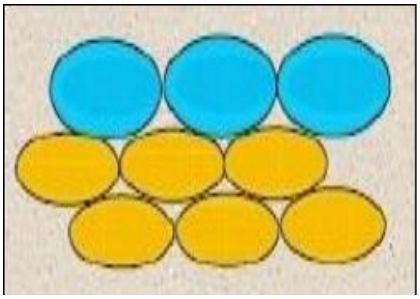
Mechanism of Soil Stabilization by Bio-Enzyme : In clay water mixture positively charged ions (cat-ions) are present around the clay particles, creating a film of water around the clay particle that remains attached or adsorbed on the clay surface. The adsorbed water or double layer gives clay particles 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 using the following, general reaction:

$$H_2O + \text{Clay} \xrightarrow{\textit{Terrazyme}} \text{Calcium Silicate Hy}$$

Objectives of present work To study the soil properties of black cotton soil.

1. To study the experimental out put by doing stabilization tests.
2. To study the effect of Bioenzyme on the quality of sub grade/base course layers and its influence on pavement system.
3. To optimize the quantity of Bioenzyme to be used as stabilizing agent and the extent of stabilization of strength gain with time.
4. To develop suitable specifications and recommendations for evolving proportions for its use in subsurface layers.
5. To validate mathematical model with experimental results

Materials and methodology :

Laboratory Tests

Grain size distribution analysis : The grain size distribution is found by mechanical analysis. The components of soils which are coarse grained were analyzed by sieve analysis and the soil fines by sedimentation analysis. The grain size analysis or the mechanical analysis is hence carried out to determine the percentage of individual grain size present in a soil sample. This test is aim at the determination of the size of the particles of the soil consists. The test result is illustrated by the grain size distribution curve. In case of the particles with size larger than 75 µm (retained on sieve no. 200), the particle sizes are determined by "Sieve Analyses". While for the particles of the sizes smaller than 75 µm (passed through sieve no. 200), the particle sizes are determined by "Hydrometer Analyses".

Grain Size Distribution Apparatus

In case of the particle with cohesion as the lateritic soil, the sieve analysis method with water is applied. The soil is put onto a sieve and rinsed by spraying water until water is clear. The soil sample which retained on the sieve is then air-dried and the particle size is determined by dry-sieve again. The total mass percent of grains within the selected sieve sizes are calculated. Subtracting these percentages successively from 100% will give the ordinates of the grain-size distribution curve. The grain size analysis (coarse and fine) are tabulated and are given in Table.

Grain size distribution analysis – Values

Type of soil	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Soil 01	18.00	62.00	16.00	4.00
Soil 02	17.60	37.40	20.00	25.00
Soil 03	18.40	41.60	20.00	20.00
Soil 04	22.80	62.90	3.37	9.97
Soil 05	6.00	82.00	4.00	8.00
Soil 06	3.00	86.00	6.00	5.00
Soil 07	17.20	44.40	17.40	21.00
Soil 08	11.20	27.80	31.00	30.00
Soil 09	7.20	41.80	24.00	27.00
Soil 10	27.60	48.40	12.00	12.00
Soil 11	9.20	67.40	10.90	12.50
Soil 12	14.40	39.40	20.00	26.00
Soil 13	12.80	75.70	1.50	10.00
Soil 14	13.60	60.80	13.00	12.60
Soil 15	14.00	75.50	1.50	9.00

The details of experimental setup for conducting sedimentation analysis of selected soil samples are given in Figures

Effect of Hydrometer Immersion

Samples Tested in Hydrometer

Specific Gravity

A systematic study of the specific gravity of soils is required for the determination of voids ratio, degree of saturation which is a very important for compaction point of view. The results of the tests for different types of samples are tabulated in Table

Specific gravity of selected samples

Type of soil	Specific Gravity
Soil 01	1.98
Soil 02	2.55
Soil 03	2.25
Soil 04	2.08
Soil 05	2.11
Soil 06	2.15
Soil 07	2.11
Soil 08	1.93
Soil 09	2.15
Soil 10	2.25
Soil 11	2.38
Soil 12	1.61
Soil 13	1.63
Soil 14	1.54
Soil 15	1.45

Atterberg's Limit

These tests are performed to determine liquid limit, plastic limit and the plasticity of cohesive soil in order to characterize its condition by water content. The apparatuses for Atterberg's Limit Test are shown in Figure

Liquid Limit and Plastic Limit apparatus

Liquid Limit is the water content, normally in percentage, at which the two sides of a groove Cut in the soil sample contained in the cup of a Casagrande device would touch over a length of 12 mm after 25 impacts. The procedures of the test are summarized as follow: the soil to be tested is put in the porcelain bowl, and gradually mixed with distilled water to create a thick paste. About 50- 80 g of the paste is then transferred to the cup of the liquid limit device, to a thickness of 12 mm. The surface is leveled by using the spatula and the groove is then made in soil by using the trenching tool. When the cup is placed onto the shaft and the whole apparatus is set on a felt pad and crank is then rotated at the rate of about 2 revolutions per second until the two surfaces separated by the groove touch each other at the bottom of the cup along an uninterrupted length of 12 mm.

Table 3.3 Atterberg's limits of selected samples

Soil	L.L %	P.L %	P.I %	IS Classification
Soil 01	36	29	7	GW
Soil 02	38	32	6	ML – OL
Soil 03	46	40	6	GC
Soil 04	49	43	6	GP
Soil 05	28	22	6	SM – GM
Soil 06	30	25	5	GP
Soil 07	28	22	6	SC
Soil 08	35	30	5	CL-ML
Soil 09	42	36	6	ML
Soil 10	60	54	6	MH – OH
Soil 11	30	25	5	OL
Soil 12	35	27	8	CL
Soil 13	30	21	9	CI
Soil 14	26	17	9	OH
Soil 15	25	17	8	CL – ML

Modified Proctor Compaction test apparatus

Maximum Dry Density with Optimum Moisture Content

Type of soil	OMC %	MDD kN / m
Soil 01	12	14.53
Soil 02	11	17.3
Soil 03	10	15.79
Soil 04	12	15.5
Soil 05	11	14.03
Soil 06	12	14.22
Soil 07	11	16.2
Soil 08	11	16.2
Soil 09	10	15.7
Soil 10	11	15.8
Soil 11	12	15.6
Soil 12	9.09	14.22
Soil 13	10	14.23
Soil 14	10	14.13
Soil 15	10	14.22

Black cotton soil

As a part of this investigation, the expansive black cotton soil was acquired and the black cotton soil thus obtained was carried to the laboratory in sacks. A small amount of soil was taken, sieved through 4.75 mm sieve, weighed, and air-dried before weighing again to determine the natural moisture content of the same. The various geotechnical properties of the procured soil are as follows

The enzyme dosage varies from 200 ml/3.5m3 to 200 ml/1.5m3 of the soil, and it depends upon soil properties. In this experimental investigation the Enzyme Dosages assumed for Expansive Clayey soil was 200 ml for bulk volume 3.5 m3 to 1.5 m3 of soil.

Bulk Density of BC soil = 1.56 g/cc

Bulk Density = Weight / Volume

Weight = Bulk Density x Volume

For Dosage 1

200 ml for 3.0 m3 of soil = 1.56 x 3.0 x 1000 = 4680 kg of soil For 1 kg = 0.042 ml of Enzyme

For Dosage 2

200 ml for 2.5 m3 of soil = 1.56 x 2.5x 1000 =3900 kg of soil For 1 kg = 0.051 ml of Enzyme

For Dosage 3

200 ml for 2.0 m3 of soil = 1.56 x 2.0 x 1000 = 3120 kg of soil For 1 kg = 0.064 ml of Enzyme For Dosage 4 200 ml for1.5 m3 of soil = 1.56 x 1.5 x 1000 = 2340 kg of soil For 1 kg = 0.085 ml of Enzyme

For Dosage 4

200 ml for1.5 m3 of soil = 1.56 x 1.5 x 1000 = 2340 kg of soil

For 1 kg = 0.085 ml of Enzyme.

Enzyme Dosages

Enzyme Dosage:

Dosage	200ml/m^3 of soil	ml/kg of soil
1	3.0	0.042
2	2.5	0.051
3	2.0	0.064
4	1.5	0.085

EXPERIMENTAL RESULTS

BASIC PROPERTIES OF INVESTIGATING SOIL:

Properties of black cotton soil.

Sl. No	Property	Value	I S Codes
1	**Specific Gravity**	2.48	IS 2720 (part III)
2	**Atterberg limits** Liquid limit (%) Plastic limit (%) Plasticity index Shrinkage limit (%)	 61.40 34.00 27.40 16.60	IS 2720 (part V)
3	**Grain size distribution** a) Gravel (%) b) Coarse Sand (%) c) Fine sand (%) d) Silt & Clay (%)	 0.00 10.17 20.87 68.70	IS 2720 (part IV)
4	**USCS Soil Classification**	CH	
5	**Free swell index %**	72.80	IS 2720(part XL)
6	**Engineering Properties** Light Compaction a) Max dry density,(kN/m^3) b) O.M.C %	 14.80 23.00	 IS 2720 (part VII) IS 2720 (part II)
7	**CBR Value (%)** IS Standard Compaction a) Un-soaked condition	 2.86	
	b) Soaked condition	1.19	IS 2720 (part XVI)
8	**Swelling Pressure (kN/m^2)**	48.00	IS 2720(part XLI)
9	**Unconfined compression test (kg/cm^2)**	3.53	IS 2720 (part X)
10	**Co-efficient of Permeability**	1.5x10^{-8} cm/sec	IS: 2720 (part XVII)

Atterberg limits:

The effect of Terrazyme at different dosage on index properties (Liquid limit, Plastic limit and Plasticity index) of Black Cotton (BC) soil have been presented in table.The enzyme treated soil sample's consistency limits were tested immediately after the mixing. The mix becomes very stiff after weeks of curing.

Consistency limits of stabilized black cotton soil

Dosage number	Enzyme dosage	Black Cotton soil		
		Liquid limit (%)	Plastic limit (%)	Plasticity index
0	Un treated	61.40	34.00	27.40
1	200 ml/3.0 m^3	60.22	33.50	26.72
2	200 ml/2.5 m^3	59.00	32.79	26.21
3	200 ml/2.0 m^3	57.75	32.23	25.52
4	200 ml/1.5 m^3	56.49	31.70	24.79

Compaction Test:

Black cotton (BC) soil with different dosage of Terrazyme, StandarD Proctor's Test was conducted. Test results are presented in table

Table OMC and MDD of stabilized Black Cotton soil

Dosage No.	Enzyme Dosages	Standard Compaction (Light Compaction)	
		OMC (%)	MDD (gm/cm^3)
0	Untreated	23.00	1.486
1	200ml/3m^3	22.40	1.521
2	200ml/2.5m^3	22.10	1.564
3	200ml/2m^3	21.00	1.590
4	200ml/1.5m^3	20.4	1.633

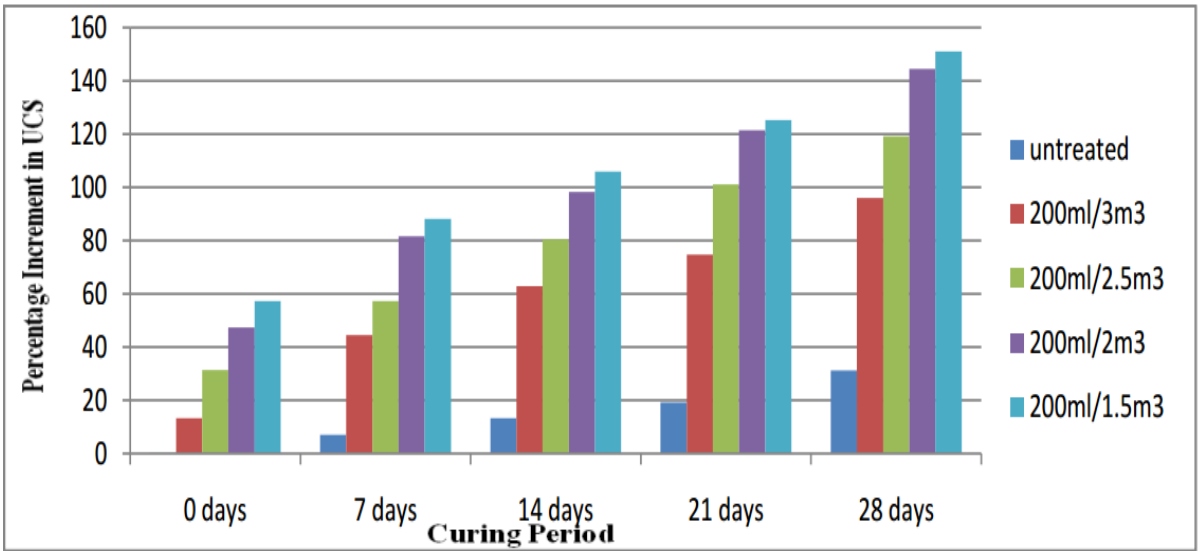
The increase in MDD with different dosages of Terrazyme is uniform till the final dosage 200ml/1.5m3 . This trend happens due to the formation of transitional compounds that had higher densities in the range of 3rd -4 th enzyme dosage.

Unconfined Compression Strength (UCS) Test:

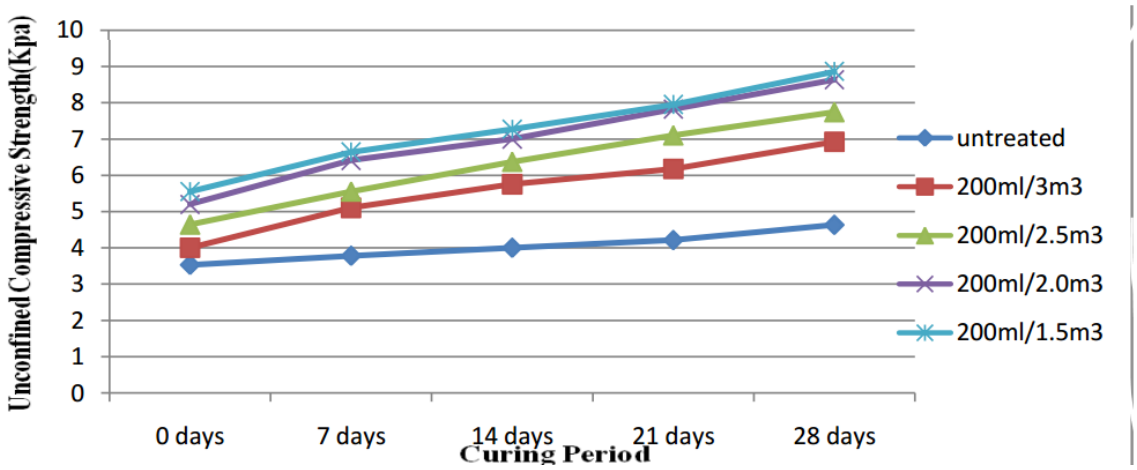
Unconfined compression strength of black cotton soil was evaluated by stabilization with variable dosages of enzyme for 0, 7, 14, 21 and 28 days curing. The specimens were prepared and kept in desiccators to retain the moisture of the sample so that reaction between soil particle and enzyme may be continued. Number of samples were tested with different dosage of enzyme i.e 200ml for 3, 2.5, 2, 1.5m3 of soil. The test results are summarized in table

Table UCS value of BC soil with varying enzyme dosage & curing time

Dosage No.	Dosages	UCS of soil in (KPa) for period of treatment				
		0 day curing	7 days curing	14days curing	21days curing	28days curing
0	Untreated	3.53	3.78	4.05	4.21	4.63
1	200ml/3m^3	4.00	5.10	5.75	6.17	6.92
2	200ml/2.5m^3	4.64	5.55	6.37	7.10	7.74
3	200ml/2m^3	5.20	6.41	7.00	7.82	8.63
4	200ml/1.5m^3	5.57	6.64	7.27	7.95	8.86



Percentage Increment in UCS



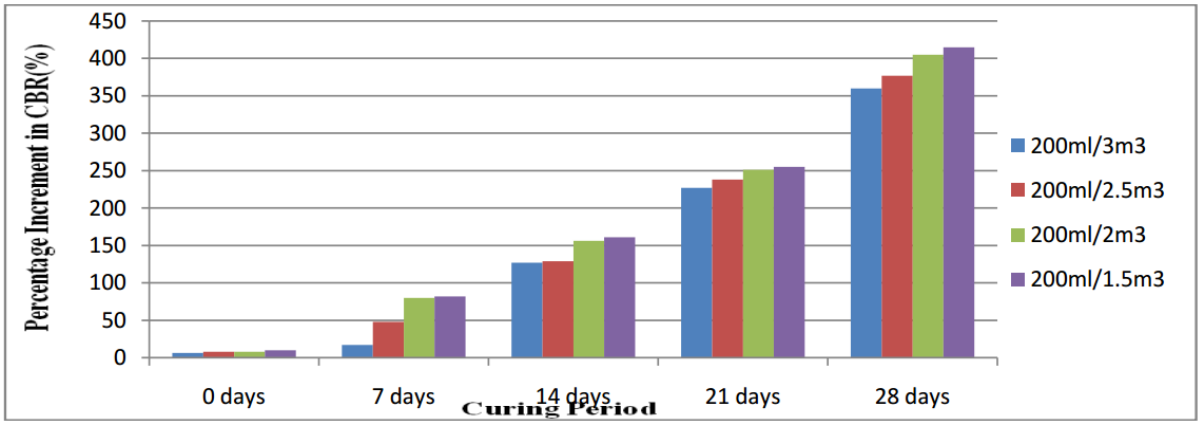
Variation of UCS for different curing period on expansive clayey soil

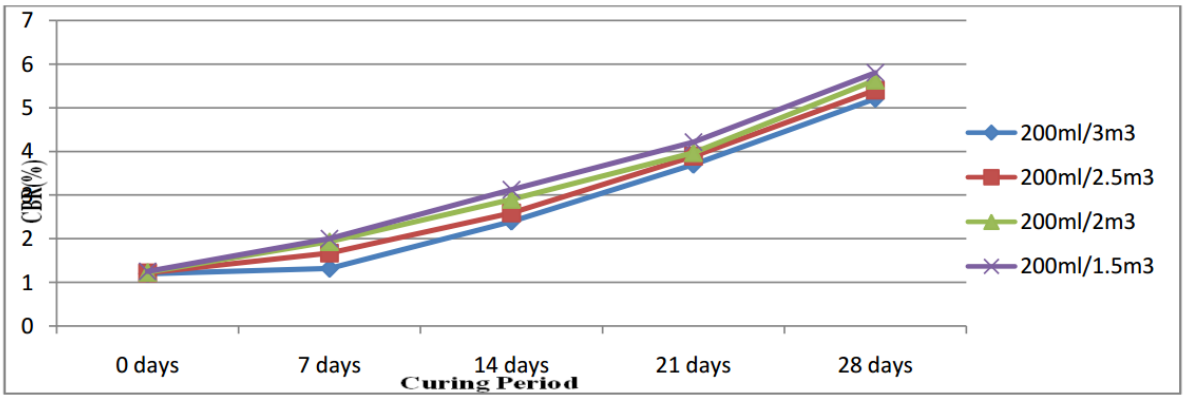
California Bearing Ratio (CBR) Test:

Black cotton soil was treated with 4 dosage of enzyme (Terrazyme) at optimum moisture content 23%. CBR moulds were prepared with different dosages by standard proctor method and kept by covering plastic bags for testing on different days. Later for soaked conditions moulds were kept in water condition for 4days and then tested for CBR. The soaked CBR values of black cotton soil with different enzyme dosages in various curing days are given in table

CBR test of BC soil with varying enzyme dosage and curing time

Dosage No.	Soil Enzyme Dosage	Curing Period				
		0 day	7 days	14 days	21 days	28 days
0	Untreated	1.19%				
1	200m//3m^3	1.20	1.32	2.40	3.70	5.21
2	200ml/2.5m^3	1.22	1.67	2.59	3.83	5.40
3	200ml/2m^3	1.23	1.93	2.91	3.97	5.63
4	200ml/1.5m^3	1.25	2.00	3.12	4.21	5.80



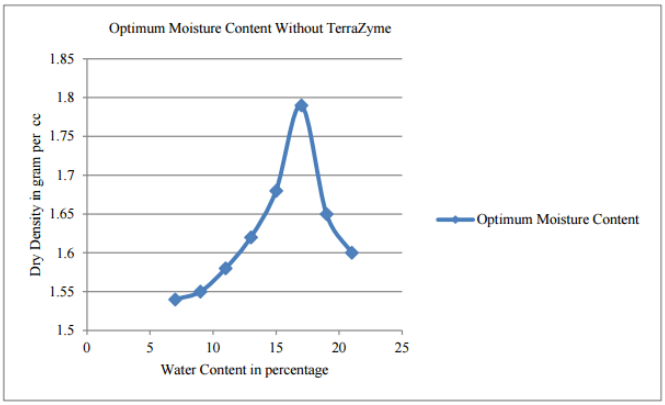


Variation of CBR for different dosage & curing period

By using terrazyme

The material which was used in the test is local soil (from Ballupur Road) and TerraZyme (bio enzyme). To find out the suitability of TerraZyme on soil laboratory test were performed. The TerraZyme was obtained by Avijeet agencies, Anna nagar Chennai, India. The dosage of TerraZyme is decided on the basis of type of soil. To study the variation of geotechnical properties of local soil we have taken 3m3 per 200ml, 2.5 m3 per 200ml, 2.0m3 per 200ml and 1.5m3 per 200ml. The prefatory tests were performed on the local soil with and without TerraZyme. The experimental analysis was carried out by taking dosage and curing time into consideration. The soil was crushed prior to tests and TerraZyme is mixed in different quantity for differ time period. Atterberg's limit test as per Standard proctor test as per Grain size analysis , Specific gravity analysis,California bearing ratio test were performed on the soil in laboratory. According to 'Indian Standard Soil Classification System ', local soil was categorized as clay 'SM' type.Shows the geotechnical properties of local soil.

S.No.	Property	Value
1	Specific gravity	2.53
2	Grain size distribution	
	Gravel (%)	0.0
	Sand (%)	7.35
	Silt (%)	77.00
	Clay (%)	15.65
3	Consistency limits	
	Liquid Limit (%)	27.00
	Plastic Limit (%)	23.21
	Plasticity Index (%)	3.79
	Shrinkage Limit (%)	21.00
4	I.S .Soil Classification	Clayey silt (CM)
	Engineering properties	
5	*Max.* Dry Density, kN/m^3	17.90
	OMC (%)	17
	C.B.R (%)	
6	Unsoaked	5.60
	Soaked	2.36
7	Unconfined compressive strength kN/m^2	270



Optimum moisture content of soil without TerraZyme

Specific gravity : Specific gravity G is the ratio of unit weight of soil to unit weight of distilled water at 4 °centigrade. Specific gravity of soil is required for the calculation of unit weight, degree of saturation; water content etc .The unit weight is ultimately used for determining the settlement, pressure and stability problem. Table 3 shows the results of specific gravity of soil with TerraZyme in different dosage and for different time period.

Specific Gravity test result

Dosages	Specific Gravity	
	Ist Week	II^{n} Week
3.0m^3/200ml	2.564	2.747
2.5m^3/200ml	2.59	2.87
2.0m^3/200ml	2.63	2.85
1.5m^3/200ml	2.54	2.72

Consistency limit test : Consistency limits are the boundary water content at which the soil undergoes from one state to another. Liquid limit test, plastic limit test and plasticity index falls under the category of consistency limit test. The initial liquid limit was 27%, plastic limit was 23.21% and plasticity index 3.79% without TerraZyme. Table shows the result of consistency limits at different dosage of TerraZyme and for different duration.

Consistency limit test result

Dosages	Consistency Limits	Ist Week	IInd Week
3m^3/200 ml	Liquid limit (%)	22.40	20.00
	Plastic limit (%)	17.00	15.50
	Plasticity index (%)	5.40	4.50
2.5m^3/200 ml	Liquid limit (%)	24.00	21.00
	Plastic limit (%)	17.50	16.00
	Plasticity index (%)	6.50	5.00
2m^3/200 ml	Liquid limit (%)	21.00	19.50
	Plastic limit (%)	17.00	16.00
	Plasticity index (%)	4.00	3.50
1.5m^3/200 ml	Liquid limit (%)	26.00	20.50
	Plastic limit (%)	17.10	16.30
	Plasticity index (%)	8.90	4.20

Standard proctor test For determining the optimum moisture content and maximum dry density of the soil standard proctor test was conducted at laboratory .With the variable dosage of TerraZyme OMC and MDD were calculated for one and two week of curing. The OMC and MDD of soil without TerraZyme were found to be 17.9 % and 17kN/m3 . The effect of different dosage of TerraZyme after one and two week on OMC and MDD of soil is shown in table

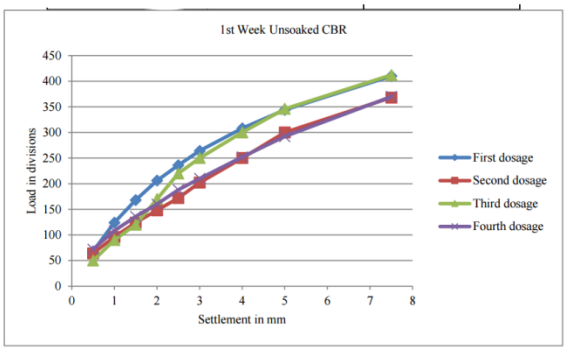
Standard proctor test results

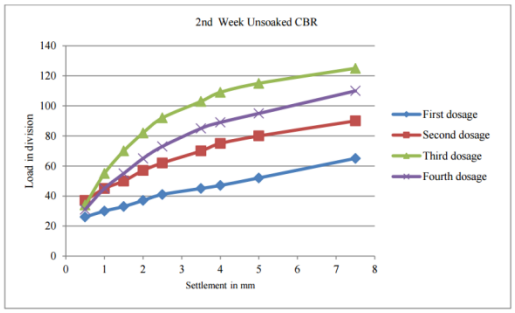
Dosages	OMC (%)		MDD (kN/m^3)	
	Ist Week	IInd Week	Ist Week	IInd Week
3.0m^3/200ml	10.00	10.00	1.79	1.80
2.5m^3/200ml	14.00	15.00	1.828	1.87
2.0m^3/200ml	10.00	14.00	1.823	1.88
1.5m^3/200ml	13.00	14.00	1.81	1.84

California bearing ratio California bearing ratio test was done for both unsoaked and soaked conditions. The test was performed by taking different dosages of TerraZyme i.e. (3.0m3 /200ml), (2.5m3 /200ml), (2.0m3 /200ml), (1.5m3 /200ml). Before performing test the sample of soil with different enzyme content are cured for one to two week. Table shows the effect of TerraZyme on the CBR value of soil sample (Unsoaked). Figure below shows the 1 week and 2 week results of Unsoaked CBR respectively. While table shows effect of Terrazyme on soil sample (soaked). Figure shows the results of soaked CBR for 1 and 2 week respectively.

Unsoaked CBR test results.

Dosages	I st Week	II nd Week
3.0m³/200ml	17.22%	20.87%
2.5m³/ml	15.16%	30.21%
2.0m³/ml	16.84%	30.9%
1.5m³/ml	14.20%	30.07%



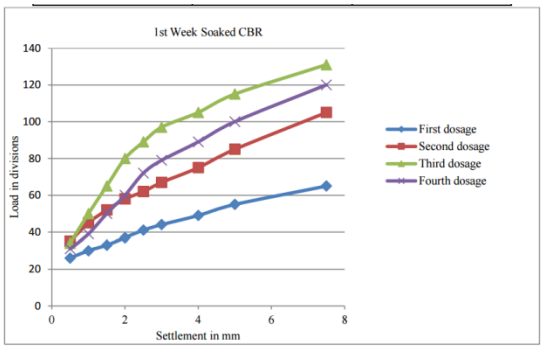


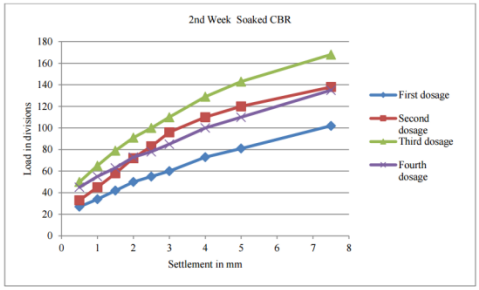
Unsoaked CBR Week 2.

Unsoaked CBR Week 1

Soaked CBR test results

Dosages	I st Week	II nd Week
3.0m³/ml	4.6	5.9
2.5m³/ml	5.3	6.0
2.0m³/ml	6.1	7.09
1.5m³/ml	5.5	6.2





Soaked CBR Week 2

CONCLUSION: Performance of Bio-Enzyme stabilized soil has been investigated in this work. Based on the tests conducted in the laboratory, the following conclusions were drawn:

- Amount of clay content plays a major role in the variation of consistency limits. It is found that liquid limit• decreases from 61.40% to 56.49% while the plastic limit reduces from 34.00% to 31.70% at the dosage no.4
- Changes are marginal for MDD of enzyme treated soil which is from 1.486 gm/cm3• to1.633gm/cm3 where as decrease in OMC is observed to be 23.00% to 20.40%. The decrease is due to effective cat ion exchange process which generally takes longer period in the absence of such stabilizers.
- The UCS value increases from 3.53 KN/m2• to 8.86 KN/m2 when compared to the original soil after 4weeks of curing period. This is due to the reaction of enzyme with clay which results in cementation effect. The reaction time is significant as the strength at 4weeks (150.99% increase from original soil) is greater than that at 1week (88.10% from the original soil).
- It is observed that the treated soaked CBR values are increased as the curing periods increase which is because• soil treated with enzyme renders improved density values by reducing the void ratios. Initially for the local soil the soaked CBR value was 1.19% but with stabilization after 4weeks of curing the soaked CBR value was 5.80% which shows an increase of 387% from the original soil.
- Bio Enzymes are non poisonous, organic and biodegradable in nature. The product formed after the application of TerraZyme is bio degradable in nature and the effect is permanent. TerraZyme eliminates the use of granular sub base and sub grade course.
- The MDD of local soil without TerraZyme was 1.79gm/cm3 and OMC to be 17%.
- The initial cost of using TerraZyme is high as compared to traditional approaches but the benefit of using TerraZyme is that the maintenance cost is zero , making this approach economically cost effective.
- The third dosage of enzyme is the optimum one because the consistency limits are reduced• and the soaked CBR increased after curing period of two weeks.

Scope for future study

- Bio-enzymes along with another additive like lime, murrum, cement, and other such materials can be used together, and may be varied in quantity to obtain the best possible stabilizing mixture.
- Terrazyme effect on the soil with varying dosage and in varying stabilizing duration.
- Further testes can be performed for permeability, direct shear test and dynamic behavior of soil to improve the soil property.

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