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An Experimental Investigation on Black Cotton Soil using Terrazyme

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ABSTRACT

The application of biodegradable substances for the improvement of weak soil has given better results in the field of geotechnical engineering. These substances are fermented and extracted from vegetation. It reduced the void ratio, thickness of absorbed water and maximize the compaction. Terrazyme contains natural protein. It is non-toxic and eco-friendly. It is soluble in water. The black cotton soil is highly plastic with swelling potential. Reduction in moisture causes shrinking, leads to differential settlement of the foundation. This will results in damage to the structure. This paper presents experimental work on black cotton soil reinforced with Terrazyme. Various proportions of Terrazyme were mixed with black cotton soil to evaluate the engineering properties of soil. The change in index properties and strength parameters were assessed by experiments on treated and untreated soil. Atterberg limits, free swell index, compaction test, triaxial tests were performed. Experimental results show a reduction in liquid limit, plasticity index, free swell index, optimum moisture content, and compression index. Triaxial tests showed improvement in cohesion and angle of shearing resistance. The optimum dosage of Terrazyme was found 2% by weight of dry soil.

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1. INTRODUCTION

Black cotton soil covers more than a one-fifth area of India. Higher compressibility with swelling and shrinking is the main attributes of the black cotton soil. It is known for its black color and suitable for growing cotton. Engineering properties are changed with water content. Its swell by 200 to 300% to its original volume leads to exert in swelling pressure up to 10 kg/cm^2. It poses high strength in dry conditions but loses strength in a saturated condition. Its shrinking characteristics lead to differential settlement further progress in damaging of structure.

Eco-friendly materials have taken a significant role to enhance the engineering properties of weak soil. Nontraditional materials which are fulfilling the criteria for the improvement of soil are applied wholly or partially. Terrazyme is a nontoxic, nonflammable, noncorrosive organic liquid extracted from vegetation. It is soluble in water and rich in natural protein. The organic cations of the Terrazyme are exchanged with soil cations. This exchange meant accelerates the bonding of soil particles.

Sen and Singh [1] stabilized black cotton soil at a dosage of 200 ml for 3m^3 and found improvement in the California Bearing Ratio (CBR) value and reduction in pavement thickness by 25 to 40%. Umar et al. [2] studied the biological process of soil improvement and suggested that it is a practicable technique. Athira et al. [3] mixed the Laterite soil of Kerala with Terrazyme and found an improvement of 139% in CBR value and 281 % in Unconfined compressive strength (UCS) at 28 days of curring. Agrawal [4] mixed 1 ml Terrazyme in 5 kg of Black Cotton soil and found 200 % increases in UCS. Khan et al. [5] performed the experiments on clayey soil treated with three different enzymes and found an enhancement in unconfined compressive strength (UCS) and reduction in Swelling and shrinking. They further confirm dense packing of clayey soil through field emission scanning electron microscopy (FESEM). Thomas [6] prepared the blend of soil from Kaloor, Kochi, and enzymatic cement-treated clay to study the

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UCS value. During the test, the stress-strain curve shows peak stress than the virgin soil at 28 days of curing with an improvement of 200 to 281% in UCS value. Greeshma et al.[7] experimented on high liquid limit clayey soil and Terrazyme, and 12 times enhancement in UCS value was found when Terrazyme mixed at the content of 210-230 ml/m^3 of soil. Enhancement in compressive strength and reduction in compaction effort was reviewed by Taha et al. [8] when soil is mixed with bio-enzymes. Increases in the density of the soil and reduction in permeability were also confirmed. Suresh et al. [9] mixed Terrazyme with local soil and fund improvement in Specific gravity from 2.45 to 2.96 plastic limit from 27.7 to 32.22, CBR from 6.16 to 8.81 with a reduction in liquid limit was found when black cotton soil was mixed with Terrazyme at 0.5 ml per 100 ml of water. Sravan. and Nagaraj [10] mixed soil, cement lime, and enzymes to prepare compressed earth blocks. 50% improvement in wet compressive strength was found in the block comparing the block prepared without enzymes. Muguda [11] applies 200 ml of Terrazyme in 1.5m^3, to 3m^3 soil at 0.5m^3 intervals and found that there is a decrease in a liquid limit. Increases in the plastic limit, and shrinkage limit resulting in the reduction of plastic and shrinkage indices. Volumetric stability and resistance against crake formation were also found. Significant increase in CBR value found in stabilization process of soil with D1-14 (Bio-enzyme). An increase in CBR value leads to a reduction in the thickness of the subgrade[12, 13]. Consistency limit, UCS, and CBR tests were performed by Greeshma et al. [14] on soil north of Calicut, India. Inferred was made from test results that enzymatic lime is more efficient than the lime only. Mekaideche et al. [15] conducted an experimental study on calcareous Tufa with 4 % Lime and found a reduction in thermal conductivity. Obinayo [16] studied the efficiency of horizontal and vertical baffle walls at 5 levels for the 5k fractional design model and conclude that horizontal baffle walls better than vertical baffle walls in a sedimentation tank. Jafer et al. [17] stabilized fine-grained soil with calcium carbide residue and rice husk ash and found interesting growth in UCS test, reduction in PI at the curing of 90 days. Suresh and Murugaiyan [18] improved the engineering properties of expansive soil with 6 % ultra-fine slag and 1% $CaCl_2$. Experimental results showed a reduction in PI, swelling pressure, and increase in dry unit weight and UCS value. Local basalt in Vietnam was stabilized with cement and DZ33 (a type of enzyme) by Tran et al. [19] and found suitability in the construction of a rural road. Sandy soil was stabilized at various water content and different percentage of epoxy resin by Rahmannejad and Toufigh [20]; they found significant improvements in (UCS) of sandy soil.

All the existing literature demonstrates that extensive experiments were conducted on the blend of soil and Terrazyme focusing on improvement in Atterberg limit, unconfined compressive strength, and CBR value. Very few studies are available that show the application of Terrazyme in clayey soil to improve unlined waterways with low discharge potential. Unlined water conveying systems are still available at the tail ends in the irrigation system, and slum water carrier in small towns of India. The water conveying system gets deteriorates as they are consist of clayey soil and unlined.

This paper demonstrates the experiments on water retention and water discharge through a laboratory model prepared for unlined waterways after evaluating the engineering properties of black cotton soil. Experimental results showed major improvements in unlined waterways when black cotton soil is stabilized with Terrazyme.

2. MATERIALS

2. 1. Soil The black cotton soil sample for the study was collected from village Bhatpore on the bank of river Tapi, Dist Surat. The soil was collected at the depth of 4-5 meters. The soil sample was collected through auger boring, sealed in a watertight plastic bag for the retention of the moisture. Collected soil was transferred to SVNIT Surat for assessing the index and engineering characteristics.

The soil was kept in the oven at temperature 60-70°C for 72h, for retention of ingredients of the clay. Lumps of the oven-dried soil were powdered and sieved through a 4.75 mm size I.S. Sieve. Table 1 represents the properties of the soil.

2. 2. Terrazyme Terrazyme is an organic liquid extracted from the vegetation. Terrazyme is a nonflammable, noncorrosive, and nontoxic echo-friendly

TABLE 1. Properties of soft soil

No	Property	Value
01	Field moisture content	49 %
02	Specific gravity	2.53
03	Shrinkage limit	14%
04	Plastic limit	21%
05	Liquid limit	73%
06	Plasticity index	52%
07	MDD with OMC	15.58kN/m^3 at 24%
08	Unit weight	14.0 kN/m^3
09	Classification (ISC)	CH
10	Fine Sand content	11%
11	Silt content	18%
12	Clay content	71%

liquid. The unit weight is equal to or nearer to that of water. Their odor does not affect. Handling does not necessitate the use of gloves or masks, but it can irritate the eyes. A temperature less than 55°C must be maintained if they are to be preserved for long periods without losing any of their properties. It has no danger of decay. Oxidizing agents interfere with the terrazyme. Terrazyme was specifically developed to improve the engineering properties of soil. For appropriate application, it must be diluted in water. Terrazyme helps to decrease absorbed water in the soil and reduce voids between soil particles for optimum compaction. This lowers permeability and decreases the swelling pressure of the soil particles. Terrazyme enhances the weather resistance of soils and increases their strength. These characteristics are particularly noticeable in fine-grained soils such as clay, where formulation affects swelling and shrinking behavior. The formula can change the soil matrix to prevent the soil from losing its reabsorption of water after compaction, and even when water is re-applied to the compacted soil, the mechanical benefits of compacted soil are not lost. The change is permanent and the product biodegradable once the enzyme reacts with soil. Terrazyme used in this experimental work was provided by Dhara Biotech (Manufacturer) village Sarasa, near Vasad, District Vadodara, Gujarat, India. The physical and chemical characteristics of the Terrazyme are listed in Tables 2 and 3, respectively.

3. EXPERIMENTAL WORK

In the first attempt, the experimental work was performed on untreated soil.

TABLE 2. Physical Property of Terrazyme

No	Property	Value
01	Water solubility	Infinite
02	Specific Gravity	1.00-1.08
03	Melting point	Liquid
04	PH value	2.8-3.5
05	Colour	Brown
06	Boiling Point	190º F- 200º F

TABLE 3. Chemical Properties of Terrazyme

No	Name of Element	Concentration (mg/L)
01	Ca	685
02	Al	2.78
03	Fe	23.79
04	K	7659
05	Mg	298
06	Si	332

3. 1. Atterberg Limits and Free Swell Test The liquid limit and plastic limit were determined as per IS 2720 part 5. The liquid limit was determined through the Casagrande apparatus.

Free swell indexed test was performed as per IS 2720 part 40. A soil sample was placed in the two measuring cylinders, one with distilled water and one with kerosene. An increase in the volume of soil was recorded and the free swell index was determined on untreated soil.

3. 2. Permeability Test Falling head permeability test was performed as per IS 2720 part 17. A sample with Optimum moisture content (OMC) and maximum dry density (MDD) was prepared with a 50 cm^2 cross-sectional area and 6 cm height. Discharge through the soil was recorded after complete saturation of the soil.

3. 3. Standard Procter Test About more than 100 kg of air-dried soil passing from IS sieve, 4.75 was taken for the test. The soil was divided into 2.5 kg for each test, a total of 40 compaction tests were done. Water was mixed into the soil with different water content and kept in an airtight container for 24 hours, for maturing. Standard Proctor test was performed according to I S 2720 part 8.

3. 4. Consolidation Test Consolidation test was performed on remolded soil with 20 mm thickness and 60 m diameter as per IS 2720 part 15. The void ratio was determined at each loading and unloading.

3. 5. Triaxial Test Triaxial tests were performed on black cotton soil- Terrazyme mixture as per IS 2720 Part 11 to evaluate strength parameters. Real stress conditions can be simulated through a triaxial test. The specimen with 38 mm diameter and 76 mm height were prepared at MDD corresponding OMC obtained from the compaction test. For each horizontal stress (Called cell pressure), Vertical stress (called deviator stress) was applied through the loading frame, up to a failure of the specimen.

3. 6. Water Retention and Discharge Test Water retention and discharge over the soil slab were performed in the transparent model with a 6 mm thick acrylic sheet.

In the second attempt, all the tests were performed on the blend of black cotton soil and Terrazyme, aiming to decide suitable content for strengthening the soil.

4. RESULT AND DISCUSSION

4. 1. Atterberg Limits and Free Swell Test The blend of black cotton soil and Terrazyme was tested for Attrerbrg Limits. Table 4 represents the effects of

Terrazyme on consistency limits of Black cotton soil. Drastic reduction in the liquid limit from 83% to 45% was found at 2% Terrazyme. A further marginal increment was found with the addition of Terrazyme at 3% and 4%. The plastic limits remain almost stagnant at all the content of Terrazyme. Maximum variation of 3% found in water content at 2% Terrazyme content with untreated soil. Clay with less content of Terrazymes attracts the moisture and makes soil wetter. But this future of Terrazyme is valid up to a specific limit until moisture-holding capacity. Beyond this stage, soil behaves like water soil with a reduction in a liquid limit. The liquid limit in black cotton soil in the presence of 2% was found to be reduced by 41% by LL of virgin soil. Untreated soil shows a plasticity index of 62%, which 27% by 2% Terrazyme. The drop in consistency limit of soil and terrazyme blends leads to improvement in shear parameters. Figure 1 illustrates the clay particles with free and adsorbed water. Figure 2 shows a free swell index. Experimental results show a reduction in the free well index up to 2% Terrazyme content. Further increase in Terrazyme content results in an increment of a free swell index. Table 4 shows Atterberge limits at various content of Teraazyme.

4. 2. Permeability Test 5 cm fall in a head was measured for the soil with and without Terrazyme. Soil without Terrazyme gives a co-efficient of permeability 3.18 X 10^{-7} cm/s.

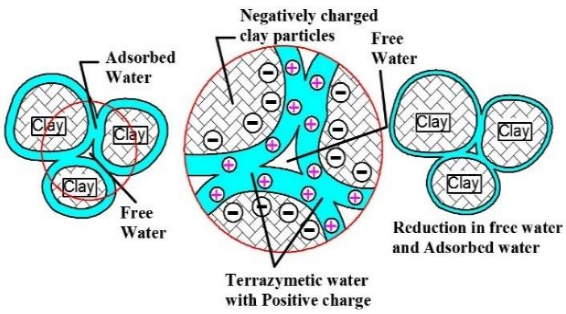

Figure 1. Clay particles with free and adsorbed water

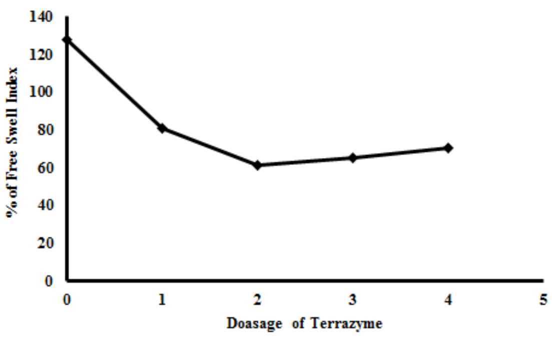

Figure 2. Free swell index at Different Terrazyme dosage

TABLE 4. Atterberg Limits at Different content of Terrazyme

Terrazyme, %	Shrinkage Limit, %	Plastic Limit, %	Liquid Limit, %	Plasticity Index, %
0	14	21	83	62
1	14	21	51	30
2	14	18	45	27
3	14	19	47	28
4	14	19	47	28

As Terrazyme diluted in water blend with soil, a reduction in permeability was found. 1 and 2% Terrazyme blended with black cotton soil gives coefficient of permeability 2.82 X 10^{-7} cm/sec and 2.58 X 10^{-7} cm/sec respectively. At 3 and 4% content of Terrazyme, marginal increases were found in the coefficient of permeability.

4. 3. Compaction Test Oven-dried pulverized soil was tested under the lightweight compaction test as per IS 2720 part 8 at 1, 2, 3, and 4% of Terrazyme. The blend of Black cotton soil, Terrazyme, and water was kept in a desiccator for 1-day curing. MDD and OMC were obtained for each dosage of Terrazyme. The effect of terrazyme addition was observed as a reduction in the electrical charge of water molecules and pressure from negatively charged ions on positively charged metal ions in adsorbed water.

The metal ions must move from the adsorbed water to free water, and the electrostatic barrier occurs by breaking down. Thus terrazyme treats adsorbed water with organic cations and neutralize the negative charge on clay particles. The organic cations also trim down the thickness of the electrical double layer. This process makes the soil structure friable with the adsorbed thinner water layer, resulting in dense packing, and allows treated soil to compact easily. Untreated soil gives the MDD of 15.58 kN/m^3 at 24% OMC. The 2% Terrazyme content gives MDD of 16.47 kN/m^3 at 20% OMC. Further increases in terrazyme content reduce the MDD and increase the OMC. Figure 3 shows the reduction in adsorbed water thickness through the ionic exchange process. Figure 3 Shows the Compaction curve for all samples.

4. 4. ConsolidationTest The one-dimensional consolidation test was performed on all samples prepared with black cotton soil and Terrazyme. Soil without Terrazyme gives a void ratio of 0.652 at a pressure of 10 kPa. The pressure was increased double of the previous pressure and up to 640 kPa. Unloading for all the tests was done up to 40 kPa. The void ratio was determined by the height of solids method at every increment of the load as well as unloading. Untreated soil shows a reduction in the void ratio of 0.24 while 1 and 2% Terrazyme treated black cotton soil shows a reduction of 0.227 and 0.191. Figure 4 depicted the consolidation curves for all treated and untreated soil. The consolidation test gives a C_c value of 0.094 for untreated soil. At 1% and 2% Terrazyme content the C_c value of the soil is 0.088 and 0.076 respectively, demonstrate improvement in resistance. At 3% and 4%, content marginal increase found in C_c value leads to a decrease in resistance. Figure 3 shows Mechanism behind the process of reduction in adsorbed water thickness.

4. 5. Triaxial Test All the tests were performed as consolidated drained tests. The untreated soil gives a cohesion value of 36 kPa with an angle of shearing resistance of 14°. The improvement in shear parameters was found as the soil is blended with Terrazyme. The 2% terrazyme gives cohesion of 59 kPa, with 63% higher than untreated soil. the angle of shearing resistance also increased 19° from 14°. A reverse trend in C and Ø was observed at 3% and 4% teraazyme. Table 5 shows details of all triaxial tests.

Untreated soil and soil blended with different content of Terrazyme are tested for a basic test of soil. All these tests have shown improvements in the engineering properties of black cotton soil. From experimental results, the water retention and water discharge tests were carried out.

TABLE 5. Summary of Triaxial Tests

No	Soil and Terrazyme content	Cell pressure (kPa)	Deviator stress (kPa)	C (kPa)	(Ø)
1		50	124		
2	Soil +TR_0	80	143.21	36	14°
3		110	162.36		
4		40	169.55		
5	Soil +TR_1	60	187.44	48.6	18°
6		85	209.81		
7		60	238.71		
8	Soil +TR_2	75	255.46	59	21°
9		90	272.22		
10		60	238.71		
11	Soil +TR_3	75	255.46	55	20°
12		90	272.22		
13		60	202.4		
14	Soil +TR_4	80	221.35	51.4	19°
15		100	239.22		

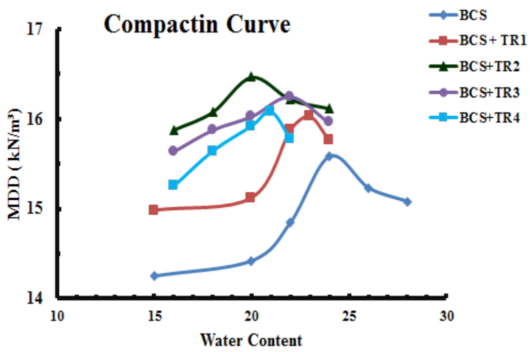

Figure 3. Compaction Curve

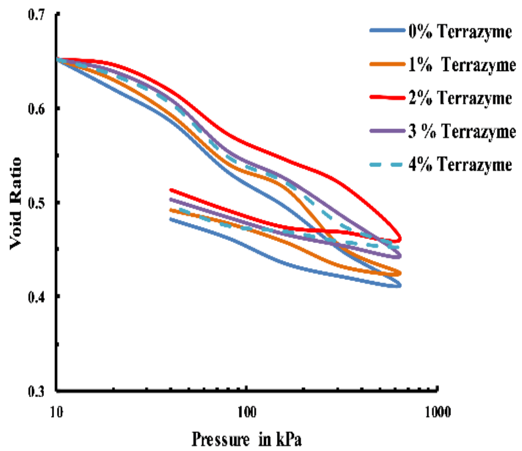

Figure 4. Consolidation Curve

4. 6. Water Retention and Discharge Test

4. 6. 1. Water Retention Test A working model with a clear width of 30 cm was prepared from a 6 mm thick transparent acrylic sheet. the depth and length of the model were kept at 20 cm and 60 cm respectively. A 30 cm X 10 Cm slab with 5 cm thickness was prepared from the blend of soil and Terrazyme. Slab kept vertically in the model with great care as shown in Figure 5. On the upstream of the soil slab, water was poured gently. Different heights of the water upstream are filled and downstream kept free. The time required for the percolation of the water is recorded. An experimental result shows no seepage found up to 3 cm water depth even up to 7 days. 4 cm of water depth gives the seepage at a rate of 3 ml/s after 5 days. 5 cm depth of water gives 5 ml/sec after 3 days. 6 cm depth of water gives seepage at 7 ml/s after 2 days.

4. 6. 2. Discharge Test Discharge tests were conducted on rectangular and trapezoidal sections. In the first attempt same model of 30 X 20 X 60 cm and soil slab with the same dimension of 30 X 10 was used. The flow of water is regulated in such a way that water height on the soil slab is maintained 1 to 4 cm at the interval of 1 cm, as shown in Figure 6. The flow of water was adjusted in such a way so 1 cm height of water flow was obtained at the discharge of 265 ml/s. the blend of soil and terrazyme resists this discharge for 45 hours and 15 minutes. The water depth of 2 cm on the soil slab gives the water flow of 750 ml/s, up to 36 hours before the failure of the slab. 1.38 lit/s discharge was obtained when 3 cm depth on soil slab was maintained for 22 hours 27 minutes. Overflow through the slab with 4 cm water thickness and 2.12 lit/s discharge rate was registered for 16 hours. Overflow with 5 cm height gives 2.5 lit/s but the resistance period was only 4.5 hours.

In the second attempt the same model was used but a section is changed from rectangular to trapezoidal. The base width was kept 15 cm. the special wooden templet is prepared to provide an inclination of 45°. The soil at

MDD and OMC was laid first at an inclination of 45°. 2 cm thick Terrazyme treated soil was placed to create the trapezoidal section as per the required dimension. Figure 7 demonstrates the schematic diagram of the trapezoidal section for the discharge test.

Flow in the trapezoidal section was adjusted to maintain a constant depth of water. 2 cm depth gave the discharge of 831 ml/s. The cross-section resists this flow for 57 hours. Flow at 3 cm depth gives discharge of 1.6 lit/s and resistance for 42 hours. 2.6 lit/s discharge was obtained at 4 cm depth. The soil resists this flow for 27 hours. At a 5 cm depth, of 3.6 lit/sec discharge was obtained for a resistance period of 18 hours.

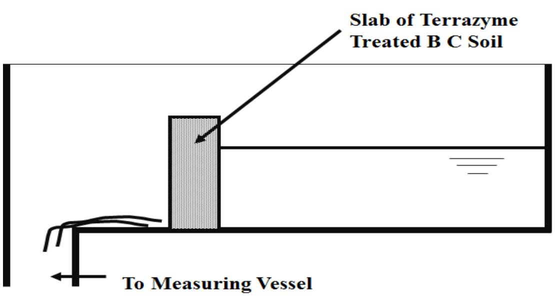

Figure 5. Schematic diagram for water retention test

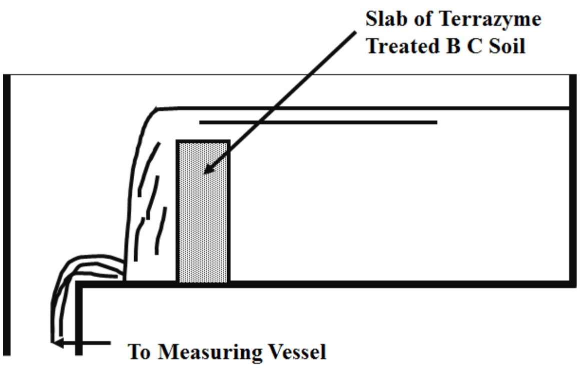

Figure 6. Schematic diagram for discharge through a rectangular section

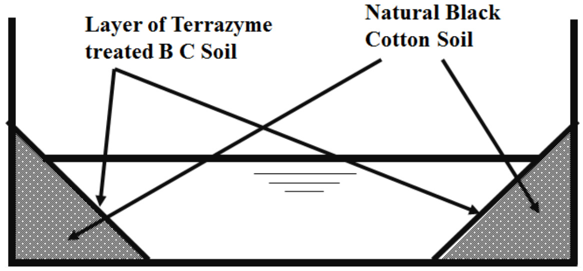

Figure 7. Schematic diagram for discharge through a trapezoidal section

5. CONCLUSIONS

Laboratory experiments were performed on the black cotton soil with and without Terrazyme. An effort was made to explain the mechanism for improvements in the engineering properties of the black cotton soil. A novel material introduced in this paper can be used as an alternative stabilizing black cotton soil. from the experimental results, the following conclusion can be made.

- As the clayey soil blended with Terrazyme drastic reduction in liquid limit was found. Significant improvement in other Atterberg limits was also obtained.
- From the experimental results, it is found that a blend of black cotton soil and Terrazyme generates dens packing through a reduction in adsorbed water thickness, results in a reduction in permeability.
- The addition of terrazyme makes clayey soil stiffer hence MDD increases and OMC decreases.
- Both shear parameters cohesion and friction angle of the treated soil was improved 1.5 times comparing with untreated soil.
- Free swell index reduced noticeably as a thickness of an adsorbed layer decreases.
- In the case where clayey soil is sensitive to high compressibility blend of terrazyme and clay reduces the compressibility up to 19%.
- The treated clayey soil behaves as an impervious barrier that retains the water for a considerable time.
- The black cotton soil with 2% diluted in water generates the best resistance in organic soil.
- The seepage rate increases as the height of retain water increases.
- As the rate of flow increases duration of resistance decreases for both sections.
- Trapezoidal sections support higher discharge with a longer duration compare to rectangular sections.

When compared to traditional stabilizers, non-traditional stabilizers like Terrazyme can be used successfully. This would reduce the erosion of unlined waterways, resulting in benefits in maintenance prevention. Since soil conditions vary by site, an evaluation of basic soil properties on treated and untreated soil is needed before applying terrazyme to clayey soil for optimum content. Present clayey soil requires 2% terrazyme for better improvements. As result research parameters are significant for commercial applications.

6. FUTURE SCOPE

The blend of Terrazyme and black cotton soil can be design to support high discharge. In addition to this, the thickness of the layer can be design, which will reduce the permeability of unlined water bodies, and store the water for a higher duration.

7. REFERENCES

1. J. Sen and J. P. Singh, “Stabilization of Black Cotton Soil using Bio- Enzyme for a Highway Material,” ***International Journal of Innovative Research in Science, Engineering and Technology***, Vol. 4, No. 12, (2015), 12453-12459, doi: 10.15680/IJIRSET.2015.0411146
2. M. Umar, K. A. Kassim, and K. T. Ping Chiet, “Biological process of soil improvement in civil engineering: A review,” ***Journal of Rock Mechanics and Geotechnical Engineering***, Vol. 8, No. 5, (2016), 767-774, doi: 10.1016/j.jrmge.2016.02.004.
3. Athira S, B K Safana, and Keerthi Sabu, “Soil Stabilization using Terrazyme for Road Construction,” ***International Journal of Engineering Research & Technology*** Vol. V6, No. 03, (2017), 547-549, doi: 10.17577/ijertv6is030515.
4. P. Agarwal, “Effect of Bio-Enzyme Stabilization on Unconfined Compressive Strength of Expansive Soil,” ***International Journal of Engineering Research & Technology***, Vol. 03, No. 05, (2014), 30-33, doi: 10.15623/ijret.2014.0305007.
5. T.A. Khan and M. R. Taha, “Effect of three bio enzymes on compaction, consistency limits, and strength characteristics of a sedimentary residual soil,” ***Advances in Materials Science and Engineering***, Vol. 2015, (2015), doi: 10.1155/2015/798965.
6. A. G. Thomas and B. K. Rangaswamy, “Strength behavior of enzymatic cement-treated clay,” ***International Journal of Geotechnical Engineering***, Vol. 13, No. 03, (2021), 259-272, doi: doi.org/10.1080/19386362.2019.1622854
7. G. Nizy Eujine, L. T. Somervell, S. Chandrakaran, and N. Sankar, “Enzyme stabilization of high liquid limit clay,” ***Electronic Journal of Geotechnical Engineering***, Vol. 19, (2014), 6989-6995.
8. M. R. Taha, T. A. Khan, I. T. Jawad, A. A. Firoozi, and A. A. Firoozi, “Recent experimental studies in soil stabilization with a bio-enzymes-a review,” ***Electronic Journal of Geotechnical Engineering***, Vol. 18 R, (2013), 3881-3894.
9. S. T, B. Y, and N. K3, “Improving the Properties of Black Cotton Soil Using Terrazyme as an Admixture,” ***International Journal of Engineering Technology***, Vol. 3, No. 1, (2017), 96-105.
10. M. V. Sravan and H. B. Nagaraj, “Potential use of enzymes in the preparation of compressed stabilized earth blocks”, ***Journal of Materials in Civil Engineering,*** Vol. 29, No. 9. (2017), 1-8.
11. S. Muguda and H. B. Nagaraj, “Effect of enzymes on plasticity and strength characteristics of an earthen construction material,” ***International Journal of Geo-Engineering***, Vol. 10, No. 1, (2019), doi: 10.1186/s40703-019-0098-2.
12. C. Venkatasubramanian and G. Dhinakaran, “Effect of bio-enzymatic soil stabilisation on unconfined compressrve strength and California Bearing Ratio,” ***Journal of Engineering and Applied Sciences,*** Vol. 6, No. 5, (2011), 295-298, doi: 10.3923/jeasci.2011.295.298.
13. Y. J. Li, L. Li, and H. C. Dan, “Study on application of TerraZyme in road base course of road,” ***Applied. Mechanics and Materials.***, Vol. 97-98, (2011), 1098-1108, doi: 10.4028/www.scientific.net/AMM.97-98.1098.
14. G. N. Eujine, S. Chandrakaran, and N. Sankar, “The engineering behaviour of enzymatic lime stabilised soils,” ***Procedings Institution of Civil Engineering Ground Improvement***, Vol. 170, No. 1, (2017), 1-11, doi: 10.1680/jgrim.16.00014.
15. K. Mekaideche, F.-E. M. Derfouf, A. Laimeche, and N. Abou-Bekr, “Influence of the Hydric State and Lime Treatment on the Thermal Conductivity of a Calcareous Tufa,” ***Civil Engineering Journal***, Vol. 7, No. 3, (2021), 419-430, doi: 10.28991/cej-2021-03091663.
16. J. I. Obianyo and J. C. Agunwamba, “Efficiencies of horizontal and vertical baffle mixers,” ***Emerging Science Journal***, Vol. 3, No. 3, (2019), 130-145, doi: 10.28991/esj-2019-01176.
17. H. Jafer, Z. H. Majeed, and A. Dulaimi, “Incorporating of two waste materials for the use in fine-grained soil stabilization,” ***Civil Engineering Journal***, Vol. 6, No. 6, (2020), 1114-1123, doi: 10.28991/cej-2020-03091533.
18. H. Jafer, Z. H. Majeed, and A. Dulaimi, “Incorporating of two waste materials for the use in fine-grained soil stabilization,” ***Civil Engineering Journal***, Vol. 6, No. 6, (2020), 1114-1123, doi: 10.28991/cej-2020-03091533.
19. B. H. Tran, B. V. Le, V. T. A. Phan, and H. M. Nguyen, “In-situ Fine Basalt Soil Reinforced by Cement Combined with Additive DZ33 to Construct Rural Roads in Gia Lai Province, Vietnam,” ***International Journal of Engineering, Transactions B Applications,*** Vol. 33, No. 11, (2020), 2137-2145, doi: 10.5829/ije.2020.33.11b.03.
20. M. Rahmannejad and V. Toufigh, “Influence of curing time and water content on unconfined compressive strength of sand stabilized using epoxy resin,” ***International Journal of Engineering, Transactions B Applications,*** Vol. 31, No. 8, 1187-1195, (2018), doi: 10.5829/ije.2018.31.08b.05.

Persian Abstract

چکیده

استفاده از مواد زیست تخریب پذیر برای بهبود خاک ضعیف نتایج بهتری در زمینه مهندسی ژئوتکنیک داده است. این مواد تخمیر شده و از پوشش گیاهی استخراج می شوند. این باعث کاهش نسبت باطل ، ضخامت آب جذب شده و به حداکثر رساندن تراکم می شود. Terrazyme حاوی پروتئین طبیعی است غیر سمی و سازگار با محیط زیست است. در آب قابل حل است. خاک پنبه سیاه بسیار پلاستیکی و دارای قابلیت تورم است. کاهش رطوبت باعث کوچک شدن ، منجر به نشست دیفرانسیل پی می شود. این باعث آسیب به ساختار می شود. در این مقاله کار آزمایشی روی خاک پنبه سیاه تقویت شده با Terrazyme ارائه شده است. بخشهای مختلف Terrazyme با خاک پنبه سیاه مخلوط شد تا خصوصیات مهندسی خاک را ارزیابی کند. تغییر در خصوصیات شاخص و پارامترهای مقاومت توسط آزمایشات روی خاک تصفیه شده و تصفیه نشده ارزیابی شد. محدوده های آتتربرگ ، شاخص تورم آزاد ، آزمون تراکم ، آزمایشات سه محوری انجام شد. نتایج تجربی کاهش محدودیت مایع ، شاخص انعطاف پذیری ، شاخص تورم آزاد ، رطوبت مطلوب و شاخص فشرده سازی را نشان می دهد. آزمایش های سه محوری بهبود انسجام و زاویه مقاومت برشی را نشان می دهد. دوز مطلوب ٪ Terrazyme 2 از نظر وزن خاک خشک حاصل گردید.