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Effects of Bio-enzyme in Soil Stabilization

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Abstract. The bioaugmentation approach of soil strenght enhancement is one of the most efficient and sustainable methods for enhancing soil engineering properties. One of the methods is by using bio-enzymes. Bio-enzymes are organic soil improvement additives which are non-toxic, environmentally friendly, and biodegradable. With this view, the major objective of the current study is to study the effectiveness of bio-enzyme on UCS and swelling properties of soil. For the experimentation, the fractional factorial planning method has been adopted with the target to maximize the UCS of soil with the factors and levels considered. SEM (scanning electron microscope) analyses were conducted at the end of each UCS test. The results obtained indicate an increase in UCS soil and a reduction in swelling of soil. It was observed from the results of SEM that with the increase in curing period soil specimens are denser. Also, the optimum value of dosage of Terrazyme was found for defined outcomes.

Keywords: *Bio-enzyme; unconfined compressive strength; swelling; soil strength*

1. Introduction

Stabilization of soil is the process of enhancing the strength and durability of soil. It comprised any physical, chemical, or biological technique, or combination of techniques, that enhances soil properties to make it more useable for engineering applications [1]. Different methods such as mechanical or chemical methods are employed soil improvement. Numerous chemical additives, both organic and inorganic, have also been employed to stabilize the soil in order to improve strength and durability.

Improving the sustainability of the materials used in geotechnical engineering projects may aid in achieving overall sustainable development as these projects are closely related to monetary and environmental challenges [1, 2]. Recently, a novel chemical for soil stability called bio-enzyme has been created as part of the bioaugmentation approach to soil stabilization [1-5]. Bio-enzymes are organic materials, environment friendly, cost-effective and convenient to use.

Enzymes are the catalyst, regulating not only the rate of reaction but also the activation energy needed to create one product from another by favoring specific transition state geometries [2]. Bio-enzymes are protein molecules that reduce the soil's affinity to water [1, 6]. Traditional stabilizer such as lime and cement is expensive and difficult to mix whereas bio-enzymes are easy to use as they can be mixed with water at OMC and then spread and compacted over the soil. The effectiveness of enzymes on soil stabilization depends upon their dosage and curing period [7]. In addition, the dosage of the enzyme is dependent on the soil type, clay percentage of soil and type of enzymes used [8].

One of such enzymes, TerraZyme (TZ) is a commercially available bio-enzyme that is all-natural, non-toxic, and environmentally safe [9]. It is produced using vegetable extracts [7]. TerraZyme was also found to be effective in reducing the swelling of clay. However, it has been found that the potential for assessing the effectiveness of TZ on soil improvement while taking many parameters into account has not been fully explored. Additionally, it is crucial to first examine the impact of TZ on soil stabilization in controlled laboratory settings before using them in field applications. In these conditions, fractional factorial approaches are used in research with large parameter sets to reduce the complexity associated with the number of tests. One such technique is the Taguchi method, which has lately acquired attention with applications distributed throughout the majority of civil engineering disciplines but few in studies of soil improvement [10, 11].

For this purpose, the major objective of the current study is to study the effectiveness of bio-enzyme on UCS and the swelling properties of soil. To achieve these two different types of TZ, different types of soil were used and variations in the dosage of TZ, and curing period (1, 7, 14, and 28 days) were also adopted. SEM images were also obtained to analyze the effect of the curing period on the microstructure of the stabilized soil

2. Materials and Methodology

2.1 Materials

To achieve the above objectives, three diverse soils were selected. Two soils (S-1 and S-2) were taken from the surrounding of the Indian Institute of Technology Mandi, India. For the third type of soil (S-3), a combination of river sand and 10% Bentonite were used. The properties of the soils were illustrated in Table 1.

Table 1. Properties of the soil

Soil properties	S-1	S-2	S-3
Specific gravity	2.72	2.67	2.6
Sand (%)	32	2	85
Silt (%)	61	80	5
Clay (%)	6	18	10
Liquid limit (%)	21	29	250
Plastic Limit (%)	NP	19	53
Plasticity Index	NP	10	197
USCS	ML	CL	CH
OMC (%)	15.27	18.2	16.44
g_{dmax} (g/cc)	1.85	1.71	1.73

TZ efficiently modifies soil when the treated soil is compacted at OMC [12]. The OMC and Y_{dmax} were presented in Table 1. Two types of TZ (TZA-5X and TZA-11X) were selected for this study, which are commercially available bioenzyme in liquid form. XPS (X-ray photoelectron spectroscopy) analyses were conducted to find out the element present in Terrazyme (Table 2).

Table 2. Elemental composition of TerraZymes

TZA-5X		TZA-11X	
Element	Atomic %	Element	Atomic %
C	72.61	C1	70.88
O	23.92	O	25.78
Cl	2.16	N	2.25
Ca	1.3	Cl	0.66
		Na	0.42

2.2 Sample preparation

For swelling test

For the determination on effect of TZ on swelling of soil 10g S-3 soil which is clayey soil were poured in six measuring cylinders. One cylinder was filled with kerosene and others with distilled water having different dosage of TZ (0, 0.25, 0.5,1 and 2 ml/500ml of distilled water). The soils in each measuring cylinder were allowed to settle for sufficient time, not less than 24 h.

For UCS test

TZ require dilution in water before application for proper application and to achieve uniform dispersion and mixing with the particles of soil. Different dosages of TZ (ml/500ml of distilled water) were used to prepare the diluted solution. The amount of soil and diluted TZ for the preparation of specimens for UCS testing were computed based on OMC and Y_{dmax}. The prepared specimen were sealed and allowed to cure in a desiccator and UCS test were conducted after the pre-fixed curing time of 1,7,14 and 28 days. The UCS tests were done on prepared specimens to examine the effect of TZ on the soil.

The curing times were selected based on the literature. It was mentioned that there was no significant improvement in UCS of treated specimen after 7 days [2]. It has also been reported that UCS increased beyond the 7-day curing period and up to the 28-day curing period [12]. Hence four curing periods were chosen in this study to examine the effect of curing period.

For SEM analysis

SEM provides magnified images of a specimen's size, shape, composition, and other physical and chemical characteristics. After each UCS test Soil sample were taken with clean spatula to avoid any contamination and placed in air tight container. From these samples small amount of soil is taken for SEM analyses. Since soil is non-conductive, a thin layer of gold coating was applied to the soil sample using a device named Sputter coater, making it conductive.

2.3 Experimental variables

A varying quantity of stabilization can cause different effects in the same soil sample. Less soil stabilization may occur with insufficient TZ, whilst excessive amounts may cause soil stabilization ineffective and uneconomical. [13]. The type of soil being used has a significant influence on the TZ dosage [14]. Keeping in view of the major factors influencing the soil strength, as per the current study, soil type (ST), TerraZyme type (ET), dosage of enzyme (DS) and curing period (CP) were considered as mentioned in Table 3. Dosages of TZ were varied as 0.5,1 and 2ml/500ml of distilled water.

Table 3. Factors and their corresponding level

Factors	Level		
	1	2	3
ST	S-1	S-2	S-3
ET	T1	T2	T1
DS (ml/500ml of water)	0.5	1	2
CP (Days)	-	-	-

2.4 Design of experiments by Taguchi method

To analyze the influence of multiple parameters, designing experiments using the Taguchi method [10, 11] can be strategic for accomplishing a quality outcome with minimal resources and in less time, with simplicity of data management. The Taguchi method proposed a set of well-distributed experiments suited to the number of parameters and factors required for the study using specially designed tables known as orthogonal arrays (OA) [15]. The experimental results were converted into a signal-to-noise (S/N) ratio and the S/N values were defined as Eq. 1 based on the target characteristics of the output [10]

$$\mathrm{LTB}\frac{S}{N} = -10\ \log_{10}\left[\frac{1}{n}\sum\frac{1}{y^2}\right] \qquad \text{Eq. 1}$$

Where LTB is Larger the better, n is the no of replicates of a particular experiment and y is the result obtained.

Optimum parameters and levels in the current study, L-9, an orthogonal array was adopted. Measuring the influence of one parameter with triplicates under full factorial experiments would result in $3\times3^4 = 243$ experiments which is complex, impractical, and uneconomical to perform. Employing the Taguchi method for planning the experiment results in 9 experiments per standard orthogonal arrays as per the factors and levels (Table 4).

In addition, analysis of mean (ANOM) has been used to select the optimum parameters for the best outcome. The larger the better (LTB) optimization function (refer to Eq. 1) was used to achieve this because the desired target (shear strength) was to maximise outcomes.

3. Results and Discussions

3.1 Effect on swelling of soil

It was revealed that the addition of TZ decreased the swelling of soil. With an increase in the enzyme dosage from 0.25ml/500ml of distilled water to 2ml/500ml of distilled water, a greater decrease in swelling was observed (Fig. 1). The Values of free swell index (FSI) of soil treated with TZ were presented in Table. 4. Since bentonite (S-3 soil) is dispersive in nature, values of FSI are very high. However a significant decrease in FSI can be observed with the addition of TZ in soil, and it continues to do so when dosage of TZ has been increased.

Fig. 1. Swelling of soil at different dosage of TerraZyme

Table 4. Free Swell Index of Terrazyme treated soil

Dosage of TZ (ml/500ml water)	Free swell index (%)
0	2400
0.25	1900
0.5	1650
1	765
2	380

The principle of double layer theory can be used to explain soil swelling [16]. Positively charged ions surround the clay particles in a clay water mixture, forming a film of water around the clay particle that stays adhered or adsorbed to the clay surface. This electrically attracted water that surrounds the clay particle is known as diffused double layer.

Terrazyme has the ability to reduce or eliminate the thickness of the adsorbed water layer of soil. In the presence of TZ, the tendency for water to seep through the spaces was reduced, and the swelling-shrinkage reaction was also reduced [17, 18].

The protein molecules of TZ reduce the soil's affinity for moisture by interacting with soil molecules to bind soil particles together, which in turn can decrease soil swelling [2, 19]. Terrazyme decreased the void between soil particles and minimised the amount of water that was adsorbed, which decreased soil swelling. Large organic molecules and enzymes combine to bind to the surface of the clay, blocking potential cation exchange locations and inhibiting moisture absorption and following swelling[1,20].

3.2 Effect of curing period on UCS

To study the influence of curing time on UCS of TZ treated specimen, the prepared soil specimens were cured for 1,7,14 and 28 days. The results of each experimental set at different curing period were presented in Fig. 2. It has been observed that UCS increases with curing period.

The increase in UCS in case of S-1 soil which is a silty soil was not significant (as shown in Fig. 2 for experimental sets 1, 2 and 3). Similarly the increase in UCS with curing period was insignificant for experimental sets 7, 8 and 9. It was observed that enzyme was not effective for cohesion less soil [6]. For S-2 type of soil which is clayey soil, significant enhancement in UCS was observed with an increment in curing period from 14 days to 28 days (experimental sets 4, 5 and 6). Bio-enzymes are effective in case of soil having minimum amount of clay particles [1, 2]. Enzymes are suitable for soils containing 12-24% of clay fraction [2].

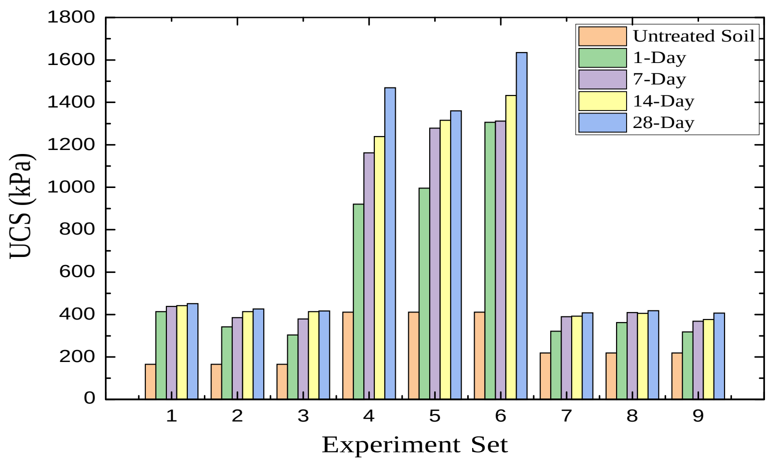

Fig. 2. UCS at different curing period

3.3 Optimum dosage of TerraZyme

The UCS of the soil treated with enzyme involving multiple parameters and the corresponding signal-to-noise ratio corresponding to larger the better (S/N-LTB) for different curing period were computed. Furthermore, statistical tools such as ANOM have been used to determine the optimum conditions for all parameters (Fig. 3).

From Fig. 3 it was observed that for soil treated with enzyme optimum conditions of soil type and dosage of enzyme are S-2, 0.5 ml/500ml of water respectively for all four curing period. Whereas the optimum condition of TZ type are T1 for CP of 1 day and 28 days, and T2 for CP of 7 and 14 days. However the difference between optimum values of TZ type was negligible.

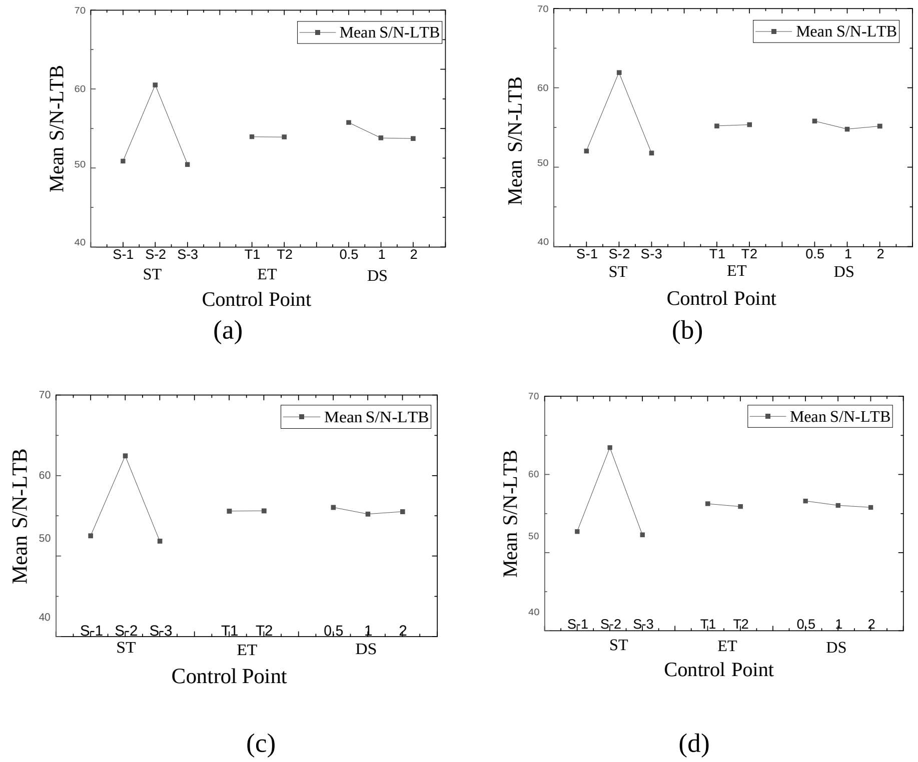

Fig. 3. Factor effect plots of UCS for curing period of (a) 1day, (b) 7days, (c) 14days and (d) 28 days.

In the same soil sample, changing the amount of stabilisers can lead to different effects. An insufficiency of TZ may result in less soil stabilisation, whereas abundance may render the stabilisation ineffective and uneconomical. Hence it is essential to find out the optimum dosage of TZ by conducting laboratory test before field application. The optimum dosage of TZ for improvement of UCS was found to be 0.5ml/500ml of water.

3.4 SEM Results

In order to explore the effect of TZ on micro scale, SEM (scanning electron microscope) analyses were conducted at the end of each UCS test. The SEM images for one particular experimental set at different curing period was illustrated Fig. 4. It was observed from the results of SEM that with increase in curing period soil specimen became denser. Fig.4 (a) illustrated a flocculated structure whereas Fig. 4(d) depicted dispersed structure. Flocculated structures have large voids, after being treated with TZ flocculated structures were transferred into dispersed structures due to change in orientation of soil particles. With increase in curing period cluster formation was found to be reduced, resulting in decreased voids between soil particles and thus increased density. This explains why strength increases when the curing time is extended as denser material will have greater strength [7].

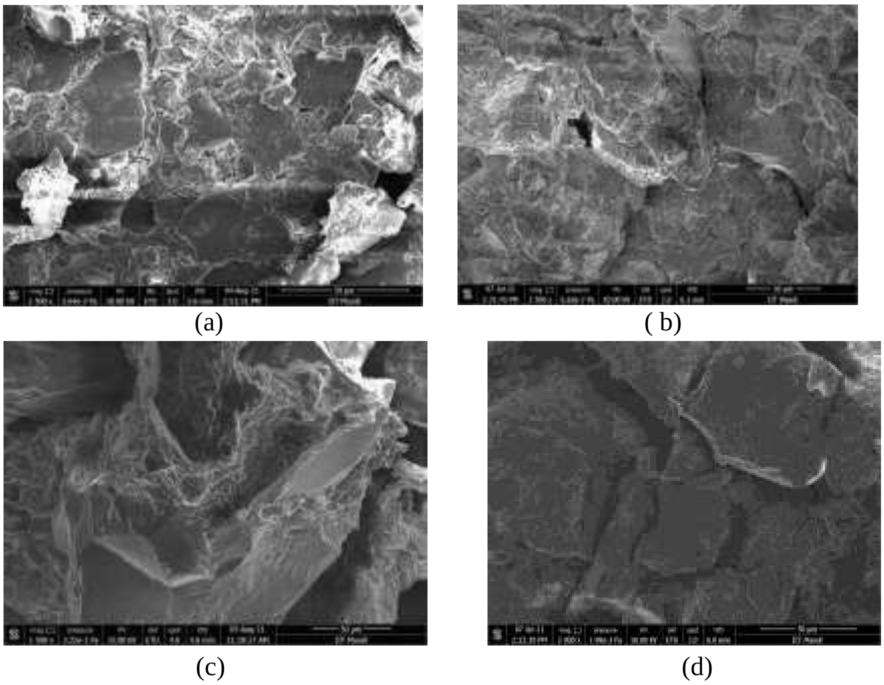

Fig. 4.SEM images after curing period of (a) 1 day, (b) 7 days, (c) 14 days and (d) 28 days

4. Conclusion

In this experimental study, the effect of two TZ on swelling and UCS of soil were examined. The following conclusions can be derived from the results obtained:

1. Soil treated with TZ exhibit lesser swelling as compare to untreated specimen. And an increase in reduction in swelling was observed with an increase in dosage of enzyme.
2. It has been observed that UCS increases with curing period.
3. The optimum dosage of TZ was found as 0.5 ml/500ml of distilled water for both TZ.

4. It was observed from the results of SEM that with increase in curing period soil specimen became denser.

5. References

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