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TERRAZYME SOIL STABILIZATION RESULTS AND FACTORS INFLUENCING

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Abstract
The findings of the enzyme soil stabilization study have been discussed, emphasizing their importance for soil stabilization using TerraZyme. The study assesses the effectiveness of TerraZyme by analyzing changes in index and engineering properties of various stabilized soils classified according to the IS Classification System (ISCS). It aims to understand how enzyme dosages, curing period, and soil types influence the effectiveness of soil stabilization. The study also investigates the correlation between soil characteristics (e.g., particle size distribution, consistency parameters, activity number) and the degree of stabilization. The findings have implications for soil stabilization decisions and can guide the application of TerraZyme in practical engineering scenarios.
Key words: Soil Stabilization, TerraZyme, Soil Index properties, Engineering properties.

1. INTRODUCTION
Enzymes used for soil stabilization are proprietary, concentrated, nonbacterial, and biodegradable preparations. They are designed to improve soil properties, such as reducing compaction efforts, increasing soil density, and bearing capacity, while also lowering soil permeability. Enzyme treatment, such as TerraZyme, offers a promising alternative for soil stabilization, with its ability to enhance soil properties while being cost-effective, eco-friendly, and easy to use. It reduces the reliance on conventional stabilizers that may contribute to environmental pollution.

TerraZyme is mentioned as one of the commonly used enzymes for soil stabilization. It is an electrochemical enzyme product formulated to react with clay-containing materials. The primary components of TerraZyme include nonionic surfactants, carbohydrates, and fermented vegetable extract. TerraZyme treatment has a positive impact on various soil properties and engineering characteristics. It is particularly effective in improving the behaviour of clayey soils, as indicated by the significant improvements in consistency limits, compaction parameters (MDD and OMC), California Bearing Ratio (CBR), unconfined compressive strength (UCS), and reduction in permeability, swell index, and swell pressures in black cotton soil.

2. LITERATURE REVIEW

The literature review emphasizes the need for careful consideration of soil-specific characteristics when using enzyme stabilization. Stabilization relies on empirical guidelines, as the exact mechanism and conducive conditions for stabilization remain uncertain. Choosing the correct stabilizer and material is essential due to this empirical nature. [1]. Enzyme stabilization's effectiveness varies depending on the specific soil characteristics [2]. The presence of fine organic matter, clay-sized particles, and clay minerals plays a vital role in achieving successful stabilization results. For effective bio enzyme stabilization, the soil should contain clay minerals that react with other chemicals during the stabilization process. Bio enzymes are found to be effective for soils with a specified percentage of clay contents. Enzymes work well in soils with high plasticity clays, which have an affinity for water and contain some organic content necessary for the enzymatic reaction [3]. Bio-Enzyme treatment reduces compressibility and enhances soil stability by optimizing consistency limits and indices through the appropriate use of enzyme doses and curing duration. This treatment results in improvements in both index and engineering properties of the treated soils [4]. To ensure the effectiveness of Bio-Enzyme treatment, it is recommended to conduct laboratory testing before applying it in the field. This step allows researchers to understand how the enzymes react with soil chemical constituents and determine the suitable enzyme doses and curing duration [5]. The presence of clay content in the soil is a critical factor affecting the performance of enzyme stabilization. The lack of clay content in the reclaimed layer can negatively affect enzyme performance [6]. literature showcases stabilization examples and improvements in soils with clay content as low as 2%, there are observations that the enzyme may be ineffective for soils with a higher percentage of cohesionless material [3].

3. METHODOLOGY

The study utilizes case studies of TerraZyme stabilized soils to assess the effectiveness of the enzyme-based stabilization process. By analyzing changes in doses, duration, and soil types, the study aims to determine the most effective application of TerraZyme for achieving desired stabilization outcomes. The evaluation of index and engineering properties serves as a critical parameter to understand the degree of stabilization achieved in different scenarios. The effect of stabilization on various indexes and engineering properties of soil is categorically analyzed and compared. This analysis is used to conclude the impact of enzyme doses and curing duration on different soil groups. Different soil types may react differently to the treatment, emphasizing the need for careful selection of the appropriate stabilization method for each soil type.

The study comprehensively evaluates the effects of TerraZyme stabilization on different soil properties through laboratory test results. It analyzes the impact of enzyme doses, curing duration, and soil type on the properties of treated soils. The average percentage variation provides a quantitative measure of the changes observed in the properties of enzyme-treated soils, aiding in understanding the overall effectiveness of TerraZyme stabilization. Top of Form

Following are the details of the soil references included in the study. CH-soils [7, 8, 9, 10, 11, 12,13], CI-soils [7, 14, 15], CL-soils [11, 16], CL-ML soil [17], MH-soil [11, 18, 19, 20, 21, 22, 23], ML-soil [24], SC-soils [4, 20], SP-SC soil [25], SM soil [25], SM-GM soil [26], SP-soils [27, 28]. The TerraZyme stabilization laboratory test results for these different soils are shown in Table.1.

Table.1 Maximum average percentage variation in properties for different soil groups. ('+' indicates increase and '-' sign indicates decrease)

Properties	CH-Soils	CI-Soils	MH-Soils	ML-Soil	SM-GM Soils
Liquid Limit	-14.47% (200ml/2m^3, 4 weeks)	-68.82% (200ml/0.6m^3, 3 weeks)	-35.44% (200ml/2m^3, 2 weeks)	-27.78% (200ml/2m^3, 2 Days)	-21.14% (200ml/2m^3, 4 Days)
Plastic Limit	-28.13% (200ml/2m^3, 4 weeks)	-50% (200ml/0.6m^3, 3 weeks)	-53.61% (200ml/2m^3, 2 weeks)	-33.22% (200ml/3m^3, 2 Days)	-4% (200ml/2m^3, 4 Days)
Plasticity Index	-24% (200ml/1.5m^3, 8 weeks)	-59.26% (200ml/6.6m^3, 4 weeks)	-16.52% (200ml/6.6m^3, 4 weeks)	-7.65% (200ml/2m^3, 2 Days)	-63.3% (200ml/2m^3, 4 Days)
Shrinkage Limit	+50% (200ml/1.5m^3, 4 weeks)	+25.38% (200ml/1.5m^3, 0 weeks)	-	-	-
OMC	-17.39% 200ml/0.25m^3, 0 weeks)	-68.71% (200ml/0.6m^3, 6 weeks)	-11.11% (200ml/0.3m^3, 0 weeks)	-41.18% (200ml/3m^3, 2 weeks)	-
MDD	+9.87% (200ml/1.5m^3, 0 weeks)	+68.71% (200ml/0.6m^3, 6 weeks)	+5.83% (200ml/0.3m^3, 0 weeks)	+5.03% (200ml/2m^3, 2 weeks)	-
Unsoaked CBR	+480% (200ml/0.25m^3, 3 weeks)	+357.14% (200ml/2.5m^3, 4 weeks)	+435% (200ml/6.6m^3, 4 weeks)	+451.79% (200ml/2m^3, 3 weeks)	+210% (200ml/2m^3, 4 weeks)
Soaked CBR	+329.85% (200ml/0.75m^3, 8 weeks)	+333.33% (200ml/6.6m^3, 4 weeks)	+380% (200ml/6.6m^3, 4 weeks)	+200.42% (200ml/2m^3, 2 weeks)	-
UCS	+493.43% 200ml/2m^3, 8 weeks)	+493.36% 200ml/2.5m^3, 8 weeks)	+102.99% 200ml/2m^3, 3 weeks)	+375% 200ml/0.5m^3, 4 weeks) (CL-ML Soils)	-

4. EFFECT OF TERRAZYME STABILIZATION SOIL PROPERTIES

The effect of stabilization on various index and engineering properties of soil is categorically analyzed and stabilization results are compared.

Consistency Characteristics: the addition of TerraZyme to the soil leads to significant changes in soil properties (CH-Soils), including decreased Liquid Limit, Plastic Limit, and Plasticity Index, increased Shrinkage Limit, and improved volumetric stability. These changes suggest that enzyme-treated soils experience enhanced stability and reduced compressibility, making enzyme stabilization an effective method for improving the engineering properties of clayey fines. The addition of TerraZyme to MH-Soils and SM-GM Soils resulted in a decrease in plasticity, while ML-Soil showed an initial increase in Plasticity Index. CI-Soils exhibited significant variation in consistency limits, and the improvements required varying enzyme doses and curing duration. Additionally, treated CH-Soil demonstrated enhanced volume stability. Overall, the TerraZyme treatment showed varying effects on different soil types, highlighting the importance of carefully considering the specific soil characteristics when applying the treatment.

Effect of TerraZyme Stabilization on Compaction Characteristics: TerraZyme stabilization improves the soil's compaction characteristics by reducing OMC and increasing MDD. TerraZyme stabilization contributes to improved compaction efficiency, reduced water content, increased soil density, and enhanced shear strength. Different soil types exhibit varying responses to enzyme treatment in terms of OMC and MDD. The trends include decreased OMC and increased MDD (slight for CH-Soils, substantial CI-Soils, moderate for MH-Soils, and significant decrease in OMC and slight increase in MDD for ML-Soils). The variations in soil composition, including clay content, particle size gradation, and Plasticity Index, among different soil groups, can lead to varying responses to enzyme treatment. The lower clay content and balanced particle size gradation in CI-Soils may explain the higher improvement in MDD compared to CH-Soils. Similarly, the lower clay size content and PI in ML-Soil may explain the improvement in OMC at a lower enzyme dose. The variation in OMC and MDD is influenced by different factors for each soil type, highlighting the complexity and unique characteristics of each soil group. These observations highlight the importance of soil types, soil composition in determining the effectiveness of enzyme treatment and the need to consider specific soil characteristics when selecting appropriate treatment approaches and doses.

California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of Soil: An increase in enzyme dosages and duration results in a continuous improvement in both unsoaked and soaked California Bearing Ratio (CBR) values. The higher enzyme dosages and longer duration of treatment contribute to significant enhancements in the strength and stability of the CH-Soils, CL-Soils, MH-Soil, and ML-Soils. The enzyme treatment significantly improves both unsoaked and soaked CBR values for ML-Soils, suggesting enhanced suitability for construction and load-bearing purposes.

The CH-Soils, CL-Soils, and MH-Soil demonstrate overall good to high soil suitability for construction and load-bearing applications, as they exhibit significant CBR improvements in both unsoaked and soaked conditions. The ML-Soils also show good soil suitability for construction based on the high unsoaked CBR improvement. However, the lower soaked CBR improvement. The suitability of SM-GM Soil is not fully clear, as only the unsoaked CBR improvement observations are available in the literature. But its moderate unsoaked CBR improvement indicates decent soil suitability for construction in dry conditions. the soaked CBR improvement of SM-GM Soil is needed to determine its complete suitability. Both clayey and silty soils show substantial improvement in CBR values after enzyme treatment. The specific enzyme dosage and curing duration required to reach the maximum CBR improvement depends on the clay content of the soil. Soils with higher clay content (such as CH-Soils) require higher enzyme doses and may take longer to reach the maximum CBR improvement. In contrast, soils with lower clay content (such as MH, ML, and SM-GM soils) respond well to lower enzyme doses and achieve the maximum CBR improvement in a relatively shorter curing duration.

The soaked CBR test requires a comparatively higher curing duration to reach the maximum average percentage CBR value compared to the unsoaked CBR test. The increased curing duration for the soaked CBR test may be necessary to achieve greater strength. During the soaked CBR test, it undergoes a period of saturation, which can lead to changes in its properties, such as increased moisture content and leaching of enzyme components. To counteract the potential leaching effect of the enzyme and ensure that the soil retains its strength and performance during the soaking process, a longer curing duration might be necessary.

Effect of TerraZyme Stabilization on Unconfined Compressive Strength (UCS) of Soil: CH-Soils and CI-Soils have a similar response to the enzyme treatment and curing duration in terms of increasing their UCS. CL-ML Soils despite a lower percentage increase compared to CH-Soils and CI-Soils, the improvement in UCS is still considerable, MH-Soils and SP-Soils show relatively lower UCS average percentage increases. CH-Soils and CI-Soils show the highest improvements, while CL-ML Soils, MH-Soils, and SP-Soils exhibit moderate to lower improvements. The enzyme dose and curing duration also seem to influence the level of improvement, with longer durations generally leading to higher increases in compressive strength. The clay content of the soil significantly influences the response to the enzyme treatment and the time required to reach the maximum UCS improvement. Soils with higher clay content (CH and CI soils) show the highest improvements in UCS values with similar enzyme doses and curing durations. However, as the clay content decreases, soils (e.g., MH and SP-Soils) exhibit faster responses to the enzyme treatment, reaching their maximum UCS values in a shorter curing duration. The CL-ML soils, with a combination of clay and silt, have specific requirements for enzyme dosage and curing duration to achieve their maximum UCS improvement.

In addition to the test observations from consistency limits, CBR, and UCS on enzyme-stabilized soils, the literature also discusses improvements in other soil properties, including permeability, consolidation parameters (compression index, coefficient of consolidation), percentage swell, and swell pressure.

Effect of enzyme treatments on permeability: enzyme stabilization with TerraZyme leads to a noticeable decrease in the permeability of treated soils. The bio-enzymes present in TerraZyme have been shown to improve the strength of the soil, reduce compaction effort, and increase soil density, thereby contributing to the reduction in permeability [26].

Effect of enzyme treatments on consolidation parameters: Enzyme treatments have a positive impact on the consolidation parameters of treated soils [7]. [29]. TerraZyme treatment on black cotton soil reduces its Free Swell Index, indicating decreased swelling potential. Additionally, bio-enzyme treatment on expansive (CH) soil reduces percentage swell and swell pressures, making the soil more stable and less compressible. These findings suggest that enzyme treatments can be beneficial in improving the consolidation behaviour of soils, making the soil more stable and less prone to volume changes. Enzyme treatments have a positive effect on the specific gravity of the soil [24]. The treatment leads to an increase in specific gravity, which can indicate improved soil density and compaction.

5. RESULTS

In summary, the observations suggest that soil properties, such as clay content, clay size, and plasticity index, have a significant influence on the effectiveness of enzyme treatment.

1. Clayey soils with intermediate clay content show the most prominent response to the enzyme treatment, with notable improvements in MDD, OMC, CBR, and UCS.
2. Intermediate clay content in CI-Soils and lower clay content in ML-Soil and MH-Soils demonstrate a more significant improvement with lesser enzyme doses. Clayey soils generally show greater improvement in UCS values but require a higher curing duration.
3. Additionally, enzyme treatment has a positive impact on other soil properties, such as permeability and specific gravity, contributing to overall soil improvement for construction and engineering applications.
4. The observations indicate significant variation in the enzyme doses and curing duration required to achieve the maximum improvement in index and engineering properties for different soil groups. Each soil type exhibits unique response patterns, reaching the maximum parametric value with different enzyme doses and curing durations. This suggests that the degree of soil stabilization varies among different soils based on the specific enzyme treatment and curing conditions applied.

6. DISCUSSION

In summary, Bio-Enzyme treatment proves effective in reducing soil compressibility and enhancing stability by optimizing consistency limits and indices. However, its effectiveness may depend on the reactivity with soil chemical constituents and the presence of clay content in the treated soils. The individual and groupwise performance of each soil has been discussed in detail by the author [30,31]. These details emphasize the importance of factors such as clay content, plasticity index, enzyme dose, and curing duration in achieving optimal results. However, it is important to note that the specific effectiveness and dosage requirements of TerraZyme may vary depending on soil types, environmental conditions, and project requirements.

1. Variation in stabilization among different soils: The significant variation in enzyme doses and curing duration required to achieve

maximum improvement in index and engineering properties of different soil groups leads to the conclusion that the degree of stabilization varies among different soils. The observations suggest that different soils have unique responses to enzyme treatment, with varying optimal enzyme doses and curing durations to reach maximum improvement in their properties.

2. Inconsistent improvement Trends with soil classified under the same group: The comparison of individual soils classified under the same group reveals inconsistent trends in variation in soil properties. not all soils within one particular group exhibit the same behaviour or response to enzymatic treatments. The variations could be attributed to inherent differences in soil mineralogical composition, or other factors that influence soil properties. Each soil group and soil within that group may have unique characteristics and behaviours, leading to different responses to enzyme treatment. This emphasizes the need to consider the specific soil type and its properties when determining the appropriate enzyme dose for effective stabilization.
3. Variable Optimum Enzyme Dose: The optimum enzyme dose, leading to the maximum improvement in engineering properties, varies significantly. The same enzyme dose exhibits variable effects on different soil properties within and across soil groups. This variability suggests that the response to enzyme treatment is complex and depends on the specific soil characteristics.
4. Lack of consistent improvements: The enzyme treatments do not consistently improve soil properties. This implies that the effectiveness of enzyme treatment in enhancing soil engineering properties can vary and may not always lead to significant improvements. There are no clear trends regarding the optimal enzyme doses and curing duration required to achieve the best performance. This suggests that the relationship between enzyme dose, curing duration, and the resulting improvement in soil properties is complex and not easily predictable. It highlights the need for further research and investigation to better understand the factors influencing the effectiveness of enzyme treatments. Inconsistent Improvements in Soil Properties.
5. Varied outcomes: While some soil cases have shown significant improvement in soil properties, the lack of definite trends implies that the outcomes of enzyme treatments can vary greatly from case to case. The effectiveness of enzyme treatments may depend on the specific soil characteristics, environmental conditions, and other factors that influence the soil's response to treatment.
6. The customized approach required: The variability in the effect of enzyme dose on different soil properties and soil groups emphasizes the importance of a customized approach for soil stabilization. A tailored strategy that considers the specific characteristics of the soil and the desired engineering properties is crucial for achieving optimal results. It underscores the need for careful evaluation, experimentation, and customization when applying enzyme stabilization to different soil groups and individual soils. The findings imply that a one-size-fits-all

approach may not be suitable for TerraZyme soil stabilization, and a customized application strategy considering the individual soil's response and requirements is essential.

7. Some soils exhibit unexpectedly large variations, which may be attributed to changes in sample preparation or laboratory testing conditions. Further investigation is necessary to understand the causes behind such unexpected results, especially when limited specimens hinder clear conclusions. The inconsistent variation in the properties of stabilized soils may be attributed to differences in curing conditions (air-dry vs. sealed container) and the absence of controlled untreated samples. It is important to consider the curing method and the inclusion of untreated control samples in assessing the effectiveness of soil stabilization. It is also important to note that the initial moisture content during sample preparation is crucial for the initiation and effectiveness of enzymatic action. Properly documenting the curing method and moisture content during testing is crucial for a comprehensive understanding of the effects of enzyme treatment on soil properties.

Further research and analysis are necessary to enhance our understanding of the factors influencing the effectiveness of enzyme treatments and to develop more reliable guidelines for their application. The discussions and observations underscore the importance of conducting a comprehensive and systematic study to better understand the effect of enzyme stabilization on different soils. Such a study should focus on the micro characterization of soils, enzyme characterization, and investigating the impacts of enzyme doses and curing durations. By carrying out this large-scale study, a deeper understanding of the mechanisms and optimal practices of enzyme stabilization can be achieved, leading to more effective and reliable soil stabilization techniques.

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