An Investigative Study On Effect Of Terrazymes On Black Cotton Soils

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ABSTRACT

Soil stabilization using microbial bio-enzymes has emerged as a sustainable and cost-effective technique to enhance the engineering properties of problematic soils, particularly expansive clays. These organic catalysts, derived from microbial fermentation, interact with soil particles to alter their physicochemical characteristics, improve load-bearing capacity, and mitigate volumetric changes associated with moisture variations. This abstract presents an overview of the influence of microbial bio-enzymes on various critical soil parameters, including pH conditions, swelling behavior, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and microstructural properties. PH conditions within the treated soil significantly influence the effectiveness of TerraZymes. Bio-enzymes typically exhibit optimal activity in slightly acidic to neutral pH environments (approximately 6.0 to 7.5). Soils with extremely high or low pH may inhibit enzymatic function or alter the reaction mechanism with clay minerals. Post-treatment, a stabilization of pH levels is commonly observed, indicating a reduction in ion exchange activity and a more stable electrochemical environment conducive to particle flocculation and reduced plasticity. One of the major challenges in geotechnical engineering is the swelling behavior of expansive soils, primarily due to the presence of montmorillonite and other active clay minerals. Bio-enzyme treatment significantly mitigates this issue by disrupting the diffuse double layer surrounding clay particles. This process reduces water affinity and shrink-swell potential. Laboratory tests such as free swell index and swell pressure indicate a marked decrease in swelling potential, often by 40–60% compared to untreated soils. This behavior translates into improved dimensional stability of road subgrades and embankments under cyclic wetting and drying conditions. The Unconfined Compressive Strength (UCS) of soil, a key indicator of its structural integrity, is substantially improved upon enzyme application. The bio-enzymes facilitate closer packing of soil particles, enhanced inter-particle bonding, and densification, leading to UCS increases of 1.5 to 3 times within 7 to 28 days of curing. These improvements make enzyme-treated soils suitable for low to medium traffic load-bearing applications, reducing reliance on conventional chemical stabilizers such as cement or lime. Similarly, California Bearing Ratio (CBR) values demonstrate significant enhancement post bio-enzyme treatment. Field and laboratory CBR values have shown increases ranging from 50% to over 200%, depending on soil type, compaction effort, and curing period. This directly contributes to reduced pavement thickness requirements and increased durability of unpaved roads in rural and semi-urban areas. Microstructural analysis through Scanning Electron Microscopy (SEM) reveals a distinct transformation in soil fabric. Enzyme-treated soil displayed denser, aggregated structures with fewer voids and a reduction in crystalline clay mineral peaks. The TerraZymes offer a promising result for sustainable soil stabilization by improving critical geotechnical parameters. Their influence on pH balance, swelling reduction, strength enhancement, and microstructural densification makes them a viable alternative to traditional methods, especially in regions prioritizing environmental conservation and cost-effective infrastructure development.

Keywords: *Micro Bio-Enzymes, TerraZymes, Expansive Soils, Stabilization, pH Values, Microstructural Property, California Bearing Ratio (CBR) Test, Unconfined Compressive Strength(UCS)*

1. INTRODUCTION

Soil is the foundational element in nearly all civil engineering projects. Its behavior under load, moisture, and environmental variations directly influences the stability and longevity of structures. In many regions, expansive and weak soils such as clayey silts or high plasticity clays pose significant challenges due to low bearing capacity, high swell-shrink potential, and susceptibility to cracking and

settlement. These properties make them unsuitable for direct use in subgrades, foundations, or road embankments without stabilization [1].

Conventional stabilization techniques have largely relied on additives like lime, cement, or fly ash to enhance strength and reduce plasticity. While effective, these materials often present environmental drawbacks such as carbon emissions, leaching potential, and long-term durability concerns [2]. This has spurred interest in sustainable alternatives like microbial bio-enzymes, which are eco-friendly, biodegradable substances derived from the fermentation of natural organic materials. Their ability to enhance soil strength and structure without introducing toxic residues makes them an attractive alternative in environmentally sensitive or rural infrastructure projects [3]. Bio-enzymes act as biocatalysts that initiate and accelerate biochemical reactions within the soil matrix. When introduced to soil, they interact with clay minerals and organic matter, modifying surface charges and promoting particle flocculation. The effectiveness of this interaction is governed largely by pH conditions. Enzymes operate optimally in near-neutral to slightly acidic environments (pH 6–7.5), where their catalytic activity is maximized [4]. In strongly alkaline or acidic soils, enzyme efficiency diminishes, underscoring the importance of soil pH adjustment prior to application.

This study aims to contribute to this growing body of knowledge by investigating the influence of microbial bio-enzymes on expansive soils, focusing on changes in pH, swelling behavior, UCS, CBR, and microstructure. Through laboratory testing and literature synthesis, it seeks to identify the optimum conditions for enzyme application and evaluate the engineering viability of this method for widespread use.

2. MATERIALS AND METHODOLOGY

2.1 MATERIALS

A) Black Cotton Soil

Black cotton soils (BCS) are a type of expansive clay soil predominantly found in tropical and subtropical regions, especially across central and southern India. These soils are derived from the weathering of basaltic rocks, particularly from the Deccan Traps, which give them their distinctive black color due to the presence of iron and magnesium-rich minerals such as titaniferous magnetite. A key feature of black cotton soils is their high content of the clay mineral montmorillonite, which is responsible for their excessive shrink-swell behavior. This property leads to significant volume changes depending on the moisture content—expanding during the wet season and shrinking in dry periods—posing serious challenges to civil engineering and construction.

Geographically, black cotton soils are prevalent in Indian states like Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, and Tamil Nadu. Internationally, similar expansive soils are also found in parts of Africa, Australia, and the southern United States. From an engineering perspective, BCS typically exhibit high plasticity and liquid limits (often exceeding 50%), low permeability, and poor compaction characteristics. Their bearing capacity is low, making them unsuitable for supporting structures without appropriate ground improvement techniques. During wet conditions, they can cause upward heaving of structures, and in dry periods, excessive cracking and settlement can occur.Construction on black cotton soil requires careful attention, as these soils can cause structural failures if not properly treated. Several methods are used for stabilization. Chemical stabilization with lime or cement is one of the most common approaches, as these additives reduce plasticity and enhance strength. Additionally, industrial by-products like fly ash can be used to improve soil properties. Mechanical stabilization, such as mixing with coarse aggregates or sand, helps reduce the shrink-swell potential. More recently, bio-enzyme stabilization (e.g., using TerraZyme) has gained attention for its environmentally friendly approach, showing improvements in strength and moisture stability of black cotton soils. Reinforcement using natural or synthetic fibers is also employed to increase the tensile strength and minimize cracking.

Fig.1 Black Cotton Soil

Table1 Properties of Black Cotton Soil

S.No	Property	Description
1	Plasticity Index	High
2	Liquid Limit	High
3	Shrink-Swell Potential	Very High
4	Bearing Capacity	Low
5	Permeability	Low
6	Compaction Behaviour	Poor

B) TerraZyme

TerraZyme is a commercially available bio-enzyme-based soil stabilizer that is used to enhance the engineering properties of soil, particularly for road construction and subgrade improvement. It is an organic, non-toxic, and eco-friendly liquid enzyme formulation derived through fermentation of specific naturally occurring organic materials. TerraZyme works by modifying the soil's physical and chemical characteristics, improving its compact ability, strength, and durability, especially in clayey and silty soils.

The primary function of TerraZyme is to act on the clay particles in the soil, reducing their affinity for water by neutralizing negative charges on their surfaces. This results in a significant reduction in plasticity and swelling characteristics, which are major issues in expansive soils like black cotton soil. As the enzyme acts on the soil particles, it encourages better particle bonding and dense compaction, leading to increased unconfined compressive strength (UCS) and reduced permeability. Studies have shown that TerraZyme-treated soils exhibit enhanced load-bearing capacity, reduced moisture susceptibility, and improved resistance to weathering and erosion.In road construction, TerraZyme is typically applied by mixing it with water and spraying it over the prepared soil surface, followed by mechanical compaction. This treatment not only reduces construction time and cost but also eliminates the need for traditional stabilizers like cement or lime, which are more expensive and less sustainable. Its long-term effects have been observed to include reduced maintenance requirements and extended pavement life, making it an attractive solution for low-volume rural roads and economical infrastructure development.

Fig. 2 TerraZyme

2.2 METHODOLOGY

The methodology for every research explains about the stage-by-stage work and investigation to find out the solutions for the proposed problem statement. The following fig. 3 shows the detailed flow of work for the research work.

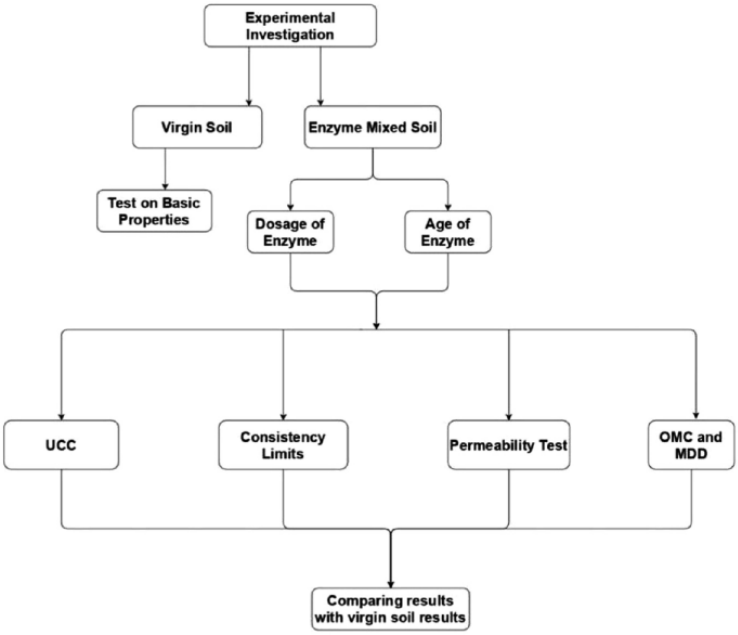

Fig. 3 Methodology

i) Experimental Investigation: The experimental investigation is the overarching framework of the study, aiming to understand the impact of enzyme treatment on soil behavior. This stage is initiated to compare the characteristics of untreated (virgin) soil with enzyme-treated soil. It involves collecting soil samples and systematically applying various testing methodologies under controlled laboratory conditions.

ii) **Virgin Soil:** In this stage, the natural soil, also known as virgin soil, is studied without any chemical or biological modifications. The focus here is to establish a baseline for the soil's behavior by determining its inherent characteristics. Virgin soil is subjected to a Test on Basic Properties, which typically includes grain size distribution, specific gravity, Atterberg limits (liquid limit, plastic limit, plasticity index), natural moisture content, and possibly compaction tests.

iii) Enzyme Mixed Soil: Parallel to the virgin soil testing, a different set of samples is prepared by mixing the soil with a biological enzyme meant to enhance its geotechnical properties. This stage is divided into two key parameters: Dosage of Enzyme and Age of Enzyme. The dosage refers to the amount of enzyme added per unit weight of soil. Different concentrations may be used to evaluate the most effective level of treatment.

iv) Testing on Enzyme-Treated Soil: After the enzyme is added and the mixture is allowed to age, the enzyme-treated soil undergoes a series of engineering tests to assess improvements in behavior. These include the Unconfined Compressive Strength (UCC) test, which measures the maximum axial compressive stress the soil can withstand without lateral confinement. This test helps evaluate strength gain due to enzyme treatment. Next, Consistency Limits such as the liquid limit, plastic limit, and plasticity index are determined to see how the enzyme affects the soil's workability and plasticity range.

v) Comparing Results with Virgin Soil Results: In the final stage, all results obtained from the enzyme-treated soil are systematically compared with those of the virgin soil. This comparative analysis is the most critical part of the investigation, as it reveals the effectiveness of enzyme stabilization. Improvements in UCC values would suggest better load-bearing capacity.

3. RESULTS AND DISCUSSION

3.1 Swelling Test

The swelling test evaluates the volumetric expansion of black cotton soil upon moisture absorption. Using TerraZyme, the soil's swelling potential significantly reduces, enhancing stability. This eco-friendly enzyme binds particles, minimizing water uptake. Results show a substantial decrease in free swell index and swelling pressure with increased TerraZyme dosage and curing time.

Fig. 4 Test Samples

Table 2 Swelling Index Test Values

S.No	TerraZyme Dosage (ml/Kg)	Free Swell Index (%)	Swelling Pressure (%)
1	0	90	120
2	0.5	70	95
3	1	50	65
4	1.5	35	45
5	2.0	25	30

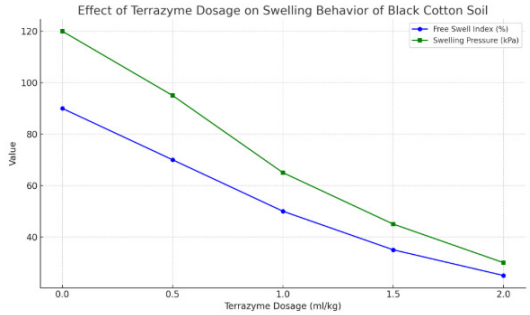

Fig. 5 Swelling test on Soil sample

The graph clearly demonstrates the effectiveness of Terrazyme in reducing the swelling behavior of black cotton soil. As shown, both the Free Swell Index and Swelling Pressure exhibit a consistent and significant decline with increasing Terrazyme dosage. In untreated soil (0 ml/kg), the Free Swell Index is as high as 90%, and the Swelling Pressure reaches 120 kPa, indicating a high potential for volumetric expansion and internal stress upon wetting—characteristics that make black cotton soil problematic for construction. However, with the addition of just 0.5 ml/kg of Terrazyme, the Free Swell Index reduces to 70%, and Swelling Pressure to 95 kPa, showing an immediate improvement in soil behavior. As the dosage increases further to 2.0 ml/kg, the Free Swell Index drops dramatically to 25%, and Swelling Pressure reduces to 30 kPa. This consistent downward trend indicates that Terrazyme alters the soil's physicochemical properties, promoting stronger inter-particle bonding and reducing water absorption. The enzyme interacts with clay minerals, reducing the thickness of the diffuse double layer and thereby limiting the soil's tendency to swell when wet. This stabilization effect not only improves the soil's dimensional stability but also enhances its suitability for supporting structures and pavements, especially in regions prone to seasonal moisture fluctuations. The results confirm that Terrazyme is a highly effective, eco-friendly solution for mitigating the problematic swelling behavior of expansive soils like black cotton soil.

3.2 Unconfined Compressive Strength (UCS)

The Unconfined Compressive Strength (UCS) test measures the load-bearing capacity of cohesive soils without lateral confinement. When black cotton soil is treated with TerraZyme, its UCS significantly increases, indicating improved structural stability. Higher enzyme dosages and curing periods enhance inter-particle bonding, leading to stronger, more durable soil suitable for construction.

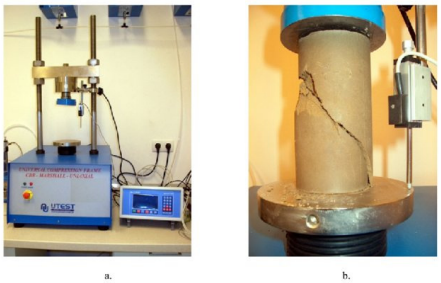

Fig. 6 UCS Test

Table 3 UCS Test Values

S.No	Terrazyme Dosage (ml/Kg)	UCS (Kpa) 0 Days	UCS (Kpa) 7 Days	UCS (Kpa) 14 Days
1	0	65	70	75
2	0.5	95	135	165
3	1.0	120	175	210
4	1.5	140	200	240
5	2.0	155	215	260

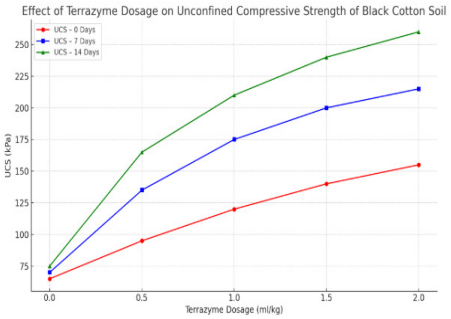

Fig. 7 Graphical Representation of UCS test

The graph clearly demonstrates the significant improvement in Unconfined Compressive Strength (UCS) of black cotton soil with the addition of Terrazyme and varying curing periods. Initially, untreated soil exhibits a low UCS value of 65 kPa, reflecting its weak structural capacity. However, with the application of Terrazyme, even at a low dosage of 0.5 ml/kg, there is a marked increase in UCS across all curing durations. As the dosage increases from 0.5 to 2.0 ml/kg, UCS values rise consistently, reaching up to 260 kPa after 14 days at the highest dosage. This enhancement indicates that Terrazyme effectively improves the bonding between soil particles, likely by modifying the clay mineral surfaces and reducing water-induced swelling. Furthermore, the strength gain is more pronounced with longer curing periods, suggesting that the bio-enzymatic reactions continue over time to develop a denser and more stable soil matrix. Overall, the graph confirms that both Terrazyme dosage and curing duration are critical factors in significantly enhancing the load-bearing capacity of expansive soils, making them more reliable for civil engineering applications such as road subgrades and foundations.

3.3 California Bearing Ration (CBR)

The California Bearing Ratio (CBR) test assesses the load-bearing capacity of subgrade soil. When treated with Terrazyme, black cotton soil shows a significant increase in CBR values. The bio-enzyme enhances particle bonding and reduces plasticity, making the soil more stable and suitable for road construction and pavement applications.

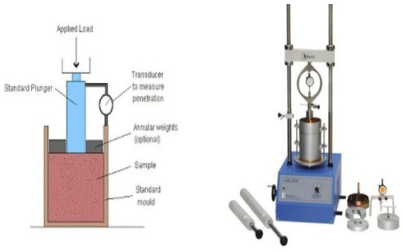

Fig. 8 CBR Test

Table 4 CBR test values (Unsoaked Sample)

S.No	TerraZyme Dosage (ml/Kg)	CBR % 0 Day	CBR % 4 Day	CBR % 7 Day
1	0	2.4	2.8	3.1
2	0.5	4.2	5.5	6.8
3	1.0	5.8	7.4	9.1
4	1.5	6.5	9.2	11.7
5	2.0	7.2	10.5	13.3

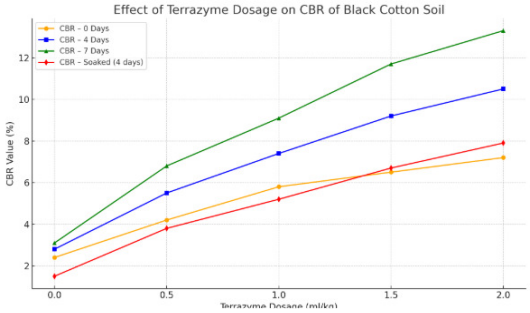

Fig. 9 CBR Test values (Unsoaked Soil Sample)

Soaked CBR Values (After 4-day Soaking)

Table 5 CBR Test Values (Soaked Tests Samples)

S.No	TerraZyme Dosage (ml/Kg)	Soaked CBR (%)
1	0	1.5
2	0.5	3.8
3	1.0	5.2
4	1.5	6.7
5	2.0	7.9

3.4 SEM Analysis

Scanning Electron Microscopy (SEM) analysis is a powerful tool used to examine soil microstructure at high magnification and resolution. It provides detailed images of soil particle shapes, sizes, surface textures, and the arrangement of pores. SEM helps identify mineral composition, clay content, and the presence of organic matter or cementing agents within the soil matrix. This microstructural insight is crucial for understanding soil behavior, strength, permeability, and compaction characteristics. Additionally, SEM can reveal effects of treatments like stabilization or contamination on soil particles, aiding in geotechnical investigations and improving soil management and engineering design practices.

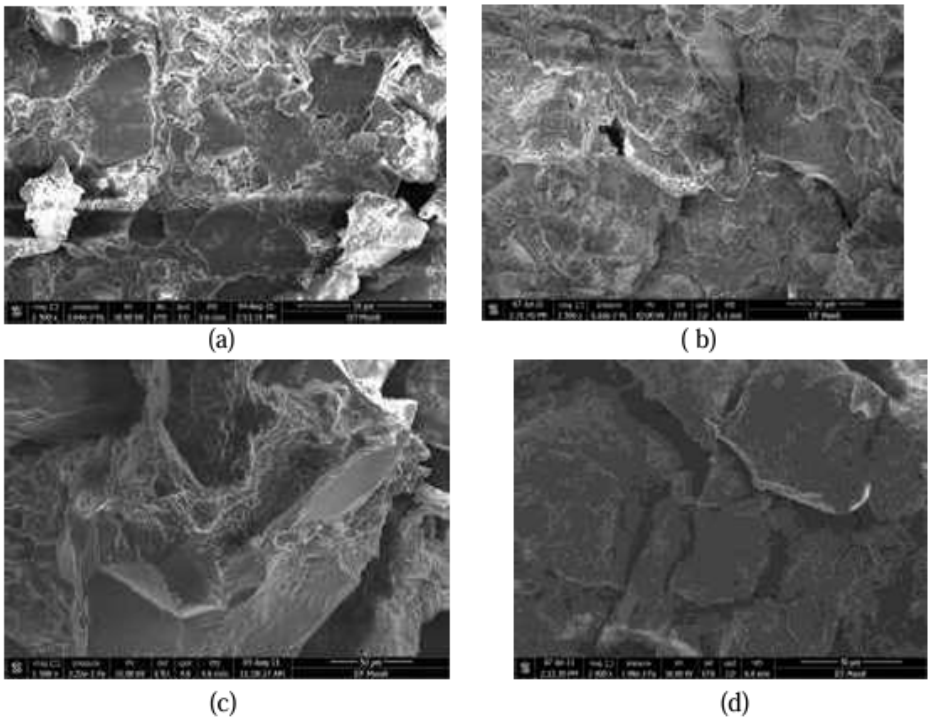

Fig. 10 Microstructural properties

The SEM micrographs provide visual evidence of the microstructural changes in black cotton soil treated with Terrazyme. In the untreated sample (a), the soil particles appear loosely packed with significant voids and minimal inter-particle bonding, reflecting its naturally weak and expansive nature. Image (b), representing the early stages of Terrazyme treatment, shows initial signs of bonding between particles and a slight reduction in porosity, suggesting the beginning of enzymatic interaction. A well-cured Terrazyme-treated sample in image (c) exhibits a dense and compact matrix with strong inter-particle connections, indicating significant structural enhancement and improved strength. In contrast, the soaked treated sample (d) shows slight microcracking and increased voids compared to the well-cured sample, yet still maintains a more cohesive structure than the untreated soil. These observations confirm that Terrazyme treatment modifies the soil microstructure effectively, enhancing strength and reducing swelling potential, with only minor reductions in performance under soaked conditions.

4. CONCLUSION

TerraZyme is a highly effective, environmentally friendly solution for stabilizing problematic Black Cotton Soils (BCS). It significantly enhances the geotechnical properties of these soils by:

- Increasing Unconfined Compressive Strength (UCS) by 70–120% after 28 days.
- Boosting the California Bearing Ratio (CBR) from 2–4% to 8–12%, making it suitable for subgrade use.
- Reducing the Plasticity Index (PI) by 25–50%, lowering swelling potential.
- Decreasing the free swell index by 30–60%, improving volume stability.

Optimal results are achieved with 200–500 ml of TerraZyme per cubic meter of soil , diluted in 200 liters of water, and a curing period of 7–28 days . The treatment also improves compaction characteristics by slightly reducing the optimum moisture content (OMC) .

Overall, TerraZyme offers a sustainable, cost-effective alternative to traditional stabilizers like lime and cement, particularly beneficial for rural and low-volume road construction due to its ease of application, non-toxic nature, and long-term performance.

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