SOIL STABILIZATION USING BIOENZYMES

B.KISHOR **19951A0121**

SOIL STABILIZATION USING BIOENZYMES

A Project Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering,

Submitted

By

B. KISHOR (19951A0121)

Under the Esteemed Guidance of

Dr. Vemula Anand Reddy

Assistant Professor

Department of Civil Engineering

INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad-500043, Telangana

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DECLARATION

I certify that

a) The work contained in this report is original and has been done by us under the guidance of our supervisor(s).
b) The work has not been submitted to any other institute for any degree or diploma.
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This is to certify that the project report entitled **SOIL STABILIZATION USING BIOENZYMES** submitted by B.KISHOR **(19951A0121)** to the institute of Aeronautical Engineering, Hyderabad in partial fulfilment of the requirements for the award of the **Bachelor of technology** in Civil Engineering is a bonafide record of work carried out by him/her under my/our guidance and supervision. This report, in its entirety or in segments, has not been previously to any other institute as a part of a degree requirement.

Supervisor	**Head of the Department**
Dr. Vemula Anand Reddy	Dr. R. Ramya Swetha
Assistant Professor	

Date:

APPROVAL SHEET

This project report **SOIL STABILISATION USING BIO-ENZYMES** done by B.KISHOR (19951A0121) Approval has been granted for the award of the Bachelor of Technologyin CIVIL ENGINEERING.

Examiners **Supervisor(s)**

Dr. V. Anand Reddy

Principal

L.V. Narasimha Prasad

Date:

Place:

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ABSTRACT

Soil stabilization is a crucial process in construction, particularly for road pavement and foundation construction, as it enhances soil properties such as strength, volume stability, and continuity. One innovative method gaining popularity worldwide is soil stabilization using bio-enzymes. In this approach, a test called California Bearing Ratio (CBR) is conducted to evaluate the soil's performance. The bio-enzyme used should be natural and non-toxic, typically in liquid form. By incorporating the enzyme into road construction, the CBR value of the soil increases. Various dosages of the enzyme tablets, such as 150 ml, 200 ml, 250 ml, and 300 ml per cubic meter of soil, are tested to analyze the results. Increasing the dosage of the enzyme tablets can yield better outcomes if an improvement in the CBR value is observed.

This approach presents a simple method for soil stabilization. Numerous bio-enzymes, including renolith, perma-zyme, terra-zyme, and fujibeton, have demonstrated effectiveness while also being environmentally friendly. Soil stabilization involves mechanical or chemical modifications to alter soil properties and create an improved soil material with desired engineering characteristics. It aims to enhance soil strength, reduce erosion, and minimize dust generation. Compared to conventional stabilizers, bio-enzymes help reduce environmental pollution by limiting carbon emissions.

Soil stabilization using bio-enzymes provides a means of ground enhancement. The CBR test is performed to assess the effectiveness of the bio-enzyme in road construction. The chosen enzyme should be natural and non-toxic, typically in liquid form. By observing any increase in the CBR value of the tested soil, adjustments can be made to the dosage of the bio-enzyme tablets to achieve better results.

Keywords: Bio-enzyme, Terra-zyme, Strength, CBR value, Bearing capacity, Soil stabilization.

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CHAPTER 1

INTRODUCTION

Soil stabilization is a crucial process in civil engineering, especially for poor soils like flaxen soils, where the soil's properties need to be enhanced to provide a strong foundation for construction. This involves increasing compressibility, shear strength, reducing permeability, and enhancing soil viscosity. Soil stabilization can be achieved through chemical or physical methods to improve the soil's physical properties. Bio-enzymes are widely used as soil stabilizers in engineering projects. They are synthetic or naturally occurring substances that are added to the soil to enhance its characteristics, such as for drawing purposes like penstocks and grout. Bio-enzymes are particularly recommended for drawing penstocks and can be used for decorative purposes as well.

The primary application of bio-enzymes lies in soil stabilization. When bio-enzymes come into contact with soil, they trigger chemical reactions that increase soil viscosity and reduce water retention. This leads to soil stabilization, making it suitable for constructing structures. Bio-enzymes can be obtained commercially or produced naturally from sources like fruit peels. In cases where poor soils require the construction of civil engineering structures, such as road laying, soil stabilization becomes necessary to improve the soil's physical properties.

Although soil stabilization can be expensive, requiring significant investments, various organic and inorganic chemical additives and stabilizers like slaked lime and Portland cement have been developed globally. However, bio-enzymes have gained considerable attention as they are cost-effective, environmentally friendly, and can also aid in corrosion prevention and dust control. Bio-enzymes contribute to reducing environmental pollution by minimizing carbon emissions associated with conventional stabilizers. Renolith, Terra-zyme, Fujibeton, Permazyme, and many other bio-enzymes have demonstrated their effectiveness and cost-efficiency as stabilizers.

Soil stabilization is crucial in civil engineering, especially when dealing with weak soils. An increasingly popular and beneficial method for improving soil properties is the use of bio-enzymes. These enzymes offer an eco-friendly and cost-effective solution to soil stabilization, making them a highly advantageous choice in the field. Black cotton soil, known for its dark hue derived from titaniferous magnetite, is highly conducive to the cultivation of cotton. This clay-rich soil is predominantly found in tropical and subtropical regions, boasting a composition that includes calcium, carbonate, potash, and excellent moisture retention properties. Although rich in iron, magnesium, and lime, black cotton soil tends to be deficient in phosphorus, nitrogen, and organic matter. Consequently, low-lying areas exhibit greater fertility compared to elevated regions. During dry seasons, the presence of cracks in many black soil regions facilitates air circulation. While this soil is ideal for agricultural purposes, its compact and erosive nature poses significant challenges for civil engineering systems. Black soil, also known as lava soil, is a sedimentary type that maintains its original position without dispersing. It originates from the weathering and erosion of particular parent stones, primarily those of igneous or basaltic origin. The creation of black soil is associated with the movement or breakdown of igneous rocks, which is followed by the cooling and solidification of lava.

- The color of this substance is black.
- It consists of extremely small particles that are not visible to the naked eye.
- Wide cracks develop during the summer season.
- In the rainy season, it takes on a muddy appearance.
- It becomes sticky when it gets wet.

Bio-enzymes are synthetic or naturally occurring substances that are commonly used in various applications, such as drawing penstocks and grout. These bio-enzymes are particularly recommended for drawing penstocks and can be utilized for creating vibrant colors. However, their primary use lies in stabilizing soils. By catalyzing chemical reactions on the soil surface, bio-enzymes increase soil viscosity and reduce water retention, resulting in soil stabilization and preparation for construction projects.

Bio-enzymes can be obtained commercially or produced through natural processes, such as extracting them from fruit peels. When dealing with poor-quality soils that require the construction of civil engineering structures, such as roadways, a soil stabilization process is employed to enhance the soil's physical properties.

Through the catalytic action of bio-enzymes on the soil surface, soil viscosity increases, and water retention decreases. Consequently, the soil becomes stabilized and ready for road construction. To ensure the effective performance of bio-enzymes, the soil should possess certain characteristics, including properties like strength, consistency, plasticity, and viscosity. By stabilizing the soil using bio-enzymes, these parameters are improved.

The soil stabilization procedures employed aim to transform weak soil into a robust foundation for structural systems. Through thorough compaction, The soil's strength experiences a notable increase.

1.1 OBJECTIVES OF THE STUDY

- To assess the properties of a soil using Bio-enzyme.
- To perform soil tests, including California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS).
- To increase the properties of soil such as compressive strength, permeability, density.

CHAPTER 2
LITERATURE REVIEW

2.0 GENERAL:

A brief review of literature, This study focuses on the investigation of soil stabilization through the utilization of bioenzymes.

Eshetu Mekonnen, Ameha Kebede, Tekle Tafesse, And Mesfin Tafesse (2020), Microbial bio-enzymes (stabilizers) offer numerous advantages over conventional stabilizers, making them a superior choice for soil stabilization. Not only are they more economical and environmentally friendly, but they also require less maintenance during transportation and handling. These bio-enzymes provide significant benefits for the soil stabilization process, which is a crucial procedure in construction projects requiring a stable base capable of supporting heavy traffic loads.

Traditional chemical and mechanical stabilization techniques often come at a higher price, prompting the search for safe, cost-effective, and easily produced soil stabilization methods. In this context, local production of bio-enzymes emerges as the optimal solution, aligning with the economy's primary interest in cost-effective technologies. Utilizing enzymes as soil stabilizers has proven effective in enhancing subgrade strength, thanks to their affordability and broad applicability compared to standard stabilizers.

Mohd Raihan Taha, Tanveer A Khan, Ibtehaj Taha Jawad, Ali Akbar Firoozi, Ali Asghar Firooz(2013), The aforementioned study highlights the importance of observing significant results in controlled laboratory conditions for a product. This is because achieving desired outcomes becomes more challenging in less favorable field conditions. It emphasizes that the product should already demonstrate approximate required results during laboratory testing, which can vary from modest to significant improvements. Consequently, it becomes necessary to subject the manufacturer's claims or results regarding these enzymes to independent laboratory testing to ensure their credibility. However, it is also important to note that laboratory tests are often criticized for their inability to replicate field conditions accurately. Nonetheless, if a product fails to exhibit significant results in controlled laboratory conditions, it becomes even more difficult to attain the desired outcomes in less favorable field conditions. Only when laboratory testing shows significant results can the next question be raised regarding the extent of improvement necessary to validate its use in the field.

Vijay Rajoria, Suneet Kaur (2014), Based on the aforementioned study, we can deduce that bio-enzymes possess several advantageous characteristics. Firstly, they are non-toxic, organic, and biodegradable, posing no harm to humans, animals, or vegetation when used under normal conditions. Furthermore, bio-enzymes effectively mitigate the characteristics of highly expensive clays regarding their tendency to swell and shrink. In relation to pavement construction, the application of bio-enzymes imparts flexibility and durability while minimizing crack formation. Additionally, bio-enzymes serve as efficient dust control agents, with numerous construction projects reporting a substantial 75% reduction in dust on unsurfaced roads following their utilization. Moreover, the use of bio-enzymes enables the creation of aggregate-free pavements, promoting the utilization of locally available materials. Lastly, The addition of bio-enzymes results in improved compressive strength and heightened hardness of stabilized soil.

Puneet Agarwal, Suneet Kaur (2014), The use of Terrazyme for soil stabilization resulted in a notable enhancement of up to 200% in the Unconfined Compressive Strength (UCS) of Black Cotton Soil. The duration of Terrazyme treatment played a crucial role in strengthening the soil, with the best results observed after a 7-day treatment. Terrazyme, an environmentally-friendly enzyme, has been found to greatly enhance the Unconfined Compressive Strength (UCS) of Black Cotton soil. After careful evaluation, it has been determined that the ideal dosage of Terrazyme for improving the UCS is 1ml per 5kg of soil. This optimal dosage demonstrates remarkable efficacy in enhancing the strength properties of Black Cotton soil.

GV Rama Rao, P Hanuma (2019), This study focuses on the investigation of major properties such as OMC (Optimum Moisture Content), MDD (Maximum Dry Density), CBR (California Bearing Ratio), UCS (Unconfined Compressive Strength), and Consolidation in Bio-Enzyme stabilized soil. By conducting laboratory tests and comparing the results with those of normal soil, the following conclusions have been drawn:

1. The consistency limits of a soil are notably affected by its clay content. Specifically, at dosage no.4, the liquid limit experiences a decrease from 55% to 48%, while the plastic limit reduces from 26% to 24%.

2. The impact of enzyme-treated soil on the moisture density relationship (MDR) is minimal, with MDR values ranging from 1.486 gm/cm3 to 1.78 gm/cm3. Nonetheless, a decrease in the Optimum Moisture Content (OMC) from 24% to 25% is observed. This decrease can be attributed to the enhanced cation exchange process facilitated by the stabilizers present, which would typically require a longer time in the absence of these agents.

3. The unconfined compressive strength (UCS) experiences a significant rise, increasing from 1.12 kN/m^2 to 5.54 kN/m^2. This notable improvement can be credited to the interaction between the enzyme and clay, leading to a cementation phenomenon.

In summary, this study investigates the performance of Bio-Enzyme stabilized soil and finds that it leads to desirable changes in consistency limits, OMC, MDD, and UCS, indicating the effectiveness of the stabilizers in enhancing soil properties.

Piyush Parik, Nihar Ranjan Patra (2023), This study examines the potential of using clay stabilized with red mud, bio-enzyme, and a combination of red mud and bio-enzyme in pavement construction. By incorporating these materials, the strength of the weak clay soil subgrade layer is greatly enhanced. This increased strength enables the pavement to better withstand the heavy loads caused by vehicular traffic, making it more resilient. Additionally, the utilization of red mud provides a solution to the land management challenges faced by aluminum industries when disposing of aluminum effluent in a safe manner.

Moreover, the service life of the stabilized subgrade pavement is significantly improved, ranging from 4 to 13 times longer than that of traditional clay subgrade pavement. Furthermore, the stabilized subgrade pavements exhibit considerably reduced surface deflection values, ranging from 15% to 42.7% compared to those of clay soil subgrade pavement.

Uzaira Rafique, Saima Nasreen, Rabbiya Naveed, Muhammad Aqeel Ashraf (2016) Ninety percent of roads and highways are typically paved with asphalt due to its lower cost and ease of construction and repair compared to concrete. However, the effects of climate change and rising construction material costs have prompted the exploration of environmentally friendly methods for road construction. An economically feasible approach to achieve these objectives involves using enzyme soil stabilization, which utilizes bioenzymes to enhance the stability of soil aggregates and materials in roadways and pavements. The purpose of this study was to introduce TerraZyme, an environmentally friendly product, to improve the engineering properties of soil for road construction.

Two types of soil were examined to evaluate their soil classification and earthwork characteristics. These soil types included pulverized local soil and transported soil, both with and without the application of TerraZyme. The findings confirmed that the implementation of TerraZyme resulted in improved engineering characteristics. This was particularly evident in the California Bearing Ratio (CBR) values, which increased by 55% from 10.47 to 16.28. Furthermore, the untreated and treated soils exhibited a respective 4.28% and 2.20% increase in dry density, as well as a decrease of 18.13% and 6.17% in moisture content.

Tanveer Ahmed Khan, Mohd Raihan Taha(2015), In this experimental study, researchers aimed to investigate the impact of three enzymes on various soil properties, including Atterberg limits, compaction characteristics, and unconfined compressive strength. They utilized a Standard Proctor test to assess changes in the optimum moisture content and maximum dry density by applying two different doses of enzymes. The study involved soil samples without treatment and soil samples treated with two doses of each enzyme for three different curing periods (28, 56, and 84 days).

After a curing period of 56 days, the researchers conducted the Atterberg limits test on both untreated and treated soil samples. Additionally, they employed X-ray diffraction (XRD), X-ray fluorescence (XRF), and field emission scanning electron microscopy (FESEM) techniques to identify any potential chemical alterations.

The results indicated that the three enzymes did not significantly improve the Atterberg limits, compaction characteristics, or unconfined compressive strength in the tests conducted. In some cases, there was a slight improvement, which could be attributed to the enzymes preventing moisture absorption and bringing the particles closer together, rather than producing any chemical changes. Therefore, it is crucial to carefully evaluate the suitability of an unvalidated stabilizer before using it on a larger scale.

The findings of this study are expected to provide valuable insights for designers, contractors, and constructors when considering the use of bio-enzymes as soil stabilizers.

H Mallikarjun, Nischith Nirmal Raj GS, S Nethravathi (2022), The performance of pavement relies heavily on the type of subgrade soil and its characteristics. Soil stabilization is a crucial aspect of highway construction, aimed at improving the fundamental engineering properties of the subgrade and meeting road construction standards. In order to address the inadequate properties of subgrade soils, various techniques for soil stabilization are employed. Historically, lime, cement, bitumen, and their combinations have been commonly employed as soil stabilizers to enhance the characteristics of challenging soil. Nevertheless, the traditional stabilizers are expensive, and the utilization of gravel or sand to enhance soil properties is depleting these resources.

Eshetu Mekonnen, Yared Amdie, Habtamu Etefa, Nurelign Tefera & Mesfin Tafesse (2022), The study revealed that ureolytic bacteria can be utilized for submerged fermentation to produce soil stabilizing bioenzymes. The results demonstrated that treating expansive soils with these bioenzymes can enhance the subgrade quality, making them suitable for road pavement layers. Despite the insufficient improvements for utilizing the soil as sub-base or base course materials, the treated soils with bioenzyme did satisfy the minimum requirements for low volume road subgrades. Consequently, these treated soils demonstrate effectiveness in applications such as light rural gravel roads, pedestrian walkways, and bicycle tracks.

To maximize the advantages offered by bioenzymes, it is advisable to explore the potentials of various microorganisms. Furthermore, conducting field trials in diverse climatic conditions and soil types is essential. These trials will help in creating a comprehensive specification manual, which will facilitate the widespread production and utilization of bioenzymes. Additionally, it is crucial to carry out fermentation trials using affordable alternative substrates. Lastly, testing the combination of bioenzymes with Portland cement should be conducted, as it has the potential to significantly enhance plasticity, strength, and permeability characteristics.

Rohit Sahu, Krishna Thakur, Pankaj Singh, Sonu Kumar, Rohit Kumar Jatav(2023), In this study, the chemical composition of bagasse ash was analyzed.

The ash was predominantly composed of silica (66.23%), potassium (6.44%), and iron (3.09%). These elements accounted for 75.76% of the composition, surpassing the minimum requirement of 70% set by ASTM 2012 standards for pozzolanic reaction. However, the inclusion of bagasse ash and lime led to a decrease in the plasticity index, which did not meet the standards specified in the Road Design Manual Part III. Consequently, using bagasse ash alone proved insufficient for stabilizing expansive Black Cotton soil, as it had a detrimental effect on its strength. Additionally, samples containing bagasse ash exhibited a decrease in the California bearing ratio due to the limited presence of calcium in the ash. However, when bagasse ash was partially substituted for lime, the plasticity index decreased and the California bearing ratio increased, depending on the ratio employed. Notably, with a lime-to-ash ratio of 4:1, the outcomes aligned with the standards outlined in the Road Design Manual Part III. This included a California bearing ratio of 36%, a plasticity index of 20%, a linear shrinkage of 9.0, and minimal swelling. Thus, this mixture can be effectively utilized for stabilizing expansive Black Cotton soil in accordance with the specified guidelines.

Nimi Ann Vincent, Grace Mary Abraham, Elna Abraham Alummoottil, Alphonsa Philip, Anisha Elsa Varghese, Jesni Anna John (2021), Soil enzymatic stabilization does not involve the creation of new chemical bonds, but rather affects the surface properties of the soil. Furthermore, enzymatic activity remains unaffected by external factors such as pH or temperature. Experimental observations have revealed that over time, the stabilized soil experiences significant improvements in its strength and plasticity characteristics. In a specific study, the optimal dosage of TerraZyme for the soil in question was determined to be 0.1 ml/L. Following a curing period of 7 days, noteworthy enhancements were observed in the unconfined compressive strength, cohesion, and angle of friction, with increases of 42%, 70%, and 35% respectively. Comparisons between unstabilized and stabilized soil revealed considerable effects on the consistency limits, likely attributed to soil particle aggregation. Furthermore, slope stability analysis utilizing GEO5 software demonstrated that Terrazyme-treated soil, with varying dosages, was suitable for slopes of different heights. The soil stabilization process requires only a small amount of enzyme dosage. Consequently, it can be inferred that the application of bio-enzymes for the stabilization of highly problematic lithomargic clay yields substantial improvements in various engineering properties of the soil.

Athira S, B K Safana, Keerthi Sabu (2017), A study comparing untreated soil on the 0th day with treated soil on the 0th day found that the treated soil exhibited a 51.3% increase in Unconfined Compressive Strength (UCC) value. After 28 days of curing, the UCC value of the treated soil sample showed a significant increase of 281.5% compared to the untreated sample on the 0th day. Furthermore, when comparing the UCC values of the treated and untreated soil samples after 28 days of curing, there was a 166.3% increase observed.

The addition of Terrazyme to the soil also impacted other properties. It resulted in a 14.8% decrease in the Optimum Moisture Content (OMC) value and a 61.59% increase in the Maximum Dry Density (MDD) value after 28 days of curing. Additionally, the California Bearing Ratio (CBR) value showed an 11.16% increase when comparing the untreated soil on the 0th day with the treated soil on the 0th day. As the curing period increased, the CBR value continued to rise. Notably, there was a substantial increase of 139.32% in the CBR value for the treated soil after 28 days of curing compared to the untreated sample on the 0th day.

Charu Chauhan , and K. V. Uday (2022), The experimental study aimed to investigate the impact of two types of terrazyme on soil swelling and unconfined compressive strength (UCS). Based on the obtained results, the following conclusions can be drawn:

1. Untreated soil specimens exhibited greater swelling compared to soil treated with terrazyme. Moreover, higher enzyme dosages led to a more significant decrease in swelling.
2. The unconfined compressive strength (UCS) of the soil increased as the curing period progressed, signifying progressive enhancement in specimen strength.
3. The ideal terrazyme dosage for both types was identified as 0.5 ml per 500 ml of distilled water.

In summary, the experimental findings suggest that terrazyme treatment can effectively decrease soil swelling, and the dosage of the enzyme and curing period play significant roles in the process.

Ayush Mittal (2020), This study investigates the utilization of bio-enzymes, specifically terrazyme, for soil stabilization purposes. The results indicate that when bio-enzymes are used on soil, it results in the creation of calcium silicate hydrate (CSH), which possesses properties similar to cement. The use of terrazyme in expansive soil reduces its plasticity characteristics, resulting in improved volumetric stability and decreased susceptibility to cracking. Additionally, terrazyme effectively enhances the strength of unstabilized earthen constructions and adobe blocks. Notably, terrazyme is derived from natural sources such as fruits and vegetables, making it environmentally friendly. Moreover, the utilization of terrazyme in subgrade soil leads to a substantial reduction in the required pavement thickness, thereby preserving crucial base and sub-base aggregate materials. However, further research is needed to fully comprehend the underlying mechanisms of terrazyme for soil stabilization. Therefore, supporting the advancement of bio-enzymes in this field is crucial.

Anjali Guptaa, Vishal Saxenab, Ayush Saxenac, Mohd. Salmand, Shamshul Aarfine, Avinash Kumarf (2017), Terrazyme is a natural, biodegradable liquid that offers a range of eco-friendly benefits without posing any harm to the user. This specially formulated solution is engineered to fortify soil without any toxic or corrosive properties. It significantly enhances the Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) values, thereby demonstrating enhanced soil performance.

One of the key advantages of Terrazyme is its ability to reduce the gaps between soil particles, resulting in enhanced compaction and increased soil density. This action leads to a decrease in the Optimum Moisture Content and Consistency Limits of the soil, making it more suitable for construction purposes. Simultaneously, the product enhances the density of the soil, further reinforcing its strength.

In addition to these benefits, Terrazyme also improves the soil's resistance to water by reducing its permeability. This means that the soil becomes less prone to erosion and maintains its stability even in the presence of water.

Overall, Terrazyme offers a sustainable solution for soil enhancement, promoting improved soil strength, compaction, density, and water resistance.

CHAPTER 3

METHODOLOGY

3.1 General

Our main objective was to enhance various properties of soil through soil stabilization using bio-enzymes such as terrazyme, fujibeton, permazyme, among others. The specific goals included increasing compressive strength, reducing compressibility, enhancing shear strength, minimizing permeability, and increasing soil density. The enzyme known as terrazyme was employed in this process. To assess the effectiveness of the stabilization, we conducted tests such as the compressive strength test, California Bearing Ratio (CBR) test, and Atterberg limit tests.

3.2 Basic materials used

During our investigation, we utilized clay soil as the primary material, along with water for sample preparation. Additionally, we employed a bio-enzyme known as terrazyme.

- Soil (black cotton soil)
- Water
- Bio-enzyme(terrazyme)

3.2.1 Soil (Black cotton soil)

Black cotton soils, also known as vertisols, are characterized by their high clay content and unique behavior related to water retention and shrink-swell properties. These soils are typically found in regions with seasonal rainfall and have distinct characteristics that make them challenging for construction and agricultural purposes. Regenerating black cotton soils involves implementing various techniques to mitigate their expansive nature and improve their stability.

Black cotton soils, also known as vertisols, indeed contain various nutrients due to their formation in tropical and subtropical regions. Regenerating these soils involves managing their unique characteristics, such as high clay content, shrink-swell behavior, and nutrient availability.

Black cotton soils are indeed characterized by their low content of phosphorus, nitrogen, and organic matter. This, coupled with their high clay content, can present challenges for plant growth and crop yields. However, regeneration techniques can be implemented to improve the fertility and structure of black cotton soils, even in upland areas It's important to note that black cotton soil regeneration is a gradual process, and results may take time to manifest. Consulting with local agricultural experts or soil scientists familiar with black cotton soils in your specific region can provide tailored advice based on local conditions and resources available.

Fig.1 Black cotton soil

3.2.1.1 Properties

Black cotton soil, also known as regular soil, is a type of soil that is black in color and is commonly found in regions with lava discharges. It is particularly suitable for the cultivation of cotton and is often referred to as black soil. Here are some key characteristics of black cotton soil:

1. Stickiness: Black cotton soil is sticky when wet, making it difficult to work with. It can become compacted and challenging to plow or cultivate.
2. Distribution: Black cotton soil is primarily located in the plateau regions of Maharashtra, Saurashtra, Malwa, Madhya Pradesh, and Chhattisgarh. Additionally, it extends southeastward along the valleys of the Godavari and Krishna rivers.

3. Formation: The formation of black cotton soil is influenced by climatic conditions and the parent rock material. The combination of these factors contributes to the development of this specific type of soil.
4. Nutrient Content: Black cotton soil has a fine texture and is rich in lime, iron, and magnesium. However, it typically has low amounts of phosphorus, nitrogen, and organic matter. This nutrient composition should be taken into account when planning for agricultural activities.
5. Moisture Retention: Black cotton soil can contain up to 50% clay content, making it highly retentive of moisture. This characteristic can be advantageous for crop cultivation in areas with limited water availability.
6. Expansion and Shrinkage: The significant clay content in black cotton soil causes it to expand when wet and shrink during arid seasons. This expansion and shrinkage can lead to the formation of large cracks, which facilitate the circulation of air and help prevent waterlogging.
7. Fertility: In most locations where black cotton soil is found, it is highly fertile. However, the nutrient deficiencies, high clay content, and specific management requirements of the soil need to be considered for effective agricultural practices.

To achieve successful crop cultivation and implement appropriate soil management techniques, it is crucial to comprehend the distinctive qualities and makeup of black cotton soil. Local agricultural experts or soil scientists can provide specific guidance and recommendations based on the particular characteristics and conditions of black cotton soil in your area.

3.2.1.2 Physical properties of the soil

Black cotton soil exhibits several specific characteristics that can affect its engineering properties. Here are some additional details about these characteristics:

Plasticity: Black cotton soil has high plasticity due to its high clay content. This means that it can be easily molded and deformed when wet, but it retains its shape when dry

Shrink-swell behaviour: Black cotton soil undergoes significant volume changes with changes in moisture content. It swells and expands when wet, leading to an increase in volume. Conversely, it shrinks and contracts when dry, resulting in a decrease in volume. This shrink-swell behavior can cause cracking and instability in the soil.

Compressibility: Black cotton soil is highly compressible, meaning it can easily be compressed under load. This property makes the soil prone to settlement when subjected to external loads.

Permeability: Black cotton soil has low permeability, which means it has poor drainage characteristics. Water has difficulty penetrating the soil and draining through it. As a result, the soil tends to retain water for extended periods, leading to waterlogging and reduced stability.

Shear strength: : Black cotton soil typically has low shear strength. Shear strength refers to the ability of the soil to resist deformation and sliding along a plane. The low shear strength of black cotton soil makes it susceptible to slope failure, landslides, and instability.

Bearing capacity: If the soil has poor bearing capacity, it means that the soil is unable to support the load imposed by shallow foundations effectively. In such cases, alternative foundation designs or soil improvement techniques may be necessary to ensure the stability and safety of the structure.

3.2.2 Bio-enzyme (Terrazyme)

Terrazyme is a natural liquid derived from extracts of vegetables and fruits. It is carefully crafted using these organic ingredients and possesses beneficial qualities that can improve the density and durability of soil. When used in soil, Terrazyme undergoes enzymatic reactions with clay particles and organic cations. These reactions result in the formation of a protective coating around the clay particles, making them water repellent. This coating helps to reduce the absorption of water by the clay particles and prevents them from swelling or becoming excessively soft when in contact with moisture.

Additionally, Terrazyme facilitates cationic interexchange, which reduces the thickening of the absorbed layer of clay particles. This helps to decrease the voids within the soil, allowing for better compaction and increasing the soil's load-bearing capacity.

By improving the compaction of soil, Terrazyme can contribute to reducing the thickness of pavements required for construction. This, in turn, can lead to cost savings in terms of material usage and maintenance.

It's important to note that the effectiveness and specific application of Terrazyme may vary depending on the soil conditions, project requirements, and other factors. Proper testing, evaluation, and consultation with experts are recommended before using Terrazyme or any other soil improvement product.

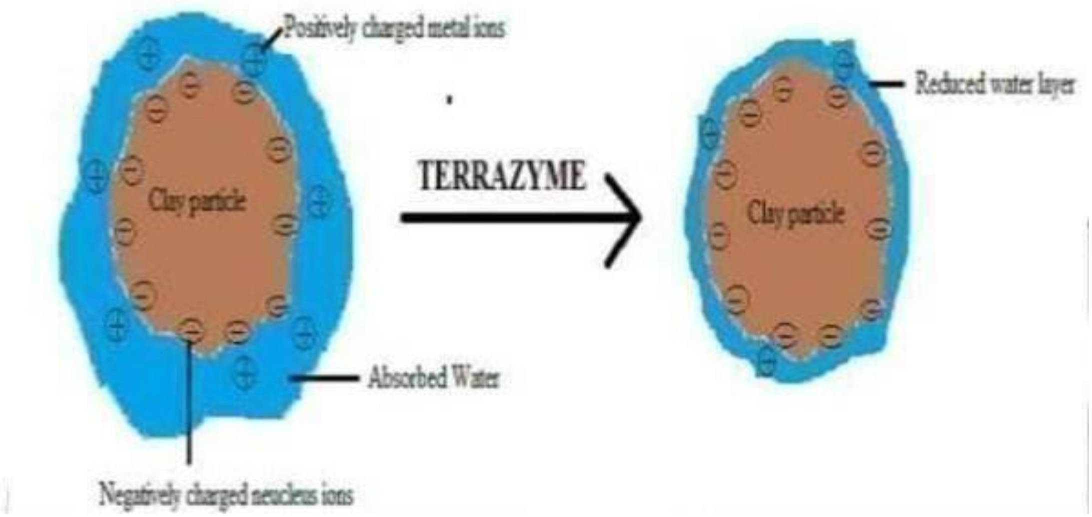


Fig.2 Mechanism of Terrazyme

3.2.2.1 Properties

- The application of Terra-zyme improves the California Bearing Ratio (CBR) value of soil.
- Terra-zyme permanently alters the soil, making it biodegradable.
- Terra-zyme forms a protective layer encompassing clay particles, rendering them resistant to water.
- Terra-zyme is conveniently provided in a liquid state and can be effortlessly mixed into water for dissolution.

- Handling Terra-zyme is simple and does not require the use of masks or gloves.
- Terra-zyme effectively minimizes the empty spaces between soil particles, resulting in a reduction in soil swelling capacity and porosity.
- Terra-zyme enhances the strength, stiffness, and load-bearing capacity of the soil.

Fig. 3 Terrazyme

3.2.2.2 Physical properties of terrazyme

Property	value
Specific gravity	1.05
pH value	3.50
Appearance	Dark brown
Total dissolved salts	19.7ppm
Hazardous content	None
Boiling point	212˚F

Evaporating rate	Equivalent to water
Solubility in water	Fully soluble
Reactivity data	Stable

Table 1. Physical properties terrazyme

3.2.3 Water

Water is the primary component used to create standard test samples. The process involves mixing the soil with an appropriate amount of water, either in terms of content or quantity. By adding the necessary quantity of water, the soil specimen or sample can be molded into desired shapes or cubes.

3.3 Basic Tests on Materials

The tests to determine the properties of soil before and after soil stabilization were conducted as follows:

1. Compaction test (standard proctor test)
2. CBR (California Bearing Ratio)
3. UCS (Unconfined Compressive Strength) test
4. Atterberg limits

3.3.1 Compaction Test (Standard Proctor test)

Compaction is a crucial process that involves applying mechanical force to soil, resulting in increased density. Soil consists of solid particles, as well as void spaces filled with air and/or water. To comprehend the three-phase nature of soils, we can consider the concept of soil as a three-phase system.

When soil undergoes stress, its particles rearrange, causing a reduction in the volume of void spaces and an overall increase in density. Different methods, such as kneading, dynamic (vibratory) compaction, or static compaction, are employed to achieve this densification.

The effectiveness of the compaction process is typically measured by quantifying the change in the soil's dry unit weight, denoted as γd. This measurement allows engineers and construction professionals to assess the degree of compaction achieved.

Compaction is of great importance in engineering applications due to several reasons. Firstly, it significantly improves the load-bearing capacity and stability of soil, making it suitable for supporting various structures such as buildings, roads, and foundations. Compacted soil exhibits reduced susceptibility to settlement or deformation, thereby ensuring the long-term durability of these structures. Secondly, compaction reduces the soil's permeability, making it less susceptible to water infiltration. This is especially crucial in areas where water seepage can cause detrimental effects, such as erosion, soil liquefaction, or compromising the stability of underground structures.

Furthermore, compacted soils exhibit improved shear strength, reducing the likelihood of slope failures and landslides. This is particularly relevant in hilly or sloping terrains where stability is a concern.

Overall, compaction is a valuable technique in engineering applications as it enhances soil properties, including density, load-bearing capacity, stability, permeability, and shear strength. By achieving a well-compacted soil, construction projects can ensure the durability and safety of their structures, while minimizing potential risks associated with soil settlement or instability.

- Soils experience enhanced strength.
- Soils exhibit reduced compressibility.
- Soils demonstrate decreased permeability.

Apparatus

1. The cylindrical compaction mold has a diameter of 10 centimeters and is equipped with a base and a collar.
2. Proctor hammer weighing 2.5 kg depending on whether the standard of the modified test is conducted
3. No.4 Sieve
4. Steel straightedge
5. Moisture containers
6. Graduated cylinder
7. Mixer
8. Controlled oven

9. Metallic tray and a scoop

Fig.4 Compaction mould

Procedure :

1. Obtain a representative sample of approximately 2.5 kg of soil.
2. Use a No. 4 sieve to remove any large particles or debris from the soil.
3. Determine the weight of the empty compaction mold (without the collar) as Wm.
4. Mix the soil with water in a mixer, gradually adding water until the desired moisture content (w) is reached. Ensure thorough mixing for even distribution.
5. Apply a lubricant to the collar of the compaction mold to prevent sticking.
6. Take the soil from the mixer and place it in the mold in either 3 or 5 layers, depending on the chosen Proctor method (Standard or Modified Proctor). Compact each layer with 25 blows using a compaction hammer or mechanical compactor, maintaining a consistent drop rate.
7. The soil should fill the mold and extend into the collar, but not exceed approximately 1 centimeter.
8. Carefully remove the collar and use a straight edge to trim any excess soil extending above the mold.
9. Weigh the compaction mold with the compacted soil as W.
10. Use a metallic extruder, ensuring alignment with the mold, to extrude the compacted soil from the mold.

11. Measure the water content of the compacted soil by sampling from the top, middle, and bottom of the extruded sample.
12. If needed for further testing or comparison, return the soil to the mixer and add water to achieve a higher water content.

These steps are a general guideline for performing a Proctor compaction test. It's important to follow specific standards and procedures outlined by relevant organizations or regulatory bodies, as they may provide additional details or variations based on specific requirements .

Fig.5 Fig.6

Filling and compacting the mould with soil

Fig.7 Compacted soil

3.3.2 California Bearing Ratio(CBR)

California Bearing Ratio (CBR) test and its significance in determining the subgrade strength of soil in pavements. The CBR test is indeed used to evaluate the strength of a soil by comparing its penetration resistance with that of a standard material.

During a laboratory CBR (California Bearing Ratio) test, a cylindrical steel mold is filled with a soil sample, and a cylindrical steel plunger with a diameter of 50 mm is gradually inserted into the sample. The force required for penetration is measured and compared to the force needed to penetrate a standard crushed rock material.

The ratio between the force required to penetrate the soil and the force needed for the standard material is calculated as the CBR value, expressed as a percentage. A higher CBR value signifies a stronger soil with better load-bearing capacity, indicating its ability to withstand higher pressures.

By introducing terrazyme, a soil additive or stabilizer, into the soil sample, the CBR values for both soaked and unsoaked samples can be significantly increased. This increase in CBR values is attributed to enhanced compaction, which improves the bonding between soil particles and their resistance to penetration.

Additionally, prolonging the curing period of terrazyme-treated samples can lead to higher CBR values. This suggests that the soil's strength improves over time due to the reinforcing effects of the soil-stabilizing agent.

The CBR test is essential in determining the thickness of materials required for road construction. By evaluating the CBR value of the subgrade soil, engineers can assess its load-bearing capacity and design appropriate pavement structures to ensure durability and stability. Soils with higher CBR values are typically preferred for road construction as they can withstand greater loads without excessive deformation or failure.

The CBR values can vary depending on the type of soil and its compaction characteristics. Clay-like substances usually have lower CBR values (around 2%), indicating relatively weaker subgrade strength, while some sands can have higher CBR values (up to 10%), indicating better strength and load-bearing capacity.

It's important to note that CBR values are just one factor considered in pavement design, and other factors such as traffic loads, climate conditions, and material properties are also taken into account for a comprehensive assessment.

Fig. 8

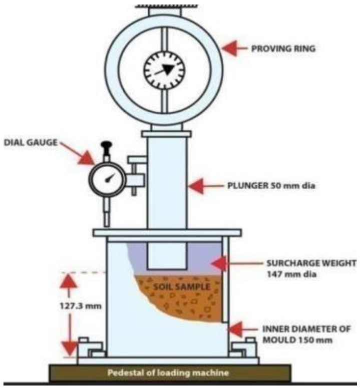


Fig.9

California Bearing Ratio

Apparatus

1. CBR Test Apparatus Consisting of Loading machine with capacity of at least 5000 kg and equipped with a movable head or base which enables Plunger of 50 mm dia. to penetrate into the specimen at a rate of 1.25 mm/ minute.
2. Test sample (Soil specimen)

CBR Testing, also known as California Bearing Ratio testing, is primarily employed to gather data essential for road pavement design. Originally developed by the California State Highway Department, this test determines the subgrade strength of roads, pavements, and foundations. It involves a penetration test that assesses the soil's characteristics. The CBR value indicates the hardness of the surface, with higher values corresponding to harder surfaces. Typically, clay has a California Bearing Ratio (CBR) value of 2%, while certain sands may possess a value of 10%. A high-quality sub-base exhibits a CBR value between 80% and 100% (maximum). The CBR test is performed on soils with a maximum particle size of 20mm. The CBR value serves as a measure to evaluate the stiffness of the natural subgrade soils. When CBR readings are below 2%, it may be necessary to introduce a capping layer or a founding stratum to provide a viable subgrade stiffness for constructing roads and pavements.

Procedure :

1. Sieve the soil sample using a 20mm IS sieve.
2. Take 5 kg of the sieved soil sample and add water to reach the optimum moisture content or field moisture content.
3. Thoroughly mix the soil and water together.
4. Place a spacer disc on the base plate of the mould, and then place a coarse filter paper on top of the spacer disc.
5. Divide the prepared soil-water mixture into five parts.
6. Clean the mould and apply oil to it. Fill one-fifth of the mould with the prepared soil mixture.
7. Compact the soil layer by giving 56 evenly distributed blows with a hammer weighing 4.89 kg.
8. Scratch the top layer of the compacted soil and repeat the process for the second layer.
9. Fill the third layer and attach the collar to the mould. Continue the process.
10. After filling the fifth layer, remove the collar and strike off excess soil from the top.
11. Remove the base plate and invert the mould, then clamp it to the base plate.
12. Place surcharge weights of 2.5 kg on top of the soil surface in the mould.
13. Position the mould with the specimen on the testing machine.
14. Bring the penetration plunger in contact with the soil and apply a seating load of 4 kg to establish contact.
15. Adjust the dial readings to zero.
16. Apply a load at a penetration rate of 1.25 mm per minute.
17. Note the loads at penetrations of 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 7.5, 10, and 12.5 mm.

3.3.3 Unconfined Compressive Strength Test

The unconfined compression test is indeed a widely used method for measuring shear strength in cohesive soils. It is particularly suitable for saturated soils with cohesive properties, such as clayey soils, that are recovered from thin-walled sampling tubes. However, it is not applicable to cohesionless or coarse-grained soils, as their shear behavior is different.

In the unconfined compression test, the soil sample is loaded axially without any confining stress. The test is strain-controlled, meaning that the applied strain rate is constant. This allows for relatively rapid testing and makes it a cost-effective method for measuring shear strength.

During the test, the pore pressures within the soil undergo changes, but they do not have enough time to dissipate due to the rapid loading. This condition represents soils in construction sites where construction activities proceed quickly, and pore waters may not have sufficient time to dissipate.

The unconfined compression test yields the unconfined compressive strength (UCS), which indicates the highest axial compressive stress a cohesive soil sample can withstand without any confining stress. It provides an indication of the soil's shear strength properties.

The advantages of the unconfined compression test include its speed and cost-effectiveness compared to other shear testing methods. It is commonly used for cohesive soils recovered from thin-walled sampling tubes, especially in engineering and construction projects where time and budget constraints are important considerations.

Practical application:

The test is utilized across various geo-technical engineering designs, such as the analysis and evaluation of foundations, retaining walls, slopes, and embankments. Its purpose is to provide an approximate assessment of soil strength and ascertain suitable construction methods.

Apparatus

1. Unconfined Compression apparatus,
2. (Loading frame) Proving ring type
3. Proving Ring of capacity corresponding to soil strength
4. Deformation Dial Gauge

Procedure :

For conducting an unconfined compression test on a soil specimen, the following steps are generally followed:

1. Prepare the specimen: Trim the soil sample to the desired dimensions and remove any visible irregularities. Ensure the specimen is representative of the in-situ soil conditions.
2. Set up the equipment: Position the specimen onto the base plate of the load frame, securely positioned between the end plates. Ensure the specimen is accurately aligned and centered. Attach a dial gauge to measure the vertical displacement or strain.
3. Apply axial load: Start applying a vertical load to the specimen using the load frame. Apply the load at a specified rate, such as 1.25 mm/minute, until failure occurs. Record the applied load and corresponding displacement or strain readings at regular intervals, typically every 5 mm of compression.
4. Please monitor the behavior of the specimen during the loading process and carefully observe any indications of deformation, cracking, or failure. Take note of the specific failure patterns, such as shear planes, crushing, or any other modes of failure that may be observed.
5. Determine the unconfined compressive strength: Calculate the unconfined compressive strength (UCS) of the soil specimen using the maximum load applied during the test and the cross-sectional area of the specimen. The UCS is the maximum stress the specimen can withstand under axial compression without any confining stress.
6. It is important to note that the specific details and equipment used in an unconfined compression test may vary depending on the laboratory and testing standards being followed. The procedure outlined above provides a general overview of the steps involved in conducting an unconfined compression test on a soil specimen to determine its unconfined compressive strength.

Fig.10 Cylindrical soil specimens

Fig.11

Fig.12

Conducting Unconfined Compressive Test on soil specimen

3.3.4 Atterberg limits

3.3.4.1 Liquid limit test

Definition: It is provided an accurate definition and description of the liquid limit (LL) of soil. The liquid limit represents the moisture content at which a soil transitions from a liquid state to a plastic state. It is a crucial property of fine-grained or cohesive soils and is determined through standardized test procedures such as the Casagrande cup method or cone penetrometer.

The liquid limit is significant in soil classification and provides information about the consistency or behavior of the soil at a particular moisture content. It is used to classify fine-grained soils and can also be used to estimate the consolidation properties, settlement, and allowable bearing capacity of the soil in foundation design and analysis.

By knowing the liquid limit, engineers and geotechnical professionals can better understand the soil's behavior, its potential for undergoing deformation, and its response to applied loads. This information is valuable in designing and constructing structures, as it helps ensure the stability and performance of foundations, embankments, and other geotechnical projects.

Apparatus

1. Squeeze Bottle
2. Grooving tool
3. Electric Oven
4. Balance
5. Spatula
6. Mixing dishes
7. Casagrande Liquid Limit device

Fig 13. Casagrande apparatus

Procedure :

The procedure you have described outlines the steps for conducting the liquid limit test using the Casagrande cup method. Here is a summary of the steps:

1. Take 250 grams of air-dried soil that has been sieved through a 425 mm sieve and place it in an evaporating dish.
2. Add distilled water to the soil and mix thoroughly until a consistent paste is formed. The paste should have a texture that requires 30 to 35 drops of the cup to close the standard groove adequately.
3. Transfer a portion of the paste into the cup of the Liquid Limit device and spread it evenly using a spatula.
4. Trim the soil in the cup to a depth of 1 cm at the thickest point, removing any excess soil.
5. Use the grooving tool to create a clean and precise groove along the centerline of the soil pat in the cup. The dimensions of the groove should be 11 mm wide at the top, 2 mm wide at the bottom, and 8 mm deep.
6. Initiate the test by lifting and dropping the cup while turning the crank at a rate of two revolutions per second. Count the number of blows (N) required for the two halves of the soil cake to make contact, flowing for a length of approximately 13 mm.
7. Take a representative portion of soil from the cup for moisture content determination.
8. Repeat the test with different moisture contents, conducting at least four more tests with blows ranging between 10 and 40.

By conducting the liquid limit test at different moisture contents and recording the number of blows, engineers can establish the liquid limit value of the soil. This value provides essential information for soil classification and engineering design purposes, as mentioned previously.

Fig 14. Preparing the soil for liquid limit test

Fig. 15 Liquid limit test

3.3.4.2 PLASTIC LIMIT TEST

Definition: The plastic limit of a soil is defined as the water moisture content at which a thread of soil with a diameter of 3.2 mm begins to crumble. Assessing the plasticity of soils relies heavily on a crucial parameter.

To determine the plastic limit of a soil using Test Method D 2216, the following steps can be followed:

1. Take a representative sample of the soil and air-dry it if necessary.
2. Break up any large clumps and remove any organic matter or debris from the sample.
3. Weigh two moisture cans or containers and record their weights (W1 and W2).
4. Take a portion of the soil sample and add a small amount of water to it.
5. Knead and roll the soil and water mixture to obtain a uniform consistency.
6. Take a small portion of the mixture and roll it into a thread with a diameter of 3.2 mm.
7. If the thread crumbles before reaching a length of 1.25 inches (32 mm), add a small amount of water to the mixture and repeat the process. If the thread does not crumble at 1.25 inches, remove a small amount of water and repeat the process.
8. Repeat steps 6 and 7 until consistent results are obtained.
9. Record the moisture content of the soil for each trial.
10. Calculate the average moisture content of the two trials that resulted in the thread crumbling at 1.25 inches.
11. Round the average moisture content to the closest whole number. This value represents the plastic limit (PL) of the soil.

The plasticity index (PI) of the soil can be calculated by subtracting the plastic limit (PL) from the liquid limit (LL) using the formula: PI = LL - PL. The plasticity index provides an indication of the soil's plastic range, which is the range of moisture content within which the soil displays plastic qualities.

Please note that the specific test method and procedures may vary depending on the standard or laboratory requirements. It is important to refer to the appropriate testing standards and follow the prescribed procedures for accurate and reliable results.

Apparatus

1. Porcelain dish
2. Squeeze Bottle and Spatula

3. Balance of capacity 200gm and sensitive to 0.01gm
4. Ground glass plate for rolling the specimen
5. Containers to determine the moisture content
6. Oven thermostatically controlled with interior of non-corroding material to maintain the temperature

Procedure

To determine the plastic limit of a soil using the procedure described in IS:2720 (Part 2)-1973, the following steps can be followed:

1. Take approximately 20 g of the soil sample that has passed through a 425-micron sieve.
2. Thoroughly mix the soil sample with distilled water in an evaporating dish until it reaches a plastic consistency that can be easily molded with fingers.
3. Allow the soil mass to season for a sufficient time period, typically 24 hours, to allow water to permeate throughout the soil.
4. Take approximately 8 grams of the plastic soil sample and gently roll it between your fingers and a glass plate. Apply moderate pressure to create a thread that has a consistent diameter along its length. Maintain a rolling rate of 80 to 90 strokes per minute.
5. Continue rolling the soil until the diameter of the thread reaches 3 mm.
6. Gather the rolled soil and knead it together to form a uniform mass. Then, roll it again using the same technique as before.
7. Repeat the rolling process until the thread breaks when it reaches a diameter of 3 mm.
8. Gather the broken pieces of the thread and handle them with care. Transfer them into an airtight container for determining the moisture content, following the procedure described in IS:2720 (Part 2)-1973.
9. Conduct the entire test a minimum of three times and calculate the average of the results, rounding it to the nearest whole number. This calculated average value represents the plastic limit (PL) of the soil.It is important to note that the specific testing procedure and standards may vary depending on the country and the version of the standard being followed. Therefore, it is crucial to refer to the appropriate testing standard, in this case, IS:2720

(Part 2)-1973, and follow the prescribed procedures to ensure accurate and reliable results.

Fig.16 Making threads with soil specimen

Fig.17 Plastic limit test

3.4 MIX PROPOTIONS

Dosages of the Bio enzyme:

The recommended dosage range for bio-enzyme is between 150 ml/m3 and 300 ml/m3.

- Bulk density of black cotton soil is 1.56g /cc.
- Weight of soil for every m3 of soil is
  = 1.56×1×1000 = 1560kg of soil
- For every meter cube of soil the black cotton soil content is 1560kg.

Fig. 18 Stabilization of soil

For dosage 1

- 150ml for 1m3 of soil
- For 1kg of soil = 0.096ml of enzyme

For dosage 2

- 200ml for 1m3 of soil
- For 1kg of soil = 0.128ml of enzyme

For dosage 3

- 250ml for 1m3 of soil
- For 1kg of soil = 0.16ml of enzyme

For dosage 4

- 300ml for 1m3 of soil
- For 1kg of soil = 0.19ml of enzyme

Dosage of bio-enzyme(terrazyme):

Dosage	For every m3 of soil in ml	For every kg of soil in ml
1.	150	0.096
2.	200	0.128
3.	250	0.16
4.	300	0.19

Table 2. Dosage of bio-enzyme

Fig.19 Soil Stabilization

CHAPTER 4

RESULTS AND DISCUSSION

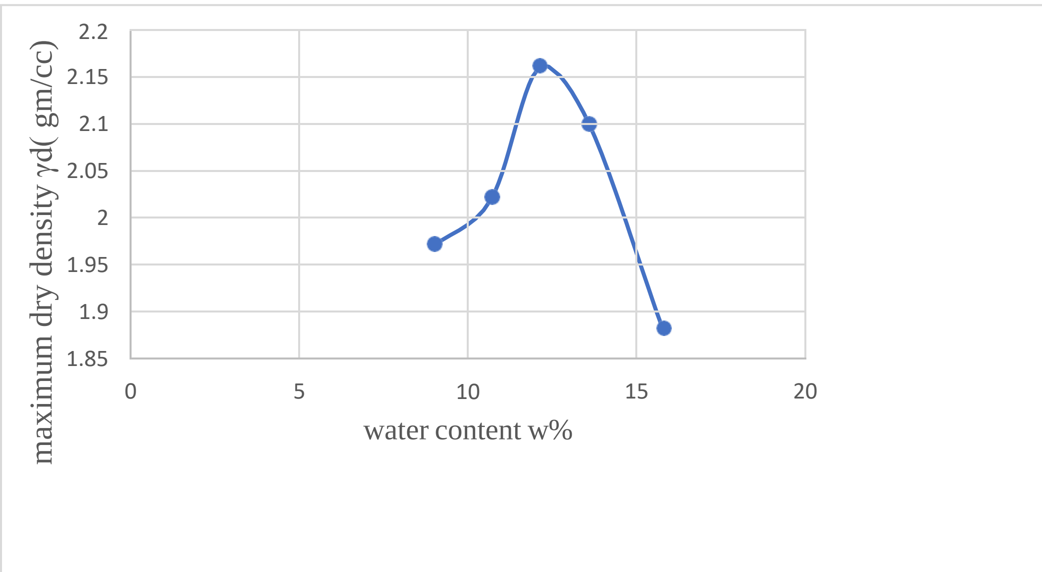
4.1 Compaction test of the given black cotton soil

The compaction test was conducted on the black cotton soil, and the resulting values are presented in the table below. Through this test, we determined the optimum moisture content (OMC) and maximum dry density (MDD) of the soil. The calculated values for the black cotton soil are as follows:

- Optimum Moisture Content (OMC):
- Maximum Dry Density (MDD):

Trial no.	Water content (W%)	Dry density (γd)
1.	9	1.97
2.	10.7	2.02
3.	12.12	2.16
4.	13.6	2.1
5.	15.8	1.88

Table 3. Compaction test



Graph 1. MDD and OMC values of the given soil

Based on the conducted compaction test, the following results were obtained for the provided black cotton soil. Here is the rewritten information:

- Maximum dry density (MDD): 2.16 gm/cc (γd)
- Optimum moisture content (OMC): 12.12% (W%)

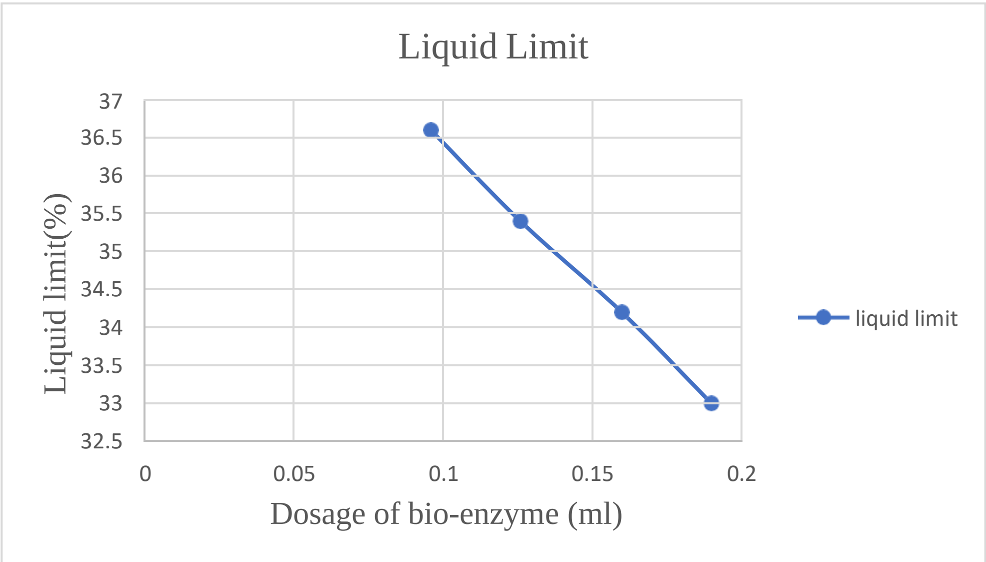
These values indicate the maximum density that can be achieved and the corresponding moisture content required to achieve optimal compaction for the black cotton soil under investigation.

4.2 Liquid limit test result of the given black cotton soil

The following table displays the liquid limit values corresponding to different dosages of bio-enzyme. A noticeable trend is observed: the treated liquid limit values decrease as the dosage of bio-enzyme increases.

S.No	**Dosage of enzyme**	**Liquid limit**
1.	0.096	36.6%
2.	0.126	35.4%
3.	0.16	34.2%
4.	0.19	33.2%

Table 4. Liquid limit



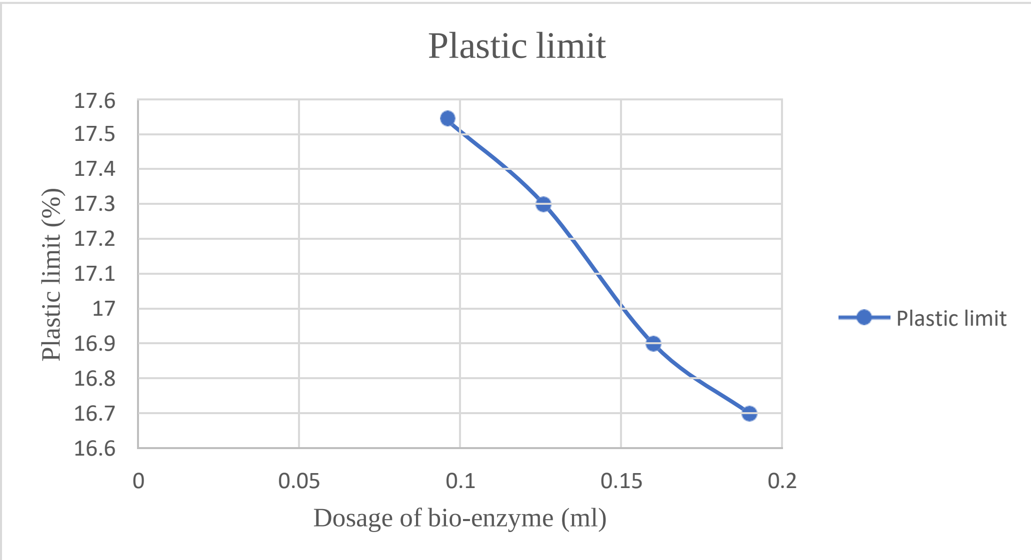
Graph 2. The Stabilizing effect of terrazyme on liquid limit

4.3 Plastic limit test results of the given black cotton soil

The table displays the plastic limit values for varying doses of bio-enzyme. The data reveals a consistent trend of decreasing plastic limit values with increasing bio-enzyme dosage.

S. No.	Dosage of enzyme	Plastic limit
1.	0.096	17.54
2.	0.126	17.32
3.	0.16	16.9
4.	0.19	16.7

Table 5. Plastic limit



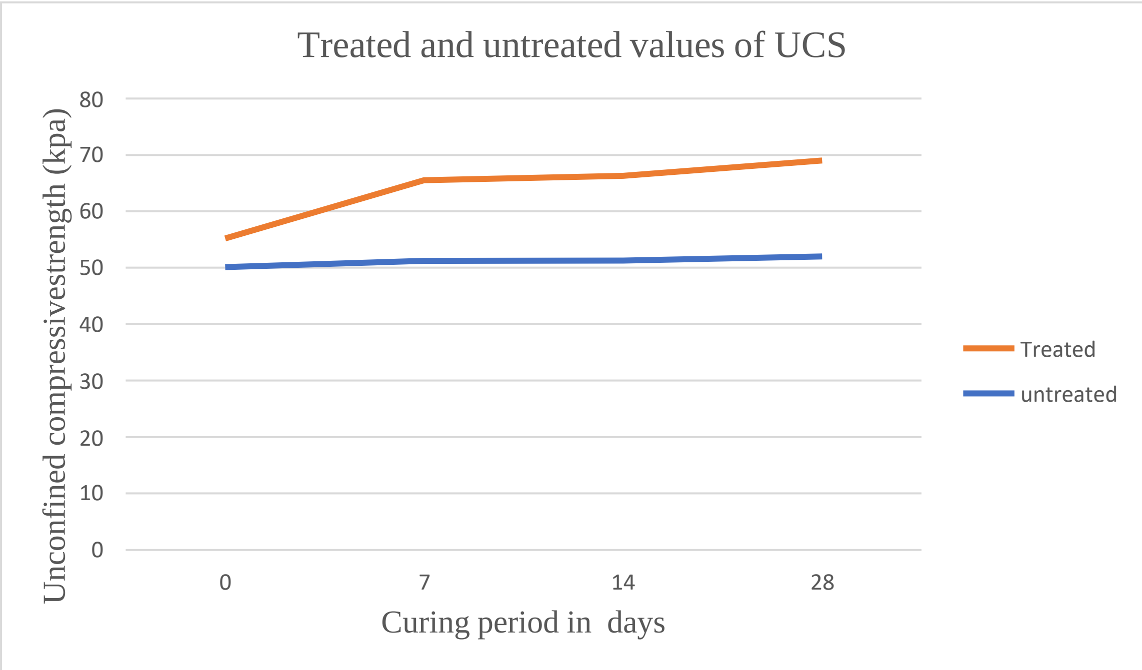
Graph 3. The Stabilizing effect of terrazyme on plastic limit

4.4 The unconfined compressive strength test results of a given black cotton soil

Below is a table presenting the values of unconfined compressive strength for different curing periods (7 days, 14 days, and 28 days) of soil treated with Terrazyme. It was discovered that the soil's unconfined compressive strength increased as the curing period was extended.

Curing period (days)	0	7	14	28
Unconfined compressive strength (kN\m2) a) Untreated b) Treated	50.1 65.2	51.2 75.28	51.3 82.4	52 97.3

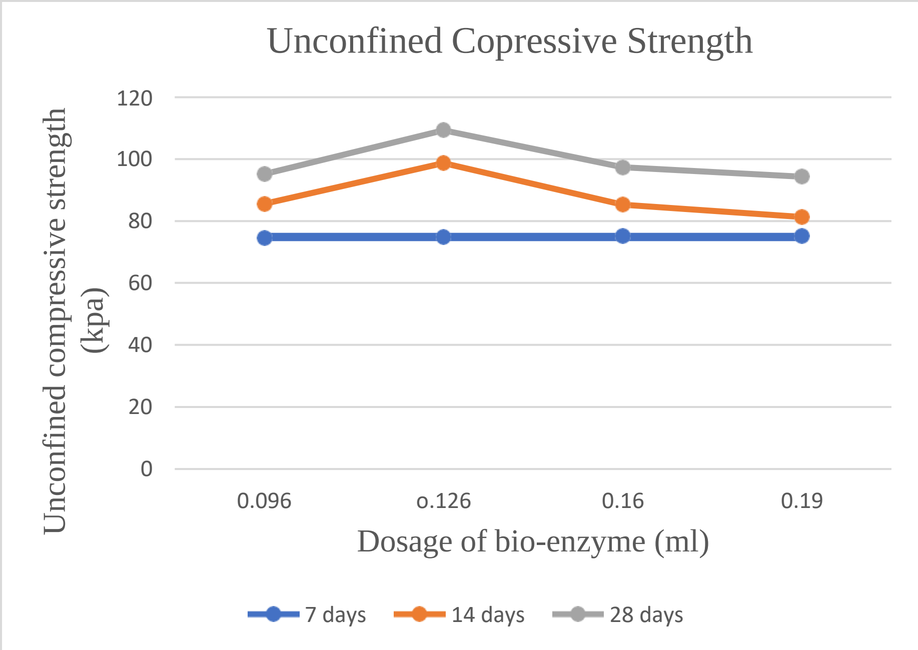
Table 6. Treated and untreated values of UCS



Graph 4. Treated and Untreated values of UCS

Dosage of bio-enzyme	**Strength after 7 days**	**Strerngth agter 14 days**	**Strength after 28 days**
0.096	74.53	80.2	90.7
0.126	74.8	81.3	92.4
0.16	75.28	82.4	97.3
0.19	75.18	81.7	92.1

Table 7. Unconfined compressive strength



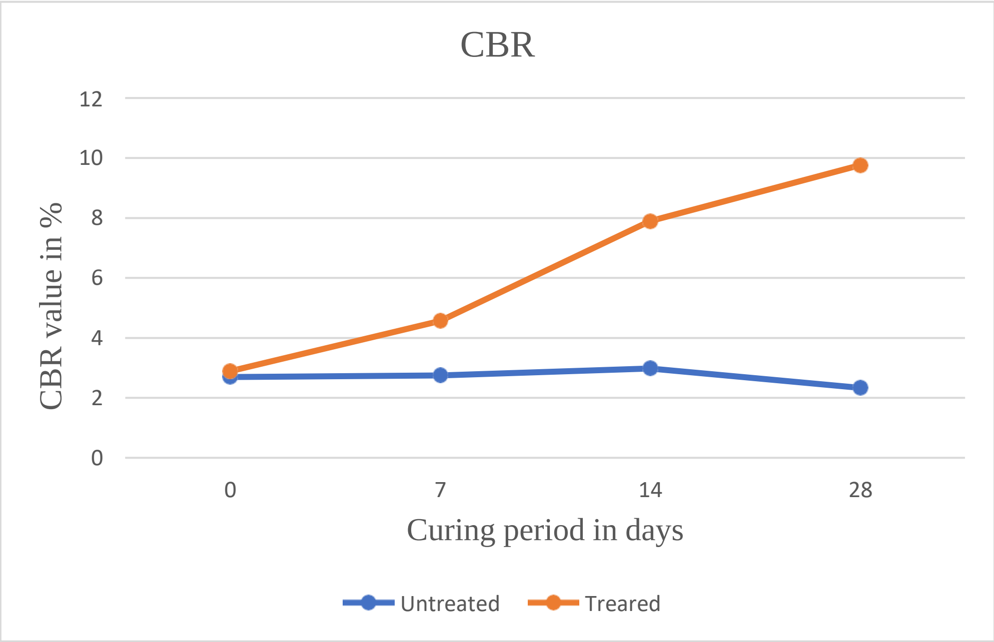
Graph 5. Stabilizing effect of terrazyme

4.5 CBR test results of the given black cotton soil

The CBR (California Bearing Ratio) test is employed to assess the structural integrity of the base course and subgrade beneath a road. During this test, soil samples are treated with enzymes at the appropriate dosage and evaluated at various curing durations (0, 7, 14, and 28 days). The outcomes of the test are documented in the following table, and a comparison is made with untreated soil samples.

Curing period (days)	0	7	14	28
CBR value in % a) Untreated b) treated	 2.7 2.89	 2.75 4.56	 2.98 7.89	 2.34 9.76

Table 8. California Bearing Ratio



Graph 6. Treated and untreated values of CBR

CHAPTER 5

CONCLUSIONS

This study focused on examining the properties of OMC (Optimum Moisture Content), MDD (Maximum Dry Density), CBR (California Bearing Ratio), UCS (Unconfined Compressive Strength), and Consolidation in relation to bio-enzyme stabilized soil. The objective was to evaluate the effectiveness of this stabilized soil in contrast to conventional soil. The conclusions drawn from the comprehensive analysis of all samples and experimental investigations are as follows:

1. The laboratory experiments have comprehensively assessed the effectiveness of soil stabilized with bio-enzymes.
2. Comparisons made between the stabilized soil and normal soil reveal significant findings.
   - The quantity of soil content has a notable impact on the fluctuation of consistency limits. As the dosage of bio-enzyme per kilogram of soil rises, there is a gradual reduction in the liquid limit, decreasing from 36.6% to 33%. Similarly, the plastic limit decreases from 17.54% to 16.7%.
   - The maximum dry density (MDD) and optimum moisture content (OMC) values are determined for the black cotton soil. The OMC value for this soil type is found to be 12.12%, while the MDD value is 2.16 gm/cc. Furthermore, it is observed that the values of MDD decrease gradually as the dosage of bio-enzyme increases.
   - The Unconfined Compressive Strength (UCS) value of the soil increases as the dosage of bio-enzyme increases, after 7, 14, and 28 days of curing. This can be attributed to the reaction between the enzyme and the soil, resulting in a cementation effect. The stabilization of the soil using Terrazyme leads to a significant increase in UCS.
   - Soil stabilization using bio-enzymes enhances various properties of the soil, such as permeability, shear strength, compressibility, and density. Additionally, the treated soil exhibits increased values of California Bearing Ratio (CBR) with an increase in the curing period. The enhanced outcomes are a result of decreased void ratios and improved density values obtained

through the application of enzyme treatment. The utilization of bio-enzymes for soil stabilization presents a straightforward, affordable, environmentally friendly, and efficient approach.

- Bio-enzymes are readily available in the market at affordable prices. They are easy to handle and do not pose any harm or release harmful gases.

APPENDIX

S.No.	IS code	Tests
1.	IS:2720 (PART-7) 1983	STANDARD PROCTOR TEST
2.	IS:2720 (PART-16) 1987	CBR TEST
3.	IS:2720 (PART-10) 1991	UCS TEST
4.	IS:2720 (PART-5) 1985	ATTERBERG LIMITS TEST

- In this study the tests called standard proctor test (compaction test), California bearing ratio (CBR) test, Unconfined Compression Strength (UCS) Test, Atterberg limits test are conducted as per the code IS:2720.

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