VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"Jnana Sangama", Belgaum-590 014

**A Dissertation Project Report on**

# "HYDRAULIC CONDUCTIVITY OF ENZYME MODIFIED BLACK COTTON SOIL"

**Submitted in partial fulfillment for the award of the degree of**

**BACHELOR OF ENGINEERING IN**

**CIVIL ENGINEERING**

BY



| | |
|---|---|
| **HARSH PRATIK** | **1CR16CV021** |
| **HITESH KUMAR V** | **1CR16CV023** |
| **MATHADA VAMSHIDHAR** | **1CR16CV035** |
| **POORNIMA G HIREMATH** | **1CR16CV042** |

*Under the guidance of*

**Mrs. DIVYA VISWANATH**

**Assistant Professor**

**DEPARTMENT OF CIVIL ENGINEERING**

**CMR INSTITUTE OF TECHNOLOGY**

**ITPL MAIN ROAD BENGALURU-560 037**


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# C.M.R. INSTITUTE OF TECHNOLOGY

(#32, AECS Layout, IT Park Road, Bengaluru-560 037)

## Department of Civil Engineering

## Certificate

*This is to certify the the project work entitled* ***"HYDRAULIC CONDUCTIVITY OF ENZYME MODIFIED BLACK COTTON SOIL"*** *has been successfully completed by Mr. HARSH PRATIK (USN 1CR16CV021), Mr. HITESH KUMAR V (USN 1CR16CV023), Mr. MATHADA VAMSHIDHAR (USN 1CR16CV035), Ms. POORNIMA G HIREMATH (USN 1CR16CV042), bonafide students of CMR Institute of technology in partial fulfillment of the requirement for the award of degree of Bachelor of Engineering in Civil Engineering of the* ***"VISVESVARYA TECHNOLOGICAL UNIVERSITY",*** *Belgaum during the academic year 2019-20. It is certified that all corrections indicated for internal assessment has been incorporated in the Report. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said Degree.*

| Mrs. Divya Viswanath | Dr. Asha M Nair | Dr. Sanjay Jain |
|---|---|---|
| (Assistant Professor) | HOD | Principal |
| | Department of Civil Engineering | CMR Institute of Technology |
| | CMR Institute of Technology | |

| Name of the Examiners | External Viva | Signature with date |
|---|---|---|
| 1. | | |
| 2. | | |

C.M.R. INSTITUTE OF TECHNOLOGY

(#32, AECS Layout, IT Park Road, Bengaluru-560 037)

Department of Civil Engineering

# DECLARATION

We, **Mr. HARSH PRATIK, Mr. HITESH KUMAR V, Mr. MATHADA VAMSHIDHAR Ms. POORNIMA G HIREMATH**, bonafide students of CMR Institute of Technology, Bangalore, hereby declare that dissertation entitled **"HYDRAULIC CONDUCTIVITY OF ENZYME MODIFIED BLACK COTTON SOIL"** has been carried out by us under the guidance of **Mrs. DIVYA VISWANATH (Assistant Professor)**, Department of Civil Engineering, CMR Institute of Technology, Bangalore, in partial fulfillment of the requirement for the award of degree of Bachelor of Engineering in **Civil Engineering** of the Visvesvaraya Technological University, Belgaum during the academic year 2019-2020. The work done in this dissertation report is original and it has not been submitted for any other degree in any university.

**HARSH PRATIK**

(1CR16CV021)

**HITESH KUMAR V**

(1CR16CV023)

**MATHADA VAMSHIDHAR**

(1CR16CV035)

**POORNIMA G HIREMATH**

(1CR16CV042)

# ABSTRACT

Expansive soils (eg: Black cotton soil) are a worldwide problem that poses several challenges for civil engineers. They are considered a potential natural hazard, which can cause extensive damage to structures if not adequately treated. Such soils swell when given an access to water and shrink when they dry out. A large part of Central India and a portion of South India are covered with black cotton soils. These soils have high swelling and shrinkage characteristics and shear strength is extremely low; hence, there is need for improvement of these properties. As the conventional soil stabilizers like gravel, sand, etc. are depleting and becoming expensive day by day at a very rapid pace, it becomes necessary to look towards for alternative stabilizers as their substitute. The current work undertaken focuses on improving/altering the compressibility and hydraulic conductivity of Black cotton soil through enzymatic treatment. It is proposed to conduct tests for varying dosages and curing periods in order to understand the long term effects of bio-stabilization on treated soil. The practical applications of expansive soil or the contaminated soil with improved engineering properties includes increased stiffness of soil which can reduce settlement and lateral deformations, enhancement of slope stability, enhancement of bearing capacity of foundation and to facilitate tunneling, canal lining, embankment construction etc.

*Keywords* – Black cotton soil, enzymatic treatment.

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**HARSH PRATIK**

**HITESH KUMAR V**

**MATHADA VAMSHIDHAR**

**POORNIMA G HIREMATH**

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# CHAPTER 1

# INTRODUCTION

A large part of central India and a portion of South India are covered with Black Cotton soils and the distribution of soil is shown in figure below **Fig 1.1**. These soils are residual deposits formed from basalt or trap rocks. Many areas of India consist of soils with high silt contents, low strengths and minimal bearing capacity.

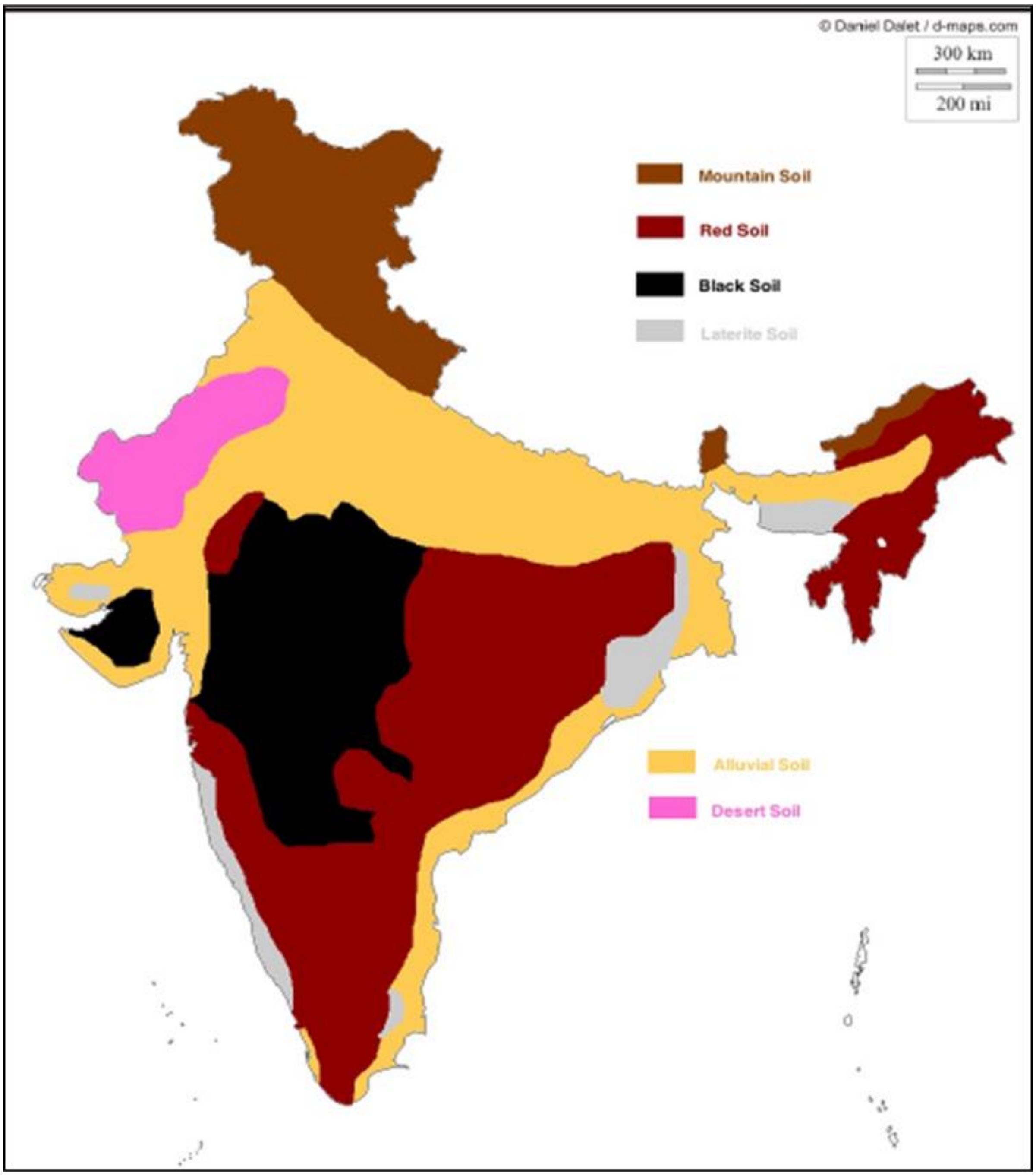


**Fig 1.1:- Distribution of soil in India**

The growth of the population has created a need for better and economical vehicular operation which requires good highways having proper geometric design, pavement condition and maintenance. The growing metropolitan cities needs more and number of good lands for both construction activities and road development. This is the major limitation for the construction industry since most of the good lands have already been built upon.

The Indian road network is over 4,689,842 kilometres long, as per 2013 statistics of which less than 50% are paved. Qualitatively India's roads are a mix of modern highways and narrow, unpaved roads, and are in need of drastic improvements. This is because even the most modern and best designed projects are subjected to the stresses and strains of an ever-increasing traffic flow and require regular maintenance. A pavement's wearing course is most prominent. It may be possible to replace the poor subgrade soil with suitable fill. But it is improbable to rely on such measures due to the declining availability of high-quality soil.

The soil is the only material which supports the structural foundation of buildings, dams and roads. "Expansive soils" are those which experience great changes in volume when their water content varies. These types of soil are widely distributed throughout the world, although they are especially abundant in arid zones, where conditions are suitable for the formation of clayey minerals of the smectite group such as montmorillonite or some types of illites. These clays are characterized by having a very small particle size, a large specific surface area and a high cation exchange capacity (CEC)

The swelling of these types of clay is related to three types of factors: geology, the engineering factors of the soil, and local environmental conditions. Geology primarily determines the presence in the soil of these types of expansive clay minerals. Among the engineering factors included are the soil moisture content, plasticity and dry density

They contain essentially the clay mineral montmorillonite, which is the most unstable clay mineral, thus the soils have high shrinkage and swelling characteristics. The shearing strength of the soil is extremely low, is highly compressible and has very low bearing capacity. It is very difficult to work with this soil, as do not possess sufficient strength to support the loads imposed upon them either during construction or during the service life of the structure. For better performance of structures built on such soils, the performance characteristics of such soils need to be improved. The poor engineering performance of such soils has forced Engineers to attempt to improve the engineering properties of poor-quality soils. There are various methods that could be used to improve the performance of poor-quality soils.

## 1.1:- STABILIZATION OF BLACK COTTON SOIL

Black cotton soil poses serious construction problems both to structures and highways whereas red earth is good for construction activities. Expansive soils show swell-shrink behaviour with the variation in moisture content whereas variation in moisture has little effect on the properties of Red earth soil.

Soil stabilization is a very useful technique for major civil engineering works. To utilize the full advantage of the technique, quality control must be adequate. Soil stabilization is the alteration of one or more soil properties by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Soils may be stabilized to prevent erosion and dust generation. Regardless of the purpose for stabilization, the desired result is the creation of a soil material or soil system that will remain in place under the desired conditions for the design life of the project. Engineers are responsible for the selecting or specifying the correct stabilizing method, technique, and quantity of material required. The compaction is the most basic form of mechanical stabilization, which increases the performance of a natural material.

The stabilization of expansive soils by the use of additives such as lime, fly ash or cement has traditionally concentrated on the elimination of the expansive power of the soil. In this type of soil, additive with calcium oxide produce the flocculation of the layers of clay by the substitution of the monovalent ions by the calcium ions. This balances the electrostatic charges of the layers of clay and reduces the electrochemical forces of repulsion between them. The adhesion of the particles of clay into flocs then occurs giving rise to a soil with improved engineering properties: a more granular structure, lower plasticity, greater permeability and above all lower expansivity.

Selecting the stabilizer type depends on number of factors including gradation, plasticity index, availability and cost of the stabilizer and appropriate construction equipment and its long term effect on strength etc. A balance between performance, economy and environmental harmony keeping in mind the limited natural and artificial resources is vital in maximizing efficiency of performance of structures.

Cementing compounds such as calcium silicate hydrates and calcium aluminate hydrates are responsible for improving the mechanical properties of the soil, as well as helping to reduce its expansivity by their cementing action. There are various methodologies for soil stabilization like mechanical, chemical methods. There is continuous research for cost effective alternate materials and novel eco-friendly techniques to process the local materials. Some of these new stabilizing techniques create hydrophobic surfaces and mass that prevent water penetration or heavy frosts by inhibiting the ingress of water into the treated layer.

## 1.2:- MECHANISM OF BIO-ENZYME

Recently Bio-Enzymes have emerged as a new chemical for stabilization. Bio-Enzymes are chemicals, organic and liquid concentrated substances which are used to improve the stability of soil of soil sub base of pavement structures. Bio-enzyme is convenient to use, safe, effective and dramatically improves road quality. The objective of any stabilization technique used are to increase the strength and stiffness of soil, improve workability and constructability of the soil and reduce the plasticity index.

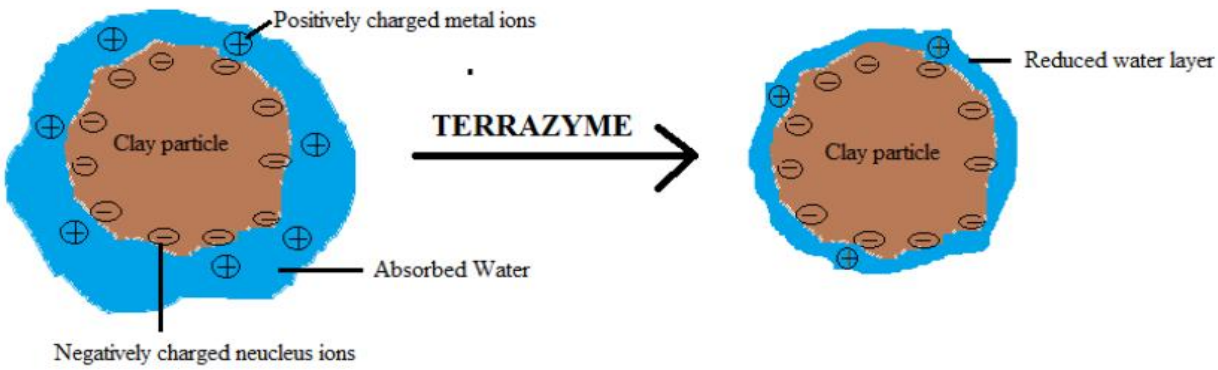


**Fig 1.2:- Mechanism of bio-enzyme on clay particle**

An enzyme is by definition an organic catalyst that speeds up a chemical reaction, that otherwise would happen at much slower rate, without becoming a part of the end product. Since the enzymes do not becomes the part of end product and are not consumed by the reaction, a very small amount of bio enzyme is required for soil stabilization. They are organic molecules that catalyse very specific chemical reactions if conditions are conducive to the reaction they facilitate. For an enzyme to be active in a soil, it must have mobility to reach at the reaction site. The pore fluid available in the soil mass provides means for mobility of the molecules of bio enzyme, the specific soil chemistry provides the reaction site, and time is needed for the enzyme to diffuse to the reaction site. An enzyme would stay active in a soil until there are no more reactions to catalyse.

Terrazyme is a natural, non-toxic, non-corrosive and non-inflammable liquid, produced by formulating vegetable extracts. Organic enzymes come in liquid form. They are perfectly soluble in water, brown in colour with smell of molasses. Their aroma has no effect. Neither gloves nor masks are required during handling. Terrazyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application.

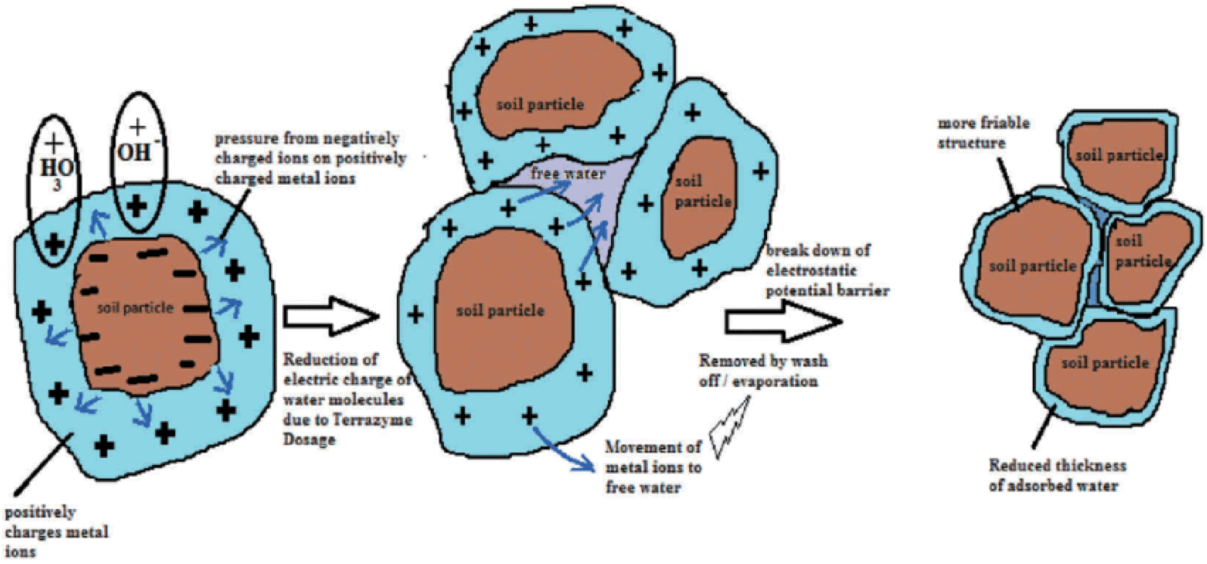


**Fig 1.3:- Detailed enzymatic reaction on soil particles**

Terrazyme when added to water and mixed with soil alters the engineering properties depending upon the type of the soil and dosage of enzyme. These enzymes are liquid additives, which act on the soil to reduce the voids between soil particles and minimize absorbed water in the soil for maximum compaction as shown in **Fig 1.2 and Fig 1.3**. The enzymes react with the organic matter (humid matter) in the soil to form cementitious material. This decreases the swelling capacity of the soil particles and reduces permeability. The application of Terrazyme enhances weather resistance and increases load bearing capacity of soils. These features are particularly evident in fine-grained soils such as clay in which the formulation affects the swelling and shrinking behaviour. The reaction is at micron level and the presence of finely divided humid matter and clay-sized particles is essential. Presence of clay is essential as the bonds formed bind this size of particles. The formulation has the ability to change the matrix of the soil so that after compaction the soil loses its ability to reabsorb water and the mechanical benefits of compaction are not lost even after water is reapplied to the compacted soil. Once the enzyme reacts with the soil, the change is permanent and the product is bio-degradable.

In clay water mixture positively charged ions (cat-ions) are present around the clay particles, creating a film of water around the clay particles that remains attached or adsorbed on the clay surface. The adsorbed water or double layer gives clay particles their plasticity. In some cases, the clay can swell and the size of double layer increases, but it can be reduced by drying.

Therefore, to truly improve the soil properties, it is necessary to permanently reduce the thickness of double layer. Cat-ion exchange processes can accomplish this. By utilizing fermentation processes specific microorganisms can produce stabilizing enzyme in large quantity. The soil stabilizing enzymes catalyse the reactions between the clay and the organic cat-ions that accelerate the cat-ionic exchange without becoming part of the end product. Bio-Enzyme (Terrazyme) replaces adsorbed water with organic cat-ions, thus neutralizing the negative charge on a clay particle.

Terrazyme has been used to improve engineering properties of low-medium liquid limit clays, and they have been widely reported. The present study aims to report the variations in the index properties and engineering properties of high liquid limit soft clays when bio-enzymatic compound - Terrazyme, is added to the soft clay. The methodology involves laboratory experiments to determine the optimum additive contents for stabilizing the clayey subgrades to obtain strength variations.

# CHAPTER 2

# LITERATURE SURVEY

**Manu A S, S P Mahendra, "STRENGTH PROPERTIES OF BIOENZYME TREATED BLACK COTTON SOIL", the Electronic Journal of Geotechnical Engineering, 2018.**

In this study, an effort was made to study the effects of varying dosages of Terrazyme viz. 200ml/0.5m$^3$, 200ml/1m$^3$, 200ml/1.5m$^3$, 200ml/2m$^3$ on strength properties of Black Cotton Soil (BCS) for different curing periods of 0$^{th}$ and 7$^{th}$ days. Tests were carried out to determine the Atterberg's limits, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) of the soil specimens. Treating black cotton soil with optimum dosage of Terrazyme (200ml/1m$^3$) resulted in increase of un soaked CBR value for desiccator curing.

**Patel, U., Singh, S. and Chaudhari, S. "IMPROVEMENT OF STRENGTH CHARACTERISTICS OF BIO-ENZYME-TERRAZYME TREATED EXPANSIVE SOIL BY GYPSUM AS AN ADDITIVE", International Journal of Advance Research and Innovative Ideas in Education, 2018.**

An expansive soil is taken and treated it with 3 different dosages of gypsum and terrazyme with 2 different curing periods and it was found that there was an improvement in the CBR values. Compaction test result shows that liquid chemical because a modest increase in maximum compacted density and a slide decrease in optimum moisture. Terrazyme speed up the chemical reaction that would happen at slower rate, without becoming a part of end product. Main reason for improvement in terrazyme treated soil is that the film of absorbed water is greatly reduced, which ultimately governs the expansion and shrinkage of colloidal soil constituents. In gypsum treated soil due to cementing action with soil it induces a stronger bond between clay particles.

**Sanjeet Sahoo, G. Sridevi, "SOIL STABILIZATION USING BIO-ENZYME", International Journal of Pure and Applied Mathematics, 2018.**

The Unconfined Compressive Strength and CBR tests were done on finely-grained natural soil material for two different dosages viz. 0.05 and 0.1 ml/kg for 0$^{th}$ and 7$^{th}$ day of curing. The soaked CBR increased by 3 times when compared with the untreated soil. It was concluded that Terrazyme is a satisfactory stabilizing agent for clayey soils.

**Hiraman A. Shirsath, Joshi S.R., Dr. Vijaykumar Sharma, "EFFECT OF BIO-ENZYME (TERRAZYME) ON THE PROPERTIES OF SUB GRADE SOIL OF ROAD", International Research Journal of Engineering and Technology (IRJET), 2017.**

In this study 2 different Black Cotton soil and 1 red soil were treated with varying dosages of Terrazyme and the effect of Terrazyme dosage on plasticity characteristics, CBR and unconfined compressive strength of soils were evaluated. The various dosages of Terrazyme were 100ml/1.5m$^3$, 200ml/1.5m$^3$, 300ml/1.5m$^3$. The samples were cured for 0$^{th}$, 7$^{th}$, 14$^{th}$, 21$^{st}$ and 28$^{th}$ days. It was concluded that the Unconfined Compressive Strength of all three soil shows increasing characteristics with increase in curing time. Compaction characteristics are not affected immediately after treatment with TerraZyme. Enzyme is found to be ineffective for improving consistency limits.

**Sandeep Panchal, Md. Mohsin Khan, Anurag Sharma, "STABILIZATION OF SOIL USING BIO-ENZYME", International Journal of Civil Engineering and Technology (IJCIET), 2017.**

In this study various geotechnical tests were performed on local soil for 4 dosages viz. 500, 700, 900, 1000 ml/m$^3$ for 7$^{th}$, 14$^{th}$ and 28$^{th}$ days of curing. Best result of CBR value were observed with the third dosage with two week curing period and percentage increment as compared to local soil sample without Terrazyme is 131.49 %.

**Priyanka M Shaka, Surekha M Shaka, "LABORATORY INVESTIGATION ON BLACK COTTON SOILS AND RED SOIL STABILIZED USING ENZYME", International Research Journal of Engineering and Technology (IRJET), 2016.**

The CBR characteristics and Free Swell Index Test of Black Cotton soils were studied for Terrazyme dosages of 200ml/0.5 m$^3$, 200ml/0.75 m$^3$, 200ml/1m$^3$ for curing periods of 7$^{th}$, 14$^{th}$, and 21$^{st}$ days. The best result for soaked CBR value was observed with dosage 200ml per 0.75 m$^3$. The Free Swell index values decreased with increasing curing periods.

**Jadhav, G., Panchal, M.G. and Mane, M.R. "A STUDY ON EXPERIMENTAL INVESTIGATION OF BIO-ENZYME STABILIZED EXPANSIVE SOIL", 5th International conference on recent trends in Engineering, Science & Management, 2016**

Four dosages of terrazyme was applied on black cotton soil and the basic geotechnical properties were found out and also UCC values were found out. The attempts made by several resources to understand the behaviour of enzymes as reinforcing material in soil, in this, various studies are carried out on behaviour of liquid stabilizer in UCC and CBR test. Researches have experimented on various parameters such as variation in binder content reinforcement content and aspect ratio of reinforcement content past experience in knowledge of material behaviour on different types of soils.

**Joydeep Sen, Jitendra Prasad Singh, "STABILIZATION OF BLACK COTTON SOIL USING BIO-ENZYME FOR A HIGHWAY MATERIAL", International Journal of Innovative Research in Science, Engineering and Technology, 2015.**

In this study Black cotton soil have been tested for stabilization process after curing period of $0^{th}$, $14^{th}$, $21^{th}$ and $28^{th}$ days for Terrazyme dosages 200ml/3m3, 200ml/2.5$m^3$, 200ml/2$m^3$, 200ml/1.5$m^3$. The tests which were carried out were CBR tests and Unconfined Compressive strength test. It was observed that the treated soaked CBR values increased as the curing periods increased.

**H.N. Ramesh, Sagar S.R., "EFFECT OF DRYING ON THE STRENGTH PROPERTIES OF TERRAZYME TREATED EXPANSIVE AND NON-EXPANSIVE SOILS", $50^{th}$ Indian Geotechnical Conference, 2015.**

In the present study, an attempt has been made to study the effect of drying on the strength and other properties of expansive and non-expansive soils stabilized by TerraZyme. The tests were conducted on Black Cotton soil and Red Earth soil at a dosage of 200 ml/$m^3$ at curing periods of $0^{th}$, $7^{th}$ and $30^{th}$ days. Unconfined Compressive Strength of both black cotton soil and red earth has shown tremendous increment with drying than curing in a laboratory desiccator after treating it with Terrazyme.

**Eujine, G.N., Somervell, L.T., Chandrkaran, S. and Sankar, N. "ENZYME STABILIZATION OF HIGH LIQUID LIMIT CLAY", The Electronic Journal of Geotechnical Engineering, 2014.**

A soil sample (22.5% clay content) and Terrazyme at three different concentrations, at four different curing periods were tested for Atterberg's limits and UCS values. It was found that the treated soil showed up to 12 times better UCS values than untreated. Application of enzyme to black cotton soil showed significant changes in test characteristics. On curing it was observed that liquid limit increased by 28% in the first 2 weeks later decreased. Enzyme had little effect on plastic limit of the soil however it is decreased by shrinkage limit by 30%.

**Puneet Agarwal, Suneet Kaur, "EFFECT OF BIO-ENZYME STABILIZATION ON UNCONFINED COMPRESSIVE STRENGTH OF EXPANSIVE SOIL", IJRET: International Journal of Research in Engineering and Technology, 2014.**

The Unconfined Compressive Strength of Black Cotton Soil using 7 different dosages of Terrazyme viz. 0.25, 0.5, 0.75, 1.0, 2.0, 3.0, 4.0 ml of enzyme /5kg of soils for 1$^{st}$ and 7$^{th}$ day of curing were studied. It was concluded that the stabilization of the soil using Terrazyme resulted in significant increase in the Unconfined Compressive Strength of the Black Cotton Soil up to 200%.

**Vijay Rajoria, Suneet Kaur, "A REVIEW ON STABILIZATION OF SOIL USING BIO-ENZYME", IJRET: International Journal of Research in Engineering and Technology, 2014.**

In this study it was concluded that Use of bio-enzymes results in higher compressive strength and increased hardness of stabilized soil, Bio-enzymes reduce swelling and shrinkage properties of highly expansive clays, Bio-enzymes provide flexibility and durability to the pavement and also reduce the formation of crack.

**Greeshma Nizy Eujine, Lamanto T. Somervell, Dr. S. Chandrakaran, Dr. N. Sankar, "ENZYME STABILIZATION OF HIGH LIQUID LIMIT CLAY", The Electronic Journal of Geotechnical Engineering, 2014.**

Unconfined Compression Strength tests were conducted on montmorillonite clay bio-enzyme (Terrazyme) treated sample for curing period of 0$^{th}$, 7$^{th}$, 14$^{th}$, 28$^{th}$ days. The dosages of bio-enzyme used were 100, 200, 300 ml/m$^3$ of soil. At 200ml/m$^3$ it was observed that the Unconfined Compression Strength of soil was enhanced up to 12 times the untreated strength.

**Venkatasubramanian.C & Dhinakaran, G. "EFFECT OF BIO-ENZYME SOIL STABILIZATION ON UNCONFINED COMPRESSIVE STRENGTH AND CALIFORNIA BEARING RATIO", Journal of Engineering and Applied Sciences, 2011**

Three different soils with four different dosages for 2 and 4 weeks of curing period after application of enzyme on its strength parameters were studied. Their results indicated that addition of bio enzyme significantly improve UCC values of selected samples. Bio enzymatic stabilization resulted significant increase in UCC and CBR of all the 3 soils tested with varying parameters. Duration of treatment of soil with bop-enzyme played a little roll in improvement of strength and soil treated with bio-enzyme for 4-week duration gives higher strength for all soil tested. In reality and practice addition of bio-enzyme gives better performance in the field and ultimately ensures durable and maintenance free pavement.

**Kanniyappan, S.P., Kumar, R.D., Faizuneesa, A. and Saranya, S. "EXPERIMENTAL INVESTIGATION ON BLACK COTTON SOIL USING BIO-ENZYME AS SOIL STABILIZER IN ROAD CONSTRUCTION", International Journal of Civil Engineering and Technology (IJCIET)**

Four dosages of terrazyme was added to black cotton for 2 different curing periods and the CBR and UCC values were found, the results of enzyme treated soils was higher than that of untreated soil. The addition of terrazyme increases the CBR and UCS value of the black cotton soil where there is an increase in dosage of terrazyme and it is cured for several days and also cost of pavement is reduced by using terrazyme. The pavement construction value is reduced by 30% of total cost. Terrazyme stabilization has shown little to very high improvement in physical properties of soil, this little improvement is due to chemical composition of soil which has low reactivity with bio-enzyme therefore it is advisable to first examine the effect of bio-enzyme on soil stabilization in the laboratory before actual field trails, in some cases where the soil is very weak like highly clay to moderate soil, like silty soil to sandy soil, the effect of stabilization has improved the CBR and UCC.

# CHAPTER 3

## OBJECTIVES

Objectives of the present work are as stated below-

- To characterize collected plain BC soil by determining the various geotechnical properties such as specific gravity, atterberg limits, MDD and OMC, shear parameters etc.
- To understand the effect of enzymatic stabilization for varying dosages of 100ml/m$^3$,150ml/m$^{3,}$ 200ml/m$^3$ and 250ml/m$^3$ and curing periods of 0$^{th}$, 7$^{th}$, 28$^{th}$ days.
- Effect on swelling behaviour.
- Effect on compressibility behaviour of enzyme stabilized soil.
- Effect of curing periods due to bio-enzyme stabilization.
- To conduct comparative studies on effect of bio-modification on BC soil.
- To optimize the quantity of Bio-enzyme to be used as stabilising agent and the extent of stabilisation of strength gain with time.

# CHAPTER 4

# MATERIALS

## 4.1:- BLACK COTTON SOIL & ITS PROPERTIES

As shown in the **Fig 4.1**, Black cotton soil is considered as a potential natural hazard, which can cause extensive damage to structures if not adequately treated. This soil swells when given an access to water and shrink when they dry out. It has high swelling and shrinkage characteristics and shear strength is extremely low; hence, there is need for improvement of these properties

**Fig 4.1:- Black cotton soil**

**Table 1:- Properties of Black cotton soil are given in the table**

| S.No | Property | Value |
|---|---|---|
| 1 | Specific gravity using pycnometer | 2.6 |
| 2 | Liquid limit by Casagrande's tool | 68% |
| 3 | Plastic limit | 29.62 % |
| 4 | Shrinkage index | 37.959 % |
| 5 | Plasticity index | 32.38 % |
| 6 | Unconfined compression test<br>Cohesion and internal angle friction | C= 18 kpa<br>Ø= 65° |
| 7 | standard compaction test<br>OMC<br>MDD | <br>24 %<br>1.865096 g/cc |
| 8 | CBR value | 8.923 % |

## 4.2:- TERRAZYME & ITS PROPERTIES

As shown in the **Fig 4.2**, Terrazyme is a natural, non-toxic liquid, formulated from sugar molasses. TZ improves the engineering qualities of the soil like CBR values and dry density. This in turn also decreases the OMC and plasticity index of soil. The cementious property is obtained when the enzyme is mixed with water and applied this enzyme solution combines the organic and inorganic material present in the soil through catalytic bonding process. Enzyme promotes the development of cementious compounds using the following reaction.

**$H_2O$+Clay+TerraZyme = Calcium Silicate Hydrates**

**Fig 4.2:- Terrazyme**

### Table 2:- Properties of Terrazyme (supplied by manufacturer)

| | |
|---|---|
| Identity (As It Appears On Label) | Enzyme |
| Hazardous Components | None |
| Boiling Point | 100ºC |
| Specific Gravity | 1.05 |
| Melting Point | Liquid |
| Evaporating Rate | Same as Water |
| Solubility in Water | Complete |
| Appearance/Odour | Brown liquid, Non obnoxious |

# CHAPTER 5

# METHODOLOGY

The procedural method followed in order to ultimately find out the hydraulic conductivity of Enzyme based Black cotton soil is shown in the following **Fig 5.1**.

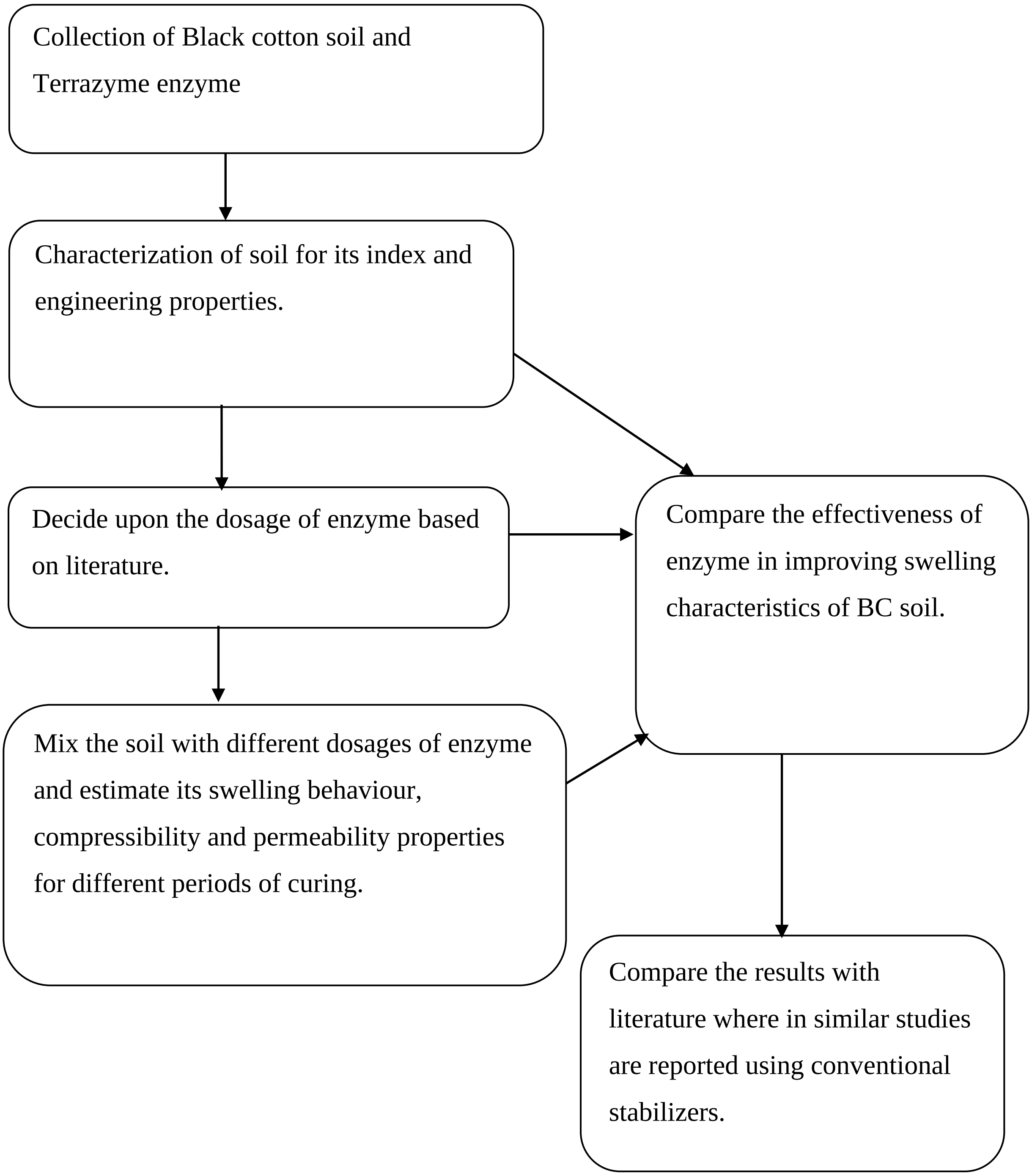


**Fig 5.1:- Flow chart of Methodology**

## Collection of Black Cotton soil and Terrazyme enzyme:

The Black cotton soil which we have used for our project work was obtained from Adoni, Kurnool (district), Andhra Pradesh. This soil was obtained by excavating 1.5 m below the ground surface. The collected Black cotton soil was sieved through different sieves and kept in an oven for minimum of one day in prior to the conduction of any test.

TerraZyme is one of the bio-stabilisers used in our project. One bottle of Terrazyme was purchased from Avijeet Agencies, Chennai.

## Characterization of soil for its index and engineering properties:

Index properties are the simple physical properties of the soils, which are used for classification of soils for various engineering applications. They indicate a qualitative behaviour of soil when subjected to various types of load. They can be listed as given below:

- Water content
- Specific gravity
- Grain size distribution
- Plasticity properties popularly known as Atterberg limits (Liquid limit, Plastic limit and Shrinkage limit) and their indices like plasticity Index, Liquidity Index, Consistency Index, Shrinkage Index.
- In-situ density
- Relative density

Engineering properties of soils are those properties which can be used for quantifying the Engineering behaviour of soils. They can be listed as given below:

- Shear strength (Cohesion intercept and angle of internal friction)
- Compressibility characteristics (compression index and coefficient of compressibility)
- Permeability (Coefficient of Hydraulic conductivity)
- Compaction characteristics (Optimum moisture content and Maximum Dry Unit weight)
- Swell/Collapse potential

Void ratio, porosity, degree of saturation, are not properties of soils, but state parameters indicating the in-situ state of soil.

## Decide upon the dosage of enzyme based on literature:

After the collection of Black cotton soil and TerraZyme enzyme and determining the engineering properties, based on various literature reviews we also decided dosages of enzyme. For our study, enzyme dosage of 100ml/m$^3$, 150ml/m$^3$, 200ml/m$^3$, 250ml/m$^3$ with a curing period of 0, 7 and 28 days are considered and the results obtained for these tests are compared with the different literatures and finally it is concluded.

## Mix the soil with different dosages of enzyme and estimate its swelling behaviour, compressibility and permeability properties for different periods of curing:

As tabulated above, The soil is mixed with different dosages and kept for different curing periods in prior to the conduction. We carried out various tests such as unconfined compressive test, California bearing ratio test, Standard Compaction test and the variation of strength; Penetration, OMC as well as MDD with the application of TerraZyme are performed. Its swelling behaviour, compressibility and permeability properties are determined. Variations of above parameters are studied for enzyme treated soil as well as for the treated soil that is tested after certain curing period. Curing periods for the different enzyme dosages are tabulated in **Table 3**.

## 5.1:- Sample Calculation:

For 250ml/m3 enzyme dosage, for conducting the consolidation cum permeability test following calculations are followed for our study for determining the enzyme dosage.

MDD=1.897922g/cc.

OMC=18%.

} MDD and OMC values are obtained from the standard proctor test

Volume of the permeameter = $\pi/4\times1.8\times6^2 = 5.086\times10^{-5}\ m^3$

Here, Height of Permeameter =1.8cm.

Diameter of Permeameter=6 cm.

Here we will take the amount of enzyme which we actually need for performing the test for three times. This is done only to get accurate amount of enzyme in the pipette and mix it thoroughly with the soil.

Enzyme dosage= $\frac{250}{1} = \frac{x}{5.086\times10-5\times3}$= 0.0381ml.

### Table 3:- Enzyme dosages and curing periods for the present study

| **Dosage** | **Curing Period in days** |
|---|---|
| Untreated BC Soil($0^{th}$ dosage) | $0^{th}$, $7^{th}$ and 28 days of curing period. |
| 100 ml/$m^3$ | |
| 150 ml/$m^3$ | |
| 200 ml/$m^3$ | |
| 250 ml/$m^3$ | |

## Compare the effectiveness of enzyme in improving swelling characteristics of BC soil:

Main purpose of our study is to know how this bio stabiliser TerraZyme enzyme can improve the characteristics of BC soil. We can compare the effectiveness of enzyme in improving swelling characteristics by carrying out standard tests with untreated soil as well as by varying the enzyme dosages. With this we can infer how the enzyme dosage can effect on swelling characteristics of BC soil.

## Compare the results with literature where in similar studies are reported using conventional stabilizers:

Final step is to compare our results with the various literatures, wherein they have used the conventional stabilizers. Thereby, we can clearly compare the results of enzyme stabilised soil and come to the conclusion that, even a small drop of enzyme can change the characteristic property to a large extent and can make change when we compare the soil only with the conventional stabilizers.

# CHAPTER 6

# RESULTS AND DISCUSSIONS

## 6.1:- COMPACTION TEST

We conducted the standard proctor test as per IS:2720(Part 8)-1983.

We Approximately take 4 kg of soil passing through 4.75 mm sieve is thoroughly mixed with known water content. For fine soil, 8-10% of water and for coarse soil, 4-5% of water is added. Then we Weight of the mould without base plate and collar is taken. The collar and base plate were fixed. In the mould, the weighed soil is compacted in 3 layers giving 25 blows per layer with the 2.5 kg rammer. Mould and soil, after making soil flush with the mould edges, are weighed. The sample is removed from the mould and sliced vertically to obtain a small sample for water content determination. The remainder of the material is thoroughly broken up. The water content is increased by one or two percentage and the above procedures are repeated for each increment. This series of determination is continued until there is a decrease in the wet unit weight of the compacted soil. Compaction test of soil is carried out using Proctor’s test to understand compaction characteristics of different soils with change in moisture content. Compaction of soil is the optimal moisture content at which a given soil type becomes most dense and achieve its maximum dry density by removal of air voids.

Black cotton (BC) soil with different dosage of TerraZyme is mixed thoroughly before conduction of any test. Standard compaction Test was conducted on Black cotton soil with different enzyme dosages. Test results are presented in the below table.

## Table 4:- Variation of MDD(g/cc) and OMC(%) of stabilized Black Cotton soil.

| Water content (%) | Dry Density(g/cc) | | | | |
|---|---|---|---|---|---|
| | Untreated BC soil | 100ml/$m^3$ | 150 ml/$m^3$ | 200 ml/m3 | 250 ml/m3 |
| 12 | 1.558723 | 1.571655 | 1.581602 | 1.591549 | 1.592544 |
| 14 | 1.630343 | 1.643274 | 1.653221 | 1.663169 | 1.664163 |
| 16 | 1.669137 | 1.682068 | 1.692015 | 1.701963 | 1.702957 |
| 18 | 1.739762 | 1.752693 | 1.762640 | 1.772588 | 1.897922 |
| 20 | 1.747720 | 1.760651 | 1.770598 | 1.895933 | 1.896927 |
| 22 | 1.809392 | 1.822323 | 1.880017 | 1.893943 | 1.894938 |
| 24 | 1.865096 | 1.878028 | 1.879022 | 1.893943 | 1.894938 |
| 26 | 1.849181 | 1.862112 | 1.863107 | 1.878028 | 1.879022 |
| 28 | 1.817350 | 1.830281 | 1.831276 | 1.846197 | 1.847191 |
| MDD(g/cc) | 1.865096 | 1.878028 | 1.880017 | 1.895933 | 1.897922 |
| OMC(%) | 24 | 24 | 22 | 20 | 18 |

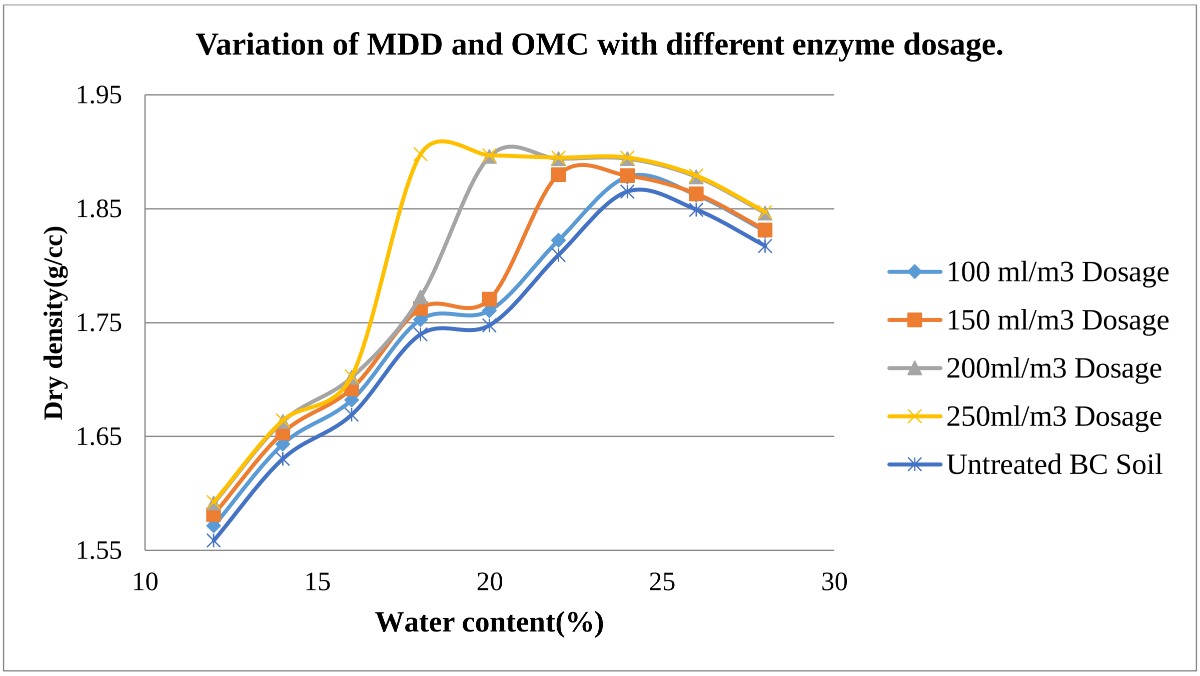


**Fig 6.1:- Variation of OMC and MDD with different enzyme dosage**

As shown in the above **Fig 6.1** as well as experimental data tabulated in **Table 4**, There is increase in MDD and decrease in OMC with the increase in dosage of TerraZyme. This trend happens due to the formation of transitional compounds that will have higher densities with the increase in enzyme dosage.

## 6.2:- CONSOLIDATION CUM PERMEABILITY TEST

Conduction of consolidation test was carried out with the standard reference of IS:2720(part 15)-1986-Determination of consolidation properties. Consolidation is the process of removal of pore water present in the soil gradually due to the application of sustained static load. Because of consolidation, there will be decrease in volume of soil mass. The Consolidation data of soil is used to predict the rate and amount of settlement of structure founded on clay primarily due to volume change. In addition, the following information can be obtained for foundations resting on clay using the consolidation data.

- Total settlement of foundation under any given load.
- Time required for total settlement due to primary consolidation.
- Settlement for any given time and load.
- Time required for any percent of total settlement or consolidation.
- Pressure due to which soil already has been consolidated or compressed.

As per IS:2720 (Part 17)-1986, We have conducted the Falling head permeability test along with the consolidation test. For a falling head test arrangement the specimen shall be connected through the top inlet to selected stand-pipe(here burette in our present study). The bottom outlet shall be opened and the time interval required for the water level to fall from a known initial head to a known final head as measured above the centre of the outlet shall be recorded. The stand-pipe(here burette) shall be refilled with water and the test repeated till three to four successive observations give nearly same time interval; the time intervals being recorded for the drop in head from the same initial to final values, as in the first determination. The coefficient of permeability of a soil sample can be obtained using Falling head method. The knowledge of this property is much useful in solving problems involving yield of water bearing strata, seepage through earthen dams, stability of earthen dams, and embankments of canal bank affected by seepage, settlement etc.


**Fig 6.2(a):- Consolidation setup wherein pressure of 0.01kg/cm2 is applied.**

**Fig 6.2(b):- Consolidation setup with the burette arrangement.**

In our present study, as shown in the **Fig.6.2(b)**, we made the burette arrangement with consolidation apparatus, so as to conduct falling head permeability test simultaneously. Here our soil specimen itself is treated as a permeameter. so there by falling head permeability test is conducted for each loading at certain interval i.e. after every 30 minutes(wherein each loading as shown in the **Fig 6.2(b)**, is done at an interval of 45 minutes).So from this test, we can determine the rate and magnitude of soil consolidation when the soil is restrained laterally and loaded axially. The consolidation parameters obtained by this test are used to determine the consolidation settlement. we can determine the co-efficient of permeability of soil using falling head permeability test which has been conducted simultaneously along with consolidation test. From the obtained OMC and MDD in standard compaction tests, we infer the mass of the soil which is nothing but our consolidation specimen. For the calculated soil mass, with different enzyme dosages like 100ml/m$^3$, 150ml/m$^3$, 200ml/m$^3$, 250ml/m$^3$, we conduct consolidation cum permeability test. Next we conducted the same test for different curing periods i.e. for 0$^{th}$, 7$^{th}$ and 28 days of curing period for all the four enzyme dosages.

For Falling head Permeability, The equation that is used to find coefficient of Permeability, k is:-

$$\mathbf{k = 2.303 \times \frac{aL}{A(tf-ti)} \times \log 10 \left(\frac{h1}{h2}\right)}$$

Where,

k=Coefficient of Permeability(cm/s).

L=Length of soil sample column(cm).

A=Sample cross-section(cm$^2$).

a=Cross section of the standpipe(cm$^2$).

($t_f$-$t_i$)=The recorded time for the water column to flow through the sample(s).

$h_1$ and $h_2$=The upper and lower water level in the standpipe measured using the same water head reference(cm).

The equation that is used to find void ratio, e is:-

$$\textbf{Void ratio, e} = \frac{(H-Hs)}{Hs}$$

Where,

e=Void ratio.

H=Height of the sample(cm).

$H_s$=Height of solids(cm).

Height of soil solids can be found by following equation:-

$$\mathbf{Hs}= \frac{\mathbf{Ms}}{(\mathbf{G\gamma wA})}$$

Where,

Hs =Height of solids(cm).

Ms=Mass of Sample(g).

G=Specific Gravity of soil.

$\gamma_w$=Unit weight of water(g/cc).

A=Area of sample($cm^2$).

## 6.2(i):- Sample Calculation for the determination of mass of the sample:

Diameter of Consolidation ring= 60mm.

Initial height of the sample =18mm.

Volume of Consolidation ring $=\frac{\pi}{4} \times 6^2 \times 1.8$

$=50.868\ cm^3$.

Let us take Sample calculation of 250ml/$m^3$ Dosage for Zeroth day test,

MDD=1.897922g/cc.
OMC=18%.
} MDD and OMC values are obtained from the standard proctor test

Mass of the sample taken in Consolidation ring, $M_s$= Density ×Volume

= 1.897922×50.868

= 96.5434963 g.

Amount of water to be added to the soil sample= $\frac{18}{100}$ ×96.5434963

= 17.377829ml.

## 6.2(ii):-Sample Calculation for the determination of coefficient of Permeability, k(cm/s):-

Specifications of Consolidation ring and sample are given as below-

Diameter of Consolidation ring, D=6cm.

Diameter of standpipe, d=1.3cm.

Length of Sample, L=1.8cm.

Area of Consolidation ring, A=$\frac{\pi}{4} \times 6 \times 6$

A=28.2744cm$^2$.

Area of standpipe, a=$\frac{\pi}{4} \times 1.3 \times 1.3$

a=1.327326cm$^2$.

For Zeroth Day, 250ml/m$^3$ Dosage consolidation cum permeability test we have got the following results-

For pressure =0.05kg/cm2.
Trial 1:

Initial time ($t_i$)=0s.

Final time ($t_f$)= 22.97s.

Initial head ($h_1$)= 57.3cm.

Final head ($h_2$)= 52.3cm.

Coefficient of Permeability, k= $2.303 \times \frac{aL}{A(tf-ti)} \times \log10\left(\frac{h1}{h2}\right)$

k= $2.303 \times \frac{1.327326 \times 1.8}{28.2744(22.97-0)} \times \log10\left(\frac{57.3}{52.3}\right)$

k= 0.000336 cm/s.

## 6.2(iii):- Sample Calculation for the determination of Void ratio, e:-

For Zeroth Day, 250ml/m$^3$ Dosage consolidation cum permeability test we have got the following results-

For pressure =0.05kg/cm$^2$.
Trial 1:

Dial gauge reading at pressure 0 kg/cm$^2$=25mm.

Dial gauge reading at pressure 0.05kg/cm$^2$=24.86mm.

Difference in dial gauge readings $\Delta$H=25-24.86

$\Delta$H=0.14mm.

Initial Height of the sample=18mm.

Height of the sample at pressure 0.05 kg/cm$^2$, H=18-0.14

H=17.86 mm.

H=1.786 cm.

Mass of the sample taken in Consolidation ring, $M_{s}$=96.5434963 g.

Specific gravity of soil sample taken G=2.6

Unit weight of Water, $\gamma_{w}$=1g/cc.

Diameter of Consolidation ring, D=6cm.

Area of Consolidation ring, A=$\frac{\pi}{4} \times 6 \times 6$

A=28.2744cm$^2$.

Height of the solids, Hs=$\frac{\text{Ms}}{(\text{G}\gamma\text{wA})}$

Hs=$\frac{96.5434963}{(2.6\times1\times28.2744)}$

Hs=1.313946 cm.

Void ratio, e= $\frac{(\text{H}-\text{Hs})}{\text{Hs}}$

e= $\frac{(1.786-1.313946)}{1.313946}$

e= 0.359264.

### 6.2.1:-consolidation cum permeability test conducted for different enzyme dosages of 0th day.

**Table 5:- Variation of permeability, k(cm/s) with different enzyme dosages for 0th day test.**

| Pressure(kg/cm2) | Permeability, k(cm/s) | | | |
|---|---|---|---|---|
| | 100ml/m3 Enzyme Dosage | 150ml/m3 Enzyme Dosage | 200ml/m3 Enzyme Dosage | 250ml/m3 Enzyme Dosage |
| 0 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.05 | 0.000865 | 0.000658 | 0.000576 | 0.000314 |
| 0.1 | 0.000633 | 0.000582 | 0.000499 | 0.000273 |
| 0.2 | 0.000455 | 0.000516 | 0.000460 | 0.000253 |
| 0.4 | 0.000412 | 0.000471 | 0.000459 | 0.000235 |
| 0.8 | 0.000383 | 0.000453 | 0.000410 | 0.000228 |
| 1.6 | 0.000368 | 0.000438 | 0.000383 | 0.000219 |

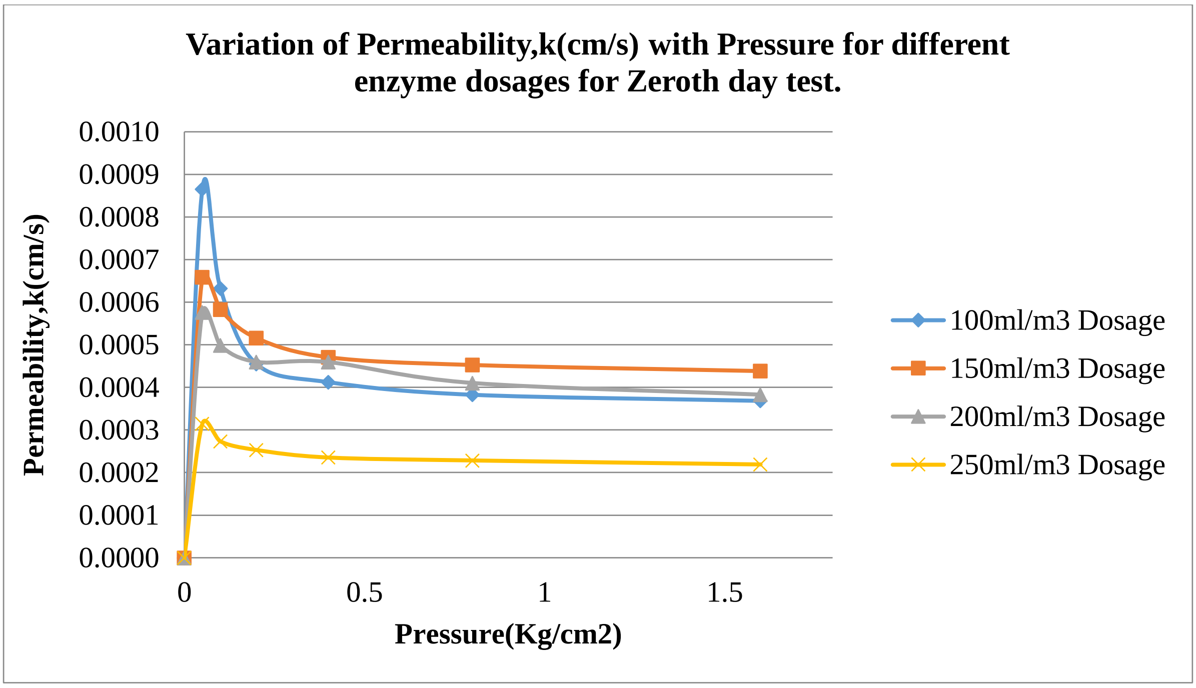


**Fig 6.2.1(a):- Variation of Permeability, k(cm/s) with pressure on BC soil for 0th Day test.**

As we can observe from the experimental data of **Table 5** & above **Fig 6.2.1(a)**, there is decrease in the permeability with the increase in the enzyme dosage.

**Table 6:- Variation of Void ratio with different enzyme dosages for 0th day test.**

| Sl no | Pressure(kg/cm2) | Void Ratio, e | | | |
|---|---|---|---|---|---|
| | | 100ml/m3 Enzyme Dosage | 150ml/m3 Enzyme Dosage | 200ml/m3 Enzyme Dosage | 250ml/m3 Enzyme Dosage |
| 1 | 0 | 0.384431 | 0.382966 | 0.371356 | 0.369919 |
| 2 | 0.05 | 0.383662 | 0.379125 | 0.363738 | 0.359264 |
| 3 | 0.1 | 0.374432 | 0.361453 | 0.346977 | 0.333388 |
| 4 | 0.2 | 0.352128 | 0.344550 | 0.322597 | 0.302945 |
| 5 | 0.4 | 0.322132 | 0.305366 | 0.292884 | 0.280113 |
| 6 | 0.8 | 0.305211 | 0.296147 | 0.270790 | 0.259565 |
| 7 | 1.6 | 0.293674 | 0.279244 | 0.250982 | 0.231405 |

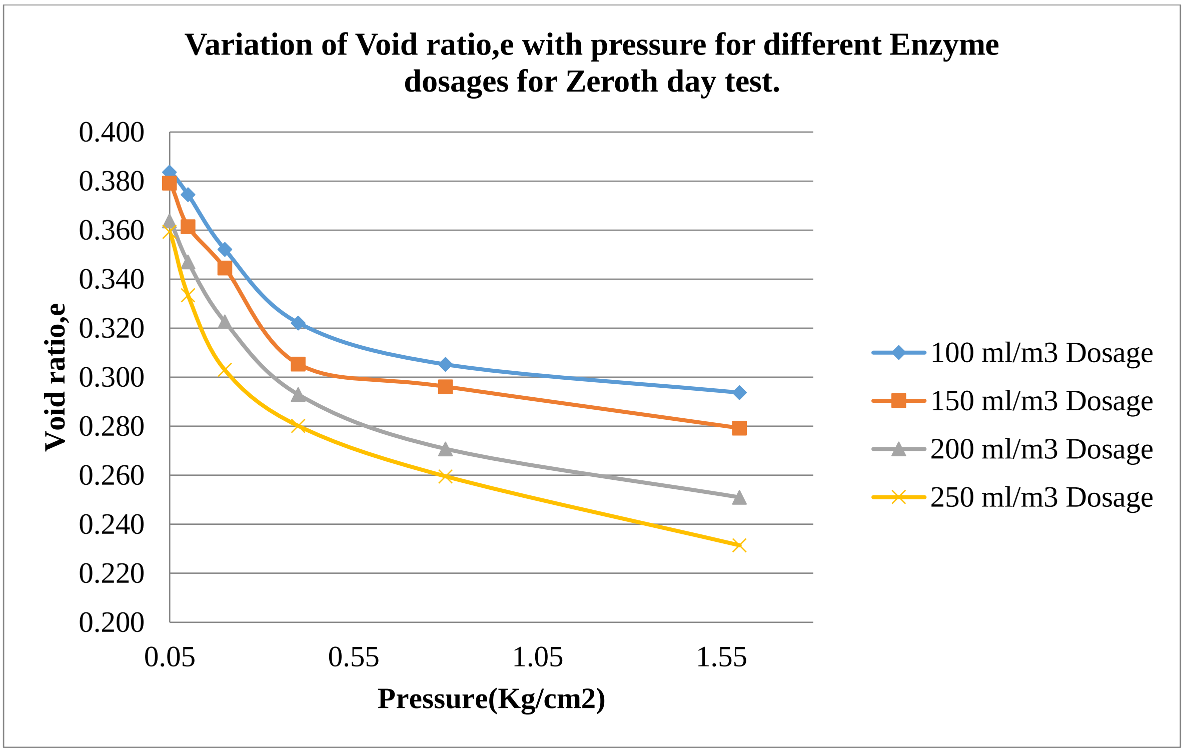


**Fig 6.2.1(b):- Variation of void ratio with pressure on BC soil for 0th Day test**

It is observed from the **Fig 6.2.1(b)** as well as from experimental data of **Table 6**, Void ratio decreases with the increase in the enzyme dosage.

## 6.2.2:- consolidation cum permeability test conducted for different enzyme dosages for 7th day.

**Table 7:-Variation of permeability, k(cm/s) with different enzyme dosages for 7th day test.**

| Sl no | Pressure(kg/cm2) | Permeability, k(cm/s) | | | |
|---|---|---|---|---|---|
| | | 100ml/m3 Enzyme Dosage | 150ml/m3 Enzyme Dosage | 200ml/m3 Enzyme Dosage | 250ml/m3 Enzyme Dosage |
| 1 | 0 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 0.05 | 0.000258 | 0.000230 | 0.000178 | 0.000112 |
| 3 | 0.1 | 0.000219 | 0.000228 | 0.000214 | 0.000084 |
| 4 | 0.2 | 0.000169 | 0.000151 | 0.000145 | 0.000093 |
| 5 | 0.4 | 0.000157 | 0.000139 | 0.000134 | 0.000073 |
| 6 | 0.8 | 0.000137 | 0.000110 | 0.000105 | 0.000067 |
| 7 | 1.6 | 0.000115 | 0.000116 | 0.000112 | 0.000068 |

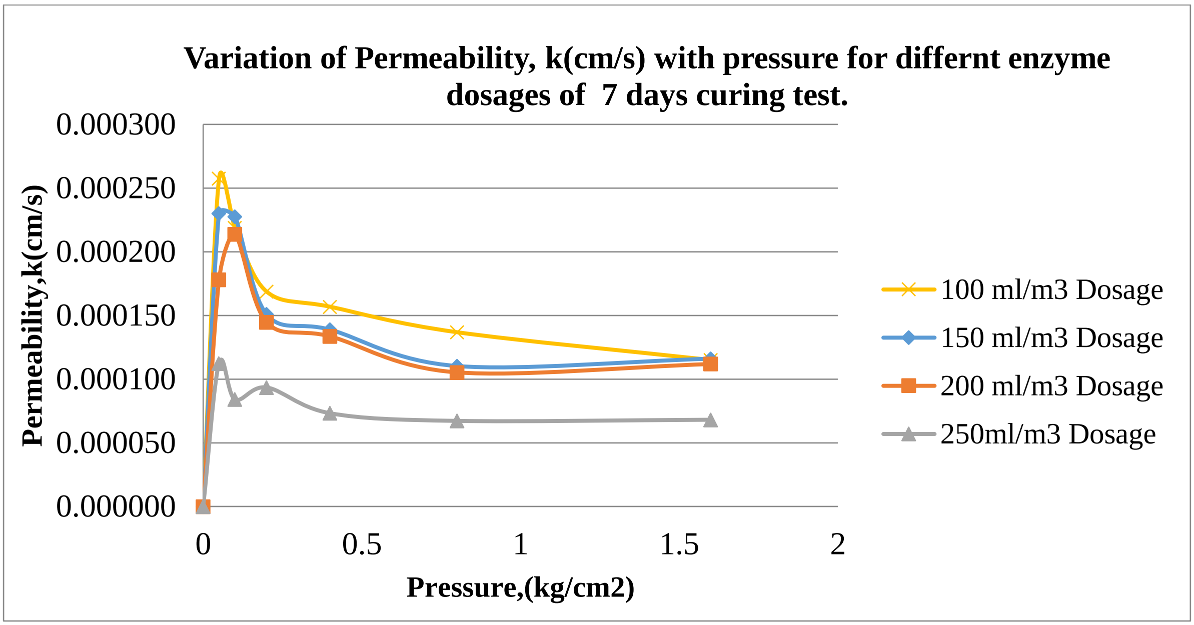


**Fig 6.2.2(a):- Variation of permeability, k(cm/s) with pressure on BC soil for 7th Day test**

From the data of **Table 7** as well as **Fig 6.2.2(a)**, we can see that there is decrease in the permeability with the increase in the enzyme dosage. This is due to the formation of transition compounds due to the enzyme effect which reduces the permeability.

**Table 8:-Variation of void ratio with different enzyme dosages for 7th day test.**

| Pressure(kg/cm2) | Void Ratio, e | | | |
|---|---|---|---|---|
| | 100ml/m3 Enzyme Dosage | 150ml/m3 Enzyme Dosage | 200ml/m3 Enzyme Dosage | 250ml/m3 Enzyme Dosage |
| 0 | 0.384431 | 0.382966 | 0.371356 | 0.369919 |
| 0.05 | 0.365203 | 0.351465 | 0.331740 | 0.315123 |
| 0.1 | 0.322901 | 0.313050 | 0.298979 | 0.277830 |
| 0.2 | 0.299827 | 0.281549 | 0.270028 | 0.254237 |
| 0.4 | 0.280599 | 0.258499 | 0.235745 | 0.216184 |
| 0.8 | 0.255986 | 0.228535 | 0.209841 | 0.183458 |
| 1.6 | 0.225990 | 0.203949 | 0.187747 | 0.167476 |

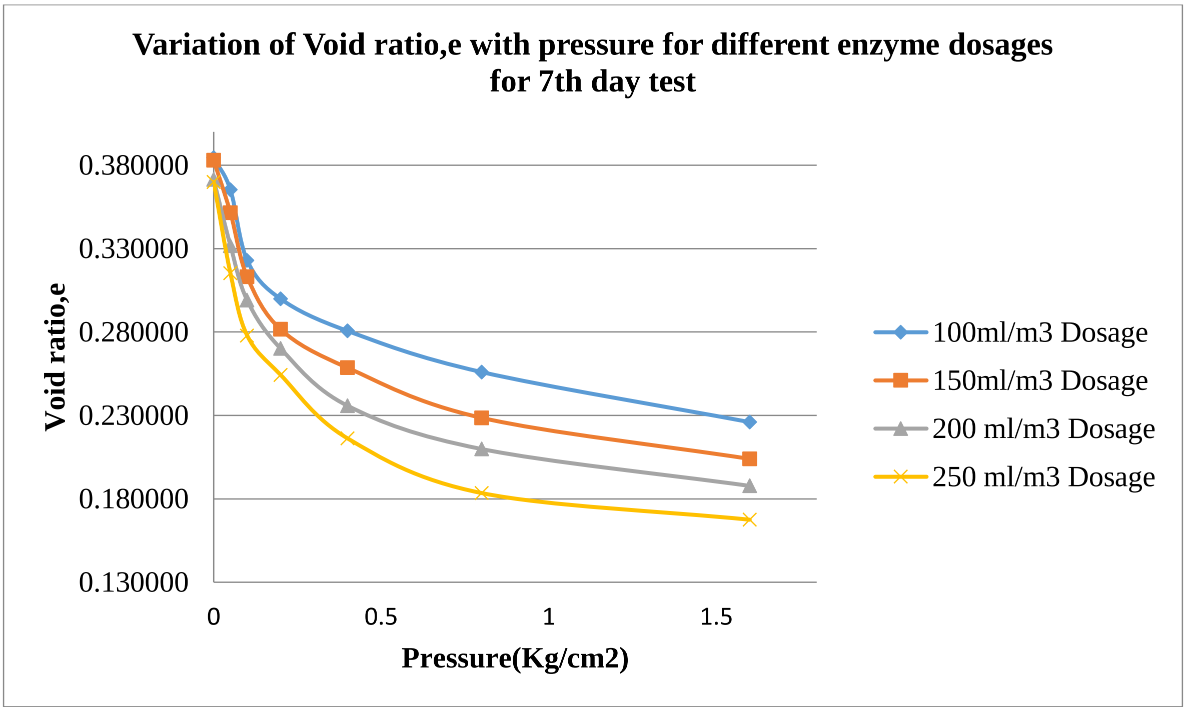


**Fig 6.2.2(b):- Variation of void ratio with pressure on BC soil for 7th Day test**

As shown in the above **Fig 6.2.2(b)** as well as the experimental data from **Table 8**, Void ratio decreased with the increase in the enzyme dosage for the test that we have conducted on sample cured for 7 days.

## 6.2.3:- consolidation cum permeability test conducted for different enzyme dosages for 28th day.

**Table 9:- Variation of permeability, k(cm/s) with different enzyme dosages for 28th day test**

| Sl no | Pressure(kg/cm2) | Permeability, k(cm/s) | | | |
|---|---|---|---|---|---|
| | | 100ml/m3 Enzyme Dosage | 150ml/m3 Enzyme Dosage | 200ml/m3 Enzyme Dosage | 250ml/m3 Enzyme Dosage |
| 1 | 0 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 0.05 | 0.000376 | 0.000287 | 0.000238 | 0.000095 |
| 3 | 0.1 | 0.000277 | 0.000253 | 0.000186 | 0.000082 |
| 4 | 0.2 | 0.000239 | 0.000223 | 0.000173 | 0.000055 |
| 5 | 0.4 | 0.000211 | 0.000186 | 0.000153 | 0.000031 |
| 6 | 0.8 | 0.000181 | 0.000161 | 0.000138 | 0.000029 |
| 7 | 1.6 | 0.000159 | 0.000122 | 0.000090 | 0.000015 |

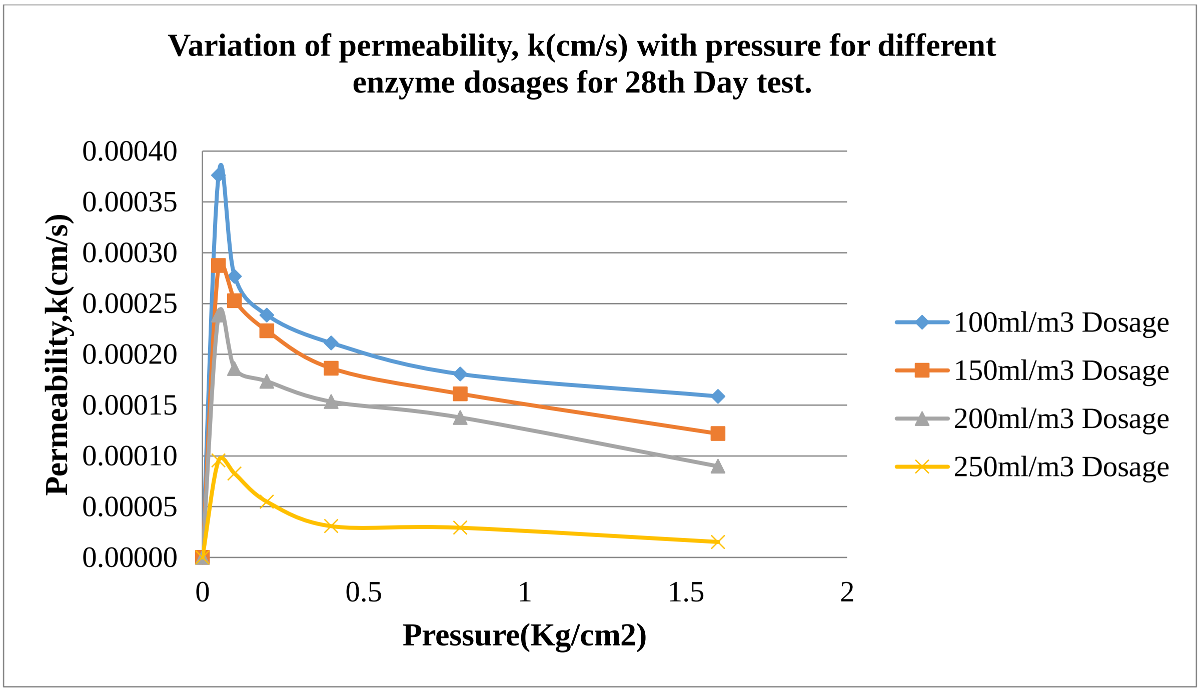


**Fig 6.2.3(a):- Variation of permeability with pressure on BC soil for 28th Day test**

After 28 days of curing when the soil was tested for permeability, we observed that there is a fall in permeability with the increase in the enzyme dosage. This we can clearly observe from the **Fig 6.2.3(a)** and the experimental values given in **Table 9**.

**Table 10:- Variation of Void ratio with different enzyme dosages for 28th day test.**

| Pressure(kg/cm2) | Void Ratio, e | | | |
|---|---|---|---|---|
| | 100ml/m3 Enzyme Dosage | 150ml/m3 Enzyme Dosage | 200ml/m3 Enzyme Dosage | 250ml/m3 Enzyme Dosage |
| 0 | 0.384431 | 0.382966 | 0.371356 | 0.369919 |
| 0.05 | 0.349820 | 0.328416 | 0.308884 | 0.300662 |
| 0.1 | 0.305980 | 0.286159 | 0.261648 | 0.242060 |
| 0.2 | 0.278291 | 0.259268 | 0.235745 | 0.216184 |
| 0.4 | 0.263678 | 0.240060 | 0.226602 | 0.204007 |
| 0.8 | 0.232144 | 0.226998 | 0.209841 | 0.181936 |
| 1.6 | 0.202917 | 0.183973 | 0.161082 | 0.148449 |

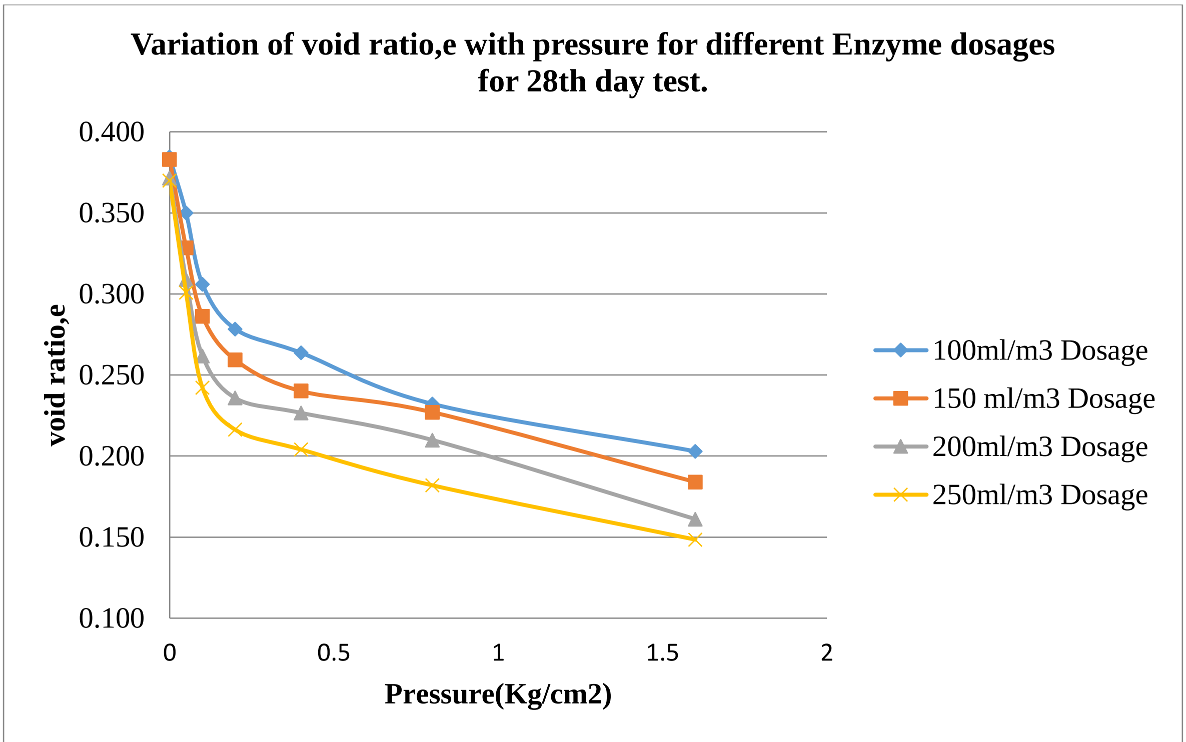


**Fig 6.2.3(b):- Variation of void ratio with pressure on BC soil for 28th Day test**

As shown in the **Fig 6.2.3(b)** and data given in **Table 10**, we can observe that there is decrease in the void ratio with the increase in the enzyme dosage for the 28 days cured sample.

# CHAPTER 7

# CONCLUSIONS

Performance of BioEnzyme stabilized soil has been investigated in this work. Based on the tests conducted in the laboratory, the following conclusions were drawn:

- Amount of clay content plays a major role in the variation of consistency limits.
- Changes are marginal for OMC of enzyme treated soil which is from be 24.00% to 18%. The decrease is due to effective cation exchange process which generally takes longer period in the absence of such stabilizers.
- Changes are even marginal for the maximum dry density i.e, there is increase in the MDD with the increase in the enzyme dosage.
- Bio Enzymes are non poisonous, organic and biodegradable in nature. The product formed after the application of TerraZyme is bio degradable in nature and the effect is permanent. TerraZyme eliminates the use of granular sub base and sub grade course.
- The initial cost of using TerraZyme is high as compared to traditional approaches but the benefit of using TerraZyme is that the maintenance cost is zero and also it is easily available, making this approach economically cost effective.
- For $0^{th}$, $7^{th}$, $28^{th}$ day consolidation cum permeability test, with the increase in enzyme dosage, we clearly observed that there is decrease in the permeability. This is due to the formation of transition compounds which hinders the flow and hence reduces the permeability.
- For $0^{th}$, $7^{th}$, $28^{th}$ day consolidation cum permeability test, with the increase in enzyme dosage, we observed that there is decrease in void ratio, this is due to the formation of compounds that are formed due to the enzyme effect which reduces voids in turn .

# CHAPTER 8

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