STABILIZATION OF LOW PLASTIC AND HIGH PLASTIC SOIL USING TERRAZYME

By

Umar Ali Arshad

(NUST-2016-MS GEOTECH- 00000172030)

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Geotechnical Engineering

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

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THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by **UMAR ALI ARSHAD (Registration No. NUST 2016 MS GEOTECH 00000172030)**, of **NUST INSTITUTE OF CIVIL ENGINEERING (NICE)** has been vetted by undersigned, found complete in all respects as per NUST Statutes/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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STABILIZATION OF LOW PLASTIC AND HIGH PLASTIC SOIL USING TERRAZYME

Submitted by

Umar Ali Arshad

has been accepted towards the partial fulfillment

of

the requirements

for

Master of Science in Geotechnical Engineering

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NUST Institute of Civil Engineering (NICE)

DEDICATED

TO

DR. ISRAR AHMED (R.A)

Whose islamic preachings always helped me to find the path of prophet Muhammad ﷺ

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ABSTRACT

Clays being expansive in nature poses a great challenge in civil engineering. When encountered with water they undergo volumetric changes; not only damaging the super structure but also experience a sudden loss in strength leading to ultimate failure.

Terrazyme an enzyme has been used to improve the strength properties and reduce swelling of high plastic clayey and low plastic clayey soil obtained from Ballewala, Nandipur, Pakistan. Hight plastic soil was made by mixing low plastic soil with twenty-five percent of bentonite. Terrazyme increased Maximum Dry Density (MDD), California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and reduced the swell potential of both clays. For low plastic clay Terrazyme increased the MDD by 1.4 percent; OMC by 5.9 percent. For high plastic, MDD was increased by 2.5 percent; OMC by 12 percent. UCS after 28 days of curing it increased by 177 percent and 253 percent for CL and CH respectively. UCS after 28 days of soaking increased by 130.2 percent and 171 percent for low plastic clay (CL) and high plastic clay (CH) respectively. Whereas LL was reduced by 3.8 percent and 5.2 percent for CL and CH respectively. The un soaked CBR value was increased by 230.5 percent and 292.6 percent for CL and CH respectively. The soaked CBR value increased by 195.5 percent and 300 percent for CL and CH respectively. Swell potential of CL and CH was reduced by 49.3 percent and 35.3 percent respectively. Cation Exchange Capacity (CEC) was reduced by 3.7 percent and 6.1 percent.

Chapter 1

INTRODUCTION

1.1 GENERAL

In civil engineering, soil plays an important role as a load bearing material. Roads, bridges, buildings, and dams etc., ultimately transfer their load to the soil. Physical and chemical properties of clay have a great impact on the life and functionality of structure constructed over it. Soil Particles having an effective diameter of 2 μm or less is considered as clay.

Clayey soils tend to undergo a volumetric change (swelling and shrinking with addition and removal of water respectively). The swelling and shrinking causes settlement/dilation which leads to cracks in structure and sometimes bearing capacity failure. Expansive clays have damaged many types of structures around the world, e.g, airports, highways, railways, and buildings etc. Alone in the USA it caused a damage of 2,225 million dollars per year (Jones and Holtz, 1973). This property of clay is greatly governed by its mineralogical composition, i.e, CEC, Surface area, particle thickness, etc. Most commonly occurring clay minerals are Kaolinite, Illite, and Montmorillonite.

Ground improvement is the method to improve soil properties as per the project requirement by changing its natural conditions, instead of changing the design in response to the soil natural limitations (Mittal, 2012). Ground improvement techniques have a very long history. About 2000 years ago lime was used in Rome for road improvement (Han, 2015). About 500 years ago Chinese made soil and lime proportions for improvement of soil as a foundation material (Chen and Wu, 1995).

Around 1400 BC people of Iraq used horizontal drains made up of reed to accelerate the consolidation process of soil (Mittal, 2012).

Soil improvement is a combination of physical and chemical methods for improving the characteristics of soil when it is used as a construction material (Winterkorn and Pamukcu, 1991). Ground improvement has been categorized into four groups which are as follows:

1. Mechanical Modification

This technique purely uses mechanical methods of modification. For example, compaction, deep dynamic compaction, vibro compaction etc.

2. Hydraulic Modification

In this technique, the excess pore water is expelled out of soil usually to accelerate the process of consolidation. The main methods for hydraulic modification are PVDs, vacuum consolidation, sand columns etc.

3. Modification by Inclusion and Confinement

This type of technique uses soil reinforcement methodology to enhance its strength, e.g, are geo-grid, mesh and bars, MSE etc.

4. Chemical Modification

It is the process of physically adding and mixing certain additives in soil to enhance its properties for, e.g, bio-enzymes, lime, cement etc. (Hausmann, 1990).

1.2 NEED FOR RESEARCH

Most of the methods of ground improvement are labor insensitive, time-consuming or very expensive to carry out. It is of paramount importance for geotechnical engineers to find a stabilization technique that improves the soil characteristics in an economical way. The obvious solution is to use locally available cheap waste or raw material for soil improvement. One of the cheap and reliable solutions to this problem is to use bio-enzymes. Bio-enzymes are a natural, non-poisonous, non-combustible, non-hazardous liquid enzyme agitated from vegetable extracts (Patel *et al.*, 2018).

The idea of using the enzyme for stabilization in construction came in when it was used in agriculture applications. Enzymes help to improve strength and compaction properties of soil permanently at a very low cost. Terrazyme requires less labor, less machinery and less construction time, a ratio of 2:5 is observed between conventional and Terrazyme construction (Rafique *et al.*, 2016). Researchers have done work to improve the CBR and UCS of different soil with an optimum dosage of Enzyme. Increase in MDD and reduction in OMC for silty clay was observed when stabilized with Terrazyme (Lacuoture and Gonzalez, 1995). The theoretical relation of Terrazyme on CEC of soil particle and with MDD and OMC was made (Sheldon and Murphy, 2000) . High plastic soil (CH) treated with 2 percent and 5 percent Terrazyme showed an increase in MDD (Yusoff *et al.*, 2017).

Much of the work has been done on soil stabilization in Pakistan but a little work has been done using bio-enzymes as a soil stabilizer. This research work is done with the intention of stabilizing the soil of Ballewala, Nandipur with Terrazyme. As Terrazyme is extracted from sugar cane juice and sugar cane is abundantly available in Pakistan.

1.3 RESEARCH OBJECTIVES

The main objective of this research is to optimize the Terrazyme as a Bio enzyme stabilizer for clayey soils (CH and CL) and to study its feasibility from both geotechnical and economic perspectives. This research will cover the following area of soil properties:

- Grain Size Analysis (GSA)
- Hydrometer analysis
- Liquid Limit (LL)
- Plastic Limit (PL)
- Plasticity Index (PI)
- Cation Exchange Capacity (CEC)
- Dry Density (γ_{dry})
- Unconfined Compressive strength (UCS)
- Optimum Moisture Content (OMC)
- California Bearing Ratio (CBR)
- Swell Potential
- Specific gravity

1.4 SCOPE AND METHODOLOGY

The scope of this research is to find an optimum dosage of Terrazyme to improve the properties of both CL and CH, which are Atterberg limits, density test, UCS test at different moisture content, CEC etc. In this effort a detailed scheme and methodology have been developed as follows and the research is divided into four phases.

1.4.1 Phase I: Characteristics of Untreated Soil

This is the first phase of testing. In this phase following test will be conducted for low plastic and high plastic soil:

- Grain Size Analysis (GSA)

- Hydrometer analysis
- Liquid Limit (LL)
- Plastic Limit (PL)
- Plasticity Index (PI)
- Specific gravity (G_s)
- Compaction (Modified Proctor Test)
- Un Confined Compressive Strength (UCS)
    - Soaked for
    - Un soaked
- California Bearing Ratio (CBR)
    - Soaked
    - Un soaked

1.4.2 Phase II: Optimization of Terrazyme Dosage

In this phase of testing, four dosages of Terrazyme will be added to both low and high plastic soil. The purpose of this phase is to get the optimum dosage of Terrazyme at which testing gives maximum results for each type of soil. Following sequence shows the testing to be conducted with Terrazyme:

- Modified Proctor Test for following Terrazyme dosages:
    - D1 = 200 ml/3.0 m^3
    - D2 = 200 ml/2.5 m^3
    - D3 = 200 ml/2.0 m^3
    - D4 = 200 ml/1.5 m^3.
- UCS at 95 percent MDD and OMC for following Terrazyme dosages.
    - D1 = 200 ml/3.0 m^3

  - D2 = 200 ml/2.5 m^3
  - D3 = 200 ml/2.0 m^3
  - D4 = 200 ml/1.5 m^3.
- UCS optimization at excess moisture (for optimum Terrazyme dosage).
  - OMC + 1 percent
  - OMC + 2 percent
  - OMC + 3 percent
  - OMC + 4 percent

1.4.3 Phase III: Characterization of Treated Soil.

This is the final phase, in this phase soil samples for each soil will be prepared with the addition of optimum dosage of Terrazym. Following scheme shows the testing procedure:

- Atterberg's limits for Terrazyme dosages (D1, D2, D3, D4)
- Plastic limit
- Liquid limit
- Plasticity index
- Cation Exchange Capacity (CEC) for Terrazyme dosages (D1, D2, D3, D4)
- Unconfined Compressive Strength at four Terrazyme dosages (D1, D2, D3, D4)
  - Soaked at 2, 7, 14, 28 days
  - Cured at 2, 7, 14, 28 days
- California Bearing Ratio (CBR) at an optimum Terrazyme dosage
  - Soaked for 96 hours in soaking tank
  - Un-Soaked

- Swell Potential at an optimum Terrazyme dosage

1.5 THESIS CONTENTS

Chapter 1 is the introductory chapter of thesis containing a general overview of problem statement and will introduce method used in the thesis. This also covers some historical aspects in selected research, i.e, introduction to ground improvement, the origin of Terrazyme, previous work and historical aspects of ground improvement.

In chapter 2 detailed literature review has been done, which will help to support the reasoning behind results obtained from testing for, i.e, Clay; its mineralogy and physical properties, previous work done on different soil using different stabilizers and findings from previous research.

Chapter 3 contains the details of process and procedure adopted to carry out the research. All testing scheme is described in this section, moreover, material and location are also mentioned in this section, i.e, test and their description are as per ASTM and AASHTO standards along with curing and soaking periods for UCS and CBR tests. This chapter helps in creating a preliminarily road map for the testing sequence.

Chapter 4 contains the data obtained from testing. Graphs, trends and numerical data is presented in this section. In discussion, the interpretation of results is done, and critical reasoning is presented against changes and trends observed in results, i.e, Index properties of soil, Modified proctor test, UCS, CBR, and swell potential etc. All findings are presented in this chapter and conclusions are made accordingly in next chapter.

In chapter 5 a comparative analysis is done. In recommendation further area of research are highlighted having potential in bringing out further knowledge in the specified area.

Chapter 2

REVIEW OF LITERATURE

2.1 GENERAL

In engineering, clay has a great significance as a foundation material. It tends to change in volume when it encounters water, and cause swerve damages to structure founded on it (Gillott, 1986). This swelling-shrinking property of clay produces repeated stresses on concrete structures.

Figure 2.1: Cracks in building walls due to clay shrinking

As a subgrade material clay also plays a vital role in their performance. Due to high water retention capacity, it experiences freeze and thaw and causes cracks in pavements. Figure

Figure 2.2: Soil frost action caused damage to the pavement

Clayey soils as subgrade material undergo erosion if proper drainage is not provided during construction. This causes the formation of pot holes, rutting and differential settlements to a permanent extent.

Figure 2.3: Pothole formation due to subgrade erosion

2.2 CLAYEY SOILS

Clay is a naturally occurring material, which behaves like a plastic at normal water content and hardens when dried. Generally, minerals found in clay are less than 2 microns, about the same size as of viruses (Guggenheim *et al.*, 1977). The size of clay mineral is so small that, the gravitational forces don't influence them but dominant force among the particles is an electrostatic forces is due to the charge present on their surface (Terzaghi *et al.*, 1996).

Material which is predominantly influenced by charge rather than gravity is said to in colloidal state (Terzaghi *et al.*, 1996). Scientifically clay is referred to as hydrous amino-silicates with other cations in a formation of the lattice structure (Holtz and Kovacs, 1981). Phyllosilicates are the sheets of Silicates, they include Micas, Chlorite, Talc, and Serpentine etc. The structure of Phyllosilicates contains six members of SiO_4^{-4} tetrahedral, forming an infinite connection to form a sheet (Nelson, 2006).

2.2.1 Clay Mineralogy

Clay consists of different lattice structures. The ionic bond between O^{-2} or OH^- with the cation of Al, Mg, and Fe etc. When atoms in a crystal arrange themselves in a certain pattern, they form a three-dimensional network termed as Lattice (Mitchell and Soga, 2005).

The formation of these structures mostly depends upon charge and radii of cations and anions. How anions will be around a cation is determined by coordination number (Al-Ani and Sarapää, 2008).

2.2.2 Structure

The two-important clay mineral structures are as follows:

1. Tetrahedron
2. Octahedron

2.2.2.1 Tetrahedral structure

It is formed when four O^{-2} makes an ionic bond with a central cation like Si^{+4}. This formation causes the overall structure to form a tetrahedral structure. All three basal oxygen atoms are shared to form a tetrahedral sheet (Holtz and Kovacs, 1981).

As valency, if Silicon is +4 and Oxygen is -2. After sharing one of two available electrons from O^{-2} the valency of Si^{+4} becomes zero, hence the net charge over the structure becomes negative 4. This formation tends to form further bonds to make up clay lattice (Al-ani and Tahir, 2008).

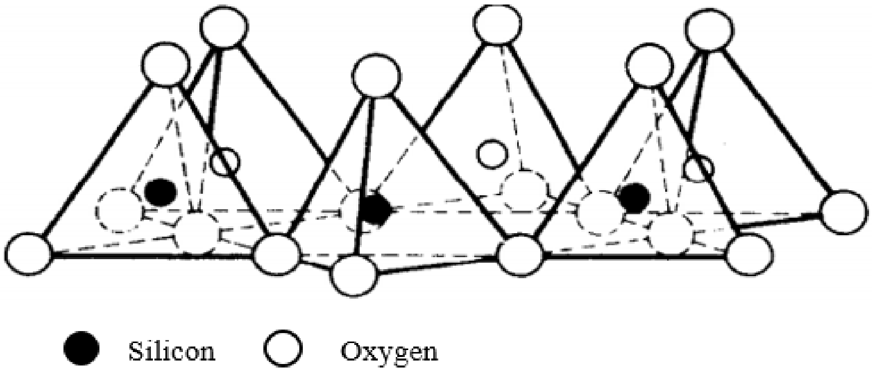


Figure 2.4: Tetrahedral sheet

2.2.2.2 Octahedral structure

When Al cations bonds with six hydroxyl anions. It forms an octahedron arrangement. This octahedron shares its corners with adjacent octahedron structures to form a sheet-like structure called as an octahedral sheet (Nelson, 2006).

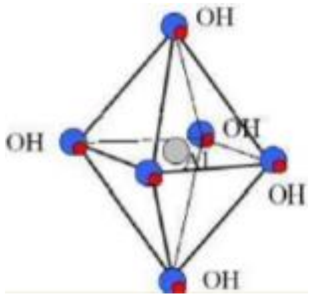


Figure 2.5: Octahedral configuration of Al-OH

2.2.3 Layering

2.2.3.1 The 1:1 structure

The apical O in silica sheet replaces OH in octahedral sheet to form 1:1 lattice. The net charge over the lattice becomes -1 at basal side of tetrahedral and -1 from basal side of octahedral. Hence nourishing net negative charge over clay particle. The arrangement is shown in Figure 2.6

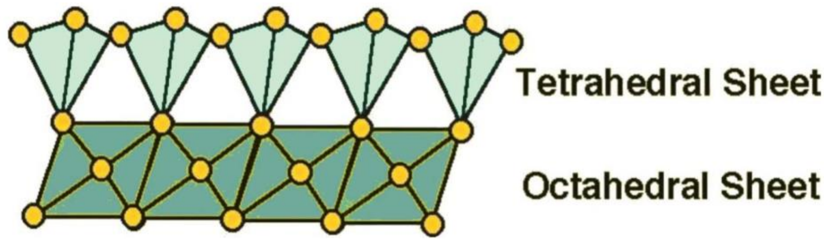


Figure 2.6: The 1:1 (Kaolinite) lattice

2.2.3.2 The 2:1 structure

In this configuration, the octahedral sheet is joined by tetrahedral sheet from both sides. Hence the overall -1 charge over clay particle is due to basal oxygen in tetrahedral sheet. As shown in Figure 2.7

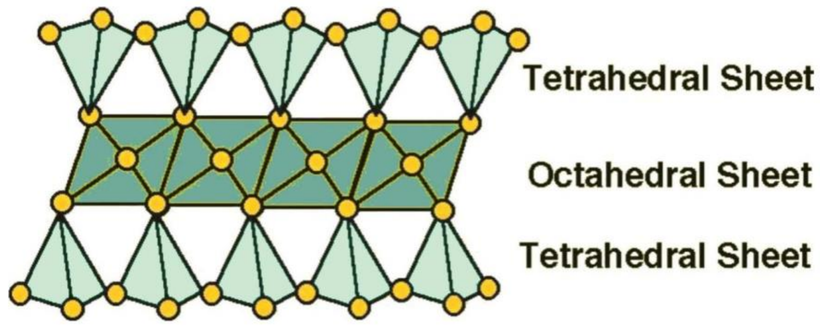


Figure 2.7: The 2:1 layer (Illite)

2.2.4 Common Clay Minerals

Here are three common clay minerals that are found abundantly.

2.2.4.1 Kaolinite

Kaolinite formed when 1:1 layer stacked in such an orientation the oxygen in tetrahedron face hydroxyl group in the octahedron. Each layer is about 7.2 Å thick, the interlayer cleavage is held together via hydrogen bonding between O in a tetrahedron and OH in octahedron group (Holtz and Kovacs, 1981). Due to strong interlayer hydrogen bond, this mineral doesn't go hydration reaction and makes up large piles of the layer stack. Usually, each crystal of Kaolinite is made up of 70-100 layers thick.

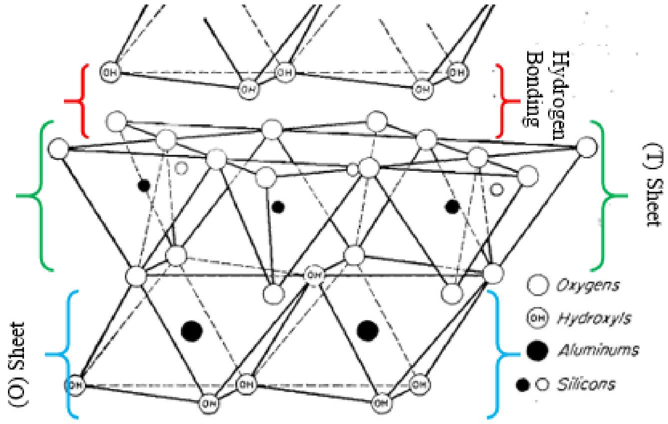


Figure 2.8: Structure of 1:1 Kaolinite mineral

2.2.4.2 Montmorillonite

Montmorillonite belongs to a group called smectite. This mineral is the primary constituent of volcanic ash (Grim, 1953). It is 2:1 mineral and resembles micas, in this mineral the sheets are stacked over each other. The stacking of layer over one and other brings O of tetrahedral face to face making excellent cleavage and allowing water or other cations to adsorb in between. The thickness of each layer is 9.6 Å. (Grim, 1953).

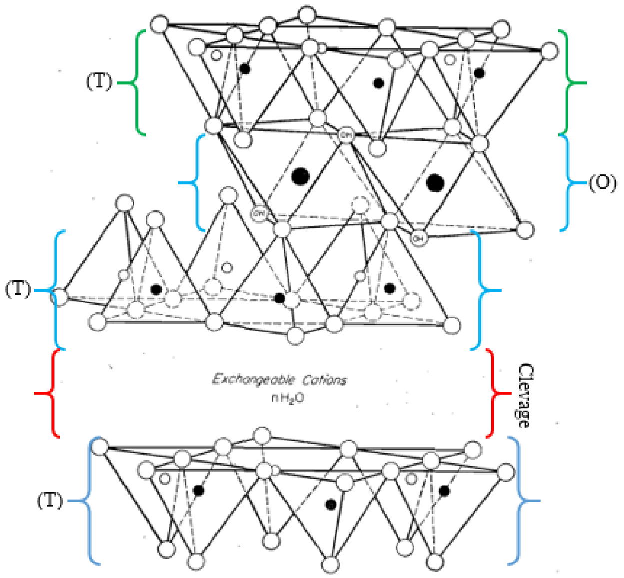


Figure 2.9: Atomic structure of montmorillonite (Grim, 1959)

2.2.4.3 Illite

Illite mineral was first discovered by Prof. Grim in Illinois, hence named Illite after Illinois. The general lattice structure of Illite is like montmorillonite but main difference comes when Si in tetrahedral is partially replaced with Al creating charge imbalance (Grim, 1953). The overall lattice becomes negatively charged and this charge is balanced by K^+ cations via cation exchange in between layer cleavage.

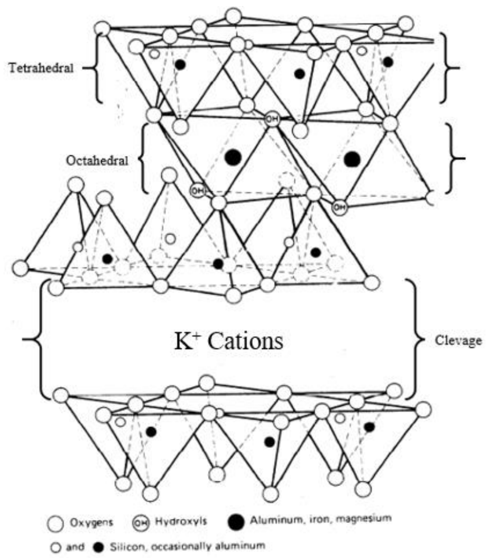


Figure 2.10: Atomic structure of 2:1 Illite (Grim, 1953)

2.2.5 Cation Exchange Capacity (CEC)

Some clay minerals tend to adjust the interlayer composition by substitution with different cations. The soil has the power to exchange cations with solutions containing other cations (Kelley, 1948). This property is known as cation exchange and the amount is the cation exchange capacity (CEC) (Velde and Meunier, 2008). It is measured by the charge held by cations as milli-equivalents per 100 g of soil. The table below shows cation exchange capacities of different clay minerals.

Table 2.1: CEC value of different clay minerals (Grim, 1953)

Mineral	**CEC (meq/100g)**
Kaolinite	3-15
Smectite	80-150
Illite	10-40
Chlorite	10-40
Vermiculite	100-150

2.2.6 Double Layer

Soil particles bear net charge imbalance at their surface, this cause attraction of dipole water molecules at surfaces called double layer (Van Olphen, 1977). The presence of net negative charge (due to isomorphous substitution) attracts positive polar water molecules in moist conditions. This balances the overall charge imbalance over the clay particle (Weber, 2015). The presence of anion adsorption in kaolinite at the edges was reported by (Schofield and Samson, 1954).

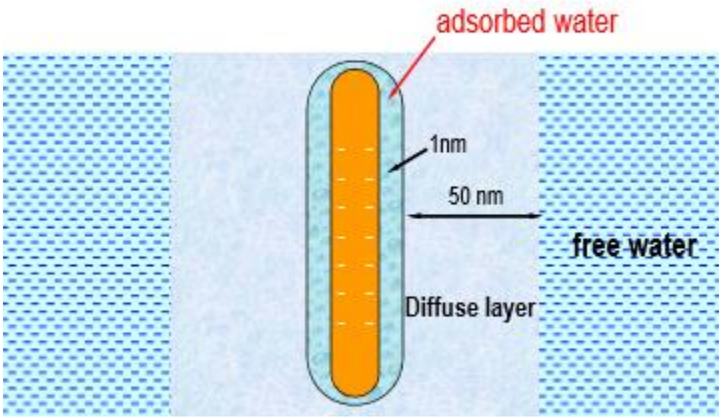


Figure 2.11: Representation of diffused water layer over clay particle

2.3 STABILIZATION

There are mainly two types of additive stabilizers for clayey soils (Tingle *et al.*, 2007).

1. Traditional Stabilizers
2. Non-traditional Stabilizers

2.3.1 Traditional Stabilizers

These types of stabilizers consist of traditional additives like Gypsum, lime, Fly ash, Bagass Ash and bituminous products etc. Much of the work has been done using traditional stabilizers (Tingle *et al.*, 2007).

2.3.1.1 Cement kiln dust

Findings concluded that the with addition of 30 percent of CKD its MDD reduced by 4 percent and OMC increased by 18 percent. UCS was improved by 85 percent. The soaked CBR was improved by 177 percent (Al-Homidy *et al.*, 2017).

2.3.1.2 Blast furnace slag

Highly compressible silt with grounded blast furnace slag and fly ash was stabilized. It was concluded that UCS value increased by 176 percent at 28 days of curing (Kumar *et al.*, 2010).

2.3.1.3 Powder glass

Addition of 5 percent glass powder with 15 percent cement to low plastic soil increased MDD by 3 percent. The CBR was improved by 112 percent (Olufowobi *et al.*, 2014).

2.3.1.4 Saw dust ash

Saw dust ash (SDA) was used to stabilized low plastic soil. It was concluded that with addition of SDA, UCS increased by 26 percent, while undrained shear strength increased by 26 percent. The MDD was reduced by 24 percent and OMC increased by 130 percent. California bearing ratio was increased by 103 percent (Butt *et al.*, 2016).

2.3.1.5 Rubber tyre waste

Rubber tire was used to improve MDD and CBR of low plastic clayey soil. It was concluded that addition of rubber tire shred decreased OMC by 14 percent and decreased MDD by 10.05 percent. The increase in CBR was around 56 percent (Jan *et al.*, 2015).

2.3.1.6 Gypsum

Addition of gypsum increased soil density and decreased OMC. While a significant increment in CBR was observed (Murthy *et al.*, 2016).

2.3.2 Non-Traditional Stabilizers

These types of stabilizers consist of a large variety of chemical compounds, their composition and interaction with soil is very complex (Tingle *et al.*, 2007). These types of stabilizers are also known as non-standard stabilizers and were first used by FHWA in 1998 (Scholen, 1995). Non-traditional stabilizers are grouped into seven categories (Kestler, 2009):

1. Chlorides
2. Electrolyte emulsions

3. Clay additives
4. Enzymatic emulsion
5. Lignosulfonate stabilizers
6. Synthetic-polymer emulsion
7. Tree-resin emulsion

2.3.2.1 Chlorides

These types of stabilizers are also known as salts. They predominantly are salts of Calcium chloride and Magnesium chloride. They are mainly used as dust suppressers and are very sensitive to change in humidity (Kestler, 2009).

Calcium chloride powder was used to improve the properties of high plastic clayey soil. It was observed that, addition of 15 percent of additive reduced swelling and plasticity by 70 and 60 percent respectively. Improvement in shear strength was around 5 percent. The addition of calcium chloride increased the UCS by 50 percent (Zumrawi and Eltayeb, 2016). Stabilization of high plastic clay using magnesium chloride was done. It was reported that at 8 percent of additive the density increased by 12 percent and OMC was reduced by 19 percent. $MgCl_2$ reduced PL and LL by 16 percent and 4 percent respectively (Abood *et al.*, 2007).

2.3.2.2 Electrolyte emulsions

These types of stabilizers ionic in nature and are mainly composed of acids and alkalis. They affect the electro-chemical properties of soil and replaces water to stabilize the soil (Scholen, 1995).

Phosphoric acid was used to stabilize A-7-6 soil. It was reported that it increased the density of soil by 2 percent and reduced OMC by 7 percent. On addition of phosphoric acid, the UCS increased by 200 percent (Lyons and McEwan, 1962).

CBR Plus was used to improve the properties of sandy soil. A significant increase in MDD was observed with increase in OMC. The UCS value was increased by around 87 percent (Mousavi and Karamvand, 2017).

2.3.2.3 Clay additives

Naturally occurring clay minerals like Montmorillonite are hydrophilic due to which they are cohesive in nature. Clay additives are mainly used in granular/crush material so to give them binding properties (Kestler, 2009).

2.3.2.4 Enzymatic emulsions

Enzymatic emulsions are used as stabilizers as well as dust suppressors. Enzymes are attracted to clay negative charge which in return helps them to cover the particle and expel the water attached to it (Scholen, 1995).

An enzyme Dz-1X was used to improve CH soil. Dz-1X improved UCS from 10.8 kPa to 49.05 kPa. It increased CBR from 3.93 to 8.03. Triaxial test showed that shear strength of soil was increased by 450 percent (Sen and Singh, 2015).

Renolith was used to stabilize black cotton soil, at optimum dosage it reduced the liquid limit of soil by 23.63 percent and increased CBR by 627 percent (Singh and Garg, 2010).

Addition of Terrazyme increased the shear strength of CL soil from 5.39 kPa to 27.5 kPa. Same percentage of Terrazyme increased CBR from 3.93 to 8.03 almost 104 percent increase in value. Triaxial results showed that Terrazyme increased the soil cohesion by 463 percent (Agarwal and Kaur, 2014).

2.3.2.5 Lignosulfonate stabilzers

They are mainly composed of Sodium, Magnesium and Ammonium lignin. They have special binding property that induces cementation among soil particles when used as stabilizers. They are water soluble polymers (Tingle *et al.*, 2007).

Effect of calcium lignosulfonate as stabilizer was studied. It was reported that it increased the MDD and reduced the OMC of soil. UCS strength increased up to 25 percent of original strength. CBR was improved by 400 percent (Ravishankar, 2017).

2.3.2.6 Synthetic-polymer emulsion

Also known as acetate polymers or acrylics, when mixed with organic emulsion they coat the clay particle make them water resistant (Kestler, 2009).

Polyester fiber was used to stabilize subgrade soil. It was reported that 0.5 percent inclusion of fibers reduced the PI of soil by 65 percent. The same amount of fiber increased the shear strength by 180 percent. The angle of friction was improved by 172 percent. The inclusion of 0.5 percent of polyester fiber improved CBR value by 159 percent (Changizi and Haddad, 2014).

The effect of acrylic polymer on the strength properties of high plastic soil was studied. On addition of polymer reduced MDD by 1.8 to 1.5 percent and increase OMC by 1.5-11.9 percent. There was a significant change in UCS, i.e, it increased by 30 to 75 percent. The CBR value was improved by 340 percent (Kolay *et al.*, 2016).

2.3.2.7 Tree-resin emulsion

They are purely natural emulsions extracted from tress like pine, fir and spruce. They are biodegradable and best suited as dust suppressors (Kestler, 2009). The famous tree-risen are Dustbinder, Dustrol EX, Enduraseal 200, Resin pavement, Resinpave, Road oyl and TerraPave

2.4 ENZYMES

A catalyst stimulates the rate of chemical reaction and remains unchanged after and before it. The enzyme is a biological catalyst and is made up of proteins (Mackean, 2014).

Bio-enzymes are chemicals (organic and liquid) used to stabilize soil and aggregate in roads and structures (Lacuoture and Gonzalez, 1995).

The fundamental structure of the enzyme is an amino acid, one or more amino acids combines via a peptide bond to form a chain of a protein or poly-peptide chain. An amino acid consists of three components attached to the central C-H bond, an amine group, R factor, carboxylic group.

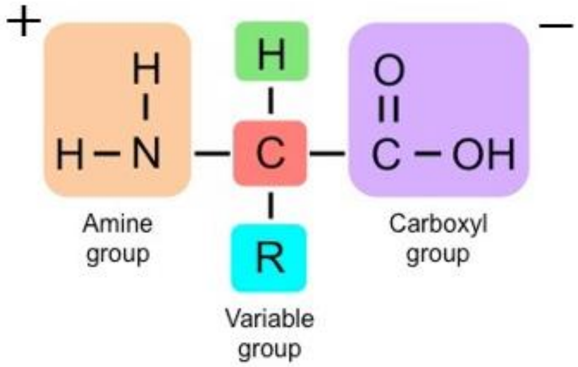


Figure 2.12: Fundamental amino acid structure

The two ends of amino acids are charged, positive (amine group) and negative (carboxyl group). This charge imbalance qualifies an amino acid to form a peptide bond with other amino acids forms a protein structure.

There are twenty-one different types of amino acids which become a part of an enzyme structure (Atkins and Gesteland, 2000). These amino acids are mentioned in the table below:

Table 2.2: Amino acids classified (Twenty first amino)

Amino Acids				
Hydrophobic	**Positive Charged**	**Negative Charged**	**Polar**	**Special**
Alanine	Arginine	Aspartic	Serine	Cysteine
Valine	Histidine	Glutamic	Threonine	Seleno Cysteine
Isoleucine	Lysine		Asparagine	Glycine
Leucine			Glutamine	Proline
Methionine				
Phenylalanine				
Tyrosin				
Tryptophan				

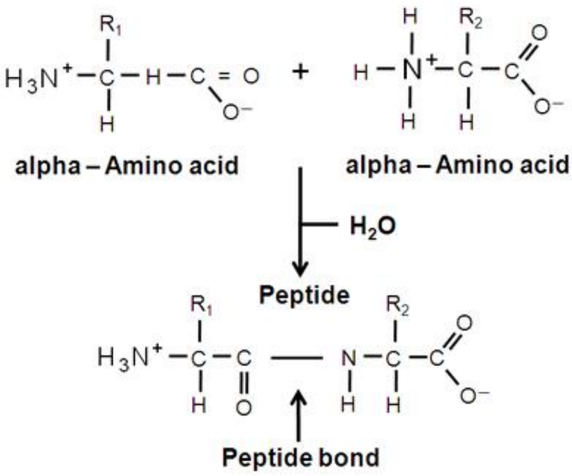


Figure 2.13: Protein formation via peptide bond

2.4.1 Nature of Enzyme

An enzyme behavior is mostly governed by the surrounding conditions, e.g, microorganisms, humus in clay and colloidal particles (Sarkar and Burns, 1984).

The chemical composition of enzyme makes it hydrophobic, hydrophilic, charged and neutral (Zimmerman and Ahn, 2010). Enzymes adsorbed on a soil molecule via hydrogen bonding, ionic interaction and Van Der Waal forces.

2.4.2 Enzyme Stabilization Process

2.4.2.1 Electrostatic attraction

The electrostatic attraction between charge enzyme and negative clay particle gives rise to this attraction (Zhuravlev, 2000), e.g, Arginine, Histidine and Lysine are charged and thus form electrostatic attraction with clay.

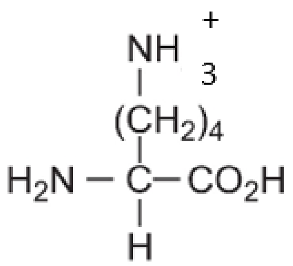


Figure 2.14: Charged Lysine-enzyme side chain molecule

2.4.2.2 Enzyme encapsulation

After electro static attraction, Enzymes attached to soil particles, start to encapsulate them and remove the double layer of water and prevent it from further water adsorption know as structural deformation of the enzyme. This phenomenon depends upon the intra molecular forces of the enzyme (Zoungrana *et al.*, 1997). The rigid enzymes will adsorb less than the softer ones.

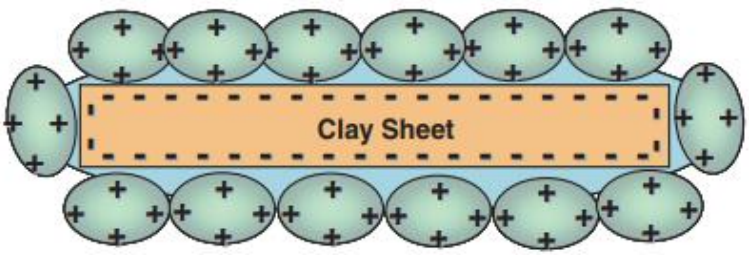


Figure 2.15: Clay particle encapsulated by charged enzymes (Tingle *et al.*, 2007)

2.4.2.3 Enzyme layring

As enzyme is a chain structure, when an enzyme is adsorbed over a particle it starts to unfold itself over it and form a layer, this phenomenon is called enzyme relaxation, it depends greatly upon inter molecular force between soil and enzyme and intra molecular forces between enzymes (Datta *et al.*, 2017).

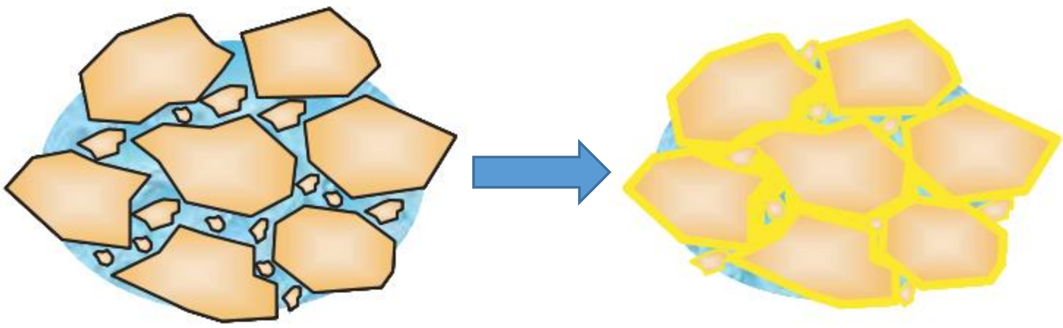


Figure 2.16: Enzymes layered clay particles leading to physical bonding

2.4.2.4 Enzyme-ionic stabilization.

As enzymes have a tendency to act as a base or an acid, they alter the electrolytic balance of the soil, due to this number of cations become available for cation exchange process with soil, this cation exchange causes flocculation between clay particles (Scholen, 1995).

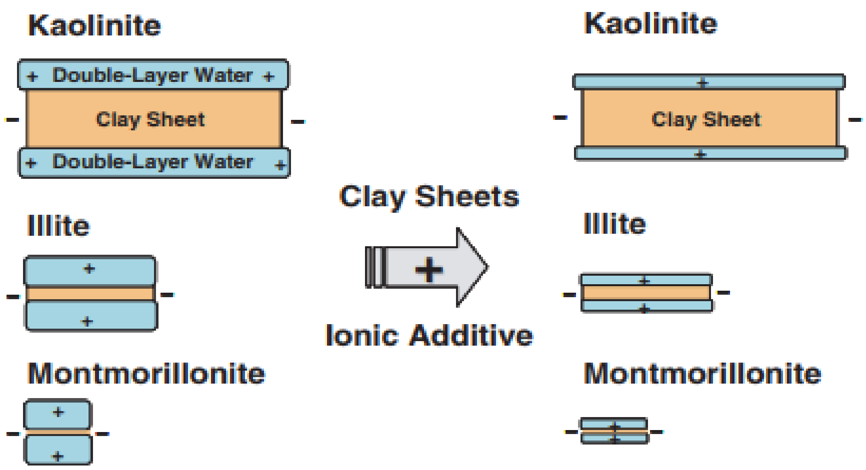


Figure 2.17: Process of clay flocculation due to cation exchange

2.5 FACTORS AFFECTING ENZYME ACTIVITY IN SOIL

2.5.1 Temperature

Temperature has a great impact over the performance of enzyme. The increase in temperature increased the adsorption capacity of Sigmacell 50 and 20 Enzymes. Increase in temperature exposes the hydrophobic structure of the protein, hence enhances the adsorption process. The increase in temperature causes structural changes in the enzyme, which in return enhances the adsorption of enzyme over the sorbent (Datta *et al.*, 2017).

2.5.2 pH

pH plays a crucial role in enzyme activity. A change in pH alters the orientation, nature or even charge of enzyme structure, which might change its nature. A change in pH from 4.8 to 5.5 for certain enzymes reduced their adsorption capacity (Datta *et al.*, 2017). pH at electrostatic point results in a net neutral molecule. At isoelectric point max repulsion in observed in enzymes, hence creating a thicker layer of enzymes which form over the clay particle. At this isoelectric point, maximum adsorption takes place (Bremer *et al.*, 2004).

2.5.3 Moisture in Soil

In natural conditions, soil moisture varies with time due to weather or ground water conditions. The loss in moisture can severely alter the enzyme physical structure, which deactivates the enzyme-soil adsorption process. The change in enzyme physical structure makes it challenging to act at the substrate site as expected, hence reducing the adsorption rate significantly (Liu and Zhu, 2010). The wet and dry cycle creates osmotic stress and leads to bacterial death.

2.5.4 Ion Concentration in Soil

The number of ions already present in soil reduces the enzyme activity. The ions already adsorb over the clay particle, hence creating electric barrier and reduces electrostatic attraction between enzyme and clay particles (K. L. Jones and O'Melia, 2001). These dissolved ions also disrupt the enzyme structure, causing entire change in function.

2.6 TERRAZYME

It is a patent enzyme product of Nature Inc. USA. Extracted from sugarcane and vegetable extracts, Terrazyme is nontoxic, non-corrosive and an environmental friendly soil stabilizer (Natureplus, 2004-2010). The main function of Terrazyme is to reduce the double layer of water around soil particles, which in return increases density and reduces the permeability of the soil, causing resistance to weathering and water erosion.

2.6.1 General

Terrazyme causes permanent alteration in soil particles, hence even it is biodegradable, but it doesn't affect the improved properties of soil (Sheldon and Murphy, 2000). Terrazyme maintains soil moisture, improves cohesion and adds cementing properties to the soil, this also makes it water resistant (Little and Thompson, 1976).

Terrazyme improves the mechanical benefit of compaction, it creates a permanent matrix of soil which doesn't reabsorb water after proper curing (Naagesh and Gangadhara, 2010). Terrazyme is available in concentrated, hence dilution in water is required prior to application to the site (Rajoria and Kaur, 2014).

2.6.2 Soil and Terrazyme

There are certain requirements that a soil needs to ful fill before using Terrazyme as a soil stabilizer.

2.6.2.1 Grain size

As enzymes adsorb only on fine particle, hence there should be at least 10 percent of clay-size fraction in soil (Kestler, 2009).

2.6.2.2 Atterberg limits

For Liquid limit between 50 to 70 percent and Plastic Limit 20 to 35, a significant improvement can be seen in soil (Yusoff *et al.*, 2017).

2.6.2.3 pH

Terrazyme works properly in slightly acidic conditions, i.e, around pH of 5-9 (Natureplus, 2004).

2.6.2.4 Temperature

As enzymes are sensitive to temperature, hence the operating temperature of Terrazyme must be between 16 to 50 ^{o}C (Yusoff *et al.*, 2017). In an organic solvent, it is much stable and resistive to external changes (Saini and Vaishnava, 2015).

2.6.3 Stabilization Mechanism of Terrazyme

Terrazyme when applied to soil, accelerates the process of cation exchange, which in result reduces the double layer (Yusoff *et al.*, 2017). Terrazyme reacts with the adsorbed layer and reduces its thickness, causing the close orientation of particles (Shah, 2016). The electrical charge of water is reduced by Terrazyme, this causes other metal cations to come and adsorb on clay particle causing densification in the matrix (Gupta *et al.*, 2017).

2.7 ADVANTAGES OF TERRAZYME

On basis of results obtained from various project where Terrazyme has been used as a stabilizing material, the manufacturer claims following main advantages of Terrazyme (Natureplus, 2004).

- Increases Durability of Soil
- Makes soil water resistant
- Enhances bearing capacity
- Reduction on construction cost by 20-40 percent by reducing hauling needs.
- Makes site material reusable
- Can be used for granular material along with other additives.
- Increased vehicle capacity of pavement.
- Environmentally safe.
- Reduces pavement cracking

Chapter 3

MATERIALS AND METHODOLOGY

3.1 GENERAL

This research has been carried on CL soil bought from Ballewala, near Nandipur, Pakistan and CH soil was made by mixing 25% bentonite to CL soil. Testing has been conducted according to ASTM and AASHTO standards. The main purpose of selecting this soil for research is its high swelling and shrinking values. All testing was conducted at geotechnical laboratory NICE, Pakistan.

3.2 MATERIAL

This section gives the details about the material used for the conducted research.

3.2.1 Soil

The soil selected was bought from Ballewala, near Nandipur, Pakistan. As this soil is famous for the making of cricket pitches, local people sell it, hence sample batches were obtained from a local vendor. The high plastic soil was artificially formed by mixing 25 percent bentonite with low plastic soil, i.e, Ballewala soil

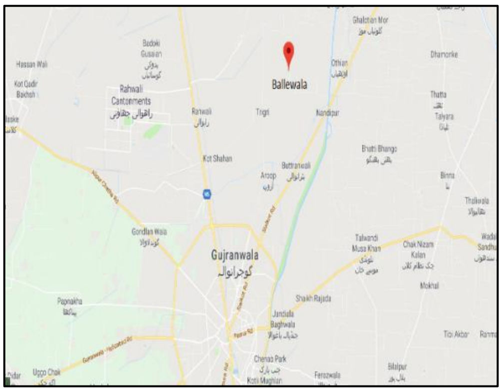


Figure 3.1: Site map

Figure 3.2: Oven dried pulverized soil

3.2.2 Bentonite

Half of the soil obtained from Ballewala was mixed with bentonite so to increase its plasticity. The bentonite was obtained from a local tile manufacturer Ittefaq Tiles, Lahore, Pakistan.

Figure 3.3: Bentonite pile

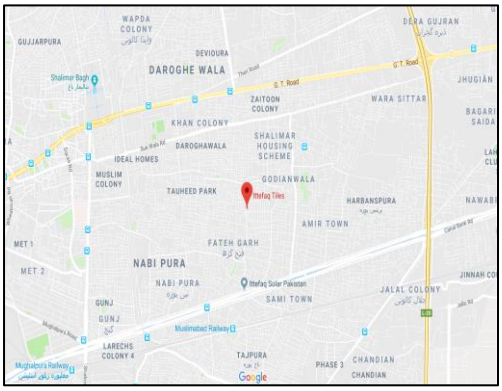


Figure 3.4: Bentonite seller location

Below table shows the composition of Bentonite provided by the vendor. This Bentonite was called as Sodium Bentonite Table 3.1 shows the chemical composition of Bentonite.

Table 3.1: Composition of Sodium bentonite (Tiles, N.D)

Chemical name	Percentage composition
SiO_2	55-65 percent
Al_2O_3	18-22 percent
Fe_2O_3	3-5 percent
MgO	1-3 percent
CaO	0.7-1.32 percent
Na_2O	0.13-1.2 percent
K_2O	0.2-0.56 percent
TiO_2	0.15-0.35 percent

3.2.3 Terrazyme

Terrazyme used in this research was obtained from Natureplus Inc USA. No direct Terrazyme retailer is available in Pakistan right now, however, it can be imported from NaturePlus Inc. USA.

Figure 3.5: Terrazyme bottle

3.3 METHODOLOGY

Testing procedures are divided into three phases as follows:

1. **Phase I**: Characterization of untreated soil
2. **Phase II**: Optimization of Terrazyme dosage
3. **Phase III**: Characterization of treated soil

3.3.1 Phase I: Characteristics of Untreated Soil

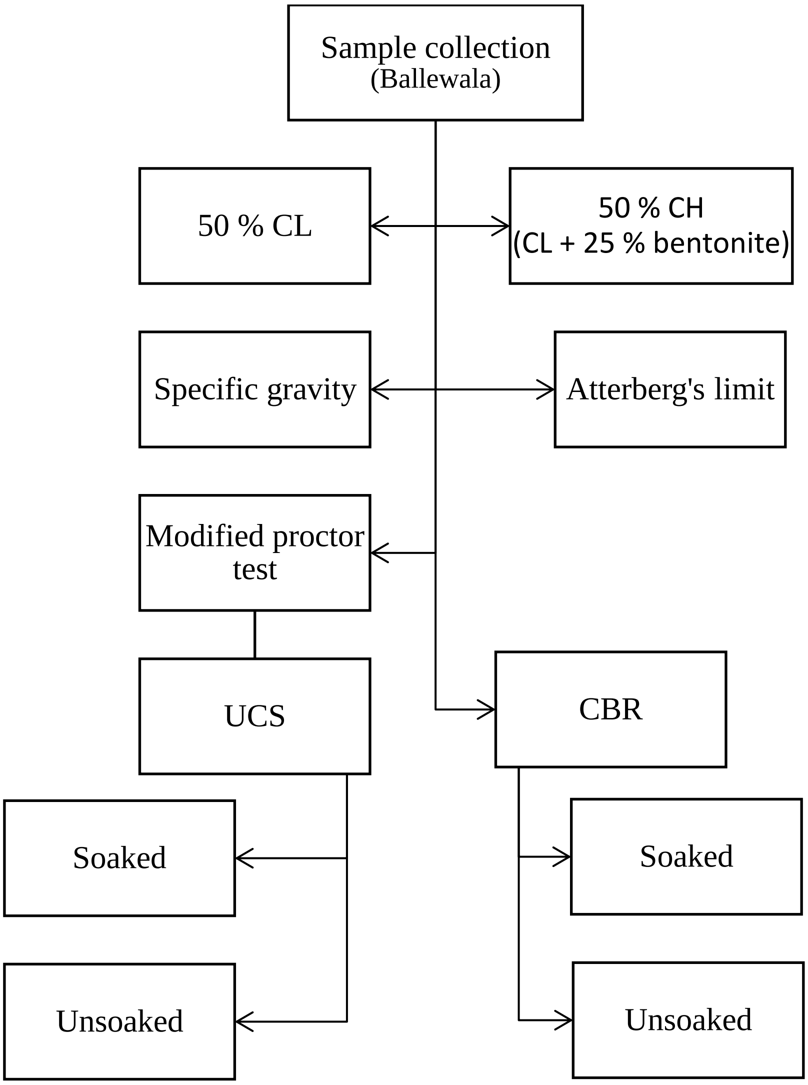


Figure 3.6: Schematic diagram of Phase I

In this phase of testing all index properties and other required properties are tested according to ASTM and AASHTO standards. About hundred kilos of soil was oven dried for 4 days, so too, maximum dry it out then half of the soil was separated, and bentonite was mixed by 25 percent of soil weight. In this way, two types of soils were prepared, i.e, low plastic and high plastic clay.

3.3.1.1 Grain size analysis (GSA)

Grain size analyses were performed as per ASTM D6913-04 standard. As most of the soil is clay and a large portion of particles passed sieve #4, Method B has been adopted for weight measurements. About 500 g of oven dried sample was pulverized for this testing.

3.3.1.2 Hydrometer analysis

Hydrometer analysis was done to find the clay particles in soil passing sieve no 200. This test was performed as per ASTM D7928-16 **s**tandard. As per code particles having dia less than 2 microns are considered clay. Distilled water was used in this test was distilled to ensure accurate results.

3.3.1.3 Atterberg's limits

Atterberg's limits were performed as per ASTM D4318-10 standard. About 200 g of oven dried sample was pulverized and sieved through sieve #40. The liquid limit test was performed with Casagrande apparatus and the plastic limit was performed using 3 mm dia wire.

3.3.1.4 Specific gravity (G_s)

Specific gravity test was performed as per ASTM D854-14 standard. Two tests were performed for each soil sample for a better result. About 30-40 g oven dried soil was used for each test.

3.3.1.5 Moisture-density relation

Modified Proctor test was conducted to find maximum dry density (MDD) and optimum moisture content relation (OMC) as per ASTM D1552-12 standard. Mass retained on sieve #4 is less than 25 percent, hence method A is used. The soil was compacted in 4-inch dia mold into five layers with 25 blows per layer.

3.3.1.6 Cation exchange capacity (CEC)

Cation exchange capacity value has been determined using the liquid limit of the soil. This value was figured after the research carried by (Yilmaz, 2004). CEC value can be correlated with a liquid limit value according to the following equation:

$$CEC = e^{2.63 + 0.02LL}$$

3.3.1.7 California bearing ratio (CBR)

CBR test was performed as per AASHTO T 193-13 standard. Soil was compacted into three layers and each layer was compacted with 65 blows of Modified Proctor Hammer, having a moisture at OMC. Similar procedure was adopted for soaked testing, the prepared samples were then placed into the soaking tank for 96 hours. During soaking the samples were subjected sustain loading of 5 kilos so to check its swell potential.

Figure 3.7: CBR apparatus

Figure 3.8: Samples in the soaking tank

3.3.1.8 Unconfined compressive strength (UCS)

Unconfined compression test was performed as per ASTM D2166-13 standard. The soil was compacted into the UCS mold at 95 percent density (obtained from compaction test). The prepared samples were then left for soaking and curing periods before testing. For excess of moisture testing samples were prepared at 1, 2, 3 and 4 percent of excess moisture. The main reason for excess moisture to see the change in compressive strength when prepared at wet side of OMC.

Figure 3.9: UCS mold and tamper

Figure 3.10: UCS sample testing

For curing, samples were individually wrapped into plastic wraps and then placed into desiccator at 30 ^{o}C temperature as per ASTM D 5102-019. For soaked strength, samples were first cured and then wrapped into bandage gauze and placed into vacuum imperginator for atleast two days.

Figure 3.11: Desiccator for curing

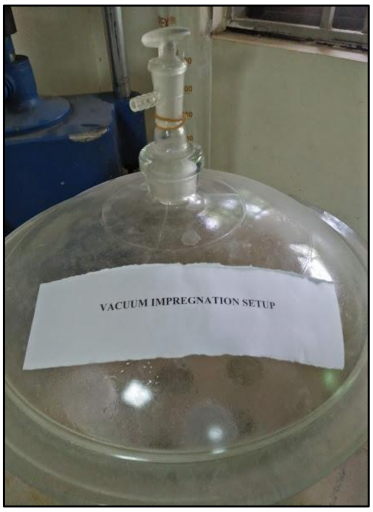


Figure 3.12: Vacuum impreganation setup

Figure 3.13: Samples wrapped for curing

Figure 3.14: UCS failed sample

3.3.2 Phase II: Optimization of Terrazyme Dosage

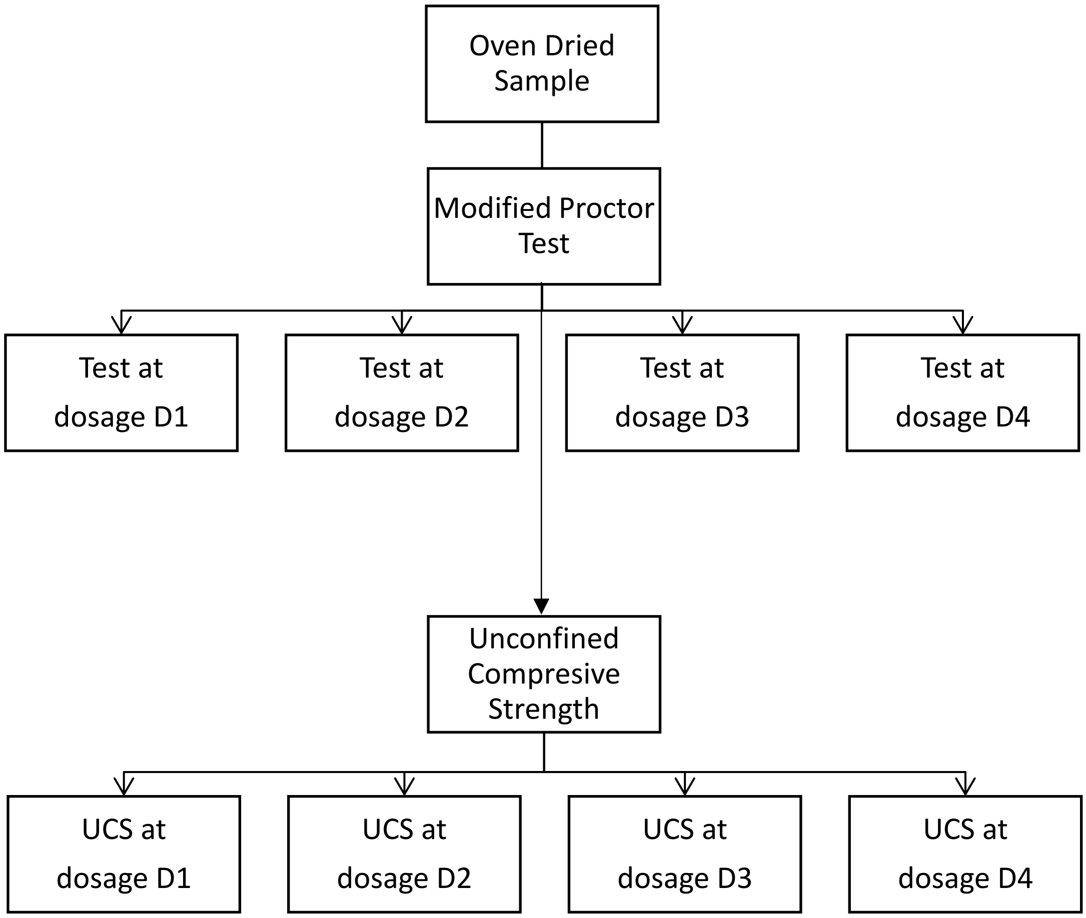


Figure 3.15: Phase II schematic diagram

In this phase of testing diluted dosage of Terrazyme is prepared and then applied to soil under testing as per calculations provided by NaturePlus, Inc.

3.3.2.1 Preparation of diluted stabilizer

First, a known quantity of Terrazyme is added to a calibrated quantity of distilled water and percent dilution is noted. In this case, 10 ml of concentration was diluted into 3000 ml of distilled water making the concentration of Terrazyme of 0.33 percent by volume.

3.3.2.2 Selected dosage

The following table provided by the manufacturer was followed and with the help of data interpolation calculations were done.

In selecting concentrated Terrazyme dosage, we require percentage passing sieve no 200 and plasticity index of the soil. After knowing the PI and fine fraction, the following table is then consulted:

Table 3.2: Relation of soil volume with its PI and percentage fines (Natureplus, 2004)

PI				
30	30 m³	28 m³	26 m³	24 m³
25	33 m³	31 m³	29 m³	27 m³
20	36 m³	34 m³	32 m³	30 m³
15	39 m³	37 m³	35 m³	33 m³
10	42 m³	40 m³	38 m³	36 m³
5	45 m³	43 m³	41 m³	39 m³
% Fines	**15**	**50**	**65**	**115**

After getting the volume of soil for one liter of stabilizer following table is then consulted:

Table 3.3: Terrazyme concentration in liters for given soil volume (Natureplus, 2004)

m3 soil/ Litr. TZ conc.		27	28	29	30	31	32	33
Soil density (kg/m3)	1400	2.65	2.55	2.46	2.38	2.3	2.23	2.16
	1500	2.47	2.38	2.3	2.22	2.15	2.08	2.02
	1600	2.31	2.23	2.16	2.08	2.02	1.95	1.89
	1700	2.18	2.1	2.03	1.96	1.9	1.84	1.78
	1800	2.06	1.98	1.92	1.85	1.79	1.74	1.68
	1900	1.95	1.88	1.81	1.75	1.7	1.64	1.59

3.3.2.3 Selection of terrazyme dosage

Under the light of calculations and literature following four dosages of Terrazyme were selected:

- D1➔ 200ml/3.0 m^3
- D2➔ 200ml/2.5 m^3
- D3➔ 200ml/2.0 m^3
- D4➔ 200ml/1.5 m^3

3.3.2.4 Soil and terrazyme mix

After performing modified proctor test, the selection of dosage was done using MDD and OMC of the soil. During stabilization, the total mass of soil was noted and divided by the MDD of the soil as to get the volume. After knowing the volume, the volume of diluted Terrazyme was drawn out of the can and applied to the soil.

3.3.3 Phase III: Characteristics of Treated Soil

This is the final phase of testing; effect on properties of stabilized soil at optimum stabilizer content is tested and then compared with the soil properties obtained in phase I.

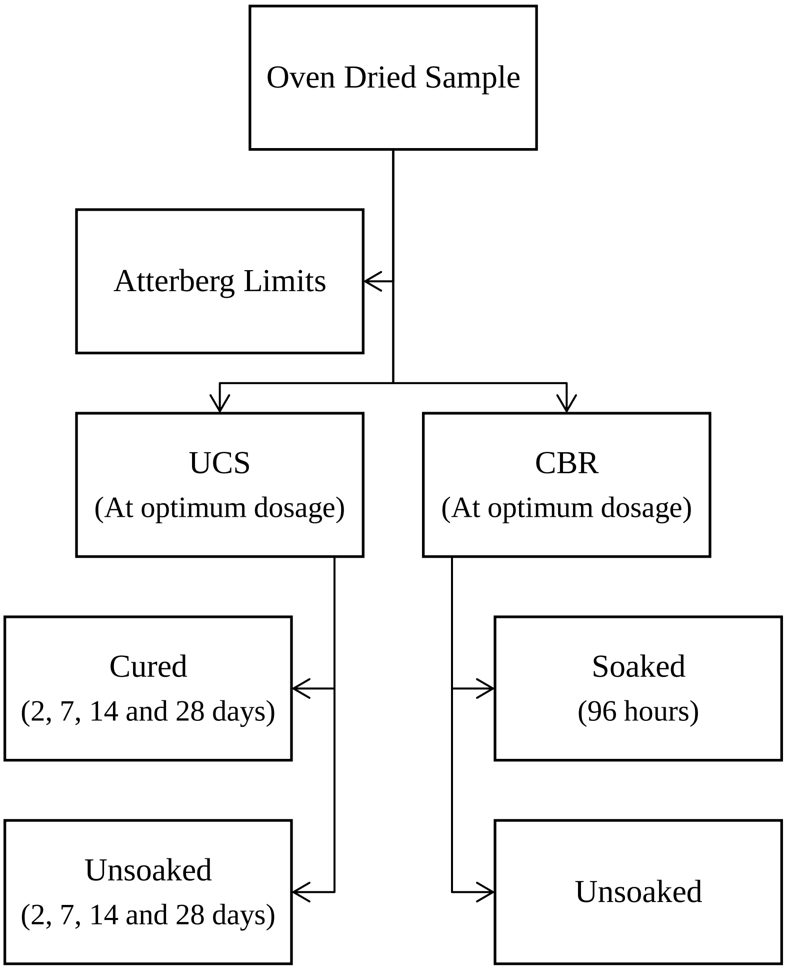


Figure 3.16: Phase III schematic diagram

3.3.3.1 Atterberg's limits

In this testing liquid limit, plastic limit and plasticity index of the soil was tested and the effect of Terrazyme as per and the trends were plotted.

3.3.3.2 Cation exchange capacity (CEC)

After knowing Atterberg's limits CEC value was calculated from correlation provided by (Yilmaz, 2004).

3.3.3.3 Modified proctor test

Modified proctor test was conducted to check the effect of Terrazyme on the OMC and MDD of soil.

3.3.3.4 Unconfined compressive strength (UCS)

UCS testing was done only for the sample containing optimum Terrazyme dosages. The main aim was to test a sample for cured and un soaked conditions and to compare it with the original one, so to check the level of improvement due to Terrazyme. Samples were cured for of 2, 7, 14 and 28 days. Four soaking samples were subjected to capillary action of water in the soaking tank for 48 hours before testing.

3.3.3.5 California bearing ratio (CBR)

CBR of treated soil was determined as per AASHTO T-193 standard. Samples were prepared at OMC obtained from modified proctor test. Each sample was compacted in 3 layers and 65 blows were applied to each layer. Soaked and un soaked tests were carried out. For soaked testing, samples were soaked in water for 96 hours. After 96 hours CBR test was conducted. The swell potential was determined.

Chapter 4

RESULTS AND DISCUSSION

4.1 GENERAL

A detail investigation of natural and treated soil has been carried out. MPT, UCS, CBR and other tests were performed to check the feasibility of Terrazyme as a stabilizing agent. Trends were observed, and comparison has been made between treated and un treated soil. Index properties of each soil have been found. Five MPT samples were made for each soil and their OMC and MDD was observed. A total of 68 UCS samples were carried out at different dosages. Curing and soaking periods. CBR test was performed at each optimum Terrazyme dosage for each soil. UCS testing is done at 95 percent of MDD obtained from MPT.

Generally, the increase in MDD up to a certain dosage of Terrazyme is observed, overdosing leads to decrease in density while OMC keeps on increasing. UCS value increased significantly especially at 14 days of curing, while for 28 days not much significant increase in strength was observed. Similar behavior was observed for CBR, at optimum dosage CBR values for soaked and un soaked sample increased and swelling decreased. Other properties like Atterberg’s limits and CEC has also changed with the addition of Terrazyme.

4.2 PHASE I: SOIL CHARACTERIZATION

At the very first phase of testing all properties of soils were found as per testing mentioned earlier and classification is done accordingly. Results obtained in this phase will be considered as bench mark for further soil testing using Terrazyme and comparison will be made accordingly.

4.2.1 Grain Size Analysis (GSA)

The very first testing of this phase, Sieve analysis was done for both soils and results graph between sieve opening and percentage passing is plotted.

4.2.1.1 Low plastic clay

For low plastic clay it has been observed that 96 percent of soil has passed sieve no 200. Figure 4.1 gives graphical representation of grain size analysis of low plastic clay.

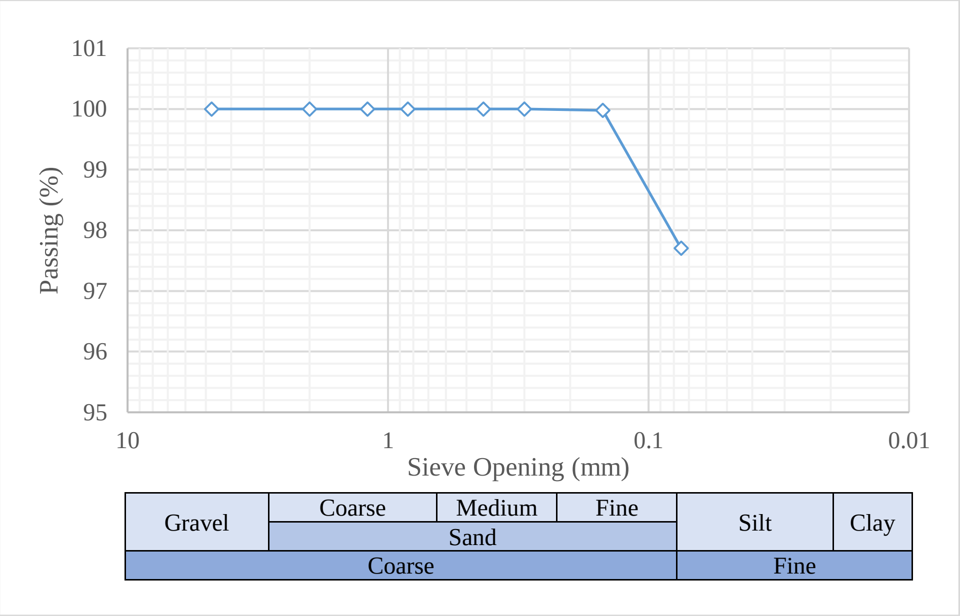


Figure 4.1: Grain size distribution CL

4.2.1.2 High plastic clay

For high plastic clay it has been observed that 99 percent of soil has passed sieve no 200. Figure 4.2 gives graphical representation of grain size analysis of high plastic clay.

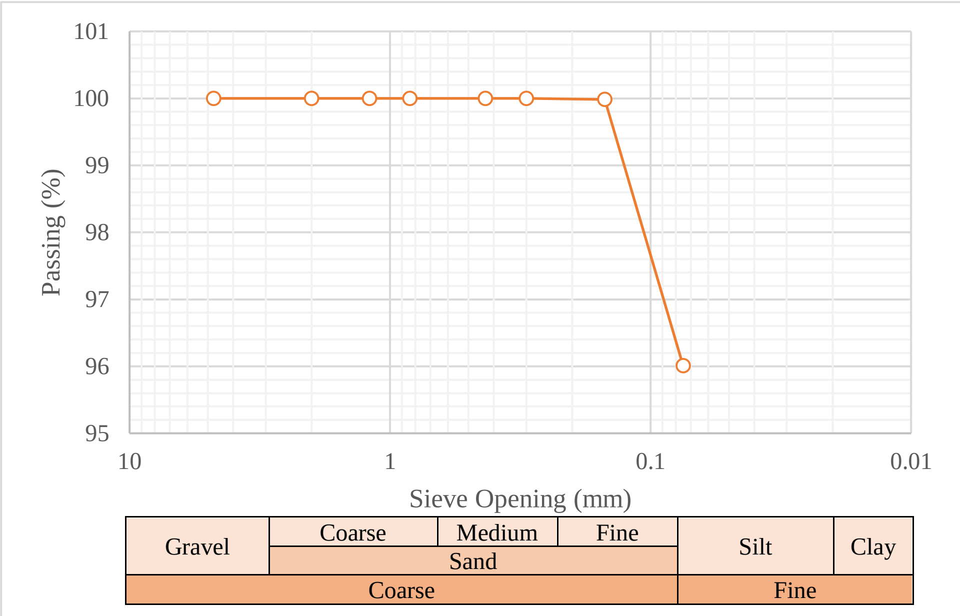


Figure 4.2: Grain size distribution CH

4.2.2 Hydrometer Analysis

Hydrometer analysis were done for both soils as per ASTM standard. Before testing as Sodium Hexa meta phosphate $(NaPO_3)_6$ solution was prepared a day before the testing in a distilled water. Oven dried sampled was pulverized and 20 g of sample was passed from sieve no 200. One liter of graduated cylinder was prepared, and the sample was thoroughly mixed into it. Mercury hydrometer 152H was used. Mixed soil and solution were then left to settle, temperature and hydrometer readings were obtained at different intervals of time.

4.2.2.1 Low plastic clay

From the graph below soil, finer than 2 microns is about 26 percent.

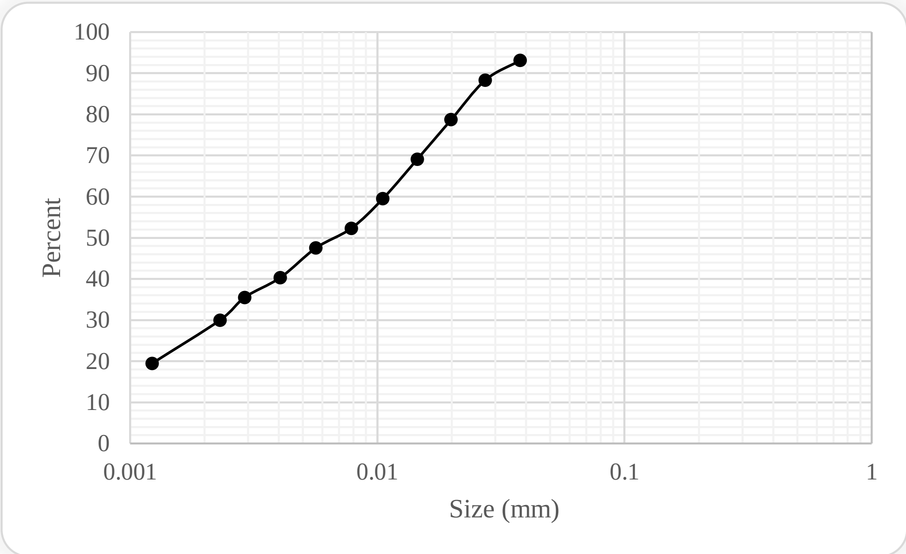


Figure 4.3: Low plastic clay Hydrometer analysis.

4.2.2.2 High plastic clay

From the graph below soil finer than 2 microns is about 28 percent.

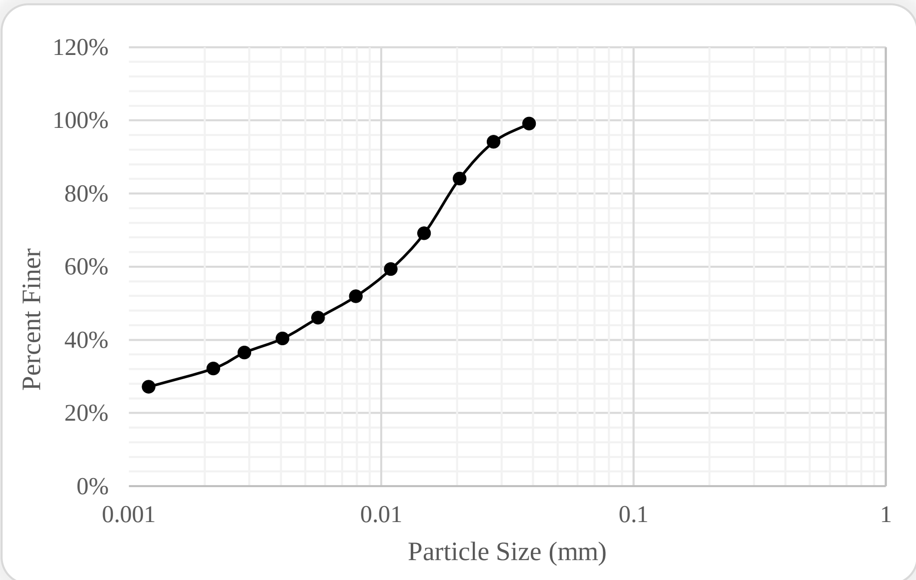


Figure 4.4: High plastic clay Hydrometer analysis.

4.2.3 Atterberg's Limits

- CL ➔
- CH ➔

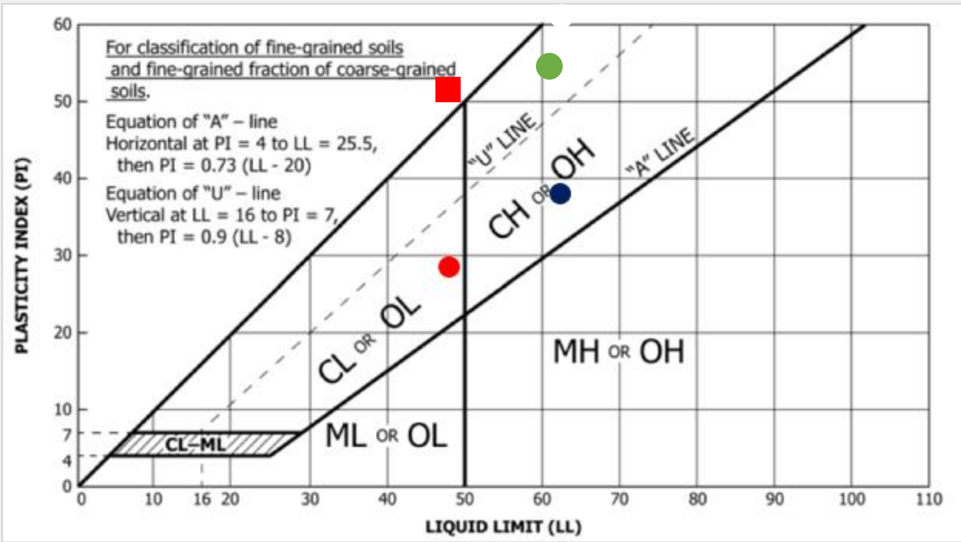


Figure 4.5: Casagrande plasticity chart

The Atterberg limits showed the that soil obtained from Ballewala had LL of 49.6 percent and PI of 27 percent, while soil made by mixing 25 percent Bentonite had LL of 61.9 percent and PI of 31.9 percent. According to Figure 4.5 soil obtained from Ballewala falls in the category of low plastic clay and soil made by mixing Bentonite falls in the category of high plastic clay, i.e, CH.

4.2.4 Specific Gravity (G_s)

This test was done according to ASTM D 854-14 standard. About 50 grams of each oven-dried sample was passed from sieve no 40. A 250 ml graduated flask was quarterly filled with distilled water and the sample was thoroughly mixed with the soil sample. Flasks were then set on a heated plate and left for boiling so to remove air voids. After boiling, the flask was filled up to marked graduation, temperature and weights were noted. After 24 hours of temperature settlement, the water level dropped, and the flask was refilled up to graduation mark and readings were noted.

4.2.4.1 Low plastic clay

The value of specific gravity of CL soil is 2.67.

4.2.4.2 High plastic clay

The value of specific gravity of CH soil is 2.70.

4.2.5 Cation Exchange Capacity (CEC)

CEC value has been determined using correlation provided by (Yilmaz, 2004).

$$CEC = e^{2.63 + 0.02LL}$$

4.2.5.1 Low plastic clay

CEC was calculated as 37.4 meq/100g.

4.2.5.2 High plastic clay

CEC was calculated as 47.8 meq/100g.

4.2.6 Soil Classification

Both soils are classified according to two classification systems, i.e., USCS and AASHTO classification system.

4.2.6.1 AASHTO

1. Soil-1- (CL)
   - LL = 48
   - PI = 29
   - More than 35 percent passing #200 ➔YES
   - AASHTO group A-7-6.
2. Soil-2- (CH)

- LL = 63
- PI = 38
- More than 35 percent passing #200 ➔YES
- AASHTO group A-7-6.

4.2.6.2 Unified soil classification system (USCS)

As per USCS standards CL has LL less than 50 percent, is inorganic, PI plots above 'A' line, hence it is Lean clay.

As per USCS standards CH has LL greater than 50 percent, is inorganic, PI plots above 'A' line, hence it is fat clay.

4.2.7 Moisture-Density Relation

Moisture and density relation for both soils were found out using modified Proctor effort. It has been found that CL has MDD of 1.84 g/cm^3 @ 11.8 percent OMC, while CH has MDD of 1.80 g/cm^3 @ 12.5 OMC. The change in OMC is because bentonite absorbs more water than the normal soil. The change in MDD is due to the heaviness of CL particles than the bentonite particles per given volume. Following graphs show the modified proctor test curves for both soils.

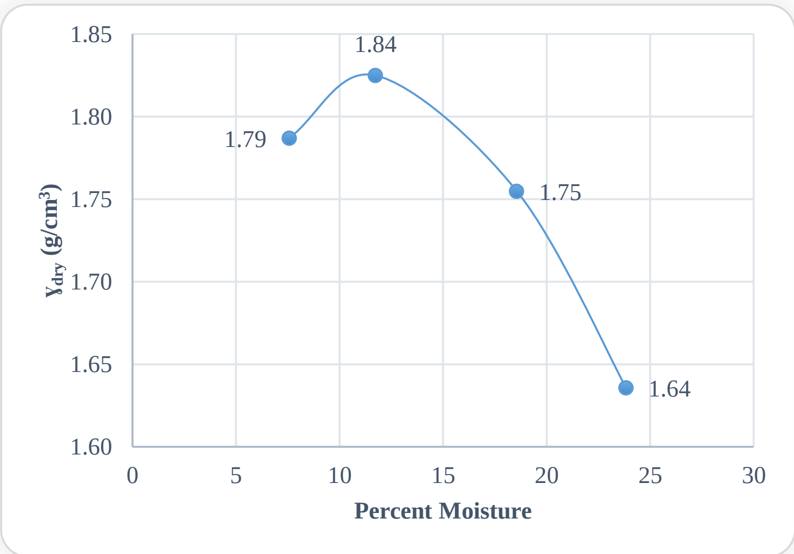


Figure 4.6: Modified proctor test (CL)

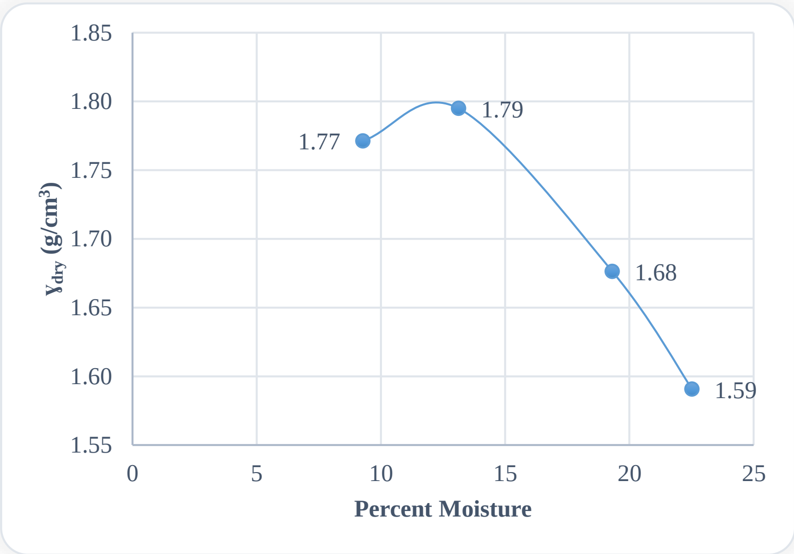


Figure 4.7: Modified proctor test (CH)

4.2.8 Unconfined Compressive Strength (UCS)

This test was performed at 95 percent of MDD and OMC of respective soil. All UCS sample was prepared at 95 percent of MDD so to check the maximum achievable strength. Untreated UCS (no curing and soaking) for CL is 25.5 psi and for CH is 33.2 psi. This change in strength could be due to extra cohesion in CH soil due to bentonite particles. The following two graphs show the strain vs strength curve of both samples.

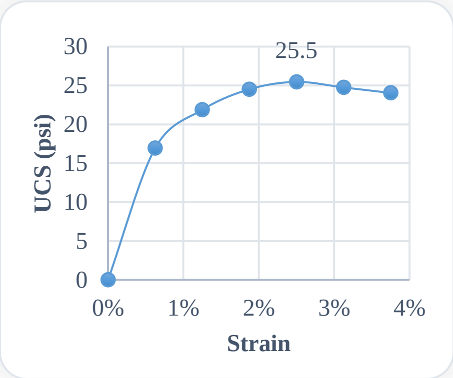


Figure 4.8: Unconfined compressive strength CL

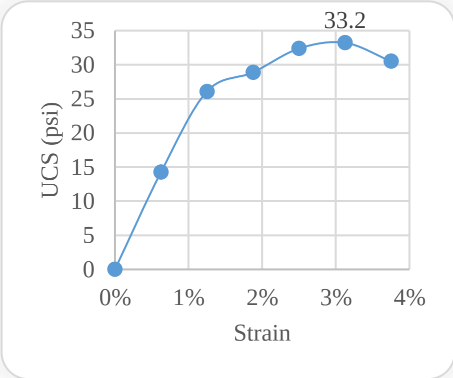


Figure 4.9: Unconfined compressive strength CH

4.2.9 California Bearing Ratio (CBR)

CBR test was done as per AASHTO T-193 standards. CBR for soils was tested for both soaked and un soaked conditions. For CL the un soaked value of CBR came out to be 3.6 while in the soaked condition it reduced to 2.2, while for CH, CBR value for un soaked condition was 2.7 and in the soaked condition it reduced to 1.2. The reason for soaking is to incorporate actual scenario for soil in the worst condition. Following graphs show the penetration vs stress graph obtained from CBR tests of both soils.

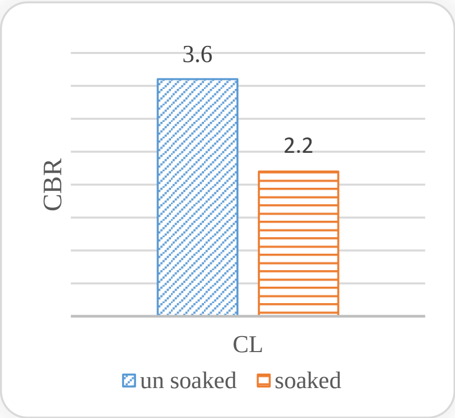


Figure 4.10: Low plastic Clay

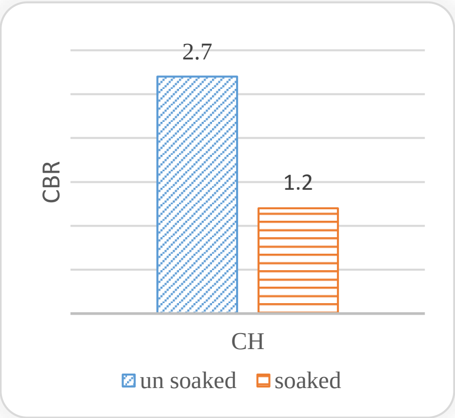


Figure 4.11: High plastic clay

4.2.10 Swell Potential

The swell potential was calculated as per AASHTO T-193 by soaking CBR samples mould in a water tank for 96 hours, the samples were subjected to surcharge load of 5.0 kg. After 96 hours the change in height to the original height of soaked sample gives the swell potential of the soil.

4.2.10.1 Low plastic clay

The swell potential value for CL is 5.58 percent.

4.2.10.2 High plastic clay

The swell potential value for CH is 7.30 percent.

4.2.11 Soil Classification Summary

Table 4.1: Summary of soil index properties

Property	Unit	CL	CH
Passing # 200	Percent by mass (percent)	96	99
Clay Size Fraction < 0.002 mm	Percent by mass passing # 200 (percent)	26	28
Liquid Limit	Moisture (percent)	49.6	61.9
Plastic Limit	Moisture (percent)	22.6	30
Plasticity Index	Moisture (percent)	27	31.9
Specific Gravity (G_s)	Ratio (unitless)	2.67	2.70
Swell Potential	Change in height (percent)	5.58	7.30
Cation Exchange Capacity (CEC)	Meq / 100g	37.4	47.8
Index category	Casagrande's chart	CL	CH
AASHTO Classification	Table	A-7-6	A-7-6
USCS Classification	Nomogram	Lean Clay	Fat Clay
Maximum Dry Density	(g/cm^3)	1.84	1.80
Optimum Moisture Content	Moisture (percent)	11.8	12.5
Unconfined Compressive Strength (UCS)	psi	25.5	33.2
California Bearing Ratio (CBR)	Unitless	3.6	15.8

4.3 PHASE II: OPTIMIZATION OF TERRAZYME DOSAGE

In this phase selected dosage of Terrazyme is added to both soil and further testing is done as follows:

4.3.1 Terrazyme Dosage

Before preparing the Terrazyme dosage, a detailed study of the company's recommendations, once soil feasibility was satisfied further calculation was done as per company's calculation tables.

4.3.1.1 Dilution of terrazyme in water

10 ml of concentrated Terrazyme was diluted in 3000 ml of distilled water making a dilution of 1:300 or 0.33 percent by volume.

4.3.1.2 Preparation of dosage

PI						
40	24 m^3	22 m^3	20 m^3	18 m^3	16 m^3	14 m^3
35	27 m^3	25 m^3	23 m^3	21 m^3	19 m^3	17 m^3
30	30 m^3	28 m^3	26 m^3	24 m^3	22 m^3	20 m^3
25	33 m^3	31 m^3	29 m^3	27 m^3	25 m^3	23 m^3
20	36 m^3	34 m^3	32 m^3	30 m^3	28 m^3	26 m^3
15	39 m^3	37 m^3	35 m^3	33 m^3	31 m^3	29 m^3
10	42 m^3	40 m^3	38 m^3	36 m^3	34 m^3	32 m^3
5	45 m^3	43 m^3	41 m^3	39 m^3	37 m^3	35 m^3
0	15	50	85	120	155	190
% Fines						

Figure 4.12: Soil volume table for Terrazyme

From the above Figure 4.13, percentage fines and PI for CL soil lies between 50-85 percent and 35-40 percent respectively, similarly for CH soil the percentage fines and PI lies between 50-85 percent and 25-30 percent respectively. The corresponding values to % fines and PI gives the volume of soil that can be treated with 1 liter of Terrazyme.

Interpolating the above data, it has been found that 21.54 m^3 of CL can be stabilized by one-liter. of Terrazyme and 26.8 m^3 of CH can be treated with one-liter Terrazyme.

The data obtained from above Figure 4.12 is then used in coordination with Table 4.2 containing the density relations so to find actual dosage required in ml. As the density of CL and CH is 1820 kg/m^3 and 1800 kg/m^3 respectively and volume of soil per liter of Terrazyme is 21.54 and 26.8 cubic meter. From the table below the required amount of Terrazyme per kg of soil is 0.024 liters. for CL and 0.021 liters. for CH.

Table 4.2: Terrazyme dosage for 1m^3 of soil

m3 soil/ Litr. TZ conc.		**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Soil density (kg/m3)	**1400**	3.35	3.25	3.15	3.05	2.95	2.85	2.75	2.65	2.55	2.46	2.38
	1500	3.1	3.01	2.92	2.83	2.74	2.65	2.56	2.47	2.38	2.3	2.22
	1600	2.87	2.79	2.71	2.63	2.55	2.47	2.39	2.31	2.23	2.16	2.08
	1700	2.74	2.66	2.58	2.5	2.42	2.34	2.26	2.18	2.1	2.03	1.96
	1800	2.62	2.54	2.46	2.38	2.3	2.22	2.14	2.06	1.98	1.92	1.85
	1900	2.44	2.37	2.3	2.23	2.16	2.09	2.02	1.95	1.88	1.81	1.75

According to company specifications it has been mentioned to consult the above method only if lab testing facility is not available otherwise each soil should be tested for optimum dosage selection.

Four different dosages are selected for the stabilization of both CL and CH soil which are as follows:

- D1 ➔ 200ml/3.0m^3
- D2 ➔ 200ml/2.5m^3
- D3 ➔ 200ml/2.0m^3
- D4 ➔ 200ml/1.5m^3

4.3.2 Moisture-Density Relation

All four dosages were added to both soils and Modified Proctor test was performed one by one. It has been seen that CL soil gave optimum value at dosage D1 whereas CH soil gave optimum density value at dosage D2. The main reason for the increase in density is that due to the availability of exchange able cations. The double layer has reduced, and soil particles are reoriented into a denser configuration. While on further increment in dosage the reduction in MDD is because soil is being replaced by excess of water added to it.

4.3.2.1 Low plastic clay

As the dosage of Terrazyme increased the MDD increased from 1.84 g/cm^3 to 1.865 g/cm^3 with OMC increased from 11.8 percent to 12.5 percent percent. Further increment in dosage decreased MDD from 1.865 g/cm^3 to 1.824 g/cm^3 while OMC kept on increasing, i.e, 12.5 percent to 14.5 percent.

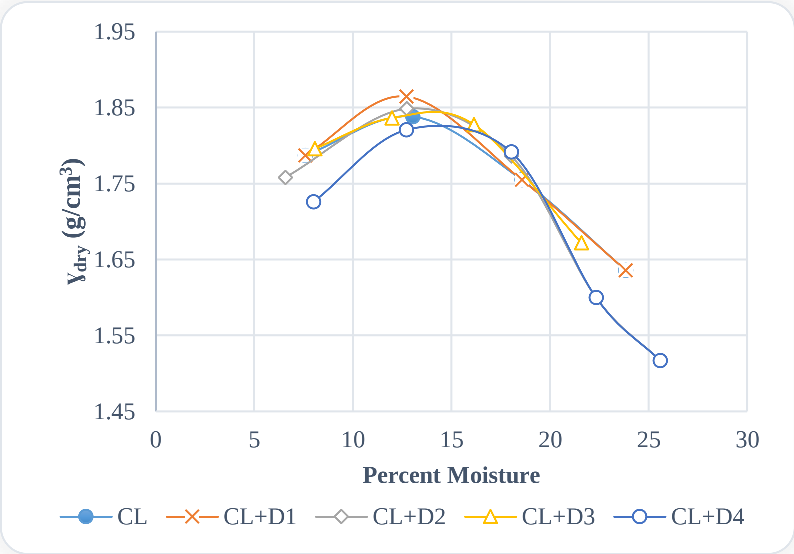
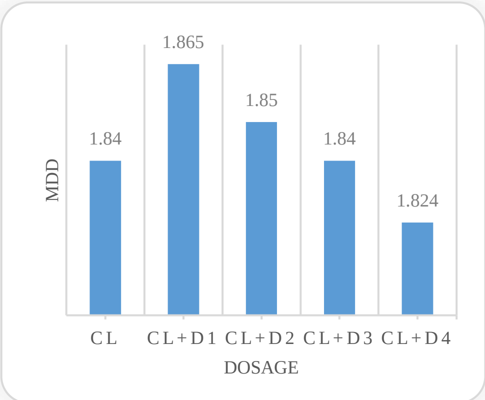


Figure 4.13: Modified proctor test trends of CL with increasing Terrazyme dosage



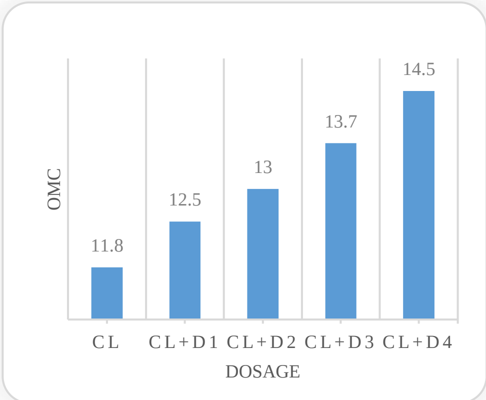


Figure 4.14: MDD trend with increasing Terrazyme dosage

Figure 4.15: OMC trend with increasing Terrazyme dosage

4.3.2.2 High plastic clay

As the dosage of Terrazyme increased the MDD increased from 1.80 g/cm^3 to 1.825 g/cm^3 with OMC increased from 12.5 percent to 14 percent percent. Further increment in dosage decreased MDD from 1.825 g/cm^3 to 1.78 g/cm^3 while OMC kept on increasing, i.e, 14 percent to 15 percent.

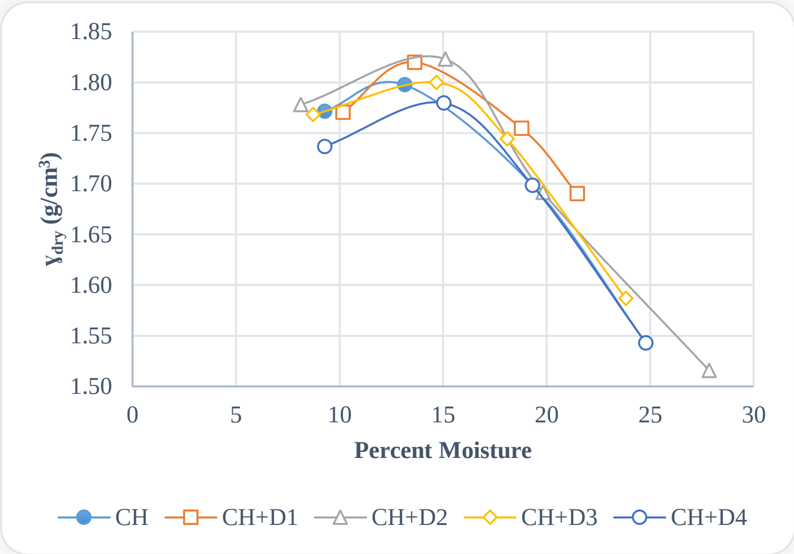


Figure 4.16: Modified proctor test trends of CH with increasing Terrazyme dosage

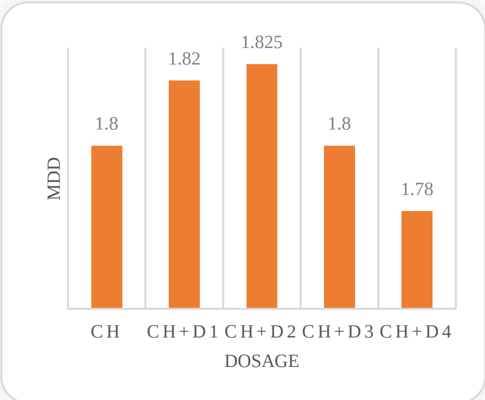


Figure 4.17: MDD trend with increasing Terrazyme dosage

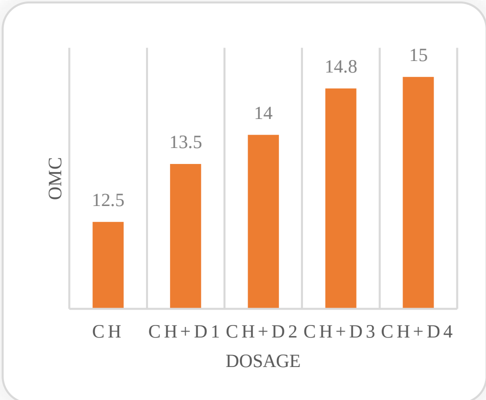


Figure 4.18: OMC trend with increasing Terrazyme dosage

4.3.3 Unconfined Compressive Strength

After performing modified proctor test UCS tests were performed at 95 percent of MDD obtained for different dosages of Terrazyme. Samples were prepared and wrapped into a plastic sheet and then left for a day, so that enzyme could complete its reaction without any loss in moisture.

4.3.3.1 Low plastic clay

It has been seen that CL soil gave maximum value at dosage D1. The value increased from 25.5 psi to 42.0 psi and on further addition of Terrazyme, this value decreased to 23.2 psi.

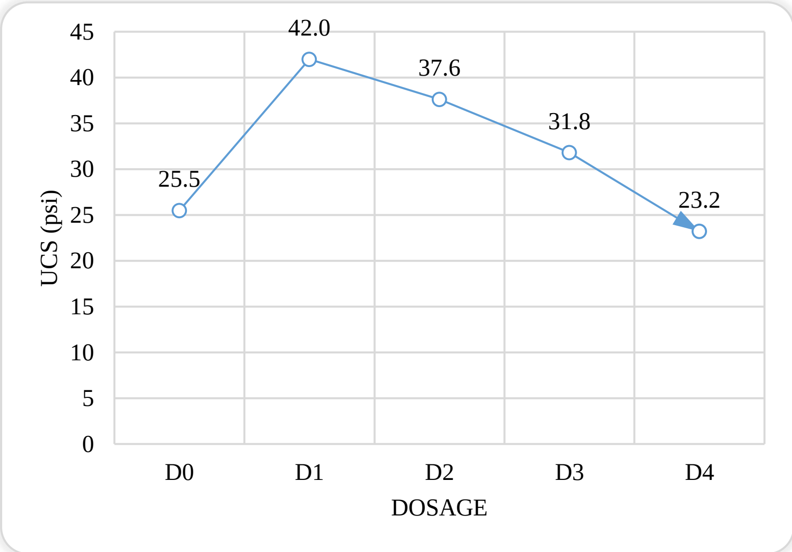


Figure 4.19: Unconfined compressive strength at different dosage (CL)

4.3.3.2 High plastic clay

It has been seen that CH soil gave maximum value at dosage D2. The value increased from 33.2 psi to 55.2 psi and on further addition of Terrazyme this value decreased to 45.4 psi.

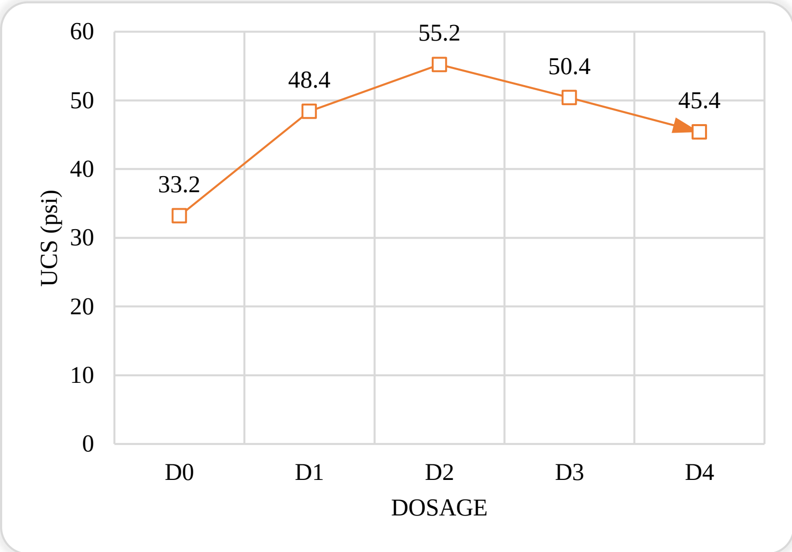


Figure 4.20: Unconfined compressive strength at different dosage (CH)

4.3.3.3 Comparison CH and CL

Figure 4.21 shows the combined results of UCS for CL and CH soil at different dosages of Terrazyme.

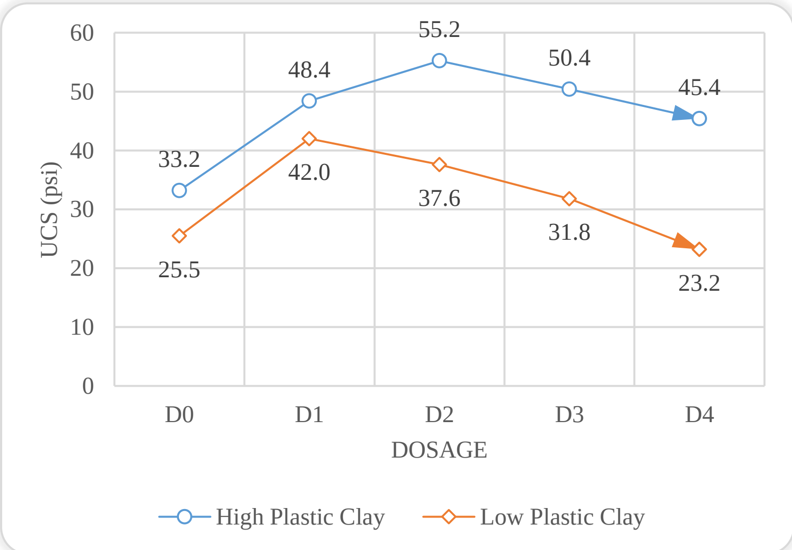


Figure 4.21: Comparison between un confined compressive strength of CL and CH

4.3.4 Atterberg's Limits

Atterberg's limit test was performed to check the effect of Terrazyme on the consistency limits of the soil. The change in liquid limit tells us the effect on double layer around the clay particle. The change in plastic limits tells us the wetting effect imparted to the soil by addition of Terrazyme dosage.

4.3.4.1 Low plastic clay

In the case of CL soil, it has been observed that with the addition of Terrazyme the liquid limit reduced from 49.6 to 45. While at optimum dosage content it is 47.7. Figure 4.22 gives graphical trend between Terrazyme dosage and liquid limit.

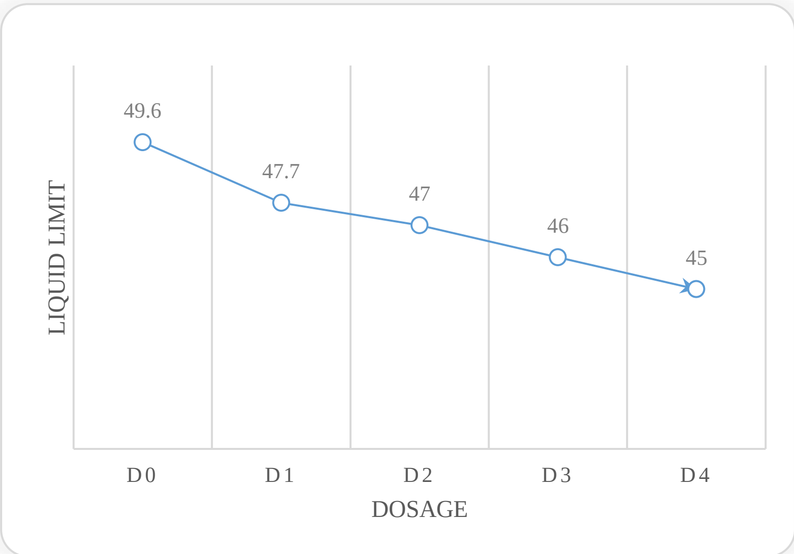


Figure 4.22: Liquid limit at different Terrazyme dosages (CL)

As Terrazyme increases wetting process between soil particle, hence causing an increase in the plastic limit of a soil. Figure 4.23 represents the Trend in the plastic limit of soil with increasing the dosage of Terrazyme.

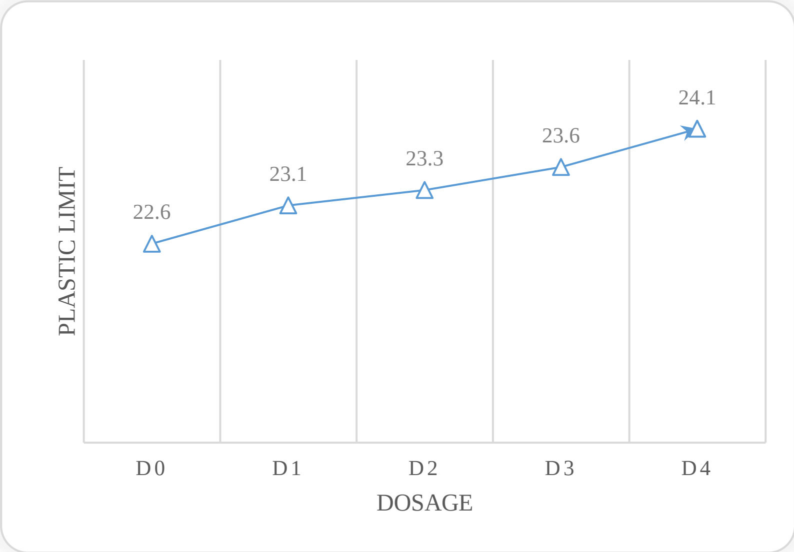


Figure 4.23: Plastic limit at different Terrazyme dosages (CL)

Plasticity index is the difference between the liquid limit and plastic limit. The increase in plastic limit and a decrease in liquid limit automatically reduces the plasticity index of soil as the dosage of Terrazyme is increased. The trend between the plasticity index and the Terrazyme dosage is shown in Figure 4.24 below.

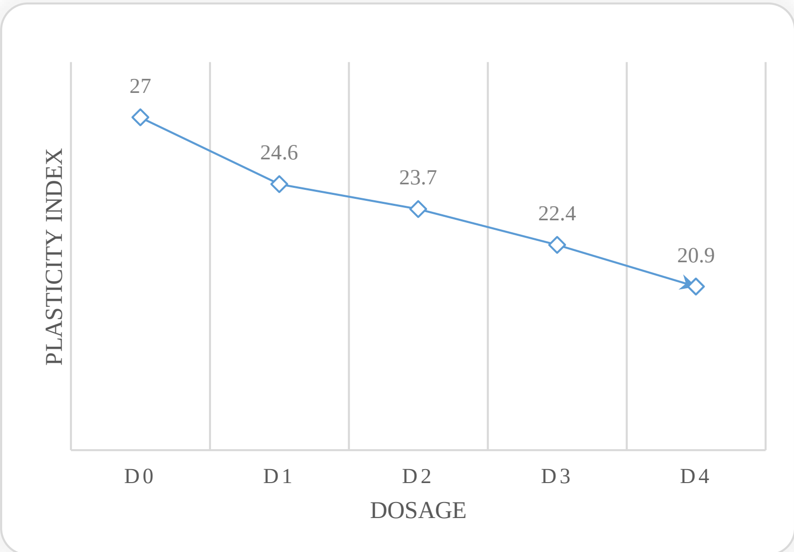


Figure 4.24: Change in plasticity index with Terrazyme (CL)

4.3.4.2 High plastic clay

In the case of CH, it has been observed that with the addition of Terrazyme the liquid limit reduced from 61.9 to 54.2. While at optimum dosage content it is 56.7. Figure 4.25 gives a graphical trend between Terrazyme dosage and liquid limit.

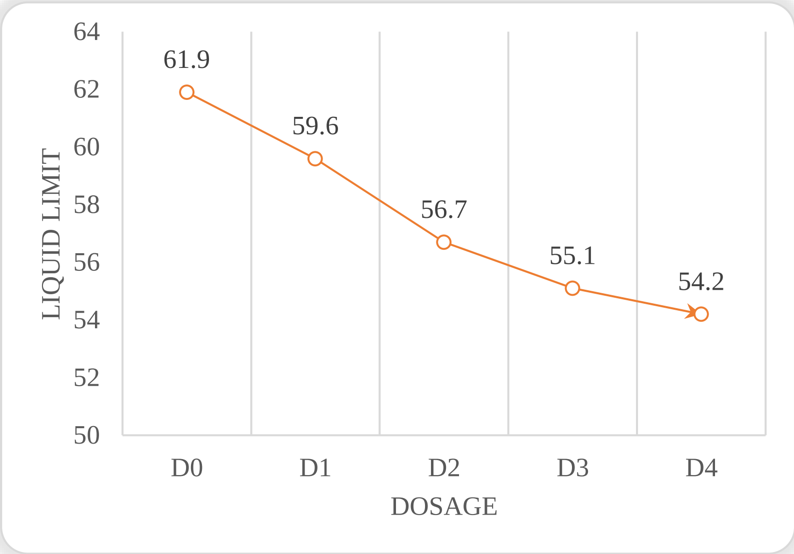


Figure 4.25: Liquid limit at the different Terrazyme dosage (CH)

As Terrazyme increases wetting process between soil particle, hence causing an increase in the plastic limit of a soil. Figure 4.26 represents the trend in the plastic limit of soil with increasing the dosage of Terrazyme.

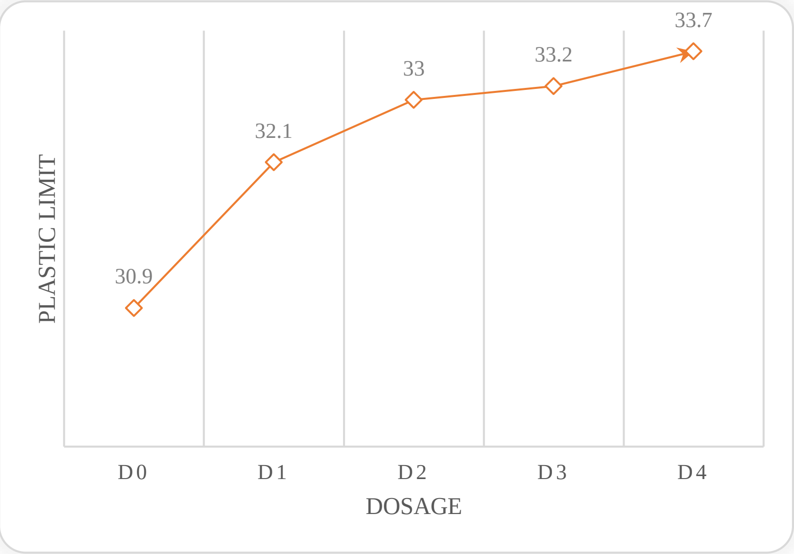


Figure 4.26: Plastic limit and Terrazyme (CH)

Plasticity index is the difference between the liquid limit and plastic limit. The increase in plastic limit and a decrease in liquid limit automatically reduces the plasticity index of soil as the dosage of Terrazyme is increased. The trend between the plasticity index and the Terrazyme dosage is shown in Figure 4.27 below.

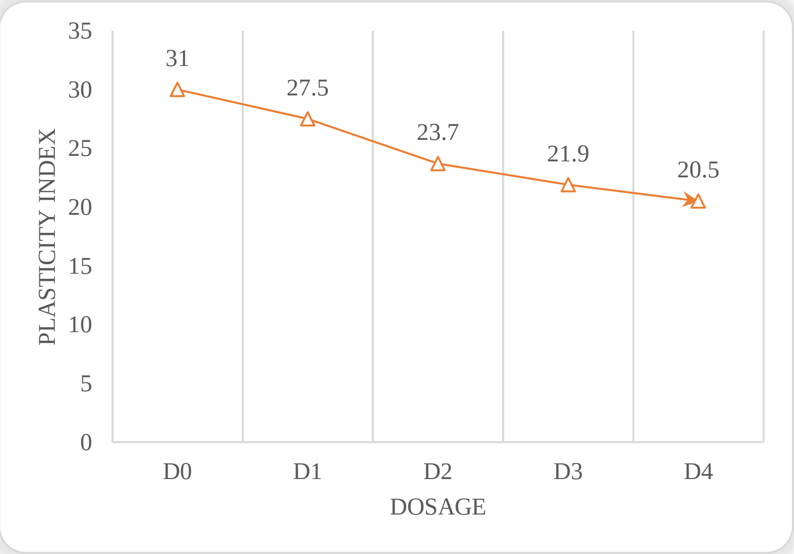


Figure 4.27: Change in plasticity index with Terrazyme (CH)

4.3.5 Cation Exchange Capacity (CEC)

Terrazyme has great effect over CEC value of soil. To study the effect of Terrazyme over soil CEC value, CEC value has been calculated using correlation provided by (Yilmaz, 2004). Reduction in CEC value is observed in both soils, this is due to Terrazyme. As Terrazyme produced enough exchangeable cations in soil that an isoelectric condition has been established around the clay particle. This prevents the clay particle to further attract the exchangeable cations present in the soil, hence causing a reduction in CEC value.

4.3.5.1 Low plastic clay

CEC of soil decreased from 37.4 to 34.1. The CEC value at optimum dosage D1 is 36.0 meg/100g. Figure 4.28 below shows the trend in CEC value as the dosage of Terrazyme increased.

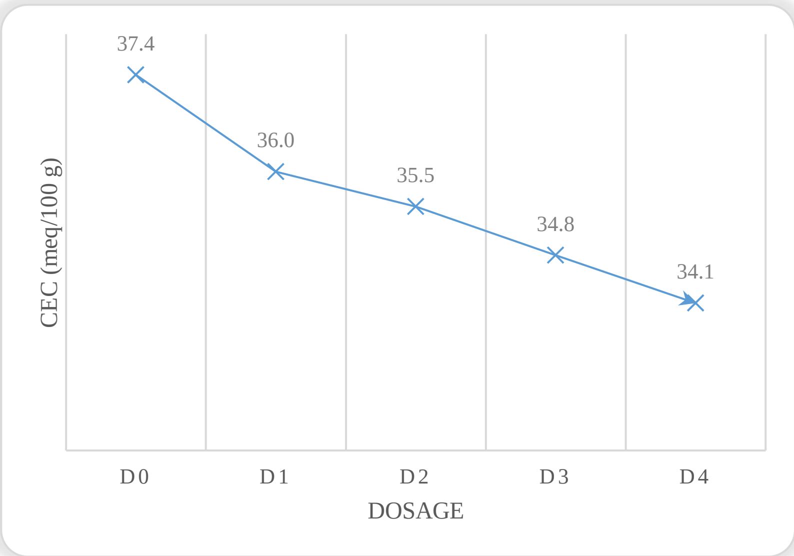


Figure 4.28: Change in CEC value with Terrazyme (CL)

4.3.5.2 High plastic clay

CEC value of soil decreased from 47.8 to 41.0. The CEC value at optimum dosage D2 is 43.1 meg/100g. Figure 4.29 below shows the trend in CEC value as the dosage of Terrazyme increased.

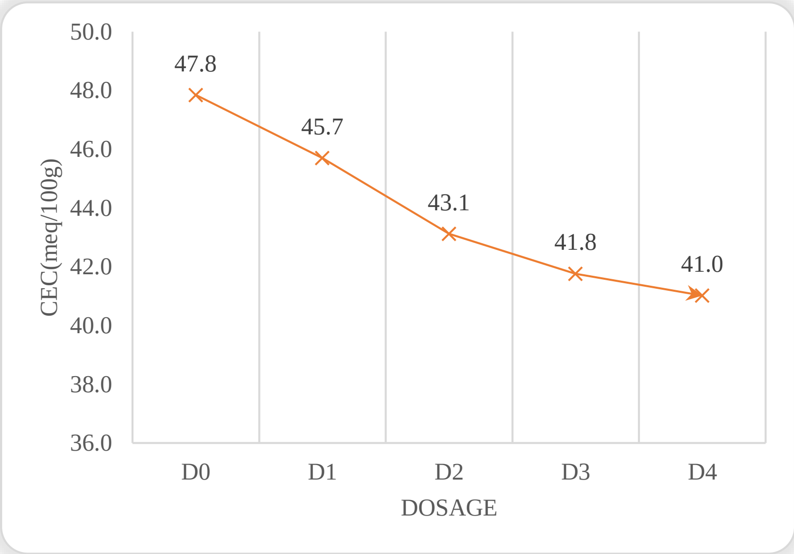


Figure 4.29: Change in CEC value with Terrazyme (CH)

4.4 PHASE III: PROPERTIES OF TREATED SOIL

In this phase of testing, soils with optimized Terrazyme contents were subjected to different tests.

4.4.1 California Bearing Ratio (CBR)

CBR value of soil greatly depends upon the density of soil. In this test, CBR mold was prepared using an optimum dosage of Terrazyme at OMC. A significant increase in CBR value has been observed. This is due to the increase in MDD due to the addition of Terrazyme.

CBR samples were also soaked as per AASHTO T-193 standards for 96 hours. Soaking is done to check the durability of stabilized soil in worst conditions.

The soaked CBR values are much lesser than un soaked ones, this is due to swelling of soil causing a decrease in density, which in return reduces CBR value.

Graphs were plotted between the pressure applied to sample and penetration of plunger. The pressure value at 0.1” of penetration was divided by 1000 and then multiplied by 100 to get the CBR value. The same calculation was done at 0.2” (1500 was used instead of 1000) of penetration. It must be noted that CBR at 0.1” should be greater than CBR at 0.2” of penetration, otherwise repeat the test.

4.4.1.1 Low plastic clay

- Unsoaked

Figure 4.30. It has been observed that CBR value in unsoaked conditions, at optimum dosage improved from 3.6 to 11.9.

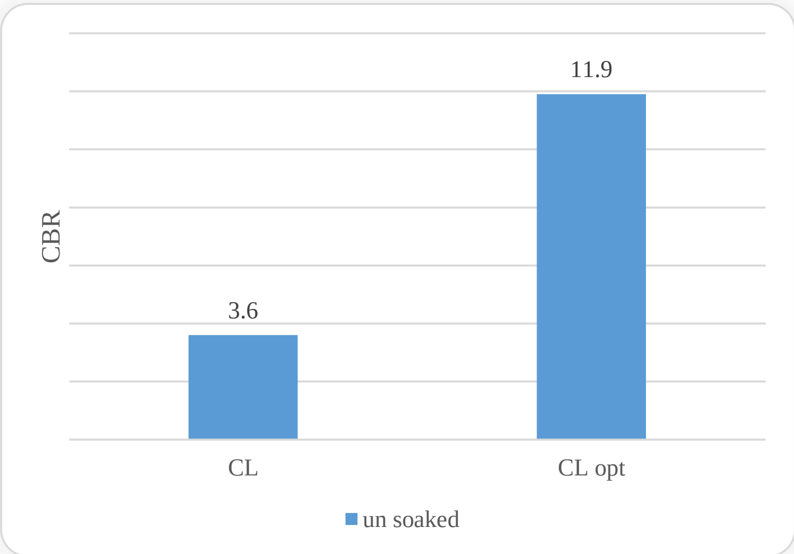


Figure 4.30: Un soaked CBR at the optimum Terrazyme dosage (CL)

- Soaked

From Figure 4.31 It can be observed that the CBR value in soaked conditions, at optimum dosage it improved from 2.2 to 6.5.

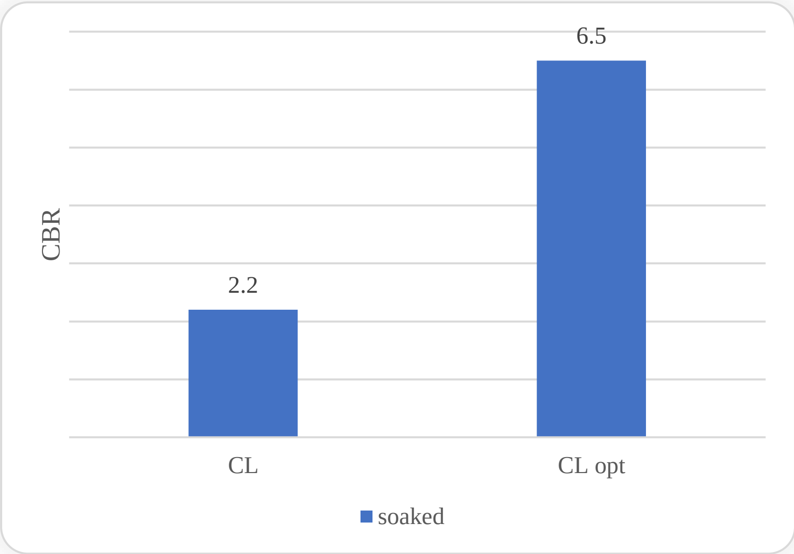


Figure 4.31: Soaked CBR at the optimum Terrazyme dosage (CL)

4.4.1.2 High plastic clay

- Unsoaked

From Figure 4.32. It has been observed that CBR value in unsoaked conditions, at optimum dosage improved from 2.6 to 10.6.

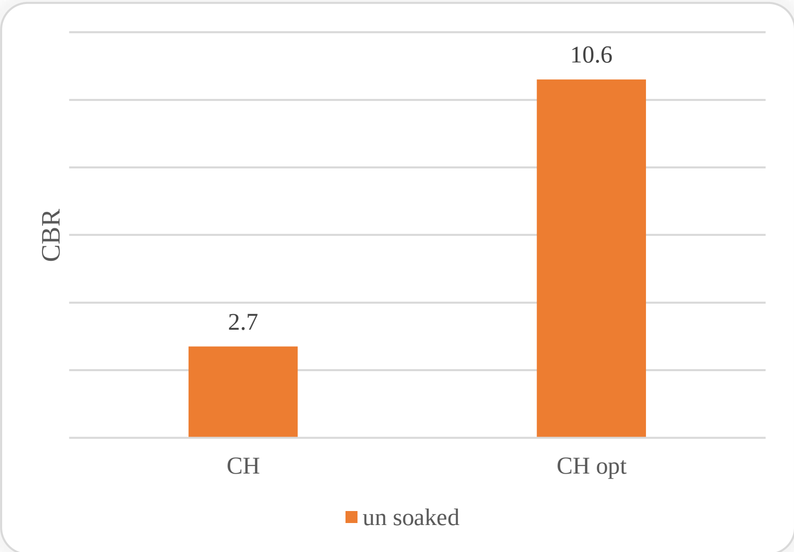


Figure 4.32: Unsoaked CBR at the optimum Terrazyme dosage (CH)

- Soaked

From Figure 4.33 It can be observed that the CBR value in soaked conditions, at optimum dosage it improved from 1.2 to 4.8.

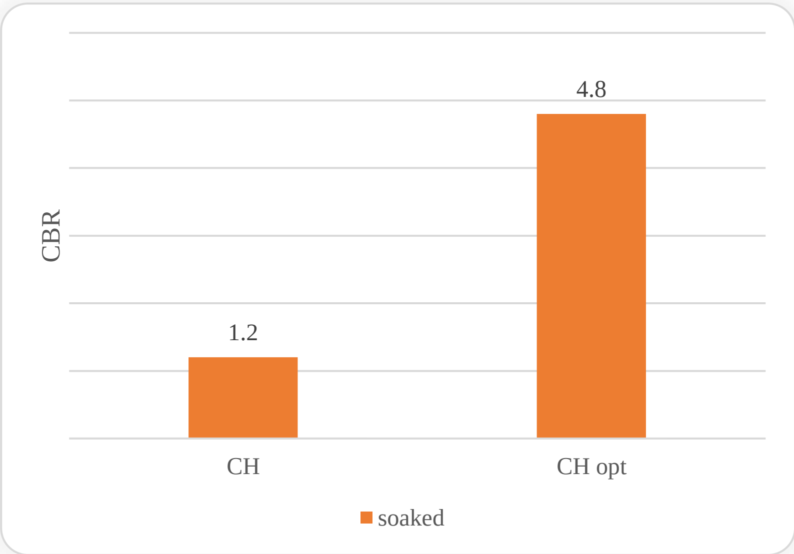


Figure 4.33: Soaked CBR at the optimum Terrazyme dosage (CH)

4.4.1.3 Comparison

Figure 4.34 shows a brief comparison between CBR values of both soils in soaked and un soaked conditions. For untreated samples, CBR value in unsoaked to soaked conditions for CL and CH reduced from 3.6 to 2.2 and 2.7 to 1.2 respectively. Similarly, for treated samples at optimum dosage, CBR value in unsoaked to soaked conditions for CL opt and CH opt reduced from 11.9 to 6.5 and 10.6 to 4.8 respectively.

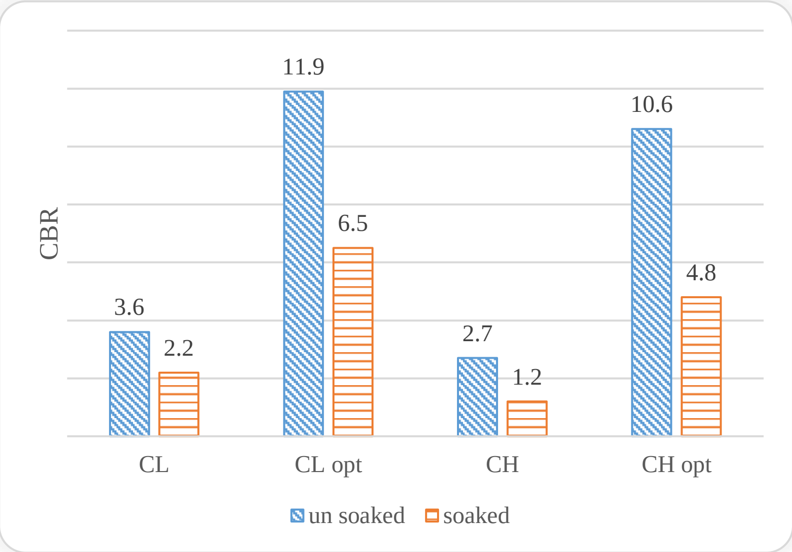


Figure 4.34: CBR comparison (untreated vs optimum)

4.4.2 Unconfined Compressive Strength (UCS)

To check the effect of Terrazyme on the strength of soil UCS testing was conducted. UCS testing for both soaked and curing conditions was done. Curing period was decided as per ASTM D 5102 standard. Four curing samples were prepared, wrapped in plastic wraps and cured for 2, 7, 14 and 28 days in a desiccator. For soaked conditions, samples were first cured and then soaked for 2, 7, 14 and 28 days in vacuum impregnation chamber.

Curing allows the enzyme to completely react and increase the stability of soil without losing its moisture to the air, while soaking represents strength behavior of soil subjected to capillary rise of water between soil particles.

4.4.2.1 Low plastic clay

- Curing

At optimum dosage of Terrazyme the first two days of curing showed an increase in UCS value of soil, i.e, 25 psi to 45.7 psi, afterward it increased gradually up to 70.6 psi. Till 28 days of curing the strength increased with decreasing rate, showing the completion of Terrazyme action in the soil, hence no further curing was done because a significant change was not seen. Figure 4.35. shows the change in UCS as a function curing in days. However, curing caused no effect over the UCS of soil with no Terrazyme added.

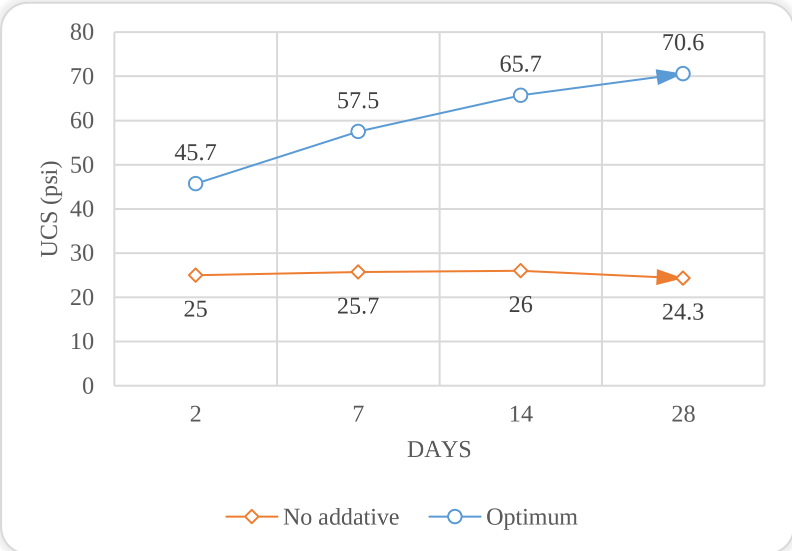


Figure 4.35: UCS at an optimum Terrazyme dosage and without any addative at different days of curing (CL)

- Soaked

Soil experiences swelling, decrease in density, this causes an overall loss in compressive strength of soil. To imitate these conditions soil was subjected to 2 days of soaking. Samples were first cured at 2, 7, 14 and 28 days. After curing samples were un wrapped and wrapped again into cotton wire gauze and left for soaking in vacuum impregnation setup.

In soaked condition soil with no additive added lost its UCS value after 2 days i.e., from 25.5 psi to 12 psi. At optimum dosage of Terrazyme UCS value at 2 days of soaking increased from 25.5 psi to 43.8 psi. Figure 4.36 shows the effect of soaking on UCS of Terrazyme treated soil. However soaked UCS value at optimum dosage increased to 58.7 psi in 28 days.

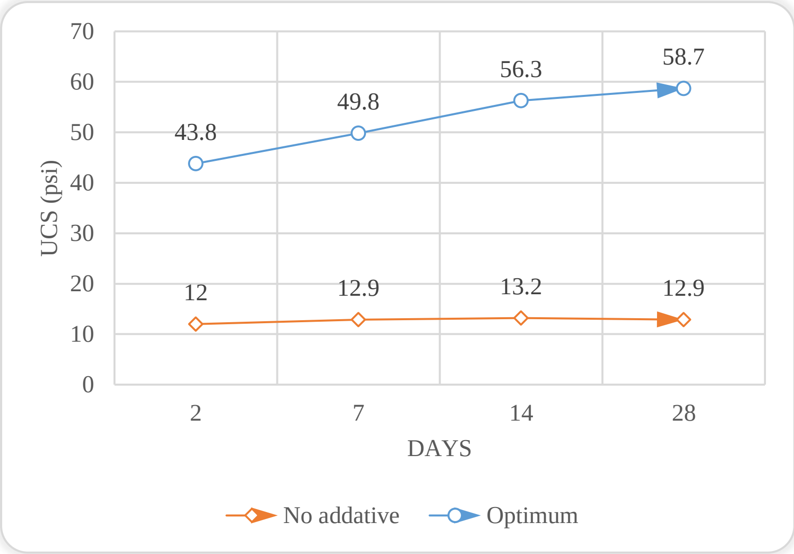


Figure 4.36: UCS at an optimum Terrazyme dosage and with no addative at different days of soaking (CL)

- Combined

For convenience, data has been plotted in Figure 4.37 so to see a combined change in UCS value of soil in soaked and cured conditions.

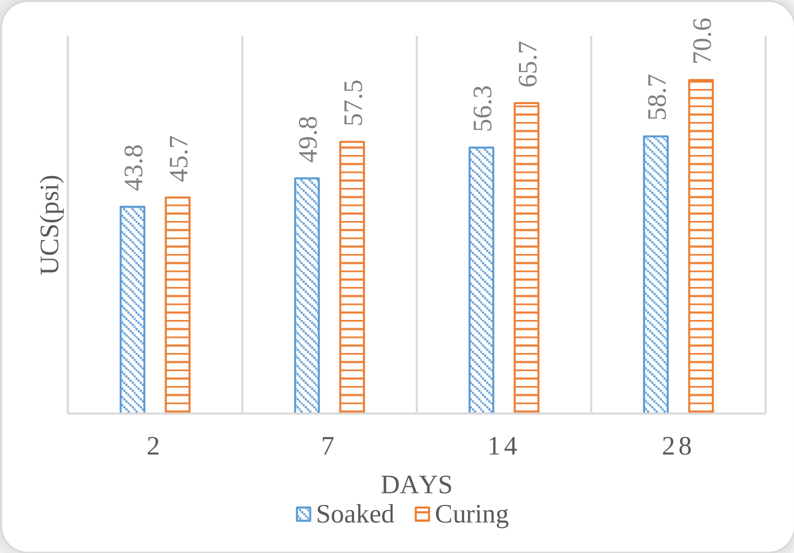


Figure 4.37: Comparison between UCS (soaked vs cured CL)

4.4.2.2 High plastic clay

- Curing

At optimum dosage of Terrazyme the first two days of curing showed an increase in UCS value of soil, i.e, 33.0 psi to 57.7 psi within, afterward it increased gradually up to 117.1 psi. Till 28 days of curing the strength increased with decreasing rate, showing the completion of Terrazyme action in the soil, hence no further curing was done because a significant change was not seen. Figure 4.38. shows the change in UCS as a function curing in days. However, curing caused no effect over the UCS of soil with no Terrazyme added.

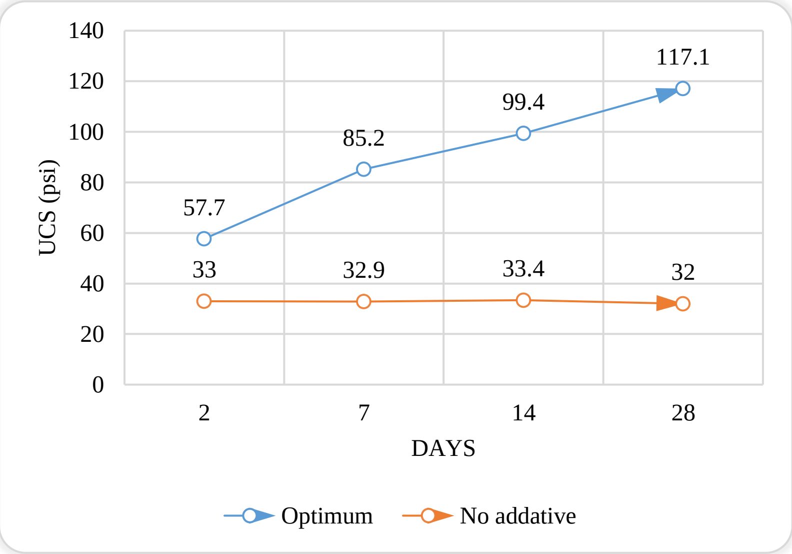


Figure 4.38: UCS at an optimum Terrazyme dosage and without any addative at different days of curing (CH)

- Soaked

Soaking for CH soil was done in similar way as of CL soil. In soaked condition soil with no additive added lost its UCS value after 2 days i.e., from 33.2 psi to 19 psi. At optimum dosage of Terrazyme UCS value at 2 days of soaking increased from 42.0 psi to 55.4 psi. Figure 4.39 shows the effect of soaking on UCS of Terrazyme treated soil. However soaked UCS value at optimum dosage increased to 90 psi in 28 days.

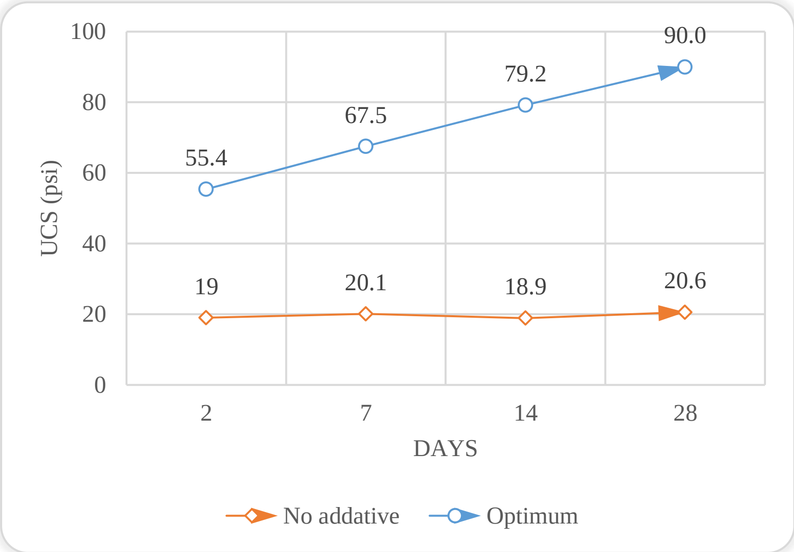


Figure 4.39: UCS at an optimum Terrazyme dosage and with no addative at different days of soaking (CH)

- Combined

For convenience, data has been plotted in Figure 4.40so to see a combined change in UCS value of soil in soaked and cured conditions.

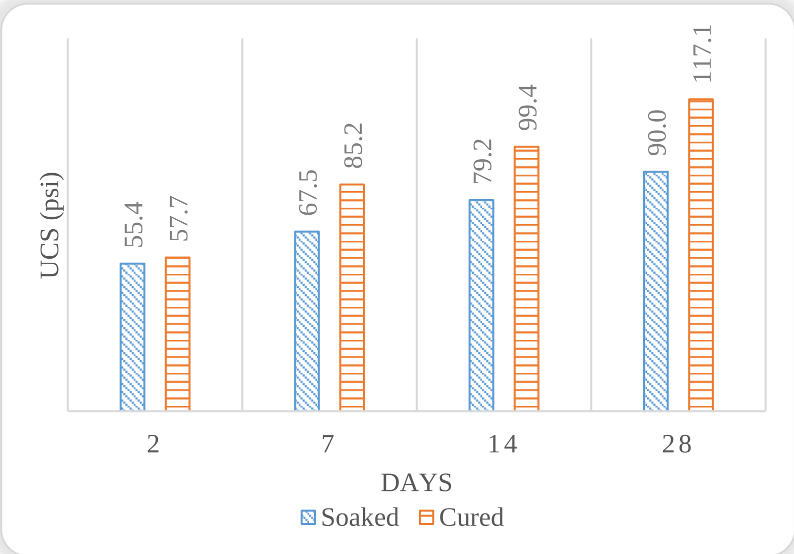


Figure 4.40: Comparison between UCS (soaked vs cured CH)

4.4.3 Optimization of Excess Moisture

In this testing, UCS samples were prepared at MDD but an extra amount of moisture other than OMC was added. All UCS samples were first cured for 14 days. The moisture values were at 1 percent, 2 percent, 3 percent and 4 percent plus the OMC value. The main purpose is to imitate the field conditions and allow Terrazyme to undergo catalytic activity under open-air environment.

It has been observed that firstly UCS values for both soils increased slightly and then decreased. The increment is due to the availability of enough moisture in the open air to complete the catalytic activity of Terrazyme. The decrease in strength is due to excess moisture which imparts weakness in the overall structure of the soil.

4.4.3.1 Low plastic clay

In low plastic clay, the UCS value increased form 42.9 psi to 43.5 with addition of 1 percent excess moisture. This so because with addition of water curing time was also given, causing increase in strength.

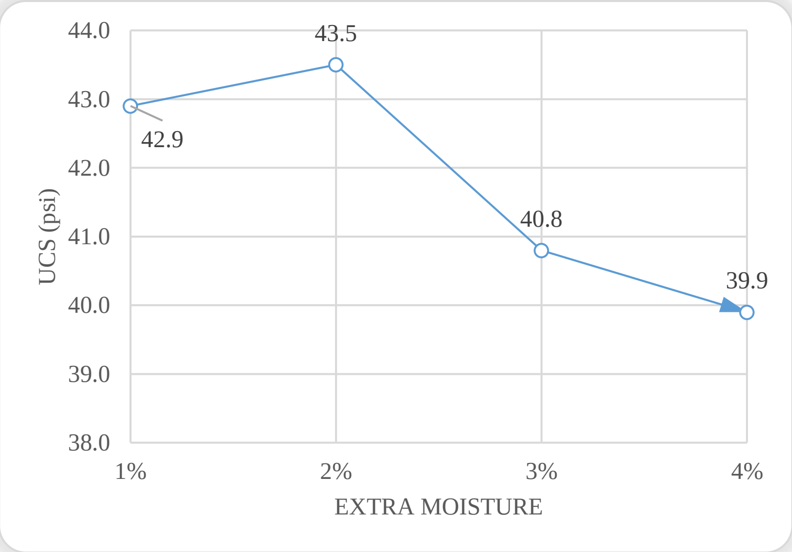


Figure 4.41: UCS at excess moisture for 14 days of curing (CL)

4.4.3.2 High plastic clay

In high plastic clay, the UCS value increased form 56.7 psi to 58.9 and then decreased to 55.0 psi. the maximum value was obtained at 2 percent of excess moisture.

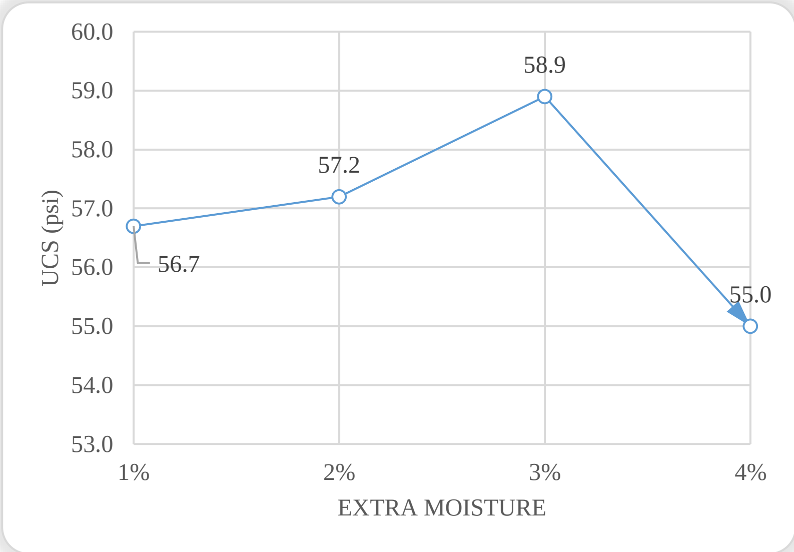


Figure 4.42: UCS at excess moisture for 14 days of curing (CH)

4.4.4 Swell Potential

A significant reduction in swelling in both soils has been observed with the addition of Terrazyme at optimum dosage. As Terrazyme with help of exchangeable cations permanently reduces the double layer around the soil, so on the addition of water, the soil experiences reduced the amount of swelling as compared to untreated conditions.

4.4.4.1 Low plastic clay

The swell potential for low plastic clays reduced from 5.58 percent to 2.83 percent making over the reduction of 49.3 percent.

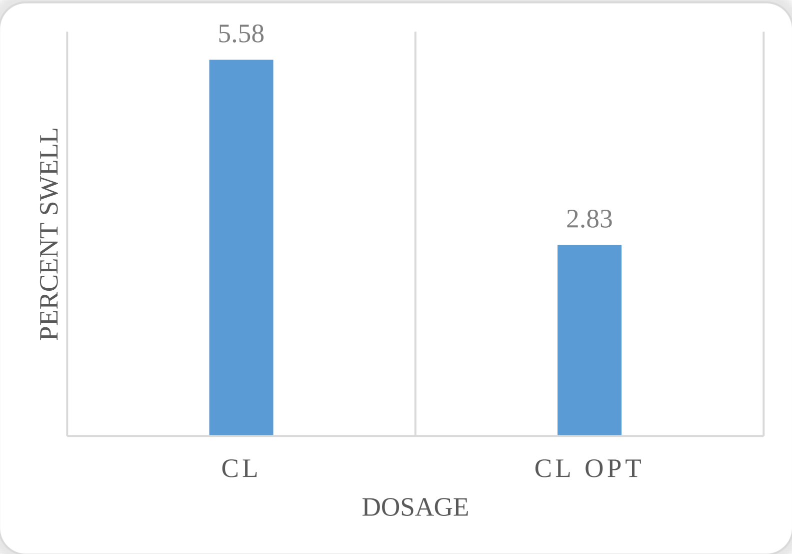


Figure 4.43: Change in the swell potential for CL soil

4.4.4.2 High plastic clay

For high plastic clay, the value decreased from 7.30 percent to 4.72 percent making a total reduction of 35.3 percent.

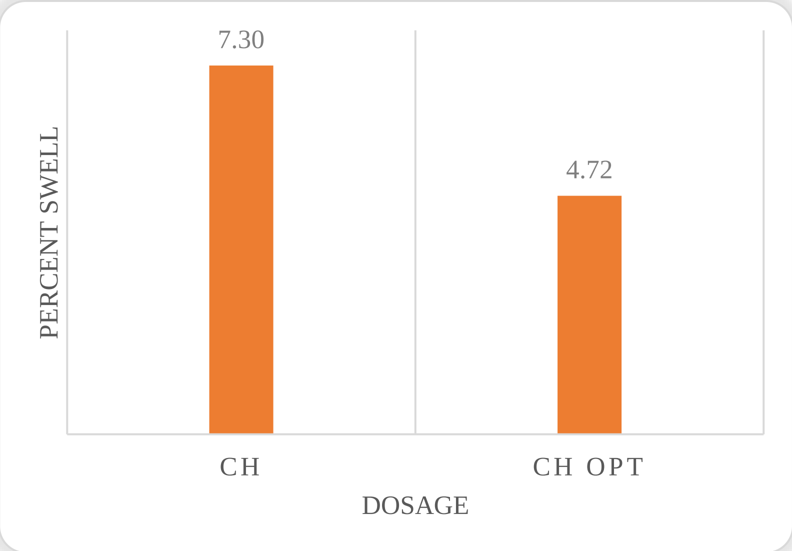


Figure 4.44: Change in the swell potential for CH soil

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Detailed study was carried out on low plastic and high plastic soils, stabilized with Terrazyme. The main purpose was to find out the Terrazyme dosage at which optimum values could be achieved. Atterberg's limit, UCS, CBR, compaction characteristics and swell potential were the selected parameters to check the feasibility of Terrazyme as a stabilizer. After finding the optimum dosage of additive, the soils were subjected to different curing and soaking periods so to check its effects on the properties of the soil. After detailed investigation conclusions were made as follows:

- With the addition of Terrazyme soil density increased up to an optimum dosage and then started to decrease. As Terrazyme releases exchangeable cations in soil which in return decrease the double layer around the clay particles, this reduction in double layer reconfigures the particles into denser configuration. The reduction in density is because as cations has been replaced and no further cation exchange is occurring after optimum dosage, so with further addition of dosage water starts to replace the soil particles and density starts to decrease. The MDD of CL increased by 1.36 percent at dosage D1 and MDD of CH increased by 1.39 at dosage D2.
- As Terrazyme reduce the double layer around the soil particles, this cause the reduction in double layer due to which LL and PI of soils decreased. For CL soil at optimum dosage LL and PI were reduces by 3.83 percent and 8.9

percent respectively, for CH soil LL and PI were reduced by 8.4 percent and 26 percent.

- At optimum dosage, Terrazyme reduced the CEC value of CL and CH reduced by 3.7 percent and 9.9 percent respectively. This is so because Terrazyme released cations into the soil, which adhere to soil particles due to which the affinity to attract more cation reduced.
- Due to reduction in double layer the particles of soil have come closer to each other creating tight bonding, this caused the increase in UCS of soil at optimum dosage of Terrazyme. Another reason for increase in UCS is that Terrazyme imparts cementation in soil. The curing time of soil gave Terrazyme enough time to diffuse cation completely into the soil structure, causing further improvement in UCS. In soaked condition as soil experience swelling, this causes decrease in UCS value of both soils at optimum dosage. At optimum dosage UCS improved by 39 percent and 67.2 percent for CL and CH respectively. For 28 days of curing UCS of CL and CH at optimum dosage improved by 177 percent and 253 percent. For 28 days of soaking UCS of CL and CH at optimum dosage improved by 130.2 percent and 171 percent.
- The increase in CBR is due to increase in the density of the soil. In unsoaked conditions CBR value at optimum dosage of Terrazyme improved by 231 percent and 293 percent for CL and CH respectively. In soaked conditions CBR was improved by 195 percent and 300 percent.
- At optimum dosage the swelling of soil was reduced by 49 percent 35.3 for CL and CH respectively. This is so because the cations adhering to soil

surface doesn’t allow water to penetrate between layers hence swell potential is reduced significantly.

5.2 RECOMMENDATIONS

- As Terazyme increases soil density, the effect on the soil permeability with addition of Terrazyme needs to be studied.
- Usually additives are used in stabilizing subgrade or foundation soil, a research is required on how slopes can be stabilized using traditional and no traditional stabilizers.
- Effects on dynamic properties of soil with addition of stabilizes needs to be studies with.
- Fujibeton is another type of enzyme. A research needs to be carried out on soil stabilized with Fujibeton and compared with Terrazyme.
- Molasses is produced as a sugarcane waste, research can be carried out to check feasibility of Molasses as a soil stabilizer.
- How traditional and non-traditional stabilizers effects the sustainability in geotechnical engineering can be studied.
- Freeze-thaw effects could be studied with the addition of Terrazyme and other additives.
- The properties of enzymes could be controlled as per conditions or desire. To study these Enzymes are added with co factor to alter their action accordingly. A research can be carried out check effects of different co factors on properties of stabilized soil.
- As Terrazyme is the most used enzyme as a soil stabilizer, hence a research should be carried out to synthesize it in Pakistan.

- Effect of additives over the resilient modulus of soil needs to be studied and compared.

INDEX

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