PERFORMANCE EVALUATION OF SOIL STABILIZED WITH IRON AND STEEL INDUSTRY WASTE AND LIME

A dissertation submitted in
partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY
In
CIVIL ENGINEERING

(With specialization in Geotechnical Engineering)

Under

ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY

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DECLARATION

I hereby declare that the work presented in the dissertation "**Performance evaluation of soil stabilized with Iron and steel industry waste and lime**" in partial fulfillment of the requirement for the award of the degree of "MASTER OF TECHNOLOGY" in Civil Engineering (With specialization in Geotechnical Engineering), submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science & Technology University, is a real record of the work carried out in the said college for six months under the supervision of Dr.Abinash Mahanta Associate Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

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ABSTRACT

Soil stabilization is a crucial process in geotechnical engineering aimed at enhancing the mechanical properties of soils to meet the demands of construction projects. Lime and cement both are considered the oldest and traditional stabilizers. Hence, this report attempts to explore the effectiveness of soil stabilization using cement and lime and investigate the resultant shear strength through triaxial testing. This study presents a comparison of strengths between the soi mixed at different percentage with iron slag and lime content keeping lime constant at 2%, 4% 6%in addition to iron slag at 2% 4% and 6%.

This study mainly aims to utilize the waste generated by the iron and steel industries and to improve the geotechnical properties of the soil for different construction purpose Geotechnical properties of soil play a crucial role in construction projects, as they directly influence the stability and performance of structures built on or within the ground. These properties are essential considerations for geotechnical engineers. Geotechnical investigations and testing are conducted to gather data on these properties, enabling engineers to make informed decisions and design structures that are safe and stable for the given soil conditions.

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LIST OF SYMBOLS/ABBREVIATION

Sl. No.	Symbols/abbreviation	Description
1	MDD	Maximum Dry Density
2	OMC	Optimum Moisture Content
3	kPa	Kilopascal (unit of cohesion)

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CHAPTER 1

INTRODUCTION

1.1 General

Soil is a fundamental component in various aspects of construction, playing a crucial role in providing support, stability, and a medium for various construction activities. Soil is extensively studied and analyzed in geotechnical engineering to understand its properties and behavior. Soil has a very important and key role in the construction industry. Soil is a versatile and essential component in construction, providing the foundation for structures, contributing to stability, and serving various other functions in both civil and architectural projects. The selection and understanding of soil properties are critical for ensuring the success and safety of construction endeavors. Continuous rise in population and the industrialization of society are correlated with an escalation in the generation of industrial and municipal waste. These developments undoubtedly contribute to a rise in atmospheric temperatures, potentially resulting in the demise of our civilization within the next 300 years, as projected by cosmological calculations. (Hawking 2018)

The engineering properties of soil can be altered and improved by addition of agents like cement, lime, fly ash, blast furnace slag, bitumen, industrial waste (iron slag or BF, steel slag, copper slag etc.) agricultural waste etc. The addition of industrial waste (iron slag or BF, steel slag, copper slag) in combination with agents like lime, cement changes the physical and chemical properties of the treated soil. The process of enhancing the strength, durability, and workability of soil, making it suitable for construction purposes is known as soil stabilization and adding to management of the waste generated. Additives like lime, cement, fly ash and asphalt are known as chemical admixture. Soil stabilization with slag in addition with lime is a well-established technique, and its application is widespread in civil engineering and construction projects to transform problematic soils into suitable materials for construction.

1.2 Methods of soil stabilization

- **Mechanical Stabilization:** It deals with Increasing the density of soil particles by compaction using rollers or compactors and applying deep vibrations to compact loose soils.
- **Chemical Stabilization:**
    1. **Lime Stabilization:** Adding lime to the soil to improve its plasticity, reduce swelling, and increase strength.
    2. **Cement Stabilization:** Mixing cement with the soil to create a stable and durable material.
    3. **Bitumen Stabilization:** Mixing bitumen or asphalt with the soil to enhance its engineering properties.
    4. **Fly Ash Stabilization:** Utilizing fly ash to stabilize soil, particularly clayey soils.
- **Electrokinetic Stabilization:** This deals with applying an electric field to promote the movement of ions within the soil, improving its engineering properties.
- **Geotextile Reinforcement:** Using geotextiles, which are synthetic materials, they are used to reinforce and stabilize soil. This method is often used in slope stabilization.
- **Soil Nailing:** This method deals with the installation of grouted or threaded rods (nails) into the soil to provide additional stability, commonly used in excavations and slope stabilization.
- **Biological Stabilization:** Plantation of vegetation are used in biological stabilization to stabilize soil and prevent erosion. The roots of plants help bind the soil particles together. Biological agents or polymers are used to improve soil structure.
- **Pozzolanic Stabilization:** In pozzolanic stabilization, pozzolanic materials such as silica fume or metakaolin are used to improve the reactivity and strength of the soil.

1.3 Materials used in soil stabilization

- Lime
- Cement
- Fly ash
- Bitumen
- Polymers
- Rice husk ash
- Geo textiles
- Waste materials

1.4 Purpose of soil stabilization

Soil stabilization serves several purposes in civil engineering and construction projects. The primary goals of soil stabilization are to improve the engineering properties of soil and enhance its performance in terms of strength, durability, and load-bearing capacity. The specific purposes of soil stabilization include:

- **Increase strength and load bearing capacity**: One of the main objectives of soil stabilization is to increase the strength of the soil, making it capable of supporting heavier loads.
- **Reduce permeability**: Stabilization can be employed to reduce the permeability of soils, making them less susceptible to water infiltration and improving their resistance to erosion.
- **Improve workability**: Stabilized soils often exhibit improved workability, making them easier to compact and shape during construction
- **Improve Durability**: Soil stabilization contributes to the long-term durability of structures by reducing the susceptibility of the soil to weathering and other environmental factors
- **Making construction more feasible**: In some cases, construction may be challenging due to the presence of weak or problematic soils. Soil stabilization allows for the improvement of these soils, making construction more feasible and cost-effective.

- **Environmental considerations**: Soil stabilization can have environmental benefits by minimizing the disruption of natural landscapes, reducing the need for earthmoving activities, and mitigating the potential for soil erosion and sedimentation.

1.5 Advantages of soil stabilization

Soil stabilization offers several advantages in construction and civil engineering projects. These advantages contribute to improved performance, longevity, and cost-effectiveness of various structures and infrastructures. Here are some key advantages of soil stabilization:

- Stabilizing the soil enhances its strength, enabling it to support heavier loads without excessive settlement or deformation.
- Soil stabilization alters the physical and mechanical properties of the soil, including its compressibility, shear strength, and permeability. This results in a more stable and predictable foundation for construction.
- Stabilized soils often allow for faster construction processes. Rapid curing times and improved workability enable quicker project completion, reducing overall construction timelines.
- Stabilizing soil can have positive environmental impacts by minimizing soil disturbance, reducing the need for excavation and disposal of soil, and mitigating erosion.
- Soil stabilization helps minimize settlement, ensuring a more uniform and stable foundation for structures.
- The improved properties of stabilized soils offer greater flexibility in design. Engineers can design structures with confidence, knowing that the stabilized soil will provide a stable and reliable foundation.
- Soil stabilization can lead to cost savings by allowing the use of in-situ soils rather than requiring the importation of expensive fill materials.

1.6 Lime

1.6.1 Introduction

Lime, a fundamental material in the stabilization of soil, emerges as a loyal material in civil engineering and construction projects. Derived from limestone through the process of calcination, lime transforms into a potent agent that revolutionizes the properties of soil. The application of lime in soil stabilization is rooted in its ability to react with clay minerals, altering their structure and enhancing the overall engineering characteristics of the soil.

One of the primary advantages of lime in soil stabilization lies in its capacity to improve soil strength and reduce plasticity. This transformation is crucial for creating a robust foundation that can withstand the rigors of construction, preventing issues such as settlement and swelling. By inducing a chemical reaction with the soil constituents, lime enhances cohesion and decreases the soil's sensitivity to moisture fluctuations, ensuring stability over time.

Moreover, lime's influence extends beyond its engineering prowess. It aids in the mitigation of expansive soils, curbing volumetric changes that often lead to structural challenges. As a sustainable and cost-effective solution, lime's role in soil stabilization underscores its significance in fostering durable and resilient infrastructures. In the intricate dance between nature and construction, lime stands as a reliable partner, fortifying the ground upon which progress is built.

1.6.2 Types of lime

- **Quick lime:**
  Quicklime, also known as calcium oxide (CaO), is a white, caustic, alkaline crystalline solid that is produced by heating limestone or calcium carbonate in a kiln. The process of producing quicklime is called calcination. The process of calcination involves heating calcium carbonate (usually in the form of limestone) to high temperatures.
  Quicklime is used to improve soil quality by raising its pH. However, it should be handled with care due to its caustic nature.

- **Fat lime:**

  Fat lime sometimes referred to as non-hydraulic lime, high-calcium lime, or pure lime is a kind of lime that is mostly made up of high-calcium calcium hydroxide ($Ca(OH)_2$) or calcium oxide (CaO) with very little to no clay. Limestone with trace amounts of impurities like silica, alumina, and iron is used to make fat lime.

- **Slaked lime:**

  Slaked lime, also known as calcium hydroxide, is a compound produced by the reaction of water with quicklime. The process of producing slaked lime is called slaking, and it involves adding water to quicklime to form a hydrated lime paste or slurry. Slaked lime can exist in different physical forms, including a dry powder, a paste, or a slurry, depending on the amount of water added.

- **Hydraulic lime:**

  Hydraulic lime is a type of lime that sets and hardens through a hydraulic reaction with water. Unlike non-hydraulic lime, which relies on carbonation to harden, hydraulic lime can set even underwater or in damp conditions. Hydraulic lime is derived from limestone containing clay or silica impurities, which contribute to its hydraulic properties.

  Hydraulic lime is often used in historic building restoration, conservation projects, and traditional construction methods. It provides a breathable and flexible material that is well-suited for structures where the movement of moisture is important.

1.6.3 Properties of a high-quality lime

- High-quality lime should have a high degree of purity, free from impurities such as excessive amounts of silica, alumina, iron, and other contaminants.
- Quicklime should exhibit good reactivity, meaning it readily reacts with water to form hydrated lime.
- High-quality hydrated lime should result in a fine, dry powder or a well-dispersed slurry, depending on the intended application.
- Fine particles contribute to better workability in mortar and plaster, while coarser particles may be suitable for certain agricultural uses.
- High-quality lime should exhibit consistency in its physical and chemical properties. Consistency ensures that the lime performs predictably and meets the specifications of the intended application.

- The color of the lime can be an indicator of its purity. High-quality lime is typically white or off-white.

1.6.4 Use of lime in soil stabilization

Lime is commonly used in soil stabilization to improve the engineering properties of soil and create a more stable foundation for construction projects. Soil stabilization involves the addition of lime to soil to alter its physical and chemical properties. Lime reacts with the clay particles in the soil, causing them to flocculate and form stable aggregates. This results in improved soil structure, reducing its plasticity and increasing its strength. Lime helps reduce the plasticity of clayey soils, making them less prone to swelling and shrinkage.

Soil stabilized with lime typically exhibits increased bearing capacity, providing a stronger and more stable foundation for structures. This is crucial in construction projects, such as roads, highways, and building foundations. Lime stabilization is often a faster and more cost-effective solution compared to other soil improvement techniques. Lime is a naturally occurring material, and its use in soil stabilization is considered environmentally friendly. It can be a sustainable alternative to synthetic stabilizers.

Common applications of lime in soil stabilization include road construction, embankment construction, foundation preparation, and the stabilization of building sites. Thespecific type and amount of lime used depend on the soil characteristics and the engineering requirements of the project.

1.6.5 Precautions while handling lime

- Workers should use chemical-resistant gloves to protect their skin.
- Safety goggles or a face shield should be used to prevent lime from encountering the eyes.
- A dust mask or respirator should be used if lime dust is present, as inhalation can cause respiratory irritation or damage.
- Proper ventilation should be ensured in the area where lime is being used to avoid inhaling d

1.6.6 Action of lime in soil

The addition of lime to soil causes a sequence of chemical reactions that improve the soil's characteristics. The pH of the soil is first raised by the lime's initial reaction with the moisture in the soil to generate calcium hydroxide. When silicates and aluminates from clay minerals dissolve in this higher pH environment, they combine with the calcium ions to generate stable calcium silicate hydrates and calcium aluminate hydrates.

The strength and stability of the soil are greatly increased by these hydration products, which also serve to bind soil particles together. Lime also makes clayey soils less pliable and less likely to swell, which lessens their vulnerability to volume fluctuations brought on by differences in moisture levels. By doing this, the possibility of foundation movement and pavement collapse is decreased, the load-bearing capacity is increased, and the base for construction is made more stable and workable. Additionally, soils treated with lime have greater compaction properties and a stronger resilience to frost heave.

Overall, adding lime to soil is an economical and effective way to improve the engineering qualities of problematic soils, which makes it a useful technique for building roads, stabilizing foundations, and undertaking other civil engineering tasks.

1.7 Slag

1.7.1 Introduction

Slag is a by-product created during the production of pig iron and steel. It results from the interaction of various fluxes with gangue materials present in the iron ore during the pig iron production process in a blast furnace, as well as during steel manufacturing in a steel melting shop. In an integrated steel plant, 2-4 tonnes of waste (including solid, liquid and gas) are generated for every tonne of steel produced. Pertinently, the concerns of today are to pay adequate emphasis on minimizing waste generation, recycling and re-use of waste, and minimizing the adverse impact of disposals to the environment. All the solid/liquid wastes, slags generated at iron making and steel making units are in such a large quantity that management of slag has become a critical component of steel production. With increasing capacities, the mechanism for disposal of large quantities of slag that get generated have gained traction as the environmental issues that it could evoke could become critical for steel makers. Over the last few years, with better understanding of slags, its functions and improvements in process technologies have led to a significant reduction in the volume of slag generated

1.7.2 Types of slag

The term "slag" originally referred to slag produced by metal manufacturing processes. Here are some types of cement:

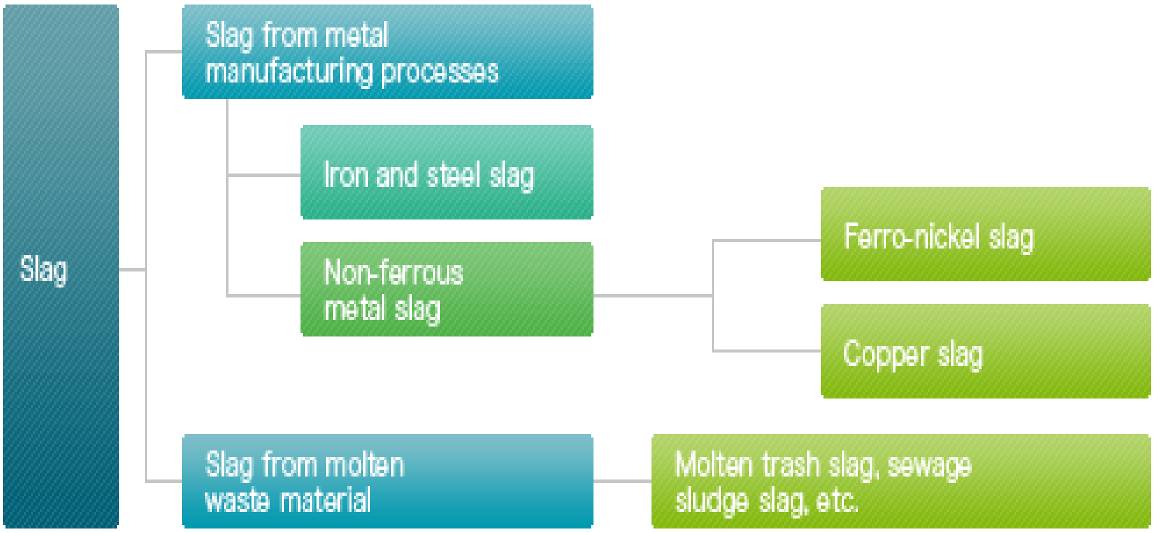

Figure:1 Classification of slag (source: Nippon Slag Association)

- **Iron and steel slag classification:**

  The iron and steel slag that is generated as a byproduct of iron and steel manufacturing processes can be broadly categorized into blast furnace slag and steelmaking slag

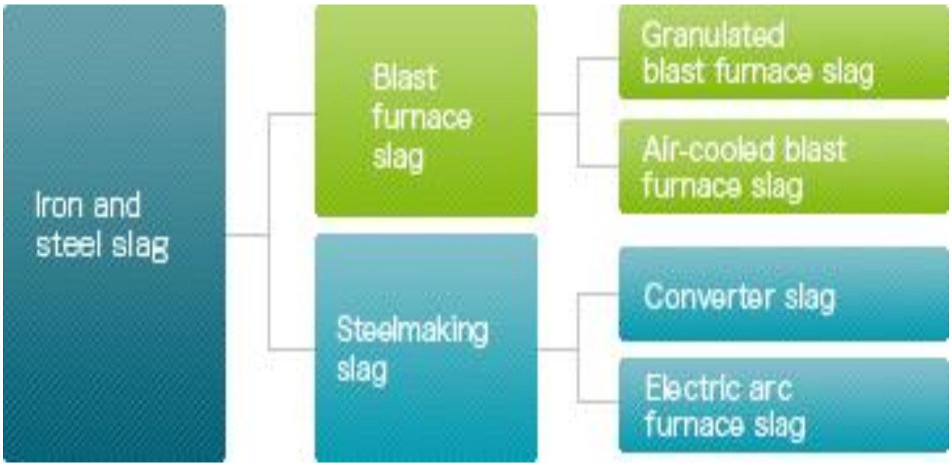

Figure:2 Classification of iron and steel slag (source: Nippon Slag Association)

1.7.3 Properties of iron slag

- Slag is chemically stable in most environments, and it does not readily degrade or break down over time, which makes it suitable for long-term use in various applications.
- Iron slag has relatively low thermal conductivity compared to metals, making it suitable for use in heat-resistant applications such as insulation and refractories.
- Due to its high melting point and mineral composition, iron slag can withstand high temperatures and is used in applications where heat resistance is required.
- Iron slag tends to be basic (alkaline) due to the high content of calcium and magnesium oxides. This property is important in its use for soil treatment and stabilization, as it can help neutralize acidic soils.
- Iron slag can exhibit high compressive strength, particularly in concrete applications, where it improves the strength and durability of the material.

1.7.4 Use of iron slag in soil stabilization

When iron slag is mixed with soil, it can significantly improve the compressive strength of the soil. This is particularly useful for weak or loose soils, as the slag's cementitious properties help bind the soil particles together, increasing their stability and load-bearing capacity. The binding properties of slag help enhance soil cohesion, making it more resistant to erosion and compaction under heavy loads. Soil stabilization with cement involves the addition of cementitious materials to the soil to enhance its strength, durability, and load-bearing capacity. This process is commonly employed in the construction of roads, embankments, foundations, and other structures.

The addition of slag can reduce the plasticity of soils, making them less prone to shrinkage and swelling due to changes in moisture content. This helps in stabilizing expansive clays or fine-grained soils. Soil stabilization with cement allows for quicker construction by reducing the time required for soil consolidation and curing.

The stabilized soil gains durability and resistance to environmental factors, ensuring the long-term stability of constructed structures. Iron slag is a byproduct of steel and iron production, which means it is often available at a lower cost compared to other commercial stabilizers. This makes it an affordable solution for large-scale soil stabilization projects, such as road construction or land reclamation. Iron slag is widely used for stabilizing soil in the construction of highways, pavements, and rural roads, improving their durability and performance.

1.7.5 Precautions while handling iron slag

- Safety goggles or a face shield should be used to protect the eyes from slag dust and splashes.
- A dust mask or respirator should be used as iron slag can release fines particles and dust.

CHAPTER 2 LITERATURE REVIEW

2.1 Review of available literatures

Osinubi et al., (2017) In this explores the potential for improving the properties of black cotton soil (BCS) using lime and iron ore tailings (IOT) including a series of laboratory tests to evaluate the effectiveness of this combination for geotechnical applications, particularly in road construction. An optimum mix of 8% lime and 8% IOT blend significantly enhanced the soil's strength, compaction, and durability properties. Unconfined Compressive Strength (UCS) increased significantly with curing time, peaking at the optimal blend. California Bearing Ratio (CBR) values indicated that the treated soil could serve as a sub-base material for lightly trafficked roads. SEM and EDS tests showed that the mix formed crystalline hydration products

Moinuddin et al., (2018) studied the enhancement of properties Industrial waste iron powder and three types of recycled plastic meshes (black grid, light green, dark green) with varying aperture sizes in black cotton soil were used where mixing 6% iron powder yielded the best results, increasing soil density and reducing swelling and shrinkage and CBR values improved with iron powder, showing increased load resistance and the black grid mesh exhibited the highest CBR among the three types, significantly enhancing the soil's strength. adding plastic mesh improved CBR up to 3.2 times compared to unreinforced soil. Combining 6% iron powder and two layers of black grid mesh further improved CBR by 2.6 times compared to untreated soil. Proper placement and configuration of the mesh layers (e.g., at specific heights) were critical for maximizing strength

Manasa et al., (2015) This study investigates the stabilization of black cotton soil using waste iron powder. Laboratory experiments analyzed Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR). Liquid limit decreased while the plastic limit remained constant with increasing iron powder. Maximum Dry Density (MDD) increased up to 6% iron powder and then decreased, while Optimum Moisture Content (OMC) decreased. CBR values significantly improved, indicating enhanced soil strength

Yan et al., (2025) – This study explores the potential of using agricultural and industrial by-products—rice husk ash (RHA), steel slag (SS), and iron tailings (IT)—for soil stabilization in road construction. The materials were combined with cement to improve soil mechanical properties, hydration, and microstructure where the steel slag and iron tailing significantly enhanced soil strength, achieving up to 60% improvement over baseline, while RHA exhibited minimal impact facilitated hydration reactions, reducing pore sizes and increasing density, which contributed to better performance. RHA showed the lowest reactivity with a much lower compressive strength compared to those of the SS- and IT-blended samples when the cement content was 4%.

Samadou (2015) - The research evaluates the potential of iron ore tailing as a stabilizer for black cotton soil. Various percentages of tailing were added to the soil and subjected to compaction and strength tests, including Unconfined Compressive Strength (UCS) and CBR Particle sizes increased, shifting soil classification from fine to coarse. UCS and CBR values improved with up to 12% iron ore tailings but did not meet requirements for lime or cement stabilization. Optimal results were observed at 10-12% iron ore tailings. Iron ore tailings improve soil properties but are not a standalone stabilizer. They are better suited as part of a composite stabilization approach.

Gupta et al., (2022) This study explores the use of industrial by-products—iron slag and fly ash—for stabilizing red soil and black cotton soil. These materials were mixed in varying proportions, and their effects on soil properties like maximum dry density, consistency limits, and UCS were analyzed. Fly ash and iron slag proved to be effective stabilizers, reducing plasticity and swelling while increasing soil strength. The study highlights the dual environmental and engineering benefits of reusing industrial waste in soil stabilization. Both soils showed improvements in strength and reduced swelling when treated with iron slag and fly ash. The optimal mix of iron slag (6-8%) and fly ash (20-25%) provided the best results. The use of these industrial by-products proved economical and environmentally friendly

Ankit Singh Negi, Mohammed Faizan, Devashish Pandey Siddharth, Rehanjot singh (2013) This paper deals with the complete analysis of the improvement of soil properties and its stabilization using lime. Based on the experiments, the following conclusions were made –

- Lime is used as an excellent soil stabilizing material for highly active soils which undergo frequent expansion and shrinkage.
- Lime acts immediately and improves various property of soil such as carrying capacity of soil, resistance to shrinkage during moist conditions, reduction in plasticity index, increase in CBR value and subsequent increase in the compression resistance with the increase in time.
- The reaction is very quick, and stabilization of soil starts within a few hours.

Ali Jamal Alrubaye, Muzamir Hasan and Mohammed Y. Fattah (2016) This study assesses the influence of lime on the compressibility and swelling traits of soil. In this study it was found that the liquid limit and plasticity index of soil was reduced with the introduction of lime. The liquid limit was increased with a 9% application of lime.

Shahzada Omer Manzoor and Aadil Yousuf (2020) This paper discusses how cation exchange, flocculation, and pozzolanic reactions collectively improve soil properties and the influence of lime quantity, lime quality, curing time and temperature on soil strength, permeability, soil-moisture relation, compressibility, plasticity characteristics and other soil properties. Soil stabilization through lime-columns, lime treatment of pavement layers and lime-based embankment stabilization as important applications of lime stabilization is discussed.

CHAPTER 3

AIM AND OBJECTIVE

The aim and objectives of this study are given below:

- Determination of properties such as liquid limit, plastic limit, specific gravity, maximum dry density (MDD) and optimum moisture content (OMC) of the collected soil.
- Determination of maximum dry density (MDD) and optimum moisture content (OMC) of the iron slag and lime stabilized soil.
- Determination of unconfined compressive strength of the iron slag and lime stabilized soil at 0 curing day.

CHAPTER 4

METHODOLOGY

4.1 Collection of soil sample

The area selected for the collection of soil samples was from the Assam Engineering College region. The first 1.5 ft layer of soil was removed which may contain leaves, organic matter, branches etc and the soil sample was collected from about 3 ft depth.

Figure 3: Collection of soil sample

4.2 Preparation of the disturbed samples for laboratory testing

To ensure repeatable results, soil samples taken from the field must first be prepared using a standard procedure. Before testing, the soil sample is often allowed to air dry, then it is ground up and any stones are taken out. The soil is left at room temperature in accordance with the IS Code technique to dry. However, in many practical situations, oven drying at 105°C can be employed. However, in certain soils with high organic matter and heavy clay content, irreversible changes occur during oven drying, leading to unusual test findings. The soil needs to be air dried in these situations. The air-dried sample for testing is shown in

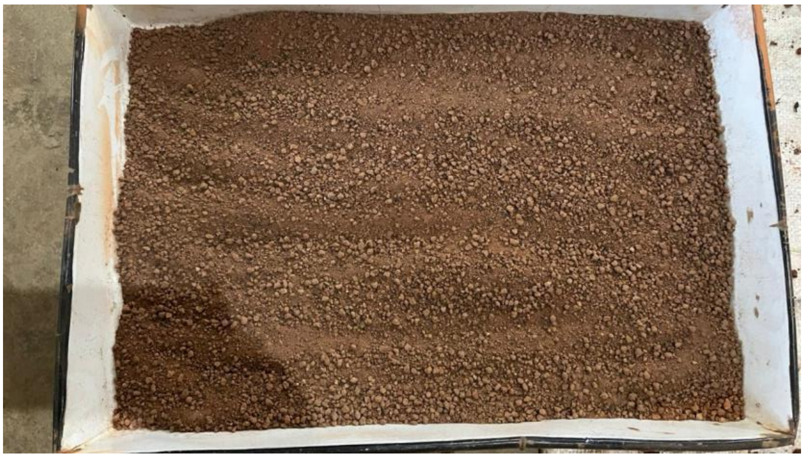

Figure 4: Air dried sample

4.3 Description of the tests performed

4.3.1 Sieve analysis

This test was carried out in accordance with IS 2720 (Part 4)-1985, which states that the gradation of the soil samples was determined by wet sieve analysis. There are two main approaches used for sieve analysis: the dry method and the wet method. When the dirt remains on a 4.75mm IS sieve after sifting, the dry sieve method is used. On the other hand, soil that has been kept on a 75-micron IS sieve after passing through a 4.75mm IS sieve is used for wet sieve analysis. Since the clay used for testing is clayey soil, only wet sieve analysis of the untreated soil is performed here due to the removal of the clay particles intact. This method uses the following sieves: 4.75 mm, 2.36 mm, 1.18 mm, 600 µ, 300 µ, 150 µ, and 75 µ. For this experiment, a 200g oven-dried soil sample is passed through a 4.75mm IS sieve. The Particle-Size Distribution of a material is ascertained through sieve analysis. Plotting the Sieve size (mm) and % Finer, which comes from the fine sieve analysis, is a graph

4.3.2 Liquid limit test

In compliance with IS specification IS:2720 (Part 5)-1985, this test was carried out. The water content that corresponds to the arbitrary boundary between the plastic and liquid limits is known as the liquid limit (WL). The lowest water content at which soil retains its liquid condition yet has a minimal shearing power to resist flowing is known as the liquid limit. Plotting a graph between cone penetration (x) and water content (y) will reveal the soil's liquid limit. The 20 liquid limit is then determined by taking the water content that corresponds to a cone penetration of 20 mm. The graphs' set of values indicates that the penetration should range from 14 to 28 mm. This experiment was conducted using a 425µ passing IS sieve.

4.3.3 Plastic limit test

In compliance with IS specification IS:2720 (Part 5)-1985, this test was carried out. The ability of soil to undergo fast deformation without rupture, elastic rebound, or volume change is known as plasticity. The water content that separates the plastic from the semi-solid soil consistency states is known as the plastic limit (WP). It is the lowest water content at which, when rolled into a thread about 3 mm in diameter, the soil will just start to collapse. This experiment uses a 425µ sieve for passage. IP = WL-WP is the plasticity index.

4.3.4 Specific Gravity

Specific gravity measurements are made in accordance with IS-2720 (Part 3/ Section 1)-1980: Technique for soil testing. Section Eight Section 1: Specific Gravity Determination soil with fine grains. The mass density of soil at standard temperature of 27℃ is equal to that of distilled water, which is known as the specific gravity of soil particles. It is the mass of a particular volume of soil divided by the mass of a corresponding volume of water. The letter G stands for it. A digital balance, vacuum desiccator, oven, and density container with a 50 ml capacity are among the equipment needed to conduct this test. The following steps are part of the procedure:

- Firstly, the density bottle was cleaned and dried properly before conducting the test.
- The density bottle along with the stopper been weighed and demoted as M1.
- 5-10g of soil sample was taken in the density bottle and weighed the bottle along with the stopper as M2.
- Now add distilled water to the soil in the density bottle upto the soil level and shake gently to mix soil and water.
- Now the stopper of density bottle was removed and placed in the vacuum desiccator and connect the vacuum pump.

- Take out the bottle after attaining constant temperature and dry the outer surface using cloth and weigh the bottle as a total of mass of bottle, soil and water as M3.
- In the last step, the bottle was emptied and filled solely with distilled water along with stopper and weighed as M4.

The specific gravity is determined by the following equation,

$$G = \frac{M2-M1}{(M4-M1)-(M3-M2)}$$

4.3.5 Proctor test

In accordance with IS: 2720 (Part 7) 1980, the standard Proctor's compaction test was conducted in the lab, and the optimal moisture contest corresponding to the maximum dry density was determined.

The following steps make up the Proctor Compaction Test process:

1. About 3 kg of soil was obtained.
2. Then the soil was passed through the No. 4 sieve.
3. The mass of soil and the mold (W_m) without the collar are weighed.
4. The soil was placed in the mixer and gradually more water was added to it to reach the desired moisture content (w).
5. The collar was then coated with lubricant.
6. The soil was taken out of the mixture and added to the mole in three layers in the following phase. The compaction procedure necessitates 25 blows per layer. After then, the droplets were applied steadily by hand or mechanically. The dirt then fills the mole and reaches, but does not penetrate, the collar by more than 1 cm.
7. As the collar was being carefully lifted from the dirt, it was trimmed with a straight edge that had been sharpened so that it extended above the mold.
8. Then the weight of the mould and soil (W) was noted.
9. In a subsequent stage, a metallic extruder is used to extrude the soil from the mold in a manner that aligns the extruder with the mold.
10. The water content of the sample was then measured at the top, middle and bottom.
11. The soil was then placed again, and water was added to it to achieve a higher water content.

4.3.6 Determination of UCS value:

The unconfined compression tests are done on 3 different soil specimens as per IS: 2720 (part10)-1991 with diameter (d) equal to 38 mm and length (l) to diameter ratio of 2. The type of soil specimen used for the determination of unconfined compressive strength are dynamically compacted specimens at their respective OMC.

Figure 5: UCS Testing Machine

4.4 Determination of dry density, moisture content, unconfined compressive test of natural soil and iron slag lime composite stabilized soil

- **Introduction**

The iron slag lime composite is mixed in proportion of (iron slag 0% + lime 0%), (iron slag 2% + lime 2%), (iron slag 2% + lime 4%), (iron slag 2% + lime 6%), (iron slag 2% +lime 8%), (iron slag 2% + lime 4%), (iron slag 4% + lime 4%), (iron slag 4% + lime 6%) and (iron slag 4% + lime 8%) by weight of soil sample respectively. Before conducting the tests, the soil samples that were combined with iron and lime composite are allowed to cure. Unconfined compressive tests are performed on soil mixed with the above-mentioned amounts of iron slag and lime on the 0th and 7th days of curing, respectively.

- **Sample preparation for Unconfined Compressive Test**

To prepare samples for 0% iron slag and 0% cement composite, 475 micron-passing soil is mixed with the necessary amount of water to achieve the desired consistency. Once the mixture is homogeneous, it is put into a proctor mold to get the necessary compaction. After that, a universal extractor frame was used to remove the sample using a sampling tube from an undisturbed sample tube. After that, the sample's ends were cut. The sample's length and diameter were measured three times, and the average value was used to calculate the results. A homogeneous mixture of soil and water (0% lime and 0% iron slag composite) is depicted in Figure 6

To prepare samples for (2% iron slag + 2% iron slag) composite, 475 micron-passing soil is mixed with the necessary amount of water to achieve the desired consistency. Then, to create a consistent mixture, a precise amount of lime and cement is blended into the soil at a soft consistency.

The mixture is put into a proctor mold to achieve the necessary compaction, and after that, the sample is taken out of the mold using a universal extractor frame and a sampling tube from an undisturbed sample tube. After that, the sample's ends were trimmed. Three measurements were made of the sample's length and diameter, and the average value was utilized in the computation. The same procedure is repeated for all the other samples

Figure: 6 Uniform mixture of soil and water (iron slag 0% + lime 0%)

CHAPTER 5

RESULT AND ANALYSIS

5.1 Observation and Calculation

5.1.1 Wet sieve analysis

Total mass of oven dried sample = 200g

Table 5.1: Particle size distribution

Sieve sizes (mm)	Retained	% Retained	Cumulative % Retained	% Finer
4.75	0	0	0	100
2.36	0.796	0.398	0.398	99.602
1.18	2.172	1.086	1.484	98.516
0.6	3.265	1.633	3.117	96.884
0.425	10.319	5.160	8.276	91.724
0.3	5.688	2.844	11.120	88.880
0.15	12.016	6.008	17.128	82.872
0.075	5.043	2.522	19.650	80.351

Sand= (100-80.351) %
=19.649%

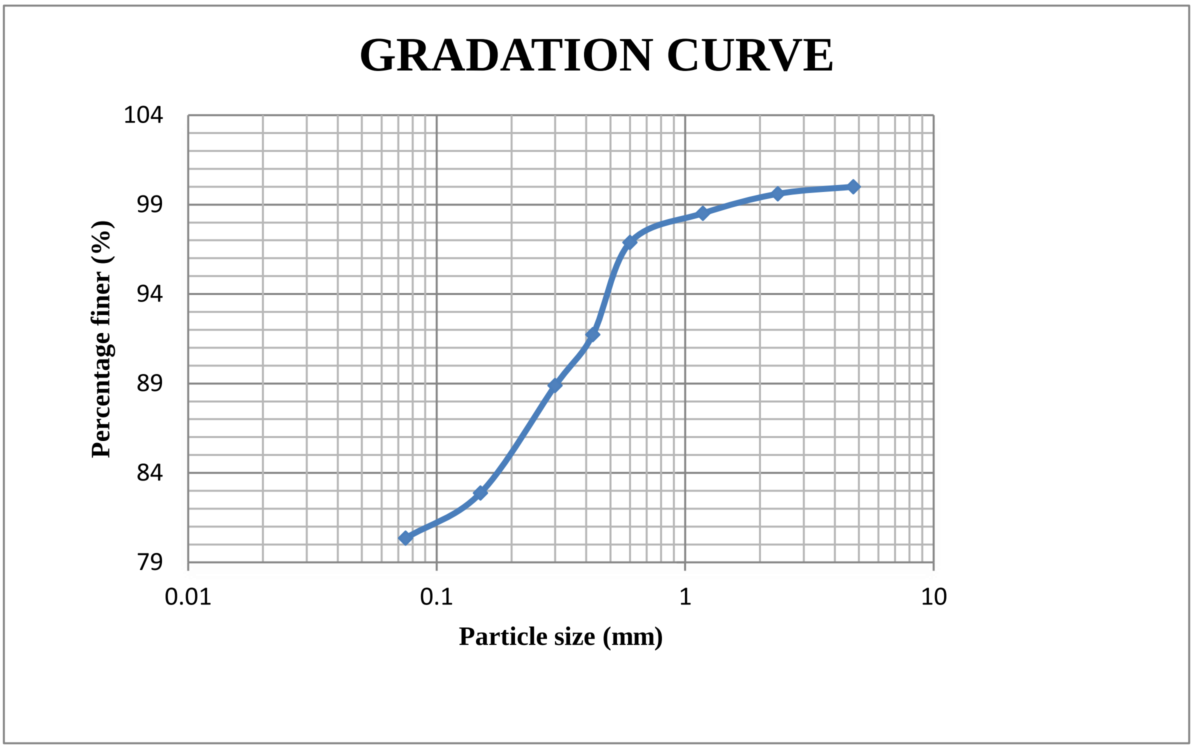

Figure: 7 Particle size distribution curve

5.1.2 Liquid limit test

Total mass of sample taken = 400g

Table 5.2: Values for water content determination for liquid limit

Cone penetration(mm)	Mass of empty container(g)	Mass of container with wet soil (g)	Mass of container with dry soil (g)	Mass of dry soil (g)	Mass of water (g)	Water content (%)
14	8.909	14.120	12.298	3.389	1.822	53.76
17	9.796	18.424	15.231	5.435	3.193	58.75
21	9.764	18.460	15.194	5.430	3.266	60.15
25	9.449	24.380	18.607	9.158	5.773	63.04

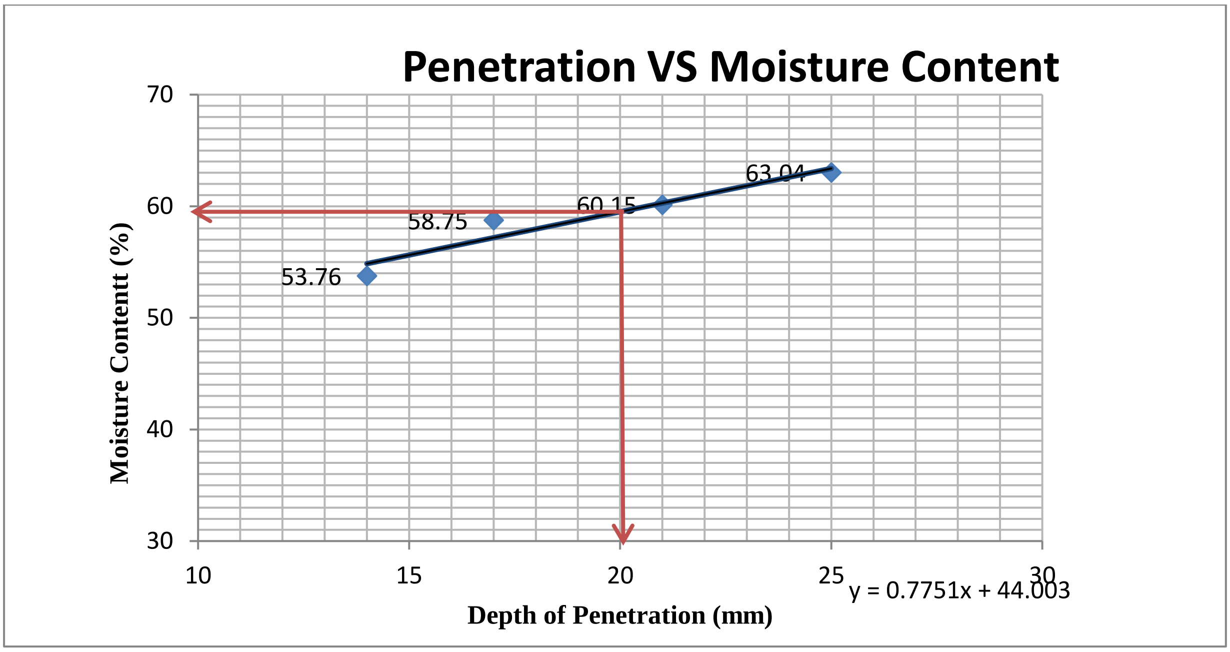

Figure: 8 Water content vs penetration curve

Liquid Limit = 59.5%

5.1.3 Plastic limit test

Table 5.3: Values for water content determination for plastic limit

Sl no.	Mass of empty container(g)	Mass of container with wet soil(g)	Mass of container with dry soil(g)	Mass of water(g)	Mass of dry soil(g)	Water content (%)
1	9.803	10.753	10.519	0.234	0.716	32.681
2	9.651	11.14	10.762	0.378	1.111	34.023
3	9.957	11.729	11.289	0.44	1.332	33.033

Plastic limit = 33.245%

Plasticity index = 26.225%

5.1.4 Specific Gravity

Total mass of sample taken = 5-10 g

Table 5.4: Specific gravity values

Density bottle no.	Mass of density bottle and stopper, M1	Mass of density bottle, stopper and soil, M2	Mass of density bottle, stopper, soil and water, M3	Mass of density bottle, stopper and water, M4	Specific gravity(G)
1	27.22	36.768	84.365	78.101	2.907
2	35.702	45.405	95.484	89.204	2.835
3	35.365	44.795	94.473	89.383	2.173

Specific Gravity = 2.638

5.1.5 Standard Proctor Test

Diameter of the mould = 100mm

Volume of the mould = 10000cc

Height of the mould = 127.5mm

Weight of the sample taken =2.5kg

Empty mould + base plate = 3302g

Table 5.5: Determination of MDD and OMC

Mass of compacted soil+mould with base plate(g)	Mass of empty container (g)	Mass of container with wet soil(g)	Mass of container with dry soil(g)	Mass of water (g)	Mass of dry soil (g)	Mass of empty mould with base plate (g)	Bulk density (g/cc)	Water content (%)	Dry density (g/cc)
5106	6.397	21.978	19.256	2.722	12.859	3302	18.04	21.08	14.90
5154	9.662	23.609	21.06	2.549	11.398	3302	18.57	22.36	15.14
5242	10.164	23.461	20.766	2.695	10.602	3302	19.45	25.25	15.51
5232	10.106	25.652	22.342	3.310	12.177	3302	19.35	27.18	15.18
5218	10.192	34.786	29.144	5.642	18.952	3302	19.21	29.77	14.76

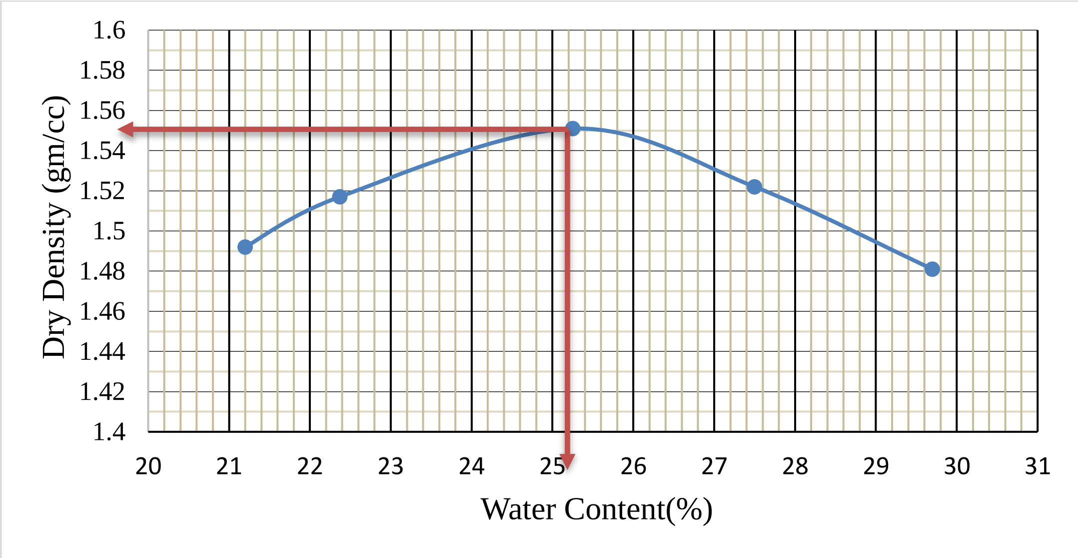

Figure: 9 Dry density vs Water content curve

Results: OMC (Optimum Moisture Content) = 25.25%

MDD (Maximum Dry Density) = 1.55 gm/cc

Table 5.6 Atterberg's limit of various percentage Iron slag and lime in soil

Iron slag % + lime %	Liquid limit %	Plastic limit %	Plasticity index %
0 IS + 0L	59.5	33.24	26.22
2IS+ 2L	54.48	33.89	20.59
4IS+4L	52.80	34.14	18.66
6IS+ 6L	50.89	35.24	15.65

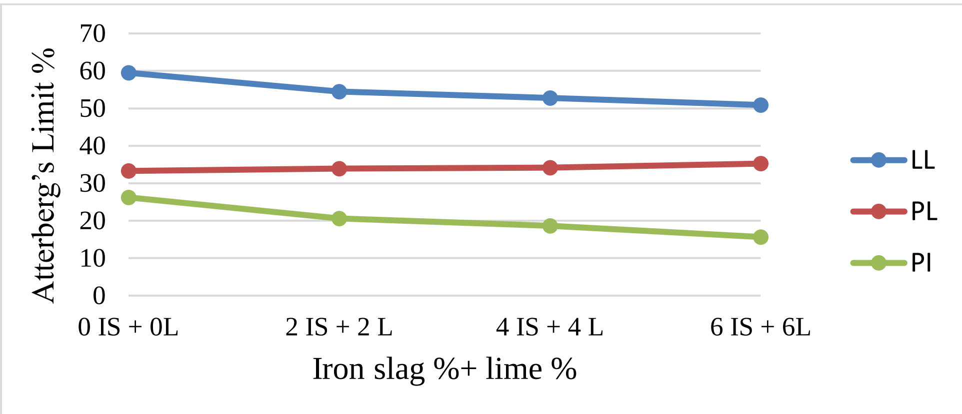

Figure:10 LL, PL and PI curve with varying % of additive

5.1.6 Test results of compaction properties of the soil:

The outcomes of the standard compaction test conducted on all the iron slag and lime stabilized soil are presented in detail in this section. Results shows that with increase in both iron slag and lime content Dry Density as well the Optimum Moisture Content increases

Iron slag (2%) and lime (2%)

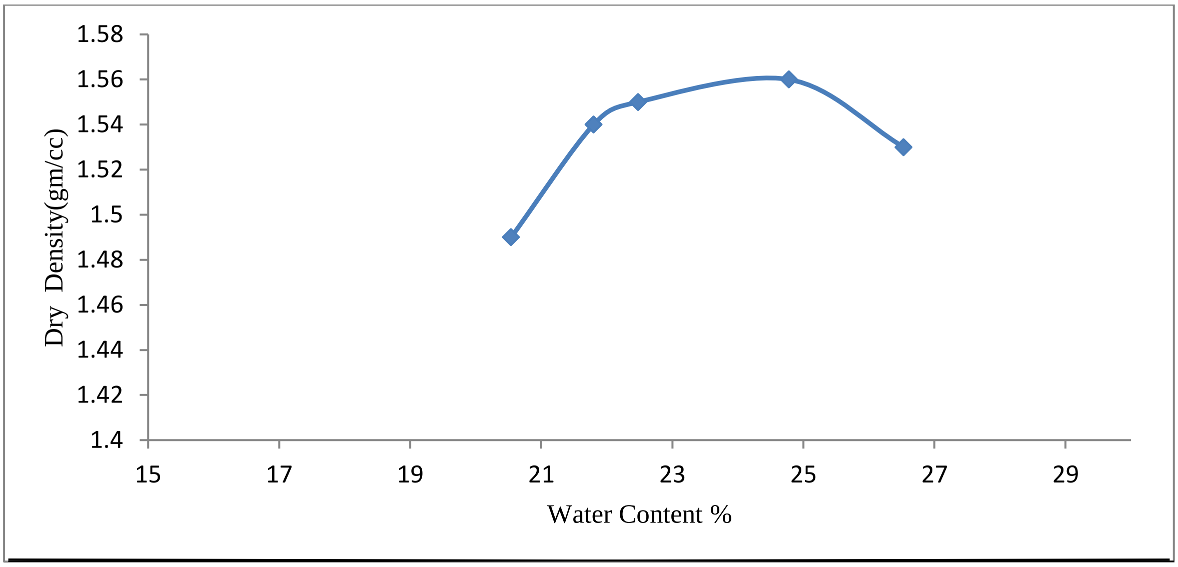

Figure:11 Compaction curve for iron slag 2% and lime 2%

Iron slag (4%) and lime (4%)

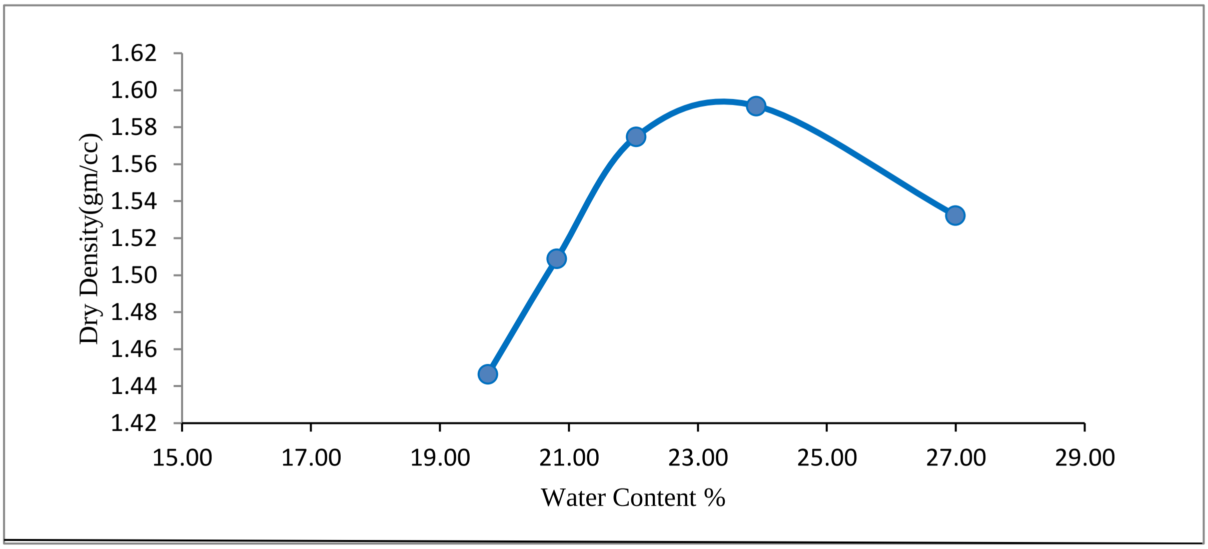

Figure:12 Compaction curve for iron slag 4% and lime 4%

Iron slag (6%) and lime (6%)

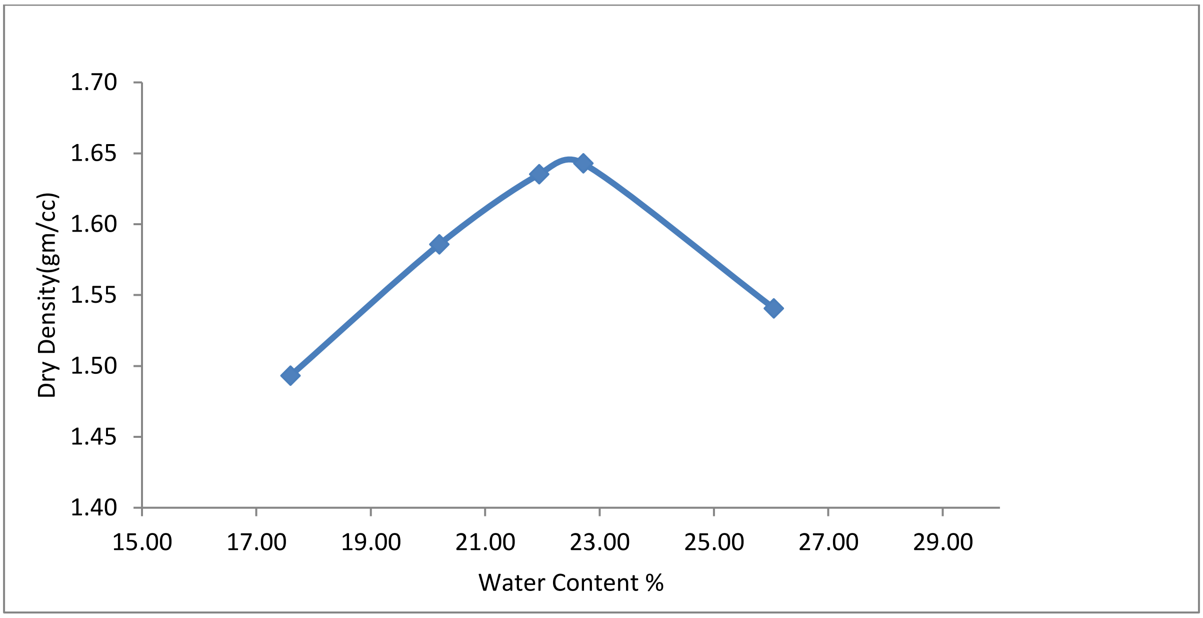

Figure:13 Compaction curve for iron slag 6% and lime 6%

Compaction curve for all the samples

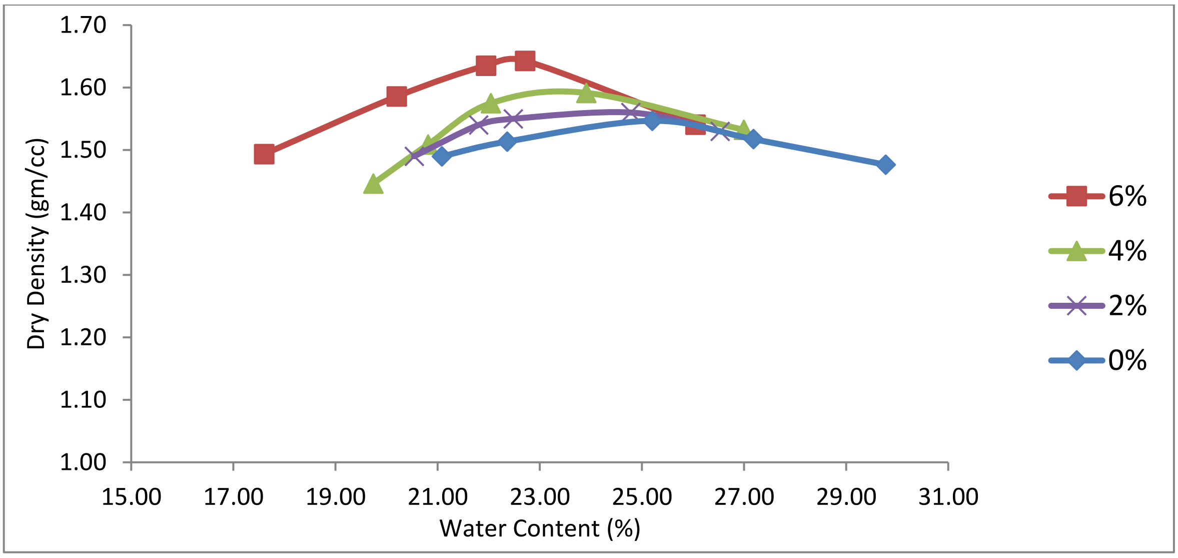

Figure: 14 Superimposed compaction curves for the samples

5.1.7 Analysis of test results of unconfined compression test (UCT)

The 4 samples were test by dry curing the sample for 24hrs tightly packed under the room temperature.

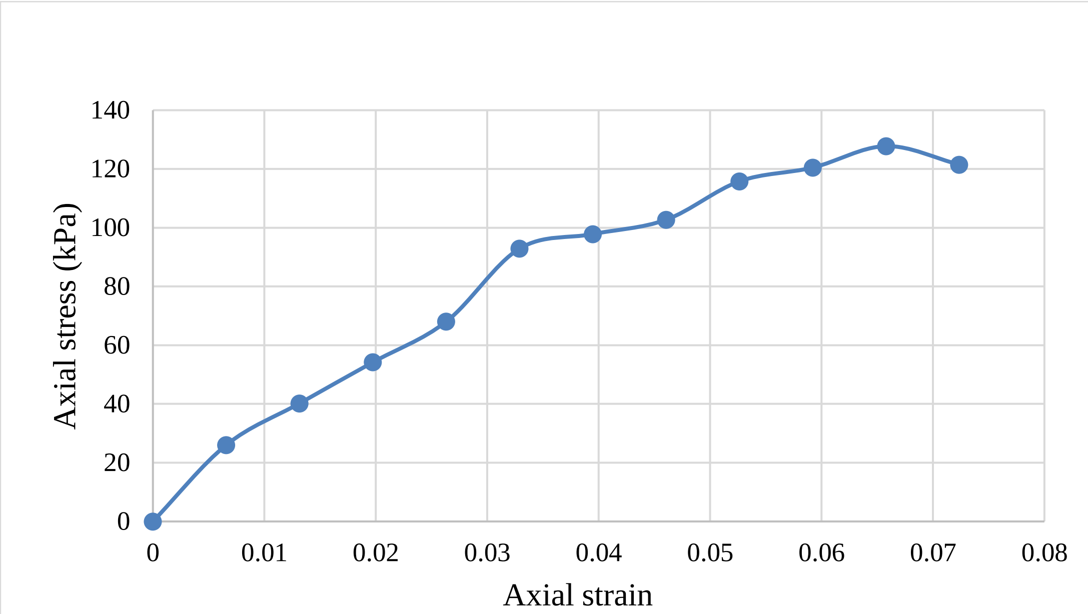

Figure: 15 Stress- strain curve for iron slag 0% and lime 0%

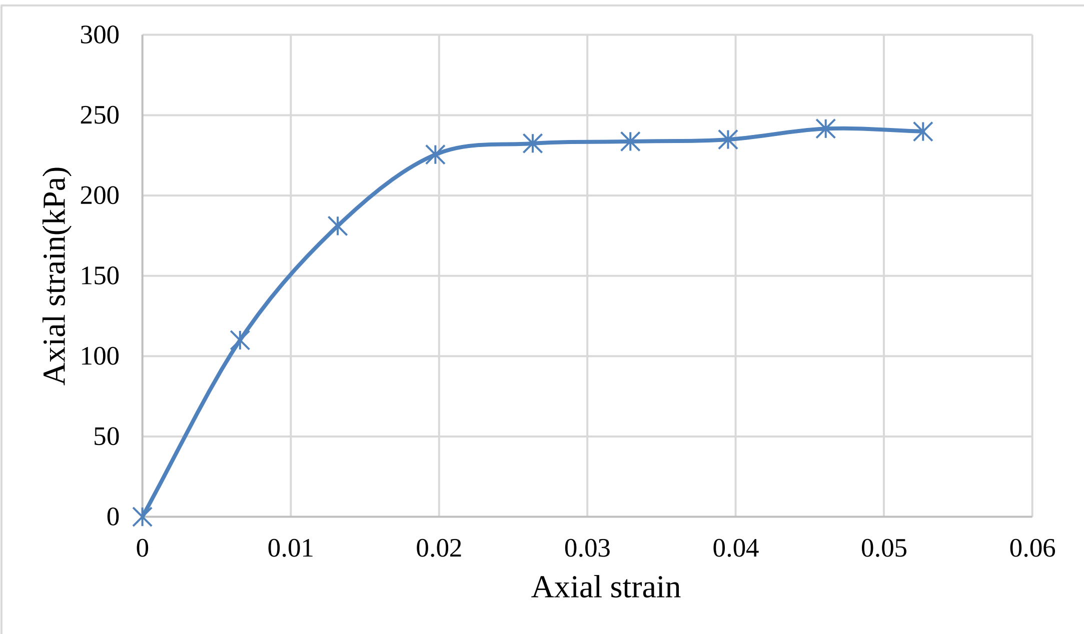

Figure: 16 Stress- strain curve for iron slag 2% and lime 2%

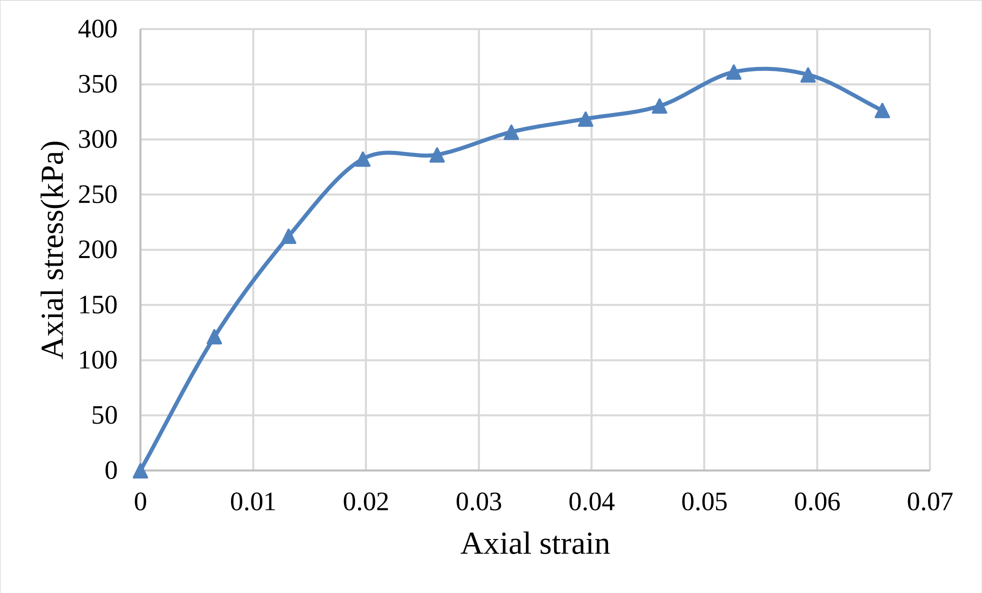

Figure: 17 Stress- strain curve for iron slag 4% and lime 4%

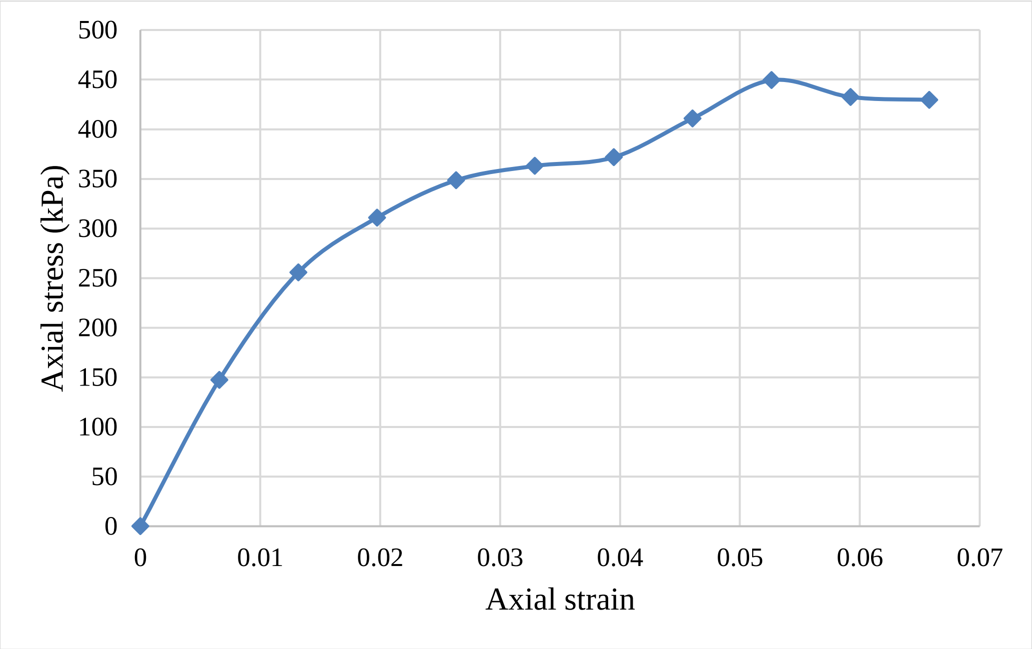

Figure: 18 Stress- strain curve for iron slag 6% and lime 6%

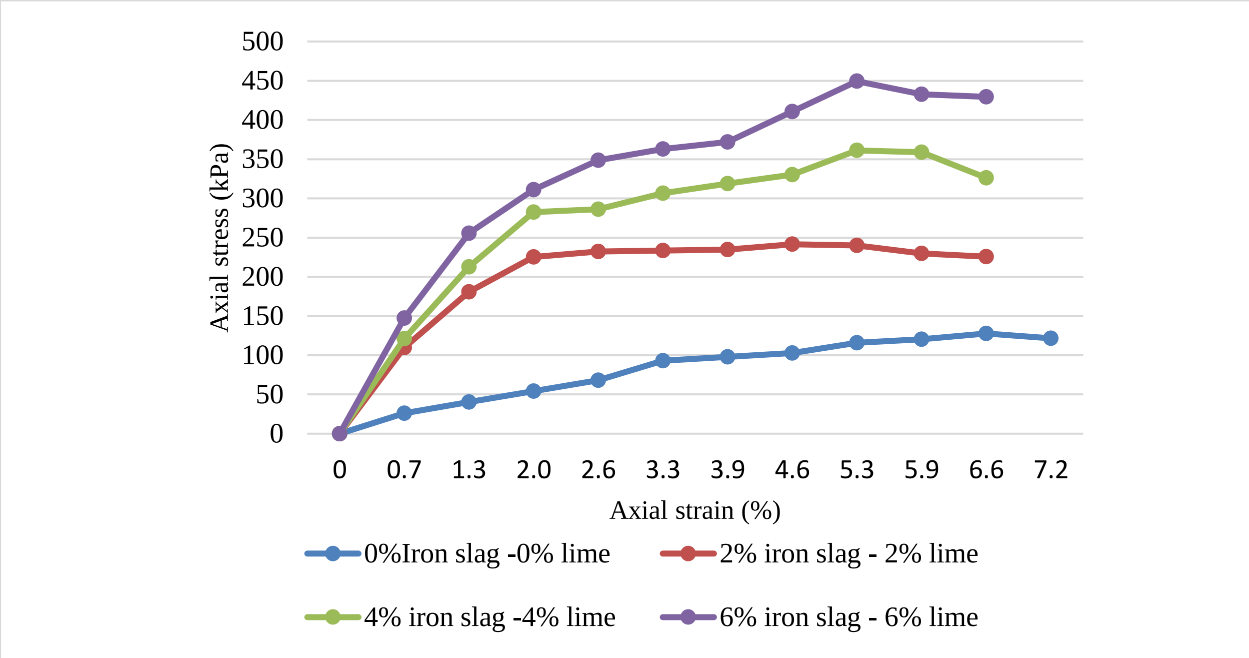

Figure:19 Superimposed Stress- strain curve for all the samples

CHAPTER 6
DISCUSSION AND FUTURE SCOPE

6.1 Conclusions

In geotechnical engineering, stabilizing soil is an essential procedure that aims to improve the physical characteristics of soil to increase its strength, durability, and capacity to support loads. Using this method, the soil is stabilized by adding lime and iron slag, which is a industrial waste The iron slag- lime-soil mixed samples were allowed to cure for 0 day and the compaction test and Unconfined Compressive Test was performed on the soil samples mixed with the previously stated amounts of iron slag and lime, The test results obtained in this study shows that the liquid limit decreases with increase in percentages of iron slag and lime. The plasticity index also decreases with increase in percentages of iron slag and lime, which indicated the reduction in the compressible nature of the soil.

The optimum moisture content decreases with increase in percentage of iron powder and lime. The maximum dry density increases on constant increase in percentage of iron powder and lime. In this study the optimum amount of iron powder and lime in the soil is found to be 6% iron powder and 6% lime by weight of dry soil. There is increase in UCS values with increase in iron slag and lime content.

Further studies can be made to see the optimum admixture content

6.2 Scope for future work

This report presents the data on shear strength parameters of iron slag lime stabilized soil. The following suggestions are made to extend future studies:

- Studies can be carried out by increasing the lime content and iron slag content and by increasing the curing period.
- Different tests such as the CBR test, triaxial test etc. can be carried out on the soil.
- To study the leaching potential of iron in the environment

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