INVESTIGATING THE SHEAR PROPERTIES OF CEMENT-LIME STABILIZED SOIL USING A SERIES OF TRIAXIAL TESTS

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

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DECLARATION

I hereby declare that the work presented in the dissertation "**Investigating the shear properties of cement-lime stabilized soil using a series of triaxial tests**" 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 Prof. Bhaskarjyoti Das, 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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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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I also thank all the faculty members and staff of the Department of Civil Engineering.

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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 keeping cement content constant at 2% and increasing the lime content and keeping lime constant at 2% and increasing the cement content. Triaxial tests were conducted for the natural soil and by mixing the soil with (cement 2% + lime 2%), (cement 2% + lime 4%), (cement 2% + lime 6%), (cement 2% + lime 8%), (lime 2% + cement 2%), (lime 2% + cement 4%), (lime 2% + cement 6%) and (lime 2% + cement 8%) by weight of the natural soil. Triaxial testings were done on the very day when the samples were prepared and after 7 days of curing period. The best proportion of cement and lime of all the tests conducted came out to be at (lime 2% and cement 8%) for 7 days of curing period. The value of cohesion and angle of internal friction obtained at (lime 2% and cement 8%) when the sample was cured for 7 days was 120.4kPa and 20.9° respectively which is significantly higher than the value of cohesion and angle of internal friction obtained when no cement and lime was added (34.4kPa and 15° respectively). In general, as the amount of cement and lime in the soil is increased and the curing period also lengthens, the value of cohesion and angle of internal friction also increases. Therefore, it's critical to assess how cement and lime affects the strength characteristics of the soil type under consideration.

Keywords: Soil stabilization, Lime, Cement, Triaxial test

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LIST OF SYMBOLS/ABBREVIATION

Sl. No.	Symbols/abbreviation	Description
1	UU	Unconsolidated Undrained
2	CU	Consolidated Undrained
3	CD	Consolidated Drained
4	MDD	Maximum Dry Density
5	OMC	Optimum Moisture Content
6	c	Cohesion
7	φ	Angle of internal friction
8	kPa	Kilopascal (unit of cohesion)
9	CBR	California Bearing Ratio

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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. This information is critical for designing foundations, retaining structures and other elements of construction projects. Soil has a very important and key role in 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.

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.

The engineering properties of soil can be altered and improved by addition of agents like cement, lime, fly ash, blast furnace slag, bitumen etc or a combination of these agents. Addition of these agents 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. Additive like lime, cement, fly ash and asphalt are known as chemical admixture. Soil stabilization with cement or lime is a well-established technique, and its application is widespread in civil engineering and construction projects to transform weak or problematic soils into stable and 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.

- **Hydrated lime :**

  Hydrated lime, also known as calcium hydroxide , is a dry powder obtained by treating quicklime (calcium oxide, CaO) with water. This process is called slaking, and it results in a chemical reaction that produces calcium hydroxide.

  Hydrated lime is applied to soil to improve its structure and reduce acidity. It is used in mortar and plaster to improve workability and durability.

- **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. The specific 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 coming into contact with 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 dust.

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 Cement

1.7.1 Introduction

Cement stands as an elemental force in the realm of construction, anchoring the structures that shape our urban landscapes and define the contours of our modern living spaces. This ubiquitous binding material plays a pivotal role in the evolution of architecture and engineering, serving as the bedrock upon which our built environment rests. Cement, in its contemporary form, is a finely ground powder composed primarily of limestone, clay, silica, and iron ore. The manufacturing process involves heating these raw materials to high temperatures in a kiln, resulting in a clinker that is subsequently ground into the fine powder we recognize as cement. This transformation releases calcium silicates and aluminates, the compounds responsible for cement's remarkable binding properties.

1.7.2 Types of cement

There are several types of cement, each designed to meet specific construction needs and requirements. Here are some common types of cement:

- **Ordinary Portland cement (OPC) :**
  OPC is the most widely used type of cement and is suitable for general construction purposes. It's a hydraulic cement that hardens over time through a chemical reaction with water. OPC is manufactured by heating limestone and clay or other materials in a kiln at a high temperature. The resulting clinker is then ground into a fine powder, which is the cement.
- **Portland pozzolona cement (PPC) :**
  Portland Pozzolana Cement (PPC) is a type of hydraulic cement that is produced by combining Portland cement clinker with pozzolanic materials. The pozzolanic materials, such as fly ash, volcanic ash, or silica fume, are added to enhance the properties of the cement. The term "Pozzolana" comes from the name of a volcanic ash found near the city of Pozzuoli in Italy, which was historically used as a pozzolanic material. The addition of pozzolanic materials to Portland cement improves certain characteristics of the cement, such as durability, workability, and long-term strength.

- **Rapid hardening cement (RHC) :**
  Rapid Hardening Cement (RHC), also known as High Early Strength Cement, is a type of Portland cement that is designed to develop higher strength at an early age compared to Ordinary Portland Cement (OPC). This property makes it particularly useful in situations where quick setting and early strength gain are crucial, such as in cold weather concreting or when a rapid construction pace is required. The manufacturing process of rapid hardening cement is similar to that of OPC, but the clinkering temperature is higher, resulting in a finer grind of the cement clinker.
- **Low heat cement (LHC) :**
  Low Heat Cement (LHC) is a type of Portland cement designed to generate less heat during the hydration process compared to Ordinary Portland Cement (OPC). The reduced heat of hydration is beneficial in certain construction scenarios where the risk of thermal cracking or damage from the heat generated during cement hydration needs to be minimized. The manufacturing process of low heat cement is similar to that of OPC, but specific adjustments are made to the composition to control the heat released during the hydration reactions.

1.7.3 Properties of a good quality cement

- The chemical composition of cement, including the amount of calcium, silica, alumina, iron oxide, and other components, must comply with established standards.
- Good quality cement should have a fine and uniform particle size distribution.
- Cement should have a well-defined setting time, indicating the time it takes for the cement paste to change from a plastic state to a solid state.
- Cement should have well-defined initial and final setting times.
- The color of cement is typically gray. Significant variations in color may indicate impurities or inconsistent manufacturing processes.

1.7.4 Use of cement in soil stabilization

Cement is often used in soil stabilization to improve the engineering properties of soil, making it more suitable for construction and infrastructure projects. 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.

Cement reacts with the soil particles, forming cementitious bonds that increase the overall strength of the soil. Stabilizing soil with cement reduces its plasticity and susceptibility to changes in moisture content. Soil stabilization with cement enhances the load-bearing capacity of the soil, making it suitable for supporting heavy structures and traffic loads. 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. Soil stabilization with cement can be a cost-effective alternative to other foundation or soil improvement methods.

1.7.5 Precautions while handling cement

- Workers should use waterproof and alkali-resistant gloves to protect their hands from cement's caustic properties.
- Safety goggles or a face shield should be used to protect the eyes from cement dust and splashes.
- A dust mask or respirator should be used if cement dust is present, especially in enclosed or poorly ventilated areas.
- Proper ventilation should be ensured in areas where cement is being mixed or used to avoid inhaling dust.

1.7.6 Action of cement in soil

When cement is mixed with soil, important processes occur that change the physical characteristics of the soil and make it more suitable for building and stabilization. These reactions are called cementation and hydration. Here's a brief note on these reactions –

Hydration Reaction

When cement is mixed with soil and water, the hydration process begins. The primary compounds in cement, such as tricalcium silicate (C_3S) and dicalcium silicate (C_2S), react with water to form calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$).

- **C_3S + Water → C-S-H + $Ca(OH)_2$**
- **C_2S + Water → C-S-H + $Ca(OH)_2$**

The hydration reaction is exothermic, releasing heat, which can further accelerate the reaction process.

Cementation Reaction

The main binding component that adds to the cement-soil mixture's strength and durability is the C-S-H gel that is created during hydration. This gel binds soil particles together by filling up the spaces between them. Particularly in clayey soils, the $Ca(OH)_2$ created during hydration elevates the pH of the soil, creating an alkaline environment that encourages additional interactions with soil minerals.

In the presence of certain soil types, particularly those containing silica and alumina, the $Ca(OH)_2$ reacts with these components to form additional cementitious compounds.

- **SiO_2 (from soil) + $Ca(OH)_2$ → C-S-H**
- **Al_2O_3 (from soil) + $Ca(OH)_2$ → Calcium Aluminate Hydrate**

These cementitious compounds grow and mature over time, greatly enhancing the compressive and shear strengths of the soil. The soil can get even stronger over time as a result of the prolonged hydration and pozzolanic reactions.

1.8 Triaxial Test

1.8.1 Introduction

A key laboratory technique in geotechnical engineering for determining the mechanical characteristics of rock and soil is the triaxial test. This test assesses these materials' strength and deformation properties under regulated stress and drainage settings. The triaxial test is used to measure strength parameters like cohesion and angle of internal friction. A triaxial test involves confining a cylindrical soil sample under pressure by a surrounding fluid, axially compressing it, and covering it with a rubber membrane. Engineers can replicate the various stress conditions that materials encounter in real-world situations by altering the confining pressure and the rate of axial loading. Triaxial test results are essential for planning stable embankments, foundations, and other structures because they reveal how rocks and soils behave under different stress conditions.

1.8.2 Different parts of triaxial system

Loading frame: The method for imparting an axial load to the soil sample is provided by the loading frame. Multiple loading frame capabilities exist. A 10kN load frame with a 10kN maximum load capacity is the one shown in Figure 1.3.

Load cell: The load cell supplies the force required to shear a specimen that is triaxial. The triaxial cell comes in a range of sizes and pressure ratings. The test involves applying pressure to the cell containing the triaxial specimen.

Triaxial cell: This type of cell holds the soil sample and enables confining pressure to be applied. A typical triaxial system with a load frame, load cell, and triaxial cell is seen in Figure 1.1.

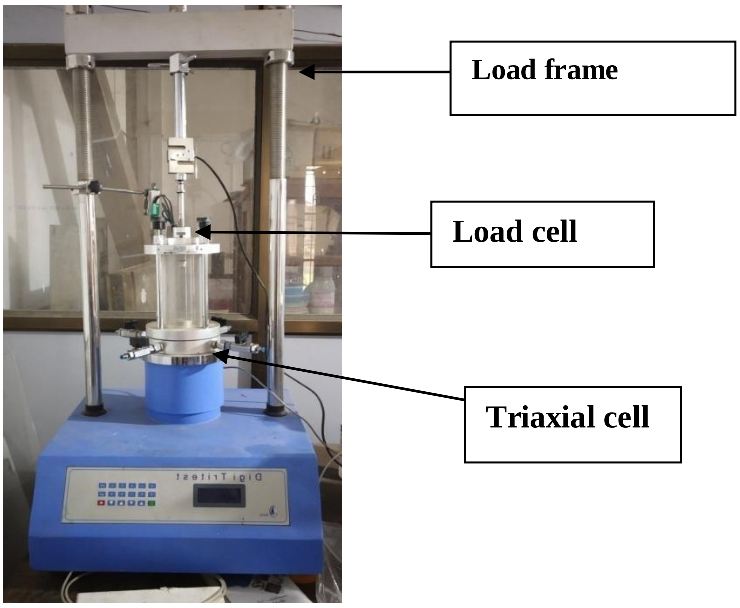

Figure 1.1: Typical triaxial system

Source: Geotechnical lab Assam Engineering College

Constant pressure system: The constant pressure system is used to establish a constant and variable pressure contact between water and oil. From this point on, back pressure and cell pressure are modified. A pressure gauge is provided so that known pressures can be applied to the test specimen using the pressure regulators mounted on the panel. A system of constant pressure is seen in Figure 1.2.

Figure 1.2: Constant pressure system

Source: Geotechnical lab Assam Engineering College

Automatic volume change device with digital indicator: The automatic volume change (AVC) device displays load, pressure, displacement, and digital indicator data. The automatic volume change device is used in some triaxial tests to measure the amount of water entering the specimen as well as the specimen's volume change during the test. This test project does not make use of an automated volume changer. An automatic volume changer and digital indicator are shown in Figure 1.3.

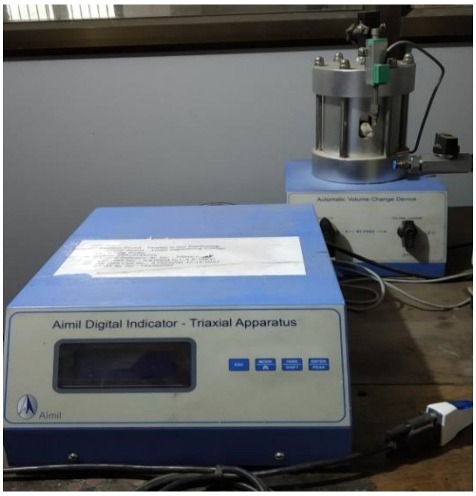

Figure 1.3: Digital indicator and automatic volume change device

Source: Geotechnical lab Assam Engineering College

Oil warer cylinder: An interface between oil and water is provided by an oil and water cylinder. Figure 1.4 depicts a water-oil cylinder.

Figure 1.4: Oil water cylinder

Source: Geotechnical lab Assam Engineering College

Sample preparation equipment: Figure 1.5 shows equipment for preparing samples.

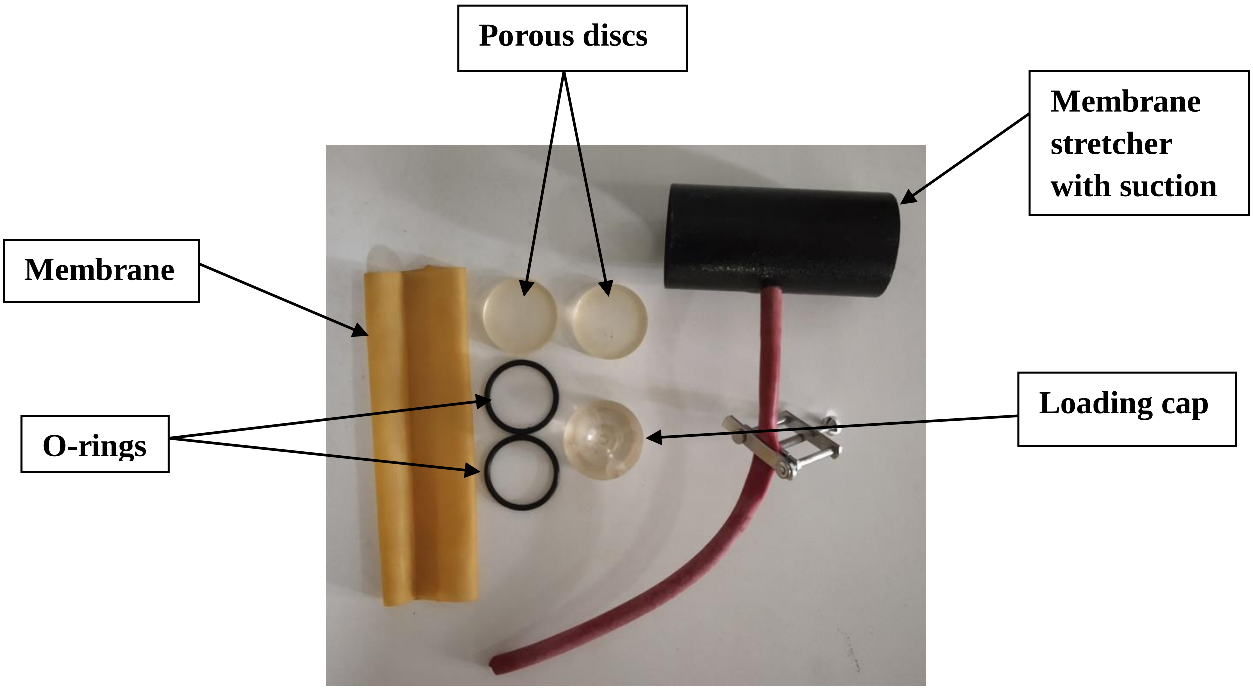

Figure 1.5: Sample preparation equipment

Source: Geotechnical lab Assam Engineering College

1.8.3 Triaxial test (stress condition)

A standard triaxial test involves placing a cylindrical soil or rock specimen in a pressurized chamber to simulate a stress state, then shearing the specimen till failure in order to evaluate the shear strength characteristics of the sample. Usually, the samples range in size from 38 to 100 mm, but larger samples can be analyzed with the correct equipment. The test specimen's height to diameter ratio is usually 2:1.

The stress conditions that are applied to a sample during a typical test are shown in Figure 1.6, and the fundamental ideas of effective stresses are shown in Figure 1.7.

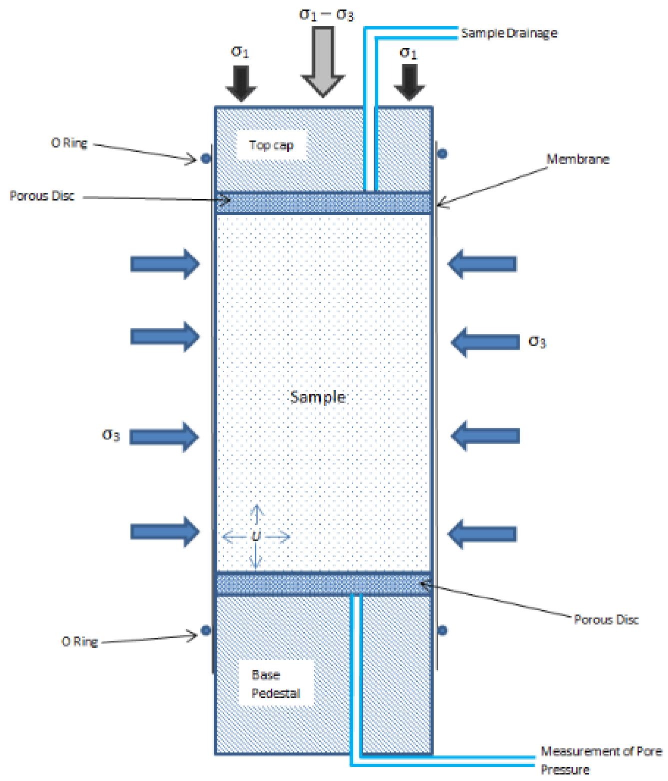

Figure 1.6: Stress conditions that are delivered to a sample during a typical test

Source: https://www.vjtech.co.uk/an-introduction-to-triaxial-testing

For a triaxial compression test, in brief:

σ_1 - Vertical or axial Stress (vertical load applied to the sample)

Another name for vertical stress is "Major Principle Stress". It is also called σ_v.

σ_3 - Confining Pressure (cell pressure)

Another name for vertical stress is "Minor Principle Stress". It is also called σ_h.

U - Pore Pressure

It is also called U_w (Pore Water Pressure (P.W.P))

$\sigma_1 - \sigma_3$: Deviator Stress (the stress caused by the specimen's axial load that is greater than the confining pressure)

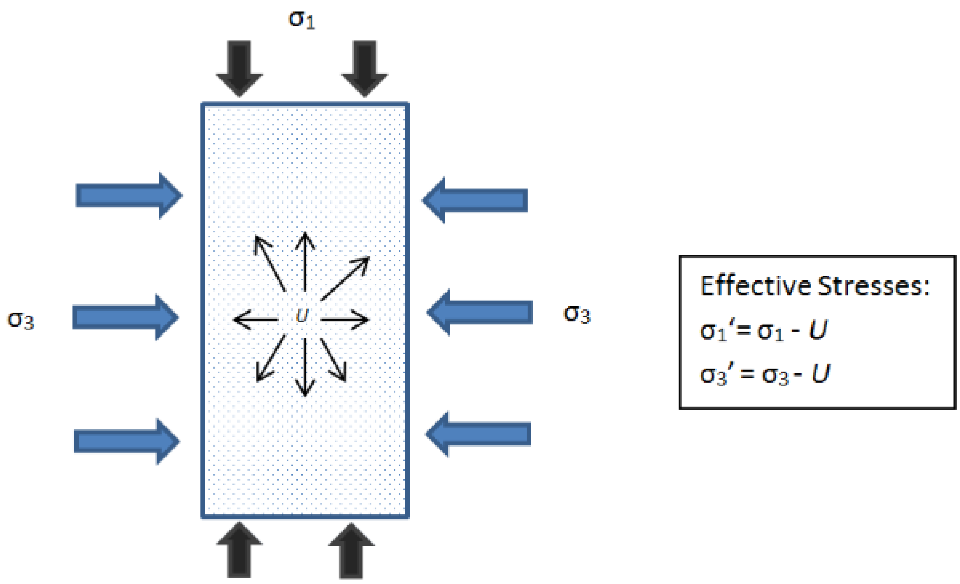

Figure 1.7: Effective stresses

Source: https://www.vjtech.co.uk/an-introduction-to-triaxial-testing

σ_1' – Effective Vertical (axial) Stress

σ_3' – Effective Confining Pressure

U - Pore Pressure

1.8.4 Types of triaxial tests

Triaxial tests are an essential part of geotechnical engineering because they shed light on how soils behave mechanically under various stress scenarios. Triaxial tests come in a variety of forms, each intended to replicate certain loading and environmental circumstances. The primary types of triaxial tests include:

- Unconsolidated Undrained (UU) Test
- Consolidated Undrained (CU) Test
- Consolidated Drained (CD) Test

UU Test: The Quick Triaxial Test, sometimes called the Unconsolidated Undrained (UU) triaxial test, is a basic geotechnical testing technique used to ascertain the undrained shear strength of soil. The soil sample is subjected to axial stress application without being allowed to consolidate or drain during the test. Here, the cell pressure is maintained constant while the applied deviator stress is increased until the sample fails.

CU Test: The Consolidated Undrained (CU) triaxial test is a widely used geotechnical test that measures the shear strength of soil under conditions where it is first allowed to consolidate under a confining pressure, and then sheared without allowing drainage. This test provides valuable information about the soil's behavior under conditions similar to those encountered in many engineering applications

CD Test: The Consolidated Drained (CD) Triaxial Test is a vital laboratory procedure used in geotechnical engineering to determine the long-term shear strength and deformation characteristics of soil. This test is particularly significant for assessing the stability of structures where drainage can occur over time, such as in foundations, slopes, and retaining walls.

1.8.5 Application of triaxial test

The triaxial test is a cornerstone in geotechnical engineering, offering crucial insights into the mechanical behavior of soils under various stress conditions. Its primary application lies in determining the shear strength and deformation characteristics of soil, which are essential for designing and assessing the stability of earth structures such as foundations, embankments, slopes, and retaining walls. By simulating different environmental conditions through various test types - Unconsolidated Undrained (UU), Consolidated Undrained (CU), and Consolidated Drained (CD), engineers can predict how soils will respond to changes in load, pressure, and drainage over time. The data obtained from triaxial tests are fundamental for evaluating the short-term and long-term stability of structures, assessing liquefaction potential during seismic events, and understanding the stress-strain relationships in soils. This information is crucial for ensuring the safety, durability, and cost-effectiveness of construction projects, making the triaxial test an indispensable tool in both academic research and practical engineering applications.

1.8.6 Limitation of triaxial test

While the triaxial test is a powerful tool in geotechnical engineering, it does have some limitations that engineers must consider. One significant limitation is related to the representativeness of laboratory conditions compared to field conditions. Despite efforts to simulate real-world scenarios, the scale and controlled environment of laboratory tests may not fully capture the complex and heterogeneous nature of soil behavior in situ. Variations in soil composition, structure, and moisture content in the field can affect results differently than in controlled laboratory settings.

Another limitation lies in the time-consuming nature of the test itself, especially in cases where multiple stages or cycles are required to fully characterize soil behavior under different stress conditions. The process of sample preparation, consolidation, and shearing can be lengthy, particularly for low-permeability soils that require extended periods for drainage to occur.

Additionally, while triaxial tests provide valuable data on shear strength parameters and deformation characteristics, they may not fully account for all environmental factors and loading conditions experienced by soil in the field. Factors such as dynamic loading, cyclic loading, and temperature variations, which can significantly impact soil behavior, may require additional testing methods or adjustments to triaxial test procedures to accurately predict real-world performance.

Despite these limitations, the triaxial test remains an essential and widely used method for characterizing soil properties and assessing the stability of geotechnical structures. Engineers mitigate these limitations through careful test planning, interpretation of results in conjunction with field observations, and often complementing triaxial tests with other testing techniques to obtain a comprehensive understanding of soil behavior.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of available literatures

Ali Hayder Shareef (2016) This study deals with some improving methods that could be utilized in ground formed mainly of a thick bed of soft clay such as that of the central and southern Iraq. The method used in this paper is to improve the soft soil via using Iraqi manufactured stabilizers where a composite from cement and quicklime was added at different rates (2 to 10%) for cement and (2% and 4%) for quicklime by dry weight of soil were added to natural soil samples. After the soil specimens treated with PC and LQ were tested in unconfined compression (UCS) and triaxial (UU), it was noticed that there is an increase in shear strength about 3.5 times for soil AL- Zaafaraniya and 4 times for soil Garma Ali in half an hour of mixing soil with composite (cement + lime). Also the shear strength was increased with an increase curing period, where at specimens test with 7 days increase shear strength about 38 times. When the specimens were cured for 28 days the shear strength increased about 51 times.

Nadhirah Mohd Zambri and Zuhayr Md. Ghazaly (2018) This paper compares the increase in shear strength when two additive Lime and Cement were added to peat soil in terms of stabilization. Direct Shear Box Test was conducted to obtain the shear strength for all the disturbed peat soil samples. The quick lime and cement was mixed with peat soil in proportions of 10% and 20% of the dry weight peat soil. The experiment results showed that the addition of additives had improved the strength characteristics of peat soil by 14% increment in shear strength. In addition, the mixture of lime with peat soil yield higher result in shear strength compared to cement by 14.07% and 13.5% respectively.

M. R. Asgari & A. Baghebanzadeh Dezfuli & M. Bayat (2013) This paper studies the effects of two types of additive for the soil (i.e., lime/cement) on the geotechnical and engineering properties of the soil. The results of this study indicated that optimum moisture content, maximum dry unit weight, and plasticity index are affected by the addition of cement or lime. The cement treatment resulted in the increment of unconfined compressive strength

(UCS) of the soils significantly. Also it was found that the mechanical behaviors of the soil due to cement treatment was noticeably higher than lime treatment.

Bulbul Ahmed, Md. Abdul Alim, Md. Abu Sayeed (2013) In this paper a comprehensive testing program had been carried out to study the stress change behavior of non stabilized soil. Compressive strength was conducted using universal testing machine. A series of tests were conducted for stabilized soil under twenty categories; ten on cement admixture and ten on lime admixture. In addition, a series of compressive strength test were also carried out for stabilized and without stabilization of soil to study the effect of admixture on shear strength. The Compressive strength test resulted the shear strength of soil varied from 25 psi to 210 psi with respect to the different percentage of cement after 3 days curing and the same value varied from 25 psi to 220 psi for 7 days curing. The compressive strength for mixing of lime admixture varied from 22 psi to 70 psi and 23 psi to 95 psi for 3 days and 7 days curing period respectively.

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. Also soil stabilization through lime-columns, lime treatment of pavement layers and lime-based embankment stabilization as important applications of lime stabilization have been discussed.

Ali Jamal Alrubaye, Muzamir Hasan and Mohammed Y. Fattah (2016) This study assess 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.

Nesar Uddin Ahmed (1984) In this paper three types of soils - silty sand, sandy silt and silty clay collected from three locations in Bangladesh were stabilized by two stabilizing agents - lime and cement at different proportions. The stabilized soil samples cured for 3, 7, 14 and 28 days were tested for unconfined compression, density, volume shrinkage, swelling potential and plasticity. The results shows that cement treated soils increased their strength with cement content. A significant reduction in swelling and shrinkage occurred when soils were stabilized with low percentages of lime (2%) and cement (5%).

Basuki Ampera and Taner Aydogmus (2005) This paper provides mainly the recent experiences on stabilization of local typical poor cohesive soil, obtained from the region Chemnitz, using cement and lime. This paper provides the general understandings of stabilization of clay soils and in particular the most beneficial type of additives and the quantities to use to achieve the design requirements. Many factors affecting stabilization such as dosage, material processing, curing conditions, etc., have been studied and recommendations have been made to attain a meaningful comparison between cement and lime usage.

Masrur Mahedi, Bora Cetin and David J. White (2020) In this paper Three different soils with variable sulfate contents were treated with Type I/II portland cement, lime, Class C fly ash (FA), and Class C FA–cement and Class F FA–cement blends. Test results presented that cement was preferable for higher strength at shorter curing times (7 days) while lime produced the maximum strength at longer curing periods (90 days). The results concluded that 10% to 12% calcium oxide (CaO) in stabilizers was optimum for stabilizing expansive soils.

Mohamed Khemissa, Abdelkrim Mahamedi (2014) This paper presents the results of a series of normal Proctor compaction tests, methylene blue tests, California bearing ratio tests and undrained direct shear tests performed on Sidi-Hadjrès expansive overconsolidated clay treated with mixture of various cement and lime contents and compacted under the optimum Proctor conditions. In this study the best test results were obtained for a treatment corresponding to 8% cement and 4% lime contents.

Mehdi Gharib, Hamidreza Saba, Arash Barazesh (2023) In this article cement and lime were used as two chemical additives to improve swelling and shrinkage properties in expansive soils in Golestan province of Iran. Four soil types with plasticity indices 25, 30, 35 and 40 were selected. Then the plasticity properties of the soils including liquid, plasticity and shrinkage limits as well as plasticity index were investigated and compared among the specimens in different mixture proportions.

Based on the experiments conducted to stabilize specimens of problematic soils with different plasticity indices using cement and lime in different proportions, some of the conclusion that were made are as follows –

- **Soil with PI=25 stablized with cement**
  1. Increased proportion of cement in clay-cement mixture did not produce uniform changes in the liquid limit of the mixture so that no generalization could be made about its behavior. In some proportions, the liquid limit of the mixture increased while in some it decreased comparing with the liquid limit of unmixed soil specimen.
  2. Increased proportion of cement in clay-cement mixture resulted in increased plasticity index in the mixture so that in the mixtures with 9-13 percent cement proportions, the plasticity index increased with a steep slope. The greatest change was onserved in the mixture with 19 percent cement addition whereby the plasticity index increased as much as 70 percent in the mixture comparing with unmixed soil specimen.
  3. Increased proportion of cement in clay-cement mixture brought about increases in shrinkage limit so that in the mixures with 9-13 percent cement, the shrinkage limit increased with a very steep slope. From small proportions of cement in the mixture up to 5 percent, the shrinkage limit was decreasing in the mixture; however, from 5 percent and over, this index increased cumulatively in the mixture until it reached its maximum value in the mixture with 19 percent cement
  4. The most appropriate proportion of cement in the clay-cement mixture was found to be 13 percent, in which volume change in the mixture was the lowest.
- **Soil with PI=25 stablized with lime**
  1. Variations in the liquid limit did not follow a discernable pattern in the clay-lime mixture so that in low proportions of lime, considerable fluctuations were

observed in the liquid limit. As the proportion of lime increased in the mixture, the liquid limit either increased or decreased randomly. However, in the mixture with 9 percent lime, the liquid limit began to follow an increasing trend and maintained this trend up to 19 percent lime addition.

2. Adding lime to clay soil increased the plasticity limit in the mixture so that the increase in this index had a uniform slope. The increase continued with a reasonable distanceat relatively identical intervals.
3. Increased proportions of lime in the clay-lime mixture increased the shrinkage limit in the mixture specimens. However, with small proportions of lime up to 5 percent, a decrease was observed in the shrinkage limit. Yet, the decrease in this limit was stopped with higher proportions of lime in the mixture and an increasing trend was observed in the limit as the lime proportion increased in the mixture.
4. The most appropriate proportion of lime in the clay-lime mixture was found to be 13 percent, in which volume change in the mixture was the lowest.

- **Soil with PI=30 stablized with cement**
    1. Increased proportion of cement in clay-cement mixture did not produce uniform changes in the liquid limit of the mixture so that with small proportions of cement, an alternate decreasing-increasing trend was observed in the liquid limit, which continued up to 9 percent cement addition. However, from over 9 to 19 percent cement proportion, an increasing trend was observed in the liquid limit of the mixture.
    2. Increased proportion of cement in the clay-cement mixture resulted in increased plasticity index in the mixture so that in the mixtures with 15-19 percent cement, the plasticity limit had a very steep slope. The increase in the plasticity index was found to show a sudden leap so that with 13 percent cement in the mixture, it showed a 55 percent growth and with 19 percent cement, it doubled up and amounted to 113 percent growth.
    3. Increased proportion of cement in the clay-cement mixture increased the shrinkage limit in the mixture. This limit, however, showed a decrease in the mixture with 1 percent cement proportion but then drammatically increased, reaching its peak in the mixture with 19 percent cement.

4. The most appropriate proportion of cement in the clay-cement mixture was found to be 13 percent, in which the volume change in the mixture was the lowest.

- **Soil with PI=30 stablized with lime**
  1. Liquid limit variaions did not show a discernible pattern in this mixture. The variations in liquid limit values were not tangible in different proportions of lime.
  2. Increased proportion of lime in the clay-lime mixture increased the plasticity index in the mixture so that with 1-3 percent lime in the mixture, the increase in the index had a steep slope. However, with over 3 percent lime, the increase in the plasticity index followed a more uniform pattern with a more gentle slope
  3. Increased proportion of lime in the clay-lime mixture increased the shrinkage limit in the mixture so that with 1-3 percent lime in the mixture, the shrinkage limit had a very steep slope.
  4. The most appropriate proportion of lime in the clay-lime mixture was found to be 13 percent, in which the volume change in the mixture was the lowest.

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 materials for highly active soils which undergo through 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 few hours.

Guy Lefebvre, Charles C. Ladd, and Jean-Jacques Pard The purpose of the paper is to compare, at two different sites, the field vane strength with the undrained shear strength measured in laboratory on intact clay specimens cut from block samples. The laboratory tests included triaxial compression, triaxial extension, and direct simple shear tests on specimens anisotropically reconsolidated to the in-situ stresses. The laboratory undrained shear strength was determined on averaged stress strain curves built from the three types of laboratory tests in order to account for strain compatibility. It was found that at both sites, the undrained shear strengths obtained by the field vane and by the laboratory tests were nearly identical.

Mohammad Nikookar, Mahyar Arabani, Seyed Mohammad Mirmoa'zen, Mehdi Karimi Pashak (2016) This study, which is the first in-depth experimental investigation on peat in Iran, uses consolidated-undrained triaxial (CU) and unconfined compressive strength (UCS) tests to examine the effects of various hydrated lime levels and curing times on peat stability. Because it provides experimental data for both test kinds and offers a novelty comparison between these tests. Lime contents of 3, 6, 9, 12, and 15% were utilized for this purpose, and varying curing times of 7, 14, 28, and 90 days were employed.After then, the outcomes of these tests were contrasted. A new value of equivalent unconfined strength—that is, the strength in the hypothetical scenario of zero confining pressure in a triaxial test—is introduced, computed, and compared with UCS values in order to compare triaxial test results. The pore water pressure generated in CU tests, which can reduce the equivalent unconfined strength of soil, is the reason why the equivalent unconfined strengths of CU tests are consistently lower than those of the UCS test. Furthermore, the undrained cohesive strength is 0.35 times the comparable unconfined strength for peat, even though it is half the UCS value.

A. M. Ajorloo, H. Mroueh, L. Lancelot (2011) In order to measure the effects of cementation on the stress-strain behavior, stiffness, and shear strength, an experimental study of cement-treated sand is carried out under triaxial testing in this work. Samples underwent 180 days of curing. The findings demonstrate that cemented sands exhibit nonlinear stress-strain behavior with contractive-dilative phases. The cement composition and effective confining pressure have a significant impact on the stress-strain response. An increase in binder content significantly improves stiffness and strength. It is routinely found that when cement content increases, the angle of shearing resistance and cohesion intercept increase. At low confining pressure and high cement content, brittle behavior is seen. The increase in dilatancy speeds up after yielding.

Balasingam Muhunthan et al (2008) – This study's first section provides a thorough examination of how different additives are used in soil development programs. The effects of cement treatment on the geotechnical properties of soils from the Palouse, Everett, and Aberdeen regions of Washington are then analyzed in detail. It was discovered that the use of cement enhanced the soils' workability, compaction qualities, and pace of drying. Significant increases in unconfined compressive strength and elastic modulus are obtained by treating these soils with cement.Undrained triaxial test results showed that different forms of failure behavior were observed despite the fact that cement treatment greatly enhanced shear strength. Cement treatment of 5%, 10%, or no cement resulted in ductile, planar, or cracking failure modes, in that order. Pore pressures swiftly rose to confining pressures in soils treated with 10% cement, leaving zero effective confining pressure at failure. The specimens split vertically as a result. Consequently, large cement percentages should only be used in field applications under the closest supervision, even though cement treatment may boost strength.

The triaxial test results on Aberdeen soil were assessed using the critical state framework. As a result of cement treatment, interlocking increased, critical state friction stayed constant, and soils displayed anisotropic behavior. The anisotropic model of Muhunthan and Masad (1997) was used to forecast the undrained stress path. This model, when combined with extended Griffith theory, allows for the prediction of the entire shear behavior of cement-treated soil in q-p space. The study's main practical implications center on evaluating the enhancement in mechanical behavior resulting from cement treatment and highlighting how adding more cement could turn stabilization into an extremely dangerous process.

Nabil AL- Joulani (2012) - From his research, it can be inferred that the soil was treated with stone powder and lime at specific weight percentages (10%, 20%, and 30% by weight) and mixed to the optimal moisture content as established by the compaction test. The samples were put through the direct shear, compaction, and CBR tests without being soaked or cured. The results demonstrated that adding 30% stone powder reduced cohesiveness by roughly

64% and raised internal friction angle (φ) by about 50%. With 30% lime added, the friction angle and cohesiveness have decreased by 57% and 28%, respectively. The maximum dry density and ideal moisture content were somewhat decreased by adding 30% stone powder. On the other hand, the maximum dry density and optimal moisture content dropped by 19% and 13.5%, respectively, with the addition of 30% lime. The CBR values increased from 5.2 to 16 and 18, respectively, with the addition of 30% stone powder and lime, respectively.

F.H.M. Portelinha et al (2012) - This study assesses how lateritic soil properties can be modified with small amounts of cement and lime, focusing on mixture behavior from the beginning of construction to the end product. Based on experimental results, the workability and mechanical strength of the soil might be changed with just 2% to 3% addition of cement or lime. Additionally, mechanistic analyses confirmed that, when applied to foundation layers of pavement, the soil modification technique is a successful technique that causes minimal elongation of the asphalt layer.

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 shear strength parameters (c and φ) of the untreated soil by using triaxial test.
- Determination of shear strength parameters (c and φ) of the cement and lime stabilized soil at different curing periods by using triaxial test.

CHAPTER 4

METHODOLOGY

4.1 Collection of soil sample

The area selected for the collection of soil sample 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 4.1: 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 let to dry at room temperature in accordance with the IS Code technique. 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 4.2.

Figure 4.2: Air dried sample for curing

4.3 Description of the tests performed

4.3.1 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.

4.3.2 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.

4.3.3 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°C 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 weigh 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 weighed the bottle as a total of mass of bottle, soil and water as M3.
- In the last step, 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,

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

4.3.4 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 for 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.

4.4 Determination of shear strength parameters of natural soil and cement lime composite stabilized soil by using a series of triaxial tests

4.4.1 Introduction

The remolded soil sample and the cement lime composite mixed soil samples, which were prepared under various conditions, underwent a series of triaxial tests as part of the experimental procedure to determine the parameters of cohesion (c) and angle of internal friction (φ) of all the soil samples, thereby examining the impact of the cement lime composite on the soil.

The cement lime composite is mixed in proportion of (cement 0% + lime 0%), (cement 2% + lime 2%), (cement 2% + lime 4%), (cement 2% + lime 6%), (cement 2% + lime 8%), (lime 2% + cement 2%), (lime 2% + cement 4%), (lime 2% + cement 6%) and (lime 2% + cement 8%) by weight of soil sample respectively. Before conducting the triaxial tests, the soil samples that were combined with cement and lime composite are allowed to cure. Triaxial tests are performed on soil mixed with the above-mentioned amounts of cement and lime on the 0th and 7th days of curing, respectively. The same tests are carried out on soil samples that have had different amounts of cement and lime added to them. The test results for each condition were noted and compared including the test in which no cement and lime was added to the soil.

4.4.2 Sample preparation

To prepare samples for 0% lime 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. For a 0 day reading, three samples were prepared and examined. In this instance, no sample was ready for curing. A homogeneous mixture of soil and water (0% lime and 0% cement composite) is depicted in Figure 4.3.

To prepare samples for (2% lime + 2% cement) 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. On that particular day 6 samples were prepared. Three samples were used on that day for the 0 day reading at 50 kPa, 100 kPa and 150 kPa cell pressure, and 3 samples were sealed with plastic bags and stored in a humidity chamber at ambient temperature for the required 7th day curing period. Samples of soil stabilized with lime are kept for curing in order to observe how shear strength parameters change as a result of the cement and lime's chemical reaction with the soil during the curing time. Figure 4.4 shows (cement 2% + lime 2%) stabilized soil.

The same procedure is repeated for (cement 2% + lime 4%), (cement 2% + lime 6%), (cement 2% + lime 8%), (lime 2% + cement 4%), (lime 2% + cement 6%) and (lime 2% + cement 8%) mixtures. Figure 4.5 shows cement + lime stabilized soil where cement content is 2% and lime content is 4; figure 4.6 shows cement + lime stabilized soil where cement content is 2% and lime content is 6%; figure 4.7 shows cement + lime stabilized soil where cement content is 2% and lime content is 8%; figure 4.8 shows cement + lime stabilized soil where lime content is 2% and cement content is 4%; figure 4.9 shows cement + lime stabilized soil where lime content is 2% and cement content is 6%; figure 4.10 shows cement + lime stabilized soil where lime content is 2% and cement content is 8%.

Figure 4.3: Uniform mixture of soil and water (cement 0% + lime 0%)

Figure 4.4: Cement lime stabilized soil (cement 2% + lime 2%)

Figure 4.5: Cement lime stabilized soil (cement 2% + lime 4%)

Figure 4.6: Cement lime stabilized soil (cement 2% + lime 6%)

Figure 4.7: Cement lime stabilized soil (cement 2% + lime 8%)

Figure 4.8: Cement lime stabilized soil (lime 2% + cement 4%)

Figure 4.9: Cement lime stabilized soil (lime 2% + cement 6%)

Figure 4.10: Cement lime stabilized soil (lime 2% + cement 8%)

Figure 4.11: Samples for curing

4.4.3 Triaxial Procedure

The following steps make up the triaxial test procedure:

1. The soil specimen, which was created using a universal extractor frame from a compacted soil specimen at the ideal moisture content, is cut from the sampling tube of an undisturbed sample tube. The trimmed specimen should have a diameter of 38.1 mm and a length of 76.2 mm. The average values area unit used for computation, and the diameter and length area unit measured at least three places. The specimen's weight (W1) is recorded.
2. Using a membrane stretcher, the specimen is then encased in a rubber membrane with a diameter of 38.1 mm and a length of around 100 mm. Rubber membranes will inhale when the ends of the membrane are spread back over the ends of the stretcher and suction is applied between the stretcher and the membranes. After that, the specimen is simply slipped over the membrane and stretcher, the suction is released, and the membrane is unrolled from the stretcher's ends.
3. Since no pressure is to be monitored and no air or water drainage is permitted, non-porous stones are utilized on each side of the specimen.
4. The bottom fly nuts are removed from the porous cylinder by unscrewing it from its base.
5. A 38.1 mm diameter rubber O-ring is rolled over to the bottom of the cylinder's pedestal, which is the spot for the specimen to be deposited. The pedestal is cleaned before being used. The specimen is positioned centrally over the pedestal, accompanied by the non-porous plate on either side. The bottom edge of the machine that is covering the specimen is sealed against the pedestal by rolling back the O-ring over the membrane.
6. The specimen's upper plate is covered by the cap, and another O-ring is carefully rolled over it to secure the rubber membrane's top against the cap. The rubber O-ring design creates an efficient seal between the specimen and the membrane, keeping the water under pressure. The specimen's coaxiality and verticality with respect to the cylinder chamber are verified.
7. The chamber and loading plunger are carefully positioned over the base of the soil specimen, being cautious not to disturb it and making sure the plunger rests in the center of the specimen's cap. Next, the loading frame is adjusted so that, to the unaided eye, it just touches the plunger top. The chamber is then rotated if required so

that the dial gauge, which measures compression, sits centrally over the top of the screw, which is fastened to the top of the cylinder chamber holding the specimen and can latch at any angle. After that, the cylinder is securely fastened to the bottom plate by tightening the nuts.

8. In order to facilitate the exit of air as water enters the chamber through another valve that connects the chamber to the water storage cylinder, the valves to drain the chamber and the valve to drain the air and water from the sample are both closed. Additionally, the air lock nut at the highest point of the cylinder is left open.
9. A valve is used to shut the top of the water storage cylinder when it has been fully filled with water. The necessary pressure is created in the cylinder holding the specimen by opening the connecting valve. When water starts to emerge through the air lock nut at the top of the chamber, the cylinder has been permitted to fill all the way up. After that, the airlock nut is closed to create the required confining pressure and to keep it there continuously.
10. A hand-operated loading device lowers the loading plunger until it comes into contact with the specimen top cap. A spike in the proving ring dial gauge's reading indicates this.
11. The deformation dial gauge reading is set to zero for this setting.
12. The proving ring and compression dial gauge's initial reading is noted.
13. The motor is started at the loading frame, applying the vertical load to the specimen. The proving ring dial gauge's shift indicates the imposed load. The deformation dial gauge provides the deformation of the soil specimen and can be used to determine the strain in the soil.
14. Proving ring dial gauge readings are obtained at 0.5, 1.0, 1.5, and 2.0% of strain, as well as at 1.0% strain intervals up to failure or 20% strain, whichever occurs first.
15. The pressure gauge on the water cylinder indicates the desired value, which is maintained throughout the test in the chamber containing pressure.
16. Following specimen failure or the recording of 20% strain, whichever the situation, the following actions should be taken: (a) stop applying the load; (b) disconnect the linger valve and close the chamber from the water storage cylinder; (c) slightly open the air lock knob; and (d) open the valve to release the water in the cylinder. A short while later, the airlock nut fully opens, allowing air to enter the cylinder at the top and facilitating the rapid draining of water.

17. Once all of the water has been drained out, the loading frame cylinder is carefully removed, and the Lucite cylinder from the base is loosed without affecting the sample.
18. The size and available space of the unsuccessful specimen are recorded.
19. After wiping the rubber membrane dry, its weight (W2) is determined; this weight should equal W1.
20. After removing the specimen's membrane, a representative specimen is taken, ideally from the sheared zone.
21. Following that, three distinct lateral pressures (confining) of 0.5, 1.0, and 1.5 kg/cm^2 (5, 10 and 15 psi or 50, 100, and 150 kpa) are applied to the test with three specimens of the same soil sample.

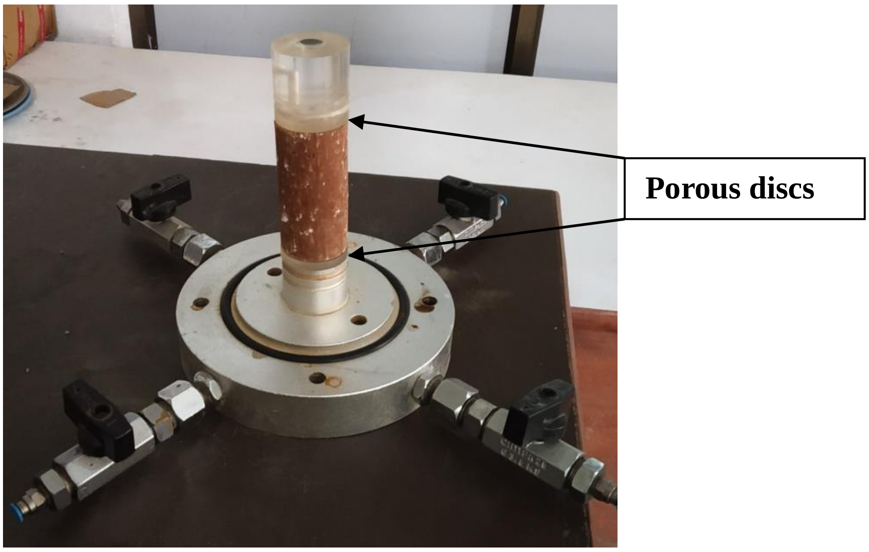

Figure 4.12: Sample in triaxial cell base with porous discs

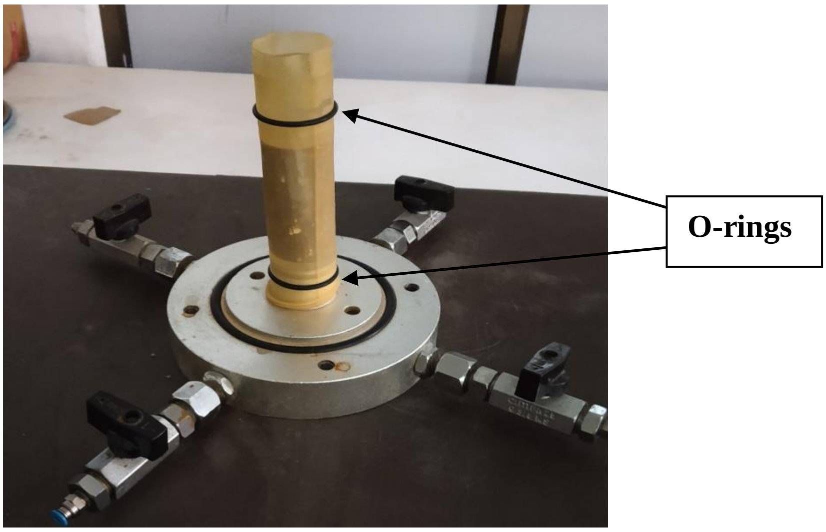

Figure 4.13: Two O-rings seal the sample to the membrane

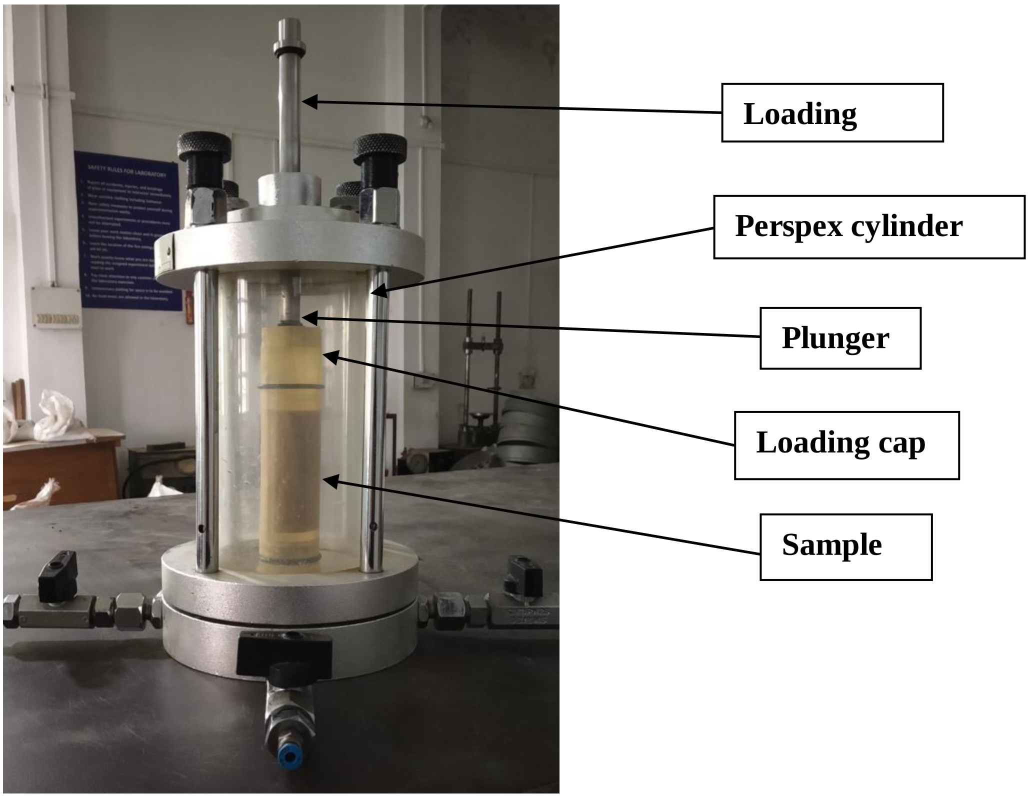

Figure 4.14: Soil sample in triaxial cell

CHAPTER 5

RESULT AND ANALYSIS

5.1 Observation and Calculation

5.1.1 Liquid limit test

Total mass of sample taken = 400g

Table 5.1: 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 (%)
13	8.773	26.280	22.388	13.615	3.892	28.586
16	10.007	30.341	25.375	15.368	4.966	32.314
18	10.027	23.721	20.208	10.181	3.513	34.505
22	6.386	17.893	14.780	8.394	3.113	37.086
24	7.110	28.210	21.965	14.855	6.245	42.040

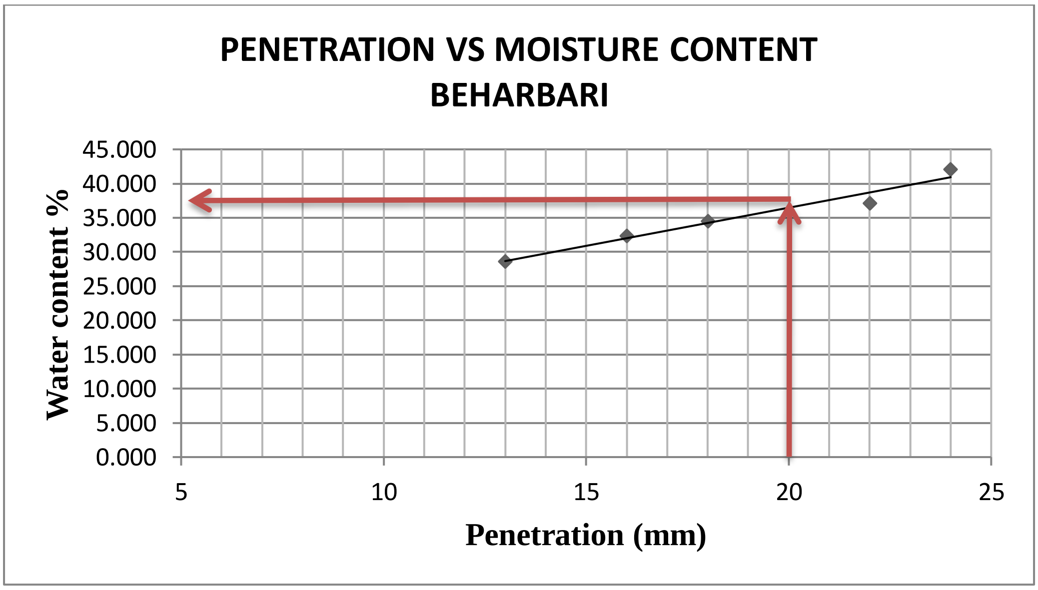

Figure 5.1: Water content vs penetration curve

Liquid Limit = 36 %

5.1.2 Plastic limit test

Table 5.2: 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	9.226	12.377	11.87	0.507	2.644	19.175
2	8.042	11.237	10.699	0.538	2.657	20.248
3	9.084	12.589	12.007	0.582	2.923	19.911

Plastic limit = 19.778%

Plasticity index = 16.222%

A-line (PI) = 11.63

Soil type = CI soil

5.1.3 Specific Gravity

Total mass of sample taken = 5-10 g

Table 5.3: 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

5.1.4 Standard Proctor Test

Diameter of the mould = 100mm

Volume of the mould = 10000cc

Height of the mould = 127.5mm

Weight of the sample taken = 2kg

Empty mould + base plate = 3328g

Table 5.4: 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)
5236	8.819	22.963	21.547	1.416	12.728	3328	18.717	11.125	16.844
5370	8.294	26.96	24.330	2.630	16.036	3328	20.032	16.401	17.210
5426	10.263	27.868	25.010	2.858	14.747	3328	20.581	19.380	17.240
5395	8.175	24.925	21.744	3.181	13.569	3328	20.277	23.443	16.426
5276	8.394	25.156	21.790	3.366	13.396	3328	19.110	25.127	15.272

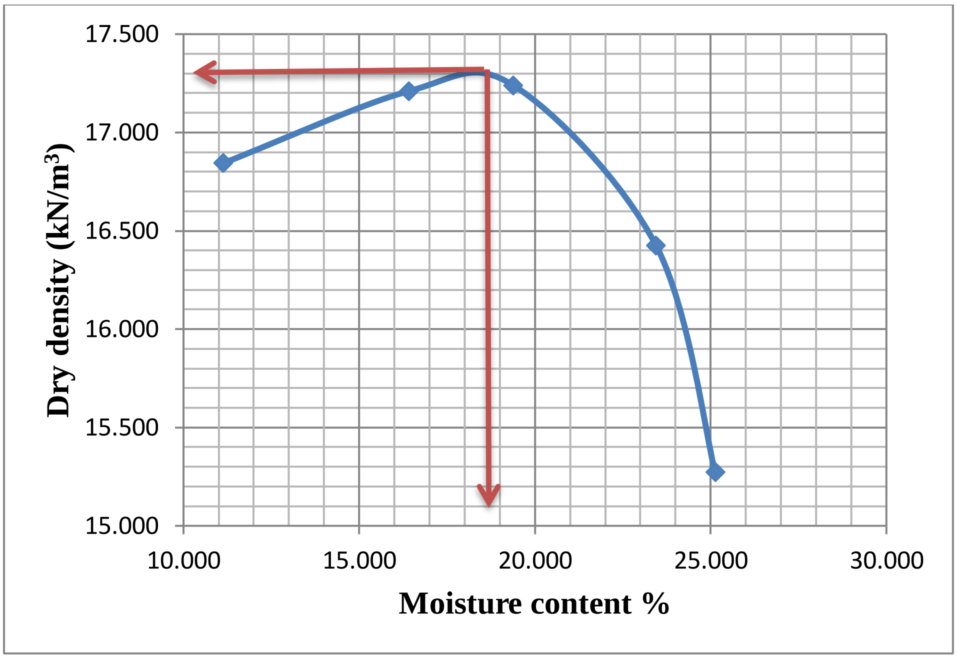

Figure 5.2: Dry density vs moisture content curve

Results : OMC (Optimum Moisture Content) = 18.5%

MDD (Maximum Dry Density) = 17.3 kN/m^3

5.2 Determination of shear strength parameters of natural soil and (cement + lime) stabilized soil by using a series of triaxial tests

5.2.1 Introduction

The outcomes of an unconsolidated undrained (UU) triaxial test conducted on both natural and cement lime stabilized soil are presented in detail in this section. The purpose of the tests was to determine the soil's undrained strength under various load scenarios. In this segment, the behavior of the strength parameters (c and ϕ) is examined in relation to varying cement and lime amounts applied to soil at optimal moisture content and varied curing times. Additionally, the strength parameters without the addition of cement and lime are shown for the soil at its ideal moisture content.

5.2.2 Results

Cement (0%) and lime (0%)

Three samples were made and examined on the day of preparation for 0% cement and 0% lime. No cement and lime were added to the soil, so no samples were ready for curing.

0th day of curing

Three samples were tested at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.3 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.4, 5.5 and 5.6 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.7 shows the Mohr circle plot.

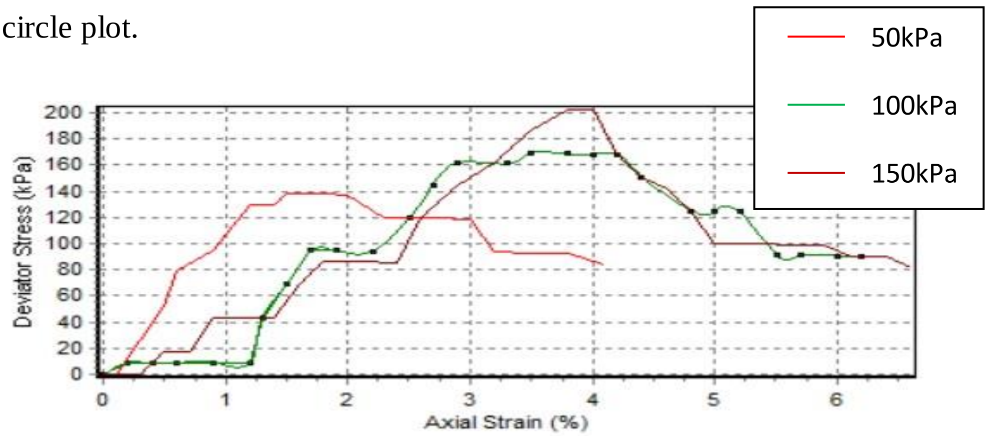

Figure 5.3: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for natural soil (0th day curing)

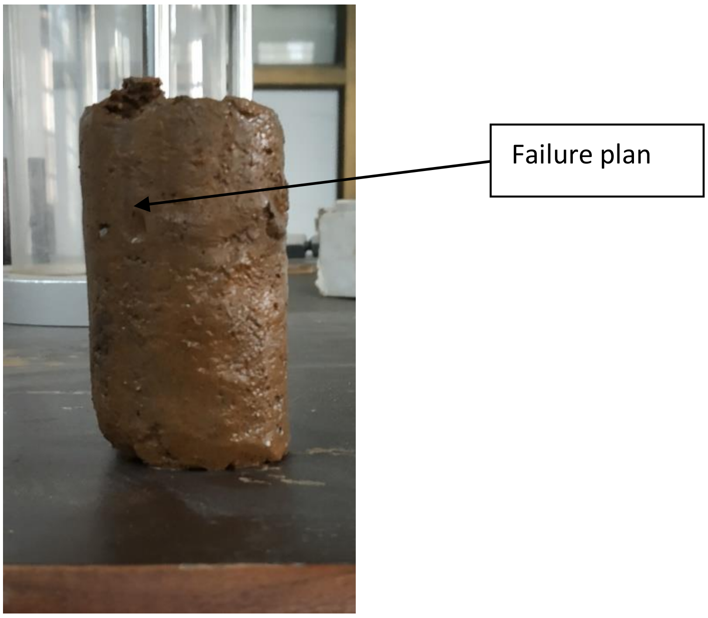

Figure 5.4: Failed sample at 50kPa cell pressure for natural soil

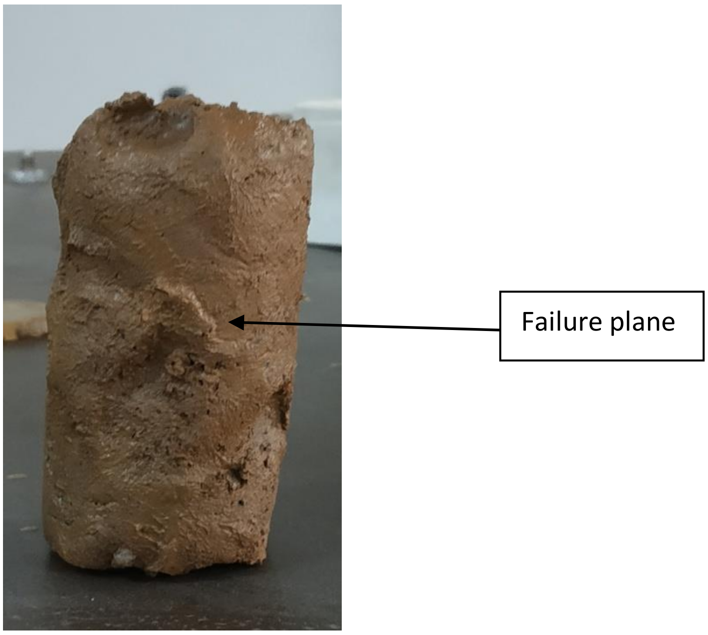

Figure 5.5: Failed sample at 100kPa cell pressure for natural soil

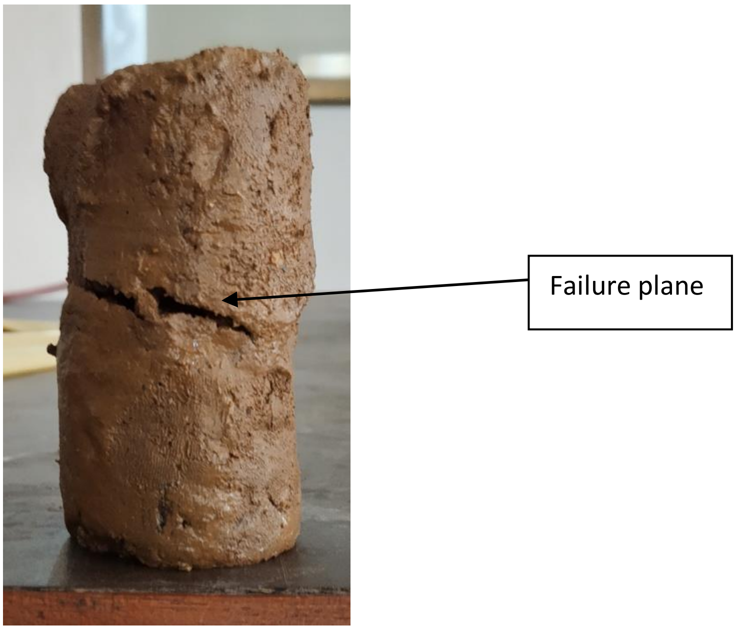

Figure 5.6: Failed sample at 150kPa cell pressure for natural soil

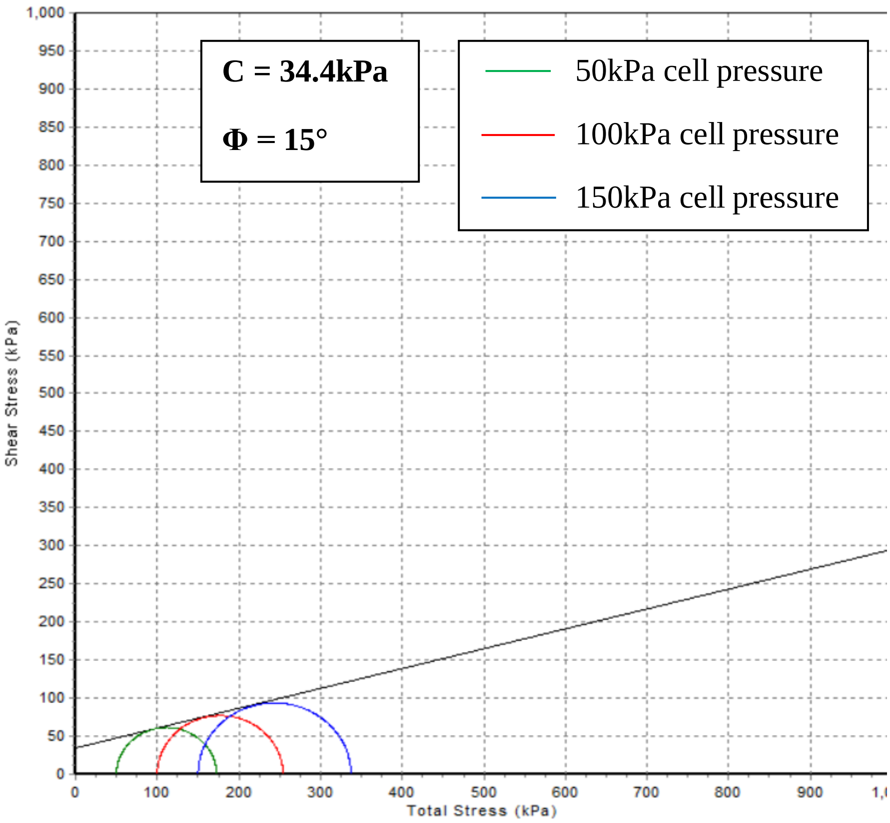

Figure 5.7: Mohr circle plot for natural soil (0^{th} day of curing)

Cement (2%) and lime (2%)

Testing for cement (2%) and lime (2%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0th day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.8 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.9, 5.10 and 5.11 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.12 shows the Mohr circle plot of the test.

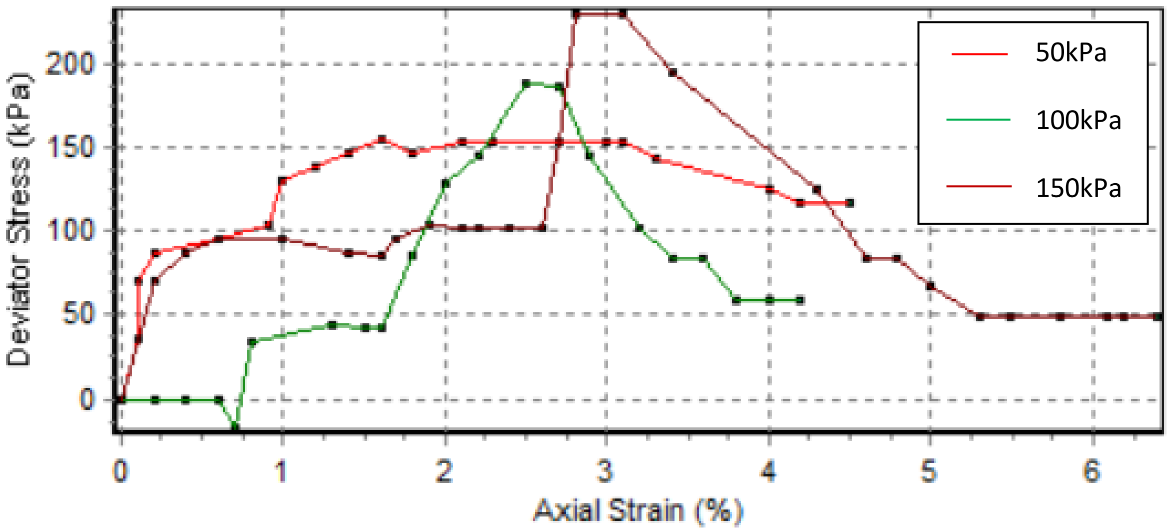

Figure 5.8: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 2% stabilized soil (0th day curing)

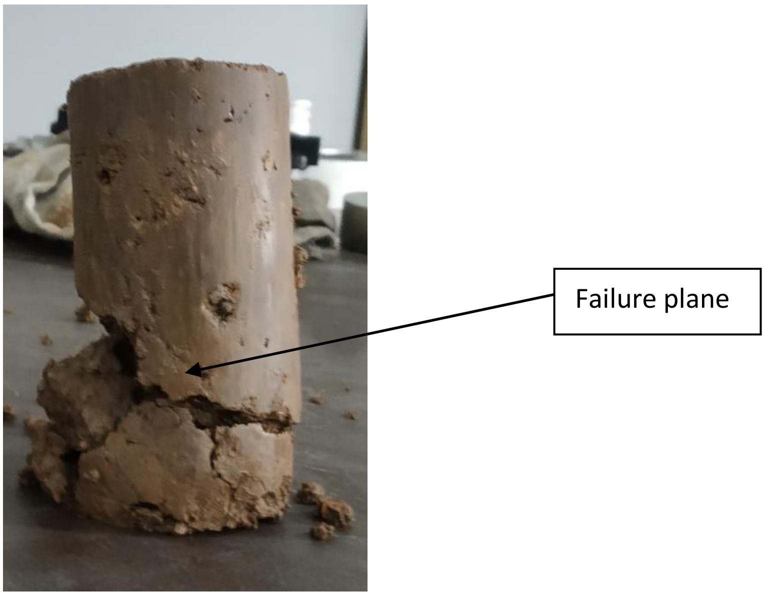

Figure 5.9: Failed sample at 50kPa cell pressure for cement 2% and lime 2% stabilized soil (0^{th} day curing)

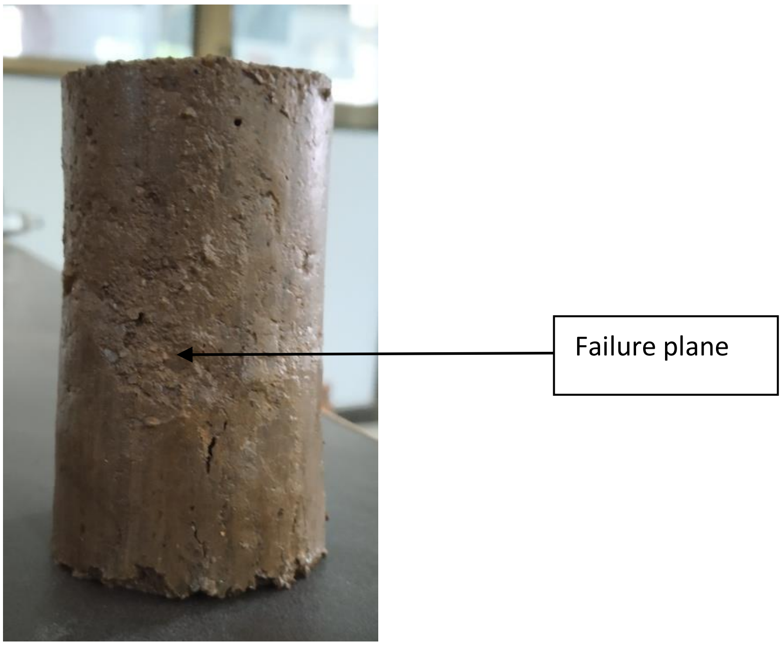

Figure 5.10: Failed sample at 100kPa cell pressure for cement 2% and lime 2% stabilized soil (0^{th} day curing)

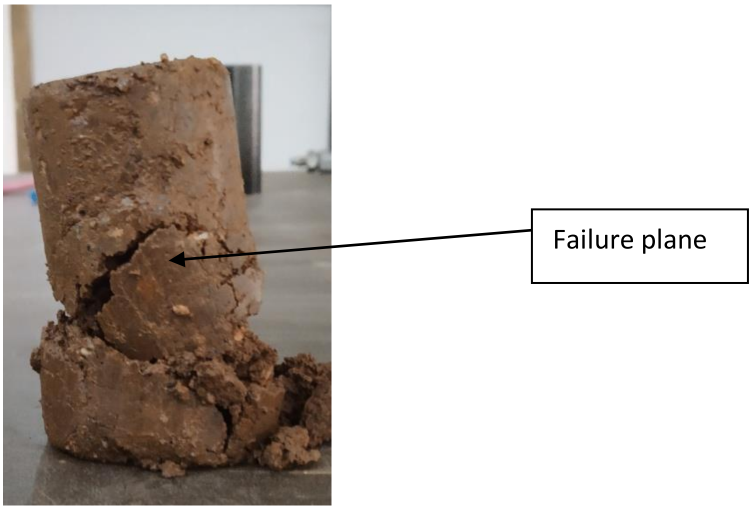

Figure 5.11: Failed sample at 150kPa cell pressure for cement 2% and lime 2% stabilized soil (0^{th} day curing)

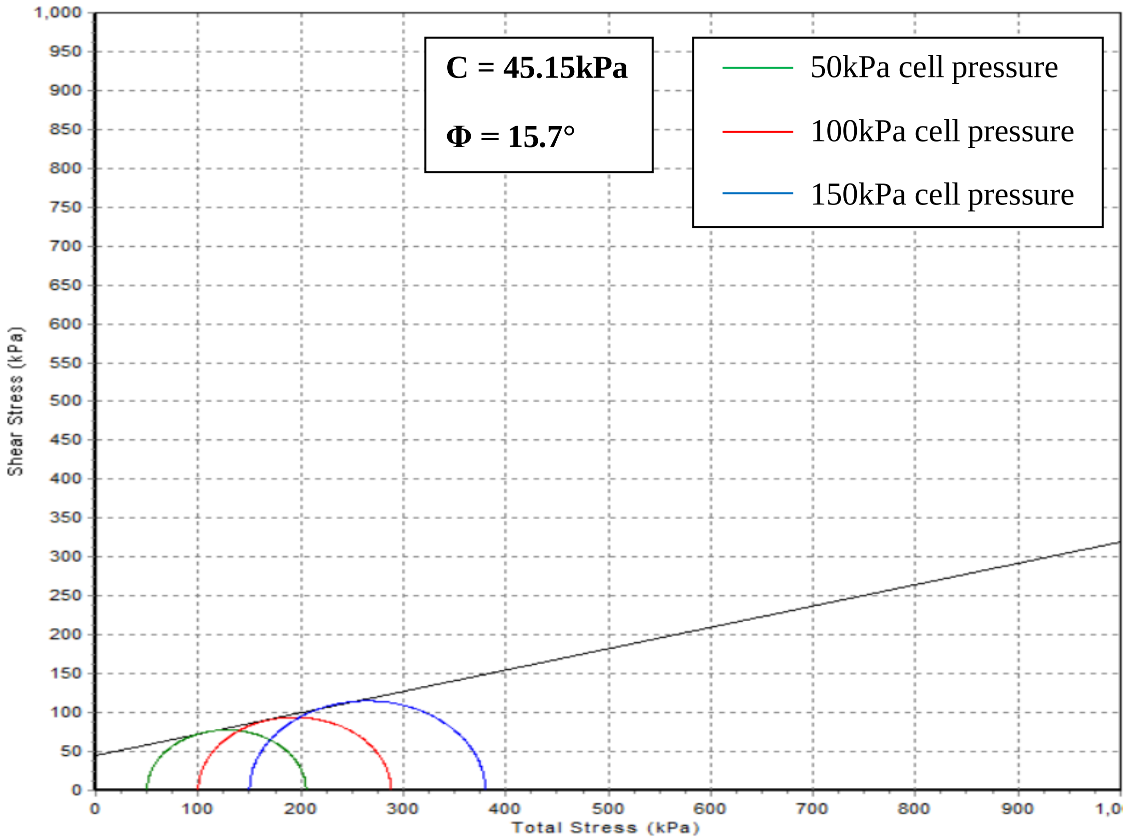

Figure 5.12: Mohr circle plot for cement 2% and lime 2% stabilized soil (0^{th} day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.13 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.14, 5.15 and 5.16 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.17 shows the Mohr circle plot of the test.

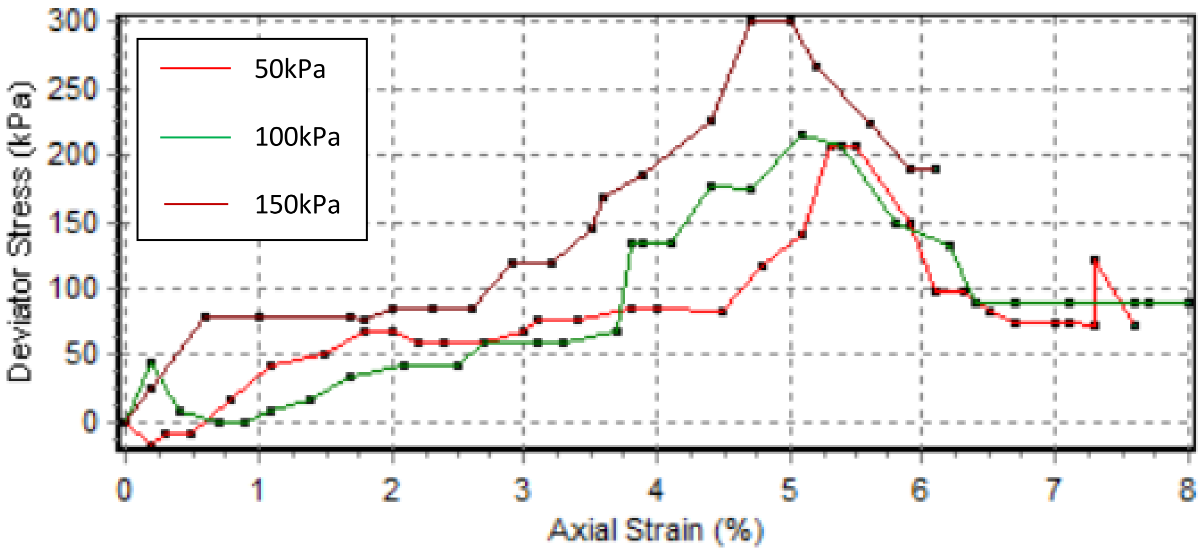

Figure 5.13: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 2% stabilized soil (7th day curing)

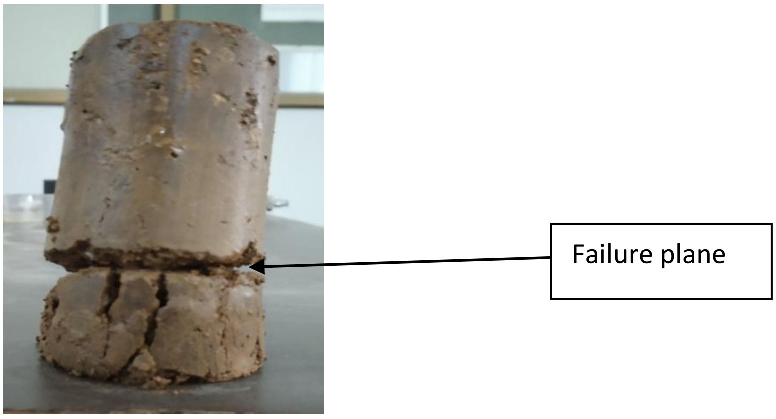

Figure 5.14: Failed sample at 50kPa cell pressure for cement 2% and lime 2% stabilized soil (7th day curing)

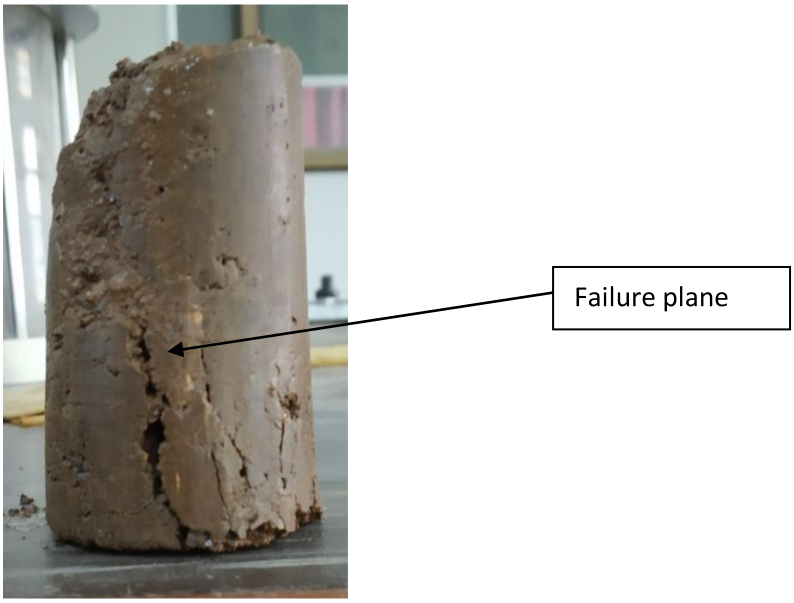

Figure 5.15: Failed sample at 100kPa cell pressure for cement 2% and lime 2% stabilized soil (7th day curing)

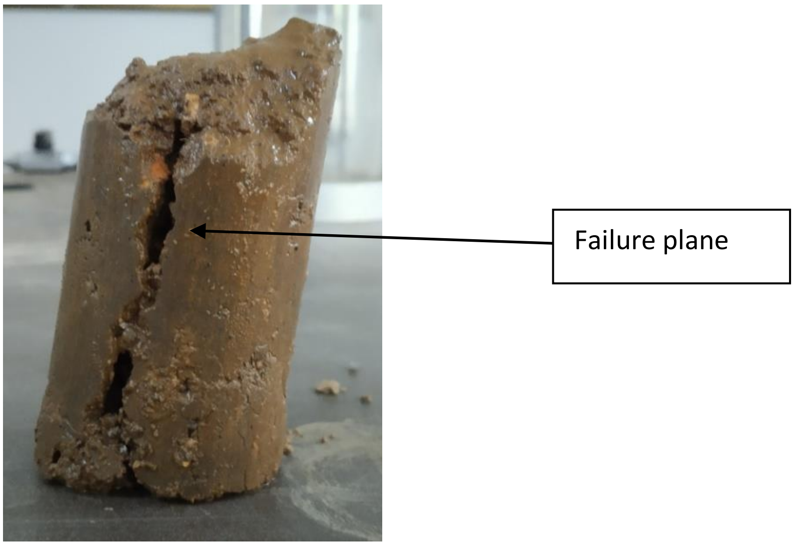

Figure 5.16: Failed sample at 150kPa cell pressure for cement 2% and lime 2% stabilized soil (7th day curing)

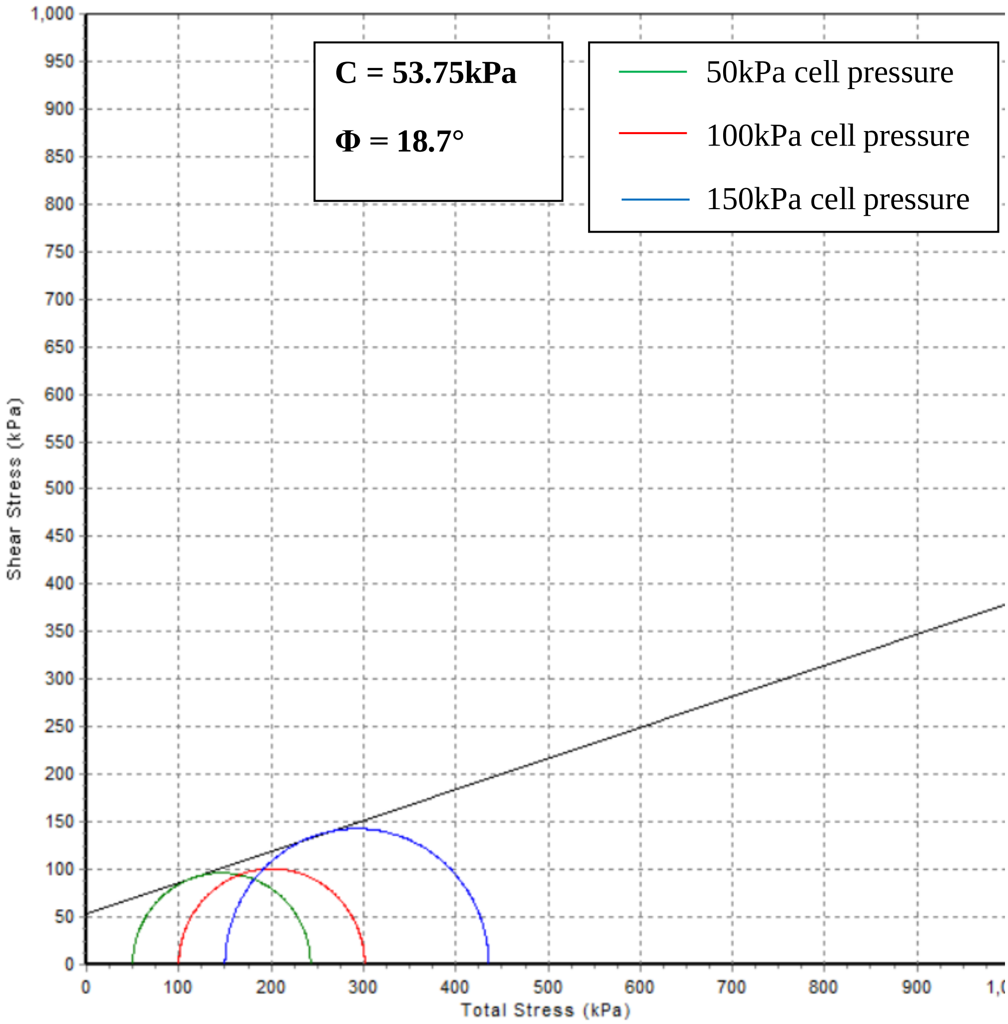

Figure 5.17: Mohr circle plot for cement 2% and lime 2% stabilized soil (7th day curing)

Cement (2%) and lime (4%)

Testing for cement (2%) and lime (4%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0th day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.18 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.19, 5.20 and 5.21 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.22 shows the Mohr circle plot of the test.

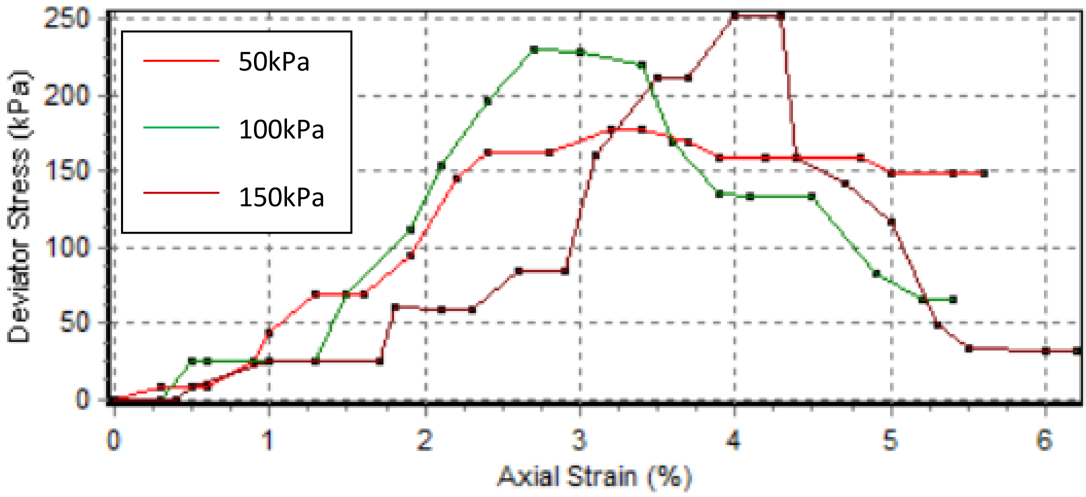

Figure 5.18: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 4% stabilized soil (0th day curing)

Figure 5.19: Failed sample at 50kPa cell pressure for cement 2% and lime 4% stabilized soil (0^{th} day curing)

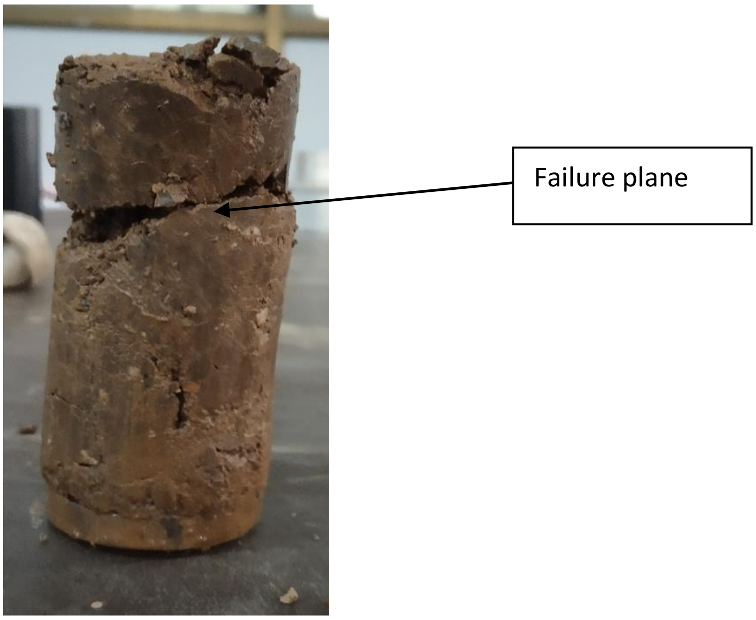

Figure 5.20: Failed sample at 100kPa cell pressure for cement 2% and lime 4% stabilized soil (0^{th} day curing)

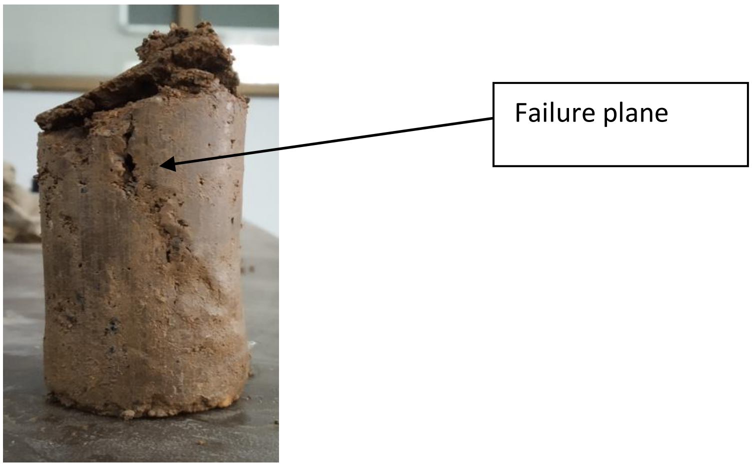

Figure 5.21: Failed sample at 150kPa cell pressure for cement 2% and lime 4% stabilized soil (0^{th} day curing)

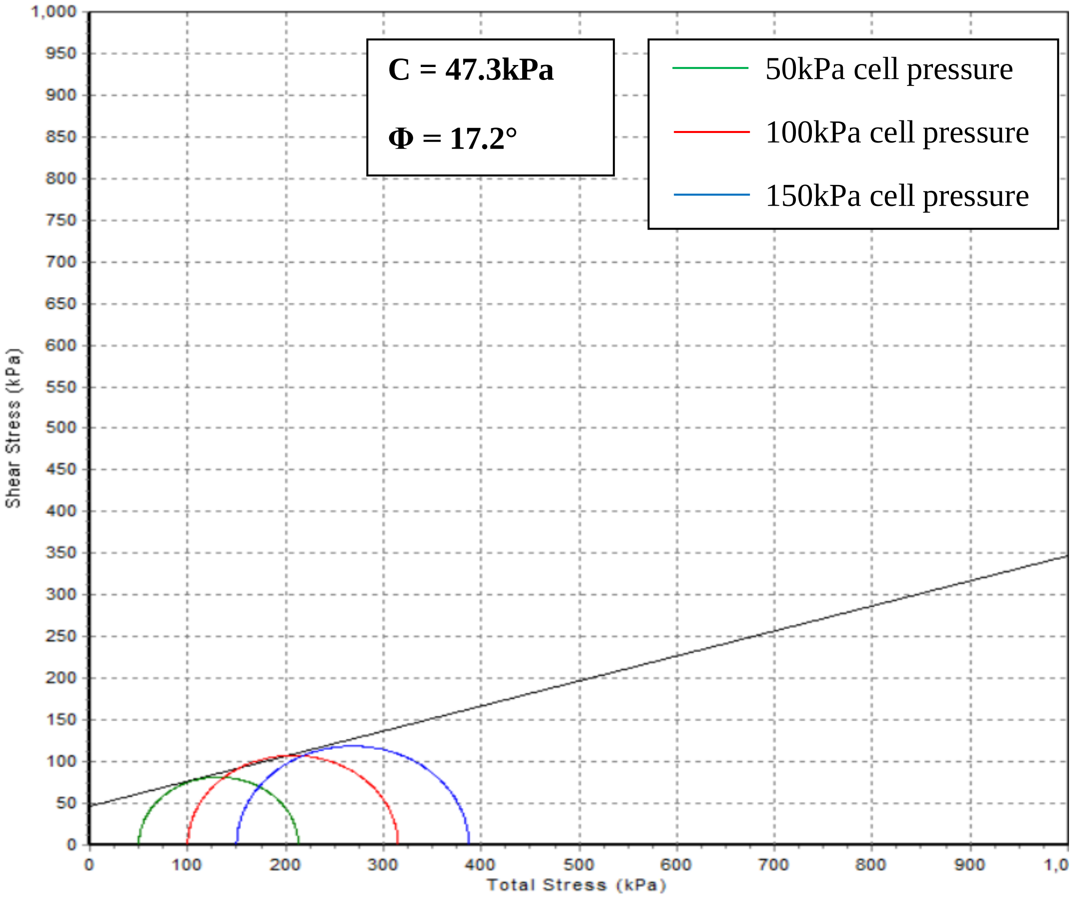

Figure 5.22: Mohr circle plot for cement 2% and lime 4% stabilized soil (0^{th} day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.23 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.24, 5.25, 5.26 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.27 shows the Mohr circle plot of the test.

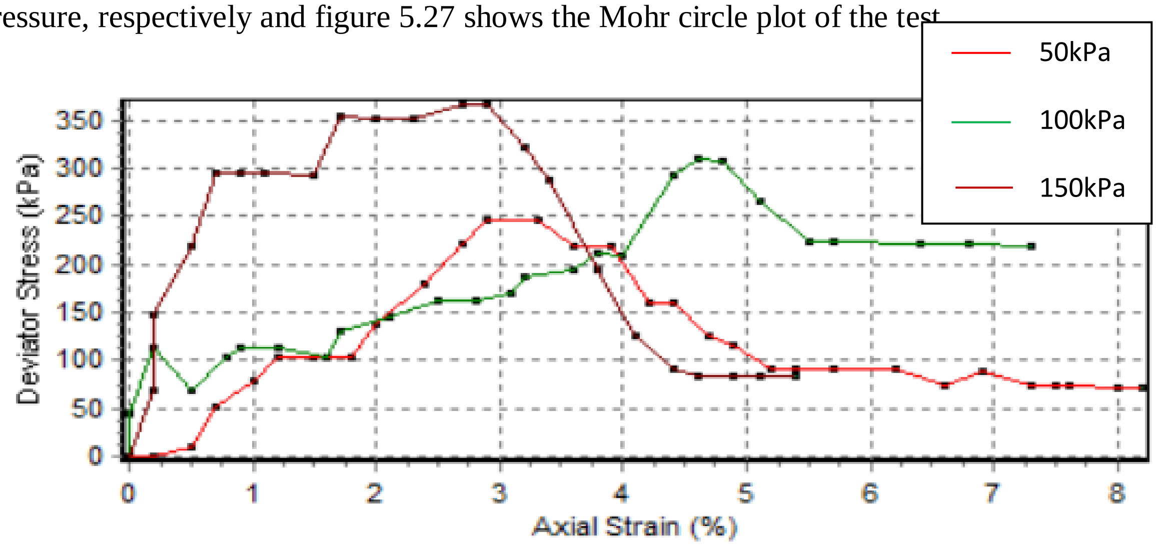

Figure 5.23: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 4% stabilized soil (7th day curing)

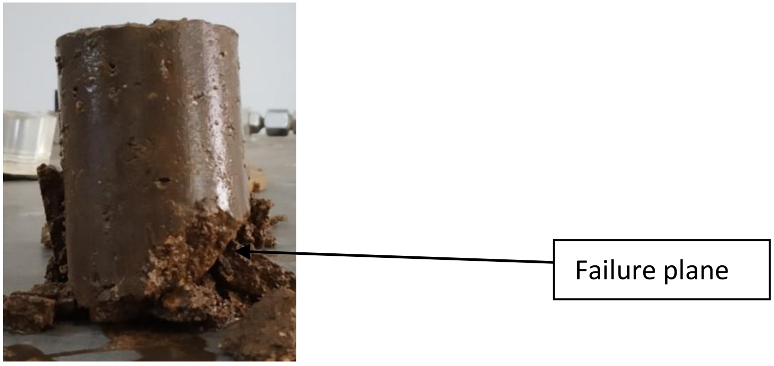

Figure 5.24: Failed sample at 50kPa cell pressure for cement 2% and lime 4% stabilized soil (7th day curing)

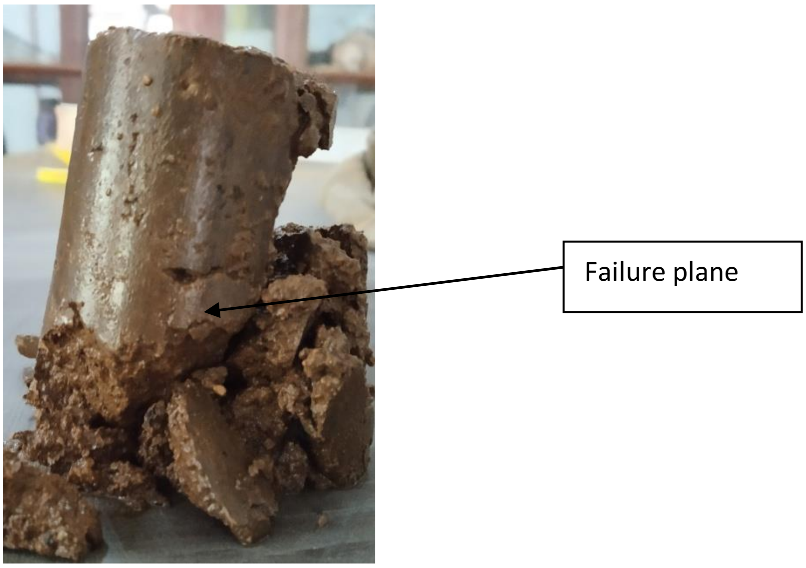

Figure 5.25: Failed sample at 100kPa cell pressure for cement 2% and lime 4% stabilized soil (7^{th} day curing)

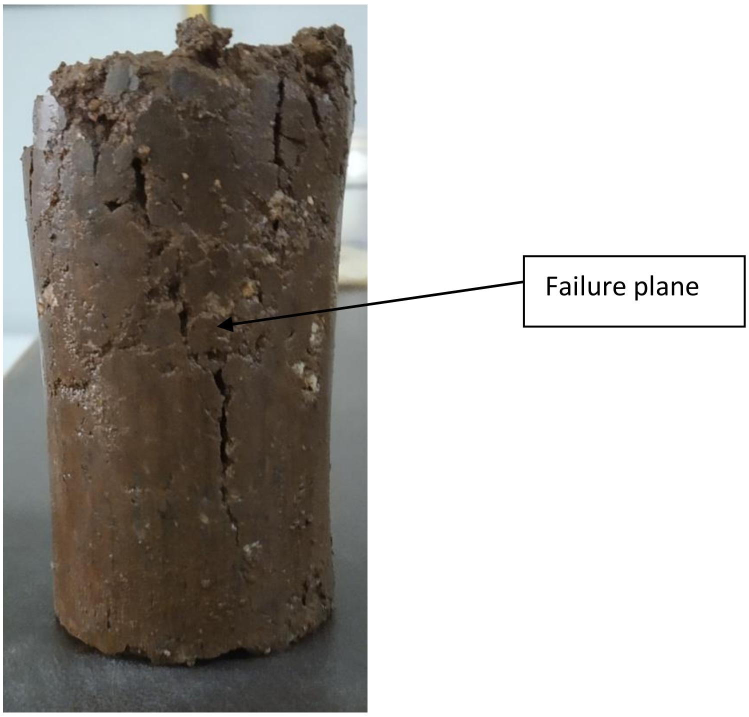

Figure 5.26: Failed sample at 150kPa cell pressure for cement 2% and lime 4% stabilized soil (7^{th} day curing)

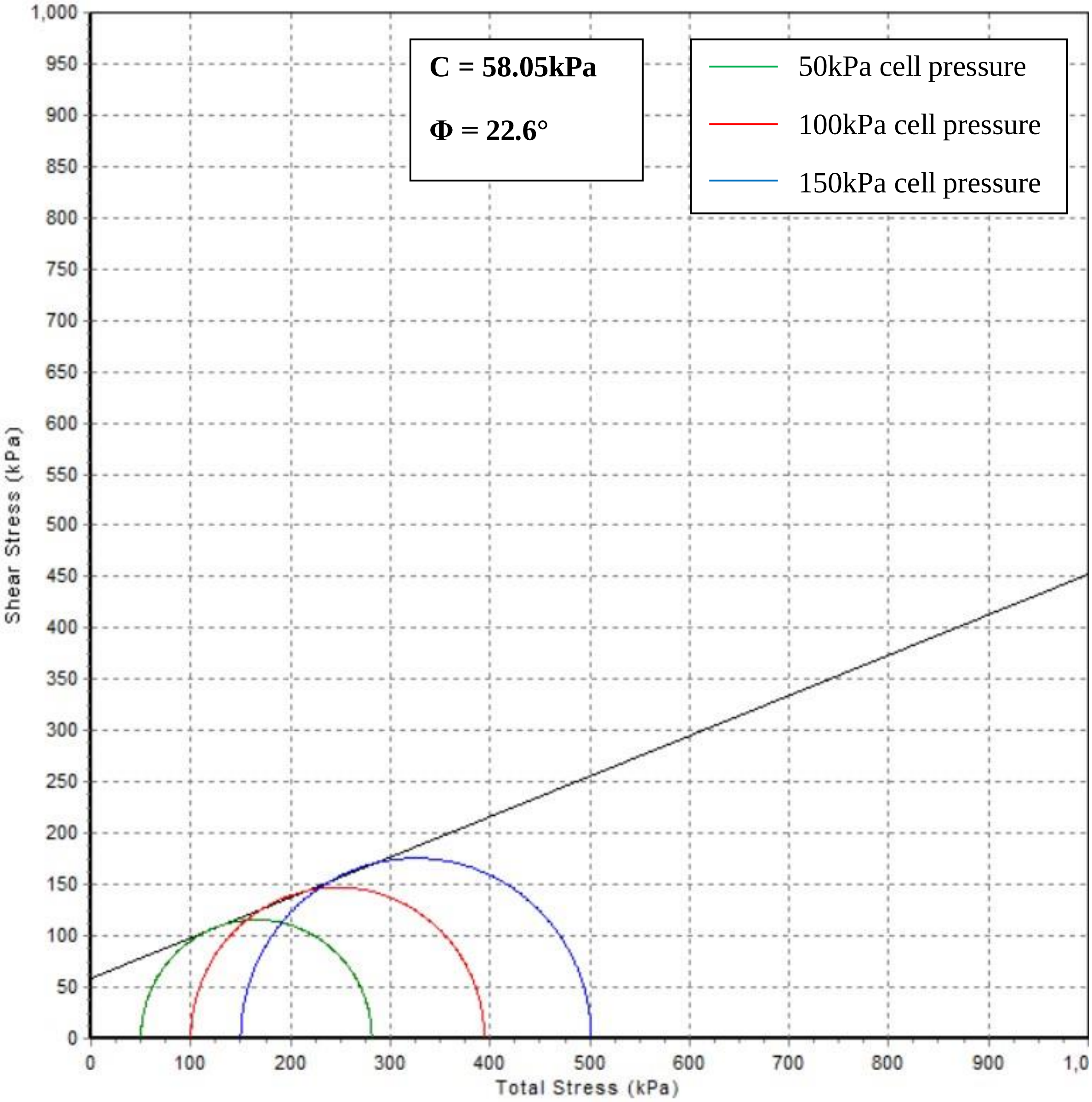

Figure 5.27: Mohr circle plot for cement 2% and lime 4% stabilized soil (7th day curing)

Cement (2%) and lime (6%)

Testing for cement (2%) and lime (6%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0th day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.28 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.29, 5.30 and 5.31 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.32 shows the Mohr circle plot of the test.

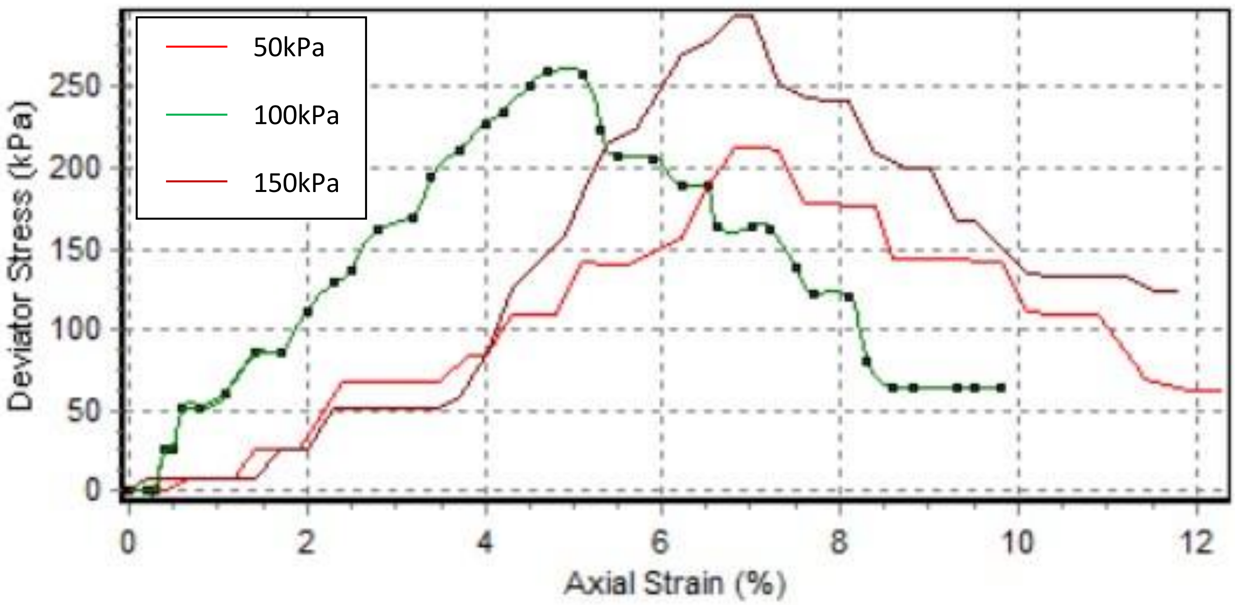

Figure 5.28: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 6% stabilized soil (0th day curing)

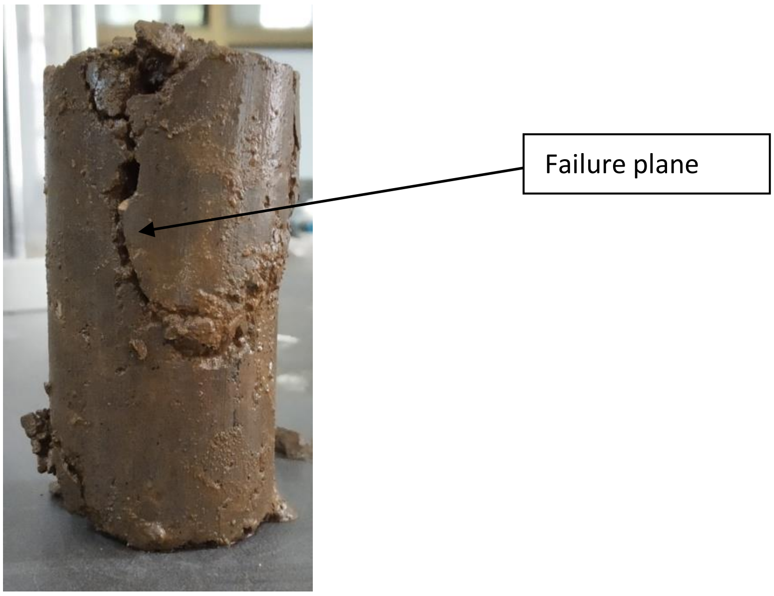

Figure 5.29: Failed sample at 50kPa cell pressure for cement 2% and lime 6% stabilized soil (0^{th} day curing)

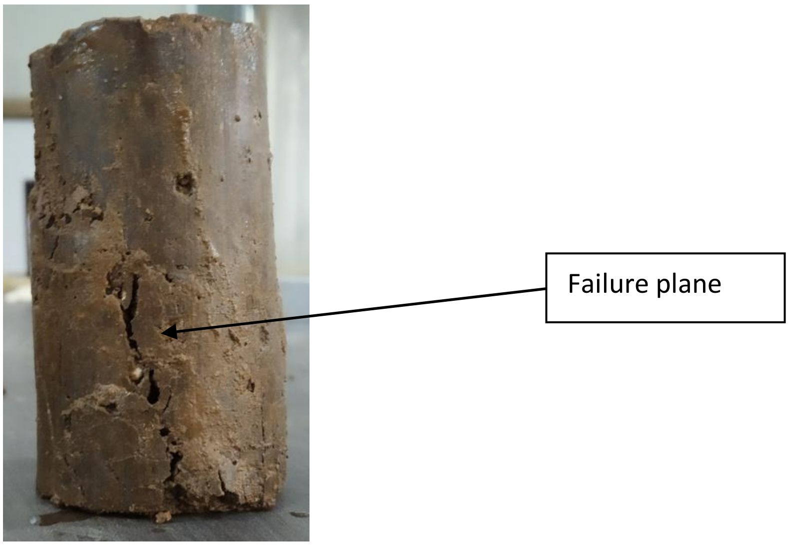

Figure 5.30: Failed sample at 100kPa cell pressure for cement 2% and lime 6% stabilized soil (0^{th} day curing)

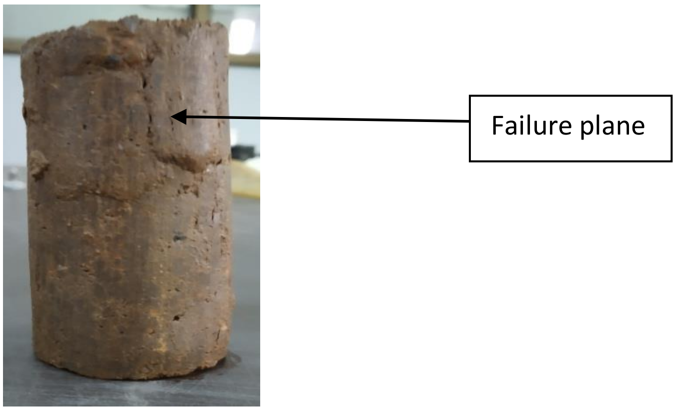

Figure 5.31: Failed sample at 150kPa cell pressure for cement 2% and lime 6% stabilized soil (0^{th} day curing)

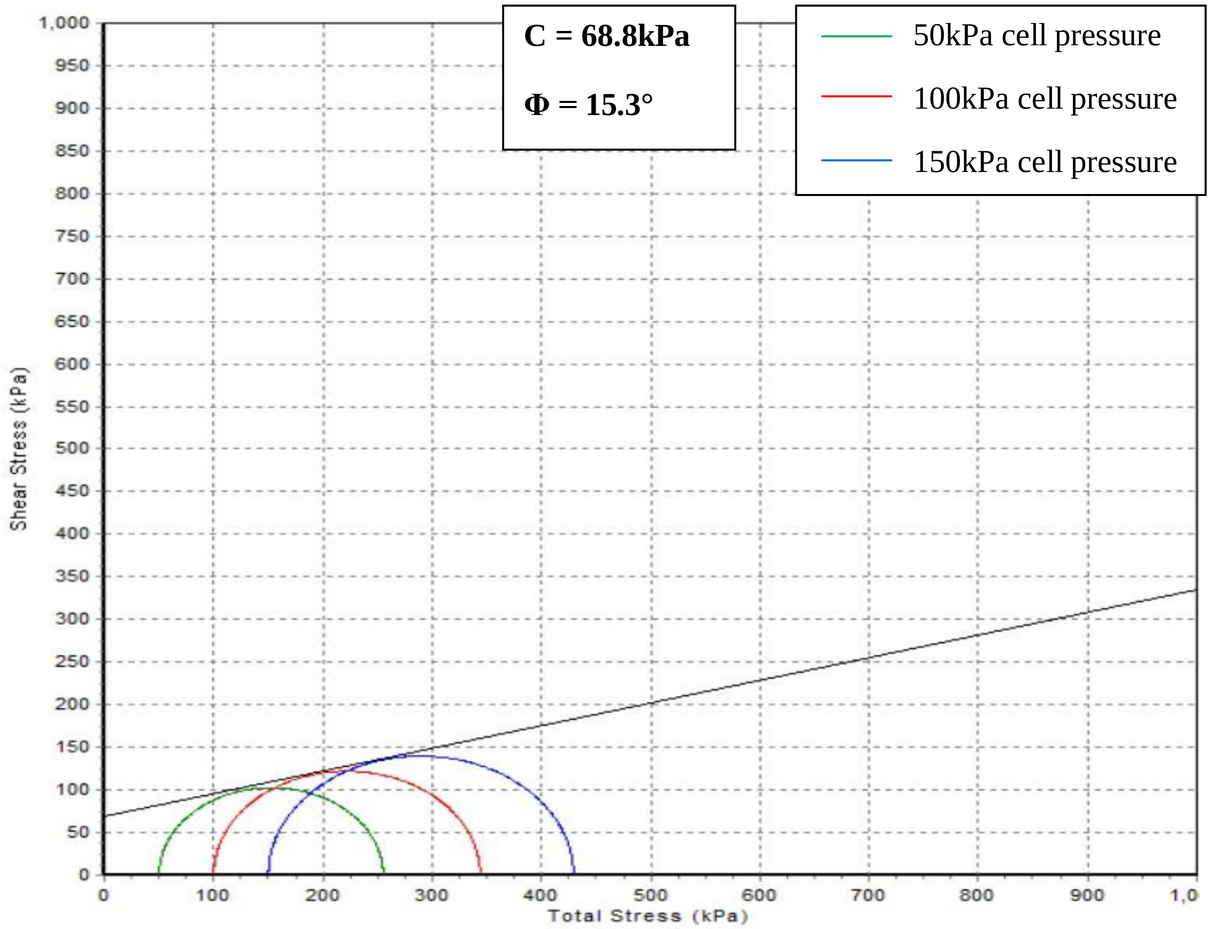

Figure 5.32: Mohr circle plot for cement 2% and lime 6% stabilized soil (0^{th} day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.33 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.34, 5.35 and 5.36 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.37 shows the Mohr circle plot of the test.

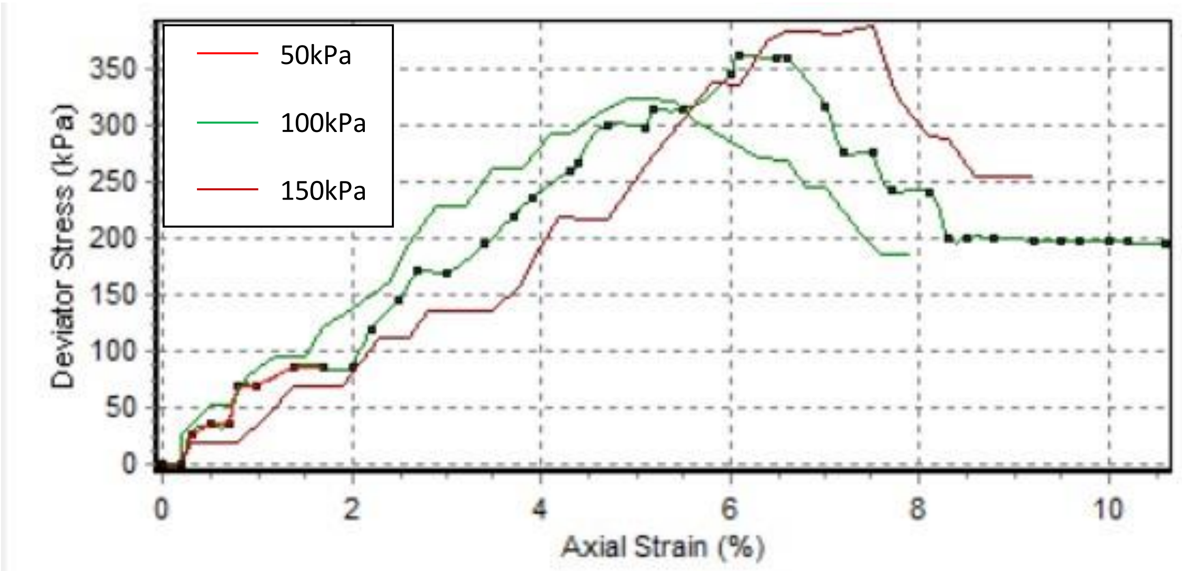

Figure 5.33: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 6% stabilized soil (7th day curing)

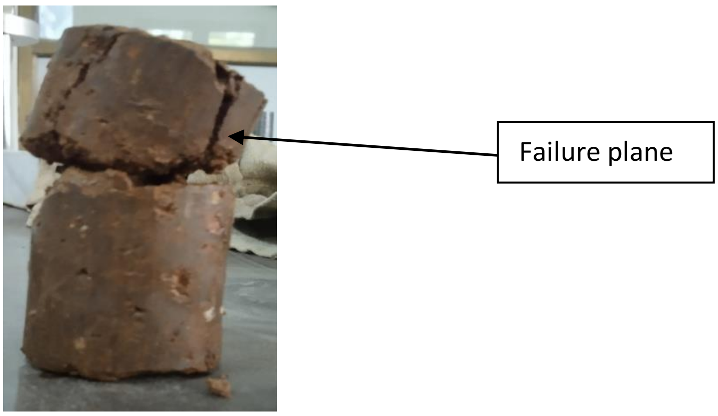

Figure 5.34: Failed sample at 50kPa cell pressure for cement 2% and lime 6% stabilized soil (7th day curing)

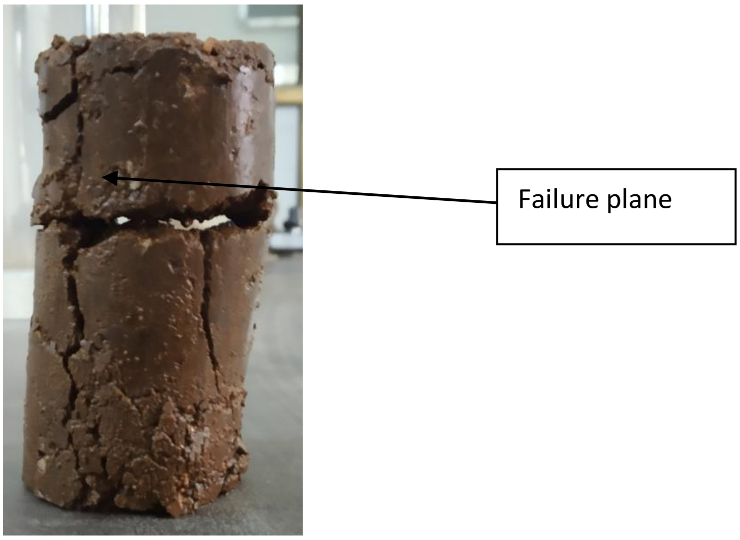

Figure 5.35: Failed sample at 100kPa cell pressure for cement 2% and lime 6% stabilized soil (7^{th} day curing)

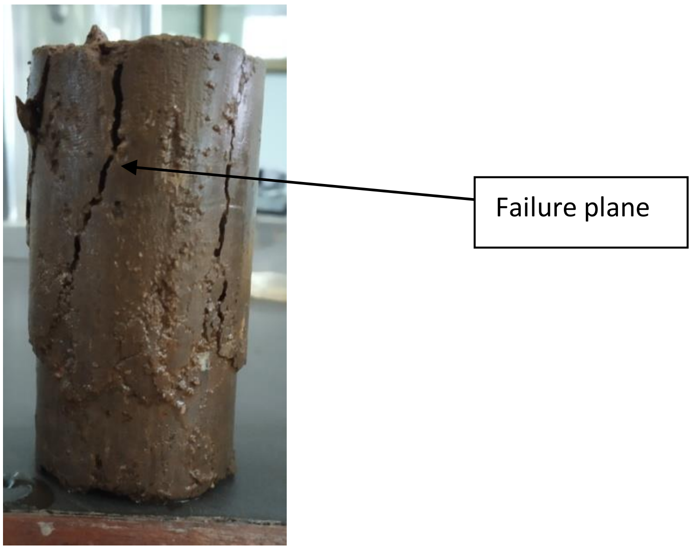

Figure 5.36: Failed sample at 150kPa cell pressure for cement 2% and lime 6% stabilized soil (7^{th} day curing)

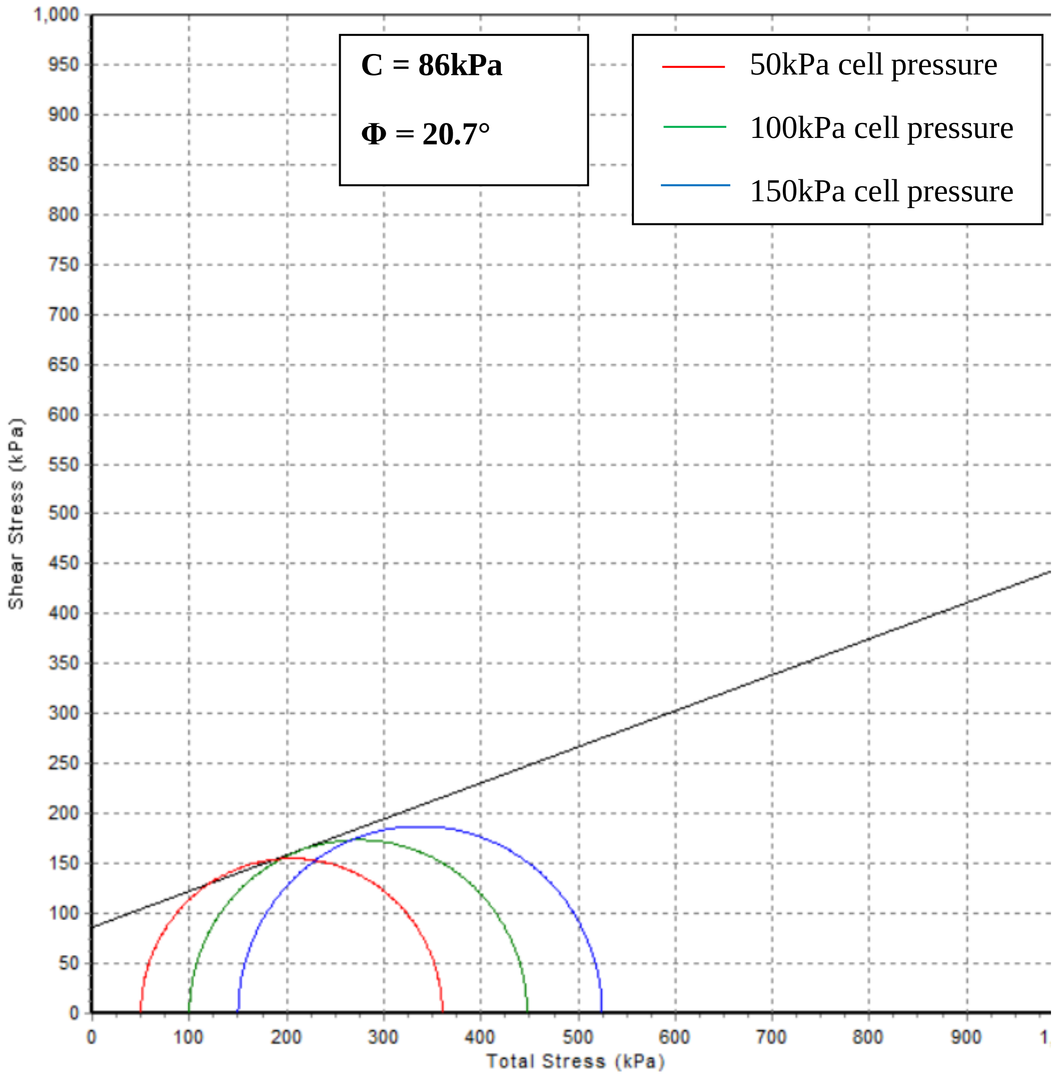

Figure 5.37: Mohr circle plot for cement 2% and lime 6% stabilized soil (7th day curing)

Cement (2%) and lime (8%)

Testing for cement (2%) and lime (8%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0th day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.38 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.39, 5.40 and 5.41 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.42 shows the Mohr circle plot of the test.

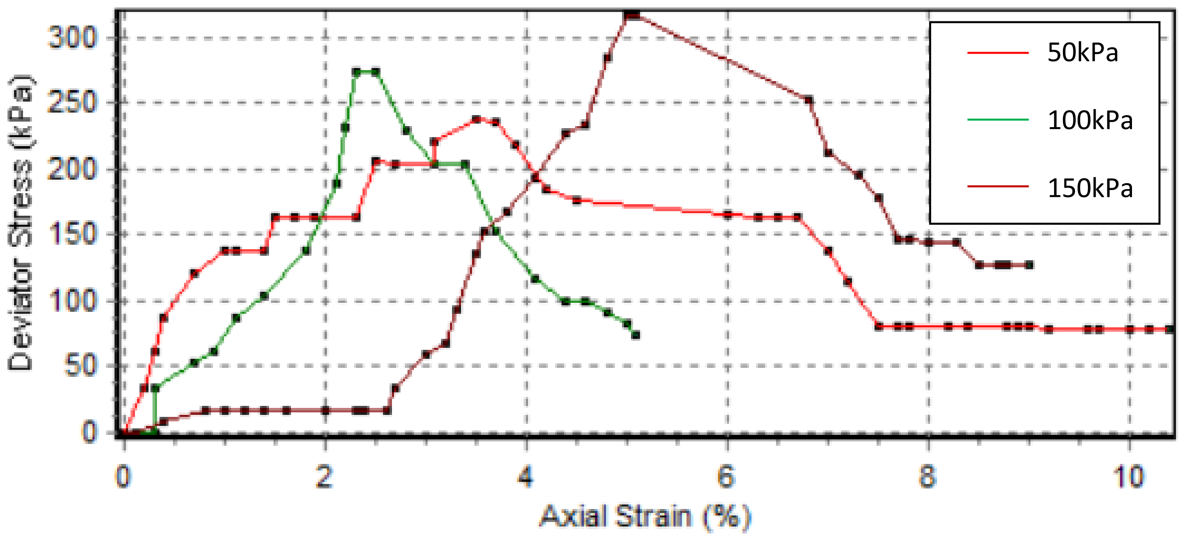

Figure 5.38: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 8% stabilized soil (0th day curing)

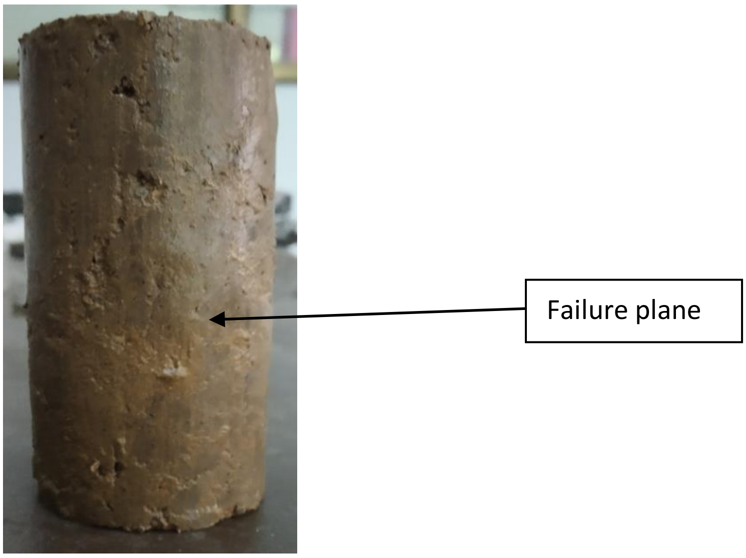

Figure 5.39: Failed sample at 50kPa cell pressure for cement 2% and lime 8% stabilized soil (0^{th} day curing)

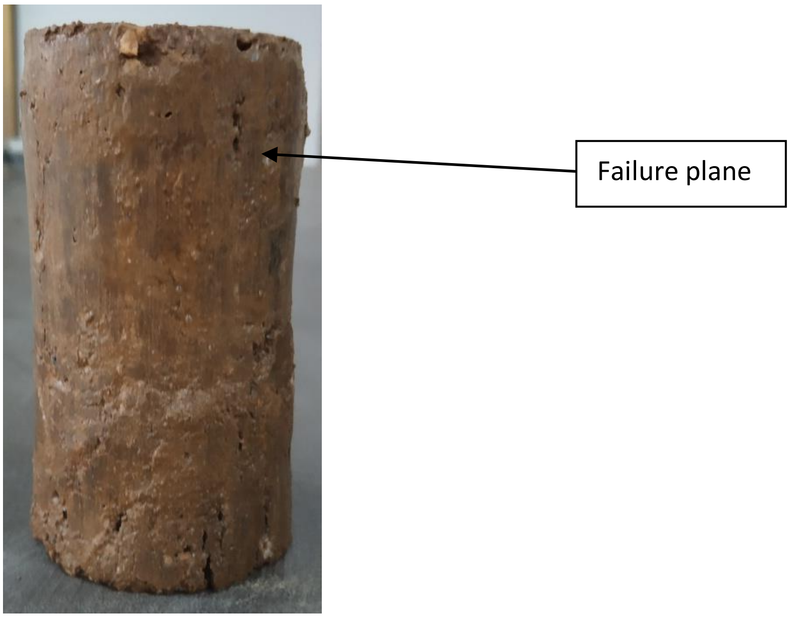

Figure 5.40: Failed sample at 100kPa cell pressure for cement 2% and lime 8% stabilized soil (0^{th} day curing)

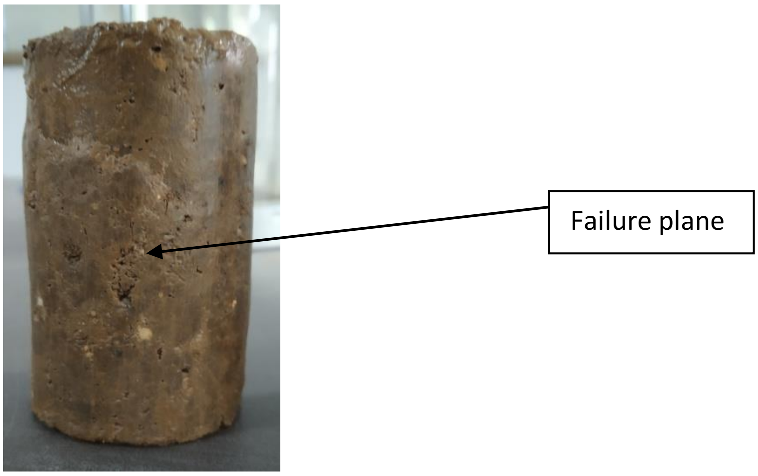

Figure 5.41: Failed sample at 150kPa cell pressure for cement 2% and lime 8% stabilized soil (0th day curing)

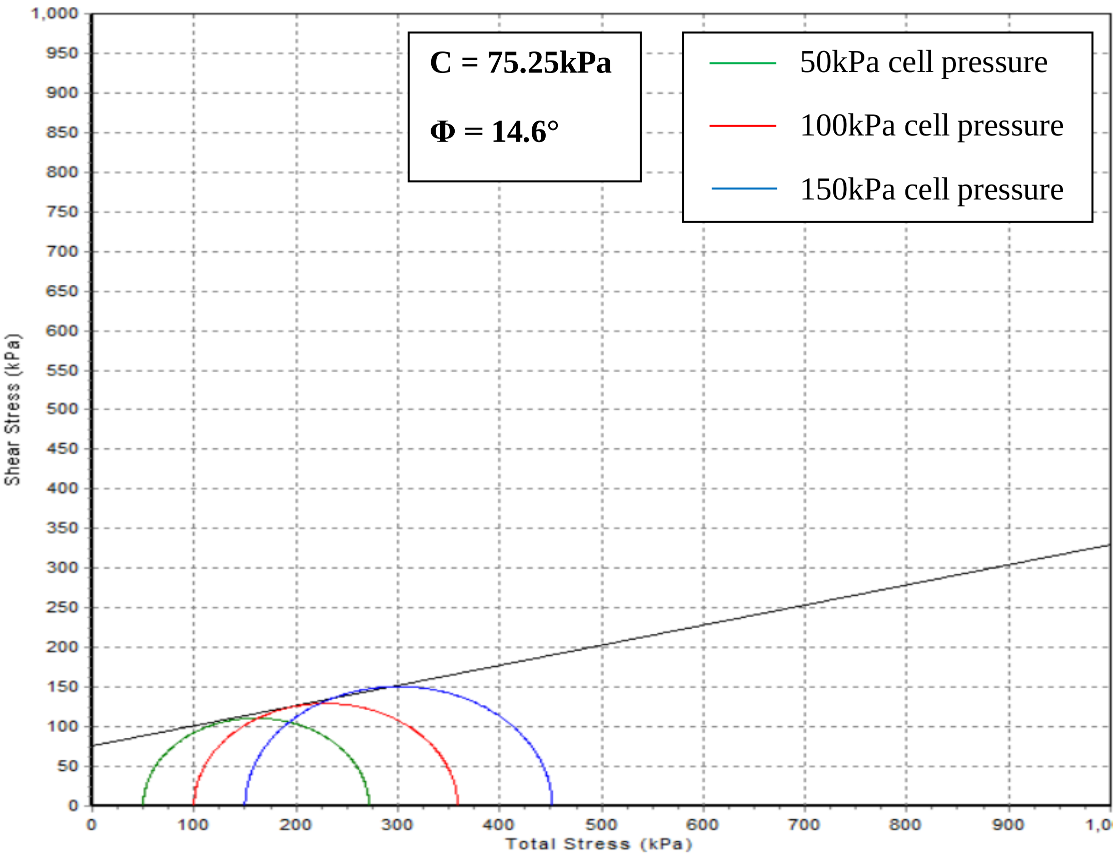

Figure 5.42: Mohr circle plot for cement 2% and lime 8% stabilized soil (0th day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.43 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.44, 5.45 and 5.46 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.47 shows the Mohr circle plot of the test.

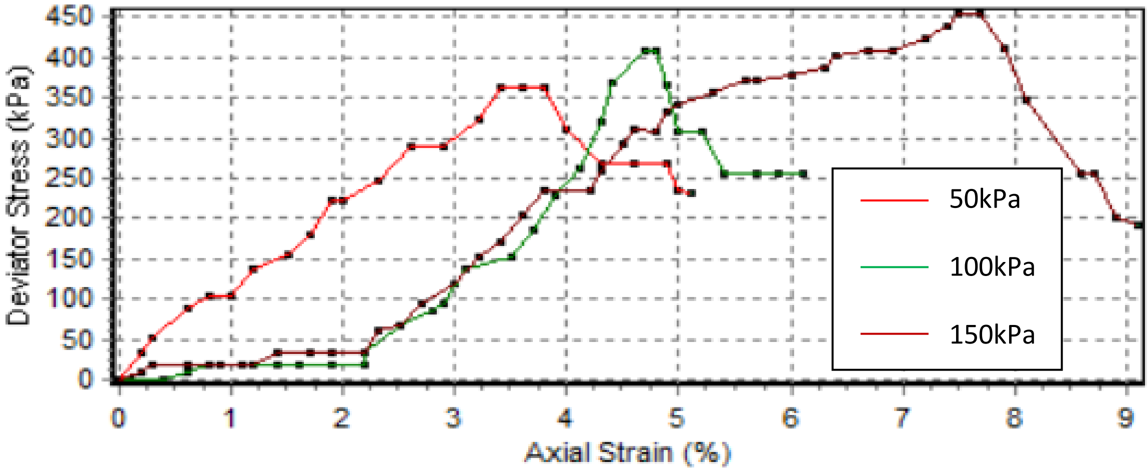

Figure 5.43: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for cement 2% and lime 8% stabilized soil (7th day curing)

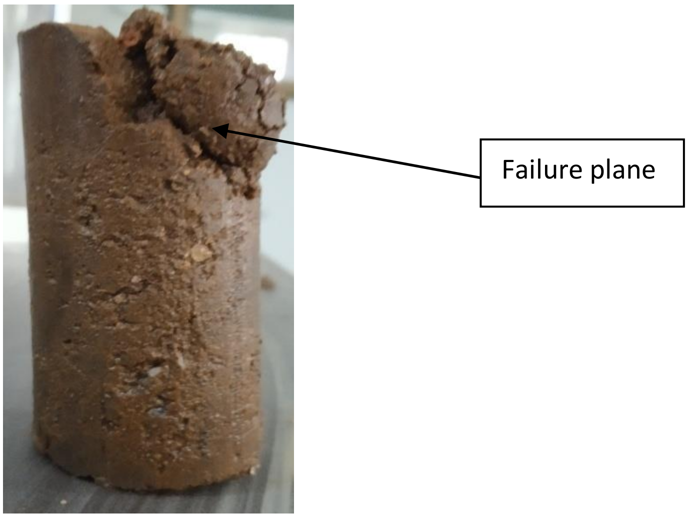

Figure 5.44: Failed sample at 50kPa cell pressure for cement 2% and lime 8% stabilized soil (7th day curing)

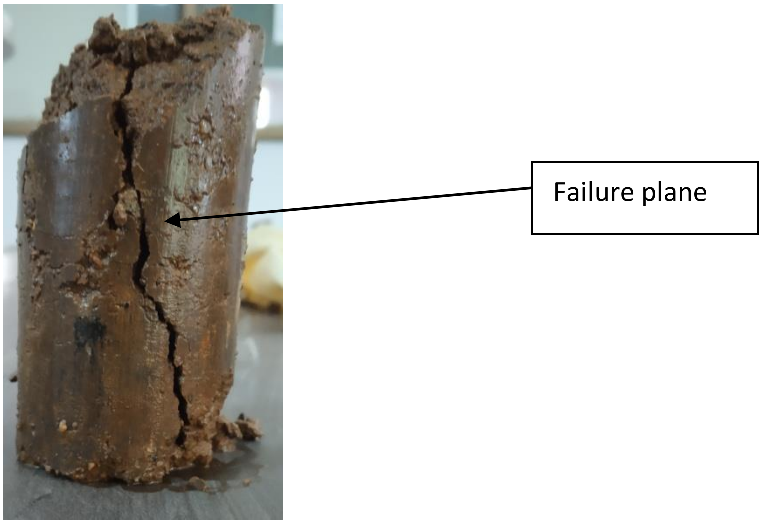

Figure 5.45: Failed sample at 100kPa cell pressure for cement 2% and lime 8% stabilized soil (7th day curing)

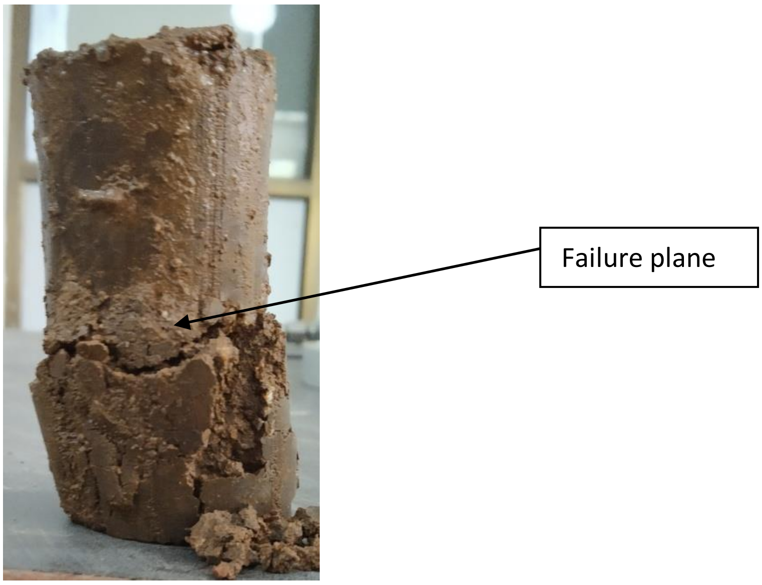

Figure 5.46: Failed sample at 150kPa cell pressure for cement 2% and lime 8% stabilized soil (7th day curing)

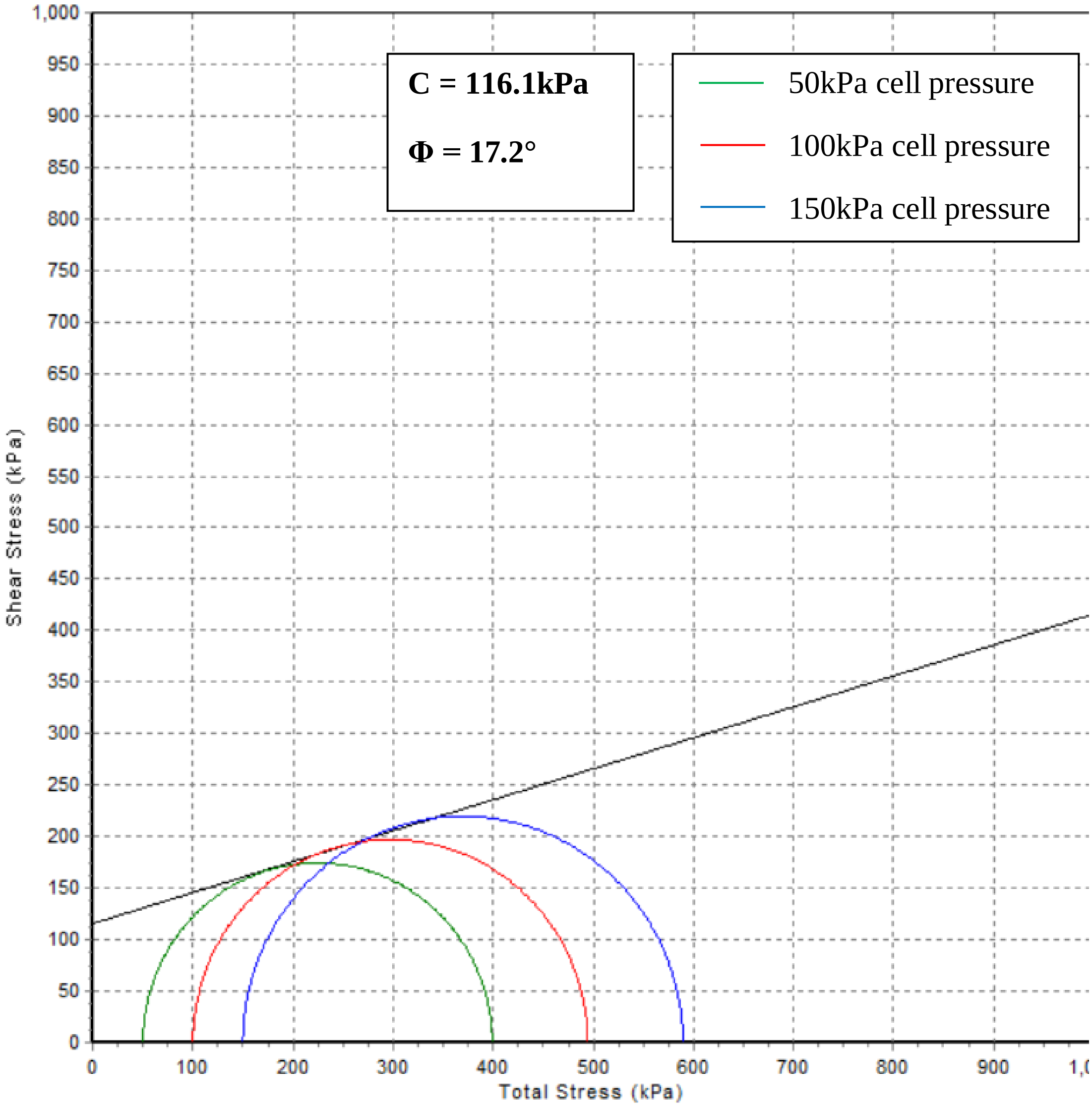

Figure 5.47: Mohr circle plot for cement 2% and lime 8% stabilized soil (7^{th} day curing)

Lime (2%) and Cement (4%)

Testing for lime (2%) and cement (4%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0^th^ day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.48 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.49, 5.50 and 5.51 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.52 shows the Mohr circle plot of the test.

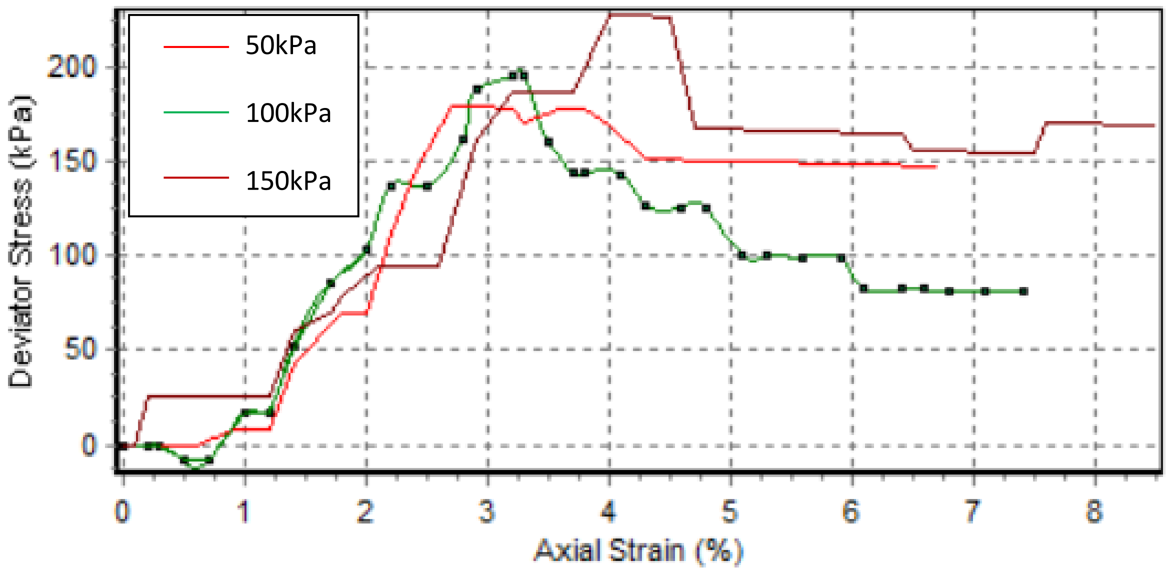

Figure 5.48: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for lime 2% and cement 4% stabilized soil (0^{th} day curing)

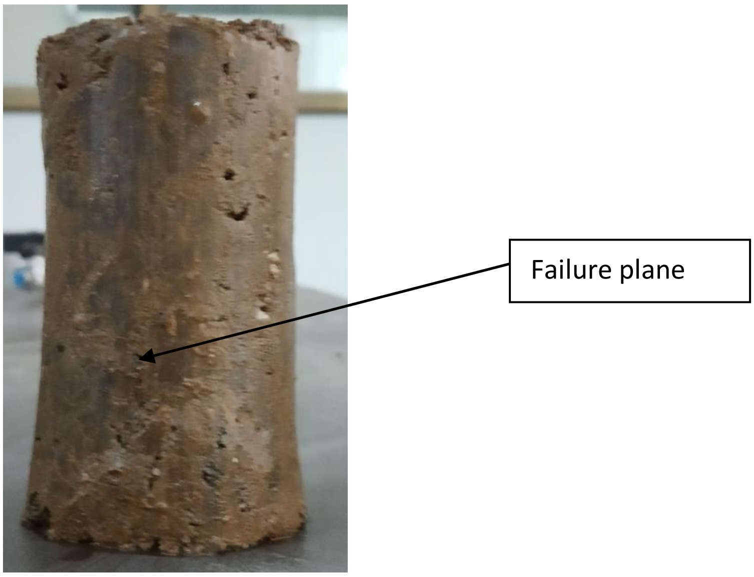

Figure 5.49: Failed sample at 50kPa cell pressure for lime 2% and cement 4% stabilized soil (0th day curing)

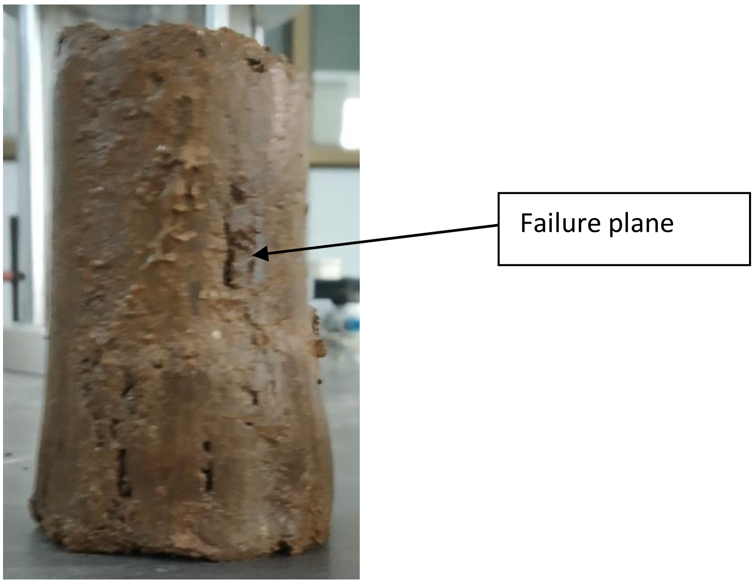

Figure 5.50: Failed sample at 100kPa cell pressure for lime 2% and cement 4% stabilized soil (0th day curing)

Figure 5.51: Failed sample at 150kPa cell pressure for lime 2% and cement 4% stabilized soil (0th day curing)

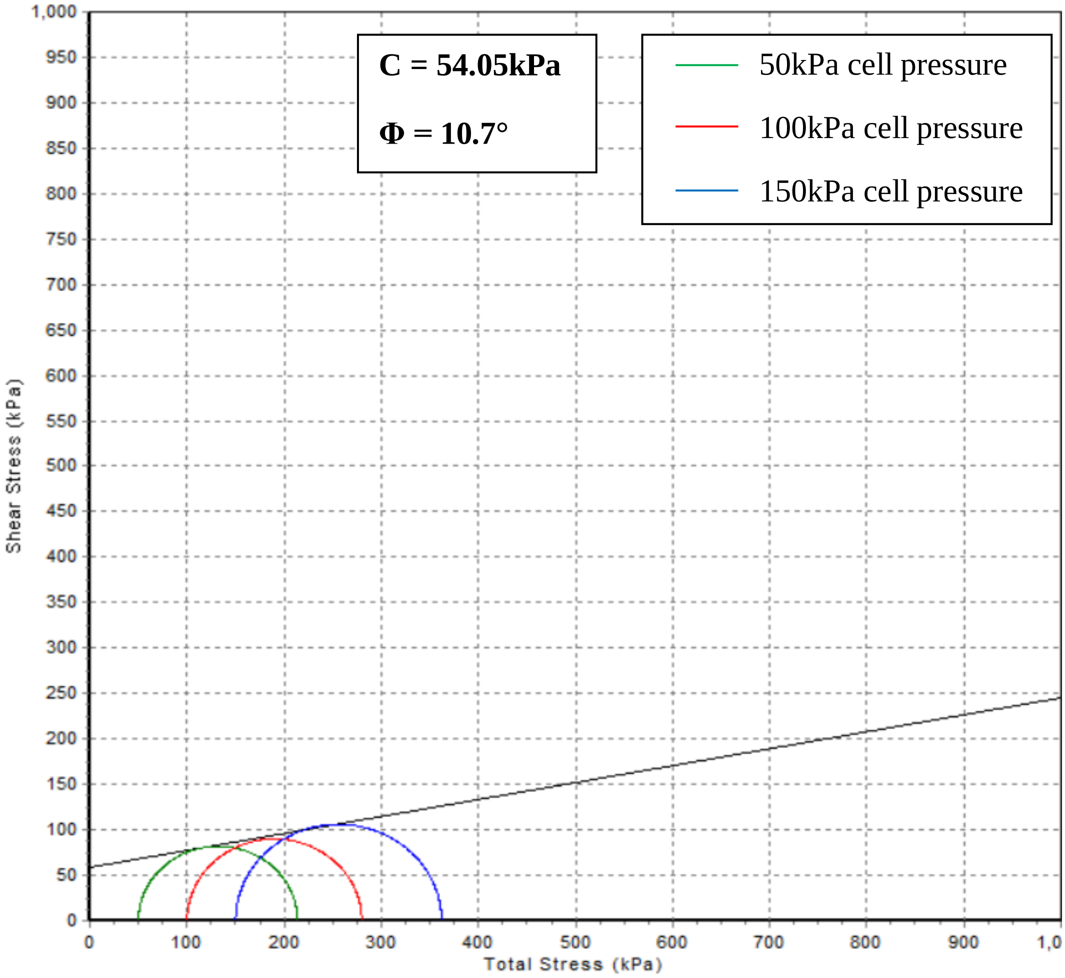

Figure 5.52: Mohr circle plot for lime 2% and cement 4% stabilized soil (0th day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.53 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.54, 5.55 and 5.56 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.57 shows the Mohr circle plot of the test.

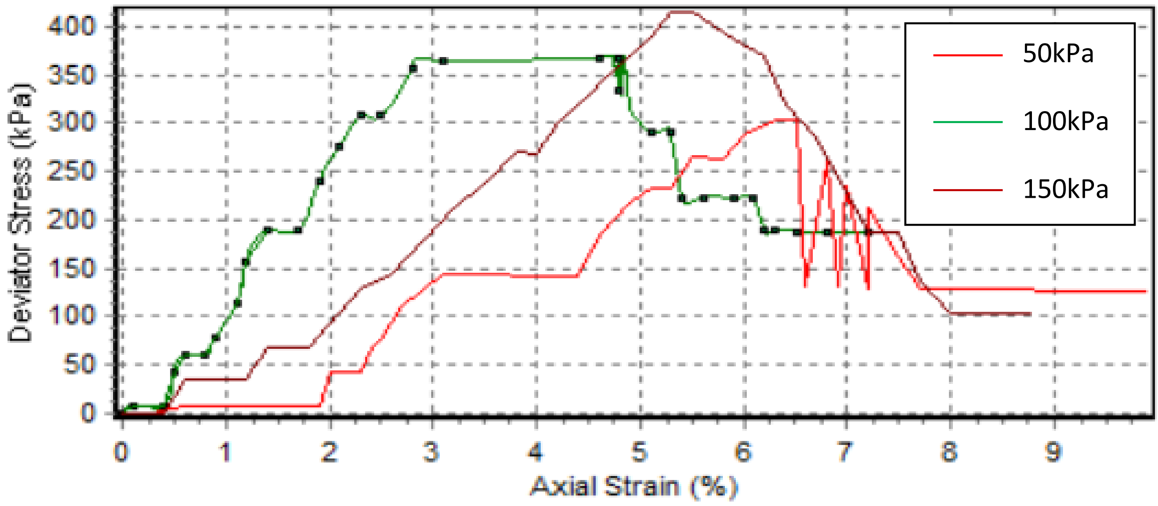

Figure 5.53: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for lime 2% and cement 4% stabilized soil (7th day curing)

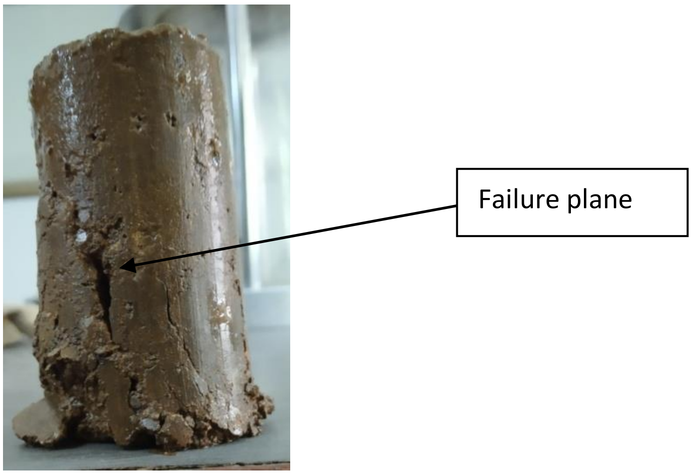

Figure 5.54: Failed sample at 50kPa cell pressure for lime 2% and cement 4% stabilized soil (7th day curing)

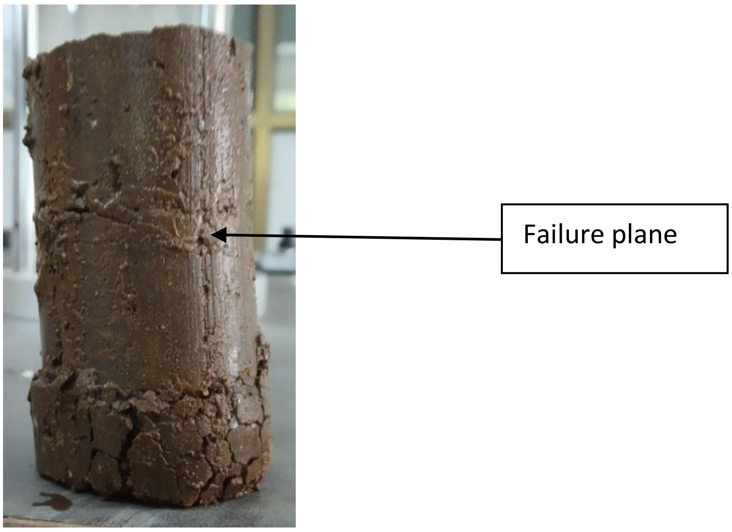

Figure 5.55: Failed sample at 100kPa cell pressure for lime 2% and cement 4% stabilized soil (7th day curing)

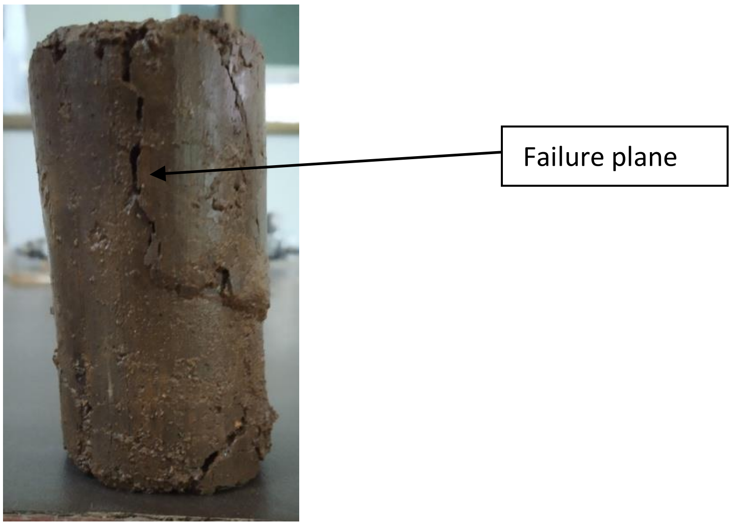

Figure 5.56: Failed sample at 150kPa cell pressure for lime 2% and cement 4% stabilized soil (7th day curing)

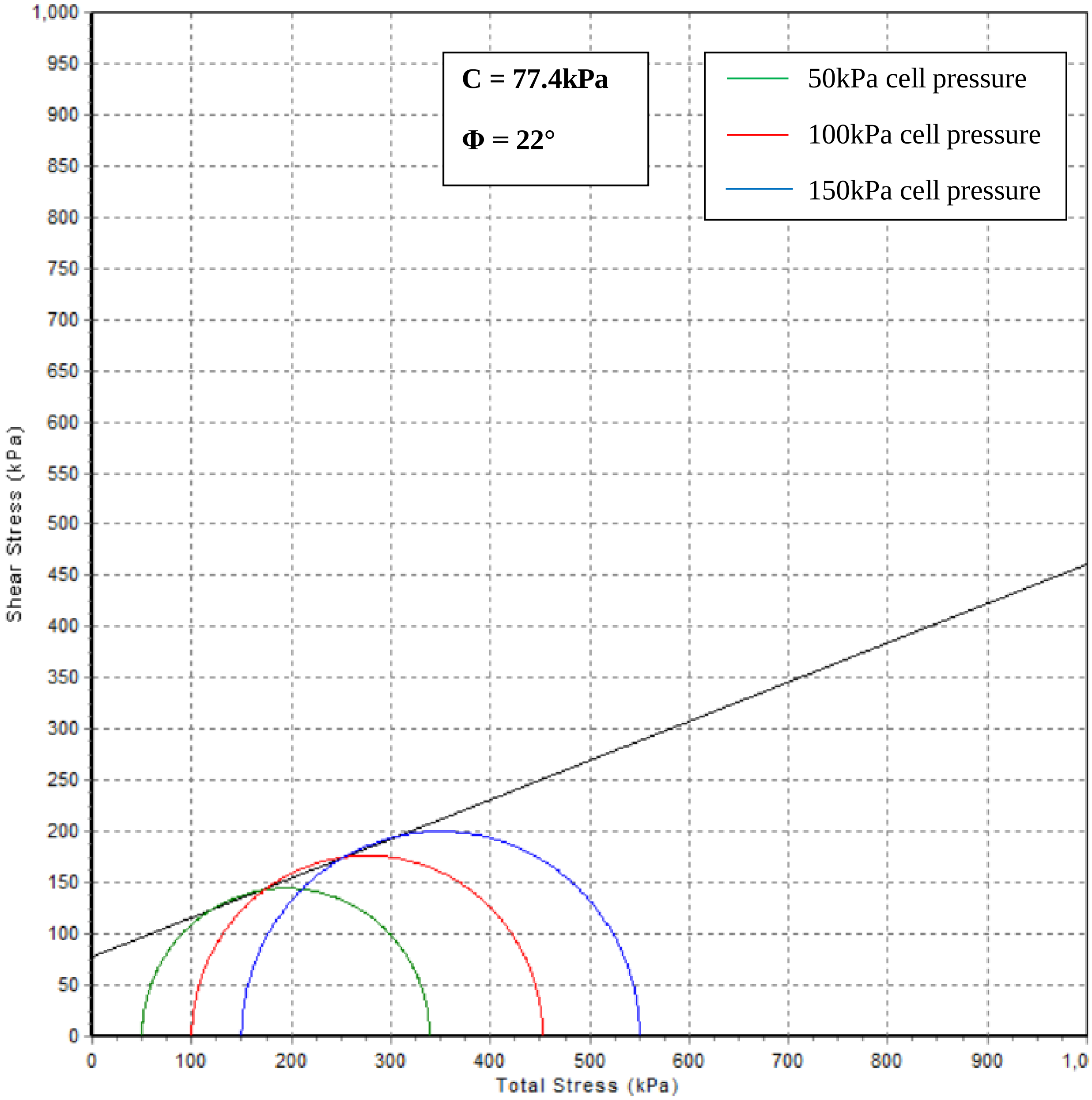

Figure 5.57: Mohr circle plot for lime 2% and cement 4% stabilized soil (7th day curing)

Lime (2%) and Cement (6%)

Testing for lime (2%) and cement (6%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0th day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.58 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.59, 5.60 and 5.61 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.62 shows the Mohr circle plot of the test.

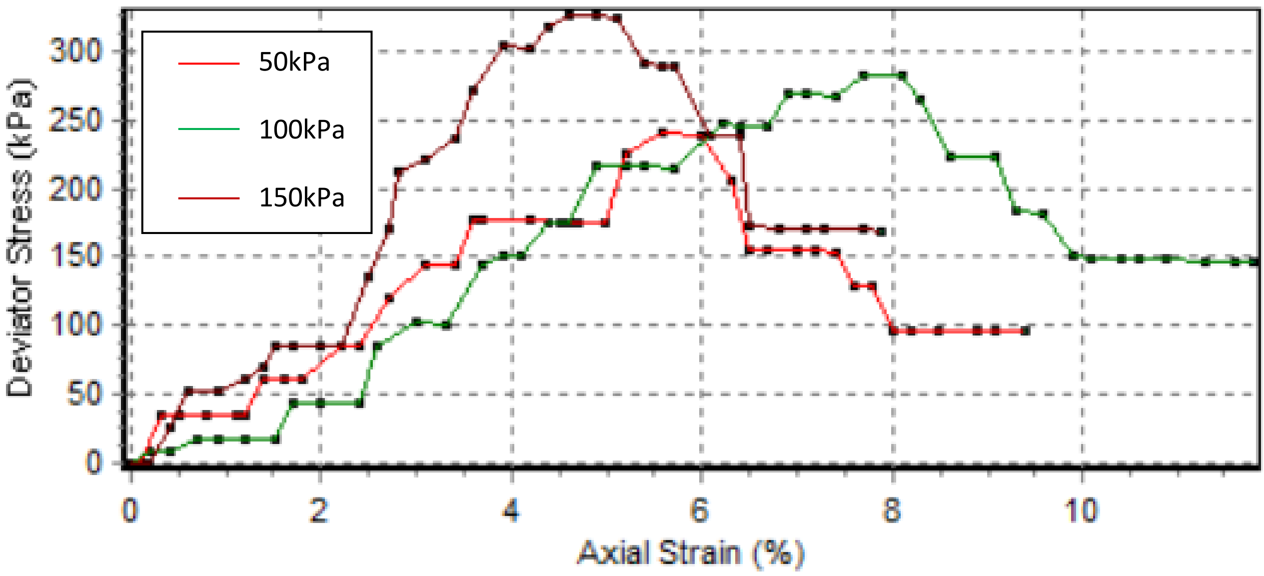

Figure 5.58: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for lime 2% and cement 6% stabilized soil (0th day curing)

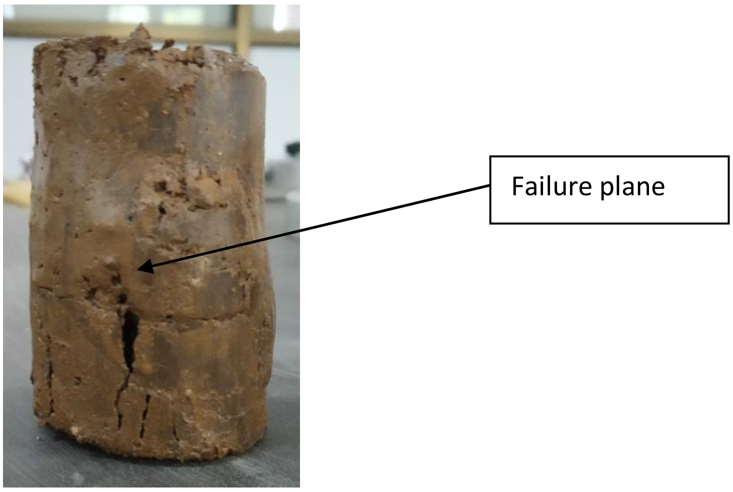

Figure 5.59: Failed sample at 50kPa cell pressure for lime 2% and cement 6% stabilized soil (0^{th} day curing)

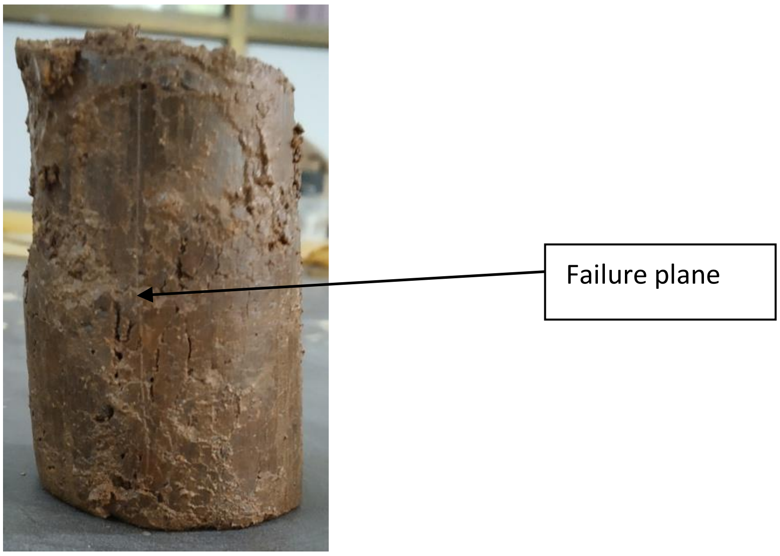

Figure 5.60: Failed sample at 100kPa cell pressure for lime 2% and cement 6% stabilized soil (0^{th} day curing)

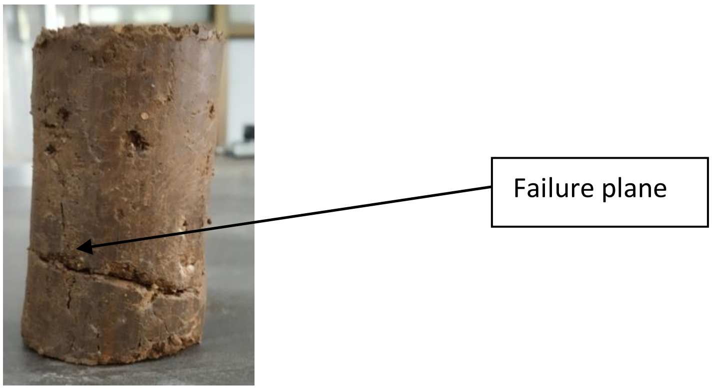

Figure 5.61: Failed sample at 150kPa cell pressure for lime 2% and cement 6% stabilized soil (0th day curing)

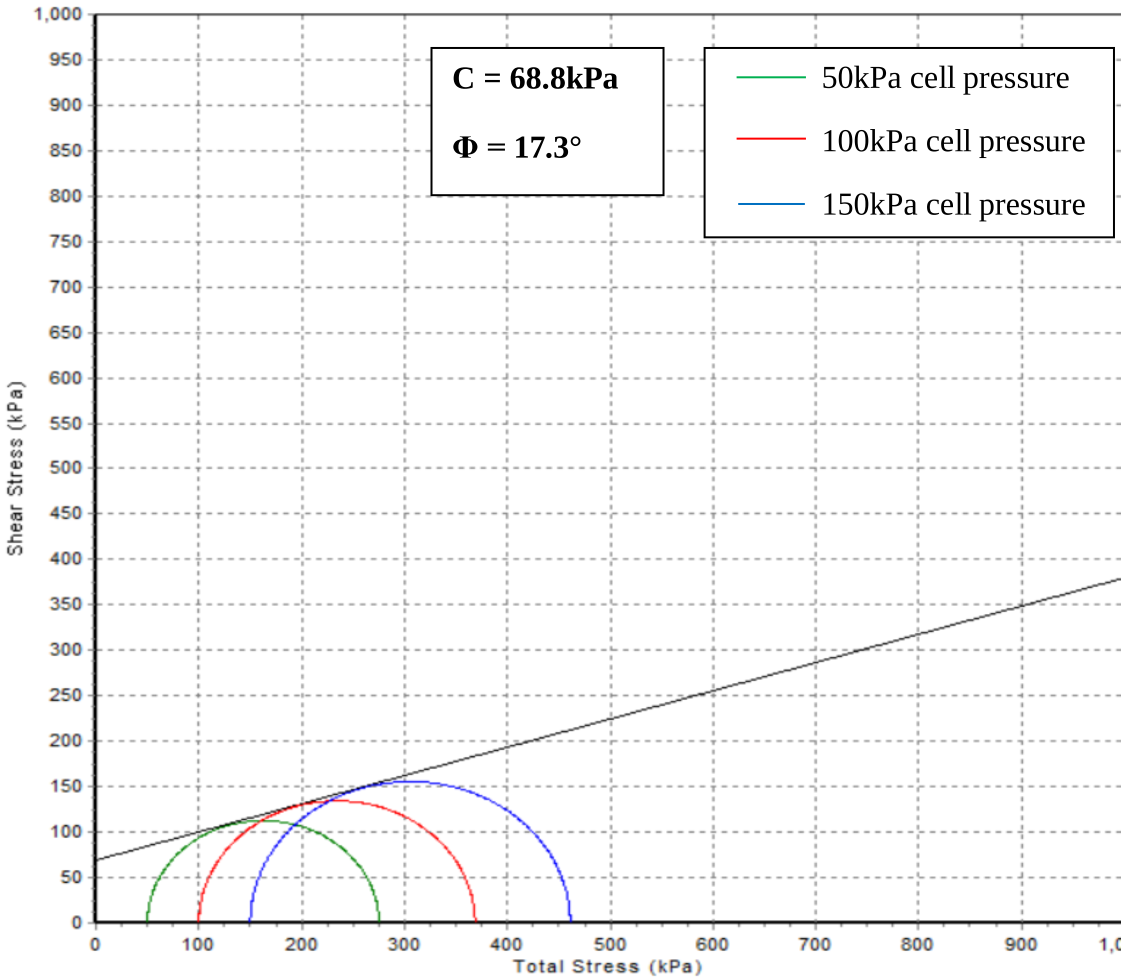

Figure 5.62: Mohr circle plot for lime 2% and cement 6% stabilized soil (0th day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.63 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.64, 5.65 and 5.66 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.67 shows the Mohr circle plot of the test.

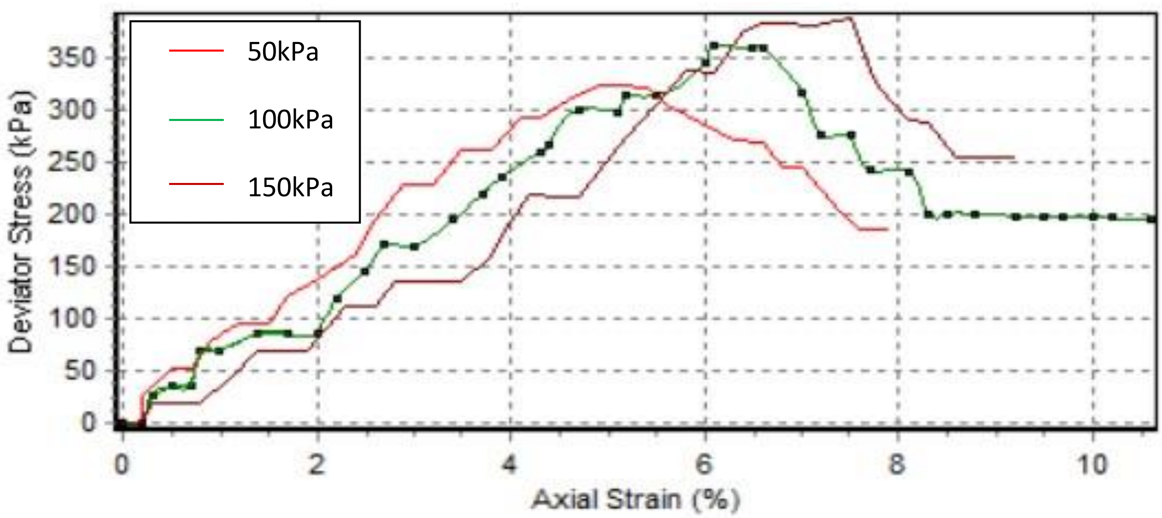

Figure 5.63: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for lime 2% and cement 6% stabilized soil (7th day curing)

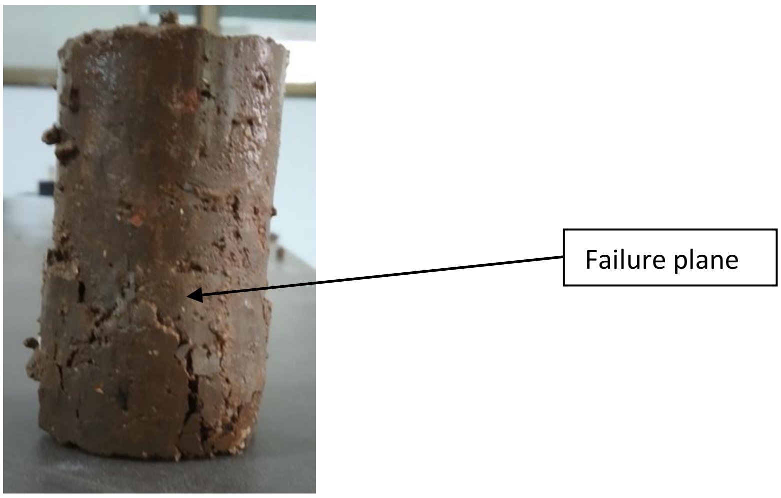

Figure 5.64: Failed sample at 50kPa cell pressure for lime 2% and cement 6% stabilized soil (7th day curing)

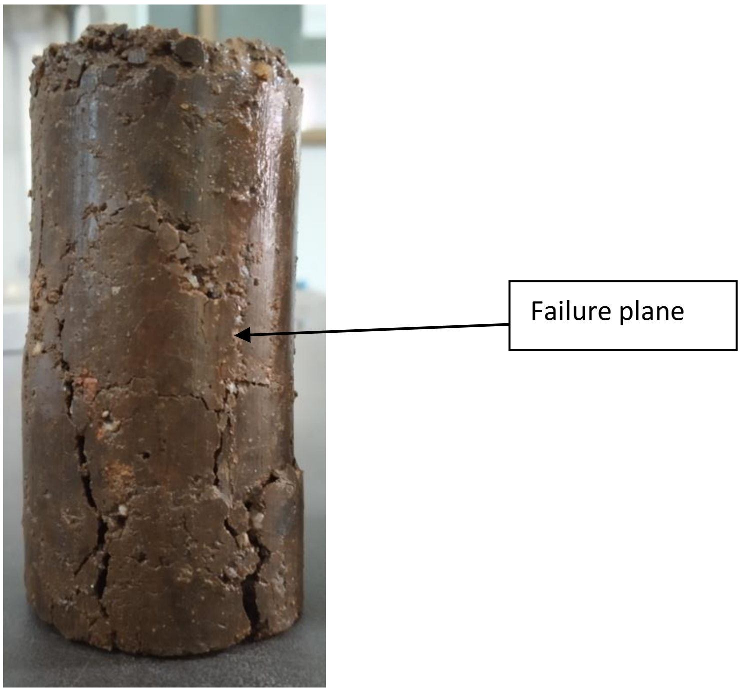

Figure 5.65: Failed sample at 100kPa cell pressure for lime 2% and cement 6% stabilized soil (7th day curing)

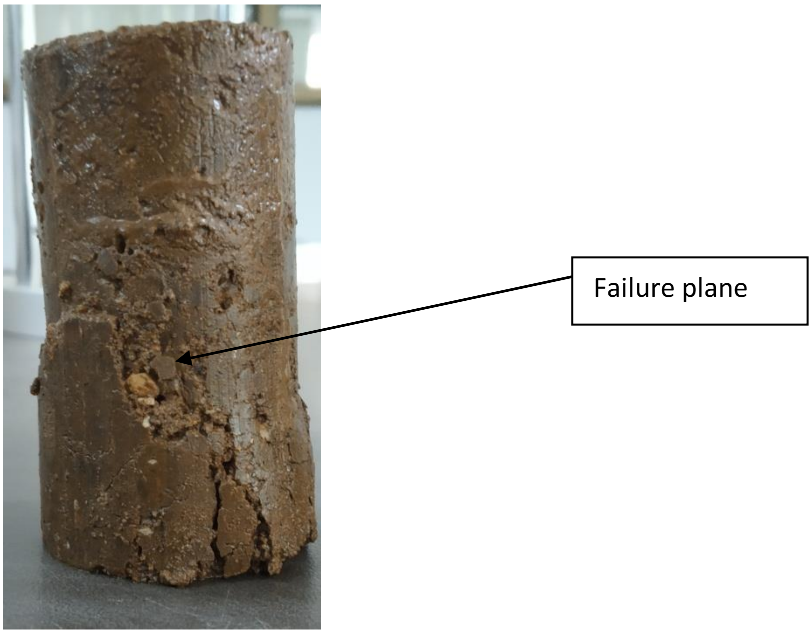

Figure 5.66: Failed sample at 150kPa cell pressure for lime 2% and cement 6% stabilized soil (7th day curing)

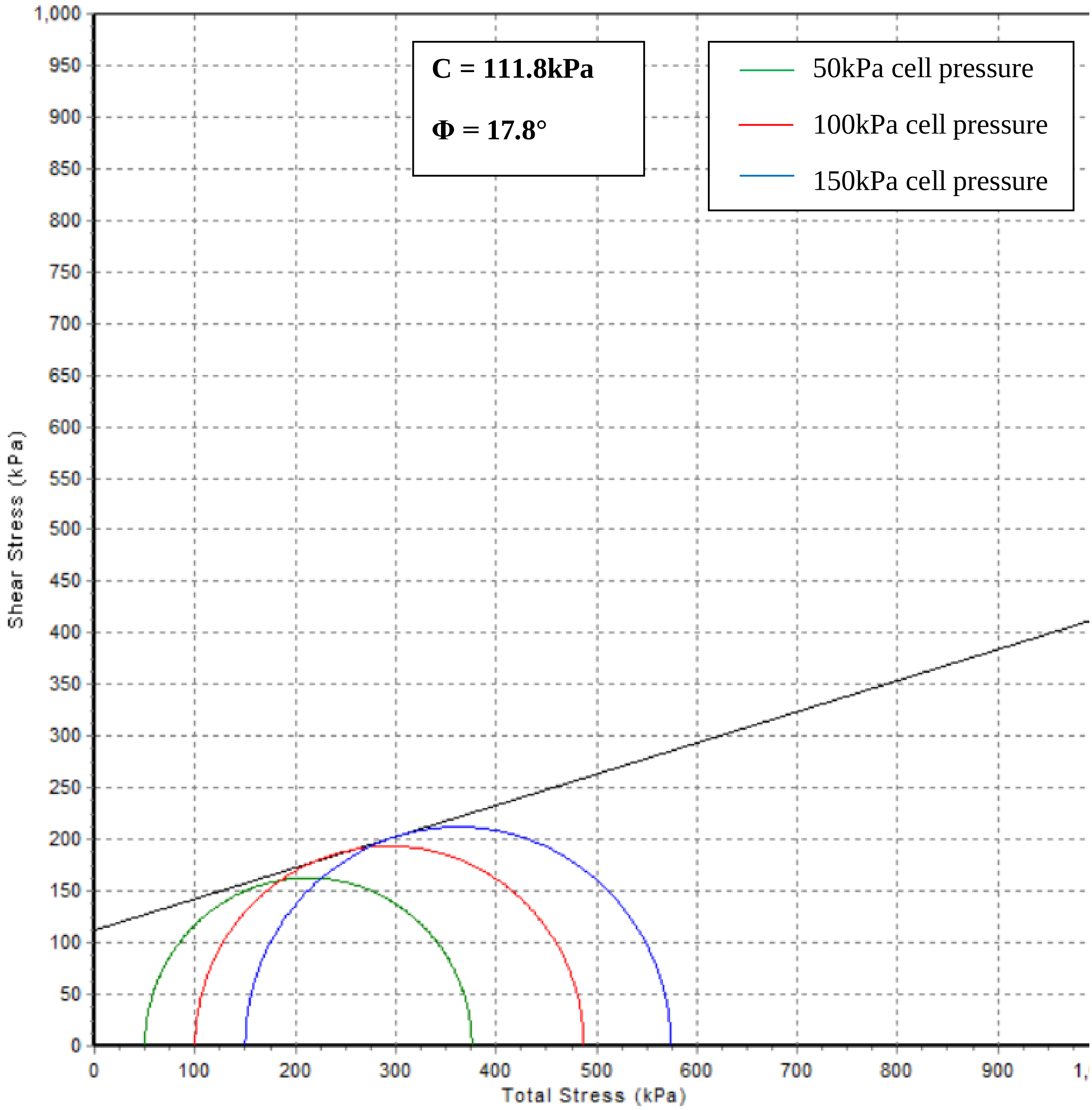

Figure 5.67: Mohr circle plot for lime 2% and cement 6% stabilized soil (7th day curing)

Lime (2%) and Cement (8%)

Testing for lime (2%) and cement (8%) was done on a total of 6 samples. Three samples were tested on the day of preparation and three were tested on the 7th day after preparation of the sample maintaining 50 kPa, 100 kPa, and 150 kPa cell pressure.

0^{th} day of curing

Three samples were tested on the day of preparation at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.68 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.69, 5.70 and 5.71 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.72 shows the Mohr circle plot of the test.

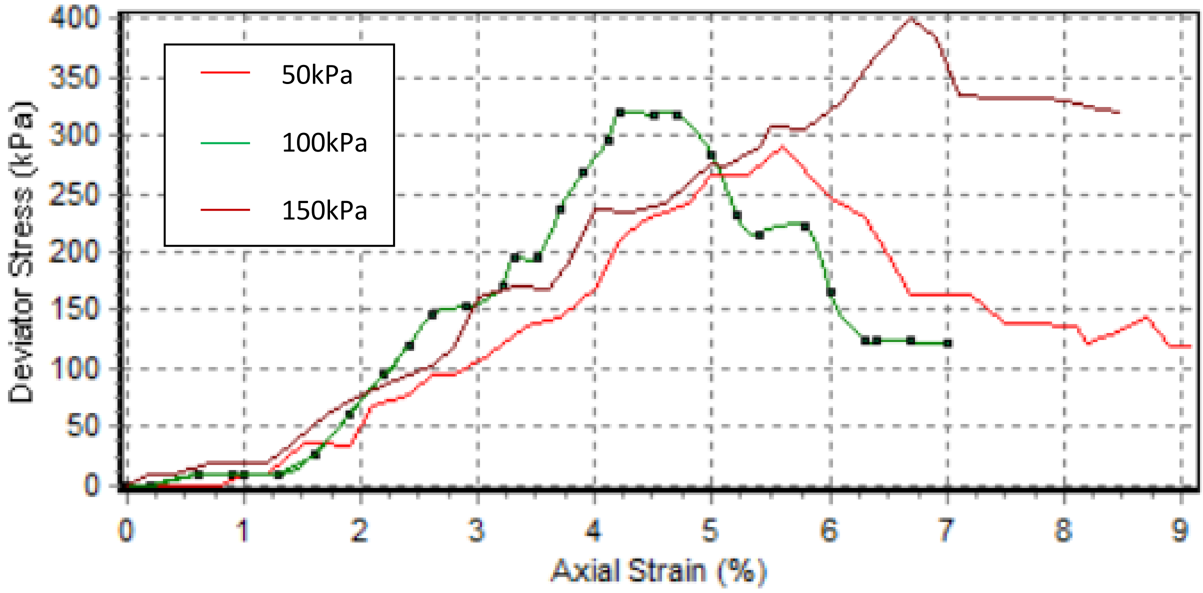

Figure 5.68: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for lime 2% and cement 8% stabilized soil (0^{th} day curing)

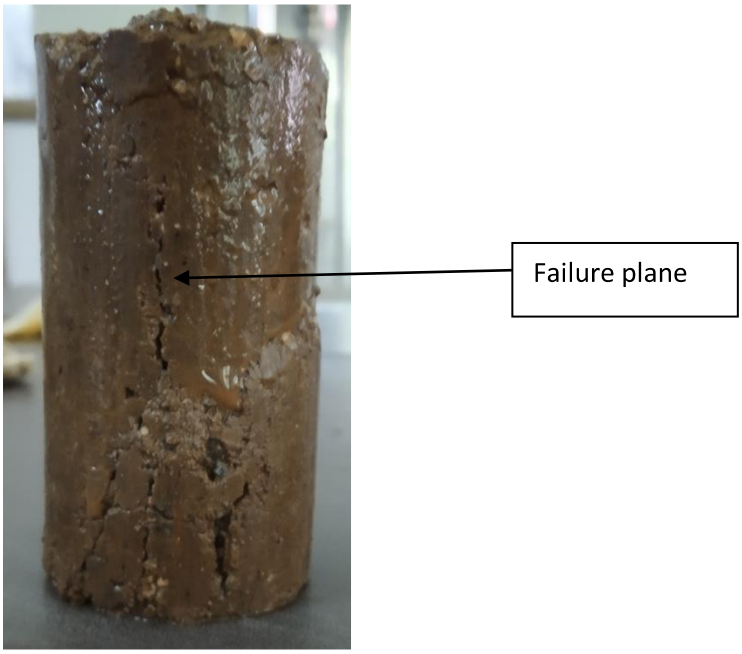

Figure 5.69: Failed sample at 50kPa cell pressure for lime 2% and cement 8% stabilized soil (0^{th} day curing)

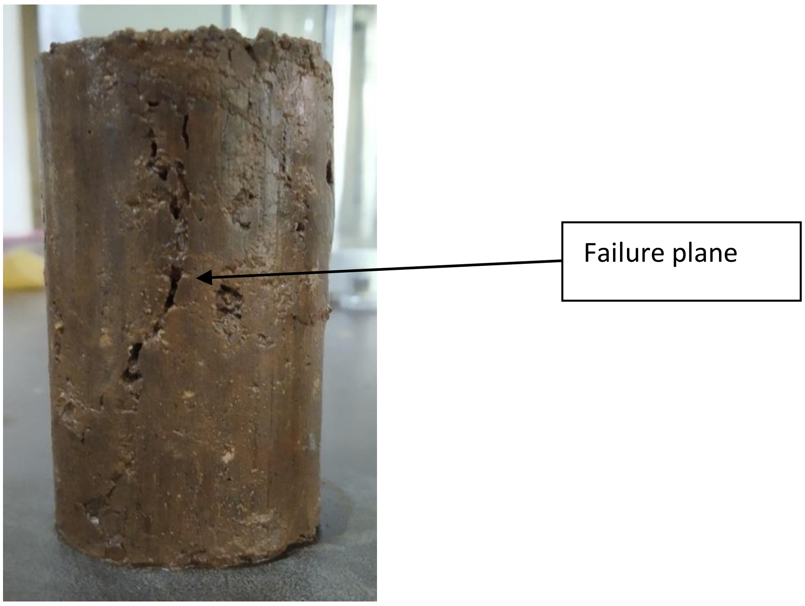

Figure 5.70: Failed sample at 100kPa cell pressure for lime 2% and cement 8% stabilized soil (0^{th} day curing)

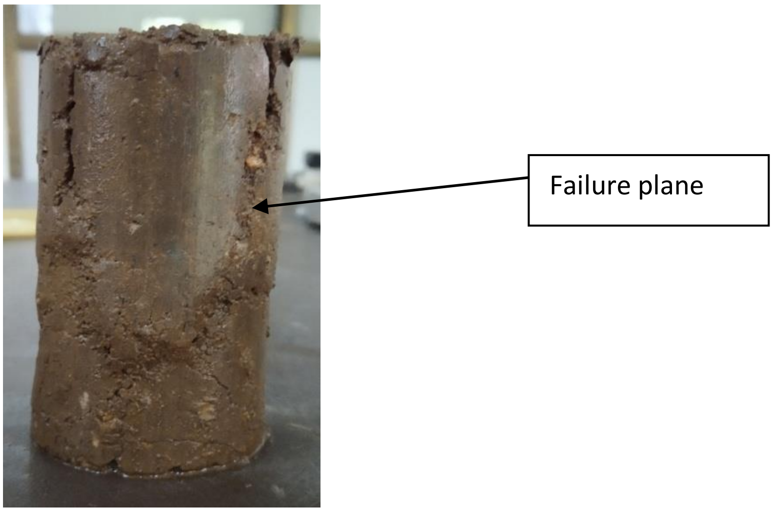

Figure 5.71: Failed sample at 150kPa cell pressure for lime 2% and cement 8% stabilized soil (0th day curing)

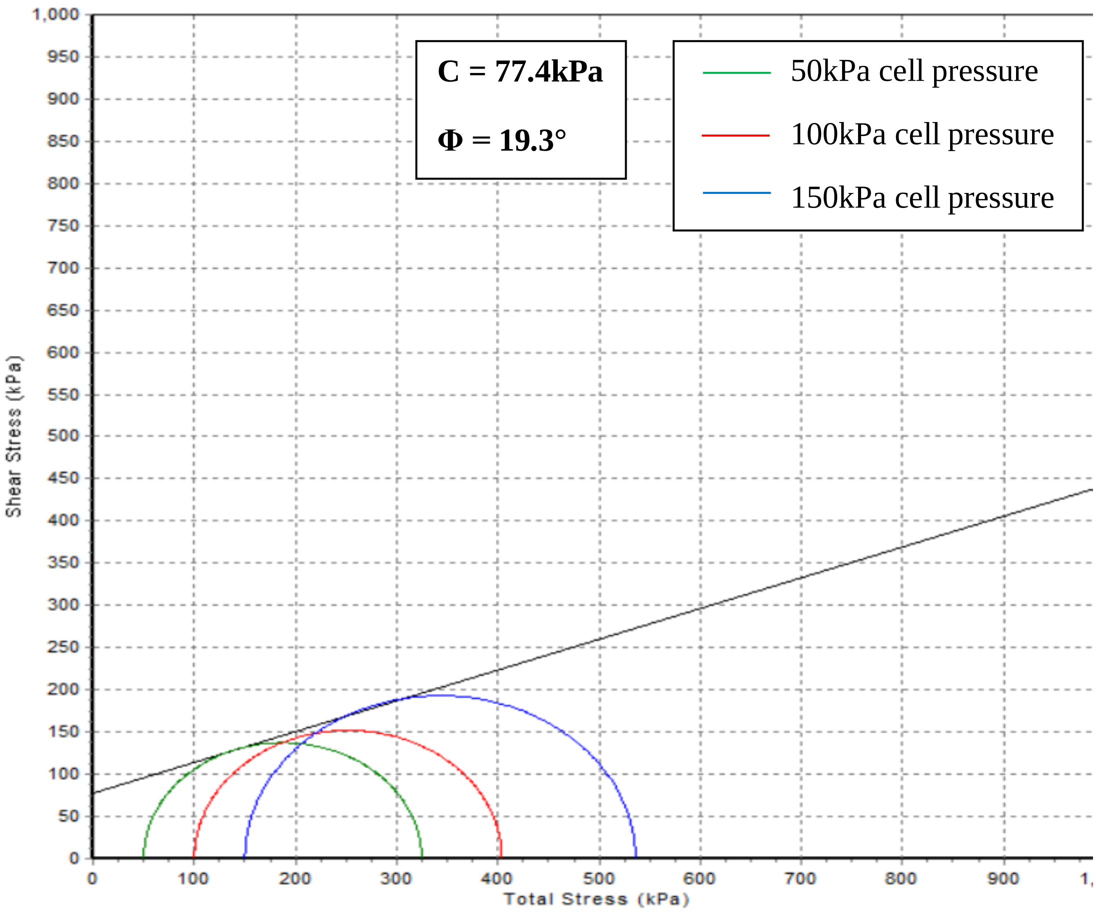

Figure 5.72: Mohr circle plot for lime 2% and cement 8% stabilized soil (0th day curing)

7th day of curing

Three samples were tested on the 7th day of curing at 50 kPa, 100 kPa, and 150 kPa cell pressure. Figure 5.73 shows the deviator stress vs. axial strain graph of all 3 samples, figure 5.74, 5.75 and 5.76 shows the failed samples at 50 kPa, 100 kPa, and 150 kPa cell pressure, respectively and figure 5.77 shows the Mohr circle plot of the test.

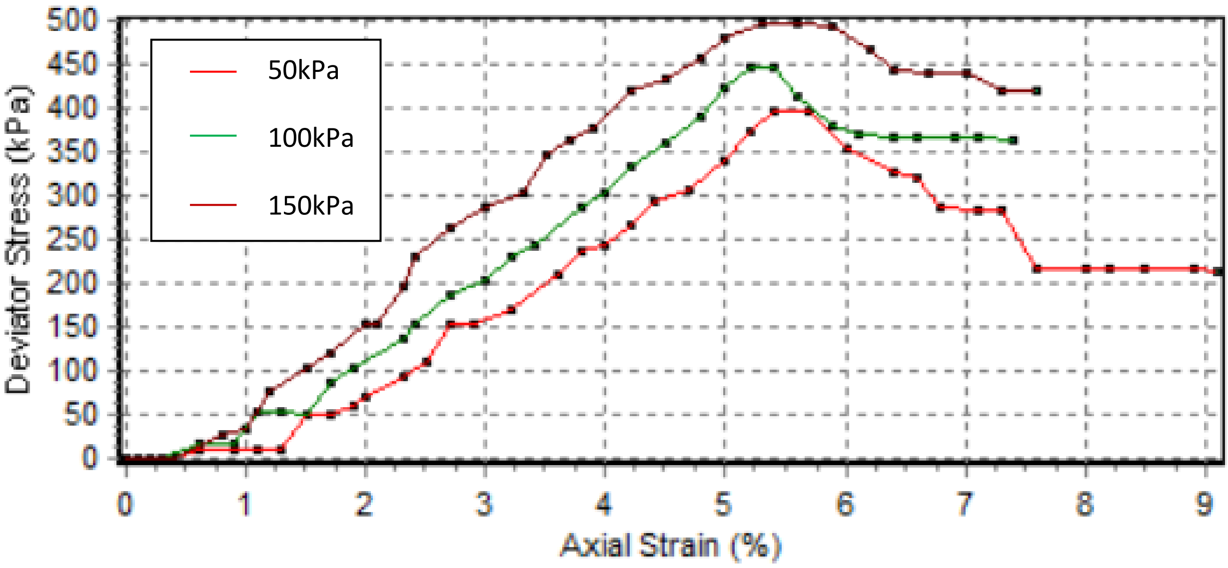

Figure 5.73: A plot of deviator stress versus axial strain for each of the three samples tested at 50kPa, 100kPa and 150kPa cell pressure for lime 2% and cement 8% stabilized soil (7th day curing)

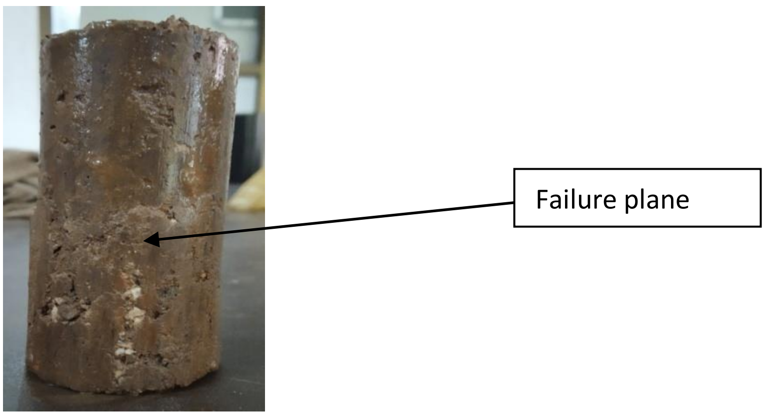

Figure 5.74: Failed sample at 50kPa cell pressure for lime 2% and cement 8% stabilized soil (7th day curing)

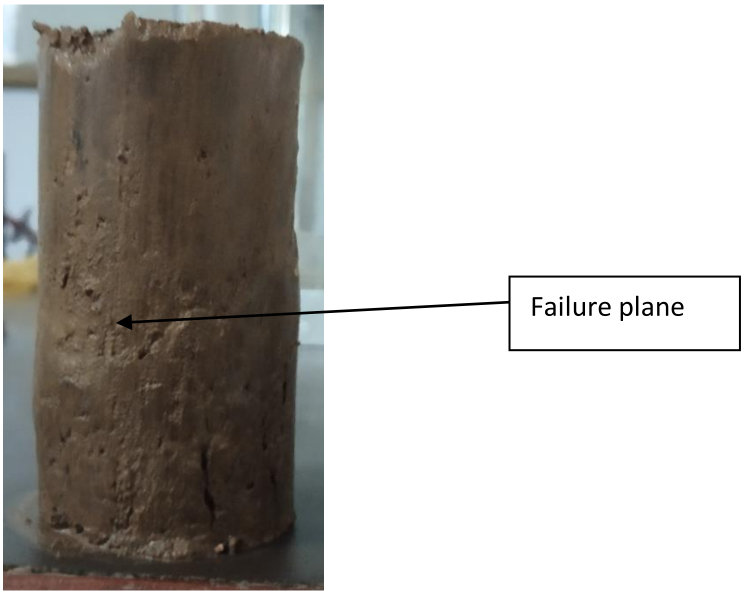

Figure 5.75: Failed sample at 100kPa cell pressure for lime 2% and cement 8% stabilized soil (7^{th} day curing)

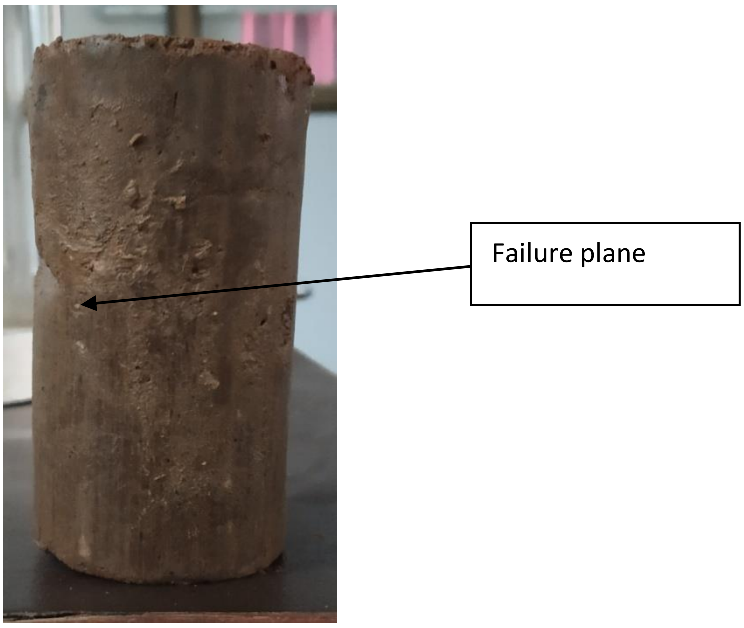

Figure 5.76: Failed sample at 150kPa cell pressure for lime 2% and cement 8% stabilized soil (7^{th} day curing)

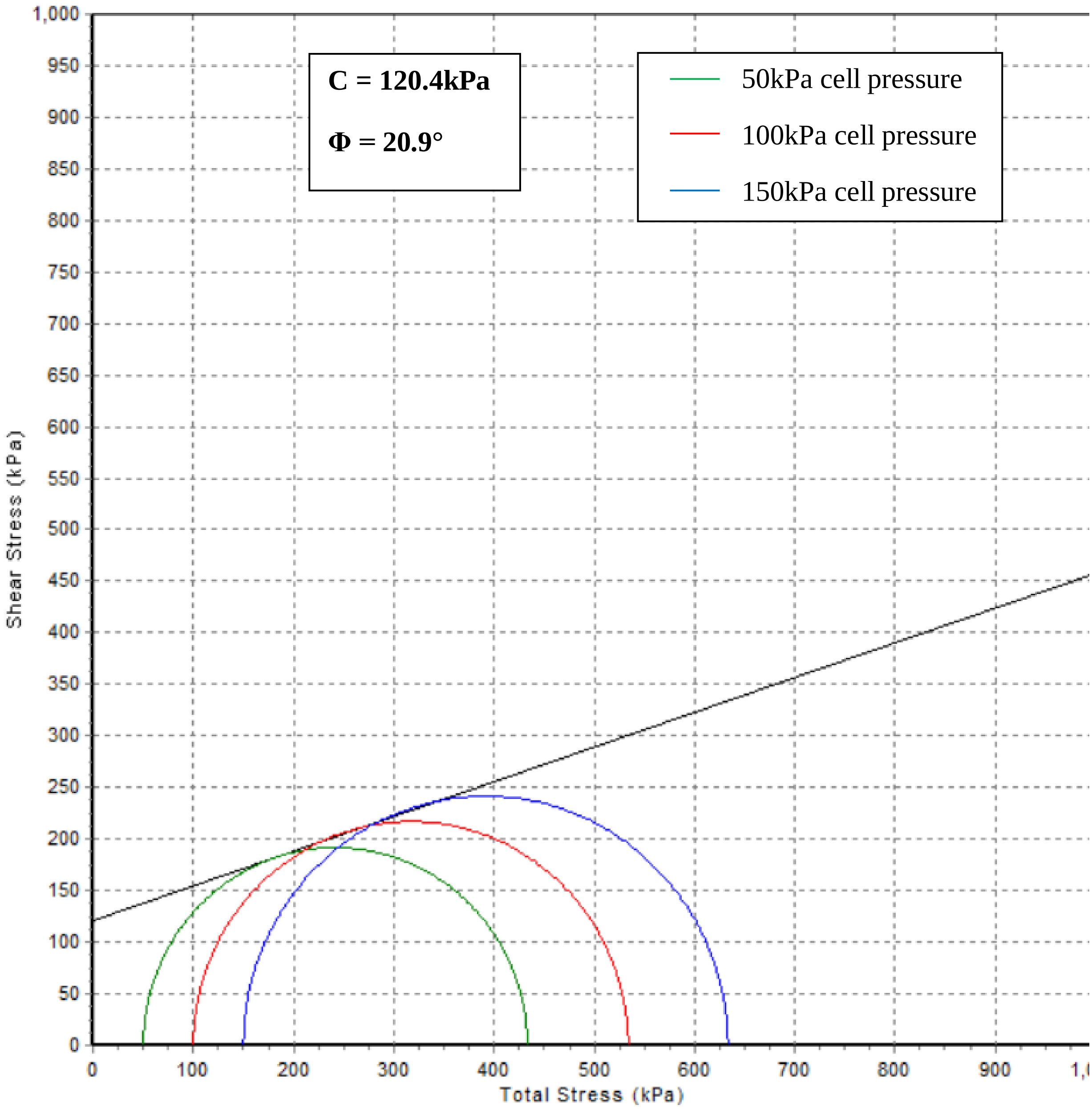

Figure 5.77: Mohr circle plot for lime 2% and cement 8% stabilized soil (7th day curing)

5.2.3 Analysis

Following a triaxial test without the addition of cement and lime, the soil's cohesion (c) and internal friction angle (φ) were determined to be 34.4 kPa and 15°, respectively.

Table below illustrates the cohesion (in kPa) obtained for soil mixed with the cement lime composite where cement was kept constant at 2% and lime content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively.

Table 5.5: Cohesion for soil specimens when cement content was kept constant at 2% and lime content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively

	Cohesion (kPa)			
	Cement 2%			
Stabilizer content (%)	**Lime 2%**	**Lime 4%**	**Lime 6%**	**Lime 8%**
Curing period (0 day)	45.15	47.3	68.8	75.25
Curing period (7 days)	53.75	58.05	86	116.1

Table below illustrates the cohesion (in kPa) obtained for soil mixed with the cement lime composite where lime content was kept constant at 2% and cement content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively.

Table 5.6: Cohesion for soil specimens when lime content was kept constant at 2% and cement content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively

	Cohesion (kPa)			
	Lime 2%			
Stabilizer content (%)	**Cement 2%**	**Cement 4%**	**Cement 6%**	**Cement 8%**
Curing period (0 day)	45.15	54.05	68.8	77.4
Curing period (7 days)	53.75	77.4	111.8	120.4

Table below illustrates the angle of internal friction (φ) obtained for soil mixed with the cement lime composite where cement was kept constant at 2% and lime content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively.

Table 5.7: Angle of internal friction for soil specimens when cement was kept constant at 2% and lime content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively

	Angle of internal friction (φ)			
	Cement 2%			
Stabilizer content (%)	**Lime 2%**	**Lime 4%**	**Lime 6%**	**Lime 8%**
Curing period (0 day)	15.7°	17.2°	15.3°	14.6°
Curing period (7 days)	18.7°	22.6°	20.7°	17.2°

Table below illustrates the angle of internal friction (φ) obtained for soil mixed with the cement lime composite where lime content was kept constant at 2% and cement content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively.

Table 5.8: Angle of internal friction for soil specimens when lime content was kept constant at 2% and lime content was increased by 2%, 4%, 6% and 8% for 0 day and 7 days respectively

	Angle of internal friction (φ)			
	Lime 2%			
Stabilizer content (%)	**Cement 2%**	**Cement 4%**	**Cement 6%**	**Cement 8%**
Curing period (0 day)	15.7°	10.7°	17.3°	19.3°
Curing period (7 days)	18.7°	22°	17.8°	20.9°

For (cement 2% and lime 2%) addition to soil, the value of cohesion (c) showed an increasing trend with the increase in the curing period of the stabilized soil. While the angle of internal friction (φ) slightly increased in the 0^{th} day but significantly increased in the 7^{th} day.

For (cement 2% and lime 4%), (cement 2% and lime 6%) and (cement 2% and lime 8%) addition to soil, similar increase in the value of cohesion was observed with the increase in curing period with the highest value being 116.1kPa for (cement 2% and lime 8%) stabilized soil for 7 day curing period. However the value angle of internal friction (φ) initially increased for the (cement 2% and lime 4%) stabilized soil but thereafter started to decrease in value.

Again for (lime 2% and cement 4%) addition to soil, the value of cohesion (c) also showed an increasing trend with the increase in the curing period of the stabilized soil. While the angle of internal friction (φ) decreased for the 0^{th} day but increased for the 7^{th} day.

For (lime 2% and cement 6%) and (lime 2% and cement 8%) addition to soil, similar increase in the value of cohesion was observed with the increase in curing period with the highest value being 120.4kPa for (lime 2% and cement 8%) stabilized soil for 7 day curing period. But the value of angle of internal friction showed an uneven trend for both the 0^{th} day and the 7^{th} day.

It is to be noted that although the value of cohesion increased in both the cases, however greater value of cohesion was obtained for the proportions when lime content was kept constant at 2% and cement content was increased as compared to the proportions when cement content was kept constant at 2% and lime content was increased. This can be seen as the highest value of cohesion was obtained for (lime 2% and cement 8%) stabilized soil cured for 7 days (which was 120.4kPa) which is more than the value of cohesion obtained for (cement 2% and lime 8%) stabilized soil cured for 7 days (which was 116.1kPa).

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusions

In geotechnical engineering, stabilizing soil is an essential procedure that aims to improve the physical characteristics of soil in order to increase its strength, durability, and capacity to support loads. Using this method, the soil is stabilized by adding cement, lime, or other chemical additives, which produces a more stable and workable substance. Cement and lime were used to stabilize the soil by keeping cement content constant at 2% and increasing the lime content and keeping lime content constant at 2% and increasing the cement content. The proportions used were (cement 2% + lime 2%), (cement 2% + lime 4%), (cement 2% + lime 6%), (cement 2% + lime 8%), (lime 2% + cement 2%), (lime 2% + cement 4%), (lime 2% + cement 6%) and (lime 2% + cement 8%) by weight of the natural soil. The cement-lime-soil mixed samples were allowed to cure for 0 day and 7 days. Triaxial testing was performed on the soil samples mixed with the previously stated amounts of cement and lime, and the value of cohesion and angle of internal friction were calculated for each condition.

The following conclusions are drawn from the triaxial tests:

- In both the above mentioned cases of addition of cement and lime to the natural soil, the value of cohesion increased significantly with also satisfactory increase in the value of angle of internal friction.
- The best proportion of cement and lime of all the tests conducted came out to be at (lime 2% and cement 8%).
- The value of cohesion and angle of internal friction obtained at (lime 2% and cement 8%) when the sample was cured for 7 days was 120.4kPa and 20.9° respectively. The value of cohesion and angle of internal friction obtained when no cement and lime was added was 34.4kPa and 15° respectively. This shows a significant improvement in the strength parameters of the soil upon mixing of cement and lime.
- In all the proportions of cement and lime and with increase in the curing period the value of cohesion was increased.

6.2 Scope for future work

This report presents the data on shear strength parameters of cement lime stabilized soil by using the UU triaxial test. The following suggestions are made to extend future studies:

- Research work on cement lime stabilized soil using CU and CD tests.
- Studies can be carried out by increasing the cement and lime content beyond 8% and also by increasing the curing period.
- Different tests such as the CBR test, unconfined compressive test etc can be carried out on the soil.
- Moreover, studies can be conducted by incorporating other stabilizing agents into the soil, and the triaxial UU, CU, and CD test methods can be used to assess the strength parameters.

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