Assessing The Impact of Fly Ash and Geogrid on Improving the Engineering Properties of Expansive Subgrade soil

Jiksa Mideksa

A Thesis Submitted to the Department of Civil Engineering,
College of Civil Engineering and Architecture

Office of Graduate Studies
Adama Science and Technology University

May, 2025
Adama, Ethiopia

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DECLARATION

I declare that this MSc. thesis entitled “**Assessing the impact of Fly ash and Geogrid on improving the Engineering Properties of Expansive Subgrade soil** "is my work and has not been submitted to any university for a similar purpose. The references used in this proposal are duly recognized by proper citations.

Jiksa Mideksa________ ________________ ____________

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I, the advisor of this MSc thesis, hereby certify that I have closely advised the student while developing this thesis and read the draft entitled "**Assessing the impact of Fly ash and Geogrid on improving the Engineering Properties of Expansive Subgrade soil**" prepared under my guidance by Jiksa Mideksa Therefore, I recommend the submission of the proposal to the department for further review and evaluation.

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Abstract

Expansive soil is known as a cause of different types of failures in lightweight structures such as road, light weight buildings, pipeline and the like. The solution of such problems should have to consider environmental safe, cost, readily availability, and long term performance. This study therefore, aims to improve the index and engineering property of selected expansive subgrade soil collected from Koye feche area by using fly ash and geogrid material. To achieve this, soil samples were collected from study area and various laboratory tests such as Atterberg limit, free swell index, specific gravity, proctor compaction, unconfined compressive strength (UCS) and California bearing ratio (CBR) tests before and after treating with fly ash ratio (0%, 5%, 10%, 15%, 17.5% and 20%) by dry weight were carried out. And also, to investigate the impact of geogrid with and without fly ash concentration, stabilization of the same subgrade material using two layers of geogrid reinforcement before and after treating with 17.5% fly ash concentration were performed. The test result indicated that the use of fly ash and geogrid reinforcement can significantly improve the bearing capacity of the selected expansive subgrade soils. At 17.5% fly ash and the first layer of geogrid application the CBR was increased by 10. 33% (sufficiently satisfying the requirement set by the ERA design standard) compared to the un-stabilized subgrade soil which is 2.7%. The results also showed a 5.44% increase in soaked CBR when using 20% fly ash alone, while a 6.17% improvement in CBR was achieved by applying only geogrid reinforcement to the expansive soil. Moreover, considerable improvement in CBR value was observed while using combined fly ash and geogrid material. This highlights the importance of geogrid and fly ash as a viable method for soil stabilization with high expansiveness tendency of the given soil.

Keywords: Fly ash, Geogrid, expansive soil, stabilization, subgrade

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List of Abbreviation

% - Percent

AASHTO - American Association of State Highway and Transport Official

Al_2O_3 - Aluminum Oxide

ASTM - American Society for Testing and Materials

Ca_2SO_4 - Calcium Sulfate

$CaCO_3$ - Calcium Carbonate

CaO - Calcium Oxide

CBR - California Bearing Ratio

CH - High Plasticity Clay

CL - Low Plasticity Clay

D – Designation

FA-Fly ash

HDPE - High Density Polyethylene

K_2SO_4 - Potassium Sulfate

Kg - Kilogram

Km - Kilometer

Kpa - Kilopascal

LOI - Loss on Ignition

^0C - Degree Centigrade

OH - High Plasticity Organic Soil

PI - Plasticity index

PLC - Private Limited Company

Psi - Pascal

Pt - Peat

PVC - Polyvinyl Chlorides

SC - Clayey Sand

SI - Swell Index

Si_2O_3 - Silicon Oxide

SL - Shrinkage Limit

UCS - Unconfined Compressive Strength

USCS - Unified Soil Classification System

XRD X – Ray Diffraction

XRF X – Ray Fluorescence

CHAPTER ONE

1. INTRODUCTION

1.1. Background

The design of foundations and embankments on weak soil poses a challenging problem for geotechnical engineers due to their undesirable settlement and bearing capacity. Expansive soils are primarily found in arid and semi-arid regions of the world (Al-Rawas, 2005). Many Countries like; Ethiopia, Ghana, India, Canada, Iran etc are reporting about the problems of expansive soils. In Ethiopia most of the expansive soils are identified during project implementation, where different construction activities are taking places, for instance, southern, southeast and southwest of Addis Ababa city, central parts of Ethiopia following major trunk road like Addis Ababa to Modjo, Addis Ababa to Woliso, Addis Ababa to Debre Berhan and Addis Ababa to Ambo and areas like Mekele, Bahirdar, Gambella can be mentioned. According to Aga S.Y. (2021), expansive soils in Ethiopia are widely distributed across the country, particularly concentrated in the central and southern highlands, covering roughly 40% of the land area, with the dominant expansive clay type causing significant structural damage due to its volume changes with moisture levels; this is most prevalent in regions with Vertisols, a type of clay soil prone to swelling and shrinking with varying water content. Moreover, as the percentage of construction activities in different parts of the country increases, the expectation of identifying more areas with expansive soils would also rises.

In Ethiopia, most of the roads under construction encounter challenges related to expansive soils (Banatayehu U.U., 2017). As shown in Figure 1.1, the coverage of expansive soil in the study area is extensive; this includes the most populated and economically active areas.

Figure 1.1: expansive soil distribution in Ethiopia

The research of expansive soil stabilization is becoming more important in order to enhance the geotechnical characteristics of expansive clay in order to fulfill technical criteria in the building sector. It is the process of modifying geotechnical qualities to meet engineering requirements (Attoh-Okine, 1995). If the soil is expansive, nothing builds on it until the strength attributes have been improved. To achieve this, the economy in construction plays important role. Therefore, mostly expansive soils were replaced by another soil with sufficient strength. If suitable soil is not available in the adjacent areas to replace expansive soil, it must be transported from a considerable distance, taking into account the cost and the duration of construction. This implies that, soil improvement by utilizing locally accessible resources is necessary approach. The damage caused by expansive soils can be controlled, and through proper application of soil stabilization methods significant reduction of the damage can be achieved (Zada U., et al, 2023).

Different stabilizing procedures are utilized in an attempt to make expansive soil more suitable for use in engineering projects. However, well-known stabilizers like as cement, lime, and bitumen are related with environmental issues (J B Niyomukiza *et al,* 2021**).** This has initiated the interest of searching for ecologically suitable, low-cost, and long-term stabilizers. Recent trend in research works in the field of geotechnical engineering and construction focuses more on cheap and locally available materials such as waste ceramic powder (Sabat, A. K., 2012), bagasse ash (Adnan M., et al, 2023), sugarcane straw ash (Chakraborty A et al, 2016), fly ash (Nalbantoglu Z. (2004), rice husk ash (Raja, K, et al, 2021), coconut husk ash (Oluremi, J.R, et a, 2012) etc. as stabilizing agents for the purpose of full or partial replacement of traditional stabilizers like cement and lime.

It is well known that geosynthetic materials are mostly produced from polymers or it is also called hydrocarbons. The common types of geosynthetic material are geogrids, geotextiles, geomembranes, geonets, geofoams and geocomposites with their primary function includes as reinforcement, separation, filtration, drainage and containment respectively (Aga S.Y., 2021) Over the past few decades, significant advances have been made in the use of physical as well as chemical stabilization techniques for ground improvement, particularly during pavement and foundation design (Abdelkrim M. et al, 2015).

In this study the efficiency of using fly ash and geogrid material to stabilize expansive subgrade soil were studied in detail. In order to investigate the effectiveness of geogrid material in comparison to chemical stabilizer the same soil will be treated through utilization of fly ash considering soaked CBR as a control parameter. This research work employs pure experimental methods to achieve its goals, and the results could provide insight into the significant potential for applying physical and chemical stabilization techniques as indexes and engineering improvements for the selected soil.

1.2. Statement of the problem

Construction on expansive soils has caused several issues for civil engineering projects such as highways, railways, embankments, and foundations. In other cases, construction on such soil cannot be avoided, and the sources of acceptable materials may be far from the site, making transportation costly and time consuming. A substantial portion of the specified study area is also covered with expansive soil, which has an impact on the stability of numerous light-weight constructions, residential buildings, and highways. The majority of them fail before their design life is completed. As a result, a corrective measure should be made to mitigate the problem while taking into account the construction quality, cost, and duration by employing an economical solutions. In Koye Feche, despite governmental intentions to develop various infrastructures, the presence of expansive soil poses a significant challenge, resulting in project failures. Moreover, in the study area considerable research is not yet sufficiently done on improving the strength of expansive soil by using combined effect of fly ash collected from cement industries and geogrid reinforcement. From which fly ash is more important due to its pozzolonic character. Accordingly, this study presents the potential use of fly ash and geogrid material for improving the index and strength of weak expansive subgrade soils using fly ash and geogrid material, respectively.

1.3. Research Questions

1. Is it possible to distinguish and identify the index and engineering properties of expansive subgrade soil collected from koye feche study area?
2. Can soil stabilization techniques, such as geogrid reinforcement and fly ash concentration, be used as a subgrade stabilization material to improve some of the engineering properties of Koye Feche expansive soil?
3. To what extent does the application of both fly ash and geogrid can improve the engineering properties of expansive soil found in Koye Feche?

4. Is it possible to identify the optimum content of fly ash and the exact position of geogrid inclusion that results better CBR value for Koye Feche expansive soil?

1.4. Objectives

1.4.1. General Objectives

The general objective of this research is to study the effect of application of chemical and physical stabilizers on enhancing the bearing capacity value of weak expansive subgrade soil using fly ash and geogrid as a soil stabilization material.

1.4.2. Specific Objectives

1. To distinguish and identify index and engineering properties of the soil from the study area through conducting different laboratory tests.
2. To investigate the potential application of fly ash and geogrid to enhance engineering properties of expansive soil found from Koye Feche.
3. To investigate the combined effects of fly ash concentration and geogrid reinforcement on expansive soil found at Koye Feche, to see if there is further improvement in the soaked CBR value.
4. To know the optimum content of fly ash and the accurate location of geogrid position to stabilize the expansive soil from the study area.

1.5. Significance of the study

A structure built on problematic soil will undergo a large settlement. To make the soil more suitable for structures, soil can be stabilized by physical or chemical improvement techniques. Modification of soft soil with a geogrid and fly ash is a promising soil improvement technique; it improves bearing capacity and reduces the settlement characteristics of the soil. The majority of construction projects have been undertaken inside the proposed study areas. Engineers face challenges due to the presence of low bearing soil. These soils have low bearing capacity and high compressibility characteristics. In order to use these soils suitable for construction, making remedial measures on the available soil to achieve the specified objectives are necessary. Hence ground improvement need to be applied. Additionally, the current construction method (removing and replacing the existing problematic soil) is very time-consuming and expensive. Therefore, the result from the study plays a crucial role, since application of fly ash and geogrid is cost effective and easily available material than others. The study can also be used to develop a soil stabilization manual, as it will have a customized nature to meet the soil stabilization requirements for future development programs.

1.6. Scope and limitation of the study

1.6.1. Scope of the study

Basically the study focuses on the effect of inclusion of chemical and physical stabilizers to enhance bearing capacity values of weak expansive subgrade soil by using fly ash and geogrid as a soil improving material. To achieve the research objectives purely experimental method was followed. The approach of the study involves the collection of representative soil sample from the specified study area as well as the identification of index and engineering properties of the given soil by conducting laboratory tests such as particle size distribution, specific gravity, Atterberg limits, free swell test, UCS, compaction, and CBR. The study is focused on identifying the optimum amount of fly ash and proper spacing of geogrid inclusion inside the expansive soil volume. Moreover, the study used CBR tests to investigate the combined effect of both geogrid and fly ash material on further subgrade improvement potential. Finally, the results and findings of the research will be analyzed, organized and presented.

1.6.2. Limitation of the study

- In this study, fly ash and geogrid were applied only to expansive soil in Koye Feche. However, it is also important to consider the impact of such materials on problematic soils other than expansive soil, including collapsible soil, soft clay, and loose soil.
- In order to comply with resource constraints, only two layers of geogrid reinforcement were applied to the provided CBR mould, both without and subsequent to the 17.5% application of fly ash concentration.
- Due to time constraint, the analysis and discussion of the result obtained is solely dependent on major laboratory tests, however, this study recommends the use of numerical models to compare the result obtained among them.
- As a result of the lack of chemical testing, SEM, XRD and other chemical tests are not considered.

1.7. Thesis organization and outline

This thesis has six chapters. The first chapter is introduction and discusses the background of the study, statement of the problem; objectives, scope and limitation of the study. The second chapter is a literature review and describes the theoretical background and the application of fly ash and geogrid reinforcement for the strength improvement of problematic soil such as expansive soil. This section covers reviews on origin, distribution, and classification of expansive soil, the concept of using fly ash and geogrid as a soil improving material and effect of using such material as a subgrade improving materials, soil distribution in the study area; and research gaps were covered. The methodology for the study is presented in the third chapter, which includes identification of study area, types of various laboratory experiments and equipment that is executed as per ASTM, BS, AASHTO and Indian standards, and along with the suggested constitutive behavior that controls them. Additionally, the expected laboratory results used for the study are explained in the fourth chapter and it relied on the presentation of laboratory test results. Analysis, interpretation discusses of laboratory test results and investigation of the effect of fly ash and geogrid on subgrade material is presented in the fifth chapter. Finally, the sixth chapter provides conclusions and recommendations of this study based on the laboratory experiments.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

Subgrade stabilization refers to the process of enhancing the performance of the subgrade natural soil or aggregate layer underneath roadways, highways, or railway tracks (SS Teja et al, 2015). The subgrade is a kin to the foundation of the road construction. The purpose behind subgrade stabilization is to reduce or minimize rutting, increase the stiffness of the subgrade, and distribute loads more evenly to prevent differential settlement (Kumar S., et al, 2023).

There are large coverage of clay soils throughout the world, causing significant damage to both infrastructure and buildings due to their expansive nature. In the rainy season, they soak up water and swell up, and in the summer, they shrink as a result of the evaporation of the water they have absorbed. In light of this alternative swelling and shrinkage, lightly loaded civil engineering structures such as residential buildings, pavements and canal linings are severely damaged due to this alternative (Aga S.Y., 2021). Expansive soil in koye feche is extensively distributed. It is, therefore, necessary to mitigate the problems posed by expansive soils and prevent cracking of structures. Extensive laboratory / field trials have been carried out by various researchers and have shown promising results for application of such expansive soil after stabilization with additives. For instance, Kollaros G et al (2017) showed that sand can modified the expansive nature of soil found in Greece. Similarly, Blayi, R.A et al (2020) stated that expansive soil stabilization can be achieved by using silt as stabilizer. Moreover, the use of lime as expansive soil stabilizer revealed by Adnan M., et al, (2023). According to Noaman, M. F., et al (2022), fly ash also used as a stabilizer to modify the expansive soil used for subgrade preparation. Since fly ash is freely available around cement manufacturing pants, for projects in the vicinity of a Thermal Power Plants, it can be used as stabilization agent for expansive soils.

According to Lu L et al (2021), expansive soil stabilization using geogrid material involves installing a network of geogrid sheets within the soil to reinforce the soil structure. This significantly reduces the potential for soil volume changes caused by moisture fluctuations, which leads to preventing expansive soil from swelling and shrinking excessively. Thus improves its stability for construction purposes. The benefits of geogrids for stabilization according to Strata G., (2025) explained as follows:

- The primary function of geogrids in pavements is to provide mechanical stability to weak subgrade soils. The confined movement minimizes lateral pressure by locking the subgrade into apertures, resulting in a more uniform load distribution from above. To prevent failures, cracking, rutting, and other maintenance challenges, this becomes increasingly crucial as the paved road ages.
- **Tensile strength:**
  Geogrids possess high tensile strength, enabling them to distribute loads across a larger area of soil and effectively resist the expansive forces generated by moisture changes soil.
- **Interlocking mechanism:**
  The grid-like structure of the geogrid forms a network that interlocks with soil particles, enhancing stability and preventing soil movement.
- **Stress distribution:**
  When expansive soil swells, the geogrid helps distribute the stress over a wider area, reducing the localized pressure points and minimizing the potential for cracking or upheaval.
- **Road construction:**
  Incorporating geogrids into road base layers can help mitigate cracking and improve the overall stability of roads built on expansive soils.
- Geogrids are easy to install when compared to other subgrade stabilization methods. Geogrids installation doesn't require skilled labour or specialized equipment.
- The use of geogrids in subgrade stabilization can help extend pavement life structure by providing a strong and durable foundation.
- By reducing the amount of aggregate needed for the project, geogrids also reduce quarrying activity required to create subgrade, as well as the logistical costs of transporting materials from the quarry site to the project site.

Moreover, DKM geosynthetics stated that soil stabilization using geogrid offers several advantages, including increased soil strength and durability, erosion control, reduced environmental impact, and potentially shorter construction times. It can also improve soil workability, reduce the need for importing materials, and potentially save on construction costs. Ccombining geogrid with chemical materials such as fly ash brings further improves (K.

B. Kumar et al, 2018) and such type of stabilization technic for expansive subgrade soil, provide a multifaceted approach of soil improvement.

Geogrids offer tensile strength and load distribution, while chemical additives like fly ash reduce the soil's plasticity and swelling potential (A.A. Fondjo et al, 2021). This multifaceted approach addresses the soil's expansive characteristics, leading to a more robust and stable subgrade.

2.2. Basics about expansive soil

Expansive soil is well-known clayey soils which has a seasonal cyclic shrink and swell behaviour when the amount of moisture in a given soil changes (Aga S. Y., 2021). When there is moisture in expansive soil, the volume of soil becomes large to cause a swell and at this time, the swell pressure of soil is greater than the downward pressure of lightweight structures like road. Hence, such cyclic movements of soil mass due to moisture variations, cause structures like road, light weight buildings, and pipelines to move excessive and differential settlement and prone to cracks on structures build on such soils. On the other hand: when the soil shrinks, the structure likely to have unequal settlement. The reason for such behaviour is that, expansive soil contains minerals such as smectite clays that are capable of absorbing water molecules and causes significant volume changes (Chen, 1988). Such movement exerts enough force on subgrades and any other structures to cause damages.

Plastic and swelling qualities of potentially swelling clays can be used in the laboratory to identify them (Jorge G. Zornberg et al, 2011). Clays with high plasticity, in general, have a high swelling potential. Expansive soils have a plasticity index more than 30%, a liquid limit greater than 50%, and a strong swelling potential (Chen, 1988). Expansive clays may be identified in the field during the dry season by deep fissures with approximately polygonal patterns (Das, 2014).

2.3. Clay Mineralogy

The swell and shrink potential of any clay soil can be determined based on the amount of clay particles and the type of clay minerals in a given soil (Chen, 1988). The shape of clay mineral is determined through the arrangements of their atoms which form thin clay crystals (Neeraj Kumari et al, 2021). The seasonal shrink and swell potential of expansive soil is mainly determined by its initial moisture content, void ratio, internal structure, vertical stress as well as the type and amount of clay minerals in a soil (Bell and Culshaw, 2001). In clays the most abundant mineral is called silicates and the principal elements in clay are silicone, aluminum and oxygen. The arrangement and chemical composition of silica and alumina sheets determine the type of clay minerals in a given soil (Chen, 1988). In tetrahedron clay mineral structure, silicone atoms are positioned in the center with oxygen atom occupying each of the four corners and due to sharing of electron, the silicone tetrahedron link together with one another to form a thin tetrahedral sheet (see figure 2.1). Conversely, in octahedron clay mineral structure, aluminium atoms are positioned in the center with oxygen atom occupying each of the eight corners and the aluminium octahedrons are link together to form octahedral sheets (see figure 2.1).

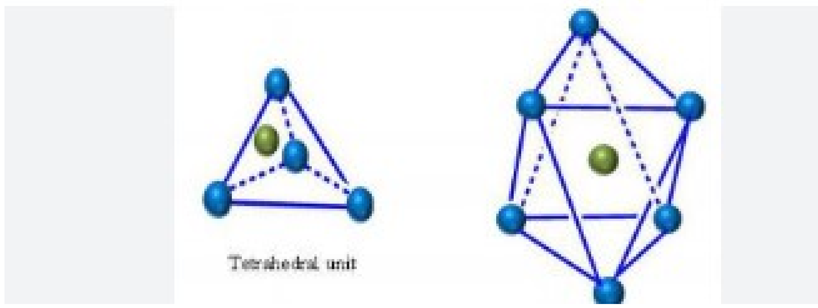

Figure 2.1: Basics of clay mineral (Neeraj Kumari et al, 2021)

From this one can say that, the actual clay crystals are a composite of aluminium and silicone which are held together by intra – molecular forces. Chen (1988), stated that the magnitude of expansion depends up on the kind and amount of clay minerals present, their exchangeable ions, electrolyte content of aqueous phase and the clay mineral structure. Moreover, he revealed that there are three most important clay mineral structural groups which are described for civil engineering purposes: such as, kaolinite, illite and monthmorilonites clay mineral groups.

Kaolinite: - this clay mineral is known as the most stable of the groups of minerals and it is also called non expansive clay soil. In this case, the actual clay crystals are a combination of aluminum and silicone atoms which are held together by intra- molecular forces. Kaolinite crystals consist of tetrahedron and octahedron sheets. The bonding between successive layers is given by van der waals forces and hydrogen (which are comparatively strong) bonds. The bonding is sufficiently strong that there is no inter layer swelling in the presence of water (Mitcher and Soga, 2005).

Illite: - Such clay mineral is classified under expansive but commonly do not possess significant problem on different structures and also has the same structural arrangement with monthmorillonite clay minerals. In illite aluminum octahedron sheet is the basic structure and it is combined between two sheets of silica tetrahedrons. In the octahedral sheet there is partial substitution of aluminum by magnesium and iron, and in the tetrahedral sheet there is also partial substation of silicon by aluminum. The combined sheets are linked together by fairly weak bonding due to potassium ions held between them (Craig, 1997).

Monthmorillonite: - This clay mineral is present in most expansive soil and it is well known that even a small amount of montmorillonite clay mineral has a significant influence on the behavior of soil material. It is also known as highly expansive and problematic clay minerals (Nelson and Miller, 1992) Montmorillonite are formed from weathering of volcanic ash under poor drainage conditions or in marine waters. The basic building sheets for smectite are the same as for illite except there is no potassium ion present. The space between the combined sheets is occupied by water molecules and exchangeable cations. There is a very weak bond between the combined sheets due to these ions. Considerable swelling of montmorillonite can occur due to additional water being absorbed between the combined sheets (Budhu, 2010).

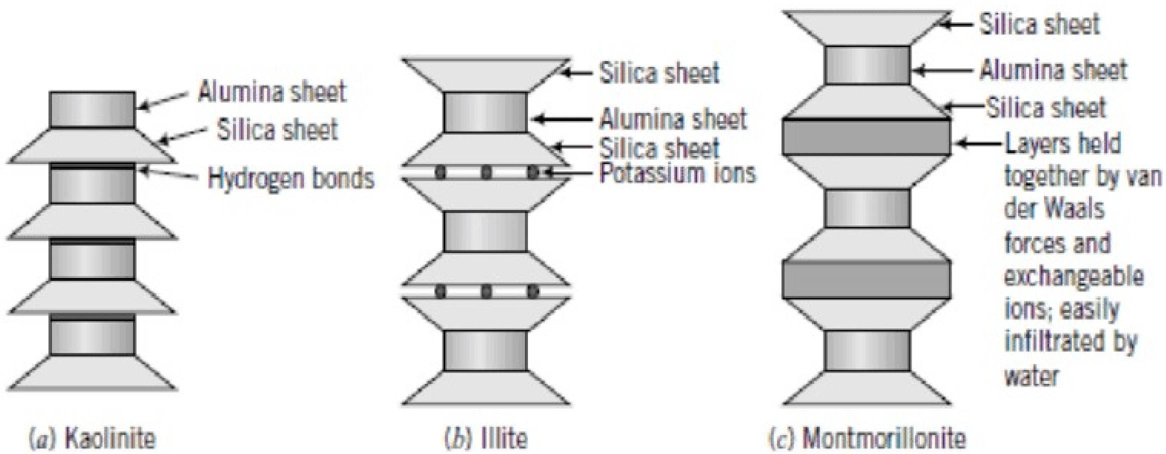

Figure 2. 2: Structure of kaolinite, illite and montmorillonite (Budhu, 2010)

2.4. Problems Associated with Expansive Soil

Expansive soils pose a unique challenge to engineers all around the world due to their distinctive character. The following issues are common in expansive soils:

- A structure constructed during the dry season, when natural water content is minimal, exhibits differential movement as a result of soils during the subsequent wet season (Chen, 1988). Structures on swelling soils rise and crack as a result.
- During the dry seasons, a structure erected near the end of the rainy season, when the natural water content is high, reveals settling and shrinkage fractures. The soil shrinks severely during the dry season, and shrinkage cracks as deep as two or three meters are

widespread. Swelling forces can cause structures to heave or lift, whereas shrinking can produce differential settling (Bamgbopa, et al, 2016).

- When saturated, expansive soils become very plastic and compressible. Footings lying on such soils experience significant consolidation settlements (Bamgbopa, et al, 2016).

2.5. Classification and Identification of expansive soil

Simple soil property tests can be used for evaluation of the swelling potential of expansive soils (Chen, 1988). Such different tests are easy to perform and should be used as routine test during investigation of different construction sites in which the site is suspected with expansive soils. The different test includes:

I. Atterberg limit test

Holtz and Gibbs, (1956) demonstrated that, plasticity index, Ip, and liquid limit, wL, are useful indices for determining the swelling potential of most soils.

Table 2.1: Relation between swelling potential and plasticity index, I_p (Gibbs and Boltz, 1956)

Plasticity Index, I_p (%)	Swelling Potential
0 – 15	Low
10 – 35	Medium
20 – 55	High
35 and above	Very High

II. Free swell index test

According to D. Nebro (2002), free swell index helps to identify the potential of a soil to swell however, it may need further detailed investigation regarding specific soil swelling and swelling pressures under different field conditions. He indicated that the test can be performed by pouring 10gm of dry soil passing a sieve of size 0.425mm (NO.40) in to a 100mm graduated jar filled with water, notifying the swelled volume of the soil after it comes to rest.

III. Colloid content test

This test method is usually used to determine the amount of soil which is smaller than 2µm sieve size; therefore, such test method requires hydrometer analysis (Chen, 1988). Seed et al, (1962) revealed that in given clay type, as the amount of clay increases the swell potential also increases (see Figure 2.2). Chen, (1988) concluded that there is direct relationship between colloid content and swelling potential.

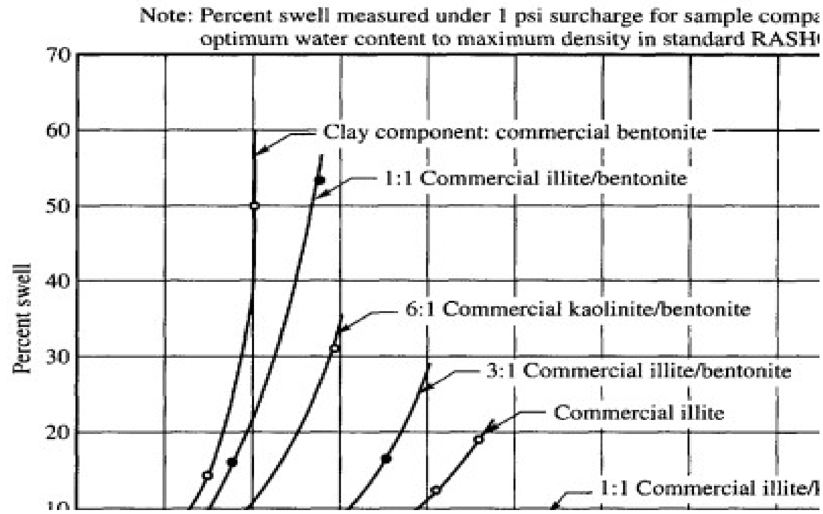

Figure 2.2: Relationship between Percentage Swell and Percentage of Clay Sizes for Experimental Soils (Seed et al., 1962)

IV. Mineralogical Identification

As mentioned in section 2.3, clay soils are mineralogically identified by the presence of clay minerals like montmorillonite, illite, and kaolinite. Mehta B., et al, (2017) stated that the amount of these minerals, particularly montmorillonite, directly correlates with the soil's swelling and shrinking potential (Mehta, B. et al, 2017). The mineralogical composition of expansive soils has a significant impact on clay soil swelling potential (Chen, 1988). The following methods can be used to determine the mineralogical composition of clay soils.

- X-ray diffraction,
- Differential thermal analysis,
- dye absorption
- chemical analysis
- Electron microscope resolution

However, these approaches are time-consuming, need costly test equipment, and the findings must be analyzed by professionally qualified professionals. As a result, these approaches are rarely employed in everyday engineering work.

2.6. Geosynthetic

Choobbasti A. J. et al, (2014) stated that in the dynamic realm of modern construction and engineering, geosynthetics are versatile and innovative solutions, playing a pivotal role in addressing many challenges and revolutionizing traditional practices. Moreover, he revealed that such materials are adaptable and creative solutions that alter conventional techniques and tackle a wide range of issues in the fast-paced world of modern engineering and construction. Geosynthetics were first developed as an answer to the shortcomings of traditional building materials and techniques (Chatrabhuj et al, 2024). Over time, they have advanced to become essential elements of many different types of construction projects (Choobbasti AJ et al, 2014).

Problems including slope instability, poor drainage, and soil erosion led engineers and researchers to look into creative fixes. Chatrabhuj et al, (2024) noted that due to their multifunctional qualities, geosynthetics have provided a paradigm shift in how these problems are addressed. Their use in building methods was marked by a dedication to improving durability, reducing environmental effects, and boosting stability. The relevance of geosynthetics now emphasizes its ongoing importance in meeting changing engineering needs (Carlos DM et al, 2016). Ground improvement with geosynthetics is an important topic of research, particularly in areas with difficult soil conditions. Researchers are looking into novel approaches for stabilizing unstable soils, reducing settlement (Lu L, Ma S et al, 2021) and improving the overall engineering qualities of the ground.

2.6.1. Why geosynthetic as an alternatives

Geosynthetics can help with environmental sustainability in a variety of ways, and their environmental impact is an important factor in modern engineering methods. Here are some characteristics of geosynthetics' environmental and sustainability impacts:

- **Soil stabilization and erosion control**: Geosynthetics help to stabilize soil and control erosion, which prevents soil degradation and loss. This is especially crucial in construction and infrastructure projects that aim to preserve natural habitats and ecosystems (Jamshidi Chenari R et al, 2023).
- **Waste reduction:** Geosynthetics often enable the use of locally available soils and materials, reducing the need for transporting and excavating large quantities of natural resources. This can lead to less environmental disruption and a reduction in waste generation (Huang J, Le V et al, 2015).
- **Recycling and reusability:** Some geosynthetics are made from recyclable or reusable materials, which reduces the overall environmental impact. Recyclability enables the recovery of valuable resources while reducing the requirement for new raw materials (Chatrabhuj et al, 2024).

- **Energy savings:** In some applications, such as road construction, using geosynthetics can result in energy savings by lowering the thickness of construction layers. This can lead to a decreased environmental footprint from energy usage in material manufacturing and transportation (Chatrabhuj et al, 2024).

2.6.2. Some properties of geosynthetic material

The material properties of geosynthetics play a crucial role in determining their performance and suitability for various applications in civil engineering and construction (Chatrabhuj et al, 2024). Here are some key material properties of geosynthetics:

- **Physical properties:** It means the composition of materials that are used to make geosynthetic material like specific gravity, type of structure, thickness, flexibility, mass per unit area and stiffness. Specific gravity is based on polymeric material which is used to originate geosynthetic, its range varies from 0.91–1.14. Thickness is the extent of layers of geosynthetic material generally it is between 0.25 to 7.5mm. Flexibility means the ability to bend under its weight. Mass per unit area expresses the mass of a material per unit area (Aga S.Y., 2021).
- **Mechanical properties***:* To use geosynthetics in soil extensively it should have some mechanical properties which imply geosynthetic material should bear some load without deformation or failure. For a good material, compressibility of geosynthetic material should be as low as possible. The tensile strength of geosynthetics is the resistance to deformation when tension is applied to it (Chatrabhuj et al, 2024.
- **Durability properties**: Durability properties of geosynthetics safeguard the long-term benefits of the material it includes, Chemical resistance—Resistance to deterioration or degradation when exposed to various chemicals present in the soil or environment (Chatrabhuj et al, 2024).
- **Stability:** The ability to withstand prolonged exposure to ultraviolet (UV) radiation without significant degradation (Chatrabhuj et al, 2024).

Some of the summarized basic properties of geosynthetic materials used for various construction activities are provided in Table 2.2.

Table 2.2: Summarized properties of geosnthetic material

No	properties	Its characteristics
1	Physical	Composition, specific gravity, arrangemet etc
2	Mechanical	High in tensile strength and low in eloangation
3	Durability	Has long term performance, it can serve for 90 years
4	Stability	Its ability to withstand load applied and UV resistant

2.6.3. Types of geosynthetic material

Geosynthetics encompass a diverse array of materials designed to address various engineering and construction challenges. Each type of geosynthetic material serves specific functions and applications (Jarrett, S et al, 2013) and the following shows some of them:

- **Geotextile**

Geotextiles, as known and used today were first used in connection with erosion control applications and were intended to be an alternative to granular soil filters (Alexander, 1997). They are the core of geosynthetic material, with properties like a strong, porous, thin, flexible, planner or sheet-like structures made from fibers. Fibers are made up of polyester, polyamide, polypropylene etc. which results in very strong as well as thin fibers. They are either weaved by machines known as woven geotextile or joined together by making mechanical, thermal or chemical bonds between fibers are known as non-woven geotextile (Tanass F et al, 2022).

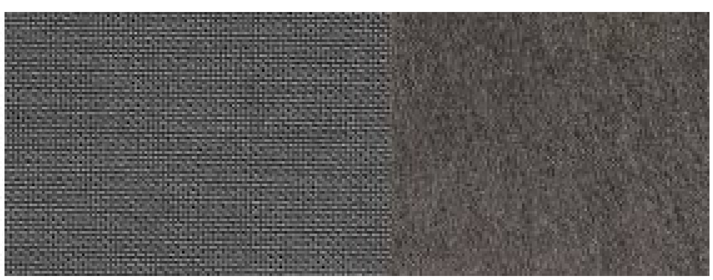

Figure 2.3: woven and non-woven geotextile (Aga S.Y., 2021)

- **Geogrid**

According to geosynthetic material association (2002), geogrid is a material that is in a net or grid-like structure. There is a wide opening in them known as aperture (Aga S. Y., 2021). They can be made by processes like extrusion and weaving using polyester, polyvinyl, and polyethene as base materials for manufacturing. These materials are designed to be very strong in tension so that it can easily distribute and transfer the load into large areas over the soil surface. Therefore, until now it is used in subgrade or sub-bases on pavements for its reinforcement properties (Šiukščius A. et al (2016). Other than road pavements it is used in dams and retaining structures also.

The resulting geogrid structure possess open spaces (called apertures) ranging from 1 to 10 centimeter, which enhance interaction with the soil or aggregate they are embedded within (Šiukščius A. et al (2016). Aga S. Y. (2021) noted that their high tensile strength and minimal elongation make them appropriate for soil reinforcement. Moreover, he stated that the use of geogrid in roadways construction in order to reinforce the base of the structure over expansive soft subgrade soil nowadays becomes an alternative advantage than removing problematic soils and replacing by other material. In any case, the traditional undercut and stabilization solution is often costly and time - consuming process; therefore, geogrids are often used as replacement for these traditional solutions. Geogrid help to increase the bearing capacity of expansive subgrade soil (Aga S. Y., 2021).

S. K. Shukla, (2002) developed a more efficient means of utilizing the basic polymer raw materials to yield a product with greater strength and elastic modulus in the form of polymer grids to be used in much soil reinforcement application. Due to its high tensile strength, minimal elongation, and long durability, geosynthetic were excellent economic alternatives than the conventional solution for different civil engineering problems (Aga S. Y., 2021).

Figure 2.4: Geogrid inclusion while subgrade preparation (Archibong GA et al, 2020**)**

- **Geomembrane**

Geomembranes are classified from water barrier membranes, which are synthetic sheets that provide an impermeable thin and strong layer (Hassan W et al, 2023). They are used as a solution for liquid flow related issue in case of for instance dames and coffer dames since, using them as a liner in landfills, and liquid storage facility, helps to control soil expansion by reducing soil exposure to water (Hassan W et al, 2023).

Figure 2.5: Geomembrane (Chatrabhuj et al, 2024)

- **Geofoam**

Tafreshi S.N.M., et al (2020) stated that geofoam is a lightweight fill material composed of expanded polystyrene (EPS) or extruded polystyrene (XPS) foam blocks used in road embankments, slope stabilization, and lightweight fill applications, has various advantages over typical fill materials such as dirt or gravel as shown in Figure 2.6. These blocks, made by expanding and moulding polystyrene beads, have low-density and excellent compressive strength, making them perfect for lowering earth pressures, minimizing settlement, and providing thermal insulation (Tafreshi SNM et al, 2020).

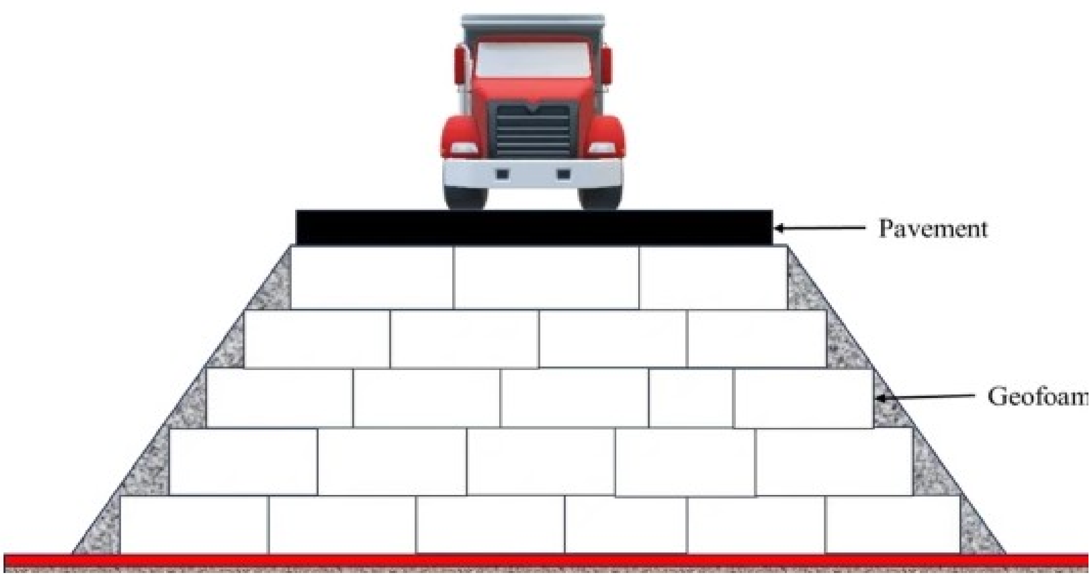

Figure 2.6: Geofaom in road construction (Chatrabhuj et al, 2024)

2.7. Fly ash

As one of the solution, chemical stabilization is the method of choice to achieve a stabilized soil using traditional or non-traditional agents, which helps to reduce the plasticity index, increase the size of soil particles, and mitigate their tendency to swell and shrink and enhance their cementation properties (Little D, 1999). Fly ash constitutes one of the most abundant and complicated industrial by-products. The burning of sub-bituminous coal generates a fly ash that exhibits self-generated cementitious properties, which have been utilized in geotechnical engineering applications to enhance the mechanical attributes of the soil (Pei et al, 2023). Fly ash is categorized into two distinct classes, namely F and C, predicated upon the chemical composition of the fly ash in accordance with ASTM 618. Class F fly ash is generated from the combustion of anthracite and bituminous coals and is characterized by minimal or absent cementitious properties. Conversely, Class C fly ash is typically derived from lignite and sub-bituminous coals, and is generally recognized for containing a substantial amount of lime (Nayak, D. K. et al (2022). According to ASTM C618, three-fourths of the ash must have a fineness of 45 µm or less, and have carbon content, called the loss on ignition (LOI), of less than 4% (Nizar K. at al, 2007).

2.7.1. Chemical properties of Fly ash

According to Nizar K. at al (2007) the amount of fly ash generated by cement factory plant in Ethiopia is increasing year by year. The combustion of coal at high temperatures and pressures in power stations produces different types of ash. The 'fine' ash fraction is carried upwards with the flue gases and captured before reaching the atmosphere by highly efficient electro static precipitators. This material is known as fly ash. It is composed mainly of extremely fine, glassy spheres and looks similar to cement (Nizar K. at al, 2007).

In addition to this, fly ash contains many chemical elements and minerals, such as aluminium, silicon, iron oxides, and unoxidised carbon. The characteristics of FA depend on charcoal types and methods used in the production of FA in the power plant station (Hassan et al., 2019). The characteristic of fly ash depends on charcoal types and methods used in the production of fly ash in the power plant station (Hassan et al., 2019). There is a study by Nizar K., et al. (2007) that provides a typical chemical composition of fly ash material collected from Stesen Janakuase Electrik plant, and the results are given in Table 2.3.

Table 2.3: Chemical composition of the pulverised fly ash used (Nizar K. at al, 2007)

Compound Content	Weightage (%)
SiO_2	59.00
Al_2O_3	21.00
Fe_2O_3	3.70
CaO	6.90
MgO	1.40
SO_3	1.00
K_2O	0.9

2.7.2. Physical Properties of Fly Ash

Fly ash has many physical properties, including its size, shape, density, and chemical composition. Some of the physical properties of fly ash performed as per Nizar K. at al, (2007) were as shown below:

Size and shape:

- Fly ash particles are typically spherical and range in size from 10 to 100 microns
- Fly ash is usually finer than cement and lime
- Fly ash particles are porous and have a honeycomb structure

Density:

- The density of fly ash is about two-thirds that of Portland cement and it is light weight.
- The density of fly ash varies depending on the particle shape, gradation, and chemical composition

Color:

- The color of fly ash indicates its carbon content and particle size
- High-calcium fly ash is usually reddish, while low-calcium fly ash is usually gray

Pozzolanic properties:

- Fly ash is pozzolanic, meaning it hardens and reacts in the presence of water
- When mixed with lime, fly ash forms cementitious compounds

2.8. Use of fly ash as a soil stabilizer

Land filling continued to be the typically adopted mode of storage to accommodate the increased production of fly ash. There are several efforts by cement industries to find practical applications of fly ash due to high cost associated with the disposal and the strict environmental regulations for management (Egbe E., 2012). According to available information, the earliest documented studies on using fly ash for soil stabilization likely date back to the mid-20th century. Researcher exploring fly ash potential to improve the strength and stability of expansive clay soils by adding fly ash also demonstrated its ability to reduce plasticity and swelling characteristics (Salim 2021, Sambre T et al, 2024).

Sambre T. et al (2024) investigated the stabilization of expansive subgrade soils using a lime-fly ash mixture. Their study utilized different proportions of lime-fly ash mixtures to assess improvements in the stabilized soils' UCS and CBR. They found out that a robust framework for engineers to improve the stability and longevity of pavements on expansive soils.

Therefore, different researches (H. Karim (2021), Nalbantoglu Z. (2004), Prabaka J. et al (2004), Noaman M.F. (2022)) which were carried out before reveal that the potential of fly ash material as soil improvement specifically expansive subgrade soil is very significant and fly ash is an alternative solution for soil improvement. Hence, from different scholar's point of view, fly ash and also geogrid materials are considered to be best stabilizing materials for such types of problematic soil.

2.9. Review of Previously Conducted Study

While many approaches have been explored, practitioners dealing with the challenges of expansive soil often find soil substitution and stabilization the preferred options. These methods have proven effective in mitigating the risks associated with expansive soil (Barman D. et al, 2022). However, it is noteworthy that replacing problematic soil with higher-quality borrowed soil can significantly increase construction costs (Aga S.Y., 2021). Therefore, the avenue of modifying soil through stabilization techniques has progressively attracted the attention of engineers over time (Ikeagwuani C. C., et al, 2019). Chemical stabilization is often used to enhance the properties of clay soils by changing their physicochemical characteristics

(S.S. Zuber et al, 2013). This process creates a strong binding network within the soil structure, resulting in improved durability, strength, and overall quality compared to unstabilized soil (S.S. Zuber et al, 2013). In considered the most suitable method for the chemical stabilization of expansive soils, fly ash has been shown to modify soil behavior by reducing plasticity index, swelling, and compressibility properties while enhancing compressive and shear strengths (Noaman M.F., 2022). Fly ash is a material that can be used to stabilize soil by improving its strength and reducing its volume change.

The application of fly ash (FA) and lime individually in stabilizing weak soils has been studied extensively; Hassan et al (2020) investigated the combined application of lime-fly ash as expansive soil stabilizer since, the disposal and recycling of fly ash products become a big concern for environment and also consumes enormous budgets.

Researchers have conducted extensive studies to find a solution to this problem. Some of these researches focused on improving the soil capacity utilising fly ash, which is produced as waste in thermal power or cement manufacturing stations (Ozdemir, 2016; Ram and Masto, 2014). Several studies and experiments were conducted to understand the behaviour of FA mixed with soil; the following sections thoroughly discuss the same:

Salim, (2021) investigated the impact of the fly ash content on the free swell index, swell potential and swelling pressure, of expansive soil. The influence of these admixtures was compared with those of natural soils. The findings show that the swelling and swelling pressure decrease with increases in the fly ash percentage. The optimum percentage of fly ash was 5 %, where the swell and swell pressure decreased by a large ratio.

Phanikumar and Sharma (2007) investigated the impact of FA on the volumetric change for two types of clay soils, expansive and non-expansive soil. Various FA ratios have been used, such as (0, 5, 10, 15, and 20) per cent by dry soil weight. The findings showed that the increment of FA content could reduce an OMC and increase the maximum dry density.

Prabakaret al. (2004) carried out an experimental work of three types of soil mixed with fly ash to improve soil stabilisation. The shear strength of soil mixed with fly ash increased with the increase of the fly ash content, and then improve the cohesiveness and internal friction angle.

Kumar and Harika (2021) studied the influence of fly ash on stabilization of expansive subgrade black cotton soil. CBR value for untreated soil was about 1.89%, while treated soil with fly ash

CBR value was 2.33% (10% fly ash). The study Proposes mixing up to 10 percent fly ash with black cotton soil for foundation and pavement work.

Trivedi et al (2013) studied the effect of different fly ash percentages with the soil sample. The results exhibit that the addition of FA in the small of fractions affects the soil considerably. With the addition of 20 % FA, CBR value increased from 5.64 % to 20.53 %. It can be observed that soil containing 20 % FA gave the best findings of soil stability compared to other percentages.

As per Aga S. Y. (2021) the geogrids used within a pavement system perform two primary functions; namely, separation and reinforcement**.** Application of geogrid in roadway construction to reinforce the base of the structure over expansive soft subgrade soil nowadays become an alternative advantage than removing and replacing problematic soil (Shahkolahi A. et al, 2014). Different studies have indicated the potential of geogrid as weak subgrade and pavement section improvement material

Naeini et al. (2009) found out that the use of geogrid reinforcement on three soft clay samples of various plasticity leads to a significant increase in soaked and unsoaked CBR values.

Calvarano et al (2017**)** applied numerical analysis methods to show the improvement of geogrid reinforced on weak subgrade material. Currently, geogrid stabilization of weak subgrade soil gains for providing effective and economical solution for road rehabilitation and construction projects over weak pavement subgrades (Shahkolahi A. et al, 2014).

A.K. Choudhary et.al (2011) placed multiple layers of reinforcement namely geo-grid and jute geo-textile within the sub-grade. They found that the expansion ratio decreases when the soil is reinforced with single layer and goes on decreasing with an increase in number of reinforcing layer, but this decrease is significant in case of jute Geo-textile and marginal in the case of Geo-grid which means the insertion of reinforcement controls swelling of the soil. Moreover they noted that the California Bearing Ratio value of the soil also increases with increase in number of reinforcing layers. In the end they concluded that geo-grid offer better reinforcing efficiency than jute geo-textile but it can be gainfully exploited in low cost road project.

The literature review clearly demonstrates that fly ash and geogrid reinforcement can enhance strength in expansive soil, even though the combined effect of these materials has not been studied in detail. Consequently, fly ash and geogrid are regarded as the best materials for stabilizing soils of this type from various scholars' perspectives (Nalbantoglu Z. (2004), Prabaka J. et al (2004), R. Rithani et al (2023), Aga S.Y. (2021).

A review of recent investigations on the effect of applying fly ash and geogrid material to expansive soil was presented. A summary table that offers a concise overview of recent research efforts is also presented in Table 2.1. The table summarizes how researchers conducted their investigation, identifying which weak soil was improved, detailing the proportion of fly ash and the proper geogrid location on the CBR mould, explaining how the stabilization process was executed, and presenting the main findings drawn from their studies.

Table 2.4: Review of previous works

Reference	**Soil Type**	**Lab/Numerical**	**Proportion and methods of stabilizer application**	**Main Conclusion**
Hadi karim et al. (2021)	Expansive soil (soft subgrades)	Both	Fly Ash with additional secondary additives	The result revealed substantial benefits of pavement thickness reduction when fly ash stabilized weak soils are treated using secondary additives.
Nalbantoglu Z. (2004)	Expansive soil	laboratory	15 to 25% of fly ash application on the soil	Laboratory test results on these soils indicate that fly ash is effective in ameliorating the texture and plasticity of the fly ash treated soils by reducing the amount of clay size particles.
Prabakar J. et al (2004)	Three different soil samples	laboratory	(9 – 46)% by weight fly ash application	Fly ash is effectively used to stabilize the given soils.
Noaman, M.	Clayey soil	Both	Various amount of fly	Fly ash improved the

F., et al (2022)			ash application	CBR value and the permeability of the soil. Volumetric soil changes become significantly reduced.
R. Rithani et al(2023)	Medium compressible clay	Laboratory	0% to 30% perlite and single layer of geogrid reinforcement(at H/2, 2H/3 and H/4)	The result indicated that a significant increase in CBR values for subgrade soil stabilized with perlite and reinforced with geogrid. The maximum CBR value was observed in the soil sample reinforced with a single geogrid layer placed at H/4.
Aga, S.Y. (2021)	Expansive subgrade soil	experimental	Klinker dust and geogrid placed at 35mm from top of CBR plunger	The test results indicated that the use of the geogrid reinforcement can significantly improve the bearing capacity of weak subgrade soil.
Badal B., et al (2021)	Black cotton soil	Experimental	0% to 8% Cement and geogrid reinforcing material	The result showed that CBR strength increases from 7.15% to 17.59%. Hence it is concluded that geogrid reinforced soils present better performance than traditional soil.

According to the literature review above, recent studies on application of fly ash and geogrid reinforcement on the given soil have yielded interesting results. The literature obviously demonstrated that the potential of adding fly ash and geogrid reinforcement to expansive soil plays a significant role for strength improvements, even if the combined effect of these materials on treating expansive soil has not yet been investigated. Hence, from different scholar's point of view, fly ash and geogrid materials are considered as best stabilizing materials for stabilizing such types of problematic soil.

CHAPTER THREE

3. RESEARCH METHOD AND MATERIALS

3.1. Introduction

The purpose of this section is to create a detail experimental program to simulate the effect of introducing geogrid and fly ash on selected expansive subgrade soil. After collecting those representative soil sample then index as well as engineering properties before and following the inclusion of stabilizers were carried out. Moreover, some property of the provided material such as expansive soil, geogrid and fly ash is presented. Furthermore, this section describes the study area and the process undertaken to attain the general and specific objectives of the study. To accomplish, several steps were followed. First, a detailed literature review was conducted to gain a deep understanding of the effect of geogrid and fly ash application on index and engineering property enhancement of the given soil.

Relevant parameters of fly ash and geogrid, methods, and the effect of these parameters on the bearing capacity improvement of the expansive subgrade soil were investigated in detail. Next, representative data were extracted from various laboratory tests. Taking into account the depth and number of boreholes and the extent of the area covered, the research area where weak expansive soil could be found was determined based on the collected data. On the basis of the laboratory test results and discussions were made. In the end, conclusions and recommendations were drawn. In Figure 3.2, the methodology flow chart of this research is shown more clearly.

3.2. Description of study area

Koye Fache Subcity is formely located in the oromia special zone surrounding Addis Ababa. Nowadays it is categorize under a newly established Shegger city sub-city, located to the south east of Addis Ababa, Ethiopia. As per the plan the city is serving as an area of growing urban development. The primary economic activity in the Koye Feche area of Ethiopia is construction, primarily due to the large-scale condominium housing development project that has transformed the previously agricultural land into a major residential area of Addis Ababa, is creating employment opportunities in various construction trades. Alongside formal construction, informal economic activities like small-scale trading, food vending, and repair services are likely to emerge to cater to the growing population in the area.

The topography of the area is characterized by gentle and relatively flat topography. The slope of the site is generally inclined downward from North-East to South-West. The entire site has a slope between 0 to 8 percent. This indicates that large part of the area is more or less flat. The following map (see figure 3) indicates the topographical characteristics and landscape of Koye-Feche area. The project site is drained by seasonal streams flowing from north east to south west direction. Some of the streams are small, intermittent and shallow while there is one relatively big river bordering the site to the western direction with deep gorge. The study area experiences a subtropical highlands and the typical climate is as similar with that of central Ethiopia that shows cyclic fluctuation of wet and dry seasons. Pattern and the seasonal variation of the rainfall significantly affects the moisture holding and permeability properties of the existing soil which result the development of soil erosion in the downstream side. The geology of koye fache sub-city may consist of volcanic soil, alluvial deposits, expansive soil up to consider depth for road construction and distribution of other soil commonly found in the Ethiopian highlands.

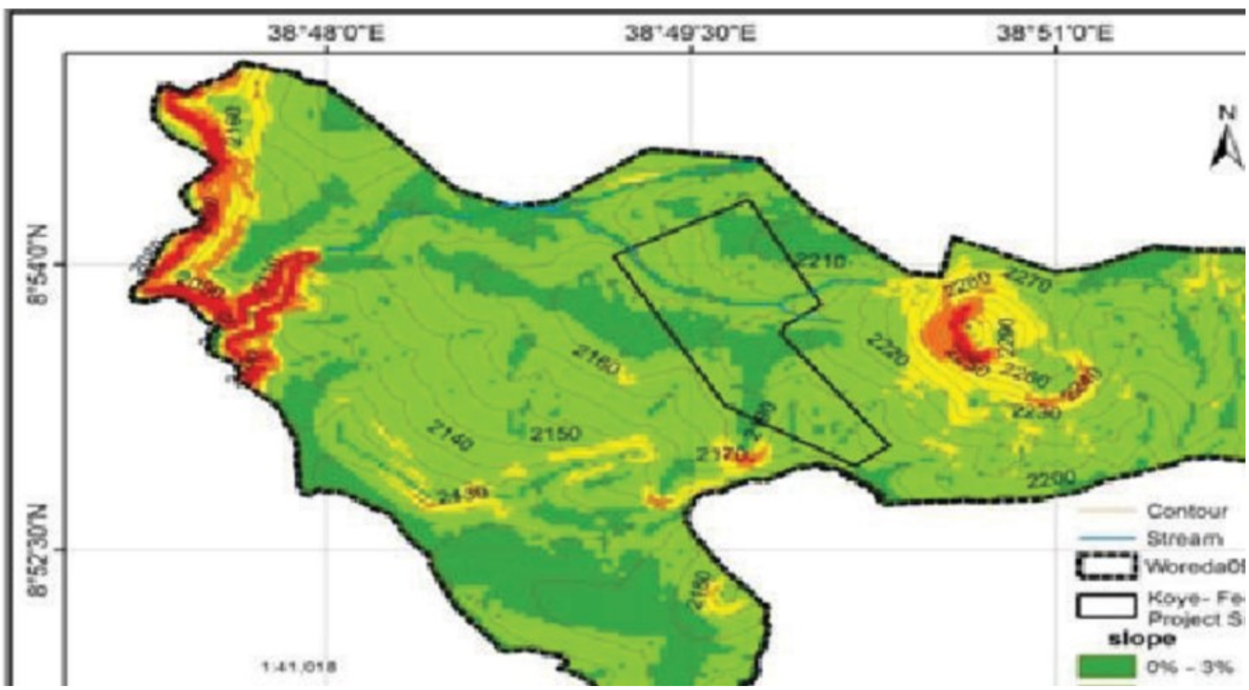

Figure 3.1: Location map of Koye Feche Study Area

3.3. Soil sample and material collection

3.3.1. Collection of expansive soil sample

Expansive soil was collected from a place called koye feche because; in such place the distribution of expansive soil is predominant. Disturbed soil samples were taken from open pits at 1.5 meter depth by digging using hand tools. Mostly depth of excavation from 1.5 up to 3m is commonly known as the depth in which different shallow foundation structures are being constructed and for road construction it is desirable to locate the pavement subgrade with in such depth (Foundation Design and construction, 2006).

3.3.2. Fly ash

According to Petry and Little (2002), stabilizers can be divided into three categories: traditional stabilizers (Portland cement, hydrated lime, and fly ash); by-product stabilizers (cement kiln dust, lime kiln dust, and other types of by-product); and non-traditional stabilizers such as potassium compounds, sulfonated oils, enzymes, ammonium chloride, and polymer. Since fly ash is a by- product of coal combustion, it is readily available at power plants, and has only transportation costs. Using fly ash in soil stabilization also promotes the reuse of a waste product that might otherwise be disposed of in landfills. This contributes to environmental sustainability and reduces the need for raw materials.

In this study, class C fly ash with high calcium content (pozzolanic) was collected from the Habesha cement factory plant in Ethiopia to be used. As can be seen from Figure 3.2 below, the fly ash material collected is typically dark brown in color, which means that the amount of calcium in the sample has been increased in proportion. High-calcium fly ash, also known as Class C fly ash, is typically brownish in color. This kind is often attributed to its high lime (calcium oxide) content. It differs from low-calcium (Class F) fly ash, which is generally grey (Phattarathicha Tepsri et al, 2018).

Figure 3.2: Fly ash collected for the purpose of soil stabilization

3.3.3. Geogrid

In this section the reinforcement details of geogrid inclusion is described and for this research High density polyethylene (HDPE) type of georgrid were used due to its high tensile strength.

3.4. Geogrid reinforced CBR testing methods before and following the application of flay ash

In this study, the California bearing ratio (CBR) value has been taken as the control parameter since it is the standard parameter for indicating the strength of subgrade materials in pavement construction. In order to perform a one point CBR soaked test on the same soil before and after the addition of fly ash and the addition of geogrid, the amount of dry soil and water required was determined based on the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil. The dry soil was mixed thoroughly at the OMC value by adding the desired amount of water to it, in order to achieve an even mixture. After the soil had been prepared, a range of fly ash amounts ranging from 5% to 20% by weight was added to it. As part of the study to be conducted on the combined effect of fly ash and geogrid reinforcement, a layer of the geogrid reinforcement was prepared from high-density polyethylene (HDPE) raw material with a circular shape that was slightly larger than the internal diameter of the CBR mold to be used for anchoring the geogrids on the CBR mold. The prepared geogrid is placed in two separate layers below the top of the standard CBR mold in between soil layers that have been carefully compacted to achieve the density that is required for the CBR to function properly. For 17.5% of the fly ash applications, the same procedures were followed. Figure 3.3 is a picture of the first layer of geogrid anchoring and reinforcement on the CBR mould (inserted at 30mm from the top of the CBR mould) on a soil sample prepared with 17.5% fly ash concentration.

Figure 3.3: Reinforcement and and anchoring of the first layer geogrid inclusion on CBR Mould

3.5. Laboratory works

Representative sampling, proper test procedures and adequate test equipment are the most important requirements for good quality laboratory testing. Expansive subgrade soil and fly ash is mixed in different proportions and a series of different laboratory tests were carried out on samples containing various percentages of fly ash and also by placing geogrid material in a CBR mould at the specified depth. After collection of the soil sample which was representative soil sample for the given specific site, the following laboratory tests were conducted; on the untreated as well as treated soil with fly ash material:

- ❖ Uncured Atterberg limit tests in accordance with ASTM D4318. It is the boundaries of several states of consistency for plastic soils. Atterberg limit tests identify and classify soil and assess their shear strength. They measure the moisture content at which fine-grained soils change from solid to liquid. It is used to classify soils and determine their behavior under different conditions. During a liquid limit test, a sample of soil is measured at the point at which it transitions from a plastic state to a liquid state. The soil sample is grooved using a standard cup and spatula. Afterwards, the cup is dropped until the groove in the bottom closes. The plastic limit test measures the point at which a soil sample transitions from a semi-solid state to a plastic state based on the amount of moisture it contains. This test is part of a much more comprehensive test called the Atterberg limits test, which measures a soil's liquid limit as well.

- ❖ Immediate maximum dry density and optimum moisture content in accordance with BS: 1377 part 4 (1990) standard test methods for laboratory compaction characteristics of soil using standard load. A soil's maximum dry density is the highest density that it can attain when it is completely dry, and it is typically determined through a compaction test, in which the soil is progressively compacted at different moisture contents, resulting in a curve with a peak that represents its maximum dry density. A soil's compacted strength and stability are assessed using this parameter. When soil reaches its maximum dry density, it is the most compact and stable state, by which the optimum moisture content of soil is determined. The moisture content of soil varies according to its type, but typically falls between 15-35% by weight. This test method is used to obtain the relationship between maximum dry density and soil moisture content.
- ❖ Determination of soaked California bearing ratio in accordance with ASTM D1883 standard test methods.
- ❖ Particle size analyses of soil both sieve and hydrometer analysis as per ASTM standards of D422. Wet sieve analysis is a method for determining the size distribution of particles in a material. It involves mixing a sample with a liquid, pouring it through a stack of sieves, and then drying and weighing the remaining material on each sieve. Hydrometer analysis is a technique used to determine the size of soil particles. It is based on Stokes' law, which states that the rate at which grains settle out of suspension depends on the size, shape, and weight of the grain.
- ❖ Uncured free swell index test according to IS 2720. The free swell index (FSI) of soil is the percentage increase in volume when the soil is submerged in water.
- ❖ Specific gravity of soil conducted as per ASTM D854 standards. The specific gravity is the ratio of the mass of a unit volume of soil solids to an equal volume of water at a specific temperature, which indicates how heavy the soil particles are compared to water.

It is typically used to determine other soil properties like porosity and density. The specific gravity of good soils is generally between 2.6 and 2.8.

- Immediate 24 hours soaked unconfined Compressive strength (UCS) test is conducted as per ASTM standards of D2166. It is the maximum axial compressive stress a soil specimen that can withstand when there is no confining stress. It's a standard geotechnical test that measures the strength of cohesive soils. Various scholarly literature reviews that after it has been treated with a stabilizing agent like cement or lime, significantly increasing its strength compared to the untreated soil. Unconfined compressive strength tests were carried out immediately depending on the test standards.

3.6. Laboratory data analysis and result

Following different laboratory tests, the results obtained for the provided expansive subgrade soil were examined, elaborated, and briefly analysed. In this study fly ash concentration ranging from 0% to 20% by weight was used to stabilize expansive subgrade soil found from Keye Feche area. Moreover, geogrid inclusion at the specified CBR mould layers with and without 17.% fly ash concentration was also carried out to investigate the combined effect of such material on the given expansive subgrade soil.

3.7. Laboratory equipment needed to perform the test

In order to accomplish the objectives of this thesis, different laboratory equipment was used such as:

- CBR and UCS test equipment with their accessories
- Specific gravity, Free swell index testing equipment
- Hydrometer, sieve, CBR and Proctor testing mold with their accessories, 100ml and 1000ml cylinder, mold for UCS, Casagrande apparatus, thermometer, and computer for analyzing the result using Microsoft excel.

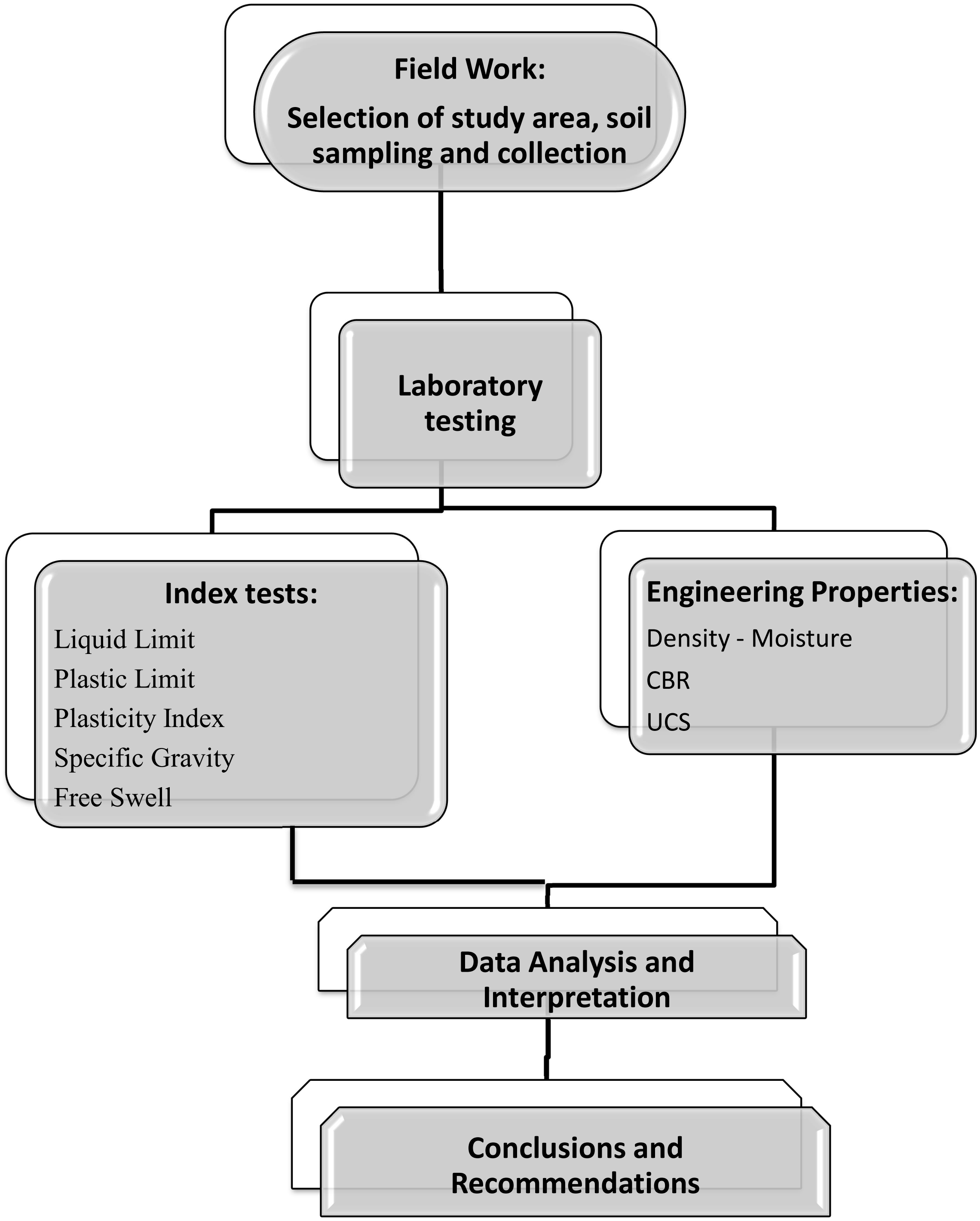

Figure 3.4: Research Methodology Flow Chart

CHAPTER FOUR

4. LABORATORY INVESTIGATION TEST RESULTS

Soil samples were obtained from specified koye feche study area and the following different laboratory tests were obtained. Test results on basic geotechnical properties of the soil before and after fly ash treatment, as well as engineering properties such as UCS, and CBR (along with geogrid reinforcement) were obtained.

4.1. Wet sieve and Hydrometer Test

This study employed wet sieving method to determine the distribution of particle size larger than 0.075mm in the soil sample after air drying the soil sample and hydrometer test is performed to determine the distribution of particle size smaller than 0.075mm. Table 4.1 below shows both sieving and hydrometer particle size distribution and also detailed a hydrometer laboratory test can be found in the appendices-1. Table 4.1 shows that the soil sample from Koye Keche is grayish in color and highly plastic clayey soil.

Table 4.1: Combine wet sieve and Hydrometer particle size distribution

Sieve No	Diameter (mm)	Mass of sieve(gm)	Mass of soil and sieve(gm)	Soil Retained(gm)	Soil Retained (%)	Soil Passing (%)
4	4.75	599	610.4	11.4	1.14	98.86
8	2.36	524	528.15	4.15	0.415	98.445
10	2	560	563.35	3.35	0.335	98.11
16	1.18	495	497.98	2.98	0.298	97.812
30	0.6	415	424.54	9.54	0.954	96.858
40	0.425	425	431.05	6.05	0.605	96.253
50	0.3	410	416.01	6.01	0.601	95.652
100	0.15	400	428.61	28.61	2.861	92.791
200	0.075	376	416.41	40.41	4.041	88.75
	0.03046					57.1896
	0.02017					51.9106
	0.01619					49.0071
	0.01199					46.1036
	0.00862					42.5843
	0.00615					39.9447
	0.00132					33.7859

Pan				887.5	88.75	-
				1000	100	-

4.2. Atterberg Test

Table 4.2 shows the liquid and plastic limit values and how to determine along with their respective plasticity indexes. From Table 4.2 the liquid limit of the soil sample indicated the high expansive nature of the soil. The plastic limits also showed selected soil were classified as highly plastic. The plasticity index tends to reduce while treated by using fly ash.

The appendices of the report contain a detailed description of the laboratory test that was conducted is found in appendix-2.

Table 4.2: Summary of laboratory test results for Attergerg limit

No	ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	**Expansive soil**	77.5	23.56	53.95
2	**5 % Fly Ash application**	73.4	25.06	48.34
3	**10 % Fly Ash application**	63.5	27.53	39.48
4	**15 % Fly Ash application**	59	28.65	30.35
5	**17.5 % Fly Ash application**	54	29.18	24.82
6	**20% Fly ash Application**	49	29.87	19.13

4.3. Specific Gravity

Following ASTM D854 – 00 standards, an experiment is carried out by placing 15g of dry sample in a pycnometer. Then the soil sample was tested with a fly ash application of 0, 5, 10, 15, 17.5, and 20 percents and found out that because of light weight nature of fly ash, the specific gravity of the stabilized soil become reduced. Table 4.3 summarizes the results of the output and the appendices (Appendix-3) provide details of laboratory tests for specific gravity.

Table4.3: Summary of test result for free swell index and specific gravity respectively

No	Sample composition	Specific Gravity	Free Swell Index (%)
1	Pure expansive soil	2.48	138
2	5% Fly ash application	2.46	120
3	10% Fly ash application	2.43	107
4	15% Fly application	2.4	83

5	17.5% Fly ash application	2.38	69
6	20% Fly ash application	2.35	48

4.4. Free swell Index

Following test method as per the IS: 2720(part 40) 1977 standard, free swell tests were carried out by applying 0%, 5%, 10%, 15%, 17.5%, and 20% of fly ash to 10 gm of the total sample. The result presented in Table 4.3 indicated that the sample soil is highly expansive soil. Appendix-4, provide details of laboratory test result for free swell index values.

4.5. Moisture Vs Density relationship

In this study compaction tests were conducted with the addition of 0%, 5%, 10%, 15%, 17.5%, and 20% fly ash application. The finding indicates that the required maximum dry density (MDD) can be achieved using 17.5% application of fly ash concentration. Their respective optimum moisture content (OMC) and MDD results are shown in the Table 4.4 below and the details of the laboratory test results are attached in the appendices-5.

Table 4.4: Summarized MDD Versus OMC laboratory test result before and following treatment

No	Sample Composition	Maximum Dry Density (gm/cm^3)	Optimum Moisture Content (%)
1	Pure expansive soil	1.268	34
2	5% Fly ash application	1.28	31.5
3	10% Fly ash application	1.327	29
4	15% Fly application	1.41	26.7
5	17.5% Fly ash application	1.48	27
6	20% Fly ash application	1.45	30.5

4.6. Unconfined Compressive Strength Test Result

Remoulded samples were prepared for natural soil and after treating with fly ash application ranging 0%, 5%, 10%, 15%, 17.5%, and 20% by weight. As seen from table 4.5 the finding indicated that due to the application of fly ash, the strength property of the soil becomes considerably improved. The summarized laboratory test results are reported in Table 4.5 below and the detail laboratory values are attached in the Appendix-7.

Table 4.5: Unconfined compressive strength test result before and after treating with fly ash

No	Sample Composition	Unconfined Compressive Strength (UCS) (kN/m^2)	Cohesion (C) = qu/2
1	Pure expansive soil	65.05	32.525
2	5% Fly ash application	72.4	36.2
3	10% Fly ash application	85.424	42.712
4	15% Fly application	113.49	56.745
5	17.5% Fly ash application	136.885	68.442
6	20% Fly ash application	154.596	77.298

4.7. California Bearing Ratio(CBR)

The outcomes of the soaked CBR tests conducted prior and subsequent to the stabilization process utilizing fly ash and the incorporation of geogrid are presented in Table 4.6 below and details of laboratory test result before and after treating with both fly ash and geogrid material is presented in the appendix-6. As Table 4.6 showed the result of the CBR values for the natural soil was very low as compared to the stabilized soil sample and the recorded CBR result for untreated soil was below the standard design requirement.

Table 4.6: Results of Soaked CBR before and after treating with flyash and geogrid material

No	Mix proportion and geogrid inclusion layers	Soaked CBR values (%)	CBR Swell (%)
1	0% Fly Ash and 100% expansive soil	2.7	5.1
2	5% Fly Ash and 95% expansive soil	3	4.64
3	10% Fly Ash and 90% expansive soil	3.71	4.04
4	15% Fly Ash and 85% expansive soil	4.35	3.61
5	17.5% Fly Ash and 82.5% expansive soil	5	3.38
6	20% Fly Ash and 80% expansive soil	5.44	3.18
7	Geogrid layered at 30mm from the top and 0% fly ash	6.17	2.92
8	Geogrid layered at 60mm from the top and 0% fly ash	4.15	3.52
9	Geogrid layered at 30mm from the top and 17.5% fly ash	10.33	1.98
10	Geogrid layered at 60mm from the top and 17.5% fly ash	7.95	2.47

CHAPTER 5

5. ANALYSIS AND DISCUSSION

5.1. Introduction

The current study was undertaken to investigate the individual and combined effects of utilizing fly ash and geogrid inclusion on the improvement potential of collected expansive subgrade soil. Several basic geotechnical properties of the soil were tested before and after treatment with fly ash, including the California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), Maximum Dry Density (MDD), Optimal Moisture Content (OMC), Specific Gravity (G), grain size analysis, free swell index, liquid limit, and plasticity index. In addition to investigating the effect of fly ash application on CBR improvement of expansive subgrade soil, in this study the effect of geogrid inclusion at various layers on the given CBR mould without and combining geogrid with 17.5% fly ash concentration is also performed. These tests determine whether treated soil meets the expected strength parameters and is volumetrically stable. Under this section execution of various representative laboratory test results obtained are briefly analyzed and discussed.

5.2. Analysis of expansive soil grain size distribution and it's characteristics found from Koye Feche study area

Sieve and Hudrometer Test Result	
Sieve No (mm)	% Passing
4.75	98.86
2.36	98.45
2.00	98.11
1.18	97.81
0.600	96.86
0.425	96.25
0.300	95.65
0.150	92.79
0.075	88.75
0.030	57.190
0.020	51.911
0.016	49.007
0.012	46.104
0.009	42.584
0.006	39.945
0.001	33.786

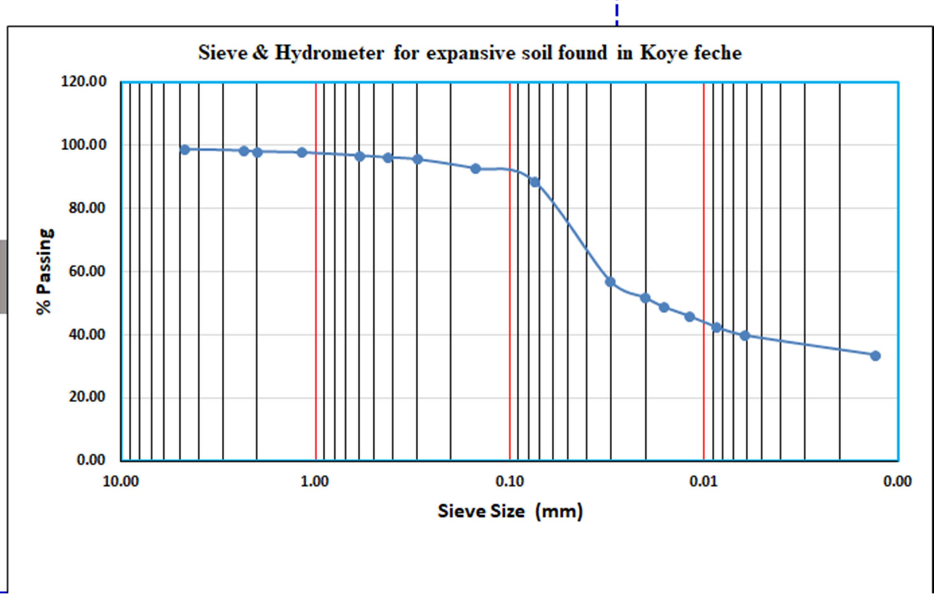

Figure 5.1: Combine wet and hydrometer sieve analysis result

The expansive soil samples collected from Koye Feche sub – city at a depth of 1.5m, is grayish-black in color. As seen from Figure 5.2, based on its liquid limit values, the soil is classified as highly plastic inorganic clayey soil with plasticity index of 53.95%, and composed of fine grained material (see section 4.1). From the grain size distribution curve shown in Figure **5.1** above, where the total percentages of particles were found to be 1.14% gravel, 6.49% sand, and 27.33% clay respectively. It can be generalized that the soil found from Koye Feche is fine-grained and highly plastic clayey type and exhibit poor engineering properties that can be used as subgrade materials. It required some improvement to meet ERA standards for subgrade material, as it was classified as A-7-6, which is considered poor subgrade material.

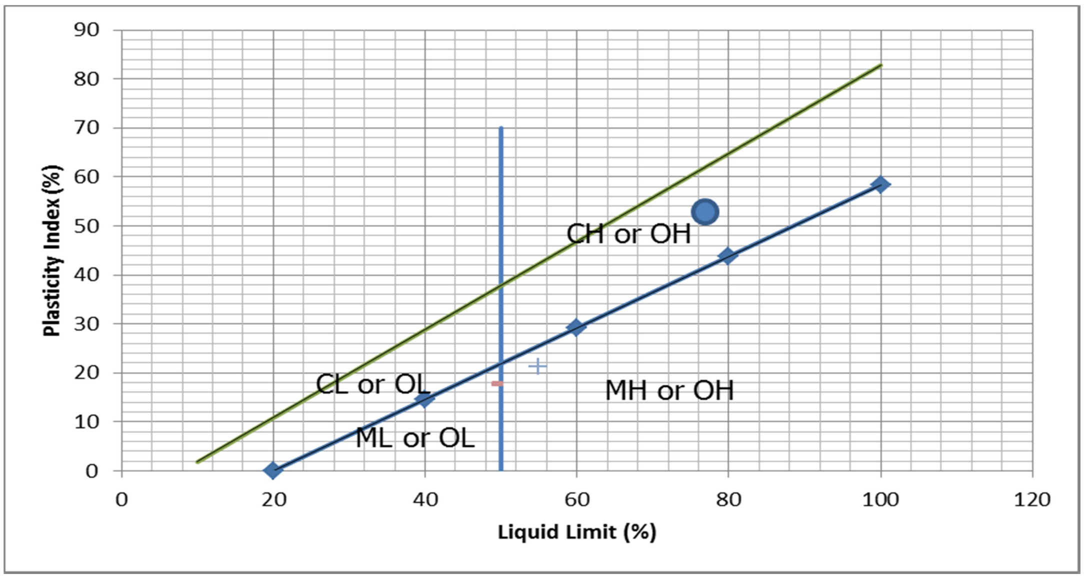

Figure 5.2: Casagrande plasticity chart

5.3. Analysis of the impact of fly ash application on the Atterberg Limit values

The results of testing Atterberg limits with varied fly ash contents are shown in Figure 5.3. Since the Atterberg limit provides a measure of the amount of moisture that can be found inside the soil, the value of liquid limit was 77.5%, 54% and 49% as the application of fly ash in percentages of 0%, 17.5% and 20% respectively. As it can be seen from Figure 5.3 the plasticity index also showed the same effect as liquid limit but in lower value due to the increasing of plastic limit. Like the values of liquid limit and plasticity index, the plastic limit showed an incremental value as the percentages of fly ash concentration become increased in the soil sample.

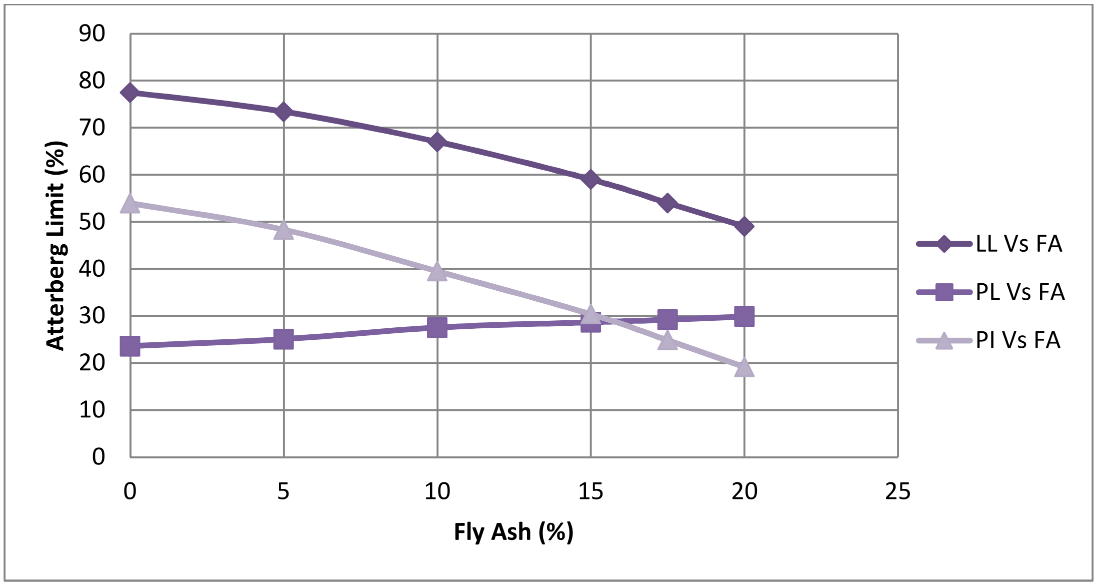

Figure 5.3: Atterberg versus percentages of fly ash application

In addition to this, as shown in figure 5.3 the value of the liquid limit of the soil decreased from 77.5% for the untreated soil to 49% for the stabilized soil due to 20% application of fly ash in the soil sample. There is a significant reduction of plasticity index of 19.13% in soil that is treated with fly ash (20% fly ash concentration) compared to soil that has not been treated with fly ash which was 53.95%. Upon adding the first amount of fly ash stabilizer to the blend, an appreciable decrease in the plasticity index was observed, and the plasticity index continued to decrease after further additions of fly ash stabilizer. After further application of fly ash to the soil sample, the plasticity index was greatly reduced.

According to the results of the study, the incorporation of fly ash into soil results in a reduction in the soil's liquid limit (LL), making it less plastic and more stable. This is due to the fact that fly ash works as a filler material, reducing the size of the pore spaces. Thus chemical additives and clay minerals held inside the expansive soil were found to form agglomerations and flocculation which resulted in a decrease in liquid limit and plasticity index values. Consequently, the increased concentration of fly ash (FA) decreased both plastic limit (PL) and liquid limit (LL), which resulted in a decline in the plasticity index (PI) as well. Unfortunately, when applying fly ash at 20%, a minor reduction in the Atterberg limit values was observed. This indicates that if the quantity of fly ash applied beyond the optimal values results in only minor improvements in the index and engineering properties of the selected soil, this may also indicate that applying fly ash beyond the optimal values is not a viable practice (GA Ahmed, 2014). Similarly a research made by GA Ahmed (2014) showed that raising the ash intensity from zero to 20% also causes a decrease in the liquid limit, a rise in the plastic limit, and a reduction in the plasticity index. However, he observed a significant reduction in liquid limit and plasticity index values when the ash content became between 0 and 15 percent by weight, unlike the output of this research, which obtained 0 to 17.5% fly ash to 20%. These differences in the output while using the same approaches confirmed that such kind of tests are unique for soil sample.

5.4. Effect of Fly ash application on its reduction potential of free swell index

As a measure of how much a soil sample increases in volume when submerged in water, free swell index (FSI) essentially quantify the swelling potential (Rai P, et al, 2021). Figure 5.4 illustrates the effect of applying fly ash soil stabilizer in varying amounts on the selected expansive subgrade soil. The figure shows that free swell index value for the untreated soil was 138% whereas following the addition fly ash at variant amount values of free swell index were greatly reduced to 48%. This result agrees with Rai P, et al (2021) since they also added fly ash to the soil to get a reduction in the free swell index. Phani Kumer et al (2024) also indicated that the reduction of free swell index means the soil swells less when water is applied due to the improvement of swell potential by using fly ash. The process involves fly ash particles to interact with the soil particles, to produce a more compact and less porous structure. Thus, this achieved in this research by adding fly ash as a stabilizer.

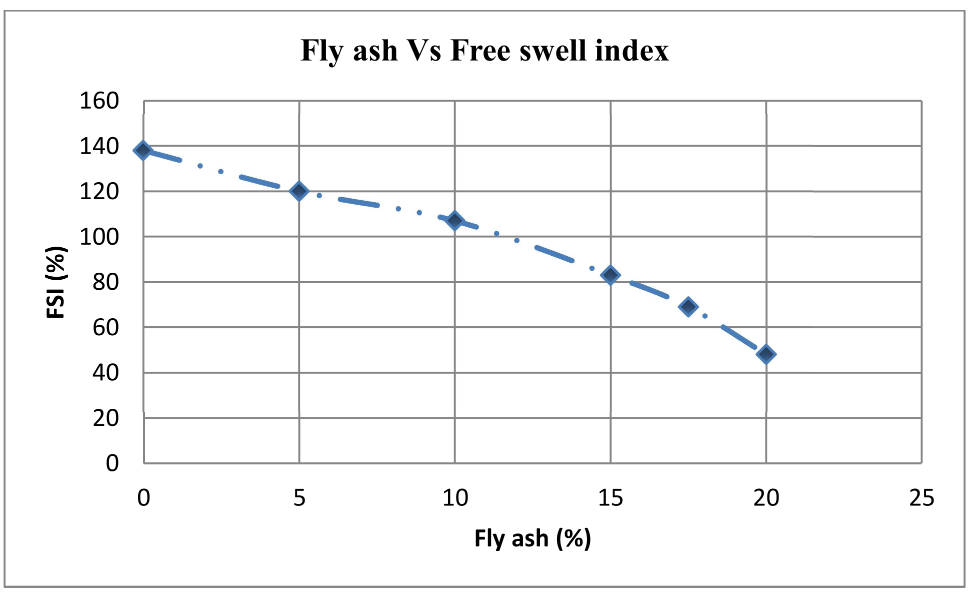

Figure 5.4: Effect of fly ash concentration on free swell index

5.5. Effect of fly ash application on the specific gravity values of the given soil

According to Karim MA et al (2020), the specific gravity of fly ash typically falls within the range of 2.2 to 2.8, but it can vary depending on the type of fly ash and the coal it's derived from (see section 3.3.2). They also stated that class C fly ash may have a specific gravity around 2.4, while Class F fly ash might be closer to 2.32. Karim MA et al (2020), Dixit A et al (2016) clearly show that adding fly ash to expansive soil generally decreases its specific gravity. Since the fly ash has a lower specific gravity than the soil sample, which is usually from 2.6 to 2.8. Dixit A et al (2016) stated that as the percentage of fly ash in the mixture increases, the specific gravity of the soil decreases, since particles of fly ash are hollow and lighter than typical soil. The result of this study also agrees with them and Figure 5.5 shows that readings of specific gravity declined with the increase of fly ash concentrations in the soil as shown by these results. At 20% application of fly ash, the specific gravity of the soil decreases from 2.47 in untreated soil, to 2.35 in soil that has been treated with 20% fly ash. The research examined the characteristics of expansive subgrade soil with fly ash addition.

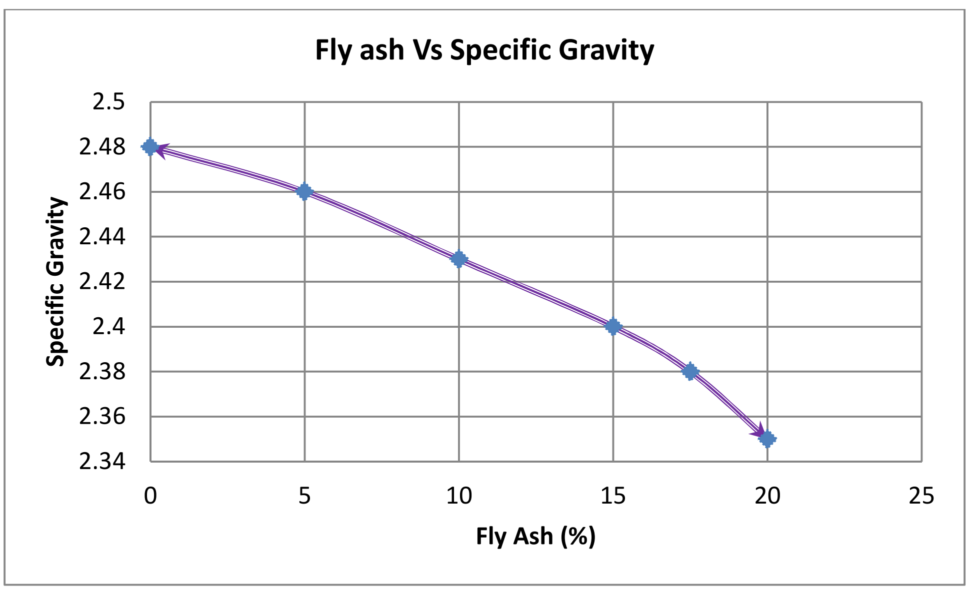

Figure 5.5: Effect of fly ash on Specific gravity value

5.6. Effect of fly ash concentration of the moisture content versus dry density relation

The density of fly ash affects geotechnical properties such as strength, compressibility, and hydraulic conductivity. Fly ash that has been properly compacted and stabilized with soil meets the standards for use in pavement subgrade preparation and load-bearing fills. In this study, fly ash was added at a rate of 0 to 20% in 5% increments. Moreover, between 15% and 20% of fly ash concentration, additional 17.5% of fly ash was added to the soil sample to investigate any further increment in maximum dry density (MDD) value. The relationship between moisture content and dry density for treated as well as untreated subgrade soil test result is shown in Figure 5.6.

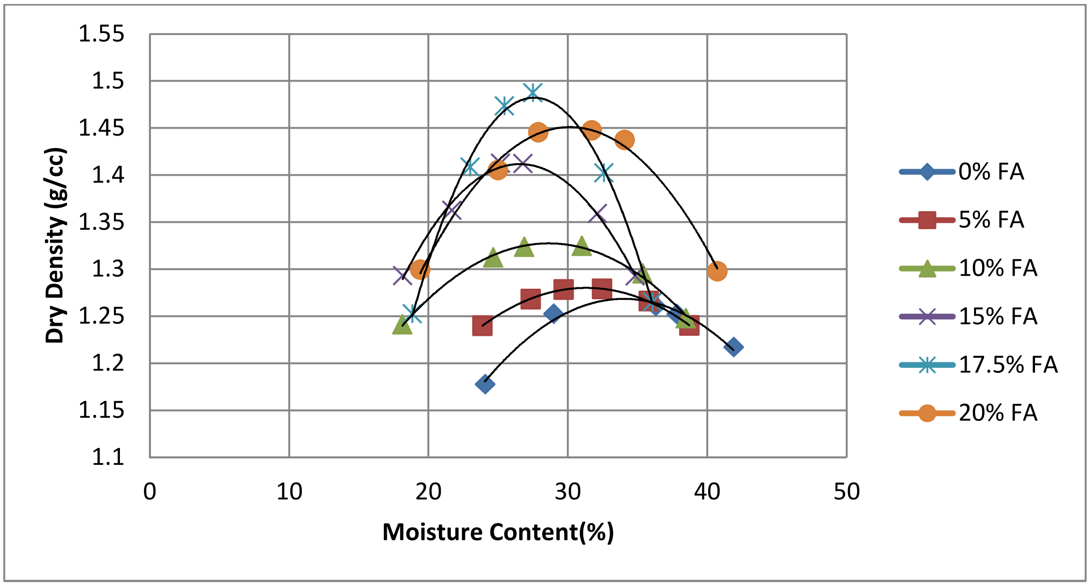

Figure 5.6: Effect of fly ash on OMC Vs MDD curve

Figure 5.6 displays results of dry density and optimum moisture content before and following treating with fly ash concentrations. According to Figure 5.7, the maximum dry density of soil continues to increase as the amount of fly ash increases whereas the optimum moisture content of soil continues to decrease as the amount of fly ash applied become increases.

The results of the laboratory tests showed that for an increase in fly ash concentration of 0 to 17.5 %, the maximum dry density increased from 1.268g/cm ^{3} to 1.48g/cm ^{3} for untreated soil. Similarly, the moisture content value was greatly reduced from 34% to 27%. This considerable reduction could be because of poorly graded soil gaps in the particle distribution, and fly ash particles may have filled these gaps to establish a better connection between soil particles. This results in the agglomeration and flocculation of the mix, and an abundance of fly ash particles has increased the maximum dry density up to a certain percentage of fly ash content. Ozdemir (2016) stated that application of fly ash as a soil stabilizer should be in limited amount and it is known as optimum fly ash–soil mixing ratio. As seen from figure 5.6 however, at 20% fly ash application, maximum dry density is reduced while optimum moisture content decreases. This may be due to the fine particles and the lighter weight of fly ash compared to the soil particles.

This result agrees with Ozdemir (2016) since he also added fly ash to the soil to get a maximum dry density and he found that application of fly ash beyond 20% shows minor improvement in dry density value.

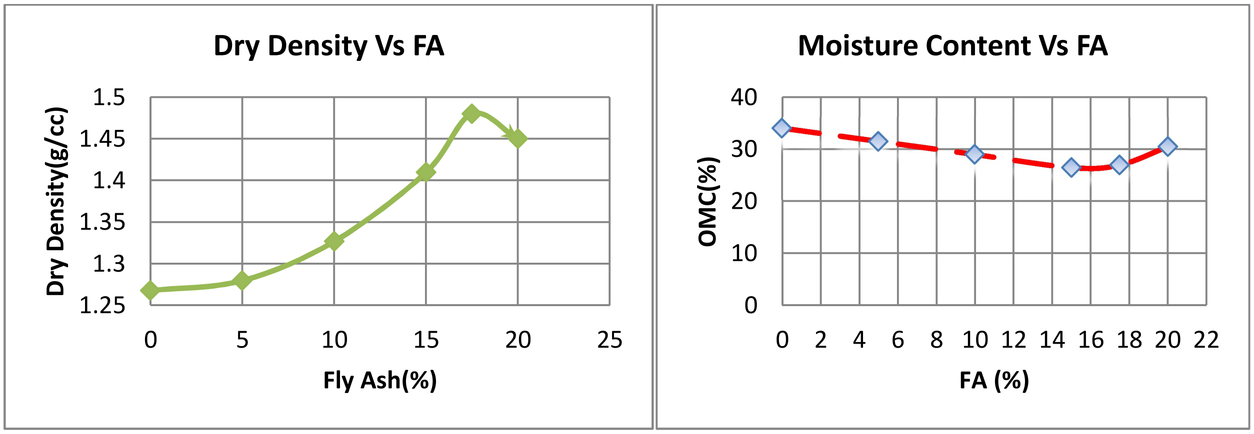

Figure 5.7: Dry density and moisture variation due to fly ash concentration

5.7. Effect of fly ash application on unconfined compressive strength values

Fly ash stabilization generally increases the unconfined compressive strength of soil, particularly expansive soils. This is due to fly ash's pozzolanic properties, which react with lime or cement to form cementitious materials, binding soil particles together and enhancing strength. The improvement in UCS is often seen with a relatively small addition of fly ash (e.g., 20% by weight). In this study, measurements for unconfined compressive strength were made for the original untreated soil, as well as for the soil that had been mixed with fly ash at 5%, 10%, 15%, 17.5%, and 20%, after soaking for 24 hours. Summarized laboratory test results of the UCS value before and after the addition of fly ash concentration are presented in Figure 5.8.

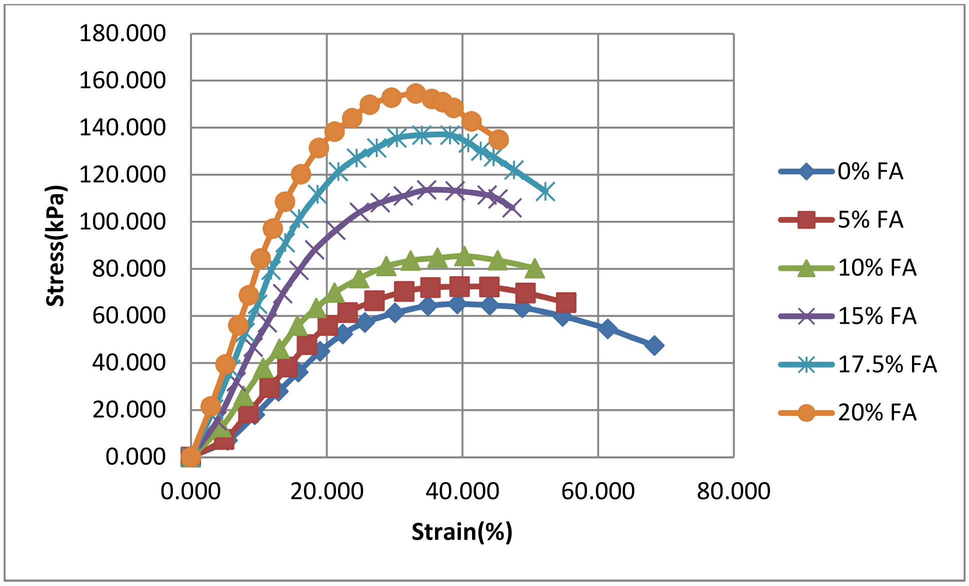

Figure 5.8: Effect of fly ash on UCS stress vs strain values

Based on the results of Figure 5.8, it appears that the use of fly ash material greatly enhances the unconfined compressive strength values of the soil that has been treated with fly ash. As can be seen from the given result, for the original soil the value of UCS was 65.05 kPa, but after adding fly ash to the soil of an amount of 20% by weight, the value of UCS increased to 154.59 kPa, which was significantly higher than the original soil value. A rise in unconfined compressive strength values was attributed to agglomeration and flocculation formation between chemical additives and clay minerals, resulting in a rise in unconfined compressive strength values. The optimum fly ash amount for the shear strength improvement of mixed soils is 20%. The findings indicated that the amount of fly ash up to optimum content can induce pozzolanic behavior and cemented materials, which effectively contributes to shear strength increase. In contrast, the additional amount of fly ash (FA) more than the optimum value acts as unbounded silt particles, which has neither appreciable friction nor cohesion, causing a decrease in strength (Nath et al, 2017).

In this study, only an immediate UCS test was conducted, and the results from soaked UCS tests conducted for 7, 14, and 28 days were found to be unreliable since, after soaking the sample into water the sample become tightly wrapped with plastic so that no water could contact the sample causing it to dry without having moisture from surrounding water then the reading become exaggerated due to wrongly testing procedure.

5.8. Effect of fly ash application on CBR values of expansive subgrade soil

California bearing ratio (CBR) is the ratio expressed as a percentage of the force per unit area required for the penetration of a soil mass using a circular plunger with a diameter of 50 mm at a steady velocity of 1.25 mm/min, which is substantially needed for the analogous penetration in a calibrated material. It is typically measured for penetrations of 2.5 mm and 5 mm separately, where the CBR ratio at 2.5 mm is higher than at 5 mm, and thus, the ratio at 2.5 mm is utilized in this study. Samples were prepared based on the optimum moisture content taken from Proctor results and then cured for 4 days of soaking. In this research, before applying stabilization the original subgrade soil values of soaked CBR and CBR swell were found out to be 2.7% and 5.1% respectively. This test result as per ERA design standard (pavement design manual,2002) was rated as poor subgrade material that can need a kind of special treatment, and CBR swell also it did not fulfill the minimum requirements of ERA specification. The result indicated that the soil shows low bearing capacity and high plasticity index that cannot satisfy the requirements. Therefore, before construction of any structures on such soil, improvement of the in-situ soil to improve its overall properties become very important. This study uses combined effect of fly ash and geogrid incorporation that is used to modify the soil properties then improve its workability and engineering property.

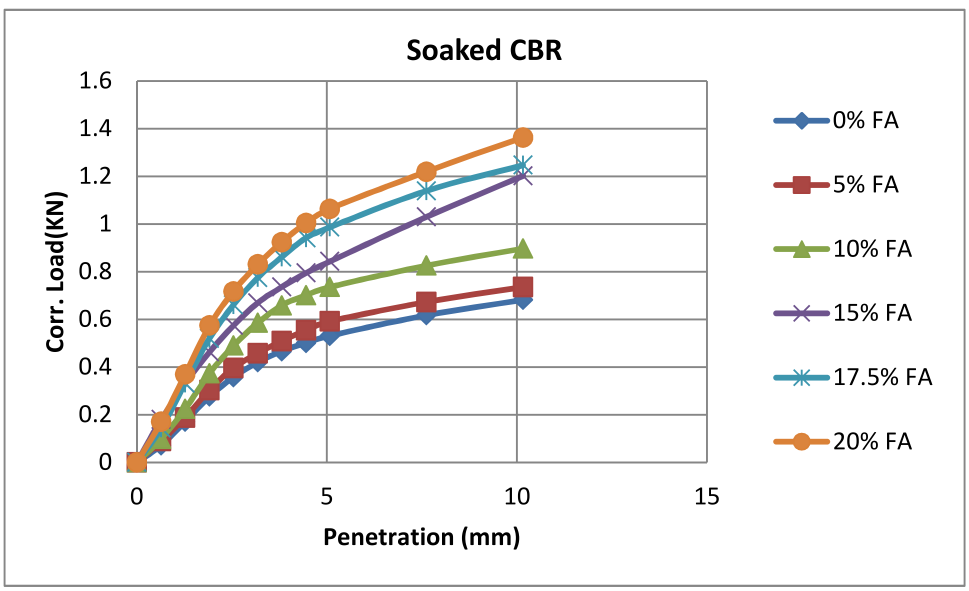

Figure 5.9: Effect of fly ash on CBR penetration Vs CBR applied load

CBR test for this study was conducted by taking air dried sample passes through sieve No.19 for natural soil mixed with different percent of fly ash concentration (5%, 10%, 15%, 17.5% & 20%). This value was determined by one-point CBR testing methods through compacting with 5 layers and applying 56 blows for each layer. CBR swell also conducted after four days soaking with different percent of fly ash concentration to the soil. Figure 5.10 shows the relationship that held CBR and CBR swell with fly ash concentrations. As seen from Figures 5.9 and 5.10, the results indicate that the addition of fly ash significantly affects the CBR values of the given soil. This improvement is attributed to the pozzolanic nature of fly ash, which causes the mix to become aggregated. CBR value before treating the original soil with fly ash was about 2.7%, while treated the given soil with fly ash CBR values was 5.44% (at 20% Fly ash application). In relation to this, Trivedi et al (2013) observed that soil containing up to 20 % fly ash application gave the best findings of soil stability compared to other percentages. The reason for this improvement is primarily due pozzolanic nature of fly ash material. Trivedi et al (2013) studied that the reason for CBR improvement was mainly due to the formation of cementing gels (hydrate) due to the reactions between CaO of fly ash with Al_2O and SiO_2 of soil. As seen from Figure 5.9 due to the application of such pozzolanic soil stabilizer, CBR swell value also considerably reduced from 5.1% of untreated soil to 3.18% of 20% fly ash treated soil.

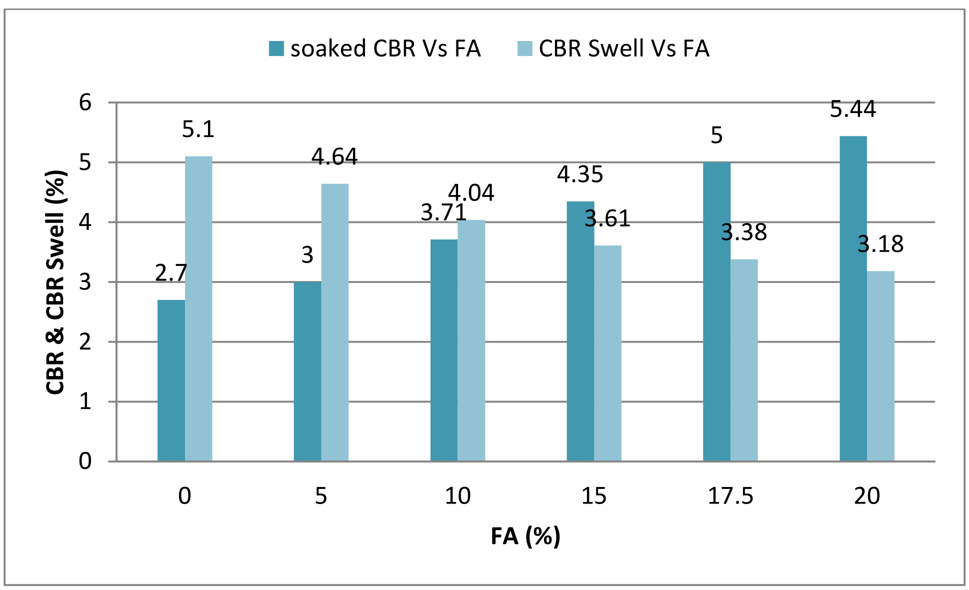

Figure 5.10: Fly ash application effect on soaked CBR and CBR swell

5.8.1. Combined effect of geogrid inclusion and fly ash concentration on CBR Values

Following similar procedures as the case of fly ash application on CBR improvement of selected expansive subgrade soil, in this study investigation of the effect of utilization of both geogrid reinforcement and fly ash application was carried out. Koerner (2012) reported that the key feature of geogrid is that the opening between adjacent sets of longitudinal and transverse ribs (apertures) should be large enough to hold the soil particles. Stabilization mechanism through geogrid reinforcement is due to lateral restraint of the stabilized soil through a process of interlocking soil inside the opening of the geogrid material. To perform one point CBR test before and after reinforcing with geogrid combined with and without fly ash, dry soil was mixed thoroughly at the OMC values through adding the required amount of water. Then a layer of geogrid reinforcement made from high density poly ethylene (HDPE) raw material was arranged with circular shape of diameter slightly larger than the internal diameter of the CBR mould. In this study, geogrid made according to S. Y. Aga (2021) was selected and Table 5.1 shows some properties of georgid material selected for this investigation.

Table 5.1: Test results for selected geogrid material (S. Y. Aga, 2021)

Sample Type	HDPE
Sample Thickness	2mm
width	13.5mm
Length	116.4mm
Peak Load at Yielding	255Kg
Elongation at Break Load	779.88mm
Stress at yield	9.44Kg/mm2
Stress at Break Load	21.074Kg/mm2
Strain at yield	12.998%
Strain at break	670%
Aperture opening	22 by 22mm

A layer of geogrid was placed at 30mm and 60mm respectively below the top of the CBR mould in between soil layers that were carefully compacted in order to achieve the required density. Fixing the geogrid between the CBR mould, anchoring and positioning of the geogrid were carried out as per D. Useche et al (2016) and S. Y. Aga (2021). Such way of sample preparation is used to represent the actual field condition in which the axial forces from the soil are shared by geogrid material mainly through its membrane action hence through such action failure of the subgrade against mobilized shear failure become considerably reduced. The relationship between penetration stresses with that of penetration depth result for geogrid reinforced soaked CBR value with and without fly ash application is presented in figure 5.11.

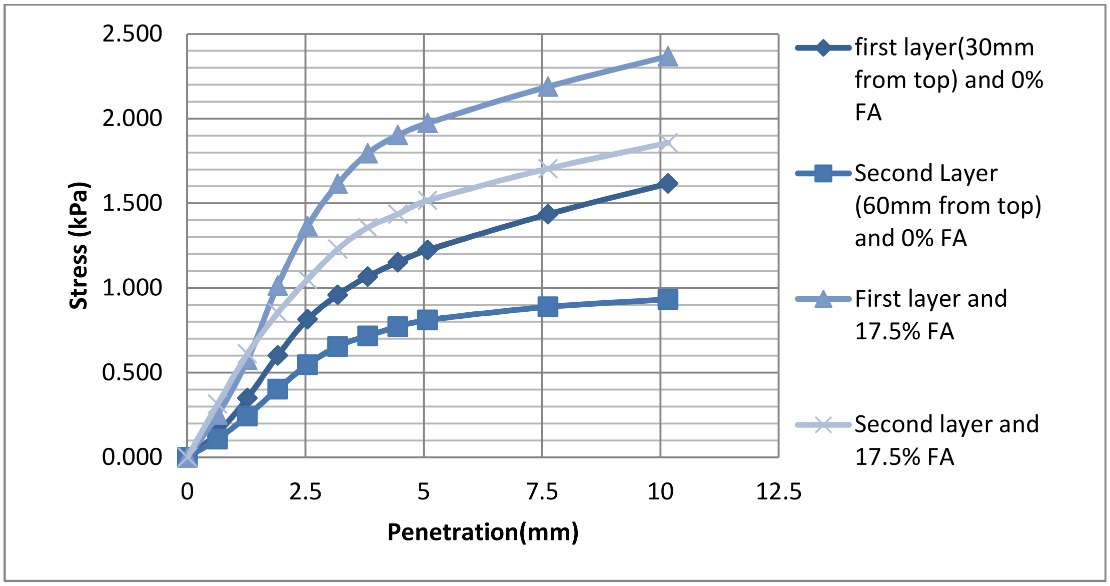

Figure 5.11: Two layer geogrid and fly ash effect on CBR penetration Vs applied Load

The result for geogrid inclusion at different layers and, combined effect of geogrid reinforcement and application of 17.5% of fly ash concentration is shown in Figure 5.11 and 5.12. From the figure, it is clearly observed that CBR value is much affected by the geogrid position and number of geogrid layer used inside the CBR mould. From figure 5.12, CBR values obtained for untreated original soil was 2.7%. Through inclusion of the first layer of geogrid without fly ash application, the CBR value increased to 6.17% which is an increment of 2.3 times greater than that of untreated soil. As seen from figure 5.12, obtained CBR values when geogrid placed first layer shows higher value than when the geogrid placed at second layer. The CBR value of 4.15% was obtained when the geogrid is position at second layer.

Figure 5.12 shows combined effect of 17.5% fly ash application with first and second layer of geogrid reinforcement. The result shows that there is a further considerable improvement in CBR value. From the figure when 17.5% fly ash concentrated soil is reinforced with first and second layer of geogrid inclusion then soaked CBR value become further increased to 10.33% and 7.95% respectively. This improvement is about 3.83 and 2.94 times greater than that of untreated soil. CBR swell value after 96 hour soaking the sample reinforced with geogrid layer is presented in Figure 5.12. The test was performed after and before treating the subgrade soil at 17.5% fly ash application. Reinforcing the subgrade material with geogrid reinforcement layered at 30mm and 60mm, led to a reduction of CBR swell values from 5.1% to 2.92% and 3.52% respectively. Likewise, when 17.5% fly ash concentration was added to the above samples then CBR swell value become considerably reduced to 1.98% and 2.47% respectively. The improvement of the CBR value is due to interlocking of the subgrade soil into the aperture opening of the geogrid and the associated anchoring of geogrid layer between CBR mould.

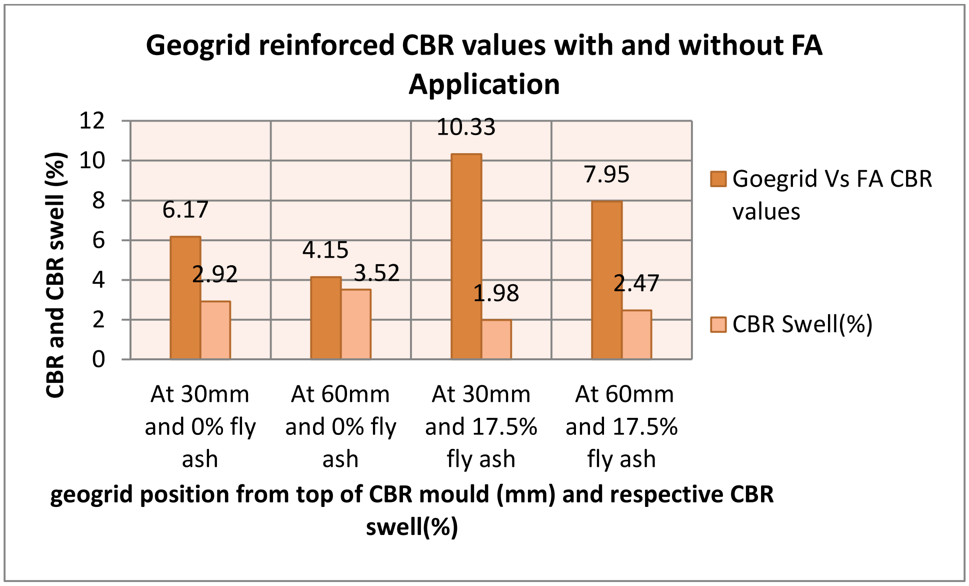

Figure 5.12: Effect of geogrid reinforced CBR values with and without fly ash application

For effective settlement reduction, it is necessary to install and place geogrids in a proper manner. Figure 5.12 below presents the deformation results after incorporating the first layer of geogrid reinforcement, both before and during the application of 17.5% fly ash by weight on the prepared soil sample. As seen from the figure deformation properties of untreated soil after the inclusion and anchoring of geogrid reinforcement on CBR mould were significantly improved. Geogrids serve as a reinforcing layer, enhancing the overall strength and stiffness of the soil, which enables it to support larger loads with reduced deformation. Geogrids improve CBR value by strengthening the soil and effectively distributing loads.

Figure 5.13: Deformation reduction potential of geogrid material while reinforced on CBR Mould

CHAPTER 6

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

When a road is built on expansive soil, it will settle extensively. In order to make soil suitable to support the given structures, physical and chemical improvements should be executed. Application of fly ash and geogrid is able to improve the index and engineering characteristics of such problematic soil. They are promising soil improvement techniques. This study investigated the performance of expansive subgrade soil while reinforced with geogrid and fly ash concentration. Fly ash concentration ranging from 0 to 20% by weight was applied in order to see the effect of application of such material on index and engineering properties of the selected high plastic inorganic clay. Additionally the effect of physical stabilizer, geogrid inclusion at two layers, with and without fly ash application has been investigated. After discussing the results presented in this study, the following conclusions were drawn:

- The types of geogrid used in this research considered in this research have shown the great potential of improving the CBR values and reducing the corresponding CBR swell considerably. The CBR values of untreated subgrade soil improved from 2.7% to 6.17% by applying the first layer of geogrid. This improvement is about 1.2 times greater than that of 20% fly ash application which got 5.44% of CBR values.
- The geogrid locations used in the soil layers significantly affect the CBR values. The effect of geogrid reinforcement, at 30mm and 60mm layer from the top of CBR mould, with and without fly ash application on selected soil was carefully performed. During first layer of geogrid reinforcement 6.17% of CBR was achieved, similarly when the geogrid was placed at second layer CBR values was reduced to 4.15%. Hence value of CBR at first layer is about 1.49 times greater than second layer.
- Combined effect of fly ash and geogrid application in the subgrade soil shows considerable improvement on CBR values. While applying 17.5% fly ash and first layer of geogrid inclusion the values of soaked CBR were appreciably increased to 10. 33% as compared to unstabilized subgrade soil which is 2.7% CBR.

- As a result of fly ash and geogrid application on expansive soil found from Koye Feche, the subgrade strength properties were significantly improved. Thus failure of road will be minimized and thereby service life of the pavement becomes continuously improved.
- Before stabilization 5.1% of CBR swell was obtained. Whereas after the application of geogrid and fly ash material on the given soil, CBR swell value were decreased from 5.1% to 2.92% (only geogrid at first layer) and 1.98% (at 17.5% fly ash and first layer geogrid) respectively. Thus it can be concluded that due to reinforcement CBR swell values of expansive soil were considerably reduced.
- By comparing the improvement degree of expansive subgrade soil stabilized using fly ash with geogrid material, better improvement was observed for geogrid reinforcement. But further considerable improvement in CBR value was observed while using both fly ash and geogrid materials.
- As shown in Table 4.2, the liquid limit, plastic limit, and plasticity index for un-stabilized original soil were 77.5%, 23.56%, and 53.95%, respectively. The addition of fly ash resulted in a reduction of the liquid limit and plasticity index to 49% and 19.13%, while an increase in the plastic limit from 23.56% to 29.87% was observed. Thus, the plasticity properties of expansive subgrade soil improved significantly.
- Free swell index value for untreated soil was 138 %. After the incorporation of fly ash, values of free swell index were considerably reduced from to 48%.
- Specific gravity was reduced from 2.48 of untreated soil to 2.35 of at 20% fly ash application. Thus due to the light weight nature of fly ash material, the specific gravity of fly ash stabilized soil become reduced.
- The finding shows that the increment of fly ash concentration is able to increase the MDD values and reduce the optimum moisture content. However at 20% fly ash application optimum moisture content become increased and dry density is reduced. Therefore, applications of fly ash beyond 20% MDD become reduced and conversely moisture content becomes increased.
- The result of using fly ash showed a considerable improvement on unconfined compressive strength by increasing the percentages of fly ash. It is concluded that with the addition of 20% of fly ash, the value of immediate UCS was increased from 65.05kPa of untreated soil to 154.6kPa of treated soil.

6.2. Recommendations

- The study basically focuses on laboratory experimental program; however application of numerical analysis and comparing the result can be studied in the future.
- Geogrid material that was used for this study was with the intention of subgrade stabilization however, the impact of geogrid inclusion between subgrade and sub-base material can be studied in detail through preparing large scale model experiments.
- This study focuses the use geogrid and fly ash for expansive subgrade soil improvement but, the improving potential of geogrid inclusion on other than expansive soil can be investigated in detail.
- The present study was conducted using fly ash and geogrid material mainly for subgrade improvement. Therefore; in order to investigate the overall impact of such material on the given soil other than subgrade preparation, it is recommended to conduct additional laboratory tests such as swelling pressure and consolidation test.

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Appendix

Appendix -1: Hydrometer Analysis Data

Summarized hydrometer analysis Table

Soil Tested By: Jointly with MCG, Date: 19/03/2025

Ra= actual hydrometer reading

Hydrometer Analysis as per ASTM D422 Standards

L = Effective length from table

Calculate percent finer as follows, P = (RC*a)/ (Ws) *100

Where Ws is the weight of soil sample in grams

K = Constant from table

P_A = adjusted percent fines as follows, P_A = P *F_{200}/100

Where F200 = % finer of #200 sieve as percent

D = diameter of particle (mm) = K* Square of[L/T], Where T-Time in minute

Weight of soil sample: 50gm

Meniscus Correction: +1

Rc = R actual - zero correction

Zero Correction: +3.5

Specific Gravity of soil:2.48

Zero correction = Determined from laboratory test

date	Time	Elapsed Time (T) in minute	Temp. (oC)	Actual Hydrmo. Rdg (Ra)	Hyd.Correction for Meniscus	L From Table 1	K From Table 2	D(mm)	CT From Table 3	a from Table 4	Corr. Hydr Rdng(Rc)	% Fine	% Adjusted Finer (PA)
19/03/2025	Start Time	2	24.5	38	39	10.1	0.01396	0.03137	1.15	1.03	35.65	73.44	66.1876
		5	24	35	36	10.6	0.01404	0.02044	1	1.03	32.5	66.95	60.3394
		8	23.5	32	33	10.1	0.01413	0.01588	0.85	1.03	29.35	60.46	54.4911
		15	23	28.5	29.5	11.6	0.01421	0.0125	0.7	1.03	25.7	52.94	47.7145
		30	23	27	28	11.9	0.01421	0.00895	0.7	1.03	24.2	49.85	44.9296
		60	23	25	26	12.2	0.01421	0.00641	0.7	1.03	22.2	45.73	41.2164
		120	23	23.5	24.5	12.45	0.01421	0.00458	0.7	1.03	20.7	42.64	38.4315
20/03/2025	end Time	1440	23	20	21	13	0.01421	0.00135	0.7	1.03	17.2	35.43	31.9334

Table 1.1: Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specific Sizes

Hydrometer 151H		Hydrometer 152H		
Aactual Hydrometer Reading	Effective Depth, L (cm)	Aactual Hydrometer Reading	Effective Depth, L (cm)	Aactual Hydromete Reading
1.000	16.3	0	16.3	31
1.001	16.0	1	16.1	32
1.002	15.8	2	16.0	33
1.003	15.5	3	15.8	34
1.004	15.2	4	15.6	35
1.005	15.0	5	15.5	36
1.006	14.7	6	15.3	37
1.007	14.4	7	15.2	38
1.008	14.2	8	15.0	39
1.009	13.9	9	14.8	40
1.010	13.7	10	14.7	41
1.011	13.4	11	14.5	42
1.012	13.1	12	14.3	43
1.013	12.9	13	14.2	44
1.014	12.6	14	14.0	45
1.015	12.3	15	13.8	46
1.016	12.1	16	13.7	47
1.017	11.8	17	13.5	48
1.018	11.5	18	13.3	49
1.019	11.3	19	13.2	50
1.020	11.0	20	13.0	51
1.021	10.7	21	12.9	52
1.022	10.5	22	12.7	53
1.023	10.2	23	12.5	54

Table 1.2: Values of k for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temprature °C	Specific Gravity of Soil Solids							
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.0394	0.01
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.

Table 1.3: Temperature Correction Factor CT

No	Temperature (o_C)	Factor C_T
1	15	1.1
2	16	-0.9
3	17	-0.7
4	18	-0.5
5	19	-0.3
6	20	0
7	21	0.2
8	22	0.4
9	23	0.7
10	24	1
11	25	1.3
12	26	1.65
13	27	2
14	28	2.5

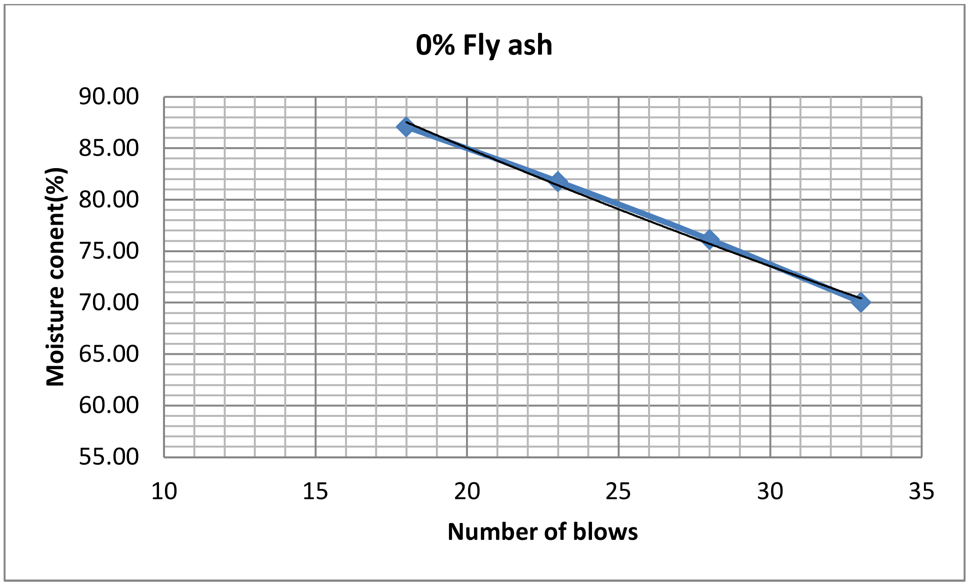
Tabale 1.4: Correction factor a for unit weight of solids

Unit Weight of Soil Solids, g/cm3	Correc fact a
2.85	(
2.80	0
2.75	0
2.70	0
2.65	1
2.60	1

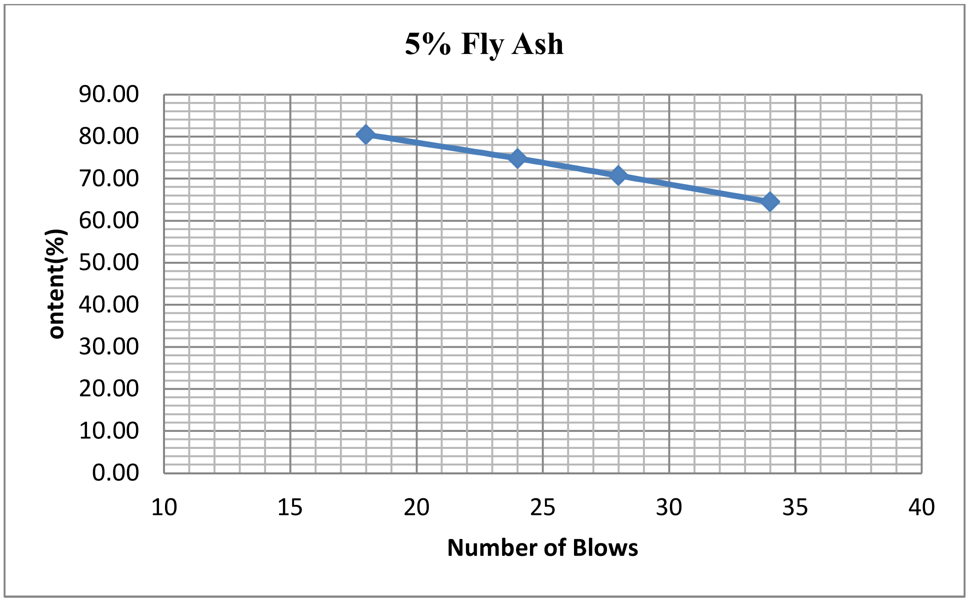
Appendix -2: Atterberg limit test results before and after treating with Fly ash material

0% Fly ash Application

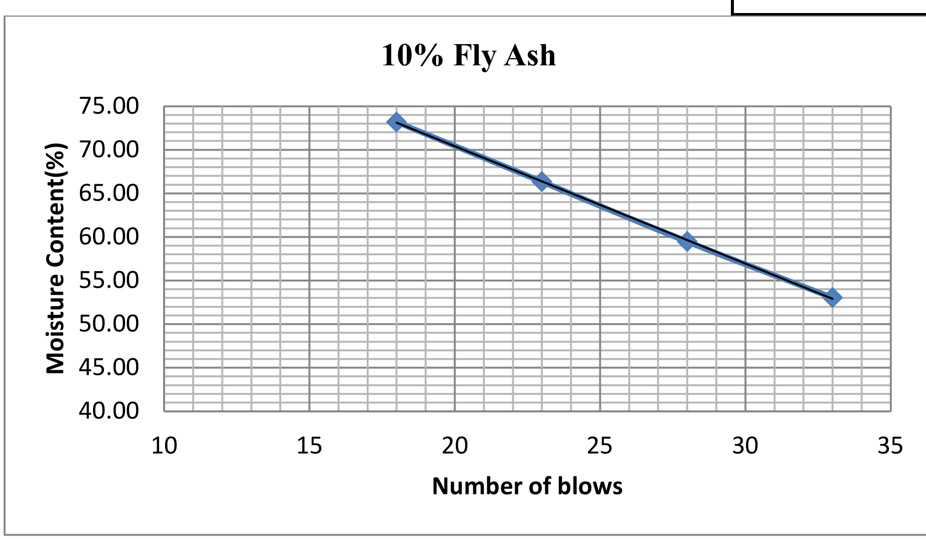
	Liquid Limit				Plastic Limit	
No of Blows	33	28	23	18		
Container No	1	7	9	8	5	4
Wt. of Cont. + Wet Soil	47.41	59.01	53.31	57.12	39.42	39.6
Wt. of Cont. + Dry Soil	37.45	45.58	40.035	41.33	36.56	36.24
Wt. of Water	9.96	13.43	13.275	15.79	2.86	3.36
Wt. of Container	23.23	27.94	23.8	23.2	23.22	23.15
Wt. of Dry Soil	14.22	17.64	16.235	18.13	13.34	13.09
Water %	70.04	76.13	81.77	87.09	21.44	25.67
	77.5				Averege P.L = 23.56 %	
					P.I. = 77.5 – 23.56 = 53.95	



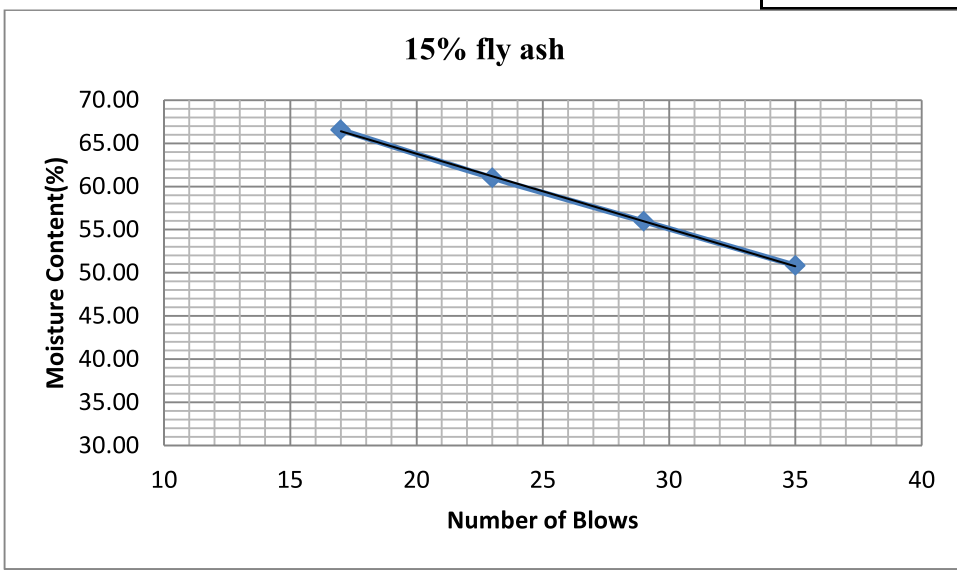
5% Fly Ash	Liquid Limit				Plastic Limit	
No of Blows	34	28	24	18		
Container No	G	8	36	4	34	35
Wt. of Cont. + Wet Soil	51.43	49.36	58.27	58.69	16.12	17
Wt. of Cont. + Dry Soil	39.59	37.70	44.38	41.98	13.8	14.6
Wt. of Water	11.84	11.66	13.89	16.71	2.32	2.40
Wt. of Container	22.22	22.2	26.8	22.22	4.6	4.96
Wt. of Dry Soil	17.37	15.495	17.5775	19.764	9.20	9.64
Water %	64.46	70.71	74.78	80.46	25.22	24.90
	73.4				Averege P.L = 25.06	
					P.I. = 48.34	



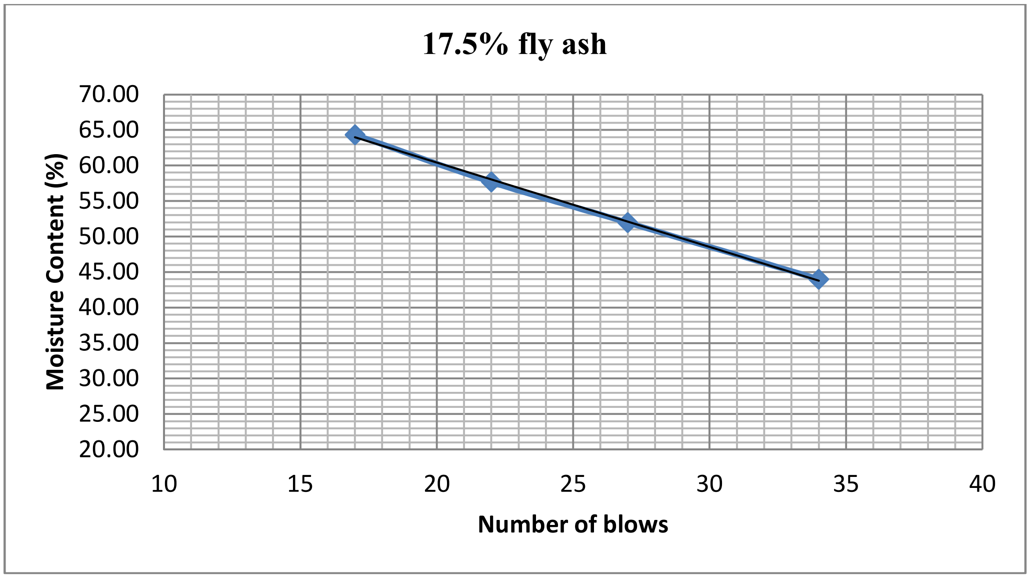
10% Fly Ash	Liquid Limit				Plastic Limit	
No of Blows	33	28	23	18		
Container No	G	H	L	N	1	2
Wt. of Cont. + Wet Soil	59.12	59.56	54.45	58.89	51.45	49.88
Wt. of Cont. + Dry Soil	47.92	45.64	41.57	43.64	46.2	44.9
Wt. of Water	11.2	13.92	12.88	15.25	5.25	4.98
Wt. of Container	26.8	22.23	22.15	22.8	26.82	26.94
Wt. of Dry Soil	21.12	23.41	19.42	20.84	19.38	17.96
Water %	53.03	59.46	66.32	73.18	27.09	27.73
	67				Averege P.L = 27.53	
					P.I. = 39.48	



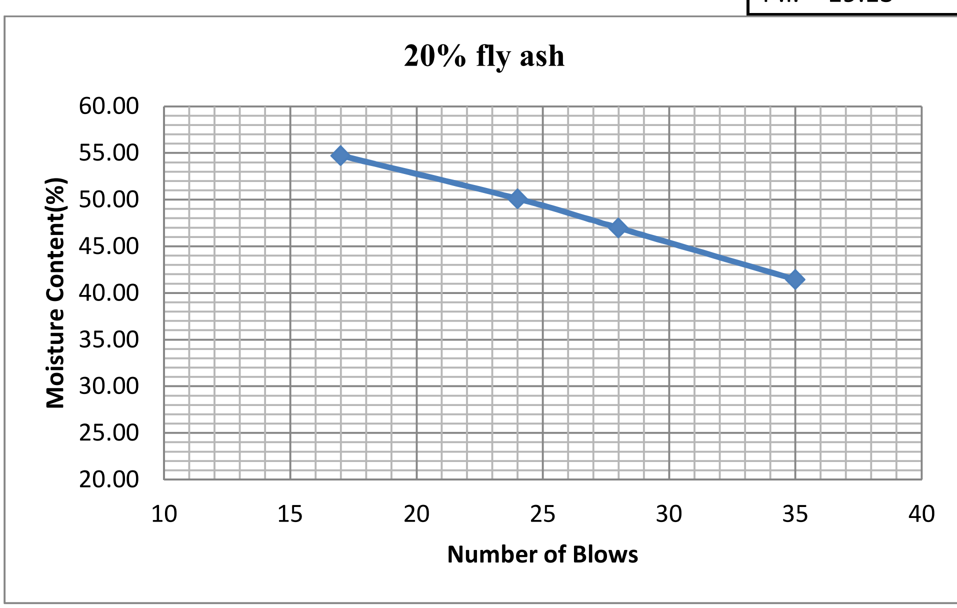
15% Fly Ash	Liquid Limit				Plastic Limit	
No of Blows	35	29	23	17		
Container No	8	1	36	4	5	60
Wt. of Cont. + Wet Soil	43.83	52.21	62.16	58.72	36.39	36.44
Wt. of Cont. + Dry Soil	36.5385	41.443	47.02	44.1281	33.2	33.3
Wt. of Water	7.2915	10.767	15.14	14.5919	3.19	3.14
Wt. of Container	22.2	22.2	22.2	22.2	22.2	22.2
Wt. of Dry Soil	14.34	19.24	24.82	21.93	11.00	11.10
Water %	50.85	55.95	61.00	66.54	29.00	28.29
	59				Averege P.L = 28.65	
					P.I. = 30.35	



17.5% Fly Ash	Liquid Limit				Plastic Limit	
No of Blows	34	27	22	17		
Container No	Z	K	G	3	43	35
Wt. of Cont. + Wet Soil	50.68	54.45	56.5	61.04	20.12	18.86
Wt. of Cont. + Dry Soil	43.39	45.04	43.96	47.6	16.54	15.79
Wt. of Water	7.29	9.41	12.54	13.44	3.58	3.07
Wt. of Container	26.83	26.94	22.22	26.7	4.96	4.6
Wt. of Dry Soil	16.56	18.10	21.74	20.9	11.58	11.19
Water %	43.99	51.95	57.68	64.31	30.92	27.44
	54				Averege P.L = 29.18	
					P.I. = 23.45	



	Liquid Limit				Plastic Limit	
No of Blows	35	28	24	17		
Container No	2	7	G	3	35	34
Wt. of Cont. + Wet Soil	49.86	51.63	52.66	56.56	19.07	20
Wt. of Cont. + Dry Soil	43	43.58	42.5	46	15.62	16.69
Wt. of Water	6.86	8.05	10.16	10.56	3.45	3.31
Wt. of Container	26.45	26.44	22.22	26.7	4.96	4.6
Wt. of Dry Soil	16.55	17.14	20.28	19.3	10.66	12.09
Water %	41.45	46.97	50.10	54.72	32.36	27.38
	49				Averege P.L = 29.87	
					P.I. = 19.13	



Appendix-3: Specific Gravity test results before and following treating with fly ash material

		Adama Science and Technology University *College of Civil Engineering and Architecture* *Department of Civil Engineering* soil lab	
Material :- Untreated Soil collected from Koye Feche Study area at 1.5m Depth **(100% Pure soil)**			
Specific Gravity Determination as per ASTM D854 Standard			
		Sample No	
S/N	**Particulars**	**Triel one**	
1	**Weight of Density bottle W_1 (g)**	57	
2	**Weight of Density bottle with dry soil W_2(g)**	72.18	
3	**Weight of Density bottle with dry soil and water W_3(g)**	176	
4	**Weight of Density bottle full of water W_4 (g)**	166.93	
5	**Weight of dry soil (W_2-W_1) (g)**	15.18	
6	**Weight of an equal volume of water(W2-W1)-(W3-W4)**	6.11	
7	**Specific gravity of the soil G= (5/6)**	**2.48**	
Date:05/03/2025		**Therefore Gs at 20 degree centigrade = K*Gt=0.9993*2.48= 2.478**	

Material :- 5% Fly Ash stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	5% Fly Ash and 95% Soil
1	Weight of Density bottle W_1 (g)	57
2	Weight of Density bottle with dry soil W_2(g)	73.45
3	Weight of Density bottle with dry soil and water W_3(g)	168.35
4	Weight of Density bottle full of water W_4 (g)	158.6
5	Weight of dry soil (W_2-W_1) (g)	16.45
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	6.7
7	Specific gravity of the soil G= (5/6)	2.46

Material :- 10%Fly Ash stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	10% Fly Ash and 90% Soil
1	Weight of Density bottle W_1 (g)	57
2	Weight of Density bottle with dry soil W_2(g)	72.14
3	Weight of Density bottle with dry soil and water W_3(g)	175.72

4	Weight of Density bottle full of water W_4 (g)	166.8
5	Weight of dry soil (W_2-W_1) (g)	15.14
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	6.22
7	Specific gravity of the soil G= (5/6)	2.43

Material :- 15% Fly Ash stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	15% Fly Ash and 85% Soil
1	Weight of Density bottle W_1 (g)	57
2	Weight of Density bottle with dry soil W_2(g)	74.5
3	Weight of Density bottle with dry soil and water W_3(g)	167.26
4	Weight of Density bottle full of water W_4 (g)	157.05
5	Weight of dry soil (W_2-W_1) (g)	17.5
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	7.29
7	Specific gravity of the soil G= (5/6)	2.40

Material :- 17.5% Fly Ash stabilizer application on the given soil		
Specific Gravity Determination		
		Sample No
S/N	Particulars	17.5% Fly Ash and 82.5% Soil
1	Weight of Density bottle W_1 (g)	57
2	Weight of Density bottle with dry soil W_2(g)	69.89
3	Weight of Density bottle with dry soil and water W_3(g)	164.45
4	Weight of Density bottle full of water W_4 (g)	156.98
5	Weight of dry soil (W_2-W_1) (g)	12.89
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	5.42
7	Specific gravity of the soil G= (5/6)	2.38

Material :- 20% Fly Ash application		
Specific Gravity Determination		
		Sample No
S/N	Particulars	20% Fly Ash and 80% soil
1	Weight of Density bottle W_1 (g)	57
2	Weight of Density bottle with dry soil W_2(g)	71.8
3	Weight of Density bottle with dry soil and water W_3(g)	166.14
4	Weight of Density bottle full of water W_4 (g)	157.63
5	Weight of dry soil (W_2-W_1) (g)	14.8
6	Weight of an equal volume of water(W2-W1)-(W3-W4)	6.29
7	Specific gravity of the soil G= (5/6)	2.35

Appendix-4: Specific Gravity test result

Adama Science and Technology University
College of Civil Engineering and Architecture
Department of Civil Engineering
Soil Lab

DETERMINATION OF FREE SWELL INDEX OF SOILS (IS 2720 part 40)

Description of Material : Expansive soil collected from Koye Feche Study area

Sampling No:- 01-06

Sampled Weigt passed through (0.075mm)=10gm

Tested by :- **Jiksa Mideksa done in ASTU**

Date of Testing: 28/**06/2017**

Determination No.	*Measuring Cylinder No.in mm*		*Reading After 24 Hours in mm*		*Free Swell Index ,%*
	Kerosene (V_k)	*Distilled Water (V_d)*	*Kerosene(V_k)*	*Distilled Water(V_d)*	
Untreated soil	10	10	10	23.8	138.00
5% Fly Ash	10	10	10	22	120.00
10% Fly Ash	9.9	10	9.9	20.5	107.07
15% Fly Ash	9.8	10	9.8	18	83.67
17.5% Fly Ash	10	10	10	16.9	69.00

20% Fly Ash	10	10	10	14.8	48

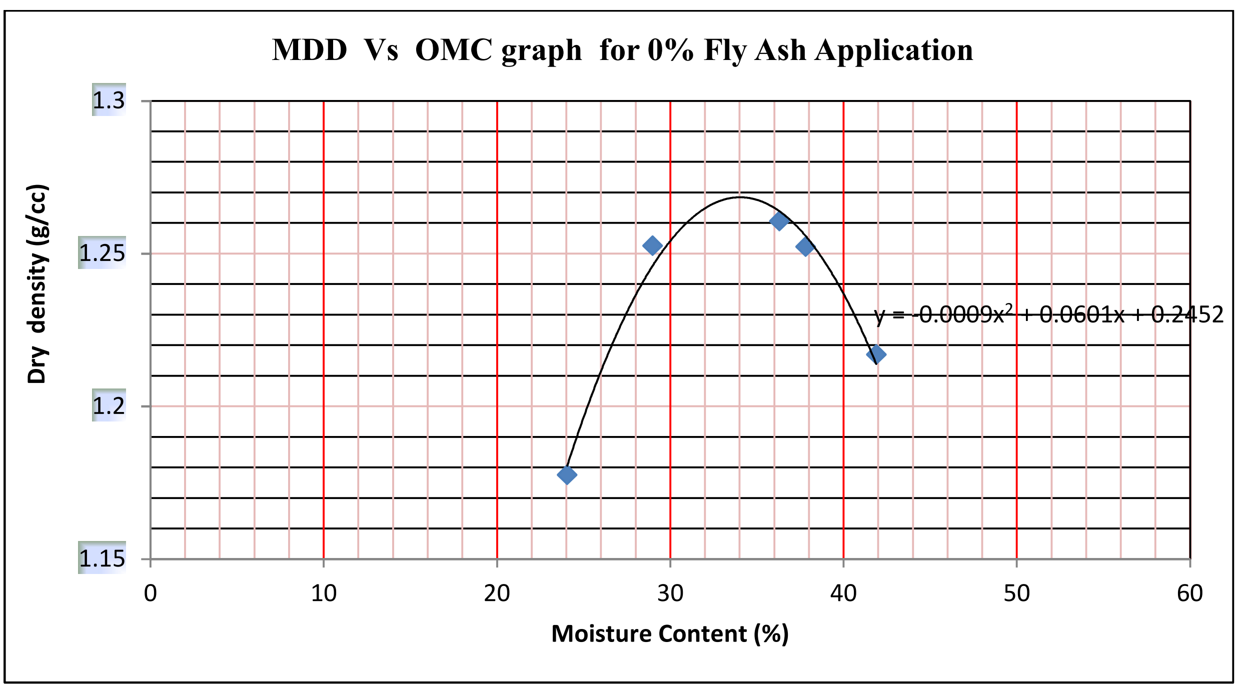
Appendix-5: Dry density-moisture Content test results

Project:- Soil Stabilization Research Project	Sample N0 :- 01
Client :-	Date Sampled :- 04/02/2025
Station:- Koye Feche Study Area	Date Tested :- 12/02/2025
Depth:- 1.5m	Date Issued :-
Material type:- Untreated expansive Subgrade soil	Lab .No:- 01

Moisture - Density relationship for 0% fly ash application on the given soil

As per AASHTO T 180 METHOD

Trial No	Mass of Compacted soil +mold	Mass of mold+baseplate (g)	Mass of Compacted Soil (g)	Volume of mold (cm3)	Wet unit weight (kn/m3)	Can No	Mass of wet Soil +can (g)	Mass of dry soil + can (g)	Mass of water (g)	Mass of can (g)	Mass of Dry Soil (g)	Moisture content (%)	Average moisture content (%)	Dry unit weight (kn/m3)
1st	5134	3755	1379	944	1.460805	G1	61.3	54.96	6.34	18.6	36.36	17.43674		
						G2	50.93	42.82	8.11	19.43	23.39	34.67294		
						G3	76.03	66.53	9.5	19.15	47.38	20.05065	24.05345	1.17756108
2nd	5280	3755	1525	944	1.615466	G4	52.27	43.55	8.72	19.37	24.18	36.06286		
						G5	69.41	59.18	10.23	19.43	39.75	25.73585		
						G6	66.64	57.15	9.49	19.39	37.76	25.13242	28.97704	1.25252221
3rd	5377	3755	1622	944	1.71822	G7	69.51	56.1	13.41	19.54	36.56	36.67943		
						G8	57.9	48.69	9.21	19.77	28.92	31.84647		
						G9	57.67	46.7	10.97	19.53	27.17	40.37541	36.30044	1.26061247
4th	5384	3755	1629	944	1.725636	G10	77.77	61.57	16.2	19.7	41.87	38.69119		
						G11	60.24	49.29	10.95	19.72	29.57	37.03077		
						G12	57.73	47.28	10.45	19.55	27.73	37.68482	37.80226	1.25225493
5th	5385	3755	1630	944	1.726695	G13	65.42	51.44	13.98	19.66	31.78	43.98993		
						G14	84.48	67.07	17.41	19.51	47.56	36.60639		
						G15	56.4	44.95	11.45	19.54	25.41	45.061	41.88577	1.21696127

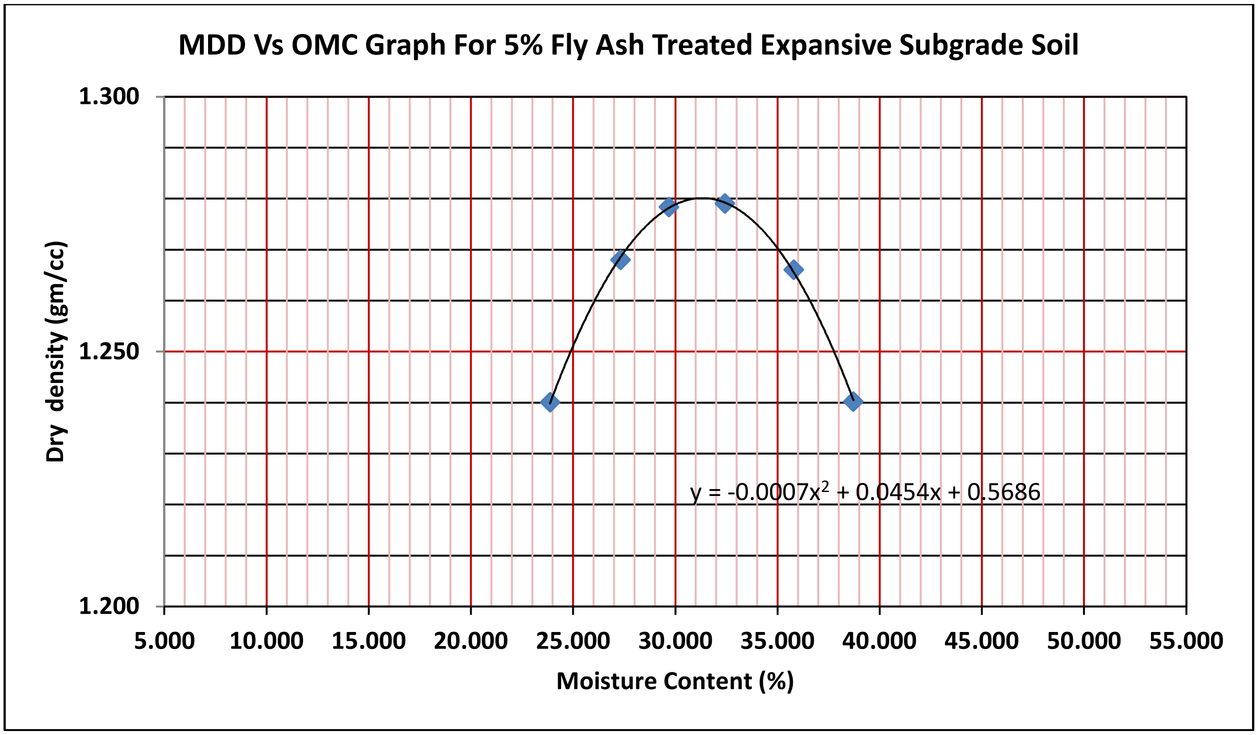


Project:- Soil Stabilization Research Project	Sample N0 :- 02
Client :-	Date Sampled :- 04/02/2025
Station:- Koye Feche Study Area	Date Tested :- 12/02/2025
Depth:- 1.5m	Date Issued :-
Material type:- 5% Fly Ash treated expansive Subgrade soil	Lab .No:- 02

MOISTURE - DENSITY RELATION OF SOIL FOR 5% FLY ASH APPLICATION

AASHTO T 180 METHOD C

Trial No	Mass of Compacted soil +mold (g)	Mass of mold+baseplate (g)	Mass of Compacted Soil (g)	Volume of mold (cm3)	Wet unit weight (kn/m3)	Can No	Mass of wet Soil +can (g)	Mass of dry soil + can (g)	Mass of water (g)	Mass of can (g)	Mass of Dry Soil (g)	Moisture content (%)	Average moisture content (%)	Dry unit weight (kn/m3)
1st	5205	3755	1450	944	1.536017	G16	89.5	74.9	14.6	19.59	55.31	26.39667		
						G17	89.5	77.2	12.3	19.55	57.65	21.33565		
						G18	89.6	76.1	13.5	19.55	56.55	23.87268	23.868	1.240
2nd	5279	3755	1524	944	1.614407	G19	85.6	74.05	11.55	19.34	54.71	21.11131		
						G20	72.72	64.2	8.52	19.5	44.7	19.0604		
						G21	83.92	65	18.92	19.72	45.28	41.78445	27.319	1.268
3rd	5320	3755	1565	944	1.657839	G22	89.94	74.67	15.27	19.58	55.09	27.71828		
						G23	75.96	62.61	13.35	19.58	43.03	31.02487		
						G24	70.52	58.68	11.84	19.61	39.07	30.30458	29.683	1.278
4th	5354	3755	1599	944	1.693856	G25	83.78	68.54	15.24	19.28	49.26	30.93788		
						G26	77.22	63.03	14.19	18.95	44.08	32.19147		
						G27	89.46	71.65	17.81	19.52	52.13	34.16459	32.431	1.279
5th	5378	3755	1623	944	1.71928	G28	95.37	76.09	19.28	18.85	57.24	33.68274		
						G29	89.42	66.69	22.73	19.6	47.09	48.26927		
						G30	106.33	88.74	17.59	19.61	69.13	25.44481	35.799	1.266
6th	5379	3755	1624	944	1.720339	G31	83	64.82	18.18	19.32	45.5	39.95604		
						G32	109.4	84.69	24.71	19.57	65.12	37.94533		
						G33	89.88	70.4	19.48	19.46	50.94	38.24107	38.71415	1.240

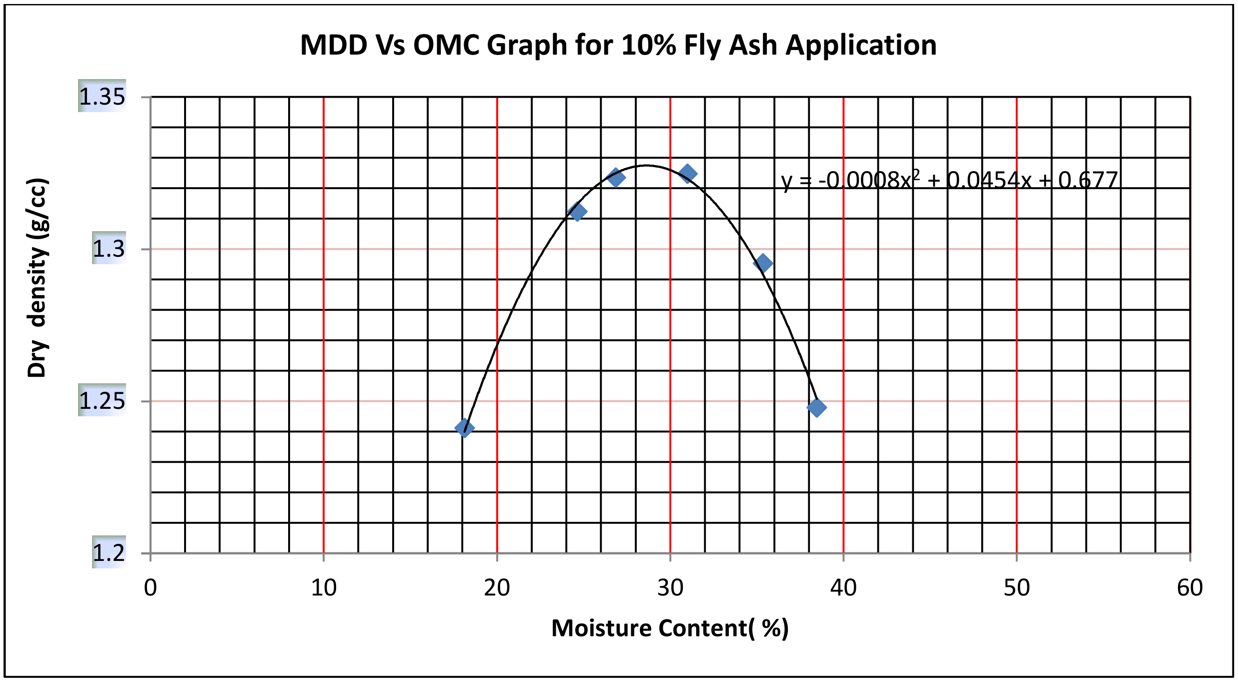


Project:- Soil Stabilization Research Project	Sample N0 :- 03
Client :-	Date Sampled :- 04/02/2025
Station:- Koye Feche Study Area	Date Tested :- 12/02/2025
Depth:- 1.5m	Date Issued :-
Material type:- 10% Fly Ash treated expansive Subgrade soil	Lab .No:- 03

MOISTURE - DENSITY RELATION OF SOIL FOR 10% FLY ASH APPLICATION

AASHTO T 180 METHOD C

Trial No	Mass of Compacted soil +mold	Mass of mold+baseplate (g)	Mass of Compacted Soil (g)	Volume of mold (cm3)	Wet unit weight (kn/m3)	Can No	Mass of wet Soil +can (g)	Mass of dry soil + can (g)	Mass of water (g)	Mass of can (g)	Mass of Dry Soil (g)	Moisture content (%)	Average moisture content (%)	Dry unit weight (kn/m3)
1st	5139	3755	1384	944	1.466102	1	138.1	122	16.1	30	92	17.5		
						2	116.9	104	12.9	30	74	17.43243		
						3	137.5	120	17.5	30	90	19.44444	18.12563	1.241138
2nd	5299	3755	1544	944	1.635593	4	85.2	74.1	11.1	29	45.1	24.61197		
						5	81.4	71.6	9.8	30	41.6	23.55769		
						6	76.9	67.3	9.6	30	37.3	25.73727	24.63564	1.3123
3rd	5340	3755	1585	944	1.679025	7	54.4	49.5	4.9	29	20.5	23.90244		
						8	75	63.9	11.1	29	34.9	31.80516		
						9	81.2	70.8	10.4	29	41.8	24.88038	26.86266	1.323499
4th	5393	3755	1638	944	1.735169	10	92	78	14	30	48	29.16667		
						11	114	90.4	23.6	30	60.4	39.07285		
						12	106.7	91.5	15.2	30	61.5	24.71545	30.98499	1.324709
5th	5410	3755	1655	944	1.753178	13	131	106.1	24.9	30	76.1	32.72011		
						14	136.8	107.3	29.5	30	77.3	38.163		
						15	139.5	111	28.5	30	81	35.18519	35.3561	1.295234
6th	5386	3755	1631	944	1.727754	16	135.5	108	27.5	30	78	35.25641		
						17	138.6	105	33.6	30	75	44.8		
						18	136.9	109	27.9	30	79	35.31646	38.45762	1.247858



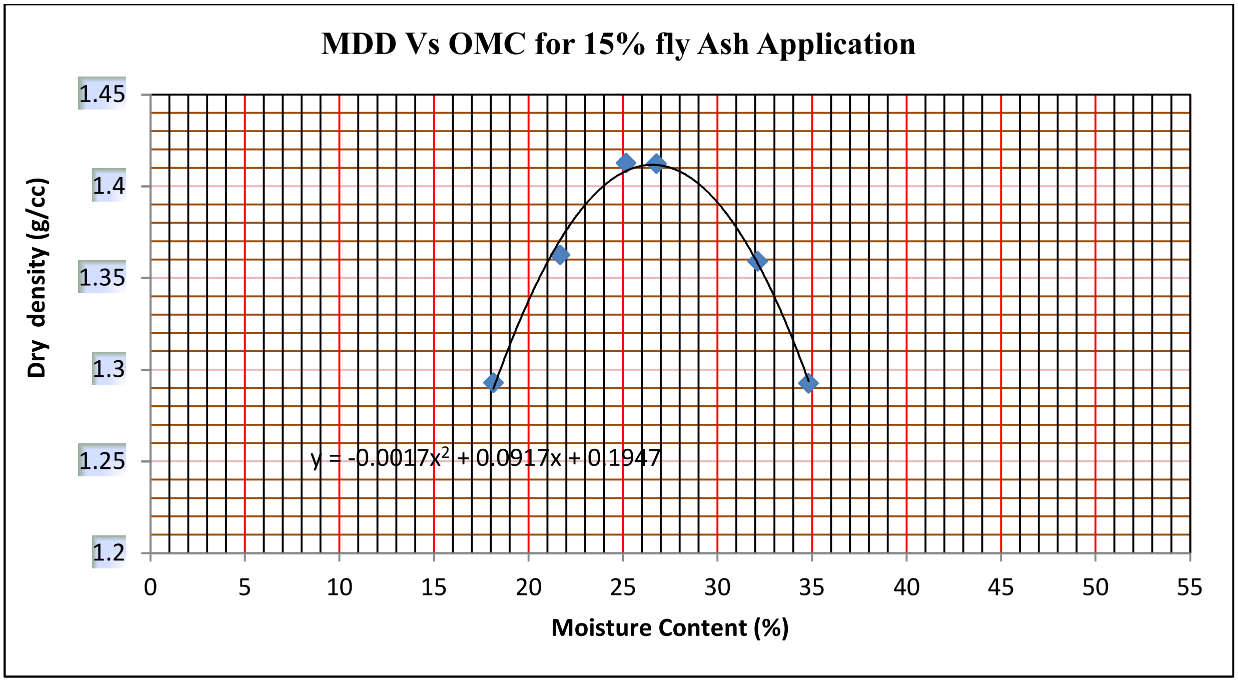
Project:- Soil Stabilization Research Project
Client :-
Station:- Koye Feche Study Area
Depth:- 1.5m
Material type:- 15% Fly Ash treated expansive Subgrade soil

Sample N0 :- 04
Date Sampled :- 04/02/2025
Date Tested :- 14/02/2025
Date Issued :-
Lab .No:- 04

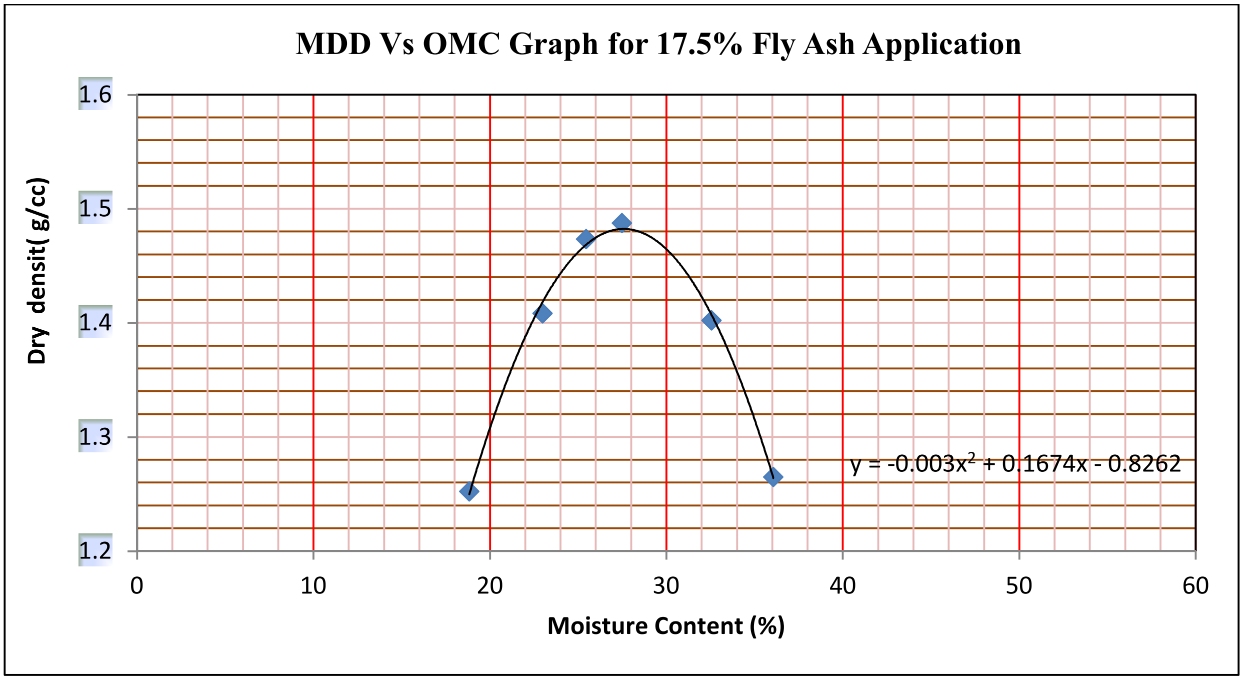
MOISTURE - DENSITY RELATION OF SOIL FOR 15% FLY ASH APPLICATION

AASHTO T 180 METHOD C

Trial No	Mass of Compacted soil +mold	Mass of mold+baseplate (g)	Mass of Compacted Soil (g)	Volume of mold (cm3)	Wet unit weight (kn/m3)	Can No	Mass of wet Soil +can (g)	Mass of dry soil + can (g)	Mass of water (g)	Mass of can (g)	Mass of Dry Soil (g)	Moisture content (%)	Average moisture content (%)	Dry unit weight (kn/m3)
1st	5197	3755	1442	944	1.527542	1	91	79.5	11.5	19	60.5	19.00826		
						2	84.5	73.5	11	19	54.5	20.18349		
						3	80.5	72.5	8	20	52.5	15.2381	18.14328	1.292957
2nd	5320	3755	1565	944	1.657839	4	96.4	85.5	10.9	30	55.5	19.63964		
						5	76	67.4	8.6	31	36.4	23.62637		
						6	91	80.1	10.9	30	50.1	21.75649	21.67417	1.362523
3rd	5424	3755	1669	944	1.768008	7	66.4	51	15.4	18	33	46.66667		
						8	59.5	54	5.5	19	35	15.71429		
						9	65.5	60	5.5	18	42	13.09524	25.15873	1.412613
4th	5445	3755	1690	944	1.790254	10	68.6	57	11.6	19	38	30.52632		
						11	87	73.5	13.5	19	54.5	24.77064		
						12	82	69.2	12.8	18	51.2	25	26.76565	1.412255
5th	5450	3755	1695	944	1.795551	13	132.9	112.5	20.4	29	83.5	24.43114		
						14	129.8	108.6	21.2	30	78.6	26.97201		
						15	103.5	80.4	23.1	29	51.4	44.94163	32.11493	1.359082
6th	5400	3755	1645	944	1.742585	16	128	100.5	27.5	30	70.5	39.00709		
						17	128	103	25	30	73	34.24658		
						18	120	98.6	21.4	30	68.6	31.19534	34.81633	1.292562



Project:- Soil Stabilization Research Project											Sample N0 :- 05			
Client :-											Date Sampled :- 04/02/2025			
Station:- Koye Feche Study Area											Date Tested :- 14/02/2025			
Depth:- 1.5m											Date Issued :-			
Material type:- 17.5% Fly Ash treated expansive Subgrade soil											Lab .No:- 05			
MOISTURE - DENSITY RELATION OF SOIL FOR 17.5% FLY ASH APPLICATION AASHTO T 180 METHOD C														
Trial No	Mass of Compacted soil +mold	Mass of mold+baseplate (g)	Mass of Compacted Soil (g)	Volume of mold (cm3)	Wet unit weight (kn/m3)	Can No	Mass of wet Soil +can (g)	Mass of dry soil + can (g)	Mass of water (g)	Mass of can (g)	Mass of Dry Soil (g)	Moisture content (%)	Average moisture content (%)	Dry unit weight (kn/m3)
1st	5160	3755	1405	944	1.488347	1	107.4	95.5	11.9	30	65.5	18.16794		
						2	106.8	94.5	12.3	30	64.5	19.06977		
						3	104.4	90.45	13.95	18	72.45	19.25466	18.83079	1.252493
2nd	5390	3755	1635	944	1.731992	4	78.9	67.54	11.36	18	49.54	22.93096		
						5	74.5	63.5	11	18	45.5	24.17582		
						6	79.9	68.8	11.1	18	50.8	21.85039	22.98573	1.408287
3rd	5500	3755	1745	944	1.848517	7	57.9	50.6	7.3	19	31.6	23.10127		
						8	62.5	53.5	9	19	34.5	26.08696		
						9	84	69.9	14.1	18	51.9	27.16763	25.45195	1.473486
4th	5545	3755	1790	944	1.896186	10	73.5	62.5	11	18	44.5	24.7191		
						11	85	70.4	14.6	18	52.4	27.8626		
						12	68	56.5	11.5	18	38.5	29.87013	27.48394	1.487392
5th	5510	3755	1755	944	1.85911	13	94	78.5	15.5	31	47.5	32.63158		
						14	107	88	19	30	58	32.75862		
						15	117.6	96.2	21.4	30	66.2	32.32628	32.57216	1.402338
6th	5380	3755	1625	944	1.721398	16	129	100.1	28.9	30	70.1	41.22682		
						17	128	104.8	23.2	30	74.8	31.01604		
						18	134	106.5	27.5	30	76.5	35.94771	36.06352	1.265143



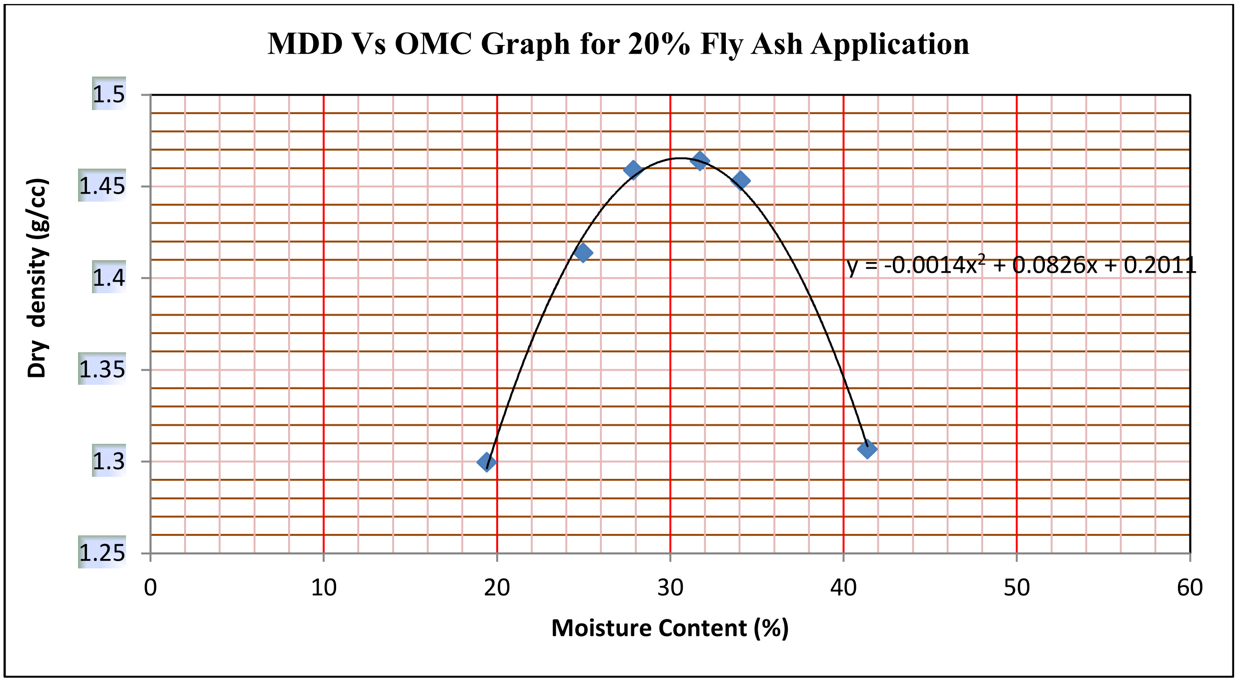
Project:- Soil Stabilization Research Project
Client :-
Station:- Koye Feche Study Area
Depth:- 1.5m
Material type:- 20% Fly Ash treated expansive Subgrade soil

Sample N0 :- 06
Date Sampled :- 04/02/2025
Date Tested :- 14/02/2025
Date Issued :-
Lab .No:- 06

MOISTURE - DENSITY RELATION OF SOIL FOR 20% FLY ASH APPLICATION

AASHTO T 180 METHOD C

Trial No	Mass of Compacted soil +mold	Mass of mold+baseplate (g)	Mass of Compacted Soil (g)	Volume of mold (cm3)	Wet unit weight (kn/m3)	Can No	Mass of wet Soil +can (g)	Mass of dry soil + can (g)	Mass of water (g)	Mass of can (g)	Mass of Dry Soil (g)	Moisture content (%)	Average moisture content (%)	Dry unit weight (kn/m3)
1st	5220	3755	1465	944	1.551907	1	72.5	60.7	11.8	18	42.7	27.635		
						2	80.7	73	7.7	19	54	14.259		
						3	67	60.4	6.6	20	40.4	16.337	19.41018	1.299644
2nd	5423	3755	1668	944	1.766949	4	80.3	70.2	10.1	19	51.2	19.727		
						5	78	60	18	18	42	42.857		
						6	64.5	59.5	5	19	40.5	12.346	24.97646	1.413826
3rd	5516	3755	1761	944	1.865466	7	64	54.5	9.5	19	35.5	26.761		
						8	76	62.5	13.5	18	44.5	30.337		
						9	82.9	69.5	13.4	19	50.5	26.535	27.87743	1.458792
4th	5575	3755	1820	944	1.927966	10	80	65.5	14.5	18	47.5	30.526		
						11	80.4	67	13.4	18	49	27.347		
						12	68	54.7	13.3	19	35.7	37.255	31.70939	1.463803
5th	5594	3755	1839	944	1.948093	13	120	98.5	21.5	29	69.5	30.935		
						14	105	84.5	20.5	30	54.5	37.615		
						15	117.2	95	22.2	29	66	33.636	34.0621	1.453128
6th	5499	3755	1744	944	1.847458	16	129	98.5	30.5	30	68.5	44.526		
						17	133	103.4	29.6	30	73.4	40.327		
						18	126.8	99.5	27.3	30	69.5	39.281	41.3777	1.306753



Appendix-6: Soaked CBR values test result for various ratios of fly ash application

CALIFORNIA BEARING RATIO (One Point Method)				AASHTO T 193 - 93	
DENSITY DETERMINATION					
Soaking Condition				**56 Blows**	
				Before	After
Mold Number				J2	J2
Weight of Soil + Mold (g)	**W_1**			9460	10105
Weight of Mold (g)	**W_2**			5818	6423
Volume of Mold (cm^3)	**V**			2124	2124
Weight of Wet Soil (g)	**$W_3 = W_1 - W_2$**			3642	3682
Wet Density of Soil (g/cm^3)	**$W_d = (W_3/V)$**			1.71	1.73
Dry Density of Soil (g/cm^3)	**$D_d = W_d/(100+J)*100$**			1.28	1.26

MOISTURE CONTENT DETERMINATION				
Soaking Condition		**56 Blows**		
		Before	After	
			TOP 1 in.	AVG.
Container Number		B8	A4	
Mass of Container + Wet Soil (gm)	E	66.7	74.23	70.47
Mass of Container + Dry Soil (gm)	F	54.3	59.0	56.65
Mass of Container (gm)	G	18.0	18.1	18.05
Mass of Dry Soil (gm)	H = F - G	36.3	40.9	38.61
Mass of Water (gm)	I = E - F	12.4	15.2	13.82
Moisture Content (%)	J = (I/H)* 100	34.16	37.23	35.69

Description: 0% Fly Ash application, Untreated Expansive Soil	Koye Feche Study Area	
Sample Ref:		Depth:1.5m
Tested By:		

PENETRATION TEST DATA				
Penetration	**56 Blows**			
(mm)	Dial Reading	Load (N)	Corr. Load (KN)	**CBR %**
0	0	0		
0.64	4.0	0.07176		
1.27	9.5	0.17043		
1.91	15.4	0.276276		
2.54	19.9	0.357006	0.36	2.70
3.18	23.4	0.419796		
3.81	26.0	0.46644		
4.45	27.9	0.500526		
5.08	29.6	0.531024	0.53	2.66
7.62	34.4	0.617136		
10.16	38	0.68172		

CBR SWELL				
No. of Blows 56				
	Time	Date	time	Swell
Reading (Before Soaking)	0	01/03/2025	9:00AM	0
Reading (After Soaking)	24	02/03/2025	9:00AM	2
	48	03/03/2025	9:00AM	3.39
	72	04/03/2025	9:00AM	4.79
	96	05/03/2025	9:00AM	5.94
Swell (%)	**5.10**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.36	0.53	2.70	2.66	**5.10**

CALIFORNIA BEARING RATIO (One Point Method)			AASHTO T 193 - 93	
DENSITY DETERMINATION				
Soaking Condition			**56 Blows**	
			Before	After
Mold Number			J1	J1
Weight of Soil + Mold (g)		W_1	9410	10046
Weight of Mold (g)		W_2	5818	6423
Volume of Mold (cm^3)		V	2124	2124
Weight of Wet Soil (g)		$W_3 = W_1 - W_2$	3592	3623
Wet Density of Soil (g/cm^3)		$W_d = (W_3/V)$	1.69	1.71
Dry Density of Soil (g/cm^3)		$D_d = W_d/(100+J)*100$	1.29	1.27

MOISTURE CONTENT DETERMINATION					
Soaking Condition			**56 Blows**		
			Before	After	AVG.
Container Number			A-1	A-2	
Mass of Container + Wet Soil (gm)		A	78.6	79	
Mass of Container + Dry Soil (gm)		B	64.3	63.7	
Mass of Container (gm)		C	18.9	18.9	
Mass of Dry Soil (gm)		D = B - C	45.4	44.8	
Mass of Water (gm)		E = A - B	14.3	15.3	
Moisture Content (%)		F = (E/D)* 100	31.48	34.14	

Description: 5% Fly Ash application, treated Expansive Soil	Koye Feche Study Area
Sample Ref:	Depth:1.5m

PENETRATION TEST DATA				
Penetration	**56 Blows**			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	5.0	0.090		
1.27	10.5	0.188		
1.91	16.9	0.303		
2.54	22.1	0.396	0.40	3.00
3.18	25.5	0.457		
3.81	28.4	0.509		
4.45	30.9	0.554		
5.08	33.0	0.592	0.59	2.96
7.62	37.5	0.673		
10.16	41	0.736		

CBR SWELL				
No. of Blows 56				
	Time	Date	time	Swell
Reading (Before Soaking)	0	01/03/2025	9:00AM	0
Reading (After Soaking)	24	02/03/2025	9:00AM	2.1
	48	03/03/2025	9:00AM	3.12
	72	04/03/2025	9:00AM	4.50
	96	05/03/2025	9:00AM	5.4
Swell (%)	**4.64**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.40	0.59	3.00	2.96	**4.64**

CALIFORNIA BEARING RATIO (One Point Method)		AASHTO T 193 - 93	
DENSITY DETERMINATION			
Soaking Condition		**56 Blows**	
		Before	After
Mold Number		J2	J2
Weight of Soil + Mold (g)	W_1	9496	10140
Weight of Mold (g)	W_2	5818	6423
Volume of Mold (cm^3)	V	2124	2124
Weight of Wet Soil (g)	$W_3 = W_1 - W_2$	3678	3717
Wet Density of Soil (g/cm^3)	$W_d = (W_3/V)$	1.73	1.75
Dry Density of Soil (g/cm^3)	$D_d = W_d/(100+J)*100$	1.35	1.32

MOISTURE CONTENT DETERMINATION				
Soaking Condition		**56 Blows**		
		Before	After	AVG.
Container Number		A-3	A-4	
Mass of Container + Wet Soil (gm)	A	49.8	62.5	
Mass of Container + Dry Soil (gm)	B	42.75	51.5	
Mass of Container (gm)	C	18.1	18.1	
Mass of Dry Soil (gm)	D = B - C	24.7	33.5	
Mass of Water (gm)	E = A - B	7.05	11.0	
Moisture Content (%)	F = (E/D)* 100	28.54	32.88	

Description: 10% Fly Ash application, treated Expansive Soil	Koye Feche Study Area
Sample Ref:	Depth:1.5m
Tested By: Jointly	

PENETRATION TEST DATA				
Penetration	**56 Blows**			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	5.5	0.099		
1.27	12.5	0.224		
1.91	20.8	0.373		
2.54	27.3	0.490	0.49	3.71
3.18	32.6	0.585		
3.81	36.7	0.658		
4.45	39.1	0.701		
5.08	41.0	0.736	0.74	3.68
7.62	46.0	0.825		
10.16	50	0.897		

CBR SWELL				
No. of Blows 56				
	Time	Date	time	Swell
Reading (Before Soaking)	0	05/03/2025	3:00PM	0
Reading (After Soaking)	24	06/03/2025	3:00PM	1.9
	48	07/03/2025	3:00PM	3
	72	08/03/2025	3:00PM	4.12
	96	09/03/2025	3:00PM	4.7
Swell (%)	**4.04**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL**
	2.54mm	5.08mm	2.54mm	5.08mm	**%**
56	0.49	0.74	3.71	3.68	**4.04**

CALIFORNIA BEARING RATIO (One Point Method)		AASHTO T 193 - 93	
DENSITY DETERMINATION			
Soaking Condition		**56 Blows**	
		Before	After
Mold Number		J1	J1
Weight of Soil + Mold (g)	W_1	9696	10280
Weight of Mold (g)	W_2	5818	6423
Volume of Mold (cm^3)	V	2124	2124
Weight of Wet Soil (g)	$W_3 = W_1 - W_2$	3878	3857
Wet Density of Soil (g/cm^3)	$W_d = (W_3/V)$	1.83	1.82
Dry Density of Soil (g/cm^3)	$D_d = W_d/(100+J)*100$	1.43	1.39

MOISTURE CONTENT DETERMINATION

Soaking Condition		**56 Blows**		
		Before	After	AVG.
Container Number		B-1	B-2	
Mass of Container + Wet Soil (gm)	A	51.5	61.6	
Mass of Container + Dry Soil (gm)	B	44.26	51.5	
Mass of Container (gm)	C	18.1	18.1	
Mass of Dry Soil (gm)	D = B - C	26.2	33.5	
Mass of Water (gm)	E = A - B	7.24	10.1	
Moisture Content (%)	F = (E/D)* 100	27.62	30.19	

Description: 15% Fly Ash application, treated Expansive Soil	Koye Feche Study Area
Sample Ref:	Depth:1.5m

PENETRATION TEST DATA

Penetration	**56 Blows**			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	10.0	0.179		
1.27	18.5	0.332		
1.91	25.8	0.463		
2.54	32.0	0.574	0.57	4.35
3.18	37.3	0.669		
3.81	41.0	0.736		
4.45	44.3	0.795		
5.08	47.0	0.843	0.84	4.22
7.62	57.4	1.030		
10.16	67	1.202		

CBR SWELL

No. of Blows 56

	Time	Date	time	Swell
Reading (Before Soaking)	0	05/03/2025	3:00PM	0
Reading (After Soaking)	24	06/03/2025	3:00PM	1.78
	48	07/03/2025	3:00PM	2.87
	72	08/03/2025	3:00PM	3.80
	96	09/03/2025	3:00PM	4.2
Swell (%)	**3.61**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.57	0.84	4.35	4.22	**3.61**

CALIFORNIA BEARING RATIO (One Point Method)		AASHTO T 193 - 93	
DENSITY DETERMINATION			
Soaking Condition		**56 Blows**	
		Before	After
Mold Number		J1	J2
Weight of Soil + Mold (g)	W_1	9890	10480
Weight of Mold (g)	W_2	5818	6423
Volume of Mold (cm^3)	V	2124	2124
Weight of Wet Soil (g)	$W_3 = W_1 - W_2$	4072	4057
Wet Density of Soil (g/cm^3)	$W_d = (W_3/V)$	1.92	1.91
Dry Density of Soil (g/cm^3)	$D_d = W_d/(100+J)*100$	1.51	1.47

MOISTURE CONTENT DETERMINATION				
Soaking Condition		**56 Blows**		
		Before	After	AVG.
Container Number		B-3	B-4	
Mass of Container + Wet Soil (gm)	A	58.7	62.9	
Mass of Container + Dry Soil (gm)	B	50.1	52.5	
Mass of Container (gm)	C	18.1	18.1	
Mass of Dry Soil (gm)	D = B - C	32.1	34.5	
Mass of Water (gm)	E = A - B	8.6	10.4	
Moisture Content (%)	F = (E/D)* 100	26.83	30.19	

Description: 17.5% Fly Ash application, treated Expansive Soil	Koye Feche Study Area
Sample Ref:	Depth:1.5m

PENETRATION TEST DATA				
Penetration	**56 Blows**			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	8.0	0.144		
1.27	18.5	0.332		
1.91	29.0	0.520		
2.54	36.8	0.660	0.66	5.00
3.18	43.2	0.775		
3.81	48.0	0.861		
4.45	52.5	0.942		
5.08	55.0	0.987	0.99	4.93
7.62	63.5	1.139		
10.16	69.5	1.247		

CBR SWELL				
No. of Blows 56				
	Time	Date	time	Swell
Reading (Before Soaking)	0	01/03/2025	9:00AM	0
Reading (After Soaking)	24	02/03/2025	9:00AM	1.64
	48	03/03/2025	9:00AM	2.6
	72	04/03/2025	9:00AM	3.20
	96	05/03/2025	9:00AM	3.94
Swell (%)	**3.38**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.66	0.99	5.00	4.93	**3.38**

CALIFORNIA BEARING RATIO (One Point Method)			AASHTO T 193 - 93	
DENSITY DETERMINATION				
Soaking Condition			**56 Blows**	
			Before	After
Mold Number			J1	J1
Weight of Soil + Mold (g)		**W_1**	9910	10490
Weight of Mold (g)		**W_2**	5818	6423
Volume of Mold (cm^3)		**V**	2124	2124
Weight of Wet Soil (g)		**$W_3 = W_1 - W_2$**	4092	4067
Wet Density of Soil (g/cm^3)		**$W_d = (W_3/V)$**	1.93	1.91
Dry Density of Soil (g/cm^3)		**$D_d = W_d/(100+J)*100$**	1.48	1.44

MOISTURE CONTENT DETERMINATION				
Soaking Condition		**56 Blows**		
		Before	After	AVG.
Container Number		B-5	B-6	
Mass of Container + Wet Soil (gm)	A	49.4	56	
Mass of Container + Dry Soil (gm)	B	42.2	46.5	
Mass of Container (gm)	C	18.1	18.1	
Mass of Dry Soil (gm)	D = B - C	24.2	28.5	
Mass of Water (gm)	E = A - B	7.2	9.5	
Moisture Content (%)	F = (E/D)* 100	29.81	33.39	

Description: 20% Fly Ash application, treated Expansive Soil	Koye Feche Study Area
Sample Ref:	Depth:1.5m

PENETRATION TEST DATA				
Penetration	**56 Blows**			
(mm)	Dial Readin	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	9.5	0.170		
1.27	20.6	0.370		
1.91	32.0	0.574		
2.54	40.0	0.718	0.72	5.44
3.18	46.3	0.831		
3.81	51.5	0.924		
4.45	56.0	1.005		
5.08	59.3	1.064	1.06	5.32
7.62	68.0	1.220		
10.16	76	1.363		

CBR SWELL				
No. of Blows 56				
	Time	Date	time	Swell
Reading (Before Soaking)	0	21/03/2025	9:00AM	0
Reading (After Soaking)	24	22/03/2025	9:00AM	1.62
	48	23/03/2025	9:00AM	2.57
	72	24/03/2025	9:00AM	3.50
	96	25/03/2025	9:00AM	3.7
Swell (%)	**3.18**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.72	1.06	5.44	5.32	**3.18**

CALIFORNIA BEARING RATIO (One Point Method)					AASHTO T 193 - 93
Description: 0% Fly Ash application and First layer (30mm from top) geogrid inclusion , treated Expansive Subgrade Soil Soaked CBR test					Koye Feche Study Area
					Depth:1.5m

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	8.0	0.144		
1.27	19.5	0.350		
1.91	33.5	0.601		
2.54	45.4	0.814	0.81	6.17
3.18	53.4	0.958		
3.81	59.5	1.067		
4.45	64.2	1.152		
5.08	68.2	1.224	1.22	6.12
7.62	80.0	1.435		
10.16	90.1	1.616		

CBR SWELL

No. of Blows 56				
	Time	Date	time	Swell
Reading (Before Soaking)	0	17/03/2025	3:00PM	0
Reading (After Soaking)	24	18/03/2025	3:00PM	1.5
	48	19/03/2025	3:00PM	2.6
	72	20/03/2025	3:00PM	3.10
	96	21/03/2025	3:00AM	3.4
Swell (%)	**2.92**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.81	1.22	6.17	6.12	**2.92**

CALIFORNIA BEARING RATIO (One Point Method)					AASHTO T 193 - 93
Description: 0% Fly Ash application and second layer (at 60 mm from top) geogrid inclusion treated expansive subgradesSoil soaked CBR test					Koye Feche Study Area
					Depth:1.5m

PENETRATION TEST DATA				
Penetration	56 Blows			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	CBR %
0	0	0.000		
0.64	8.2	0.147		
1.27	17.6	0.316		
1.91	27.8	0.499		
2.54	36.0	0.646	0.65	4.89
3.18	42.4	0.761		
3.81	46.1	0.827		
4.45	48.7	0.874		
5.08	50.4	0.904	0.90	4.52
7.62	55.6	0.997		
10.16	60	1.076		

CBR SWELL					
No. of Blows 56					
	Time	Date	time	Swell	
Reading (Before Soaking)	0	17/03/2025	3:00PM	0	
Reading (After Soaking)	24	18/03/2025	3:00PM	2.7	
	48	19/03/2025	3:00PM	3.2	
	72	20/03/2025	3:00PM	3.7	
	96	21/03/2025	3:00AM	4.1	
Swell (%)	**3.52**				

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	0.65	0.90	4.89	4.52	**3.52**

CALIFORNIA BEARING RATIO (One Point Method)					AASHTO T 193 - 93
Description: 17.5% Fly Ash application and First layer (at 30 mm from top) geogrid inclusion treated expansive subgradesSoil soaked CBR test					Koye Feche Study Area Depth:1.5m

PENETRATION TEST DATA				
Penetration	**56 Blows**			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	14.0	0.251		
1.27	32.0	0.574		
1.91	56.5	1.014		
2.54	76.0	1.363	1.36	10.33
3.18	90.0	1.615		
3.81	100.0	1.794		
4.45	106.0	1.902		
5.08	110.0	1.973	1.97	9.87
7.62	122.0	2.189		
10.16	132	2.368		

CBR SWELL					
No. of Blows 56					
	Time	Date	time	Swell	
Reading (Before Soaking)	0	24/03/2025	3:00PM	0	
Reading (After Soaking)	24	25/03/2025	3:00PM	1.4	
	48	26/03/2025	3:00PM	1.85	
	72	27/03/2025	3:00PM	2.1	
	96	28/03/2025	3:00AM	2.3	
Swell (%)	**1.98**				

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	1.36	1.97	10.33	9.87	**1.98**

CALIFORNIA BEARING RATIO (One Point Method)					AASHTO T 193 - 93
Description: 17.5% Fly Ash application and Second layer (at 60 mm from top) geogrid inclusion treated expansive subgradesSoil soaked CBR test					Koye Feche Study Area Depth:1.5m

PENETRATION TEST DATA

Penetration	56 Blows			
(mm)	Dial Reading	Load (KN)	Corr. Load (KN)	**CBR %**
0	0	0.000		
0.64	17.5	0.314		
1.27	34.0	0.610		
1.91	47.5	0.852		
2.54	58.5	1.049	1.05	7.95
3.18	68.5	1.229		
3.81	75.6	1.356		
4.45	80.0	1.435		
5.08	84.5	1.516	1.52	7.58
7.62	95.0	1.704		
10.16	103.5	1.857		

CBR SWELL

No. of Blows 56

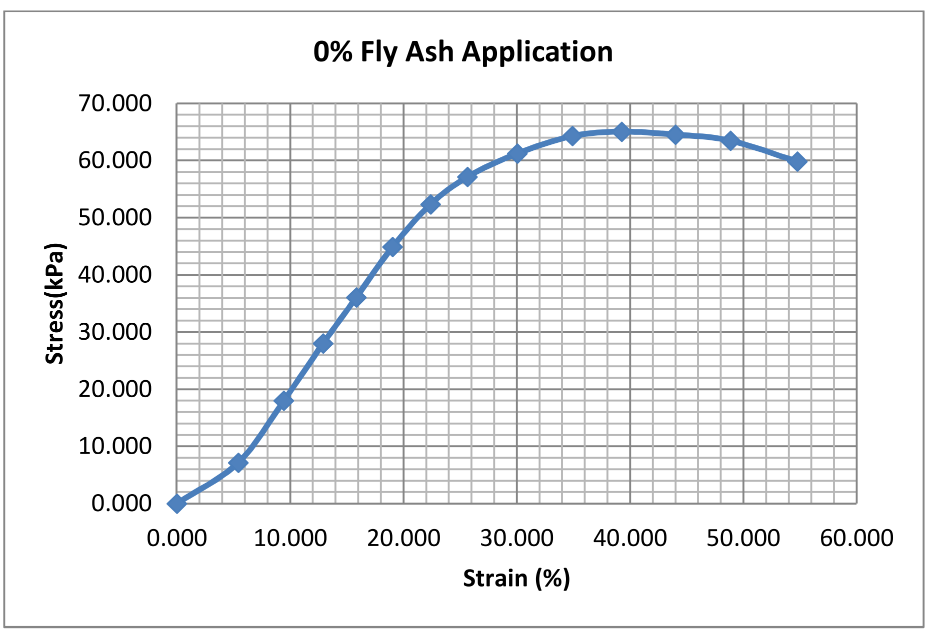
	Time	Date	time	Swell
Reading (Before Soaking)	0	24/03/2025	3:00PM	0
Reading (After Soaking)	24	25/03/2025	3:00PM	1.85
	48	26/03/2025	3:00PM	2.3
	72	27/03/2025	3:00PM	2.6
	96	28/03/2025	3:00AM	2.88
Swell (%)	**2.47**			

Blows	**Load (KN)**		**CBR(%)**		**SWELL %**
	2.54mm	5.08mm	2.54mm	5.08mm	
56	1.05	1.52	7.95	7.58	**2.47**

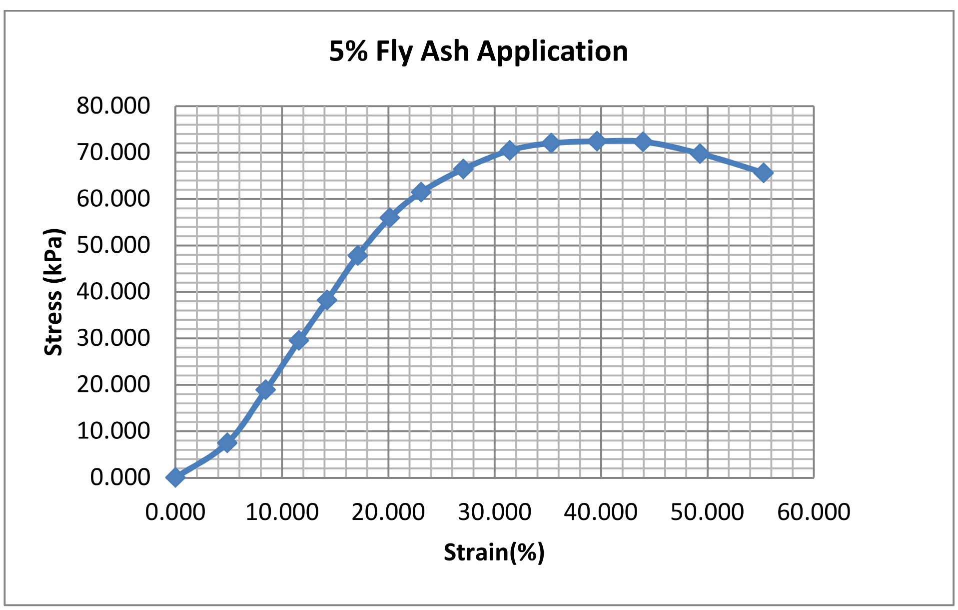
Appenddix-7: Unconfined compressive strength test result for various fly ash ratios

UNCONFINED COMPRESSION TEST				
Data Sheet				
Tested Date :-28/06/2017				
Project Name :-UCS test for 0% Fly Ash Application (Thesis Research)				
Test Station :- Koye Feche, at 1.5m depth				
Sample Number:- 01				
Diameter (D) (cm)	**3.80**	**3.80**		
Length (L_o) (cm)	**7.60**	**7.60**	**KN/M2= Kpa**	
Mass (M) (gram)	**177.17**	**177.17**		
Area (A_o)= ((3.142*$d^{2)}$/(4)) cm^2	**11.335**	**11.335**	0.0011335	0.00113354
Volume (V) = A_0*L_0	**86.15**	**86.15**		

Reading No.	**Time (dd:hh:mm:ss)**	**Sample Deformation (mm)**	**Strain (ΔL/L0)**	**Strain %**	**Corrected Area A_c= ((A_0)/(1-Σ))**	**Load (N)**	**Load (kN)**	**Stress (Kpa)**
2	00.00.00.01	0.000	**0.00000**	**0.000**	0.001134	0.000	0.000	0.000
3	00.00.00.27	0.412	**0.05418**	**5.418**	0.001198	8.568	0.009	7.149
4	00.00.00.43	0.717	**0.09436**	**9.436**	0.001252	22.500	0.023	17.976
5	00.00.01.22	0.980	**0.12899**	**12.899**	0.001301	36.414	0.036	27.981
6	00.00.01.58	1.203	**0.15833**	**15.833**	0.001347	48.552	0.049	36.051
7	00.00.02.48	1.446	**0.19031**	**19.031**	0.001400	62.832	0.063	44.881
8	00.00.03.14	1.701	**0.22388**	**22.388**	0.001461	76.398	0.076	52.309
9	00.00.03.32	1.949	**0.25639**	**25.639**	0.001524	87.108	0.087	57.144
10	00.00.03.44	2.284	**0.30053**	**30.053**	0.001621	99.246	0.099	61.242
11	00.00.04.03	2.654	**0.34916**	**34.916**	0.001742	111.956	0.112	64.281
12	00.00.04.18	2.983	**0.39251**	**39.251**	0.001866	121.380	0.121	65.050
13	00.00.04.32	3.345	**0.44009**	**44.009**	0.002024	130.662	0.131	64.541
14	00.00.04.45	3.712	**0.48846**	**48.846**	0.002216	140.658	0.141	63.476
15	00.00.05.00	4.162	**0.54766**	**54.766**	0.002506	149.940	0.150	59.833
16	00.00.05.15	4.668	**0.61427**	**61.427**	0.002939	159.936	0.160	54.424
17	00.00.05.30	5.191	**0.68299**	**68.299**	0.003576	169.218	0.169	47.324



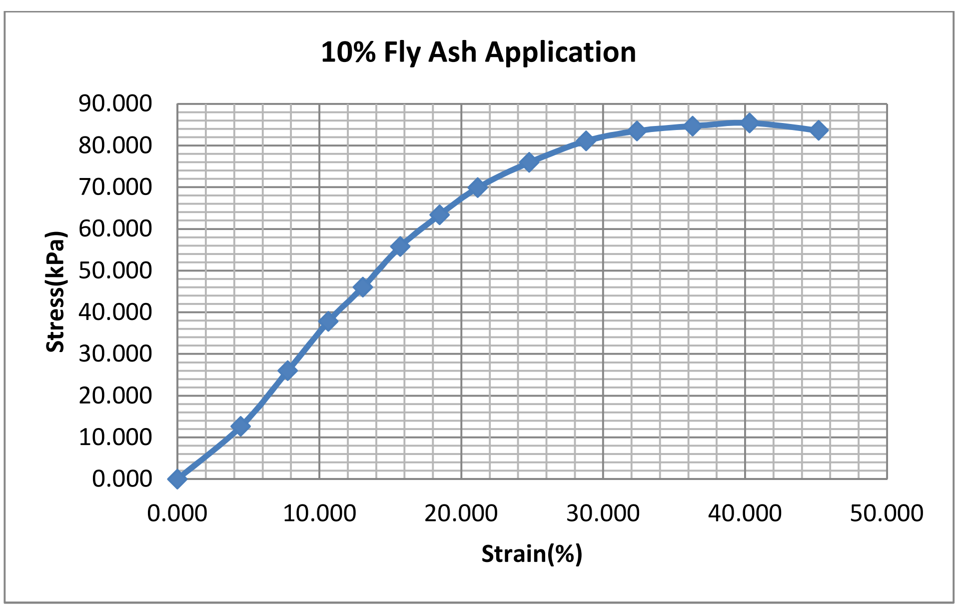
UNCONFINED COMPRESSION TEST								
Data Sheet								
Tested Date :-28/06/2017								
Project Name :-UCS test for 5% Fly Ash Application (Thesis Research)								
Test Station :- Koye Feche, at 1.5m depth								
Sample Number:- 02								
Diameter (D) (cm)					3.80	3.80		
Length (L_o) (cm)					7.60	7.60	KN/M2= Kpa	
Mass (M) (gram)					177.17	177.17		
Area (A_o)= $((3.142*d^{2)}/(4))$ cm^2					11.335	11.335	0.00113354	0.00113354
Volume (V) = A_0*L_0					86.15	86.15		
Reading No.	**Time (dd:hh:mm:ss)**	**Sample Deformation (mm)**	**Strain ($\Delta L/L0$)**	**Strain %**	**Corrected Area A_c= $((A_0)/(1-\Sigma))$**	**Load (N)**	**Load (kN)**	**Stress (Kpa)**
1	00.00.00.00	0.000	**0.00000**	**0.000**	0.001134	0.000	0.000	0.000
2	00.00.00.36	0.371	**0.04877**	**4.877**	0.001192	8.911	0.009	7.478
3	00.00.00.56	0.645	**0.08492**	**8.492**	0.001239	23.400	0.023	18.890
4	00.00.01.22	0.882	**0.11609**	**11.609**	0.001282	37.871	0.038	29.531
5	00.00.01.45	1.083	**0.14249**	**14.249**	0.001322	50.494	0.050	38.198
6	00.00.02.08	1.302	**0.17128**	**17.128**	0.001368	65.345	0.065	47.773
7	00.00.02.40	1.531	**0.20149**	**20.149**	0.001420	79.454	0.079	55.971
8	00.00.03.32	1.754	**0.23075**	**23.075**	0.001474	90.592	0.091	61.479
9	00.00.03.56	2.056	**0.27047**	**27.047**	0.001554	103.216	0.103	66.428
10	00.00.04.33	2.388	**0.31425**	**31.425**	0.001653	116.434	0.116	70.439
11	00.00.04.50	2.685	**0.35326**	**35.326**	0.001753	126.235	0.126	72.024
12	00.00.05.32	3.010	**0.39608**	**39.608**	0.001877	135.888	0.136	72.398
13	00.00.06.05	3.341	**0.43961**	**43.961**	0.002023	146.284	0.146	72.319
14	00.00.06.40	3.746	**0.49290**	**49.290**	0.002235	155.938	0.156	69.761
15	00.00.07.15	4.202	**0.55284**	**55.284**	0.002535	166.333	0.166	65.615



UNCONFINED COMPRESSION TEST

Data Sheet

Tested Date :-28/06/2017								
Project Name :-UCS test for 10% Fly Ash Application (Thesis Research)								
Test Station :-	***Koye Feche, at 1.5m depth***							
Sample Number:-	***03***							
Diameter (D)		**(cm)**			**3.80**	**3.80**		
Length (L_o)		**(cm)**			**7.60**	**7.60**	**KN/M2= Kpa**	
Mass (M)		**(gram)**			**177.17**	**177.17**		
Area (A_o)= ((3.142*$d^{2)}$/(4)) cm^2					**11.335**	**11.335**	0.00113354	0.00113354
Volume (V) = A_0*L_0					**86.15**	**86.15**		
Reading No.	**Time (dd:hh:mm:ss)**	**Sample Deformation (mm)**	**Strain (*ΔL/L0*)**	**Strain %**	**Corrected Area A_c= ((A_0)/(1-Σ))**	**Load (N)**	**Load (kN)**	**Stress (Kpa)**
1	00.00.00.00	0.000	**0.00000**	**0.000**	0.001134	0.000	0.000	0.000
2	00.00.00.40	0.340	**0.04472**	**4.472**	0.001187	15.000	0.015	12.641
3	00.00.00.59	0.592	**0.07788**	**7.788**	0.001229	32.000	0.032	26.032
4	00.00.01.26	0.809	**0.10645**	**10.645**	0.001269	48.000	0.048	37.837
5	00.00.01.49	0.993	**0.13067**	**13.067**	0.001304	60.000	0.060	46.015
6	00.00.02.18	1.194	**0.15706**	**15.706**	0.001345	75.000	0.075	55.773
7	00.00.02.48	1.404	**0.18476**	**18.476**	0.001390	88.114	0.088	63.371
8	00.00.03.46	1.608	**0.21160**	**21.160**	0.001438	100.467	0.100	69.877
9	00.00.04.06	1.885	**0.24802**	**24.802**	0.001507	114.466	0.114	75.935
10	00.00.04.38	2.190	**0.28816**	**28.816**	0.001592	129.126	0.129	81.088
11	00.00.04.59	2.462	**0.32394**	**32.394**	0.001677	139.995	0.140	83.495
12	00.00.05.42	2.760	**0.36320**	**36.320**	0.001780	150.700	0.151	84.660
13	00.00.06.25	3.064	**0.40312**	**40.312**	0.001899	162.229	0.162	85.424
14	00.00.06.55	3.435	**0.45199**	**45.199**	0.002068	172.935	0.173	83.606



UNCONFINED COMPRESSION TEST

Data Sheet

Tested Date :-26/03/2025

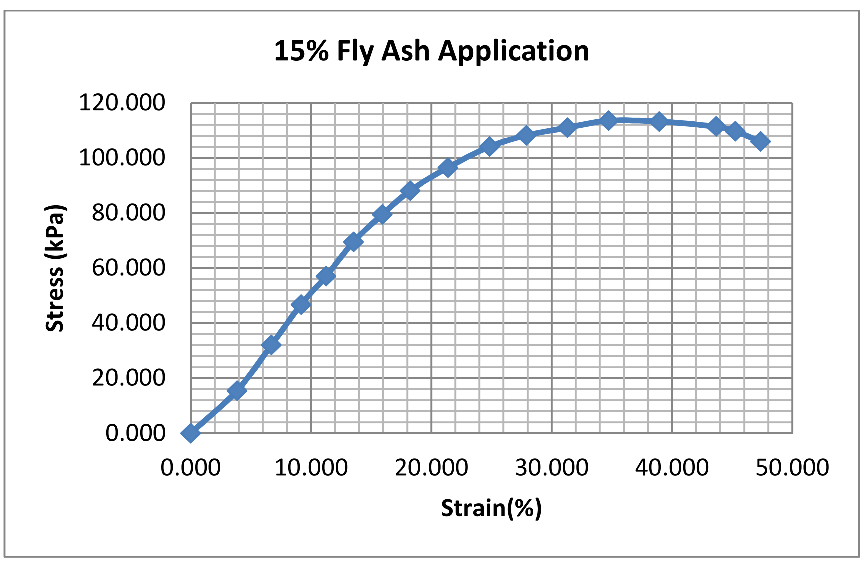
Project Name :-UCS test for 15% Fly Ash Application (Thesis Research)

Test Station :- ***Koye Feche, at 1.5m depth***

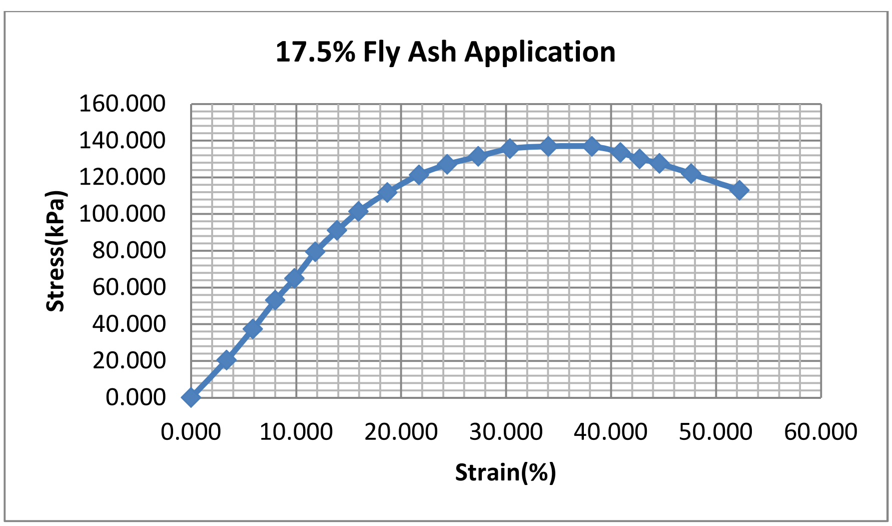
Sample Number:- ***04***

Diameter (D)	**(cm)**	**3.80**	**3.80**		
Length (L_o)	**(cm)**	**7.60**	**7.60**	**KN/M2= Kpa**	
Mass (M)	**(gram)**	**177.17**	**177.17**		
Area (A_o)= ((3.142*$d^{2)}$/(4)) cm^2		**11.335**	**11.335**	0.00113354	0.00113354
Volume (V) = A_0*L_0		**86.15**	**86.15**		

Reading No.	Time (dd:hh:mm:ss)	Sample Deformation (mm)	Strain ($\Delta L/L0$)	Strain %	Corrected Area A_c= ((A_0)/(1-Σ))	Load (N)	Load (kN)	Stress (Kpa)
1	00.00.00.00	0.000	**0.00000**	**0.000**	0.001134	0.000	0.000	0.000
2	00.00.00.30	0.293	**0.03852**	**3.852**	0.001179	18.222	0.018	15.456
3	00.00.00.48	0.510	**0.06707**	**6.707**	0.001215	38.873	0.039	31.993
4	00.00.01.32	0.697	**0.09169**	**9.169**	0.001248	58.310	0.058	46.724
5	00.00.01.52	0.855	**0.11254**	**11.254**	0.001277	72.887	0.073	57.064
6	00.00.02.22	1.028	**0.13528**	**13.528**	0.001311	91.109	0.091	69.503
7	00.00.02.38	1.209	**0.15914**	**15.914**	0.001348	107.041	0.107	79.403
8	00.00.03.49	1.385	**0.18225**	**18.225**	0.001386	122.046	0.122	88.046
9	00.00.04.16	1.624	**0.21362**	**21.362**	0.001441	139.053	0.139	96.466
10	00.00.04.28	1.886	**0.24819**	**24.819**	0.001508	156.861	0.157	104.036
11	00.00.04.49	2.120	**0.27901**	**27.901**	0.001572	170.065	0.170	108.170
12	00.00.05.40	2.377	**0.31283**	**31.283**	0.001650	183.069	0.183	110.980
13	00.00.06.24	2.639	**0.34721**	**34.721**	0.001736	197.075	0.197	113.493
14	00.00.06.53	2.959	**0.38930**	**38.930**	0.001856	210.080	0.210	113.182
15	00.00.07.50	3.318	**0.43664**	**43.664**	0.002012	224.085	0.224	111.368
16	00.00.08.21	3.438	**0.45243**	**45.243**	0.002070	227.060	0.227	109.684
17	00.00.08.53	3.598	**0.47348**	**47.348**	0.002153	228.120	0.228	105.959



UNCONFINED COMPRESSION TEST								
Data Sheet								
Tested Date :-26/03/2025								
Project Name :-UCS test for 17.5% Fly Ash Application (Thesis Research)								
Test Station :-	***Koye Feche, at 1.5m depth***							
Sample Number:-	***05***							
Diameter (D)		**(cm)**			**3.80**	**3.80**		
Length (L_o)		**(cm)**			**7.60**	**7.60**	**KN/M2= Kpa**	
Mass (M)		**(gram)**			**177.17**	**177.17**		
Area (A_o)= ((3.142*$d^{2)}$/(4)) cm^2					**11.335**	**11.335**	0.00113354	0.00113354
Volume (V) = A_0*L_0					**86.15**	**86.15**		
Reading No.	**Time (dd:hh:mm:ss)**	**Sample Deformation (mm)**	**Strain (*ΔL/L0*)**	**Strain %**	**Corrected Area A_c= ((A_0)/(1-Σ))**	**Load (N)**	**Load (kN)**	**Stress (Kpa)**
1	00.00.00.00	0.000	**0.00000**	**0.000**	0.001134	0.000	0.000	0.000
2	00.00.00.22	0.256	**0.03369**	**3.369**	0.001173	24.000	0.024	20.459
3	00.00.00.58	0.446	**0.05866**	**5.866**	0.001204	45.000	0.045	37.370
4	00.00.01.45	0.609	**0.08019**	**8.019**	0.001232	65.301	0.065	52.989
5	00.00.02.32	0.748	**0.09843**	**9.843**	0.001257	81.627	0.082	64.922
6	00.00.02.59	0.899	**0.11831**	**11.831**	0.001286	102.033	0.102	79.363
7	00.00.03.38	1.058	**0.13918**	**13.918**	0.001317	119.875	0.120	91.034
8	00.00.03.50	1.211	**0.15939**	**15.939**	0.001348	136.680	0.137	101.358
9	00.00.04.35	1.420	**0.18684**	**18.684**	0.001394	155.725	0.156	111.712
10	00.00.04.59	1.650	**0.21707**	**21.707**	0.001448	175.668	0.176	121.333
11	00.00.05.39	1.855	**0.24402**	**24.402**	0.001499	190.455	0.190	127.018
12	00.00.05.58	2.079	**0.27360**	**27.360**	0.001560	205.019	0.205	131.382
13	00.00.06.28	2.308	**0.30367**	**30.367**	0.001628	220.704	0.221	135.578
14	00.00.07.13	2.588	**0.34048**	**34.048**	0.001719	235.268	0.235	136.885
15	00.00.07.55	2.902	**0.38189**	**38.189**	0.001834	250.953	0.251	136.843
16	00.00.08.29	3.107	**0.40885**	**40.885**	0.001918	256.000	0.256	133.505
17	00.00.09.10	3.247	**0.42727**	**42.727**	0.001979	257.472	0.257	130.090
18	00.00.09.35	3.39	0.446053	44.605263	0.002046	261.000	0.261	127.548
19	00.00.09.29	3.62	0.476316	47.631579	0.002165	264.000	0.264	121.965
20	00.00.10.02	3.97	0.522368	52.236842	0.002373	268.000	0.268	112.925



UNCONFINED COMPRESSION TEST

Data Sheet

Tested Date :-26/03/2025

Project Name :-UCS test for 20% Fly Ash Application (Thesis Research)

Test Station :- ***Koye Feche, at 1.5m depth***

Sample Number:- ***06***

Diameter (D)	**(cm)**	**3.80**	**3.80**		
Length (L_o)	**(cm)**	**7.60**	**7.60**	**KN/M2= Kpa**	
Mass (M)	**(gram)**	**177.17**	**177.17**		
Area (A_o)= ((3.142*$d^{2)}$/(4)) cm^2		**11.335**	**11.335**	0.00113354	0.00113354
Volume (V) = A_0*L_0		**86.15**	**86.15**		

Reading No.	Time (dd:hh:mm :ss)	Sample Deformation (mm)	Strain ($\Delta L/L0$)	Strain %	Corrected Area A_c= ((A_0)/(1-Σ))	Load (N)	Load (kN)	Stress (Kpa)
1	00.00.00.00	0.000	**0.00000**	**0.000**	0.001134	0.000	0.000	0.000
2	00.00.00.14	0.222	**0.02924**	**2.924**	0.001168	25.069	0.025	21.469
3	00.00.00.36	0.387	**0.05092**	**5.092**	0.001194	47.005	0.047	39.356
4	00.00.01.05	0.529	**0.06960**	**6.960**	0.001218	68.210	0.068	55.986
5	00.00.01.42	0.649	**0.08544**	**8.544**	0.001239	85.263	0.085	68.792
6	00.00.02.09	0.780	**0.10270**	**10.270**	0.001263	106.578	0.107	84.367
7	00.00.02.35	0.918	**0.12081**	**12.081**	0.001289	125.215	0.125	97.118
8	00.00.02.46	1.051	**0.13835**	**13.835**	0.001316	142.768	0.143	108.523
9	00.00.02.58	1.233	**0.16217**	**16.217**	0.001353	162.662	0.163	120.227
10	00.00.03.19	1.432	**0.18842**	**18.842**	0.001397	183.493	0.183	131.376
11	00.00.03.39	1.610	**0.21181**	**21.181**	0.001438	198.939	0.199	138.329
12	00.00.03.58	1.805	**0.23748**	**23.748**	0.001487	214.152	0.214	144.057
13	00.00.04.29	2.003	**0.26358**	**26.358**	0.001539	230.535	0.231	149.769
14	00.00.04.43	2.246	**0.29553**	**29.553**	0.001609	245.748	0.246	152.726
15	00.00.04.56	2.519	**0.33148**	**33.148**	0.001696	262.131	0.262	154.596
16	00.00.05.32	2.697	**0.35489**	**35.489**	0.001757	267.404	0.267	152.183
17	00.00.05.45	2.819	**0.37087**	**37.087**	0.001802	271.941	0.272	150.931
18	00.00.05.59	2.94252	0.387174	**38.717**	0.001850	274.626	0.275	148.471
19	00.00.06.25	3.14216	0.413442	**41.344**	0.001933	275.760	0.276	142.694