DECLARATION OF ORIGINALITY

I do hereby declare that the work submitted in this dissertation is my own contribution to the best of my knowledge. The same work has never been submitted to any other University or Institution. I, therefore declare that this work is my own for the partial fulfilment of the award of Advanced Diploma with honors in Civil Engineering at Ulk Polytechnic Institute

The candidate name: **Tuyizere Thierry**

Signature of the candidate: ……………..

Date of submission: ……/………/…......

APPROVAL

This is to certify that this dissertation work entitled **"detailed study on sub-grade stabilization by the use o steel slag"** is an original study conducted by Tuyizere Thierry under my supervisor's guidance.

The supervisor's name: **Eng. Mukeshimana Annoncee**

Signature of the supervisor: ………………………….

Submission date: ………/……….…../....................

DEDICATION

This research project is dedicated to:

The Almighty God

My Parents

My Siblings

My Classmates and friends

My supervisor

The Laboratory technicians

ACKNOWLEDGEMENT

First, I express my deep heartfelt gratitude to the Almighty God, for giving me a safe life and blessing me abundantly during my studies and all our life. Am thankful for how much he cares, loves me abundantly without any cost .

I am deeply appreciative to my supervisor **Eng. Mukeshimana Annoncee** for her acceptance to supervise this work; special thanks goes to her for her relevant advice, help and ideas. Mam, I can't find words for appreciating you, May God bless you so much.

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My heartfelt thanks to the family members, especially my lovely mother and father, siblings, relatives and friends whose unconditional love, prayers, encouragement and material support have never been withdrawn for the successful completion of my studies.

I cannot forget to thank especially my fellow civil engineering students with whom we worked together.

May God bless you all

ABSTRACT

The goal of this project was to use steel slag in construction projects to stabilize expansive soil for a building which is going to be constructed in Kimihurura Sector, Gasabo District, Kigali City. Different particular objectives led this, including learning about soil classification and carrying capacity, stabilizing soil using by using steel slag in construction projects, and evaluating the function and utility of steel slag in construction projects. The following methods was utilized to accomplish this. Different soil tests were performed on both the non-stabilized and stabilized soils in order to compare the findings; the soil was classed as A-6(9), indicating a fair to poor sub-grade, and the engineering qualities of expansive clays needed to be improved. In this project research, an investigation was carried out to assess the impact of stabilizing expansive soils with steel slag. Research was done on expansive soil sample from Gasabo district at the building site with addition of steel slag in concentrations of 5% steel slag at first trial and 10% steel slag at second trial, each of weight of the soil. For the analysis of the effect of the stabilizers on soil, comparison was made on geotechnical properties of the native soil and stabilized soil which was done by conducting those different tests such as: Sieve analysis, AASHTO classification system, Atterberg limits test, maximum dry density (MDD) by modified proctor test and California Bearing Ratio (CBR) test on both the native soil and stabilized soil. Since 58.2% of the soil is passing through No 200 Sieve, where the soil was classified in silt-clayey material in group of A-6(9) indicating a fair to poor subgrade soil. Before stabilization MDD was 1.82g/cm^3 at optimum moisture content of 16.5% and after adding 5% of steel slag, the MDD was increased to the value of 1.96g/cm^3 at optimum moisture content of 16%. By adding 10% of steel slag the MDD increased from 1.96g/cm^3 to 2.05g/cm^3 at optimum moisture content of 15.7%. CBR value was 4.45 at 95% of compaction before stabilization and after adding 5% of steel slag, CBR value became 8.70% at 95% and for 10% CBR value became 15.0% of compaction which is fair for sub-base to be used in road construction projects. The results indicated that bearing capacity rose on the stabilized soil. As a result of this study, it can be inferred that in road construction projects, the soil must be stabilized with steel slag.

Soil stabilization is a crucial process in construction and infrastructure development, which aims to improve the mechanical properties of soil and increase its load-bearing capacity. However, traditional methods of soil stabilization using cement and lime can be expensive, resource-intensive, and have negative environmental impacts. On the other hand, the disposal of industrial waste such as slag is a significant challenge for many industries, as it poses environmental and health hazards. Therefore, finding an effective and sustainable solution to utilize slag as a soil stabilizer could address both environmental and economic concerns

Key words: stabilization, steel slag, case study ,soil

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO : American Association of State Highway and TransportationOfficials

GBFS : Granulated Blast Furnace Slag

U.S.A : United States of America

Al_2O_3 : Aluminium oxide

MDD : Maximum dry density

OMC : Optimum moisture content

IMC : Initial moisture content

BOF: Basic Oxygen Furnace

EAF: Electric Arc Furnace

CBR: California bearing ratio

MC: Moisture content

SiO_2: Silicate dioxide

OH : Open Hearth

PI : Plastic index

CaO : Calcium oxide

FeO : Iron oxide

GI : Group index

PL : Plastic limit

LL : Liquid limit

SS : Steel slag

LIST OF APPENDICES

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background of the study

Soil stabilization is an important process in civil engineering that involves improving the mechanical properties of soil to increase its load-bearing capacity and resistance to deformation. .(Muntohar A. S., 2017).

Steel Slag, is a by-product of various industrial processes, has recently emerged as a promising alternative to traditional stabilizers due to its availability, cost-effectiveness, and eco-friendliness. Tastan's research on soil stabilization with steel slag highlights its effectiveness in improving the engineering properties of soils, especially expansive soils. The addition of steel slag significantly enhances the unconfined compressive strength and the California Bearing Ratio (CBR) of the soil. This makes it a viable material for stabilizing subgrade soils in road construction, Building construction, providing both environmental and economic benefits by utilizing industrial waste to improve soil performance (Tastan, 2020).

Chang and colleagues conducted a study in 2023 focusing on the use of steel slag as a soil stabilization material. The research explored how steel slag, particularly when used with additives like cement or other binders, can improve the geotechnical properties of weak and expansive soils. They found that incorporating steel slag into soil mixtures significantly enhanced the soil's compressive strength, reduced its swell potential, and improved overall stability. The study highlighted that steel slag could be an effective and sustainable alternative to traditional stabilization methods, offering both environmental and economic benefits (Chang, 2019).

In 2022, several studies explored the use of steel slag for soil stabilization. These studies confirmed that steel slag can significantly enhance the mechanical properties of various soils, particularly by improving compressive strength and reducing plasticity. Steel slag was especially effective when combined with other materials like rice husk ash, offering a sustainable solution for construction applications, such as subgrade stabilization in road construction. This approach not only improves soil properties but also promotes the recycling of industrial by-products (Xin Kang ,2022)

Once a Building is constructed on a weak soil, it will not last forever because with time, signs of destruction will appear due to the loads applied on soil. These signs include cracking, Cutting

.Expansive soils are soils that undergo significant volume changes with changes in moisture content, leading to serious damage to structures built on them. In the road industry, expansive soils are commonly used as sub-grade material, and their expansive nature can lead to significant problems, such as pavement cracking, deformation, and loss of structural support. To mitigate these issues, various stabilization techniques are used to improve the engineering properties of the soil (Dixit, 2016).

Studies have shown that the addition of steel slag to soil can increase its mechanical properties, such as compressive strength, tensile strength, and shear strength. The addition of slag can also reduce soil deformation and increase its resistance to erosion. For instance, studies have shown that adding 10-30% slag to a soil mixture can increase its compressive strength by up to 40% (Xinxin & Guoqing, 2018).

In inference, the use of steel slag as a soil stabilizer offers a sustainable and eco-friendly alternative to traditional stabilizers. The effectiveness of slag as a soil stabilizer depends on several factors, including soil type, slag content, and compaction energy. Further research is needed to optimize the use of slag in soil stabilization and assess its long-term environmental impacts.

1.2 Problem statement

Soil stabilization is a crucial process in construction and infrastructure development, which aims to improve the mechanical properties of soil and increase its load-bearing capacity. However, traditional methods of soil stabilization using cement and lime can be expensive, resource-intensive, and have negative environmental impacts. On the other hand, the disposal of industrial waste such as slag is a significant challenge for many industries, as it poses environmental and health hazards. Therefore, finding an effective and sustainable solution to utilize slag as a soil stabilizer could address both environmental and economic concerns (U Zada, 2023)

This justifies that the idea of steel slag to stabilize the expansive soils and since the steel slag are readily available and affordable on the market, the stabilization process will become quite cheap in building projects.

The primary purpose of reinforcing soil mass is to improve its stability, increase its bearing capacity and reduce settlements and lateral deformation. The requirement of stabilization is to improve the adequate strength of soil by using steel slag. The objective of stabilizing the soil is to reduce the moisture holding capacity, plasticity to improve stability of soil (SHA shan , 2023)

1.3 The study objectives

The objective of the study is to provide recommendations for the practical use of steel slag as a soil stabilizer in construction projects.

1.3.1 Main objectives

This main objective is to do the case study of the site with this UPI:1717,1718 that’s located at kimihurura to do the soil stabilization by use of steel slag

1.3.2 Specific objectives

- ✓ To evaluate the impact of steel slag on the physical properties of soil.
- ✓ To classify the soil according to AASHTO classification system.
- ✓ To determine the optimum mix ratio of steel slag and soil for stabilization.
- ✓ To assess the economic feasibility of using steel slag for soil stabilization.

1.4 Research questions

- ✓ What is the impact of steel slag on soil compaction characteristics?
- ✓ How can expansive soil be classified using sieve analysis and AASHTO classification system?
- ✓ What is the effect of varying percentages of steel slag on soil strength and stability?
- ✓ How can the use of steel slag for soil stabilization contribute to sustainable and environmentally friendly construction practices?

1.5 Choice of the study

This project was Chosen because that , the case study is near his home , it is located at kimihurura place called Djamena this case study made him Realize that, about instead of digging day and night they might use soil stabilization to solve those issues

Figure 1.1: the retaining wall in front view

Figure 1.2: Trucks that dig and carry Soil

This is where they putted all soil they Burst on the site , being honestly this soil is killing the environment even the view of the school where they putted it and made it a playground for kids

Figure1.3: School playground

This information would also be useful for engineers, contractors, and other professionals involved in geotechnical engineering and construction, enabling them to make informed decisions on the use of steel slag for soil stabilization in their projects.

1.6 Significance of the study

This study has different interests including but not limited to personal interests, academic interest and public interest

1.6.1 Personal significance

The importance of conducting this research is that, it allows you to develop in-depth knowledge and expertise in the field of soil stabilization and the utilization of industrial waste which covers some studied courses in engineering like soil mechanics, building construction materials. It is important to use what learnt in order to solve the real problem and enhance your professional growth and open up potential career opportunities in civil engineering.

1.6.2 Academic significance

The study contributes to the existing body of knowledge in the field of soil stabilization by exploring the effectiveness of slag as a soil stabilizer.

It can be served as a valuable reference for future students interested in this similar academic research. Furthermore, the research findings can also be employed as a reference for any academic purpose, particularly for civil engineering students at ULK Polythechnic .

1.6.3 Public significance

This study clearly demonstrated that using slag as soil stabilizer benefits the public by promoting sustainable construction practices, reducing reliance on environmentally harmful stabilizers, and improving infrastructure durability. This contributes to a greener, more sustainable in road construction industry, resulting in environmental conservation and long-term cost savings for the public.

1.6.4 Socio-economic significance

Socio-economically, the research contribute to the National Strategy for Transformation (NST 1) and Vision 2050 aspirations through enhancing modern infrastructure, which goes with development of transportation program. In the development of transportation program the construction of roads in different part of the country will raise the sector of transporting goods and people. This research offer new strategies of how soft subgrade soil can be stabilized by using steel slag in economical way without spending much money in soil replacement. Also that technics of expansive soil stabilization contribute to the environment protection. Thus the region where the infrastructure is built the surrounding population enjoy the healthy and safe life without road damage caused by poor subgrade soil.

1.7 Study delimitation

The finding of the research is limited to the expansive soil type considered in this research which is soil subgrade. Steel slag was mixed with soil in other to get required bearing capacity and to determine it, before and after adding the additive. The results are also specific to the type of additive which was used and test procedures that was performed in the experimental work. Therefore, the design of road was not included.

1.8Organization of the study

The study was subdivided into five chapters as indicated: **Chapter 1: General Introduction**, this chapter deals with the background of the study, problem statement, objectives, research questions, choice of study, the significance of the study, delimitation of the study, and organization of the study. **Chapter 2: Literature Review**, this chapter deals with some concepts and definitions of different terms used in this study, soil properties, some materials used to stabilize weak soil and some appropriate tests to be conducted in order to check the soil behavior. C**hapter 3: Researched methodology**, this chapter deals with the presentation of the location or area of the study and all methods used to analyze the data collected from the field and some test procedures. **Chapter 4: Results and Discussions**; this chapter represented the obtained results like figures and other related results and their corresponding explanations. **Chapter 5: Conclusions and Recommendation**, this chapter represented the conclusions related to different findings from the study and some recommendations based on the obtained results.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Soil stabilization is a critical technique in civil engineering that enhances the properties of soil for construction purposes. Various methods of soil stabilization exist, including chemical, mechanical, and thermal methods. One material that has gained considerable attention in soil stabilization is slag, a by-product of steel production.

Several studies have investigated the effectiveness of using slag in soil stabilization. For example, (Dey & Pal, 2017) evaluated the effectiveness of using granulated blast furnace slag (GBFS) in stabilizing a clayey soil. The study found that the addition of GBFS improved the soil's strength and reduced its compressibility.

Similarly, (Nishanthi, Sivakumar, & Ananthanarayanan, 2019) investigated the effect of using slag in stabilizing an expansive soil. The study found that the addition of slag reduced the soil's swelling potential and improved its strength and stiffness properties.

2.1. Steel Slag

Figure 2.1: Steel Slag

2.1.1 Production

Steel slag is produced as a byproduct during the steelmaking process, particularly in basic oxygen furnaces (BOF) and electric arc furnaces (EAF). The production involves melting scrap steel or iron ore along with fluxing agents like limestone. During the process, impurities in the metal combine with the flux to form slag, which is then separated from the molten steel. The slag is cooled and processed, typically by crushing and screening, to be used in various applications, including soil stabilization, construction aggregates, and cement production (Akinwumi, 2015)

2.2.2 Properties

- **High Density**: Steel slag is dense, making it suitable for applications requiring weight and stability, like construction aggregates.

- **High Strength**: It possesses significant compressive strength, which is beneficial for soil stabilization and road construction.

- **Alkalinity**: Steel slag is highly alkaline, with a pH typically between 8 and 10, which can affect the surrounding environment.

- **Good Cementitious Properties**: When mixed with water, steel slag can exhibit binding properties, aiding in stabilization and concrete production.

- **Durability**: It's resistant to wear and degradation, ensuring longevity in construction applications.

Steel slag usually contains four major oxides, namely lime; magnesia; silica and alumina. Minor elements include sulfur; iron; manganese; alkalis and trace amount of several others, (Zumrawi & Khalill, 2015).

The physical properties of steel slag according to (NSA, 2016) are angular shape, generally well-graded material, has a high degree of internal friction angle and high shear strength. Steel slag has high bulk specific gravity and usually less than 3% water absorption as well as dry unit weight 1600 – 1920 kg/m3. According to (Proctor, et al., 2020), the slag particle size is generally larger than silt or clay, which has an upper size 0.075 mm, and smaller than gravel which has a lower limit of 2 to 5 mm. The mechanical properties of steel slag include good abrasion resistance, good soundness characteristics, and high bearing strength. Due to these mechanical properties steel slag can be used as aggregates in construction projects.

2.3 soil

Soil is the upper layer of the Earth's crust, composed of mineral particles, organic matter, water, air, and microorganisms. It plays a crucial role in building construction by providing the foundation on which structures are built. The type, strength, and stability of the soil determine the load-bearing capacity of the ground, affecting the design and safety of the foundation. Soil properties, such as compaction, permeability, and moisture content, are critical factors in ensuring that buildings remain stable and secure over time. (Das, 2017).

2.3.1 Soil description

Soil is a dynamic natural resource consisting of a mixture of mineral particles, organic matter, water, and air. It provides the foundation for plant growth, regulates water and nutrient cycles, and supports diverse ecosystems. Understanding soil properties and processes is essential for sustainable land use and various fields such as agriculture, ecology, and environmental science (Jenny, 2014).

Figure 2.2: Soil Layers

2.3.2 Characteristics of soil

Soils consist of grains (mineral grains, rock fragments, etc.) with water and air in the voids between grains. The water and air contents are readily changed by changes in conditions and location: soils can be perfectly dry (have no water content) or be fully saturated (have no air content) or be partly saturated (with both air and water present).

Although the size and shape of the solid (granular) content rarely change at a given point, they can vary considerably from point to point.

- Composition of grains
- The size range of grains
- Shape of grains
- Soil as an engineering material
- Structure or fabric

Soils consist of grains with voids filled by water and air. These contents can change based on conditions and location, resulting in different states of moisture. While the size and shape of the grains are relatively stable at a given point, they can vary significantly across different points in the soil (Nebraska and Iowa, 2016)

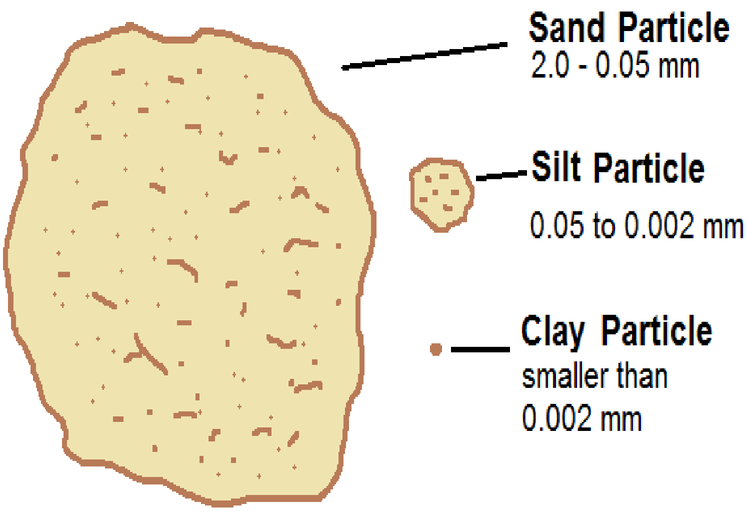


Figure 2.3: Soil particles

2.2.3 The Five soil forming factors

The Five Soil Forming Factors, as outlined by Hudson, are:

1. **Parent Material**: The mineral or organic material from which soil forms. It influences soil texture, mineral composition, and fertility.

2. **Climate**: Temperature and precipitation patterns that affect weathering of parent material and the processes of soil formation, such as leaching and organic matter decomposition.
3. **Topography**: The landscape's shape and slope, which influence drainage, erosion, and accumulation of soil materials.
4. **Organisms**: Plants, animals, and microorganisms that contribute to soil formation through organic matter addition, biological activity, and nutrient cycling.
5. **Time**: The duration over which soil formation processes occur, which affects soil depth, horizon development, and overall soil properties.

The properties of soil, such as texture, structure, color, and fertility, are the result of the complex interactions among these factors. Each factor influences the others, leading to a diverse range of soil types and characteristics in different environments (Nebraska and Iowa, 2017)

2.2.4 Soil as an engineering material

Soil is a crucial material in engineering, particularly in geotechnical engineering, which deals with the behavior of soil under various conditions. Here are some key aspects of soil as an engineering material:

1. **Soil Classification**: Engineers classify soil based on its texture (sand, silt, clay) and its behavior (cohesive vs. non-cohesive). Classification helps in understanding how soil will respond to different loads and environmental conditions.
2. **Soil Properties**: Important properties include:
    - **Shear Strength**: The ability of soil to resist shear forces. It's critical for designing stable foundations and retaining structures.
    - **Compaction**: The process of increasing soil density by reducing air voids, which affects soil strength and stability.
    - **Permeability**: The rate at which water flows through soil, impacting drainage and stability.
    - **Settlement**: The gradual downward movement of the ground due to the compression of soil under load.

3. **Soil Testing**: Various tests (e.g., Atterberg limits, Proctor compaction test, triaxial shear test) are conducted to determine soil properties and behavior, guiding engineering decisions.
4. **Foundation Design**: Soil's load-bearing capacity affects the design of foundations for structures. Engineers must ensure that the soil can support the loads imposed by buildings, bridges, and other structures (JR Dungca, 2018)
5. **Slope Stability**: Soil stability on slopes is essential to prevent landslides and erosion. Engineering measures such as retaining walls, soil nailing, and drainage systems are used to maintain stability.(JG Collin, 2015)
6. **Earthworks**: In construction projects involving excavation, embankments, or cut-and-fill operations, soil behavior affects the design and execution of earthworks.
7. **Geosynthetics**: Materials like geotextiles and geomembranes are used to enhance soil properties and stabilize soil structures.

The term "soil" carries different meanings depending on the perspective of the individual. For a geologist, soil represents the result of past surface processes, reflecting the accumulated effects of historical environmental conditions. On the other hand, for a pedologist, soil represents the ongoing physical and chemical processes that are actively shaping the soil at present. To an engineer it is a material that can be: Built on: Bridges and foundations; Built in: Basements, culverts, tunnels; Built with: Embankments, roads, dams, runways; Supporting: Retaining walls, quays. Soil descriptions vary based on different purposes. Engineers use engineering terms to understand the current state of the soil and its susceptibility to future changes for their construction and design needs(According to Terezgi)

2.2.5 Size range of grains

The size range of grains in soil can vary significantly and is typically classified into different categories based on their diameters. Here are some common size ranges of soil grains:

Gravel: >2 mm

Sand: 0.05 mm to 2 mm

Silt: 0.002 mm to 0.05 mm

Clay: <0.002 mm

Some clay contains particles less than 1 mm in size which behave as colloids, i.e. do not settle in water due solely to gravity (Tyler & Wheatcraft, 2015).

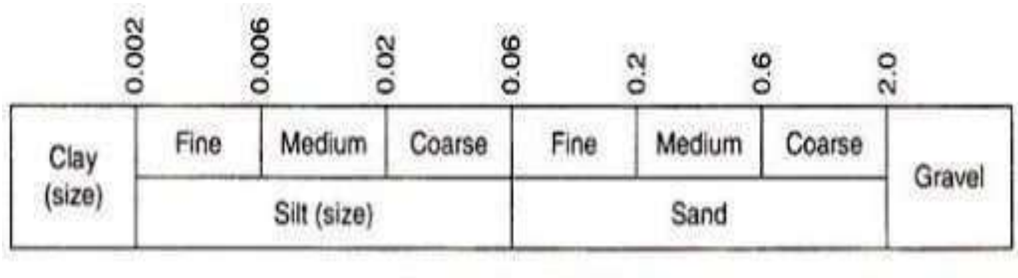


Figure2.4: Soil size identification **(Tyler & Wheatcraft, 2015).**

The British Soil Classification System categorizes soils into named Basic Soil Type groups based on size. These groups are then subdivided into coarse, medium, and fine sub-groups, as detailed in the following Table 1:

Table 2.1: Soil Classification System

Types of material		**Size (mm)**
Boulders		over 200
Cobbles		60-200
Gravel	Coarse	20-60
	Medium	6-20
	Fine	2-6
Sand	Coarse	0.6-2
	Medium	0.2-0.6
	Fine	0.06-0.2
Silt	Coarse	0.02-0.06
	Medium	0.006-0.02
	Fine	0.002-0.006
Clay		Less than 0.002

2.2.6 Engineering properties of soil

When utilizing soil as a construction material, the following soil properties are considered:

- Cohesion
- The angle of internal friction
- Capillarity
- Permeability
- Elasticity

2.2.6.1 Cohesion

It is the internal molecular attraction that provides resistance to rupture or shear in a material. In fine-grained soils, cohesion is established through water films that bind the individual particles together within the soil mass. This property is specifically attributed to fine-grained soils with particle sizes below 0.002 mm. As the moisture content of the soil increases, cohesion diminishes. Well-compacted clays generally exhibit higher cohesion, and this property remains unaffected by the external load applied to the soil. (Mitchell, et al., 2017)**.**

2.2.6.2 Angle of internal friction

The resistance to sliding of soil grain particles relies on the angle of internal friction. Typically, the value of the angle of internal friction is considered nearly unaffected by the normal pressure but varies based on the packing density of the particles. Soils experiencing higher normal stresses tend to have lower moisture content and higher bulk densities at failure compared to those under lower normal stresses, which can cause variations in the angle of internal friction. The true angle of internal friction for clay is rarely zero and can be as high as 26°. For granular soils, the angle of internal friction may vary within the range of 28° to 50° (Mitchell, et al., 2017)

2.2.6.3 Capillarity

Refers to the ability of soil to transport moisture in all directions, independent of gravitational forces. This phenomenon occurs as water is drawn upward through the soil pores due to capillary attraction. The maximum height of capillary rise is influenced by the pressure that drives water into the soil, and this force becomes stronger as the soil particle size decreases.

When wet, a soil's capillary rise can reach as much as 4 to 5 times the height it achieves when dry.

Capillary rise varies depending on the soil type: Coarse gravel exhibits no capillary rise, while coarse sand can rise up to 30 cm. Fine sand and other soils may have capillary rises of up to 1.2 m, although dry sand has limited capillarity. Clays, on the other hand, can demonstrate capillary rises of 0.9 to 1.2 m, but pure clays exhibit relatively low values (Holtz W. G., 2019).

2.2.6.4 Permeability

Permeability in soil refers to the speed at which water moves through it under the influence of a hydraulic gradient. The process of water passing through the inter-spaces or pores of the soil is known as 'percolation.' Soils that have enough porosity to allow percolation are considered 'pervious' or 'permeable,' while those that do not permit water passage are termed 'impervious' or 'impermeable.' The rate of water flow is directly related to the water pressure.

Permeability is a property that pertains to the entire soil mass rather than individual particles. Cohesive soils generally exhibit very low permeability. Knowledge of permeability is essential not only for dealing with seepage, drainage, and groundwater issues but also for understanding the rate of settlement of structures built on saturated soils

(Kirkham, 2015)

2.2.6.5 Elasticity

An elastic soil is one that experiences a reduction in volume or undergoes changes in shape and bulk when subjected to a load. However, once the load is removed, the soil quickly recovers its initial volume and shape. The key feature of the elastic behavior of soil is that regardless of the number of load repetitions, as long as the stress applied to the soil remains below the yield stress, the soil does not undergo permanent deformation. This elastic behavior is particularly characteristic of peat (Nazarian, 2014).

2.2.6.6 Compressibility

Gravels, sands, and silts are considered incompressible, meaning that when a moist mass of these materials is subjected to compression, there is minimal volume change. On the other hand, clays are compressible. When a moist mass of clay undergoes compression, moisture and air may be expelled, leading to a reduction in volume that is not immediately recovered when the compression load is removed.

The degree of volume change per unit increase in pressure is known as the compressibility of the soil, and the rate at which consolidation occurs is quantified by the coefficient of consolidation. For sand and silt, their compressibility varies based on their density, whereas the compressibility of clay is directly influenced by its water content and inversely related to its cohesive strength (Muntohar A. S., 2014).

The principal terms used by civil engineers to describe soils are:

- Gravel (particle size larger than 4.75 mm)
- Sand (particle size within 4.75 mm to 0.075mm)
- Silt & Clay (particle size less than 0.075mm)

Natural soils often comprise a blend of two or more of the aforementioned constituents, and they may also include organic material in a partially or completely decomposed state. When describing these mixed soils, the name of the constituent with the most significant impact on its behavior is used, and the other constituents are indicated using adjectives. This naming convention helps in classifying and understanding the behavior of the soil based on its dominant constituent while acknowledging the presence of other components (Muntohar A. S., 2016)

For example, silt clay has predominantly the properties of clay but consists of a significant amount of silt. While identifying and classifying the soils in the field, we need to use the following steps in a logical sequence.

1. Identifying as Coarse-Grained Soil or Fine-Grained Soil
2. Classifying Coarse-Grained Soil
3. Classifying Fine-Grained Soil

2.3 Soil stabilization

The general term for any method that alters a natural soil to serve an engineering purpose is "soil improvement." Soil improvement encompasses various physical, chemical, biological, or combined techniques aimed at enhancing the properties of natural soils to meet specific engineering requirements. These improvements may involve increasing the weight-bearing capacity, tensile strength, and overall performance of in-situ subsoil, sands, and other waste materials to strengthen road surfaces or other construction projects.

The goal is to modify the soil's characteristics to make it more suitable and stable for the intended engineering application (Ingles & Metcalf, 2018).

When soils lack the desired characteristics for a particular construction project, they can be enhanced through the addition of one or more stabilizers.

Each stabilizer employed in soil improvement can typically fulfill one or, at most, two of the following functions:

1. **Increase Strength:** Stabilizers can enhance the soil's load-bearing capacity and overall strength, making it more suitable for supporting structures and heavy loads.
2. **Improve Durability:** Stabilization helps to increase the soil's resistance to weathering, erosion, and other environmental factors, enhancing its long-term performance.
3. **Reduce Settlement:** Stabilizers can minimize soil settlement, preventing excessive subsidence and potential damage to structures.
4. **Enhance Cohesion:** Stabilizers can improve the cohesive properties of soils, particularly in clayey materials, increasing their resistance to deformation and shear.
5. **Reduce Permeability:** Stabilization can lower the soil's permeability, reducing water infiltration and improving its ability to resist seepage and water-induced issues.
6. **Control Swelling and Shrinkage:** Stabilizers can mitigate the volumetric changes in soils due to moisture variations, helping to prevent undesirable swelling and shrinkage.

The selection of the appropriate stabilizer depends on the specific requirements of the construction project and the desired soil improvement objectives.

Soil stabilization benefits:

- Improve the mechanical qualities of local road construction soils
- Increase loading capacity (CBR)
- Improve structural integrity
- Reduce harmful moisture penetration
- Provide longer economic life of the roadbed
- Reduce maintenance costs

2.4 Soil tests

2.4.1 Compaction test

Compaction is a soil densification process that aims to reduce the air voids within the soil mass. The extent of compaction achieved in a particular soil is quantified by its dry density, which refers to the density of the soil when all moisture content is eliminated. To determine the optimum compaction characteristics of a soil, a curve is plotted between the water content and the corresponding dry density. This curve helps identify the maximum dry density and the corresponding water content that yields the highest level of compaction achievable for that soil (Hogentogler, 2017).

$$Dry\ density\ of\ soil = \frac{M}{V(1 + \mathrm{W})}$$

Where,

M: total mass of the soil

V: volume of the soil

W: water content

2.4.2 Atterberg Limit Test

(Zuhaibu., 2017) Detailed that when a clayey soil is mixed with an excessive amount of water, it can exhibit a semi-liquid consistency and flow like a liquid. As the soil gradually loses water through drying, its behavior shifts, and it can resemble a plastic, semisolid, or solid material, depending on its remaining moisture content. The point at which the soil transforms from a liquid to a plastic state is defined as the liquid limit (LL).

Similarly, the moisture content levels, expressed as a percentage, at which the soil transitions from a plastic to a semisolid state and from a semisolid to a solid state are defined as the plastic limit (PL) and the shrinkage limit (SL), respectively. This limit referred to as Atterberg limits.

The behavior of soil is intimately tied to the quantity of water it contains. In 1911, A. Atterberg established four states of consistency for soil, delineated by specific limits. These limits are used to define the boundaries of each state based on the moisture content.

The consistency limits of soil are influenced by the pore fluid pressure within the soil. When fluid is present in an unconsolidated material, it enhances inter-granular cohesion, contributing to the overall strength and behavior of the soil. The fluid within the soil can generate excess pressure, leading to soil behaving in a manner similar to a fluid. This fluid-like behavior is a crucial factor in understanding soil mechanics, as it affects the soil's response to external forces and loading conditions. Pore fluid pressure plays a significant role in controlling the strength, compressibility, and stability of the soil, making it a fundamental consideration in geotechnical engineering and construction projects (A. K. Al-Shamrani, 2018)

Figure 2.5: Atterberg

Plastic Limit (PL)

The moisture content, in percentage, at which the soil changes from a plastic to a semisolid state. When the clayey soil's moisture content decreases to the plastic limit, it loses its plasticity and behaves more like a semisolid material (Whyte, 2018).

Liquid Limit (LL)

The moisture content, in percentage, at which the soil transitions from a liquid to a plastic state. At the liquid limit, the clayey soil exhibits a plastic behavior and can be molded into various shapes (Whyte, 2016).

Plasticity Index

The plasticity index (PI) of a soil is determined by calculating the difference between its liquid limit (LL) and plastic limit (PL), represented as PI = LL - PL. The plasticity index indicates the range of moisture contents over which the soil exhibits plastic behavior, transitioning from a liquid-like state at the liquid limit to a semisolid state at the plastic limit (Whyte, 2016)

PI Range Description

1. **Low Plasticity (PI < 7):** Soils with a low plasticity index have a narrow range of moisture content where they behave plastically. They exhibit minimal volume changes and have relatively stable properties. These soils are less susceptible to shrinkage and swelling.
2. **Medium Plasticity (7 ≤ PI ≤ 15):** Soils with a medium plasticity index have a moderate range of moisture content where they exhibit plastic behavior. They may experience moderate volume changes and show some sensitivity to changes in moisture content.
3. **High Plasticity (PI > 15):** Soils with a high plasticity index have a wide range of moisture content where they behave plastically. They are more susceptible to volume changes, especially in response to variations in moisture content. These soils may experience significant swelling when wet and shrinkage when dry.

The liquid limit, plastic limit, and shrinkage limit aid in correlating soil behavior with previous experiences in similar consistency states. Each limit represents a specific water content at which the soil undergoes a distinct state change (Zuhaibu., 2017).

Equipment

Liquid limit device (Casagrande's apparatus), Porcelain (evaporating) discs, Flat grooving tool with gauge, Moisture cans, Balance, Glass plate, Spatula, Wash bottle filled with distilled water, Drying oven set 105^0C.

Figure 2.6: Laboratory Equipments I used

2.4.3 California Bearing Ratio

The California Bearing Ratio Test (CBR Test) is a penetration test originally developed by the California State Highway Department in the United States. Its primary purpose is to assess the bearing capacity of subgrade soil, which is crucial for designing flexible pavements. The CBR test can be performed on both natural and compacted soils, and it can be conducted under water-soaked or unsoaked conditions. This test is a significant tool in geotechnical engineering, providing essential data for designing safe and durable flexible pavements on various types of soils (ASTM, 2017)

Figure 2.7: CBR 1

Figure 2.8: CBR 2

2.4.4 Sieve analysis

A sieve analysis or gradation test is a standard procedure used to determine the particle size distribution of granular materials. This test involves passing the material through a series of sieves with progressively smaller mesh sizes. The material is then weighed to determine the amount that is retained on each sieve, representing a fraction of the total mass.

It provides valuable information about the grading and uniformity of the granular material, aiding in the selection of appropriate materials for construction projects such as roads, concrete, and aggregates. The results of the sieve analysis help engineers understand the behavior and performance of the granular material, ensuring its suitability and optimizing its use in construction and engineering works (Liu, Zhou, You, Ma, & Gong, 2019).

Figure 2.9: Sieve Analysis

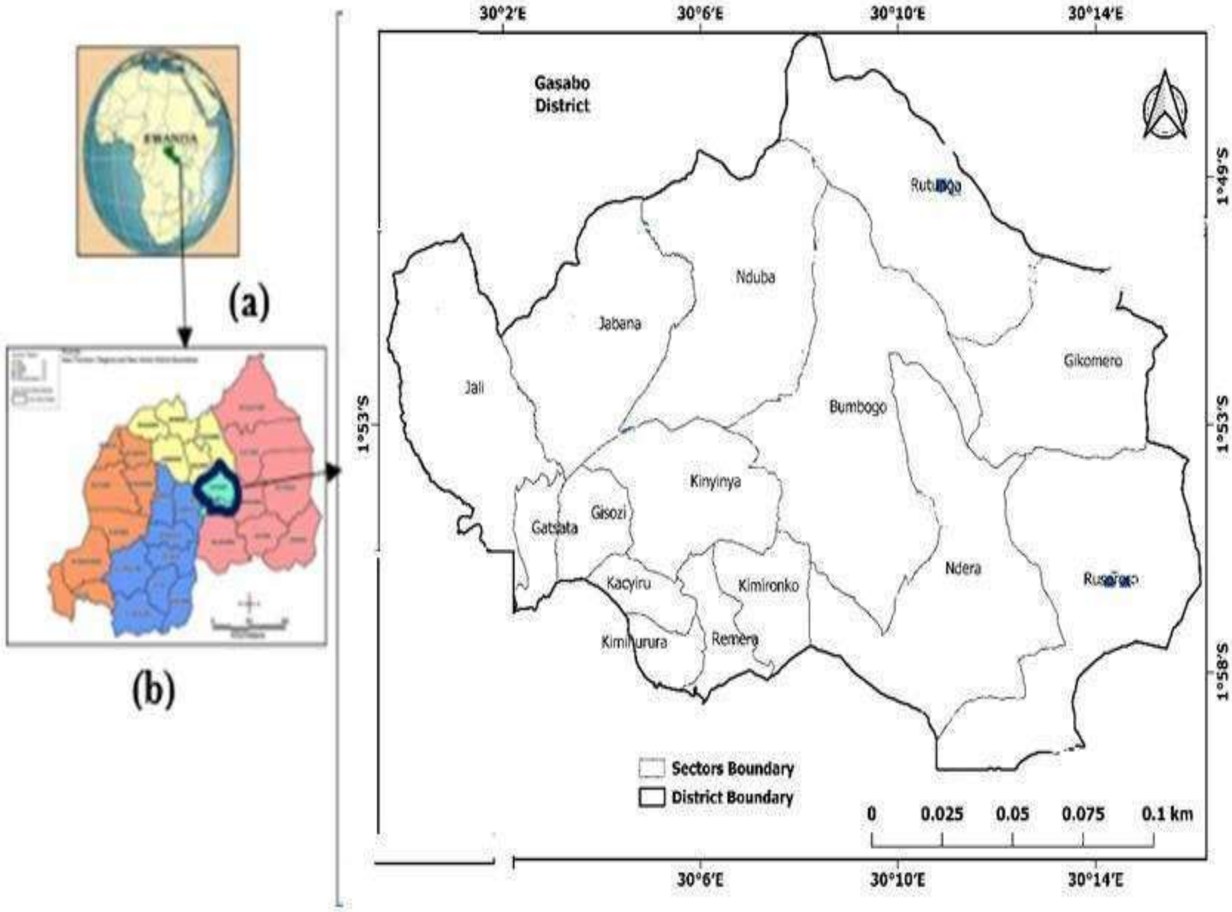
CHAPTER III: RESEARCH METHODOLOGY

3.1. General

Soil stabilization is a critical process in geotechnical engineering aimed at improving the properties of soil to enhance its load-bearing capacity, durability, and overall performance in construction applications. Among various stabilization techniques, the use of industrial by-products has gained significant attention due to their potential for sustainable development and cost-effectiveness. Steel slag, a by-product of steel manufacturing, has emerged as a promising material for soil stabilization, offering both environmental and engineering benefits.

This chapter provides a comprehensive overview of the materials and methodologies employed in the stabilization of soil using steel slag. The discussion begins with a detailed characterization of the steel slag, including its chemical composition, physical properties, and its suitability for soil stabilization purposes. The chapter then outlines the experimental methods used to assess the effectiveness of steel slag in improving soil properties, including laboratory testing procedures and soil-slags mix design.

3.2 Description of study area



3.3 Methodology

In this study the different materials were used, which included steel slag, soil, and water. Soil samples were collected. The samples were air-dried and sieved to obtain a uniform particle size distribution. The samples were then mixed with varying percentages to investigate the effect of slag on soil stabilization.

Laboratory experiments were conducted to evaluate the mechanical and physical properties of the prepared samples, including compressive strength, permeability, and durability. The experiments were conducted using standard testing procedures. The tests included Compaction tests, California Bearing Ratio (CBR) tests, Atterberg limit and Sieve analysis tests.

The results from carried tests were analyzed and discussed using Microsoft Word, and the values obtained, along with their graphic representation, were created using Microsoft Excel. The final report, along with important conclusions and recommendations, was documented.

3.4 Source of data

The data is collected from both primary and secondary sources. Primary sources involved gathering information directly from the field, while secondary sources included reviewing existing documents with relevant information about the subject.

3.4.1 Primary data

On the field, am taking soil and steel Slang as Primary data of my project to be examine and analyze their properties

3.5 Data collection

The soil samples were collected from the site on 29th September 2024, while the steel slags were gathered from a steel manufacturing company for further analysis or use in the research.

3.6 Data analysis

Various methods were employed in this study, including the Atter berg limit, sieve analysis, and California bearing ratio (CBR) test. All of these methods is going to be conducted to assess the soil's resistance and strength after being stabilized with steel slag.

3.6.1 Atterberg limit test

This laboratory test aimed to determine the plastic and liquid limits of a fine-grained soil. The liquid limit (LL) was defined as the water content at which a soil paste, cut by a groove in a standard cup, moved for a distance of 13mm after a specific number of shocks from the cup being dropped. The plastic limit (PL) was defined as the water content at which the soil could no longer be rolled into 3.2mm diameter threads without crumbling. These limits provide valuable information about the soil's plasticity and behavior under different moisture conditions, aiding in engineering applications and soil classification.

- ✓ Calculate the water content of each of the liquid limit moisture cans after they have been in the oven of 105°c for at least 24 hours.
- ✓ Plot the number of drops, **N** (on the log scale) versus the water content **w.** Draw the best-fit straight line through the plotted points and determine the liquid limit (LL) as the water content at 25 drops.

- ✓ Calculate the water content of each of the plastic limit moisture cans after they have been in the oven of 105°c for at least 24 hours.
- ✓ Compute the average of the water contents to determine the plastic limit, PL. Check to see if the difference the water content is greater than the acceptable range of two results (2.6%).
- ✓ Calculate the plasticity index, **PI=LL-PL**

Report the liquid, Plastic Limit and Plasticity index to the nearest whole number, omitting the percent designation.

3.6.1.1 Liquid limit

Taken roughly ¾ of the soil and placed it into the porcelain dish. The soil was previously passed through a 0.425mm sieve. Thoroughly mixed the soil with a small amount of distilled water until it appears as a smooth uniform paste, weighed five empty moisture cans with their lids, and record the respective weights and can number on the data sheet.

Adjusting the Casagrande by checking the height for the drop of the cup, the point on the cup that comes in contact with the base should rise to a height of 10mm. The block on the end of the grooving tool is 10mm high and should be used as a gage. Practice using the cup and determine the correct rate to rotate the crank so that the cup drops approximately two times per second. Then, Placed a portion of the previously mixed soil into the cup of the liquid limit apparatus at the point where the cup rests on the base. Squeeze the soil down to eliminate air pockets and spread it into the cup to a depth of about 10mm at its deepest point. The soil pat should form an approximately horizontal surface. After use the grooving tool, carefully cut a clean straight groove down the center of the cup. The tool should remain perpendicular to the surface of the cup as the groove is being made. Use extreme care to prevent sliding the soil relative to the surface of the cup.

Make sure that the base of the apparatus below the cup and underside of the cup is clean of the soil. Turn the crank of the apparatus at a rate of approximately two drops per second and count the number of drops **N**; it taken to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13mm. If the number of drops exceed 50, then gone directly to above step and do not record the number of drops, otherwise, record the number of drops on the data sheet.

Take a sample, using the spatula, from edge to edge of the soil pat. The sample should include the soil on both sides of where the groove came into contact. Placed the soil into moisture can and cover it. Immediately weighed the moisture can containing the soil, record it mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours. Place the soil remaining in the cup into the porcelain dish. Clean and dry the cup on apparatus and the grooving tool. Remix the entire soil specimen in the porcelain dish. Add a small amount of distilled water to increase the water content so that the number of drops required closing the groove decrease.

Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

3.6.1.2 Plastic limit

Weighed the remaining empty moisture cans with their lids, and record the respective weights and can number on the data sheet. After it taken, the remaining ¼ of the original soil sample and add distilled water until the soil is at a consistency where it can be rolled without sticking to the hands. After that, the soil was rolled into an ellipsoidal mass. The mass was rolled between the palm or the fingers and the glass plate. Use sufficient pressure to roll the mass into a thread of uniform diameter by using about 90 strokes per minute. (A stroke is one complete motion of the hand forward and back to the starting position). The thread shall be deformed so that its diameter reaches 3.2mm, taking no more than two minutes.

3.6.1.3 Plastic index

The plastic index obtained when the results of plastic limit and limited was obtained, take the difference of liquid limit to plastic limit as shown below,

$$PI = LL - PL$$

3.6.2.2 Calculation

1. Determine weight of the mold **(W1)**.

2. Determine weight of the mold + compacted moist soil, **(W2)**.

3. Determine weight of the compacted moist soil = W2 − W1.

4. Moist unit weight **γ** = weight of the compacted moist soil / volume of mold

$$\gamma = (\mathrm{W2} - \mathrm{W1}) / \mathrm{W2}.$$

5. Determine mass of moisture can, **W3.**

6. Determine mass of moisture can + moist soil, **W4**

7. Determine mass of moisture can + dry soil, **W5**

8. Compaction moisture content, $\mathrm{w}\ (\%) = \frac{(\mathrm{w4}-\mathrm{w5})*100}{\mathrm{w5}-\mathrm{w3}}$,

9. Dry unit weight **γd**= $\frac{\gamma}{1+(\frac{\mathrm{w}}{100})}$,

3.6.3 California bearing ratio test

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) for evaluating the bearing capacity of sub grade soil for design of flexible pavement.

Tests are carried out compacted soils in water soaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the subgrade soil.

3.6.3.1 Test Procedure

Prepare representative samples of about 6 kg material passing the 20 mm test sieve. Three 6 kg specimens were compacted at the same percentage of water as determined by the compaction or proctor tests, and all samples were compacted with five layers and varying numbers of blows. The first trial consisted of 55 blows, the second of 25, and the final 10 blows in three layers. ; Remove the collar and trim the soil flush with the top of mold with the scraper. Weigh mold with wet sample. After compaction, the material was soaked in a soaking tank to check for swelling or expansion, and the sample was tested after 4 days of soaking.

The strength of the subgrade is the main factor in determining the required thickness of flexible pavements for roads and airfields and it's expressed in terms of their California Bearing Ratio (CBR) value. Prior to conducting the test, the initial moisture content (IMC) of the air-dried soil sample was determined as the water to be used in the test using the following equation;

$$\frac{OMC - IMC}{IMC + 100} * 6000g$$

Where; OMC: optimum moisture content (in modified proctor test) of the sample, and 6000g is the mass of sample to be used in the test.

Formula used;

$$Load = readings * 7.5$$

CBR indices

- $2.5mm = (load\ on \frac{2.5mm}{19.35})\ /0.7$
- $5.00mm = (load\ on\ 5.00mm/19.35)/1.05$

Dry Density CBR at;

- $100\%\ of\ dry\ density = (reference\ proctor * 100)/100$
- $98\ \% = (reference\ proctor * 98)/100$
- $95\ \% = (reference\ proctor * 95)/100$

✓ $Mass\ of\ wet\ material = (mass\ mould + wet\ material) – mass\ of\ mould$
✓ $Wet\ density = (mass\ wet\ material)/\ (volume\ of\ mould)$

- ✓ $Moisture\ content\ = (mass\ \text{of}\ water\ /\ mass\ of\ dry\ material)\ *100$
- ✓ $Dry\ density = \ wet\ material/\ (1\ +\ moisture\ content/100)$
- ✓ $\%\ of\ compaction\ = Dry\ density/reference\ proctor$

3.6.4 Sieve analysis

The sieve analysis test referred to a practice or procedure used in civil engineering to assess the particle size distribution of granular material. This test was conducted in order to determine the coarse and fine soil which contained in soil sample by washing the soil in sieve of 2mm, 0.075mm from above. It was weighed after washed and soaked into a bucket a least 16hrs. The soil sample was washed by water the remaining in sieve was putted at plate after brought it into an oven of 105°c. After that, set of IS sieves were arranged in ascending order used for sieving the sample from oven. Finally, Cumulative weight passed through each sieve is calculated as a percentage of the total sample weight and dividing the sum by 100.

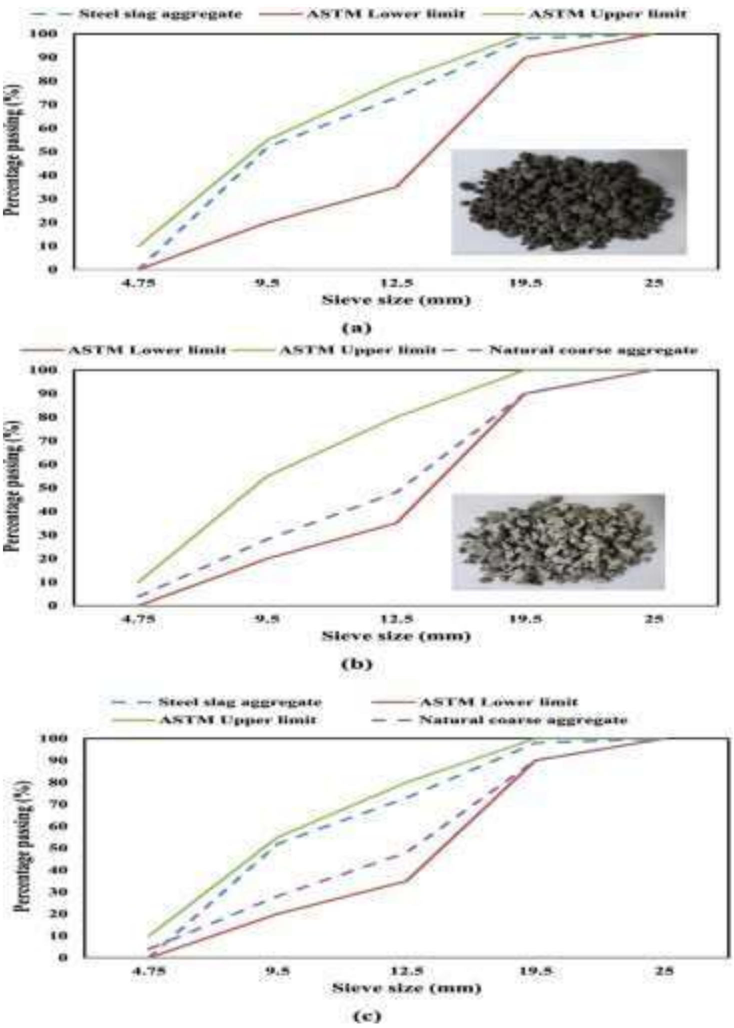


Figure 3.3: Sieve and Steel Slag size

3.6.5 AASHTO Soil classification system

The American Association of State Highway and Transportation Officials (AASHTO) soil classification system considers particle size as well as plasticity. Soils are classified into eight groups, A-1 to A-7, with peat or muck being the last. Soils within each group are evaluated using the group index (GI) calculated using the empirical formula below **Invalid source specified.**.

$$GI = 0.2a + 0.005ac + 0.01bd$$

∝ **a:** that portion of percentage of particles passing No. 200 sieve greater than 35% and not exceeding 75%

- **b:** that portion of percentage of particles passing No. 200 sieve greater than 15% and not exceeding 55%
- **c:** that portion of the liquid limit greater than 40 and not exceeding 60
- **d:** that portion of the plasticity index greater than 10 and not exceeding 30.

The group index value should be rounded off to the nearest integer; in case any of the above values is less than the minimum limit, it should be taken as zero **Invalid source specified.**

CHAPTER IV: RESULTS AND DISCUSSION

This chapter presented the result from experimental research plan. The results were obtained after laboratory testing of soil sample. The results are related to soil sample for sieve analysis and impact of steel slag to Atterberg limit, modified proctor test, and CBR test.

4.1 Sieve analysis test

For determining the sieve analysis of soil sample, the 2000g of soil sample was taken.

The table one indicated the sieve analysis of soil after washing. It was observed that the sample has fine soil of 54.8% of initial sample.

4.1.1 Calculation

Percentage retained on sieve$=\frac{\text{cumulative retained}}{\text{initial weight}} * 100$

The first weight retained on sieve of 14mm is 23.5 when the initial weight is 2000g. So that the percentage retained= $23.5/2000 * 100 = 1.2\%$

Percentage passing in sieve=100-percentage passing

On sieve of 14mm the percentage passing=100-1.2=98.8%

4.1.2 The Cost Estimation Between Soil Stabilization & Digging Up to Hard Soil

1. Digging Until Hard Soil is Reached

1.1. Costs Involved:

- Excavation Costs:
  - Labor: Costs for skilled and unskilled labor to operate excavation machinery 20,000 Rwf
  - Machinery: backhoes, bulldozers it’s between 120,000 Rwf to 130,000 Rwf per hour
  - Fuel and Maintenance: Costs associated with fuel consumption and maintenance of machinery it’s 14,920 Rwf per hour

- Disposal of Soil:
    - Hauling: Costs of transporting excavated soil to a disposal site it’s 45,000 Rwf for each Truck per Hour * 5 Trucks = 225,000 Rwf
    - Disposal Fees: Charges for disposing of soil, which may vary based on local regulations it was Free
- Site Preparation:
    - Grading and Compaction: Additional costs for grading the site and compacting the soil once hard soil is reached they did it in 9 days which costed around 12 millions
- Delays and Overheads:
    - Project Delays: Potential delays due to the time taken to reach hard soil, which can impact overall project timelines.
    - Overhead Costs: Additional costs associated with site management and supervision.

2. Soil Stabilization by Use of Steel Slag

2.1. Costs Involved:

- Steel Slag Costs:
    - Material Purchase: Around 700,000 Rwf for 3 Trucks including Transport
- Soil Preparation:
    - Mixing and Application: 50,000 Rwf for Labors
    - Labor: 5000 per each
- Testing and Quality Control:
    - Laboratory Testing: Costs for conducting soil tests (Atterberg limits, compaction tests) to ensure proper stabilization it’s on Engineer
    - Quality Control: Costs for monitoring and ensuring the correct application of steel slag which is also for Engineer
- Site Preparation and Compaction:
    - Compaction Costs: 150,000 Rwf
- Environmental and Regulatory Compliance:
    - Permitting: Potential costs associated with obtaining permits for the use of steel slag Hard to know this one

- Environmental Fees: Costs related to compliance with environmental regulations regarding the use of steel slag which is also hard

Table 4.1: Sieve Analysis Results

sieve(mm)	partial retained	cumulative retained	%retained	%passing
75	0	0	0.0	100.0
63	0	0	0.0	100.0
50	0	0	0.0	100.0
37.5	0	0	0.0	100.0
28	0	0	0.0	100.0
20	0	0	0.0	100.0
14	23.5	23.5	1.2	98.8
10	48.5	72	3.6	96.4
6.3	85	157	7.9	92.2
5	42.5	199.5	10.0	90.0
3.35	115	314.5	15.7	84.3
2.36	30	344.5	17.2	82.8
1.7	54.5	399	20.0	80.1
1.18	73	472	23.6	76.4
0.85	49.5	521.5	26.1	73.9
0.6	19	540.5	27.0	73.0
0.425	50.5	591	29.6	70.5
0.3	61.5	652.5	32.6	67.4
0.212	108	760.5	38.0	62.0
0.15	40	800.5	40.0	60.0
0.075	103	903.5	45.2	54.8

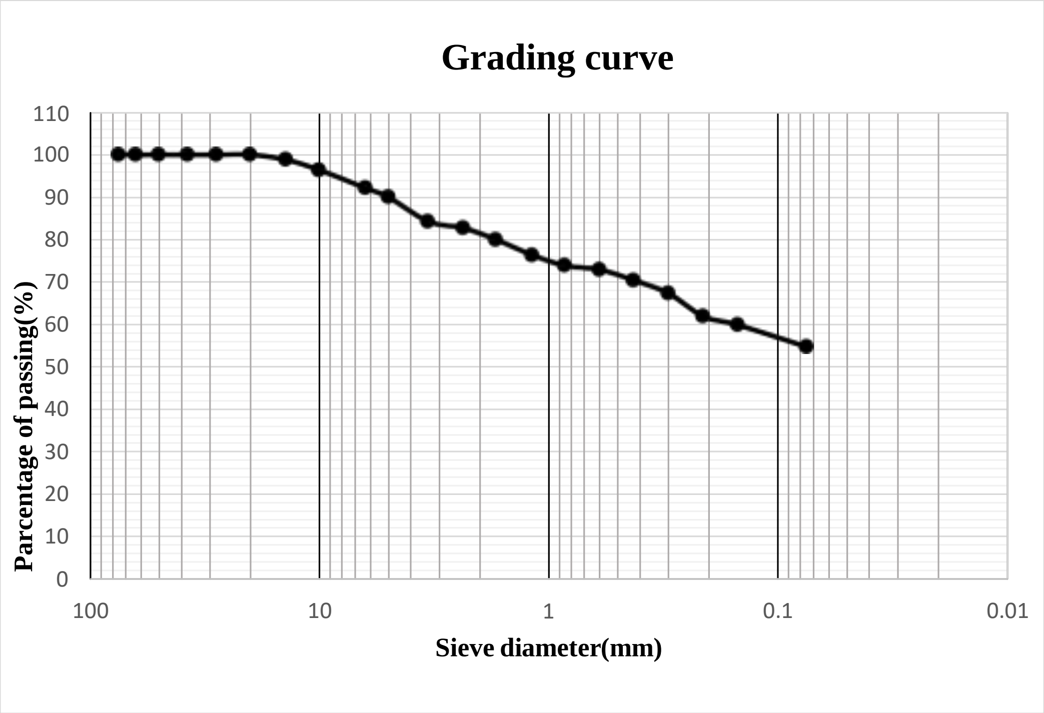


Figure 4.1: Result on Sieve Analysis

The results in (Fig.14) based on sieve analysis of the sample after washing it, showed that the sieve of 0.075 the sample passed in it is 54.8%. This means that the retained in this sieve is 45.2% of sample sieved. Soil sample taken was 2000g only 903.5g remained after washing means that 1096.5g is silt – clayey type material.

4.2 Atterberg limit

The plastic and liquid limits of a fine-grained soil were determined independently on the soil sample and water content at which soil changes from a plastic to a liquid state (liquid limit) and water content at which soil changes from a plastic to a semi-solid state (plastic limit).

4.2.1 Calculations and discussions

$$\text{Weight of water} = \text{Wet weight} - \text{Dry weight}$$

$$\text{Dry weight} = (\text{Dry weight} + \text{Pan}) - \text{Weight of pan}$$

$$\text{Wet weight} = (\text{Wet weight} + \text{Pan}) - \text{Weight of pan}$$

$$\text{Water content} = \frac{\text{Weight of water}}{\text{Dry weight}} * 100$$

$$\text{Plastic limit} = \frac{\text{sample 1} + \text{sample 2}}{2}$$

$$\text{Plastic index} = \text{liquid limit (wl)} - \text{plastic limit (wp)}.$$

The table below hold the data recorded during determination of liquid and plastic limits of the soil.

Table 4.2: Results obtained for Atterberg limit

		LIQUID LIMIT			
Number of blows	**15**	**20**	**25**	**30**	**35**
Pan No.	**R**	**RntR**	**B13**	**FK2**	**MK**
Wet weight + pan	**56**	**68**	**45.5**	**49.5**	**54.5**
Dry weight + pan	**48**	**57.5**	**40.5**	**44**	**47.5**
Weight of pan	**25**	**25**	**25**	**26**	**24.5**
Weight of water	**8**	**10.5**	**5**	**5.5**	**7**
Dry weight	**23**	**32.5**	**15.5**	**18**	**23**
Moisture content	**34.78**	**32.31**	**32.26**	**30.56**	**30.43**
Estimation for 25 blows					

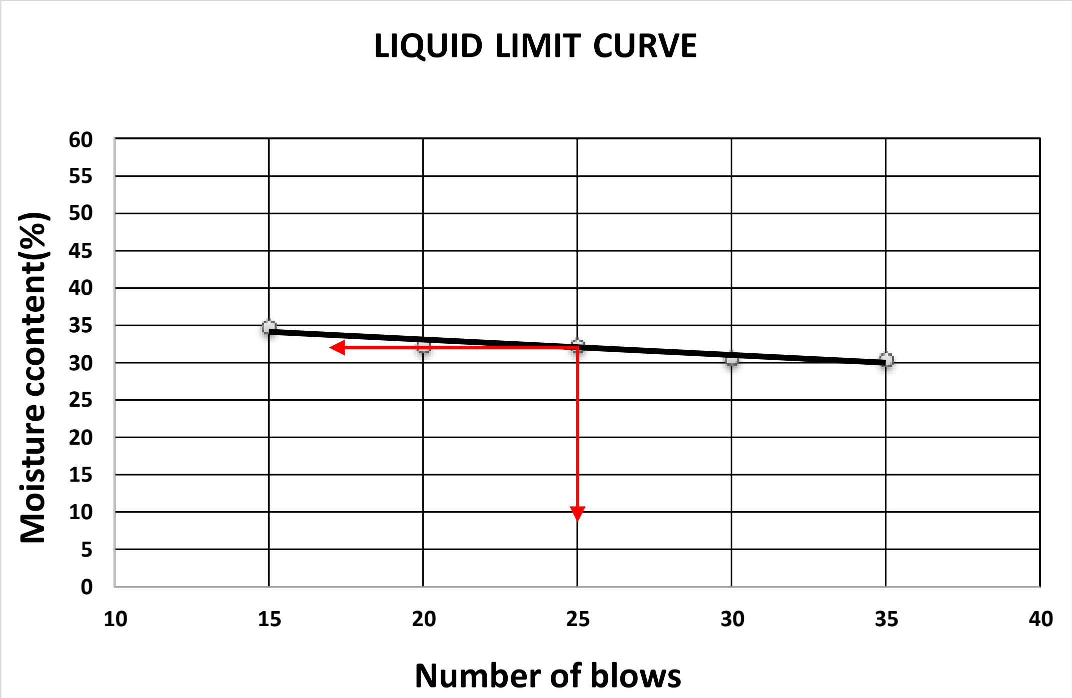


Figure 4.2: Curve for Atterberg Limits

From the graph above liquid limit (LL) equal 32.26%, which corresponds to 25 blows

Plastic limit =average of water content= 20

Plasticity index (PI) =Liquid limit (LL)-Plastic limit (PL) = 32.26-20

PI=12.26%

Plasticity index indicate the degree of plasticity of soil. The greater the difference between liquid limit and plastic limit, the greater is the plasticity of soil. Using AASHTO classification table in fig.13, since 54.8% of the soil is passing through No 200 Sieve, it falls under the silt-clayey type of material (A-4, A-5, A-6 or A-7). Proceeding from left to right using liquid limit (A-5 and A-7 cancel out) and plastic index (A-4 cancels out) therefore, it falls under group A-6.

Group index calculation

GI = 0.2a + 0.005ac + 0.01bd

a = 54.8-35 = 19.8

b = 54.8-15 = 39.8

c = 32.26-40 = -7.74

d = 20-10 = 10

GI = 0.2x19.8 + 0.005x19.8x-7.74 + 0.01x39.8x10= 9

The soil is classified as A-6 (9). Hence the soil is fair to poor subgrade soil.

4.3 Compaction Test

Typical results of modified Proctor tests are representing the relationship between the moisture content and the dry density of the soil. At the peak point of the curve, moisture content is called the optimum moisture content, and the density is called the maximum dry density.

4.3.1 Modified proctor test of expansive soil before and after stabilization

Table 4 illustrates the test results obtained during compaction of soil.

Table 2.3: Description of Soil after Compaction

Description	Moisture content	Dry density(g/cm^3)
Soil alone	16.5	1.82
Soil+5% steel slag (SS)	16	1.96
Soil+ 10% steel slag (SS)	15.7	2.05

For compaction test the result obtained was for maximum dry density and optimum moisture content. Where, MC=$\frac{\text{wetmaterial+pan}-\text{drymaterial+pan}}{\text{drymaterial+pan}-\text{weightofpan}}*100$

Dry density=$\frac{M/V}{1+MC/100}$

4.4 California Bearing Ratio test

This test was conducted in order to know how soil can bear with load applied on it. Test was performed on soil without stabilizer and soil with stabilizer Steel slag. Before carried out of this test the compaction was done for knowing the OMC needed for CBR test.

4.4.1 CBR test of expansive soil before stabilized

The results from CBR tests carried on expansive soil before stabilization was obtained and interpreted in the following table.

Table 4.4: CBR test of non-stabilized soil

DRY DENSITY				
N° of mould	**...**	**NG1**	**NG2**	**NG3**
Number of blows	**...**	62	55	15
Mass mould - Wet mat	**[g]**	11552	11335	10736
Mass mould	**[g]**	7080.5	6944.5	7080.5
Mass Wet material	**[g]**	4472	4391	3656
Volume of mould	**[cm³]**	2248.44	2248.44	2248.44
Wet density	**[g/cm³]**	1.99	1.95	1.63
Moisture content	**[%]**	9.09%	12.31%	15.84%
Dry Density	**[g/cm³]**	**1.823**	**1.739**	**1.404**
Reference Proctor	**[g/cm³]**	1.82	1.82	1.82
% compaction	**[%]**	100.16%	95.53%	77.12%
C.B.R Indice	**[1]**	**6.28**	**3.88**	**3.32**
C.B.R @ 95%	**4.45**	Dry Density @95% compaction		**1.729**
C.B.R @ 98%	**4.92**	Dry Density @98% compaction		**1.784**
C.B.R Indice 55Blows	**7.20**	Dry Density -C.B.R		**1.823**
C.B.R Indice 25Blows	**4.43**	Dry Density -C.B.R		**1.739**
C.B.R Indice 10Blows	**3.88**	Dry Density -C.B.R		**1.404**

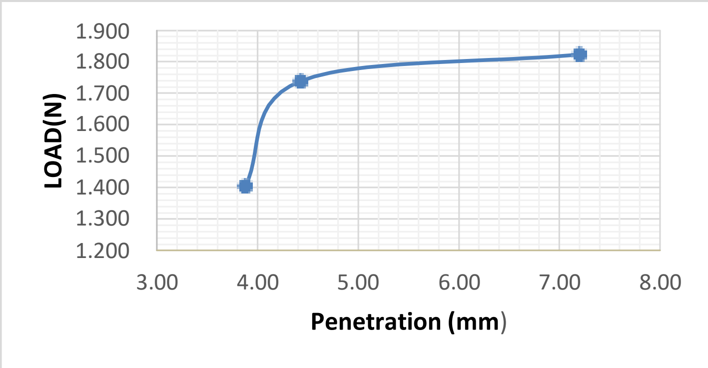


Figure 4.3: CBR curves for non-stabilized soil

4.4.2 CBR test results of expansive soil stabilized with 5% of steel slag.

The results from CBR tests carried on expansive soil stabilized with 5% of steel slag was obtained and interpreted in the following table.

Table4.5: CBR test of soil stabilized with 5% of steel slag.

DRY DENSITY				
N° of mould	**...**	**NG1**	**NG2**	**NG3**
Number of blows	**...**	62	55	15
Mass mould - Wet mat	**[g]**	14482	13145	12176
Mass mould	**[g]**	7080.5	6944.5	7080.5
Mass Wet material	**[g]**	7402	6201	5096
Volume of mould	**[cm³]**	3091	3091	3091
Wet density	**[g/cm³]**	2.39	2.01	1.65
Moisture content	**[%]**	22.92%	10.98%	10.42%
Dry Density	**[g/cm³]**	**1.948**	**1.808**	**1.493**
Reference Proctor	**[g/cm³]**	1.96	1.96	1.96
% compaction	**[%]**	99.39%	92.22%	76.17%
C.B.R Indice	**[1]**	**13.29**	**8.31**	**5.17**
C.B.R @ 95%	**8.7**		Dry Density @95% Compaction	**1.862**
C.B.R @ 98%	**12.03**		Dry Density @98% compaction	**1.921**
C.B.R Indice 55Blows	**13.29**		Dry Density -C.B.R	**1.948**
C.B.R Indice 25Blows	**8.31**		Dry Density -C.B.R	**1.808**
C.B.R Indice 10Blows	**5.17**		Dry Density -C.B.R	**1.493**

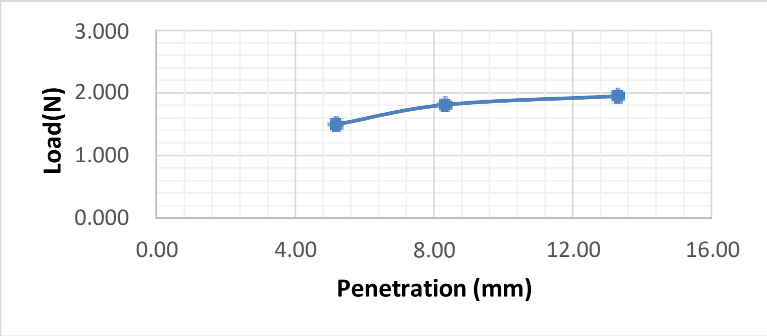


Figure 4.4: CBR curve for soil stabilized with 5% of steel slag

4.4.3 CBR test results of expansive soil stabilized with 10% of steel slag.

The results from CBR tests carried on expansive soil stabilized with 5% of steel slag was obtained and interpreted in the following table

Table 4.6: CBR test of soil stabilized with 10% of steel slag.

DRY DENSITY				
N° of mould	**...**	**NG1**	**NG2**	**NG3**
Number of blows	**...**	62	55	15
Mass mould - Wet mat	**[g]**	14052	13435	11876
Mass mould	**[g]**	7080.5	6944.5	7080.5
Mass Wet material	**[g]**	6972	6491	4796
Volume of mould	**[cm³]**	3091	3091	3091
Wet density	**[g/cm³]**	2.26	2.10	1.55
Moisture content	**[%]**	10.35%	8.62%	9.09%
Dry Density	**[g/cm³]**	**2.044**	**1.933**	**1.422**
Reference Proctor	**[g/cm³]**	2.05	2.05	2.05
% compaction	**[%]**	99.70%	94.30%	69.37%
C.B.R Indice	**[1]**	**19.38**	**14.40**	**5.54**
C.B.R @ 95%	**15.0**		Dry Density @95% compaction	**1.948**
C.B.R @ 98%	**15.2**		Dry Density @98% compaction	**2.009**
C.B.R Indice 55Blows	**19.38**		Dry Density -C.B.R	**2.044**
C.B.R Indice 25Blows	**14.40**		Dry Density -C.B.R	**1.933**
C.B.R Indice 10Blows	**5.54**		Dry Density -C.B.R	**1.422**

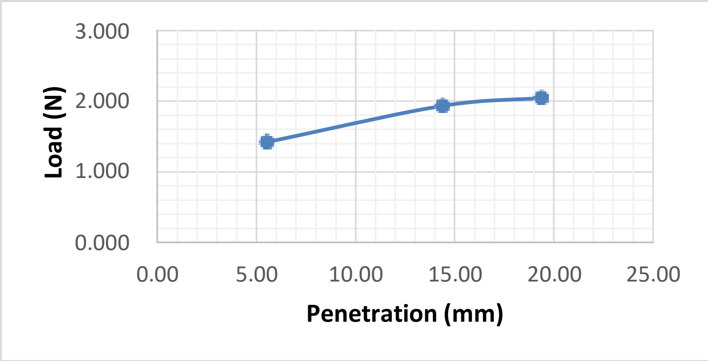


Figure 4.5: CBR curve of soil stabilized with 10% steel slag

4.4.2 Discussions of CBR test results obtained in laboratories

The bearing capacity of a soil is a direct measure of the resistance of the soil to lateral displacement, and since the CBR test was designed to measure this property. According to Terzaghi, the bearing capacity is the capacity of soil to support the loads applied to the ground that the maximum average contact pressure between the foundation and the soil should not produce shear failure in the soil. To improve the bearing capacity of soil compaction and stabilizing the soil with chemicals was done.

By referring to the following table, which contains the standard CBR values for different soil classifications, the discussion on the performed CBR tests before and after stabilization of expansive soil sample was facilitated.

Table 4.7: Classification of soil based on CBR Indices (Janjua & Chand, 2016).

CBR	General Rating	Uses
0-3	Very poor	Sub-grade
3-7	Poor to poor	Sub-grade
7-20	Fair	Sub-base
20-50	Good	Base or Sub-base
>50	Excellent	Base

CBR indices obtained before stabilization localized the sample in poor to fair sub-grade when 10 blows and 25 blows were considered and for 55 blows localized the sample in fair sub-base, this implies that the soil need to be improved by stabilization. But the number of blows counts, as it correspond with CBR indices where it diminished as the number of blows reduced.

When CBR test performed on stabilized expansive soil at 5% of steel slag, the CBR Indices start to increases depending to the much number blowing. Where for 10 blows soil considered in poor to fair sub-grade and that of 25 blows and 55 blows are in fair sub-base.

For 10% of steel slag stabilizing the expansive soil, the CBR indices at 10 blows localized the soil in poor to fair sub-grade, and those of 25 and 55 blows having fair sub-base and can be used in construction projects. Therefore, the more percentage of stabilizers increase the more excellent CBR indices are obtained and favorable in construction projects. This confirm the achievement of the general objectives of the research.

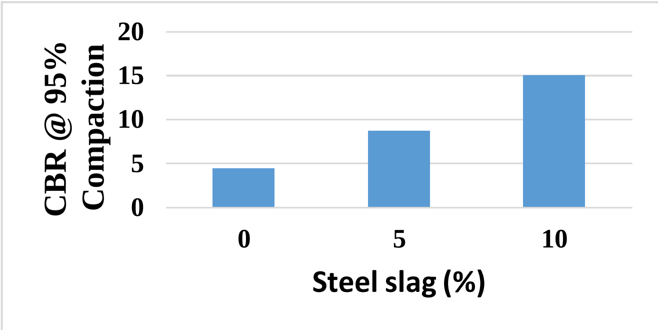


Figure 4.6: Variation in CBR values as a function of steel slag percentage

The California Bearing Ratio (CBR) is a comprehensive penetration test for determining the strength of the soil. The CBR value was determined by soaking the samples for seven days at the optimum moisture content, as determined by the Proctor compaction test. Figure 20 shows that the steel slag was effectively worked, resulting in significant increases in CBR value. As a result, using 10% SS resulted in a greater CBR value. This is because the raw iron content of the steel slag additive is high. Figure 20 also shows that when 10% steel slag was mixed into the soil specimen, the CBR values increased from 4.45 to 15%. The increased CBR value could be as a result of the iron material's role in the steel slag. Several studies have confirmed that adding steel slag to weak expansive soil improves CBR values. According to the study by Abdalqadir et al. (2020), the CBR value rises from 4.5 to 16% when steel slag is added to the soil sample from 0 to 20%.

CHAPTER V: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This investigation was performed to evaluate the performance of steel slag in stabilization and in improving geotechnical properties And objective got achieved by cost estimation , The soil used in the experiments was silty type material by performing some tests such as Sieve analysis, Atterberg limits test, California bearing ratio and modified proctor test. Steel slag changes the geotechnical properties of the expansive soil dramatically. As a result, the liquid limit was 32.26%, the plastic limit 20%, and the plasticity index 12.26 % according to the Atterberg limit test results. The MDD rises from 1.82 to 1.96g/cm^3 in the addition of 5% of steel slag, while the OMC decreases from 16.5to 16%. For addition of 10% of steel slag rises to 2.05g/cm^3 in standard compaction test, while the OMC decreases to 15.7%. According to the California Bearing Ratio test, a 5% addition of steel slag increases the California Bearing Ratio value from 7.2 to 13.29%. For 10% addition of steel slag increases the California Bearing Ratio value from 13.29 to 19.38%. As a result, this study concludes that steel slag is a cost-effective material for improving soil geotechnical properties and a viable option for reducing the environmental impact of steel slag waste.

5.2 Recommendation

- It is recommended that the steel slag can be used as alternative stabilizers since they can minimize the cost of construction project; the researchers and final-year students should continue their research to find more cost-effective soil improvement materials.
- It is recommended to other researchers to determine the strength and durability of steel slag in soil subgrades, as well as to conduct additional tests like laboratory tests, such as chemical tests, and other tests to which is better to describe the effects of the used stabilizers in this study.
- Recommended to Steel Rwa Industry , if it wasn’t for them , it was going to be hard to Get the Steel slag sample to be used

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APPENDICES

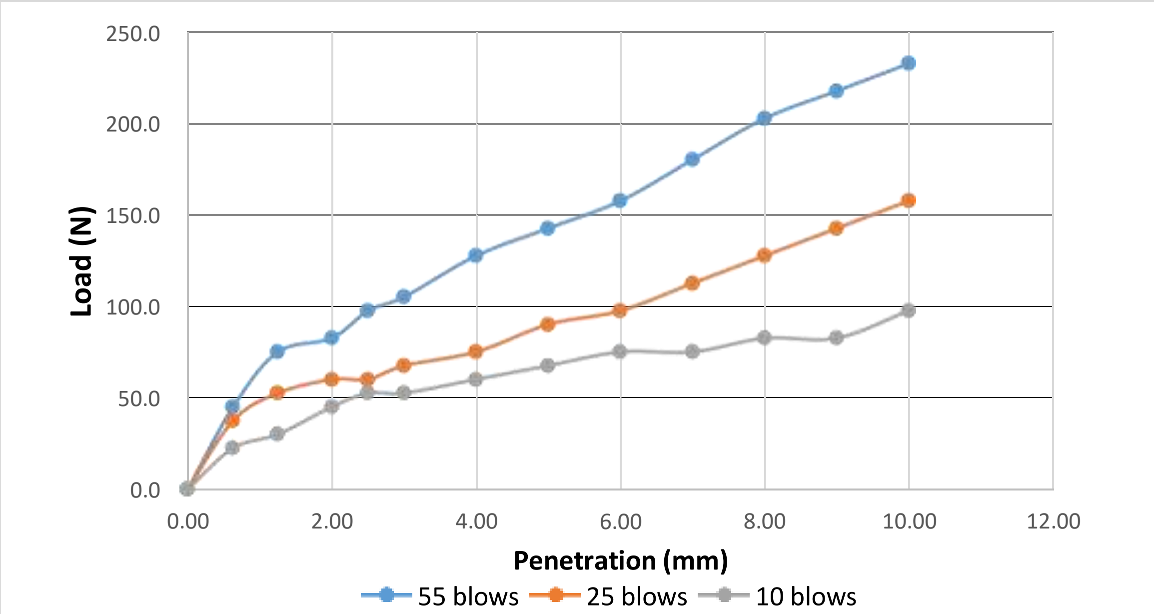
Appendix A: Moisture content after compaction of non-stabilized soil.

MOISTURE CONTENT AFTER COMPACTION			
Number of blows	62	55	15
Pan N°	A1	A2	A3
Mass pan - Wet mat	44.0	61.5	72.5
Mass pan - Dry mat	42.5	57.5	66.0
Mass pan	26.0	25.0	25.0
Mass water	1.5	4.0	6.5
Mass Dry material	16.5	32.5	41.04
Moisture content	9.09%	12.31%	15.84%

Appendix B: CBR penetration of non-stabilized soil.

Blows	**62**		**55**		**15**	
Penetration(mm)	**Reading**	**Load (N)**	**Reading**	**Load (N)**	**Reading**	**Load (N)**
0.00	**0**	0.0	**0**	0.0	**0**	0.0
0.63	**6**	45.0	**5**	37.5	**3**	22.5
1.25	**10**	75.0	**7**	52.5	**4**	30.0
2.00	**11**	82.5	**8**	60.0	**6**	45.0
2.50	**13**	97.5	**8**	60.0	**7**	52.5
3.00	**14**	105.0	**9**	67.5	**7**	52.5
4.00	**17**	127.5	**10**	75.0	**8**	60.0
5.00	**19**	142.5	**12**	90.0	**9**	67.5
6.00	**21**	157.5	**13**	97.5	**10**	75.0
7.00	**24**	180.0	**15**	112.5	**10**	75.0
8.00	**27**	202.5	**17**	127.5	**11**	82.5
9.00	**29**	217.5	**19**	142.5	**11**	82.5
10.00	**31**	232.5	**21**	157.5	**13**	97.5
C.B.R Indice :	**2.5 mm**	7.20	**2.5**	4.43	**2.5 mm**	3.88
	5.0 mm	7.01	**5.0 mm**	4.43	**5.0 mm**	3.32
	choice :	7.20		4.43		3.88

Appendix C: Graphic penetration of CBR for non-stabilized soil



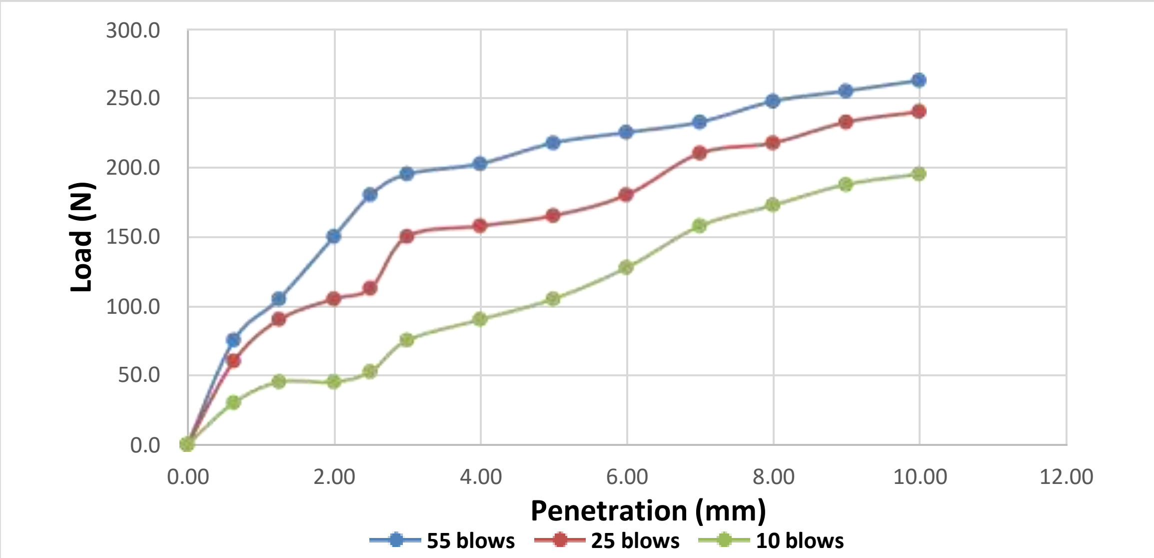
Appendix D: Moisture content after compaction of stabilized soil with 5% of steel slag.

MOISTURE CONTENT AFTER COMPACTION			
Number of blows	62	55	15
Pan N°	A1	A2	A3
Mass pan - Wet mat	54.0	71.5	52.0
Mass pan - Dry mat	48.5	67.0	49.5
Mass pan	24.5	26.0	25.5
Mass water	5.5	4.5	2.5
Mass Dry material	24.0	41.0	24.00
Moisture content	22.92%	10.98%	10.42%

Appendix E: CBR penetration of stabilized soil with 5% of steel slag.

Blows	**62**		**55**		**15**	
Penetration(mm)	**Reading**	**Load (N)**	**Reading**	**Load (N)**	**Reading**	**Load (N)**
0.00	**0**	0.0	**0**	0.0	**0**	0.0
0.63	**10**	75.0	**8**	60.0	**4**	30.0
1.25	**14**	105.0	**12**	90.0	**6**	45.0
2.00	**20**	150.0	**14**	105.0	**6**	45.0
2.50	**24**	180.0	**15**	112.5	**7**	52.5
3.00	**26**	195.0	**20**	150.0	**10**	75.0
4.00	**27**	202.5	**21**	157.5	**12**	90.0
5.00	**29**	217.5	**22**	165.0	**14**	105.0
6.00	**30**	225.0	**24**	180.0	**17**	127.5
7.00	**31**	232.5	**28**	210.0	**21**	157.5
8.00	**33**	247.5	**29**	217.5	**23**	172.5
9.00	**34**	255.0	**31**	232.5	**25**	187.5
10.00	**35**	262.5	**32**	240.0	**26**	195.0
C.B.R Indice :	**2.5 mm**	13.29	**2.5**	8.31	**2.5 mm**	3.88
	5.0 mm	10.71	**5.0 mm**	8.12	**5.0 mm**	5.17
	choice :	13.29		8.31		5.17

Appendix F: Graphic penetration of CBR for stabilized soil with 5% of steel slag



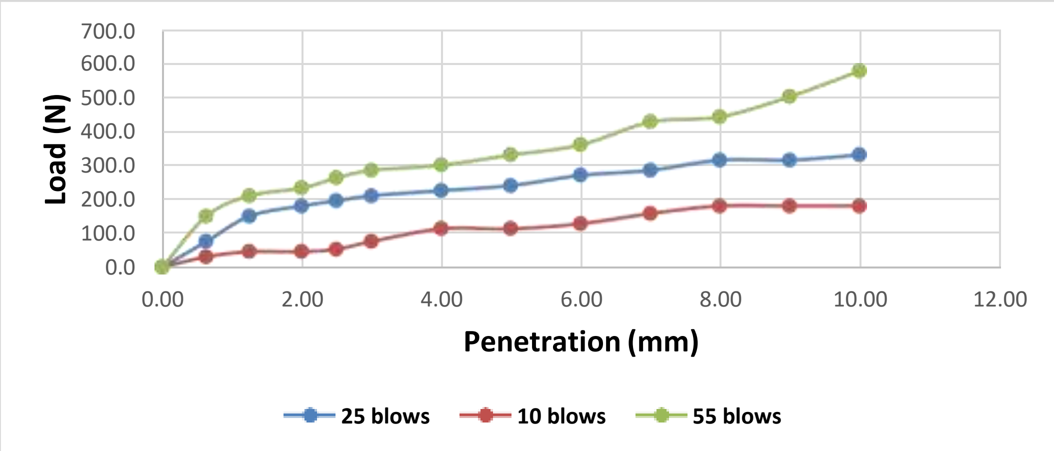
Appendix G: Moisture content after compaction of stabilized soil with 10% of steel slag.

MOISTURE CONTENT AFTER COMPACTION			
Number of blows	62	55	15
Pan N°	A1	A2	A3
Mass pan - Wet mat	93.8	82.2	80.0
Mass pan - Dry mat	87.3	77.7	75.5
Mass pan	24.5	25.5	26.0
Mass water	6.5	4.5	4.5
Mass Dry material	62.8	52.2	49.50
Moisture content	10.35%	8.62%	9.09%

Appendix H: CBR penetration of stabilized soil with 10% of steel slag.

Blows	**62**		**55**		**15**	
Penetration(mm)	**Reading**	**Load (N)**	**Reading**	**Load (N)**	**Reading**	**Load (N)**
0.00	**0**	0.0	**0**	0.0	**0**	0.0
0.63	**20**	150.0	**10**	75.0	**4**	30.0
1.25	**28**	210.0	**20**	150.0	**6**	45.0
2.00	**31**	232.5	**24**	180.0	**6**	45.0
2.50	**35**	262.5	**26**	195.0	**7**	52.5
3.00	**38**	285.0	**28**	210.0	**10**	75.0
4.00	**40**	300.0	**30**	225.0	**15**	112.5
5.00	**44**	330.0	**32**	240.0	**15**	112.5
6.00	**48**	360.0	**36**	270.0	**17**	127.5
7.00	**57**	427.5	**38**	285.0	**21**	157.5
8.00	**59**	442.5	**42**	315.0	**24**	180.0
9.00	**67**	502.5	**42**	315.0	**24**	180.0
10.00	**77**	577.5	**44**	330.0	**24**	180.0
C.B.R Indice :	**2.5 mm**	19.38	**2.5**	14.40	**2.5 mm**	3.88
	5.0 mm	16.24	**5.0 mm**	11.81	**5.0 mm**	5.54
	choice :	19.38		14.40		5.54

Appendix I: Graphic penetration of CBR for stabilized soil with 10% of steel slag



Appendix J: Results of atterberg limits

	LIQUID LIMIT					**PLASTIC LIMIT**				**VALUE**
number of blows	15	20	25	30	35		2	3	LIQUID LIMIT	**32.26**
pan No.	R	RntR	B13	FK2	MK	MG	MYK	JJ		
wet weight + pan	56	68	45.5	49.5	54.5	28	38	15		
dry weight + pan	48	57.5	40.5	44	47.5	27.5	37.5	14.5	PLASTIC LIMIT	**20.00**
weight of pan	25	25	25	26	24.5	25	35	13		
weight of water	8	10.5	5	5.5	7	0.5	0.5	0.5		
dry weight	23	32.5	15.5	18	23	2.5	2.5	1.5	PLASTIC INDEX	**12.26**
moisture content	**34.78**	**32.31**	**32.26**	**30.56**	**30.43**	**20.00**	**20.00**	**33.33**		
Estimation for 25 blows										