DEGREE OF LATERALIZATION OF TROPICAL SOILS AND THEIR IMPLICATIONS FOR ROAD CONSTRUCTION
(CASE OF TIS ESAT ROAD PROJECT, BAHIR DAR)

By
Mohammed Yesuf

A Master Thesis Submitted to the Department of Civil Engineering School of Civil Engineering and Architectural presented in partial fulfillment of the requirement of the Degree of Masters of Science in Geotechnical Engineering

Office of Graduate Studies
Adama Science and Technology University

Jun-2021
Adama, Ethiopia

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Approval Page

I, the advisor of the thesis entitled “Degree of lateralization of Tropical soils and their Implications for Road construction (case of Tis Esat road project, Bahir Dar)” and developed by Mohammed Yesuf, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

Afzal Khan (PhD)	______________	______________
Advisor/Supervisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Mohammed Yesuf have read and evaluated the thesis entitled “Degree of lateralization of Tropical soils and their Implications for Road construction (case of Tis Esat road project, Bahir Dar)” and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geotechnical Engineering.

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Finally, approval and acceptance of the thesis are contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Declaration

I hereby declare that this Master Thesis entitled “Degree of lateralization of Tropical soils and their Implications for Road construction (case of tis esat road project, Bahir Dar)” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Mohammed Yesuf	_____________	____________
Name of the Student	Signature	Date

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Abbreviations

ASTM	American Society for Testing and Materials.
AASHTO	American Association of State Highway and Transportation Officials.
ERA	Ethiopian Road Authority
USCS	Unified Soil Classification System
BS	British Standard
AR	As Received /at the natural moisture content/
AD	Air Drying or oven drying at a temperature of 50oc with maximum Relative humidity (RH) 30%
RH	Maximum relative humidity
OD	Oven drying at a temperature of 105^0C
LL	Liquid limit
PL	Plastic limit
PI	Plasticity Index
LS	Linear shrinkage
FS	Free Swell
G_s	Specific gravity
w	Moisture content
NMC	Natural Moisture Content
OMC	Optimum Moisture Content for a compaction test
MDD	Maximum Dry Density for a compaction test
CBR	California Bearing Ratio
SCM	Standard proctor Compaction Method
MCM	modified compaction method
UCS	unconfined compression strength test
Qu	Unconfined Compression Strength
GI	Group Index

Abstract

An increase in construction and material use in tropical environments has made way for engineering knowledge of related basic properties of soils within those areas. One such soil found abundantly is the lateritic soils. The main objective of this research work was to study the degree of lateralization of tropical soils and their implication for road construction. The objectives of this study were satisfied by a series of standardized geotechnical and geochemical laboratory tests of lateritic soils which are observed to occur in the Bahir Dar-Tis Esat road project. Five sites were randomly chosen throughout the road from which disturbed and undisturbed lateritic soil samples at a depth of 0.6m and 1.5m were collected. Comparison of the determined engineering properties was compared with properties of similar studies done on lateritic and laterite soils with local researchers and found in Africa. The findings show particle size distribution of the soil throughout the study area is very similar. While most classification could be said as highly plastic inorganic soils and some are gravels falls above and below A-line. NMC range between 4.53 to 12.2%. Average MDD and OMC were found to be 1.563 and 20.58 respectively. The specific gravity ranges between 1.75 to 2.69 with an average of 2.23. LL, PL, and PI range between 42 to 86.3%, 28.38 to 38.4%, and 13.12 to 49.7% respectively. The soaked CBR ranges from 1.22 to 10.41% and the corresponding swell percent ranges from 1.49to 14.36% respectively at 65 blows of the modified proctor. UCS test is found between 40.42 to 146.26Kpa. the silica to sesquioxide ratio of the most geochemical test (complete silicate analysis) shows between 1.33 and 2, indicated that they are lateritic soils. The free swell result gives an average value of 56% indicates a medium potential of expansiveness. Generally, the soils are classified as A-7-6 to A-7-5 subgroups of AASHTO classification. According to the material requirement of ERA-2013, only test pit C (sample C-1 and C-2) satisfies to be subgrade or embankment material. Finally, based on the general findings of the study, suitable recommendations and conclusions have been forwarded.

Keywords: *Geochemical test, Geotechnical properties, Free swell, Lateritic soil, Particle size analysis, NMC, LL, PL PI, UCS, CBR, Modified compaction, Specific gravity*

CHAPTER ONE

INTRODUCTION

1.1 Background

A thorough and comprehensive geotechnical investigation is an important demand for the look and construction of engineering projects. the right style of civil engineering structures just like the foundation of buildings, retaining walls, high ways, etc. needs adequate data of subsurface conditions at the sites of the structures. Many damages to buildings, roads, and different structures supported on soils are primarily because of the shortage of correct investigation of substructure conditions. The town of Bahir Dar, having an adequate land area for expansion and being an important industrial, commercial, educational, and tourist center in the region will have a high potential for future development. A lot of civil engineering structures are under construction; however, nothing has been done on the investigation of soil for the intended urban development plan (Fasil, 2003).

To examine the engineering behavior of the native sub-grade soils and to see the effect of degree of lateralization (weathering), verification tests have been conducted on samples recovered from test pits excavated to a minimum depth of 1.5m below ground surface, accordingly 5 test pits at a depth of 0.6m and 1.5m (10 samples total) have been recovered and the necessary tests have been conducted to represent the entire project alignment.

Laterites and lateritic occur largely in tropical and sub-tropical regions with hot, wet climates. it's been recommended that a mean annual temperature of around 25°C is needed for their formation, and in seasonal things, there should be a coincidence of the warm and wet periods. The minimum annual precipitation needed for soil formation is usually a minimum of 750 millimeters. the upper the precipitation higher than this worth, the larger is that the leaching effect and so will increase the degree of lateralization(Zelalem, 2005).

Laterites are grouped under the group of soils with a strong mineralogical influence derived from clay minerals only found in residual soils (Blight & Leong, 1999). Soil engineering properties under this group are highly influenced by the presence of sesquioxide. The sesquioxide among the fine fraction of tropical soils tends to coat the surface of individual soil particles. It may also cause physical cementation of adjacent grains, therefore producing mass particles of coarser size. Both factors reduce plasticity, but intensive remolding of the soil breaks down the aggregations and the sesquioxide coatings which is called disaggregation, increases plasticity.

Physical properties of some lateritic soils show variation when tested under different pretreatment conditions (sample preparation condition before testing). The influence of sample preparation on index property tests and compaction characteristics of tropical soils is recommended (Sintayehu, 2003).

When some laterite soils are oven-dried before testing at a temperature of l05°C, they exhibit lower Atterberg Limit values. This is partly because dehydration of the sesquioxide creates a stronger bond between the particles, which is resistant to the penetration of water. Drying is also accompanied by shrinkage, which brings the particles closer together, and the attractive forces become so strong that water no longer penetrates. The process cannot be reversed by re-wetting. The effect takes place during air-drying but becomes more pronounced on oven-drying at higher temperatures (Zelalem, 2005).

The highway which is constructed using tropical soils such as lateritic soils as a subbase, base course, and sub-grade has a great advantage in that they are constructed from locally available materials within sound technical and affordable financial capacity. To use tropical soils safely and economically, acceptable strategies of determining the geotechnical properties like index properties, compaction, and strength (CBR) properties got to be assessed. The suitability of tropical soils to be used as sub-base, base course, and sub-grade materials should take into account how these materials are affected by the testing procedures and their sensitivity to different pretreatment. Therefore, laboratory testing should be simulated to site conditions. According to (Lyon Associates Institute Inc., 1971), In addition to the variable nature of tropical soils, the absence of uniform methods for the preparation of samples and testing is the main reason that leads to limited studies so far. As a consequence, the drawing of any rational conclusions on the engineering properties of tropical soils has been very difficult (Yohannes, 2019).

Laterite is a widely available material in Ethiopia as mentioned by the ERA manual (Ethiopian Roads Authority (ERA), 2013). Nowadays most infrastructures of the country have been constructed in the area where laterites are available. The engineering properties of such soils have not been studied satisfactorily. Some roads constructed on such area faces a shortage of construction materials. To use laterites as construction materials detail engineering properties would be known.

The change of rock mass into soil particles reduces its apparent density while increases the hydraulic conductivity of porous media, resulting in a weathering profile. Residual soils vary from transported soils in that their geotechnical properties are highly dependent on the degree of breakdown caused by their origination. Soil genesis is influenced by factors such as climate, geography, and drainage. Physical and chemical weathering causes:

- ✓ changes in particle size and mineralogy
- ✓ decreases in particle bond strength,
- ✓ increases in porosity and permeability
- ✓ loss in stiffness and soil density
- ✓ induced changes in physical and mechanical soil properties and
- ✓ changes in soil fabric as a result of wetting and drying cycles.

Thus, weathering is a phenomenon of great importance in the geotechnical behavior of tropical residual soils (Bogado et al., 2017).

The town of Bahir Dar which have a lot of civil engineering structures are under construction and Tis Esat Road project is one of the on-going project currently which is located in the northern part of the country. The proposed road is creating enhanced access to Tis Abay (water fall of the blue nile). The falls are one of the Ethiopia's best tourist attraction site. Therefore the objective of the research is study the degree of lateralization of tropical soils and their implications for road construction. After collecting the representative disturbed and undisturbed samples from proposed test pits they are tested to check the extent of lateralization, to characterize the study area soil through chemical, index and strength property tests and to check the suitability of the materials for road construction under the material requirement of ERA, 2013.

1.2 Problem Statements

Tropical residual soil properties vary from region to region due to their heterogeneous nature and highly variable degree of weathering, controlled by regional climatic and topographic conditions and the nature of bedrock. Previous site investigation and characterization studies in other parts of the country have revealed that large amounts of tropical rainfall combined with hot and humid climatic conditions favor weathering of the bedrock to a considerable depth and to a varying degree. Consequently, the engineering properties of the tropical residual soils varies with depth in particular location and across a different climatic regions. Therefore, the residual soil from a particular region needs to be characterized individually for an appropriate assessment of its engineering behavior.

Characterizing changes in the engineering properties of a weathered residual soil has been a concern of civil engineers. Because the majority of foundations, excavations, and embankments will be built on or in such soil, and because tropical soils are frequently employed as construction material, the features and characteristics of tropical residual soils must be thoroughly recognized.

Despite the large coverage and use of the tropical soils in Ethiopia, and Bahir Dar, having land area for expansion and being an important commercial and tourist center in the region and will have a high potential for future development there has been no systematic research, standardization in testing, classification, or investigation of these materials. The conditions, characteristics, and properties are all too important in determining the feasibility of its use in construction and also its behavior and impacts in surrounding areas.

1.3 Objectives

1.3.1 General Objectives

The general objective is to study the degree of lateralization of tropical soils and their implication for road construction.

1.3.2 Specific Objectives

- ✓ To check the extent of lateralization of the soil.
- ✓ To conduct chemical, index, and mechanical property tests to characterize the tropical soils in the case study area.
- ✓ Implicate the suitability of these soils for road construction.
- ✓ Compare the results with other local and global researchers and Provide recommendations for future geotechnical studies on the findings and conclusions of the study.

1.4 Scope and Limitation of the Study

1.4.1 Scope

In this study, the degree of lateralization of soils of the study area and the soil characteristics for the implication of road construction is done. Index property tests such as particle size analysis, moisture content, free swell, specific gravity, and Atterberg limits are carried out. Also, strength characteristic tests and chemical property tests such as compaction, CBR, UCS, strength test, and geochemical are done.

1.4.2 Limitation

Ethiopian geological survey-geochemical laboratory could not able to conduct an X-ray diffraction test to identify the mineralogical composition, in the account of the fact that x-ray diffraction testing equipment is down.

1.5 Significance of the Study

- ✓ develop a better understanding of the behavior, characteristics, and short-come of tropical soils as subgrade material.
- ✓ Add additional information on the engineering properties of tropical soils thus to minimize the risk of any probable damage to road construction in the study area.
- ✓ It is also wise to understand that areas with plenty of prior engineering geological studies in the study areas will possibly attract more investment than areas with less similar studies.

1.6 Structure of the Thesis

This thesis is mainly allocated in Five chapters, which started with an introductory chapter that gives a general briefing, a background of the study, problem statement, the objective of the study, scope, and limitations. The literature review takes the second chapter describing weathering process of tropical soils, characterization, classification, chemical and mineralogical composition of tropical soils, and also these soils as construction material from conventional materials by reviewing published and unpublished literature. Procedures, Materials, and methods covered in chapter three, which describes Geological seating, Topographic feature and Climatic conditions of sampling area then sampling location and with reference standards of testing practices is described in the third chapter and followed by chapter four, which explain test results and analysis with a brief discussion presented under each test. Further discussions on findings of this thesis work and comparison with well-known African and Ethiopian lateritic soils and also the overall implication of the suitability of these soil for road construction under the material requirement of ERA-2013 included in chapter four. The main body of the thesis windup by conclusion and recommendations under chapter five, then after references presented, pictures and test results with corresponding curves and figures appended.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Tropical soils have different definitions for various employees. the definition projected by the general public works institute of Malaysia (1996) defines residual soils as ‘a soil that has been shaped unaltered by decomposition of parent material and that has not been transported any vital distance’ and defines tropical residual soil as “a soil shaped in place below tropical weathering conditions”. Further, in reviewing the international application for the sampling and testing of residual soils, complete & Phillipson (1985) found that authors from totally different regions had some variation within the interpretation of what can be outlined as “residual soil”. Generally, the bulk of the employees primarily outlined residual soils as “soil weather-beaten in place wherever the initial rock structure is destroyed by weathering” (Mulugeta, 2019).

Soils may be thought of as the corollary of the Earth’s exogenic processes. They form as a result of the dynamics of geomorphic systems through the interplay of climatic elements with materials forming the subsurface of the landscape. Residual soils originated with the formation of the climatic systems and are part of the geological cycle, which has been in existence for hundreds of millions of years of geological time, as they formed from geological material over this time. Igneous activity leading to the formation of igneous rocks provides the beginning of the geological cycle. The Subjection of igneous rocks to sedimentary and metamorphic processes resulted in the formation of sedimentary and metamorphic rocks. Exposure of all these three rock types at the interface with the atmosphere to exogenic processes resulted in the formation of a mantle of in situ soils termed residual soils as a result of the gradual breakdown of the rocks. The terrestrial subsurface is constituted from rocks that provide the parent materials for soils. Rocks have been divided into three main types based upon their method of formation viz. igneous rocks, sedimentary rocks, and metamorphic rocks. Each group contains a wide variety of rock types that differ from one another by either the chemical composition, texture, or both (Bujang B.K et al., 2012).

Tropical decomposition tends to favor the formation of the clay mineral kaolinite. This is the most common clay mineral in tropical residual soils. Halloysites occur when the conditions are wet enough. Silica can be eliminated to the point where only free alumina and iron oxides remain after a long period of decomposition. (Blight & Leong, 1999). Lateritic soil formation is characterized by three key processes, which are listed below (Zelalem, 2005):

Decomposition: is the physical and chemical disintegration of fundamental minerals, resulting in the release of component elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and so on) in simple ionic forms.

Leaching: removing of combined silica and bases and the relative accumulation or enrichment of oxides and hydroxides of sesquioxide which is called lateralization. The level to which the second stage is carried depends on the nature and the extent of the chemical weathering of the primary minerals. Under conditions of low chemical and soil-forming activity, the Physico-Chemical weathering does not continue beyond the clay-forming stage and tends to produce end products consisting of clay minerals predominantly represented by kaolinite and occasionally by hydrated or hydrous oxides of iron and aluminum.

Desiccation /dehydration/: Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide-rich materials in a manner that is generally not reversible upon wetting. Dehydration also influences the formation processes of clay minerals.

The silica-sesquioxide (S-S) ratio (SiO_2/(Fe_2O_3, + Al_2O_3)) is used to calculate the degree of lateralization. Laterite is defined as an S-S ratio of 1.33 or below. Lateritic soil has an S-S ratio of 1.33 to 2.0. A non-lateritic, tropical soil has an S-S ratio of 2.0 or greater. Laterites and lateritic soils may vary from a loose material to a massive rock. The term "laterite" is used in engineering to refer to coarse-grained vermicular materials, such as massive laterite. The phrase "lateritic soils" describes materials with low oxide contents. Detail description of laterites and lateritic soils is given below (Rossiter, 2004).

Laterites The majority of laterites are found hardened. In some areas of the world, natural laterite deposits that have not been revealed to drying are soft with a clayey texture and mottled coloring, which may include red, yellow, brown, purple, and white. When the laterite is exposed to the atmosphere or dried out by reducing the groundwater Table, irreversible hardening often occurs, producing material suitable for use as a building or road stone. Commonly, laterite is gravel-sized, ranging from pea-sized gravel to 3 inches minus (passing 3 inches), even though larger cemented masses are possible. A specific form of laterite rock, known as plinthite is soft enough to cut with a metal tool, but it hardens irreversibly when removed from the ground and dried.

Lateritic soils resemble fine-grained sands, gravels, and soft rocks in their behavior. Lateritic soil is often porous or vesicular in appearance. Lateritic soil particles tend to collapse easily on impact, dissolving into a plastic-like soil material. Lateritic soils may self-harden when exposed to drying, or they may include significant quantities of hardened laterite rock or laterite gravel if they are not self-hardening.

Laterite is a reddish-brown colored result of intense tropical weathering composed of mineral assemblages that may include iron or aluminum oxides, oxy-hydroxides or hydroxides, kaolinite, and quartz, with a SiO2:R2O3=1.33 (where R2O3 = Al_2O_3 + Fe_2O_3) and exposed to hardening upon exposure to alternate wetting and drying. Materials with a Fe_2O_3: Al_2O_3 ratio more than 1 and a SiO_2: Fe_2O_3ratio less than 1.33 are referred to as "ferruginous laterite," whereas those with a Fe2O3: Al_2O_3 ratio less than 1 and a SiO2: Fe_2O_3ratio less than 1.33 are referred to as "aluminous laterite" (Ghosh et al., 2015).

Laterite soil behavior is mostly determined by particle size characteristics, the type and strength of gravel particles, the degree to which the soils have been compacted, and traffic and environmental conditions. Site performance and geotechnical characteristics of lateritic soils including their reaction to different stabilizing agents may be interpreted in light of all or some of the following parameters (Klohn, 1977):

- ✓ Genesis and pedological factors (parent material, climate, topography, vegetation, period time in which the process has operated)
- ✓ Degree of weathering (decomposition, sesquioxide enrichment, and clay-size content, degree of leaching)
- ✓ Position in the topographic site, and
- ✓ Depth of soil in the profile Lateralized soils works well in pavement construction particularly when their special characteristics are carefully recognized. Lateritic soil has also been successfully used in the construction of slopes, embankments, foundations, reinforced retaining walls, and dams in both tropical and sub-tropical regions.

2.2 History and Occurrence of Tropical Soils

The name laterite comes from the Latin word "latere," which meaning "brick." In his many published journals and observations during his travels around the western coast of southern India in 1807, an English surgeon named Francis Buchanan originated the word. He associated the word with the very ferruginous clay material used in the construction of earth bricks. He described the soil material as being widely spread without obvious strata, with numerous voids and crevices, a high iron concentration, and being so soft that it could be hacked to form with iron tools but afterward cemented like bricks when exposed. The very first application of the word thereby was for the use of laterite material for brick making in India and Cambodia Latosol is a name used to describe all tropical and equatorial zone soils with a low silica-sesquioxide ratio, poor base exchange, low primary mineral content, low soluble components, and some red color as its major characteristics. As a result, this word refers to all lateritic soils. Since then, it has become normal practice to use the term laterite to describe any red soil or rock in the tropics that resembles laterite. Laterite soils have been referred to by a variety of names through the years, including Brick-stone, Iron clay, Ironstone, Murram, and Ferricrete, to name a few (Ahmed, 2015).

Although there are some discrepancies in how the topic is interpreted, laterite soils and their studies have resulted in a significant rise in our knowledge of the topic's origins, contents, development, usage, and effects. Following investigations and debates, experts agreed that laterite soil is similar to fine-grained sands of various sizes and is categorized as one that has weathered and has a ratio of silica to iron oxide and aluminum. This conclusion although agreed upon is not in its full capacity, accepted and practiced, leading to the frequent misuse of the term and assumptions made that any type of red soils are laterites. The use of the term laterite to describe a broad group of tropical soils with similar properties is simply misleading and untrue because research shows differences in properties vary with location, climate, topography, and soil conditions. For this reason, any such type of soil that shows characteristics of laterites needs to be investigated in detail for that particular area of interest.

Laterite and lateritic soils are largely predominant in tropical areas with a moist climate. Coverage of laterites around the world mainly pertains to Africa, India, Australia, Southeast Asia, Central America, and South America. Residual soil and especially recent lateritic soils are present dominantly in major parts of southeast Asia, Laos, Vietnam, and Malaysia. These locations generally fall between latitudes 35^{O}S and 35^{O}N (Ahmed, 2015). A collective laterite world occurrence and distribution map is shown in the Figure below.

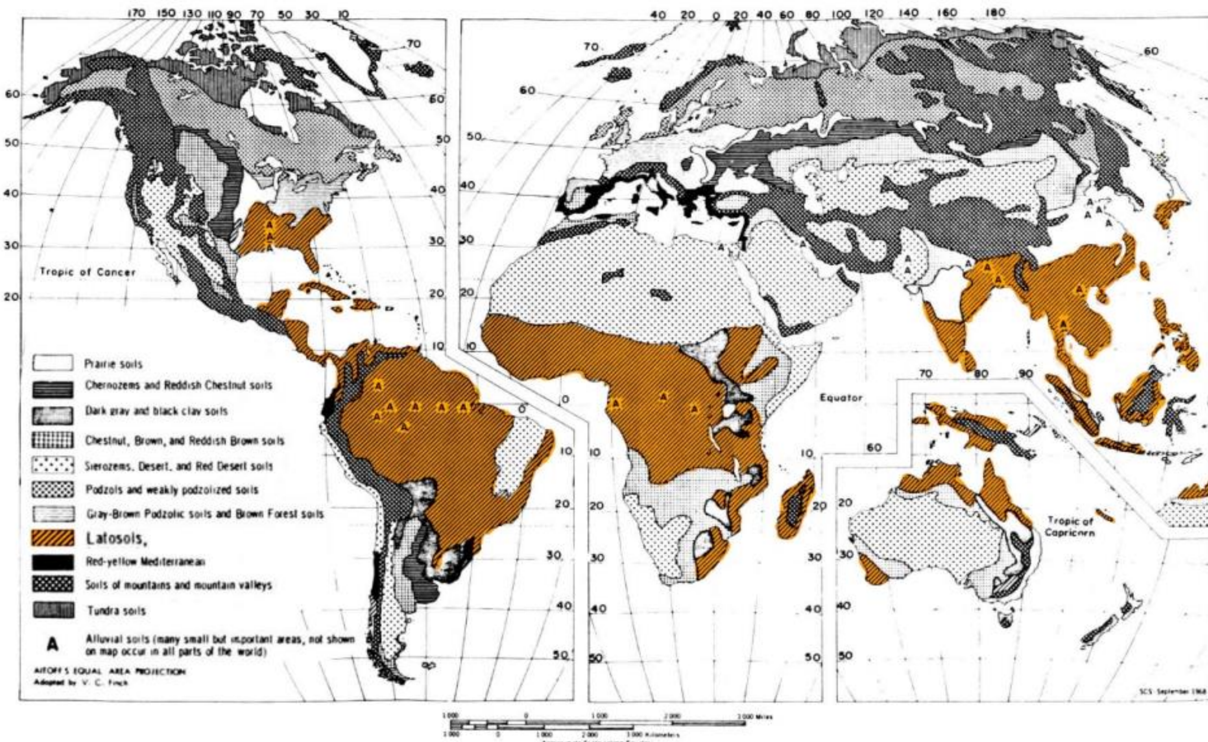


Figure 2.1: Latosol soil (collective laterite) world distribution (http://www.nzdl.org)

2.3 Lateralization: Formation of Laterite and Lateritic Soils

Residual tropical soils can be classed as lateritic or laterites, depending on the degree of lateralization. Lateritic soils are severely weathered and changed residual soils developed in tropical and subtropical locations with hot, humid climatic conditions by in-situ weathering and decomposition of rocks. Their formation also consists of leaching out of free silica and bases and accumulation of oxides of iron, aluminum, or both, and this process is termed lateralization. Moreover, they are rich in sesquioxide, i.e.; iron oxides, aluminum oxides, or both, and low silicate content with a considerable amount of Kaolinite. Lateritic soils are usually red due to the existence of the mineral iron oxides (Fekede, 2007).

The degree of lateralization is characterized by the ratio of Silica (SiO_2) to Sesquioxide ratio (S-S) as described in the previous section. Sesquioxide (R2O3) is the combined name for Iron oxide (Fe_2O_3) and Aluminum oxide (Al_2O_3) the following classes of soils could be possible based on lateralization

S-S ratio >2, un-lateralized soil
S-S ratio 1.33 – 2, Lateritic soil
S-S ratio <1.33 true laterite.

Laterite and lateritic soils formed are due to, extreme weathering conditions and when the chemical processes proceeded more extensively and rapidly. Which are extremely leached soils, and are examples of such forms of residual soils. When extensive weathering with leaching happens in humid tropical regions, it leaves behind laterites, which are soils rich in Fe and Al oxides and have a deep red color. When soils in these groups are dry, they produce hard, impermeable, and frequently irreversible pans (Blight & Leong, 1999).

Some more descriptive terms, such as ferruginous soil, ferrallitic soils, and Ferrisols are recommended in place of laterite soils. Laterites are formed by tropical and subtropical weathering; their chemical composition and morphological characteristics are greatly influenced by the degree of weathering to which the parent materials are subjected. Laterites are highly weathered materials rich in secondary oxides of Iron, Aluminum, or both. Primarily these soils are formed during weathering of Aluminous Silicates in the tropics, the Silica alkaline earth is removed in solution by leaching during chemical processes while the Alumina and Ferric Oxide became hydrated and remains behind. It may also contain large amounts of Quartz and kaolinite (Mulugeta, 2019).

Lateralization is a process of weathering a parent material/mineral, which occurs under conditions favorable to tropical weathering, and when the weathering processes may be so intense and may continue so long that even the clay minerals, which are hydrous aluminum silicate, are destroyed. In the continued weathering, the silica is leached and the remainder consists merrily of aluminum oxides such as gibbsite, or hydrous iron oxide such as limonite or goethite derived from the iron. The lateralization process takes place in three stages.

The first stage is the breakdown of primary rock-forming minerals occurs, and this results in the release or formation of clay minerals, mainly kaolinite, and constituent elements such as silica, alumina, iron oxides, and oxides of other elements such as calcium and magnesium. In the second stage, the silica and alkali (calcium and magnesium oxide, among others) are leached and accumulation of sesquioxide takes place. This occurs during wet seasons of the year and its extent depends on the PH of the groundwater and drainage conditions. Iron, being carried in ferrous form by water, is mobile until it is oxidized to Ferric ions Following the dry season, evaporation causes ferrous ions to migrate higher, allowing for oxidation by air oxygen. After then, iron forms a hydrated ferric oxide gel. Aluminum travels through the solution until dehydration or a PH change causes it to precipitate as an Alumina gel. On the surfaces of the clay minerals, the sesquioxide (hydrated Ferric Oxide gel and Alumina gel) is adsorbed. The adsorption occurs through the interaction of positively charged sesquioxide and negatively charged clay particles. At the third stage, partial or complete dehydration of hydrated colloidal Sesquioxide occurs (Mulugeta, 2019).

2.4 Weathering Process

Under tropical circumstances, most tropical soils are extensively weathered and changed residual soils generated by in-situ weathering and decomposition of rocks. The three major agencies of weathering being physical, chemical, and biological processes. In the process the parent rock and rock minerals break down, releasing internal energy and forming soils having lower internal energy which are more stable. Physical processes increase the surface area so that chemical attack increases. Biological weathering includes both physical and chemical actions (Blight & Leong, 1999).

Generally, there are three types of weathering:

Physical weathering

The physical decomposition of rock into smaller particles is known as physical or weathering.
Frost wedging, exfoliation, thermal expansion and contraction, and abrasion are all examples of physical weathering.

Chemical weathering

The chemical dissolution or change of the chemical and mineralogical composition of minerals is referred to as chemical weathering. It involves the breakdown of minerals into new compounds by the action of chemical agents (e.g., the acid in the air, in the rain, etc.). The rock-forming minerals are vulnerable to attack by water, oxygen. and carbon dioxide at the new surface environment they are exposed to and tend to undergo chemical changes to form new stable minerals.

Chemical weathering is dependent on the amount of surface area, temperature and the availability of chemically active fluids. Smaller sized particles weather more rapidly due to a larger surface area. The presence of water and dissolved materials like ammonia, oxygen, carbonic acid, chlorides, sulfates, and other materials cause chemical weathering As the temperature rises, the efficacy of carbonic acid and oxygen rises, as shown in humid regions where the severity of chemical weathering processes rises due to the increased temperature. As a result, the tropical regions have the highest intensity of the chemical weathering processes of rocks (Das, 2004).

Table 2.1 common chemical processes(Bujang B.K et al., 2012)

process	Description
solution	Decomposition of minerals involving water as a solvent and in rainwater aided by carbonic acid (H_2CO^{-3}) formed due to the presence of Co_2.
oxidation	The combination with oxygen, the most common oxidizing agent, forms oxides and hydroxides or any other reaction which causes the loss of an electron that increases in the positive charge.
hydration	Hydration involves the absorption of water into the mineral causing the expansion of the mineral leading to eventual weakening
hydrolysis	The reaction of water directly with minerals where metal cations, replaced by hydrogen (H+) ions, combine with hydroxyl (OH-) ions.
Carbonation	The carbon dioxide (CO2) dissolves in water to form carbonic acid (H_2CO^{-3}) that reacts with minerals to e.g dissolve calcite into bicarbonate ions and calcium.
leaching	This involves the migration of ions by dissolution into water. The mobility of ions depends upon their ionic potential. For example, Ca, Mg, Na, K are easily leached by moving water, Fe is more resistant, Si is difficult to leach while Al is almost immobile

Biological weathering

Biological weathering is the process of biological organisms disintegrating rock by acting as chemical and/or physical weathering agents. As a result, chemical or physical processes are involved in biological weathering. These creatures produce acids that react with rocks or break them down mechanically. Weathering may be caused by a wide range of creatures, from microbes to plants and animals. The following are some of the most important processes:

a) Rock fractures because of animal burrowing or the pressure from growing roots.
b) Movement and mixing of materials by movement of soil organisms.
c) Carbon dioxide produced by organism respiration mixing with water forming carbonic acid augments simple chemical processes like solution.
d) Minerals and rocks disintegrate by removing metallic cations using organic molecules called chelates generated by organisms.
e) Because water is a crucial component in weathering processes, organisms promoting weathering alter the moisture regime in soils (Bujang B.K et al., 2012).

Table 2.2 Products of weathering from mineral phases (Fekede, 2007).

	Weathering process	
Minerals	Solid products	Other products (mostly soluble)
Feldspar	Clay (New mineral phase)	Ions (Na+, Ca++, K+), SiO_2
Ferromagnesian (including biotite mica) minerals	Clay (New mineral phase)	Ions (Na+, Ca++, K+), SiO_2, Fe oxides
Muscovite mica	Clay (New mineral phase)	Ions (Na+, Ca++, K+), SiO_2
Quartz	Quartz (grains) (Mechanical breakdown)	Ions (K+), SiO_2
Calcite	(Dissolution)	Ions (Ca++, HCO^{-3})

Table 2.3 Weathering products of some common rock types (Brink, 2015).

Rock type	Product
Igneous	-
Granite	Quartz sand and clay minerals
Basalt	Clay minerals
Sedimentary	-
Shale	Clay minerals

Sandstone	Quartz sand
Limestone	Dissolved ions and residual clay-sized particles
Metamorphic	-
Metasediments (schist/phyllite/ amphibolite/slate)	Clay minerals (from biotite and muscovite), micaceous silt, and clay size particles.
Gneiss, granulite and other quartz rich rocks	Quartz sand

The weathering of rocks produces the minerals that makeup clays. The majority of clay minerals of importance to geotechnical engineers are made up of two of the most plentiful elements on the planet: oxygen and silicon. A silica tetrahedron is a structural unit in silicates, a category of minerals. Four oxygen anions, one at each corner of the tetrahedron, surround a center silica cation (Fig 2.1a). Silicate sheets are made up of silica tetrahedrons that have been combined (Fig 2.1b). Other structural components, such as alumina sheets, can be found in silicate sheets. Alumina sheets are formed by a combination of alumina minerals, which consist of an aluminum ion surrounded by six oxygen or hydroxyl atoms in an octahedron (Fig 2.1d).

The main groups of clay crystalline materials that make up clays are the minerals kaolinite, illite and montmorillonite.

Kaolinite has a structure that consists of one silica sheet and one alumna sheet bonded together into a layer about 0.72nm thick and stacked repeatedly (Fig 2.2a). The layers are held together by hydrogen bonds. Kaolinite has few or no exchangeable cations, and the interlayer bonds are relatively strong preventing any hydration between layers and allowing many layers to build up. Kaolinite is relatively stable and water is unable to penetrate between the layers. Consequently, Kaolinite shows little swelling on wetting. Kaolinites are found in soils that have undergone considerable weathering in warm, moist climates. They have a low liquid limit and low activity. Another member of the Kaolinite group appearing in some tropical soils is called halloysite, in which water molecules separate the layers. The halloysites are distinguished by one additional water molecule to the basic kaolinite. In contrast to most other clays, which are flaky, halloysite particles are tabular or rod-like.

Montmorillonites are made up of sheet-like units comprising an alumina octahedral sheet between two silica tetrahedral sheets, as shown in Fig. 2.2(c). As the electrons rotate around the nucleus of an atom there will be times when there are more electrons on one side of the atom than the other, giving rise to a weak instantaneous dipole. Weak Vander Waals forces hold layers together and the bonding of these sheets is rather weak, resulting in a rather unstable mineral, especially when wet. Montmorillonite displays a significant affinity for water, with subsequent swelling and expansion. Its excessive swelling capacity may seriously endanger the stability of overlying structures and road pavements. Bentonite is part of the montmorillonite clay family, usually formed from the weathering of volcanic ash.

Illites are somewhat similar to montmorillonites in the structural units but are different in their chemical composition. In illite, the layers are separated by potassium ion, whereas in montmorillonite the layers are separated by loosely held water and exchangeable metallic ions (Fig 2.2 (b)). Unlike montmorillonite particles, which are extremely small and have a great affinity for water, the illite particles will normally aggregate and thereby develop less affinity for water than montmorillonites. Correspondingly, their expansion properties are less. The cation exchange capacity of illite is less than that of montmorillonite. The inner layer bonding by the potassium ions is sufficiently strong. Illites usually occur as very small, flaky particles mixed with other

clay and non-clay materials (Fasil, 2003).

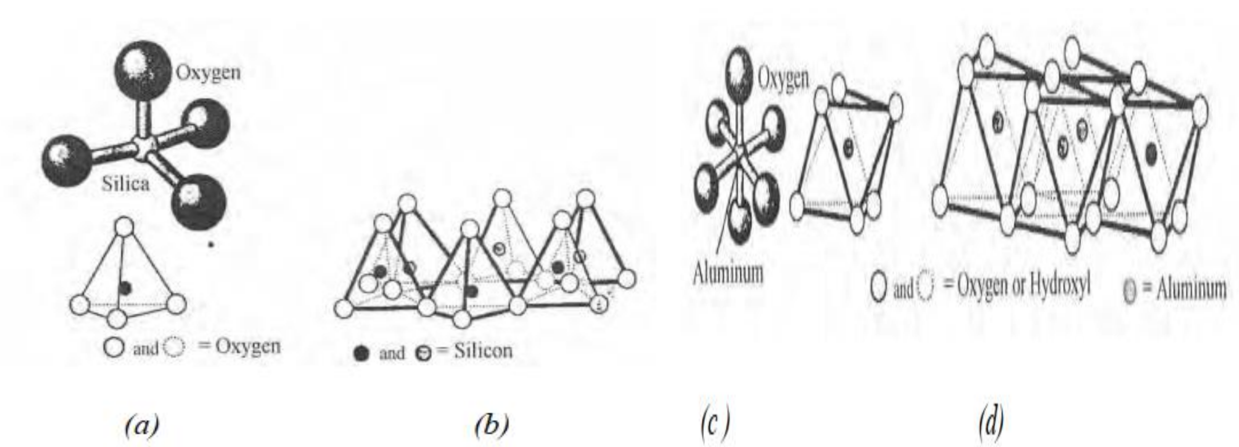


Figure 2.2 (a) A silica tetrahedron, (b) Silica sheets, (c) An Aluminum octahedron, and (d) aluminum sheets (Bujang B.K et al., 2012).

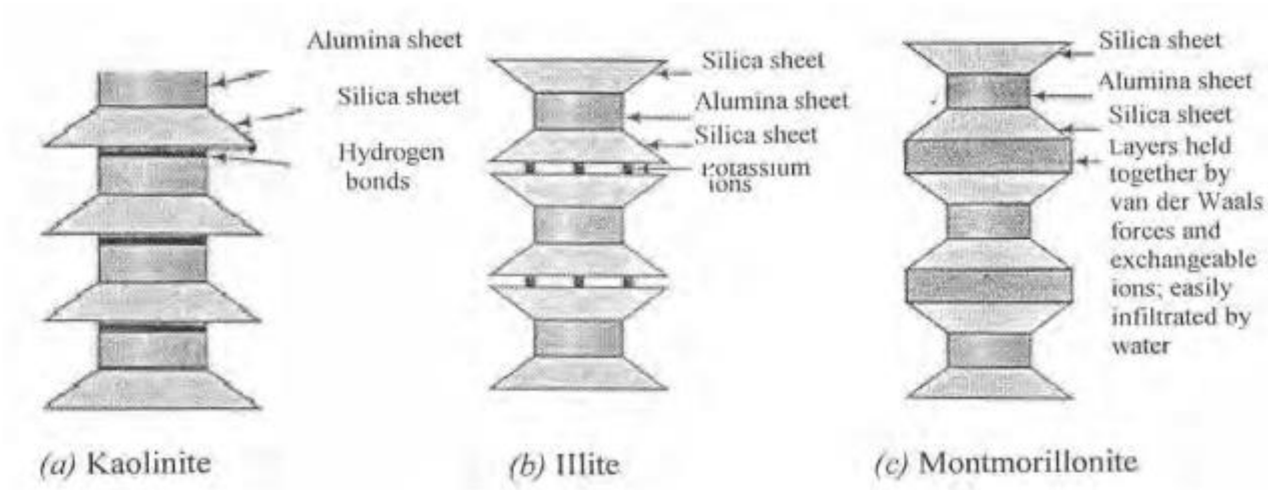


Figure 2.3 Structure of Kaolinite, Illite, and Montmorillonite (Bujang B.K et al., 2012)

Climate and topography influence the rate of weathering. Physical weathering is more predominant in dry climates while the extent and rate of chemical weathering are largely controlled by the availability of moisture and temperature. Topography, on the other hand, controls the rate of weathering by partly determining the amount of available water and the rate at which it moves through the zone of weathering. It also controls the effective edge of the profile by controlling the rate of erosion of weathered material from the surface. Thus, deeper profiles will generally be found in valleys and on gentle slopes rather than high ground or steep slopes (Blight & Leong, 1999).

The weathering profiles were divided into two significant horizons for residual soils: (a) eluvial soil which is homogeneous and shows no more traces of the original rock and (b) saprolite that shows significant heterogeneities and still maintains several properties inherited from the parent rock. The degree of alteration of the material was evaluated by determining two weathering indexes. The first determines the degree of weathering from the silica to sesquioxide ratio. The second index was the Weathering Index of Parker (1970) (WIP) that considers Na+, K+, Ca+, and Mg2+ mobilization and leaching (Bogado et al., 2017).

Tropical residual soils have a wide range of index and engineering properties depending on their parent rock-forming minerals, the intensity of weathering, amount of rainfall, and temperature. These factors are in turn governed by the geographical location and the prevailing weather conditions. Engineering properties not only vary with spatial locations but also with depth. The development of residual soil profile depends on the interaction of three natural features: these are, the chemical composition of the rock, environmental conditions, and time (Bujang B.K et al., 2012).

The formation of soil commences by chemical alteration and physical disintegration of rocks at their exposed surface. The parent material refers to these rocks. The parent material has the largest impact on incipient soils and drier regions in the early stages of soil formation, but as other soil-forming forces become more active, the parent material's effect diminishes. There are a variety of parent materials when their minerals undergo weathering, they exchange material with the environment through chemical reactions forming new minerals and assimilate water, gases, and organic matter. The thickness of the soil layer and the chemical changes that have occurred are influenced by a variety of factors, including the length of time that soil-forming activities have been taking place (Jenny, 1941).

Parent material/mineral weathering: residual soils are found more or less covering the parent rocks. The degree of weathering and the extent to which the original structure of the rock mass is destroyed varies with depth from the ground surface Residual soils are most typically created from igneous and metamorphic parent rocks, although they can also be generated from sedimentary rocks. Occasionally residual soils can be formed by in-situ weathering of unconsolidated sediments (SINGH, 2014).

There are two weathering actions taking place in the development of tropical soils, these are the formation of clay minerals of kaolinite type from the primary minerals (kaolinization) and, the decomposition of the clay minerals with the accumulation of free oxides of iron, aluminum, and titanium. Clays with different and specific chemical characteristics are found in each category of soil, and these qualities were utilized to classify lateritic soils into numerous categories. Climate is believed to have a key influence on the evolution of these soils since they exist in locations with varying climatic conditions. Given the wide range of geological ages of the parent materials, the duration of exposure to soil-forming processes will have had a significant impact on soil formation. An extremely complicated pattern of soil development has evolved from the enormous range in age of the soil parent material, as well as the large variety in climate owing to the impacts of elevation and trade winds on temperatures and rainfall regions (Sherman, 1949).

In tropical and sub-tropical climatic conditions, tropical residual soils are created ‘in place' by extensive weathering/alteration of the underlying parent rock. Residual soils dominate the terrain in humid tropical areas. Igneous (e.g., basalt lavas, tuffs, granites, etc.) and sedimentary parent rocks (e.g., sandstone, limestone, etc.). Tropical ‘black' soils and tropical ‘red' soils are two main kinds of residual soils to consider. The first group of soils, known as 'black cotton soils' or 'black swelling clays,' are a relatively unique group of soils rich in smectite clay minerals. whose behavior is dominated by volume changes (i.e., shrinking and swelling) when they are subjected to changes in natural moisture content. These soils almost always occur in low-drainage locations. However, there is some ambiguity about the materials that make up so-called tropical red soils, as well as the terminology used to describe them. It is a common mistake to think of tropical red soils as a separate, well-defined soil type since they include a wide range of soils with a wide range of technical features. For a long time, this variation has been reflected in the growing literature on tropical soils, with red, brownish red, reddish-brown, and brown soils being referred to as 'laterites,' 'laterite soils,' 'lateritic soils,' 'non-lateritic tropically weathered soils,' 'latosols,' and 'tropical red clays.' Under certain conditions, hardened horizons often referred to as "laterite", may be associated with the soil profiles (Styles et al., 2001).

The chemical alteration of primary minerals, the release of iron and aluminum sesquioxide, increasing silica loss, and the increasing dominance of new clay minerals formed from dissolved materials (such as smectites, allophane, halloysite, and, as weathering progresses, kaolinite) are all part of the tropical weathering of parent rocks. Apart from the structure, which is a defining feature of many residual soils, geotechnical engineers should be aware of a special group of clay minerals found only in residual soils. Allophane and imogolite, two minerals that are frequently discovered together, and halloysite, a third mineral, are the minerals in question (Wesley, 2004).

The extremely unusual properties of soils containing these minerals, especially allophane, can be a source of considerable puzzlement to engineers encountering them for the first time. Continued depletion of silica under prolonged weathering in hot humid climatic zones may eventually cause alteration of kaolinite to the aluminum oxide, gibbsite, as free alumina is formed in the soil profile. At any particular site, mineral composition and microstructure will depend on numerous factors such as the nature of the parent material, the age of the land surface (time for soil formation), climate, topography, and drainage conditions (Styles et al., 2001).

Residually formed soils are formed in different places however, a distinct type of soil called laterite and lateritic soils having their engineering characteristics and importance develop in a certain favorable circumstance. Commonly in hot and humid tropical regions with an annual rainfall range between 750mm to 3000mm and abundantly in areas with significant dry seasons. These soils formed are due to, extreme weathering conditions and when the chemical processes proceeded more extensively and rapidly. Which are extremely leached soils, and are examples of such forms of residual soils. In humid tropical climates when intense weathering involving leaching occurs, it leaves behind a soil rich in Fe and Al oxides giving the soil a deep red color called laterites. Soils under these classifications are characterized by forming hard, impermeable, and often irreversible pans when dried (Mulugeta, 2019).

Lateralization is a process of weathering a parent material/mineral, which occurs under conditions favorable to tropical weathering, and when the weathering processes may be so intense and may continue so long that even the clay minerals, which are hydrous aluminum silicate, are destroyed. In the continued weathering, the silica is leached and the remainder consists merrily of aluminum oxides such as gibbsite, or hydrous iron oxide such as limonite or goethite derived from the iron. The lateralization process takes place in three stages (Mahalinga-Iyer & Williams, 1997).

The first stage is the breakdown of primary rock-forming minerals occurs, and this results in the release or formation of clay minerals, mainly kaolinite, and constituent elements such as silica, alumina, iron oxides, and oxides of other elements such as calcium and magnesium. In the second stage, the silica and alkali (calcium and magnesium oxide, among others) are leached and accumulation of sesquioxide takes place. This occurs during wet seasons of the year and its extent depends on the PH of the groundwater and drainage conditions (Gidigasu, 1974).

2.5 Characterization of Tropical Soils

Tropical residual soils form a mantle of significant thickness. Thickness of such soils varies from place to place depending upon the factors of formation like climate and the extent to which the soil forming processes have advanced. The formation of deep residual soils may be on account of very rapid rate of their formation or due to the lengthy persistence of the soil forming processes without subsequent removal by erosion. They generally show no formational stratification but display identifiable in situ differentiated horizontal horizons. This is due to the process of leaching as water for instance rainwater moving through soils dissolves minerals, transports the solutes and precipitates these further down the soil profile resulting in the leached and precipitation levels forming visible horizons. The composition of residual soils is initially defined principally by the nature of the parent rocks. Residual soils are derived from various rock types like granites, gabbro's, basalts, limestone and others. In the case of old residual soils, however, the advanced chemical decay, alteration and leaching may render the recognition of the parent rock materials very difficult or they may be obliterated.

Tropical residual soils are widely used as construction materials, mostly as fill for embankment dams and road embankments, as well as in the construction of chosen strata in airfields. Because of insufficient strength, excessive volume variation with varying water content, or loss of strength on wetting, some residual soils, such as those containing smectite or halloysite clays, may be inappropriate for these purposes. If the compaction process is to be understood and the effort and expense of compaction maximized, several particular properties of tropical residual soils must be known. For design purposes, the relevant engineering properties of interest are strength and stiffness/ compressibility profiles, and in some cases the permeability. In their natural state, tropical soils exhibit different behavior partly due to grading, index properties, mineral composition, structure, and bonding inherited from the parent rock. tropical red soils are highly sensitive to changes in the natural moisture content of the material, with such changes typically resulting in irreversible changes in the physical properties of the material. Similarly, they are highly sensitive to structural breakdown and treatment (Brink, 2015).

The material can exist in four phases depending on the original moisture level of the soil: solid, semi-solid, plastic, and liquid. The consistency and behavior of the soil vary with condition, and these factors impact the soil's engineering qualities. The Atterberg Limits are the lines that separate each condition and indicate a change in the soil's features and behavior at that exact moisture content (Braja, 2007).

The following points are reported to be some of the characteristics anticipated with special considerations for efficient compaction of residual soils. Residual soils especially those of volcanic and igneous origin are reported to have (Sintayehu, 2003):

- high in situ moisture minerals
- meta-stable clay minerals

- soil structures that are lightly cemented
- weathered soil particles that break down under compaction effort sesquioxide minerals that are affected by wetting and drying.

The starting point for many engineering uses of soil is the in situ, borrow pit. Many tropical and subtropical environments are characterized by frequent or seasonal heavy rainfall. Handling of soils under these conditions is known to be difficult and the characteristics of the soils may add further complexity to the problem of effective compaction.

Table 2.4 Classification system and characteristics for laterite depending on the degree of concretionary development (Zelalem, 2005).

Recommended name	Characteristics	Equivalent terms in literature
Plinthite	Soil fabric containing a significant amount of laterite material. Hydrated oxides at the expense of some soil material. Unhardened nodules present, but maybe slight evidence of concretionary development	Plinthite, laterite, lateritic clay
Nodular laterite	Distinct hard concretionary nodules present as separate particles	Laterite gravel, ironstone gravel, pisolitic gravel
Honeycomb laterite	Concretions have coalesced to form a porous structure that may be filled with soil material.	Ferricrete, ironstone, laterite crust, vermiform laterite, packed pisolitic laterite
Hardpan laterite	Indurated laterite layer, massive and tough.	Ferricrete, ironstone, laterite crust, vermiform laterite, packed pisolitic laterite
Secondary laterite	It may be a nodular honeycomb or hardpan, but the result of erosion of pre-existing	

	layer and may display brecciated appearance.	

Based on the existing data on lateritic soils, it appears that the red color has been considered by most writers as the most relevant attribute for identifying these soils. Texture, structure, consistency, and other important basic physical qualities were frequently overlooked. It's also worth noting that the lack of consistency in pretreatment and testing processes (because of associations with different standards in different regions of Africa) makes comparing even textural data on the same soils challenging. The engineering characteristics and field performance of lateritic soils are influenced by three key elements. These are;

- Soil forming factors (e.g., parent rock, climate vegetation conditions, and topography and drainage conditions).
- Degree of weathering (degree of lateralization) and texture of the soils, genetic soil type, the predominant clay mineral type, and depth of the sample.
- Pretest treatments and laboratory test procedures as well as interpretation of test results

Climate and topography influence the rate of weathering. Physical weathering is more pronounced in dry climates, while the extent and rate of chemical weathering are largely controlled by the availability of moisture and temperature. Topography, on the other hand, controls the rate of weathering by partly determining the amount of available water and the rate at which it moves down through the zone of weathering. It also controls the effective edge of the profile by controlling the rate of erosion of weathered material from the surface. Hence deeper profiles will generally be found in valleys and on gentle slopes rather than high ground or steep slopes. (Hanna, 2008)

2.6 Classification of Tropical Soils

Tropical Residual soils classified into three groups based on mineralogical composition alone (Blight & Leong, 1999):

1. Group A Soils having little or no mineralogical impact.
2. Group B: Clay minerals have a strong mineralogical impact on soils, which is frequent in transported soils.

3. Group C: Residual soils with a significant mineralogical effect derived from clay minerals.

Group C is further grouped into three sub-groups according to clay minerals of soils. These are

- Sub-group (a) Halloysitic soils
- Sub-group (b) Allophanic soils
- Sub-group (c) Sesquioxide-affected soils

Classification of laterites is also possible according to their genetic basis, size of particles, and degree of concretion. A pedological classification system is given by D' Hoore. The soils are broadly differentiated on a genetic basis, determined by soil-forming factors. It is a means of identification of lateritic soils. Three main units are used for the description and classification of red tropical soils.

Ferruginous soils show a marked separation of free iron oxide, either leached out of the profile or precipitated within the profile as concretions. There may be a high proportion of weatherable primary minerals remaining. Kaolinite is the dominant clay mineral. These soils are generally found in areas with under 1850mm rainfall a year and pronounced dry seasons.

Ferrallitic soils are generally deep, with only slightly differentiated horizons. Kaolinite is the dominant clay mineral, and they contain free iron oxides and hydrated oxides of aluminum. They generally occur in more humid areas with more than 1500mm rainfall per year.

Ferrisol soils have profiles similar to ferralitic soils, but with very few weatherable minerals remaining. The entire clay size fraction comprises kaolinite and amorphous oxides of iron and aluminum. Ferrisol tends to develop at deeper levels, because of surface erosion and occurs in regions of between 1250- and 2750-mm rainfall per year. According to Morine W.J. and Todor P.C., Ethiopian laterites fall under this group (Morin & Todor, 1971).

2.7 Chemical and Mineralogical Composition

The higher amount of iron and/or aluminum sesquioxide in laterite and lateritic soils compared to other chemical components is a distinguishing feature. To distinguish between Aluminous and Ferruginous types, the quantity of Alumina or Iron Oxide is a key component. Except for some Ferruginous crusts generated in alluvium and some concretionary horizons in Ferruginous tropical soils, the base (alkalis and alkaline earth) is practically absent in lateritic layers. Manganese, Titanium, Chromium, and Vanadium oxide are the other lateritic constituents.

Chemical investigations of laterites and lateritic soils rarely indicate their origin, nature, or even composition. The mineralogical composition of laterite and lateritic soil is thought to be more essential in understanding their physical qualities. Major elements, which are required for lateralization, and minor elements, which do not affect the lateralization process, are the two types of mineralogical components. The main components are aluminum and iron oxides and hydroxides, as well as clay minerals and, to a lesser amount, manganese, titanium, and silica. The minor constituents are residual remnants or elastic material. The clay mineral most common in lateritic soils is Kaolinite. Halloysite is also reported. Illite and Montmorillonite are rare. The secondary minerals resulting mainly from the lateralization process are Gibbsite, Goethite, Limonite, and Hematite. Neither Manganese nor Titanium minerals were observed in significant amounts (Hanna, 2008).

Soil mineralogy can be assessed in various ways. Very specialized techniques have been developed for practical purposes, but the most common approaches are X-ray diffraction, thermogravimetry, and optical microscopy combined with some form of spectral element identifications. Mineralogical identification using these techniques requires specialized training and procedures. The X-ray diffraction (XRD) technique is by far the most widely used but is only appropriate for minerals with distinctive crystallography. Since 1923, X-ray analysis became the most widely used method for the investigation of clay minerals. Kaolinite and halloysite are the predominant clay minerals of red soils in Ethiopia (Fasil, 2003).

Geochemical (oxide) and Mineralogical composition of the soil is essential to understand the fundamental behavior of the soil. Mineralogy is the primary factor controlling the size, shape physical and chemical properties of soil particles. The solid phase of a soil sample is known to contain various amounts of crystalline clay material, oxides, organic matter and precipitated salts. It has been understood that the property of tropical residual soil is quite dependent on the Geochemical & Mineralogical composition of the soil (Sintayehu, 2003).

Geochemical Test furnishes the oxide composition of the soil material. The existence of oxides and hydroxides of aluminum iron, and silicon are of greatest interest since they are the ones most frequently encounter. These materials coat mineral particles, or cement soil particles together. They may also occur as distinct crystalline units, such as hematite and magnetite.

Soil mineralogy can be assessed in various ways. Very specialized techniques like X-ray diffraction, thermo- gravimetry, scanning or transmission electron microscopy, etc. have been developed. Mineralogical identification using these techniques requires specialized training and procedures. Often, combinations of techniques are necessary to make definite identifications (Blight & Leong, 1999).

There is very little information on the pysico-chemical characteristics of lateritic soils. A few data published on this subject have been confined. The conclusions reached show that the lateritic medium is either neutral or acidic and organic content is generally low, below 2%. The Calcium Carbonate content is either very small or lacking in most lateritic soil's profiles. The distribution of such properties as the PH, base exchange capacities, hygroscopic moisture content, calcium carbonate content, and chemical composition of soil can form a basis for the understanding of the behavior of lateritic soils as a material of construction (Morin & Todor, 1971).

2.8 Tropical Soils as Construction Material

Concretionary laterites are important road pavement materials that are commonly utilized as sub-bases, base materials, and gravel roads in the tropics. However, in tropical highway engineering, the name laterite has been given indiscriminately to any red soil, and as a result, the use of laterites for road construction has been overestimated. Laterites are a suitable material for the construction of embankments. Because some laterites are gap-graded with a depleted sand-size fraction, have a variable proportion of fines, and have coarse particles of varying strength that may break down in performance, their use as pavement materials on heavily used roads is limited. Appropriate stabilizing methods are required to improve such laterites. In the tropics, lime and cement treatments are widespread (Zelalem, 2005).

Laterites with significant granular sizes are used for this purpose rather than clayey material. For such applications, thin strata from shallow depth are used ensuring the need for careful excavation and handling. For embankments, the quality, thickness, and depth are all important variables to be examined before the application along and down the slope. Laterites in their natural state are generally considered unusable for road construction purposes due to the high clay contents in them.

The best method of stabilization for road construction requires the need to determine the classification of soils. several kinds of research have been done on laterites where a detailed investigation of basic engineering geological properties of soil is employed (Ahmed, 2015).

The main characteristics of lateritic gravels and gravel soils are the high content of fines. Consequently, such materials do not fit into the existing temperate zone classification systems for coarse-grained soils. In addition, laterites undergo property changes during construction. The most sensitive property is gradation as the nodules tend to crush under heavy compaction (Morin & Todor, 1971).

A great number of studies have been made on the subject of laterites since the discovery of iron, aluminum, and other minerals within the soil. The possibility existed for laterites to be used as an ore for aluminum which is an expensive and very frequently used element in almost all aspects of engineering. A very obvious use of laterite soils has been brick making. As discussed earlier, laterite soils have been cut into a brick shape, dried, and used extensively in parts of the world such as India and Cambodia for building construction.

As such, laboratory tests are frequent, and at times, the only method of determining the suitability of laterites. Based on the geotechnical properties, one could conclude whether the soil is a good engineering construction material or not. These tests need to be conducted before planning and application. There is a need to evaluate the test results, analyze and determine if the particular laterite is fit for use or needs to be modified to strengthen it as in the case of the addition of stabilization material being added to highway pavement application. However, due to the sensitivity of the soils to test procedures, site conditions need to be simulated for proper testing and consequent data collection.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter mainly provides the materials methods and procedures that are required for undertaking the study. The methodology described in this chapter is the comprehensive physical system or model of choice undertaken to satisfy the objectives of the study. Specifically, the methodology chosen was a tentative one, taking into consideration the tools, methods, and approaches utilized by researchers in the past to achieve similar or exact objectives.

3.2 Approach

A structured approach was devised to tackle the task at hand. This involved separating the project into two phases and complete each one during a semester.

The first phase was structured to introduce the topic at hand, to deliver a literature review on the topic concerning past research on the subject, and to formulate a simplified physical based model to carry out for the past methodologies used by researchers.

The second phase dealt with the execution of chosen methodology, mainly conducting experiments and collecting data. Here, samples were collected from the chosen sites and laboratory equipment was used to determine the properties of tropical soils by conducting standard accepted tests and whose results can be compared with past research data. A conclusion with recommendation hence was made based on the results.

The flow chart in Figure 3.1 shows the planned approach for the project as a whole.

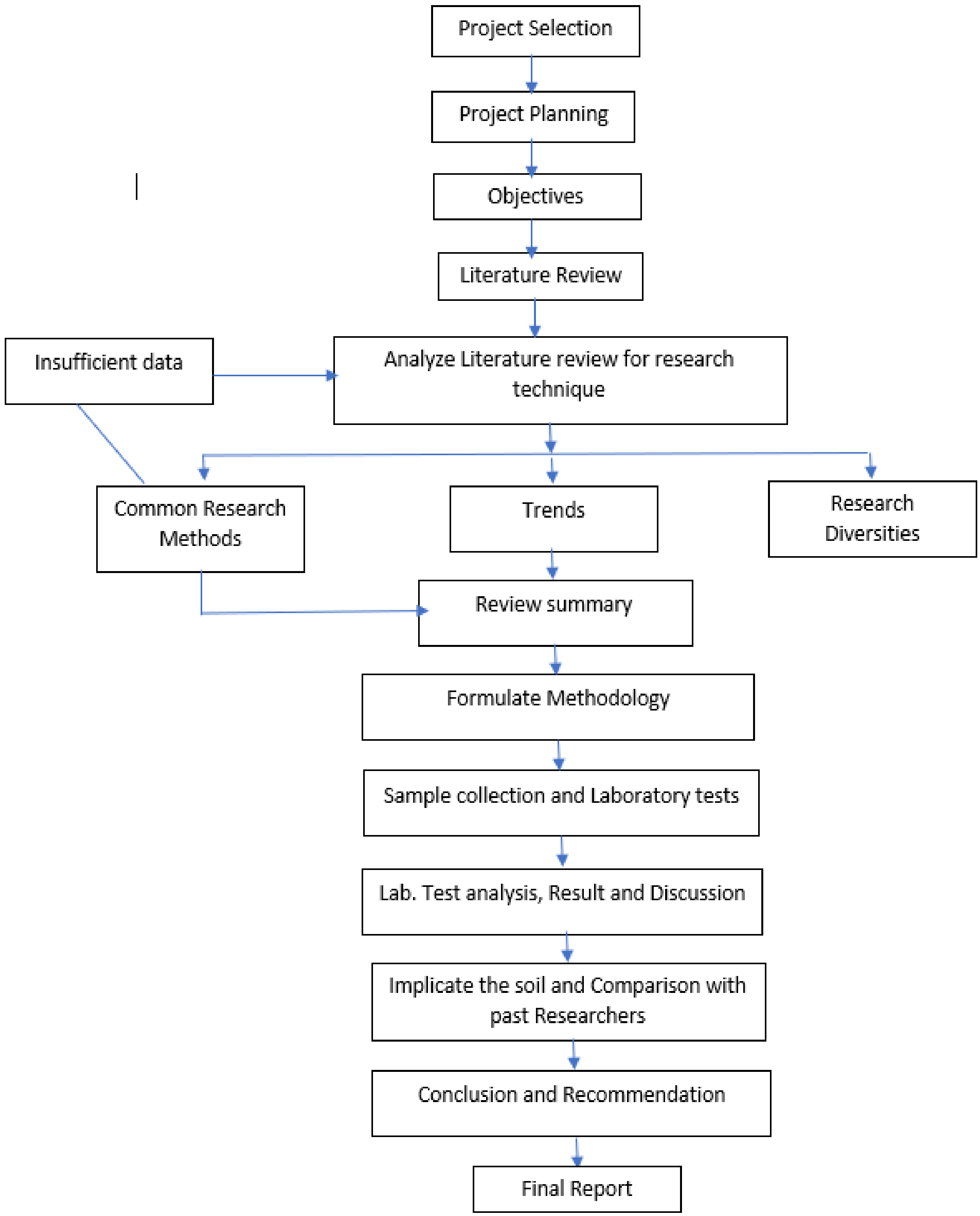


Figure 3.1 project flow chart

3.3 Description of the Study Area

3.3.1 General

The Bahir Dar – Tis Esat Design and Build Road Project is approximately 21.2 Km and located in the Amhara Regional State. The project starts at Bahir Dar town and ends at Tis Abay Town and spur walkway to the left of Tis Abay town to Tis Abay fall. The design and construction work has been undertaken by Melcon Construction PLC, and the supervision work is taken by Value Engineering PLC.

3.3.2 Topography

The road traverse in flat terrain for the whole stretch of the project and passes through,

Table 3.1: Percentage distribution of road alignment terrain type

No	Type of Terrain	Km	Percentage
1	**Urban**	10.60	50.0%
2	**Rural**	10.60	50.0%
	Total	**21.20**	**100%**

3.3.3 Climate

The traditional classification of climatic zones in Ethiopia is based on altitude and temperature. It divides the country into five climatic zones are shown in the following table,

Table 3.2: Ethiopian climatic zones (Ethiopian Roads Authority (ERA), 2013)

Climatic Zone	Elevation (m)	Average Temperature (°C)	Average Annual Rainfall (mm)
Wurch (cold)	> 3 200	< 10	< 800
Dega (cool-cold)	2 300 – 3 200	10 - 16	1 000 - 2000
Weina Dega (warm-cool)	1 500 – 2 300	16 - 20	1 200
Kolla (hot-warm)	500 – 1 500	20 - 28	600 (1 000 in places)
Berha (hot)	< 500	28 - 34	< 400

The project area has an elevation from 1,603m to 1,779m above mean sea level. The monthly climate data of Bahir Dar Station has been analyzed to characterize the climate condition of the project.

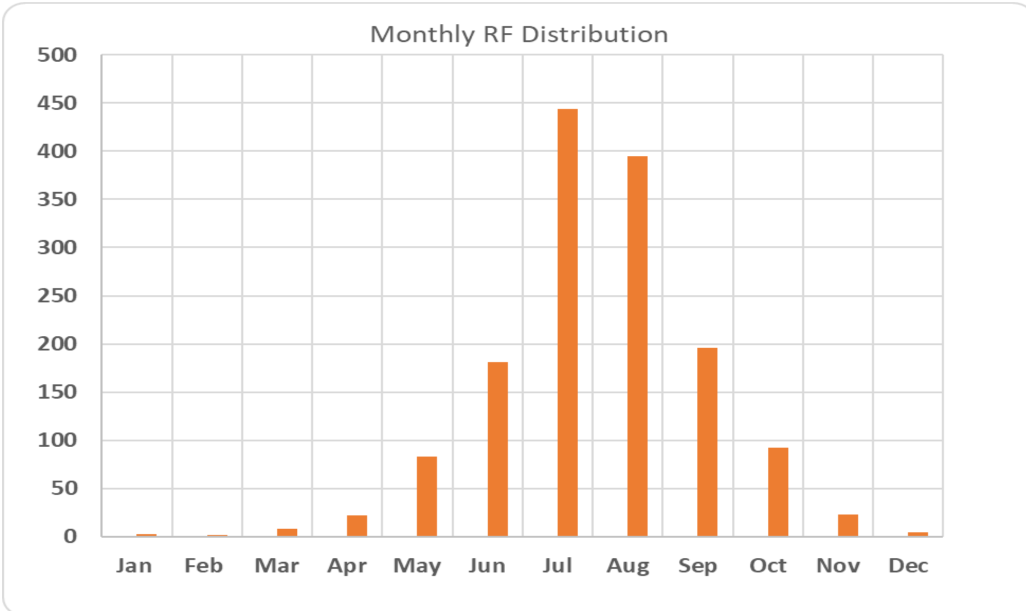


Figure 3.2: Monthly mean Rainfall distribution Bahir Dar Station

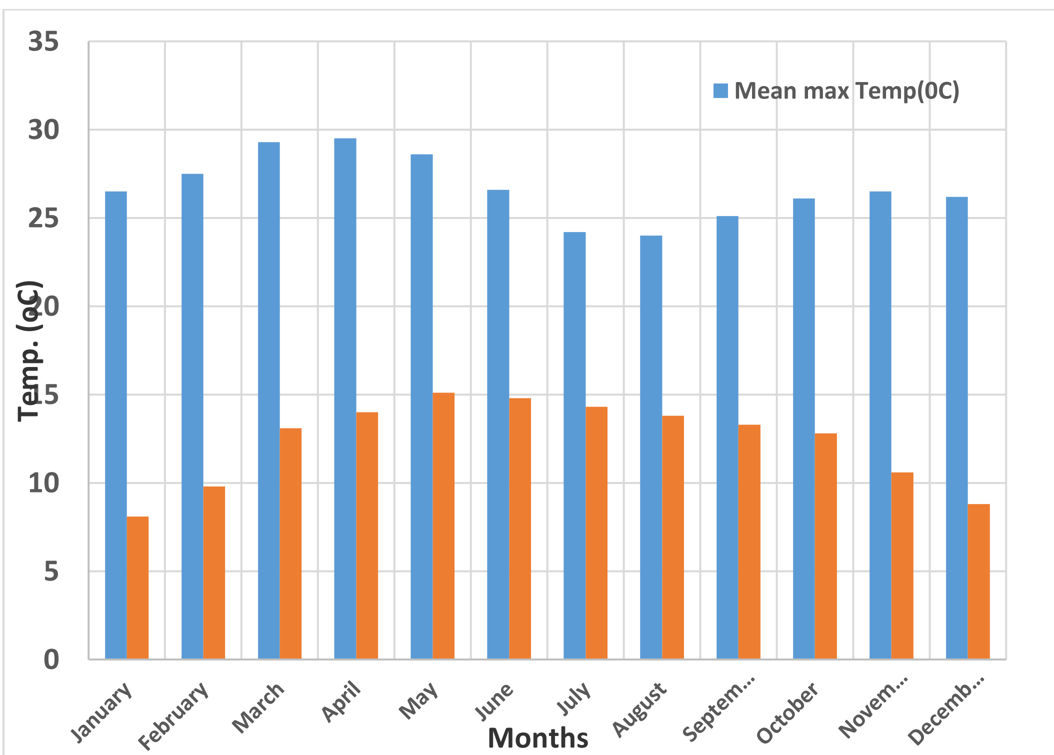


Figure 3.3: Monthly mean Min & max temperature for Bahir Dar Station

Mean annual rainfall varies from 1400 to 1550mm along the project corridor. Extended unimodal rainfall distribution is realized from June to September where the peak in July and August. Accordingly, project corridor climate zonation tends to behave as Weina Dega.

3.3.4 Geology

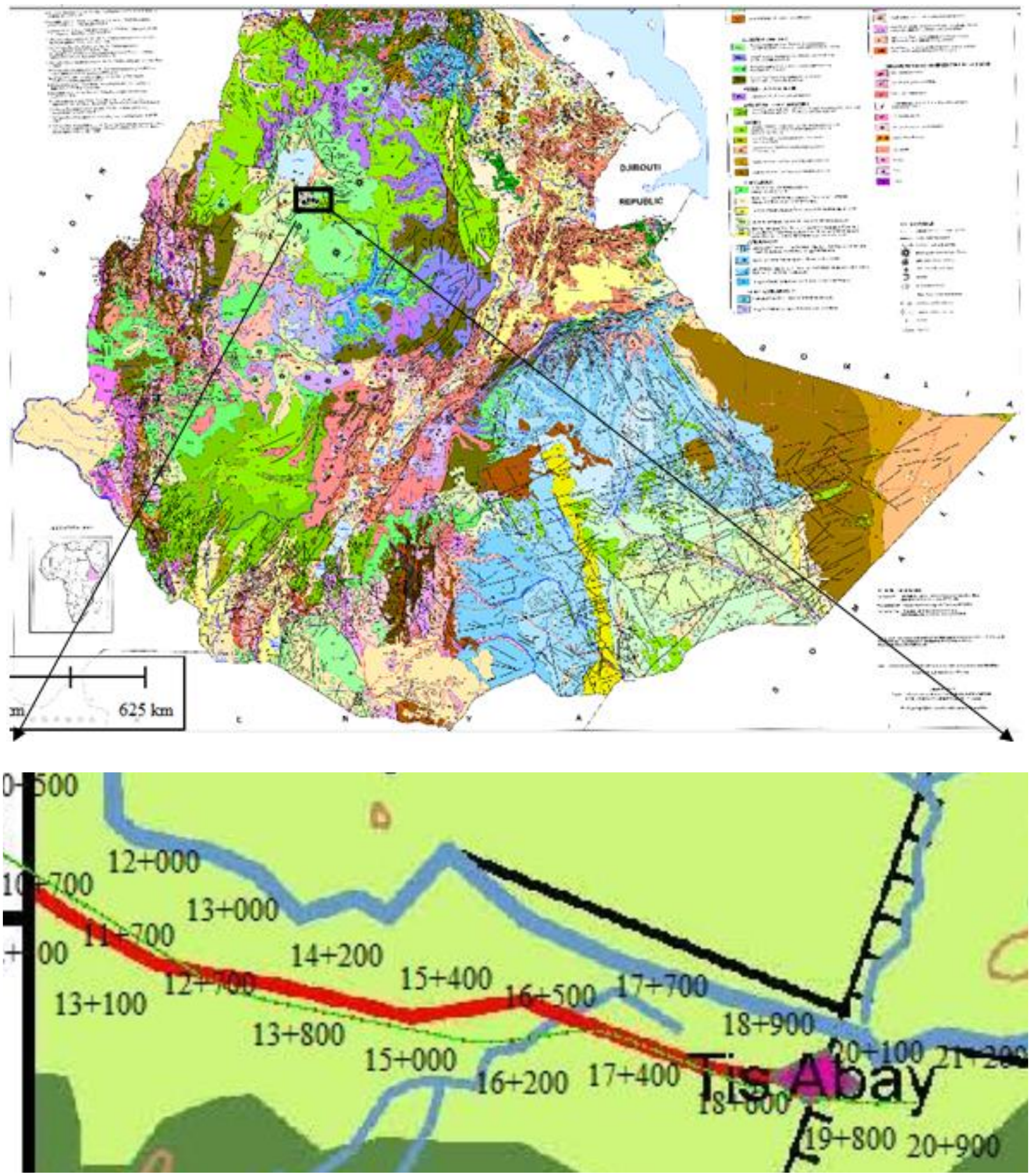
Ethiopia has a complex geological history represented in three major geological terrains. The Eastern part of Ethiopia is home to Late Paleozoic, Mesozoic, and Cenozoic continental and marine deposits. There are also Cenozoic volcanic and sedimentary rocks, such as those from the East African rift valley, which run through the nation from south to north.

The geology of the route corridor was evaluated using the Ethiopian Geological Map. (Mengesha et al. 1996). It is identified from the geological map that the route crosses a single geological unit, Quaternary Plateau Basalt (Qb1).

Quaternary Plateau Basalt (Qb1)

Quaternary volcanic and sedimentary rocks geological unit cover the entire project alignment. According to the Geological Map of Ethiopia (Mengesha et al. 1996), quaternary alkaline basalts and trachyte erupted along with preexisting structures on the northwestern and southeastern plateaus. Although not dated, their relatively unmodified geomorphologic features such as the prevalence of prominent cinder cones and small collapse craters in particular in a region of heavy rainfall and perennial streams indicate their recent age.

Alkaline basalts and trachytic lavas prevail in the lake Tana Graben which belong to this group. Field evidence suggests a Pleistocene age to all these rocks. Volcanic cones and flows of coriaceous basalts are well preserved in the lake Tana Graben. The final pulse of basaltic volcanism on the Ethiopian plateau is represented by the Quaternary basalt flows, which are notably alkaline



QV1 Quaternary volcanics: scoriaceous basalts, fine grained black basalts, layered basalt with scoria cones. Zeoloite rich vesicular basalts, also occur.

Figure 3.4: Geological Map of the Project Area

3.3.5 Location map

Site location maps

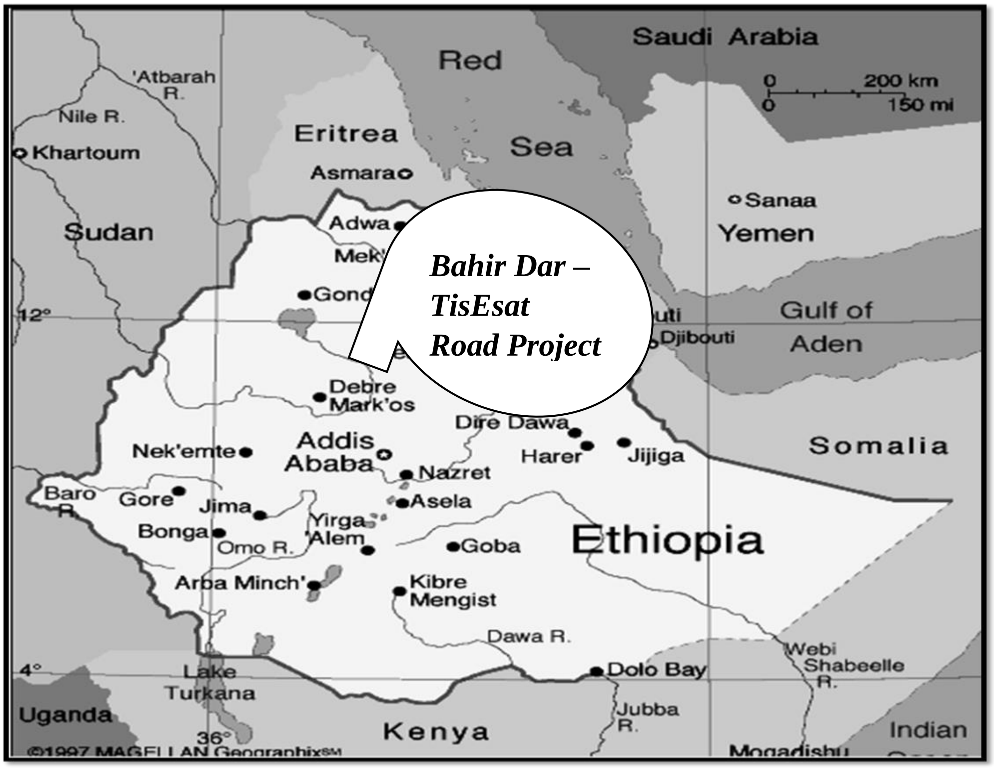


Figure 3.5: Project Site Location map

Project layout

Figure 3.6: Project Layout

3.4 Soil Sample Collection and Preparation

Sampling areas were selected from different parts of the road section and five pits were excavated to a maximum depth of one and a half meters (1.5m). To conduct the different laboratory tests, about 40kg of disturbed soil sample was collected in bulk randomly from each site and at each depth. Both ends of the steel tube will be sealed with wax (melted candle) when the undisturbed samples are extracted. Both the disturbed and undisturbed samples were delivered to the Geotechnical laboratory after careful sampling.

Tropical residual soils, which often act differently from other conventional soils in terms of characteristics and structure, require special attention. The soil fabric, particle bonding, void ratio (e), and moisture content (w) must all be preserved since they have a substantial impact on a variety of engineering parameters (Mulugeta, 2019).

Accordingly, five test pits are enough to represent the road section. To consider the effect of depth (lateralization) two samples at a depth of 0.6 m and 1.5m have been excavated and taken.

Table 3.3 Sample depth and the designation

Test pit	Sample location (Km)	Depth (m)	Sample designation	Visual color observed
A	0.0-4.0	0.6	A-1	Brown silty clay soil
		1.5	A-2	Black cotton soil
B	4.0-8.0	0.6	B-1	Dark Brown clay
		1.5	B-2	Brown silty clay soil with gravel
C	8.0-12.0	0.6	C-1	Red clay soils
		1.5	C-2	Brown silty clay soil with gravel
D	12.0-16.0	0.6	D-1	Dark brown with weathered gravel
		1.5	D-2	Dark brown
E	16.0-21.2	0.6	E-1	Black cotton soils
		1.5	E-2	Black cotton soils

To study the behavior of these soils, the first procedure after field study and soil sampling is conducting the geochemical and mineralogical composition, the effects of sample preparation and testing, and the relative influence of each factor. To do this, methods of evaluations (tests) have been centered on their physical property as this characteristic is of importance to engineers. Chemical analysis has also been made to supplement the results. The physical properties of soils that serve mainly for identification and classification are commonly known as index properties (Mulugeta, 2019).

Before collection, site visits were made to inspect for potential places for collection of lateritic soil, and choices were made. Less vegetated areas were selected since it is a good indication of lateritic soil.

Figure 3.7 test pit A and C at (0-4km and 8-12km respectively)

Figure 3.8 air drying of samples and sample preparation for the test

Figure 3.9 tube sample collection

3.5 Laboratory Tests Description

Soil is a more complex material. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solid, liquid, and gases. In many instances, the solid particles vary in size from big boulders to colloidal size. Furthermore, the relative quantities of solid, liquid, and gases in a given soil are found to change due to physical causes such as loading, seasonal variation, and change of temperature. The physical properties of soils, which serve mainly for identification and classification, are commonly known as index properties (Fekede, 2007).

The structural differences between tropical soils and dispersed temperate zone soils demanded changes to mechanical or grading tests; conventional pretreatment procedures have a significant impact on the index characteristics of tropical soils. As a result, particular attention is necessary (Blight & Leong, 1999).

The various properties of soils, which could be considered as index properties are:

- Grain size analysis
- Moisture content
- Atterberg limit
- Free swell
- Specific gravity

Strength tests

- Compaction test
- CBR
- UCS test

Geochemical and mineralogical tests

The AASHTO and ASTM testing procedure is used in the laboratory.

3.5.1 Moisture content

Moisture content (MC) is the weight of water in a specific soil mass divided by the weight of solid particles expressed as a percentage of dry soil mass. The loss of mass caused by drying is known as "pore" or "free" water. Furthermore, MC is employed to create a link between soil behavior and its index properties. (Yohannes, 2019).

Determination of moisture content of the soil is further required as a guide to the classification of soils and to evaluate the behavior of soils during construction. This is determined by using the oven drying method. The moisture content relates only to the water which is removable by oven drying at 105-110°C. Moisture is considered to be present in most soils. The amount of moisture, expressed as a proportion of the mass of the dry solid particles, has a profound effect on the soil characteristics and engineering behavior (Medhanit, 2017).

The conventional test is based on the loss of water when soil is dried to a constant mass at a temperature between 105℃ and 110℃. In many residual soils, some moisture exists as water of crystallization, within the structure of the minerals present in the solid particles. Some of this moisture may be removed by drying at the above temperature, that is not only the free water but also the structural water will be removed from the soil (Amare, 2008).

Two test specimens should be prepared for water content determinations. One specimen should be oven-dried at 105℃ until successive weighing shows no further loss of mass. The water content should then be calculated in the normal way. The second sample should be air-dried (if possible) or oven-dried at a temperature of no more than 50°C and a maximum relative humidity (RH) of 30% until no additional mass loss is observed. The two water content results should then be compared: a significant difference (4–6% of the water content obtained by oven drying at 105℃) indicates that "structural'' water is present and is driven off at high temperatures. (Blight & Leong, 1999).

Figure 3.10 moisture content testing

3.5.2 Specific Gravity (Gs) Tests

The mass of a certain volume of a substance divided by the mass of an equivalent amount of water is known as specific gravity. In effect, it informs us how much heavier (or lighter) the substance is than water. The particular specific gravity of soil refers to the mass of solid matter in a given soil sample compared to the mass of an identical volume (i.e., equal to the volume of the solid matter) of water. The specific gravity of soil may also be defined as the ratio of the unit mass of solids in the soil to the unit mass of water, the mass of solids divided by the volume of solids (Negesse, 2016).

In tropical residual soils, Gs may be unusually high or unusually low depending on whether the “particle’’ consists of a void less solid particle of a heavy mineral, e.g., iron Sesquioxide or a porous aggregation of elementary particles. The soil to be used in this test should be at its natural water content. Pre-test drying of the soil should be avoided as this tends to reduce the measured Gs as compared with measurements at natural water content. (Teklay et al., 2015).

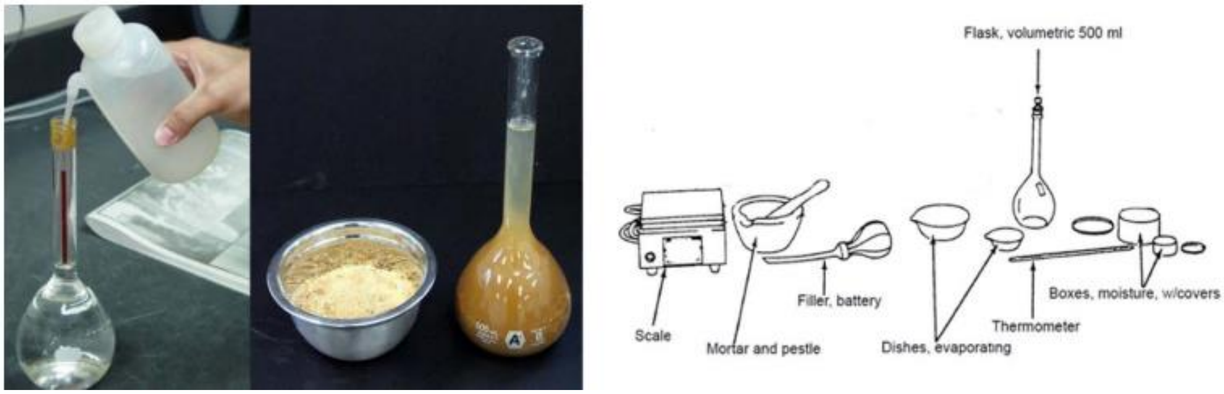


Figure 3.11 Specific gravity experiment apparatus

Hence specific gravity of TWR soil may be unusually low if the soil highly leached and pores and also if the soil contains high organic content or unusually high if leaching and desiccation of soil develop a high accumulation of iron oxide and aluminum oxides (Yohannes, 2019).

3.5.3 Free Swell Tests

Free swell is a test that helps to determine the expansion potential by pouring a soil passing 425µm into a graduated cylinder without any external constraints (consolidating pressure), on submergence in water. The amount of swelling and the magnitude of swelling pressure is known to be dependent on the clay minerals, the soil mineralogy and structure, fabric, and several physicochemical aspects of the soil. Among clay minerals, Montmorillonite influences the magnitude of swelling as compared to Illite and Kaolinites. Drying of soil samples also makes soil particles come closer and hide the potential of some of the active minerals to swell.

The test is performed by slowly pouring 10cm3 of dry soil which has passed the No. 40 (0.425mm) sieve into a 100 cm3 graduated cylinder filled with tap water. After 24 hours, the final volume of the suspension is read. Hence, the free swell is defined as:

$$\text{Free swell} = \frac{Final\ volume\ of\ soil - Initial\ volume\ of\ soil * 100}{Initial\ volume\ of\ soil}$$

Free swell test is defined as the ratio of the increase in the volume of the soil from a loose dry powder form to the equilibrium sediment when it is proved into the water, expressed as the percentage of the original volume. The free swell test is used to indicate the swell potential of soil and or it can be used to assess the existence and predict the type of mineral by evaluating the severity of swelling potential. Because soil's potential to swell depends on the impregnated soil" structure and mineralogical composition and also chemical alteration (Yohannes, 2019).

3.5.4 Atterberg Limits

Atterberg Limits, also known as consistency limits, are the water levels at which the soil transitions from one state to another. Are arbitrary boundaries that separate the liquid, plastic, semi-solid, and solid stages of soil. Moisture content determines these boundaries. They're utilized to figure out how fine-grained soils are made. Soft, firm, or hard soil consistency is a term used to define the degree of hardness of the soil. It generally refers to fine-grained soils whose condition is influenced by moisture content changes. Fine-grained soils' consistency limitations are critical index features. The engineering characteristics of soil alter as the consistency of the soil varies. Shearing strength and bearing capacity are two examples of soil qualities that vary significantly with consistency (Negesse, 2016).

Liquid Limit (LL)

The water content at the liquid-plastic state boundary is known as the liquid limit of soil. The water content at this boundary is arbitrarily defined as the water content at which two halves of a soil pat put in a metal cup with a standard groove and dropped from a height of 1cm will close the groove by around 1.3 cm after 25 drops at a rate of 2 drops per second.

Plastic Limit (PL)

The water content at the plastic-to-semisolid state transition is known as the plastic limit of soil. This boundary's water content is arbitrarily defined as the water content at which soil begins to disintegrate when rolled into threads of a particular size (3.0 mm).

The goal of the Atterberg limits test is to gather fundamental index information on the soil's plasticity. It is the most used method of classifying cohesive soils. Liquid, plastic, and shrinkage limits, which are moisture contents that define boundaries between material consistency states, are investigated in fine-grained soils. These standardized tests yield similar values that may be used to identify, classify, and correlate soil properties.

Table 3.4 classification of soil and soil aggregate AASHTO (M-145-91)

General Classification	Granular Materials (35 Percent or Less Passing 75 µm)							Silt-Clay Materials (More Than 35 Percent Passing 75 µm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, percent passing:											
2.00 mm (No. 10)	50 max	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max	50 max	51 min	—	—	—	—	—	—	—	—
75 µm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid limit	—		—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to Good							Fair to Poor			

[a] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30. (See Figure 2.)

3.5.5 Particle Size Distribution

Soils are products of mechanical and chemical weathering and are found in a wide range of particle sizes and shapes. Simple sieve analysis can be used to differentiate the different size particles of coarse-grained soils. In the sieve analysis square holes between the wires of the sieve mesh provide a limiting size of particles retained on a particular sieve. However, it has to be noted that not all soil particles are spherical, cubical, or of any regular shape. The sieve analysis does not provide any information on the shape of the soil grains regarding whether they are angular or rounded. Generally, the behavior of cohesionless soil does not depend predominantly on the shape of the soil grains. Most cohesion-less soils consist of roughly equal dimensional block particles and sieve analysis provides useful information for engineering purposes. Statistical relationships have been established between grain size and significant soil properties.

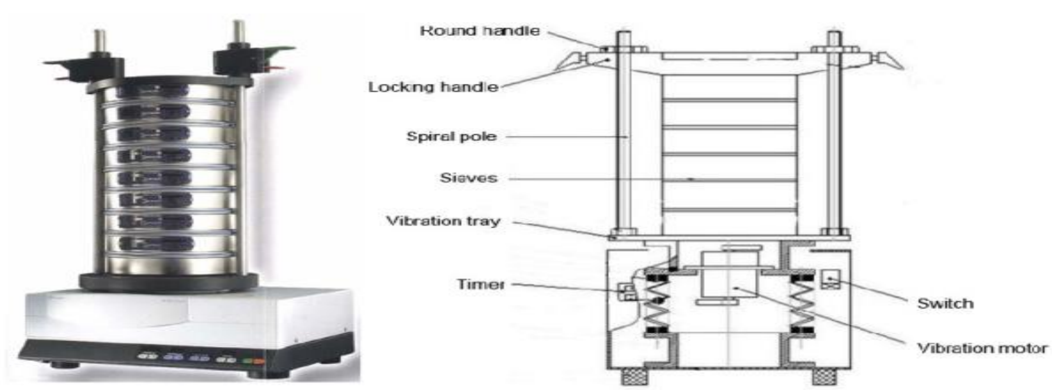


Figure 3.12 mechanical shaker equipment

The suitability criteria for road airfield and embankment construction have been based on grain size distribution. Particle size analyses are useful for various practical applications, ranging from the selection of fill and aggregate materials to road construction, drainage, filters, and grouting. Hence it is intensively used to achieve intended engineering property like achieving the densest pack that brought maximum strength, durability, by minimizing permeability and voids. Or to increase the permeability of different filter layers. The prediction of permeability can be done using grain size analysis. The proper gradation of filter material is established from particle size distribution. Grain size analysis is usually used in engineering soil classifications (Negesse, 2016).

particle size distribution of residual soil may be affected by the effect of drying, chemical pre-treatment, variation of specific gravity, and sedimentation. The most widely reported effect of drying is to reduce the percentage that is reported as the clay fraction (finer than 2μm). The variation in the percentage of particle sizes in the different test procedures is not significant and comparable to that which might be expected in the testing of temperate soils (Blight & Leong, 1999).

After the grain size analysis, the soil shall be categorized based on the particle size distribution of particles.

ASTM D 422-63 (1998), suggests;

- ✓ Gravel is a particle that passes 75mm - and is retained on 4.75mm.
- ✓ Coarse sand is a particle that passes 4.75mm - and is retained on 2.0mm.
- ✓ Medium sand is a particle that passes 2.0mm - and is retained on 0.425mm.
- ✓ Fine sand is a particle that passes 0.425mm - and retained on 0.074mm
- ✓ Silt is a particle that passes 0.074mm - and retained on 0.005mm
- ✓ Clay is a particle that passes 0.005mm

The mass of the soil collected in each sieve was recorded, amount passing each sieve (or percent finer) expressed in percentage of the total dry weight of soil and plotted on a semi-logarithmic graph paper to produce a particle size distribution curve

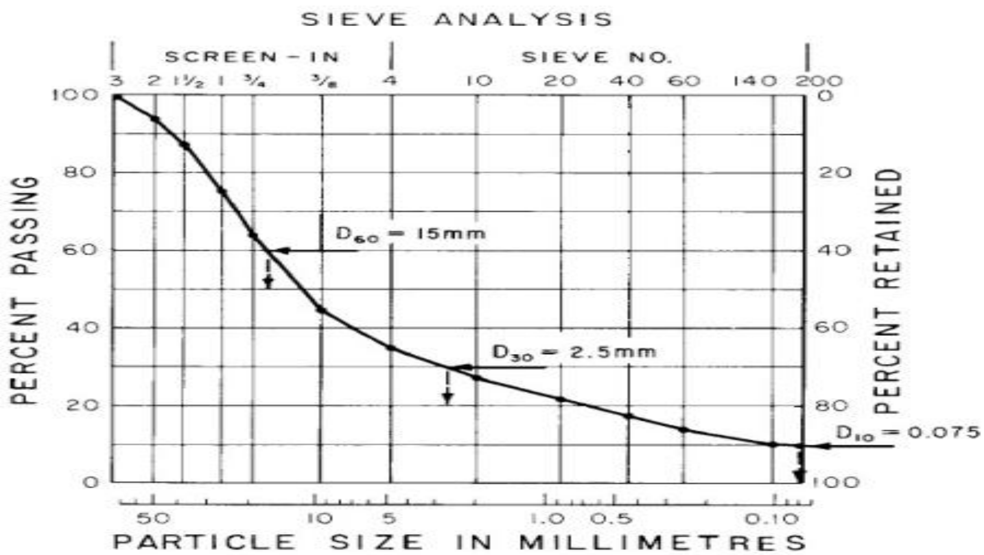


Figure 3.13: Particle size distribution curve (ASTM, 2006)

3.5.6 Compaction test

Compaction is the process of using mechanical force to densify soil and reduce air gaps. By rearranging the fabric of the soil, compaction enhances its strength, lowers its compressibility, and lowers its permeability. The mechanical effort employed in compaction forces the soil fabric into a denser structure. Compaction is the most often used technique for improving soils (Burt G., 2007).

Compaction compacts soils, which reduces additional settling, enhance shear strength and decreases permeability. During compaction, water plays a crucial role. When a little quantity of water is introduced to soil and subsequently compacted with a set amount of energy, the soil is compressed to certain unit weight. The dry unit weight of the soil will progressively increase if the moisture content of the same soil is steadily raised and compaction is done in the same manner. The optimal moisture content is the moisture content at which the highest dry unit weight is reached. Adding water beyond optimum value reduces density. Water replaces soil particles and the curve more or less straight and parallel to zero - void line. Zero - void line is a line drawn with a proctor curve to check the acceptability of the test. It represents the relationship of water content to dry density for a 100% degree of saturation (Zelalem, 2005).

Figure 3.14 compaction testing materials

With a given expenditure of energy (or “compactive effort’’) only a relatively low compacted dry density can be achieved. As the water content is increased, the resistance of the soil to compaction decreases and higher dry densities result, but as the air-filled voids decrease, the resistance to the escape of air increases until the air-filled voids become occluded, or sealed off from the atmosphere by surrounding water-filled pore space, this point corresponds approximately with the maximum dry density and optimum water content for the particular compactive effort being used. From the optimum point onwards, as water is added to the soil, it occupies increasing space in the voids, while the air content remains almost constant. The result is that the dry density of the soil decreases progressively with increasing water content (Blight & Leong, 1999).

Residual soils, especially those of volcanic and igneous origin, often have:

- ✓ High in situ moisture contents.
- ✓ Metastable clay minerals.
- ✓ Soil structures that are lightly cemented.
- ✓ Weathered soil particles that break down under compactive effort.
- ✓ Sesquioxide minerals are affected by wetting and drying (Blight & Leong, 1999).

3.5.7 Unconfined compression strength (UCS) tests

Unconfined compression strength (UCS) tests were performed on soil samples by compacting them with a conventional proctor compaction device at various moisture contents and periods after compacting (at OMC). The experiments were carried out on cylindrical soil samples that were gradually loaded at both ends until brittle or plastic failure occurred. During the loading procedure, the sample's vertical compression was recorded, but the sample could flex laterally without being confined (Amare, 2008).

Unconfined compression test (UCS) is a basic test to determine the unconfined compression strength (qu) and failure shear strength parameter of a cohesive soil sample, meaning a sample that is inclusive of clay. The failure shear strength parameter is equal to the cohesion (Cu) of the soil. The unconfined compression test is the most popular means used to determine the shear strength parameter of the soil and it is has become one of the most common tests used to date. It is also one of the easiest tests to be carried out in determining the said failure stress. Due to the lack of lateral supports, the sample itself has to have sufficient cohesion to maintain its shape and support its weight. Hence the determination of cohesion (Cu) is considered the strength of the soil sample (Gidigasu, 1974).

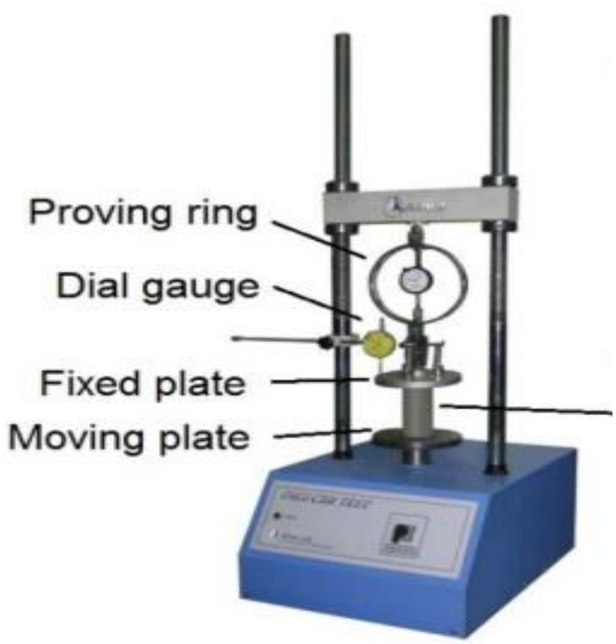


Figure 3.15 Unconfined compression test apparatus

3.5.8 California Bearing Ratio (CBR)

California Bearing Ratio test was developed by the California Division of Highways in 1929 as a means of classifying the suitability of a soil for use as a subgrade or base course material in highway construction. The test measures the shearing resistance of a soil under controlled moisture and density conditions, i.e., usually at optimum moisture content and the corresponding degree of MDD relevant to field compaction value (Zelalem, 2005).

CBR test is a penetration test used to determine the mechanical strength or load-bearing capacity of subgrade, sub-base, and base course materials used in road pavements. The CBR value may be thought of as the strength of the soil relative to that of crushed rock. The thickness required for flexible pavements for airfields and highway pavements can be determined by the use of CBR. This test can be carried out on most types of soil ranging from clay to gravel. The principle behind the test deals with determining the force required to maintain a fixed rate of penetration of a known area of soil sample with a plunger by use of the CBR equipment. The measured pressure is to be divided by the pressure required to achieve equal penetration on crushed rock (Ahmed, 2015).

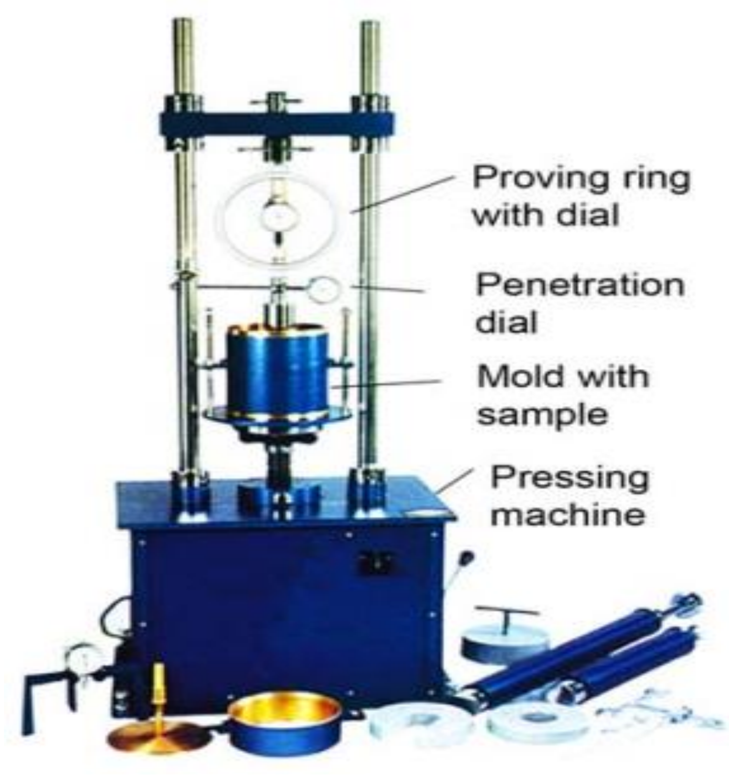


Figure 3.16 CBR testing equipment

Structural and supporting capabilities are evaluated by penetrating compacted specimen often penetration takes place after soaking for 96 hours to evaluate the possible maximum worst condition and maximum density essentially obliged to achieve in the field compaction. Whereas soaking reduces approximately 50% of unsoaked laboratory CBR of the compacted specimen. In the laboratory CBR test, a (50mm diameter cross-section) cylindrical plunger is penetrated at a standard rate (1.27mm/minute) into a compacted, confined sample. The CBR is calculated by expressing the load required to cause penetration of 2.5mm (2.54mm) as a percentage of 13.2kN (6.9MPa) or penetration of 5mm (5.08mm) as a percentage of 19.8kN (10.3MPa) whichever is the larger. CBR is commonly referred to as a strength parameter but it also an indicator of stiffness with a considerable limitation of conventional practice towards the treatment of maximum particles size (19 mm), sensitivity to particle break down, selection of target dry density ratio, and compaction moisture content, curing or moisture equilibration, stress relief period and soaked or unsoaked test conditions. (Yohannes, 2019).

3.5.9 Geochemical & Mineralogical Tests

The Geochemical (oxide) and Mineralogical composition of soil are essential to understand the fundamental behavior of the soil. The solid phase of a soil sample is known to contain various amounts of crystalline clay material, oxides, organic matter, and precipitated salts. It has been understood that the property of tropical residual soil is quite dependent on the Geochemical & Mineralogical composition of the soil. It has also been mentioned that soil classification and performance ratings, which are based on mineralogical composition and structure (Mitchell & Soga, 2005).

The amount and type of oxides and hydroxides in the soil have a great effect on the determination of the engineering properties for that soil. Sesquioxide (a combination of aluminum oxide and iron oxide) had a major cementing effect which changes fine mineral constituents into clusters and aggregations. Geochemical tests (Silicate analysis) help to determine the available amounts of oxides and hydroxides in a soil sample as a percentage (Mulugeta, 2019).

Mineralogy controls the sizes, shape & surface characteristics of the particles in the soil. These features along with interactions with the fluid phase determine plasticity, swelling, compression strength, and hydraulic conductivity behavior. Thus, mineralogical composition (together with structure) is an important factor that is fundamental to the understanding of geotechnical properties. Soil mineralogy can be assessed in various ways. Very specialized techniques like X-ray diffraction, thermo- gravimetry, scanning or transmission electron microscopy, etc. have been developed. (Mitchell & Soga, 2005).

The mineralogical components can be separated into major elements that are required for lateralization and minor elements that do not. The major constituents are Oxides and Hydroxides of Aluminum and Iron, with clay minerals and, to a lesser extent, Manganese, Titanium, and Silica. (Hanna, 2008).

The degree of lateralization of the soil samples can be evaluated based on the ratio of Silica/Sesquioxide. the Sesquioxide, designated as R_2O_3, is the combination of Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3). Silica is designated by the chemical formula SiO2. True laterites have ratio's less than 1.33, lateritic soils have ratio's between 1.33 and 2.00, and non-lateritic tropically weathered soils have ratio's more than 2.00 (Hanna, 2008).

CHAPTER FOUR

LABORATORY TEST RESULTS AND DISCUSSION

4.1. Index Property Tests

4.1.1 Moisture Content

Using Fourie et al., (2012) recommendation two subsamples for each sample were taken. Then, the first samples dried at a temperature of 110±5^0C using drying oven and the following results recorded through ASTM D 2216-98 test approach as shown in Table 4.1. The second samples dried at a temperature of 50^0C with 30% RH at the oven, and it shows no change in weight after drying for seven consecutive days as shown in Table 4.2.

Table 4.1 Moisture content at 110 ± 5℃ oven temperature drying

Sample location (Km)	Depth (m)	Sample designa tion	Wt. of can a(gm)	Wt. of wet soil + can, b (gm)	Dry soil + can, c (gm)	Wt. of moisture loose=b-c	Wt. of dry soil=c-a	Moisture content (%)
0.0-4.0	0.6	A-1	77	380	347	33	270	12.2
	1.5	A-2	81	359	333	26	252	10.3
4.0-8.0	0.6	B-1	80	481	461	20	381	5.25
	1.5	B-2	80	472	455	17	375	4.53
8.0-12.0	0.6	C-1	80	407	383	24	303	7.92
	1.5	C-2	80	359	335	24	255	9.4
12.0-16.0	0.6	D-1	81	372	355	17	274	6.2
	1.5	D-2	80	365	340	25	260	9.6
16.0-21.2	0.6	E-1	81	378	352	26	271	9.59
	1.5	E-2	82	370	346	24	264	9.09

Table 4.2 Moisture Content at 50℃ oven temperature drying with 30%RH

Sample location (Km)	Depth	Sample designation	Moisture content (%)
0.0-4.0	0.6	A-1	11.1
	1.5	A-2	7.4
4.0-8.0	0.6	B-1	4.3
	1.5	B-2	3.6

8.0-12.0	0.6	C-1	6.8
	1.5	C-2	8.3
12.0-16.0	0.6	D-1	3.5
	1.5	D-2	6.1
16.0-21.2	0.6	E-1	5.8
	1.5	E-2	5.1

Table 4.3 Variation of moisture between drying on 110℃ and 50℃

Sample designation	Moisture content at 110℃ (%)	Moisture content at 50℃ (%)	Variation (%)
A-1	12.2	11.1	1.1
A-2	10.3	7.4	2.9
B-1	5.25	4.3	0.95
B-2	4.53	3.6	0.83
C-1	7.92	6.8	1.12
C-2	9.4	8.3	1.1
D-1	6.2	3.5	2.7
D-2	9.6	6.1	3.5
E-1	9.59	5.8	3.79
E-2	9.09	5.1	3.99

From the result, the maximum variation is 3.99% which is less than 4%, which means the soil in the study area doesn't have a significant amount of loosely bound structural water. Hence, all the upcoming moisture content determination can be done by drying at an oven temperature of 110℃ for all samples.

4.1.2 Specific Gravity (Gs) Tests

The test results vary from 1.75 to 2.69, and as previously noted, the result might be high or low. Because of the high iron concentration, the value is higher.

The available data indicate that specific gravities vary not only with the soil textural but also within different fractions. The specific gravity has been used as a measure of the degree of maturity (lateralization). Lateritic soils have been found to have very high specific gravities (Hanna, 2008).

Table 4.4 Values of Specific Gravity

Sample designation	NMC (%) at oven-dry	Specific gravity
A-1	12.2	2.02
A-2	10.3	2.29
B-1	5.25	2.35
B-2	4.53	2.47
C-1	7.92	2.37
C-2	9.4	2.34
D-1	6.2	2.07
D-2	9.6	1.75
E-1	9.59	2.69
E-2	9.09	1.99

Lower values of specific gravity strongly suggest coarser soil while higher values suggest fine-grained soils. Hence specific gravity of Tropical soil may be unusually low if the soil is highly leached and pores and also if the soil contains high organic content or unusually high if leaching and desiccation of soil develop a high accumulation of iron oxide and aluminum oxides.

4.1.3 Free Swell Tests

The oven-dried samples will be placed into the cylinder and immersed in water to record the initial height of the soil samples, which will be measured using a 0.425mm sieve. Measure the sample's ultimate height after 24 hours of soaking.

Free swell (%) = $((H_f - H_i)/ H_i) *100$

Where; H_f = Final measured height after 24 hour soaking time

H_i = initially measured height

Table 4.5 free swell test values

Sample location	Depth	Sample designation	Free swell (%)
0.0-4.0	0.6	A-1	55
	1.5	A-2	66
4.0-8.0	0.6	B-1	60

	1.5	B-2	65
8.0-12.0	0.6	C-1	40
	1.5	C-2	20
12.0-16.0	0.6	D-1	55
	1.5	D-2	60
16.0-21.2	0.6	E-1	70
	1.5	E-2	68

According to the practice, which is based on the suggestion of (Holtz, 2004), soils with the free swell value of less than 50% are considered to be non-expansive, while those with the free swell value of 50% to 100% are considered to be of an intermediate degree of expansiveness. A free swell value of greater than 100% is supposed to indicate that the soil is expansive. According to the free swell test result, all the samples except C-1 and C-2 are considered to have an immediate degree of expansiveness, while C-1 and C-2 having a free swell value of 40% and 20% respectively are non-expansive.

4.1.4 Atterberg Limits

The plastic limit (PL) and liquid limit (LL) of all-air dried samples from all locations were determined using the test techniques described in section 3.7.4.

The plasticity index (P.I) shows the range over which the soil is in the plastic state. A high numerical value of the plasticity index is known to be an indicator of the presence of a high percentage of clay in the soil sample. As far as conventional classification system such as USCS is concerned, information regarding the type of fines in the sample may be obtained by considering the plasticity index concerning the liquid limit. Experiments on soils from across the world were plotted on a graph of plasticity (ordinate) vs liquid limit (abscissa), and it was discovered that clays, silts, and organic soils all fall into various areas of the graph (Sintayehu, 2003).

Table 4.6 Atterberg Limit test values

Sample location (Km)	Depth (m)	Sample designation	Liquid limit (%)	Plastic limit (%)	Plasticity Index PI (%)
0.0-4.0	0.6	A-1	61	29.6	31.4
	1.5	A-2	63.4	30.3	33.1
4.0-8.0	0.6	B-1	61.5	33.65	27.85
	1.5	B-2	67.1	28.49	38.61
8.0-12.0	0.6	C-1	42.5	28.88	13.62
	1.5	C-2	42.0	28.88	13.12
12.0-16.0	0.6	D-1	55.47	28.38	27.09
	1.5	D-2	77.8	38.1	39.6
16.0-21.2	0.6	E-1	86.3	36.6	49.7
	1.5	E-2	82.6	38.4	44.2

Tropical soils are susceptible to breakdown with manipulation, hence test procedures should be more rigidly controlled. Excessive manipulation during testing leads to crumbling of the soil structure and disaggregating; both consequences produce fines which result in higher liquid limit values. The mixing time was kept to a minimum, generally about 5 minutes for each point (Zelalem, 2005).

4.1.5 Particle Size Distribution

The test results are shown in Table 4.8. As stated in the previous sections (3.7.5), pre-drying residual soils result in a lesser clay fraction due to the aggregation (cementing) effect of tropical soils, and the as-received sample result in a relatively coarser fraction.

It is known that for laterites, the coarser fraction is iron-rich and the fine fraction is kaolinite. The coarser fraction which is rich in iron had higher specific gravity than the fine fraction. During grain size analysis by inspecting the material and evaluating its composition; it is important to decide whether using separate specific gravity for fine and coarse fractions is necessary or not. Performing sieve analysis without separating coarser and fine friction will mislead the result by the effect of variable bulk relative density if the specific gravity variation is large. In the case of the study area soil, the specific gravity ranges from 1.75 to 2.69.

Table 4.8 Particle size distribution by wet sieving (ASTM 422-63)

Sample	Depth (m)	Clay content (%)	Silt content (%)	Sand content (%)	Gravel content (%)
A-1	0.6	40.4	20.06	24.16	15.38
A-2	1.5	31.2	20.2	28.4	20.2
B-1	0.6	26.2	43.5	1.9	28.4
B-2	1.5	30.1	17.05	2.75	50.1
C-1	0.6	30.42	17.2	16.39	35.99
C-2	1.5	31.4	17.13	4.4	47.07
D-1	0.6	39.5	19.5	8.4	32.6
D-2	1.5	42.7	18.7	2.1	36.5
E-1	0.6	40.5	20.2	12.6	26.7
E-2	1.5	43.6	17.6	10.6	28.2

Lateralization and decomposition affect the size of the soil particles. When depth increases lateralization and decomposition decrease and the soil particles remain coarser. During hydrometer analysis (Sedimentation process) using a diluted solution of sodium hexametaphosphate dispersing agent with a mechanical stirrer helps to eradicate the problem of flocculation on clay particles.

Classification of soil

Soil description/identification is the systematic, precise, and comprehensive naming of particular soils in both written and spoken forms (AASHTO M 145, ASTM D-2488), whereas soil classification is the grouping of the soil into a category; for example, group name and symbol.

Unified Soil Classification System

The USCS is a method for classifying mineral and organo-mineral soils for engineering applications, based on laboratory determinations of particle-size characteristics, liquid limit, and plasticity index. It should be used when precise classification is necessary. The USCS initially classifies the soil based on whether it passes or is retained on a 0.075mm sieve. Then, coarse-grained soils, employ grain size analysis, whereas fine-grained soils are classified using Atterberg limits.

Table 4.9 Classification of Soil According to USCS

Sample	Depth (m)	LL (%)	PI (%)	Percentage passes		Group symbol	Group name
				0.075mm	4.75mm		
A-1	0.6	61	31.4	98.37	99.91	CH	Fat Clay
A-2	1.5	63.4	33.1	98.33	99.78	CH	Fat Clay
B-1	0.6	61.5	27.85	99.64	100	CH	Fat Clay
B-2	1.5	67.1	38.61	41.67	50.27	GC	Clayey Gravel
C-1	0.6	42.5	13.12	48.6	62.8	GM	Silty Gravel
C-2	1.5	42.0	13.12	49.12	63.47	GM	Silty Gravel
D-1	0.6	55.47	27.09	97.96	99.36	CH	Fat Clay
D-2	1.5	77.8	39.6	98.19	99.76	MH	Elastic Silt
E-1	0.6	86.3	49.7	97.4	99.24	CH	Fat Clay
E-2	1.5	82.6	44.2	97.45	99.61	MH	Elastic Silt

The soil samples of A-1, A-2, B-1, D-1, D-2, E-1, and E-2 had < 50% amount by weight retained on 0.075mm sieve size and categorized as fine-grained soils. The second evaluation is based on the liquid limit value, the soils from a test sample of A-1, A-2, B-1, D-1, D-2, E-1, and E-2 had LL greater than and equal to 50% and classified as highly plastic soils. The third evaluation is differentiating as organic and inorganic, and the soils from test samples A-1, A-2, B-1, D-1, D-2, E-1, and E-2 are inorganic soils. The final evaluation is based on the location of PI and LL on the USCS plasticity chart. A line referred to as “A” line with an equation PI = 0.73 (LL-20) is a separating line between clay soils and slit. the soils from sample D-2 and E-2 falls below this “A” line; which shows the soils are classified as group symbol of “MH” and group name of “Elastic Silt” but soil sample A-1, A-2, B-1, D-1, and E-1 falls above “A” line; which shows the soil is classified as group symbol of “CH” and group name of “Fat Clay”.

The soils from test samples B-2, C-1, and C-2 had > 50% amount by weight retained on 0.075mm sieve size and categorized as coarse-grained soils. The second evaluation is based on the percentage by weight of the soil retained on 4.75mm sieve, for soils from test samples B-2, C-1, and C-2 the percentage retained on 4.75mm sieve < 50% and classified as Gravel. The third evaluation is based on the available percentage of fines within the sands, for test pit B-2, C-1, and C-2 soils there have been more than 12% fines available, and the soils from these test pits are categorized as gravel with fines. The final evaluation is based on the location of PI and LL on the USCS plasticity chart. A line referred to as "A" line with an equation PI = 0.73 (LL- 20) is a separating line between clay soils and slit. The soils from test C-1 and C-2 fall below this "A" line; which shows the soils are classified as group symbol of "GM" and group name of "Silty Gravel" whereas soil sample B-2 falls above the "A" line, which shows the soil is classified as group symbol of "GC" and group name of clayey Gravel.

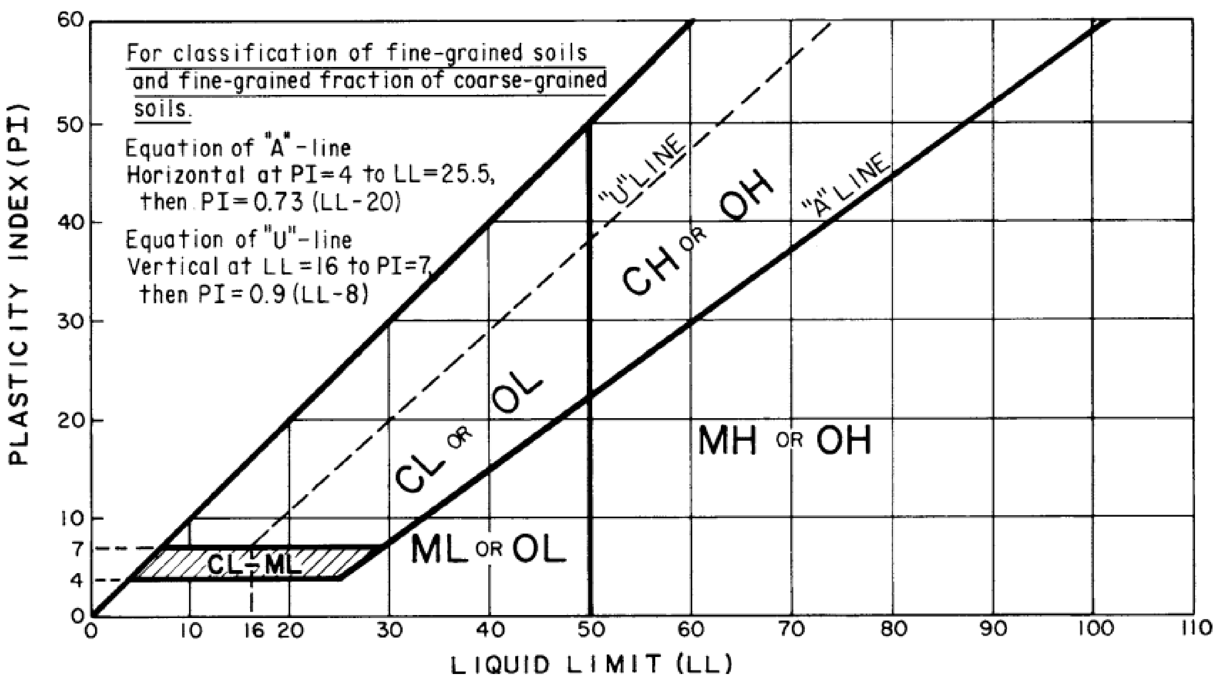


Figure 4.1 plasticity chart

AASHTO Classification System

Using particle size distribution, liquid limit, and plasticity index values collected from laboratory testing, AASHTO divides soils and soil-aggregate mixes into seven groups and subgroups for highway construction. The group index, which is a number calculated using an empirical formula, is used to evaluate soils within each group. The group classification, including the group index, should help determine the relative quality of soil material for use in earthwork structures such as embankments, subgrades, sub-bases, and bases.

Table 4.10 classification of soil according to AASHTO (M-145-91)

Sample location	Depth	Sample designation	Classification
0.0-4.0	0.6	A-1	A-7-6(37)
	1.5	A-2	A-7-5(39)
4.0-8.0	0.6	B-1	A-7-5(58)
	1.5	B-2	A-7-6(10)
8.0-12.0	0.6	C-1	A-7-6(2)
	1.5	C-2	A-7-5(7)
12.0-16.0	0.6	D-1	A-7-6(33)
	1.5	D-2	A-7-5(49)
16.0-21.2	0.6	E-1	A-7-5(54)
	1.5	E-2	A-7-5(45)

Table 4.11 AASHTO classification (M145-91) for sample C-2.

Sieve no. (size)	2.0mm (10)	0.425mm (40)	0.075mm (200)
Percent pass	54.75	51.26	49.67
LL	42.0		
PL	28.88		
PI	13.12		
Classification	A-7-5 (7)		

Those two manuals are more effective for coarse-graded and well-graded soil aggregate mixtures. AASHTO soil classification system uses both particle size distribution and Atterberg limits consecutively for classifying the soils and aggregates into the desired soil group.

All the test samples had more than 35% by weight which passes 0.075mm and hence all soils from these pits are categorized under Silt-Clay materials. The second evaluation is based on the liquid limit and plasticity index. All the soils from the test pit had a LL > 40% and PI > 10% which is categorized under group classification A- 7. The final evaluation is based on the gap between LL and PI. If PI ≤ LL-30 the soil is classified as A-7-5 else it is classified as A-7-6. All the soils from test pit A-2, B-1, C-2, D-2, E-1, and E-2 had a PI which is less than LL minus 30, hence, the soils were classified as A-7-5. Whereas test samples A-1, B-2, C-1, and D-1 had a PI which is greater than LL minus 30, hence the soil classified as A-7-6.

Range of Gradation Curves

The range of grain size distribution curves for the soil samples under investigation for this thesis work is shown in Figure 4.2 below

The position of a curve on the chart indicates the fineness or coarseness of the grains; the higher and further to the left the curve lies, the finer the grains, and vice versa. The steepness, flatness, and general shape indicate the distribution of grain sizes within the soil.

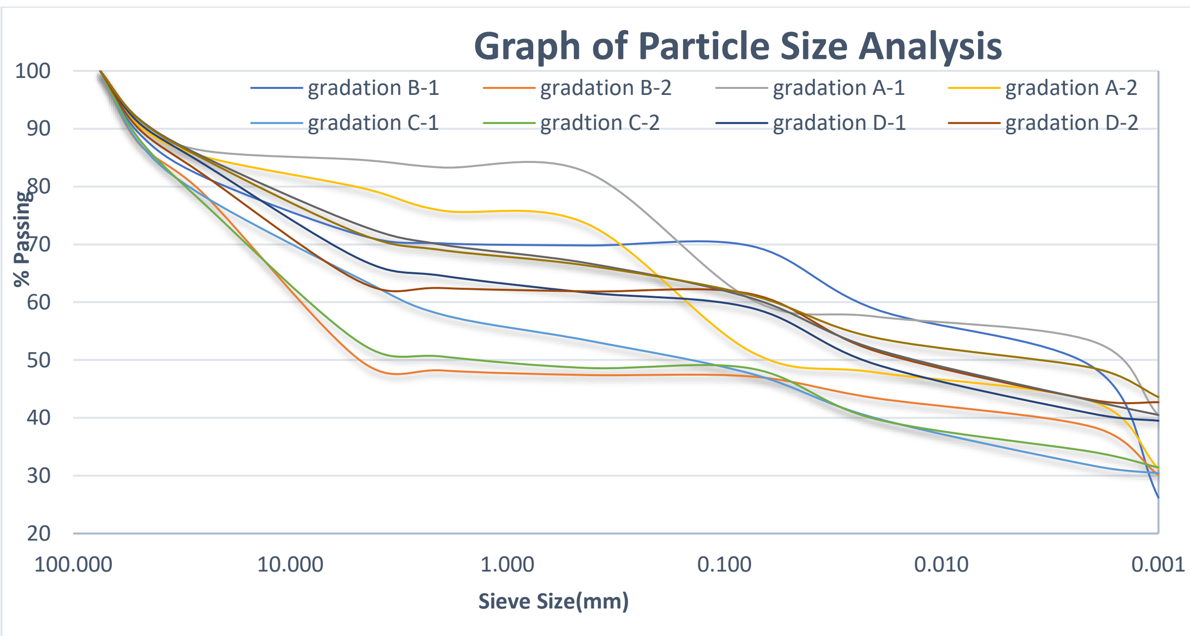


Figure 4.2 Grain size distribution curves

As we see the above graph, it contains a wide and even distribution of particle size, A well-graded Gravely silt sand is shown as a smooth concave upward grading curve. The graph represents particles of all sizes from gravel down to clay. This type of soil is often loosely called boulder clay, which in geological terminology is considered to be inaccurate, and contains enough clay to give it cohesion, and is well-graded from clay to gravel.

4.2 Strength Tests

4.2.1 Compaction Test

The effect of the degree of lateralization in a given profile helps to judge whether in a given profile varies the degree of lateralization or not. Theoretically, a higher degree of lateralization can be expected at the top part of the profile considering that the parent rocks are the same in the profile. To determine the effect of degree of lateralization on the maximum dry densities and the corresponding optimum moisture contents, the compaction test data was summarized for the samples as received from the site as follows:

The values obtained from the modified compaction test are shown in the table below 4.12 and the curves are plotted in the figures below. To stimulate the actual site condition on the laboratory compaction the as-received samples were exposed to sunlight and air blow for one day. To represent the actual soil properties on the compaction, each point had done by using a fresh sample.

Table 4.12 Compaction test data (for soils as received, using MCM)

Sample location (Km)	Depth (m)	Method of testing	Maximum Dry Density (MDD)	Optimum Moisture Content (OMC)
0.0-4.0	0.6	Modified	1.487	24.30
	1.5	Modified	1.529	23.83
4.0-8.0	0.6	Modified	1.656	17.0
	1.5	Modified	1.698	15.85
8.0-12.0	0.6	Modified	1.51	20.7
	1.5	Modified	1.598	21.6
12.0-16.0	0.6	Modified	1.498	21.8
	1.5	Modified	1.595	19.0
16.0-21.2	0.6	Modified	1.515	22.90
	1.5	Modified	1.542	18.80

The modified compaction test results of all samples reveal, when depth increases downward, MDD increases and OMC decreases. MDD increases because of downward the depth the void between gravels and soils is filled by the accumulation of leached silica grain and the percentage of hard concretionary particles increases through depth. Downward a depth a soil becomes coarser which results in the reduction of surface area. This reduction in surface area influences by decreasing the OMC during compaction.

Table 4.13 determination of MDD and OMC for sample B-2

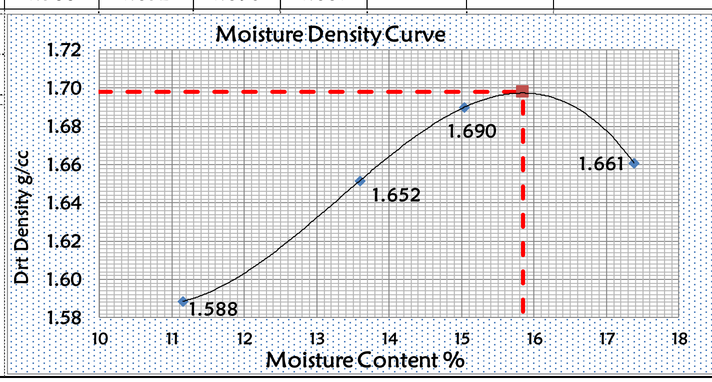
Relationship of Moisture and Density AASHTO T-180 Test Method D			
SOURCE LOCATION	Km 4-8+000km	SAMPLE TAKE FROM	OGL
REPRESENTING SECTION	Km 4-8+000km	DATE SAMPLED	5/2/2021
MATERIAL DESCRIBTION	Dark Brown clay	DATE TESTED	18/2/2021
PURPOSE	sub-grade	Lab No:-	
OFF SET FROM CL		DEPTH	1.5m

	Trial Number	1	2	3	4	5	6	NMC
Density	Weight of Sample (g)	5000	5000	5000	5000			
	Water Added (%)	6	8	10	12			
	Weight of Soil + Mold(g)	9,070	9,305	9,449	9,461			
	WeightT of Mold (g)	5320	5320	5320	5320			
	Weight of Soil (g)	3750	3985	4129	4141			
	Volume of mold cc	2124	2124	2124	2124			
	Wet Density of soil g/cc	1.766	1.876	1.944	1.950			
Moisture	Container Number	C	B1	B7	B			A_{10}
	Wet Soil + Container (g)	429.0	453.0	433.0	439.0			472.0
	Dry Soil + Container (g)	394.0	408.0	387.0	386.0			455.0
	Weight of Water (g)	35.0	45.0	46.0	53.0			17.0
	Weight of Container (g)	80.0	77.0	81.0	81.0			80.0
	Weight of Dry Soil (g)	314.0	331.0	306.0	305.0			375.00
	Moisture Content (%)	11.15	13.60	15.03	17.38			4.53
Dry Density of Soil (g/cc)		1.588	1.652	1.690	1.661			

MDD(g/cc) = 1.698

OMC (%) = 15.85

Remark:-



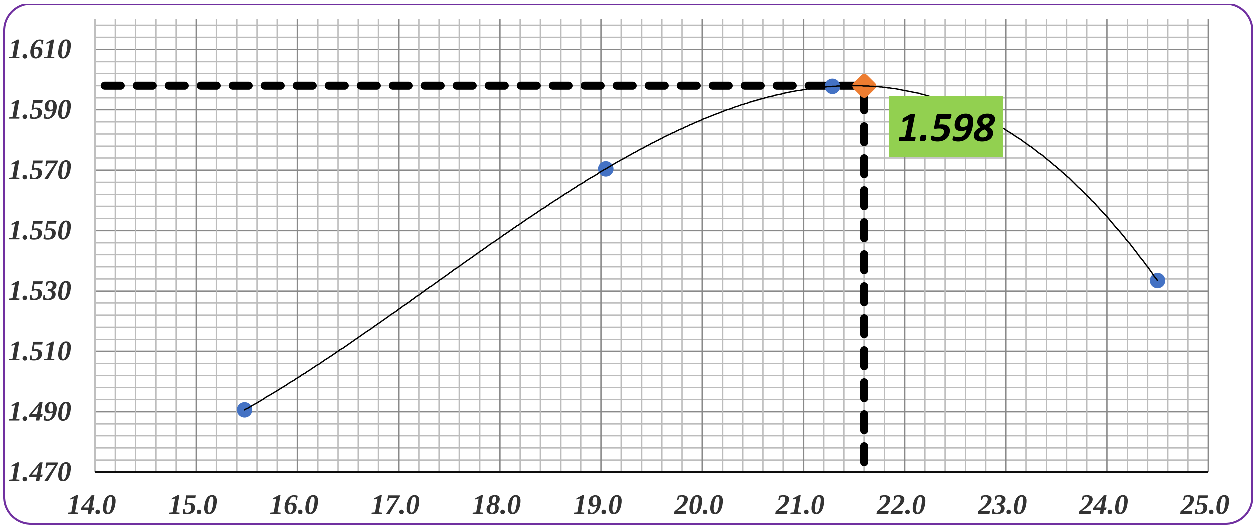


Figure 4.3 compaction curve for sample C-2

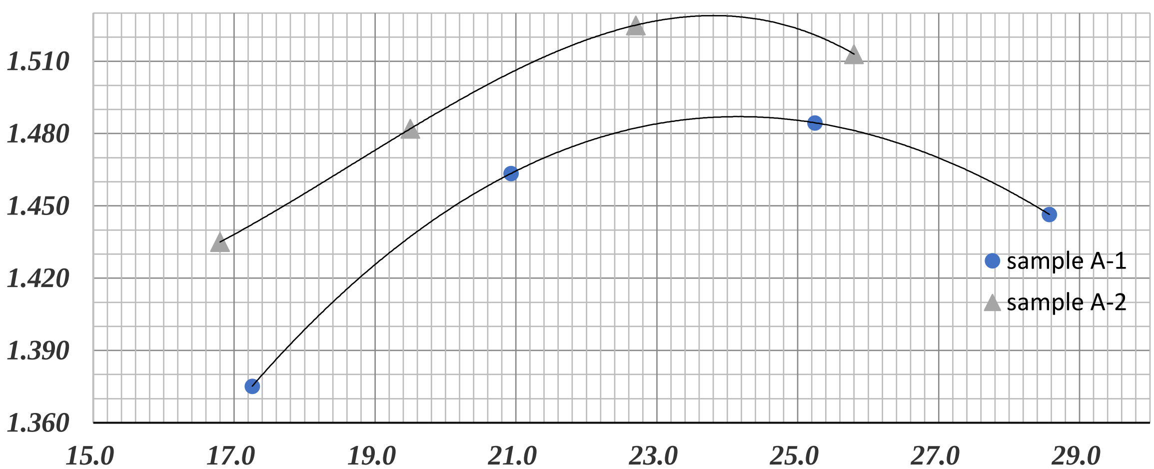


Figure 4.4 effect of depth (lateralization) on compaction, test pit A

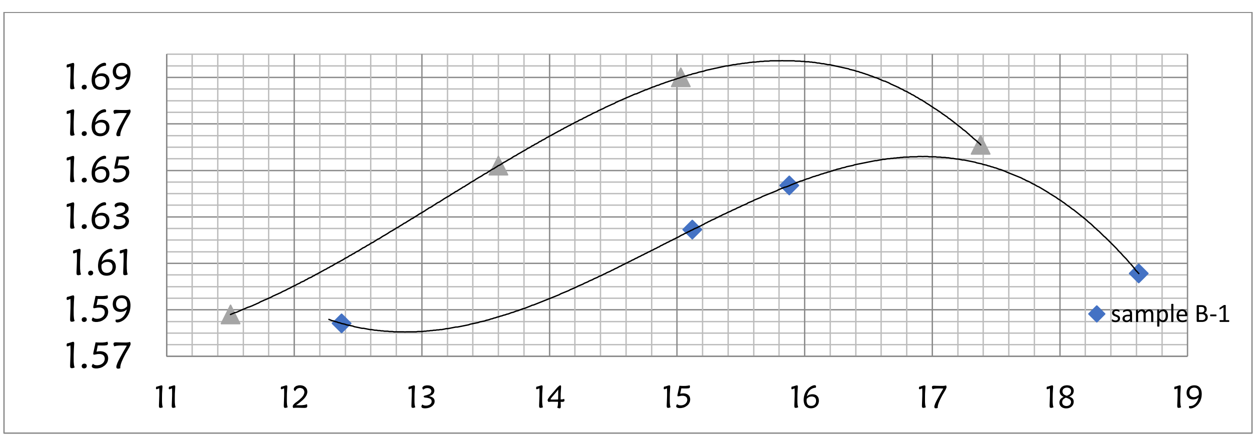


Figure 4.5 effect of depth (lateralization) on compaction, test pit B

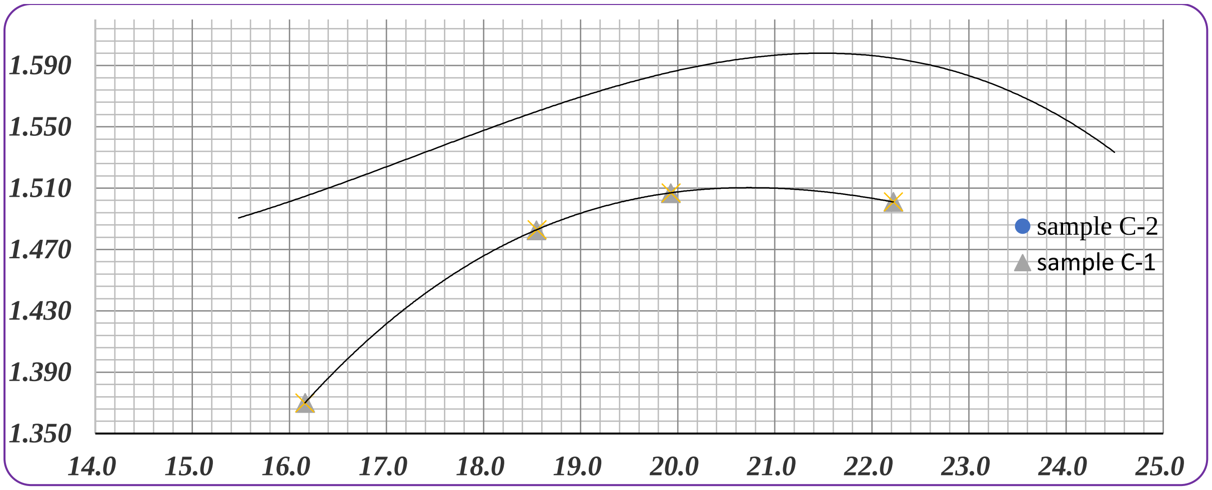


Figure 4.6 effect of depth (lateralization) on compaction, test pit C

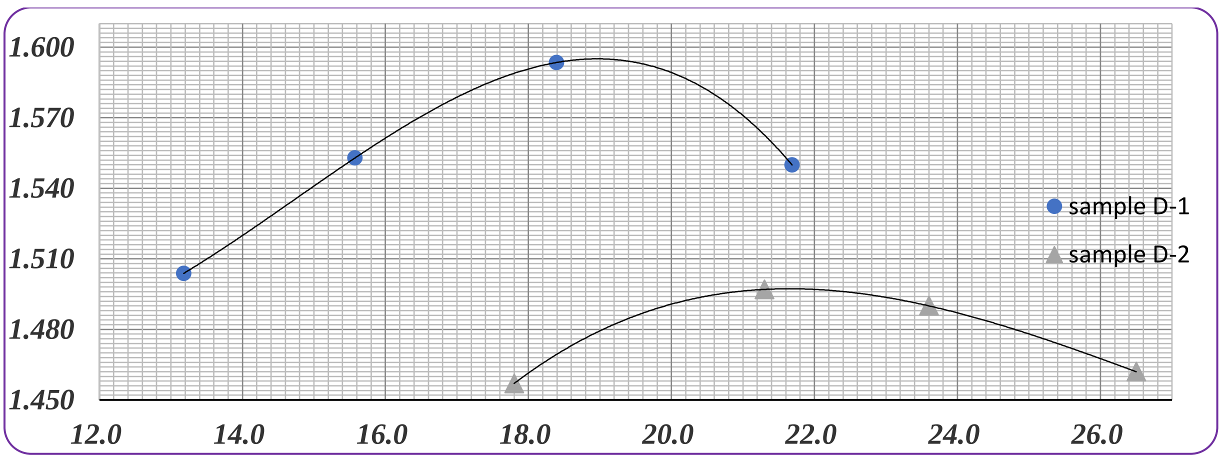


Figure 4.7 effect of depth (lateralization) on compaction, test pit D

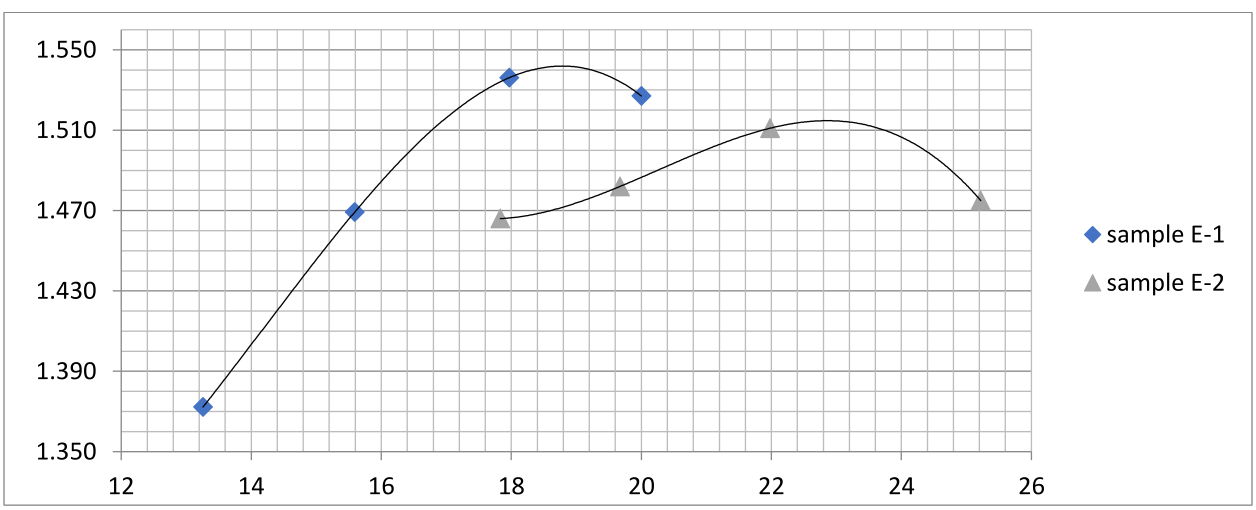


Figure 4.8 effect of depth (lateralization) on compaction, test pit E

4.2.2 Unconfined Compression Strength (UCS) Tests

The unconfined compression test was conducted on tropical soils found in the study area according to procedures specified in section 3.4.7. Test samples were brought into the laboratory in specified cylindrical tubes and extracted. Tests were conducted on these cylindrical samples. The average results have been compiled in Table 4.13.

Table 4.14 UCS test results

Test pit	Depth	UCS, qu (Kpa)	Shear strength, Cu (Kpa)
A	1.5	40.42	20.21
B	1.5	48.68	24.34
C	1.5	146.26	73.13
D	1.5	68.88	34.44
E	1.5	74.50	37.25

As seen from Mohr's circle at failure from Figure 4.9, the major principal stress is $\sigma 1$=qu at failure and the minor principal stress $\sigma 3$ remains zero. Since the shear strength τf is equal to cohesion (Cu) and is independent of the confining pressure, it is taken as half of Qu. The angle of internal friction (ø_u) is zero in all cases.

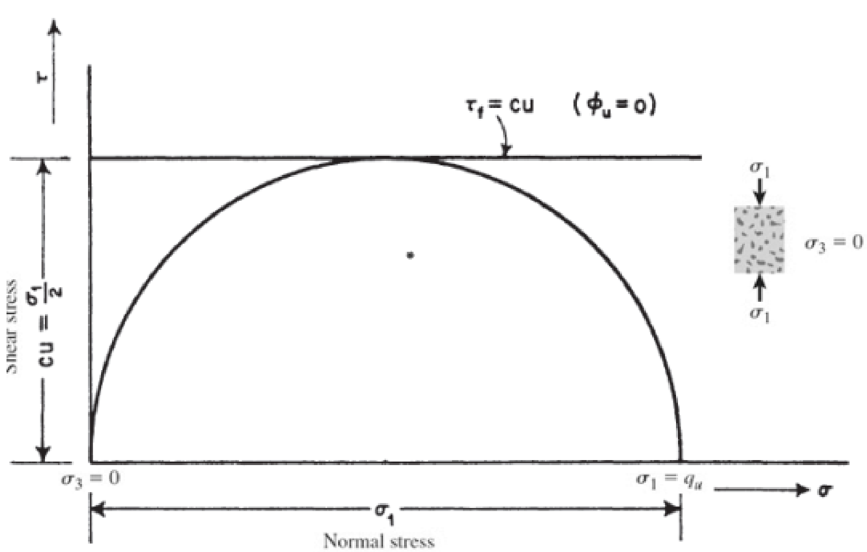


Figure 4.9: Unconfined compression test interpretation (Ahmed, 2015).

Practical applications such as determining the bearing capacity of soils for foundations, dams, etc. are dependent on the undrained shear strength Cu. Hence, the results from this investigation can be used to definitively say whether the tropical soils found in the study area could be used for certain applications or not. The governing factors for a high unconfined compression strength are sesquioxide strengths, moisture content, particle size constituents, and plasticity.

4.2.3 California Bearing Ratio (CBR)

The California Bearing Ratio tests were carried out following the procedures mentioned in AASHTO T193-99. The specimens were soaked in water for 96 hours with a surcharge weight of about 5.54 kg.

CBR tests using the AASHTO T 193-99 test method were performed using the maximum dry densities and optimum moisture contents obtained from modified proctor compaction tests. The CBR tests are done at the exact moisture content recorded at the time of compaction to consider the influence of moisture content on CBR test results.

Table 4.15 CBR test results and their corresponding swell values

Sample location (Km)	Depth	Sample designation	OMC (%)	MDD	No. of blows	CBR (%)	CBR swell (%)
0.0-4.0	0.6	A-1	24.3	1.487	10	1.63	5.89
					30	2.45	5.0
					65	3.06	4.86
	1.5	A-2	23.83	1.529	10	0.2	12.5
					30	1.02	11.53
					65	1.84	10.27
4.0-8.0	0.6	B-1	17.0	1.656	10	1.04	9.49
					30	2.04	8.71
					65	2.25	7.36
	1.5	B-2	15.85	1.698	10	2.45	5.2
					30	3.47	8.98
					65	3.88	10.41

8.0-12.0	0.6	C-1	20.7	1.51	10	4.12	2.58
					30	7.26	1.96
					65	8.58	1.64
	1.5	C-2	18.55	1.595	10	4.08	2.15
					30	9.19	1.89
					65	10.41	1.49
12.0-16.0	0.6	D-1	21.8	1.498	10	0.61	12.88
					30	2.04	12.07
					65	2.65	11.26
	1.5	D-2	19.0	1.595	10	0.41	11.55
					30	1.02	10.80
					65	1.84	9.34
16.0-21.2	0.6	E-1	22.9	1.515	10	0.41	16.1
					30	0.82	14.93
					65	1.22	14.36
	1.5	E-2	18.8	1.542	10	0.82	14.56
					30	1.22	14.02
					65	1.63	13.54

CBR can be described as the strength of soil relative to crushed rock. The standard loads used in determining CBR of laterite soils are said to have a CBR value of 100% which is obtained from tests done on crushed stones. The CBR value at 2.5mm penetration is generally taken as the norm as long as CBR at 5mm is lower in comparison. Since this test is a penetration test, the deformation happens due to shear and hence the CBR is an alternative measurement of shear force. However, this test is most appropriate for the purpose for which it was developed which is the thickness of the highway base.

Comparing CBR at 10 blows, 30 blow, 65 blows prevailed similar argument made regarding grain breakage. Generally, increment of bearing ratio as the applied number of blows increases is related to increase in densification but the rate of increase as blows progressed from 10 to 30 and 65 gives some idea about grain breakage hence CBR increases rapidly as the blow increase from 10 to 30 but after 30 blows, when blows increased to 65, rate of CBR increment is not as much as in lower blows. This is due to grain breakage caused by compaction effort that aggravated after 30 blows whereas this grain breakage effect is not highly affected CBR increment in B-2 and C-2. This is due to the degree of lateralization is higher in C-2.

The lowest swell (1.49%) was observed as the sample compacted using field density and natural moisture content. This arisen from its high natural water content and separated air voids or the existence of almost neared to zero air voids in its in-situ condition. And its CBR was the highest among all testing treatments (10.41%). The maximum swell recorded was 16.1% due to highly availed interconnected voids.

In general, if the CBR value is less than 5, it is not suitable for subgrade use. For use as sub-base material, the CBR has to be more than 30%, which for the tropical soils in the study area is not. Base material requires CBR to be even higher. Zelalem (1995) reports that the lower CBR is attributed to the sesquioxide bonds of laterite soils being weak leading up to low cementation between soil particles. Overall, the tropical soil of the study area can be concluded as having a low CBR value and inadequate as road construction material by itself.

Table 4.16 determination of density moisture and CBR of sample B-1

CALIFORNIA BEARING RATIO TEST

TEST MATHOD : AASHTO T-193

SAMPLING STATION	Km 4-8+000km	SAMPLE TAKE FROM	OGL
REPRESENTED SECTION	Km 4-8+000km	DATE SAMPLED	5/2/2021
MATERIAL DESCRIPTION	Dark Brown clay	DATE AND TIME SOAKED	21/02/2021
PUROPSE	sub-grade	DATE AND TIME TESTED	25/02/2021
DEPTH	60 cm	Lab NO	0

D E N S I T Y D E T E R M I N A T I O N

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
MOLD NUMBER	D		E		F	
WEIGHT OF SOIL + MOLD g	10314	10811	10739	11216	10860	11232
WEIGHT OF MOLD g	6716	6716	6735	6735	6714	6714
WEIGHT OF SOIL g	3598	4095	4004	4481	4146	4518
VOLUME OF MOLD g/cc	2124	2124	2124	2124	2124	2124
WET DENSITY OF SOIL g/cc	1.694	1.928	1.885	2.110	1.952	2.127
DRY DENSITY OF SOIL g/cc	1.45	1.45	1.61	1.63	1.66	1.63

M O I S T U R E D E T E R M I N A T I O N

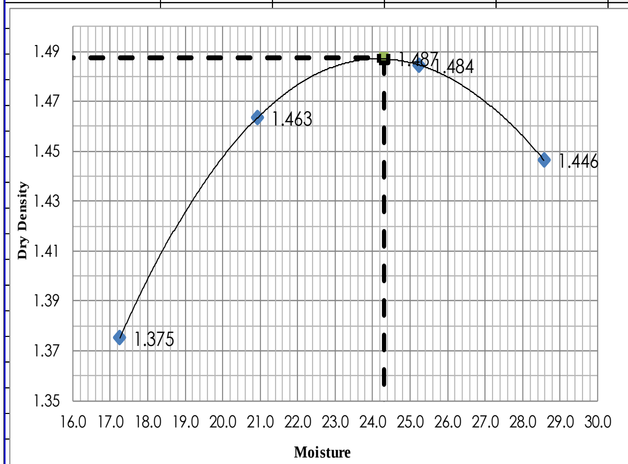
SOAKING CONDITION	10 Blows			30 Blows			65 Blows		
	BEFORE	AFTER	AVG.	BEFORE	AFTER	AVG.	BEFORE	AFTER	AVG.
CONTAINER NUMBER	A7	B6		C3	C		B10	A2	
WET SOIL + CONTAINER g	465.0	425.0		448.0	446.0		426.0	434.0	
DRY SOIL + CONTAINER g	409.0	338.00		394.0	363.0		375.0	352.00	
WEIGHT OF WATER g	56.0	87.0		54.0	83.0		51.0	82.0	
WEIGHT OF CONTAINER g	80.0	76.0		81.0	80.0		80.0	81.0	
WEIGHT OF DRY SOIL g	329.0	262.0		313.0	283.0		295.0	271.0	
MOISTURE CONTENT %	17.02	33.21		17.25	29.33		17.29	30.26	

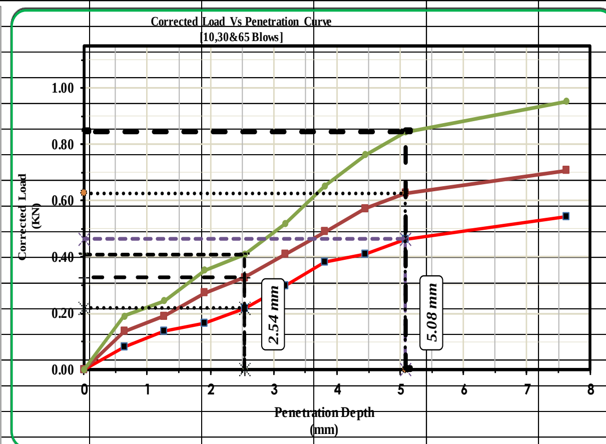
P E N E T R A T I O N T E S T D A T A

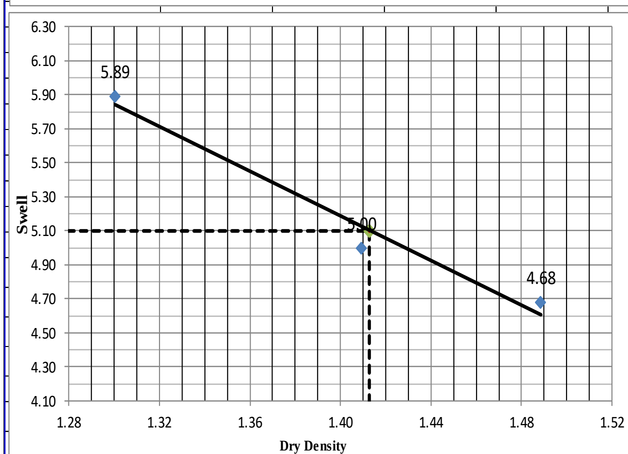
PENETRATION (mm)	10 Blows				30 Blows				65 Blows			
	DIAL RDG	LOAD (kn)	COR. LOAD(kn)	CBR %	DIAL RDG	LOAD (kn)	COR. LOAD (kn)	CBR %	DIAL RDG	LOAD (kn)	COR LOAD (kn)	CBR %
0	0	0	0		0	0	0		0	0	0	
0.64	0.2	0.054	0.05		0.2	0.054	0.05		0.4	0.109	0.109	
1.27	0.7	0.191	0.19		0.4	0.109	0.109		0.5	0.136	0.136	
1.91	0.9	0.245	0.25		0.7	0.191	0.191		0.8	0.218	0.218	
2.54	1.0	0.272	0.27	2.04	1.0	0.272	0.272	2.04	1.0	0.272	0.272	2.04
3.18	1.1	0.300	0.30		1.1	0.300	0.300		1.1	0.300	0.300	
3.81	1.1	0.300	0.30		1.1	0.300	0.300		1.2	0.327	0.327	
4.45	1.2	0.327	0.33		1.2	0.327	0.327		1.3	0.354	0.354	
5.08	1.3	0.354	0.35	1.78	1.3	0.354	0.354	1.78	1.5	0.409	0.409	2.05
7.62	1.4	0.381	0.38		1.3	0.354	0.354		1.6	0.436	0.436	

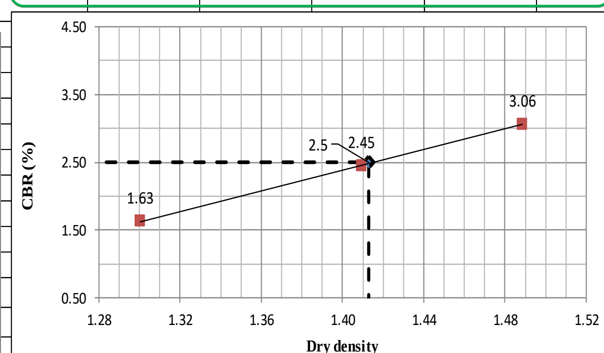
Height of Specimen(mm)		116.43	
No.OF BLOWS	10	30	65
RDG (BEFORE SOAKING)	0.00	0.00	0.00
RDG(AFTER SOAKING)	11.05	10.14	8.57
PERCENT SWELL	9.49	8.71	7.36
AVERAGE PERCENT SWELL		8.52	

3-Point California Bearing Ratio (CBR) AASHTO :T193			
Representative Section	KM 0-4+000KM	**Lab Job No**	
Sampled Station	KM 0-4+000KM	**Date and Time Soaked**	24/02/2021
Material Type	Sub grade	**Date and Time Penetrated**	28/02/2020
Material Description	Brown Silty clay soil	**Test Run No**	1
Sampled From	OGL	**Water to Be Added**	592 ml
Date Sampled	5/2/2021	**Surcharge Type and Weight**	Slotted and 4.54 Kg
Depth 0.6m			









MDD (gm/cm3)	**1.487**
OMC (%)	**24.30**
95 % of MDD	**1.413**
CBR VAUE 95% MDD	**2.50**
SWELL % at 95% MDD	**5.10**

CBR Calculations and Results from the Penetration Data

No of Blows Per Layer	Corrected Load (KN) @		CBR (%) @		CBR Reported	Swell %		From CBR Data		
	2.54 mm	5.08 mm	2.54 mm	5.08 mm		10 Blows	5.89	Blow	CBR-Dry Density (Remolded)	CBR%
10 Blows	0.22	0.46	1.63	2.32		30 Blows	5.00	10	1.30	1.63
30 Blows	0.33	0.63	2.45	3.13	2.50	65 Blows	4.68	30	1.41	2.45
65 Blows	0.41	0.84	3.06	4.22		Avg	5.19	65	1.49	3.06

Figure 4.10 Three-point CBR test result graphs of sample A-1 obtained by using four days-soaked air-dried sample treatments.

4.3 Geochemical Test

Determination of major and minor oxides undertaken by Ethiopian geological survey, geochemical laboratory. Which is a very busy laboratory. The laboratory was unable to execute x-ray diffraction due to equipment failure, hence the laboratory unable to identify clay minerals. Using analysis of Atomic absorption spectrometer, Gravimetric, Colorimetric, LiBO2 fusion, AAS, and florid attack (complete silicate analysis) all oxides were determined. The outcomes are shown in the table below.

The degree of lateralization of soil samples can be evaluated based on the ratio of silica (SiO_2) to sesquioxide ratio (Alumina (Al_2O_3) and Iron oxide (Fe_2O_3). Based on the ratio un-lateritic soils have a silica to sesquioxide ratio greater than 2.0. For lateritic soils, the ratio lies between 1.3 and 2.0 and for true laterites, the ratio is less than 1.

Table 4.17 oxide composition in percent

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_3O_5	TiO_2	H_2O	LOI	$(SiO_2)/(Fe_2O_3 + Al_2O_3)$	**Remark**
A-1	47.0	22.4	10.2	3.68	1.24	2.12	1.48	0.48	<0.1	0.69	3.93	8.41	1.441	**lateritic**
A-2	50.01	19.38	13.68	1.08	1.64	0.44	0.52	0.36	0.20	0.86	2.51	8.64	1.513	**lateritic**
B-1	51.2	18.72	11.68	1.28	2.0	0.56	<0.1	0.52	<0.1	0.58	5.64	8.86	1.684	**lateritic**
B-2	49.16	19.38	11.40	1.96	2.60	0.76	<0.1	0.52	0.1	0.49	5.21	7.65	1.597	**lateritic**
C-1	51.26	17.2	12.56	<0.1	1.24	<0.1	<0.1	0.16	<0.1	0.69	6.56	10.76	1.722	**lateritic**
C-2	44.06	22.66	12.92	1.64	2.32	0.8	0.48	0.16	<0.1	0.72	6.14	8.39	1.238	**laterite**
D-1	47.94	22.0	8.76	2.32	1.92	1.2	0.52	0.6	0.1	0.73	5.59	9.04	1.559	**lateritic**
D-2	57.14	13.46	12.24	0.74	2.22	0.16	<0.1	0.2	0.1	0.78	5.01	8.51	2.223	**Un-lateritic**
E-1	52.04	11.08	22.08	0.1	0.48	0.72	<0.1	0.28	<0.1	1.18	3.81	9.12	1.569	**lateritic**
E-2	51.66	13.51	13.36	3.72	2.56	0.70	<0.1	0.16	0.26	0.98	3.73	8.74	1.923	**lateritic**

Based on the results using the silica-sesquioxide ratio all the test samples except samples C-2 and D-2 are lateritic. Soil samples C-2 and D-2 are laterites and un lateritic soils respectively.

With increasing in-depth, the geological nature of the soil in test Pit C and D is variable. The sample at a depth of 0.6m and 1.5m have different geological formations. Thus, it is not possible to compare the lateralization of these soils.

4.4 Implications for Road Construction Material

The new (ERA, 2013) Standard Technical Specifications and Method of Measurement for Road Works defines the following limiting standard requirements. To use lateritic as a sub-base;
CBR>30%
PI < 25%
Plasticity Modulus less than or equal to 500

The requirements to be subgrade, embankment material, and lateritic as a sub-base are described in table 4.18 below with the material properties of soil from test pit C-1 and C-2 alongside.

After evaluating the soil sample properties, soils from test pit A, B, D, and E cannot be used for earthworks without further treatments/stabilizations. Soil from test pit C-1 and C-2 satisfies to be subgrade or embankment material; while soil from test pit C-1 and C-2 does not satisfy the requirement to use lateritic as sub-base.

AASHTO classification categorizes the soil from test pit C as good sub-grade materials while soil from other test pit is very poor to be subgrade materials.

Table 4.18 ERA-2013 Material Requirements

Material property	Requirement as sub-grade or embankment material	The requirement to be used as a sub-base material	Properties of soil from test pit C-1	Properties of soil from test pit C-2
Particle size	Maxi. 150mm		Maxi. 75mm	Max.75
CBR (%)	≥5%	≥30%	8.58	10.41
Swell	≤2%		1.64	1.49
LL	≤60		42.5	42
PI	≤30	≤25	13.62	13.12
MDD	≥95%MDD	-	-	-
Remark	Soil from test sample C-1 and C-2 satisfies ONLY to be subgrade or embankment material			

4.5 Comparison with Previous Researchers

Table 4.19 Tropical soils of Ethiopian in comparison to the current study

Researcher	Morin & parry (1971)	H/marim (1992)	Fasil Abegna (2003)	Zelalem (2005)	Fekede Wakuma (2007)	Hanna (2008)	Eyasu Minichle (2015)	Berhane (2017)	Current study
Location	Ethiopia	Addis Ababa	Bahir Dar	Nejo-Mendi	Assosa	Welayta Soda	Merawi	SNNPR	Bahir Dar
Soil type	Red clay	Red clay	Red clay	Lateritic	Lateritic	Lateritic	Lateritic	Red clay	Lateritic
Clay content	34-76	48-73	74-82	2-20.6	2.5-60	48-69.7	63.6-91.3	35.4-44.5	26.2-43.6
LL (%)	44-66	54-81	61-68	48-67	41-72	48-71	53-68.3	52-70	42.0-86.3
PI (%)	14-30	21-30	24-30	17-27	20-48	19-30	28.6-39.8	16-25	13.12-49.7
Free well (%)	-	0-40	-	20-40	0-45	28-38	-	17.5-27.5	20-70
G_s (g/cc)	2.61-2.9	2.61-2.79	2.75-2.83	2.78-3.03	2.19-2.94	2.61-2.97	2.7-2.76	2.69-2.83	1.75-2.69
Qu (KN/m^2)	146.5-251	49-250	147-220	165-553	-	215-385	63.7-117.8	63-118	40.42-146.26
CBR (%)	-	-	-	22-79	-	-	-	-	1.22-10.41

The average OMC and MDD of the current study are 20.58% and 1.563 g/cc respectively, which shows MDD and OMC slight decreased from Nejo-Mendi lateritic soil (Zelalem 2005) which are 24.9% and 1.613.

Laterites and Lateritic soils of Africa were studied by Morin W.J. and Todor P.C. (Lyon, 1971). The characteristics and mineral content of the soil samples taken from Ethiopia were classified as Ferrisol. For the soil under investigation; Index property was studied and a comparison was made with known laterites and lateritic soils of Africa.

Tables 4.20 show that the average values of the various properties, i.e., liquid limit, plasticity index, compaction, and CBR, indicate that the Ferrisol represents distinct soil groups with a characteristic range of properties of the subgroup of African laterite and lateritic soils.

Ferrisol soils occur in regions of between 1250 and 2750mm rainfall per year, The soil under investigation falls in this range of annual rainfall according to Figure 3.1. Comparison of the gradation, compaction values, and Atterberg Limits values of the soil under investigation are similar to Ferrisol soils of Ethiopia previously determined.

Table 4.20 Typical Soil Test Results for Ferrisol Soils (Lyon, 1971)

Country	LL (%)	PL (%)	PI (%)	AASHTO	GI	OMC	MDD	CBR
Ghana	53	34	19	A-7-5	3	17	1.745	45
Niger	28	16	12	A-2-6	0	-	-	-
Ivory cost	48	24	24	A-7-6	18	17	1.729	12
Mali	55	31	24	A-7-5	3	15	1.886	9
Uganda	46	21	25	A-2-7	0	14	1.894	16
Kenya	-	-	-	A-7-5	27	-	-	-
Cameron	65	37	27	A-7-5	19	-	-	-
Ethiopia	68	33	35	A-7-5	19	28	1.509	12

CONCLUSION AND RECOMMENDATION

Depending on test results and comparative study, the following conclusions and recommendations are drawn.

Conclusion

- ✓ Geochemical test using complete silicate analysis ascertained all soils along Bahir Dar-Tis Esat road project is lateritic soil, except sample C-2 and D-2 which are laterite and un-lateritic soils respectively.
- ✓ The specific gravity test results are ranging from 1.75 to 2.69. the slightly high specific gravity is a result of a medium accumulation of heavy minerals like iron and aluminum in different forms. And also, low specific gravity observed on most samples, indicating highly leached porous soil grains.
- ✓ According to free swell test results, all the soil samples except C-1 and C-2 are expansive soils that are susceptible to volume change, while C-1 and C-2 are non-expansive.
- ✓ The strength parameters which were obtained from the UCS test q_u ranges from 40.2 to 146.26Kpa.
- ✓ The CBR values are low with such high plasticity and fine-grained size. This is attributed to the sesquioxide bonds of lateritic soils being weak leading up to low cementation between soil particles.
- ✓ By considering the Atterberg limit and USCS plasticity chart, soil samples of A-1, A-2, B-1, D-1, D-2, E-1, and E-2 are highly plastic with LL > 50%, from which A-1, A-2, B-1, D-1, and E-2 are fat clay (CH) with PI values located above A-line whereas D-2 and E-2 are Elastic silt (MH) with PI value located below A-line. On the other hand, soil samples of B-2, C-1, and C-2 are coarse-grained gravel soil, from which C-1 and C-2 are silty gravel (GM) located below A-line. And B-2 is clayey gravel (GC) which is located above A-line.
- ✓ AASHTO classification system categorizes the soil from test samples A-2, B-1, C-2, D-2, E-1, and E-2 under A-7-5 with group index >7 while the soil from test sample A-1, B-2, C-1, and D-1 categorized under A-7-6.
- ✓ The Moisture-Density relationship of the soil was determined by the modified proctor test. When compacted at the modified proctor test's optimal moisture level, they produce a

moderate dry density. The investigated sample's maximum dry density (MDD) value is 1.698, whereas sample B-2's optimum moisture content (OMC) value is 15.85. The discrepancy in the compaction test results may be due to the different degrees of weathering profiles in the soil.

- ✓ The soaked CBR values, swell percent of CBR, LL, and PI values of all soil samples except C-1 and C-2 under the material requirement of ERA-2013 implicates these soils cannot be used for subgrade or embankment and sub-base materials, whereas test samples C-1 and C-2 satisfies only to be sub-grade or embankment material.

Recommendations

- ✓ The identified sections of expansive soils should be excavated to the required depth in line with ERA Standard Technical Specification, 2013, Section 4106, and replace with suitable fill material with a minimum CBR of 5% at 95% of MDD (AASHTO 180).
- ✓ In addition, for unsuitable subgrade sections, which have high expansiveness potential, according to ERA Geotechnical Design Manual-2013, section 2.3.1.4, one of the proposed treatment options for expansive soil sections is Loading expansive soils with stress greater than the swelling pressure is also a way of preventing swelling.
- ✓ All the study area soils except test pit C (sample C-1 and C-2) have higher values of LL and PI which is higher than the specification seated to use in road sub-grade and sub-base materials so, further studies have to be carried out on the influence of the higher PI on the performance and durability of these materials in the practical assessment.
- ✓ The maximum sampling depth of the soil under investigation is 1.5m. detailed investigations have to be made along with more samples of profiles.
- ✓ Continuous and extensive studies have to be done to investigate the variable properties of tropical soils. Besides, within a country or geological origin with the same parent rock, guidelines and manuals have to be prepared for the investigation and classification of such tropical soils.
- ✓ In the present study, an attempt has been done to determine the average physical and Chemical properties of tropical soils in Bahir Dar. However, due to the lack of a well-organized geotechnical database, not all available historical geotechnical data were compiled to produce the soil thickness map.
- ✓ A detailed study on the mineral composition through XRF/XRD test and bearing capacity of tropical soil are essential as it is part of the engineering geology study and it is advised to have a further study on this.

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APPENDIX

Appendix-1 Atterberg Limit Test Result

REPRESENT SECTION	Km 0-4+000km	SAMPLE TAKEN FROM	OGL
SAMPLING STATION	Km 0-4+000km	DATE SAMPLED	5/2/2021
VISUAL DESCRIPTION	black cotton soil	DATE TESTED	16/2/2021
PURPOSE	subgrade	SAMPLE Depth	1.5m

	LIQUID LIMIT			PLASTIC LIMIT	
Tare Number	T	K	E	H	K
No of Blows	30	24	18	-	-
A. Weight of Wet Soil + Tare	35.51	40.36	40.77	26.43	27.37
B. Weight of Dry Soil + Tare	30.32	33.06	33.45	25.48	26.20
C. Weight of Water (A – B)	5.19	7.30	7.32	0.95	1.17
D. Weight of Tare	21.91	21.58	22.38	22.32	22.38
E. Weight of Dry Soil (B -D)	8.41	11.48	11.07	3.16	3.82
Water Content % (C / E x 100)	61.71	63.59	66.12	30.06	30.63
Avearage Moisture Content %	63.81			Average	30.3

Liquid Limit	63.4
Plastic Limit	30.3
Plasticity Index	33.1
Classification	A-7-5(39)

Soil Grading For Classification

Sieve	mass	% ret	% Pass
4.750	1.1	0.22	99.78
2.0	3	0.61	99.16
0.425	2.63	0.54	98.63
0.075	1.45	0.30	98.33
After wash	481.8		
Befor Wash	490		

AASHTO Classification (M145-91)

ASTM SIEVE No.	10	40	200
Sieve Size (mm)	2.00	0.425	0.075
% Passing	99.16	98.63	98.33

A-7-5(39)

APPENDIX-2 MODIFIED PROCTOR TEST

MOISTURE DENSITY RELATIONSHIP OF SOIL

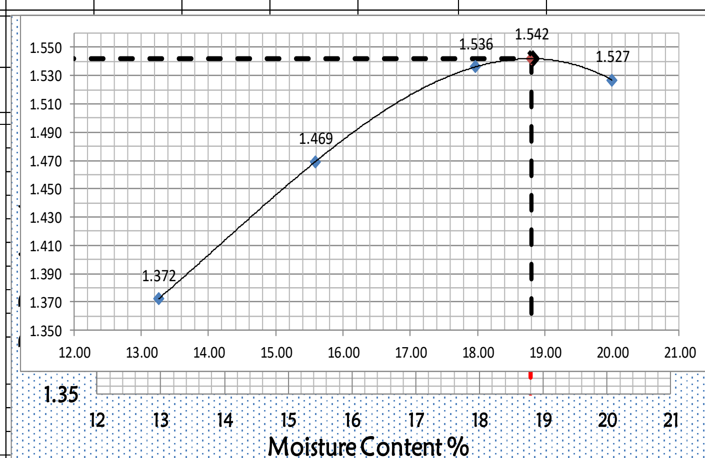
TEST METHOD : AASHTO T-180 METHOD D

SOURCE LOCATION	Km 16-21+200km	SAMPLE TAKE FROM	OGL
REPRESENTING SECTION	Km 16-21+200km	DATE SAMPLED	5/2/2021
MATERIAL DESCRIBTION	Dark brown Clay soil	DATE TESTED	20/2/2021
PURPOSE	Sub grade	Lab No:-	Sub grade 001/2020
		DEPTH	1.5M

		1	2	3	4	5	6	NMC
DENSITY	TRIAL NUMBER	1	2	3	4	5	6	
	WEIGHT OF SAMPLE (g)	5000	5000	5000	5000			
	WATER ADDED (%)	2	4	6	8			
	WEIGHT OF SOIL + MOLD(g)	8,617	8,923	9,165	9,208			
	WEIGHT OF MOLD (g)	5316	5316	5316	5316			
	WEIGHT OF SOIL (g)	3301	3607	3849	3892			
	Volume of mold cc	2124	2124	2124	2124			
	Wet Density of soil g/cc	1.554	1.698	1.812	1.832			
MOISTURE	CONTAINER NUMBER	B	A6	A7	A8			A5
	WET SOIL + CONTAINER (g)	381.0	381.0	379.0	382.0			378.0
	DRY SOIL + CONTAINER (g)	346.0	340.0	333.0	331.0			352.0
	WEIGHT OF WATER (g)	35.0	41.0	46.0	51.0			26.0
	WEIGHT OF CONTAINER (g)	82.0	77.0	77.0	76.0			81.0
	WEIGHT OF DRY SOIL (g)	264.00	263.00	256.00	255.00			271.00
	MOISTURE CONTENT (%)	13.26	15.59	17.97	20.00			9.59
DRY DENSITY OF SOIL (g/cc)		1.372	1.469	1.536	1.527			

MDD(g/cc):-	1.542
OMC (%) :-	18.80

REMARK:-



APPENDIX-3 CBR TEST RESULTS AND GRAPH

3-Point California Bearing Ratio (CBR) AASHTO :T193 [ASTM :D1883] Observation Sheet				
Representative Section	Km 8-12+000km	Lab.No.		
Sampled Station	Km 8-12+000km	Date and Time Soaked	03-Mar-21	
Purpose	Borrow	Date and Time Penetrated	7/3/2021	
Material Description	Brown Silty Clay Soil with gravel	Test Run No	1	
Sampled From	OGL	Water to Be Added	613	ml
Date Sampled	5/2/2021	Surcharge Type and Weight	Slotted and 4.54 Kg	
Depth	1.5m	Rammer Weight	4.536 Kg	

CBR-Dry Density Determination

SOAKING CONDITION		10 Blows		30 Blows		65 Blows	
		BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
MOLD NUMBER		F	F	A	A	E	E
WEIGHT OF SOIL + MOLD	(g)	10425	10753	10652	11021	10875	11090
WEIGHT OF MOLD	(g)	6718	6718	6657	6657	6707	6707
VOLUME OF MOLD	(Cm^3)	2124.0	2124.0	2124.0	2124.0	2124.0	2124.0
WEIGHT OF WET SOIL	(g)	3707	4035	3995	4364	4168	4383
WET DENSITY OF SOIL	(g/cm3)	1.75	1.90	1.88	2.05	1.96	2.06
DRY DENSITY OF SOIL	(g/cm3)	1.43	1.38	1.54	1.52	1.62	1.57

CBR-M O I S T U R E D E T E R M I N A T I O N

SOAKING CONDITION	10 Blows		30 Blows		65 Blows	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
CONTAINER NUMBER	B5	B10	B8	C3	B1	C4
WET SOIL + CONTAINER (g	388.0	385.0	393.0	397.0	382.0	384
DRY SOIL + CONTAINER (g	333.0	301.0	336.0	315.0	329.0	310
WEIGHT OF CONTAINER (g	82.0	80.0	82.0	80.0	77.0	76
WEIGHT OF WATER (g	55.0	84.0	57.0	82.0	53.0	74.0
WEIGHT OF DRY SOIL (g)	251.0	221.0	254.0	235.0	252.0	234.0
MOISTURE CONTENT (%	21.91	38.01	22.44	34.89	21.03	31.62

1	Check List for DD Relation@ 10,30 and 65 blows	Dry Density Relation-Acceptable
		Dry Density Relation-Acceptable
	Check List for DD@65 Blows with MDD Relation	OK

PLUNGER PENETRATION in mm	10 Blows			30 Blows			65 Blows		
	PROVING RING DIAL RDG	COR. LOAD ON PLUNGER(KN)	CBR %	PROVING RING DIAL RDG	COR. LOAD ON PLUNGER (KN)	CBR %	PROVING RING DIAL RDG	COR. LOAD ON PLUNGER (KN)	CBR %
0	0	0.00		0	0.00		0	0	
0.64	1.0	0.27		1.5	0.41		1.7	0.46	
1.27	1.3	0.35		2.6	0.71		2.9	0.79	
1.91	1.5	0.41		3.7	1.01		4.2	1.14	
2.54	2.0	0.54	4.08	4.5	1.23	9.19	5.1	1.39	10.41
3.18	2.2	0.60		5.0	1.36		5.6	1.53	
3.81	2.4	0.65		5.5	1.50		6.3	1.72	
4.45	2.5	0.68		5.8	1.58		6.6	1.80	
5.08	2.6	0.71	3.54	6.0	1.63	8.17	6.9	1.88	9.40
7.62	2.9	0.79		6.5	1.77		7.4	2.02	

.

No. OF BLOWS	10	30	65
RDG (BEFORE SOAKING) (mm)	0.00	0.00	0.10
RDG (AFTER) SOAKING) (mm)	2.50	2.20	1.84
Height of Spcimen (mm)	116.4		
PERCENT SWELL	2.15	1.89	1.49
AVERAGE SWELL (%)	1.84		

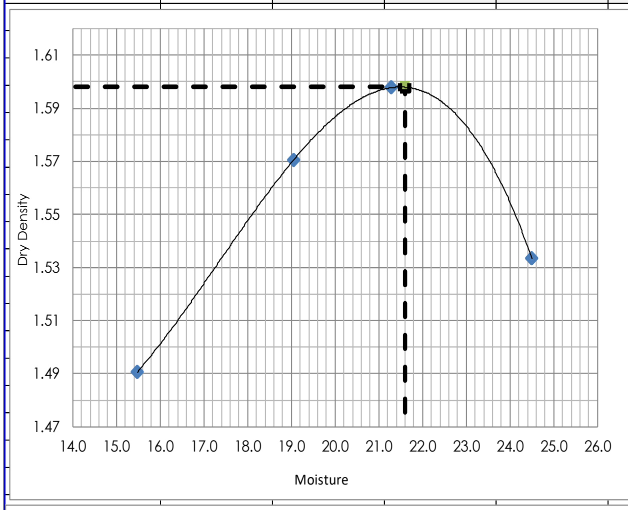
Proving Ring Factor	
272.38	N/Div

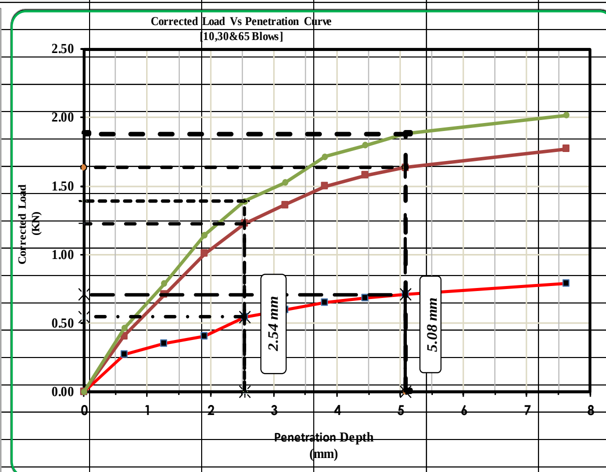
Modified Proctor MDD (gm/cm^3)	*1.598*
Modified Proctor OMC (%)	*21.6*
CBR @ 95 % Modified MDD (%)	*7.51*
Swell @ 95 % Modified MDD (%)	*1.87*

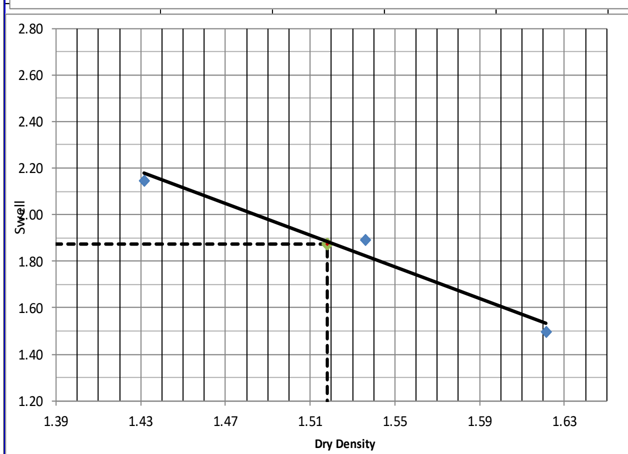
/

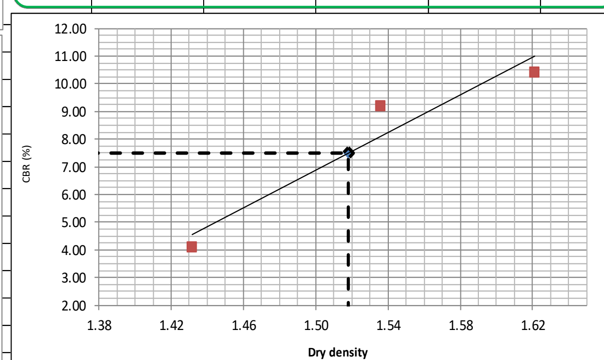
3-Point California Bearing Ratio (CBR) AASHTO :T193

Representative Section	**Km 8-12+000km**	**Lab Job No**	
Sampled Station	**Km 8-12+000km**	**Date and Time Soaked**	**7/25/2020**
Material Type	**Sub grade**	**Date and Time Penetrated**	**1/1/1900**
Material Description	**Brown Silty Clay Soil with gravel**	**Test Run No**	**1**
Sampled From	**OGL**	**Water to Be Added**	
Date Sampled	**5/2/2021**	**Surcharge Type and Weight**	**Slotted and 4.54 Kg**
		Rammer Weight	**4.536 Kg**









MDD (gm/cm3)	**1.598**
OMC (%)	**25.20**
95 % of MDD	***1.518***
CBR VAUE 95% MDD	***7.51***
SWELL % at 95% MDD	***1.87***

CBR Calculations and Results from the Penetration Data

No of Blows Per Layer	Corrected Load (KN) @ 2.54 mm	Corrected Load (KN) @ 5.08 mm	CBR (%) @ 2.54 mm	CBR (%) @ 5.08 mm	CBR Reported	Swell %		From CBR Data: Blow	CBR-Dry Density (Remolded)	CBR%
						10 Blows	2.15			
10 Blows	0.54	0.71	4.08	3.54		*30 Blows*	1.89	*10*	1.43	4.08
30 Blows	1.23	1.63	9.19	8.17	7.51	*65 Blows*	1.49	*30*	1.54	9.19
65 Blows	1.39	1.88	10.41	9.40		*Avg*	1.84	*65*	1.62	10.41

Appendix-4 Geochemical test (Complete silicate Analysis) and specific gravity test result from Geological Survey of Ethiopia

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Issue Date: -05/04/2021

Customer Name:-Mohammed Yesuf

Request No:- GLD/RQ/790/21

Report No:- GLD/RN/328/21

Sample type :- Soil

Sample Preparation: - 200 Mesh

Date Submitted :-17/03/2021

Number of Sample:- Ten (10)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
A-1	47.00	22.4	10.20	3.68	1.24	2.12	1.48	0.48	<0.01	0.69	3.93	8.41
A-2	50.01	19.38	13.68	1.08	1.64	0.44	0.52	0.36	0.20	0.86	2.51	8.64
B-1	51.20	18.72	11.68	1.28	2.00	0.56	<0.01	0.52	<0.01	0.58	5.64	8.86
B-2	49.16	19.38	11.40	1.96	2.60	0.76	<0.01	0.52	0.09	0.49	5.21	7.65
C-1	51.26	17.2	12.56	<0.01	1.24	<0.01	<0.01	0.16	<0.01	0.69	6.56	10.76
C-2	44.06	22.66	12.92	1.64	2.32	0.80	0.48	0.16	<0.01	0.72	6.14	8.39
D-1	47.94	22.00	8.76	2.32	1.92	1.20	0.52	0.60	0.09	0.73	5.59	9.04
D-2	57.14	13.46	12.24	0.74	2.22	0.16	<0.01	0.20	0.06	0.78	5.01	8.51
E-1	52.04	11.08	22.08	0.08	0.48	0.72	<0.01	0.28	0.01	1.18	3.81	9.12
E-2	51.66	13.51	13.36	3.72	2.56	0.70	<0.01	0.16	0.26	0.98	3.73	8.74

Note: - This result represent only for the sample submitted to the laboratory.

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw			
Nigist Fikadu	Tizita Zemene	Yohannes Getachew	Gosa Haile

Geological Survey of Ethiopia Central Geological Laboratory

Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy and Geotechnical Laboratory | **Lab section: - Mineralogy** [ ] | **Physical** [x]

Client /Originator Name: - Mohammed Yesuf

Client Category: - Survey [ ] **Gov.** [ ] **Pvt.** [x]

File name: - 0870/21 PVT | **Area Ref: - Bahir Dar** | **No of Samples: - 10** | **Sample No.**

Sample Type: - Soil | **Lab No: -**

Type of Analysis: - Specific gravity | **Preparation required: -** | **Date Submitted: - 07/07/13 E.C**

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
A-1	0870/21	60/60	29.2975	79.064	1 g/cm³	38.8962	9.5987	83.9336	4.7291	2.02	2.02
		56/56	27.6979	77.8773	1 g/cm³	36.5651	8.8672	82.3629	4.3816	2.02	
A-2	0871/21	1/1	28.4496	78.4642	1 g/cm³	36.9012	8.4516	83.3012	3.6146	2.33	2.29
		52/52	28.5978	78.5256	1 g/cm³	37.1581	8.5603	83.3089	3.777	2.26	
B-1	0872/21	51/51	28.639	78.585	1 g/cm³	37.5013	8.8623	83.6687	3.7786	2.34	2.35
		20/20	27.7637	77.8153	1 g/cm³	36.4313	8.6676	82.8139	3.669	2.36	

Described By / Analysts: - Aregahagn Kefelegn | **Checked by: -** Girma Asemu | **Date Completed: - 30/03/21**

Misikir Zewdu

Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy and Geotechnical Laboratory | **Lab section: - Mineralogy** [ ] | **Physical** [x]

Client /Originator Name: - Mohammed Yesuf

Client Category: - Survey [ ] **Gov.** [ ] **Pvt.** [x]

File name: - 0870/21 PVT | **Area Ref: - Bahir Dar** | **No of Samples: - 10** | **Sample No.**

Sample Type: - Soil | **Lab No: -**

Type of Analysis: - Specific gravity | **Preparation required: -** | **Date Submitted: - 07/07/13 E.C**

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
B-2	0873/21	60/60	29.2975	79.064	1 g/cm³	38.6875	9.39	84.6213	3.8327	2.45	2.47
		56/56	27.6979	77.8773	1 g/cm³	36.1568	8.4589	82.9481	3.3881	2.49	
C-1	0874/21	1/1	28.4496	78.4642	1 g/cm³	36.8803	8.4307	83.3697	3.5252	2.39	2.37
		52/52	28.5978	78.5256	1 g/cm³	37.2508	8.653	83.5122	3.6664	2.36	
C-2	0875/21	51/51	28.639	78.585	1 g/cm³	36.5683	7.9293	83.1014	3.4129	2.32	2.34
		20/20	27.7637	77.8153	1 g/cm³	35.4885	7.7248	82.2783	3.2618	2.36	

Described By / Analysts: - Aregahagn Kefelegn | **Checked by: -** Girma Asemu | **Date Completed: - 30/03/21**

Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy and Geotechnical Laboratory **Lab section: - Mineralogy** ☐ **Physical** ☒
Client /Originator Name: - Mohammed Yesuf
Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☒
File name: - 0870/21 PVT **Area Ref: - Bahir Dar** **No of Samples: - 10** **Sample No.**
Sample Type: - Soil **Lab No: -**
Type of Analysis: - Specific gravity **Preparation required: -** **Date Submitted: - 07/07/13 E.C**

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
D-1	0876/21	60/60	29.2975	79.064	1 g/cm³	39.2009	9.9034	84.1052	4.8622	2.03	2.07
		29/29	28.2451	78.1815	1 g/cm³	37.404	9.1589	83.027	4.3134	2.12	
D-2	0877/21	1/1	28.4496	78.4642	1 g/cm³	38.4342	9.9846	82.7091	5.7397	1.73	1.75
		52/52	28.5978	78.5256	1 g/cm³	37.4162	8.8184	82.4093	4.9347	1.78	
E-1	0878/21	51/51	28.639	78.585	1 g/cm³	37.3112	8.6722	84.053	3.2042	2.70	2.69
		24/24	28.1297	78.1358	1 g/cm³	36.6964	8.5667	83.5187	3.1838	2.69	

Described By / Analysts: - **Checked by: -** **Date Completed: - 30/03/21**
Aregahagn Kefelegn **Girma Asemu**

Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy and Geotechnical Laboratory **Lab section: - Mineralogy** ☐ **Physical** ☒
Client /Originator Name: - Mohammed Yesuf
Client Category: - Survey ☐ **Gov.** ☐ **Pvt.** ☒
File name: - 0870/21 PVT **Area Ref: - Bahir Dar** **No of Samples: - 10** **Sample No.**
Sample Type: - Soil **Lab No: -**
Type of Analysis: - Specific gravity **Preparation required: -** **Date Submitted: - 07/07/13 E.C**

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
E-2	0879/21	60/60	29.2975	79.064	1 g/cm³	38.9115	9.614	83.9819	4.6961	2.04	1.99
		56/56	27.6979	77.8773	1 g/cm³	36.7242	9.0263	82.2562	4.6474	1.94	

Described By / Analysts: - **Checked by: -** **Date Completed: - 30/03/21**
Aregahagn Kefelegn **Girma Asemu**