2020-03-15

COMPACTION PROPERTIES FOR TROPICAL RESIDUAL SOILS TARGETING IMPROVEMENTS IN ERA HIGHWAY MATERIALS SPECIFICATIONS ALTERNATIVE, CASE IN BURE TOWN

Tesfaye, Mulugeta

http://hdl.handle.net/123456789/10312

Wisdom at the source of the Blue Nile

BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY

SCHOOL OF RESEARCH AND GRADUATE STUDIES

FACULTY OF CIVIL AND WATER RESOURCE ENGINEERING

COMPACTION PROPERTIES FOR TROPICAL RESIDUAL SOILS TARGETING IMPROVEMENTS IN ERA HIGHWAY MATERIALS SPECIFICATIONS ALTERNATIVE, CASE IN BURE TOWN

BY
MULUGETA TESFAYE

BAHIR DAR, ETHIOPIA

July 24, 2019

COMPACTION PROPERTIES FOR TROPICAL RESIDUAL SOILS TARGETING IMPROVEMENTS IN ERA HIGHWAY MATERIALS SPECIFICATIONS ALTERNATIVE, CASE IN BURE TOWN

Mulugeta Tesfaye

A thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering (Geotechnical Engineering)

Advisor: Dr. Addiszemen Teklay (PhD)

Bahir Dar, Ethiopia
July 24, 2019

DECLARATION

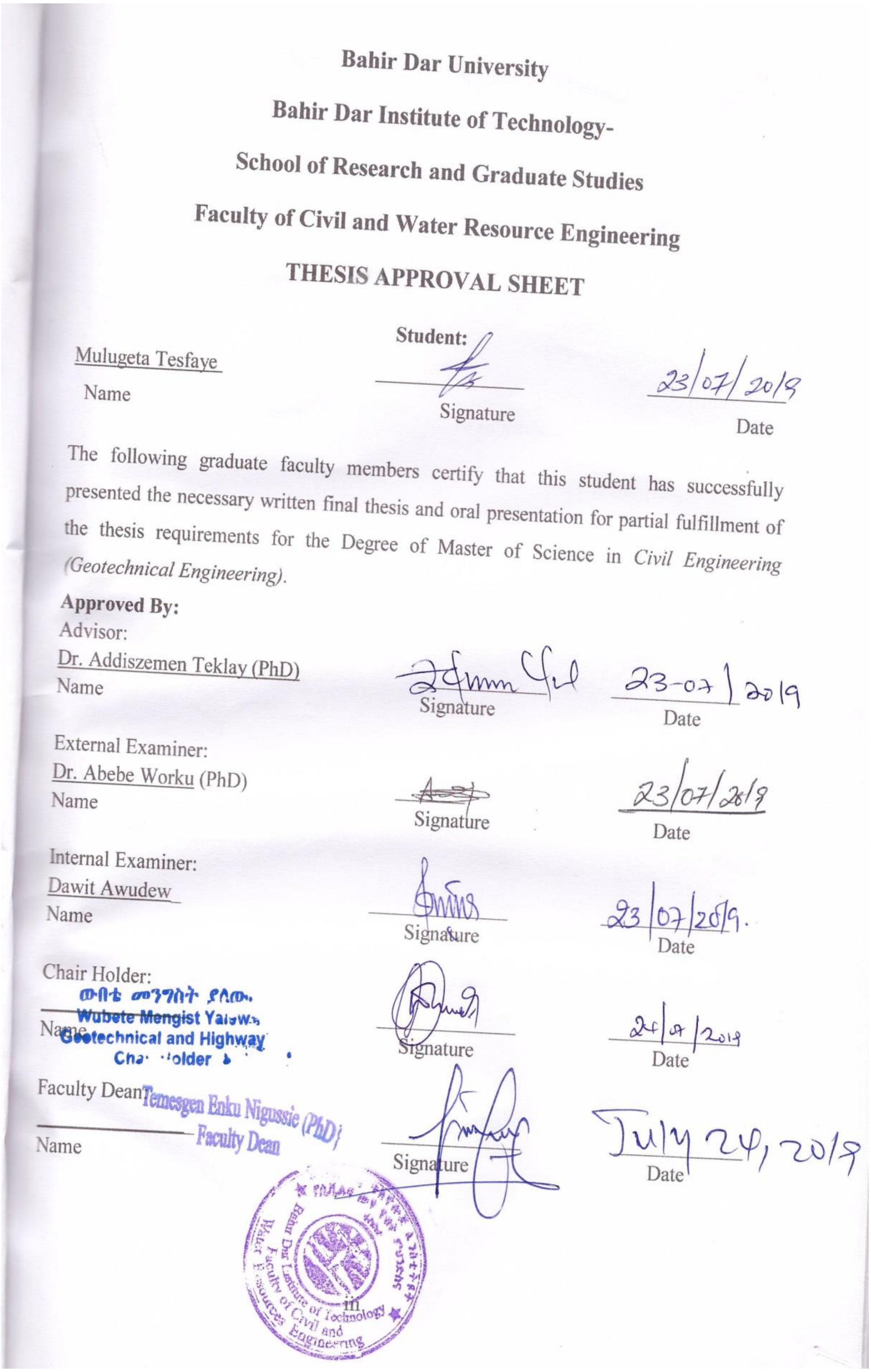
I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

Name of the student: Mulugeta Tesfaye_ Signature _____________
Date of submission: ________________
Place: Bahir Dar

This thesis has been submitted for examination with my approval as a university advisor.

Advisor Name: Dr. Addiszemen Teklay (PhD)

Advisor's Signature: ______________________________



Bahir Dar University

Bahir Dar Institute of Technology-

School of Research and Graduate Studies

Faculty of Civil and Water Resource Engineering

THESIS APPROVAL SHEET

Student:

Mulugeta Tesfaye
Name
Signature
23/07/2019
Date

The following graduate faculty members certify that this student has successfully presented the necessary written final thesis and oral presentation for partial fulfillment of the thesis requirements for the Degree of Master of Science in *Civil Engineering (Geotechnical Engineering)*.

Approved By:

Advisor:
Dr. Addiszemen Teklay (PhD)
Name
Signature
23-07/2019
Date

External Examiner:
Dr. Abebe Worku (PhD)
Name
Signature
23/07/2019
Date

Internal Examiner:
Dawit Awudew
Name
Signature
23/07/2019.
Date

Chair Holder:
ውበቴ መንግስት ያለው
Wubete Mengist Yalew
Geotechnical and Highway
Chair Holder
Name
Signature
24/07/2019
Date

Faculty Dean
Temesgen Enku Nigussie (PhD)
Faculty Dean
Name
Signature
July 24, 2019
Date

To my family

Acknowledgements

At the first I thank my God (captain of my life), I reach to this place and time by the power of almighty God.

I give my honorable thanks to my advisor Dr. Addiszemen Teklay (PhD) for his invaluable guidance and advice to realize this work. I would like to express my sincere gratitude to Staff members of Faculty of Civil and Water Resource Engineering and all guest staff's without them it's nothing.

I am very grateful to Ethiopian Construction Works Corporation – Gondar District and many thanks to the Laboratory staff members for their assistance during the experiment.

Finally great thanks to Ethiopian Road Authority (ERA) for arranging this postgraduate scholarship program.

Abstract

When African modern construction system establish with the colonization by Europe, it starts with soil investigation trend of western sedimentary soil which is different from African tropical residual soils. Ethiopian soil, as a country located in tropical region needs to be investigated in a tropical weathered residual soil concern than simply adopted sedimentary soil investigation trend. Providing the basic engineering properties of the Tropically Weathered Residual (TWR) soil will lead the government organizations, consulting and contracting firms to accept and practicing the contracting, design and construction works with respect to TWR soils concern.

In this study, After site visit, disturbed sample with its natural moisture content were taken in to laboratory. Index properties, compaction and CBR tests have been carried out in the laboratory by altering deterministic parameters and keeping the necessary standard and requirements which is recommended for investigation of tropically weathered residual soils. Besides geochemical tests have been done at Ethiopian geological survey laboratory.

Based on modified testing procedures and treatements, the TWR soils basing USCS categorized majority of the soils under group name Elastic Silt while the soils from test pit D only are silty sands; and AASHTO classification system classified soils from test pit A, B, C and E under group classification A-7-5 with Group Index > 20, which are referred as poor subgrade material; while soils from test Pit D-1.5 and D-4.0 are classified as A-7-5 and A-2-7 with group index values 10 and 0 respectively, which are good to be subgrade materials. Using the geochemical test analysis (silicate analysis) result, the soil are laterites and lateritic with a Silica-Sesquioxides Ratio less than two and Wesley's classification system classified the soil as Group-C (c) under a group of soils strongly influenced by clay minerals found only in residual soils.

From the laboratory results it is observed that compaction is greatly affected by the compactive effort applied and the slightly affected by depth (laterization). CBR values for fine grained Elastic Silt Soil ranges from 2.49% to 3.80% which is weak and insufficient to bear loads, and the soaked CBR for coarse grained silty sand, taken from test Pit D, ranges from 15.92% to 35.87%. The soils from Test Pit D can be used for subgrade or for embankement construction and can be used as sub-base construction material as a laterites, bear in mind that the results and the classifications presented here would have been diffirent if we have used the steps and methods recommended from ERA pavement materials specification manuals.

Table of Content

CHAPTER 3 22

MATERIALS, METHODS AND PROCEDURES 22

.

List of Symbols, Abbreviations and Acronyms

AASHTO = American Association of Highway and Transportation Officials
AD = Air Dried
AR = As-Received
ASTM = American Society of Testing and Materials
CBR = California Bearing Ratio
CH = Inorganic clays of High Plasticity
CL = Inorganic cays of low to Medium Plasticity
FC = Fine content (i.e. percentage of soil passing No. 200 sieve)
FS = Free Swell
GS = Specific Gravity
LL = Liquid Limit
MDD = Maximum Dry Density
MH = Inorganic Silts of High Plasticity
ML = Inorganic Silts of Low Plasticity
OD = Oven Dried
OH = Organic Clays of Medium to High Plasticity.
OL = Organic Silts of Low Plasticity
OMC = Optimum Moisture Content
PI = Plasticity Index
PL = Plastic Limit
RH = Relative Humidity
TWR = Tropically Weathered Residual
USCS = Unified Soil Classification System

List of Tables

List of Figures

Chapter 1

Introduction

1.1. GENERAL

1.1.1. Background of the Study

The (Public Works Institute of Malaysia, 1996) defines residual soils as ‘a soil which has been formed in situ by decomposition of parent material and which has not been transported any significant distance’ and concludes that tropical residual soil as ‘a soil formed in situ under tropical weathering conditions’.

Historically, the development of large cities took place mainly along sedimentary basins due to water-course proximity and flatter geomorphology. Consequently, geotechnical studies have been concentrated in Quaternary, Neogenic and Paleogenic sediments, in areas with more economic prominence and major construction works. Nowadays, after the urban center expansion, the geotechnical information on tropical residual soils from the outer city has become more and more important (Daniela, 2017). In 1967, the United States Agency for International Development decided that lateritic materials, so plentiful in tropical areas, should be studied in a thorough research program. It was believed that a major research effort would provide a satisfactory engineering definition, classification and utilization criteria for these materials to insure adequate but not overly conservative design and construction (Lyon Associates Inc., 1971).

Now a day Ethiopian town are growing faster above the expected rate. Among those, Bure town located in West Gojjam Administration of Amhara Region is the one. High Agricultural productivity surrounding the town leads Bure to be one of the locations to Agro-industry Park in Amhara region. Besides, the Woreta - Bahir Dar - Finote selam rail road proposed through leads the town to be the core socio-economic center all around. For these reasons, studying the properties of the soil for the town is the first milestone task for the upcoming multi-sector development.

Recent studies and construction failures implies that Ethiopian soil shall be investigated in tropical residual soil (soils located in tropical and sub-tropical climates) aspect in reverse to the common and adapted sedimentary transported soils. Here with this concept, compaction tests are the routine tests which demands relatively more time, effort and money as compared to the simple index property tests. Geotechnical Engineers uses compaction to increase the strength characteristics of soils, which in turn increases the bearing capacity of foundations, decreases the amount of excessive settlement of structures, increases the stability of slopes of embankments, increase shear strength, reduce permeability and seepage, reduce compressibility, optimizes swelling and shrinkage characteristics (Sridharan & Nagaraj , 2005; Arora, 1992). Compaction has a great effect on soil properties, such as strength and stress strain characteristics, permeability, compression, swelling and water absorption. The properties of a soil under compaction depend upon the water content, amount and type of compaction. For both standard and modified proctor tests, the two important compaction characteristics/ behavior descriptors of geomaterials are the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC).

This study is conducted in TWR soils located in Bure town. The soil of Bure being fine sized soil, with a high content of clay and red in color suggests that deep weathering activities in a tropical environment is the cause for soil formation. In Bure, it has been assumed that TWR soils dominantly covers parts of the town where recent construction and future town expansion will be carried out. Considering on a global scale, decomposition by chemical weathering is more prevalent and effective in breaking down rocks than mechanical disintegration. Chemical weathering is especially effective in the presence of water/high rainfall (due to its reactivity) and high temperature (which influences the rates of chemical reaction by accelerating them). Moreover, it is favored by warm humid climates by the presence of vegetation, and by gentile slope (Desai M.D., 1985).

However, related researches have been done to reflect the problem of determination of TWR soil engineering properties by the adopted European and American sedimentary transported soil laboratory testing system started with European colonization over Africa. The researches' conducted in Nedjo-Mendi road area (Abebaw, 2005), Assossa town (Fekede, 2007), Assossa town (Amare, 2008), Wolayita Sodo (Hanna, 2008), Nedjo - Jarso-Begi road area(Wossen, 2009), Bako - Nedjo highway project (Addiszemen et al., 2015) leads researchers to conclude investigation of the soil shall be carried out in TWR soil concern in place of transported sedimentary soil.

Conventional soil classification systems focus primarily on the properties of soil in its remolded state. This is often misleading for residual soils; whose properties are likely to be strongly influenced by in situ structural characteristics derived from the original rock mass or developed as a consequence of weathering. Thus, conventional soil classification systems mainly proposed/suited for temperate zone soil testing, identification and classification don’t reflect their true properties (Hanna T., 2008).

This thesis secedes its objectives by determinining the Index Properties and identifying controlling parameters for compaction of TWR soils located in and around Bure town.

1.1.2. Statement of the Problem

At present Ethiopia's infrastructure is expanding rapidly, as a result large number of new urban and lightly trafficked roads are planned or are under construction. This in addition to maintenance work of existing roads and construction of the new roads results in a large amount of material testing. Numerous information and engineering characteristics of soils needs to be determined; thus, the correct prediction of its engineering behavior is of a research interest in Civil Engineering field by Geotechnical Engineers.

Despite the existence of TWR soils come in to stage before half a century; Ethiopian construction sector stakeholders still practice the conventional soil testing, classification and investigation systems. Applying this sedimentary transported soil investigation system for Ethiopian TWR soils misleads geotechnical engineers to the estimation of incorrect bearing and settlement capacity for foundation of structures; wrong selection of materials as a sub grade material for highway projects, inappropriate width and slope determination for embankment dam construction and so on. Compaction tests requires large amounts of material and is time-consuming undertaking and it has additional drawbacks include haulage. It is also known that, the conventional compaction characteristics testing of fine-grained soils in laboratory, is expensive, time consuming and its repeatability is low, therefore several factors need to be considered in the geotechnical characterization.

To build a city with safe, economical and serviceable infrastructures; investigating the sub-soil surface in a correct way plays a dominant role. Proceeding the design and construction process in Ethiopia (areas with TWR soils) by the conventional sedimentary transported soil approach is like long walking on the darkness. TWR soils must be sampled, investigated, tested and analyzed in its own aspect. For these reason investigations of the physical and engineering properties in TWR approach is the first step.

Before this study there wasn not available data whether the soil in Bure town is TWR or not. Providing the basic engineering properties of the soil will lead the government organizations, consulting and contracting firms to accept and practicing the contracting, design and construction works with respect to TWR soils concern. This study covers investigation of soils in Bure town through TWR soils approach, especially the geotechnical engineering properties of compaction of TWR soils by altering the deterministic parameters.

1.2. OBJECTIVE OF THE STUDY

1.2.1. General Objective

Achieving the following general and specific objectives is vital for the success of this study. Therefore, the general objective of the study is determination of index properties and identification of controlling parameters for compaction of TWR soils located in and around Bure town.

1.2.2. Specific Objectives

To fulfill, the main objective, the specific objective part of the study considers the following:

a) Identify the type of TWR soils through laboratory testing including chemical content identification,

b) Investigate the effect of sample depth variation,

c) Investigate the effect of testing temperature variations,

d) Investigate the effect of moisture variations and method of testing,

e) Investigate the effect of testing procedures and testing methods.

1.3. SCOPE AND SIGNIFICANCE OF THE STUDY

1.3.1. Scope of the study

Area of investigation is in and around Bure town up to four km radius from the down town; totally represented by five test pits. Investigation of the soil to a pit excavation depth of four meter; laboratory experiments includes: determination of Index and compaction properties, and Geochemical tests. Testing is entirely based on methods only proposed for TWR soils. Classification methods of using USCS, AASHTO and Wesley mineralogical classification system.

1.3.2. Significance of the study

The result of this research will be an alarming ring for the government organizations, Owners, consulting and contracting firms to practice investigation of soil through TWR soils approach. Appropriate parameters for the control of compaction investigated here will give sufficient information on type, characteristics and distributions of a soil underlying at a site of proposed structures for feasibility and economic studies for the proposed project; and serve as a design parameter for small scale projects to cut down initial costs of soil investigation. The findings of this research will motivate practicing civil engineers and researchers, which practice in the area of study, to commence and add our knowledge on the behaviors of TWR soils in the area covered in this study. This research adds new dimension by identifying the deterministic parameters of compaction for construction of infrastructures like residential development, high rise structures, bridge construction and highway project which are helpful for the town overall development. This research may enlighten the shadow over TWR soil investigation study in Ethiopia.

Chapter 2

Literature Review

2.1. INTRODUCTION

This chapter provides a brief review of literatures focusing those related to compaction property TWR soil testing. Literatures regarding the definition, identification and testing for TWR soils are severely disturbed. Since it is dependent on climate, topography, parent material, biological activity and age of soil formation; the TWR soils behaves differently in different countries for engineering use. Its definition varies from country to country, different literates provides different definitions. Some of these are listed below;

According to McCarthy (1993) residual soils are those that form from rock or accumulation of organic material and remain at the place where they are formed.

Brand and Phillipson (1985) define it as 'Residual soil is a soil formed by weathering in place, but with the original rock texture completely destroyed'. This term is commonly used in a wider sense to include highly and completely decomposed rock, which as an engineering material behaves like a soil in places like Hong Kong.

2.2. NATURE AND OCCURRENCE OF TWR SOILS

2.2.1. Concepts of Residual Soils

This part overviews the origin, formation and occurrence of residual soils with special emphasis on tropically formed red clay laterite and lateritic soils. Soil materials form a mantle of unconsolidated superficial cover that is variable in thickness. The factors such as climate, topography and the nature of the subsurface are responsible for variation in thickness of soils formed and the alteration of the rock materials through weathering process through time. These factors in tropical region favored a very thick soil formation (Birkeland, 1984). Soils may therefore, be grouped into two broad categories: residual and transported soils (Birkeland, 1984). Unlike transported soils formed elsewhere and have displaced to the present site where they constitute the unconsolidated superficial layer, residual soils are those that form from rock or accumulation of organic material and remain at the place where they were formed (Mc.Carthy, 1993). However, according to Bland & Rolls (1998) this mantle is also termed the regolith, which is separated into an upper part/soil i.e. of a thickness of 0.3–2.0 m or more and the portion below this that progressively grades into the bedrock called the saprolite, which has been chemically altered especially in humid tropical regions.

Tropical residual soils have characteristics that are quite different from those of transported soils. Residually formed soils called tropical red clays laterite and lateritic soils form the largest soil group in Ethiopia (Abebaw, 2005; Amare G. , 2008; Fasil, 2003; Sintayehu, 2003). However, the author believes the use application and testing procedure practiced in these groups of soils in Ethiopia is not uniform. Good results can be obtained by proper handling of these groups of soils even though residual formed soils by nature are heterogeneous with depth and extent (Ting & R.Nithiaraj, 2004). In this review section, details will be given for features such as impacts of local geo-morphological factors on weathering processes, residual tropical red clay laterite and lateritic soil formations and on overall implications of testing of these soils in engineering design. Moreover, typical soil profile identifications of red and laterite/lateritic soils are also reviewed.

2.2.2. Tropical Weathered Residual soils: Formation & Weathering Processes

2.2.2.1. Major factors affecting soil formation

An understanding of the origin, development and use of soil materials is a basic requirement for the field and laboratory personnel who work with them. In has long been appreciated that pre-test treatment, laboratory testing and the engineering classification of soils are greatly facilitated by taking into account of the soil forming processes by which nature has created the various types of soil conditions (Blight, Mechanices of Residual soils, A guid to the formation, classification and geotechnical prporties of residual soils, with advice for geotechnical design., 1997). Similar combinations of soil forming processes in different parts of the world have been found to lead to materials of similar index properties and similar engineering characteristics. As a result, identification of localities in which the soil forming processes have been similar is important (Lyon Associates Institute Inc., Laterite and Lateritic soil, and other problem soils of Africa, 1971). It is therefore first essential to review formation and weathering processes of residual soils in general and later, review of the red clay laterite and lateritic soil development process and a discussion about the properties, which influence design will follow.

Table 2 - 1. Major factors affecting soil formation.

Factor	**Description**
Climatic	Refers to the effects on the surface by temperature and precipitation
Geologic	Refers to the parent material (bedrock or loose rock fragments) that provide the bulk of most soils
Geomorphic/ Topographic	Refers to the configuration of the surface and is manifested primarily by aspects of slope and drainage
Biotic	Consists of living plants and animals, as well as dead organic material incorporated into the soil
Chronological	Refers to the length of time over which the other four factors interact in the formation of a particular soil.

Tropical residual soils have a wide range of index and engineering properties depending on their parent rock forming minerals, intensity of weathering, amount of rainfall and temperature (Bujang, Asmidar, & Suhaimi, 2004). 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. This section provides an overview of description, identification and classification of tropical residual soils. The development of residual soils profile depends on the interaction of three natural features: these are, the chemical composition of the rock, environmental conditions and time (Huat Bujang Sew & Ali, 2004). The complex natural processes involved in the formation of soils are greatly affected by the factors or variables given in Table 3 -1 and are discussed below. The transformation of rock into soil is designated as soil formation (Hans, 1994). Soil is an exceedingly complex system possessing of a great number of properties. However, the following are major factors, which decide the type of soil formed from parent material weathering. Climate is the representation of the average weather conditions over the long-term , taking into account, the extremes, means and frequencies of departures from theses means (Whittow, 1988); it governs the amount of precipitation and temperature available that in turn determines like the rate of rock weathering and the influence of vegetation on soil. The Köppen Climate Classification System, an empirical classification system, is the most widely used system for classifying the world’s climates (Huat, Sew, & Ali, 2004).

Areas with tropical climates (i.e. the A category climate in the Köppen Classification System) are extensive, occupying almost all of the continents between latitudes 20°N to 20°S of the equator and is for the coolest month to have a temperature of more than 18°C making it the only true winterless climate category of the world. Regarding moisture, warm, moist and unstable air masses frequent the oceans at these latitudes. High rainfall and temperatures generally increase the propensity for weathering by increasing the susceptibility of rocks to chemical reactions. Thus, warm humid climatic regions generally have more weathered rock with higher rates of weathering than colder dry climates (Hans, 1994). The formation of soil commences by chemical alteration and physical disintegration of rocks at their exposed surface. These rocks are termed as the parent material.

The parent material has the greatest influence on the incipient soils in the early stages of soil formation and in the drier regions but lessens over time as other soil forming factors become more active (Birkeland, 1984). 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 taken place depend upon, amongst others, on the time the soil forming processes have been occurring. For example, in warm and humid climates typical of the tropics, the time required for chemical alteration of a rock material is considerably less than in temperate climate. Topography has a significant control on surface processes like erosion and drainage (Blight, Mechanices of Residual soils, A guid to the formation, classification and geotechnical prporties of residual soils, with advice for geotechnical design., 1997). The primary contribution of plants and animals is to provide organic matter that is incorporated with the weathered parent material especially at the upper part of the regolith. These factors are also critical in determining the state of soils, (i.e. saturated or partially saturated). Generally, wet and cold climates increase the rate of weathering dramatically and hot and dry climates decrease the rate of weathering. These materials are commonly found in unsaturated state in tropical regions.

Parent material/mineral weathering: residual soils are found more or less covering the parent rocks (Singh P. & Kataria, 1980.). The degree of weathering and extent to which the original structure of the rock mass is destroyed varies with depth from the ground surface. Most commonly residual soils are formed from igneous and metamorphic parent rocks, but residual soils formed from sedimentary rocks are also not-uncommon (Bland & Rolls, 1998). Occasionally residual soils can be formed by in-situ weathering of unconsolidated sediments (Blight, Mechanices of Residual soils, A guid to the formation, classification and geotechnical prporties of residual soils, with advice for geotechnical design., 1997). The products of weathering are important, as these constitute the residual soils.

2.2.2.2. Definitions of Residual Soils

The review on the definition of residual soils indicates that, there is, even, no universally accepted definition of residual soils (Harwant & Bujang, 2004). Different workers provide different definitions for residual soils , the definition proposed by the public works institute of Malaysia (1996) defines residual soils as '*a soil which has been formed in-situ by decomposition of parent material and which has not been transported any significant distance*' and defines tropical residual soil as "*a soil formed in situ under tropical weathering conditions*". Further, in reviewing the international practice for the sampling and testing of residual soils, Brand & Phillipson (1985) found that authors from different regions had some variation in the interpretation of what might be defined as "*residual soil*". Generally, the majority of the workers primarily defined residual soils as a "*soil weathered in situ where the original rock structure is totally destroyed by weathering*".

2.2.3. Tropical Weathering: *Red Clay, Laterites/Lateritic Soils Formation*

2.2.3.1. Tropical weathering

The consequences of tropical weathering have been of overriding significance in the formation of the soils in most parts of Africa including Ethiopia (Lyon Associates Institute Inc., Laterite and Lateritic soil, and other problem soils of Africa, 1971). Hence, no system of classification or no attempt to identify the significant engineering characteristics can succeed if not based on an appreciation of tropical weathering processes (Gidigasu M.D., 1976). Considering on a global scale, decomposition by chemical weathering is more prevalent and effective in breaking down rocks than mechanical disintegration. Chemical weathering is especially effective in the presence of water/high rainfall (due to its reactivity) and high temperature (which influences the rates of chemical reaction by accelerating them). Moreover, it is favored by warm humid climates by the presence of vegetation, and by gentile slope (Dresai M.D., 1985).

Sherman, (1949) emphasis two weathering actions are 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. Each group of soils possesses clays that have distinct and definite chemical properties and these properties were used as a basis for the classification of lateritic soils into several groups. Since each group of these soils occurs in regions having different climatic conditions, it is likely that climate plays a major role in development. Since the geological ages of the parent materials vary greatly, the time of exposure of the parent material to soil-forming processes will also have had a major effect on soil development. Due to the great variation of the age of the soil parent material, and the great variation in climate due to the effects of elevation and trade winds on temperatures and rainfall regions, a very complex pattern of soil development has resulted.

Tropical red clay, laterites and lateritic soils are generally found in warm, humid, tropical areas of the world (R.Maiginien, 1956). The geotechnical properties of these soils are quite different from those of soils developed in temperate or cold regions of the world (Gidigasu M.D., 1976). Deep, strongly leached red, brown, and yellow profiles are manifestation of the effects of sever chemical weathering (Morin & Todor, Laterite and lateritic soils and other problematic soils of the tropics., 1975). The chemical changes in temperate or semi-tropical zones tend to produce clay minerals predominately represented by kaolinite and occasionally by halloysite and by hydrated or anhydrous oxides of iron and aluminum. Quartz remains unchanged (R.Maiginien, 1956; Umarany M. & D.J.Wiliams, 1990). These soils may be very thick in areas with conditions favorable for intense weathering such as the tropics or they may be very thin or absent in areas of unfavorable conditions like arid regions or steep mountains slopes subject to erosion by mass movements. The properties of lateritic soils are influenced by climate, geology and the degree of weathering or laterization (Gidigasu M.D., 1972; Gidigasu M.D., 1976). It has been found that the geotechnical properties of these soils in different tropical countries are also different and that lateritic soils formed on the same parent rock in the same tropical country, but under different climatic conditions, have different geotechnical properties (Gidigasu M.D., Mode of formation and geotechnical characteristics of laterite materials of Ghana in relation to soil forming factors., 1972; Lin Zongyuan, 1986). Laterite and lateritic soils are the product of intensive weathering called laterization under tropical and sub-tropical climatic conditions (Umarany & Daviid J., 1991). Laterization involves the leaching out of silica and alkali, and the accumulation of hydrated iron and aluminum oxides (sesquioxides). Alexander and Cady (1962) cited in R.Maiginien, 1956 state that; "laterite is a highly weathered material rich in secondary oxides of iron, aluminum or both. It is nearly void of bases and primary silicates but it may contain large amounts of quartz and kaolinite. It is either hard, or capable of hardening on exposure to wetting and drying."

2.2.3.2. Kaolinization: Pedogenesis of Tropical Red Clay Soils

Tropical residual soils are those formed ‘in place’ by intense weathering/alteration of the underlying parent rock in tropical and sub-tropical climatic environments. In humid tropical climates, residual soils dominate the landscape. The parent rocks may be both igneous (e.g. basalt lavas, tuffs, granites, etc.) and sedimentary (e.g. sandstones, limestone’s, etc.). According to (Styles M. T., et al., 2001) explanations, two very broad categories of residual soils may be considered: tropical ‘black’ soils and tropical ‘red’ soils. The former category, which includes those soils termed 'black cotton soils' or 'black swelling clays', comprise a relatively distinct 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 invariably form in areas of poor drainage. However, there is some confusion as to what materials comprise the so-called tropical 'red' soils and the terms used to describe them (Styles M. T., et al., 2001). It is a misconception to consider tropical red soils as forming a distinct clearly defined soil type as they encompass a wide variety of soils whose engineering property vary considerably. This variation has been reflected in the ever-increasing literature on tropical soils since a long period, which has seen red, brownish red, reddish brown and brown soils described 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. These form because of the accumulation of iron which, in some areas, may develop into a continuous sheet of indurated Ferricrete (grains cemented by Fe-oxides/hydroxides) ("laterite") forming a surface or near-surface duricrust (hard layer). However, not all red clay soils harden irreversibly on exposure to form laterite (as defined by the original description of Buchanan, 1807) and it is unfortunate that the terms: 'lateritic clays' and even 'laterite' are still used by some workers to describe any reddish/brownish red tropical soil. It should be appreciated that some of the soils broadly described as tropical 'red' clays, may be brown/dark brown rather than red. For example, ‘andosols’ are tropical soils that range from dark brown or yellowish brown to brownish red in color, but are part of the same weathering process that, given the appropriate conditions, leads to the development of more typical tropical red soils. Andosol soils are typically found in the tropics at higher and wetter elevations on recent volcanic rocks (particularly ashes, tuffs and pyroclastic material) where allophane clay minerals are formed from the rapid weathering and alteration of volcanic “glass”.

The tropical weathering of parent rocks is complex but primarily involves the progressive chemical alteration of primary minerals, the release of iron and aluminum sesquioxides, increasing loss of silica and the increasing dominance of new clay minerals (such as smectites, allophane, halloysite and, as weathering progresses, kaolinite) formed from dissolved materials. Apart from structure as a distinctive feature of many residual soils, geotechnical engineers should be aware of a group of very unusual clay minerals found only in residual soils. These are the two minerals, allophane and imogolite, which are normally linked together and a third called halloysite (Wesley, 2010). 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 M. T., et al., 2001).

(Duchaufour, Pedology, Pedogenesis and Classification.(English edition tras.), 1982), developed a scheme that attempts to put the soils formed under the complex tropical weathering process into a logical context. The scheme places emphasis on the compositional soil characteristics (particularly mineralogical composition). Duchaufour recognized three main phases of residual 'red' soil development in tropical areas: fersiallitisation (fersiallitic soils), ferrugination (ferruginous soils) and ferrallitisation (ferrallitic soils). Each of these phases are typically related to a broad set of climatic conditions and are characterized by an increasing degree of weathering of primary minerals, an increasing loss of silica, and an increasing dominance of new clay minerals formed from dissolved materials. This overall process is generally referred to as 'ferrallitisation' (or commonly, and confusingly, as ‘laterization'). Ferrallitisation represents the final phase, where complete weathering of all primary rock-forming minerals has taken place under hot humid climatic conditions over a long period. Thus, the development of these soils should be seen as phases in the same weathering process, forming part of a weathering continuum from fersiallitic through to ferrallitic soils.

An important aspect of these soils is that as weathering proceeds new clay minerals are formed that are in equilibrium with the climatic, temperature and moisture conditions acting upon them. As conditions change so, do the minerals that are formed. The final ferrallitic soil phase of development is dominated by ‘stable’ clay minerals (such as kaolinite). However, the fersiallitic and ferruginous soils are characterized by clay minerals that are ‘less stable’ and often in a poorly crystalline state (amorphous or gel like). These clays may undergo irreversible changes when subjected to drying and/or marked changes in humidity. These changes not only influence the nature of the clay minerals themselves but also the structural (or ‘fabric’) characteristics of the soil that, in turn, influence its density, porosity and moisture-holding properties. This is a critical issue as tests undertaken on a tropical soil that has been allowed to dry out may bear little relation to the material properties of the same soil in situ (Nortlunor K. J., Bntwillie, Hobb, Culshaw, & Jones, 1992). As the mineralogical changes subject to drying are irreversible, re-wetting of the dried material in the laboratory does not return the soil to its in situ pre-dried state.

2.2.3.3. Laterization: formation of laterite and lateritic soils

Residually formed soils are formed in different places however, a distinct type of soil called laterite and lateritic soils having its own engineering characteristics and importance develop in a certain favorable circumstance. Commonly in hot and humid tropically regions with an annual rainfall range between 750mm to 3000mm and abundantly in areas with significant dry seasons (Huat Bujang Sew & Ali, 2004). These soils formed are due to, extreme weathering condition 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 (Blight, Mechanices of Residual soils, A guid to the formation, classification and geotechnical prporties of residual soils, with advice for geotechnical design., 1997). Some more descriptive terms, such as ferruginous soil, ferrallitic soils, and Ferrisols are recommended in lieu of laterite soils (Lyon Associates Institute Inc., Laterite and Lateritic soil, and other problem soils of Africa, 1971). 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 (Gidigasu M.D., 1976). 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 earths are 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.

The American Geological Institute (1972) defines laterite as "highly weathered, red subsoil or material rich in secondary oxides of iron, aluminum, or both, nearly void of bases and primary silicates, and may be containing large amounts of quartz and kaolinite. It develops in a tropical or forested warm to temperate climate, and is a residual or product of weathering. Laterite is capable of hardening after a treatment of wetting and drying. The Geological definition of lateritic soil is "A soil containing laterite; also, any reddish tropical soil developed from much weathering. “The last term is highly generalized but it is not always possible to be more precise in the field.

Laterization is a process of weathering of 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 oxide such as gibbsite, or of hydrous iron oxide such as limonite or goethite derived from the iron. Laterization process takes place in three stages (Umarany M. & D.J.Wiliams, 1990).

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 sesquioxides takes place. This occurs during wet seasons of the year and its extent depends on the PH of the ground water and drainage conditions (Gidigasu M.D., 1976). Iron, being carried in ferrous form by water, is mobile until it is oxidized to Ferric ions. Following the dry season, evaporation leads upward migration of ferrous Ions and opportunity for oxidation by atmospheric oxygen. Iron then precipitates as hydrated ferric oxide gel. Aluminum moves in solution until precipitated as an Alumina gel by dehydration or a change in PH (Umarany M. & D.J.Wiliams, 1990).

The sesquioxides (hydrated Ferric Oxide gel and Alumina gel) are adsorbed on the surfaces of the clay minerals. The adsorption occurs through the interaction of positively charged sesquioxides and negatively charged clay particles (Towensend F. P., 1969). At the third stage, partial or complete dehydration of hydrated colloidal Sesquioxide occurs.

Dehydration is accompanied by crystallization of amorphous iron colloids into dense crystalline forms in the sequence of Limonite, Goethite, and Hematite. This is accompanied by a change color from yellow or yellow-brown to red. Gelatinous, free iron oxide coats the soil particles, exerting a cementing effect upon the clay, silt and sand size fractions (Gidigasu M.D., 1976). Based on the above discussion, the three major processes responsible for the formation of laterites can be summarized as follows:

Decomposition: Physico-chemical breakdown of primary minerals and the release of constituent elements such as SiO2, Al2O3, CaO, MgO, etc. These appear in simple ionic forms.

Laterization: is leaching under appropriate condition of combined silica, bases and the relative accumulation or enrichment of oxides, and hydroxides of sesquioxides such as Fe2O3. The soil conditions under which the various elements are rendered soluble and removed through leaching or combination with other substances depend mainly on the PH of the ground water and the drainage conditions (R.Maiginien, 1956). The level to which this process is carried depends on the nature and the extent of the chemical weathering of primary minerals.

Desiccation/Dehydration: this involves partial or complete dehydration of the Sesquioxide rich minerals and secondary minerals. The dehydration of colloidal hydrated iron oxide involves loss of water and the concentration and crystallization of amorphous iron colloids into dense crystals, in the sequence *Limonite, Goethite with Hematite to Hematite*. Dehydration may be caused by climate changes, upheavals of the land, or may also be induced by human activates, e.g. clearing the forests.

2.3. TWR SOILS IN ETHIOPIA

TWR soils are highly variable from place to place, to obtain geotechnical design parameters and performance of TWR soils, it is necessary to study profoundly the effect of testing treatments on geotechnical characteristics of these soils. Even though, conducting the appropriate laboratory testing using modified methods proposed and appropriate for TWR soils is the right path to build safe and economical infrastructures, research in investigating the geotechnical engineering properties of the Tropically weathered Residual (TWR) soils in Ethiopia limited (Abebaw Zelalem, 2005; Addiszemen , Messele, Alemayehu, & Murray, 2014). Moreover, TWR soils of Ethiopia like soils of other tropical countries are very heterogynous, hence vary with depth profile and vary from place to place arising because of high variability in degree of weathering in turn which controlled by local climate, terrain, parent material and internal drainage. TWR soils engineering properties which are more dependent on mineralogical composition, testing procedure, pre-treatment condition, moisture variation and temperature variation (Abebaw, 2005).

Changes in pre-treatment type have minor effect on Ferrisols with in which Morin W.J. and Todor P.C. in 1971 recommend that areas with volcanic soils of Ethiopia should be investigated towards susceptibility of pre-treatment to be given for laboratory testing (Wesley, 2010). Engineering interest in the properties of soil materials centers about such characteristics as gradation, permeability, strength, deformation under load and change in properties with wetness (Fookes P. , 1997).

Chapter 3

Materials, Methods and Procedures

3.1. INTRODUCTION

This chapter mainly provides the materials methods and procedures that are required for undertaking the study.

3.2. DESCRIPTION OF THE STUDY AREA AND IN-SITU PROPERTIES

3.2.1. General

The study area, Bure, is town administration located in West Gojjam administration zone, Amhara Region, Ethiopia. This town has a latitude of 10°42′N and longitude of 37°4′E with elevation of 2091 meters above sea level. Bure enjoys a flourishing small business and connection point of businesses between Wolega, Gonder and Shewa. Now a days Bure is becoming the home for Agro industry parks which is helpful to collect and process large amount of agricultural goods harvested around the town. The study area map of Bure Town and the location of test pits are shown below in Figure 3 - 1 and Figure 3 - respectively.

3.2.2. Climate

The climatic classification of Bure town is “woina dega” having mean annual temperature of 11-23^{o}C and the precipitation ranges between 1210 and 1460mm. Average annual rain fall of 1337 mm is observed.

3.2.3. Topography

The topography of Bure town varies from +2031m to +2156m with undulations at some portions of the town, moderate slopping from north east to south and from south west to south which is a slopping ground in to the gorge that crosses the town. Figure 3 - 3 shows the Geological map of Bure town and surroundings,

3.2.4. Vegetation and Land Use

The vegetation and land use in Bure town is a town section with dense vegetation in between residential houses while the land use around the town can generally be classified as moderately cultivated land and grazing land in between farms with intermittent tropical forests.

3.2.5. Geology

According to geological map of Ethiopia, 2007 (1999E.C.), the geological formation in and around Bure town is Alluvial soil (Black cotton and Dark brown silty clay).

Figure 3 - 1. Location map of Bure town

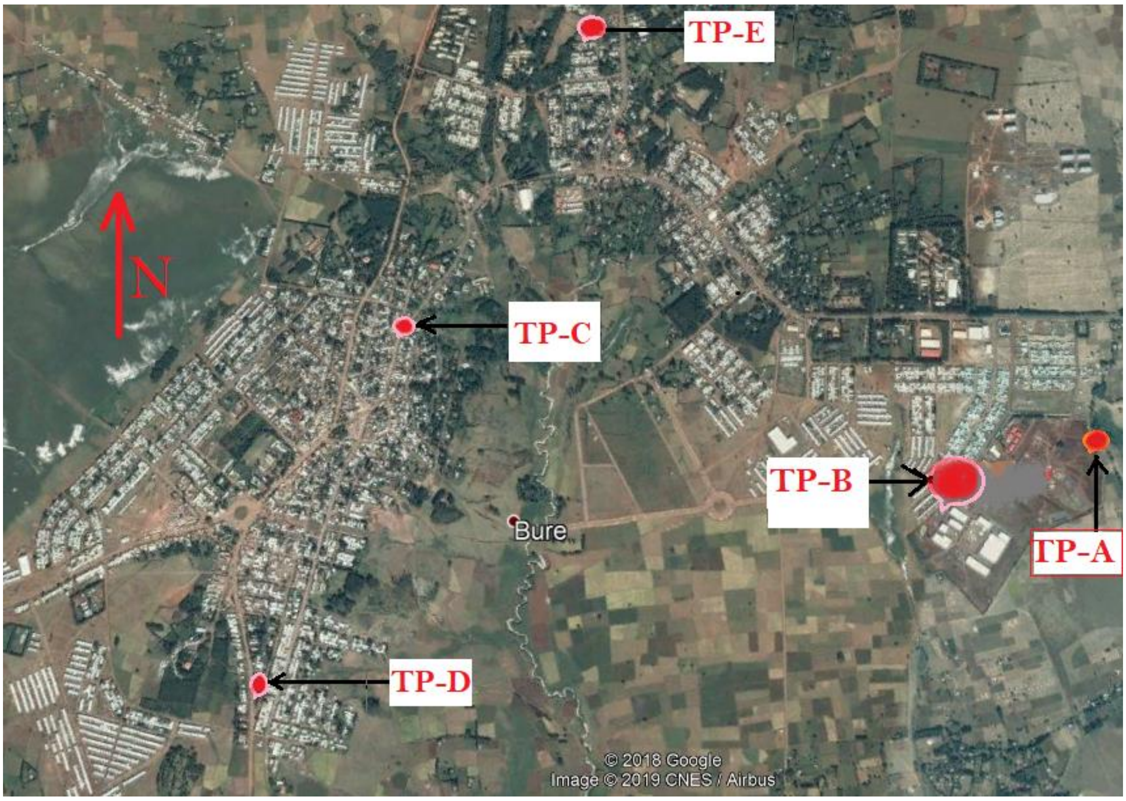


Figure 3 - 2. Location of test pit

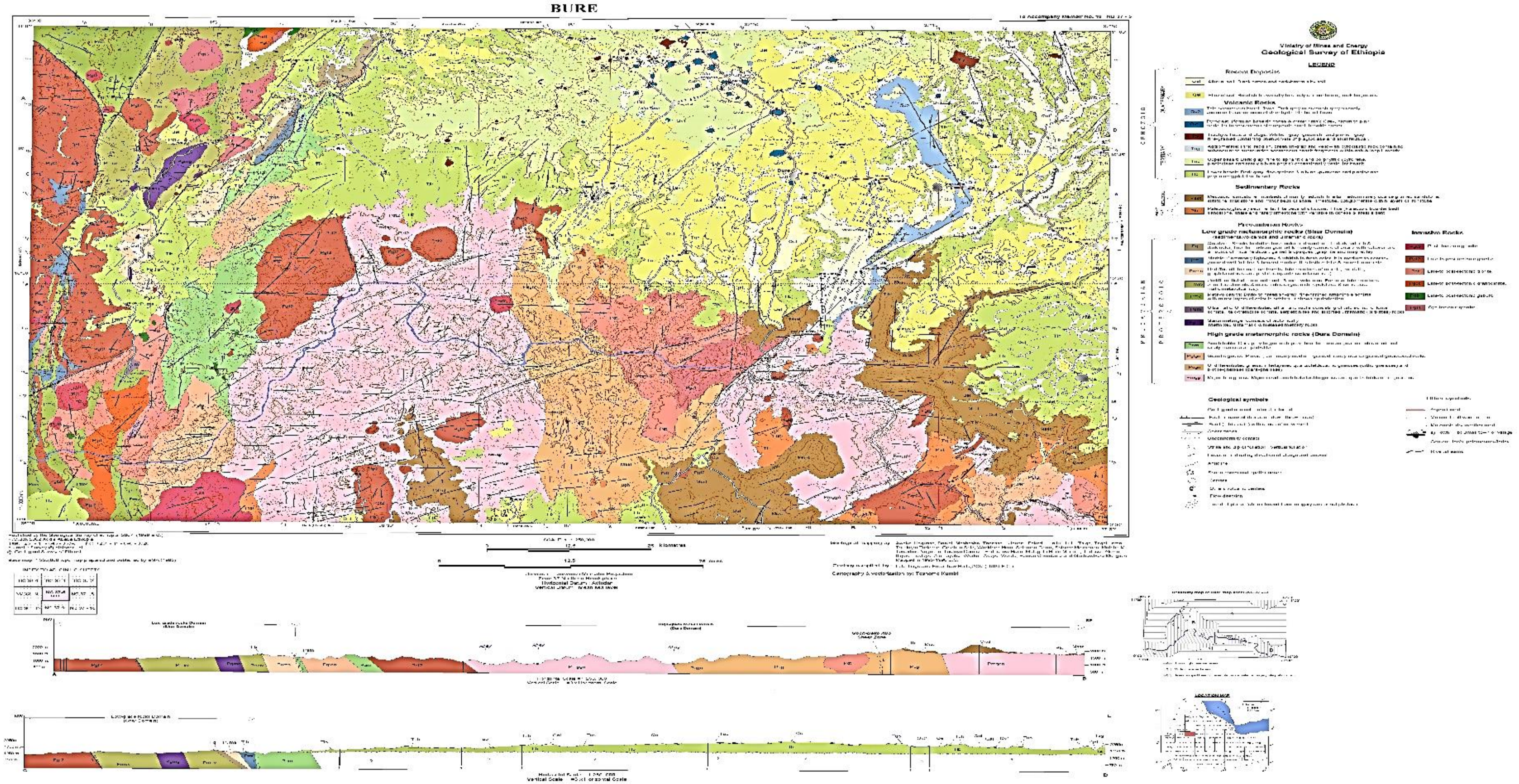


Figure 3 - 3. Geological map of Bure town and surroundings

3.3. SOIL SAMPLING AND IN-SITU SOIL PROPERTIES

Sampling tropical residual soils, which usually behave differently from other conventional soils particularly in relation to the properties and structure, need to be given attention. The soil fabric, bonding between particles, void ratio (e) and moisture content (w) of the soil must be preserved because these factors have a significant influence on several engineering properties.

The only way to get good quality samples of tropical residual soils is by fully utilizing the experience, competence and capabilities of personnel involved with the sampling and testing processes.

After assessing the topography and nature of the soil in the town in detail identification of sampling area has been done by defining the spots for test pits by considering the current town master plan and future possible expansions.

Accordingly, five test pits are enough to represent the town section with different topography and geological condition.

To consider the effect of depth (laterization) two samples at a depth of 1.5m and 4.0m has been excavated and taken.

Disturbed soil samples with its natural moisture content were taken at 1.5m and 4.0m depths and sealed in a plastic bag to keep the sample at as-received condition. By naked eye visualization Soil samples from test pit A, B and E are red clay soils, while the sample from test pit D is light gray gravel.

The sample from test pit C is variable through the depth of excavation; the sample at 1.5m depth of excavation is white silt while the sample taken from 4.0m depth of excavation is light red silt. Accordingly, Table 3 - 1 shows the soil sampling location and designation used in the study.

Table 3 - 1. Soil Sampling Location and Disgination

Test Pit	Depth (m)	Sample Designation	Color	Northing	Easting	Elevation (m)
A	1.5	A-1.5	Red	1183580	291644	2075
A	4.0	A-4	Red	1183580	291644	2075
B	1.5	B-1.5	Red	1182966	290144	2046
B	4.0	B-4	Red	1182966	290144	2046
C	1.5	C-1.5	white	1183956	287970	2122
C	4.0	C-4	Light red	1183956	287970	2122
D	1.5	D-1.5	Light gray	1182676	287797	2142
D	4.0	D-4	Light gray	1182676	287797	2142
E	1.5	E-1.5	Red	1185640	288364	2128
E	4.0	E-4	Red	1185640	288364	2128

3.4. LABORATORY TESTS: MATERIALS METHODS AND PROCEDURES

Tropical red clay and lateritic soils show changes in physical properties when tested under different sampling procedures, pretest preparation and testing and laboratory equipment has used and handling conditions (Gidigasu M.D., Mode of formation and geotechnical characteristics of laterite materials of Ghana in relation to soil forming factors., 1972). After soil sampling, laboratory tests were performed in Ethiopian Construction Works Corporation – Gondar district laboratory. All tests were done according to the modified practices suggested for TWR soils.

The laboratory testing includes determination of natural Moisture Content and specific gravity at different testing temperature, grain size distribution, Atterberg limits and compaction characteristics of the soil. The details of the test procedures to determine test results are described below.

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 are of importance to the 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.

Hence, index properties and engineering properties should be tested by simulating the actual site condition. The various properties of soils, which could be considered/studied as index properties under this study are natural moisture content (with temperature variation, Atterberg limit tests (liquid limit, plastic limit, and shrinkage limit) at different sample pretreatment and remolding, grain size analysis, activity of clay, specific gravity of TWR soils. The compaction characteristics of the soils are also studied as detailed in literature review. Moreover, the geochemical and mineralogical characteristics of the laterite soils of the study areas are also investigated in this study as a control testing.

3.5. INDEX PROPERTY TESTS

3.5.1. Moisture Content (w_n)

The conventional test is based on the loss of water when a soil is dried to a constant mass at a temperature between 105°C and 110°C. 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 G. , 2008).

Two test specimens should be prepared for water content determinations. One specimen should be oven dried at 105°C until successive weighing’s show no further loss of mass. The water content should then be calculated in the normal way. The second sample should be air-dried (if feasible), or oven-dried at a temperature of no more than 50°C and a maximum relative humidity (RH) of 30% until successive weighing’s show no further loss of mass. The two water content results should then be compared: a significant difference (4–6% of the water content obtained by oven-drying at 105°C) indicates that “structural” water is present and is driven off at high temperatures. This water forms part of the soil solids, and should therefore be excluded from the calculation of water content. If a difference is detected using the two different drying procedures, all subsequent tests for water content determination (including those associated with Atterberg limit tests, etc.) should be carried out by drying at the lower temperature (i.e., either air-drying, or oven-drying at 50°C and 30% relative humidity). If possible, the lower drying temperature of 50°C should be used (Fourie et. al., 2012)

3.5.2. Specific Gravity (Gs) Tests

In 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 beat 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. The dry mass of the soil used in the test should be calculated by drying the soil specimen after the particle unit weight test has been completed (Fourie et. al., 2012); (Addiszemen et. al., 2015).

TWR soils should be at their natural moisture content for specific gravity analysis; avoiding pretest drying as it tends to reduce the measured specific gravity compared with that at the natural moisture content (Addiszemen et al., 2015).

3.5.3. Particle Size Distribution

(Fourie et. al., 2012) reports the particle size distribution of a residual soil may be affected by effect of drying, chemical pre-treatment, variation of specific gravity and sedimentation.

3.5.3.1. The Effect of Drying

The most widely reported effect of drying is to reduce the percentage that is reported as the clay fraction (finer than 2µm). Drying of the soil prior to testing should be avoided (Fourie et. al., 2012).

The variation in percentage of particle sizes in the different test procedures is not significant and comparable to that which might be expected in testing of temperate soils. Although, pre-drying did not significantly affect the results, it is recommended that pre-test preparation and testing is performed on soils in their natural state (AR soil). It is also recommended that the wet preparation (i.e. soaking the soil until the coating material is fully softened) and the wet sieving procedures should be used in practice (Addiszemen et. al., 2015).

When carrying out particle size or Atterberg limit tests on residual soils, it is highly desirable that the material not be air or oven dried prior to testing, especially if the soil is of volcanic origin. It should be dried only to the water content needed to carry out the test (Wesley, 2010).

3.5.3.2. The Effect of Chemical Pre-treatment

This should be avoided wherever possible. Pre-treatment with hydrogen peroxide is only necessary when organic matter is present (Fourie et. al., 2012).

3.5.3.3. The Effect of Variation of Specific Gravity

The assumption of constant specific gravity for the soil particles while carrying out particle-size distribution analysis assumes one average value over the full range of particle-sizes. For some laterites, whose coarse fraction is iron-rich and whose fine fraction is kaolinite, this convention may be misleading as it would overestimate the volume content of coarser particles and exaggerate any gap-grading in the material, and would not represent the true packing and mechanical stability of the material as a whole. In order to address this problem, separate specific gravity tests were conducted for coarser and finer particles (Charman, Laterite in road pavements: Transport Research Laboratory, Department of Transport., 1995); (Wossen, 2009).

In case of Bure town the specific gravity on fine grained soils on pit A,B,C and E supposed to have lower specific gravity than the soils from test pit D. By nature the soils samples are either of coarse grained or fine grained. Thus, in this study specific gravity tests is conducted for coarse grained and fine grained soils separately.

Specific gravity values vary somewhat with pre-treatment conditions, the grading curves using mass and modified mass proportions do not vary significantly, especially for samples tested under wet sieving (i.e. AR pretreatment condition). The need to modify the grading curves using modified mass proportion is not considered important when the wet sieving method on AR soil is used (Addiszemen et. al., 2015).

3.5.3.4. Sedimentation

It is essential to achieve complete dispersion of fine particles prior to carrying out a sedimentation test or hydrometer analysis. The use of alkaline sodium hexametaphosphate is suggested. In some instances, a concentration of twice the standard value may be required. If the above dispersant is ineffective, an alternative such as trisodium phosphate should be used. In all cases the dispersant solution should be freshly made before use in the laboratory (Fourie et. al., 2012).

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 which passes 75mm - and retained on 4.75mm
- Coarse sand is a particle passes 4.75mm - and retained on 2.0mm
- Medium sand is a particle passes 2.0mm - and retained on 0.425mm

- Fine sand is a particle which passes 0.425mm - and retained on 0.074mm
- Silt is a particle which passes 0.074mm - and retained on 0.005mm
- Clay is a particle which passes 0.005mm

AASHTO 1990, suggests;

- Gravel is a particle which passes 75mm - and retained on 2mm
- Coarse sand is a particle passes 2mm - and retained on 0.425mm
- Fine sand is a particle which passes 0.425mm - and retained on 0.074mm
- Silt is a particle which passes 0.0.074mm - and retained on 0.002mm
- Clay is a particle which passes 0.002mm

And Lyon, 1971 suggests;

- Lateritic clays < 0.002mm
- Lateritic silts between 0.002-0.06mm
- Lateritic sands between 0.06-2.0mm
- Lateritic gravels between 2.0-60mm

3.5.4. Atterberg Limits

The major problems when carrying out Atterberg limit tests are effects of pre-test drying, duration of mixing and method of mixing.

3.5.4.1. Pre-test Drying

The effect of drying prior to testing may be attributed to:

a) Increased cementation due to oxidation of the iron and aluminum sesquioxides, or

b) Dehydration of allophane and halloysite, or

c) Both 1and 2 above.

Thus, in order to be meaningful, Atterberg limit tests on residual soils should therefore be performed without any form of drying prior to carrying out the test (Fourie et. al., 2012).

Sample pre-treatment conditions affect the Atterberg limit of TWR soils. The AR samples give liquid limits somewhat greater than those of AD samples, which in turn give values greater than those of the OD samples. It is recommended that AR soils are used for plasticity index with fresh soil used for each moisture content point in the Atterberg limit tests. The soils should be broken-down by soaking in water, and not by drying and grinding, as is suggested for temperate zone soil. Pre-testing treatment should reflect the field conditions at the time of construction as represented by AR conditions (Addiszemen et. al., 2015).

When carrying out particle size or Atterberg limit tests on residual soils, it is highly desirable that the material not be air or oven dried prior to testing, especially if the soil is of volcanic origin. It should be dried only to the water content needed to carry out the test (Wesley L. D., 2010).

3.5.4.2. Duration of Mixing

In general, the longer the duration of mixing (i.e., the greater the energy applied to the soil prior to testing), the larger the resulting liquid limit, and to a lesser extent, the larger the plasticity index. This is because longer mixing results in more extensive break down of cemented bonds between clay clusters and within peds, and thus the formation of greater proportions of fine particle (Fourie et. al., 2012).

When carrying on Atterberg limit tests to prevent the effect of disaggregation and clods the testing should limit the mixing times to not more than 5 minutes and make use of fresh soil for each water content point (Fourie et. al., 2012); (Tiruneh, 2015).

Comparison of the differences of the liquid limits for 5- and 30-minutes remolding time for each of the three pretesting preparation cases (AR, AD and OD) indicates increased mixing increases the liquid limit by around 5%. Disaggregation results in increased fines and higher liquid limit values. The time of mixing causes a greater change in the liquid limit data than the pretest drying procedures considered. The laterite soils in Ethiopia are sensitive to handling and manipulation. To obtain consistent and repeatable plasticity data it is recommended that remolding of samples prior to Atterberg limit testing is restricted to no more than 5 minutes with fresh soil used for each moisture content point in the Atterberg limit test on as received soil using the drying-back technique (Addiszemen et. al., 2015).

3.5.4.3. Method of Mixing

The soil should be broken down by soaking in water, and not by drying and grinding. The soil should be immersed in water to form a slurry, which is then washed through a 425µm sieve until the water runs clear. The material passing the sieve should be collected and used for the Atterberg limit tests (Fourie et. al., 2012).

3.5.5. Linear Shrinkage Limit

The linear shrinkage of a soil is defined as the decrease in one dimension of the soil mass when the water content is reduced from a given percentage to the shrinkage limit (AASHTO, 2004).

Air-dried soil samples have higher values of linear shrinkage than that of oven-dried soil samples even if the variation is insignificant. Hence, for soil samples under investigation higher drying temperatures during sample preparation causes the soil particles to come closer and create higher cementation by sesquioxides that can’t be reversed upon rewetting as a result linear shrinkage values will be reduced (Wossen, 2009).

3.5.6. Free Swell Tests

Free swell is a test which helps to determine the expansiveness potential by pouring a soil passing 425µm in to a graduated cylinder without any external constraints (consolidating pressure), on submergence in water. Among clay minerals Montomorillonite influence the magnitude of swelling as compared to Illite and Kaolinites. Drying of soil samples also makes soil particles to come closer and hide the potential of some of the active minerals to swell (Dibisa, 2008).

3.5.7. Activity Number

Skempton's colloidal activity is determined as the ratio of the plasticity index and the quantity of colloidal clay particles present in soil. Skempton classifies clays according to their activity number.

$$A_c = \frac{PI}{\%Clay} \qquad [3.1]$$

Where: PI is the plastic index and C is the percentage of clay fraction which passes 2 microns.

3.5.8. TWR Soil Classification

There are specific characteristics of residual soils that are not adequately covered by methods of soil classification originally designed for transported soils, such as the Unified Soil Classification System (USCS). Among these are the following:

a) The clay mineralogy of some residual soils gives them characteristics that are not compatiblewiththosenormallyassociatedwiththegrouptowhichthesoilbelongs according to existing systems such as the USCS.

b) The soil mass may display a sequence of materials in situ ranging from a true soil to a soft rock depending on degree on weathering, which cannot be adequately described using existing systems based on classification of transported soils.

c) Soil classification systems such as the USCS focus on the properties of the soil in its remolded state: this is usually misleading with residual soils, whose properties are likely to be strongly influenced by in situ fabric and structural characteristics relict from the original rock mass or developed as a consequence of weathering (Fourie et. al., 2012).

Hence, no system of classification or no attempt to identify the significant engineering characteristics can succeed if not based on appreciation of tropical weathering process (Gidigasu M.D., 1976).

3.6. COMPACTION TESTS AND ITS PARAMETERS

3.6.1. Compaction and its Application

Compaction is a process whereby a soil is densified by expending energy on it. At low water contents the resistance of the soil to compression and deformation is relatively high. The air-filled void spaces are interconnected and air can freely leave the soil.

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 & Simmons, 2012).

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 that are affected by wetting and drying (Blight & Simmons, 2012).

3.6.2. Effect of Pre-treatment Conditions (Drying)

It is essential to avoid drying of a soil destined for compaction testing between taking the sample in the borrow pit and conditioning it in the laboratory for compaction testing (Blight & Simmons, 2012).

Samples shall represent the actual site conditions. Drying by air, sun or oven greatly affects the engineering properties of the soil, in order to simulate the actual site conditions, it is better to air dry the sample or drying by sun for one to two days.

3.6.3. Effect of Compactive Effort

An increase of compactive effort from standard compaction to modified compaction caused the increase of MDD values and the decrease of OMC values. This may be true particularly in cases where the breakdown of particles is insignificant. However, additional compaction energy above the maximum density would be damaging to particles as breakdown may occur to cause a decrease in density (Quadros & Ndimbo, 2011).

3.6.4. Effect of Repeated Compaction (Ductility)

Samples should be stored in sealed plastic buckets and never be re-compacted to produce a compaction curve. Use a fresh sample for each point in the curve (Blight & Simmons, 2012).

Where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, and in cases where the soil is heavy textured clayey material in to which it is difficult to incorporate water, a separate and new sample shall be used in each compaction test (AASHTO, 2004).

3.6.5. Effect of Depth (Laterization)

The increase in maximum dry densities and decrease in optimum moisture content down the horizon signifies that down the horizon, the soil becomes more suitable for use as a sub-grade and sub-base material for road construction works, because the higher the maximum dry density the more well graded, coarse and granular the soil will be (Efeoghene et. al., 2016).

3.6.6. Proctor Compaction Test

Proctor compaction approach can be applied to many TWR soils in the same way as it can to sedimentary soils; at the same time the characteristic of some TWR soils make its application very difficult. Some rethinking of conventional wisdom is called for, with the possible adoption of alternative approaches. Among these characteristics are the following:

a) Residual soils are often much more variable than sedimentary soils, so that there is a continuous and random variation of OMC and MDD throughout the soil.

b) The natural water content of some TWR soils, especially those of volcanic origin, is often substantially higher than the optimum water content, and climatic conditions didn’t allow the soil for drying. At the same time, it is true that many TWR soils have natural water contents close to, or even below, their optimum water content and can be satisfactorily compacted without significant drying.

c) The highly structured nature of some TWR soils tends to be destroyed by normal compaction methods so that the soil becomes progressively softer during the compaction process.

d) Some residual soils do not show clear peaks of dry density during conventional compaction tests, and thus do not have clearly defined OMCs (Wesley, 2010).

The simplicity and widespread use of use of the proctor compaction test has possibly tended to blind the profession to the possibly of using parameters other than dry density and water content. It is important to recognize that the compaction of soil using mechanical methods (whether in the laboratory or the field) is likely to have two effects, one of which is not an intended effect and is not compaction at all. These effects are:

a) “Densifying” the soil, that is, pushing the particles closer together and squeezing out air trapped between the particles.

b) Remolding the soil, causing it soften. This involves the destruction of structure and is usually accompanied by the release of water trapped within or between the particles, adding to the softening process (Wesley, 2010).

Chapter 4

Laboratory Test Results and Discussion

4.1. INDEX PROPERTY TESTS

4.1.1. Moisture Content

It is known that some types of tropical residual soils had structural water or water of hydration in between the particles. During determination of moisture content, the soil shall be dried at a temperature of 110 ± 5°C (AASHTO, 1993; ASTM, 1998), but in practice the soil to be compacted is not exposed for such amount of temperature. Then to get the actual moisture content for engineering performance, we shall simulate the actual condition.

The compacted soil on site is supposed to be air dried and sun dried by considering a maximum temperature of 50°C.Then by preparing two sub samples from each samples; the first will be performed using AASHTO or ASTM testing procedure by drying to a temperature of 110 ± 5°C at oven; and the second by drying the sample on air or at a temperature of 50°C at oven with RH 30% for successive days until the change in weight between successive days becomes negligible. By comparing the above two moisture contents if the result varies 4-6% or more, it shows there is loosely bound structural water with in the samples. If the variation is below 4% it shows that the soil doesn't have loosely bound structural water, else, there is a structural water which can alter the engineering performance then to address the effect of loosely bound structural water all upcoming moisture content determinations will be done by drying the sample on air or at a temperature of 50°C at oven with RH 30% (Fourie et al., 2012).

Using Fourie et al., (2012) recommendation two sub samples for each sample were taken. Then, the first samples dried at temperature of 110 ± 5^{o}C using drying oven and the following results recorded through ASTM D 2216-98 test approach as shown on Table 4.1. The second samples dried at a temperature of 50^{o}C with 30% RH at 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°C oven temperature drying

Sample location	Weight of can, a(gm)	Weight of wet soil + can, b(gm)	Weight of dry soil + can, c(gm)	Weight of moisture loose, =b-c(gm)	Weight of dry soil, =c-a(gm)	Moisture content (%)
A-1.5	34.5	161.2	129.8	31.4	95.3	32.9%
A-4	31.5	153.4	122.3	31.1	90.8	34.3%
B-1.5	31.5	163.9	131.2	32.7	99.7	32.8%
B-4	32.8	166.1	131.9	34.2	99.1	34.5%
C-1.5	32.0	158.5	121.0	37.5	89.0	42.1%
C-4	33.0	153.4	114.8	38.6	81.8	47.2%
D-1.5	32.4	164.2	128.6	35.6	96.2	37.0%
D-4	34.4	158.4	124.3	34.1	89.9	37.9%
E-1.5	34.9	150.6	121.1	29.5	86.2	34.2%
E-4	32.0	162.4	128.5	33.9	96.5	35.1%

Table 4 - 2. Moisture Content at 50°C oven temperature drying with 30%RH

Sample location	Weight of can, a(gm)	Weight of wet soil + can, b(gm)	Weight of dry soil + can, (gm), on 7th days	Weight of moisture loose, =b-c(gm)	Weight of dry soil, =c-a(gm)	Moisture content (%)
A-1.5	949.90	1078.20	1047.10	31.10	97.20	32.0%
A-4	906.00	1101.30	1053.40	47.90	147.40	32.5%
B-1.5	948.00	1082.34	1050.55	31.79	102.55	31.0%
B-4	944.00	1300.00	1214.72	85.28	270.72	31.5%
C-1.5	1260.80	1394.20	1356.43	37.77	95.63	39.5%
C-4	943.40	1129.10	1072.00	57.10	128.60	44.4%
D-1.5	1147.60	1354.65	1300.29	54.36	152.69	35.6%
D-4	1204.50	1480.21	1405.90	74.31	201.40	36.9%
E-1.5	1253.20	1475.10	1420.29	54.81	167.09	32.8%
E-4	908.70	1134.60	1077.41	57.19	168.71	33.9%

The moisture content variations between drying at 50℃ and 110℃ is illustrated and summarized in Table 4.3 below.

Table 4 - 3. Variation of moisture between drying on 50℃ and 110℃

Sample Location	Moisture Content at 110℃ in %	Moisture Content at 50℃ in %	Variation (%)
A-1.5	32.9%	32.0%	0.9%
A-4	34.3%	32.5%	1.8%
B-1.5	32.8%	31.0%	1.8%
B-4	34.5%	31.5%	3.0%
C-1.5	42.1%	39.5%	2.6%
C-4	47.2%	44.4%	2.8%
D-1.5	37.0%	35.6%	1.4%
D-4	37.9%	36.9%	1.0%
E-1.5	34.2%	32.8%	1.4%
E-4	35.1%	33.9%	1.2%

From the result the maximum variation is 3.0% which is less than 4%, which means the soil in and around Bure town doesn’t have significant amount of loosely bound structural water. Hence, all the upcoming moisture content determination can be done by drying at oven temperature of 110± 5°C for all samples.

The moisture content at 4.0m depth is greater than the moisture content at 1.5m since it is prone to ground water and far from evaporation lose. Besides the voids increases downward the depth helps the particles to contain water on the void space.

4.1.2. Specific Gravity

Since more percentage of the sample is fine grained, the specific gravity test was performed using ASTM D 854-98, Method B testing procedures by using as-received soils. For as-received soil samples the dry mass of the soil is measured by drying the specimen at oven temperature of 110± 5°C after conducting specific gravity test.

Table 4 - 4. Specific Gravity values

Sample location	Average Specific Gravity Value (As-Received)
A-1.5	2.81
A-4	2.88
B-1.5	2.80
B-4	2.85
C-1.5	2.67
C-4	2.72
D-1.5	2.92
D-4	3.01
E-1.5	2.75
E-4	2.81

For the whole experiment the specific gravity values obtained using as received samples ranges from 2.67 to 3.01. The results from test pit A, B, C and E lies between 2.67 and 2.88 which is around 2.7 (average value for sedimentary soils), while the results from test pit D (2.92 and 3.01) are much higher. This increment in specific gravity is due to the internal soil texture, geological origin and grain size. Downward the depth specific gravity increases due to the presence of hard concretionary particles available.

4.1.3. Grain Size Analysis (Particle Size Distribution)

Grain size distribution of the soil samples as a fraction of clay, silt, sand and gravel is indicted below in table 4.5; conducted through wet sieving method using ASTM D-2217-85 for sample preparation and ASTM D 422-63 for testing. During grain size analysis it is necessary to evaluate the specific gravity since grain size distribution is much dependent on specific gravity.

It is known that for laterites, coarser fraction is iron rich and fine fraction is kaolinite. The coarser fraction which is rich 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 fraction 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 case of Bure town, the specific gravity ranges from 2.67 to 3.01, almost it represents similar packing arrangement for a soil of constant specific gravity. No modification of grain size analysis is needed since the samples had near to similar specific gravity values.

Table 4 - 5. Particle size distribution by wet sieving (ASTM 422-63)

Sample location	Clay content (%)	Silt content (%)	Sand content (%)	Gravel content (%)
A-1.5	82.1	16.3	1.6	0.0
A-4	79.4	15.8	4.8	0.0
B-1.5	83.5	15.9	0.6	0.0
B-4	76.8	14.8	8.4	0.0
C-1.5	60.6	31.3	8.1	0.0
C-4	58.7	28.9	12.4	0.0
D-1.5	23.8	19.2	57.0	0.0
D-4	7.1	9.0	77.7	6.2
E-1.5	83.1	14.9	2.0	0.0
E-4	80.3	16.8	2.9	0.0

The soils from test pit A, B, C and E are fine grained soils whereas samples from test pit D are coarse grained soils.

Laterization and decomposition affects the size of the soil particles. When depth increases laterization and decomposition decreases and the soil particles remains coarser. During hydrometer analysis (Sedimentation process) using a diluted solution of sodium hexametaphosphate dispersing agent with mechanical stirrer helps to eradicate the problem of flocculation on clay particles

4.1.4. Atterberg Limits

Atterberg limit can be done in two methods; dry to wet method and wet to try method. Tropical residual soils can be easily affected by drying and manipulation, so it is better to take as-received sample and using wet to dry method. For this work, after soaking in water for 24 hours, a soil is washed by 0.425mm sieve and allowed to dry until it gets a consistency which is comfortable to liquid limit test. The test is conducted through

ASTM D 4318 – 98 testing procedure using multi point test and wet to dry method. Since tropical residual soils are sensitive to handling and manipulation, to reduce this effect the specimens are mixed for a mixing time of not more than five minutes by using a new specimen for each experiment trial.

Table 4 - 6. Atterberg limit values using as-received sample

Sample Location	Liquid Limit, LL	Plastic Limit, PL	Plastic Index, PI
A-1.5	51.0	36.0	15.0
A-4	58.9	38.0	20.9
B-1.5	52.1	35.3	16.8
B-4	57.9	37.4	20.5
C-1.5	54.7	41.5	13.2
C-4	63.1	32.6	30.5
D-1.5	56.4	38.3	18.1
D-4	50.0	34.6	15.4
E-1.5	54.3	35.3	19
E-4	55.8	35.9	19.9

The LL values ranges from 50.0 to 63.1 and the PL values ranges from 32.6 to 41.5 while the PI values ranges from 13.2 to 30.5. All the test pits had related LL, PL and PI but the values from test pit C shows unpredicted and special values.

On USCS plasticity chart the results from all test pits lie below the A-line and at the right side of 50% LL which shows all the soils in Bure town are highly plastic silts. However, a soil from test pit D at a depth of 1.5m and 4.0m depth are low plastic soil (sand). This supports the conclusion for coarse-grained soils, particle size gives a good indication of properties.

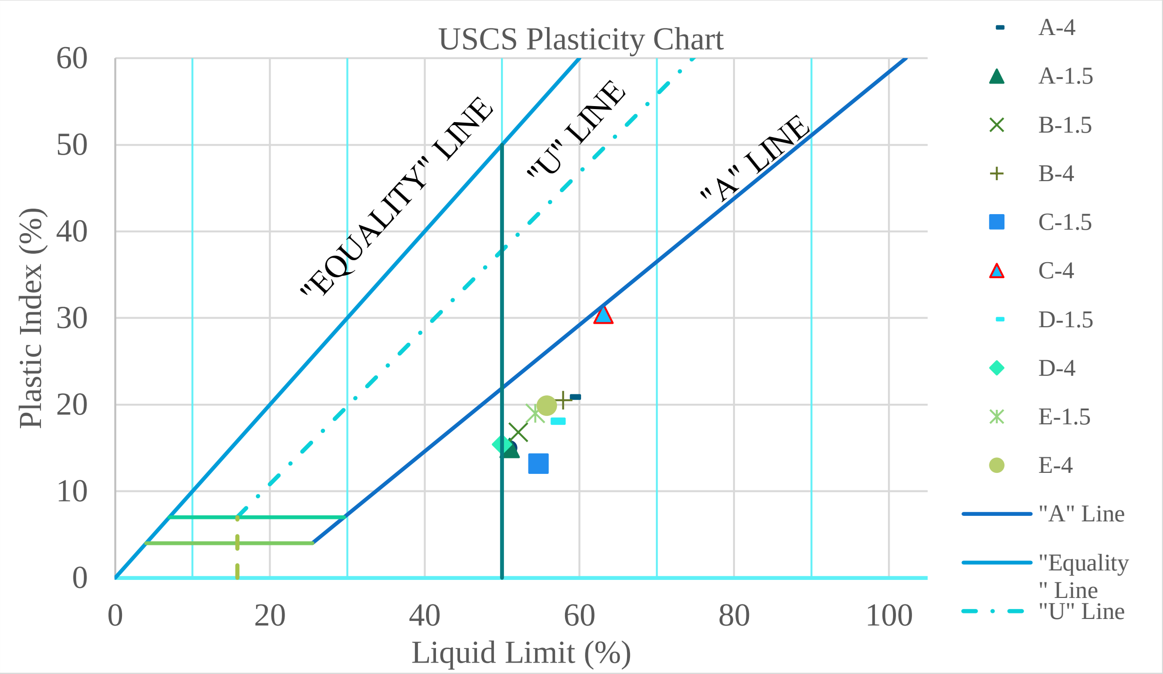


Figure 4 - 1. LL and PI on USCS plasticity chart

For test pit A, B, C and E the grain size analysis indicates that the soils are clay but the plasticity chart shows the soils are highly plastic silts; this supports the conclusion of for fine-grained soils particle size distribution is an unreliable indicator of properties.

Test pit D had lower Atterberg limit values when compared with the remaining soil samples. This is because of Soils from pit D is much coarser than the remaining samples. Decomposition and disintegration of coarser particles in to fine particles increase the plasticity value from low to high. The soil Atterberg limit increases when its plasticity increases.

4.1.5. Linear Shrinkage Limit

Linear shrinkage limit is done to determine shrinkable amount of the soil samples. According to test method (BS) 1377-2:1990; after leveling the soil along the top of the mould, Place the mould where the soil/water can air dry slowly in a position free from draughts until the soil has shrunk away from the walls of the mould. Then complete the drying, first at a temperature not exceeding 65 °C until shrinkage has largely ceased, and then at 105 °C to 110 °C to complete the drying. Calculate the linear shrinkage of the soil as a percentage of the original length of the specimen, Lo (in mm), from the equation:

Percentage of linear shrinkage = $(1-\frac{L_D}{L_O})*100$ [4 – 1]

Where L_D is the length of the oven-dry specimen (in mm).

Table 4 - 7. Linear shrinkage value using as-received samples

Sample Location	Linear Shrinkage (%)
A-1.5	8.5
A-4	8.8
B-1.5	8.9
B-4	9.0
C-1.5	11.2
C-4	11.0
D-1.5	7.5
D-4	7.3
E-1.5	8.6
E-4	8.7

The linear shrinkage values for sandy soil of test Pit D is much lower than the remaining test pits while the linear shrinkage values of test pit C are much higher than the others.

4.1.6. Free Swell

Free Swell is the increase in volume of a soil, without any external constraints, on submergence in water by a cylinder to confine laterally. Using IS: 2720 (Part 40) 197 test method, oven dried samples passing through 0.425mm sieve will be poured in to cylinder and submerged in water and record initial height of soil samples. After 24 hours soaking measure the final height of the sample. Then

Free swell (%) = $((H_f - H_i)/ H_i)*100$ [4 – 2]

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

H_i = initially measured height

Table 4 - 8. Free swell value using Oven dried samples

Sample Location	Free Swell (%)
A-1.5	28
A-4	18
B-1.5	30
B-4	24
C-1.5	24
C-4	28
D-1.5	20
D-4	18
E-1.5	28
E-4	20

From all the test specimens the maximum swelling potential is 30% which is less than 50%, a limiting value for expansiveness based on Alemayehu and Mesfin (1999) recommendation. Based on the result the soils investigated are non-expansive.

4.1.7. Activity Number

Activity number is the ratio of the plasticity index of the soil to the percent by weight of particles having an equivalent diameter smaller than 0.002mm. Alemayehu and mesfin (1999) suggests a soil with activity number < 0.75 is inactive clay and between 0.75 and 1.25 is normal clay while a soil with activity number > 1.25 is referred as active clay.

Table 4 - 9. Activity number with degree of activity

Activity number	Degree of activity
<0.75	Inactive clay
0.75-1.25	Normal clay
>1.25	Active clay

Table 4 - 10. Activity number values

Sample Location	Plasticity Index, PI (%)	Clay fraction (%)	Colloidal Activity, AC	Remark
A-1.5	15.0	64.3	0.23	Inactive clay
A-4	20.9	62.6	0.33	Inactive clay
B-1.5	16.8	65.7	0.26	Inactive clay
B-4	20.5	58.4	0.35	Inactive clay
C-1.5	13.2	32.8	0.40	Inactive clay
C-4	30.5	29.9	1.02	Normal clay
D-1.5	18.1	13.1	1.38	-
D-4	15.4	5.2	2.96	-
E-1.5	19	66.7	0.28	Inactive clay
E-4	19.9	53.2	0.37	Inactive clay

The samples from test pit D cannot be classified on this classification because of this classification is applicable for fine grained soils. The soil from test pit C at a depth of 4.0m excavation is normal clay while the remaining samples are inactive clay.

4.1.8. Classification of soil

Soil description/identification is the systematic, precise, and complete naming of individual soils in both written and spoken forms (AASHTO M 145, ASTM D-2488), while soil classification is the grouping of the soil into a category; e.g., group name and symbol (AASHTO M 145, ASTM D-2487).

4.1.8.1. Unified Soil Classification System

USCS is a system for classifying mineral and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit and plasticity index and shall be used when precise classification is required. USCS first classifies the soil by grain size analysis of whether passing or retained on 0.075mm sieve. Then it uses grain size analysis for coarse grained soils while it uses Atterberg limits for fine grained soil classification.

Table 4 - 11. Classification of Soil According USCS

Sample location	Sample Depth (m)	LL (%)	PI (%)	Percentage passes		Group Symbol	Group Name
				0.075mm	4.75mm		
A-1.5	1.5	51.0	15.0	98.4	100	MH	Elastic silt
A-4	4.0	58.9	20.9	95.2	100	MH	Elastic silt
B-1.5	1.5	52.1	16.8	99.4	100	MH	Elastic silt
B-4	4.0	57.9	20.5	91.6	100	MH	Elastic silt
C-1.5	1.5	54.7	13.2	91.9	100	MH	Elastic silt
C-4	4.0	63.1	30.5	87.6	100	MH	Elastic silt
D-1.5	1.5	56.4	18.1	43	100	SM	Silty Sand
D-4	4.0	50.0	15.4	16.1	93.8	SM	Silty Sand
E-1.5	1.5	54.3	19	98	100	MH	Elastic silt
E-4	4.0	55.8	19.9	97.1	100	MH	Elastic silt

The soils from test pit A, B, C and E 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 test pit A, B, C and E 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 pit A, B, C and E are inorganic soils. The final evaluation is based on the location of PI and LL on USCS plasticity chart. A line referred as “A” line with an equation PI = 0.73 (LL-20) is a separating line between clay soils and slit soils. All the soils from test pit A, B, C and E fall below this “A” line; which shows the soils are classified as group symbol of “MH” and group name of “Elastic Silt”.

The soils from test pit D 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 pit D the percentage retained on 4.75mm sieve < 50% and classified as Sands. The third evaluation is based on the available percentage of fines with in the sands, for test pit D soils there have been more than 12% fines available, and the soils from test pit D are categorized as sands with fines. The final evaluation is based on the location of PI and LL on USCS plasticity chart. A line referred as “A” line with an equation PI = 0.73 (LL-20) is a separating line between clay soils and slit soils. The soils from test D fall below this “A” line; which shows the soils are classified as group symbol of “SM” and group name of “Silty Sand”.

4.1.8.2. AASHTO Classification System

AASHTO classifies soils and soil-aggregate mixtures for highway construction purposes in to seven groups and additional subgroups using particle size distribution, liquid limit and plasticity index values obtained from laboratory tests. Evaluation of soils with in each group is by means of group index, which is a value calculated from an empirical formula. The group classification, including group index should be useful in determining relative quality of the soil material for use in earth work structures, particularly embankments, subgrades, sub bases, and bases.

Table 4 - 12. Classification of soil according to AASHTO

Sample Location	Sample depth (m)	Passing 2mm	Passing 0.425mm	Passing 0.075mm	LL	PI	AASHTO	Group Index
A-1.5	1.5	100.0	99.3	98.4	51.0	15.0	A-7-5	51
A-4	4.0	100.0	98.4	95.2	58.9	20.9	A-7-5	77
B-1.5	1.5	100.0	99.9	99.4	52.1	16.8	A-7-5	57
B-4	4.0	100.0	98.6	91.6	57.9	20.5	A-7-5	71
C-1.5	1.5	100.0	98.1	91.9	54.7	13.2	A-7-5	56
C-4	4.0	100.0	96.5	87.6	63.1	30.5	A-7-5	87
D-1.5	1.5	98.0	86.2	43.0	56.4	18.1	A-7-5	10
D-4	4.0	39.6	24.5	16.1	50.0	15.4	A-2-7	0
E-1.5	1.5	100.0	99.6	98.0	54.3	19	A-7-5	65
E-4	4.0	100.0	99.2	97.1	55.8	19.9	A-7-5	69

AASHTO 145-91 and ASTM D 3282-93 (1997) are both prepared to address the classification soils and soil aggregate mixtures for highway construction purposes commonly named AASHTO soil classification system. 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 in to the desired soil group.

The soils from test pit A, B, C, E and D (at 1.5m depth excavation only) 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 test pit A, B, C, E and D (at 1.5m depth excavation only) 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, B, C, E and D (at 1.5m depth excavation only) had a PI which is less than LL minus 30, hence, the soils classified as A-7-5.

The soil from test pit D (at 4.0 m depth excavation only) had less than 35% by weight which passes 0.075mm and hence a soil from this pit is categorized under Granular materials. The second evaluation is based on percentage of passing 2.0mm, 0.425mm and 0.075mm; soil from test pit D (at 4.0 m depth excavation only) had 39.6, 24.5 and 16.1 percentage of passing respectively. Based on the percentage of passing the soil fall under a group of either A-1-b, A-2-4, A-2-5, A-2-6 or A-2-7. The final evaluation is using the liquid limit and plasticity index. Soil from test pit D (at 4.0 m depth excavation only) had LL = 50% and PI = 15.4% which is LL > 40% and PI > 10% leads the soil to be categorized under group classification A-2-7.

According to AASHTO a group index of 0 indicates as a good subgrade material and a group index of more than 20 indicates a very poor subgrade material. From the soils investigated in thesis work the soils from test pit D (With group index 10 and 0) is a good subgrade material while Soils from test pit A, B, C and E (with group index >20) are very poor subgrade materials.

4.1.8.3. Wesley Soil Classification System

Wesley (2009) classifies residual soils in to three major groups and eight sub groups by using soil composition and structure respectively as shown in Table 4.13 below.

Table 4 - 13. A Classification System for Residual Soils

Grouping System		**Common Pedological Names Used for Groups**
Major Group	**Sub Group**	
GROUP A **Soils without a strong mineralogical influence**	(a) Strong macro-structure influence	Miscellaneous
	(b) Strong micro-structure influence	Miscellaneous
	(c) Little or no structural influence	Miscellaneous
GROUP B **Soils strongly influenced by normal clay minerals**	(a) Smectite (montmorillonite) group	Black cotton soils
		Black soils
		Tropical black earths
		Grumusols
		Vertisols
	(b) Other clay minerals?	?
GROUP C **Soils strongly influenced by clay minerals essentially found only in residual soils**	(a) Allophane sub-group	Volcanic ash soils
		Andosols or Andisols
		Andepts
	(b) Halloysite sub-group	Tropical red clays
		Latosols
		Oxisols
		Feralsols
	(c) Sesquioxide sub-group -gibbsite, geoththite, Haematite	Lateritic soils
		Laterites
		Ferralitic soils
		Duricrusts

Classifying tropically weathered residual soils by using results from grain size analysis and Atterberg limit values leads to erroneous result, since those tests are widely affected by sample preparation. The specific characteristics of the tropically weathered residual soils are presence of unusual clay minerals, un weathered or partially weathered rock, planes of weakness, inter particle bonds and so on; which can be generalized as composition and structure of the soil. For the selected test pits the geochemical test result by silicate analysis test using LiBO2 Fusion, HF attack, Gravimetric, Colorimetric and AAS analytical method shows that the soils are true laterites and lateritic. The classification using Wesley soil classification system for the selected test pits are summarized in the following table.

Table 4 - 14. Classification of soil according to Wesley, 2009

Sample Location	Depth (m)	(SiO_2/ R_2O_3)	Major Group	Sub Group	Pedological name	Designation
A-1.5	1.5	1.09	C	(c)	True laterites	C (c)
A-4	4.0	1.07	C	(c)	True laterites	C (c)
C-1.5	1.5	1.12	C	(c)	True laterites	C (c)
C-4	4.0	1.61	C	(c)	Laterites	C (c)

Based on Wesley classification the soil from test pit A-1.5, A-4, C-1.5 and C-4 are categorized as True laterites and lateritic. Presence of Iron and aluminum oxides (sesquioxides) creates cementing agent with in particles which leads the formation clods and hard granules. The soils in Bure town are soil type which are strongly influenced by clay minerals essentially found only in residual soils; those minerals are Aluminum oxide and Iron oxide as shown on the geochemical analysis.

4.2. GEOCHEMICAL TESTS

4.2.1. General

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. Sesquioxides (a combination of aluminum oxide and iron oxide) had a major cementing effect which changes fine mineral constituents in to clusters and aggregations. Geochemical tests (Silicate analysis) helps to determine the available amounts oxides and hydroxides with in a soil sample as a percentage.

4.2.2. Laterites and Laterization

Laterites are usually highly weathered and altered residual soils, low in silica, that contain a sufficient concentration of the sesquioxides of iron and aluminum to have been cemented to some degree; and the process referred as laterization.

According to Desai (1985) degree of laterization is the ratio of silica (SiO_2) to Alumina (Al_2O_3). Based on the ratio unlateritized soils have SiO_2/Al_2O_3 greater than 2.0. For lateritic soils SiO_2/Al_2O_3 lies between 1.3 and 2.0 and for true laterites the ratio is less than 1.3.

Table 4 - 15. Oxides composition percentage (Using Silicate Analysis).

Sample Location	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
A-1.5	43.66	27.82	12.12	0.14	0.58	<0.01	0.60	0.10	0.16	0.40	4.18	10.56
A-4	41.38	25.74	13.02	0.16	0.54	0.12	0.52	0.14	0.13	0.44	5.06	11.32
C-1.5	39.72	26.86	8.72	0.86	2.08	0.20	0.10	0.04	0.07	0.51	12.17	9.69
C-4	46.64	20.56	8.46	0.96	3.00	0.20	<0.01	0.10	0.09	0.46	10.09	9.73

Blight and other authors prefer to use degree of laterization calculated by Silica - Sesquioxides, S-S ratio.

Degree of laterization,

$$\text{S-S ratio} = \frac{SiO_2}{R_2O_3} = \frac{SiO_2}{Fe_2O_3 + Al_2O_3} \qquad [4-3]$$

where

- If S-S ratio < 1.33 the soil classified as true laterites
- If S-S ratio is between 1.33 and 2.0 the soil classified as laterites
- If S-S ratio >2.0 the soil classified as non-lateritic tropically weathered residual soils

Table 4 - 16. Evaluation of laterization (Blight, 2012).

Sample location	**Depth**	SiO_2	Al_2O_3	Fe_2O_3	$R_2O_3 = Al_2O_3 + Fe_2O_3$	ratio = (SiO_2/R_2O_3)	**Remark**
A-1.5	1.5m	43.66	27.82	12.12	39.94	1.09	True laterites
A-4	4.0m	41.38	25.74	13.02	38.76	1.07	True laterites
C-1.5	1.5m	39.72	26.86	8.72	35.58	1.12	True laterites
C-4	4.0m	46.64	20.56	8.46	29.02	1.61	Laterites

Table 4 - 17. Evaluation of laterization (i.e. using Desai recommendation)

Sample location	**Depth**	SiO_2	Al_2O_3	ratio = $(SiO_2/Al_2O_3$	**Remark**
A-1.5	1.5m	43.66	27.82	1.57	Lateritic
A-4	4.0m	41.38	25.74	1.61	Lateritic
C-1.5	1.5m	39.72	26.86	1.48	Lateritic
C-4	4.0m	46.64	20.56	2.28	Unlateritized

Based on Lyon (1971) suggestion using Silica-Sesquioxides ratio all the test pits from soils are laterites and true laterites. And using Desai (1985) recommendation soils from test pit A-1.5, A-4.0 and C-1.5 are lateritic soils while soil from test Pit C-4 is unlaterized.

With increasing in depth, the geological nature of the soil in test Pit C is variable. The sample at a depth of 1.5m and 4.0m have different geological formation. Thus, it is not possible to compare the laterization of these soils.

On test Pit A when depth increases Silica and Alumina decreases while Iron oxide increases. Sometimes long term laterization may affect the content of such oxides through evaporation and leaching.

4.3. COMPACTION TESTS

4.3.1. Test Results

To investigate the effect of applied energy both standard effort compaction and modified effort compaction are using AASHTO T 99 - 97 (1999) and AASHTO T 180-95 test methods respectively. To simulate the actual site condition on the laboratory compaction the as-received sample exposed to sun light and air blow for one day. To represent the actual soil properties on the compaction each point had done by using afresh sample.

To realize the effect of depth (laterization) on the compaction of tropical residual soil samples are taken at 1.5m and 4.0m depths. Standard proctor compaction was performed using AASHTO T-99-97 (1999) method A test method using a mold of diameter 101.6mm with 2.5kg rammer and 305mm falling height.

Modified Proctor compaction performed using AASHTO T 180 – 95 method D test method to follow Ethiopian Road Authority requirement. The experiment was done using a mold of diameter of diameter 152.4mm with 4.54 kg rammer and 457mm falling height.

Table 4 - 18. Compaction data (Standard Proctor)

Sample Location	Moisture Content (%)	Dry Density (g/cm^3)
A-1.5	26	1.19
A-1.5	29	1.25
A-1.5	34	1.34
A-1.5	37	1.25
A-4	26	1.29
A-4	30	1.33
A-4	33	1.38
A-4	38	1.36
B-1.5	25	1.26
B-1.5	30	1.29
B-1.5	34	1.35
B-1.5	39	1.32
B-4	26	1.33
B-4	32	1.40
B-4	37	1.38
C-1.5	26	1.24
C-1.5	31	1.26
C-1.5	39	1.29
C-1.5	42	1.24
C-4	27	1.06
C-4	35	1.17
C-4	42	1.21
C-4	47	1.18
D-1.5	25	1.38
D-1.5	29	1.43
D-1.5	33	1.41
D-4	20	1.39
D-4	23	1.41
D-4	27	1.49
D-4	29	1.46
E-1.5	23	1.35
E-1.5	30	1.38
E-1.5	34	1.39
E-1.5	37	1.36
E-4	27	1.35
E-4	34	1.40
E-4	37	1.38

Table 4 - 19. Compaction Data (Modified Proctor)

Sample Location	Moisture Content (%)	Dry Density (g/cm^3)
A-1.5	25	1.33
A-1.5	30	1.44
A-1.5	33	1.41
A-1.5	38	1.32
A-4	25	1.39
A-4	32	1.46
A-4	34	1.43
B-1.5	26	1.35
B-1.5	32	1.42
B-1.5	37	1.33
B-4	25	1.40
B-4	31	1.45
B-4	35	1.42
C-1.5	28	1.32
C-1.5	33	1.34
C-1.5	36	1.30
C-1.5	40	1.25
C-4	29	1.07
C-4	38	1.29
C-4	42	1.26
D-1.5	23	1.43
D-1.5	26	1.45
D-1.5	27	1.50
D-1.5	28	1.45
D-4	19	1.54
D-4	21	1.59
D-4	24	1.61
D-4	27	1.56
E-1.5	24	1.34
E-1.5	30	1.45
E-1.5	36	1.38
E-4	25	1.38
E-4	31	1.46
E-4	35	1.41

4.3.2. Effect of Compaction Energy

For all test pits when the compactive energy increases from standard to modified the MDD increases while the OMC decreases. When the applied energy increases the void space reduces significantly which increases OMD and decrease OMC.

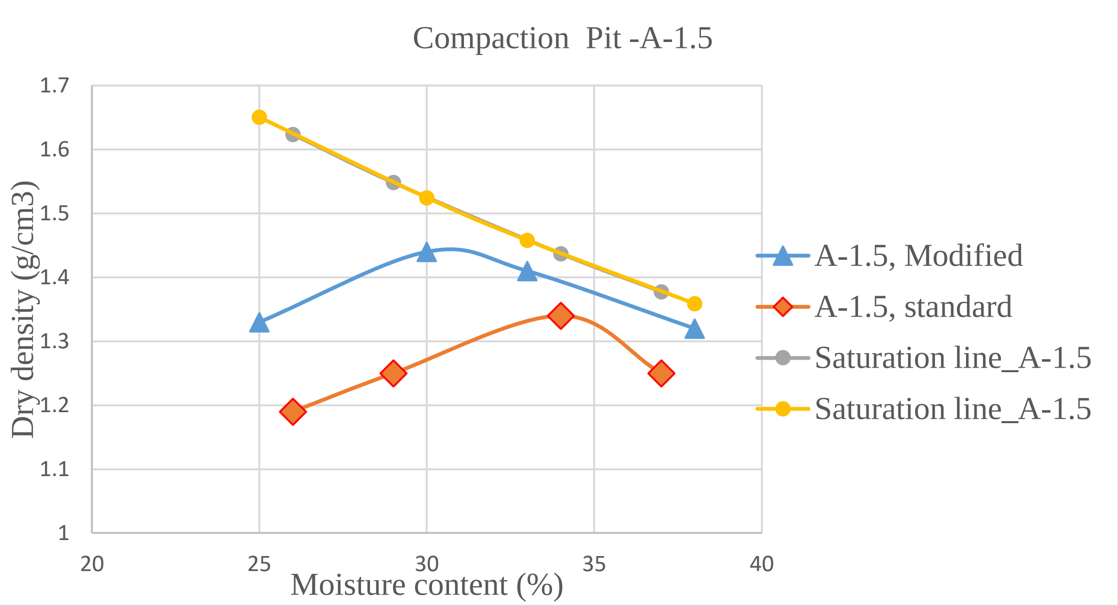


Figure 4 - 2. Effect of compaction energy on compaction, Pit – A-1.5

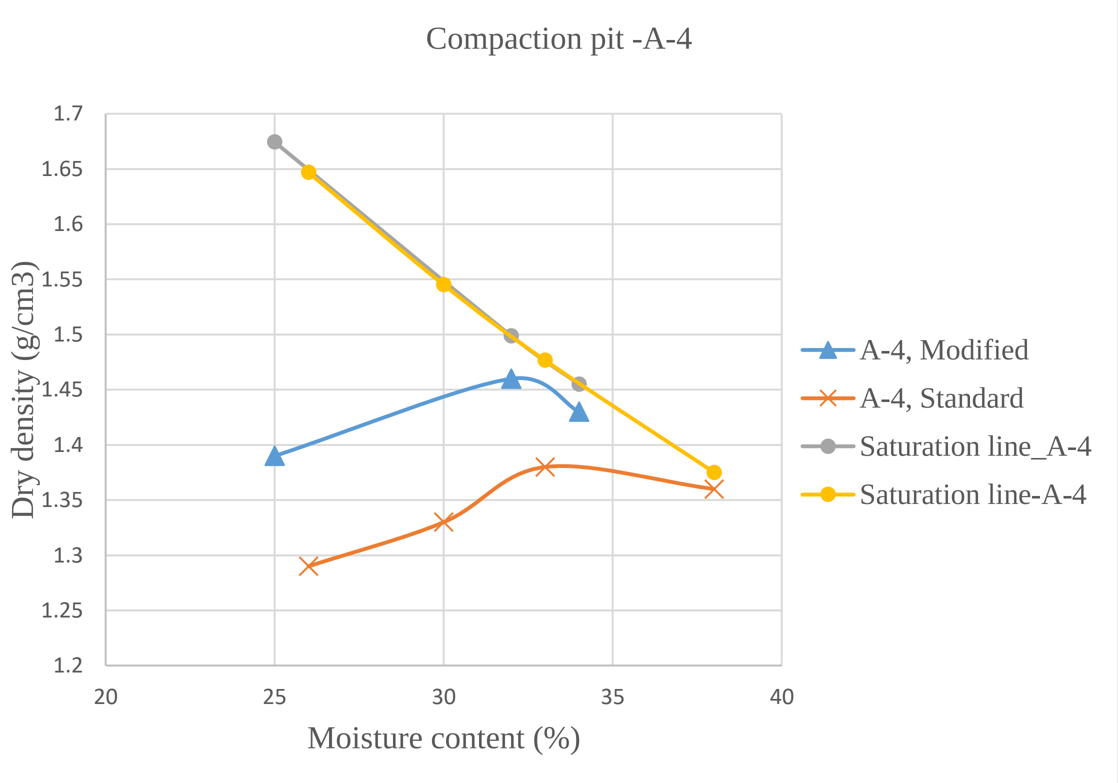


Figure 4 - 3. Effect of compaction energy on compaction, pit – A-4

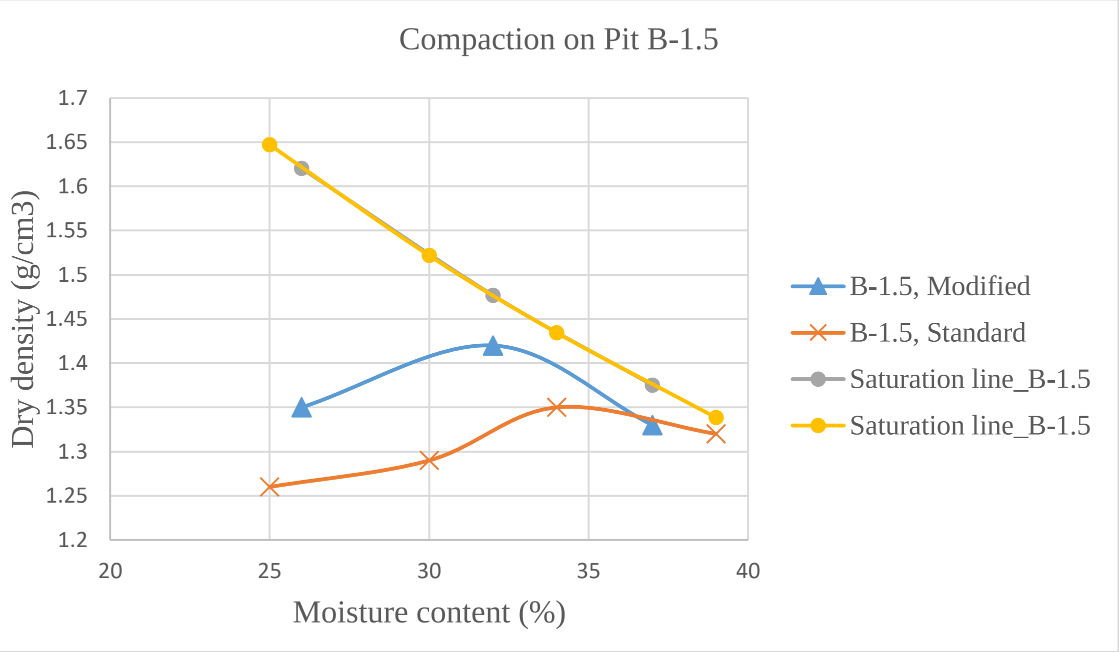


Figure 4 - 4. Effect of compaction energy on compaction, pit – B-1.5

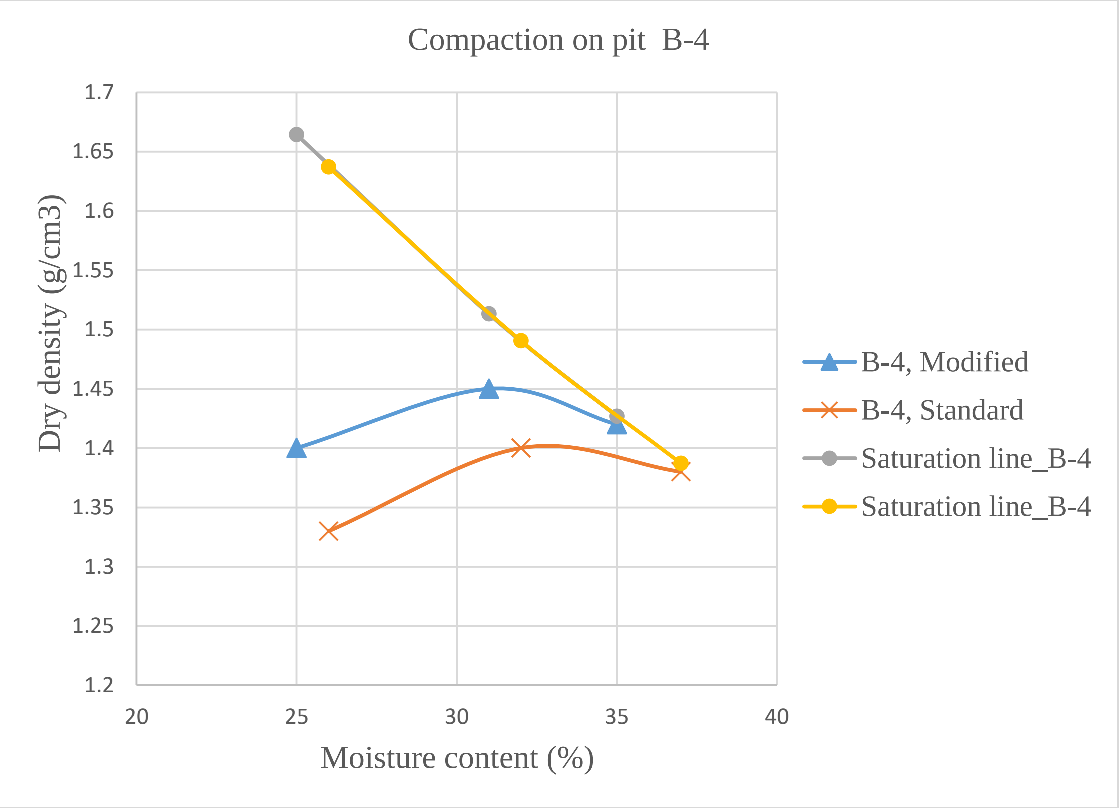


Figure 4 - 5. Effect of compaction energy on compaction, pit – B-4

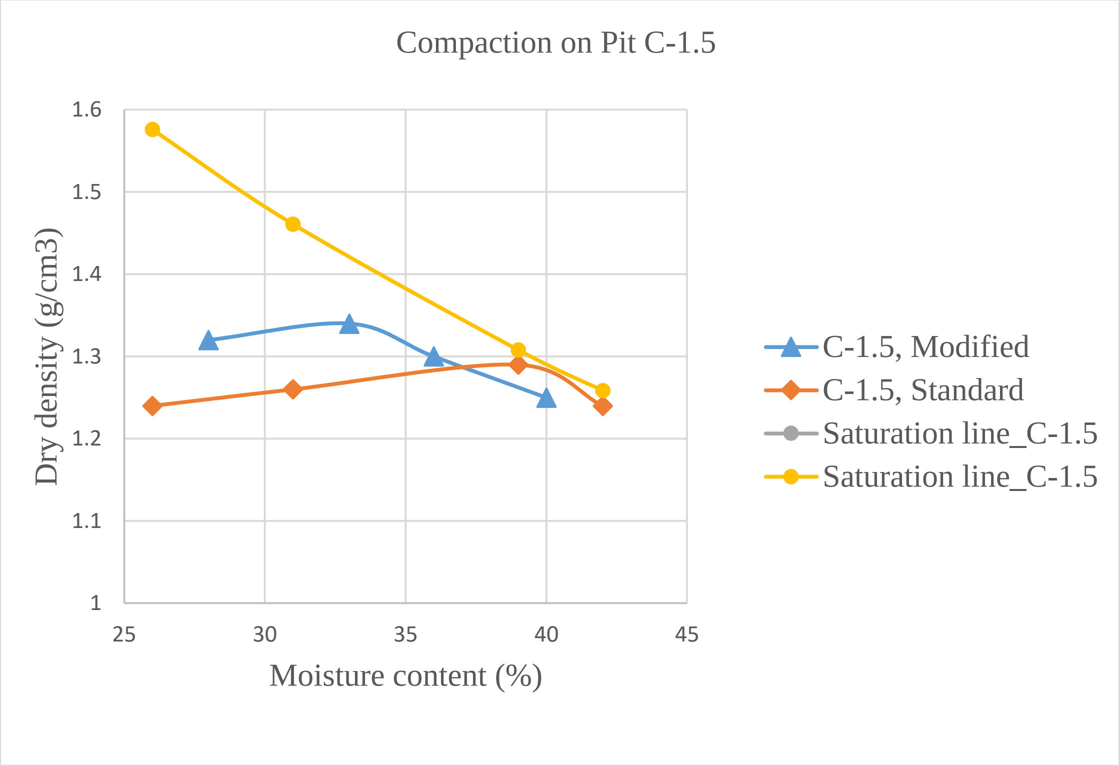


Figure 4 - 6. Effect of compaction energy on compaction, pit – C-1.5

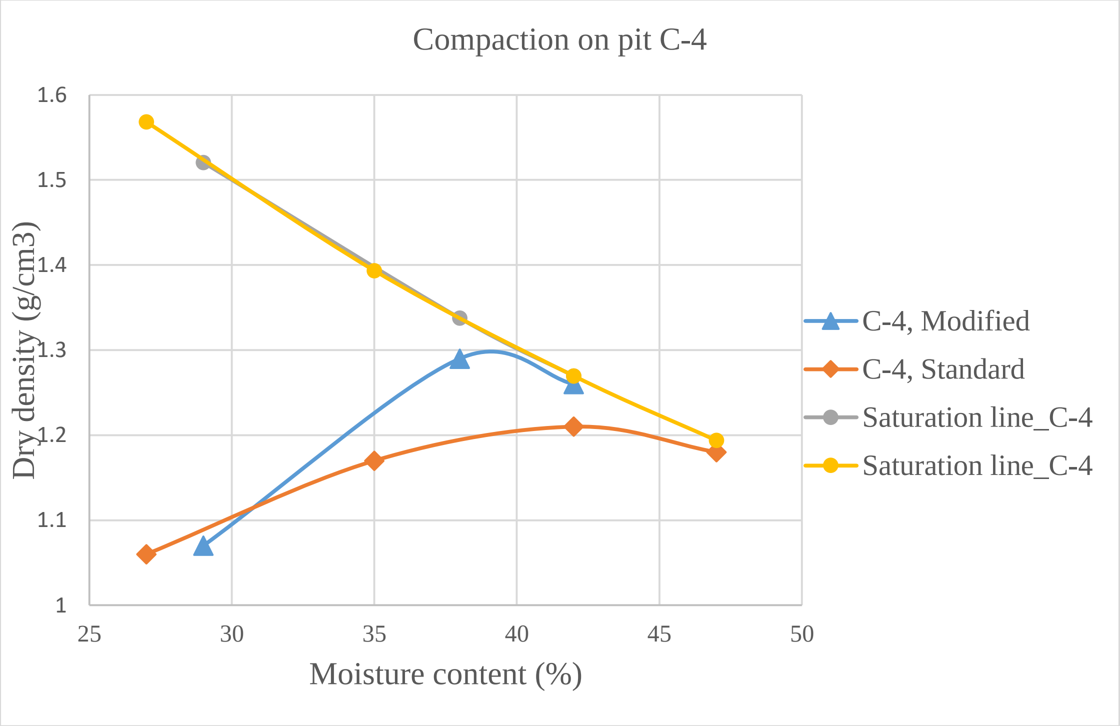


Figure 4 - 7. Effect of compaction energy on compaction, pit – C-4

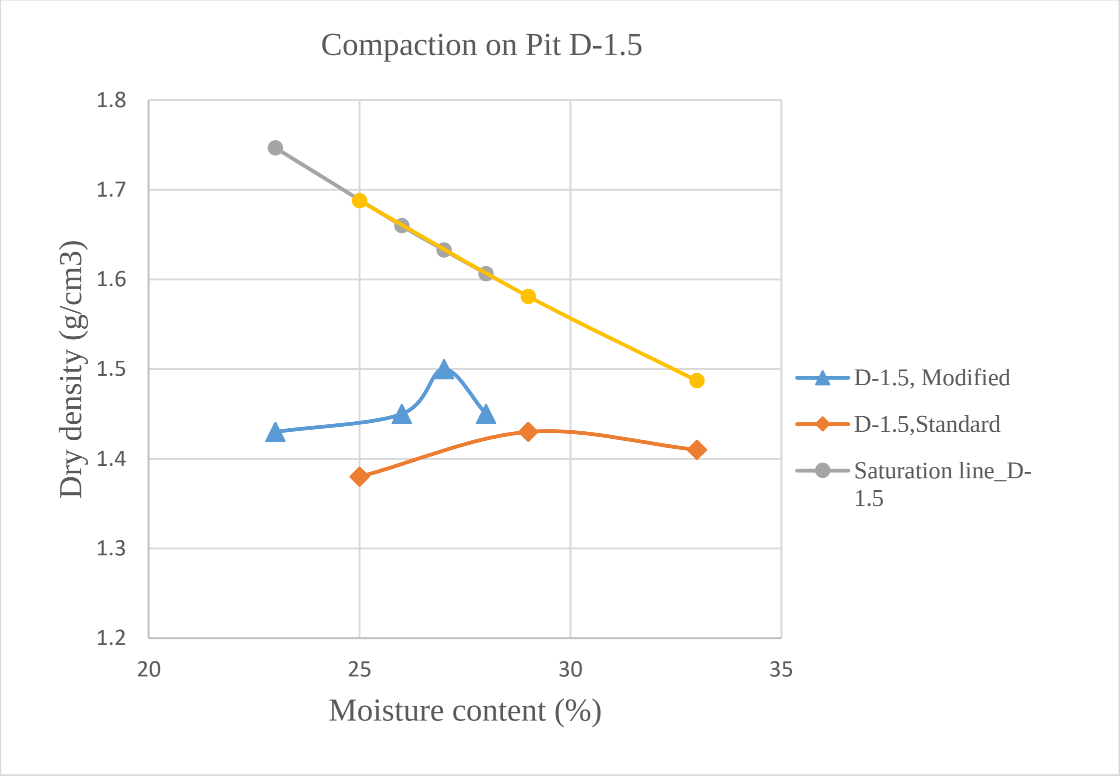


Figure 4 - 8. Effect of compaction energy on compaction, Pit – D-1.5

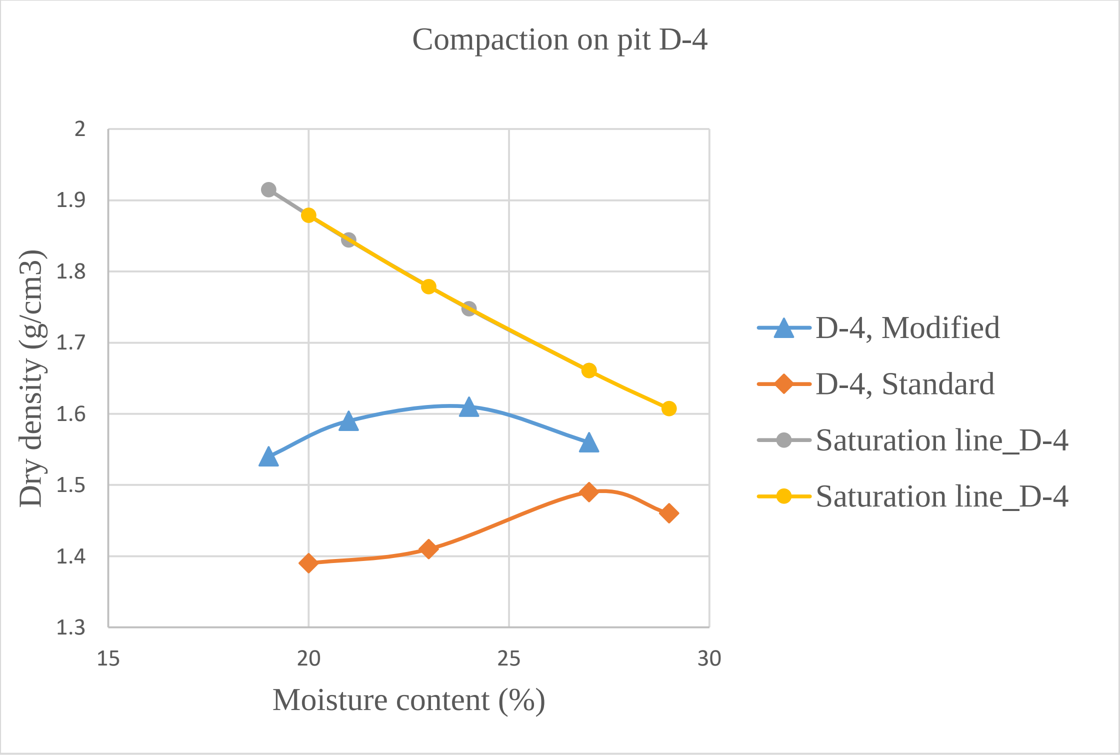


Figure 4 - 9. Effect of compaction energy on compaction, Pit – D-4

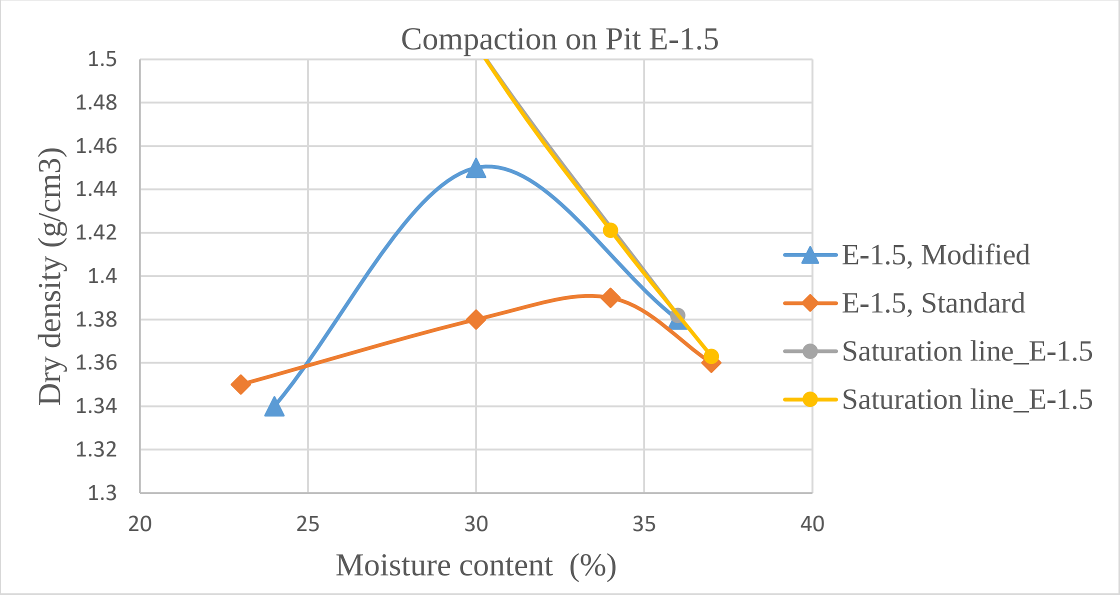


Figure 4 - 10. Effect of compaction energy on compaction, Pit – E-1.5

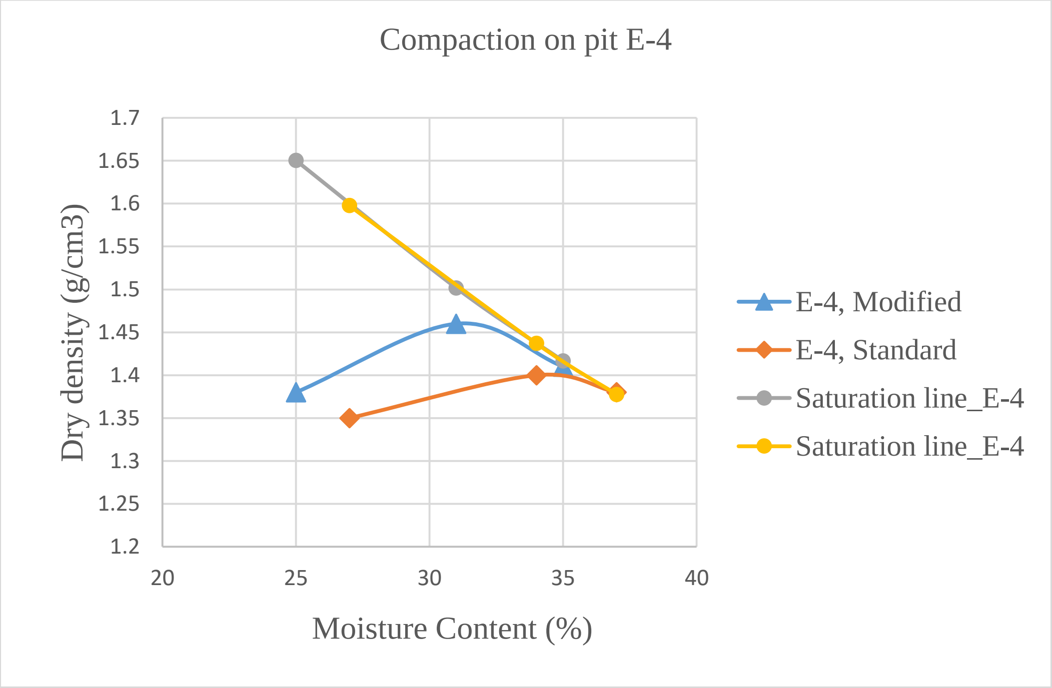


Figure 4 - 11. Effect of compaction energy on compaction, Pit – E-4

4.3.3. Effect of depth (laterization)

As shown on figure 4.12, 4.13, 4.15 and 4.16 both standard and modified compaction on test pit B, and D and only standard compaction on test pit A and E reveals, 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 accumulation of leached silica grain and percentage of hard concretionary particles increases through depth. Downward a depth a soil becomes coarser which result in reduction of surface area. This reduction in surface area influences by decreasing the OMC during compaction. Figure 4.12 and 4.16 shows only modified compaction on test pit A and E reveals, when depth increases down ward both MDD and OMC increases. For some TWR soils, as we go deep down laterization decreases and cementation between particles reduces which helps the water to pass and infiltrate between soil particles. This water increases the OMC during compaction.

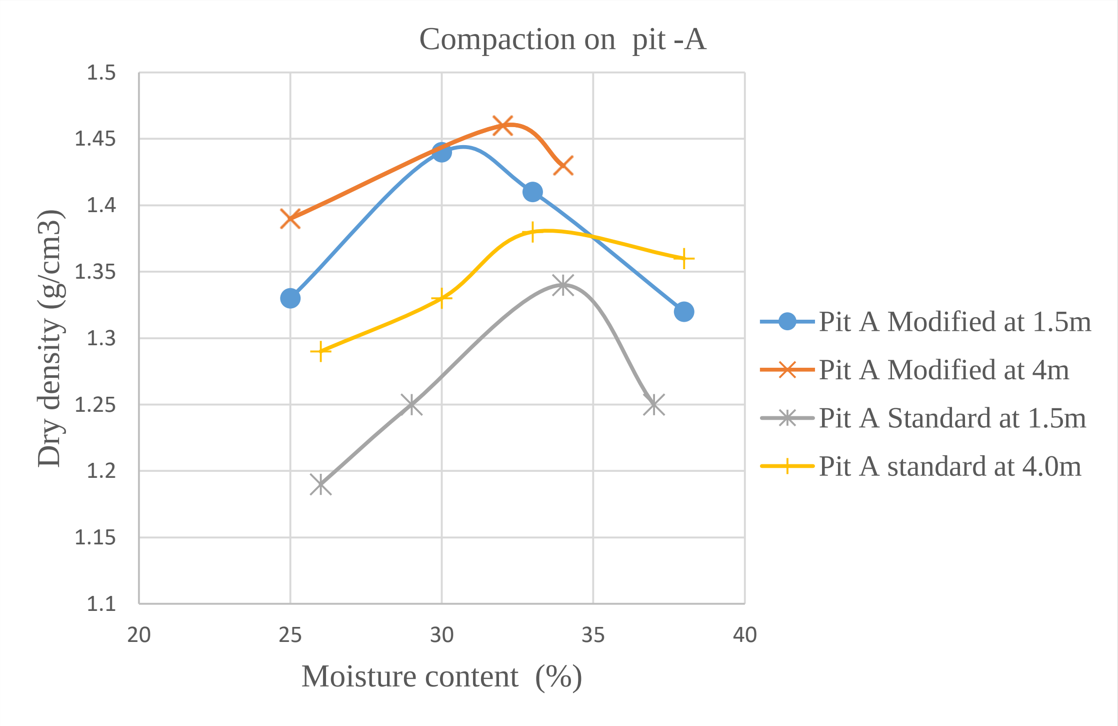


Figure 4 - 12. Effect of depth (laterization) on compaction, pit-A

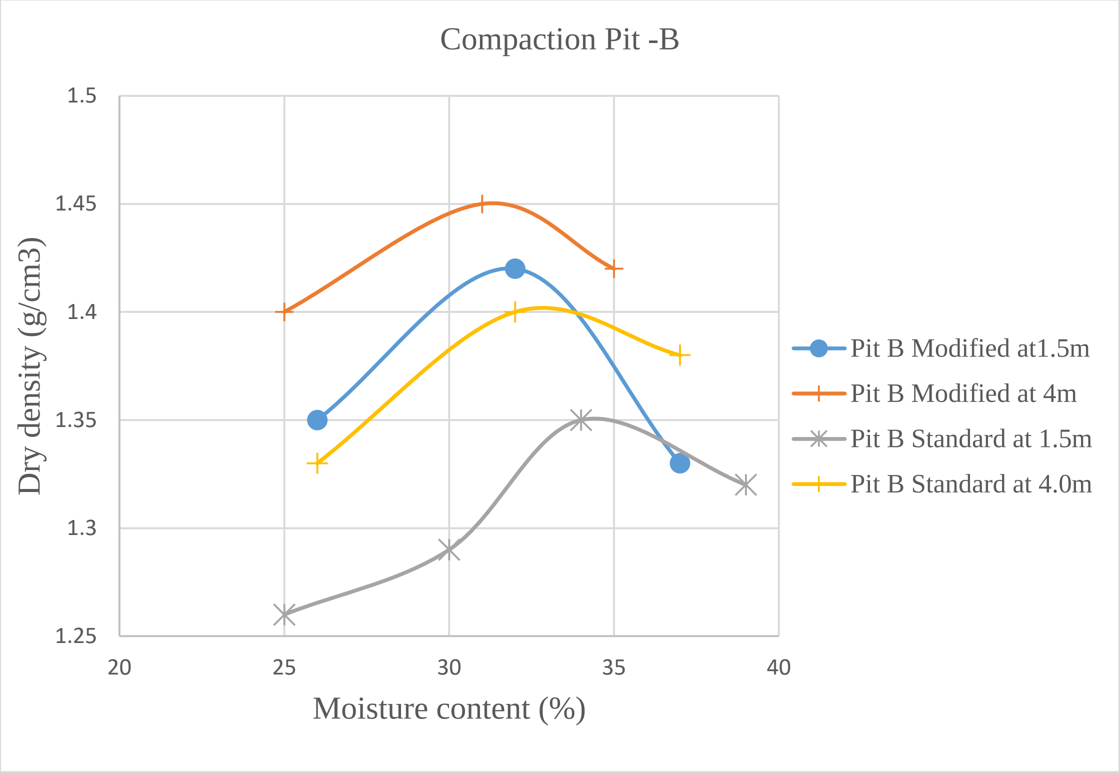


Figure 4 - 13. Effect of depth (laterization) on compaction, pit-B

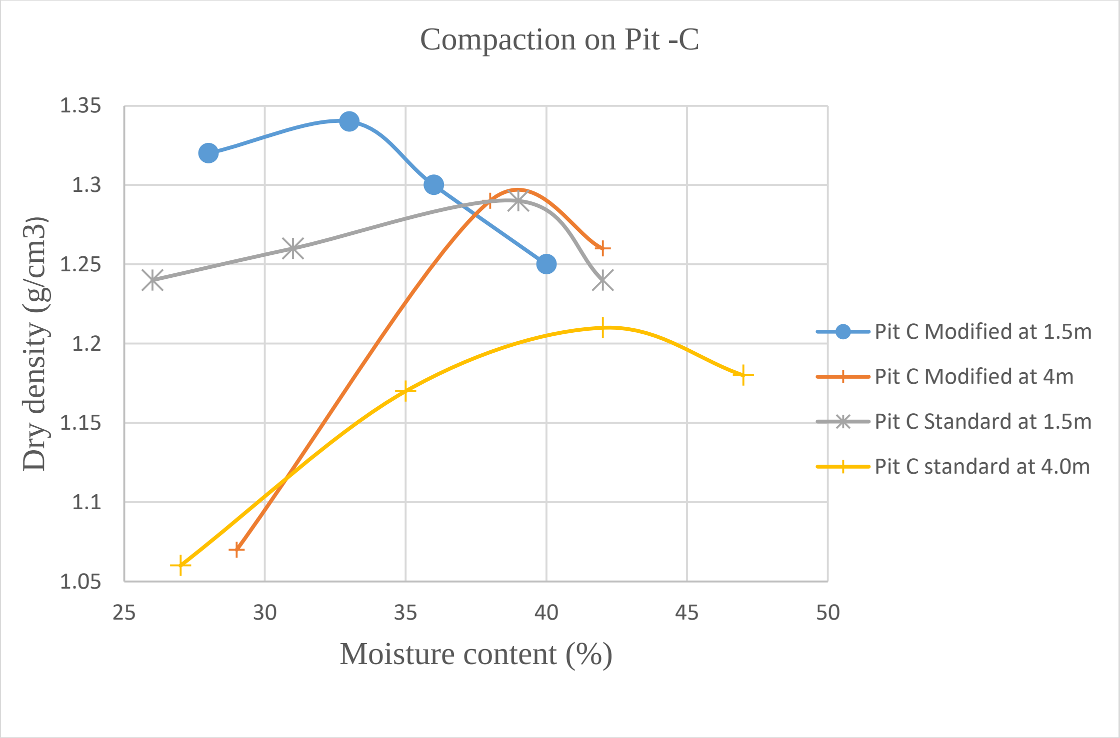


Figure 4 - 14. Effect of depth (laterization) on compaction, pit-C

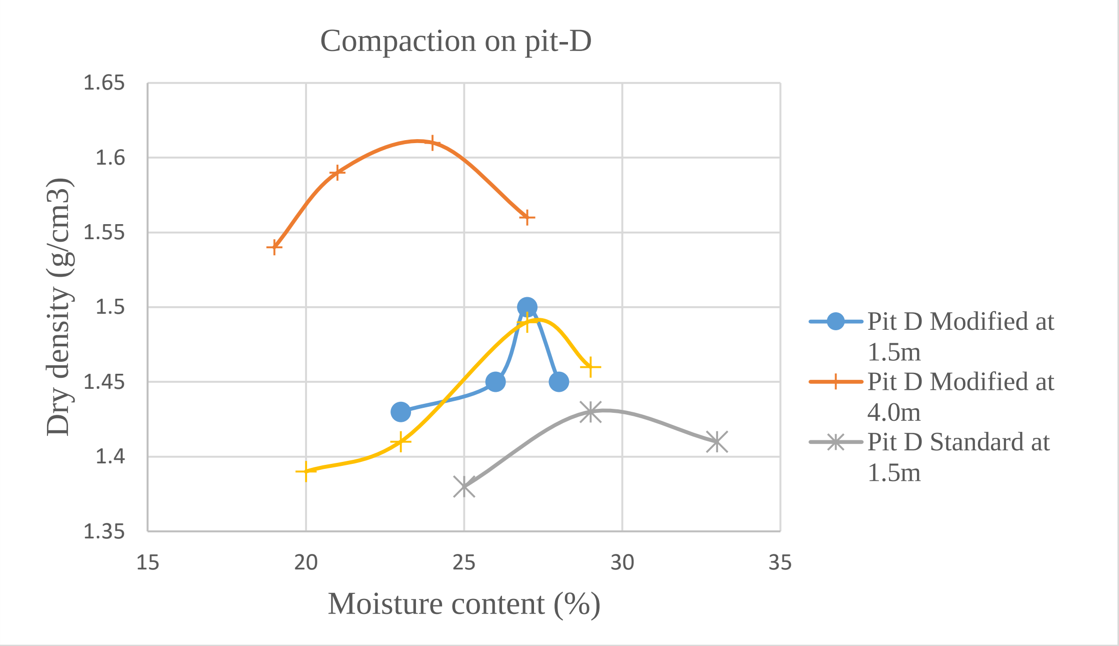


Figure 4 - 15. Effect of depth (laterization) on compaction, pit-D

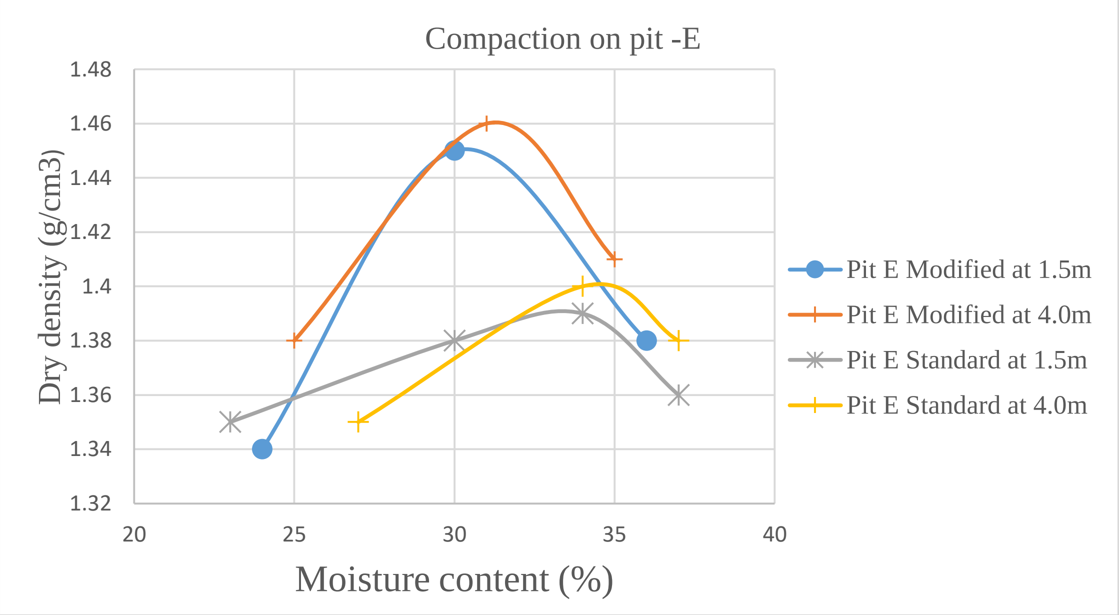


Figure 4 - 16. Effect of depth (laterization) on compaction, pit-E

As shown on Figure 4.14, both standard and modified compaction on test pit C reveals, when depth increases downward MDD decreases and OMC increases. During sampling the samples on test pit C at a depth of 1.5m and 4.0m excavation were different type of soils by their geologic origin. This geological origin difference results unexpected compaction result during testing.

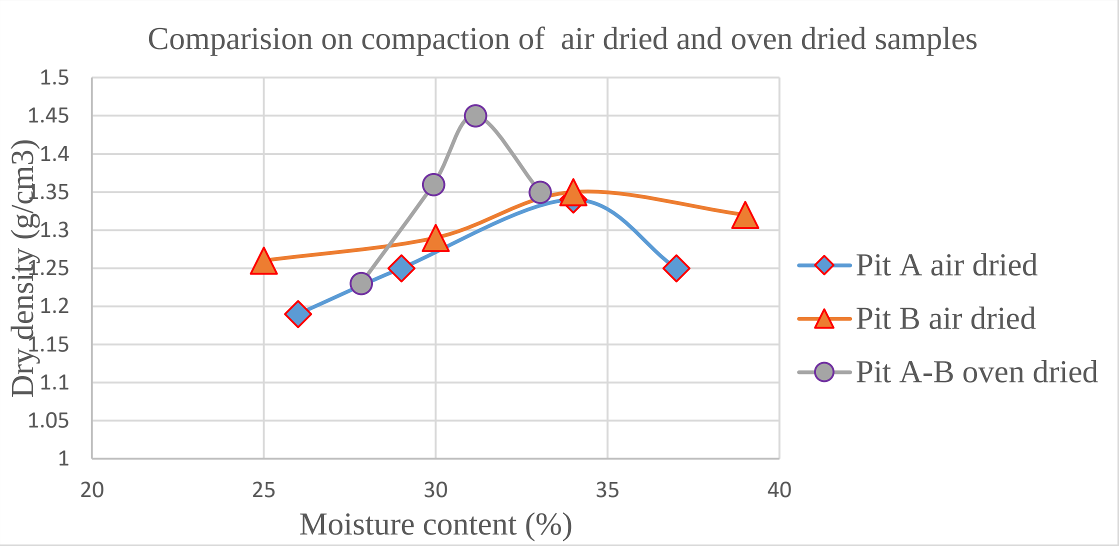


Figure 4 - 17. Comparision of compaction using ovendried and one day air dried samples

Table 4 - 20. Effect of pre treatment on compaction

Sample Location	**Depth (m)**	**Sample Pre-treatment**	**MDD (g/cm^3)**	**OMC (%)**
Pit- A	1.5	One day air/sun dried	1.34	34
Pit-B	1.5	One day air/sun dried	1.35	34
Between pit A and B (*after Fikre,2018*)	1.5	Oven dried	1.45	31.15

As shown on figure 4-17 and table 4-20 the sample from test pit A and B are treated for one day air blow drying condition and sample taken between test pit A and B is oven dried.

Oven dried samples had higher MDD and lower OMC than air dried samples. Besides, OD samples shows significant dry density changes with a minimal change of moisture content which might be the effect of loosing its microstructure by cyclic wetting and drying.

4.4. CBR TESTS

After compacting the soil by altering the factors California bearing ratio (CBR) test have been done in order to evaluate the performance of the compacted fill.

Table 4 - 21. CBR values for the compacted soil

Sample Location	Depth (m)	Proctor Test Method	MDD (g/cm^3)	OMC (%)	Soaked CBR in (%)	
					at 2.54mm	at 5.08mm
A-1.5	1.5	Standard	1.34	34	3.03	2.85
A-1.5	1.5	Modified	1.44	30	3.21	3.09
A-4	4.0	Standard	1.38	33	3.56	3.44
A-4	4.0	Modified	1.46	32	3.92	3.68
B-1.5	1.5	Standard	1.35	34	3.21	2.97
B-1.5	1.5	Modified	1.42	32	3.38	3.33
B-4	4.0	Standard	1.40	32	3.74	3.33
B-4	4.0	Modified	1.45	31	4.10	3.80
C-1.5	1.5	Standard	1.30	39	2.85	2.61
C-1.5	1.5	Modified	1.30	36	3.03	2.97
C-4	4.0	Standard	1.21	50	2.67	2.61
C-4	4.0	Modified	1.29	49	2.85	2.85
D-1.5	1.5	Standard	1.43	2.9	17.64	15.92
D-1.5	1.5	Modified	1.50	2.7	19.78	19.72
D-4	4.0	Standard	1.49	27	33.14	30.53
D-4	4.0	Modified	1.61	24	35.99	35.87
E-1.5	1.5	Standard	1.39	35	3.03	2.49
E-1.5	1.5	Modified	1.45	30	3.03	2.97
E-4	4.0	Standard	1.40	34	3.21	3.09
E-4	4.0	Modified	1.46	31	3.74	3.68

CBR tests using AASHTO T 193-93 test method was performed using the maximum dry densities and optimum moisture contents obtained from both standard and 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.

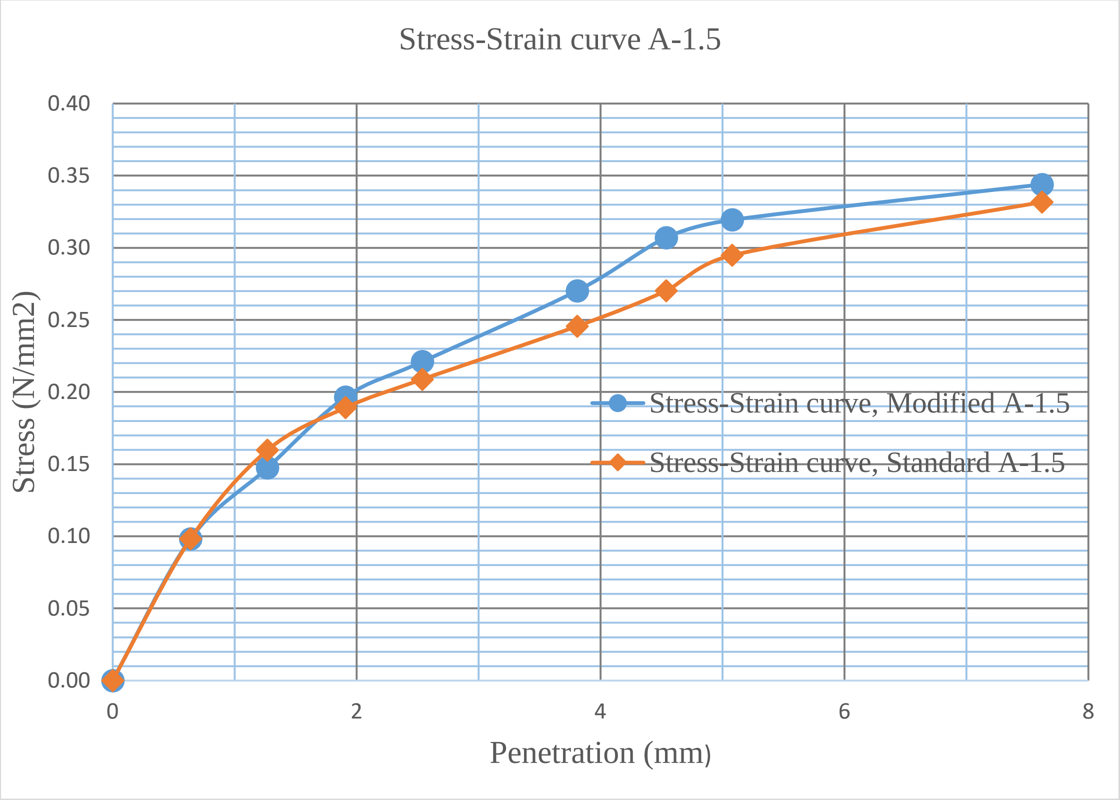


Figure 4 - 18. Influence of method of compaction on CBR, test Pit A-1.5

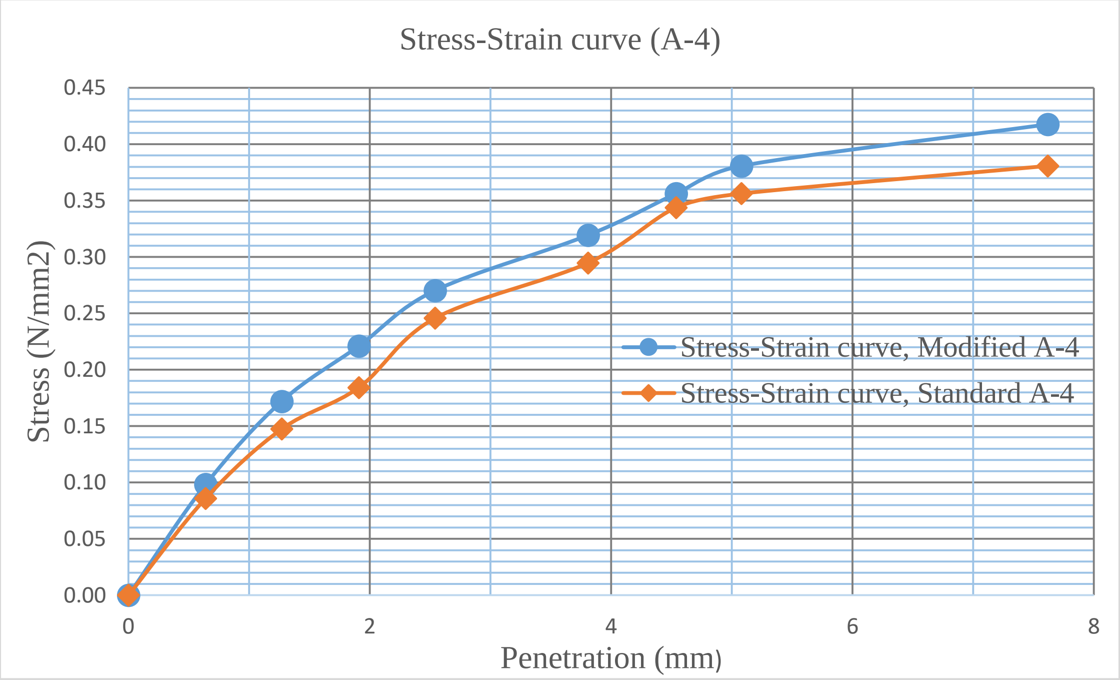


Figure 4 - 19. Influence of method of compaction on CBR, test Pit A-4.0

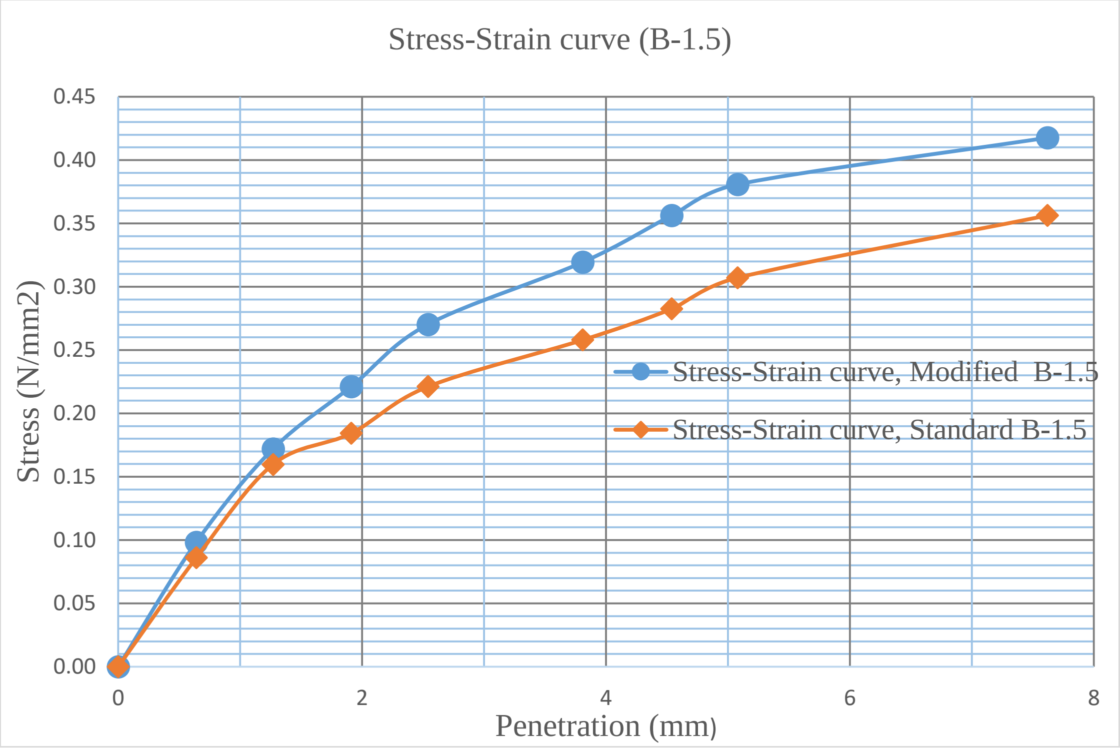


Figure 4 - 20. Influence of method of compaction on CBR, test Pit B-1.5

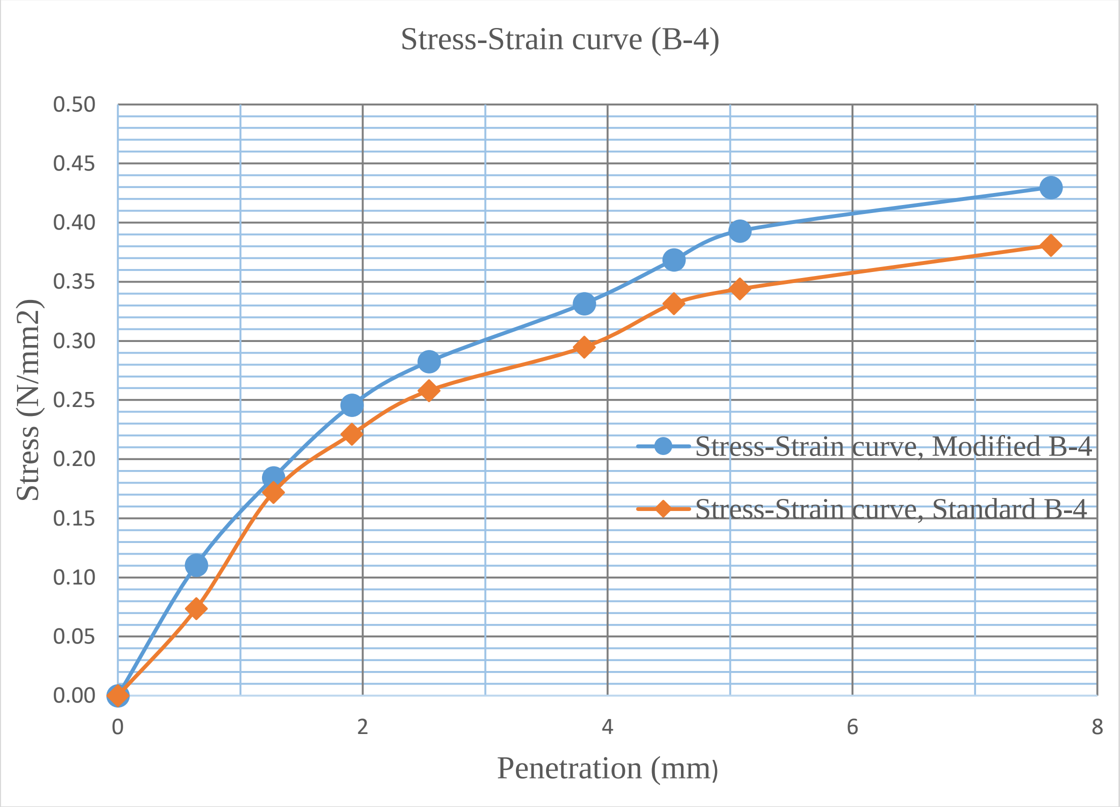


Figure 4 - 21. Influence of method of compaction on CBR, test Pit B-4.0

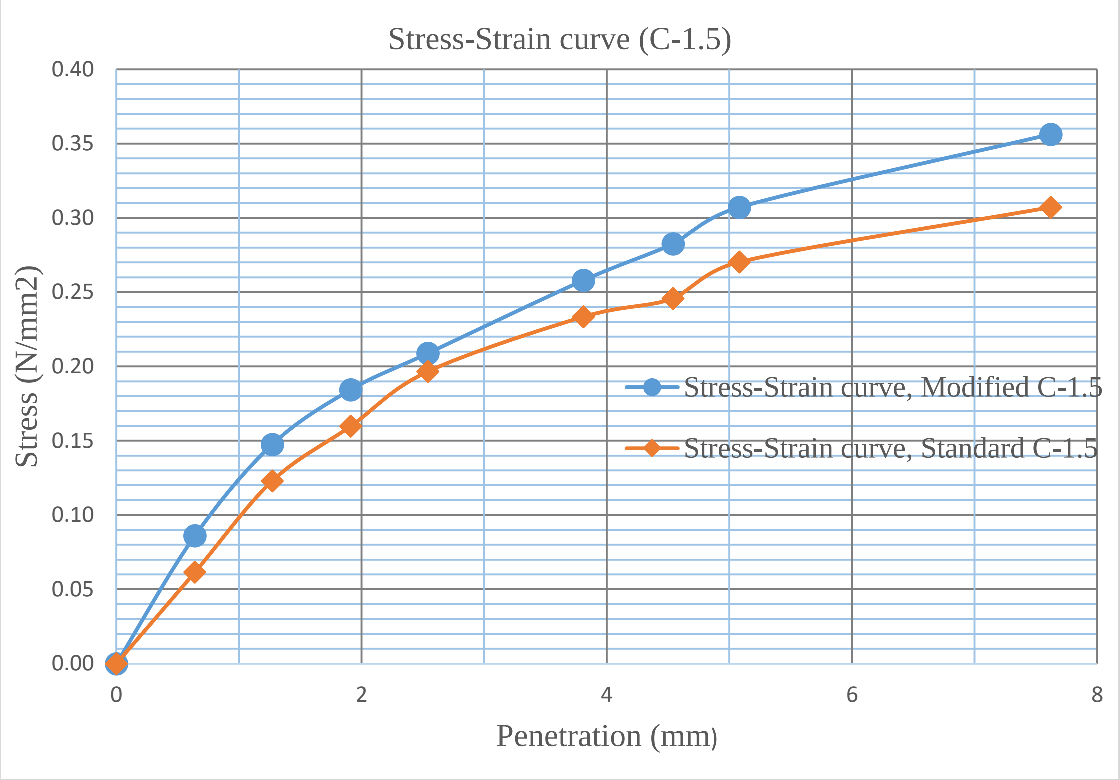


Figure 4 - 22. Influence of method of compaction on CBR, test Pit C-1.5

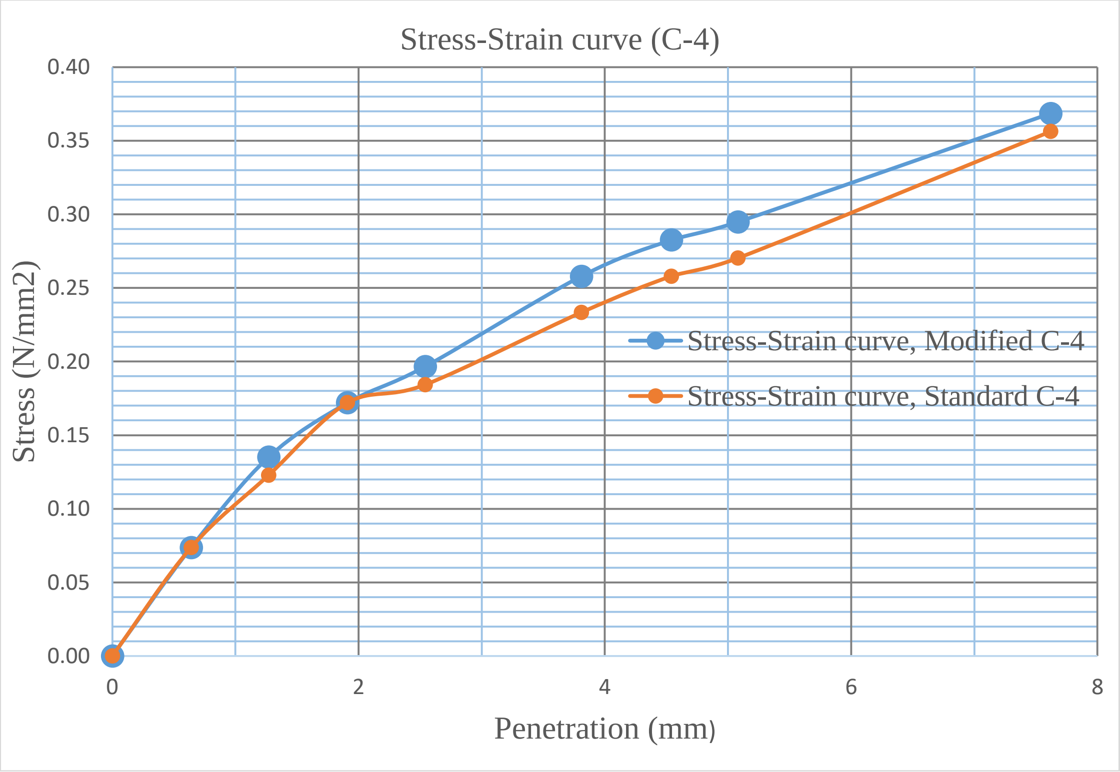


Figure 4 - 23. Influence of method of compaction on CBR, test Pit C-4.0

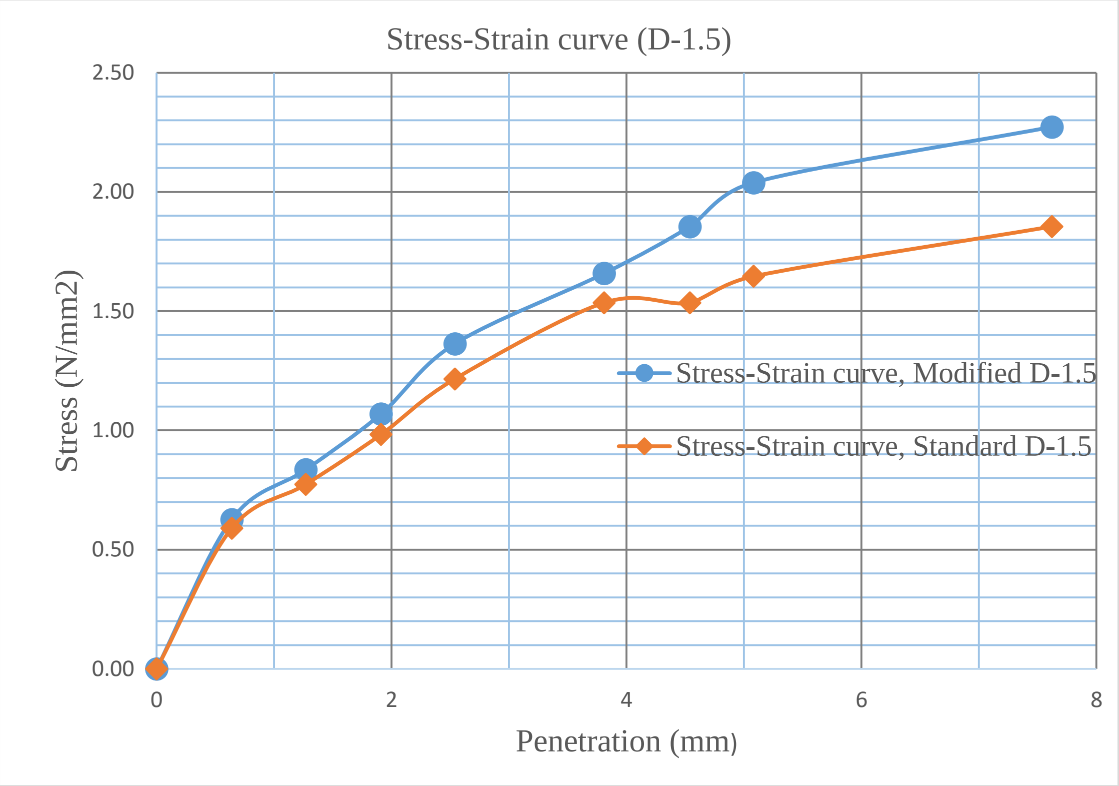


Figure 4 - 24. Influence of method of compaction on CBR, test Pit D-1.5

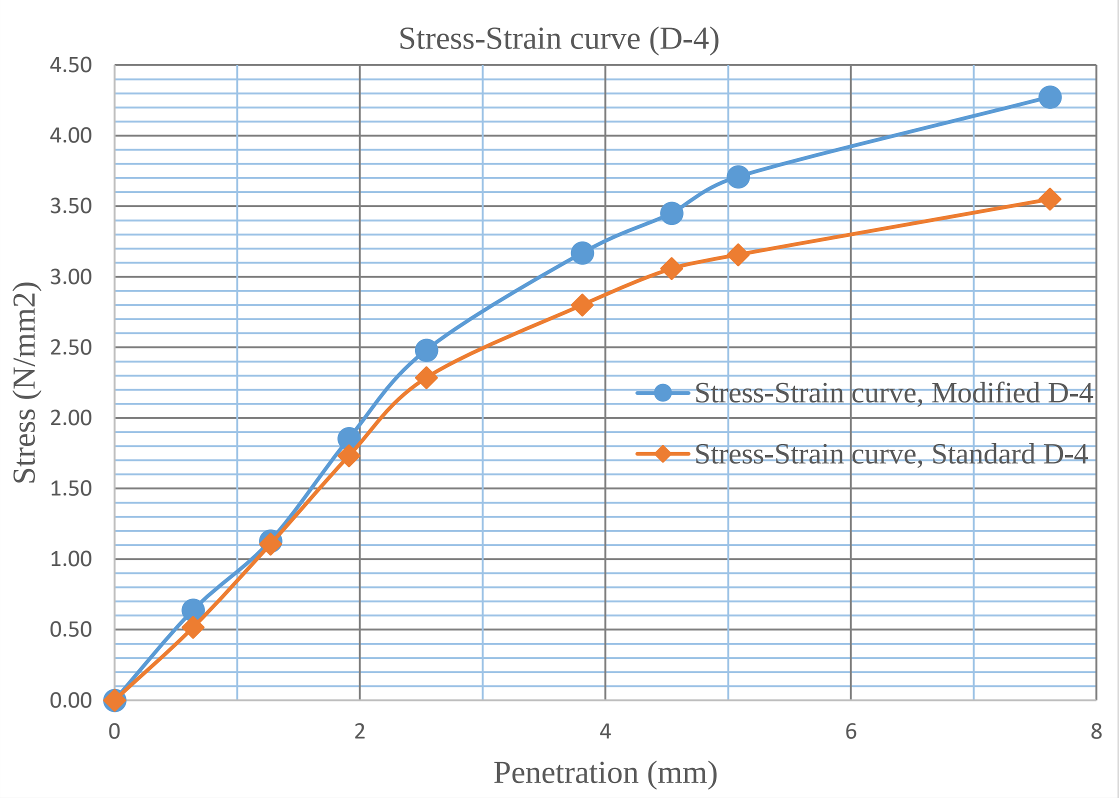


Figure 4 - 25. Influence of method of compaction on CBR, test Pit D-4.0

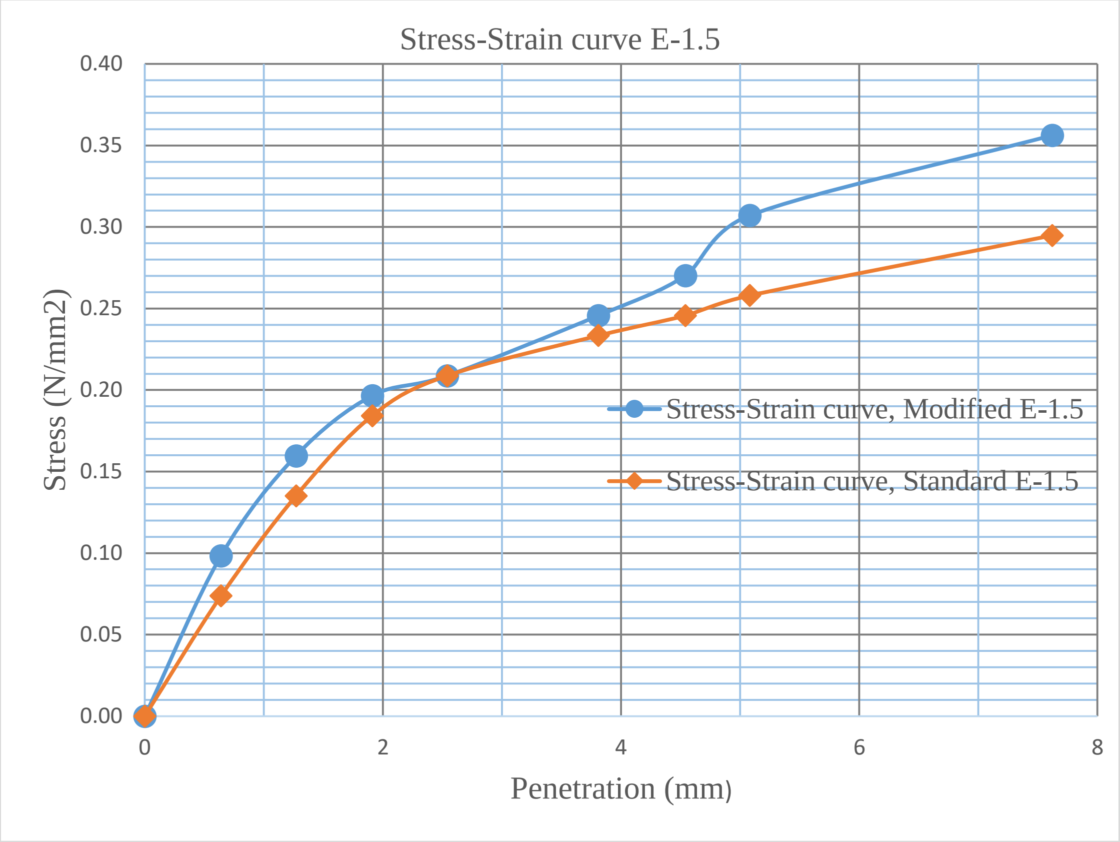


Figure 4 - 26. Influence of method of compaction on CBR, test Pit E-1.5

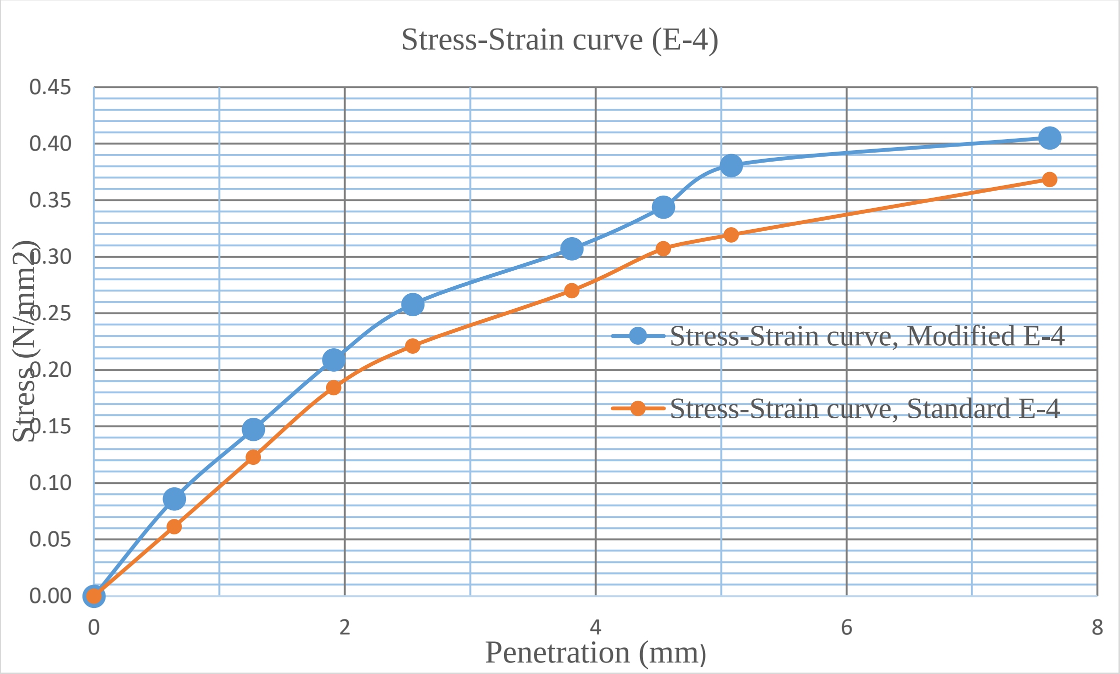


Figure 4 - 27. Influence of method of compaction on CBR, test Pit E-4.0

As shown on Figure 4.18 – 4.27 the CBR value for a modified compaction is slightly higher than the value for standard compaction. To attain the full strength of soils on compaction works it is better to use the modified compaction test result.

4.5. EVALUATION AS A CONSTRUCTION MATERIAL

AASHTO classification categorizes the soil from test pit D as good subgrade materials while soil from other test pit are very poor to be subgrade materials

The new (ERA, 2013) Standard Technical Specifications and Method of Measurement for Road Works defines the following limiting standard requirements.

To use laterites as a sub base;

CBR>30%

PI < 25%

Plasticity Modulus less than or equal to 500

The necessary requirements to be subgrade, embankement material and laterites as a sub-base are described in table 4.21 below with the material properties of soil from test pit D-1.5 and D-4.0 along side.

After evaluating the soil sample properties, soils from test pit A, B, C and E can not be used for earthworks with out further treatments/stabilizations. Soil from test pit D-1.5 satisfies to be subgrade or embankement material; while soil from test pit D-4 satisfies to be subgrade or embankement material and satisfies the requirement to use laterites as sub-base.

Table 4 - 22. ERA-2013 Material Requirements

Material Property	Requirement for embankement construction or as a subgrade material	Requirement to use as laterites as a sub-base	Properties of soil from Pit D-1.5	Properties of soil from Pit D-4.0
Particle size	Max. 150mm	-	Max 20mm	Max. 20mm
CBR	≥ 5%	> 30%	19.78	35.99
Swell	≤ 2%	-	0.6	0.5
LL	≤ 60	-	56.4	50
PI	≤ 30	< 25%	18.1	15.4
MDD	≥ 90% MDD	-	*	*
PM	-	≤500	1560	377.3
Remark	Soil from test pit D-1.5 satisfies to be subgrade or embankement material While Soil from test pit D-4 satisfies to be subgrade or embankement material and satisfies the requirement to use laterites as sub-base			

Chapter 5

Conclusion and Recommendation

5.1. CONCLUSIONS

After the investigation of index properties, geochemical/oxide compositions, compaction and CBR testing on TWR soils of Bure town, the following conclusions are drawn:

(a) The soil in Bure town doesn't have loosely bound/structural water. During moisture content determination drying the sample using oven temperature of 110±5°C is possible.

(b) The activity number and free swell value of the soil indicates that the soils in the town are inactive clay and are non-expansive.

(c) The specific gravity values recorded are slightly higher than the average for sedimentary soils; this is because of the accumulation higher density iron oxides on the laterites of Bure town.

(d) By considering the Atterberg limit and USCS plasticity chart, the soil investigated are highly plastic with LL $\geq$ 50% and silty soil with PI values located below the A line.

(e) The silicate analysis proves the soil investigated are laterites.

(f) Classification of soil defines the investigated soil in to different types depending on classification system. USCS classifies the soil from test pit A,B,C and E as Elastic Silt and soils from test pit D classified as Silty Sand. AASHTO classification system categorizes the soil from test pit A, B, C and E under A-7-5 with group index > 20 while the soil from test pit D-1.5 and D-4.0 categorized under A-7-5 and A-2-7 with group index value of 10 and 0 respectively. Wesley mineralogical classification puts the soil under group C(c) as a laterite.

(g) The soil achieved low MDD after compaction which is the effect of fine-grained soils have less heavy concretionary particles with maximum voids.

(h) Compactive effort had great influence on the compaction of lateritic soils. When the effort increases from standard to modified MDD increases and OMC decreases.

(i) The soaked CBR value for elastic silt soil ranges from 2.49% to 3.80%; which is weak and insufficient to bear loads. And the soaked CBR for silty sand, taken from test Pit D, ranges from 15.92% to 35.87% which shows the material can be used as good subgrade and sub base as a laterite.

5.2. RECOMMENDATIONS

The following recommendations are suggested for further study:

(a) The soil from Test Pit C had variable and unexpected properties. To study such type of soil considering its geologic nature by support of mineralogical tests is preferable and will lead to better conclusion.

(b) Continuous and extensive studies have to be done to investigate the variable properties of TWR soils. Besides, with in a country or geological origin with the same parent rock, a guidelines and manuals have to be prepared for the investigation and classification of such TWR soils.

(c) During investigation of TWR soils considering the depth (laterization) is mandatory. And the borrow pit shall be classified in to depths besides to stations to use the actual engineering parameters of the soil.

(d) During laboratory tests, especially, when we do with drying oven most of the peoples take care about wearing the hand gloves. In addition, we must take care by wearing eye glasses and mouth masks in order to prevent from the smell of contaminated samples.

References

AASHTO. (2004). Standard Specification for Transportation Materials and Methodsof Sampling and Testing.

Abebaw Z. (2005). *Basic Engineering Properties of Lateritic Soils found in Nedjo-Mendi Road Construction Project, Welega. M.Sc. Thesis, School of Graduate Studies of Addis Ababa University*. AAiT/AAU, Department of Civil Engineering. Addis Ababa, Ethiopia: AAU.

Addiszemen , T. G., Messele, H., Alemayehu, T., & Murray, E. J. (2014). Improved Mathematical models for particle size Distribution Data Representation of Tropical Weathered Residual soils. *31*.

Addiszemen , T. G., Messele, H., Alemayehu, T., & Murray, E. J. (2015). The Effect of Sample Preparation and Testing Procedure on the Geotechnical Properties of Tropically Weathered Residual Laterite Soils of Ethiopia. *Journal of EEA*, 45-61.

Amare, G. (2008). Compaction properties of Lateritic Soils. M.Sc. Thesis, School of Graduate Studies of Addis Ababa University. *School of Graduate Studies of Addis Ababa University*.

Arora, K. (1992). *Soil Mechanics and Foundation Engineering in SI Units*. India: Standard publishers distributors.

ASTM. (2004). Special Procedures for Testing Soil and Rock for Civil Engineering Purpose. Philadelphia, PA, USA: American Society for Testing Materials.

ASTM - D2216 - 98. (1998). Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil - Aggregate Mixtures. In *Annual Book of ASTM Standards*. Philadelphia, PA, USA: American Society for Testing Materials.

ASTM - D5298 – 94. (1994). Standard Test Method for Measurement of Soil Potential (Suction) using Filter Paper. In *Annual Book of ASTM Standards*. Philadelphia, PA: American Society for Testing Materials.

ASTM D1557. (n.d.). Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (56,000 ft-lb/ft3 (2,700 kN-m/m3)).

ASTM D698. (n.d.). Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lb/ft3 (600 kN-m/m3)).

ASTM: D 421 – 85 (Reapproved 1998). (2004). Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants. In Barr Harbor Dr., *Special Procedures for Testing Soil and Rock for Civil Engineering Purpose.* West Conshohocken: American Socity for Testing and Materials.

ASTM: D 422 –63. (2004). Standard Practice for Particle-Size Analysis of Soils. In B. H. Dr., *Special Procedures for Testing Soil and Rock for Civil Engineering Purpose.* West Conshohocken: American Socity for Testing and Materials.

Birkeland, P. W. (1984). *Soils and geomorphology.* New York: Oxford University Press.

Bland, W., & Rolls, D. (1998). Weathering.: . London: Arnold.

Blight, G.E., & Simmons, J.V. (2012). The Mechanics of Compaction and Compacted Residual Soil. In G. Blight, & E. Leong, *Mechanics of Residual soils* (pp. 81-118). Boca Raton: CRC Press.

Blight, G. (1997). *Mechanices of Residual soils, A guid to the formation, classification and geotechnical prporties of residual soils, with advice for geotechnical design.* A.A. Balkema, Rotterdam: Printed in Netherlands.

Blight, G. (2012). *Mechanics of Residual Soils, a Guide to the Formation, and Classification and Geotechnical Properties of Residual Soils, With Advice for Geotechnical Design.* Balkema, Rotterdam, Netherlands: Printed in Netherlands.

BS, (1998). *Methods of Tests for Soilsfor Civil Engineering Purposes-part 2: classification tests.* Britania.

Buchan, G., Grewal, K., & Robson, A. (1993). Improved Models of Particle-Size Distribution: An Illustration of Model Comparison Techniques. *Journal of Soil Science Society of American, 57*, 901-908.

Bujang, B. H., Asmidar, A., & Suhaimi, J. (2004). Sampling and testing of tropical residual soils. In S.-S. &. Huat, *Tropical Residual Soils Engineering* (p. 21). London: Taylor & Francis Group.

Bujang, B., Faisal, H., & Affendi, A. (2005). *Shear Strength Parameters of Unsaturated Tropical Residual Soils of various Weathering Grades.* EJGE Journal.

Carter M., & Bentley S.P. (1991). *Correlations of soil properites.* London: Pentech Press.

Charman, J. H. (1995). Laterite in road pavements: Transport Research Laboratory, Department of Transport. *Special publication 47.* London: Construction Industry Research and Information Association (CIRIA).

Chen, F. (1988). *Foundations on Expansive Soils.* USA: Elsevier Science Publishing Company Inc.

Chin, K., Leong, C., & Rahardjo, H. (2010). *A Simplified Method to Estimate the Soil-Water Characteristic Curve.* Canada: Canadian Geotechnical Journal.

Daniela, G. (2017). Tropical residual soil data compilation as guidance for laboratory tests and EPB excavation process simulation. *Research gate*, https://www.researchgate.net/publication/309564759_ Residual Soil Compilation Final.

Das, B. M. (2007). *Principles of geotechnical engineering.* India: Thomson.

Das, B. M. (2013). *Principles of Geotechnical Engineering, CEng Learning.*

David, A. (1982). *Geology and Engineering Properties of laterites from Ilorin, Nigeria.* Amsterdam, Netherlands: Elsevier Science Publishers B.V.

Dibisa, J. (2008). *Detail Investigation on Index properties of Lateritic Soils.* Addis Ababa: MSc. Thesis presented to School of Graduate Studies, Addis Ababa University.

Desai, M.D. (1985). *Geotechnical aspects of Residual Soils of India, In: Brand, E.W. & Phillipson, Sampling and testing of Residual Soils.* Hong Kong, Scorpion.

Duchaufour, P. (1982). *Pedology, Pedogenesis and Classification.(English edition tras.).* T R Paton London: George Allen & Unwin.

Efeoghene, E., Felix, C.U., Oluwatosin, J.R. (2016). The Geochemistry and Geotechnical (Compaction) Analysis of Lateritic Soils: A case study of OKapanam Area. *AshEse Journal of Engineering*, Vol 2(3) 075-082.

ERA. (2013). *Standard Technical Specifications and Method of Measurement for Road Works.* Ethiopia.

Ethiopian Ministry of Water Resources. (2001). *National Meteorological Services Agency.* Addis Ababa, Ethiopia: National Meteorological Services Agency under the GEF supported Climate Change Enabling Activities Project of Ethiopia.

Ethiopian Roads Authority. (1998). *Ethiopian Roads Authority (1998). Nekempte-Assosa Road upgrading project.* Addis Ababa Ethiopia.

Farooq, K. e. (2016). Prediction Of Compaction Characteristics Of Lateritic Soils In Ghana, Near East University.

Fasil A. (2003). *Investigation into some of the Engineering properties of Red Clay Soils in Bahirdar. M.Sc. Thesis, A thesis presented to School of Graduate Studies, Addis Ababa University.* AAiT/AAU, Civil Engineering. Addis

Ababa, Ethiopia: A thesis presented to School of Graduate Studies, Addis Ababa University.

Fekede W. (2007). *Investigating the Index properties of Residual Tropical Soils of western Ethiopia (The case of Asossa). M.Sc. Thesis, Graduate studies of Addis Ababa University.* AAiT/AAU, Department of Civil Engineering. Addis Ababa, Ethiopia: Graduate studies of Addis Ababa University.

Fikre T. (2018). *Stabilizing Subgrade Expansive Soil Using Lime(Case study for Bure Agro Industry Park Project). Project Report, Faculty of Cicil and water Resource Engineering.* BiT/Bahir Dar University

Fookes, P. (1997). Tropical Residual Soils. In *A geological Society Engineering Group Working Party Revised Report.* UK: The Geological Society Publishing House.

Fourie, A.B.,Irfan, T.Y., Queiroz de Carvalho, J.B., Simmons, J.V., Wesley, L.D. (2012). Microstructure, mineralogyand classification of residual soils. In B. G. E.C., *Mechanics of Residual Soils* (pp. 41-62). Boca Raton: CRC press.

Gidgasu, M. (1976). *Laterite soil Engineering, Pedogensis and Engineering Principles.* Soil Mechanics and F Gidigasu, M. (1974). Degree of Weathering in the Identification of Laterite Materials for Engineering Purposes - a review. *Engineering Geological Journal, 23*, 213 - 266.

Gidigasu, M. (1974). Degree of Weathering in the Identification of Laterite Materials for Engineering Purposes - a review. *Engineering Geological Journal, 23*, 213 - 266.

Gidigasu M.D. (1972). Mode of formation and geotechnical characteristics of laterite materials of Ghana in relation to soil forming factors. *Eng. Geol., 6(2): 0.*, 79-85.

Hanna T. (2008). *Study of Index Properties and shear Strength Parameters of Laterite soils in Southern Part of Ethiopia, the case of Wolayita - Sodo. M.Sc.Thesis, School of Graduate Studies of Addis Ababa University.* AAiT/AAU, Department of Civil Engineering. Addis Ababa, Ethiopia.: School of Graduate Studies of Addis Ababa University.

Hans, J. (1994). *Factors of soil formation, A system of quantitative pedology.* New York: Dover Publications, Inc.

Harwant, S., & Bujang, B. H. (2004). Origin, formation and occurrence of tropical residual soils. In S.-S. &. Huat, *Tropical Residual Soils Engineering.* London: Taylor & Francis Group.

Hossain, A. (2001). *The Engineering behavior of the tropical Clay Soils of Dhaka, Bangladesh. Durham thesis,.* Durham: Durham University.

Huat, B., Sew, G., & Ali, F. (2004). *Tropical Residual Soils Engineering.* London/New York/Singapore: Taylor and Francis Routledge.

Jesmani, M., & et al. (2008). "Optimum water content and maximum dry unit weight of clayey gravels at different compactive efforts. *13*(1-14).

Lin, Z. (1986). On the Engineering Classification of Laterite. *Proc. Int. I.A,E.G. Congress, 5th* , (pp. 811 - 820). (Buenos Aires, Argentina), Balkema, Rotterdam.

Lyon Associates Institute Inc. (1971). *Laterite and Lateritic Soils and Other Problem Soils of Africa, Consulting Engineers, USA Building and Road Research Institute.* Kumasi, Ghana: Lyon Associates Institute Inc.

Mc.Carthy, D. (1993). Essentials of soil mechanics: Basic geotechnics. Englewood Cliffs, New Jersey: Regents/ Prentice Hall.

Morin, W., & Parry, W. (1971). Geotechnical Properties of Ethiopian Volcanic Soils. *Department of Mining and Geological Engineering, University of Utah*, 223 - 232.

Morin, W., & Todor, P. (1975). *Laterite and Lateritic soils and other Problematic Soils of the Tropics, Instruction Manual.* USA: Lyon Associates Inc. and Road Research Institute Brazilian National Highway Department Rio de Janeiro. Brazil.

Nebiet, T. (2010). *Investigation in to Appropriateness of Lateritic Soils for Sub-Grade and Sub-Base in Road Construction. M.Sc. Thesis Submitted to the School of Graduate Studies of Addis Ababa University, Technology Faculty, Civil Engineering Department.* AAiT/AAU, Addis Ababa, Ethiopia.

Nortlunor, K. J., Bntwillie, D. C., Hobb, P. R., Culshaw, M. G., & Jones, L. D. (1992). *Engineering geology of tropical red clay soils: Geotechnical characterization: index properties and testing procedures. Report WN/93/12.* Keyworth, Nottingham: British Geological survey.

Nortlunor, K. J., Bntwillie, D. C., Hobb, P. R., Culshaw, M. G., & Jones, L. D. (1992). *Engineering geology of tropical red clay soils:Summary findings and their application for engineering purposes. Report WN/93/15.* Keyworth, Nottingham: British Geological survey.

Public Works Institute of Malaysia. (1996). *GEOGUIDES 1-5, Tropical weathered in situ materials.*

Quadros, C., & Ndimbo, R. (2011). Effect of Compaction on Engineering Properties of Residual Soils of Tete-Mozambique. *15th African Regional Conference on Soil Mechanics and Geotechnical Engineering* (pp. 389-395). doi:10.3233/978-1-60750-778-9-389.

R.Maiginien. (1956). Review of Research on Laterites. *United Nations Educational Scientific and Cultural Organizations.*

Sherman, D. (1949). *Factors Influencing the Development of Lateritic and Laterite Soils in the Hawaiian Islands'.* Technical Paper, University of Hawaii Agricultural Experiment Station, Honolulu, T. H.

Shukri, M., Bujang, B. H., & Suhaimi, J. (2004). Index, engineering properties and classification of tropical residual soils. In H. S.-S. Ali, *Tropical Residual Soils Engineering* (p. 37). London: Taylor & Francis Group.

Singh P. & Kataria, D. (1980.). *Engineering and general geology.* Ludhiana, India: Katson Publishing House.

Sintayehu, H. (2003). *Investigation of Influence of Compaction on the Stability of Earth-fill Dams of Tropical Soils.* Addis Ababa, Ethiopia.: A thesis presented to School of Graduate Studies, Addis Ababa University.

Skempton, A. W. (1953). *The colloidal activity of clays. Selected papers on soil mechanics.* England.

Sridharan, A., & Nagaraj , H. (2005). Plastic limit and compaction characteristics of finegrained soils. *Proceedings of the Institution of Civil Engineers-Ground Improvement*, (pp. 9(1): 17-22.).

Steven, A. N. (2003). *Physical geology, weathering and soils.* Tulane.

Styles M. T., D. C. Entwisle, D. A. Gunn, E. Hodgkinson, P. D. Jackson, S. J. Kemp, . . . E. J. Steadman. (2001). *BGS Commissioned Report CR/01/096N, A mineralogical examination of a magnetic tropical brown soil from Cambodia and a possible synthetic analogue made with soil from Devon.* Keyworth, Nottingham: British Geological Survey.

Suhaimi, J., Asmidar, A., Huat, K., & Bujang, B. (2004). *Sampling and Testing of Tropical Residual Soils.* London: Taylor and Francis Group.

Tan, B. (2004). Country case study: engineering geology of tropical residual soils in Malaysia. In S.-S. Huat, & Ali, *Tropical Residual Soils Engineering* (p. 237). Universiti Kebangsaan Malaysia, Bangi, Malaysia: Taylor & Francis Group, London.

Ting, W. H., & R.Nithiaraj. (2004). Characterization of tropical soils in the design of material as natural foundation and fill. London: Taylor & Francis Group.

Tiruneh, A. (2015). *Consolidation and Settlement Behavior of Residual Lateritic Soils of Western Ethiopia (The case of Tongo-Begi-Muji Road Project, Contract-I, Tongo-Gidami).* Addis Ababa University.

Towensend, F., Phillip, G., & Parcher. (1969). Effect of Remolding on the Properties of a Lateritic Soils.

Umarany, M. I., & Daviid J., W. (1991). Engineering properties of a lateritic soil profile. *Engineering Geology 31*, 45-58.

Umarany, M., & Wiliams, D. (1990). *Engineering Properties of Lateritic Soil Profiles.* University of Queensland, Australia .

Vargas, M. (1982). Characterisation, identification and classification of tropical soils. *Proceedings of the 2nd International Conference on geomechanics in Tropical Soils*, *vol. 2*, pp. pp. 469-487. Singapore, A.A. Balkema, Rotterdam.

Verghese, T. (1987). *Laterite Soils and their Management.* Kerala Agricultural University, Department of Soil Science, Vellayani, India.

Volkoff, B. (1972). Red and Lateritic soils: World Scenario.

Wesley. (2010). *Geotechnical engineering in residual soils.* Hoboken, New Jersey: John Wiley & Sons, Inc.

Wesley, L. (1973). *Cluster Hypothesis and the Shear Strength of Tropical Red Clay.* Imperial College, formerly Department of Public Works, Department of Civil Engineering. Indonesia: Imperial College, formerly Department of Public Works.

Wesley, L. (2009). Behavior and Geotechnical Properties of Residual Soils and Allophane Clays. (pp. 5-10). Auckland, New Zealand: Obras Proyectos Private Bag.

Wesley, L.D. (1988). Engineering Classification of Residual soils. *Proc. Second int. Conf. on Geomechanics in Tropical Soils.*, *1*, pp. 77 - 84. Singapore.

Whittow, J. (1988). *The Penguin Dictionary of Physical Geography.* Penguin Books.

Wossen M. (2009). *Investigation into the Appropriate Laboratory Testing Procedures for the Determination of the Index Properties of the Lateritic Soils of Western Ethiopia (Nedjo-Jarso-Begi Road Area). M.Sc. Thesis, School of Graduate Studies of Addis Ababa University.* AAiT/AAU, Civil Engineering. Addis Ababa, Ethiopia: School of graduate studies of Addis Ababa University.

Appendix

Appendix A - Laboratory Test Sample Data Sheets

A-1. Moisture Content Data Sheet

Moisture Content-Data Sheet

Location: Bure, West Gojjam
Test Pit: All
Depth of Sample: 1.5m and 4.0m

Tested by: Mulugeta T.
Date: 25/05/11 E.C.
Test method: ***Moisture content at 105 Oc***

Sample Location	Weight of can, a(gm)	Weight of wet soil + can, b(gm)	Weight of dry soil + can, c(gm)	Weight of moisture loose, =b-c(gm)	Weight of dry soil, =c-a(gm)	Moisture content (%)
A-1.5	34.5	161.2	129.8	31.4	95.3	32.9%
A-4	31.5	153.4	122.3	31.1	90.8	34.3%
B-1.5	31.5	163.9	131.2	32.7	99.7	32.8%
B-4	32.8	166.1	131.9	34.2	99.1	34.5%
C-1.5	32	158.5	121	37.5	89	42.1%
C-4	33	153.4	114.8	38.6	81.8	47.2%
D-1.5	32.4	164.2	128.6	35.6	96.2	37.0%
D-4	34.4	158.4	124.3	34.1	89.9	37.9%
E-1.5	34.9	150.6	121.1	29.5	86.2	34.2%
E-4	32	162.4	128.5	33.9	96.5	35.1%

A-2. Moisture Content Data Sheet

Moisture Content-Data Sheet

Location: Bure, West Gojjam

Tested by: Mulugeta T.

Test Pit: All

Date: 02/06/11 E.C.

Depth of Sample : 1.5m and 4.0m

Teest method: Moisture content determination using 60 Oc oven temperature

Sample location	Weight (gm)									weight of moisture loose, =b-c(gm)	weight of dry soil, = c-a (gm)	Air dried Moisture content (%)
	Can, ((a)	wet soil+can, (b)	60 Oc oven/Air/sun dried + can									
			Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	Day-7, (c)			
A-1.5	949.90	1078.20	1061.20	1051.40	1049.60	1048.40	1047.72	1047.21	1047.10	31.10	97.20	32.0%
A-4	906.00	1101.30	1071.80	1059.60	1055.10	1054.30	1053.80	1053.54	1053.40	47.90	147.40	32.5%
B-1.5	948.00	1082.34	1064.60	1054.60	1051.90	1051.25	1050.77	1050.59	1050.55	31.79	102.55	31.0%
B-4	944.00	1300.00	1241.65	1231.40	1224.67	1218.60	1215.40	1214.80	1214.72	85.28	270.72	31.5%
C-1.5	1260.80	1394.20	1375.90	1364.30	1359.90	1358.14	1357.09	1356.48	1356.43	37.77	95.63	39.5%
C-4	943.40	1129.10	1085.20	1083.70	1078.60	1075.86	1073.90	1072.50	1072.00	57.10	128.60	44.4%
D-1.5	1147.60	1354.65	1318.90	1310.80	1305.78	1302.05	1301.21	1300.60	1300.29	54.36	152.69	35.6%
D-4	1204.50	1480.21	1420.37	1410.80	1408.04	1407.10	1406.53	1406.20	1405.90	74.31	201.40	36.9%
E-1.5	1253.20	1475.10	1437.30	1426.70	1421.90	1421.26	1420.70	1420.31	1420.29	54.81	167.09	32.8%
E-4	908.70	1134.60	1086.90	1079.79	1078.64	1077.98	1077.58	1077.42	1077.41	57.19	168.71	33.9%

A-3. Specific Gravity Data Sheet

Specific Gravity Data Sheet

Test Pit: A-1.5 Tested by: Mulugeta T.// Depth of sample: 1.5m // Test date: 04/06/11 E.C.//Location: Bure, West Gojjam,

Determination No.	1 (B3)	2 (B1)	3(B5)
Weight of density bottle. W1 (gm)	479	468.1	475
Weight of density bottle + dry soil, W2 (gm)	693.9	646.44	684.7
Weight of density bottle + Soil + Water, W3 (gm)	1089.6	1116.80	1139.8
Weight of density bottle. + Water, W4 (gm)	1005.4	1001.9	1004.7
Specific Gravity, G = $\frac{W2-W1}{(W4-W1)-(W3-W2)}$	2.80	2.81	2.81

Average specific gravity at 27o_c = 2.81

Specific Gravity Data Sheet

Test Pit: A-4 // Tested by: Mulugeta T.// Depth of sample: 4.0m /// Test date: 04/06/11 E.C.// Location: Bure, West Gojjam,

Determination No.	1 (B1)	2 (B5)	3(B3)
Weight of density bottle. W1 (gm)	468.1	475	479
Weight of density bottle + dry soil, W2 (gm)	648.0	640.45	641.2
Weight of density bottle + Soil + Water, W3 (gm)	1122.2	1114.9	1104.2
Weight of density bottle. + Water, W4 (gm)	1004.8	1006.8	998.4
Specific Gravity, G = $\frac{W2-W1}{(W4-W1)-(W3-W2)}$	2.88	2.88	2.88

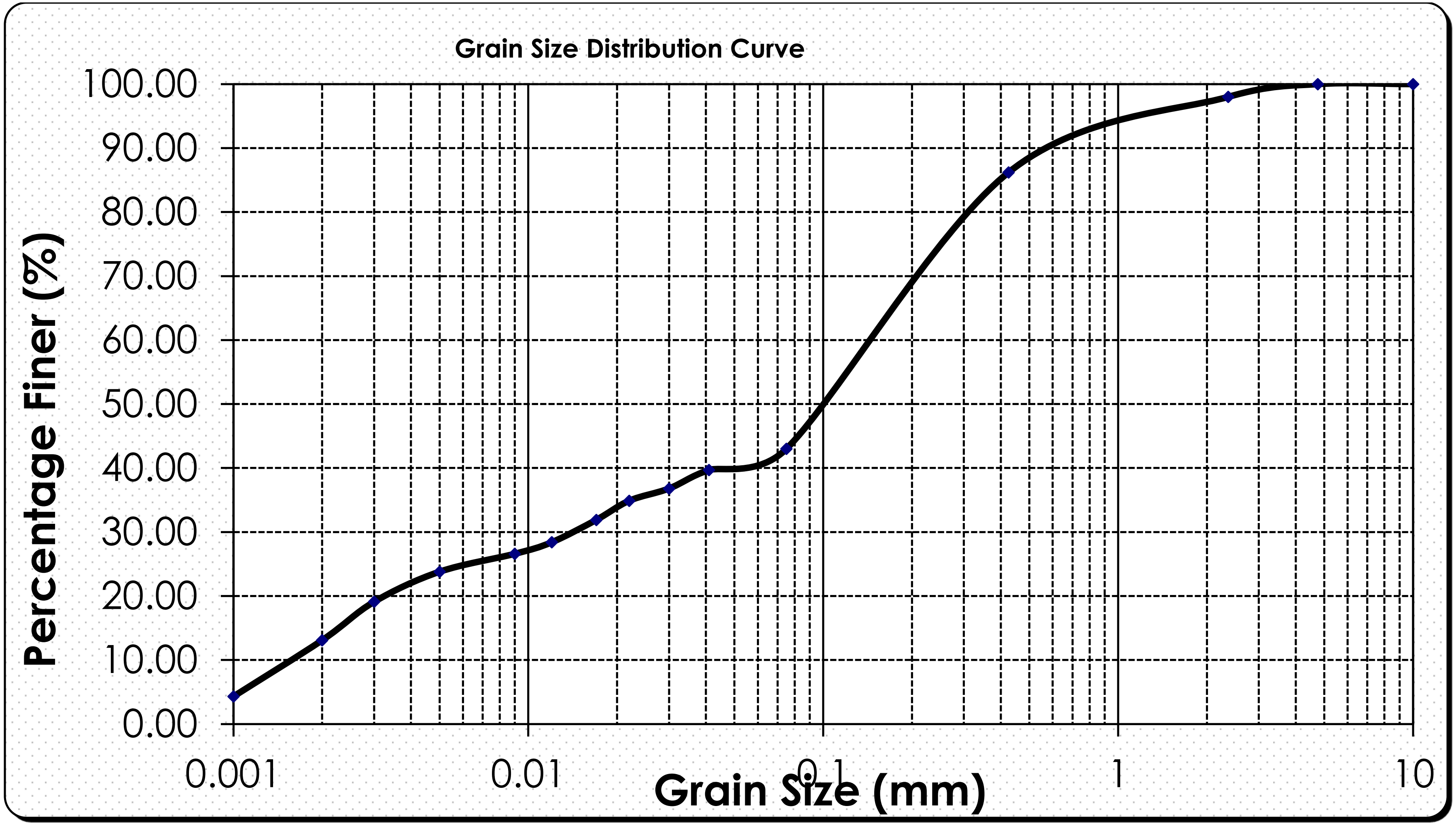
Average specific gravity at 27o_c = 2.88

A-4, Grain size analysis/particle size distribution data sheet

Grain size analysis----Data Sheet	
Test Method: Sieve analysis & hyrometer analysis	Tested by: Mulugeta T.
Test Pit- D-1.5	Testing Date: 09/06/11 E.C.
Depth of Sample:1.5m	Location: Bure, West Gojjam,

Sieve size (mm)	**% passed**
50	100.00
37.5	100.00
19	100.00
10	100.00
4.75	100.00
2.36	98.00
0.425	86.20
0.075	43.00
0.041	39.70
0.030	36.80
0.022	34.90
0.017	31.90
0.012	28.40
0.009	26.60
0.005	23.80
0.003	19.10
0.002	13.10
0.001	4.3

A-4, Particle size distribution Data sheet



A-5, Liquid limit Data Sheets

Test Method: Wet preparation and Wet to dry method   Tested by: Mulugeta T.   Test Pit: A-1.5///// Test Date: 11/06/11 E.C.

Depth of Sample:1.5m   Location: Bure, West Gojjam,

Determination No.	1	2	3
Number of Blows	18	26	31
Container No.	C3	K4	L4
Weight of Container, W0 (gm)	9.4	16.1	9.8
Weight of Container +wet soil, W1 (gm)	26.8	38.5	31.3
Weight of Container +Oven dried soil, W2 (gm)	20.4	30.8	24.9
Weight of Water = W1-W2 (gm)	6.4	7.7	6.4
Weight of Oven dried soil = W2-W0 (gm)	11	14.7	15.1
Water Content , ω = $\frac{W1-W2}{W2-W0}$ *100 (%)	58.2	52.4	42.4
Liquid limit value interpolated (LL) = 51%			

Test Method: Wet preparation and Wet to dry method Tested by: Mulugeta T. Test Pit : C-1.5

Test Date: 12/06/11 E.C.

Depth of Sample:1.5m Location: Bure, West Gojjam,

Determination No.	1	2	3
Number of Blows	23	29	35
Container No.	Y2	K6	P2
Weight of Container, W0 (gm)	16.2	15.8	9.3
Weight of Container +wet soil, W1 (gm)	41.5	37.5	28.4
Weight of Container +Oven dried soil, W2 (gm)	32.4	30.1	21.9
Weight of Water = W1-W2 (gm)	9.1	7.4	6.5
Weight of Oven dried soil = W2-W0 (gm)	16.2	14.3	12.6
Water Content , ω = $\frac{W1-W2}{W2-W0}$ *100 (%)	56.2	51.7	51.6
Liquid limit value interpolated (LL) = 54.7%			

A-6, Plastic limit Data Sheets

Test Method: Wet preparation and Wet to dry method Tested by: Mulugeta T. Test Pit : A-1.5

Test Date: 11/06/11 E.C.

Depth of Sample:1.5m Location: Bure, West Gojjam,

Determination No.	1	2
Container No.	A8	L2
Weight of Container, W0 (gm)	21.9	16.1
Weight of Container +wet soil, W1 (gm)	31.2	27.9
Weight of Container +Oven dried soil, W2 (gm)	28.8	24.7
Weight of Water = W1-W2 (gm)	2.4	3.2
Weight of Oven dried soil = W2-W0 (gm)	6.9	8.6
Water Content , ω = $\frac{W1-W2}{W2-W0}$ *100 (%)	34.8	37.2
Plastic limit value-Average- (PL) = 36%		

Test Method: Wet preparation and Wet to dry method   Tested by: Mulugeta T.   Test Pit : C-1.5

Test Date: 12/06/11 E.C.

Depth of Sample:1.5m   Location: Bure, West Gojjam,

Determination No.	1	2
Container No.	M4	M1
Weight of Container, W0 (gm)	9.4	9.7
Weight of Container +wet soil, W1 (gm)	15.63	17.9
Weight of Container +Oven dried soil, W2 (gm)	13.8	15.5
Weight of Water = W1-W2 (gm)	1.83	2.4
Weight of Oven dried soil = W2-W0 (gm)	4.4	5.8
Water Content , ω = $\frac{W1-W2}{W2-W0}$ *100 (%)	41.6	41.4
Plastic limit value-Average- (PL) = 41.5%		

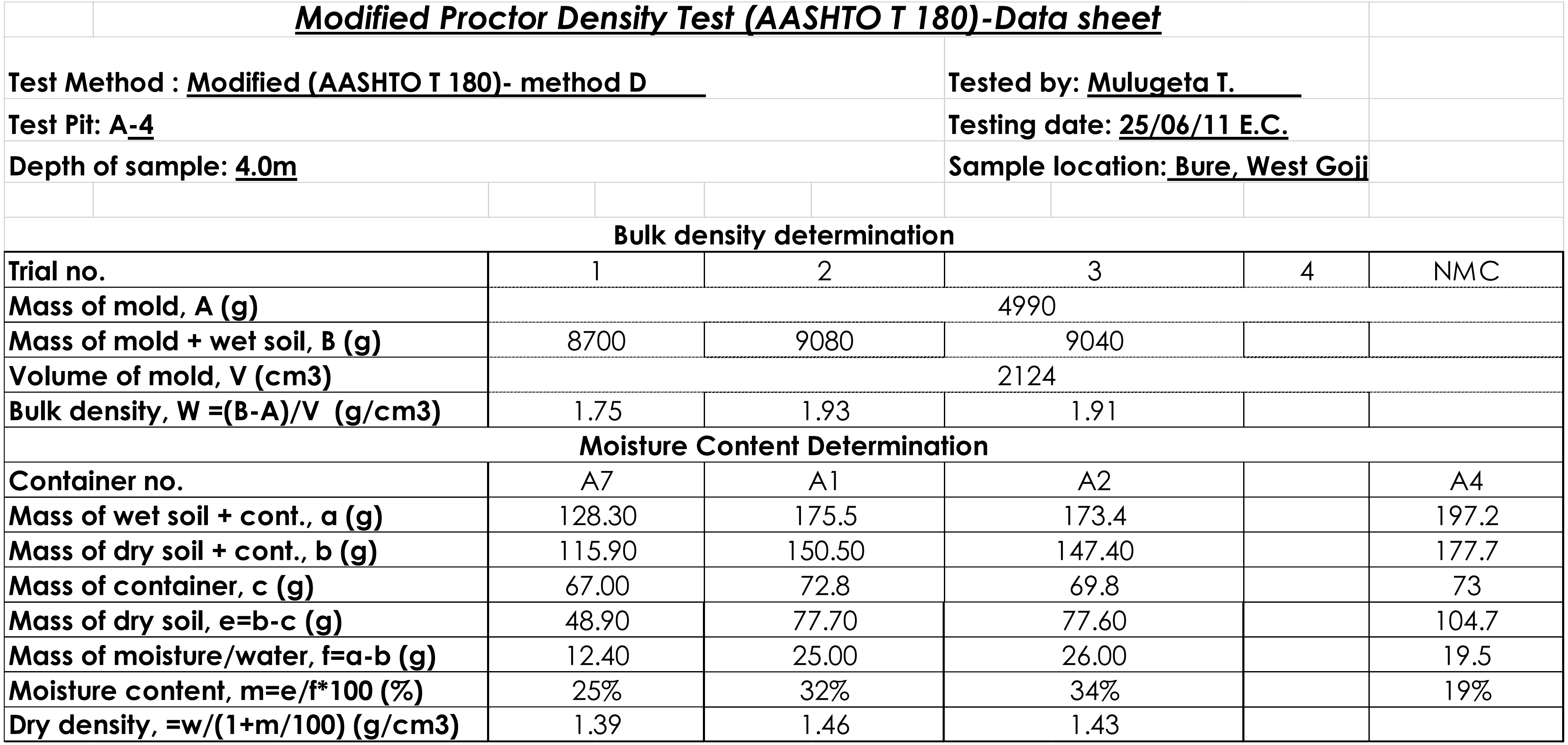
A-7, Linear shrinkage Data sheet

Test Method: BS 1377-2 Tested by: Mulugeta T. Test Pit : A-1.5 Test Date: 11/06/11 E.C.

Depth of Sample:1.5m Location: Bure, West Gojjam,

Determination No.	1	2
Mould no.	3	1
Length of mould, Lo (mm)	136	136
Length of sample after drying, Ld (mm)	124	125
Shrinkage (%) = $\frac{Lo-Ld}{Lo}$ *100	8.8	8.1
Linear shrinkage value , %	8.5	

A-8, Modified Proctor Compaction Test – data sheet



Modified Proctor Density Test (AASHTO T 180)-Data sheet

Test Method : Modified (AASHTO T 180)- method D
Test Pit: A-4
Depth of sample: 4.0m
Tested by: Mulugeta T.
Testing date: 25/06/11 E.C.
Sample location: Bure, West Gojj

Bulk density determination

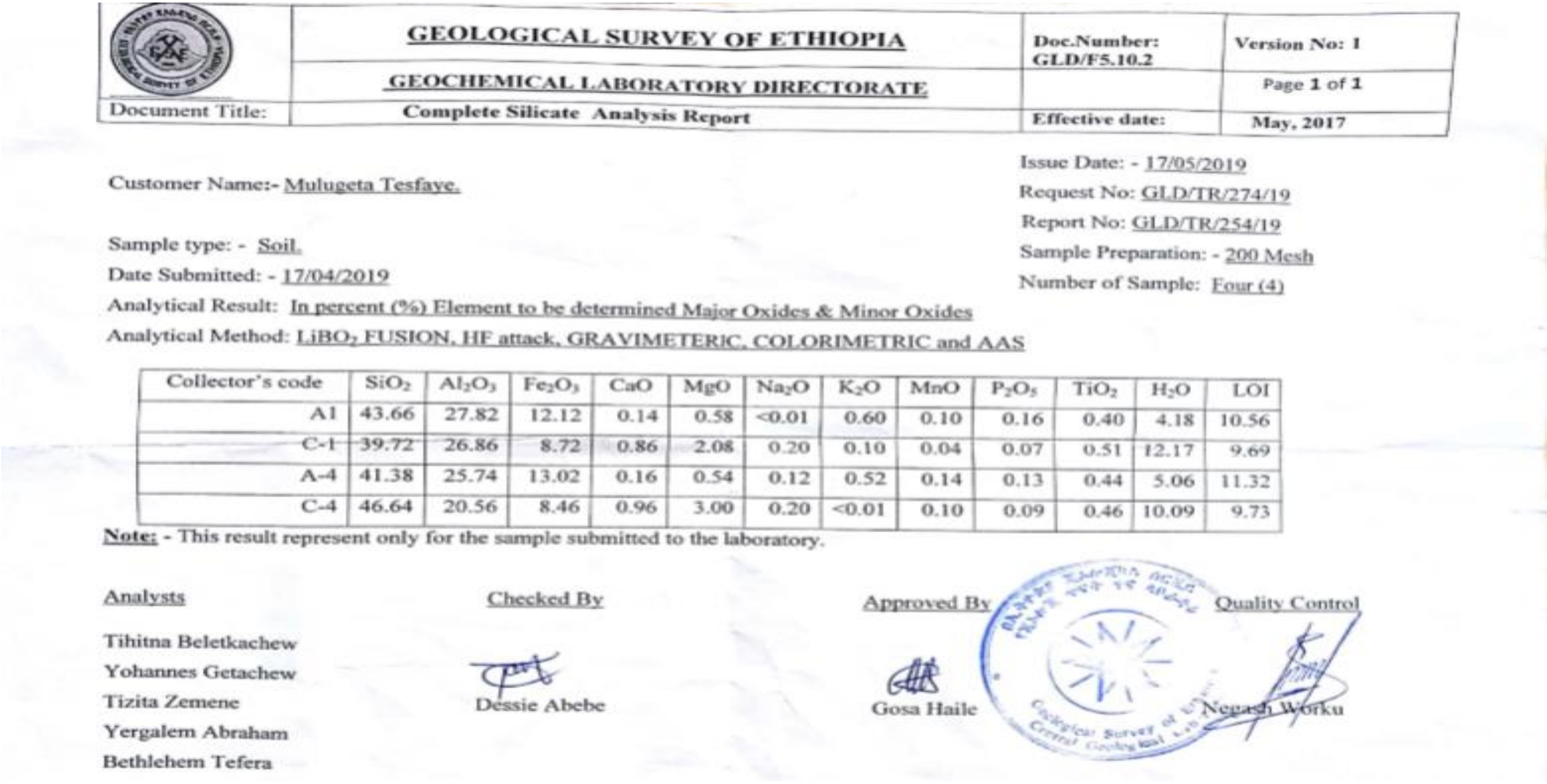
Trial no.	1	2	3	4	NMC
Mass of mold, A (g)	4990				
Mass of mold + wet soil, B (g)	8700	9080	9040		
Volume of mold, V (cm3)	2124				
Bulk density, W =(B-A)/V (g/cm3)	1.75	1.93	1.91		

Moisture Content Determination

Container no.	A7	A1	A2		A4
Mass of wet soil + cont., a (g)	128.30	175.5	173.4		197.2
Mass of dry soil + cont., b (g)	115.90	150.50	147.40		177.7
Mass of container, c (g)	67.00	72.8	69.8		73
Mass of dry soil, e=b-c (g)	48.90	77.70	77.60		104.7
Mass of moisture/water, f=a-b (g)	12.40	25.00	26.00		19.5
Moisture content, m=e/f*100 (%)	25%	32%	34%		19%
Dry density, =w/(1+m/100) (g/cm3)	1.39	1.46	1.43		

Appendix B – Geochemical Test Data sheet

B-1, Geochemical Analysis Test – Data Sheet



	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: - 17/05/2019
Request No: GLD/TR/274/19
Report No: GLD/TR/254/19
Sample Preparation: - 200 Mesh
Number of Sample: Four (4)

Customer Name:- Mulugeta Tesfaye.

Sample type: - Soil.
Date Submitted: - 17/04/2019
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
A1	43.66	27.82	12.12	0.14	0.58	<0.01	0.60	0.10	0.16	0.40	4.18	10.56
C-1	39.72	26.86	8.72	0.86	2.08	0.20	0.10	0.04	0.07	0.51	12.17	9.69
A-4	41.38	25.74	13.02	0.16	0.54	0.12	0.52	0.14	0.13	0.44	5.06	11.32
C-4	46.64	20.56	8.46	0.96	3.00	0.20	<0.01	0.10	0.09	0.46	10.09	9.73

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

Analysts	Checked By	Approved By	Quality Control
Tihitna Beletkachew Yohannes Getachew Tizita Zemene Yergalem Abraham Bethlehem Tefera	Dessie Abebe	Gosa Haile	Negash Worku

Appendix C – Sample Laboratory Photographs

C-1, Grain size analysis (wet sieving)

C-2, Grain Size Analysis (Hydrometer Analysis)

C-3, Liquid Limit Determination (Sample on Casagrande Cup)

C-4, Plastic Limit Determination

C-5, Linear Shrinkage Determination (Specimen after oven drying)

C-6, Compaction for CBR testing (using CBR mould)

C-7, Compacted specimen with porous disks (before soaking)