



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

**Detail Investigation on Index Properties of Lateritic
Soils: The Case of Nedjo-Mendi-Assosa**

**By
Jiregna Dibisa**

March, 2008

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- The Case of Nedjo-Mendi-Assosa**

A thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering

**By
Jiregna Dibisa**

**Advisor
Dr. Messele Haile**

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**By
Jiregna Dibisa
Faculty of Technology**

Approved by Board of Examiners

(Advisor)

(Internal Examiner)

(External Examiner)

(Chairman)

Declaration

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Messele Haile and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

Name Jiregna Dibisa

Signature _____

Place Faculty of Technology,
Addis Ababa University,
Addis Ababa.

Date March, 2008

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Symbols and abbreviations

Designation		Units
LL	Liquid limit	%
PL	Plastic limit	%
PI	Plasticity Index	%
NA1	Nedjo, test pit number one at 1m depth	---
NC1	Nedjo, test pit number three at 1m depth	---
ND1	Nedjo, test pit number four at 1m depth	---
AA3	Assosa, test pit number one at 3m depth	---
AD1	Assosa, test pit number four at 1m depth	---
AF1	Assosa, test pit number five at 1m depth	---
LS	Linear shrinkage	%
FS	Free Swell	%
σ	standard deviation	---
S_g	Specific gravity	---
W	Moisture content	%
AD	Air drying or oven drying at a temperature of 50°C with maximum Relative humidity (RH) 30%	---
OD	Oven drying at a temperature of 105°C	---
S	Soaking (saturation)	---
AR	As received /at the natural moisture content/	---
RH	Maximum relative humidity	%
AASHTO	(American Association of State Highway and Transportation Officials)	---
USCS	(unified soil classification system)	---
ASTM	(American Society for testing and Materials).	---

Abstract

The classification properties and composition of lateritic soils, developed on Tertiary basalt, granite and metamorphic rocks like gneiss and Shists in Nedjo, Mendi and Assosa areas have been investigated. X-ray diffraction analyses showed that the soil comprised minerals of Kaolinite and Smectite group such as Kaolinite, Quartz, Dickite, Nacrite, Muscovite, Vermiculite, Geigerite, Zektzerite, Tridymite and Gibbsite. Chemical analyses showed there was a concentration of sesquioxide minerals but no amorphous material present in the soil.

Comparison between moisture content at air-dry temperature (50°C with 30% relative humidity) and that of oven drying at 105°C indicates that there is no structural water.

For the lateritic soil of Nedjo, Mendi and Assosa, unlike the oxidation of the free secondary clay minerals, the fact that there is no pronounced structural water found and/or amorphous clay minerals showed that, dehydration does not significantly affect the index and/or engineering properties of lateritic soils of this area.

In all the cases there is no significant difference observed between the Atterberg limits obtained from test on a specimen mixed for 5min and that of 25min, this indicates that the cementation of the clay particles is too high to be disaggregated with in 25min further mixing and can also be related to the degree of laterization. Analysis of specific gravity of the soils shows that, increase in temperature from its in situ condition to an air-dried equivalent of 50°C oven temperature reduces specific gravity by an average of 4%.

Analyses of the grain size distribution and other physical properties indicated that the soil was not homogeneous within the laterite zone. Atterberg Limit test results for the soil falls below the Casagrande A-line. There were significant differences between the values of plasticity index determined for as received condition compared with air dried samples. High values for both the liquid and plastic limits may be due to the water retention capacity of porous micro-aggregations in the soil. This can be correlated with the degree of laterisation, which depends on the ambient climate, topography and vegetation of the area.

1. Introduction

1.1, General

Laterites and lateritic soils are generally found in warm, humid, tropical areas of the world. The geotechnical properties of these soils are quite different from those soils developed in temperate or cold regions of the world. The properties of lateritic soils are influenced by climate, geology and the degree of weathering or laterization. It has been found that the geotechnical properties of these soils in different tropical countries are also different. Lateritic soils formed on the same parent rock in the same tropical country, but under different climatic conditions have different geotechnical properties (Umarany, M., and Williams D.J., 1990).

In addition, various horizons are often found in lateritic soil profiles. The properties of lateritic soils measured in the laboratory are affected by sample pre-treatment such as air drying, oven drying and mixing time (Umarany, M., and Williams D.J., 1990).

Some of the engineering properties of lateritic soils of western Ethiopia have been studied by (Zelalem, A., 2005) and Wakuma F., (2007). In their study, both have taken five test specimens from selected areas of the region and have made tests on some of the engineering properties of same. But, for the fact that index properties of lateritic soils vary in short distances within the same area and that they are sensitive to factors governing soil formation, test procedures, specimen handling, and pre test treatments; it was found essential to take more soil samples and make detailed investigation on their index properties.

The index properties of red, highly weathered lateritic soils of western Ethiopia are presented in this study. Chemical and mineralogical properties are the criteria for distinguishing between lateritic materials and those only partially laterized.

For the areas of Nejo, Mendi and Assosa, all lateritic soil-forming factors are fulfilled, and hence one can consider the soils as lateritic (Zelalem, A., (2005). In this research work physical property tests, X-RAY diffraction and chemical test results confirmed that the soils under consideration are indeed laterites.

Both laterites and lateritic type soils are utilized in highways and other engineering applications, usually without distinction. The properties of both are sufficiently similar that separating them has little engineering significance. Exceptions are those soils, which change properties upon drying and the test procedure adopted. Such soils like ferrallite are usually highly laterized. Halloysitic soils, which are only partially laterized, also display large changes in properties with drying.

1.2 Objectives of the research

The main objective of this research is to:

- 1, make detail investigation of index properties of laterite and lateritic soils of Nedjo - Mendi - Assosa soils.
- 2, investigate the effect of pre test treatment and test procedures on index properties of these soils.

1.3 Experimental program

Classification testing was performed on all recovered samples in accordance with ASTM (American Standard Testing Materials), AASHTO (American Association of State Highway and Transportation Officials), and USCS (unified soil classification system and mineralogical composition of the soils. Sieve analyses, hydrometer testing and specific gravity determinations were carried out, together with Atterberg Limit testing, which was performed on fractions of the total samples finer than 0.425 mm. The Atterberg Limit tests were made for three cases on specimens that had been at their natural moisture content, air-dried (50°C equivalent oven temperature) for 24hours; and on specimens that were oven-dried at 105°C. The specimens were cured overnight at water content close to their plastic limit. Liquid limit testing was carried out using the Casagrande apparatus. The mixing time after adding increments of water was for 5 min and 25min to evaluate the effect of mixing time. Each test was repeated for the 28 soil samples recovered from different depths of the area.

A mineralogical analysis was performed on air-dried random powdered samples using a Philips X-ray diffractometer, Chemical analyses was also carried out in accordance with Fields and Perrott (1966). Tests were performed to check for the presence of secondary minerals Sequoxides, Halloysite and amorphous colloidal Allophane. The specimens are all obtained from disturbed bag samples.

1.4 Scope of the study

The research is limited to the index property tests on samples taken from different locations of Nedjo, Mendi and Asossa areas. Due to unavailability of test equipment in the country, it was not possible to conduct scanning electro microscope test to assess in the qualitative explanation of the observed macro structural behavior of the soil in terms of its microstructure.

1.5 Organization of the thesis

The thesis consists of six chapters. The introductory chapter consists of the background, objective and a brief summary of the work. The second chapter covers the literature review on residual soils, weathering and formation, effects of pre-test treatment and test procedures on the index properties of lateritic soils. The third chapter consists of the sampling area descriptions and soil characteristics of the area of study. The fourth chapter is devoted to laboratory test results and analysis. The conclusions and recommendations are presented in the fifth chapter. References and Appendix are presented at the end of this thesis.

2. Literature review

2.1 General

The soil name "laterite" was coined by Buchanan in India, from a Latin word "later" meaning brick. Laterite is a residual of rock decay that is red or reddish in color. Soils under this classification are characterized by forming hard, impenetrable and often irreversible pans when dried. However, there is confusion in the use of the term, because a variety of materials with many types of compositions and various origins have been called laterites, ranging from iron cappings to the zonal soils of the humid tropics and the whole weathered profile beneath a laterite of Buchanan's meaning to the iron-rich breccias and slope wash accumulations. Because of this confusion, most workers now prefer to use the definitions based on hardening, such as "Ferric" for iron-rich cemented crusts, "Alcrete" or Bauxite for Aluminium-rich cemented crusts, "Calcrete" for Calcium Carbonate-rich crusts, and "Silcrete" for silica rich cemented crusts. (Umarany, M., and Williams D.J., 1990).

Other definitions have been based on the ratios of silica (SiO_2) to Sesquioxides (Fe_2O_3 , Al_2O_3). In laterites the ratios are less than 1.33. Those between 1.33 and 2.0 are lateritic soils, and those greater than 2.0 are indicative of non-lateritic soils (Blight, G.E., 1997).

In this tropical part of the world, lateritic soil are used as a road making material and they form the sub-grade of most tropical road, they are used as sub base and bases for a low cost roads and these carry low to medium traffic. Further more, in rural areas they are used as building material for molding of blocks and plastering.

2.2 Formation of Lateritic Soils

Laterite soils are formed in hot, wet tropical regions with an annual rainfall between 750mm to 3000mm, (usually in areas with a significant dry season) on a variety of

different types of rocks with high iron content. The locations on the earth, that characterize these conditions fall between latitudes 35° S and 35° N (figure 2.1).

laterite is a highly weathered material rich in Secondary Oxides of Iron, Aluminium 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 (Alexander and Cady, 1962)

The laterisation process appears to take place in three stages. Initially, 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 alkalis (Calcium and Magnesium Oxides, among others) are leached and accumulation of sesquioxides takes place. Leaching occurs during the wet season due to infiltrating water and its extent depends on the pH of the ground water and drainage conditions (Gidigas, 1976).

Iron is usually carried in Ferrous form by the water. Ferrous ions are mobile until they are oxidized to Ferric ions. Following the dry season, evaporation leads to upward migration of Ferrous ions and the opportunity for oxidation by atmospheric Oxygen. Iron then precipitates as hydrated Ferric oxide gel. Aluminium moves in solution until precipitated as an Alumina gel by dehydration or a change in pH (Umarany, M., and Williams D.J., 1990).

The Sesquioxides (hydrated Ferric oxide gel and Alumina gel) are adsorbed on the surfaces of the clay minerals. This adsorption occurs through the interaction of positively charged Sesquioxides and negatively charged clay particles (Townsend et al., 1969). At the third stage, partial or complete dehydration of hydrated colloidal Sesquioxides occurs. Dehydration is accompanied by crystallisation of amorphous iron colloids into dense crystalline forms in the sequence of Limonite, Goethite, and Haematite. This is accompanied by a change in colour from yellow or yellow-brown to red. Gelatinous, free Iron oxide first coats the soil particles, exerting a cementing effect upon the clay, silt and sand size fractions. On dehydration, larger particles and nodules are formed (Gidigas, 1972).

Many authors have revealed, through petrographic studies, that lateritic soils often possess a porous granular structure consisting of Iron-impregnated clayey material in minute (1-10 μm) spherical aggregations (Humbert, 1948; Alexander and Cady, 1962; Hamilton, 1964). The strength of these aggregations is derived from thin Ferruginous films found within the micro-joints of the elementary clay particles and as coatings over the particles.

The hardening process has been explained by Humbert (1948) from field observations and microscopic studies. Initially, the soil has a large specific surface area, reflected by the amount of absorbed water present. On dehydration, the amorphous iron oxide loses its water and changes to the crystalline form resulting in high liquid limit. Terzaghi explained this anomalous behavior by assuming that the clay existed in clusters of interconnected clay particles. The clay was considered strongly aggregated, a state unlikely to change during construction.

The aggregating effect of the Iron oxide in the Sasumua clay was later demonstrated by Newill (1961). He removed the iron chemically and found the clay aggregations had been dispersed. These did not reform as had been the case after mechanical manipulation. The Atterberg Limits were determined before and after chemically removing the free iron oxide. The liquid limit and plasticity index increased considerably.

The dehydration of other clay materials also causes changes in properties. Variations in the values of maximum density tests depend on whether the tests were performed after air drying or without air drying, or by determining the points backward along the moisture-density curve as the soil dries.

In well-drained soils, therefore, the resulting residual soils often have characteristically high contents of aluminum and Iron oxides and a loss of Silica and bases from leaching which is referred to as *laterization* these highly weathered tropical materials may irreversibly change properties when dried, and even simply remolding the material may cause significant change in properties.

This irreversible change in engineering properties on drying or remolding means conventional laboratory testing that relies on disturbed bulk sampling and usually oven-dried material before testing will give erroneous estimates of in-situ properties. Consequently, laboratory testing procedures, specifications, and construction techniques based on temperate climate experiences the need of modification for lateritic materials. The self-hardening properties that some lateritic materials possess are probably too difficult to reliably ascertain and use for most engineering purposes.

As a part of the lateritic weathering process, deposits containing hardened sand and gravel size particles or even massive hardened boulders or extensive rock may form. These lateritic gravel particles or rock are cemented by various Iron and sometimes Aluminum oxide and hydroxide weathering products. These may provide a useful or even the only source of construction aggregate in some areas. Conditions favoring their formation include:

- (1) Parent materials rich in Iron and Aluminum bearing minerals and prone to reasonably rapid weathering (e.g., Basalts or Granodiorites)
- (2) Warm climate with alternating wet and dry seasons.
- (3) Topography that provides a well-drained regime that aids leaching.
- (4) The Quartz content of the parent rock. Where Quartz is a substantial component of the original rock, it may remain as Quartz grains.

Hence, lateritic gravels tend to be found on slopes (sometimes locally termed *ridge gravels*), to a lesser extent on uplands and not in low poorly drained areas. On the level ground, where drainage is poor, expansive clays dominate at the expense of laterites.

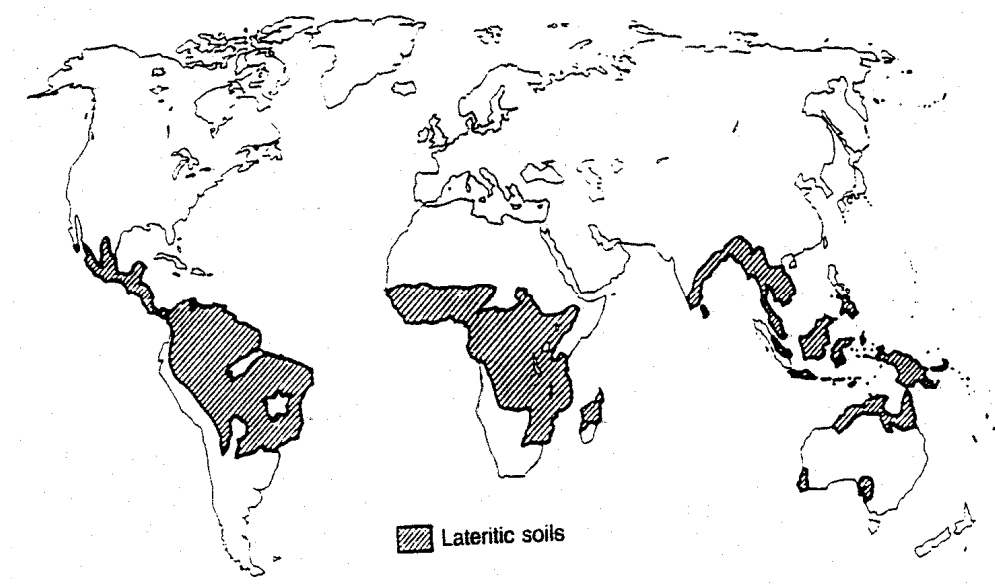


Figure 2.1 World-wide distributions of laterite soils.

Based on the above discussion, the three major processes responsible for the formation of laterites can therefore be summarized as follows:

Decomposition: physico-chemical breakdown of primary minerals and the release of constituent elements (SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , MgO , K_2O , Na_2O , etc), which appear in simple ionic forms.

Laterization: leaching under appropriate conditions, of combined silica and bases and the relative accumulation or enrichment of Oxides and Hydroxides of Sesquioxides (Fe_2O_3 , Al_2O_3 , and TiO_2). 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.

The level to which the second stage is carried depends on the nature and the extent of the chemical weathering of the primary minerals. Under conditions of low chemical and soil-forming activity, the physico-chemical weathering does not continue beyond the clay-forming stage, and tends to produce end products consisting of clay minerals predominantly represented by Kaolinite and occasionally by hydrated or hydrous oxides of Iron and Aluminium.

Desiccation: desiccation or dehydration involves partial or complete dehydration (sometimes involving hardening) of the Sesquioxide rich materials and secondary minerals. The dehydration of colloidal hydrated Iron oxide involves loss of water and the concentration and crystallization of the amorphous Iron colloids into dense crystals, in the sequence; Limonite, Goethite with Hematite to Hematite (Hamilton, 1964).

Dehydration may be caused by climatic changes, upheaval of the land, or may also be induced by human activities, for example by clearing of forests,

2.3 Profiles of Lateritic Soils

Laterite profiles are generally of three types, those in which the crust is derived from

- the overlaying soil (downward transport / leaching),
- from underlying weathered rock (upward transport), and
- those in which the crust forming material is detrital (transported and deposited and precipitated).

The laterite profiles that develop in-situ have a number of horizons. The horizons vary in thickness, hardness and color depending upon the degree of development and preservation of the profile. If laterite soil profiles are dried out, because of the lowering of the water table, the top of the laterite soil may grade into a hard duricrust .

Laterites may occur as surface deposits of unhardened clayey soils, gravels, and as hardpans, found as capping on detached plateau remnants, but would be in lower parts of the slopes. The hardpans can be subjected to a new cycle of weathering and transportation in which hardpan fragments are re deposited elsewhere as secondary deposits. Rock-like laterite is usually very heavy and abrasive and unsuitable for quarrying and processing to road aggregates.

Lateritic gravels stand out as low humps in the terrain. They consist of gravel sized concretionary nodules in a matrix of silt and clay. They may take up an area of several hectares and a thickness of between 1 to 5m.

2.4 Engineering properties of lateritic soil

Geotechnical characteristics and field performance of lateritic soils may be interpreted in the light of all or some of the following parameters:

- ▶ Genesis and pedological factors (parent material, climate, topography, and vegetation, period of time in which the weathering processes have operated),
- ▶ Degree of weathering (decomposition, Sesquioxide enrichment and clay-size content, degree of leaching),
- ▶ Position in the topographic site, and
- ▶ Depth of soil in the profile (Gidigashu, 1976).

2.5 Engineering Classification

2.5.1 The need for special classification

There are specific features or characteristics of residual soils that are not adequately covered by conventional methods of soil classification such as the Unified Soil Classification System. Among these features are the following (Blight, G.E., 1997)

- a) The unusual clay mineralogy of some tropical and subtropical soils results in characteristics that are not compatible with those normally associated with the group to which the soil belongs according to existing systems such as the Unified Soil Classification System.
- b) The soil mass in-situ may display a sequence of materials ranging from a true soil to a soft rock depending on the degree of weathering, which can not be adequately described using existing systems based on classification of transported soils in temperate climates.
- c) Conventional soil classification systems focus primarily on the properties of the soil in its remolded state; this is often misleading with residual soils as their properties are likely to be most strongly influenced by in situ structural characteristics inherited from the original rock mass or developed as a consequence of weathering.

Wesley proposed a practical system for classifying all residual soils, based on the mineralogical composition and soil micro and macro-structure. Wesley's classification system is intended to provide an ordinary division of residual soils in to groups that belong together because of common factors in their formation and /or composition, which can be expected to give them similar engineering properties (Blight, G.E., 1997).

2.5.2 The proposed grouping

The first step in grouping of residual soils is to divide them into groups on the basis of mineralogical composition alone with out reference to their undisturbed state (Blight, G.E., 1997). These groups are

- I. **Group A:** Soils without a strong mineralogical influence, e.g., Saprolites (Residual soil with clear structural feature inherited from its parent rock).
- II. **Group B:** Soils with a strong mineralogical influence deriving from clay minerals also commonly found in transported soils (Black Cotton Soils).
- III. **Group C:** Soils with a strong mineralogical influence deriving from clay minerals only found in residual soils (based on clay mineral these can be, Allophane sub group, Halloysite sub group, Sesquioxide sub group).

The group C can be classified as the following sub-groups

A) Halloysite soils: The principal influence of Halloysite appears to be that the engineering properties of the soil are good, despite a high clay fraction, and fairly high values of natural water content in terms of Atterberg Limits (i.e. a high liquidity index).

B) Allophonic soils: Allophonic soils are probably the most distinctive of all residual soils due to the very unusual properties of the amorphous mineral Allophane. Allophane soils have a natural moisture content ranging from about 80% to 250%, but

which still perform satisfactorily as a construction material. They are superior to other soils with similar water content.

C) Soils influenced by the presence of Sesquioxides: The principal role of Sesquioxides appears to act as cementing agents, which bind the other mineral constituents in to clusters or aggregations. With sufficient concentration of Sesquioxides, the hard concretionary material called laterite will be formed. This sub groups may perhaps be termed as Lateritic group (Blight, G.E., 1997).

Generally, classification of laterites is also possible according to its genetic basis, size of particle and degree of concertion. Besides the suggested grouping system presented, an additional item of formation which is usually of major importance in influencing the properties of residual tropical soils is the type of the parent rock and should always be included in the grouping processes.

It was found during a recent study that most of the residual soils of Africa could be divided into three groups on a genetic basis, determined by the soil-forming factors. The three major groups of significance have been defined by (Lyon, 1971). These are;

i) Ferruginous Soils: These occur in extremely arid conditions for lateritic soils, in areas with pronounced dry seasons. Ferruginous soils are common, they are hard and durable. Marked separation of Iron oxide is frequently observed which may be leached or precipitated with the profile. Kaolinite is the predominant clay mineral in this type. It requires an average annual rainfall of 600-1800mm for its formation.

ii) Ferallitic Soils: These occur in more humid areas for lateritic soils and in areas with dense vegetation cover. Gibbsite is the most common clay mineral observed and other hydrated forms of alumina occur as well as hydrated iron minerals. Halloysite is fairly common over volcanic rocks. The annual average rainfall requirement for its formation is 1500- 4000mm. Both of the above soils have $\text{SiO}_2 / \text{R}_2\text{O}_2$ ratio of less than 2.0 and are classified either as lateritic or laterite soils.

iii) Ferrisols: These are formed over all types of rocks in intermediate to high rainfall areas where erosion has kept the place with profile development. They have similar profiles to ferallitic soils, but with few weatherable minerals remaining. The entire clay fraction comprises Kaolinite and amorphous oxides of iron and aluminum. These are developed at deeper levels due to the surface erosion, and occur in regions of annual average rainfall of 1250-2750mm. Ethiopian laterites fall under this group.

Moreover, based on soil forming factors, climate, topography, vegetation and parent rock, tropical soils may be classified as, Latosols, Andosols and Saprolites in addition to the above three groups. (Lyon, 1971)

I) Latosols and Andosols: These are generally formed from weathering of volcanic rocks under humid tropical conditions. Halloysite and Allophane are common clay minerals and these soils have usually high moisture content.

II) Saprolite Soils: They are residual soils with clear structural features inherited from its parent rock. These soils have fragile character in grain size and the bond could be strongly affected when pulverizing.

On the other hand, other suggested interesting lithological classification of lateritic soils is as follows; (Lyon, 1997)

Lateritic clays	< 0.002mm
Lateritic silts	= 0.002-0.06mm
Lateritic sands	= 0.06-2mm
Lateritic gravel	= 2-60mm
Lateritic stones and cuirasse	> 60mm

Moreover, Anthony has distinguished the following main types and sub-divisions of laterite (Lyon, 1997):

- 1) **Massive laterite:** Possesses a continuous hard fabric, subdivided in to:
 - a. Cellular laterite: - with cavities approximately rounded.

- b. Vascular laterite: - with cavities approximately tubular.
- 2) **Nodular laterite:** - Consists of individual particles approximately rounded (also called Pisolithic laterite) subdivided in to:
- a. Cemented nodular laterite: Individual concretions can be seen but are strongly joined together by the same iron stone material.
 - b. Partially cemented nodular laterite.
 - c. Non-cemented nodular laterite: Concretions from over 60 percent by weight of the total soil.
 - d. Iron concretions: Are separated by soil-but forms less than 60 percent by weight of the total horizon.
- 3) **Recemented laterite:** This contains fragments of massive laterite or ferruginized rock, broken and wholly or partly cemented.
- 4) **Ferruginized rock:** Here, rock structure is still visible, but with substantial isomorphous replacement by Iron.
- 5) **Soft laterite:** Mottled iron-rich clay, which hardens irreversibly on exposure to air to, repeated wetting and drying.

The usual methods of soil classification, involving grain-size distribution and Atterberg Limits, should be performed on laterites or suspected laterites that are anticipated for use as fill, base-course, or surface-course materials. Consideration should be given to the previously stated fact that some particles of laterite crush easily; therefore, the results obtained depend on such factors as: the treatment of the sample, amount of breakdown, and the method of preparing the minus Number 40 sieve material. The more the soil structure is handled and disturbed, the finer the aggregates become in grading and the higher the Atterberg Limit. While recognizing the disadvantage of these tests, it is still interesting to note the large spread and range of results for both laterites and lateritic soils.

2.6 Effects of secondary minerals, drying and remolding on Atterberg limits of lateritic soil

Many authors (for example, Newill, 1961; Townsend, 1969; Gidigas, 1976) have shown that lateritic soil may contain secondary minerals such as Halloysite and Allophane. The presence of these minerals depends on the parent rock and climatic conditions. Halloysite is a member of the Kaolinite group and has a structure similar to Kaolinite, except that there is a layer of water between the Alumino silicate layers. This mineral exists in two states of hydration, as hydrated Halloysite (4 H₂O) and as Metahalloysite (2 H₂O). Dehydration of hydrated Halloysite causes an irreversible change into Metahalloysite. This change occurs when the moisture content is reduced below 10%, or when the relative humidity is below about 40%, or at temperatures above 60°C (Newill, 1961). Allophane is a general term for amorphous Aluminosilicate gels, which can vary widely in composition. Allophane occurs characteristically in soils as a product of the weathering of volcanic ash. However, it is also likely to occur in soils derived from basalt (Fieldes and Perrott, 1966). Like hydrated Halloysite, Allophane also loses water progressively with rise in temperature. When Halloysite and Allophane are present the determination of plasticity characteristics using oven-dried samples gives erroneous results. In addition, soils containing hydrated Sesquioxides are sensitive to drying (Gidigas and Yebo, 1972) even if the above-mentioned problem causing minerals are not present. The drying of lateritic soil causes aggregation of the soil particles and hence a decrease in plasticity. Wallace showed that air drying caused the clay content of a lateritic soil found in the continually wet climate of Papua New Guinea to decrease by 24-46%. Due to the fact that the extraction of iron has been found to be more difficult in oven-dried soil than in soil maintained at natural moisture content (Newill, 1961), it is generally believed that drying causes stronger iron oxide bonding. This results in a decrease in clay content and/or liquid Limit. Townsend et al. (1969) have shown that manipulation causes the breakdown of cementation, which leads to an increase in plasticity.

In general, remolding and removal of free iron oxide increases the content of fines by 35% to 65%. Atterberg Limits for lateritic soil plot above the Casagrande A-line.

Casagrande found empirically that soils which fall below the A-line include organic silts and clays, and Micaceous soils. However, when lateritic soils contain secondary minerals such as hydrated Halloysite or an amorphous colloid such as Allophane, their Atterberg limits plot below the A-line (Gidigas, 1976). It is therefore important to carry out mineralogical analyses of lateritic soil, since the mineral constituents will affect the properties of the soil.

2.7. Particle Size Distribution

Texturally lateritic soils are very variable and may contain all fraction sizes; boulders, cobbles, gravel, sand, silt, and clay as well as concretionary rocks. Quartzitic gravels, which are formed from the alteration of Quartz rich parent rocks, are generally well graded with 20% of silt and clay-size fraction. Concretionary laterites have a higher content of fines ranging from 35% to 40%. Foot slope concretionary laterite gravels are coarse and gap graded (less sand), compared to high level gravels (Gidigas, 1976).

2.8. Plasticity Characteristics of Laterite Soils

Plasticity tests may be affected by pre-test preparation, degree of moulding and time of mixing, drying and re-wetting, and irreversible changes in plasticity on drying. Drying drives off adsorbed water which is not completely regained on re-wetting (this is the case in both oven and air-drying (Fookes, 1997)). Distilled water should always be used to minimize the effect of ion exchange on plasticity. Soils which contain hydrated oxides of iron and aluminium may become less plastic on drying. This is partly because dehydration of Sesquioxides creates a stronger bond between the particles, which resists penetration by water. The process can not be reversed by re-wetting. The effect is observed during air-drying but is more pronounced on oven drying at higher temperature (Ne will, 1961).

The susceptibility to change of physical properties due to dehydration was investigated by the aggregation index as proposed by Tateishi (Ne will, 1961). The aggregation index is the ratio of the oven dried sand equivalent value to the sand equivalent value at the field moisture content. The sand equivalent test will run in accordance with ASTM D2419-69 except for the field moisture sample which was not

dried prior to testing. An aggregation index value greater than 2 indicates the susceptibility of the soil to changes in physical properties when dried.

Samples to be tested shall thus be subjected to the four pre treatment conditions in the following manner:

As received (AR) – at natural moisture content.

Soaked (S) – immersed in water for 24 hours

Air dried (AD) – dried at constant weight under normal temperature (23 to 30 °C)

Oven dried (OD) – dried in an oven for 24 hours at 105°C

Studies on the relationship between the natural moisture content and the liquid limit and plastic limit have shown that generally the natural moisture content is less than the plastic limit in normal lateritic soils. However, the lateritic soils from high rainfall areas may have moisture contents as high as the liquid limit (Hirashima, 1948).

3. Site description

3.1 geology, topography, climate and vegetation in the area of study

The area studied is located in western Ethiopia, in the Oromia Regional State. Nedjo, Mendi and Assosa are found in the range of longitude 34.6-35.7°E, latitude 9.55-10°N, about (510-680) km west of Addis Ababa, the capital of Ethiopia. Figures 3.1, 3.2 and 3.3 shows satellite images of the study area (Google earth software, 2007).

The climate is tropical humid with seasonal variations associated with the oscillation of inter-tropical convergence zone /ITCZ/. Between June and September, the ITCZ is located north of Ethiopia and the area is under the influence of Atlantic equatorial westerly and southern winds from the Indian Ocean. This south - westerly winds ascend over the south-western highlands of Ethiopia to produce the main rainy season. About 80% of the mean annual rainfall occurs during the period of these four months. Although the location is in tropics, temperatures are mild. Only occasionally does the temperature exceed 30°C or drop below 10°C. The area lies in the medium to high rain fall area with an average annual rain fall of around 1600mm.

(Zelalem, A., 2007).

Geology of the area specifically comprises granites and various metamorphic rocks including Genesis and Schist which underlie most of the area, with Basalts of tertiary age being found largely to the west of Mendi that under went laterization and as intrusions and volcanic plugs in the areas near Nejo. These rocks have been subjected to very deep and intensive weathering processes, and rock exposures are mainly evident only in the areas underlain by granite and genesis (Rites and UNICONE, 2002).

Topography of the area comprises broadly convex hills with slopes of more than 20%. The area has native vegetation which is dominated by trees of different species including coffee. The ground surface is covered with grass.

3.2 General characteristics of soil profile

The site of the sampling pit was approximately (1600-1850) m above sea level, and covered by trees and grass. The soil profile in the pit had a topsoil cover of about 120 mm, underlain by reddish and reddish brown lateritic soil. The laterite zone can extend beyond 3m depth, with a mottled zone below this depth. Samples were taken at 1.5m and 3m depth intervals within the laterite zone; the lateritic soil was very brittle. It contained many soft concretions (which could not be crushed by hand, even after soaking overnight) and a few hardened ironstones. However, at 2m depth all the gravel-size particles were hardened. The soil collected as disturbed bag samples.

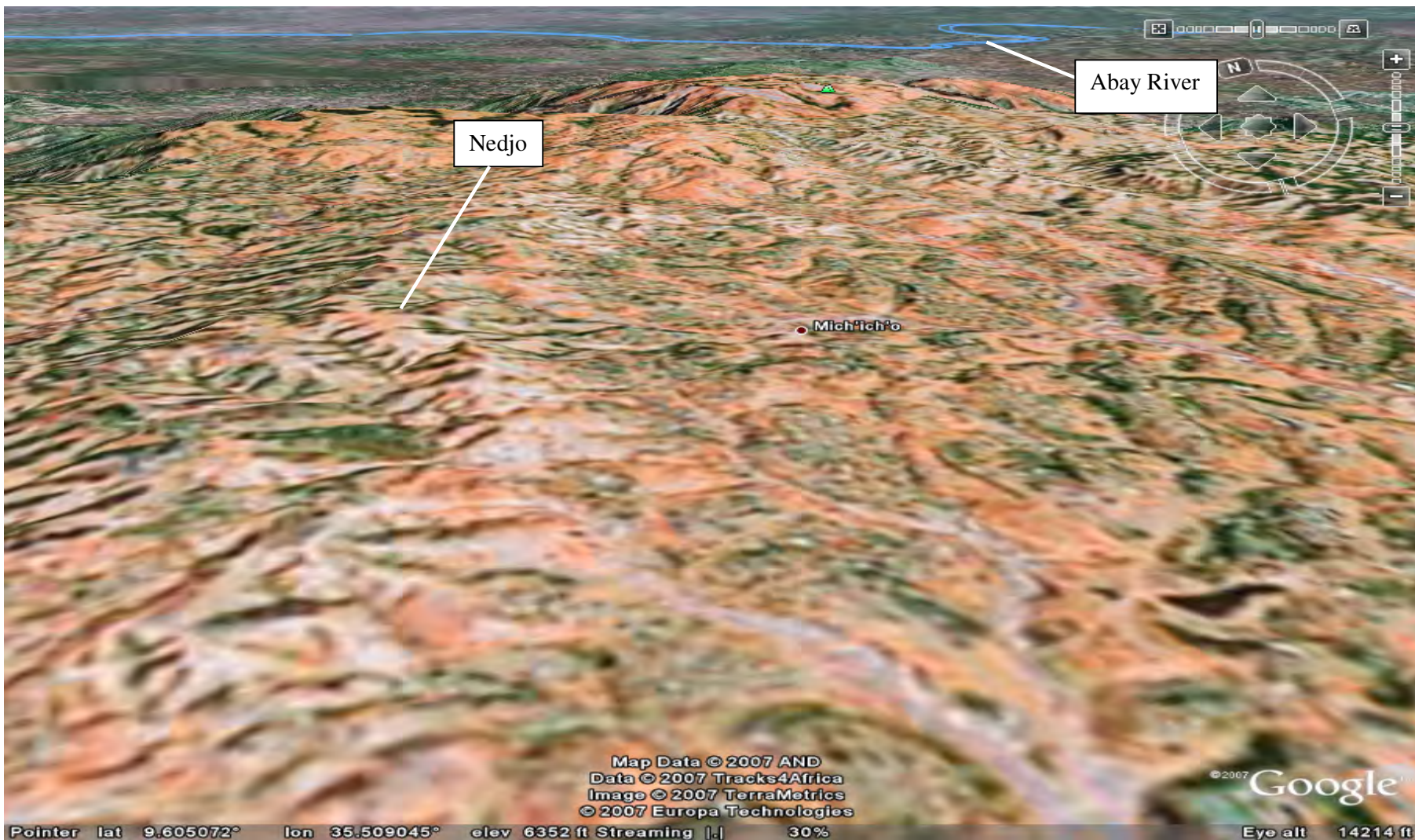


Figure 3.1 Satellite photo of Nedjo area

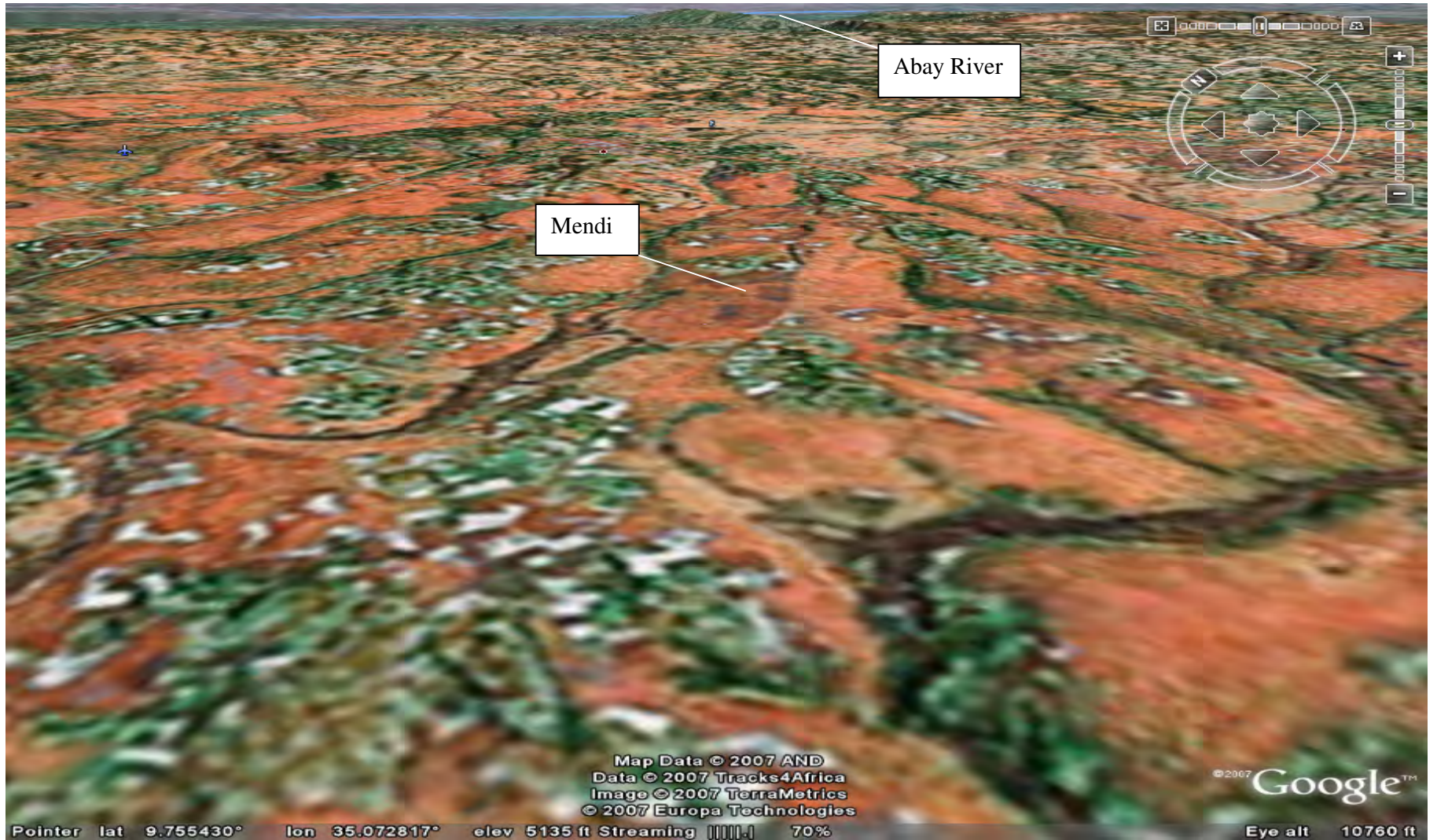


Figure 3.2 Satellite photo of Mendi area

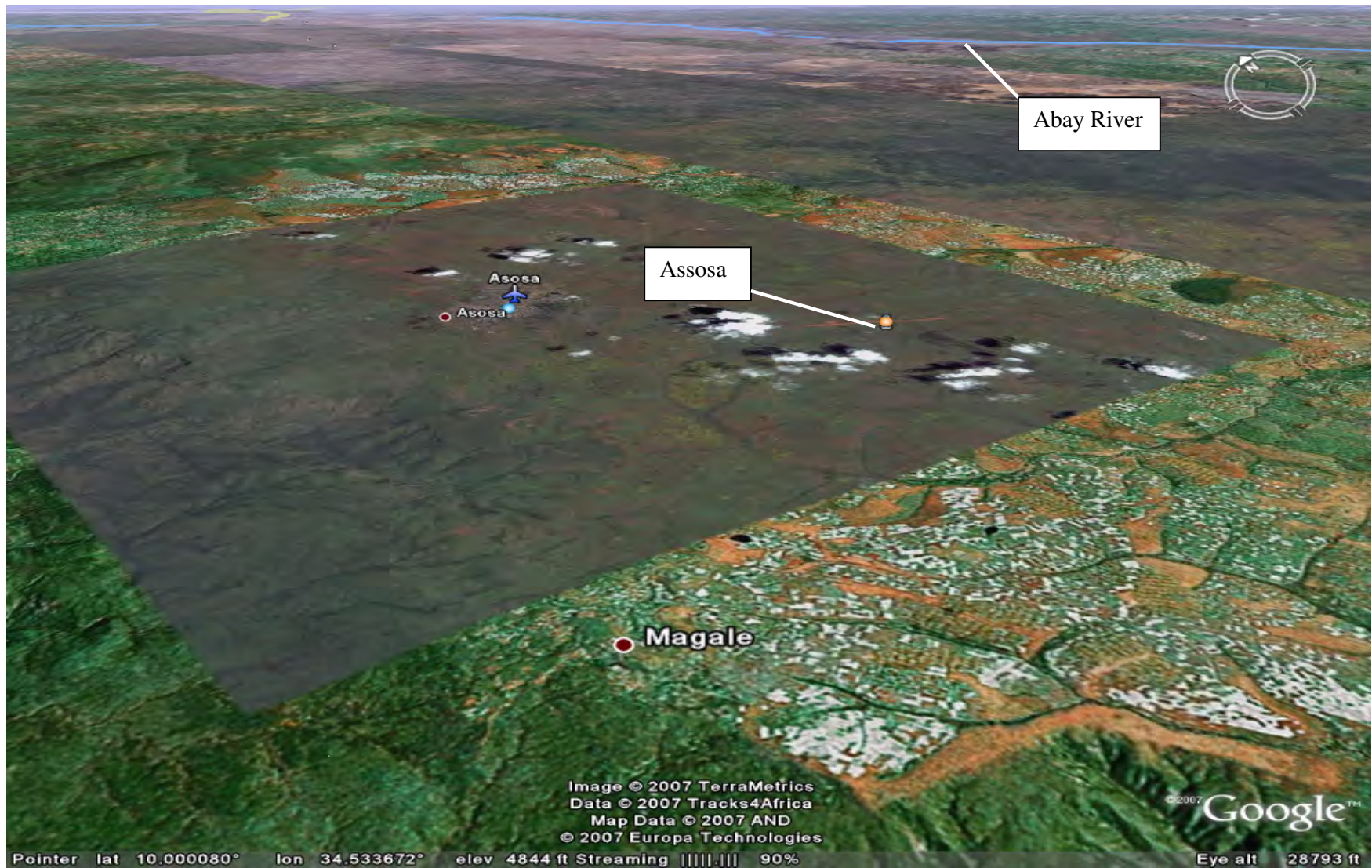


Figure 3.3 Satellite photo of Assosa area.

4. Laboratory test results and discussions.

Most of the laboratory tests were carried out in accordance with the ASTM procedures for soil testing. The laboratory tests conducted are explained in the following section.

4.1 Index Property Tests

Basically, soil is a more complex material usually realized. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solid, liquid and gases, where in many instances the solid particles vary in size ranging from big boulders to colloidal size.

Furthermore the relative quantities of solid, liquid and gases in a given soil is bound to change due to any physical cause, such as loading, seasonal variation and change of temperature. Besides, because of their peculiar formation processes and strong mineralogical influences lateritic soils add further complexities. To understand the behavior of soils, the composition, effect of temperature and pre test treatments and the relative influence of each component must be known. To do this, methods of evaluations (tests) have been centered on their physical property as the physical characteristics are of importance to the engineers. Chemical analysis has also been made to supplement the results. The physical properties of soils which serve mainly for identification and classification are commonly known as index properties.

The various properties of soils which could be considered as index properties under this specific case are:

- Moisture content determination
- Atterberg limits
- Grain size analysis
- Shrinkage limit
- Free swell
- Specific gravity
- Chemical analysis

4.2 Moisture Content Determination

In many residual soils, some moisture exists as water of crystallization within the structure of the mineral present in the solid particles, which may not have an effect on the engineering performance of the soil. However, some of this moisture may be removed by drying at temperatures above the conventional drying temperature (105°c), to the extent that all the index tests reliant on moisture content are affected. To see the existence of such water in the lateritic soils of Nedjo, Mendi and Assosa areas, thirty test specimens were prepared for moisture content determination. Part of the thirty specimens were oven dried at 105°c until successive weighing shows no further loss of mass, while the other thirty from the respective soil specimen are air dried at 50°c in an oven which is equivalent to drying at room temperature for ten days until successive weighing shows no further loss of mass. The moisture content is then calculated in the normal way (equation 1). The two sets of results are then compared (Table 4.1). In all the cases, it can be observed that the difference in moisture content is less than 4%, which shows that the amount of structural water is insignificant. There fore, all the subsequent tests in need of moisture content determinations are based on the conventional drying temperatures.

$$w = \frac{(W_i - W_f)}{W_i} * 100 \dots \dots \dots (1)$$

- w = moisture content
- W_i = moist weight of the sample
- W_f = dry weight

Table 4.1 moisture contents at 50°C and 105°C

Site location	Designation	Depth (m)	Natural moisture content at		Difference
			50°C	105°C	
Nedjo	NA1	1.0	20.82	23.08	2.27
	NA3	3.0	16.15	19.30	3.15
	NB1	1.0	30.90	32.20	1.30
	NB3	3.0	20.40	22.16	1.76
	NC1	1.0	36.76	37.80	1.04
	NC3	3.0	27.58	28.11	0.53
	ND1	1.0	24.39	26.22	1.82
	ND3	3.0	30.22	31.61	1.38
	NE1	1.0	30.69	33.20	2.51
	NE3	3.0	39.74	41.80	2.06
Mendi	MA1	1.0	28.36	30.75	2.39
	MA3	3.0	31.77	31.83	0.07
	MB1	1.0	19.05	21.14	2.09
	MB3	3.0	27.89	29.98	2.09
	MC1	1.0	30.67	33.69	3.02
	MC3	3.0	30.95	33.30	2.35
	MD1	1.0	31.33	33.38	2.45
	ME3	3.0	30.94	33.10	2.15
Assosa	AA1	1.0	25.46	26.61	1.15
	AA3	3.0	27.05	27.92	0.88
	AB1	1.0	28.53	30.38	1.85
	AB3	3.0	29.32	31.26	1.94
	AC1	1.0	31.42	33.23	1.81
	AC3	3.0	17.93	18.95	1.03
	AD1	1.0	31.43	33.29	1.86
	AD3	3.0	34.05	35.74	1.69
	AE1	1.0	27.55	29.55	1.99
	AE3	3.0	29.69	31.70	2.01

4.3 Effects of pre test treatment

Lateritic soil properties change with drying; these are because of the (1) tendency to form aggregations due to oxidation of the iron and aluminium sesquioxides (2) the loss of water of hydration or both.

4.3.1 Effects of drying temperature on Atterberg Limits

Air drying and soil specimens prior to carrying out the Atterberg Limit tests, rather than testing at natural moisture content, in the case of Nedjo-Mendi-Assosa have resulted in a significant decrease in the liquid limit and to a lesser extent in the Plasticity Index,(Table 4.2.)

For the lateritic soil of Nedjo, Mendi, and Assosa, due to the fact that there is no pronounced structural water found (section 4.2) and/or amorphous clay minerals (section4.6), dehydration of Sesquioxides does not significantly affect the index and/or engineering properties of lateritic soils of this area.

From Fig (4.1) one can see that the liquid limit and Plastic limits of the typical soil presented the rapid decrease at air drying temperatures, which can be due to oxidation of secondary minerals while the change in liquid limit at the above temperature is nearly constant. Because the liquid limit and plastic limit decreases at different rate with an increase in temperature, it is difficult to deduce a general conclusion that the PI of these soils decrease with temperature (Table 4.2).

Table 4.2 variation of liquid and plastic limits with temperature.

Site	Design-ation	Depth (m)	Liquid limit			Plastic limit			Plastic index		
			As received	50°C	105°C	As received	50°C	105°C	As received	50°C	105°C
Nedjo	NA1	1.0	73.3	54.1	52.8	36.8	34.9	32.3	36.5	19.2	20.5
	NA3	3.0	70.6	55.2	52.3	41.0	34.2	32.2	29.6	21.0	20.1
	NB1	1.0	59.4	54.6	54.2	36.9	29.0	27.3	22.5	25.6	26.9
	NB3	3.0	62.0	51.6	47.7	39.4	36.3	35.0	22.58	15.3	12.7
	NC1	1.0	64.5	55.1	57.3	38.8	37.8	36.2	25.7	17.3	21.1
	NC3	3.0	53.3	50.7	49.6	36.3	34.8	32.7	17.0	15.9	16.9
	ND1	1.0	58.8	52.1	49.1	47.7	40.3	41.1	11.1	11.8	8.0
	ND3	3.0	73.3	65.5	61.9	48.2	42.8	40.1	25.10	22.7	21.8
	NE1	1.0	64.5	61.3	58.2	44.8	41.0	39.3	16.6	23.5	18.9
NE3	3.0	79.2	69.3	65.4	48.8	45.3	44.0	30.4	24.0	21.4	
Mendi	MA1	1.0	60.1	59.3	56.3	43.0	40.0	38.8	17.1	19.3	17.5
	MA3	3.0	59.7	58.9	51.5	38.5	34.7	33.4	21.2	24.2	18.2
	MB1	1.0	55.0	45.3	NP	35.0	34.7	28.4	20.0	10.6	13.6
	MB3	3.0	59.8	52.4	48.3	40.1	37.3	35.3	19.7	15.1	13.0
	MC1	1.0	68.1	59.3	56.3	51.6	48.6	46.3	16.5	10.7	10
	MC3	3.0	76.3	70.9	60.6	36.5	33.5	29.3	39.8	37.4	31.3
	MD1	1.0	60.7	56.8	47.7	43.3	30.1	29.5	17.4	26.7	18.2
	ME3	3.0	57.3	50.3	47.3	37.7	34.4	32.8	19.6	15.9	14.5
Assosa	AA1	1.0	38.9	37.6	34.0	23.5	22.8	21.3	14.1	16.1	12.7
	AA3	3.0	46.3	40.1	38.1	28.9	26.3	24.2	17.4	13.8	13.9
	AB1	1.0	56.4	47.9	43.8	30.9	30.7	30.1	25.5	17.2	13.7
	AB3	3.0	58.0	51.0	45.0	41.2	35.0	33.3	16.8	16.0	11.7
	AC1	1.0	60.5	52.4	49.1	39.6	35.5	33.6	20.9	16.9	15.5
	AC3	3.0	53.7	52.8	48.8	28.7	27.9	26.4	24.1	15.8	19.1
	AD1	1.0	57.9	51.2	47.4	32.0	29.7	27.1	25.9	21.5	20.3
	AD3	3.0	53.6	47.8	45.3	34.2	31.6	30.0	19.4	16.2	15.3
	AE1	1.0	58.4	51.0	48.1	32.4	30.4	28.3	26.0	20.6	19.8
	AF1	3.0	57.2	53.9	48.3	41.7	39.6	37.1	15.6	14.3	11.2

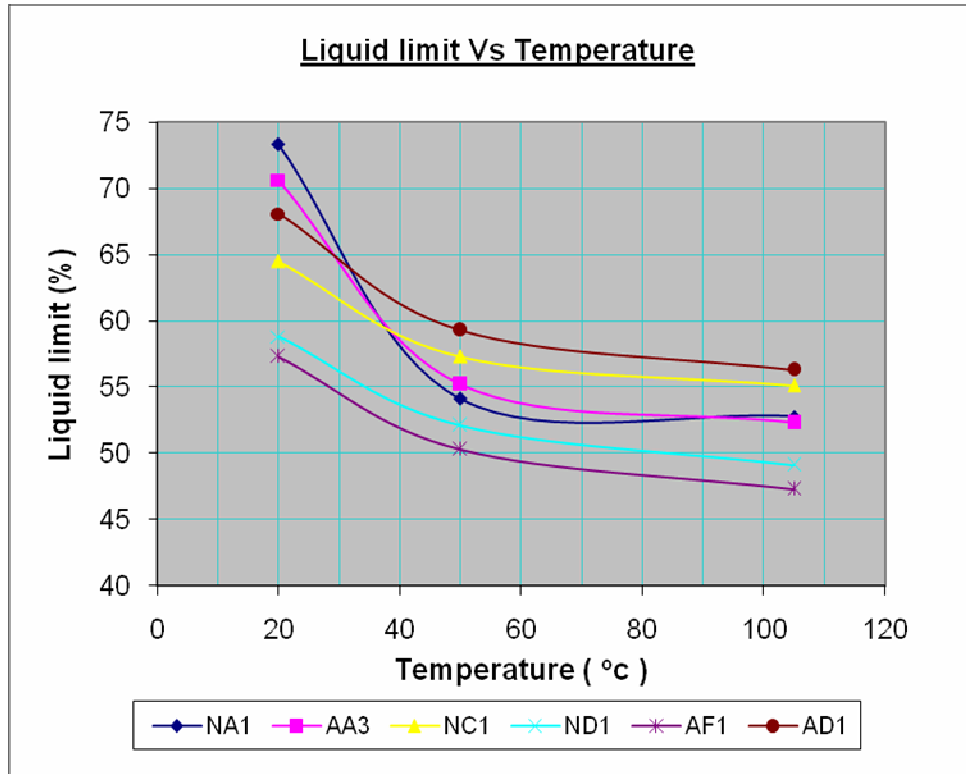


Figure 4.1 Effect of drying temperature on liquid limit

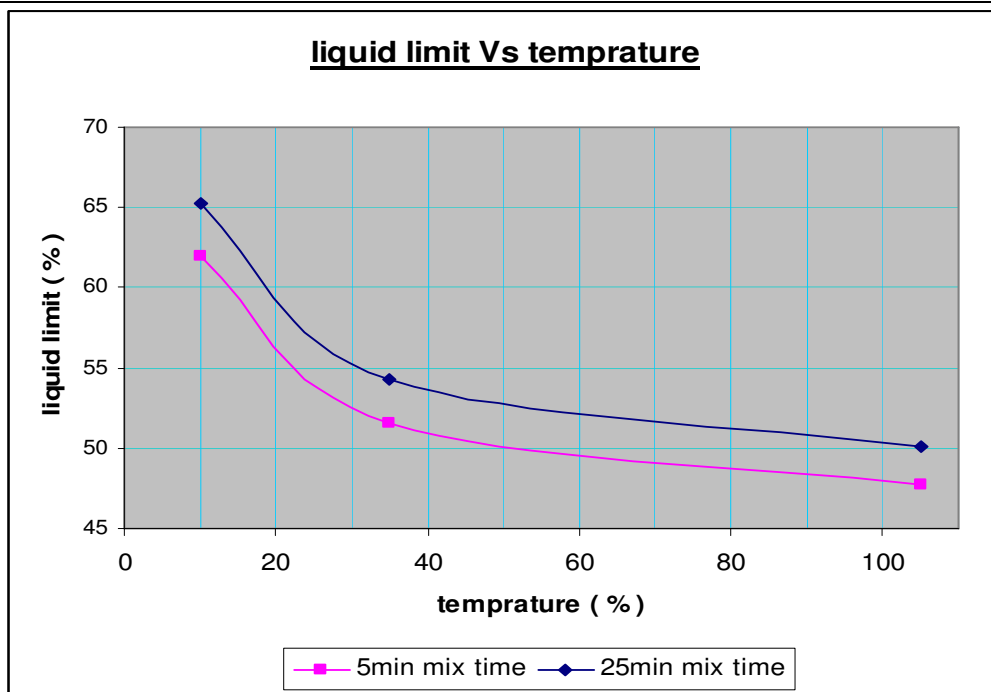


Figure 4.2 Effect of mixing time on the liquid limit.

4.3.2 Effects of mixing time on Atterberg Limits

In general it is believed that, the greater the energy applied and longer mixing time will result in more extensive breaking down of cemented bonds between clay clusters and with in peds and thus the formation of greater portions of fine particles. This effect can be seen on the extent to which liquid limit value increases for an increment of mixing time.

To address this problem, liquid limit and plastic limits of thirty test samples collected from 1m and 3m depth from Nedjo, Mendi and Assosa areas and are checked under different pre treatment conditions. Table 4.3 shows the difference in the liquid limit for 5 and 25min increased mixing times (ASTM D422 test procedure is adopted).

In all the tests there is no significant difference observed between the liquid limit obtained from test on a specimen mixed for 5min and that of 25min, which indicates the high degree of cementation of the clay particles and/or laterization of the soil.

From the table one can observe that, the increase in cementation due to oxidation of Iron and Aluminum Sequoxides or the dehydration of Sequoxides is still high to be disintegrated by elongation of mixing time. Thus, provided that the as received temperature is maintained, (section 4.2) the observed difference with mixing time (figure 4.2) does not significantly affect the properties of lateritic soils of this region and one can follow the usual procedures recommended for temperate region soils.

The liquid limit Vs temperature graph for the 5min and 25min mixing time (figure 4.2) shows nearly constant slope with an average of 3% increase in LL.

Table 4.3 Effect of mixing time on LL value

site location	designation	depth	Difference in Liquid limit between the 5 and 25min mixing time (%)		
		(m)	as received	air dried	oven dried
Nedjo	NA1	1.0	5.5	2.4	4.0
	NA3	3.0	2.2	2.9	2.3
	NB1	1.0	0.7	4.4	1.0
	NB3	3.0	0.0	2.7	2.1
	NC1	1.0	2.7	4.3	2.3
	NC3	3.0	3.1	2.7	1.1
	ND1	1.0	2.8	0.0	0.0
	ND3	3.0	0.0	0.6	0.1
	NE1	1.0	3.3	0.9	3.2
	NE3	3.0	0.8	0.0	0.6
Mendi	MA1	1.0	6.3	0.0	0.8
	MA3	3.0	2.5	7.7	4.9
	MB1	1.0	1.2	2.3	1.5
	MB3	3.0	2.9	0.0	0.9
	MD1	1.0	1.7	0.0	0.5
	MD3	3.0	0.0	5.3	0.9
	ME1	1.0	1.9	3.4	5.1
	MF1	3.0	2.5	0.0	0.2
Assosa	AA1	1.0	6.6	3.8	5.2
	AA3	3.0	0.0	0.0	0.6
	AB2	1.0	1.2	1.6	1.5
	AB3	3.0	2.5	6.2	4.9
	AC1	1.0	0.0	0.0	0.8
	AC3	3.0	0.4	3.4	0.7
	AD1	1.0	0.2	0.0	1.3
	AD3	3.0	1.5	1.6	1.7
	AE1	1.0	1.7	1.0	0.8
	AE3	3.0	0.2	2	1.6
	AF3	1.0	8.4	4.3	1.8

4.3.3 Effects of drying on specific gravity.

The specific gravity is used in the computations of most of the laboratory tests and identification of minerals.

Unlike lateritic soils, Specific gravity of most temperate zones and non lateritic soils of tropical soils fall in a narrow range, and thus has a limited value in identification and classification of soils.

Laboratory test results on lateritic soils of Nedjo, Mendi and Assosa areas (Table 4.4) show, increased temperature from insitu condition to oven drying temperature decreases specific gravity by an average of 4%.

A decrease in specific gravity is due to aggregation of clay particles on drying and an increased value in test result indicates the presence of minerals constituting iron, which later recognized through chemical analysis.

There were no cases where the specific gravity of these soils was unusually high or low, which may insight to the inexistence of amorphous clay minerals, which also been confirmed through chemical analysis (Section 4.6)

The specific gravities were determined using ASTM designation D854 – 58.

Table 4.4 Specific gravity at different temperatures

Site location	Designation	Depth (m)	Specific gravity	
			As received	Oven dried
Nedjo	NA1	1.0	3.10	2.73
	NA3	3.0	3.00	2.74
	NB1	1.0	3.12	2.74
	NB3	3.0	2.94	2.72
	NC1	1.0	2.90	2.79
	NC3	3.0	2.98	2.74
	ND1	1.0	2.88	2.82
	ND3	3.0	2.94	2.80
	NE1	1.0	2.81	2.70
	NE3	3.0	3.20	2.80
Mendi	MA1	1.0	2.81	2.70
	MA3	3.0	2.87	2.81
	MB1	1.0	2.98	2.90
	MB3	3.0	3.10	2.93
	MC1	1.0	2.94	2.79
	MC3	3.0	2.85	2.80
	MD1	1.0	2.97	2.89
	ME3	3.0	2.94	2.83
Assosa	AA1	1.0	2.95	2.83
	AA3	3.0	3.00	2.89
	AB1	1.0	2.72	2.70
	AB3	3.0	2.79	2.71
	AC1	1.0	2.70	2.67
	AC3	3.0	2.81	2.72
	AD1	1.0	2.89	2.72
	AD3	3.0	2.91	2.83
	AE1	1.0	2.87	2.71
	AE3	3.0	2.72	2.64

4.3.4 Grain Size Analysis

The usual grain size analysis (temperate zone soils) consisted of first drying the soil sample brought from the test pit and then pulverizing it before letting run through a nest of sieves. The soil passing the No. 10 sieve was subjected to hydrometer analysis and the result obtained was expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale. But, lateritic soils of Nedjo, Mendi and Assosa areas are highly affected by pre test drying than remolding. To address the problem six-test samples taken from Nedjo, Mendi and Assosa areas are subjected to grain size analysis tests under two pre treatment conditions (AR&AD). Air drying soils of the area were observed to result in an increase of clay and silt fractions. Table 4.5 shows the impact of increased temperature on clay and silt fraction. Air drying decreases clay and silt fraction by an average of 19 and 10% respectively.

Drying was observed to hardly affect the percentage by silt size.

Table 4.5 Effect of pre test treatment on clay and silt fraction

Site location	designation	Particle size			
		As received		Air dried	
		Clay	Silt	Clay	Silt
Nedjo, Mendi and Assosa	AA1	81.4	16.5	76	15.2
	AA3	56.2	15.7	49.4	14.0
	ND1	74.9	21.2	67.4	19.4
	NC3	27.4	19.5	19.8	17.6
	MC1	66.0	28.0	47.5	26.3
	MC3	42.4	25.3	31.0	21.4

From the curve thus drawn (Fig 4.3), the in situ relative amount of each type of soil constituting the sample was computed for typical soil samples collected from the area for the as received condition. The same procedure was repeated for all soil samples brought from the test pits and the results were tabulated below (table 4.6).

The detailed procedure of this analysis can be obtained from the ASTM Designation D422-63.

Table 4.6 In situ Grain size analysis test results of the samples.

Site Location	Design -ation	depth (m)	Liquid limit	Percentage of Particle size (%)			
				clay	silt	sand	gravel
Nedjo	NA1	1.0	73.3	71.4	26.5	2.1	0.0
	NA3	3.0	70.6	46.2	22.7	17.1	14.0
	NB1	1.0	59.4	68.3	22.8	5.4	3.5
	NB3	3.0	62.0	52.4	21.0	15.9	10.7
	NC1	1.0	64.5	61.5	32.1	6.4	0.0
	NC3	3.0	53.3	27.4	19.5	31.5	21.6
	ND1	1.0	58.8	74.9	21.2	3.9	0.0
	ND3	3.0	73.3	35.4	23.6	32.4	8.6
	NE1	1.0	61.3	56.4	28.2	11.0	4.4
	NE3	3.0	79.2	51.2	24.6	14.2	10.0
Mendi	MA1	1.0	60.1	74.2	22.7	3.1	0.0
	MA3	3.0	59.7	62.4	35.3	2.1	0.0
	MB1	1.0	55.0	37.3	21.0	40.0	10.8
	MB3	3.0	59.8	23.2	17.8	21.6	37.4
	MC1	1.0	68.1	66	28.0	6.0	0.0
	MC3	3.0	76.3	42.4	25.3	17.6	14.8
	MD1	1.0	60.7	80	17.0	3.0	0.0
	MD3	3.0	57.3	41.2	31.4	16.6	10.8
Assosa	AA1	1.0	37.6	81.4	16.5	2.1	0.0
	AA3	3.0	46.3	56.2	15.7	14.1	14.0
	AB1	1.0	56.4	72.3	20.8	5.0	1.9
	AB3	3.0	58.0	48.4	23.0	17.9	10.7
	AC1	1.0	60.5	76.5	20.1	3.4	0.0
	AC3	3.0	52.8	54.4	39.5	2.1	4.0
	AD1	1.0	57.9	79.9	18.2	1.9	0.0
	AD3	3.0	53.6	38.4	25.6	22.4	13.6
	AE1	1.0	58.4	71.4	24.2	4.4	0.0
	AE3	3.0	57.2	47.2	24.6	23.6	4.6

Some typical grain size distribution curves of Nedjo, Mendi and Assosa lateritic soils are shown on Fig. 4.3. Curves I and II of Fig. 4.4 shows the range between which the grain size distribution of Nedjo, Mendi and Assosa soils fall. From the curves and tables one can observe that the quantity of clay fraction reduces with depth, which is in agreement with the fact that degree of weathering decreases with depth. The top one meter layer is bounded by 2mm grain size while the other does extend beyond.

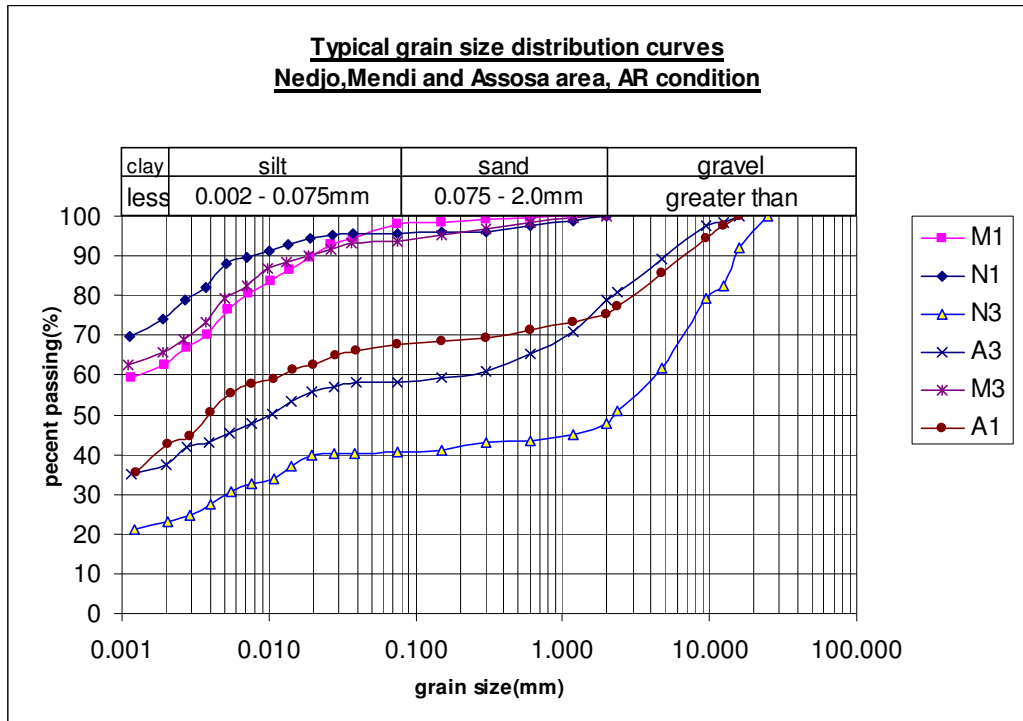


Figure 4.3 Typical grain size distribution curves, as received condition.

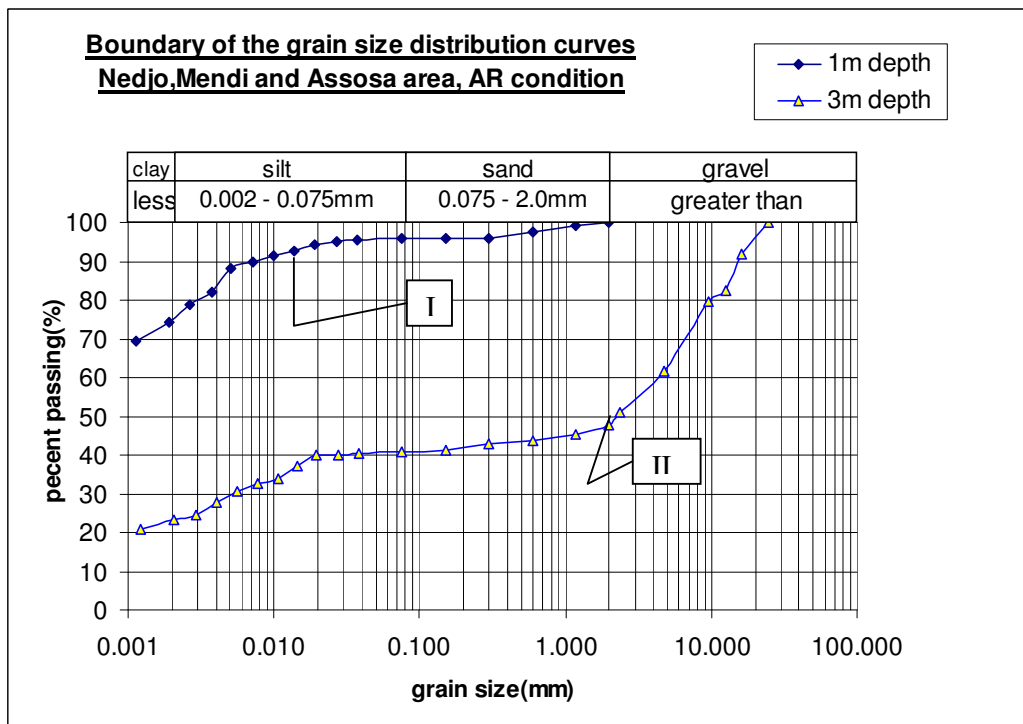


Figure 4.4 Boundaries of the grain size distribution curves.

4.3.5 Free swell

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

$$\text{Free swell} = \frac{(\text{Final volume} - \text{Initial volume})}{\text{Initial volume}} \times 100\%$$

Swelling potential and the magnitude of swelling pressure are known to be dependent on the clay minerals. The soil mineralogy of laterites on the other hand is affected by different factors; climate, topography, geographical location nature of the base rock from which the soil is derived. In Nedjo, Mendi and Assosa area, all the physical and chemical test results revealed that the soils constitutes less active clay mineral Kaolinite and Smectiet group. Among clay minerals contributing to swelling of soil is Montimorillonite and Illites are the common once.

The drying of soil samples also makes soil particles to come closer and hide the potential of some of the activity minerals to swell.

Free swell test results for both air and oven 105^oc dried samples are summarized in Table 4.7. From the test result one can see that the free swell of the soil under investigation ranges from 15% to 40%. Those soils having a free swell less than 50% are considered as low in degree of expansion (Teferra and Leikun, 1999). Hence, all soil samples under investigation are non expansive soils which are in agreement with the other supplementing physical and chemical test results.

Table 4.7 Free swell test results at different Conditions.

site location		Nedjo					
designation		NA1	NA3	NB1	NB3	NC1	NC3
depth		1m	3m	1m	3m	1m	3m
moisture		23.09	16.15	30.90	22.16	36.76	28.11
liquid limit	air dried	56.10	55.20	54.60	51.60	55.10	50.70
	oven dried	52.80	52.30	54.20	47.70	53.30	49.6
plastic limit	AD	34.90	34.20	28.00	36.30	37.80	34.80
	OD	32.30	32.2	28.3	35.0	36.2	33.9
free swell	AD	30.00	30.0	29.0	35.0	30.0	29.0
	OD	22.00	25.00	25.00	30.00	30.00	22.00
site location		Mendi					
designation		MA1	MA3	MB1	MB3	MD1	MD3
depth		1m	3m	1m	3m	1m	3m
moisture		30.75	31.83	21.14	29.98	33.69	33.30
liquid limit	air dried	58.30	53.90	46.30	52.40	59.30	70.90
	oven dried	56.3	51.5	42	48.3	56.30	60.6
plastic limit	AD	40.00	36.70	30.74	37.30	47.60	33.51
	OD	38.8	34.4	28.4	35.3	46.3	29.3
free swell	AD	30.0	25.0	29.0	31.0	28.0	38.0
	OD	28.00	22.00	29.00	26.00	21.00	30.00
site location		Assosa					
designation		AA1	AA3	AB2	AB3	AC1	AC3
depth		1m	3m	1m	3m	1m	3m
moisture		26.61	27.92	30.38	31.26	33.23	18.95
liquid limit	air dried	38.90	40.10	47.90	51.00	52.40	53.70
	oven dried	34.00	38.10	43.80	45.00	49.1	48.8
plastic limit	AD	22.80	26.30	30.70	35.00	35.50	28.90
	OD	21.3	25.2	30.1	33.3	33.6	27.7
free swell	AD	35.0	40.0	42.0	38.0	30.0	36.0
	OD	31.00	35.00	36.00	31.00	29.00	35.00

4.3.6 Shrinkage limit

When moisture is gradually lost from soil, the soil mass as a whole shrinks. During drying to a certain limiting value of water content, any loss of water is accompanied by a corresponding change in bulk volume (or void ratio). Below this limiting value of water content, no further change in volume occurs with loss of pore water. The moisture content in percent at which the volume change of the soil mass ceases is defined as the shrinkage limit. Volumetric shrinkage (V_s) calculated as follows.

$$V_s = \frac{(V_o - V_f)}{V_o} * 100 \dots\dots\dots \text{Eq.4/6}$$

- Where: V_s = Volumetric shrinkage
- V_o = Volume of wet soil bar.
- V_f = Volume of dry soil bar.

Volumetric shrinkage test results are summarized in Table 4.8 for different pre treatment conditions. From the test results one can see that air dried soil samples have generally higher values of volumetric shrinkage than that of oven dried. The variation is significant for soil samples with high natural moisture content.

The drying of soil samples makes solid particles come closer due to high cementation by sesquioxides. That was not reversed up on rewetting results in volumetric shrinkage reduction.

Table 4.8 Volumetric Shrinkage limits at different Conditions.

site location		Nedjo					
designation		NA1	NA3	NB1	NB3	NC1	NC3
depth		1m	3m	1m	3m	1m	3m
Moisture		23.09	16.15	30.90	22.16	36.76	28.11
liquid limit	air dried	56.10	55.20	54.60	51.60	55.10	50.70
	oven dried	52.80	52.30	54.20	47.70	53.30	49.6
plastic limit	AD	34.90	34.20	28.00	36.30	37.80	34.80
	OD	32.3	32.2	28.3	35.0	36.2	33.9
Volumetric shrinkage	AD	37.87	31.36	23.80	19.95	40.14	35.4
	OD	34.30	28.80	18.40	17.30	35.32	32.90
site location		Mendi					
designation		MA1	MA3	MB1	MB3	MD1	MD3
depth		1m	3m	1m	3m	1m	3m
moisture		30.75	31.83	21.14	29.98	33.69	33.30
liquid limit	air dried	58.30	53.90	46.30	52.40	59.30	70.90
	oven dried	56.3	51.5	42	48.3	56.30	60.6
plastic limit	AD	40.00	36.70	30.74	37.30	47.60	33.51
	OD	38.8	34.4	28.4	35.3	46.3	29.3
Volumetric shrinkage	AD	35.00	28.40	22.70	27.00	31.20	35.00
	OD	32.73	27.21	20.03	24.71	27.40	
site location		Assosa					
designation		AA1	AA3	AB2	AB3	AC1	AC3
depth		1m	3m	1m	3m	1m	3m
moisture		26.61	27.92	30.38	31.26	33.23	18.95
liquid limit	air dried	38.90	40.10	47.90	51.00	52.40	53.70
	oven dried	34.00	38.10	43.80	45.00	49.1	48.8
plastic limit	AD	22.80	26.30	30.70	35.00	35.50	28.90
	OD	21.3	25.2	30.1	33.3	33.6	27.7
Volumetric shrinkage	AD	13.80	25.40	47.60	25.00	30.20	30.53
	OD						

4.4. Soil classification

4.4.1 General

Though different disciplines find a soil classification based purely on particle-size classification satisfactory for their professional needs, the Civil Engineer requires a classification that has engineering applications. The demand led to the development of a number of engineering soil classifications. All widely used engineering soil classifications involve a combination of particle size and measures of plasticity and texture.

Engineering soils are subdivided into two main groups as a function of their predominant sizes and associated plasticity. The coarse-grained soils are composed of sand size and larger particles. They are separated into size ranges by sieving of materials up to cobble size. Except for minor fractions of plastic fines, they characteristically are non-plastic. The fine grained soils consist predominantly of silt and clay-sized particles with differing degrees of plasticity measured by their Atterberg limits rather than by sieving and settling velocity methods.

The most widely used classification schemes are those that divide soils into an orderly, easily remembered system of groups, or classes, that have similar physical and engineering properties and that can be identified by simple and inexpensive tests. These groups ideally provide estimates of both the engineering characteristics and performance of soils for design and construction engineers. The descriptions of soils within the groups of a given classification typically are represented by alphabetical or alphanumeric symbols for rapid identification in written material, graphic boring logs, and on engineering drawings. The continued use of a few engineering soil classification systems is the result of the provision in each for the needs of the Civil Engineer as well as the adaptability of the classification to the variety of soils encountered in engineering practice.

Here classification was made based on the two most popular engineering soil classifications: USCS, AASHTO, soil grouping based on their mineralogical composition and soil grouping on their genetic basis and soil forming factors is also made.

4.4.2. Unified soil classification system (USCS)

The USCS system is a textural-plasticity classification scheme. Soils are divided into two major groups, coarse-grained and fine-grained soils, using the No. 200 sieve as the size criterion. When more than half of the soil sample is larger than the No. 200 sieve, it is classified as coarse grained and is further subdivided by sieving and gradation. When more than half of the soil sample is finer than the No. 200 sieve, it is classified as fine-grained and is subdivided primarily based on liquid limit values and degree of plasticity. The presence of organic material is an additional classification factor for fine-grained soils. Paired letter symbols are used for each soil group in the USC system. The first symbol refers to, the predominant particle size (with the exception of organics). The second symbol for coarse-grained soils refer to gradation for clean (little or no fines) soils and the presence of silt and clay-size particles for soils with appreciable amounts of fines. The second symbol for fine-grained soils subdivides on the basis of low (L) or high (H) plasticity.

For the cases under consideration; except the two samples collected from less weathered rocky areas (MB1 and NC3). Grain size analysis of the entire samples revealed that more than 50% from each samples pass the No 200 sieve. They are classified as fine-grained soils and are sub divided based on their Atterberg limit values.

By making use of laboratory determined Liquid Limit and Plasticity Indexes for a soil sample (Table 4.2) the proper group of the soil for the as received condition has been made by use of the plasticity chart, or A- line diagram, as illustrated by Figure 4.5.

Laboratory results show that drying causes stronger Iron Oxide bonding. This results in a decrease in clay content by an average of 19% (section 4.3.3), and test made under different procedures have also shown that manipulation causes the breakdown of cementation, which leads to an increase in plasticity to a lesser extent.

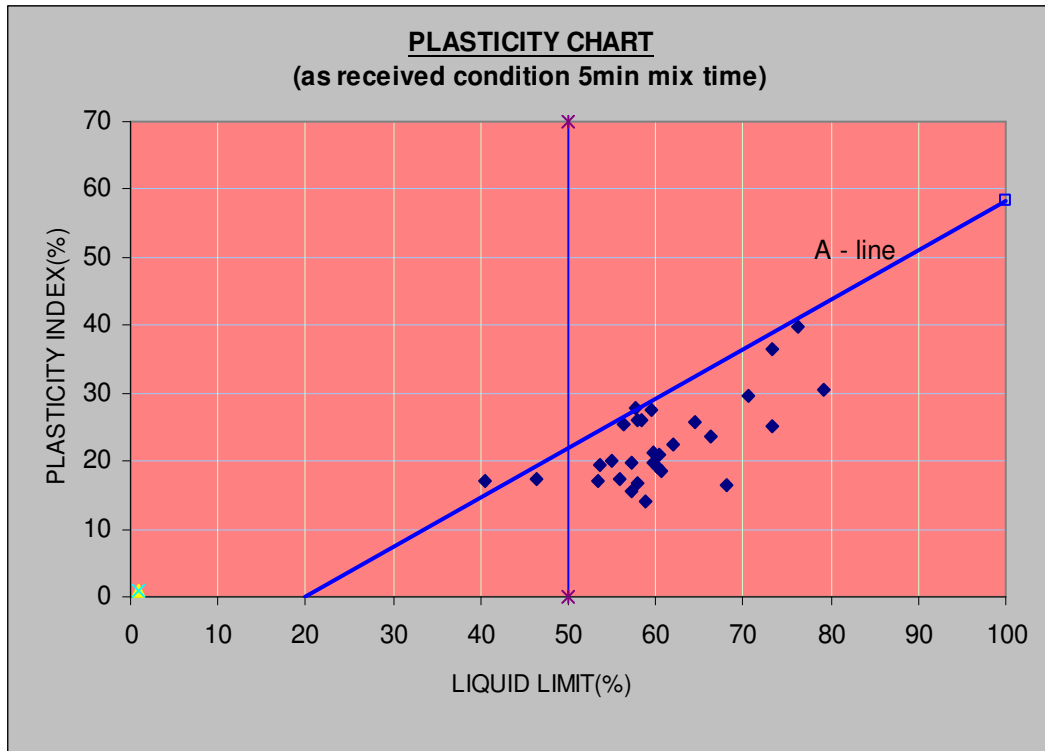


Figure 4.5 Plasticity chart for insitu condition.

Fig.4.5.1 Fig.4.5.2 & Fig.4.5.3 shows the variation of PI with LL on the Casagrande chart, for as received, air-dried and oven-dried samples respectively. From the graphs drawn one can observe that increase in temperature from its in situ conditions tend to aggregate soil particles either through oxidation of free iron or dehydration of clay minerals or both and thus decreases the liquid limit and plasticity index which in turn shifts soil group from high plastic silt (MH) to low plastic silt (ML). The experimental trend lines shown in Figures 4.5.1, 4.5.2 and 4.5.3 lie below the A-line.

For temperate zone soils Seed et al. (1964) found the following relationship between PI and LL:

$$PI = N(LL - n) \dots \dots \dots (1)$$

Where, N and n are constants depending on the mineral composition of the soil. Seed et al. found the value of n to be reasonably constant, with a mean value of 15 and a measured range of 13.9-16.9 for the range of clay minerals tested. However, the value

of N ranged from 0.46 (for kaolinite) to 0.96 (for montmorillonite). In applying equation (1) to other soils, N may be used as a fitting parameter, taking $n = 15$. For the lateritic soil described in this paper, n values out of the ranges specified by seed. Therefore, it is applicable only for the as received conditions.

These are relationships obtained for all pre treatment conditions considered

For as received specimens:

$$PI = 0.50 (LL - 15.00), \quad \sigma = 6.0 \dots \dots \dots (2)$$

For air- dried specimens:

$$PI = 0.455 (LL - 12.96), \quad \sigma = 5.1 \dots \dots \dots (3)$$

For oven - dried specimens:

$$PI = 0.424 (LL - 10.67), \quad \sigma = 4.9 \dots \dots \dots (4)$$

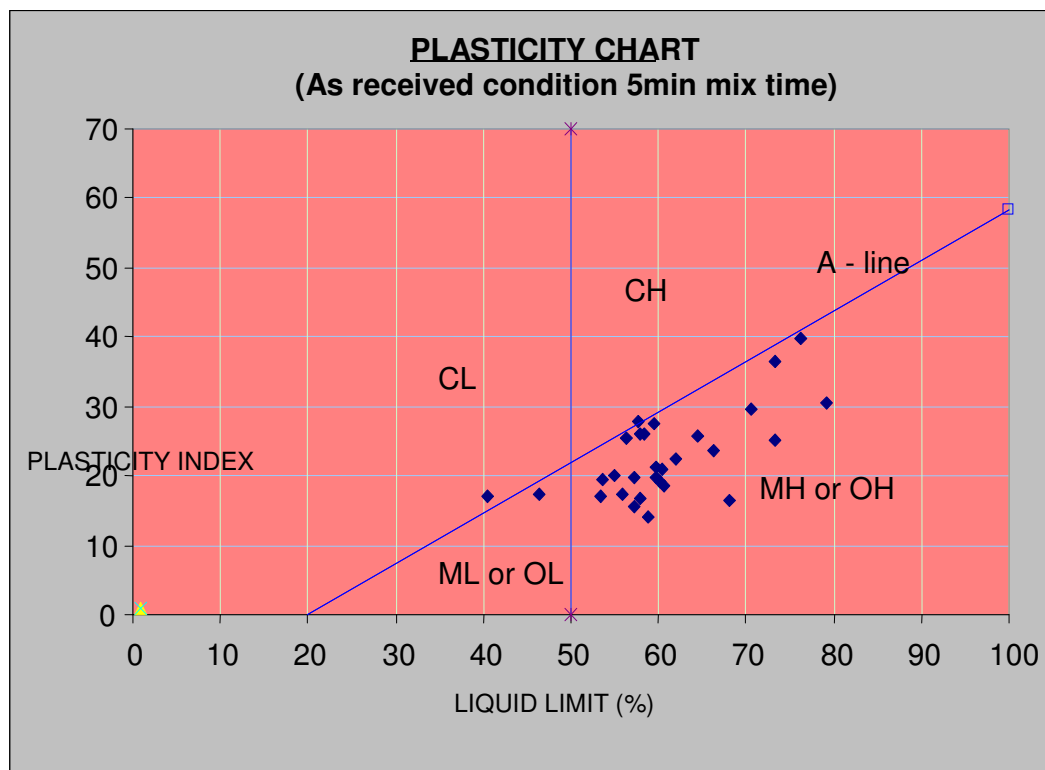


Figure 4.5.1 plasticity chart for as received conditions.

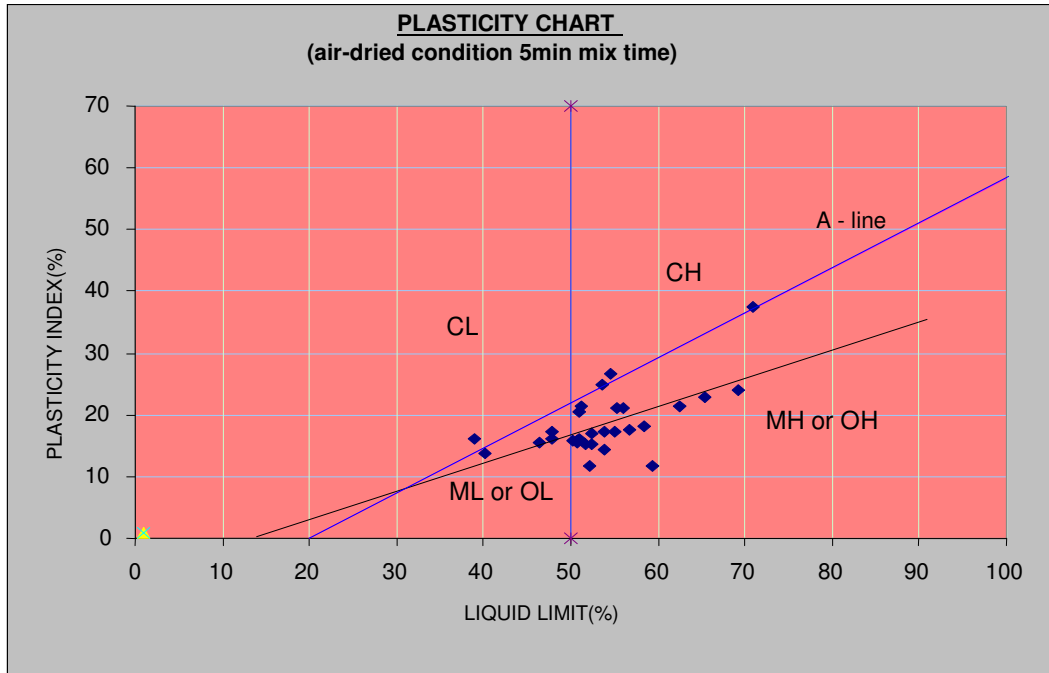


Figure 4.5.2 plasticity chart for air-dried conditions.

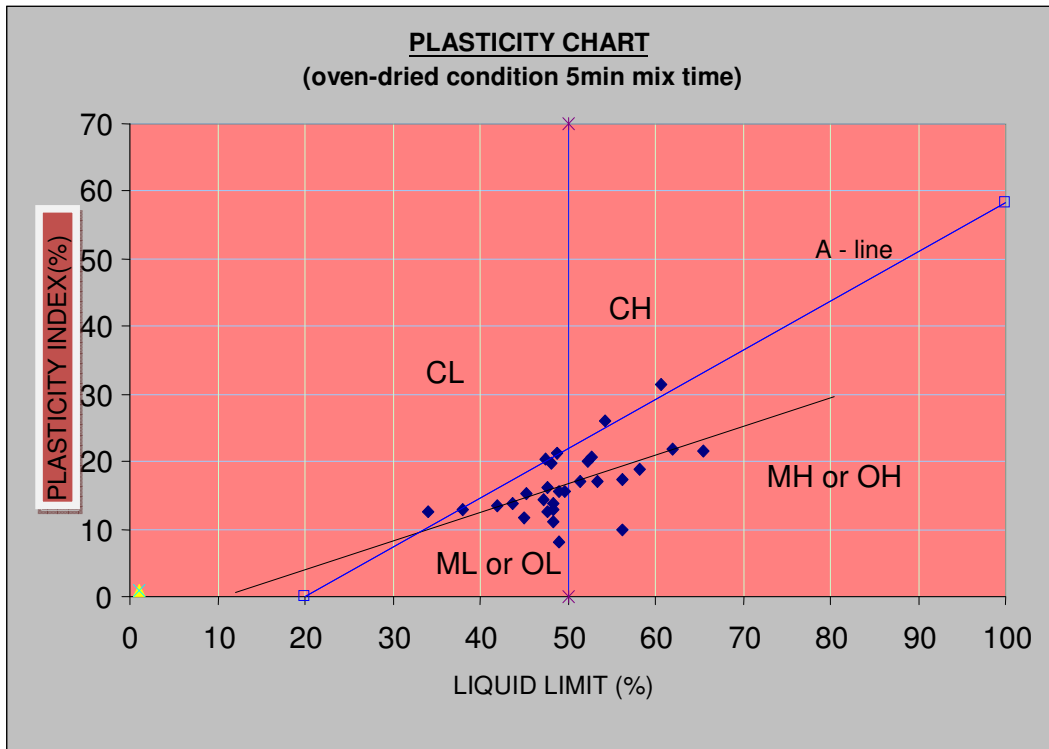


Figure 4.5.3 plasticity chart for oven-dried conditions.

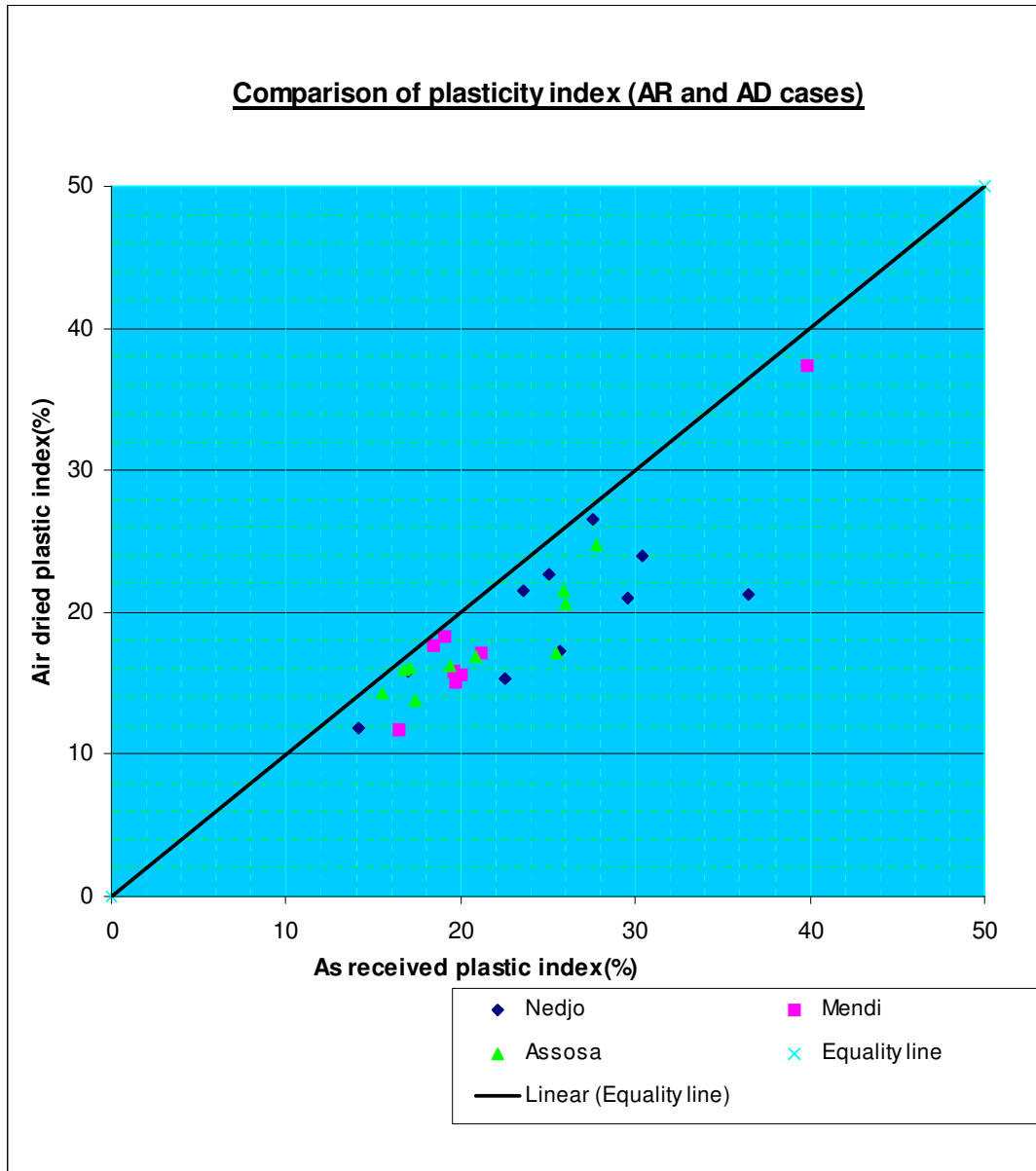


Figure 4.5.4 Comparison of as-received and air-dried plasticity indexes.

Figure 4.5.4 shows a comparison between the as received and air dried plasticity index test results

The differences between equations (2) and (3) are attributable to aggregation on air-drying as the bonding due to the presence of iron oxides becomes stronger. The statistical test (equations 2-4) was used to assess whether the difference in the results obtained by the two methods of drying is significant.

The results of this analysis show that the difference in PI resulting from sample preparation involving air-drying at room temperature decreases by an average of 4% compared with oven-drying at 105°C which is insignificant. The differences between equations (3) and (4) are attributed to aggregation on oven drying as the bonding due to the dehydration.

Generally According to the Casagrande classification, soils which falls below the A-line are described as organic silts, or micaceous soils. Lateritic soils, which have problematic minerals such as Halloysite or Allophane, also plot below the A-line. However, the lateritic soil from Nedjo, Mendi and Assosa are inorganic and does not contain Mica, Halloysite or Allophane (section 4.4.5). Although there are no problematic minerals present, the soil exhibits a capacity to retain water, and this result in high values of LL and PL. This needs to assess the presence of porous micro-aggregates, through the scanning electron micrograph. But, due to time limit and budget factor the analysis does not extended to.

Therefore, Casagrande's classification system is inapplicable to this soil.

4.4.3. AASHTO classification

It is a textural-plasticity classification that uses sieved fractions and Atterberg Limits for assignment of soils to seven main groups and several subgroups. The classification is more specific than the USC system. In the limits placed on Silt-Clay (fine-grained) soils as required by soil gradations, rather than using the No.4 sieve (4.75 mm) of the USC system as the upper limit of the sand-size range, the AASHTO classification uses the No. 10 sieve (2.0 mm) as the upper size limit of sand. However, the No. 200 sieve (0.075 mm) used in the USC system is retained to separate the finer fractions from sand.

The increased number of soil groups in the AASHTO classification compared with the USC system as well as the different upper size limits of sand makes comparisons of the two systems difficult.

The AASHTO system classifies soils into eight groups, A-1 through A-8. As per this system of soil classification, soils of Nedjo, Mendi and Assosa fall under A-7-5 with group index higher than 8.

Even though the AASHTO classification system is more specific, Unlike the USC classification system the AASHTO system does not clearly set out the effects of drying temperature. The decrease by the clay fractions does not affect the group to which the soil was assigned. Though this is the fact, it is the AASHTO classification system, which deserves priority in classifying lateritic soils of Nedjo-Mendi-Assosa next to chemical analysis.

Table 4.9 shows particle size distribution and classification of the soils according to AASHTO systems.

site location				Nedjo									
Designation and depth				NA1	NA3	NB1	NB3	NC1	NC3	ND1	ND3	NE1	NE3
Particle size (%)	Less than 0.075mm(NO.200)	clay	(<0.002mm)	71.4	46.2	68.3	52.4	61.5	27.4	74.9	35.4	56.4	51.2
		silt	(0.002-0.075mm)	26.5	22.7	22.8	21	32.1	19.5	21.2	23.6	28.2	24.6
	Greater than 0.075mm(NO.200)	sand	(0.075-2mm)	2.1	17.1	5.4	15.9	6.4	31.5	3.9	32.4	11	14.2
		gravel	Greater than2mm	0	140	3.5	10.7	0	21.6	0	8.6	4.4	10
LL				73.30	70.60	59.40	62.00	64.50	53.30	58.80	73.30	66.30	79.20
PI				36.48	29.60	27.54	22.58	25.69	17.00	14.10	25.10	23.55	30.40
USC				MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
AASHTO				A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5
site location				Mendi									
depth				MA1	MA3	MB1	MB3	MD1	MD3	ME1	ME3		
Particle size (%)	Less than 0.075mm(NO.200)	clay	(<0.002mm)	62.4	74.2	23.2	37.3	66	42.4	80	41.2		
		silt	(0.002-0.075mm)	35.3	22.7	17.8	21	28	25.3	17	31.4		
	greater than 0.075mm(NO.200)	sand	(0.075-2mm)	2.1	3.1	21.6	40	6	17.6	3	16.6		
		gravel	Greater than2mm	0	0	37.4	10.8	0	14.8	0	10.8		
LL				60.10	59.70	55.00	59.80	68.10	76.30	60.70	57.30		
PI				19.10	21.20	20.00	19.70	16.5	39.8	18.4	19.6		
USC				MH	MH	MH	MH	MH	MH	MH	MH		
AASHTO				A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5		
site location				Assosa									
depth				AA1	AA3	AB2	AB3	AC1	AC3	AD1	AD3	AE1	E3
Particle size (%)	Less than 0.075mm(NO.200)	clay	(<0.002mm)	81.4	56.2	72.3	48.4	76.5	54.4	79.9	38.4	71.4	47.2
		silt	(0.002-0.075mm)	16.5	15.7	20.8	23	20.1	39.5	18.2	25.6	24.2	24.6
	greater than 0.075mm(NO.200)	sand	(0.075-2mm)	2.1	14.1	5	17.9	3.4	2.1	1.9	22.4	4.4	23.6
		gravel	Greater than2mm	0	14	1.9	10.7	0	4	0	13.6	0	4.6
LL				40.60	46.30	56.40	58.00	60.50	57.80	57.90	53.60	58.40	57.20
PI				17.1	17.4	25.5	16.8	20.9	27.8	25.9	19.4	26	15.55
USC				ML	ML	MH	MH	MH	MH	MH	MH	MH	MH
AASHTO				A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5

Table 4.9 Grain size distribution and soil grouping.

4.4.4 Soil grouping based on mineralogical composition.

It is a kind of soil grouping proposed by Wesley L.D. and Irfan (Blight, 1997). Based on their mineralogical composition. Mineralogical identification using X-RAY diffraction and chemical tests reveal that the soil is composed of Kaolinite and Smectite minerals mainly Kaolinite, Quartz, Dickite, Nacrite, Muscovite, Vermiculite, Geigerite, Zektzerite, Tridymite and Gibbsite. Chemical analyses showed there is a great concentration of Sesquioxide of Aluminium and Iron. No amorphous material present in the soil. Accordingly Soils of Nedjo, Mendi and Assosa area is grouped under **sub group c of group C**; Soils with a strong mineralogical influence of sesquioxide which are derived from clay minerals only found in residual soils.

4.4.5 Soil grouping based on their genetic basis and soil forming factors.

It was found during the recent studies that most of the tropically weathered soils of Africa could be divided into three groups on a genetic basis, determined by the soil-forming factors. The three major groups of significance have been defined by D'hoore (1964) (Lyon, 1971).

The soils under investigation are formed over basaltic and metamorphosed types of rocks in intermediate to high rainfall areas where erosion has kept the place with profile development. Chemical and X-RAY diffraction analysis show that the entire clay fraction comprises Kaolinite, minerals of Smectite group and Oxides of Iron and Aluminum. These have deeper profile due to the surface suitability.

Based on their genetic basis and the soil forming factors, laterite soils of Nedjo, Mendi and Assosa area fall under a Ferrisol group.

4.5 Activity

From the result of atterberg limits and particle size distributions, it is possible to estimate the degree of expansiveness by plotting the result on an established Skempton's activity chart shown in figure 4.5.4. Skempton's colloidal activity is determined as the ratio of the plasticity index of the clay content to fines. He observed that, for a given soil, the plasticity index is directly proportional to the percent of clay-size fraction. The plasticity and grain size in percent finer than 0.002mm of Nedjo, Mendi and Assosa soils are plotted on this chart. It can be observed from the chart that most of the Nedjo, Mendi and Assosa lateritic soils lie below activity number 0.75 which is categorized as in active soil. The average activity number of the soil, calculated as PI divided by the percentage of clay (passing 2 μ m) (Table 4.6), is about 0.44. Skempton (1953) has shown that, for kaolinite clay, the activity lies between 0.33 and 0.46. The low value for this particular soil is due to the coating of Sesquioxides which reduces the specific surface area of the clay particles and hence suppresses the activity. The result is in agreement with X-RAY diffraction and mineralogical analysis test results.

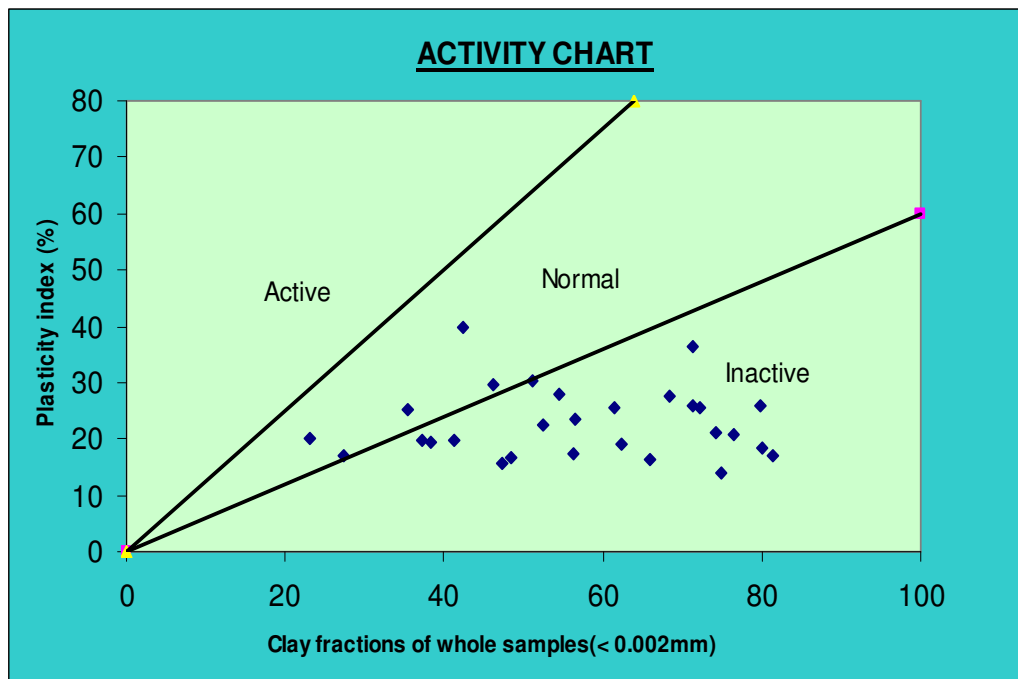


Figure 4.5.4 Activity chart for as received conditions.

Table 4.10 Summary of Skempton's colloidal activity number

	Nedjo									
Designation	NA1	NA3	NB1	NB3	NC1	NC3	ND1	ND3	NE11	NE3
depth (m)	1m	3m	1m	3m	1m	3m	1m	3m	1m	3m
PI (%)	36.5	29.6	27.5	22.6	25.7	17.0	14.1	25.1	23.6	30.4
clay fraction (%)	71.4	46.2	68.3	52.4	61.5	27.4	74.9	35.4	56.4	51.2
Ac= PI/Clay fraction (%)	0.51	0.64	0.40	0.43	0.42	0.62	0.19	0.71	0.42	0.59
	Mendi									
Designation	MA1	MA3	MB1	MB3	MD1	MD3	ME1	ME3		
depth (m)	1m	3m	1m	3m	1m	3m	1m	3m		
PI (%)	19.1	21.2	20	19.7	16.5	39.8	18.4	19.6		
Clay fraction (%)	62.4	74.2	23.2	37.3	66	42.4	80	41.2		
Ac= PI/Clay fraction (%)	0.31	0.29	0.86	0.53	0.25	0.94	0.23	0.48		
	Assosa									
Designation	AA1	AA3	AB2	AB3	AC1	AC3	AD1	AD3	AE1	AE3
depth (m)	1m	3m	1m	3m	1m	3m	1m	3m	1m	3m
PI (%)	17.1	17.4	25.5	16.8	20.9	27.8	25.9	19.4	26	15.6
Clay fraction (%)	81.4	56.2	72.3	48.4	76.5	54.4	79.9	38.4	71.4	47.2
Ac = PI/Clay fraction (%)	0.21	0.31	0.35	0.35	0.27	0.51	0.32	0.51	0.36	0.33

4.6 Mineralogical and Chemical test

Mineralogical analyses were performed on air-dried powder samples using a Philips X-ray diffractometer (PW 1729), at the mineralogical and petrography laboratory department of Geological Survey of Ethiopia. Chemical analyses were performed to check for the presence of amorphous colloidal Allophane.

The results of the X-ray diffraction analyses showed that the lateritic soil was composed of Kaolinite, Quartz, Dickite, Nacrite, Muscovite, Vermiculite, Geigerite, Zektzerite, Tridymite and Gibbsite. Halloysite was not present. Comparison of the XRD patterns at each depth indicated that the proportion of Kaolinite increases with depth in the laterite zone, while the proportion of Quartz is low through out the study area. Some lateritic soil sampled from 3 m depth are composed of only Kaolinite and the quantitative analysis of the XRD results was not possible due to the large number of minerals present in the specimens. The results of the analyses showed there was no Allophane present in the soil and thus, higher plasticity is due to a high water retention capacity, which can be related to microaggregate structure of the minerals. The scanning electron micrograph test should be conducted to check for the micro aggregate structure of the soils.

The X-RAY analysis result is presented on the appendix A.

Geochemical (oxide) tests are carried out to know quantitatively main Oxides of the soil material. Almost all soils on earth contain some amount of colloidal oxides and hydroxides. The oxides and hydroxides of Aluminium, Iron and Silicon are of greatest interest since they are the ones most frequently encountered. Iron and Aluminium oxides coat mineral particles, or cement particles of soils together. They may also occur as distinct crystalline units, such as Hematite, Gibbsite and Magnetite.

Chemical tests were carried out at Geological Survey of Ethiopia Geochemical Laboratory. To obtain the percentage oxide composition of the soils under investigation Atomic Absorption Spectrometer and Colorimeter Analysis methods were used. The test results are shown in Table 4.11

Table 4.11 chemical analysis test result

Designation	depth (m)	Elements determined and their chemical contents (%)												
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	H ₂ O	LOI	TiO ₂	P ₂ O ₅	$\frac{\text{SiO}_2}{(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3)}$
ND1	1m	28.40	23.68	28.18	0.08	0.24	< 0.01	0.12	0.09	0.87	13.72	3.12	0.32	0.55
ND2	3m	32.79	27.60	19.02	< 0.01	0.22	< 0.01	0.03	0.19	0.64	12.75	4.99	0.39	0.70
MB1	1m	17.48	21.95	43.18	< 0.01	0.07	< 0.01	0.05	0.09	0.83	13.53	2.33	0.45	0.27
MB3	3m	19.88	22.47	38.50	< 0.01	0.15	< 0.01	0.11	0.10	0.93	14.33	3.14	0.52	0.33
MA1	1m	28.75	25.97	24.96	0.16	0.33	< 0.01	0.37	0.12	1.29	13.76	3.70	0.28	0.56
MA3	3m	29.22	25.09	23.93	0.04	0.36	< 0.01	0.19	0.18	1.05	14.61	3.65	0.30	0.60
AB1	1m	48.57	25.00	11.44	0.25	0.18	< 0.01	0.19	0.03	0.68	11.02	1.16	0.10	1.33
AB3	3m	50.30	24.18	12.28	< 0.01	0.10	< 0.01	0.19	0.05	0.54	10.20	0.91	0.04	1.38
AD1	1m	42.89	26.62	13.49	< 0.01	0.36	< 0.01	0.21	0.05	0.83	12.13	1.87	0.10	1.07
AD3	3m	28.26	29.41	25.30	< 0.01	0.05	< 0.01	0.08	0.06	0.30	14.96	0.96	0.07	0.52
AE1	1m	46.17	25.32	11.21	0.08	0.43	< 0.01	0.38	0.04	1.03	11.99	1.76	0.10	1.26
AE3	3m	46.97	25.72	10.98	< 0.01	0.30	< 0.01	0.38	0.04	0.52	11.53	1.95	0.12	1.28

The degree of laterization of the soil samples can be evaluated based on Silica – Sesquioxides (s-s) ratio as detailed in section 2.3. The Sesquioxide, designated as R_2O_3 , is the combination of Aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3).

Accordingly unlaterized soils have S-S ratio greater than 2. For lateritic soils s-s ratio lie between 1.33 and 2 and for true laterites the ratio is less than 1.33. Lateritic soil has not under gone a considerable degree of laterization as compared to true laterite.

The test results in Table 4.11 show that the soils under investigation have Silica – Sesquioxide ratio below 1.33. This indicates that the soils are all true laterites which are in agreement with soil forming factors of the area. True laterites are simply referred as laterites. The soil of such kind is highly laterized and has high Sesquioxides content.

The test results also reveal that degree of laterization is higher in Nedjo and Mendi areas as compared with Assosa this can directly be related to topographic feature of the area. Asossa area is a flat terrain with fertile land .The area is covered with grasses stretching up to 4m height. Therefore, leaching is not well facilitated and degree of laterization is relatively less.

From the test results one can also see that the degree of laterization decreases with depth which is in line with the X-RAY diffraction test result. On mineralogical classification bases, one can conclude from the results that the soil is categorized under **sub group c, of group C**, which comprises Soils with a strong mineralogical influence of **Sesquioxides** clay minerals.

Table 4.12 ranges of insitu soil index parameters.

No	Index parameters		Range of index parameters		
			Nedjo	Mendi	Assosa
1	Moisture content		(15.3-41.8%)	(19.0-32.0%)	(17.9-34.0%)
2	Liquid limit		(53.3-79.2%)	(55.0-76.3%)	(40.6-60.5%)
3	Plastic limit		(31.9-48.8%)	(35.0-51.6%)	(23.5-41.7%)
4	Plasticity index		(21.4-30.4%)	(20.0-24.7%)	(17.1-18.9%)
5	Clay content		(27.4-74.9%)	(23.2-80.0%)	(38.4-81.4%)
6	Silt content		(19.5-32.1%)	(17.0-35.3%)	(15.7-39.5%)
7	sand		(2.10-34.4%)	(2.10-40.0%)	(1.90-23.6%)
8	gravel		(0.00-21.6%)	(0.00-37.4%)	(0.00-14.0%)
9	Group index		(7.0-47.0)	(8.3-28.2)	(12.4-32.0)
10	Activity		(0.19-0.79)	(0.23-0.94)	(0.21-0.51)
11	Volumetric shrinkage		(19.2-40.0%)	(22.7-39.2%)	(13.8-47.6%)
12	Free swell		(29.0-35.0%)	(30.0-42.0%)	(25.0-35.0%)
13	Specific gravity		(2.81-3.20)	(2.80-3.10)	(2.70-3.00)
14	Mineral constituent	Depth(1m)	Kaolinite Dickite Nacrite quartz	Kaolinite Muscovite Vermiculite Zektzerite	Kaolinite Gibbsite Geigerite quartz
		Depth(3m)	Kaolinite Vermiculite Gibbsite	Kaolinite Vermiculite Zektzerite	Kaolinite Vermiculite quartz
15	USC system		MH	MH	MH
16	AASHTO classification system		A-7-5	A-7-5	A-7-5

5. Conclusion and recommendation

5.1 Conclusion

The following conclusions can be drawn from the results of the investigation:

(1) The lateritic soil developed on granites and various metamorphic rocks including Genesis and Schist which underlie most of the area, with Basalts of tertiary at Nedjo, Mendi and Assosa areas is highly laterized and is composed of the minerals of Kaolinite and Smectite group such as Kaolinite, Quartz, Dickite, Nacrite, Muscovite, Vermiculite, Geigerite, Zektzerite, Tridymite and Gibbsite. The depth of this soil extends beyond 3m depth. The engineering properties and composition of the lateritic soil vary with depth. Particle size distribution curves for samples from the laterite zone show decreases in degree of weathering with depth. The gravel content increases with depth.

(2) The lateritic soil is sensitive to sample pre-treatment and the test procedure adopted prior to laboratory classification testing. Air-drying and Oven-drying cause aggregation and decrease in Plasticity Index. The statistical test shows a significant difference in plasticity index determined for specimens prepared for the as received condition compared with those prepared by air-drying. It is recommended that the plasticity properties of lateritic soils be determined at insitu condition, as this is more representative of in situ conditions.

(3) The relationship between Plasticity Index and Liquid Limit suggested by Seed et al. (1964) is applicable only to lateritic soils at insitu condition for soils studied under this thesis.

(4) The Atterberg limits determined for the lateritic soil plot anomalously below the Casagrande A-line, despite the absence of Mica, Halloysite, Allophane or a high organic matter content in the soil. This may be due to water retention in micro-aggregates. Because of this effect, Casagrande's classification system is inapplicable to these soils studied.

(5) The specific gravity test results are higher values than the temperate zone soil. This is due to high amount of Iron Oxide for soil under investigation and is increased by an average of 4% for increment of temperature from its insitu condition to air drying (equivalent oven temperature).

5.2 Recommendations

1. Further detailed investigation has to be carried out on the micro structural behavior of the soil.
2. As can be seen from test results, the plasticity indices are about 20%. To use the laterite soils as a construction material for heavy traffic roads, the Atterberg limits should be reduced so as to satisfy the specification ($< PI=15\%$). For that purpose, further research need to be carried out on blending the soil material with non plastic soil, lime and / or cement. Cost benefit analysis should also be made to use the soils as construction materials for heavy traffic roads as compared with crushing of basaltic rocks or other alternatives.

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