ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Investigating the Index Properties of Residual Tropical Soils of Western Ethiopia (The Case of Asossa)

BY

Fekede Wakuma

January 2007

Investigating the Index Properties of Residual Tropical Soils of Western Ethiopia (The Case of Asossa)

A thesis submitted to a 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

Fekede Wakuma

Advisor

Dr :- Mesele Haile

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Investigating the Index Properties of Residual Tropical Soils of Western Ethiopia

(The Case of Asossa)

BY

Fekede Wakuma

Faculty of Technology

Approved by Board of Examination

________________________ __________________

(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 been duly acknowledged.

Name: Fekede Wakuma

Signature: ______________

Place Faculty of Technology
Addis Ababa University
Addis Ababa.

Date January, 2007

Acknowledgments

I would like to thank Jesus my lord who is always with me in each and every step of my life.

I wish to express my genuine appreciation to my advisor, Dr. Messele Haile for his limitless support, direction, advice and patience with me during the preparation of this thesis.

I express my sincere gratitude to the mayor of Asossa town, Ato Husen Kedir for his assistance during the data collection.

I am very greatful to my friends Dagitu B., Desalegn F., Getu C., Temesgen D., Matwos T., Temesgen G., Abebe G., Argaw A., Amenew M. and to my parents who contributed to this research work morally and financially.

Table of contents

Contents **Pages**

Symbols and Abbreviations

Designation		Units
LL	Liquid Limit	%
PL	Plastic Limit	%
PI	Plasticity Index	%
FS	Free Swell	%
NMC	Natural moisture content	%
AD	Air drying	---
OD	Oven drying	---
AR	As received sample	---
RH	Relative humidity	%
AASHTO	American Association of state Highway and transport Officials	---
ASTM	American Society for Testing Materials	---
BS	British Standard	---
GI	Group Index	---

List of Tables

List of Figures

Abstract

The engineering behavior of soils, wheather formed under temperate or tropical conditions, is determined by certain physical characteristics designated as engineering properties. In practice, since the determination of all the engineering properties of soils is expensive, often index properties, simpler and cheaper engineering characteristics which are indicative are investigated.

Residual soil is a soil material derived from the in-situ weathering and decomposition of rock, which has not been transported from its original position.

Residual tropical soils can have characteristics that are quit distinctively different from those of transported soils, That is: the conventional concept of soil mechanics is not applicable to many residual soils as it consists of aggregates or crystals of weathered mineral matter that break down and become progressively finer under continuous manipulation.

Western part of Ethiopia is characterized by such soils. As mentioned in ERA (Ethiopian Roads Authority) design manual (ERA, 2001) Residual laterites are widely available soil material in these areas. The index properties of such soils have not been studied in detail as per the test recommendations for residual tropical soils. This Thesis is conducted to indicate the index properties of soils of Asossa Town (Capital of Beneshangul Gumuze), which is located in western Ethiopia and covered by residual soils.

In this thesis work, the index properties of residual tropical soil have been investigated on the soil specimens taken from Asossa Town by following the test procedures recommended for residual soils.

The specimens were tested at different sample preparation conditions prior to conducting the laboratory test and resulted in different end values. The index property investigation in this research includes; Specific Gravity Test, Particle Size Distribution, Atterberg

Limit Tests and Free Swell Tests, all tests were conducted at three different test temperatures (at received moisture, air-dried and oven dried at a temperature of $105^{o}{}_{c}$).

Generally it was found that, sample pre-treatment and commonly used soil test procedures for temperate soils when applied to Asossa soils resulted in completely altered test result as compared to the actual test result values obtained by following testing procedures recommended for tropical soils. It was found that there is considerable structural water that could be destroyed by oven drying at a temperature of 105 degrees and must be deducted from every moisture content determinations in Atterberg Limit tests. Sample manipulation is also found to alter the results of the Atterberg Limit values by affecting the bond between soil structures. Therefore, the appropriate test procedures for tropical soils are strongly recommended for research and practical engineering application where such soils are likely to exist.

Introduction

1.1General

Asossa, which is located in southwest Ethiopia is predominantly covered with reddish and few brown colored soil. The red color of a residual tropical soil in most cases comes from the presence of the iron mineral in the soil. Depending on the soil forming factors such as climate, topography, drainage and the parent material, red soils can be lateritic soils. The formation of laterites favor rolling slope with good water runoff, distinict rainy season having warm summer. Asossa shares some common, soil-forming factors (climate, rainfall, geology topography and temperature) with that of Najo-Mandi (Wollega) area. (Zelalem, 2005), in his research work presented to school of graduate studies), conducted the geochemical test for Nejo-Mandi areas and found that the soil in these area is laterite.

Accordingly the soil of Asossa is supposed to be laterite. Lateritic soils are highly weathered and altered residual soil formed by the in-situ weathering and decomposition of rocks in the tropical and sub-tropical regions with hot humid climatic conditions. Due to the presence of iron oxides lateritic soils are red in color ranging from light bright to brown shades.

Depending up on the extent of laterization, residual tropical soils could be classified as; lateritic and laterites. Lateritic soils are highly weathered and altered residual soil formed by the in-situ weathering and decomposition of rocks in the tropical and sub-tropical regions with hot, humid climatic conditions. Their formation also consists of leaching out of free silica and bases and accumulation of oxides of iron, aluminum or both, and this process is termed as laterization. Moreover they are rich in sesquioxides, i.e.; iron oxides, aluminum oxides or both and have low silicate content with considerable amount of Kaolinite.

Laterites as residual soils are mostly placed under a group with strong mineralogical influence derived from clay minerals only found in residual soils. These soils are characterized to be highly influenced by the presence of sesquioxides which tends to act as a cementing agent that bind the other mineral constituents in to cluster or aggregations. With sufficient concentration of sesquioxides, the hard cemented materials commonly known as laterite are formed. But the term laterite is generally used very loosely, some times to include both halloysite and allophane and other clay minerals which contain only trace amount of sesquioxides, and whose behavior is not significantly influenced by the sesquioxides.

Laterites occur mostly in tropical and subtropical regions with hot, humid climatic conditions. It has been suggested that a mean annual temperature of around $25^{o}{}_{c}$ is required for their formation. And in seasonal situations there should be coincidence of warm and wet periods.

Residual soils are widely used as a construction material, mainly as fill material for embankments, dams and road embankments and as selected layers in highways and airfield construction. Certain residual soils, such as those containing smectite or halloysite clays may be unsuitable for those uses, either because of inadequate strength, or excessive change of volume with varying water content, or because of loss of strength on wetting. However, these materials have been used to form impervious layers in water-retaining embankments. The Sesquioxide content of residual soil coat the surface of soil particles and cause a cementing effect on the adjacent grains, hence they produce aggregated soil particles. This effect tends to reduce plasticity, but progressive manipulation of the soil grain breaks down the aggregations and the sesquioxide bonding, phenomena known as disaggrgation of the soil particles. This effect increases both the liquid limit and plastic limit of these soils could be checked by conducting the Atterberg limits at different mixing times, usually 5 minutes and 25 minutes mixing times and by comparing the results.

Some residual soils tend to exist as hydrated and de-hydrated forms. That is water of hydration in the sesquioxides of iron and aluminum may be driven off by oven drying at $105^{o}{}_{c}$, which is the standard laboratory test temperature for conventional soil mechanics of temperate regions. This water normally takes part in the engineering performance of the residual soil. This effect could be detected in the laboratory by conducting the moisture content of a given soil specimen at different drying temperatures. If this procedure resulted in a considerable difference in moisture content, the test temperature must be limited to air drying or drying at oven of $50^{o}{}_{c}$ and relative humidity of 30%. Hence, this difference in moisture content must be deducted from moisture content determined at a $105^{o}{}_{c}$ oven drying.

Most lateritic soils exhibit a decrease in the Atterberg limit values when pre dried at the temperature of $105^{o}{}_{c}$ oven drying. This is as the result of the dehydration of the sesquioxides which creates a stronger bond between the soil particles, which is resistant to water ingression between soil particles. Drying is also accompanied by, increased cementation due to oxidation of the iron and aluminum sesquioxides, dehydration of allophane and halloysite, or both. Moreover, this process could not be reversed by re-wetting of the soil specimen.

The influence of sample preparation prior to testing on index property tests of tropical soils is recommended by (Hunde 2003) in his thesis entitled “Investigation of influence of compaction on the suitability of earth fill dams of tropical soils”, Lyon Association Ltd., (1971) in their work, “Lateritic and Laterite Soil and other Problematic Soils of Africa” observed that the index properties of lateritic soils of Ethiopia change with drying temperature. Moreover, the work of (Zelalem, 2005) “Basic engineering properties of lateritic soils found in Nejo-Mendi road construction" shows that the effect of oven drying changes the finer content of the soil. And this thesis work strongly gives emphases to the effects of sample pre-treatment and test procedures on the determination of the index properties of Asossa soil.

1.2 Objective of the study

The objectives of this research are:

a. To check the extent of laterization of Asossa soil based on index properties and chemical tests.
b. Carefully investigate the effect of sample pre-treatment and method of mixing on index properties of soils of Asossa.
c. Investigate some limitations of the concept of conventional soil mechanics as applied to residual tropical soils of Asossa.
d. To recommend the appropriate test procedures for Asossa soil and other tropical soils with similar geological formation.

1.3 Methodology used

In this work, the effect of temperature on the determination of the moisture content was investigated by conducting the laboratory test at air drying and at oven dry of $105^{o}{}_{c.}$ it was found that oven drying affected the structural water, hence air drying was recommended, Likewise, the effect of mixing time on the test results was investigated.

This thesis work consists of different sample pre-treatment conditions for all index property determinations. These methods were air-drying (AD), oven drying (OD), Soaked (S) and as received conditions (AR) that is at its natural moisture condition.

The four pre-treatment methods according to (Lyon, 1971) are

As received (AR)	-- at natural moisture content.
Soaked (S)	-- immersed in water for 24 hours moisture equilibration.
Air dried (AD)	--dried until constant weight is found under normal temperature.
Oven dried (OD)	--dried in an oven for 24 hours at $105^{o}c$

Execution of soil tests at its natural moist condition is considered if the field moisture content was about 13% (Lyon, 1971). Instead of air-drying one can use oven drying at a temperature of 50^{o}c and relative humidity 30%equivalently (Blight, 1997).

1.4 Limitation of the study

The research is limited only to the index property tests taken from different locations of Asossa Town. Due to the financial constraints, it was not possible to conduct geochemical test for the town and since Asossa has some common soil forming factors as that of Najo-Mandi area of Wollega, the degree of laterization is simply taken from the work of (Zelalem, 2005).

1.5 Organization of the thesis

The thesis consists six chapters. This introductory part consists background, objective and brief summary of the work. The second chapter covers the literature review on residual soils, weathering and formation, effects to pre-test treatment and test procedures. The third chapter consists of the sampling area descriptions and soil characteristics of Asossa Town. The fourth chapter covers types of laboratory tests results along with some photos of the in-situ soil behaviors. The fifth chapter consists of comparison of the characteristics of Asossa soil with previously conducted test results of other countries of Africa and with the Nejo-Mandi soil (Zelalem, 2005). The conclusions and recommendations drawn from this research are presented in the sixth chapter. Appendix are presented at the end of this thesis along with the AASHTO designation equivalent to ASTM testing procedures and the Grain Size Distribution curves at different testing conditions.

1. Literature Review

2.1 General characteristics of residual soils

The process of formation of a residual soil profile is extremely complex, difficult to understand and difficult to generalize. In many countries of Africa and Asia, lateritic residual soils are the traditional material for road and airfield construction. Though a good deal of literature is available on lateritic soils and several excellent reviews have been prepared on this subject. There has generally been very little discussion on the engineering behavior of laterites. Until the U.S. Agency for International Development sponsored the study on laterite and lateritic soils of Southeast Asia, the engineering investigations have been isolated studies. The reason for the limited studies is understood to be due to the absence of uniform methods for the preparation of samples and testing and the variable nature of laterites soils. As a consequence, the drawing of any rational conclusions on the engineering properties of lateritic soils has been very difficult, (Layon, 1971). As weathering proceeds from the surface down and inwards from joint surface and other percolation paths, the intensity of weathering generally reduces with increasing depth and reducing intensity of jointing in the material between joint surfaces (Blight, 1997).

The soil name "laterite" was coined by (Buchanan, 1807) in India, from a Latin word "later" meaning brick (Raychaudhuri, 1980). The extensive literature on laterite published since Buchanan's time has produced a range of terms referring to many soil types. On the other hand, laterite is also known by the following names; Brick stone, Iron clay, Laterite (India), Cabook (Ceylon), Canga, Picarra (Brazil), Carapace, Cuirasse (France), Eisenkruste, Krusteneisnsteine (Germany), Ironstone (Nigeria), Mantle rock (Ghana, Moco de hierro (Venezuela), Murram (East Africa), Pisolite (Australia), Plinthite (USA) and Ferricrete (South Africa)(Zelalem, 2005).

According to (Blight, 1997), laterites are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks under tropical conditions.

The three major weathering processes are physical, chemical and biological processes. In the weathering process, the parent rock and rock minerals break down, releasing internal energy and forming soils of lower internal energy that are stable. Physical processes increase surface area and fractures so that chemical attack takes place where as biological phenomena includes both of them.

The available data on lateritic soils gives the impression that the red color seems to have been accepted by most authors as the most important property by which these soils could be identified. Other obviously significant basic physical properties such as texture, structure, consistency, etc., often were ignored .It is also noted that the lack of uniformity in pretreatment and testing procedures (resulting from association with different standards in different parts of Africa) makes it difficult to compare even textural data on the same soils. It is noted that three major factors influence the engineering properties and field performance of lateritic soils. These are;

a. Soil forming factors (e.g. parent rock, climate vegetation conditions, topography and drainage conditions).
b. Degree of weathering (degree of laterization) and texture of the soils, genetic soil type, the predominant clay mineral type and depth of sample.
c. Pretest treatments and laboratory test procedures as well as interpretation of test results (Lyon, 1971).

According to (Blight, 1997), Climate and topography influences the rate of weathering. Physical weathering is more pronounced in dry climates, while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature. Topography on the other hand, controls the rate of weathering by partly determining the amount of available water and the rate at which it moves down through the zone of weathering. It also controls the effective edge of the profile by controlling the rate of erosion of a weathered material from the surface. Hence deeper profiles will generally be found in valleys and on gentle slopes rather than high ground or steep slopes.

2.1.1 Mineralogical composition related to weathering

The distinctive feature of laterite and lateritic soils is the higher proportion of sesquioxide of iron and/or aluminum relative to the other chemical components. The amount of alumina or iron oxides is an important factor in differentiating aluminous and ferruginous varieties. The base (alkalis and alkaline earths) is almost absent in lateritic horizons, except in some ferruginous crusts developed in alluvium and some concretionary horizons in ferruginous tropical soils. Other lateritic constituents are manganese, titanium, chromium and vanadium oxides (Lyon, 1971).

The mineralogical composition is considered to be more important in explaining the physical properties of laterite and lateritic soil. The mineralogical constituents can be divided in to major elements, which are essential to laterization, and minor elements, which do not affect the laterization process. The major constituents are oxides and hydroxides of aluminum and iron, with clay minerals and, to a lesser extent, manganese, titanium and silica. The minor constituents are residual remainants.

The clay mineral most common in lateritic soils is Kaolinite. Halloysite is also reported. Illite and Montimorillonite are rare. The secondary minerals resulting mainly from the laterization process are Gibbsite, Goethite, Limonite and Hematite. Neither Manganese nor Titanium minerals were observed in significant amounts.

2.1.2 Formation, existence and profile of weathering

2.1.2.1 Formation and existence of residual tropical soils

The mineral that is formed is usually dependent on the type and extent of weathering that has taken place. Tropical decomposition tends to favor formation of the clay kaolinite. This is the most common clay mineral in tropical residual soils. Under suitably moist conditions, halloysite will be formed. Under prolonged decomposition, silica can be removed so that free alumina and iron oxides are present (Blight, 1997). Physical and chemical reactions are weathering process leading to the formation of tropical and residual soils. Tropical weathering of volcanic ashes frequently produces an abundance of Allophane, a virtually amorphous clay mineral having unusually high natural moisture content. Allophane may be identified by its characteristically large, irreversible change of plasticity properties upon drying at different temperatures. In strongly oxidizing conditions, hematite may be formed. Physical breakdown rates are controlled by exposure and energy transmitted to the parent material through the local environment. Chemical processes can be summarized a follows :(Blight, 1997)

I) Decomposition: This includes the physical breakdown of the rock fabric and the chemical breakdown of constituent minerals, usually rock forming minerals. Typical products being clay minerals, oxides, hydroxides, and free silica. Under tropical conditions, reactions may occur relatively quickly so that recently transported soils may subsequently be modified in to material with residual soil characteristics. Decomposition according to (Makasa, 1998), (Zelalem, 2005) is Physio-chemical breakdown of primary minerals and release of constituent elements (SiO_2, Al_2O_3 ,Fe_2O_3 , CaO, MgO, K_2O, Na_2O, etc), which appear simple ionic forms.

II) Leaching and Re-Deposition: This includes laterization process; involve removal of combined silica, alkaline earth, and alkalies. There is a consequent accumulation of oxides and hydroxides of sesquioxides and the leached material may be redeposited and accumulated elsewhere in the soil profile (Blight, 1997).

The level to which the secondary stage is formed is carried depending on the nature and extent of the chemical weathering of primary minerals. Under conditions of low chemical and soil-forming activity, the physio-chemical weathering does not continue beyond the clay-forming stage, and tends to produce end products consisting of clay minerals predominantly represented by Kaolinite and occasionally by hydrated or hydrous oxides of iron and aluminum (Blight, 1997) (Zelalem, 2005)

III) Dehydration / Desiccation: (Either partial or complete alter), this is the process that the composition and distribution of the sesquioxide-rich minerals in a manner, which is generally not reversible upon wetting. Dehydration also influences the formative process of clay minerals. That is, in the case of total dehydration, strongly cemented soils with a unique granular soil structure may be formed(Blight, 1997).

Laterites occur mostly in tropical and sub-tropical regions with hot, humid climatic conditions. It has been suggested that a minimum annual temperature of around $25^o{}_c$ is needed for their formation, and in seasonal situations there should be a concidence of the warm and wet periods. If there is high rainfall during the cold seasons, laterite does not develop freely. The minimum rain fall required for the formation of laterites is generally at least 750mm.The higher rain fall above this value, the greater the leaching effect, which removes the silica, reducing the Silica/Sesquioxide ratio and increase the degree of laterization (CIRIA, 1995).

Regarding topography and drainage, the slope angle controls the amount of water available to move downward through the weathering zone. On steep slopes run-off is greater than infiltration; erosion is active, and conditions are generally not suitable for the development of deep weathering. On the other hand on flatter slopes, run-off is not so marked; only limited amount of erosion takes place; and long uninterrupted periods of weathering can take place; producing deep weathered soil profile. On a level ground, however, where drainage is impeded and the ground is waterlogged, black Montimorillonite soils dominate instead of red soils (CIRIA, 1995).

ASCE, Geotechnical Engineering Division (Journal vol.111 NOS.1-6, 1985), describes the weathering products of various environments, and suggested that clay mineral (Illites, Montimorillonites, etc.) are favored by alkaline non leaching environment, while the minerals (Kaolinite, Halloysite) are favored by acid leaching environments.

2.1.2.2 Profile of weathering

The alteration of rock by the process of chemical weathering takes place progressively through a number of events and stages which result in a profile of weathering. Those who have worked with tropically weathered residual soils have noted the frequent occurrence of an upper clayey zone a few feet thick, underlain by a silty or sandy zone which, in turn, pass through a very irregular transition in to weathered and finally into sound rock. The thickness of each member of the profile varies from site to site because of the complexity of the interrelationships among the controlling soil forming factors of rainfall, temperature, time, character of parent rock, topography and vegitation. Soils formed under similar weathering profiles will have similar characteristics (Lyon, 1971).

2.1.3 Hydrated and dehydrated laterite

In continuously wet regions the end products of the process of laterization are likely to be characterized by high natural water contents, high liquid limits, and irreversible changes up on drying. Limonite and goethite are hydrated oxides of iron, and gibbsite is hydrated oxide of aluminum. Drying alters the characteristics of the material markedly. The plasticity decreases and the grain size increases such that much of the clay sized material agglomerates to the size of silt. When dealing with such materials, the engineer may need to determine the index properties and the engineering properties on the basis of tests performed at a natural water content and at varies degrees of air drying in order to evaluate fully the range of properties associated with the physical conditions that may be manifested at the test time. Serious engineering and construction problems have arisen through failure to recognize materials likely to experience irreversible changes as a consequence of desiccation (Lyon, 1971).

On the other hand, in regions subjected to distinct wet and dry seasons, the products of laterization are likely to be characterized by low natural water content, low plasticity, and the presence of concertions and cemented horizons. The alternate upward and dawn ward movement of water causes concentration of iron or of alumina. Laboratory tests run on the natural water content or on the air-dried samples lead to the essentially the same results (Lyon, 1971).

The difference in behavior of hydrated and de-hydrated forms of laterites soils deserves attention because of the danger of being misled by reports in the literature in which the significance of the distinction may not be realized (Lyon, 1971).

2.1.4 Classification of residual soils

2.1.4.1 Reason for special classification requirements for residual soils

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, 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) Conventionl 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 in-herited from the original rock mass or developed as a consequence of weathering.

Wesley (1988) 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, 1997).

1.1.4.2 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 (Wesley L.D. and Irfan)(Blight, 1997). These groups are

I. **Group A:** Soils without a strong mineralogical influence, eg, 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 (Blight, 1997).

A) Halloysitc 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 perhaps be termed as Lateritic group (Morin and Todor, 1976), (Blight, 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 the recent study that most of the tropically weathered soils of Africa could be divided in to 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). 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. Gibsite 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 SiO_2 / R_2O_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 develoment. 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. According to Morine W.J. and Todor P.C., Ethiopian laterites fall under this group (Blight, 1997)

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 fragial character in grain size and the bond could be strongly affected when pulverizing**.**

On the other hand, Nascimento et al. (1959) have suggested an interesting lithological classification of lateritic soils 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 Young, 1976), (Lyon, 1997) has distinguished the following main types and sub-divisions of laterite:

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 ferrugnized rock, broken and wholly or partly cemented.

4) **Frruginized 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.

2.1.5 Regional Setting

Lateritic soils are beleved to corrospond to climates in which the wet period is warm; this applies to semi-humid tropical and equatorial climates. On the other hand, sub-tropical climates in which precipitation occurs in the cold season do not seem to favor laterization even if the temperature is above $20^{o}{}_{C}$. Laterites cover extensive areas in tropical countries with intermittently moist climate. Generally the six main regions of the world in which laterites occur are Africa, India, South-east Asia, Australia, Central and South America. It should be emphasized that, because of shifts of climatic zone in the geological past, Important areas of laterite can be found in areas now out side the tropics, (Zelalem, 2005).

2.2 Residual soil and laterization

Depending up on the extent of laterization, residual tropical soils could be classified as; Lateritic and laterites. Lateritic soils are highly weathered and altered residual soil formed by the in-situ weathering and decomposition of rocks in the tropical and sub-tropical regions with hot, humid climatic conditions. Their formation also consists of leaching out of free silica and bases and accumulation of oxides of iron, aluminum or both, and this process is termed as laterization. Moreover they are rich in sesquioxides, i.e.; iron oxides, aluminum oxides or both and low silicate content with considerable amount of Kaolinite. Lateritic soils are usually red in color due to the existence of the mineral iron oxides.

The degree of laterization is characterized by the ratio of Silica (SiO_2) to Sesquioxide ratio (S-S) as described in the previous section. Sesquioxide (R_2O_3) is the combined name for Iron oxide (Fe_2 O3) and Aluminum oxide (Al_2 O_3) the following classes of soils could be possible based on laterization

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

2.2.1 Lateritic soils

These are residual soils with a silicon dioxide (Silica) to sesquioxide ratio of between 1.33 to 2.0. Morin W.J. and Todor P. C, (Blight, 1997) use the term lateritic soil for all reddish tropically weathered materials, irrespective of the presence of or absence of concertions. They behave like fine-grained sands, gravels, and soft rock sand which typically have a porous or vesicular appearance. Some Particles of lateritic soils tend to crush easily under impact, disintegrating in to a soil material that may be plastic. They could be self-hardening when exposed to drying; or if they are not self-hardening, they may contain appreciable amounts of hardening laterite rock or laterite gravel.

2.2.2 Laterites

This is a surface formation in tropical areas enriched in iron and aluminum and develops by intensive and long lasting weathering of the underlying parent rock. Laterites consist mainly of Kaolinite, Goethite, Hematite and Gibbsite, which form in the course of weathering. Moreover, many laterites contain Quartz as relatively stable relic mineral from parent rock.

They occur most of the times in an already hardened state. It is also common for some areas of the world to be observed having deposits that have not been exposed to the drying process and are soft with a clayey texture and mottled coloring, which may include red, yellow, brown, purple, and white. Moreover when these soils are exposed to air or dried by lowering their water table, irreversible hardening will take place, producing a material that is suitable for use as a building or road stone. As a result, laterite is gravel sized; ranging From pea sized gravel to 3 inches minus (Passing 3 inches), although larger cemented masses are possible. A specific form of laterite rock, known as plinthite is soft enough to cut with a metal tool, but it hardens irreversibly when removed from the ground (Zelalem, 2005).

2.3 Sample preparations for tropical soils

2.3.1 Effect of pre-treatment

2.3.1.1 Effect of pre-test drying

Laterites formed under continuously wet regions are likely to be characterized by high natural water contents; high liquid limits are observed to result in irreversible changes up on drying. Up on drying the plasticity decreases and grain size increases such that much of clay sized particles agglomerates to the size of silt (Lyon, 1971).

On the other hand, lateritic soils formed under seasons of distinct wet and dry seasons are likely to be characterized by low natural moisture content, low plasticity, and presence of concertions and cemented horizons. Laboratory tests run from natural water content or from the air-dried state lead to essentially the same result (Lyon, 1971).

According to Townsed (1985), the effect of drying prier to testing is attributed to:(Blight, 1997)

a) Increased cementation due to oxidation of the iron and aluminum sesqueoxides, or
b) Dehydration of Allophane, or both.

The geotechnical behavior of soil is then altered up on drying due to the above reasons. An important factor contributing to the closing up of the particle spaces is due to the development of capillary stresses of significant magnitude. These capillary stresses lead to particle aggregation and reduce the available surface for interaction with water, which is reflected in the reduction of plasticity characteristics.

The water of hydration in the sesquioxides of iron and aluminum may be driven off by oven drying at $105^o{}_C$, which is conventionally the standard testing temperature for temperate regions. This water normally takes part in the engineering performance of the material, but is reflected in the test results as higher moisture content. These can be checked by the following procedures; two specimens should be prepared for the determination of moisture content. One specimen should be oven dried at $105^o{}_c$ until successive weighing show no further decrease in mass. The moisture content should then be calculated. The second sample should be air-dried (if feasible), or oven dried at temperature of no more than $50^o{}_C$ and at maximum relative humidity (RH) of 30% until successive weights show no further loss of mass. The two-moisture content should then be compared. A significant difference (4-6%of moisture content obtained by oven drying at $105^o{}_C$) indicates that " Structural" water is present. This water forms part of the soil solids, and should therefore be excluded from the calculation of moisture content. If a difference is detected using the two different drying process, all subsequent tests for moisture content determination (including those associated with Atterberg Limit tests, etc) should be carried out by drying at lower temperature (i.e. either air-drying, or oven–drying at $50^o{}_C$ and 30% RH) if possible, the lower drying temperature of $50^o{}_C$ should be used to avoide the removing out of this water (Blight, 1997).

2.3.1.2 Effect of method and time of mixing on Atterberg Limits

In general, the greater the duration of mixing (i.e., the greater the energy applied to the soil prier to testing), the larger the value of the resulting liquid limit, and to a lesser extent, the larger the plasticity index. This has been attributed to longer mixing results in more extensive break down of the cemented bonds between the clay clusters and within peds (disaggregation of the particles), and thus formation of greater proportions of fine particles (Blight, 1997).

In order to address this problem A.B.Fourie recommends the following, (Blight, 1997)
Five test specimens should be mixed with water to give a range of moisture contents suitable for liquid limit and plastic limit determinations. The minimum amount of air-drying should be used, and preferably none at all. Thus should not be too difficult as the in-situ moisture content of majority of soils is at or below the relative plastic limit. The mixing time should be standardized at 5 minutes, and the mixed specimens should be left for moisture content equilibration overnight before testing.

On the following day the liquid limit should be determined with a minimum of further mixing. A sub-sample from each of the specimens used in the test should be used for the determination of moisture content, using the procedure. The remainder of each specimen should then be mixed continuously for a further 25 minutes before again determining the liquid limit. A significant difference (i.e. >5% of the liquid limit obtained from the test on a specimen mixed for 5minutes) between the liquid limit from tests using 5 and 30minutes mixing times indicates a disaggregatinon of the clay-sized particles in the soil. If this disaggregation is confirmed by repeating the above procedures, the entire program of testing should:

I. Limit the mixing times to no more than 5 minutes
II. Make use of fresh soil for each moisture content point in Atterberg Limit tests.

The soil should be broken-down by soaking in distilled water, and not by drying and grinding.

2.4 Tropical black clays

Dual (1965), More recently has adopted a more descriptive term "Dark Clay Soils". The term "Tropical Black Clays", or "Black Clay Soils", and "Black Cotton Soils" are used more or less interchangeably. Although the term Dark Clay Soils is retained because of its extensive occurrence in the literature and because it is widely used in many parts of Africa (Lyon, 1971).

An appropriate engineering definition for tropical black clays is "dark gray to black soils" with a high content of clay usually over 50%, in which Montimorillonite is the principal clay mineral and which are commonly expansive. They are formed when there is poor internal drainage and flatter slops exist (Blight, 1997). The main characteristics among most tropical black clays are high clay content, dark color, tendency to expand and shrink with change in moisture content (Lyon, 1971).

2.5 Tropical soils as construction materials

The behavior of residual tropical soils as construction materials varies with the group characteristic and the constructional value depends on the type of the soil at hand. Tropical soils generally are overconsolidated soils with high strength values (Blight, 1997). Lateritic soils used as a road and embankment construction materials are generally thin strata occurring at shallow depth. So great care should be taken during material investigation and excavation for construction material production. The deposit is likely to vary in thickness, depth and quality both along-slop and down-slope (CIRA, 1995). Hence, care should be made to prevent contamination of laterite while removing overburden and stockpiling.

Concretionary laterites are valuable road pavement materials, widely used in tropics as a sub-base, base material and for gravel roads. The term laterite, however, has tended to be indiscriminately applied in tropical red soils. As a result the usefulness of laterites for road construction has been underestimated. The sensitivity of these materials to test procedures has to be assessed and the laboratory testing has to simulate the site condition.

It is clear that sensitive laterites change property during the construction processes due to the disaggregation (Zelalem, 2005).

Lateritic soils, like any other group of soils, present certain chalenges as foundation materials, though there is no specific stability of deformation problems associated particularly with the process of laterization. The cementing action of iron oxide tends to improve the strength and deformation characteristics of lateritic formation.

3. Sampling Area Description

3.1 General information

Asossa Town is the capital city of Beneshangul Gumuz Regional Government and located at 675km from Addis Ababa in southwest direction. It is 96km from the Ethio-Sudan border. The town has a flat terrain with an elevation of about 1650m above mean sea level. All of the urban roads are almost earth roads of red to brown soil. Even, the route connecting Asossa to the central part of Ethiopia and to Ethio-Sudan border is an earth road or easily friable material for a significant length, which creates a problem for the traffic movement in rainy season and not suitable in the dry season too (Pavement Design of Asossa Town Urban Roads Upgrading Project, TCDE, 2000). The geographical location of Asossa Town is shown on Fig 3-1 below.

3.2 Land cover and land use

Asossa area is a flat terrain with fertile land .The area is covered with grasses stretching up to 4m height. Most of the area is cultivated following the route connecting Asossa to central Ethiopia and Ethio-Sudan border (TCDE, 2000).

3.3 Geology

According to the Geological map of Ethiopia, 1996, the Geological formation of Asossa Town and the surrounding are: flood basalt. The flood basalt is a good crushed aggregate material for concrete works, base course, and asphalt works when it exists in sound form. Granite is also observed during the field investigation around Asosaa Town existing in sound form (TCDE, 2000). Moreover, All of the urban roads are almost earth roads of red to brown sandy silty clay soil with a considerable amount of dark to gray soils

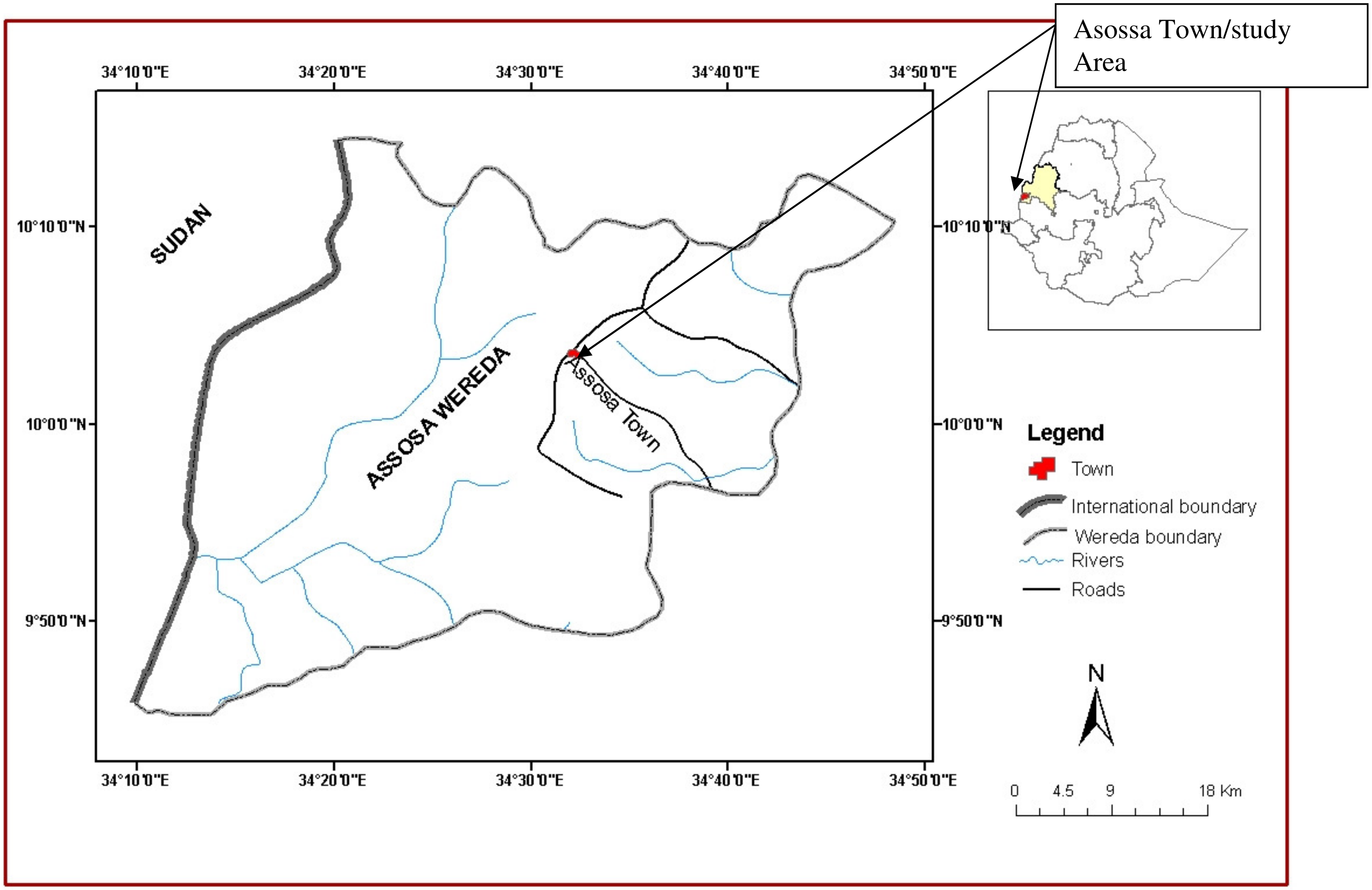


Fig 3-1 The geographical location of Asossa Town

3.4 Climate

The climatic classification of Asossa Town is warm (“Kola”) with a temperature greater than $20^o{}_C$ (Very warm), which is most of the times uncomfortable. It has a moisture index ranging from 50 to 100 (intermediate or moist), i.e.; potential evapotranspiration is mostly greater than precipitation.

It has mean annual rainfall of 1200mm with maximum rainfalls from the month of June to September. Mean period of onset of the “Kiremt rains” is 26-30May and mean period of cessation of the “Kiremt rains” is between 23 and 27 October. The area has a maximum temperature of $33^o{}_C$ and a minimum temperature of $15^o{}_C$.

The mean monthly rainfall and mean monthly maximum and minimum temperature are presented in table below.

Table showing the mean monthly rainfall and mean monthly maximum and minimum temperature (TCDE,2000).

Month		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
RF		1	25	10	50	100	200	230	200	200	150	25	1
Tem. ($^o{}_C$)	**Max.**	33	33	33	30	30	30	25	25	25	30	30	30
	Min	15	15	17	17	20	15	15	15	15	15	15	15

The elevation difference along the Nekemte – Asossa is shown in Fig 3-1

3.5 Soil Characteristics of Asossa

The soil type from Nekemte-Asossa is covered with a reddish soil type and rolling terrain with high rainfall amount and the elevation above sea level reducing from 2500m to 1650m. The town has a flat terrain with an elevation of around 1650m above mean sea level. All of the urban roads are almost earth roads of red to brown sandy silty clay soil with a considerable amount of dark to gray soils. The natural ground water table is located at 7m minimum and 35m maximum with almost the same soil type up to 1.0m and changing in grain size for soils is relatively stiff at 2m below the ground for most locations. The Geological formation of Asossa Town and the surrounding are formed from basalt.

All lateritic soils require minimum rainfall of 750mm for their formation with hot periods and soil geology of mostly basaltic rock as a parent material. It is known that the rate of chemical weathering is controlled by moisture and temperature (other conditions being constant, chemical reaction rates approximately double for each $10^o{}_c$ rise in average temperature). Generally based on the soil forming conditions and the actual situation of the water table observed, one can classify Asossa soil as hydrated form of laterite soil with high natural water content, high laboratory liquid limit changes irreversibly up on drying.

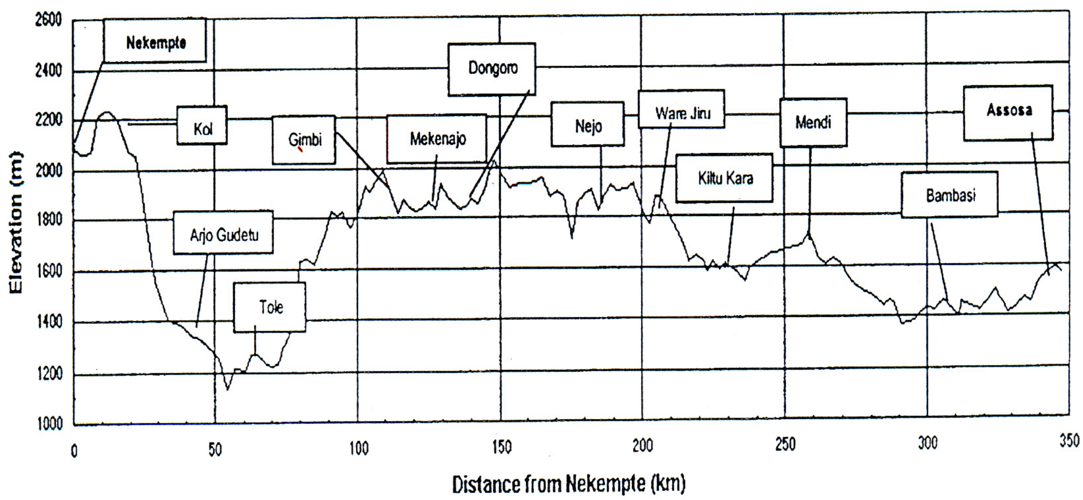


Fig 3-2. Elevation difference along the main road, Nekempte-Asossa Town (Zelalem, 2005).

4. In-situ Properties and Laboratory test results

4.1 In-situ properties description

4.1.1 Sample description

The soil specimens for this Thesis work were collected from Asossa. Prior to sampling, visual site investigations were made to consider the different soil types and to sample evenly in the town. Accordingly nine test pits were chosen. Disturbed samples were collected for this work, weighing about 6,500kg. The location of the test pits are shown in Fig4-1

Table 4-1 Sample depth and the designation used for Asossa samples.

Serial No.	Sampling Depth (m)	Designation	Sample Location	Visual Color observed
1	0.5-1	TP1-1	TP1	Reddish
2	2	TP1-2		
3	0.5-1	TP2-1	TP2	Reddish
4	2	TP2-2		
5	0.5-1	TP3-1	TP3	Reddish
6	2	TP3-2		
7	0.5-1	TP4-1	TP4	Reddish
8	2	TP4-2		
9	0.5-1	TP5-1	TP5	Reddish to brown
10	1.5-2	TP5-2		
11	0.8-1	TP6-1	TP6	Reddish
12	1.5-2	TP6-2		
13	0.5-1	TP7-1	TP7	Dark to black soil
14	2	TP7-2		
15	3	TP7-3		
16	0.5-1	TP8-1	TP8	Reddish
17	2	TP8-2		
18	0.5-1	TP9-1	TP9	Grayish selected fill
19	1.5-2	TP9-1		
20	3	TP9-3		

Where; TP = Test Pit

Samples desiginated as **TP1** were collected along the on going asphaltic road side and are named as TP1-1, TP1-2, etc referring to the first sample of the first test pit and the second sample of the first test pit respectively. The top 50cm was removed prier to sampling. All samples were sealed with plastic cover for the moisture content determination to reduce moisture loss. TP2, TP3, TP4, TP6 and TP8 were also taken in the same way and tagged as shown in the Table 4-1. The pit for TP1 is shown in Fig 4-2

TP5 and TP7 were taken at the lower levels but on a flat terrain positions with few vegetation cover and were found to be almost black soils with different color but having almost the same texture as the other soils.

TP9 samples were collected at the quarry site, the place where SATCON Construction uses for a fill material for the road construction. The soil over this area has a grayish color with coarser graded soil of pluveraizable texture and relatively high density. The sample place is shown in Fig 4-2a. The soils having different colors were observed in the laboratory and are presented as in Fig4-2a, 4-2b, 4-2c bellow.

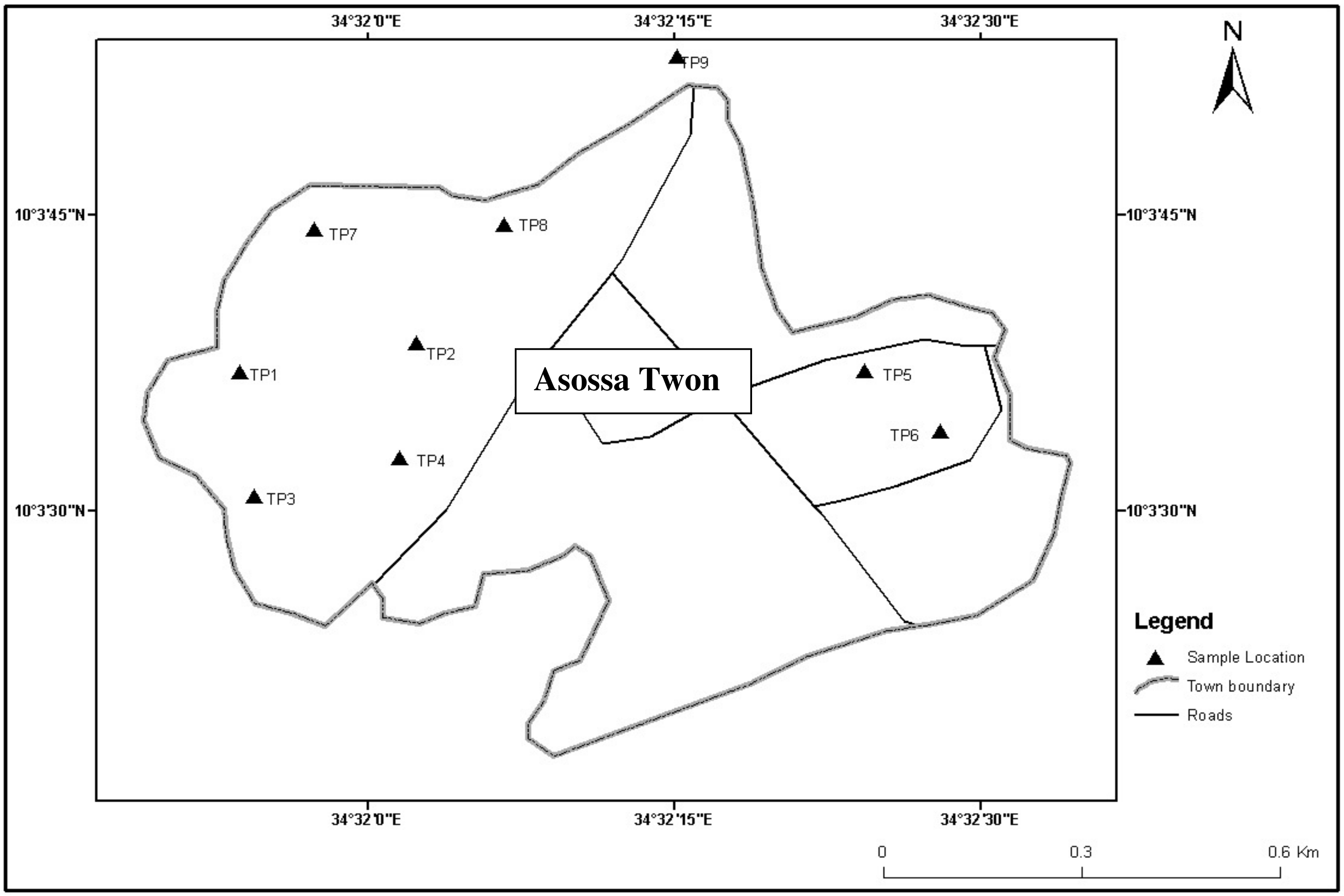


Fig 4-1 Locations of the samples taken in Asossa Town

Fig 4-2 The profile view of pit for the specimen TP1

Fig 4-2a Sampling location of the specimen TP9 used for the fill material

Fig4-2b Sample location TP9 which has less vegetation cover

Fig 4-2c The in-situ color observation for the soil sample

4.1.2 In-situ Atterberg Limit Values

Moist samples were collected, by sealing the specimen by plastic bags to minimize the loss of moisture content of the soil. The in-situ moisture content was determined by air-drying the sample. It took 4 days to dry to a constant weight. The Atterberg Limit tests were conducted on a natural, as received soil specimen. The natural moisture content are generally below the plastic limit and increase with depth for red soils and is nearly equal or greater and increases with depth for black and grayish soils. The natural moisture content along with its Atterberg Limit values are shown in Table 4-2

Table 4-2 Natural moisture content and Atterberg Limit values

Serial No.	Designation	Sampling Depth (m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	NMC (%)
1	TP1-1	0.5-1	57	22	35	23
2	TP1-2	2	54	23	31	24
3	TP2-1	0.5-1	57	22	35	22
4	TP2-2	2	58	26	32	23
5	TP3-1	0.5-1	55	24	31	21
6	TP3-2	2	48	20	28	23
7	TP4-1	0.5-1	57	27	30	24
8	TP4-2	2	52	20	32	22
9	TP5-1	0.5-1	68	22	46	27
10	TP5-2	1.5-2	67	21	46	26
11	TP6-1	0.8-1	57	25	32	22
12	TP6-2	1.5-2	52	21	31	25
13	TP7-1	0.5-1	58	24	34	23
14	TP7-2	2	56	25	31	25
15	TP7-3	3	55	25	30	27
16	TP8-1	0.5-1	60	22	38	21
17	TP8-2	2	57	23	34	25
18	TP9-1	0.5-1	69	31	38	27
19	TP9-2	1.5-2	72	40	32	26
20	TP9-3	3	71	38	33	28

4.1.3 Variation of Soil Properties along the Profiles

The soil was characterized along its profile for selected samples TP1 (TP1-1, TP1-2), TP3 (3-1, 3-2) and TP9 (TP9-1, TP9-2, and TP9-3). The test result from the grain size analysis showed that the coarser fraction increases down the profile. The plasticity index of the soil under investigation decreases with depth and the natural moisture content is found to increase with depth.

Table 4-3 Grain size distribution along test pit profiles

Serial NO.	Designation	Percentage amount of Particle size				Plasticity index (%)	NMC (%)
		Gravel	Sand	Silt	Clay		
1	TP1-1	0	10	45	45	35	23
2	TP1-2	30	60.2	3.0	6.7	31	24
3	TP3-1	0	5	45	50	31	21
4	TP3-2	31	58	8.5	2.5	28	23
5	TP9-1	18.7	68.2	9.6	3.5	38	27
6	TP9-2	14	74	7	5	32	26
7	TP9-3	20.5	63.6	12.6	3.4	33	28

From the Table 4-3,one can see that for the small clay proportion, the plastic limit is high. These large values show that the plastic limits were found after the manipulation of Sensitive samples. However, the insitu soil may not have as large value as in the laboratory. Moreover, the test conditions for Gradation and Atterberg Limit were not the same, as the sample for the Atterberg Limit test were sieved and manipulated.

4.2 Laboratory tests and their results

4.2.1 Index Properties

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

However, studies have revealed that tropical soils are different from temperate zone soils in terms of genesis and structure. Their structures as compared to dispersed temperate zone soils have necessitated modifications to the mechanical or grading tests; the conventional pretreatment methods have considerable effect on the index properties of tropical soils. Therefore, special consideration is required. (Blight, 1997).

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

- Grain size analysis
- Atterberg limits
- Free swell
- Specific gravity

The ASTM testing procedure is used in the laboratory. Most of the literature for tropical soils is carried out using this method. For comparisons of the methods, ASTM equivalent to that of AASHTO testing procedure is attached in Appendex-1.

Temperature effect on moisture content determination

Using an oven drying of $105^{o}c$ is by far high for certain tropical soils as it can drive out their water of hydration and resulting in an irreversible property change on the soil. This effect can be overcome in the laboratory by conducting the natural moisture content of the soil at different test temperatures.

Accordingly, the natural moisture content of the samples were determined in the laboratory as suggested by (Blight, 1997), (CIRIA, 1995). That is drying the sample to an oven temperature of 105^{o}_{C} and oven temperature of $50^{o}c$ with maximum relative humidity (RH) of 30% or equivalently air-drying. For this thesis work eight (8) samples were collected and air-dried until no loss of weight is achieved and the same sample were treated in an oven drying up to 105^{o}_{C} until constant mass is obtained. The values of the moisture contents are presented and compared in Table 4-4. As it was stated in section 2.3.1.1, moisture variations of 4-6% or more indicates that there is loosely bounded molecular 'structural water' present in the soil. From the test results, it is clear that the natural moisture content difference is greater than 4%, which indicates that the soil of Asossa contains a considerable amount of 'water of hydration' or 'structural water' leading to irreversible changes on drying, hence the test for this soil types must be conducted by air drying.

Table 4-4 Moisture content at different temperatures

Serial No.	Designation	Sampling Depth (m)	Oven dry at 105$^o{}_c$	Air dried	Difference (%)
1	TP 1-1	0.5-1	29	23	6
2	TP 4-1	1.5-2	29	24	5
3	TP 4-2	2	27	22	5
4	TP 6-2	1.5-2	30	25	5
5	TP 7-1	1	30	23	7
6	TP 7-3	3	32	27	5
7	TP9-1	.5-1	32	27	5
8	TP9-3	1.5-2	34	28	6

4.2.1.1 Grain size Analysis

Soil particles may consist of size ranges from boulders to fine-sized clays. Grain size analysis is used to determine the effective diameter of the soil particles that constitute and strongly affect the uniformity characteristics of the soil mass. Mechanical analysis is used for the coarse sized soils by using nest of sieve and hydrometer analysis is used for fine-grained soils. For a soil-containing fine to coarse sized particles the combined analysis is employed.

4.2.1.1.1 Test Procedures

I) Dry preparation

Particle size analyses were performed on the air- dried and oven- dried (AD and OD) samples in accordance to ASTM D421-85. The air dried sample were prepared by spreading the material in trays out side the room for nearly three to four days. The oven dried samples were prepared by drying the sample at oven temperature of 105$^o{}_c$. All the samples were screened through the nest of sieves. During the preparation, the samples were divided in to two portions, particle sizes retained on 2mm sieve (Coarse size, Mechanical analysis), and the particles passing 2mm sieve (fine analysis, hydrometer analysis), and finally for soils of both sizes combined analysis was made. The results of these analyses were expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale.

Remillon, (1967) and Terzaghi, (1958) found out that, it is nearly impossible to completely deflocculate lateritic soils (Lyon, 1971). But for this thesis work, Sodium Hexamosphate was used as a dispersing agent and 24-hours sedimantation time were used. However, it was very difficult to disperse the particles of the specimen because of the high cementing effect of the sesquioxide content in the soil. The soil after 24hours of sedimentation in the graduated cylinder has shown little difference from the original reading. Accordingly, longer time has to be used for Asossa soil. Generally, it has to be noted that the dispersant should be standardized as well as the dispersing time. The laboratory observation of the hydrometer after 24-hour solutions is shown in Fig4-2c.

II) Wet preparation

Wet soil preparations (As Received, AR) were carried out on moist samples for grain size analysis tests following the procedures mentioned in (ASTM D2217-85), (Lyon, 1971).

4.2.1.1.2 Test results and discussions

The grain size analysis test results for all soil samples under investigation were summarized in Table 4-5. The corresponding grain size distribution curve is shown in Figs 4-3 and Figs 4-4 partly. The figures for all test results are shown on Appendix-B.

I) Effect of pre-drying

As received (AR), air-dried (AD) and oven dried (OD) samples were used to investigate the grain size distribution of the specimen under investigation. The test results are shown in Table 4-5 and Fig4-4 and Appendix-B. As stated in the previous sections (2.3.1.1), pre-drying residual soils result in a lesser clay fraction due to the aggregation (cementing) effect of tropical soils and the as received sample result in a relatively coarser fraction. Moreover, this was observed during the investigation of Asossa soil as shown in the Figures and Table4-5. Even though drying resulted in a coarser particle, temperature variation has a lesser cumulative effect on the grain size distribution. This is because the aggregated particles becomes weaker in bond and results in fine particles after washing and up on drying. The loose particles can not regain their total bond to re-aggregate to their initial bond due to the an irreversible mineralogical changes made up on washing

The specific gravity determined at an oven-dried condition resulted in a very small value leading to an erratic out put on the hydrometer results leading to a distinct gradation chart. Otherwise, the soil under investigation shows little difference on their gradation chart up on temperature variations. Oven drying the sample gave ambiguous results for the soil under investigation and should not be exercised for such soils.

II) Effect of sample location

Residual soils formed at the same profile and locations show similar characteristics due to their mode of weathering, deposition and soil forming factors to which they are exposed. Residual soils vary from a highly weathered soil to a strong un weathered rock at the bottom. From the test results one can see that, the soil has distinct characteristics where sampled at different conditions. TP9 samples are coarse sized particles and have different index properties compared to the other samples, where as the remaining soils of investigation show a common fine-sized particles.

The soil under investigation also shows different characteristics along its depth. This is the fact that residual soils vary from highly weathered topsoil to unweathered (Intact rock) which is stiff at the bottom. The soil under investigation showed a change of fine-grained soil at the top and stiff to gravel sized soils when sampled along its profile. One can see from Figs below for TP1 (TP1-1 and TP1-2) and TP3 (TP3-1 and TP3-2) that the grain size changes completely from fine grained to gravel. Generally, one can see from the test results and the site conditions of Asossa Town that the soil shows change of the fine fraction from the topsoil to an increased coarse particle at a depth. From the actual situation and the laboratory results, the soil of Asossa shows a decreased in fine proportion and an increase in coarse sized particles in going down along the profile. It is also observed that the soil changes to a very stiff (impossible to sample) gravel sized particle over 2.5m. Soil samples with similar gradation curves have high probability of having the same engineering properties. The result for each of the soil under investigation is shown in Table4-5.

Table 4-5. Percentage amount of the gradation sizes for different conditions and profiles

Serial No.	Designation	Natural moisture content (%)	Test condition	Percentage amount of particle size			
				Gravel	Sand	Silt	Clay
1	TP1-1	23	OD AD AR	0 0 0	10 10 5	25 44 50	65 46 45
2	TP1-2	24	OD AD AR	32 30 28	61.5 60.2 60	3.0 3.1 3.2	3.5 6.7 8.8
3	TP2-1	22	OD AD AR	0 0 0	8 8 8	32 52 52	60 40 40
4	TP2-2	23	OD AD AR	0 0 0	12.5 12.5 12.5	42.5 40 40	45 47.5 47.5
5	TP3-1	21	OD AD AR	0 0 0	10 5 10	45 45 45	40 50 40
6	TP3-2	23	OD AD AR	27 31 30	60.5 58 58	8.5 8.5 8.5	4.0 2.5 3.5
7	TP4-1	24	OD AD AR	0 0 0	10 10 5	52 50 45.5	38 40 49.5
8	TP4-2	22	OD AD AR	0 0 0	5 10 15	65 45 60	30 45 25
9	TP5-1	27	OD AD AR	0 0 0	6 10 6	44 35 50.5	50 55 43.5
10	TP5-2	26	OD AD AR	0 0 0	12.5 12.5 12.5	47.5 32.5 47.5	40 45 40
11	TP6-1	22	OD AD AR	0 0 0	15 5 15	50 60 60	35 35 25
12	TP6-2	25	OD AD AR	0 0 0	10 10 10	55 40 55	35 50 35
13	TP7-1	23	OD AD AR	0 0 0	9 10 15	35.2 32.5 50	35 50 35

14	TP7-2	25	OD AD AR	0 0 0	10 10 10	35 40 55	35 50 35
15	TP7-3	27	OD AD AR	0 0 0	10 10 10	40 55 55	50 35 35
16	TP8-1	21	OD AD AR	0 0 0	5 5 8	60 40 37	30 55 45
17	TP8-2	25	OD AD AR	0 0 0	10 10 6	45 55 59	45 35 35
18	TP9-1	27	OD AD AR	18 18.7 18	69.5 68.2 67	10.5 9.6 7.6	2.0 3.5 4
19	TP9-2	26	OD AD AR	26 14 24	54.6 74 24	11.6 7 8	7.8 5.0 4
20	TP9-3	28	OD AD AR	20.8 20.4 20.5	63.9 63.6 63.4	12.8 12.6 12.4	2.5 3.4 3.7

OD = oven-dried at temperature of 105degrees
AD = air-dried condition
AR = as received condition

III) Range of gradation curves

The range of gradation curves for Asossa soil is relatively wide. This is due to the fact that for residual soils the sequence of materials ranging from a true soil to soft rock is obtained depending on the degree of weathering. The range of grain size distribution curves for the soil samples under investigation for this work is as shown in Fig4-4.

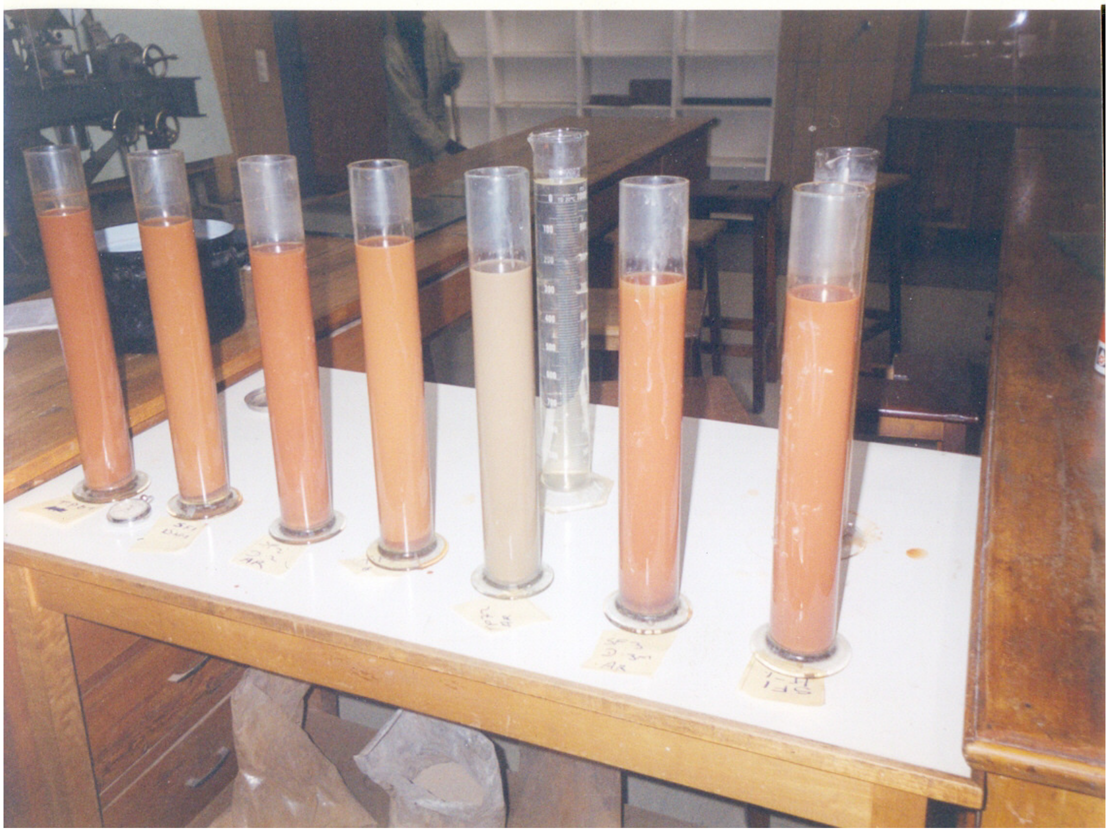


Fig 4-3 The hydrometer cylinder after the 24hour suspension

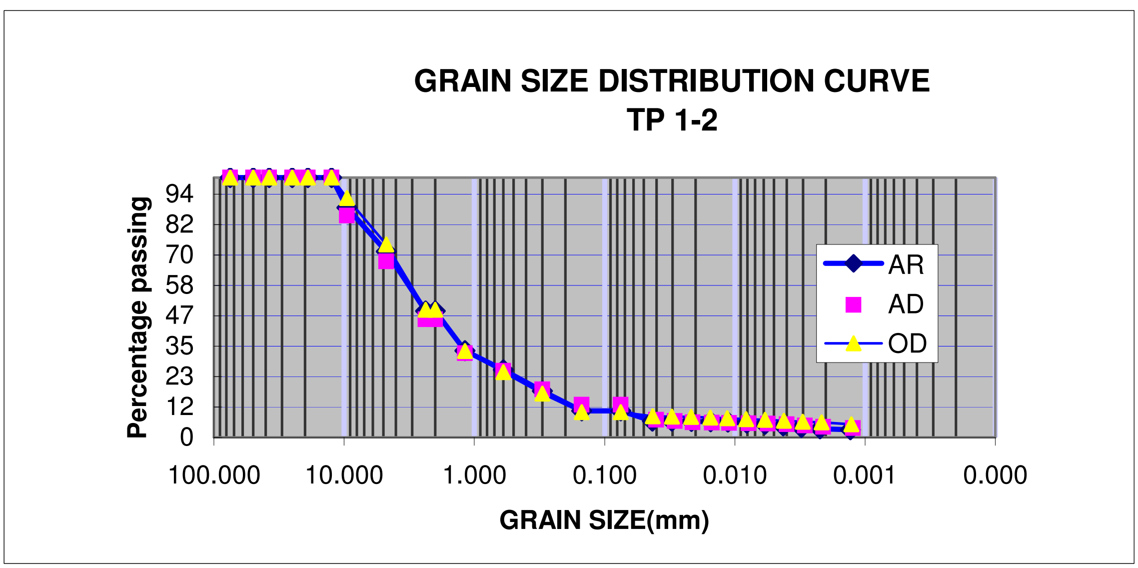


Fig 4-4a Grain size distribution curve under different pretreatment temperatures

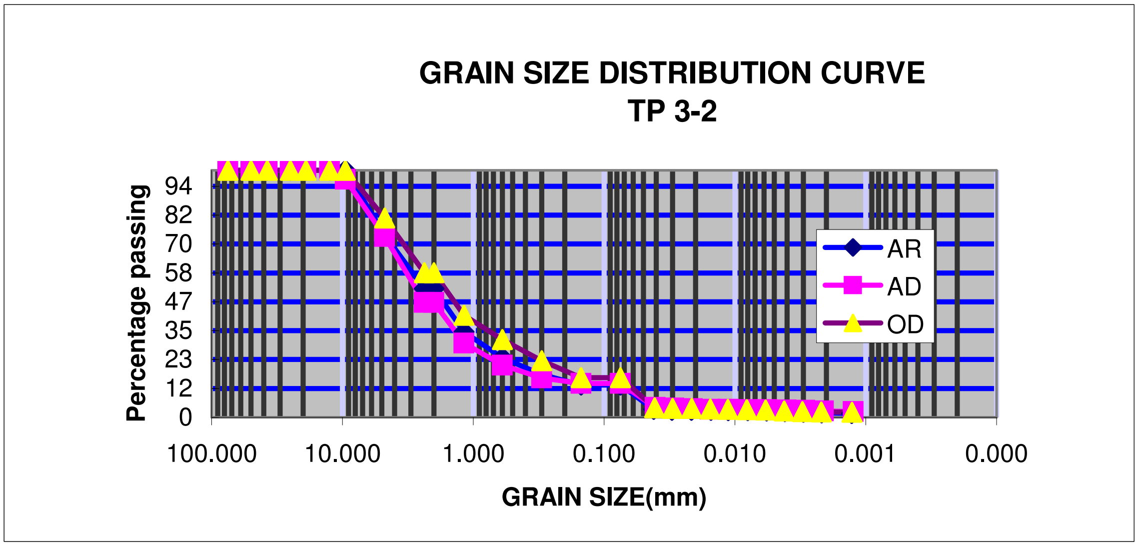


Fig 4-4b Grain size distribution for specimen TP3 at different conditions

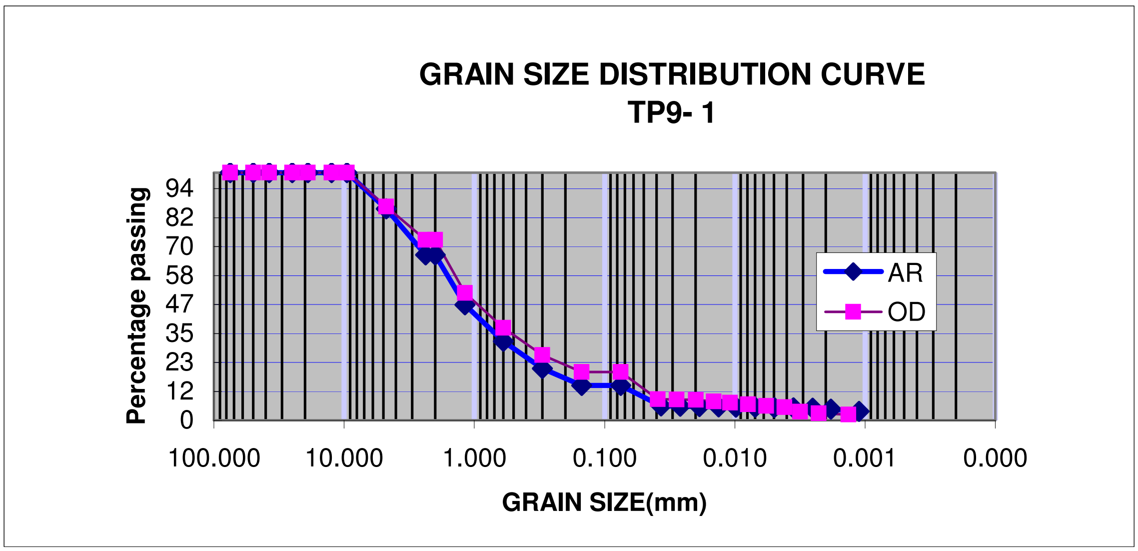


Fig4-4c Grain size distribution for specimen TP9-1 at different conditions

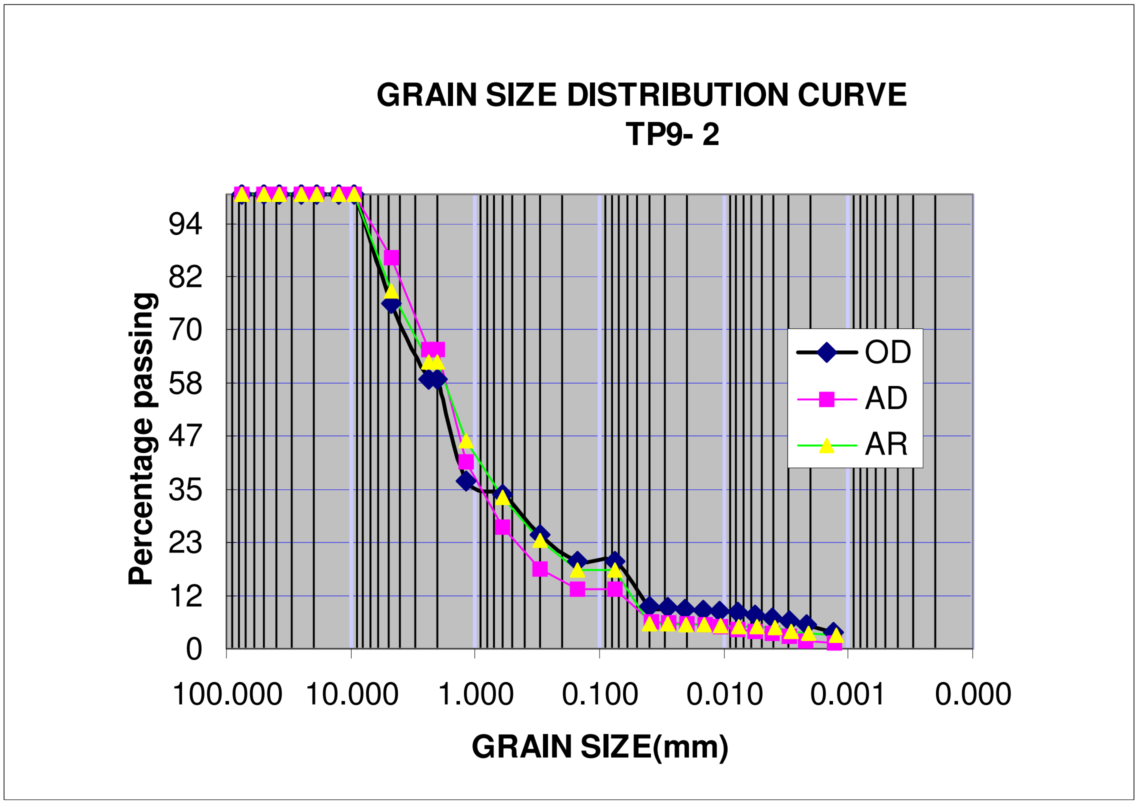


Fig4-4d Grain size distribution for specimen TP9-2 at different conditions

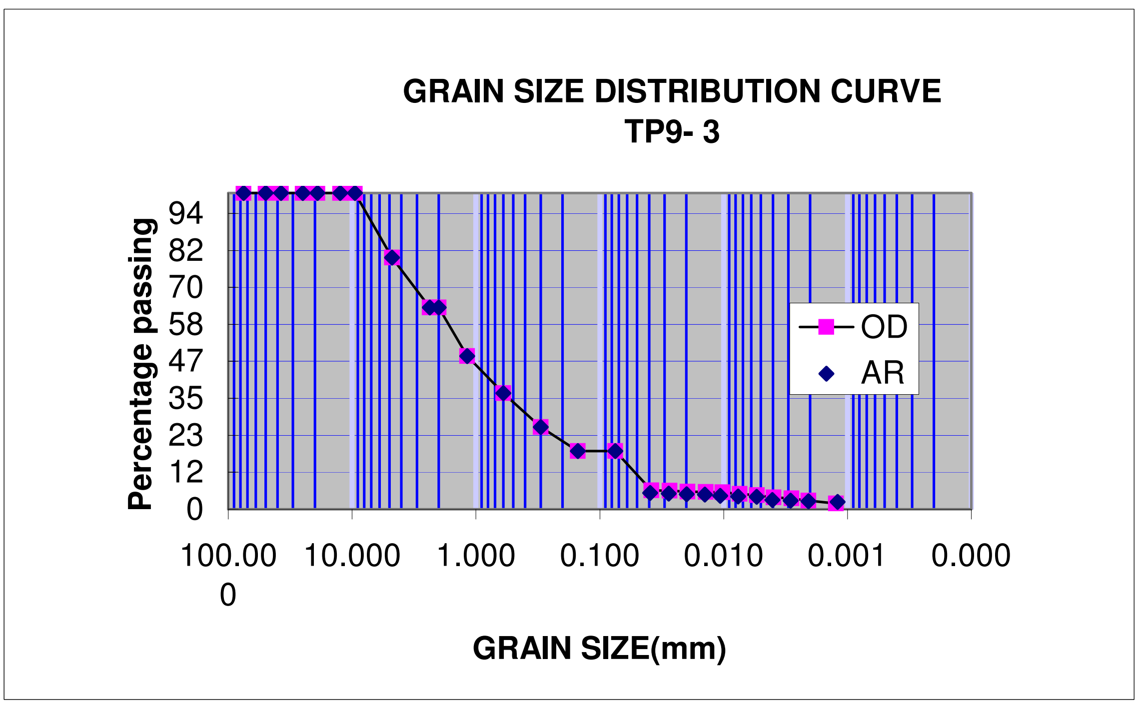


Fig4-4e Grain size distribution for specimen TP9-3 at different conditions

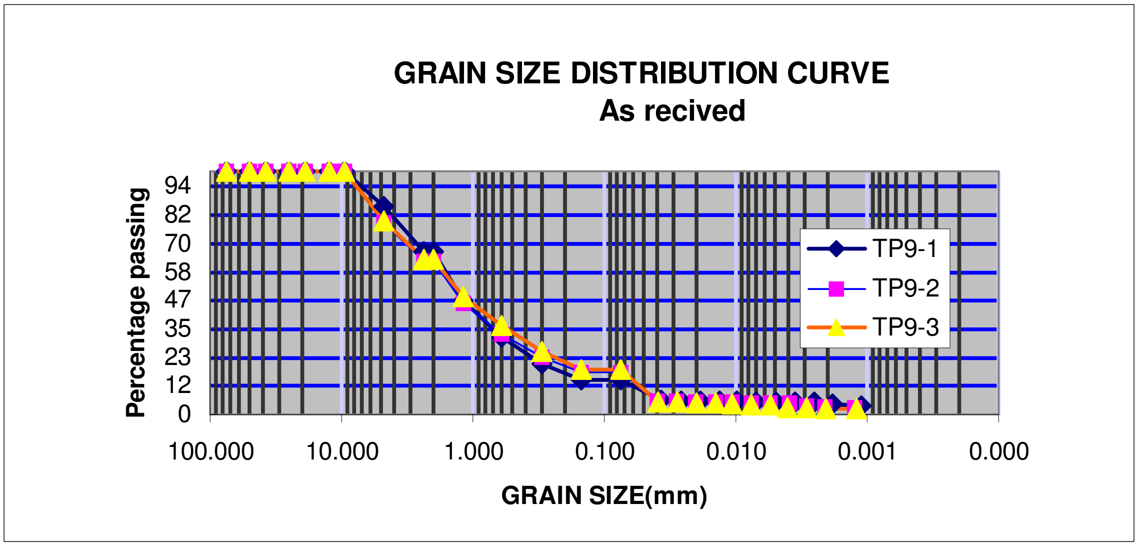


Fig4-5 grain size distribution for specimen TP9 at different depths

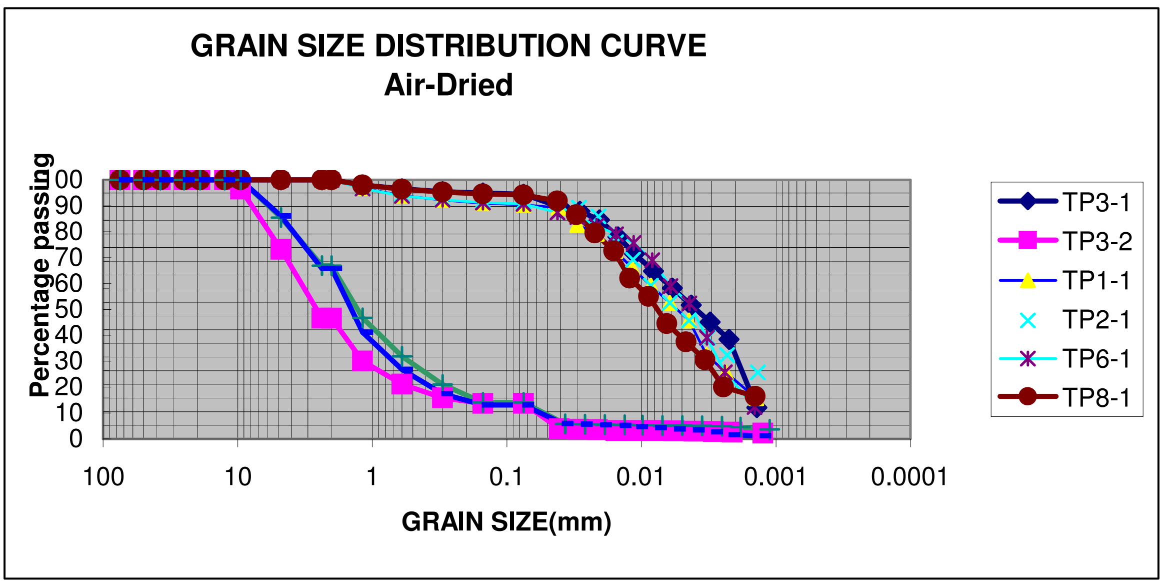


Fig4-6 The graph showing the range of grain size distribution curve of Asossa soil

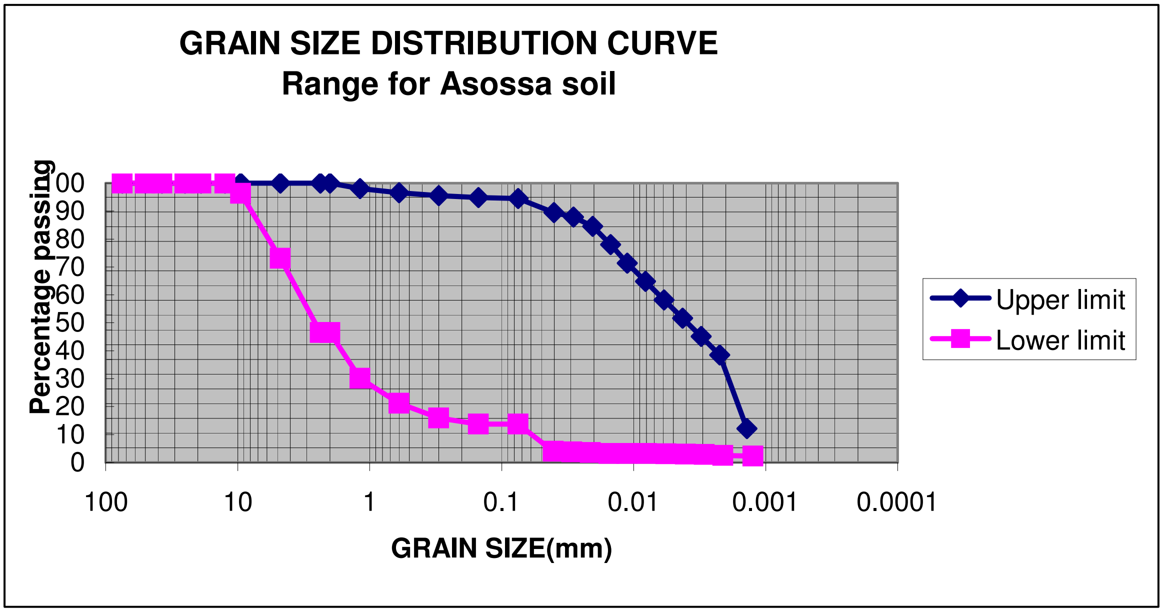


Fig4-7 The upper and lower bounds for gradation analysis

4.2.1.2 Atterberg Limits

Atterberg Limits are arbitrary boundaries through which a soil passes from liquid, to plastic, semi solid and solid states. These boundaries are defined by moisture contents. They are used to determine the consistency of fine-grained soils. Lateritic soils give large range of results and it was also indicated that laterites result in the disaggregation of the particles up on manipulations as stated in section 2.3.1.2 (Blight, 1997)

4.2.1.2.1 Test procedures

Atterberg Limits were determined for air-dried and oven dried samples (AD and OD as per the ASTM D4318-00). The air-dried samples were prepared by spreading the specimen in the air for about 3-4 days. The temperature was about 27^{o}c. However, the OD samples were prepared by putting the sample in an oven at a temperature of 105^{o}c. The wet preparation is also applied for the as received (AR) samples. The portions of the samples passing the No. 40(0.425mm) sieve were used for the preparation of the sample for this purpose.

4.2.1.2.2 Test results and discussions

In order to investigate the effect of temperature on the Atterberg Llimits, the samples were oven dried (OD), air-dried (AD) and treated as received (AR). The test results are shown in Table 4-6. From the test results one can see that the different treatments affect the Atterberg Limits of these particular soils. The test results show great difference for almost all soils. The Liquid Limit and the Plastic Limit decrease with temperature increment and the increment is the large value, normally 5 to 6 percent would be the acceptable range (Lyon, 1971). Hence the treatment conditions (temprature treatments) strongly affect the Atterberg values for Asossa soil.

Unsoaking is drying the soil at oven of 105^{o}c and conducting the Atterberg Limit with out keeping the sample for moisture equilibration for 24-hours. Hence the treatment conditions (temperature treatments) strongly affect the Atterberg Limit values for Asossa soil and it is shown on Table4-6 below that the PI values do not vary significantly. As it is seen on the Table4-6, the soil of Asossa is moist (Field moisture content of 13% and above) and oven drying had already removed the structural water off the soil, hence the as received property could not be reversed on soaking or unsoaking. More over this shows that the clay fraction is not getting enough moisture when taken from oven and mixed with water to determine the Atterberg values. Hence it is clear that one cannot use oven temperature of $105^{o}{}_{C}$ for all the cases of the Atterberg Limit tests. For this thesis work, the air-dried sample and a 24hrs soaked samples were taken as the appropriate samples (Lyon, 1971).

Table 4-6 Atterberg Limit values at different testing conditions

Serial No.	Designation	Sampling Depth (m)	NMC (%)	Test condition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	TP1-1	0.5-1	23	Unsoaked	54	18	36
				Oven-dried	55	19	34
				Air dried	57	22	35
				As received	58	24	34
2	TP1-2	2	24	Unsoaked	49	19	30
				Oven-dried	50	16	34
				Air dried	54	23	31
				As received	54	20	34
3	TP2-1	0.5-1	22	Unsoaked	53	18	35
				Oven-dried	54	18	36
				Air dried	57	22	35
				As received	57	20	37
4	TP2-2	2	23	Unsoaked	56	22	34
				Oven-dried	56	22	34
				Air dried	58	26	32
				As received	63	26	37
5	TP3-1	0.5-1	21	Unsoaked	53	22	31
				Oven-dried	53	22	31
				Air dried	55	24	31
				As received	56	26	30
6	TP3-2	2	23	Unsoaked	41	19	22
				Oven-dried	41	20	21
				Air dried	48	20	28
				As received	55	29	26
7	TP4-1	0.5-1	24	Unsoaked	49	17	31
				Oven-dried	49	17	31
				Air dried	57	27	30
				As received	59	27	32
8	TP4-2	2	22	Unsoaked	52	19	31
				Oven-dried	52	19	31
				Air dried	52	20	32
				As received	53	24	29

9	TP5-1	0.5-1	27	Unsoaked Oven-dried Air dried As received	65 66 68 68	19 19 22 20	46 47 46 48
10	TP5-2	1.5-2	26	Unsoaked Oven-dried Air dried As received	67 56 67 67	19 15 21 19	48 41 46 48
11	TP6-1	0.8-1	22	Unsoaked Oven-dried Air dried As received	54 54 50 58	26 26 25 27	28 28 25 31
12	TP6-2	1.5-2	25	Unsoaked Oven-dried Air dried As received	47 47 52 55	12 12 21 20	35 35 31 35
13	TP7-1	0.5-1	23	Unsoaked Oven-dried Air dried As received	56 57 58 58	20 21 24 25	36 36 34 38
14	TP7-2	2	25	Unsoaked Oven-dried Air dried As received	50 50 56 52	20 20 25 25	30 30 31 27
15	TP7-3	3	27	Unsoaked Oven-dried Air dried As received	52 52 55 55	20 20 25 25	32 32 30 27
16	TP8-1	0.5-1	21	Unsoaked Oven-dried Air dried As received	56 57 60 60	18 18 22 19	38 39 38 41
17	TP8-2	2	25	Unsoaked Oven-dried Air dried As received	50 52 57 57	16 16 23 20	24 36 34 37
18	TP9-1	0.5-1	27	Unsoaked Oven-dried Air dried As received	54 54 69 69	18 18 31 31	36 36 38 38
19	TP9-2	1.5-2	26	Unsoaked Oven-dried Air dried As received	60 61 72 72	40 24 40 40	20 37 32 32
20	TP9-3	3	28	Unsoaked Oven-dried Air dried As received	53 56 57 71	17 19 25 38	36 37 32 33

- Unsoaked –Atterberg Limit conducted on an oven-dried sample at a temprature of ($105^{o}{}_{C}$) with out keeping over night for moisture equilibration.

a) Effect of Test Procedure on Atterberg Limits

The effect of mixing time on the Atterberg Limits (disaggregation) was investigated by conducting the Atterberg Limits at different test procedures as mentioned in section 2.3.1.2. The Atterberg Limit tests were conducted on the soil samples TP3-1, TP3-2, TP4-1 TP4-2, TP6-1, TP7-1, TP7-2, TP9, according to the procedures mentioned in (ASTM D4318-00, Lyon, 1971, Blight 1997). The Atterberg Limit tests were also carried out on the as received soil sample (moist sample). The test results with their treatment conditions are shown on Table 4-7.

As per the recommendations in the section 2.3.1.2, five moist (as received) soil samples for each specimen were mixed with water to give the ranges of moisture contents. The soil specimen were left overnight for moisture equilibration, the next day the Atterberg Limit were conducted by mixing the specimens for not more than 5 minutes. The portion of these specimens was continuously mixed for 25 minutes before conducting the Atterberg Limits. The 5 minutes (LL 5min) and 25 minutes (LL 25min) Atterberg Limits mixing times were conducted and the result summarized on Table 4-7. The difference of '>5%' indicates that, there is a disaggregation of the clay sized particles up on manipulation.

The test results indicate that, the soil of Asossa is susceptible to manipulations. The more the manipulation (energy applied to the sample), the finer the resulting soil will be and the larger the liquid limit and plastic limit and to a lesser extent the larger plasticity index.

Hence the test for Asossa soils should be as per Fourie A.B (Blight, 1997), that is;

I). Limit the mixing times to not more than 5 minutes.

II). Make use of fresh soil for each moisture content point in Atterberg Limit tests.

The 5 minutes mixing time has almost the result as of the conventional test method. For the purpose of investigating the effect, only Liquid limit were used and all samples are at their natural condition (AR).

Table 4-7 Liquid Limit at different conditions and mixing times

Designation	NMC (%)	Pretreatment	Sample manipulation	Liquid limit (%)	LL30-LL5min
TP3-1	21	As Received	5 min 25 min	56 60	4
TP3-2	23	As Received	5 min 25 min	55 59	4
TP4-1	24	As Received	5 min 25 min	57 63	6
TP4-2	22	As Received	5 min 25 min	53 58	5
TP6-1	22	As Received	5 min 25 min	58 64	6
TP7-1	23	As Received	5 min 25 min	62 68	6
TP7-2	25	As Received	5 min 25 min	52 58	6
TP9-3	28	As Received	5 min 25 min	71 79	8

b) Effect of rewetting on Atterberg Limits

The effect of re-wetting was investigated by conducting and comparing Atterberg Limit tests on soil samples prepared from its natural moisture content and that of the oven drying at 105^{o}c and rewetted. The results are shown in Table4-6 for all soils. From these test results for the As Received and oven dry condition, one can see that there is a large discrepancy between the two. Accordingly, this indicates that the laboratory results of the Atterberg limit values for Asossa soil has to necessarily be simulated with the field conditions with respect to wetting and drying prior to the test. The comparison between AD and AR samples are also possible, however, they showed almost closer results.

Plasticity Chart

Basically, plasticity index, which is the numerical difference between liquid limit and the plastic limit, represents the range of water content through which a soil is in plastic range. The higher the numerical value of the plasticity index, the higher percentage of clay fraction in the soil sample. This shows the plasticity index increases with the high percentage of clay fraction present.

The type of the clay, however determined by considering the plasticity index in relation to the liquid limit values. This could be obtained by a plasticity chart developed from soils tested at different parts of the world (Budhu, 2000), (Zelalem, 2005). Clays, silts, inorganic and organic soils lie in different regions on the plasticity chart. The line defined as "A-line" is expressed by (Eq4-1). Is used to separate, inorganic clays of high or low plasticity and organic clays and silts. The Graph showing the A-Line is shown in Fig4-8. The results of soil under investigation on the plasticity chart is shown in Fig4-8. The soil under investigation fall above the A-line, except the sample taken from TP9 (TP9-1, TP9-2, TP9-3). A test result above the A-line shows red clays with Latosols having strong montimorillonitic influence, which are inorganic. Almost all Soils of Asossa fall in this region. The values below the A-line shows that there is a mineral content of Kaolinite, Chlorite and Volcanic ash soils (Andosols) with strong Allophanic influence, accordingly TP9 soils of Asossa were found to fall in this region. As stated in the section 2.2.2, the predominant mineral content of laterite soils is Kaolinite.

PI = 0.73(LL-20) --Eq.4-1

"U-Line" defined by equation 4-2 represents the upper limit of the correlation between plastic index and liquid limit. It is true that results above this line indicates erroneously execute hence repeating the test is usually recommended. For the soil under investigation, the test results lie below the line defined by;

PI = 0.9(LL-8) ---Eq.4-2

Note: The liquid limit and plastic limit values are in percent.

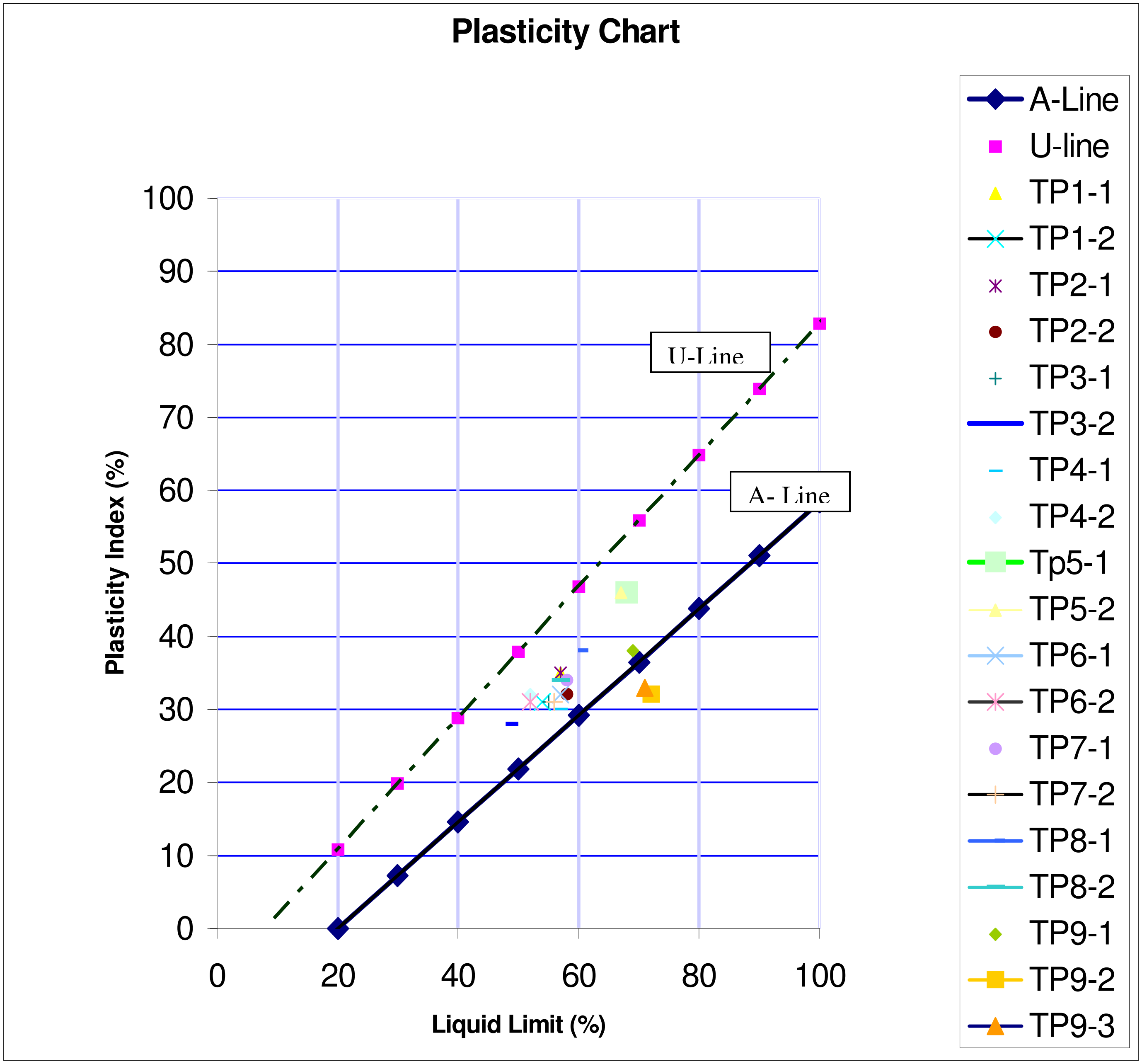


Fig4-8 Figure showing the locations of Asossa soil on plasticity chart

One Point Liquid limit Tests

One-point liquid limit tests can be used for tropical soils effectively. One-point liquid limit method has been described and investigated by a number of authors, and various formulas have been proposed. The most widely used one was developed by U.S waterway experiment station (1949) and was given in the formula (Lyon, 1971);

$LL = W (N/25)^{\tan\beta}$ --Eq.4/3

Where: LL = Liquid limit

W= moisture content

N = No.ofblows for Liquid limit

β = 0.12 (ASTM, Waterway Experiment for Tropical soils, Lyon, 1971)

One can use the value of tanβ equal to zero when the number of blows is between 20 and 30 with in the accuracy. But, ASTM recommends β value of 0.12 is adequate for determining the one-point liquid limit for lateritic and temperate soils. The results were calculated and shown in Table 4-8.

From the test results, one can judge that the one-point Liquid Limit has almost close results with the Cassagrande results and could be used for tropical soils. Moreover, for the 25 number of blows the calculated result shows almost reasonably close values as the test. Generally, this method could be used to determine the Liquid Limit values.

Table 4-8 Liquid limit value comparisons between one-point and conventional methods

Serial No.	Designation	Test condition	No. Of blows	Moisture Content (%)	Calculated. LL (%)	Tested LL (%)
1	TP 1-2	Air-dried	32	39	41	54
			27	57	63	
			24	57	63	
		Oven-dried	31	58	64	50
			27	57	63	
			24	85	98	
2	TP 3-2	Air-dried	30	52	53	48
			27	45	46	
			23	50	49	
			29	31	31	

		Oven-dried	26	37	38	41
			22	50	49	
3	TP 4-2	Air-dried	31	37	38	52
			26	50	50	
			22	47	46	
		Oven-dried	29	37	37	52
			26	53	53	
			22	60	59	
4	TP 6-1	Air-dried	29	62	63	50
			26	55	55	
			23	62	61	
		Oven-dried	31	51	52	54
			26	55	55	
			22	56	55	
5	TP9- 1	Air-dried	30	36	37	69
			27	48	48	
			23	44	43	
		Oven-dried	28	53	54	54
			24	64	64	
			20	72	70	
6	TP9-2	Air-dried	31	40	41	72
			26	56	56	
			24	72	71	
		Oven-dried	30	43	44	61
			27	53	57	
			23	74	73	

4.2.1.2.3 **Activity (Colloidal Activity)**

Skempton's colloidal activity is determined as the ratio of the plasticity index of the clay content in the fines. It is generally low for lateritic soils. Because the predominant clay minerals in lateritic soils are of Kaolinite group. These soils are known to be inactive (activity less than 1.25). The low activity of most lateritic soils is due to the mode of weathering that involves the coating of soil particles with sesquioxides, resulting in the suppression of the surface activity of the clay particles (Lyon, 1971). Skempton observed that, for a given soil, the plasticity index is directly proportional to the percent of clay-size fraction (i.e., percent by weight finer than 0.002mm in size). Activity designated by 'A_c' is given by;

$A_c = PI / C$ --Eq 4-4

Where C is percent of clay-sized fraction by weight. Activity has been used for determining the swelling potential of clays. The colloidal activity values for the soils under investigation are calculated and summarized in Table 4-9. The soil classification according to Activity is shown on Table 4-10.

Table4-9 Degree of Colloidal activity

Activity Number, Ac	Soil Type
<0.75	Inactive
0.75 –1.25	Normal
>1.25	Active

As mentioned by Morin W.J. and Todor P.C. (Lyon, 1997), residual soils have low activity number. This is the due to the mode of weathering involving the coating of the soil particles with the sesquioxides. From Table 4-10, one can see that the soil under investigation has activity number <1.25(Normal), which agrees with the Morin's investigation of lateritic soils.

Table 4-10 Skemptons colloidal activity values

Serial No.	Sample Depth (m)	Designation	Clay fraction (%)	Plasticity Index (%)	AC (%)
1	0.5-1	TP1-1	46	35	0.76
2	0.5-1	TP2-1	40	35	0.88
3	2	TP2-2	47.5	32	0.67
4	0.5-1	TP3-1	50	31	0.62
5	0.5-1	TP5-1	55	46	0.84
6	2	TP5-2	45	46	1.02
7	1	TP7-1	50	34	0.68
8	1.5-2	TP7-2	50	31	0.62

4.2.1.3 Free Swell

This test gives a fair approximation of the degree of expansiveness of a soil samples. It is done by pouring very slowly 10 cubic centimeter of dry soil passing No. 40 (0.42mm) sieve in to a 100 cubic centimeter graduated measuring cylinder. It is let to stay for approximately twenty-four hours until all the soils settle completely to the bottom of the cylinder. Free swell is given by;

$$\text{Free Swell (\%)} = \frac{Vf - Vi}{Vi} \text{--Eq 4-5}$$

Where Vf = final volume

Vi = initial volume

The laboratory free swell test results were done on an air-dried and oven dried ($105^{o}{}_{c}$) samples and is shown in Table 4-11. Accordingly one can see from the test that the free swell values for Asossa soils range from 20% to 55%. Those soils with free swell of less than 50% are considered to have low degree of expansion, Alemayeu .T and Mesfin. L, (1999). Accordingly, the soil of Asossa is non-expansive soil (low expansion).

Table 4-11 Free Swell test results at different Conditions

Serial No.	Designation	NMC (%)	Test condition	Liquid Limit (%)	Plastic Limit (%)	Plasticty Index (%)	Free swell (%)
1	TP1-1	23	Oven-dried Air dried	55 57	19 22	34 35	33 25
2	TP1-2	24	Oven-dried Air dried	50 54	16 23	34 31	25 22
3	TP2-1	22	Oven-dried Air dried	54 57	18 22	36 35	32 25
4	TP2-2	23	Oven-dried Air dried	56 58	22 26	34 32	30 20

5	TP3-1	21	Oven-dried Air dried	53 55	22 24	31 31	30 40
6	TP3-2	23	Oven-dried Air dried	41 48	20 20	21 28	25 30
7	TP4-1	24	Oven-dried Air dried	49 57	17 27	31 30	30 40
8	TP4-2	22	Oven-dried Air dried	52 52	19 20	31 32	35 41
9	TP5-1	27	Oven dried Air dried	66 68	19 22	47 46	45 27
10	TP5-2	26	Oven-dried Air dried	56 67	15 21	41 46	40 35
11	TP6-1	22	Oven-dried Air dried	54 50	26 25	28 25	30 25
12	TP6-2	25	Oven-dried Air dried	47 52	12 21	35 31	29 22
13	TP7-1	23	Oven-dried Air dried	57 58	21 24	36 34	40 50
14	TP7-2	25	Oven-dried Air dried	50 56	20 25	30 31	32 55
15	TP7-3	27	Oven-dried Air dried	52 55	20 25	32 30	34 25
16	TP8-1	21	Oven-dried Air dried	57 60	18 22	39 38	29 25
17	TP8-2	25	Oven-dried Air dried	52 57	16 23	36 34	22 25

18	TP9-1	27	Oven-dried Air dried	54 69	18 31	36 38	19 21
19	TP9-2	26	Oven-dried Air dried	61 72	24 40	37 32	15 11
20	Tp9-3	28	Oven-dried Air dried	56 57	19 25	37 32	30 25

4.2.1.4 Specific Gravity

The specific gravity, Gs, is used to calculate parameters such as clay fraction, void ratio and porosity. In residual soils the specific gravity may be unusually high or unusually low. It is thus essential that the specific gravity be determined in the laboratory using an accepted standard test procedure.. The soil has to be in its natural moisture content. Pre-test drying of the sample should be avoided as it tends to reduce the measured specific gravity as compared to one at the natural moisture content (Blight, 1997).

The soil samples under investigation were determined using the ASTM procedure, designation D854-58. Moreover, the tests were conducted at different test temperatures (as received, air-dried and oven-dried) to see the effect of pre-drying the test results is shown in Table 4-12. . From the test results, one can see that the as received and the air-dried results are almost close even though it slightly reduces with air-drying. The specific gravity of Asossa soil reduces strongly with oven drying. Generally, the specific gravity of a soil under investigation reduces with laboratory test temperature increment. The range of the test results are from 2.19 to 2.94 and this is as stated above that the result could be high or low. The higher value is due to the fact that there is high iron content.

Table 4-12 Values of Specific Gravity at different test conditions

Serial No.	Designation	Sampling Depth (m)	NMC (%)	Test condition	Specific gravity
1	TP1-1	0.5-1	23	As received Air dried Oven-dried	2.55 2.49 2.27
2	TP1-2	2	24	As received Air dried Oven-dried	2.26 2.59 2.43
3	TP2-1	0.5-1	22	As received Air dried Oven-dried	2.56 2.48 2.3
4	TP2-2	2	23	As received Air dried Oven-dried	2.66 2.5 2.4
5	TP3-1	0.5-1	21	As received Air dried Oven-dried	2.67 2.55 2.45
6	TP3-2	2	23	As received Air dried Oven-dried	2.63 2.63 2.55
7	TP4-1	0.5-1	24	As received Air dried Oven-dried	2.63 2.4 2.18
8	TP4-2	2	22	As received Air dried Oven-dried	2.57 2.45 2.19
9	TP5-1	0.5-1	27	As received Air dried Oven-dried	2.48 2.43 2.22
10	TP5-2	1.5-2	26	As received Air dried Oven-dried	2.59 2.5 2.37
11	TP6-1	0.8-1	22	As received Air dried Oven-dried	2.64 2.46 2.44

12	TP6-2	1.5-2	25	As received Air dried Oven-dried	2.54 2.5 2.45
13	TP7-1	0.5-1	23	As received Air dried Oven-dried	2.55 2.5 2.46
14	TP7-2	2	25	As received Air dried Oven-dried	2.52 2.45 2.24
15	TP7-3	3	27	As received Air dried Oven-dried	2.54 2.44 2.36
16	TP8-1	0.5-1	21	As received Air dried Oven-dried	2.46 2.33 2.28
17	TP8-2	2	25	As received Air dried Oven-dried	2.51 2.44 2.33
18	TP9-1	0.5-1	27	As received Air dried Oven-dried	2.94 2.62 2.57
19	TP9-2	1.5-2	26	As received Air dried Oven-dried	2.65 2.76 2.21
20	TP9-3	3	28	As received Air dried Oven-dried	2.85 2.48 2.4

4.3 Classification of the Soils

Different Autors used different classification techniques to classify residual tropical soils; Wesley L.D. and Irfan T.Y. (Blight, 1997) classify soils based on the mineralogical composition alone, While D'Hoor (1964) classify residual soils based on soil forming factors. As stated in (Lyon, 1971), the AASHTO classification system is convenient as the bases for classifying residual soils. The soil in this work was classified according to the AASHTO M-145.The soil used for the classification purpose was air-dried sample. Moreover, the soil was classified according to the USCS method and the result is shown in Table 4-13.

According to the AASHTO classification, all soils except TP1-2, TP3-2, and TP9 lie in the group A-7-6, which is inorganic clay of high to medium plasticity clay according to the USCS classification. TP9 soils are grouped under the A-2-7 as the AASHTO method, silty sands according to the USCS classification method. Soil from TP1-2 is grouped under A-2-7 of AASHTO that is, clayey sand according to the USCS classification. Generally, the soil under investigation consists mainly inorganic clay of high to medium plasticity up to the depth of 2m and with some fractions of silty or clayey sands.

Table 4-13 Soil classification according to the AASHTO and USCS.

Serial No.	Designation	LL (%)	PI (%)	Percentage passing			AASHTO classification		%age amount of particle size				USCS classification system
				2	0.425	0.075	Group	Group Index	Gravel	Sand	Silt	Clay	
1	TP1-1	57	35	100	92	90.42	A-7-6	35	0	10	44	46	Inorganic clay of high plasticity, CH
2	TP1-2	54	31	45.5	18.4	12.52	A-2-7	0	30	60.2	3.1	6.7	Clayey sands, SC
3	TP2-1	57	35	100	92	91.63	A-7-6	35	0	8	52	40	MH
4	TP2-2	58	32	100	90.5	88.2	A-7-6	32	0	12.5	40	47.5	CH
5	TP3-1	55	31	100	96	94.5	A-7-6	33	0	5	45	50	CH
6	TP3-2	48	28	46.54	18.4	13.71	A-7-5	0	31	58	8.5	2.5	CL, inorganic clay of low to medium plasticity
7	TP4-1	57	30	100	94.4	93.04	A-7-6	32	0	10	50	40	MH
8	TP4-2	52	32	100	93	90.46	A-7-6	31	0	10	45	45	CH/MH
9	TP5-1	68	46	100	90.6	87.55	A-7-6	44	0	10	35	55	CH
10	TP5-2	67	46	100	89.5	87.4	A-7-6	44	0	12.5	32.5	45	CH
11	TP6-1	50	25	100	94.3	92.1	A-7-6	26	0	5	60	35	MH
12	TP6-2	52	31	100	92.3	90.7	A-7-6	30	0	10	40	50	CH
13	TP7-1	58	34	100	94	92.9	A-7-6	35	0	10	32.5	50	CH
14	TP7-2	56	31	100	93.5	92	A-7-6	32	0	10	40	50	CH
15	TP7-3	55	30	100	94	92.5	A-7-6	31	0	10	55	35	MH
16	TP8-1	60	38	100	95.2	94.2	A-7-6	40	0	5	40	55	CH
17	TP8-2	57	34	100	94.6	93.81	A-7-6	36	0	10	55	35	MH
18	TP9-1	69	38	85.42	20.95	14.10	A-2-7	0	18.7	68.2	9.6	3.5	SM, Silty sands
19	TP9-2	72	32	86.06	17.43	13.06	A-2-7	0	14	74	7	5	SM
20	TP9-3	57	32	79.6	25.99	18.44	A-2-7	0	20.4	63.6	12.6	3.4	SM

5. Comparison and Discussions of the Test Results

5.1 Comparison of the test results with laterites and lateritic soils of Africa and soils of Nejo-Mandi

Laterites and lateritic soils of Africa were studied by Morin W.J. and Todor P.C. (Lyon, 1971). During the study, samples were collected from different parts of Africa such as Ghana, Ethiopia, Kenya, Uganda etc. the characteristics and mineralogical content of the soils taken from Ethiopia was studied as Ferrisol (Zelalem , 2005).

Index property comparisons

For the soil under investigation, Index property tests, were studied and comparisons were made with known lateritic and laterites of Africa. Based on the soil forming factors as stated in section 2.1.4.2, lateritic soils are classified by D'Hoore as; Ferrugineous, Ferrallitic or Ferrisols . Accordingly the results of the index properties, gradation of these soils of Africa and the corresponding values for Asossa soils are shown in Table 5-1 (5-1a, 5-1b, 5-1C, 5-1d)

Tables 5-1a to 5-1c show the average values of various tests done at different countries, i.e., Liquid Limit, Plastic Index and Gradation for Ferruginous, Ferrallitic and Ferrisols showing different properties. As indicated in section 2.1.4.2, and on the tables, Ferruginous soils are formed at a pronounced dry seasons, have hard and durable nature and show lower plasticity as compared to the two. On the other hand, as stated in the same section, Ferrallitic and Ferrisols show similar and higher plasticity values compared to Ferruginous due to their formation at wet seasons. The data indicate that there is a considerable similarity in the physical properties of these two soils. However, it is clear that the mineralogical composition differs (Lyon, 1971) and the mineralogical compositions are shown in Table 5-2.

The soil of Asossa when compared with the previous tested laterite and lateritic soils of Africa show considerable similarities with the Ferrallitic and Ferrisols soils: More similarity is observed with respect to the index tests shown in Tables 5-1b to5-1c. Moreover, the test result shows that the value of plasticity is high as these soils due to the mode of formation, i.e., they are formed at relatively wet climatic conditions. Average soil test results for the three sub-groups of African laterite and Lateritic soils and Nejo-Mandi soils along with the test results of Asossa soil is shown in Table 5-3 (Zelalem, 2005).

Generally, the soil of Asossa could be classified as Ferrisol, with almost close characteristics with Cameron, Mali, Uganda and Ghana soils having high plasticity and to a lesser extent, with Ferrallitic soils found in Kenya and Tanzania. However, Asossa soil has a large value of clay fraction.

Plasticity Chart comparisons

The location of common clays and percentage Kaolinite soils on the Casagrande's plasticity charts, and the plasticity charts as investigated for Asossa soils are shown in Fig5-a to 5-d. Fig5-a show the plot of Casagrande's plasticity chart for soils containing different amount of Kaolinite minerals. The results fall below the A-Line with respective increase along the plasticity chart. The corresponding Montimorillonite, Illites, Kaolinites, Halloysites and Chlorites are also shown in Fig5-b, showing Chlorites, Halloysites and Kaolinites falling below the A-line.

The soil under investigation as stated in the section 4.2.1.2.2, fall above the region A-line, except the sample taken from TP9 (TP9-1, TP9-2, TP9-3). Test results above the A-line show red clays with Latosols behavior and could have strong montimorillonitic influence, which are inorganic. Almost all soils of Asossa fall in this region. The values below the A-line shows that there is a mineral content of Kaolinite, chlorite and volcanic ash soils (Andosols) with strong Allophanic influence. Accordingly TP9 soils of Asossa were found to fall in this region. As stated in the section 2.2.2, the predominant mineral content of laterite soils is kaolinite.

Table 5-1aTypical Soil Test Results for Ferruginous soils

COUNTRY	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
Ghana	26	15	11	A-2-6	0						45	20
Senegal	39	20	19	A-2-7	0	95	91	68	46	33	27	20
Upper Volta	38	14	24	A-2-6	1	100	97	80	66	51	38	25
Niger	21	11	10	A-2-4	0	97	89	73	64	55	40	25
Tanzania	34	19	15	A-2-6	6	100	100	100	100	100	93	61
Kenya	45	31	14	A-2-7	0	100	100	94	88	52	40	28
Uganda	38	17	22	A-2-6	2	100	100	96	83	61	51	34
Sudan	21	12	9	A-2-4	0	100	100	100	100	98	57	27
Gambia	36	16	20	A-2-6	0	98	77	53	42	34	28	22

Table 5-1bTypical Soil Test Results for Ferrallitic soils

COUNTRY	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
Ghana	38	18	20	A-6	6	100	100	100	95	81	67	47
Liberia	56	29	27	A-2-7	2	100	95	72	72	41	36	27
Gabon	35	18	17	A-2-4	0							
SerraLeone	55	31	24	A-2-6	1	100	98	90	68	37	29	27
Burundi	31	16	16	A-6		100	100	92	84	76	74	70
Dahomey	45	21	24	A-2-7	4	100	100	99	85	72	55	39
Ivory Cost	62	31	31	A-7-6	22	100	100	100	100	99	88	69
Mali	35	21	14	A-6	3	100	100	89	67	55	51	40
Uganda	39	19	20	A-6	2	100	100	91	82	73	53	38

Table 5-1cTypical Soil Test Results for Ferrisol soils

COUNTRY	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
Ghana	53	34	19	A-7-5	3						50	37
Niger	28	16	12	A-2-6	0	100	100	98	82	68	39	26
Ivory Cost	48	24	24	A-7-6	18	100	99	83	65	60	50	40
Mali	55	31	24	A-7-5	3	100	100	89	61	51	43	38
Uganda	46	21	25	A-2-7	0	100	100	91	56	31	24	20
Kenya				A-7-5	27	100	100	100	100	99	98	91
Cameron	65	37	27	A-7-5	19	100	100	100	98	97	88	66
Ethiopia	68	33	35	A-7-5	19	100	100	98	84	63	62	58
Ghana	57	25	32	A-7-6	12	100	100				65	50

Table 5-1d Soil Test results for Nejo-Mandi

COUNTRY	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
Nejo-Mandi	58	37	21	A-2-7	0	92	82	61	45	31	25	20
	57	37	20	A-7-5	17.5					100	87.5	78

Table 5-1e Typical Soil Test Results for Asossa soils

Designation	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity index (%)**	**AASHO**	**GI**	**25 mm**	**19 mm**	**9.5 mm**	**4.75 mm**	**2 mm**	**0.425 mm**	**0.075 mm**
TP1-1	57	22	35	A-7-6	35	100	100	100	100	100	92	90.42
TP1-2	54	23	31	A-2-7	0	100	100	85.34	67.8	45.5	18.4	12.52
TP2-1	57	22	35	A-7-6	35	100	100	100	100	100	92	91.638
TP2-2	58	26	32	A-7-6	32	100	100	100	100	100	90.5	88.2
TP3-1	55	24	31	A-7-6	33	100	100	100	100	100	96	94.5
TP3-2	48	20	28	A-7-5	0	100	100	96.4	73.13	46.54	18.4	13.71
TP4-1	57	27	30	A-7-6	32	100	100	100	100	100	94.4	93.0366
TP4-2	52	20	32	A-7-6	31	100	100	100	100	100	93	90.458
TP5-1	68	22	46	A-7-6	44	100	100	100	100	100	90.6	87.550
TP5-2	67	21	46	A-7-6	44	100	100	100	100	100	89.5	87.4
TP6-1	50	25	25	A-7-6	26	100	100	100	100	100	94.3	92.1
TP6-2	52	21	31	A-7-6	30	100	100	100	100	100	92.3	90.7
TP7-1	58	24	34	A-7-6	35	100	100	100	100	100	94	92.9
TP7-2	56	25	31	A-7-6	32	100	100	100	100	100	93.5	92
TP7-3	55	25	30	A-7-6	31	100	100	100	100	100	94	92.5
TP8-1	60	22	38	A-7-6	40	100	100	100	100	100	95.2	94.19
TP8-2	57	23	34	A-7-6	36	100	100	100	100	100	94.6	93.81
TP9-1	69	31	38	A-2-7	0	100	100	100	100	85.42	20.95	14.10
TP9-2	72	40	32	A-2-7	0	100	100	100	100	86.06	17.43	13.06
TP9-3	57	25	32	A-2-7	0	100	100	100	100	79.6	25.99	18.44

Table 5-2 Dominant mineralogical content for Laterite sub-group (Lyon, 1971)

Ferruginous	Ferralitic	Ferrisol
Hematite	Gibbsite	Kaolinite
Goethite	Goethite	Goethite
Kaolinite	Kaolinite	Hematite Gibbsite

Table 5-3 Average soil property comparisons (Lyon, 1997) and (Zelalem, 2005)

Test Executed	Ferruginous		Ferralitic		Ferrisols		Nejo-Mendi	Asossa
	Ghana	Other countries	Ghana	Other countries	Ghana	Other countries		
Passing sieve size (%)								
25	99	99	99	99	95	99	94.6	100
19	98	96	96	97	94	99	88.3	100
9.5	93	89	86	90	86	92	73.3	99
4.75	75	76	70	80	73	74	62.2	94.6
2	51	65	54	70	52	61	51.6	89
0.425	46	51	46	54	40	51	45.0	74.7
0.075	30	32	34	40	37	44	38.3	72
0.002	13	16	19	26	25	24	9.2	21
`LL	31	33	42	47	46	55	59	59
PL	18	12	24	24	23	29	38	25
PI	14	15	19	23	23	27	22	34
FS	-	-	-	-	-	-	-	30

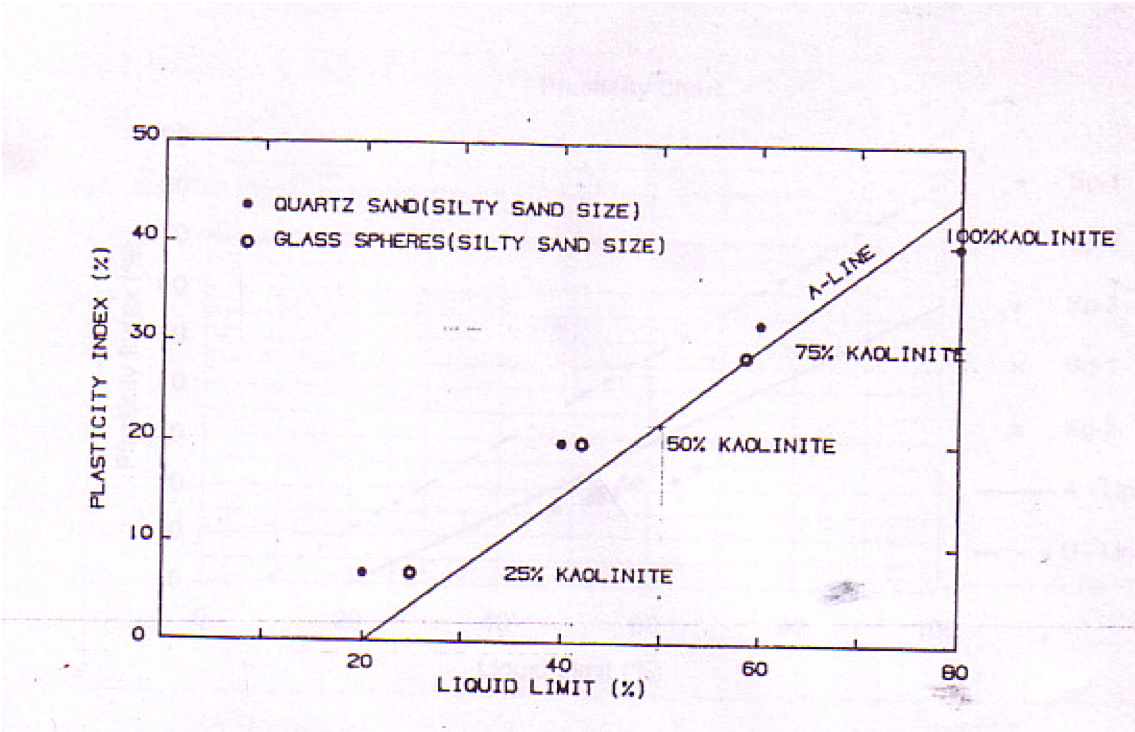


Fig 5-a Kaolinite with various percentages of silts and admixtures plotted on Casagrande's chart (Zelalem, 2005)

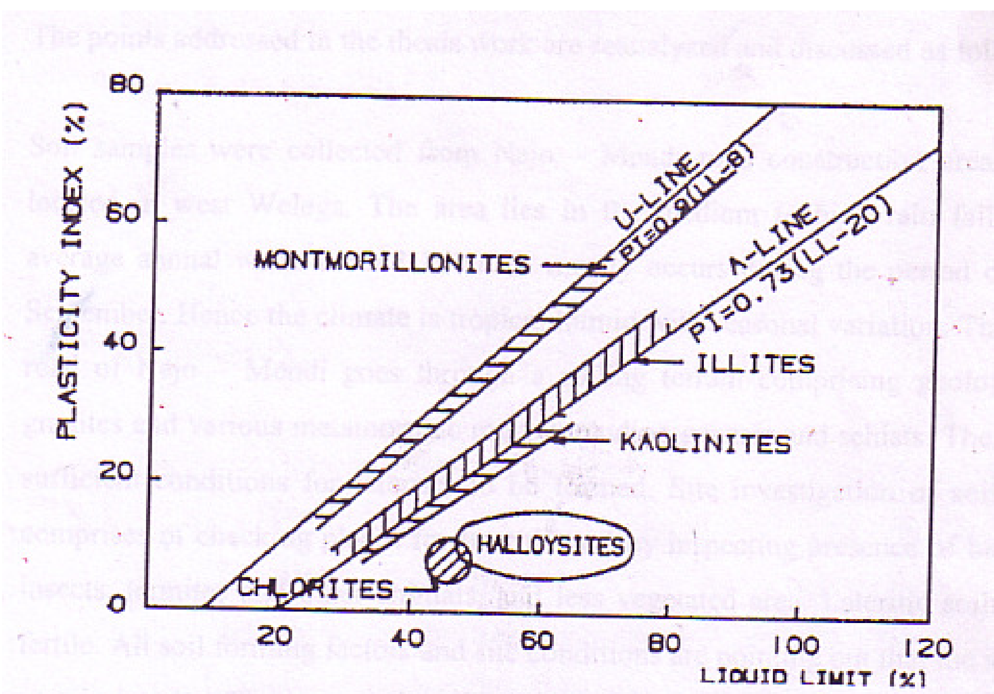


Fig 5-b Location of common clay minerals on Casagrande's plasticity chart (Zelalem, 2005)

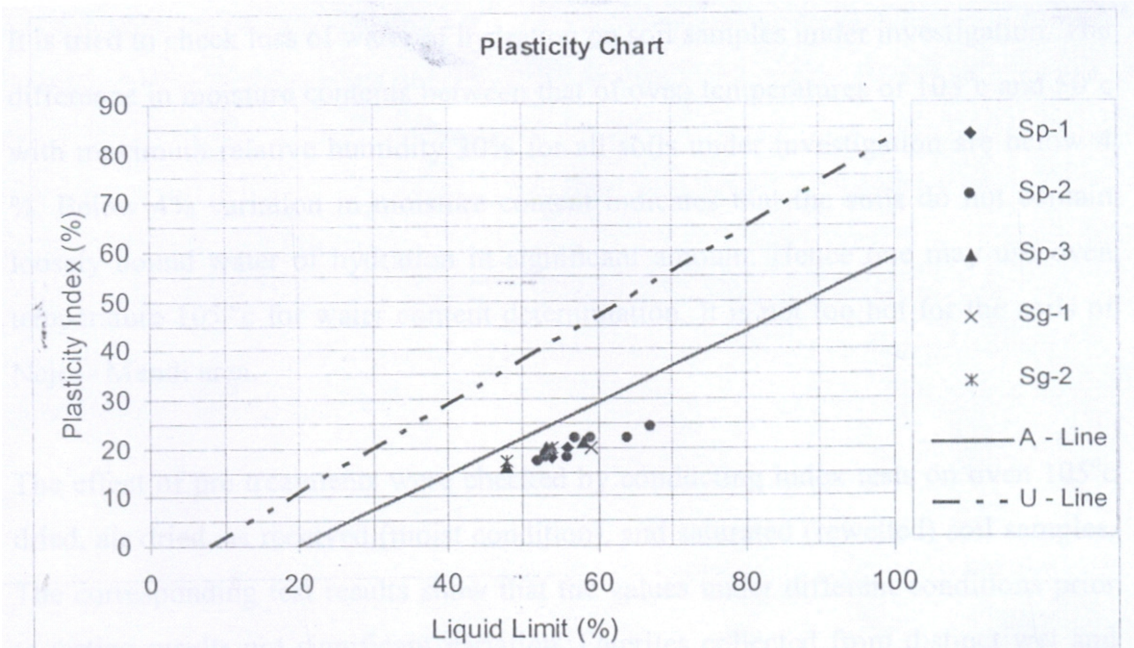


Fig 5-c Plasticity chart of Nejo-Mandii Soils (Zelalem, 2005)

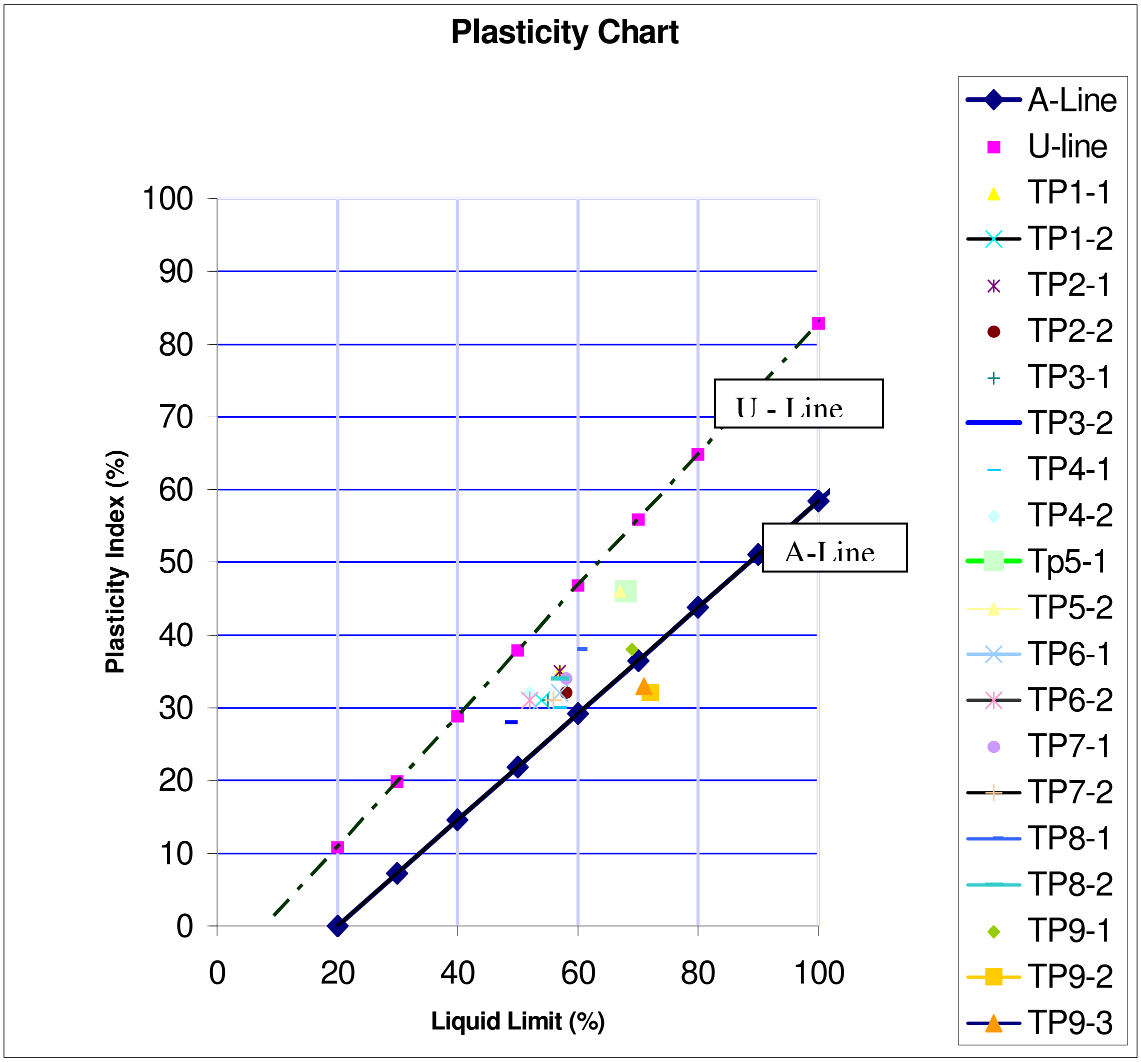


Fig 5-d Plasticity Chart for Asossa soils

5.2 Discussions

The soil samples were collected from southwest Ethiopia, Asossa Town. The area had the maximum annual rainfall of 1200mm occurring during June to September and temperature varying between 15 ^{o}C to 35 ^{o}C, which is warm. Hence, one can classify the climatic condition of Asossa to be Tropical warm humid with seasonal variations occurring. Asossa has a flat terrain with a geological formation of basalt. These conditions are the most favorable condition for the formation of lateritic soils except the flat terrain favors Black laterite formation. The test results added with the Geochemical tests done for Nejo-Mandi soils by (Zelalem, 2005) show that the soil of Asossa could be classified as laterite soil

.

Detailed investigations were done to determine the existence of 'Structural Water' that could be driven off the sample during oven drying the sample at 105^{o}c The difference in the natural moisture content determined at the oven of 105^{o}c and the air-dried sample showed that there is structural water, i.e., the difference is greater than 4%. Hence one should not use the oven temperature of 105^{o}c, instead air-drying or equivalently oven-dried at 50 ^{o}C and relative humidity (RH) of 30% could be used.

The disaggregating effect of the soil particles during manipulation was also investigated by taking the liquid limit for the soil at different mixing times for the as received sample, 5 minutes and 25minutes. The difference of >5%implies that the manipulation has a disaggregation effect on the soil sample. The test result showed that the soil has concretions, which are sensitive to test manipulation. This is to mean that applying too much energy to the sample destroys the structure of the soil and the resulting soil has different index properties from the soil tested at a minimum mixing time. Hence one has to conduct Atterberg Limit tests and compaction tests with a fresh sample for each point on the curve with a minimized mixing time of 5 minutes.

Investigations was carried to see the effect of drying and wetting on Atterberg Limits of soils prepared from natural moisture content with those of oven dried soil rewetted to the point of test. The results are shown on Table 4-6 for all soils. From these test results for the as received and oven dry condition, one can see that there is a large discrepancy between the two. Accordingly, this indicates that the laboratory results of the Atterberg Limit values for Asossa soil has to necessarily be simulated with the field conditions with respect to wetting and drying prier to the test.

From the soil classification, almost all soils are clay-sized particles with the highest probability of changing to a coarse graded fraction over 2m depths. All the soils except the sample TP9 lie above the A-line which is characterized by a red inorganic clay and having Montimorillonitic influence according to the pervious tests done on other lateritic soils of Africa. This is in fact manifested in the behavior of the soil under investigation. However, it is clear that, Classification of residual tropical soil using the USCS method alone does not tell us exactly the mineralogical composition, hence, mineralogical tests or field situations have to simulate with this method of classifying (Blight, 1997).

Lateritic soils are known to be inactive or normal with an activity number of <1.25, this is the fact that the cementing agent (Sesquioxide) of the lateritic soil overcomes the activity effect of the soil resulting in a strong bondage. For the soil under investigation, the activity test results for all fine-grained soils show the value of less than 1.25, which is the normal fact of lateritic soils. Hence, one can see that the soil of Asossa is inactive or normal. This could also be shown by the free swell, that is, the free swell test result shows that the soil under investigation has relatively low degree of expansion (<50%)

The in-situ Specific Gravity of the soil under investigation is between 2.46 to 2.94, with the maximum value higher than the specific gravity of temperate soils, 2.65-2.70. The higher value of specific gravity is the result of existence of iron oxide. The Specific Gravity of coarse-grained soil is greater than that of fine-grained soil due to the high concentration of iron oxide in the gravel fraction. This is also true that TP9 samples got higher Specific Gravity, as they were the coarser of the samples collected.

6. Conclusions and Recommendations

6.1 Conclusion

Based on the investigations made on the soils of Asossa Town, the following conclusions are drown:

1. Based on the soil forming factors, actual field condition and the similarity observed between Nejo-Mandi areas, the soil of Asossa is laterite having a high concentration of iron and Aluminium oxides (sesquioxide).

2. The test results showed that, Asossa soil is sensitive to the temperature applied prior to testing. The soil also contains considerable structural water that could be driven off irreversibly when using oven drying of $105^o{}_c$ (Hydrated tropical soil). Hence air-drying or oven drying of $50^o{}_c$ with relative humidity (RH) of 30% should be used for every test during sample preparation.

3. It is observed that Asossa soil is sensitive to test procedures and the energy applied to the soil during laboratory testing, hence disaggregation results in the test value different from the in-situ condition. Accordingly, the minimum mixing time, usually of 5minutes and fresh soil has to be used for each point on the Atterberg Limit.

4. The Activity test also showed that, the soil under investigation has activity number of less than 1.25 and analogously the free swell tests give an average free swell of less than 50%(Low Swell Potential). Therefore, Asossa soil is inactive as compared to the swelling characteristic of fine grained soil.

5. From the gradation charts and the soil classifications made, Asossa soil is a fine-grained soil with characteristics some how similar to Ferrisol soils. From the mode of formation and comparisons of gradation charts, Asossa soil could be grouped as hydrated forms of Ferrisol soil. According to the (Anthony Young, 1976) classification of laterites, the soil of Asossa could be classified as Soft Laterite.

6. The test result showed that Asossa soil lies above the A-line for all soils except the samples TP9.This is the due to the fact that, the clay fractions are higher after the manipulation of the soil in the laboratory due to the sensitivity of the soil.

6.2 Recommendations

1. In this study Geochemical test results are correlated with the soil forming factors and the seasonal variations existing with that of Najo-Mandi area and the actual field situations and laboratory investigation, however, one has to conduct Geochemical tests exclusively for Asossa soil in order to determine the extent of laterization.

2. The samples were collected from 675km from the laboratory. Moreover, the sample was found sensitive to the energy applied to it. Hence, fresh soil representing the actual field condition has to be further investigated for Asossa soil in order to determine the actual soil behaviors.

3. The maximum sampling depths of the soil under investigations were 3m for two soils and at 2m for the rest samples. Detailed investigations have to be made along more samples of profiles.

REFERENCES:

1. AASHTO, 2004, Standard specification for Testing materials and Methods of sampling and Testing.

2. Zelalem., 2005, Basic Engineering Properties of Lateritec Soils found in Nejo-Mandi Road Construction, a Thesis presented to a School of Graduate Studies

3. Alemauew, T., and Mesfin, L.(1999), Soil Mechanics. Faculty of technology Addis Ababa University, Addis Ababa.

4. ASCE, 1985, Geotechnical Engineering Division.
   Journal Vol. 111 Nos. 1-6.

5. ASTM, 2004, Special Procedures for Testing Soil and Rock for Civil Engineering Purpose
   .

6. Blight, G.E., (1997), Mechanics of Residual soils, A.A Balkema, the Netherlands

7. Bowles, J.E., (1978), Engineering Properties of Soils and their Measurement. McGraw Hill Book Company.

8. British Standards, 1990, Method of testing for Soils for Civil Engineering purpose.

9. Budhu, M., 2000, Soil mechanics and foundation. John Wily and Sons, U.S America.

10. ERA Design Manual, 2001. Addis Ababa, Ethiopia.

11. International Focus on Rural Roads Engineering (IFG), 2004, Design, construction and Performance. Laterite.
    Http/www.ifgworld.org/index.asp

12. K.R ARORA, Soil Mechanics and Foundation Engineering

13. Lambe, T.W., 1951, Soil testing for Engineers. John Wily and Sons, London.

14. LYON ASSOCIATIONS, INC. 1971, LATERITE AND LATERITIC SOILS AND OTHER PROBLEM SOILS OF AFRICA. Kumasi, Ghana.

15. LYON ASSOCIATIONS, INC,1971, USAGE MANUAL for Sampling and testing LATERITE AND LATERITIC SOILS and other Problem Soils of AFRICA.BUILDING AND ROAD RESEARCH INSTITUTE, Kumasi, Ghana.

16. Rites and UNICONE, 2002, Designing Review study Report for Soils and materials, Ethiopia.

17. Samuel, T., 1989, Investigation in to some of the Engineering Properties of Addis Ababa Red Clay soils, a Thesis presented to school of Graduate studies, Addis Ababa University

18. TCDE, 2000, Ethiopian Transport and Construction Design manual

19. The Occurrence, Distribution, Classification and Management of laterite and lateritic soils. http/www.bondy.ird.fr/pleins_texts/chaiers/ptp/1423.PDF

.

.

Appendix – A

Comparison of AASHTO versus ASTM standards

The Table for the Appendix shows the summary of similarity between ASTM and AASHTO standards. Except for the method of preparations for the Atterberg limits, all the tests were conducted using the ASTM standards. Writing AASHTO equivalent under remark column differentiates equivalent test procedures for both methods.

Table A-1. ASTM versus AASHTO standards

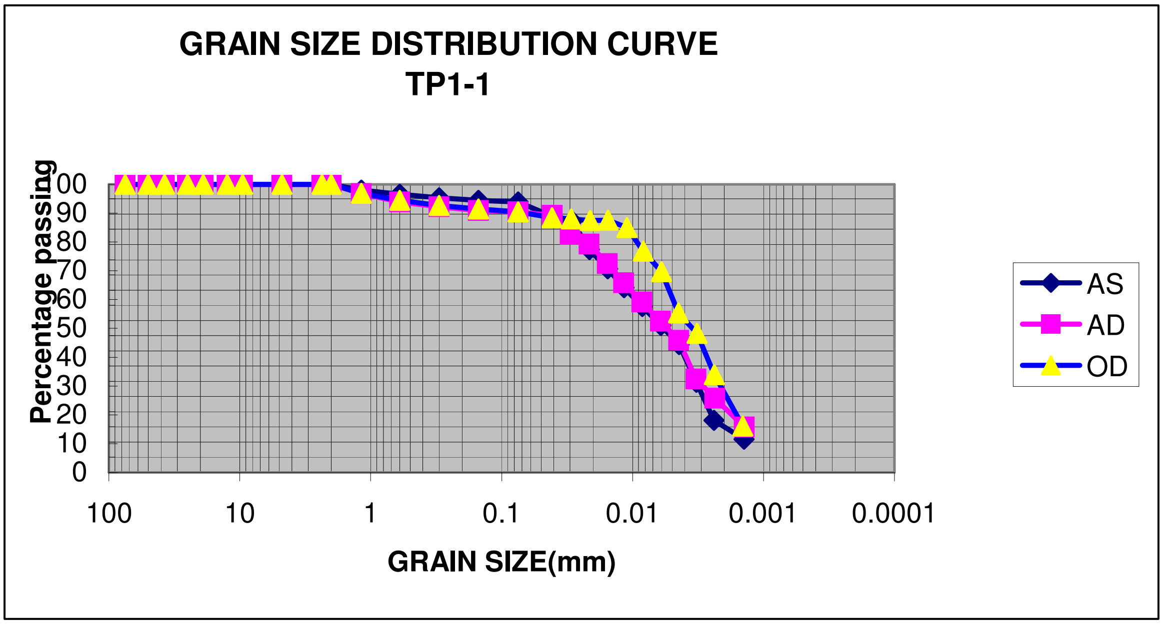
No	ASTM Designation	Test description	AASHTO Designation	Remarks
1	D421-85	Dry preparation of disturbed sample	T87-86	
2	D422-63	Particle size analysis	T88-00	
3	D4318-00	Liquid limit	T89-02	
4	D4318-00	Plastic limit, Plasticity index	T90-00	
5	D2216-98	Laboratory determination of moisture content	T256-93	
6	D854-00	Specific gravity of soils	T100-03	ASTM Equivalent
7	D2217-85	Wet preparation of the sample	T146-96	

Appendix-B

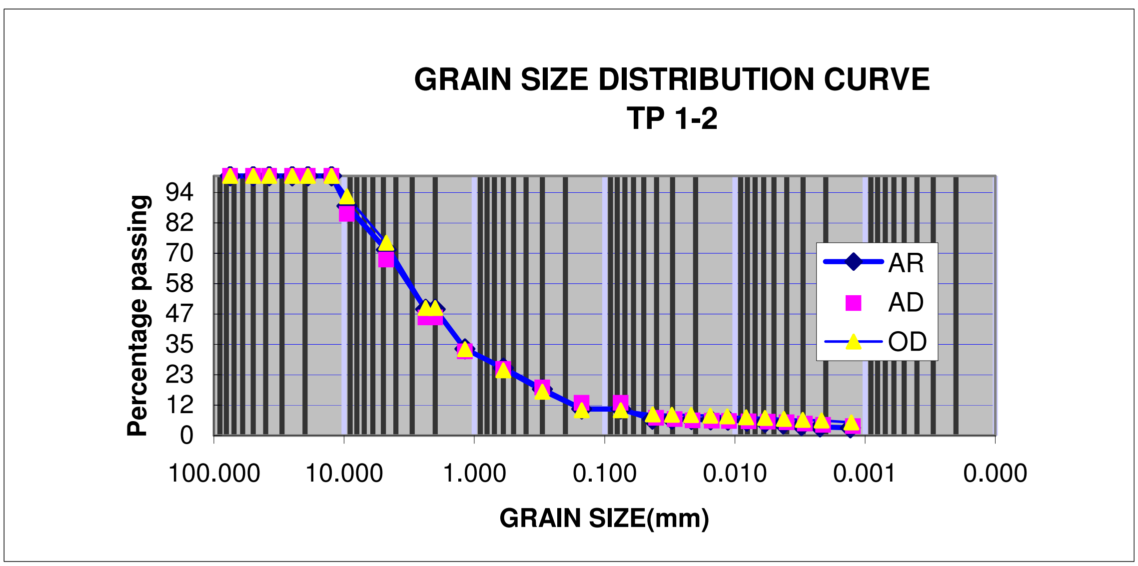
Grain size distribution curves under different testing conditions

The graphs in this appendix show the grain size distribution curves for various soils and test conditions. FigsB-1a, b, c… was plotted for the soil samples treated at different testing temperature. Grain size distribution curves for soils collected from different locations are shown on Figs B-2. Profile consideration is also shown in the FigsB-3. The range of grain size distribution curve is finally shown as FigB-3.

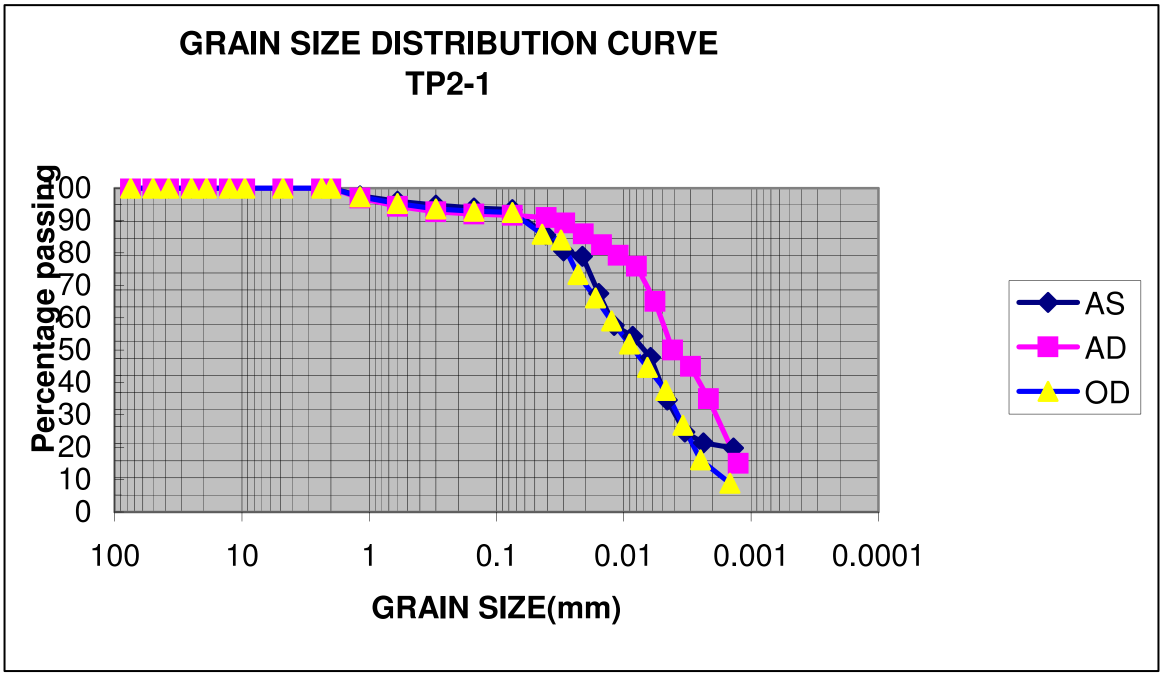
Grain size distribution curves under different pretreatment conditions for some soils are shown in the Fig B-1a, b, c, d, e, f, g, h, I, j shown below;



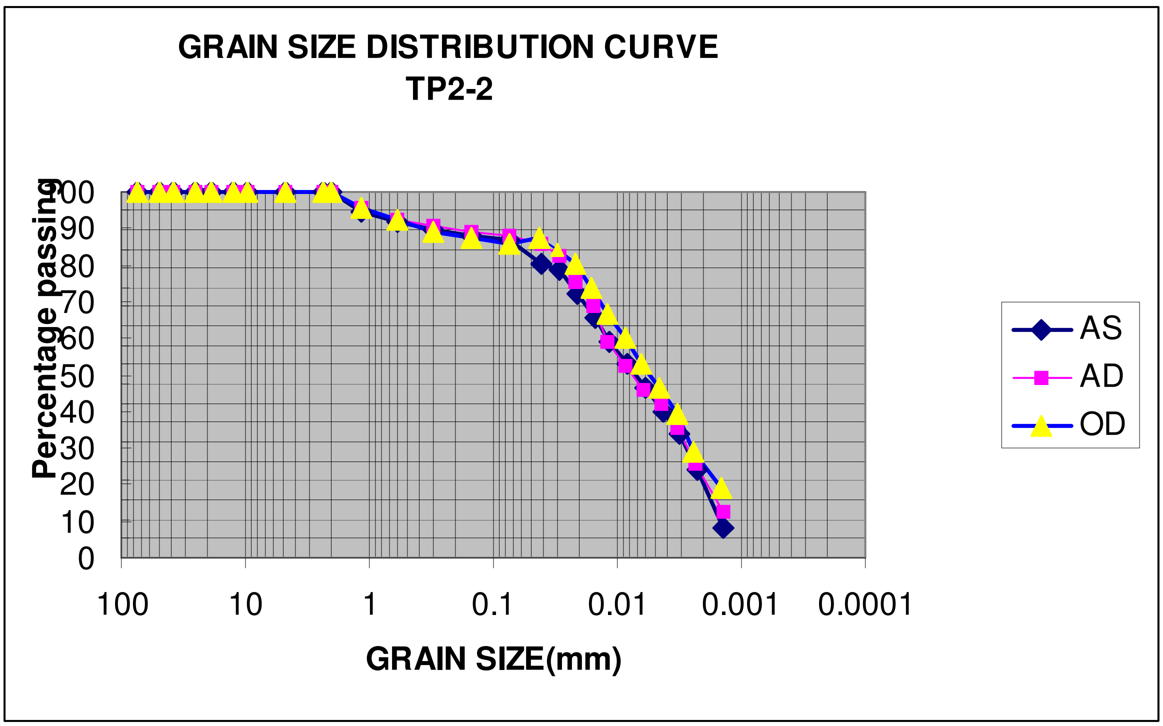
FigB-1a Grain size distribution at different conditions



FigB-1bGrain size distribution



FigB-1c Continued



FigB-1d

-----Continued

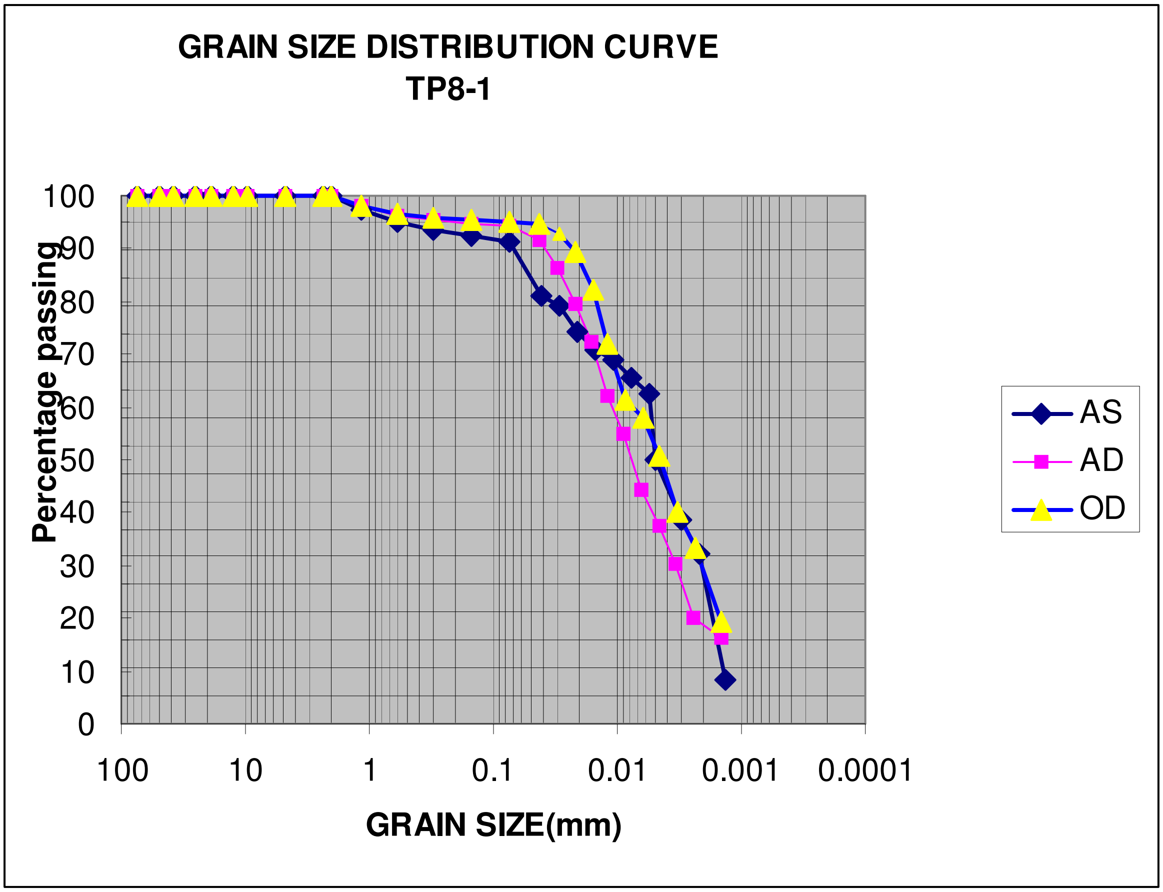


Fig4-1e

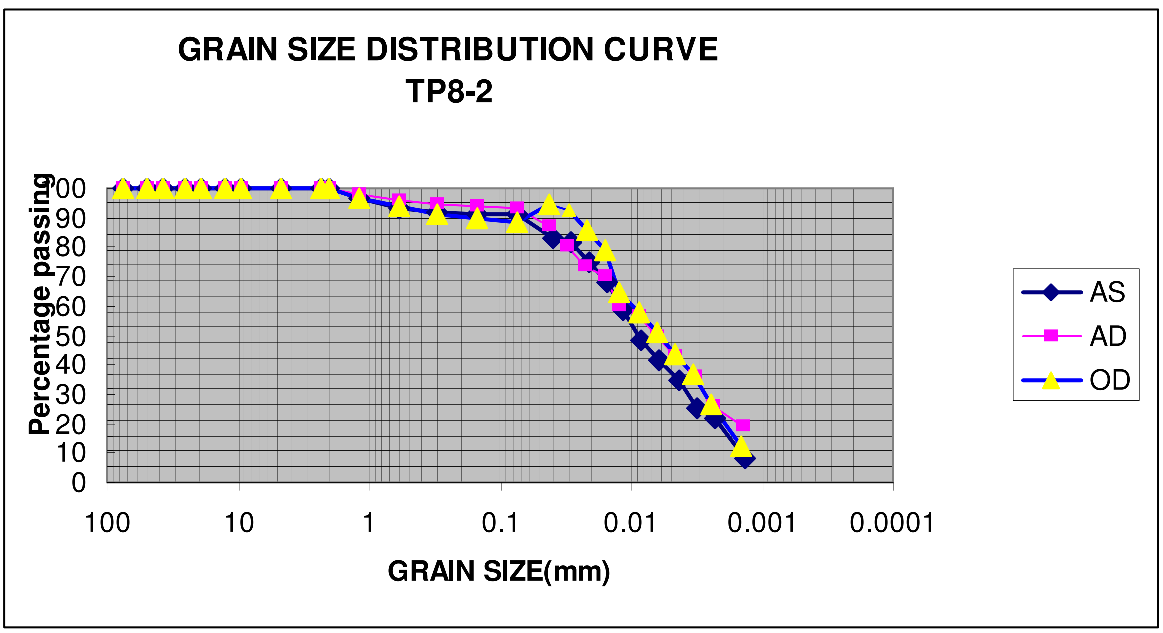


Fig4-1f

--------Continued

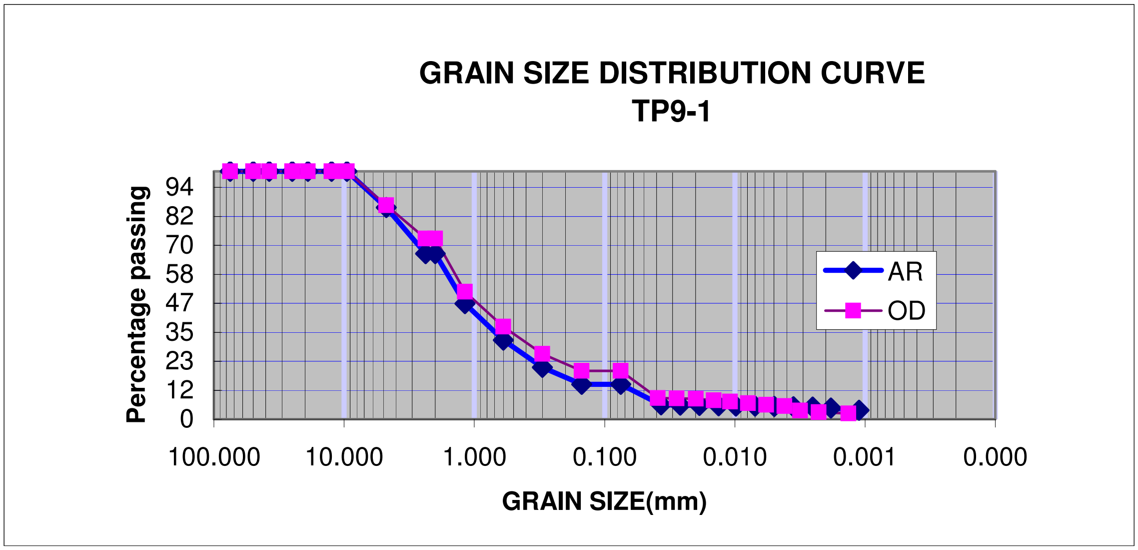


Fig4-1g

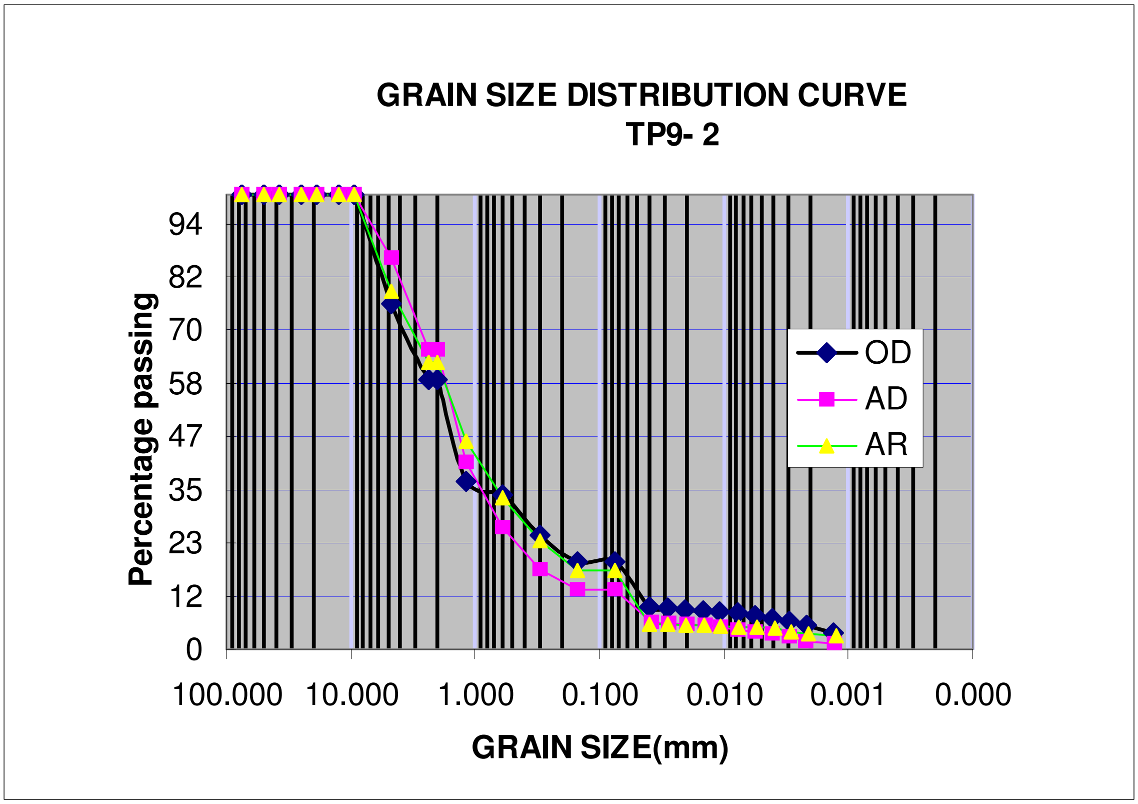
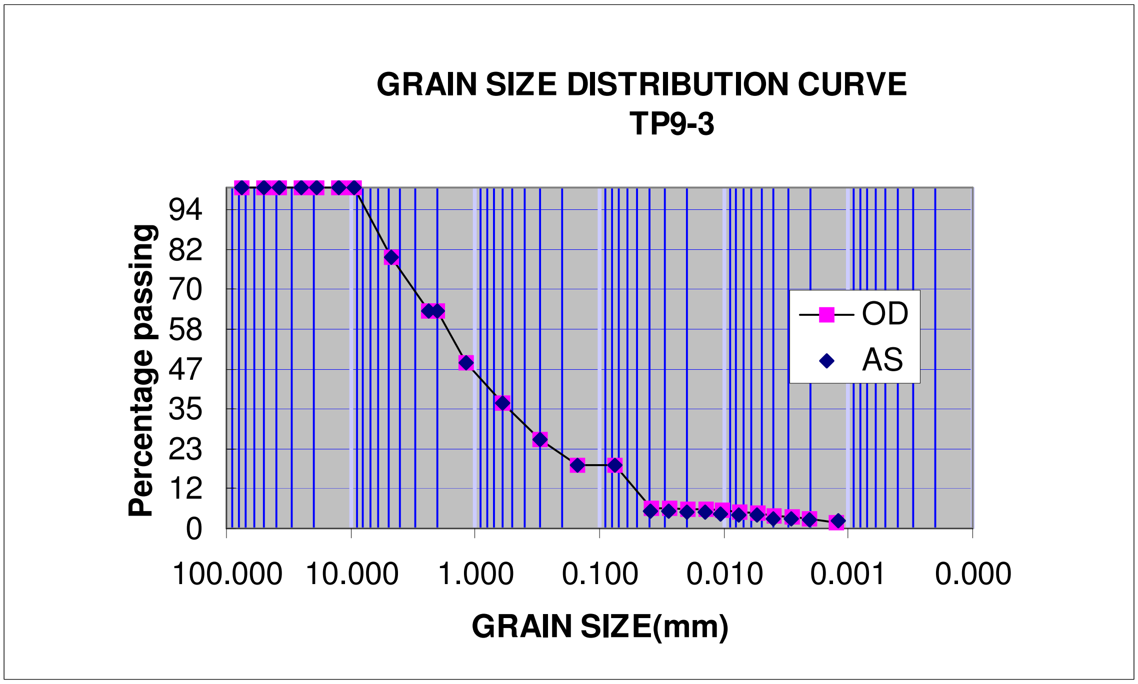


Fig4-1h

----------Continued



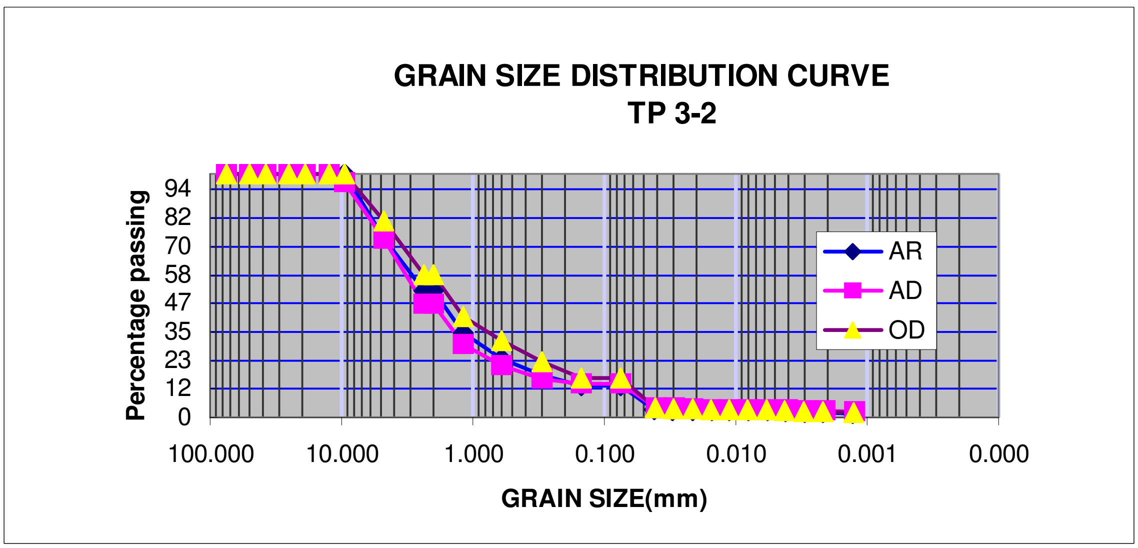
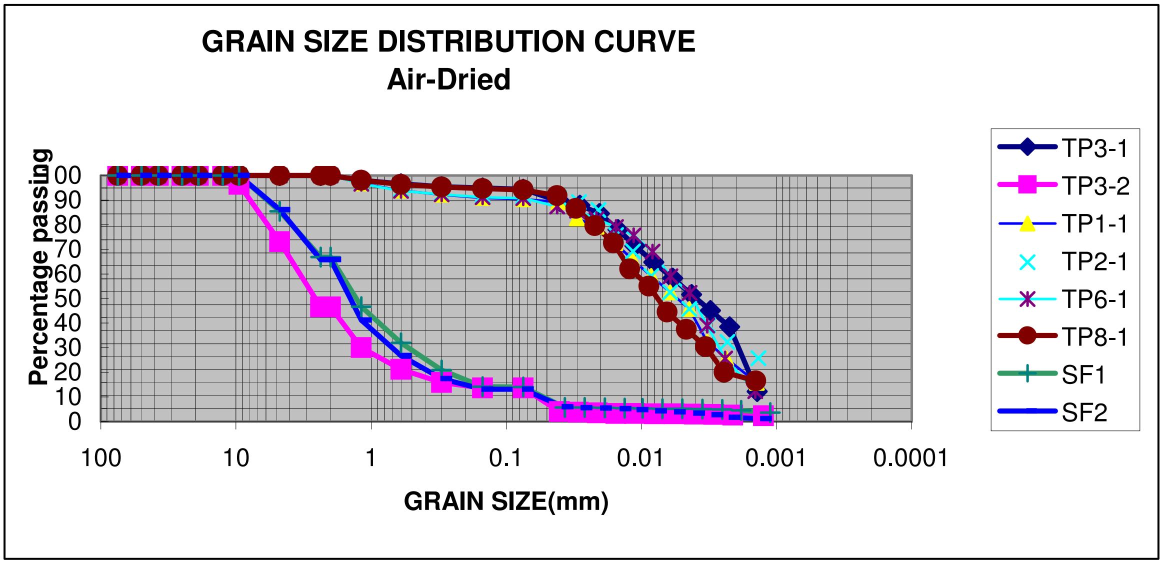


Fig4-1j

Grain size distribution curves for some soils collected from different places, and different test conditions could be shown, but for air-dried condition only is presented for some soils because the change was almost the same with varied temperatures.



Figs B-2.Grain size distribution curves for different soils.

Range of grain size distribution curves for the soil under investigation showing the maximum and minimum range of gradation charts

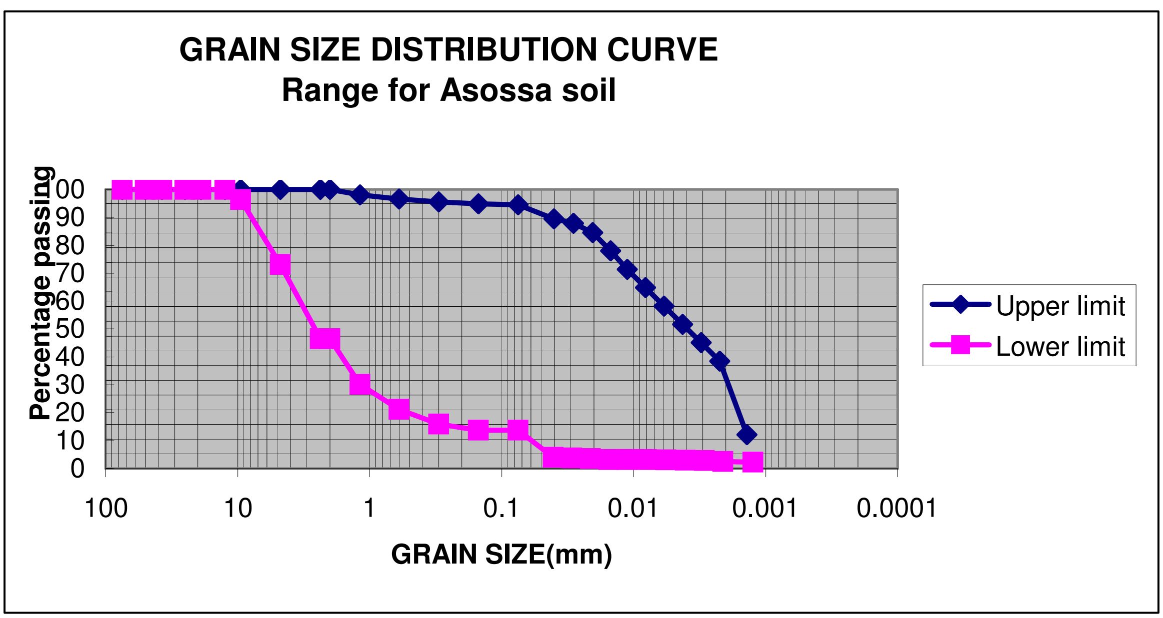


Fig B-3. Range of grain size distribution.