ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF ENGINEERING

Index Properties of Typical Tropical Residual Soils of Adama Town (The Case of Adama Science & Technology University, Research Park Project Area)

A Thesis Submitted to a School of Engineering of Adama Science & Technology University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Geotechnical Engineering

BY

Esmael Mustefa

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Declaration

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr.Yoseph Birru 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.

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Symbols and Abbreviations

Designation		Units
ASTU	Adama Science & Technology University	---
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	

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Abstract

Residual tropical soils can have characteristics that are quite distinctively different from those of transported soils, i.e., the conventional concept of soil mechanics is not applicable to many residual soils as it consists of relict of parent rocks and weathered mineral matter that break down and become progressively finer under continuous manipulation.

In practice, since the determination of all the engineering properties of soils is expensive, often index properties are simpler and cheaper to characterize engineering properties of a given soil.

In this study typical index properties of residual soils have been studied in detail as per literature recommendations considering the case study of Adama Science & Technology University, Research Park Project area.

The specimens were tested at different sample preparation conditions prior to conducting the laboratory test and consequently resulted in different end values. The index properties studied includes; Particle Size Analysis, Atterberg Limits, Free Swell Index and Specific Gravity in which samples were conditioned for three different test temperatures (at received moisture, air-dried and oven dried at a temperature of 105^{o}C).

Moisture content determination using oven temperature of l05°C and air dry conditions were also carried out on the soil samples to investigate presence of loosely bound water of hydration. It was found that the soil samples contain considerable amount of water of hydration or structural water which leads to irreversible changes on drying. Sample manipulation is also found to change the results of the Atterberg limit values by affecting the bond between soil structures.

From the soil classification, almost all soils are clayey sands with the highest probability of changing to a coarse graded fraction over 2.5m depths.

The laboratory results of the Atterberg limit values for the soil has to necessarily be simulated with the field conditions with respect to wetting and drying prior to the test.

The free swell test result shows that the soil under investigation has relatively low degree of expansion (<50%), whereas the in-situ specific gravity of the soil under investigation is between 2.33 to 2.98.

Therefore, the appropriate test procedures for tropical soils are strongly recommended for research and practical engineering application where such soils are likely to exist.

1. Introduction

1.1 General

Adama, which is located in Eastern part of Ethiopia is covered with clayey sand, silty sand and other soil types. Particularly, the Research Park Project area bounded by the corner coordinate points with easting and northing of P1 (532428.9892, 946059.1225), P2 (532428.312, 945842.0817), P3 (532267.9291, 945842.118) and P4 (532268.6887, 946059.2904), which is located inside Adama Science & Technology University, has tropical residual soils such as clayey sand and poorly graded sandy soils with yellow, brown and dark in color.

Deep, strongly leached red, brown, and yellow profiles are manifestation of the effects of sever chemical weathering process (Morin & Todor, 1975). The properties of lateritic soils are influenced by climate, geology and the degree of weathering or laterization (Gidigasu, 1972; Gidigasu, 1976).

Hence, with the above analogy the soil of Adama, the case of ASTU Research Park Project area is expected to be lateritic. 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. It has been found that the geotechnical properties of these soils in different tropical countries are also different and that lateritic soils formed on the same parent rock in the same tropical country, but under different climatic conditions, have different geotechnical properties (Gidigasu, 1972; Lin, 1986).

As a result of more extreme weathering conditions, the chemical processes may proceed more extensively and rapidly to produce distinctive forms of residual soils.
The consequences of tropical weathering have been of overriding significance in the formation of the soils in most parts of Africa including Ethiopia (Lyon Associates Institute Inc., 1971). Chemical weathering is especially effective in the presence of water/high rainfall (due to its reactivity) and high temperature (which influences the rates of chemical reaction by accelerating them). Moreover, it is favored by warm humid climates by the presence of vegetation, and by gentle slope, Dresai, (1985).

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 such uses, either because of inadequate strength, or excessive change of volume with varying water content, or because of loss of strength on wetting. Though, 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 disaggregation 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, Fekede, (2007).

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.

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 Adama, ASTU Research Park Project area soils.

1.2 Problem Statement

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

Characterizing changes in the engineering properties of a weathered residual soil has been a concern of civil engineers in relation to the stability of slopes, underground space construction and tunneling. Most previous studies such as Zelalem (2005), have emphasized the geological or engineering characteristics of residual soils from different formations in Ethiopia. However, these studies have not explicitly examined the relationship between degree of laterization and index properties of residual soils.

In this thesis work, it has been tried to investigate the effect of sample pre-treatment, method of mixing and mixing time; investigation of the limitation on the concept of conventional soil mechanics; determination of index properties as well as recommendation of appropriate test procedures for Adama, ASTU Research Park Project area soils.

It is well-known that oven-drying and even air-drying, affects the properties of soils, although this effect is usually small for transported soils. Because of their origin, by slow in situ-decomposition in a largely anaerobic environment, residual soils are particularly prone to hangs in properties caused by drying and exposure to air. Drying can cause partial or complete dehydration of the clay minerals and can change them and their properties irreversibly. Even air-dying at ambient temperature can cause changes that cannot be reversed by re-wetting, even if re-wetted soil is allowed to mature for long periods.

1.3 Objective of the Study

A. General Objectives

The general objectives of this research are:

a. To investigate the effect of sample pre-treatment and method of mixing on index properties of typical residual soils in Adama town.
b. To demonstrate some of the limitations of the concepts of conventional soil mechanics as applied to tropical residual soils.

B. Specific Objectives

The specific objectives of this research are:

a. Determine the Atterberg limits, Particle size analysis, Specific gravity and Free swell of the soil.
b. To determine the degree of laterization of the soil based on index properties and chemical tests.
c. To recommend appropriate test procedures for tropical soils with similar geological formation to that of the current study area.

1.4 Methodology Used

The different activities that will be carried out in this research work are classified into three phases: pre-field work, field work and post field work. Each of the three steps comprises different activities. The main activities in the pre-field work are literature review and field preparation. During the field work stage, visual identification of soils around the study area and soil sampling (disturbed), will be made. During post field work, laboratory test for collected samples will be conducted and some index properties will be determined. These results together with the visual identification and field test results will be interpreted and then thesis report preparation will be carried out.

i. <u>Pre-field work</u>

Pre-field work is a fundamental step before the field survey. At this stage, the available information about the study area will be compiled as follows:

- Review of literatures from different sources both published and unpublished will be used to get some priority information about the study area.

- Analysis of previous data on topographic, geographical, geologic maps and Geotechnical works if any.

ii. <u>Field work</u>

In the field work, the following data will be collected:

- Selection of representative test pit locations from the study area.
- Disturbed samples will be taken for determination of index properties.
- Photographs of important features of the site will be taken.
- Field visual identification of the soil in the area will be made.

iii. <u>Post Field Work</u>

Post field work is a Data processing and analysis stage.

- Laboratory analysis of samples taken from the field will be made.
- Interpretation of test results will be made.
- Thesis report preparation will be carried out.

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, and 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 $105^{o}c$

1.5 Limitation of the Study

The research is limited only to the index property tests taken from different building locations of Adama, ASTU Research Park Project area. Due to the financial constraints, it was not possible to conduct chemical test for the soil under this investigation and hence degree of laterization could not be determined.

Besides, samples were taken up to a depth of 2.5m depth (shallow depth) though for such big Project detailed investigation should have been made with deeper depth along more samples.

1.6 Organization of the Thesis

The thesis consists six chapters. The first chapter is the introductory part which consists of introduction, problem statement, objective, methodology used, limitation of the study and organization of the thesis. The second chapter covers the literature review on residual soils, residual soils and laterization, sample preparation for tropical soils, a review of literatures on tropical black clays. The third chapter consists of the sampling area descriptions such as general information, land cover and land use, Geology, precipitation and temperature conditions and soil characteristics of Adama. The fourth chapter covers in-situ properties descriptions, laboratory tests and their results and soil classification according to AASHTO and USCS. The fifth chapter consists of comparison of the test results of laterites and lateritic soils of Africa and Adama, ASTU Research Park Project area soil. The conclusions and recommendations drawn from this research are presented in the sixth chapter. Appendix are presented at the end of this thesis report.

2. Literature Review on 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 been generally 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, (Lyon, 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).

2.1 Origin, General Characteristics and Formation of Residual Soils

Soil materials are a vital element in all civil engineering designs. Therefore, an understanding of the origin, characteristics and formation of residual soils is a basic requirement for the field and laboratory personnel who work with them. This part overviews the origin, characteristics and formation of residual soils.

2.1.1 Definitions of Residual Soils

There is no universally accepted definition of residual soil; its definition varies from country to country, different workers provide different definitions. Some of these are listed below:

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

Blight (1985) gave the definition of residual soil in South Africa as all material of a soil consistency that is located below the local ancient erosion surface i.e. below the pebble marker. The exceptions are the extensive deposits of ancient windblown desert sands with some cohesion. Materials of this type are also considered to be residual soils. Soil reworked in situ by termites is also strictly, residual and not transported material.

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

2.1.2 Origin of Residual Soils

Residual soils originated with the formation of the climatic systems and are part of the geological cycle, which has been in existence for hundreds of millions of years of geological time, as they formed from geological material over this time.

Igneous activity leading to the formation of igneous rocks provides the beginning of the geological cycle. Subjection of igneous rocks to sedimentary and metamorphic processes resulted in the formation of sedimentary and metamorphic rocks. Exposure of all these three rock types at the interface with the atmosphere to exogenic processes resulted in the formation of a mantle of in situ soils termed residual soils as a result of the gradual breakdown of the rocks.

2.1.3 General Characteristics of Residual Soils

Residual soils have distinct characteristics that are ubiquitous. These prominent features may be summarized as follows.

Thickness

Residual soils form a mantle of significant thickness. Thickness of such soils varies from place to place depending upon the factors of formation like climate and the extent to which the soil forming processes have advanced. The formation of deep residual soils may be on account of very rapid rate of their formation or due to the lengthy persistence of the soil forming processes without subsequent removal by erosion.

Horizons

Residual soils generally show no formational stratification but display identifiable in situ differentiated horizontal horizons. This is due to the process of leaching as water for instance rainwater moving through soils dissolves minerals, transports the solutes and precipitates these further down the soil profile resulting in the leached and precipitation levels forming visible horizons.

Composition

The composition of residual soils is initially defined principally by the nature of the parent rocks. Residual soils are derived from various rock types like granites, gabbro’s, basalts, limestone and others. In the case of old residual soils, however, the advanced chemical decay, alteration and leaching may render the recognition of the parent rock materials very difficult or they may be obliterated.

According to Blight, (1997), lateritic 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.

2.1.4 Mineralogical Composition Related to Weathering

The distinctive feature of 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 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.

2.1.5 Formation, Existence and Profile of Weathering

2.1.5.1 Formation and Existence of Tropical Residual Soils

The development of residual soils depends on the interaction of three natural features that are intrinsic/state variables. These variables are the: chemical composition of the rock, environmental conditions and time. These give rise to natural factors that control the formation of residual soils. Consequently the character or qualities they assume express themselves through the complex natural processes involved in the formation of soils.

2.1.5.2 State Factors for Residual Soil Formation

The state factors or variables are climate, parent materials, topography, biological activity and time. These are briefly reviewed below.

- Climate

Climate is perhaps the most important factor in soil formation. It governs: the amount of precipitation and temperature available and the rate of rock weathering.

As time passes, climate tends to play a more predominant role in soil formation and alteration. Soils tend to show a strong geographical correlation with climate, especially at the global scale. This is due to the different climatic regions developing residual soils with distinctly different characteristics as a consequence of their different temperature and precipitation patterns.

- Parent materials

The formation of soils commences by chemical alteration and physical disintegration of rocks at their exposed surface. These rocks are termed the parent material. The parent material has the greatest influence on the incipient soils in the early stages of soil formation and in the drier regions, Birkeland, (1984) but lessens over time as other soil forming factors become more active. There are a variety of parent materials as there are a variety of rock types with different mineral phases and chemical composition.

- Time

Time is a critical factor in soil formation as it determines the degree to which other factors either undergoes change or is able to express them. The thickness of the soil layer and the chemical changes that have taken place depend upon, amongst others, on the time the soil forming processes have been occurring.

- Topography

Topography is important in soil formation as it exercises a significant control on surface processes like erosion and drainage. Different topographic terrains with different landscapes uniquely affect soil development.

- Biological activity

Plants and animals play important roles in soil formation. Their primary contribution is to provide organic matter that is incorporated with the weathered parent material especially at the upper part of the regolith.

2.1.5.3 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 vegetation. Soils formed under similar weathering profiles will have similar characteristics.

Hence, a convenient means for regional description of soil properties for engineering purposes is the determination of the engineering characteristics of the various members or zones in typical profiles of weathering. Such investigations constitute a framework by means of which information and further experience can be coordinated, Lyon, (1971).

2.1.6 Classification of Residual Soils

2.1.6.1 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 cannot be adequately described using existing systems based on classification of transported soils in temperate climates.

c) Conventional soil classification systems focus primarily on the properties of the soil in its remolded state; this is often misleading with residual soils as their properties are likely to be most strongly influenced by in situ structural characteristics in-herited from the original rock mass or developed as a consequence of weathering.

Wesley's Classification Scheme for Residual Soils

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).

The system is based on a grouping framework designed to enable engineers to place any particular residual soil into a specific category on the basis of common engineering properties.

This scheme, which is set out here in its latest published form, Wesley, (2010), is not intended to provide an all-embracing method for the detailed systematic description or logging of residual soils in the field, or in the laboratory. Neither is it intended as a replacement for any other particular method of classification such as the Unified Soil Classification System.

2.1.6.2 The Proposed Grouping

The first step in grouping of residual soils is to divide them into groups on the basis of mineralogical composition alone without reference to their undisturbed state, Blight, (1997). These groups are

I. **Group A:** Soils without a strong mineralogical influence, 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 or 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 concretion. 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) and 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 development. They have similar profiles to ferallitic soils, but with few weatherable minerals remaining.The entire clay fraction comprises Kaolinite and amorphous oxides of iron and aluminum. These are developed at deeper levels due to the surface erosion, and occur in regions of annual average rainfall of 1250-2750mm. 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 fragile 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 and 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.

2.1.7 Regional Setting

Lateritic soils are believed to correspond 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 outside the tropics, Zelalem, (2005).

2.2 Residual Soil and Laterization

Depending up on the extent of laterization, tropical residual 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 subtropical 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.

2.2.1 Lateritic Soils

These are residual soils with a silicon dioxide (Silica) to sesquioxide ratio of between 1.33 and 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 or absence of concretions. 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 Laterization: Formation of Laterite and Lateritic soils

Residually formed soils are formed in different places however, a distinct type of soil called laterite and lateritic soils having its own engineering characteristics and importance develop in a certain favorable circumstances. Commonly in hot and humid tropically regions with an annual rainfall range between 750mm to 3000mm and abundantly in areas with significant dry seasons, Huat Bujang Sew& Ali, (2004). These soils formed are due to extreme weathering condition and when the chemical processes proceeded more extensively and rapidly. Which are extremely leached soils, and are examples of such forms of residual soils. In humid tropical climates when intense weathering involving leaching occurs, it leaves behind a soil rich in Iron and Aluminum oxides giving the soil a deep red color called laterites. Soils under these classifications are characterized by forming hard, impermeable and often irreversible pans when dried, Blight, (1997).

2.2.2.1 Laterization

It is a process of weathering of a parent material/mineral, which occurs under conditions favorable to tropical weathering and when the weathering processes may be so intense and may continue so long that even the clay minerals, which are hydrous aluminum silicate, are destroyed. In the continued weathering, the silica is leached and the remainder consists merrily of aluminum oxide such as gibbsite or of hydrous iron oxide such as limonite or goethite derived from the iron. Laterization process takes place in three stages, Umarany and Wiliams, (1990).

2.2.2.2 Laterization Indices

The degree of laterization of the soil samples can be evaluated based on several laterization indices/ratios. To measure the extent of laterization, different workers have defined a number of indices. One of the earlier attempts to define laterites was based on Silica: Sesquioxide molar ratios. The sesquioxide designated as R_2O_3 is the combination of aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). The chemical formula SiO_2 designates the silica. Laterization or desilicification results in a progressive change in the proportions of silica and sesquioxides present in the weathering material, which is in the silica sesquioxide ratio. Iron enrichment, alumina enrichment and desilicification can therefore be expressed by these ratios, which lower as the silica content of clay is reduced and iron and alumina are accumulated. Based on equation following, ratio k_r less than 1.33 have been considered as true laterites, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of non-lateritic tropically weathered soils.

$$k_r = \frac{SiO_2}{R_2O_3} = \frac{\mathrm{SiO_2}}{\mathrm{Al_2O_3 + Fe_2O_3}}$$

In other words, the degree of laterization is characterized by the ratio of Silica (SiO_2) to Sesquioxide ratio (S-S) as described above. 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.

2.3 Sample Preparations for Tropical Soils

The samples must be representative of an area for the purpose of generalization of the properties, for identification and use in engineering design. Generally obtaining representative soil samples is still a challenge since, by nature, soils type and their properties vary greatly both vertically and horizontally.

It is more difficult when dealing with tropical residual soils due to their nonhomogeneous and anisotropic condition, the soil fabric, bonding between particles, void ratio and moisture content of the soil must be preserved because these factors have a significant influence on their shear strength.

2.3.1 Effect of Pre-treatment

Effect of pre-treatment can cause irreversible changed on tropical residual soils as described in the following sections.

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 particle 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 concretions 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 prior 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°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°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°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 l05°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°C and 30% RH) if possible, the lower drying temperature of 50°C should be used to avoid the removing out of this water, Blight, (1997).

2.3.1.2 Effect of Mixing Method and Time on Atterberg Limits

In general, the greater the duration of mixing (i.e., the greater the energy applied to the soil prior 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 disaggregation 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. The soil should be immersed in water to form a slurry, which is then washed through a 425µm sieve until the water runs clear. The material passing the sieve should be collected and used for the Atterberg limit tests. The particles retained on the sieve should be dried and weighed. The percentage by dry mass passing the 425µm sieve should be calculated and recorded.

It is common practice in soil mechanics laboratories to use distilled water for adjusting the water content of soils. This is a practice that should be abandoned, as adding distilled water may affect the soil properties. Where the water table is at a shallow depth, a sample of the ground water should be obtained and stored in a sealed polyethylene or glass container. This water should be used for increasing the water content of the soil, if required.

In cases where the soil contains appreciable quantities of soluble salts, distilled water should definitely not be used as it is likely to cause a change in the properties of the soil. The soluble salt content of the soil is most conveniently assessed by measuring the conductivity of a soil paste at the liquid limit. If the conductivity exceeds 50 ms/m (ms=millisiemens), distilled water should not be used for mixing. In this case an equivalent “soil water’’ can be prepared by making up a 1.5:1 by mass mixture of distilled water and soil (about a 3:1 by volume mix of water to soil). After allowing the mixture to settle, the clear water is decanted and used for adjusting the water content of the soil.

3. Sampling Area Description

3.1 General Information

Adama is one of the largest and most populated town in Oromia National Regional State. It is located in the Misraq Shewa Zone of Oromia at $8^o33`35``$N - $8^o36`46``$ N latitude and $39^o11`57``$ E – $39^o$ 21`15`` E longitude. The altitude of the town is 1,712 m above mean sea level. Adama has a total area of about 13,000 hectares, which has been subdivided into 14 urban kebele (least administrative structure) administrations. All of the urban roads are almost asphalt & cobble stone roads. And the site location where samples were collected is from Adama Science & Technology University, Research Park Project area in Adama town, 99km from Addis Ababa.

3.2 Land Cover and Land Use

Adama Science & Technology University (ASTU) Research Park Project area is a gentle sloppy terrain with fertile land .The area is covered with grasses and bushes stretching up to 1m and 2m heights respectively. Most of the area has been used as a grazing material for fattening center and related activities.

3.3 Geology

Adama town is located between the base of escarpment to the west and the Main Ethiopian Rift (MER). Its physiographic condition is, therefore, mainly the result of volcano-tectonic activities that occurred in the past and also partly the result of the deposition of sediments, which are considered largely of fluvial and lacustrine origin. It is regarded as seismically active area with expected earthquake hazards having probability occurrence of 0.99 in every 100 years (NUPI, 1995). MER may be geographically subdivided into three sectors. These sectors are: Northern (location of Adama town), Central and Southern. The MER of northern sector includes 7 00' – 8 40' latitude to the north. In this range of latitude four successive periods of volcanic activity have been identified, Abu, (2005).

According to others studies, there are two main volcanic units in the northern part of the rift system, namely Nazret series and Wonji series. Nazret series is represented by ignimbrites, basaltic and rhyolitic lava flows, trachyte flows and ash flows.

The geological formation of each kebele of Adama is not identical in terms of time of formation and geological events throughout the area. For instant Kechema ridge represented by upper aphanitic basalt, middle pumice, ash deposits and lower intensely welded ignimbrite (light green) which has an absolute age of 1.7 million whereas Boku ridge is rhyolitic lava flows, obsidian interlayerings, fiamme ignimbrite, thin ash flow and pumice layers in some places, Abu, (2005). Besides, Adama town is Subdivided into 14 Kebele as shown in Fig 3.1.

The Geographical Map of Adama Town is shown on Fig 3-1 below (Abu, 2005).

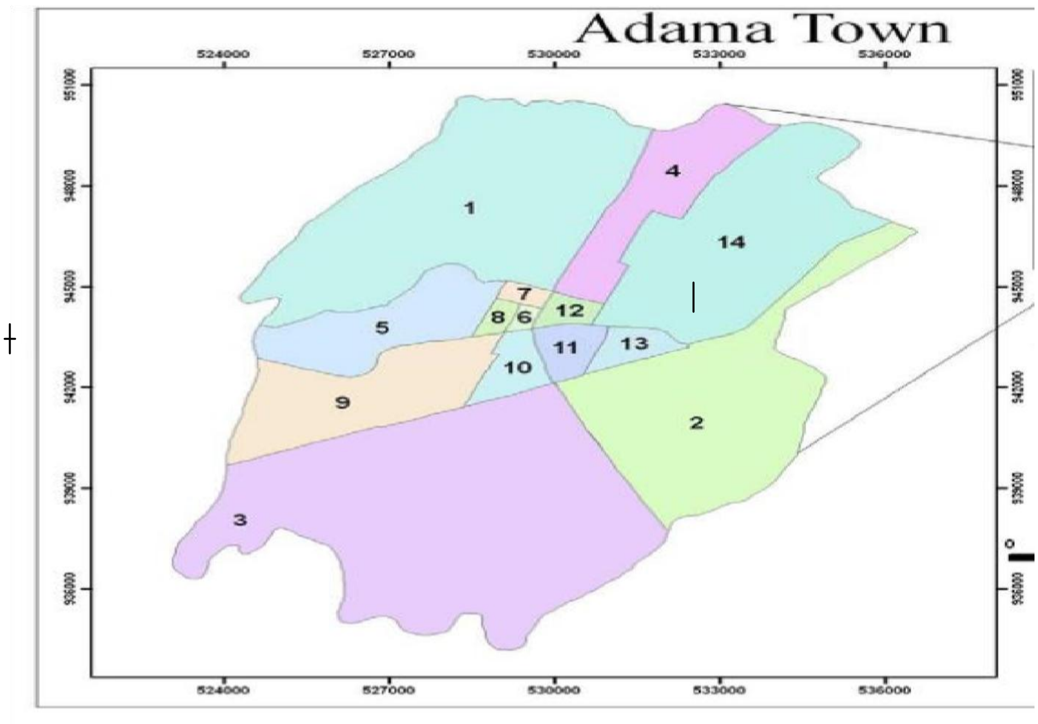

Fig. 3.1 Geographical Map of Adama Town

3.4 Precipitation and Temperature Conditions

Adama Master Plan (1995) reveals that the mean annual precipitation depth recorded for Adama is 82.25cm for the period of 1952 to 1991. The mean annual rainfall for the period of 1998 to 2006 was computed to be 72.7cm as indicated in Table B.1 in Appendix-B and also the monthly mean temperature maximum, minimum and average temperature of Adama town from 1998-2007 is shown in Table B.2 in Appendix–B. The figure is a little bit lower than the average total annual rainfall for most highland areas of Ethiopia, Alemneh, (1990), Messay, (2001).

3.5 Soil Characteristics of Adama

Soil formation in Adama town is mainly governed by the topographical feature of the area. Normally for the formation of the soils, physical and chemical agents are involved. Therefore the soil is formed by weathering process such as erosion by water and chemical reaction. The effects of weathering and transportation largely determine the basic nature of the soil (i.e. the size, shape, composition and distribution of the grains). The environment into which deposition takes place, and subsequent geological events that took place there, largely determine the state of the soil, (i.e. density, moisture content) and the structure or fabric of the soil (i.e. bedding, stratification, occurrence of joints or fissures, tree roots, voids, etc.). The soil in Adama is clayey sand and silty sand soils.

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), Fekede, (2007). Generally based on the soil forming conditions and the actual situation of the water table observed, one can assume the soil of Adama as lateritic soil and changes irreversibly up on drying.

4. In-situ Properties and Laboratory Test Results

4.1 In-situ Properties Description

In this thesis work in-situ properties such as Atterberg Limits, Particle Size analysis, Specific gravity and Free Swell of the soil are considered.

4.1.1 Sampling

The samples must be taken according to the type of test to be performed and the samples has to be properly sealed in glass or plastic containers, tins or plastic bags in order to avoid moisture loss.

4.1.1.1 Criteria of Good Quality Samples

The 'Good Quality Samples' or 'Perfect Samples' is defined by Ladd & Lambe (1963) as sample which has not been disturbed by boring, sampling and trimming but has experienced stress released. Sampling of residual soil needs special care in which usually behaves differently from other conventional soils particularly in relation to the properties and structure.

4.1.1.2 Purpose of Sampling

As far as residual soils are concerned, the disturbance of mechanical force can alter the structure and soil fabric. For the purpose of sampling which involves remolding soil or changing of moisture condition from the field condition, there is no need to preserve the samples in an undisturbed state.

However, the need for disturbed samples is for gradation analysis, classification, determination of Atterberg Limits, Free Swell and Specific Gravity tests.

4.1.1.3 Description and Location of Samples Taken

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

Besides personnel capabilities, the laboratory and testing equipment must also be capable of produce good quality results. It is important to note that some of conventional testing methods might not reliable for tropical residual soils which may need some calibration and special tools.

The soil specimens for this Thesis work were collected from Adama, ASTU Research Park Project area. Prior to sampling, visual site investigations were made to consider the different soil types and to sample evenly in the Project area from each building typology. Accordingly ten test pits were chosen. Disturbed samples were collected for this work, weighing about 6,600kg.

Table 4.1 Sample Depth and Designation used for ASTU Soil Samples

Serial No	Sampling Depth in meter	Designation	Sample Location	Visual Color Observed
1	0.5 – 1.5	TP1 – 1	TP 1	Dark
2	1.5 – 2.5	TP1– 2		
3	0.5-1.5	TP2 – 1	TP 2	Light Brown
4	1.5 – 2.5	TP2 – 2		
5	0.5 – 1.5	TP3– 1	TP 3	Dark to Brown
6	1.5 – 2.5	TP3 – 2		
7	0.5 – 1.5	TP4– 1	TP 4	Brown
8	1.5 – 2 .5	TP4 – 2		
9	0.5 – 1.5	TP5– 1	TP 5	Yellow
10	1.5 – 2.5	TP5 – 2		
11	0.5 – 1.5	TP6– 1	TP 6	Yellow
12	1.5 – 2.5	TP6 – 2		
13	0.5 – 1.5	TP7– 1	TP 7	Yellow
14	1.5 – 2.5	TP7 – 2		
15	0.5 – 1.5	TP8– 1	TP 8	Yellow
16	1.5 – 2.5	TP8 – 2		
17	0.5 – 1.5	TP9– 1	TP 9	Dark to light Brown
18	1.5 – 2.5	TP9 – 2		
19	0.5 – 1.5	TP10– 1	TP 10	Yellow
20	1.5 – 2.5	TP10 – 2		

<u>Remarks</u>:

Where; TP= Test Pits

Samples designated as TP1 were collected from the ongoing Adama, ASTU Research Park Project area 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 prior to sampling. All samples were sealed with plastic bag for the moisture content determination to reduce moisture loss. TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9 and TP10 were also taken in the same way and tagged as shown in the Table 4.1. The test pit for TP3, TP6, TP8 and TP10 are shown respectively in Fig. C.1, Fig. C.2, Fig. C.3, Fig. C.4 in the Appendix-C part.

TP1, TP2 and TP3 samples were collected respectively from Guest House, Gymnasium and Work shop Building, where as TP4, TP5 and TP6 were collected from Administration Building and TP7, TP8, TP9 and TP10 were collected from Research Building.

4.1.1.4 Sampling of Disturbed Samples

Disturbed samples can be readily gathered from all methods of site investigation. Tests for classification of soils such as moisture content, plasticity tests, specific gravity tests, particle size distribution and other related tests normally use disturbed or remolded samples.

Crushing or splitting technique must be avoided in disaggregating tropical residual soils for purposes of the classification test (Blight 1997, Fookes 1997). Disaggregation process must be done with care and with regard for what is meant by ‘individual particles’. The samples should be soaked in the water overnight. For particles which have a cemented characteristic, the disaggregation should be done by applying finger pressure only.

The degree of disturbances that occurs in a fabric influenced material may vary considerably depending on the project or sampling conditions. A fundamental aspect of the characterization of materials for civil engineering construction is in recognizing and establishing various levels of behavior based not only on scale but upon the influencing elements. These aspects should be considered in preparing remolded residual soil; drying, disaggregation and subdividing.

4.1.1.5 Samples Storage

Large disturbed samples in polythene bags should not be piled one on top of another, but placed individually on shelves or racks.

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 nearly three to four 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 yellow soils and is nearly equal or greater and increases with depth for dark and light brown 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	0.5-1.5	27	17	10	21
2	TP1-2	1.5-2.5	36	23	13	23
3	TP2-1	0.5-1.5	22	11	11	20
4	TP2-2	1.5-2.5	22	11	11	21
5	TP3-1	0.5-1.5	45	35	10	23
6	TP3-2	1.5-2.5	44	33	11	25
7	TP4-1	0.5-1.5	49	30	19	24
8	TP4-2	1.5-2.5	41	27	14	25
9	TP5-1	0.5-1.5	38	29	9	23
10	TP5-2	1.5-2.5	41	32	9	25
11	TP6-1	0.5-1.5	49	38	11	25
12	TP6-2	1.5-2.5	47	38	9	27
13	TP7-1	0.5-1.5	49	41	8	23
14	TP7-2	1.5-2.5	68	58	10	24
15	TP8-1	0.5-1.5	49	38	11	26
16	TP8-2	1.5-2.5	44	34	10	27
17	TP9-1	0.5-1.5	22	11	11	22
18	TP9-2	1.5-2.5	52	41	11	24
19	TP10-1	0.5-1.5	47	33	14	26
20	TP10-2	1.5-2.5	48	39	9	27

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), TP4 (TP4-1, TP 4-2), TP5 (TP5-1, TP5-2), TP6 (TP6-1, TP6-2), TP7-1, TP8-2, TP9-1 and TP10-2. The test result from the particle size analysis showed that the coarser fraction increases down the profile. Generally, the plasticity index of the soil under investigation decreases or equal with depth whereas the natural moisture content is found to increase with depth as shown in Table 4.3.

Table 4.3 Particle Size Distribution along Test Pit Profiles

Serial NO.	Designation	Percentage Amount of Particle Size				Plasticity Index (%)	NMC (%)
		Gravel	Sand	Silt	Clay		
1	TP1-1	12.4	72.4	6.84	8.36	10	21
2	TP1-2	12.8	69.8	6.61	10.79	13	23
3	TP4-1	11.2	63.2	6.4	19.2	19	24
4	TP4-2	12	73.2	2.96	11.84	14	25
5	TP5-1	5.2	69.2	9.22	16.38	9	23
6	TP5-2	10.6	71.2	6.55	11.65	9	25
7	TP6-1	11	72.6	5.08	11.32	11	25
8	TP6-2	5.8	79.2	4.95	10.05	9	27
9	TP7-1	9.2	73.4	5.74	11.66	8	23
10	TP8-2	18.8	57.8	8.19	15.21	10	27
11	TP9-1	6.6	73	7.75	12.65	11	22
12	TP10-2	7.8	67.6	9.35	15.25	9	27

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. Furthermore, the relative quantities of solid, liquid and gases in a given soil are found to change due to physical causes such as loading, seasonal variation and change of temperature. The physical properties of soils, which serve mainly for identification and classification, are commonly known as index properties.

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

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

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 twelve (12) 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 Adama, ASTU Research Park Project area contains a considerable amount of ‘water of hydration’ or ‘structural water’ leading to irreversible changes on drying, hence the test for these 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	TP1-1	0.5-1.5	26	21	5
2	TP1-2	1.5-2.5	29	23	6
3	TP4-1	0.5-1.5	28	24	4
4	TP4-2	1.5-2.5	30	25	5
5	TP5-1	0.5-1.5	27	23	4
6	TP5-2	1.5-2.5	30	25	5
7	TP6-1	0.5-1.5	29	25	4
8	TP6-2	1.5-2.5	32	27	5
9	TP7-1	0.5-1.5	29	23	6
10	TP8-2	1.5-2.5	33	27	6
11	TP9-1	0.5-1.5	28	22	6
12	TP10-1	1.5-2.5	30	26	4

4.2.1.1 Particle Size Analysis

Soil particles may consist of size ranges from boulders to fine-sized clays. Particle 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. The following Table 4.5 shows an example of the calculations required in a sieve analysis for Test Pit 1-1.

Table 4.5 Sieve Analysis of Soils of TP1-1 (Mass of Dry Soil Sample = 500 g).

Sieve No.	Sieve Size (mm)	Mass Retained in each sieve in gram	cumulative mass retained in gram	Mass passing in gram	Cummulative mass retained in %	Percent Passing
No.4	4.75	62.00	62.00	438.00	12.40	87.60
No.8	2.36	0.00	62.00	438.00	12.40	87.60
No.10	2.00	55.00	117.00	383.00	23.40	76.60
No.16	1.18	50.00	167.00	333.00	33.40	66.60

No.18	1.00	0.00	167.00	333.00	33.40	66.60
No.30	0.600	100.00	267.00	233.00	53.40	46.60
No.40	0.425	30.00	297.00	203.00	59.40	40.60
No.50	0.300	0.00	297.00	203.00	59.40	40.60
No.100	0.150	92.00	389.00	111.00	77.80	22.20
No.200	0.075	35.00	424.00	76.00	84.80	15.20
Pan		76.00	500.00	0.00	100.00	0.00
Total Weight (gram)		500.00				

As an example, the particle size distribution curves for soils of TP1-1 are shown in Figure 4.1a, whereas particle size distribution curves for the soil samples under investigation for this work is partly shown in Fig. 4.1 and the rest curves are shown in the Appendix-A.

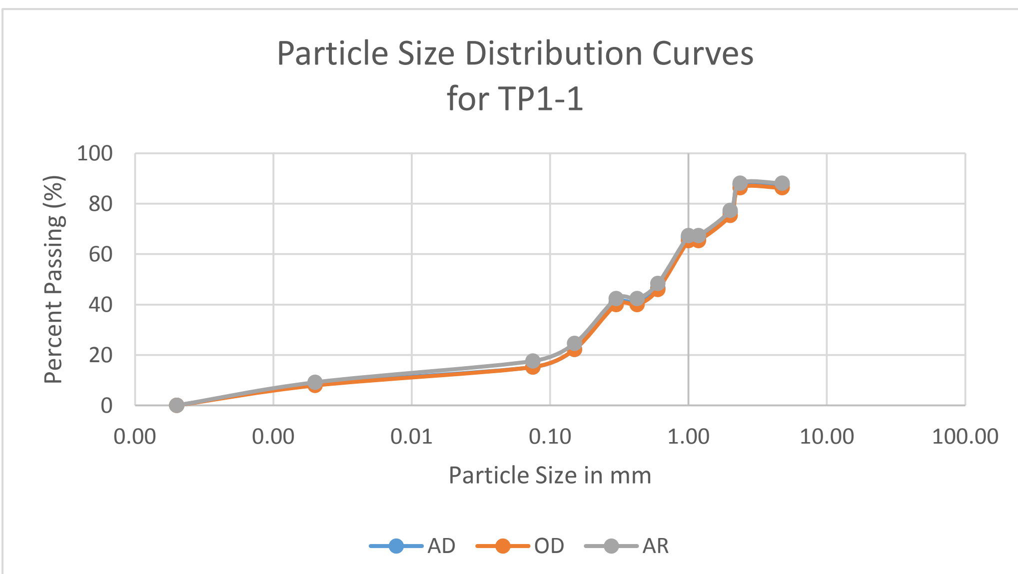

Fig. 4.1a Particle Size Distribution Curves for TP1-1 Soil Type

The percentages of gravel, sand, silt, and clay-size particles present in a soil can be obtained from the sieve analysis. According to the Unified soil classification soil TP1-1 has:

- **Gravel** (size limit - greater than 4.75 mm) = 12.4%
- **Sand** (size limits - 4.75 to 0.075 mm) = percent finer than 4.75 mm diameter - percent finer than 0.075 mm diameter = 87.6–15.2=72.4%
- **Silt and clay** (less than 0.075 mm) = 15.2%

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 outside 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. The results of these combined 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 sedimentation 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 been used for Adama, ASTU Research Park Project area soil. Generally, it has to be noted that the dispersant as well as the dispersing time were standardized.

II) Wet Preparation

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

4.2.1.1.2 Test Results and Discussions

The particle size analysis test results for all soil samples under investigation were summarized in Table 4.6. The corresponding particle size distribution curve for TP1-1 is shown in Fig. 4-1a. Some of the particle size distribution curves are shown in Fig. 4.1 whereas the rest test results are reported in Appendix-A.

Table 4.6 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	21	OD AD AR	13.6 12.4 11.8	71.2 72.4 70.6	7.3 6.84 8.45	7.9 8.36 9.15

2	TP1-2	23	OD AD AR	13.8 12.8 12.8	67.8 69.8 67.8	7.36 6.61 7.76	11.04 10.79 11.64
3	TP2-1	20	OD AD AR	14.8 14 13.4	70.4 71.8 69.6	4.44 4.83 6.8	10.36 9.37 10.2
4	TP2-2	21	OD AD AR	16 15.2 15	67.8 69.2 67.8	4.86 5.3 5.16	11.34 10.3 12.04
5	TP3-1	23	OD AD AR	19.6 19 19.6	68.2 68.2 66.8	6.34 3.84 7.07	5.86 8.96 6.53
6	TP3-2	25	OD AD AR	17.2 16 17.8	66 68 65.4	7.56 4.8 7.56	9.24 11.2 9.24
7	TP4-1	24	OD AD AR	10.8 11.2 11	62 63.2 61.2	12.24 6.4 12.51	14.96 19.2 15.29
8	TP4-2	25	OD AD AR	12.4 12 13	73.2 73.2 73.2	5.04 2.96 4.83	9.36 11.84 8.97
9	TP5-1	23	OD AD AR	5.8 5.2 5	67.8 69.2 66.4	11.88 9.22 12.87	14.52 16.38 15.73
10	TP5-2	25	OD AD AR	11.2 10.6 11.2	69.8 71.2 69.8	8.55 6.55 8.55	10.45 11.65 10.45
11	TP6-1	25	OD AD AR	10.4 11 10.8	72.6 72.6 71.2	6.12 5.08 6.48	10.88 11.32 11.52
12	TP6-2	27	OD AD AR	7.8 5.8 7	77.4 79.2 76.2	7.7 4.95 8.74	7.1 10.05 8.06
13	TP7-1	23	OD AD AR	10 9.2 8.4	73 73.4 72.6	9.18 5.74 10.26	7.82 11.66 8.74
14	TP7-2	24	OD AD AR	9 5.8 8	75 77.8 74.8	7.68 5.41 8.6	8.32 10.99 8.6

15	TP8-1	26	OD AD AR	7.8 4.6 6.8	72.6 75 71.2	10.78 7.14 12.1	8.82 13.26 9.9
16	TP8-2	27	OD AD AR	17.2 18.8 17.2	58.6 57.8 58.6	10.89 8.19 10.89	13.31 15.21 13.31
17	TP9-1	22	OD AD AR	9.4 6.6 6	70.4 73 69.8	6.87 7.75 8.23	13.33 12.65 15.97
18	TP9-2	24	OD AD AR	15.2 14.4 14	66.8 69 66.8	5.76 5.31 11.52	12.24 11.29 7.68
19	TP10-1	26	OD AD AR	9 8.2 9.6	68.6 70.2 68.6	8.96 8.64 8.72	13.44 12.96 13.08
20	TP10-2	27	OD AD AR	7 7.8 6.4	67.6 67.6 68.2	12.19 9.35 12.19	13.21 15.25 13.21

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

I) Effect of Pre-drying

As received (AR), air-dried (AD) and oven dried (OD) samples were used to investigate the particle size distribution of the specimen under investigation. The test results are shown in Table 4.6, Fig4-1 and Appendix-A. 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 Adama, ASTU Research Park Project area soil as shown in Table 4.6. Even though drying resulted in a coarser particle, temperature variation has a lesser cumulative effect on the particle size distribution. This is because the aggregated particles become weaker in bond and result in fine particles after washing and up on drying. The loose particles cannot regain their total bond to re-aggregate to their initial bond due to the 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 output 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 unweathered rock at the bottom. From the test results one can see that, the soil has distinct characteristics where sampled at different conditions.

The soil under investigation also shows different characteristics along its depth. This is due to the fact that residual soils vary from highly weathered topsoil to unweathered (intact) rock which is stiff at the bottom. Generally, 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 Table 4.6 for TP1 (TP1-1 and TP1-2), TP2 (TP2-1 and TP2-2), TP4 (TP4-1 and TP4-2), TP5 (TP5-1 and TP5-2), TP8 (TP8-1 and TP8-2) and TP9 (TP9-1 and TP9-2) that the particle size changes partly from fine grained to gravel. Generally, one can see from the test results and the site conditions of Adama, ASTU Research Park Project area 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 Adama shows a decreased in fine proportion and an increase in coarse sized particles in going down along the profile. 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 Table 4.6.

III) Range of Gradation Curves

The range of gradation curves for Adama, ASTU Research Park Project area soil is relatively narrow. This is due to the fact that the soil samples under this investigations shows more or less similar index properties. The range of particle size distribution curves for the soil samples under investigation for this work is partly shown in Fig. 4-1.

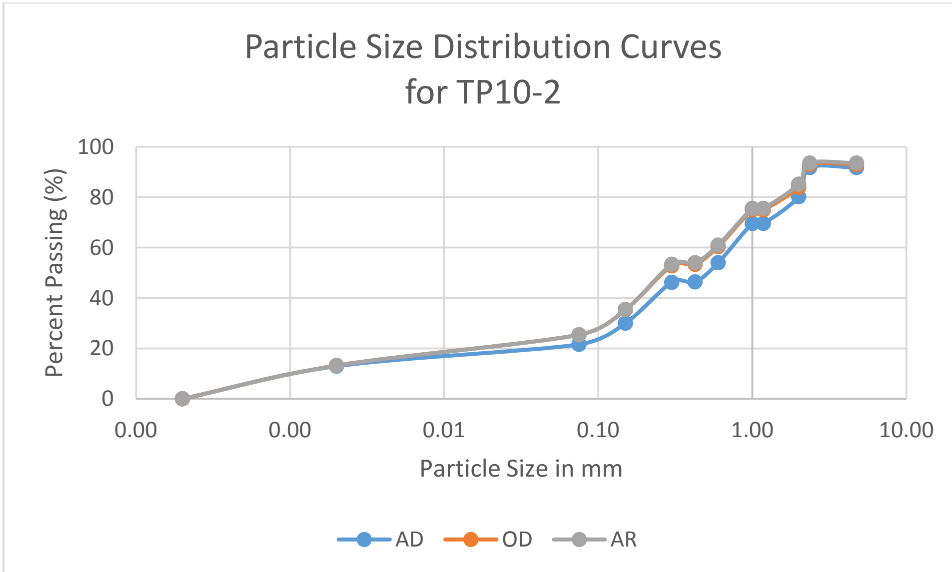

Fig. 4.1b Particle Size Distribution Curves under Different Pretreatment Temperatures

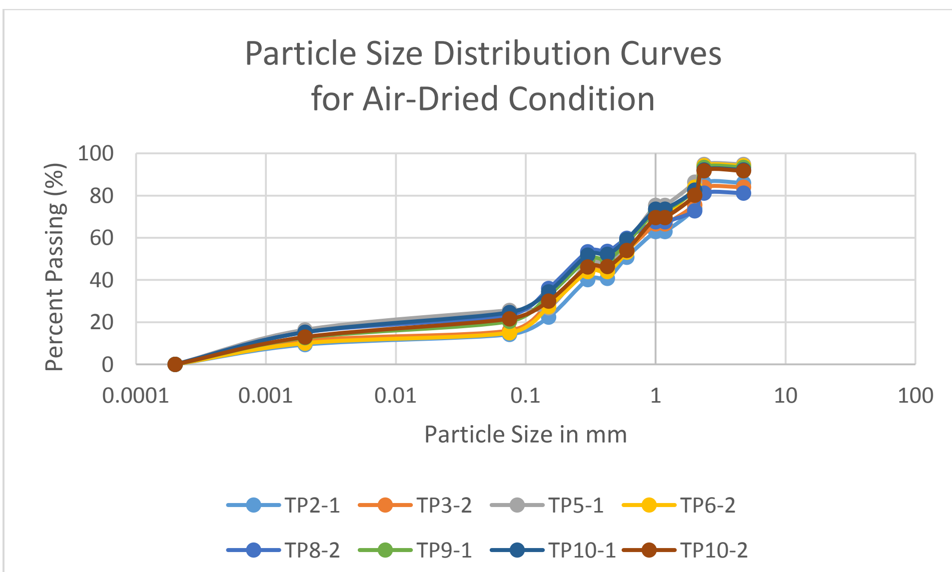

Fig. 4.1c Particle Size Distribution Curves for Air-Dried Conditions

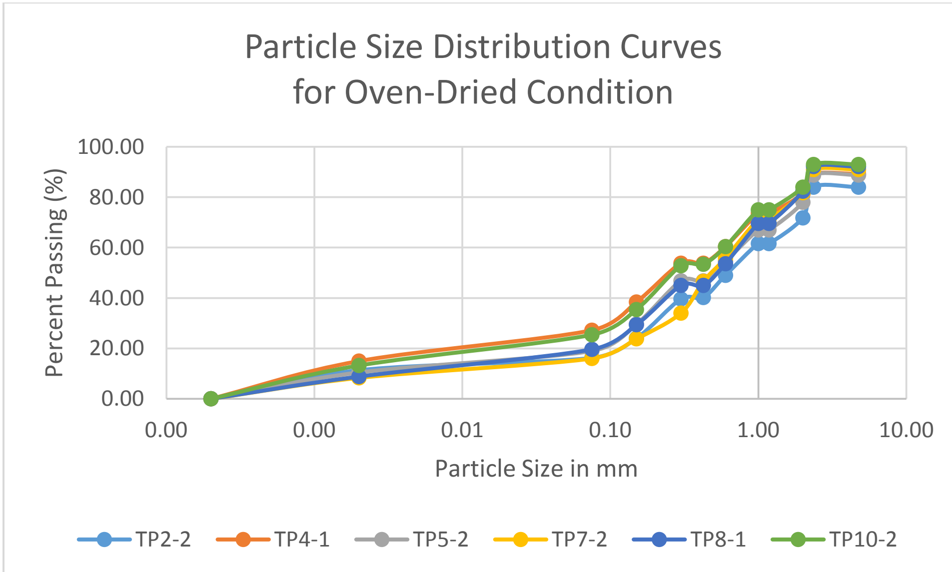

Fig. 4.1d Particle Size Distribution Curves for Oven-Dried Conditions

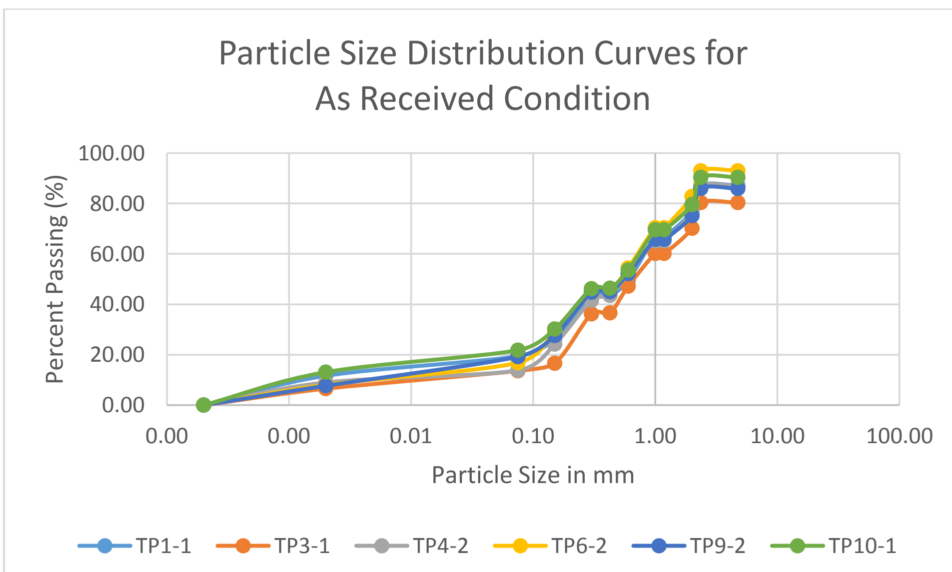

Fig. 4.1e Particle Size Distribution Curves for As Received Conditions

4.2.1.2 Atterberg Limits

Atterberg limits, which has proved to be very useful to classify cohesive soils was developed by Atterberg, (1911) and Casagrande, (1932). The concept is based on the fact that the consistency of a fine-grained soil depends largely on its water content. Four stages can be distinguished and the boundaries between these stages, called 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.

A fine-grained soil can exist in any of several states; which state depends on the amount of water in the soil system. When water is added to a dry soil, each particle is covered with a film of adsorbed water. If the addition of water is continued, the thickness of the water film on a particle increases. Increasing the thickness of the water films permits the particles to slide past one another more easily. The behavior of the soil, therefore, is related to the amount of water in the system. Approximately sixty years ago, A. Atterberg defined the boundaries of four states in terms of "limits" as follows:

- Liquid limit: The boundary between the liquid and plastic states;
- Plastic limit: The boundary between the plastic and semi-solid states;

These limits have since been more definitely defined by A. Casagrande as the water contents which exist under the following conditions:

- Liquid Limit

According to Casagrande Liquid Limit Test it is also defined as “the moisture content at which two sides of a groove come close together for a distance of 12.7 mm under the impact of 25 number of blows” OR liquid limit is defined as “the moisture content at which soil changes from liquid state to plastic state”

- Plastic Limit
- Plasticity Index (PI) the range of water content over which a soil behaves plastically. It is defined as “the range of consistency with in which the soil exhibit plastic properties”.
- It may also be defined as “The moisture content at which the soil changes from plastic state to semi solid state"

It is also defined as “the numerical difference between the liquid limit and plastic limit”.

Mathematically, Plasticity index = Liquid Limit – Plastic Limit

It is denoted by PI and PI = LL – PL

Plasticity Index

The plasticity index of a clay is defined as the numerical difference of Liquid limit (LL) and Plastic limit (PL). Liquid limit is the water content at which soil changes its state from the liquid state to the plastic state. Plastic limit is the water content at which the soil changes its state from the plastic state to the semi-solid state.

The plasticity index can be written as: Plasticity Index (PI) = LL – PL, where LL = liquid limit and PL = plastic limit. The Table 4.7 represents the degree of expansion of soil based on the plasticity index. From the Table 4.7, it is understand that as the plasticity index of soil increases, the degree of expansion of clayey soil is increasing. The Atterberg limits of clays depend on the quantity of water that clay can imbibe. The higher the plasticity index, the greater the quantum of water that can be imbibed by the soil and hence the greater would be its swell potential.

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 limits, the samples were oven dried (OD), air-dried (AD) and treated as received (AR). The test results are shown in Table 4-7. From the test results one can see that the different treatments affect the Atterberg limits of these particular soils. The test results show some 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 (temperature treatments) strongly affect the Atterberg values for Adama, ASTU Research Park Project area soil.

Unsoaking is drying the soil at oven of 105^{o}c and conducting the Atterberg Limit without keeping the sample for moisture equilibration for 24-hours. Hence the treatment conditions (temperature treatments) strongly affect the Atterberg Limit values for Adama, ASTU Research Park Project area soil and it is shown on Table 4-7. As it is seen on the

Table 4.7, the soil of Adama, ASTU Research Park Project area soil 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. Moreover 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 4.7 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	0.5-1.5	21	Unsoaked	24	13	11
				Oven-dried	26	14	12
				Air dried	27	17	10
				As received	29	21	8
2	TP1-2	1.5-2.5	23	Unsoaked	34	20	14
				Oven-dried	35	21	14
				Air dried	36	23	13
				As received	38	27	11
3	TP2-1	0.5-1.5	20	Unsoaked	19	8	11
				Oven-dried	21	9	12
				Air dried	22	11	11
				As received	25	16	9
4	TP2-2	1.5-2.5	21	Unsoaked	20	10	10
				Oven-dried	20	9	11
				Air dried	22	11	11
				As received	25	16	9
5	TP3-1	0.5-1.5	23	Unsoaked	38	28	10
				Oven-dried	40	29	11
				Air dried	45	35	10
				As received	49	39	10
6	TP3-2	1.5-2.5	25	Unsoaked	41	28	13
				Oven-dried	41	29	12
				Air dried	44	33	11
				As received	49	38	11
7	TP4-1	0.5-1.5	24	Unsoaked	44	26	18
				Oven-dried	47	27	20
				Air dried	49	30	19
				As received	52	34	18
8	TP4-2	1.5-2.5	25	Unsoaked	38	21	17
				Oven-dried	38	23	15
				Air dried	41	27	14
				As received	49	36	13

9	TP5-1	0.5-1.5	23	Unsoaked	36	25	11
				Oven-dried	37	26	11
				Air dried	38	29	9
				As received	42	34	8
10	TP5-2	1.5-2.5	25	Unsoaked	39	27	12
				Oven-dried	40	29	11
				Air dried	41	32	9
				As received	46	36	10
11	TP6-1	0.5-1.5	25	Unsoaked	45	34	11
				Oven-dried	46	34	12
				Air dried	49	38	11
				As received	53	43	10
12	TP6-2	1.5-2.5	27	Unsoaked	44	35	9
				Oven-dried	46	36	10
				Air dried	47	38	9
				As received	50	42	8
13	TP7-1	0.5-1.5	23	Unsoaked	45	35	10
				Oven-dried	47	38	9
				Air dried	49	41	8
				As received	51	42	9
14	TP7-2	1.5-2.5	24	Unsoaked	58	41	17
				Oven-dried	60	47	13
				Air dried	68	58	10
				As received	70	61	9
15	TP8-1	0.5-1.5	26	Unsoaked	45	32	13
				Oven-dried	46	33	13
				Air dried	49	38	11
				As received	52	42	10
16	TP8-2	1.5-2.5	27	Unsoaked	41	30	11
				Oven-dried	41	28	13
				Air dried	44	34	10
				As received	45	37	8
17	TP9-1	0.5-1.5	22	Unsoaked	19	8	11
				Oven-dried	21	8	13
				Air dried	22	11	11
				As received	29	18	11
18	TP9-2	1.5-2.5	24	Unsoaked	47	35	12
				Oven-dried	49	37	12
				Air dried	52	41	11
				As received	52	41	11
19	TP10-1	0.5-1.5	26	Unsoaked	45	28	17
				Oven-dried	45	30	15
				Air dried	47	33	14
				As received	50	37	13
20	TP10-2	1.5-2.5	27	Unsoaked	45	35	10
				Oven-dried	46	36	10
				Air dried	48	39	9
				As received	50	41	9

- Unsoaked –Atterberg Limit conducted on an oven-dried sample at a temperature of (105°C) without keeping over night for moisture equilibration.

Liquid Limit determination for some soil samples under this investigation are as shown in Fig4-2.

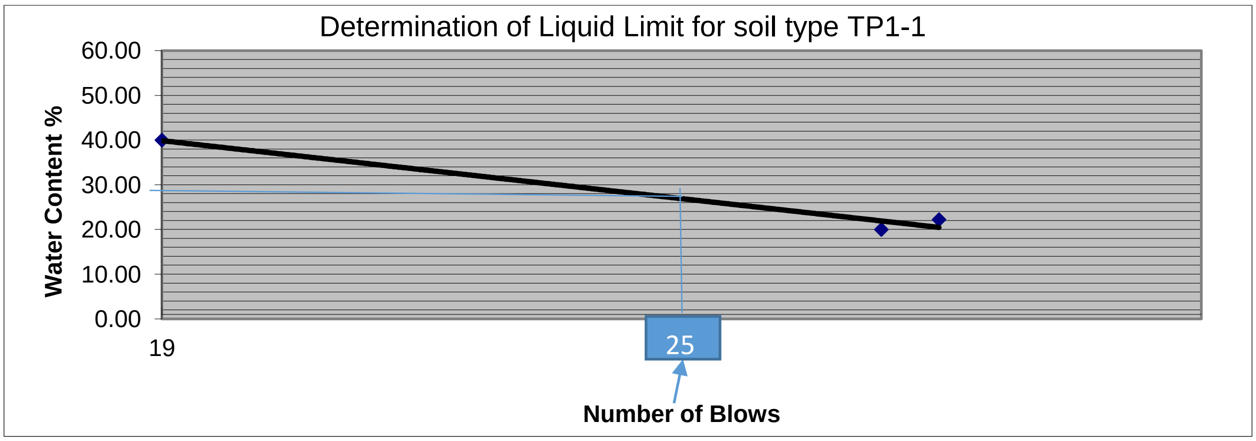

Fig. 4.2a Determination of Liquid Limit for soil type TP1-1

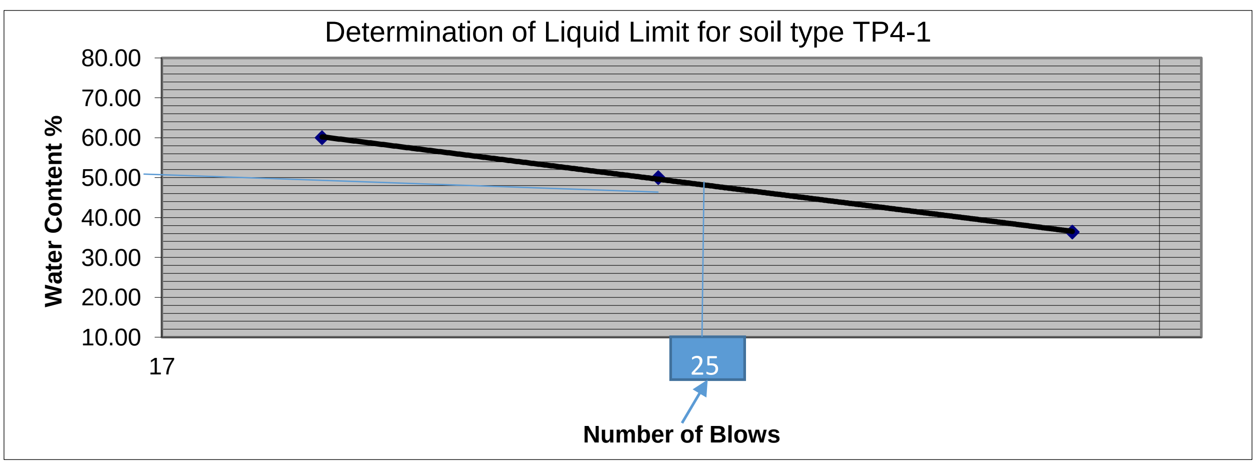

Fig. 4.2b Determination of Liquid Limit for soil type TP4-1

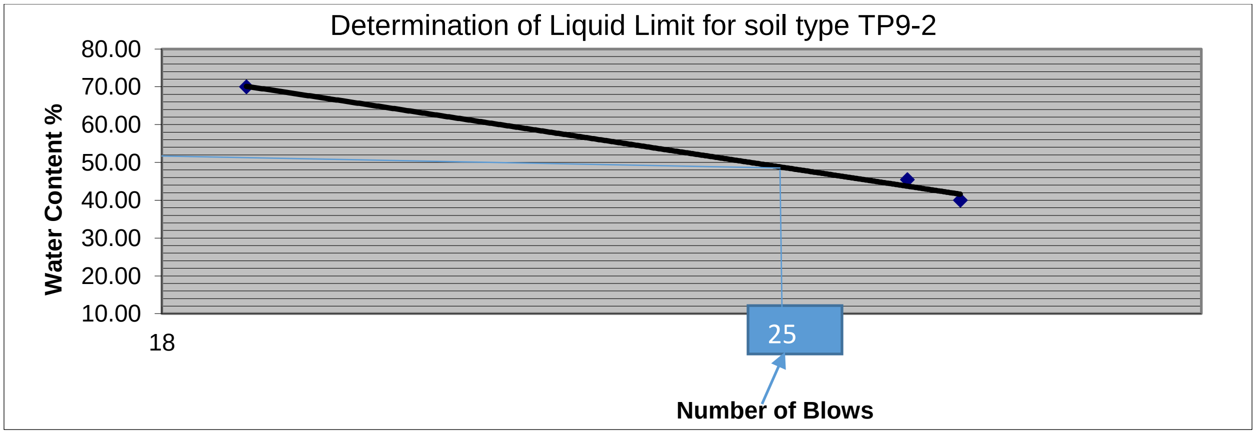

Fig. 4.2c Determination of Liquid Limit for soil type TP9-2

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 TP1-2, TP2-2, TP3-2, TP4-2, TP5-1, TP6-1, TP7-2, TP9-1, TP9-2 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 reported in Table 4.8.

As per the recommendations in the section 2.3.1.2, nine 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 in Table 4.8. The difference of '>5%' indicates that, there is a disaggregation of the clay sized particles up on manipulation.

Generally, the test results indicate that, the soil of Adama, ASTU Research Park Project area 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 Adama, ASTU Research Park Project area 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 4.8 Liquid Limit at Different Conditions and Mixing Times

Designation	NMC (%)	Pretreatment	Sample Manipulation	Liquid Limit (%)	LL30-LL5min
TP1-2	23	As Received	5 min 25 min	38 42	4
TP2-2	21	As Received	5 min 25 min	25 30	5
TP3-2	25	As Received	5 min 25 min	49 55	6
TP4-2	25	As Received	5 min 25 min	49 54	5
TP5-1	23	As Received	5 min 25 min	42 48	6
TP6-1	25	As Received	5 min 25 min	53 57	4
TP7-2	24	As Received	5 min 25 min	70 75	5
TP9-1	22	As Received	5 min 25 min	29 36	7
TP9-2	24	As Received	5 min 25 min	52 57	5

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°C and rewetted. The results are shown in Table 4.7 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 Adama, ASTU Research Park Project area 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 (Eq. 4-1), 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 Fig. 4.3. The results of soil under investigation on the plasticity chart is shown in Fig. 4.3 and soils of TP1-1, TP1-2, TP 2-1, TP2-2, TP9-1 are lies above the A-Line whereas soils of TP3-1, TP3-2, TP4-1, TP4-2, TP5-1, TP5-2, TP6-1, TP6-2, TP7-1, TP7-2, TP8-1, TP8-2, TP9-2, TP10-1, TP10-2 are lies below the A-Line. Hence, generally the soils under this investigation fall below the A-line. 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, as stated in the section 2.2.2. Almost all Soils of Adama, ASTU Research Park Project area fall in this region.

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

"U-Line" defined by equation 4-2 represents the upper limit of the correlation between liquid limit and plastic index. 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.

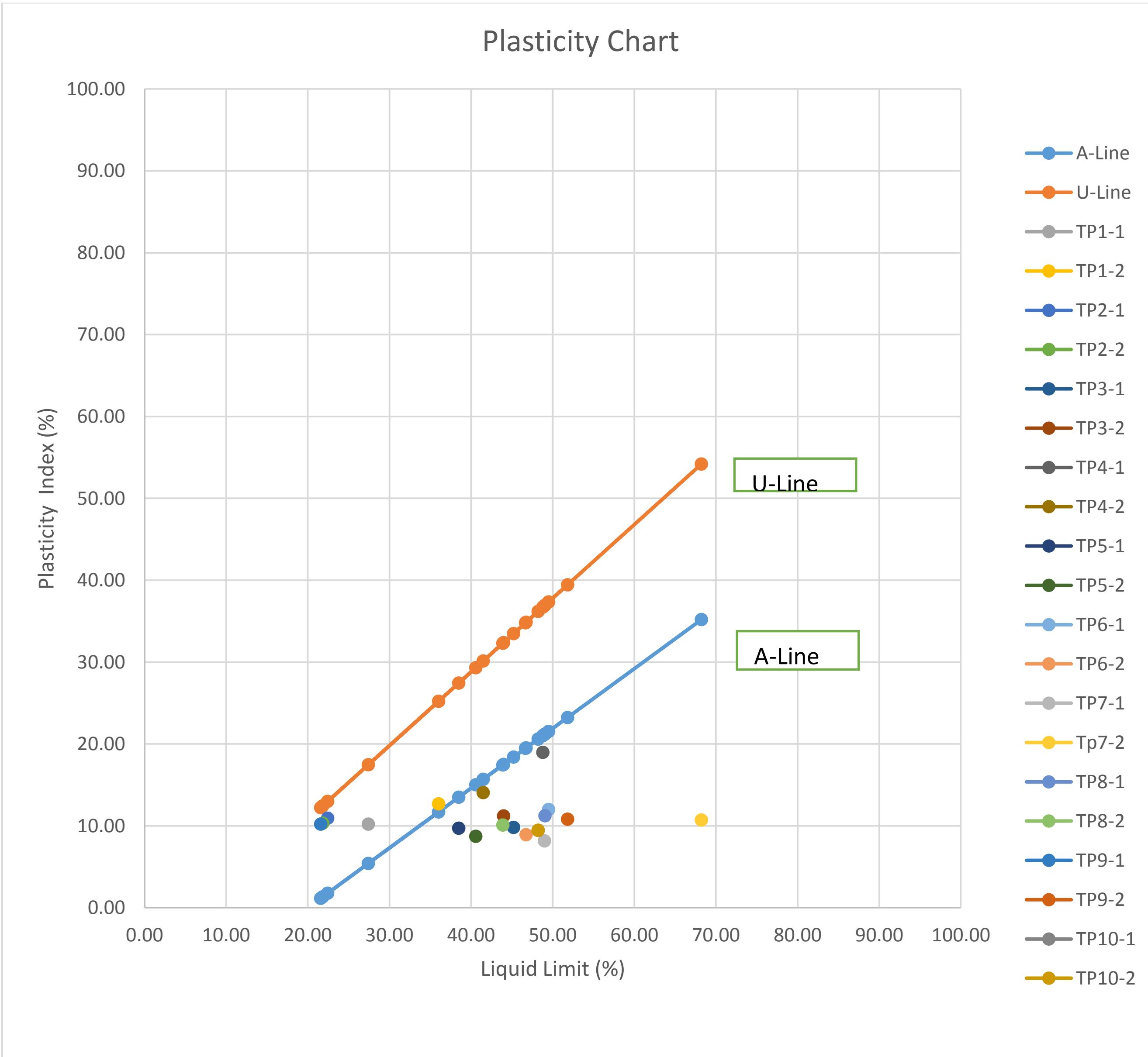

Fig. 4.3 Showing the Location of Adama, ASTU Research Park Project Area Soil on Plasticity Chart

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. of blows for Liquid Limit

β = 0.121 (ASTM, Waterway Experiment for Tropical soils, Lyon, 1971)

This relationship subsequently became the single point liquid limit method implemented as 'Method B' in ASTM D4318 (2010)

One can use the value of tanβ equal to zero when the number of blows is between 20 and

30 within the accuracy. But, ASTM recommends β value of 0.121 is adequate for determining the one-point liquid limit for lateritic and temperate soils. The results were calculated and shown in Table 4-9.

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 laboratory test results. Generally, it can be concluded that, the one-point liquid limit determination method could be used to determine the liquid limit values for tropical residual soils.

Table 4.9 Liquid Limit Values Comparisons between One point and Conventional Methods

Serial No.	Designation	Test Condition	No. Of blows	Moisture Content (%)	Calculated LL in %, using one-point Method	Average of the Calculated LL (%), using one-point Method	Tested LL (%)
1	TP1-1	Air-dried	19	40	39	27	27
			29	20	20		
			30	22	23		
2	TP1-2	Air-dried	20	56	54	35	36
			22	40	39		
			33	13	13		
3	TP2-1	Air-dried	19	27	26	22	22
			29	20	20		
			30	20	20		
4	TP2-2	Air-dried	19	27	26	22	22
			29	18	19		
			30	20	20		
5	TP3-1	Air-dried	19	75	73	45	45
			27	33	34		
			30	27	28		
6	TP3-2	Air-dried	19	78	75	43	44
			23	38	37		
			30	17	17		
7	TP4-1	Air-dried	19	60	58	48	49
			24	50	50		
			32	36	37		
8	TP4-2	Air-dried	20	44	43	42	41
			28	50	51		
			31	30	31		
9	TP5-1	Air-dried	19	50	48	38	38
			24	45	45		
			35	20	21		
10	TP5-2	Air-dried	22	50	49	40	41
			23	44	44		
			33	27	28		
11	TP6-1	Air-dried	22	67	66	50	49
			29	45	46		

			34	36	38		
12	TP6-2	Air-dried	22	54	53	47	47
			29	50	51		
			34	36	38		
13	TP7-1	Air-dried	22	64	63	49	49
			29	50	51		
			34	33	35		
14	TP7-2	Air-dried	23	88	87	68	68
			24	60	60		
			33	57	59		
15	TP8-1	Air-dried	22	90	89	49	49
			27	50	50		
			32	7	7		
16	TP8-2	Air-dried	22	50	49	44	44
			29	42	42		
			34	40	42		
17	TP9-1	Air-dried	20	30	29	21	22
			22	22	22		
			33	13	13		
18	TP9-2	Air-dried	19	70	68	52	52
			29	45	46		
			30	40	41		
19	TP10-1	Air-dried	19	67	64	47	47
			28	40	41		
			35	33	35		
20	TP10-2	Air-dried	23	63	62	48	48
			26	57	57		
			34	25	26		

4.2.1.3 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 soil classification according to Activity is shown on Table 4.10. The colloidal activity values for the soils under investigation are calculated and summarized in Table 4.11.

As will be discussed in this section, the total surface area of the particles in a mass of soil will increase with decreasing particle size. Therefore the amount of attracted water will be influenced by the amount and type of clay present in the mass of tested soil (Skempton, see Figure 4-4).

Table 4.10 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 due to the mode of weathering involving the coating of the soil particles with the sesquioxides. From Table 4-11, one can see that the soil under investigation has activity number <1.25 (Normal).

Table 4.11 Skempton's Colloidal Activity Values

Serial No.	Designation	Sampling Depth (m)	Plasticity Index (%)	Clay sized fraction by weight in %	A_c=PI/C
1	TP1-1	0.5-1.5	10	8.36	1.22
2	TP1-2	1.5-2.5	13	10.79	1.18
3	TP2-1	0.5-1.5	11	9.37	1.17
4	TP2-2	1.5-2.5	11	10.30	1.07
5	TP3-1	0.5-1.5	10	8.96	1.09
6	TP3-2	1.5-2.5	11	11.20	1.00
7	TP4-1	0.5-1.5	19	19.20	0.99
8	TP4-2	1.5-2.5	14	11.84	1.19
9	TP5-1	0.5-1.5	9	16.38	0.55
10	TP5-2	1.5-2.5	9	11.65	0.75
11	TP6-1	0.5-1.5	11	11.32	0.97
12	TP6-2	1.5-2.5	9	10.05	0.89
13	TP7-1	0.5-1.5	8	11.66	0.70
14	TP7-2	1.5-2.5	10	10.99	0.91
15	TP8-1	0.5-1.5	11	13.26	0.85
16	TP8-2	1.5-2.5	10	15.21	0.66
17	TP9-1	0.5-1.5	11	12.65	0.87
18	TP9-2	1.5-2.5	11	11.29	0.96
19	TP10-1	0.5-1.5	14	12.25	1.14
20	TP10-2	1.5-2.5	9	15.25	0.59

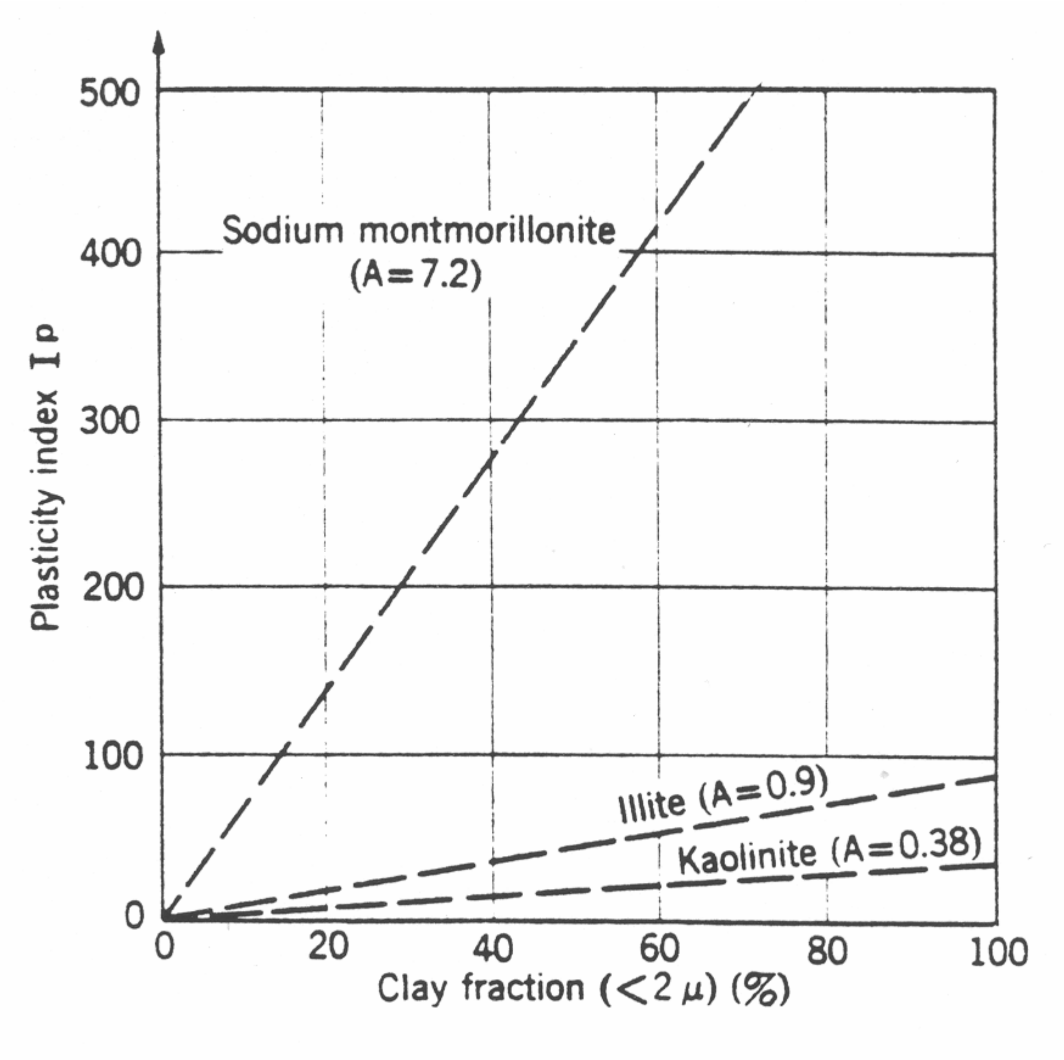

Fig. 4.4 Activity Index by Skempton

4.2.1.4 Free Swell Index (FSI)

Free swell Index (FSI) is a measure of the swelling or expansive nature of clayey soil. It can be estimated by using simple 100 ml measuring jar. The jar is filled with water up to the 100ml mark noted on the jar. The dry clay sample passing through 425 micron (0.425mm) sieve can be weight about 10gm and gently poured into the measuring jar by using the funnel. After settling almost all the soil particles at the bottom of the jar, the initial volume (V_i) of sample in the jar is noted. The soil and water system in the jar is kept undisturbed for about 24 hours. After twenty four hours lapse of time, the final volume (V_f) of expanded soil suspension in the jar is noted. The jar system is shown in Figure 4.5.The free swell index can be estimated by the following expression:

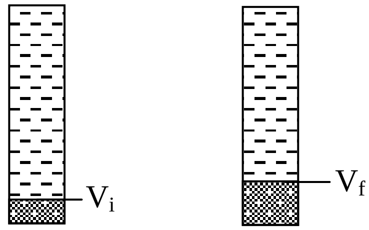

Fig.4.5 Measuring jar with soil water suspension and respective volumes

$$FSI(\%) = \frac{Final\,Volume - Initial\,Volume}{Initial\,Volume} x100 == \frac{V_f - V_i}{V_i} x100 \text{................. Eq. 4-5}$$

Where V_f = final volume

V_i = initial volume

Soils with free swell index less than 50% are not likely to show expansive property, while soils with free swell index in excess of 50 percent could present swell problems. Values of 100% or more are associated with clay which could swell considerably, especially under light loadings.

The laboratory free swell test results were done on an air-dried and oven dried ($105^o{}_c$) samples and is shown in Table 4.12. Accordingly one can see from the test that the free swell values for Adama, ASTU Research Park Project area soils range from 13% to 26%. 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 Adama, ASTU Research Park Project area is non-expansive soil (low expansion).

Table 4.12 Free Swell Test Results at Different Conditions

Serial No	Designation	NMC (%)	Test Condition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Free Swell (%)
1	TP1-1	21	Oven-dried	26	14	12	21
			Air-dried	27	17	10	20
2	TP1-2	23	Oven-dried	35	21	14	20
			Air-dried	36	23	13	18
3	TP2-1	20	Oven-dried	21	9	12	25
			Air-dried	22	11	11	21
4	TP2-2	21	Oven-dried	20	9	11	23
			Air-dried	22	11	11	18

5	TP3-1	23	Oven-dried	40	29	11	26
			Air-dried	45	35	10	22
6	TP3-2	25	Oven-dried	41	29	12	23
			Air-dried	44	33	11	20
7	TP4-1	24	Oven-dried	47	27	20	24
			Air-dried	49	30	19	23
8	TP4-2	25	Oven-dried	38	23	15	24
			Air-dried	41	27	14	19
9	TP5-1	23	Oven-dried	37	26	11	26
			Air-dried	38	29	9	24
10	TP5-2	25	Oven-dried	40	29	11	25
			Air-dried	41	32	9	21
11	TP6-1	25	Oven-dried	46	34	12	21
			Air-dried	49	38	11	22
12	TP6-2	27	Oven-dried	46	36	10	19
			Air-dried	47	38	9	18
13	TP7-1	23	Oven-dried	47	38	9	20
			Air-dried	49	41	8	20
14	TP7-2	24	Oven-dried	60	47	13	20
			Air-dried	68	58	10	15
15	TP8-1	26	Oven-dried	46	33	13	21
			Air-dried	49	38	11	15
16	TP8-2	27	Oven-dried	41	28	13	25
			Air-dried	44	34	10	13
17	TP9-1	22	Oven-dried	21	8	13	20
			Air-dried	22	11	11	15
18	TP9-2	24	Oven-dried	49	37	12	19
			Air-dried	52	41	11	17
19	TP10-1	26	Oven-dried	45	30	15	20
			Air-dried	47	33	14	20
20	TP10-2	27	Oven-dried	46	36	10	20
			Air-dried	48	39	9	15

4.2.1.5 Specific Gravity

The particle relative unit weight (Gs), also called the specific gravity, and is used to calculate volumetric parameters such as void ratio and porosity. In residual soils, Gs may be unusually high or unusually low depending on whether the “particle’’ consists of a void less solid particle of a heavy mineral, e.g., iron sesquioxide or a porous aggregation of elementary particles. It is thus essential that Gs be determined in the laboratory using an accepted standard test procedure, for the purpose of calculating void ratio, dry density, porosity, etc.

The soil to be used in this test should be at its natural water content. Pre-test drying of the soil should be avoided as this tends to reduce the measured Gs as compared with measurements at natural water content. The dry mass of the soil used in the test should be calculated by drying the soil specimen after the particle unit weight test has been completed, it may be necessary to air-dry the soil, or to dry at a reduced temperature (Blight, 1997).

The weight of all construction materials can be compared with respect to water (standard substance), as the property of water such as surface tension, viscosity and density do not vary with changes of temperature and pressure.

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 4.13. 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 Adama, ASTU Research Park Project area soil reduces strongly with oven drying. Generally, the specific gravity of a soil under investigation reduces with laboratory test temperature increment and the range of the test results are from 2.33 to 2.98.

Table 4.13 Values of Specific Gravity at Different Test Conditions

Serial No.	Designation	Sampling Depth (m)	NMC (%)	Test Condition	Specific Gravity
1	TP1-1	0.5-1.5	21	As received Air dried Oven-dried	2.60 2.68 2.75
2	TP1-2	1.5-2.5	23	As received Air dried Oven-dried	2.89 2.85 2.80
3	TP2-1	0.5-1.5	20	As received Air dried Oven-dried	2.6 2.6 2.6
4	TP2-2	1.5-2.5	21	As received Air dried Oven-dried	2.52 2.42 2.33
5	TP3-1	0.5-1.5	23	As received Air dried Oven-dried	2.65 2.58 2.50
6	TP3-2	1.5-2.5	25	As received Air dried Oven-dried	2.66 2.54 2.33
7	TP4-1	0.5-1.5	24	As received Air dried Oven-dried	2.5 2.4 2.33
8	TP4-2	1.5-2.5	25	As received Air dried Oven-dried	2.77 2.69 2.6
9	TP5-1	0.5-1.5	23	As received Air dried Oven-dried	2.62 2.53 2.40
10	TP5-2	1.5-2.5	25	As received Air dried Oven-dried	2.8 2.71 2.6
11	TP6-1	0.5-1.5	25	As received Air dried Oven-dried	2.49 2.42 2.33

12	TP6-2	1.5-2.5	27	As received Air dried Oven-dried	2.50 2.42 2.33
13	TP7-1	0.5-1.5	23	As received Air dried Oven-dried	2.80 2.64 2.50
14	TP7-2	1.5-2.5	24	As received Air dried Oven-dried	2.55 2.47 2.33
15	TP8-1	0.5-1.5	26	As received Air dried Oven-dried	2.68 2.45 2.33
16	TP8-2	1.5-2.5	27	As received Air dried Oven-dried	2.98 2.84 2.6
17	TP9-1	0.5-1.5	22	As received Air dried Oven-dried	2.54 2.42 2.33
18	TP9-2	1.5-2.5	24	As received Air dried Oven-dried	2.56 2.44 2.33
19	TP10-1	0.5-1.5	26	As received Air dried Oven-dried	2.73 2.57 2.40
20	TP10-2	1.5-2.5	27	As received Air dried Oven-dried	2.93 2.86 2.80

4.3 Soil Classification According to AASHTO and USCS

Different Authors used different classification techniques to classify tropical residual 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 4.14.

According to the AASHTO classification, soils of TP1-1 and TP5-1 lie in the group A-2-4; soils of TP3-1, TP5-2, TP6-2,TP7-1, TP7-2, TP8-2 and TP10-2 lie in the group A-2-5: soils of TP1-2, TP2-1, TP2-2,TP9-1 lie in the group A-2-6 and soils of TP3-2, TP4-1, TP4-2,TP6-1, TP8-1, TP9-2 and TP10-1 lie in the group A-2-7. All soil samples except TP1-1 are grouped under SC i.e. clayey sands, sand-clay mixture of low plasticity clay according to the USCS classification and soil sample of TP1-1 is grouped under SP-SC as the percentage of fine is from 5% to 12% which is poorly graded sand and clayey sand of low plasticity according to the USCS classification. Generally, the soil under investigation consists mainly clayey sands and sand-clay mixtures of low plasticity up to the depth of 2.5m.

Table 4.14 Soil Classification of Adama, ASTU Research Park Project area According to AASHTO and USCS.

Serial No.	Designation	LL (%)	PI (%)	Percent Passing in different sieve sizes in mm			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	27	10	76.6	40.6	15.2	A-2-4	3	12.4	72.4	6.84	8.36	SP-SC which is poorly graded sand and clayey sand
2	TP1-2	36	13	76.2	42.2	17.4	A-2-6	3	12.8	69.8	6.61	10.79	SC, Clayey Sands
3	TP2-1	22	11	73.98	40.78	14.2	A-2-6	2	14	71.8	4.83	9.37	SC, Clayey Sands
4	TP2-2	22	11	72.6	40.6	15.6	A-2-6	2	15.2	69.2	5.3	10.3	SC, Clayey Sands
5	TP3-1	45	10	70.8	35.8	12.8	A-2-5	5	19	68.2	3.84	8.96	SC, Clayey Sands
6	TP3-2	44	11	75.6	45.8	16	A-2-7	4	16	68	4.8	11.2	SC, Clayey Sands
7	TP4-1	49	19	80.6	52.2	25.6	A-2-7	3	11.2	63.2	6.4	19.2	SC, Clayey Sands
8	TP4-2	41	14	77.2	44.6	14.58	A-2-7	4	12	73.2	2.96	11.84	SC, Clayey Sands
9	TP5-1	38	9	86.4	48	25.6	A-2-4	2	5.2	69.2	9.22	16.38	SC, Clayey Sands
10	TP5-2	41	9	78.6	46.4	18.2	A-2-5	3	10.6	71.2	6.55	11.65	SC, Clayey Sands
11	TP6-1	49	11	80	47.2	16.4	A-2-7	5	11	72.6	5.08	11.32	SC, Clayey Sands
12	TP6-2	47	9	84	44	15	A-2-5	5	5.8	79.2	4.95	10.05	SC, Clayey Sands
13	TP7-1	49	8	81.8	48.4	17.4	A-2-5	4	9.2	73.4	5.74	11.66	SC, Clayey Sands
14	TP7-2	68	10	84.4	47.2	16.4	A-2-5	6	5.8	77.8	5.41	10.99	SC, Clayey Sands
15	TP8-1	49	11	84.8	47	20.4	A-2-7	4	4.6	75	7.14	13.26	SC, Clayey Sands
16	TP8-2	44	10	72.8	53.6	23.4	A-2-5	3	18.8	57.8	8.19	15.21	SC, Clayey Sands
17	TP9-1	22	11	82.6	49.8	20.4	A-2-6	2	6.6	73	7.75	12.65	SC, Clayey Sands
18	TP9-2	52	11	74	42.6	16.6	A-2-7	5	14.4	69	5.31	11.29	SC, Clayey Sands
19	TP10-1	47	14	80.2	46.4	21.6	A-2-7	3	7.8	67.6	9.35	12.25	SC, Clayey Sands
20	TP10-2	48	9	82.6	52.2	24.6	A-2-5	3	7.8	67.6	9.35	15.25	SC, Clayey Sands

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 Adama, ASTU Research Park Project Area

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.

Index Property Comparisons

For the soil under investigation, Index property tests, were studied and comparisons were made with known lateritic and laterites soils of Africa. Based on the soil forming factors as stated in section 2.1.7.2, 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 Adama, ASTU Research Park Project area soils are shown in Table 5-1 (51a, 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 limit, plasticity index and gradation for Ferruginous, Ferrallitic and Ferrisols showing different properties. As indicated in section 2.1.7.2, 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 Adama, ASTU Research Park Project area when compared with the previous tested laterite and lateritic soils of Africa show considerable similarities with the Ferrallitic and Ferrisols soils: Somehow closer similarity is observed with respect to the index tests shown in Tables 5-1b to5-1c. Average soil test results for the three sub-groups of African laterite and lateritic soils and Nejo Mendi, Zelalem, (2005) soils along with the test results of Adama, ASTU Research Park Project area soil is shown in Table 5.3, as a comparison between this thesis work with the previous test results of Laterite and Lateritic soils of different locations.

Generally, the soil of Adama, ASTU Research Park Project area could be classified as Ferrisol, with some close characteristics with Niger and Ghana soils having low plasticity and to some extent, with Ferrallitic soils found in Mali and Uganda and to a lesser extent with Ferriginous soils found in Kenya. However, Adama, ASTU Research Park Project area soil has a small value of clay fraction except that of Nejo-Mendi soils. Whereas the liquid limit is equal with that of Ferralitic soils of Ghana.

Plasticity Chart Comparisons

The plasticity charts as investigated for Adama, ASTU Research Park Project area soils are shown in Fig. 4.3.

Soils of TP1 (TP1-1, TP1-2), TP2 (TP2-1, TP2-2) and TP9-1 fall above the region A-Line as stated in the section 4.2.1.2.2, except the rest test pits samples. Some of the soils of Adama, ASTU Research Park Project area fall in this region.

Generally, most soil samples of Adama, ASTU Research Park Project area were found to fall below A-Line, except Soils of TP1 (TP1-1, TP1-2), TP2(TP2-1, TP2-2) and TP9-1.

Table 5.1a Typical 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 5.1b Typical 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 5.1c Typical 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-Mendi

COUNTRY	Liquid Limit (%)	Plastic Limit (%)	PlasticityIndex (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
Nejo-Mendi	59	38	21	A-2-7	0	92	82	61	45	31	25	20
	59	38	20	A-7-5	17.5					100	87.5	78

Table 5.1e Typical Soil Test Results for Adama, ASTU Research Park Project Area Soils

Designation	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHTO Classification	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
TP1-1	27	17	10	A-2-4	3	100	100	100	87.6	76.6	40.6	15.2
TP1-2	36	23	13	A-2-6	3	100	100	100	87.2	76.2	42.2	17.4
TP2-1	22	11	11	A-2-6	2	100	100	100	87.6	73.98	40.78	14.2
TP2-2	22	11	11	A-2-6	2	100	100	100	84.8	72.6	40.6	15.6
TP3-1	45	35	10	A-2-5	5	100	100	100	81	70.8	35.8	12.8
TP3-2	44	33	11	A-2-7	4	100	100	100	84	75.6	45.8	16
TP4-1	49	30	19	A-2-7	3	100	100	100	88.8	80.6	52.2	25.6
TP4-2	41	27	14	A-2-7	4	100	100	100	88	77.2	44.6	14.58
TP5-1	38	29	9	A-2-4	2	100	100	100	94.8	86.4	48	25.6
TP5-2	41	32	9	A-2-5	3	100	100	100	89.4	78.6	46.4	18.2
TP6-1	49	38	11	A-2-7	5	100	100	100	89	80	47.2	16.4
TP6-2	47	38	9	A-2-5	5	100	100	100	94.2	84	44	15
TP7-1	49	41	8	A-2-5	4	100	100	100	90.8	81.8	48.4	17.4
TP7-2	68	58	10	A-2-5	6	100	100	100	94.2	84.4	47.2	16.4
TP8-1	49	38	11	A-2-7	4	100	100	100	95.4	84.8	47	20.4
TP8-2	44	34	10	A-2-5	3	100	100	100	81.2	72.8	53.6	23.4
TP9-1	22	11	11	A-2-6	2	100	100	100	93.4	82.6	49.8	20.4
TP9-2	52	41	11	A-2-7	5	100	100	100	85.6	74	42.6	16.6
TP10-1	47	33	14	A-2-7	3	100	100	100	91.8	80.2	46.4	21.6
TP10-2	48	39	9	A-2-5	3	100	100	100	92.2	82.6	52.2	24.6

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), Zelalem, (2005) and Adama ASTU Research Park Project Area

Test Executed	Ferruginous		Ferralitic		Ferrisols		Nejo-Mendi	ASTU, Adama
	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	100
4.75	75	76	70	80	73	74	62.2	89.05
2	51	65	54	70	52	61	51.6	78.79
0.425	46	51	46	54	40	51	45.0	45.77
0.075	30	32	34	40	37	44	38.3	18.37
0.002	13	16	19	26	25	24	9.2	12.13
LL	31	33	42	47	46	55	59	42
PL	18	12	24	24	23	29	38	31
PI	14	15	19	23	23	27	21	11
FS	-	-	-	-	-	-	-	19

5.2 Discussions

The soil samples were collected from Adama town, ASTU Research Park Project area. The area had the maximum annual rainfall of 3551mm occurring during June to September and temperature varying between $12.3^{o}{}_{C}$ to $31.1\ ^{o}{}_{C,}$ which is warm. Hence, one can classify the climatic condition of Adama town to be tropical warm humid with seasonal variations occurring. Adama has a gentle sloppy terrain with a geological formation of basalt.

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 (4-6) %. 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 results are shown in Table 4.8 for all soil samples. 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 in Table 4.7 for all soil samples. 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 Adama, ASTU Research Park Project area soil has to necessarily be simulated with the field conditions with respect to wetting and drying prior to the test.

From the soil classification, almost all soils are clayey sands with the highest probability of changing to a coarse graded fraction over 2.5m depths. However, it is clear that, Classification of tropical residual 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). The soil classification results are shown in Table 4.14 for all soil samples.

For the soil under investigation, the activity test results for all fine-grained soils show the value of less than 1.25, hence, one can see that the soil of Adama, ASTU Research Park Project area is inactive or normal. The results are shown in Table 4.11 for all soil samples. 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 results are shown in Table 4.12 for all soil samples.

The in-situ specific gravity of the soil under investigation is between 2.33 to 2.98, 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 results are shown in Table 4.13 for all soil samples.

6. Conclusions and Recommendations

6.1 Conclusion

Based on the investigations made on the soils of Adama, ASTU Research Park Project area, the following conclusions are drawn:

1. The test results showed that, Adama, ASTU Research Park Project area 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.

2. It has been realized that Adama, ASTU Research Park Project area 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.

3. In fact, it has been assumed that, the soils of Adama, ASTU Research Park Project area could be classified as lateritic soils, though from the soil classification, it was revealed that almost all soils are clayey sands as per Unified Soil Classification System.

4. From the actual situation and the laboratory results, the soil of Adama shows a decreased in fine proportion and an increase in coarse sized particles in going down along the profile.

5. 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, Adama, ASTU Research Park Project area soil is inactive and non-expansive soil (low expansion).

5. 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. Hence the treatment conditions (temperature treatments) strongly affect the Atterberg values for Adama, ASTU Research Park Project area soil.

6. From the specific gravity 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 Adama, ASTU Research Park Project area soil reduces strongly with oven

drying. Generally, the specific gravity of a soil under investigation reduces with laboratory test temperature increment.

7. The plasticity chart showed that most of Adama, ASTU Research Park Project area soil lies below the A-line except the soil samples TP1-1, TP1-2, TP2-1, TP2-2 and TP9-1 (which lies above A-Line).

6.2 Recommendations

1. In this study chemical tests are not conducted due to financial constraint, hence one can conduct chemical tests exclusively for Adama, ASTU Research Park Project area soil in order to determine the extent of laterization.

2. The samples were collected from about 1.2km away 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 Adama, ASTU Research Park Project area soil in order to determine the actual soil behaviors.

3. The maximum sampling depths of the soil under investigations were 2.5m for all samples. Detailed investigations have to be made with deeper depth along more samples of profiles.

4. Any researcher can conduct Engineering properties such as shear strength parameters, compressibility and permeability characteristics for Adama, ASTU Research Park Project area soils for further detailed investigations besides to the investigation of the Index properties in this Thesis work.

5. From the soil classification, almost all soils are clayey sands with the highest probability of changing to a coarse graded fraction over 2.5m depths. However, it is clear that, Classification of tropical residual 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).

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Appendix-A

Particle Size Distribution Curves under Different Testing Conditions

The figures in this appendix show the particle size distribution curves for some the soils samples under this thesis work, which were collected from different building locations and treated with different pretreatment conditions.

Accordingly, the particle size distribution curves are plotted as shown in Figures A-1a, A-1b, A-1c, A-1d, , A-1e, A-1f, A-1g while some of particle size distribution curves were plotted in Fig. 4.1.

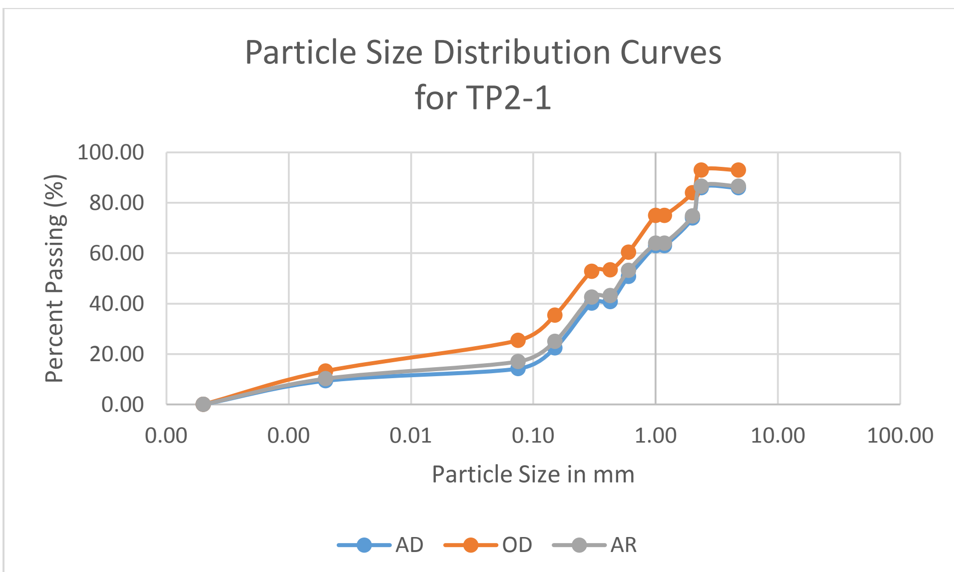

Fig. A.1a Particle Size Distribution Curves under Different Pretreatment Temperatures

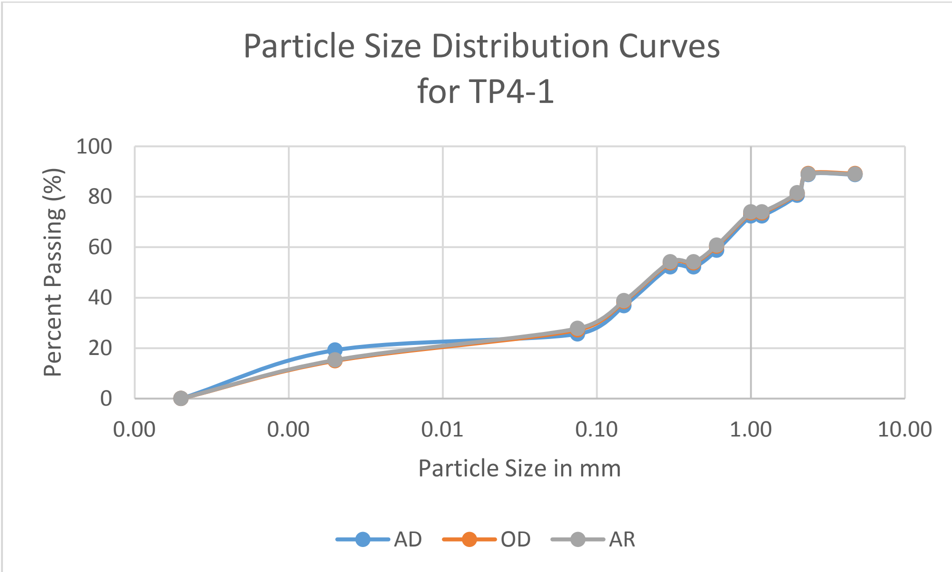

Fig. A.1b Particle Size Distribution Curves under Different Pretreatment Temperatures

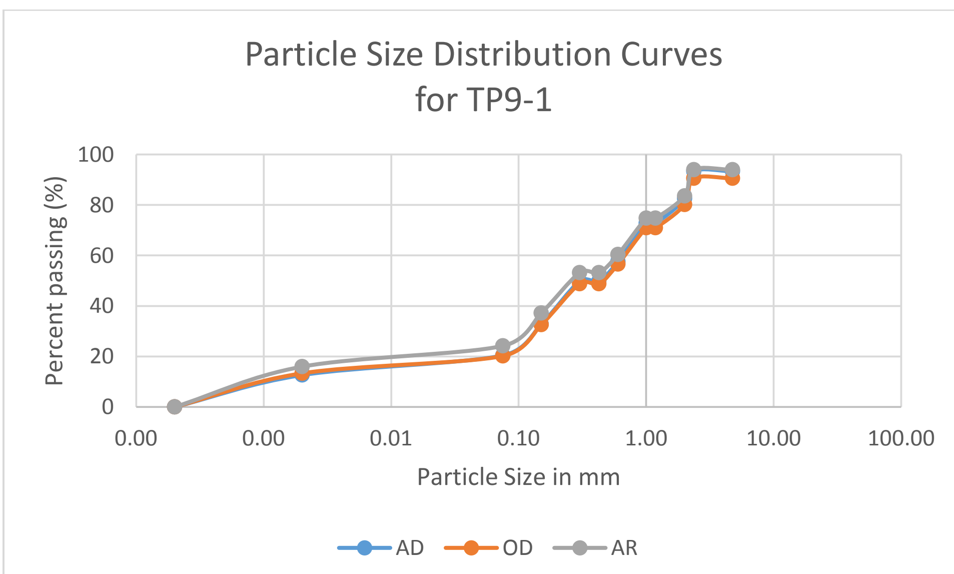

Fig. A.1c Particle Size Distribution Curves under Different Pretreatment Temperatures

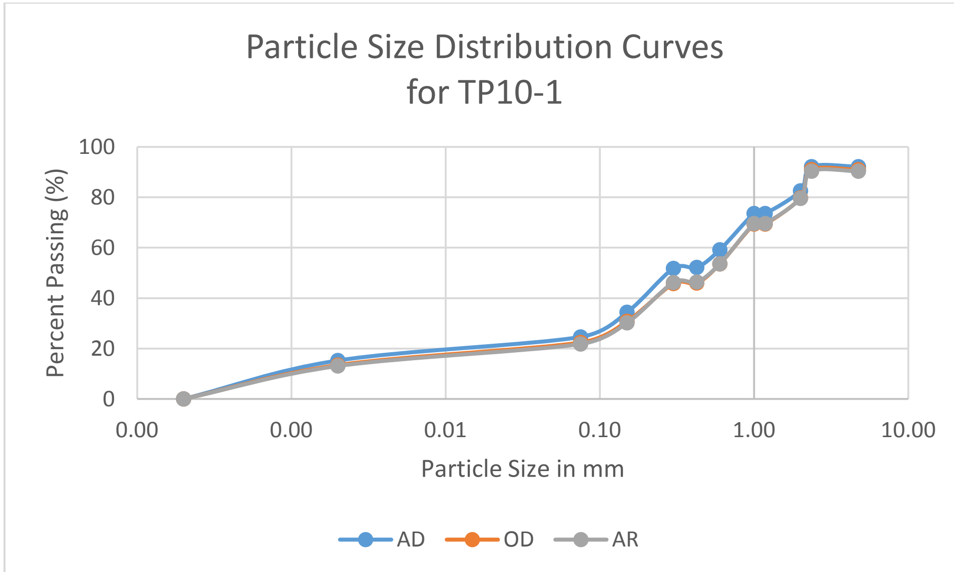

Fig. A.1d Particle Size Distribution Curves under Different Pretreatment Temperatures

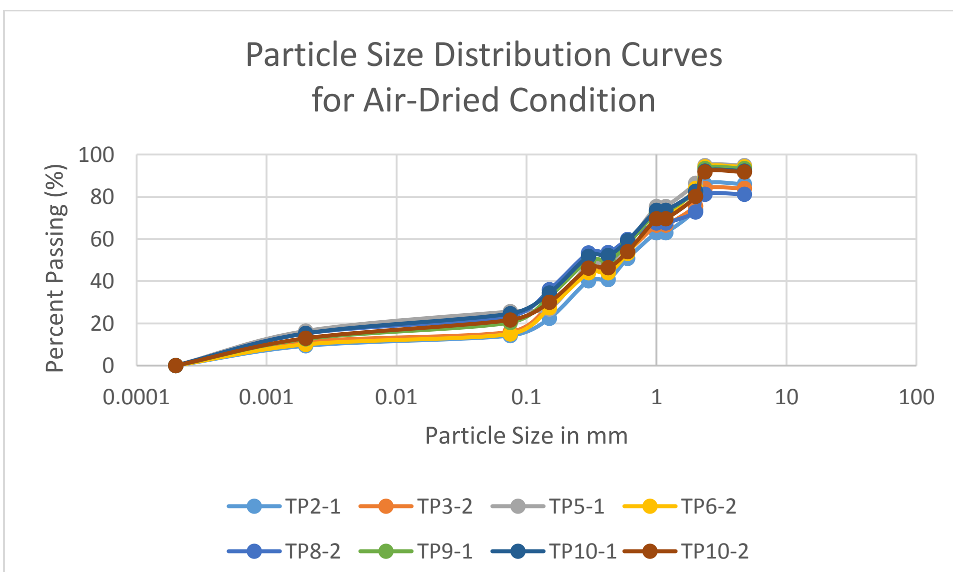

Fig. A.1e Particle Size Distribution Curves at Air-dried condition

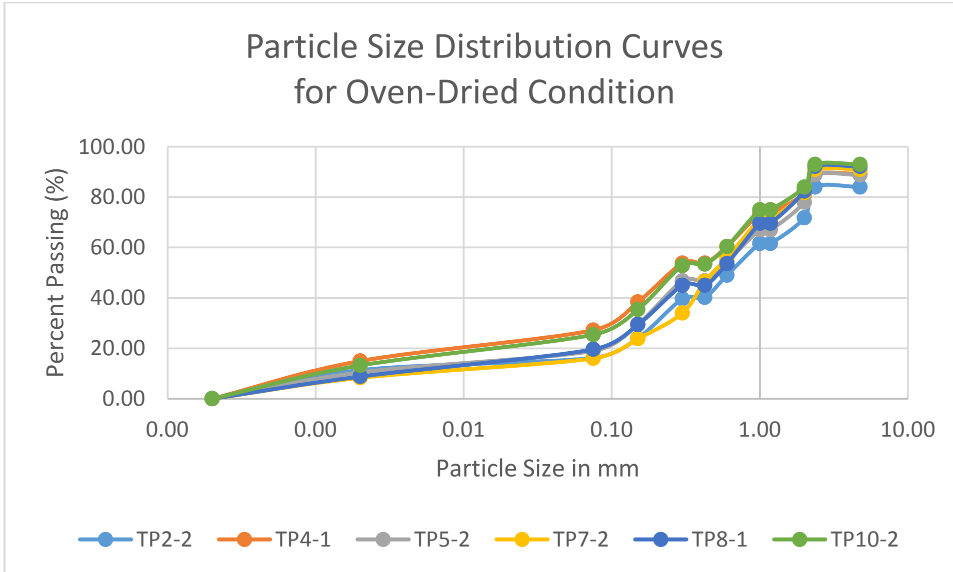

Fig. A.1f Particle Size Distribution Curves at Oven-dried condition

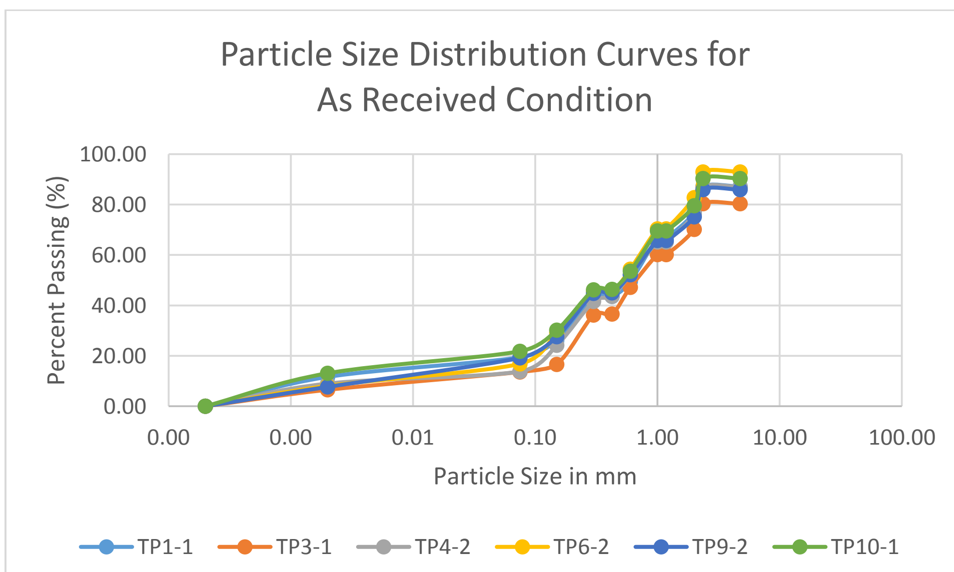

Fig. A.1g Particle Size Distribution Curves at As-Received condition

Appendix-B

Precipitation and Temperature Conditions

The tables in this appendix show the mean annual rainfall in centimeter (cm) from 1998-2006 and monthly mean temperature maximum, minimum and average temperature of Adama Town from 1998-2007.

Table B.1 Mean Annual Rainfall in Centimetre (cm)-from 1998-2006

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept	Oct	Nov	Dec	Ave.
1998	11.8	25.6	105.2	19.8	49	55.3	196.5	220.6	144.7	132.8	0	0	80.13
1999	9.2	0	34.6	1.2	19	74	283.2	194.4	66.3	164.7	3.1	0	70.78
2000	0	0	20.2	16.1	52	60.8	355.1	269	133.6	85.7	57.8	12.9	88.56
2001	0	6.2	108.3	28.7	177	51.2	216.9	145.3	107.8	1.7	0	6.6	70.8
2002	20.9	11.1	*	51.3	23	50.2	235.6	205.7	65.3	1.1	0	34.5	53.86
2003	46.5	69.1	151.2	88.9	3.6	75.2	114.4	279.7	122.8	0	5.3	48.8	93.89
2004	28.8	3.3	77.4	53.1	1.9	63.3	144.3	227.3	77.1	58.6	12.8	1.6	59.97
2005	72.5	6.3	90.1	41.3	71	50.2	173.5	165	68.4	6	5.3	0	60.04
2006	17.6	88.4	64.6	88.7	28	58.7	205.5	225	128.8	10.1	0.5	28.5	76.02
Ave.	23.1	23.3	81.5	43.2	47	59.9		214.7	101.6	51.2	9.4	14.8	72.7

Source: National Metrological Service Agency (Computed)

Table B.2 Monthly mean temperature maximum, minimum and average temperature of Adama Town from (1998-2007)

	Jan	Feb	Mar	Apr	may	Jun	Jul	Aug	Sep	Oct	Nov	Dec	yearly
Mean max	26.7	28.9	29.3	29.9	31.1	29.8	26.2	25.7	27.1	27.6	27	25.9	26.7
Mean min	13.1	14.4	15	15.9	16.6	17.6	16.3	16.2	15.2	13.9	13.1	12.3	13.1
Ave.	19.9	21.7	22.2	22.9	23.9	23.7	21.3	21	21.2	20.8	20.1	19.1	19.9

Source: National Metrological Service Agency (Computed)

Appendix-C

Profile View of the Test Pits for Some of the Specimens

In this Appendix part profile view for some of the test pits are shown below in Figure C.1, Figure C.2, Figure C.3 and Figure C.4 and also test samples under air drying and oven drying conditions are shown in Figure C.5 and Figure C.6.

Fig. C.1 The profile view of Pit for the specimen TP 3

Fig. C.2 The profile view of Pit for the specimen TP 6

Fig. C.3 The profile view of Pit for the specimen TP 8

Fig. C.4 The profile view of Pit for the specimen TP 10

Test samples under air drying and oven drying conditions are shown respectively in Fig. C.5 and Fig. C.6

Fig. C.5 Test Samples under Air Drying Condition

Fig. C.6 Test Samples under Oven Dry Condition