ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Investigating some of the Engineering Properties of Durame soil

(Southern Ethiopia)

By

Fitsum Markos

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Investigating some of the Engineering Properties of Durame soil

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

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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. Messele Haile and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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Table of contents

Symbols and abbreviations

Designation		Units
q_u	Unconfined Compressive Strength	KN/m^2
e	Void ratio	---
LL	Liquid Limit	%
PL	Plastic Limit	%
PI	Plasticity Index	%
LS	Linear shrinkage	%
FS	Free Swell	%
Sg	Specific gravity	-----
W	Moisture content	%
N	No. of blows for Liquid limit	---
AD	Air drying	
OD	Oven drying at a temperature of 105oc	
USCS	Unified soil classification system	
AASHO	American Association of State Highway Officials.	
AASHTO	American Association of State Highway and Transportation Officials.	
ASTM	American Society for testing and Materials.	
C_c	Compression index	
C_r	Recompression index	
C_v	Coefficient of consolidation	
P_c	Pre-consolidation pressure	KN/m^2

List of Figures

List of Tables

Abstract

Project delays, failures and cost over-run are the results of inadequate and inappropriate soil investigation. Therefore, a thorough and comprehensive geotechnical investigation is an essential requirement to the design and construction of civil engineering projects.

This research is intended to investigate some of the engineering properties of Durame soil. To achieve this objective samples from different parts of the city were collected and laboratory tests were done on the collected samples.

Identifying the soil characteristic is essential to determine the type of test and test procedure that is applied during sampling, sample preparation and testing. Accordingly, the soil under investigation was identified as Lateritic soil.

Moisture content determination using oven temperature of l05°C and Air drying for 15 days were carried out on the soil samples to investigate presence of loosely bound water of hydration. It was found that there is considerable amount of structural water.

Atterberg Limits were done for different testing procedures on the soil samples to see effect of test manipulation on concretionary bond. The liquid limit tests were carried out on soil specimens mixed for 5 minutes and 30 minutes durations. It was observed from the test results that the mixing durations has significant effect on the values of liquid limits. Accordingly, the soil samples have been sensitive to test procedures.

Analysis of specific gravities of the soils using different pretreatment conditions showed that, increase in drying temperature from an air-dried to 105^{o}C oven drying temperature reduces specific gravity of the soils.

Specific Gravity test, Particle Size Distribution, Atterberg Limit tests and Free Swell tests were conducted on air dried and 105^{o}c oven dried pretreatment conditions, and resulted in different values.

According to the study for air dried and oven dried temperature of 105^{o}c ; LL ranges between 44 – 79%, PI ranges between 16 – 42%,Clay fraction ranges between 15 – 75%, Free swell ranges between 20-70% and Specific Gravity ranges between 2.52-2.97.

One-dimensional consolidation tests were done and the soils have compression index ranging from 0.219-0.596, recompression index ranging from 0.033-0.097, coefficient of consolidation ranging from 0.012 to 0.351 cm^2/sec.

1. Introduction

1.1. Background of the problem

Geotechnical investigations are performed to evaluate those geologic, seismologic, and soils conditions that affect the safety, cost effectiveness, design, and execution of a proposed engineering project. From project conception through to construction and throughout the operation and maintenance phase, geotechnical investigations are designed to provide the level of information appropriate to the particular project development stage. In most instances, initial geotechnical investigations will be general and will cover broad geographic areas. As project development continues, geotechnical investigations become more detailed and covers smaller, more specific areas. For large, complex projects, the geotechnical investigation can involve highly detailed geologic mapping such as a rock surface for foundations.

A thorough and comprehensive geotechnical investigation is an essential requirement to the design and construction of civil engineering projects. The proper design of civil engineering structures like foundation of buildings, retaining walls, high ways, etc. requires adequate knowledge of sub surface conditions at the sites of the structures. Insufficient geotechnical investigations, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs, delays in construction schedules, costly construction modifications, use of substandard borrow material, environmental damage to the site, postconstruction remedial work, and even failure of a structure and subsequent litigation [29].

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Geotechnical investigation on the engineering properties of the soil of Ethiopia, which is developing at high growth rate and which needs many construction works in the future, is very essential. The investigation provides data which is very important for civil engineers in preliminary design and in designing foundation, pavement, retaining structures, etc for future construction projects in the country.

Many researches are done on residual soils affected by testing procedures and pre treatment conditions. To mention some of them: The influence of sample preparation prior to testing on index property tests of tropical soils is studied by Hunde (2003) in the thesis titled “Investigation of influence of compaction on the suitability of earth fill dams of tropical soils”, the thesis titled

"Lateritic and Laterite Soil and other Problematic Soils of Africa" observed that the index properties of lateritic soils of Ethiopia change with drying temperature [16]. The thesis titled "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 [31]. Wossen (2009) in his thesis titled" Investigation into the appropriate laboratory testing procedures for the determination of the index properties of the Lateritic Soils of Western Ethiopia (Nedjo-Jarso-Begi Road area)" proposed appropriate laboratory testing procedure. The work "study of the index properties and shear strength parameters of literite soils of Wolayita –Sodo" observed the sensitivity of the soils for the testing procedures [25].

Durame which is located in southeastern Ethiopia is covered with red colored soil. Depending on the soil forming factors such as climate, topography, drainage and the parent material, red soils can be lateritic soils. Durame shares some common, soil-forming factors (rainfall, topography and temperature) with that of Wolayita Sodo. Accordingly the soil of Durame is supposed to be laterite.

There is no previously done research in Durame area, thus this thesis gives us better understanding about the engineering properties of the soil. Identifying the soil characteristic is essential to recommend the appropriate testing procedures and pretreatment conditions.

1.2. Objectives of the study

- To investigate some of the index properties of the Durame soil: Specific gravity, free swell, Grain size analysis, etc.
- To check whether the soil of Durame is lateritic or not by conducting index and chemical tests
- To investigate the effect of temperature variations, pre-treatment conditions and testing procedures, on the behavior of the soil.
- To investigate shear strength of Durame soils using UCS.
- To investigate the consolidation characteristics of Durame soils.

1.3. Methodology

To achieve the above mentioned objectives seven sampling areas were selected. From the selected sampling areas, pits were excavated to a depth of around three meters. Disturbed samples of soils were collected for laboratory testing. Specimens were taken from the following sites: At the back of High school--TP1,To the right side of Luba--TP2, Gocho green area--TP3, At the back of Kala Hiwot Church--TP4 ,Isac school--TP5 ,Kutere Ande school-TP6 and Durame Hospital--TP7.

Effect of temperature variations on moisture content determination have been checked in the laboratory using different temperature conditions. Different pretreatment methods have been applied to a number of samples tested in the laboratory. These methods were air drying (AD) - dried to constant weight under normal temperature and oven drying (OD) - dried in an oven for 24 hours at 105ºc. The effect on the Atterberg Limits of varying mixing time and sample preparation were also studied.

1.4. Limitation of the study

Fourteen samples of soil were collected from seven pits. The scope of this study is limited to investigating the index properties, and UCS and consolidation characteristic. The depth of investigation in this research is limited to the maximum depth of three meters.

1.5. Organization of the Thesis

This thesis work consists of six Chapters. In this introductory Chapter the background of the problem, objectives, methodology, limitation and organization of the thesis are presented. Chapter two deals with literature review which discusses about residual soil origin and formation, classification, sensitivity to pre-treatment and testing procedure. Chapter three deals with sampling areas description. The fourth Chapter deals with insitu properties with sample description and the types of laboratory tests conducted and results obtained. The test results obtained from this work by comparing with previously done test for red clay and laterities soils is indicated in Chapter five. Chapter six includes the conclusions and recommendations drawn from the research. Finally, Grain size distribution curves under different testing conditions and testing depth, percentage amount of grain sizes for different test conditions and classifications are included in appendices.

2. Literature review

2.1. General characteristics of residual soil

The word 'latérite' was suggested by Buchanan (1807) to denote a building material used in the mountain regions of Malabar (India). Its appearance is that of a ferruginous deposit of vesicular structure, apparently unstratified and occurring not far below the surface. When fresh it can readily be cut into regular blocks with a cutting tool. On exposure to the air it rapidly hardens and becomes highly resistant to weathering. Because of these properties it is frequently used as a building material comparable to bricks. The word for it in some local dialects means brick earth and the name 'latérite' is merely a translation from the Latin *later,* meaning 'brick' and so relating solely to the use to which these blocks are put [21].

There is some dispute in regard to the authorship of the term. Prescott, however, suggests that Babington (1821) was the first to use it scientifically. Buchanan soon realized the disadvantage of using too specific a word for a material of which the analytical characters were little known and during the period 1807-14 he used the words 'latérite' and 'brickstone' indiscriminately. The unusual feature of the occurrence first described by Buchanan under the name latérite was that it had a soft consistency in situ but hardened rapidly on exposure. Buchanan himself noted that morphologically similar occurrences observed in Bihar were already hardened in the soil. It was only towards the end of his life that Buchanan restricted the use of latérite to a material of soft consistency which hardened on exposure to the air [21].

The general definition of residual soils varies from country to country, but reasonably general definition would be: A residual soil is a soil like material derived from the in situ weathering and decomposition of rock which has not been transported from its original location. Residual soil can have characteristics that are quite distinctively different from those of transported soils. And it is difficult to relate the properties of a residual soil directly to its parent rocks. Each situation requires individual consideration and it is rarely possible to extrapolate the experience in one area to predict conditions in another, even if the underlying hard rock geology in the two areas are similar [5].

2.1.1. Origin and Formation of Residual Soils

The formations of residual soils are affected by weathering process, climate and topography.

Weathering process

In the weathering process the parent rock and rock minerals break down, releasing internal energy and forming substances having a lower internal energy which are therefore more stable. The three major agencies of weathering being Physical,Chemical and Biological processes.

Occasionally, residual soils may be formed by the in situ weathering of unconsolidated sediments. But most commonly, they are formed from igneous or metamorphic parent rocks, Residual soils formed from sedimentary rocks are not uncommon. Chemical processes tend to predominate in the weathering of igneous rocks, whereas physical weathering are closely interrelated that one process never proceeds without some contribution from the other [5].

Physical process (e.g. stress release by erosion, differential thermal strain and ice and salt crystallization pressures) pulverize the rock, expose fresh surfaces to chemical attack and increase the permeability of the material to percolation of chemically reactive fluids. Chemical process, chiefly hydrolysis, cation exchange and oxidation alter the original rock minerals to form more stable clay minerals [18]. Biological weathering includes both physical action (e.g. splitting by root wedging) and chemical action(e.g. bacteriological oxidation, chelation and reduction of iron and sulphur compounds (e.g. pings) [5].

Physical breakdown and chemical reactions lead to the formation of tropical and residual soils. Chemical reaction process can be decomposition, leaching and dehydration. These processes may proceed simultaneously, cyclically, or sequentially, depending on the climatic conditions and the time of exposure relative to the reaction rates.

*I) Decomposition***:** This includes the physical breakdown of the rock fabric and the chemical breakdown of constituent minerals, usually rock forming minerals. Typical products being clay minerals oxides, hydroxides, and free silica. Under tropical conditions, reactions may occur relatively quickly so that recently transported soils may subsequently be modified in to material with residual soil characteristics. Decomposition according to [17] [31] is Physio-chemical breakdown of primary minerals and release of constituent elements (SiO_2, Al_2O_3 ,Fe_2O_3, CaO, MgO, K_2O, Na_2O, etc), which appear in simple ionic forms.

II) Leaching and Re-Deposition: This includes laterization process; involving removal of combined silica, alkaline earth, and alkalies. There is a consequent accumulation of oxides and hydroxides of sesquioxides and the leached material may be redeposited and accumulated elsewhere in the soil profile [5]. The level to which the secondary stage is formed is carried depending on the nature and extent of the chemical weathering of primary minerals. Under conditions of low chemical and soil-forming activity, the physio-chemical weathering does not continue beyond the clay-forming stage, and tends to produce end products consisting of clay minerals predominantly represented by Kaolinite and occasionally by hydrated or hydrous oxides of iron and aluminum [5][31].

III) Dehydration / Desiccation: (Either partial or complete alter), this is the process that the composition and distribution of the sesquioxide-rich minerals in a manner, which is generally not reversible upon wetting. Dehydration also influences the formative process of clay minerals. That is, in the case of total dehydration, strongly cemented soils with a unique granular soil structure may be formed [5].

Climate

Climate exerts a considerable influence on the rate of weathering. Physical weathering is more predominant in dry climates while chemical and biological processes are dominant in wet climates. The extent and rate of chemical weathering is largely controlled by the availability of moisture and by temperature. The clay minerals of the soils of the world changed in predictable way with distance from the equator.

Climate has a further effect on the properties of tropical residual soils. In sub humid tropical and subtropical areas water tables are often deeper than 5 to 10 m and the effects of unsaturation, desiccation and seasonal or longer term rewetting have to be taken into account in geotechnical design. There are many accounts of the effect of unsaturation on the behavior of soils. The effective stress relationship for unsaturated soils is governed by the stress difference ($\sigma - u_a$) and the suction (u_a- u_w). In most practical situations u_a equals to the atmospheric pressure and can be zero. The conventional form of the effective stress equation can be used with little error for soils that are unsaturated [14].

Topography

Topography controls the rate of weathering by partly determining the amount of available water for each zone of weathering. Precipitation will tend to run off hills and accumulate soils in valleys and hollows. Soil profiles developed from basic Igenous Rocks on hillsides the depth of weathering increase down the slope where as Kaolinite / Halloysite are the predominant clay minerals at the top of the slope and Smectite at the bottom of the slope [5].

Regarding topography and drainage, the slope angle controls the amount of water available to move downward through the weathering zone. On steep slopes run-off is greater than infiltration; erosion is active, and conditions are generally not suitable for the development of deep weathering. On the other hand, on flatter slopes, run-off is not so marked; only limited amount of erosion takes place; and long uninterrupted periods of weathering can take place; producing deep weathered soil profile. On a level ground, however, where drainage is impeded and the ground is waterlogged, black Montimorillonite soils dominate instead of red soils [9].

2.1.2. Classification of residual soils

2.1.2.1. 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 [5].

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.

2.1.2.2. 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 [5].

2.1.2.2.1. Basis of the system

The specific characteristic of residual soils which distinguish them from transported soils can generally be attributed either to the presence of specific clay or structural effects, such as the presence of unweathered or partially weathered rock, relict discontinuity and other planes of weathering and inter- particle bonds [5].

2.1.2.2.2. The proposed grouping

The first step in the grouping of residual soils is to divide them into groups on the basis of mineralogical composition alone, without referring to their undisturbed state. The following three groups are often suggested [5] [13].

1. *Group A:* Soils without a strong mineralogical influence, e.g., Saprolites (Residual soil with clear structural feature inherited from its parent rock).
2. *Group B:* Soils with a strong mineralogical influence deriving from clay minerals also commonly found in transported soils (Black Cotton Soils).
3. *Group C*: Soils with a strong mineralogical influence deriving from special clay minerals only found in residual soils (i.e. based on the silicate clay minerals, Halloysite and Allophone, and non-silicate minerals ('oxide' minerals) which are the hydrated forms of aluminium and iron oxide (the sesquioxides),Gibbsite and Goethite).

The group C, can be classified as the following sub-groups [5]

*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 laterites are formed. The silica/alumina ratio (SiO_2 /Al_2O_3) and Silica/Sesquioxide ratio have both been used as indicators of degree of laterization and served as basis for classification of residual soils. Ratios less than 1.33 have sometimes been considered indicative of true laterites, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of nonlateritic tropically weathered soils. This sub groups perhaps be termed as Lateritic group [16] [5].

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

Laterites occur mostly in tropical and sub-tropical regions with hot, humid climatic conditions. It has been suggested that a minimum annual temperature of around 25^oC is needed for their formation, and in seasonal situations there should be a coincidence of the warm and wet periods. If there is high rainfall during the cold seasons, laterite does not develop freely. The minimum rain fall required for the formation of laterites is generally at least 750mm.The higher rain fall above this value, the greater the leaching effect, which removes the silica, reducing the Silica/Sesquioxide ratio and increase the degree of laterization [9].

Most of the time literates occur in an already hardened state. It is also common for some areas of the world to be observed having deposits that have not been exposed to the drying process and are soft with a clayey texture and mottled coloring, which may include red, yellow, brown, purple, and white. Moreover when these soils are exposed to air or dried by lowering their water table, irreversible hardening will take place, producing a material that is suitable for use as a building or road stone. As a result, laterite is gravel sized; ranging from pea sized gravel to 3 inches minus (Passing 3 inches), although larger cemented masses are possible. A specific form of laterite rock, known as Plinthite is soft enough to cut with a metal tool, but it hardens irreversibly when removed from the ground [31].

2.1.3. Other classifications of residual soils

Laterites classification is also possible according to their genetic basis, size of particle and degree of concretion/cementation. Besides the grouping system presented above, 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. Most of the residual soils of Africa can be divided into three groups based on their genetic basis, determined by the soil-forming factors and given below [16]:

i. Ferruginous Soils: occur in the more arid extremes for lateritic soils, in areas with pronounced dry seasons. They are formed over all rock types: igneous, metamorphic and sedimentary. It requires an average annual rainfall of *600-800 mm* for its formation.

ii. Ferrallitic Soils: These soils in the humid extremes for lateritic soils and in areas with dense vegetation. These soils are also formed over all rock types. The annual average rainfall requirement for its formation is *1500- 4000mm*. Both of the above soils have SiO_2 / (Fe_2O_3 + Al_2O_3) 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 Ferrallitic 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 [16].

The mineral composition of the three types of soils are shown in table 2.1

Table 2.1. Dominant mineral contents for laterite sub group [16]

Ferruginuous	Ferralitic	Ferrisol
Hematite Geothite Kaolinite	Gibbsite Geothite Kaolinite	Kaolinite Geothite Gibbsite Hematite

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.[16]

*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**.**

Moreover, Anthony has distinguished the following main types and sub-divisions of laterite [16]

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) Ferruginized rock: Here, rock structure is still visible, but with substantial isomorphous replacement by Iron.

5) Soft laterite: Mottled iron-rich clay, which hardens irreversibly on exposure to air to, repeated wetting and drying.

Lithological classification on the other hand, depends on particle size of laterites [16]

Lateritic clays < 0.002 mm

silts = 0.002 ~ 0.06 mm

sands = 0.06 ~ 2 mm

gravels = 2 ~ 60 mm

and cuirasse > 60 mm

2.2. Index Tests of Residual Soils

2.2.1. Moisture content

The conventional test for the determination of moisture content is based on the loss of water when a soil is dried to a constant mass at a temperature between 105^{o}C and 110^{o}C. In many residual soils however, some moisture exits as water of crystallization, within the structure of minerals presented in the soils particle. Some of this structural moisture may be removed by drying at the above temperature assuring the behavior of the soil. The following procedure is therefore recommended:

Two test specimens should be prepared for moisture content determinations. One specimen should be oven dried at 105ºC until successive weighing show that no further loss of mass. The moisture content should then be calculated in normal way. The second sample should be air dried (if feasible); or oven dried at a temperature of no more than 50ºC and a maximum relative humidity (RH) of 30% until successive weighing show that no further loss of mass. The two moisture content results should then be compared; a significant difference (4-6% of moisture content obtained by oven drying at 105ºC) indicates that structural water is present. This water forms part of 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^oC and 30% RH) if possible, the lower drying temperature of 50^oC should be used [5].

2.2.2. Atterberg Limits

Two further problems may be experienced when carrying out tests to determine the Atterberg Limits.

2.2.2.1. 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. Upon drying the plasticity decreases.

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 [16].

According to Blight, the effect of drying prier to testing is attributed to [5]:

- Increased cementation due to oxidation of the iron and aluminum Sesqueoxides, or
- Dehydration of Allophane and Halloysite, or both.

2.2.2.2. Effect of method and time of mixing on Atterberg Limits

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

In order to address this problem:

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 (of >5% of the liquid limit obtained) 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:

• Limit the mixing times to no more than 5 minutes

• 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 distilled water to form slurry, which is then washed through a 425 µm sieves until the water runs clear. The material passing the sieve is collected and used for Atterberg Limit test [5].

2.2.3. Specific Gravity

The soils to be used in this test should be in its natural moisture content. Pre- test drying of the soil should be avoided as this tends to reduce the measured specific gravity. In residual soils the specific gravity may be unusually high or unusually low depending on mineralogy [5].

The available data indicate that specific gravities vary not only with the textural soils but also within different fractions. Lateritic soils have been found to have very high specific gravities of between 2.6 to 3.4 [16].

2.2.4. Particle Size Distribution

Texturally lateritic soils are very variable and may contain all fraction sizes; boulders, cobbles, gravel, sand, silt, and clay as well as concretionary rocks. Quartzitic gravels, which are formed from the alteration of Quartz rich parent rocks, are generally well graded with 20% of silt and clay-size fraction. Concretionary laterites have a higher content of fines ranging from 35% to 40%. Foot slope concretionary laterite gravels are coarse and gap graded (less sand), compared to high level gravels [15].

The particle size distribution of residual soils is affected by [5]

i) Effect of drying: The most widely reported effect of drying is reduce the percentage that is reported as the clay fraction (finer than 2µm).It is accordingly recommended that drying of the soil prior to testing be avoided. Oven dried lateratic soils were found to give the least amount clay fraction, as compared to air dried or as received (natural moisture content) samples

ii) Chemical pretreatment: If it is considered necessary to eliminate Carbonates or Sesquioxides, then pretreatment with hydrochloric acid is recommended.

iii) Sedimentation: is essential to achieved complete dispersion of fine particles prior to carrying out a sedimentation test. The sample should be immersed in a solution of dispersant such as dilute alkaline Sodium Hexametaphosphate and therefore washed through the standard nest of sieves [5].

Lyon found that wet sieving increase the silt and clay fraction from 7 to 20 % as compared to dry sieving. It has been found that sodium Hexametaphosphate generally gives better dispersion of the fine fractions [16].

3. Sampling Area Description

3.1. General

Durame is a town in southeastern Ethiopia. The administrative center of the Kembata Tembaro Zone in the Southern Nations, Nationalities and Peoples Region (SNNPR).The town has a latitude and longitude of 7°14′N and 37°53′E with an elevation of 2101 meters above sea level. Based on figures from the Central Statistical Agency in 2005, Durame has an estimated total population of 12,849 of whom 6,461 are men and 6,388 are women [29]. It is about 219Km from Addis Ababa. Two roads connect the town from Addis Ababa through Shashamene and from Addis Ababa through Hossana.

3.2. Climate

3.1.1. Rainfall

The records of National Meteorological Service Agency from Durame Observatory substation show that the mean annual rainfall for twenty seven years i.e. from 1983 to 2010, at an altitude of 2101m above mean sea level, latitude of 7°14′N and longitude of 37°53′E is 1260mm and shown in Fig 3.1. The rainy season is from the months of April to September. Around 75% of the rainfall arrives in these months.

3.2.2. Temperature

In a mountainous tropical country like Ethiopia altitude is by far the most important factor in controlling climate. It affects distribution of both temperature and rainfall. Generally, regions between 1500 - 2300 meters above mean sea level. (categorized as 'woina dega' or sub tropical climate) have temperatures that range between 15 – 20^{o}C, areas between 500 – 1500 meters above mean sea level. (i.e. 'Kola' or tropical climate) have 20 -30^{o}C and areas below 500meters above mean sea level (i.e. 'Bereha' or desert climate) have a temperature of 30^{o}C and above [20].

The altitude of the Woreda ,where Durame is located ranges from 1700 to 3028 m above sea level. Durame has a mean minimum and mean maximum monthly temperatures of 8.6 and 24.4°C respectively. The highest temperatures occur during months of Feb., March, April, Nov., and Dec. where as Oct. Nov .and December have low temperature (Fig.3.2 and Fig. 3.3.)

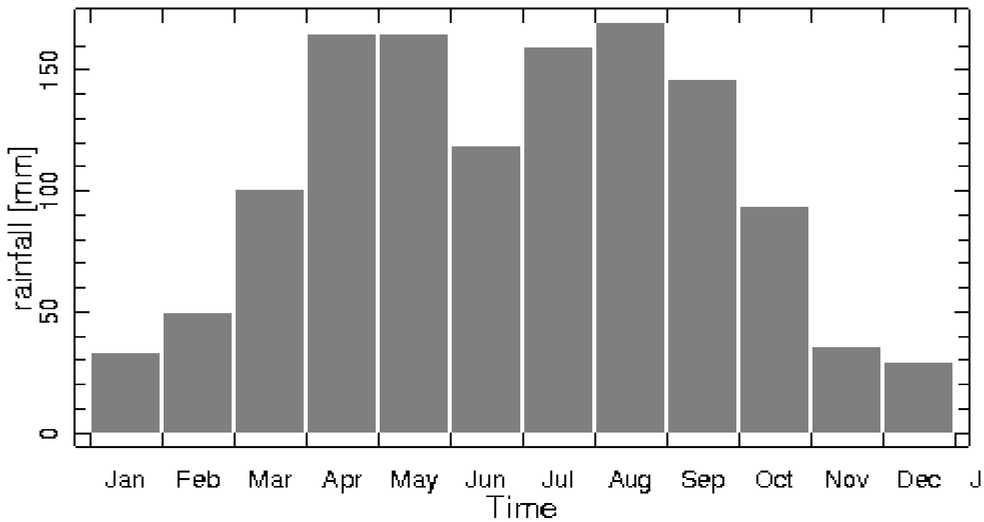

Fig. 3.1 Mean monthly rainfall distribution of Durame (1983 - 2010 G.C.)

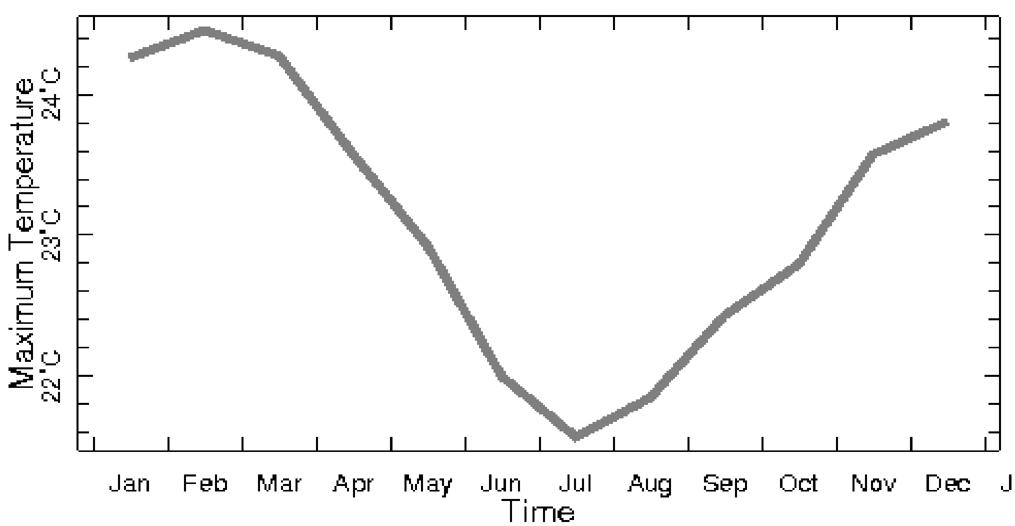

Fig. 3.2. Mean Monthly maximum Temperature distribution of Durame (1983 - 2010 G.C)

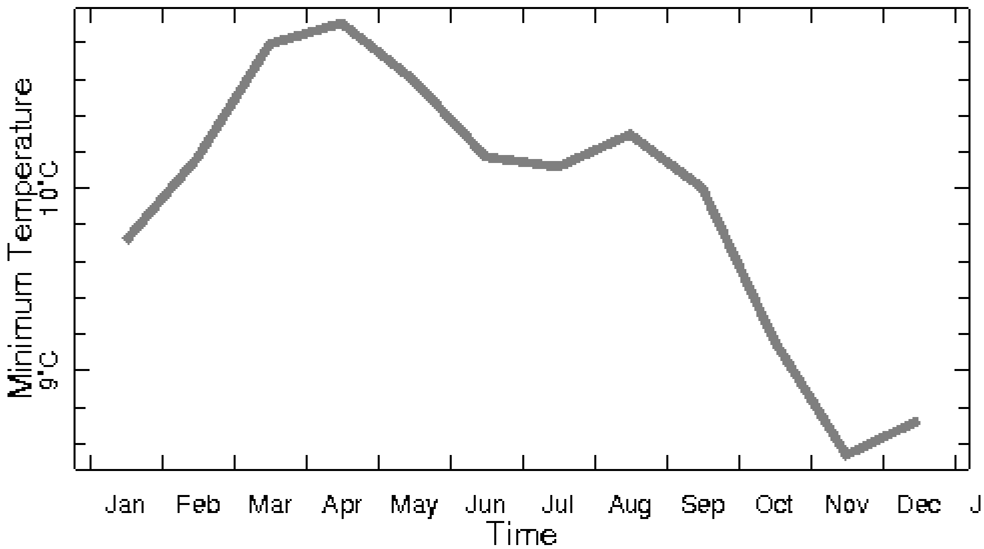

Fig.3.3. Mean monthly minimum Temperature distribution of Durame (1983 - 2010 G.C)

4. In-situ Properties and Laboratory Test Analysis and Results

4.1 In-situ Properties Description

The soil samples for this thesis work are collected from Durame. Before selecting sampling areas, visual site investigation were made. The soil has the same color in different places but the topography is different. Accordingly, seven sampling areas were selected from different locations of the town depending on the topography.TP1-at the back of high school;TP2-to the right side of Luba;TP3-Gocho green area;TP4-at the back of Kale Hiwot Church;TP5-to the market side of Isac school;TP6-Around Kutere Ande school and TP7-infront of the first entrance of the Durame Hospital. The distance between TP1 and TP2 is about 200m.The distance between TP3 and TP4 is around 300m. TP5 ,TP6 and TP7 are about 1 Km apart (Fig 4.1). Pits were excavated to the maximum depth of three meters. Undisturbed and disturbed samples are taken from 1.5m and 3m depth for each test pits. The disturbed samples taken are around 10kg for each test pits depth, that means a total of around 140kg was collected. Distributed samples were covered with plastic bag and undisturbed samples were sealed with wax and covered with plastic bag to maintain surrounding moisture.

Table 4.1 Sample location, depth and the designation used for the samples

Sample designation	Sampling depth(m)	disturbed sample amount(Kg)	Undisturbed sample number	Sample location	Visual color observed
TP1-1	1.3-1.5	10	1	At the back of High School	Reddish Brown color
TP1-2	2.8-3.0	10	1		
TP2-1	1.3-1.5	10	1	Right side of Luba	Chocolate Brown
TP2-2	2.8-3.0	10	1		
TP3-1	1.3-1.5	10	1	Gocho green area	Reddish color
TP3-2	2.8-3.0	10	1		
TP4-1	1.3-1.5	10	1	Back of Kale Hiwot Church	Reddish color
TP4-2	2.8-3.0	10	1		
TP5-1	1.3-1.5	10	1	Market side of Isac School	Reddish Brown color
TP5-2	2.8-3.0	10	1		
TP6-1	1.3-1.5	10	1	Around Kutere Ande school	Reddish Brown
TP6-2	2.8-3.0	10	1		
TP7-1	1.3-1.5	10	1	At the first entrance of Durame Hospital	Reddish color
TP7-2	2.8-3.0	10	1		

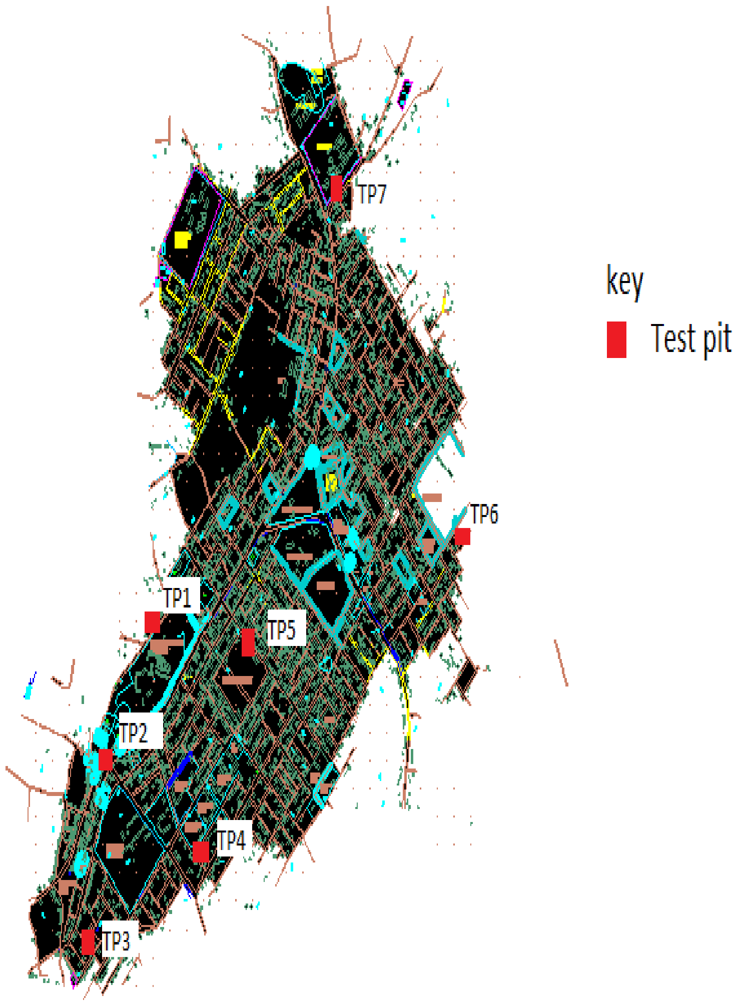

Fig.4.1. Durame town plan with test pits location

Fig. 4.2. Typical soil profiles

4.2. Laboratory test results and discussions.

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

4.2.1 Index Properties

4.2.1.1 General

The tests required for the determination of engineering properties are generally elaborate and time-consuming. Sometimes, the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests. This is possible if index properties are determined. The properties of soils which are not of primary interest for the geotechnical engineer but which are indicative of the engineering properties are called index properties of soils. The soils are classified and identified based on the index properties [3].

However, studies have revealed that tropical soils are different from temperate zone soils in terms of genesis and structure. Their structures as compared to dispersed temperate zone soils have necessitated modifications to the mechanical or grading tests; the conventional pretreatment methods have considerable effect on the index properties of tropical soils. Therefore, special consideration is required during pretreatments and testing methods while testing tropical soils [5].The various properties of soils, which could be considered as index properties are: Grain size analysis, Atterberg Limits, Free swell and Specific gravity.

4.2.1.2. Moisture Content

4.2.1.2.1. Effect of Temperature on Moisture Content Determination

The conventional method for the determination of moisture content is based on the loss of water when a soil is dried to a constant mass at a temperature between 105 and 110^{0}C. Using the above temperature 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.

Moisture contents of the soil samples were determined in the laboratory according to ASTM and Blight [4] [5]. The method allows drying the sample to an oven temperature of 105^0C and oven temperature of 50^0C with maximum relative humidity (RH) of 30% or equivalently air-drying. For this thesis work seven samples were collected and air-dried until no loss of weight is achieved. The same samples were treated in an oven drying up to 105^0C until constant mass is obtained. The values of the moisture contents are presented and compared in Table 4.2. As it was stated in section 2.2.1, 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 moisture content difference is greater than 4%, which indicates that the soil of Durame contains a considerable amount of 'water of hydration' or 'structural water' leading to irreversible changes upon drying, hence the test for this soil types must be conducted by air drying or partial oven drying to 50^oC at RH of 30%.

Table 4.2. Moisture content at different temperatures

Serial No.	Test pits	depth(m)	Oven dry at 105 ^{0}c	Air dried	Difference
1	TP2	1.3-1.5	22.22	15.6	6.62
		2.8-3.0	24.42	18.06	6.36
2	TP3	1.3-1.5	32.49	23.76	8.73
3	TP4	1.3-1.5	20.95	14.19	6.76
		2.8-3.0	27.50	20.00	7.50
4	TP6	1.3-1.5	15.35	10.18	5.57
5	TP7	1.3-1.5	28.57	20.65	7.92

4.2.1.3. Atterberg Limits

The presence of clay mineral in fine grained soils makes the soil to be remolded without crumbling if some moisture exists. This cohesive nature is caused by the adsorbed water surrounding the particle. At very low moisture, the soil behaves more like solid but when the moisture gets very high, the soil and water may flow like a liquid. Atterberg developed Liquid Limit, Plastic Limit and Shrinkage Limit to describe soil consistency [11]. As stated in section 2.2.2. lateritic soils are affected by pretreatment and mixing time.

4.2.1.3.1. Test procedures

For the determination of the Atterberg Limit values, air-dried and oven-dried soil samples were tested following the procedures given in ASTM D 421-85 and D 4318-98.The air-dried soil samples were prepared by spreading the material out in trays in the laboratory and leaving it open to the air for at least 15 days. The room temperature was about 20^0C. The oven-dried samples were prepared by drying the soils overnight at 105^0C oven temperature. The portions of the samples passing the No. 40(0.425mm) sieve were used for the preparation of the samples.

4.2.1.3.2. Test results and discussions

In order to investigate the effect of temperature on the Atterberg Limits, the samples were oven dried (OD) and air-dried (AD). The test results are shown in Table 4.3. From the test results one can see that the different treatments affect the Atterberg Limits of the soils resulting a decrease in the liquid limit and plasticity index for OD samples. The test results show great difference for almost all soil samples. It may be because of: (1) the tendency to form aggregations due to oxidation of the iron and aluminium Sesquioxides (2) the loss of water of hydration or both. Hence the treatment conditions (temperature treatments) strongly affect the Atterberg Limit values of Durame soil.

Table 4.3. Atterberg Limit values at different testing conditions

Test pits	Depth(m)	condition	LL(%)	PL(%)	PI(%)
		AD	64.42	37.95	26.47
		OD	53.06	36.35	16.71
		AD	75.00	46.68	28.32
TP1	2.8-3.0	OD	60.00	43.05	16.95
		AD	65.22	34.98	30.24
	1.3-1.5	OD	59.38	34.84	24.54
		AD	65.83	40.00	25.83
TP2	2.8-3.0	OD	63.88	38.68	25.20

Table 4.3. Continued

TP3	1.3-1.5	AD	64.90	28.58	36.32
		OD	61.41	34.96	26.45
	2.8-3.0	AD	60.63	36.10	24.53
		OD	51.19	29.63	21.56
TP4	1.3-1.5	AD	79.22	37.47	41.75
		OD	57.02	35.36	21.66
	2.8-3.0	AD	62.08	35.36	26.72
		OD	54.59	31.97	22.62
TP5	1.3-1.5	AD	68.11	30.93	37.18
		OD	59.94	33.53	26.41
	2.8-3.0	AD	67.19	30.98	36.21
		OD	54.04	36.36	17.68
TP6	1.3-1.5	AD	50.46	26.03	24.43
		OD	43.61	22.69	20.92
	2.8-3.0	AD	69.88	38.73	31.15
		OD	47.52	31.23	16.29
TP7	1.3-1.5	AD	71.18	38.04	33.14
		OD	55.19	33.67	21.52
	2.8-3.0	AD	76.35	53.89	22.46
		OD	66.97	48.96	18.00

4.2.1.3.3. Effects of mixing time on Atterberg Limits

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

The effect of mixing time on the Atterberg Limits was investigated by conducting the Atterberg Limits at different test procedures as mentioned in section 2.2.2.2. The Atterberg Limit tests were conducted on the air dried soil samples according to the procedures mentioned in ASTM and Blight [4][5]. The test results with their treatment conditions are shown on Table 4.4.

Five air dried test portions were mixed with water to give the range of water contents suitable for liquid and plastic limit determinations. The mixing time was about 5 minute, and the mixed samples were left for moisture equilibrium for 24 hour before testing. After determining the moisture content for each test point on each test portion, the remaining soil was then mixed for a further 25minutes before determining the liquid limit again. The liquid limit values of the specimens 5 minutes (LL5min) and 30 minutes (LL30min) mixing times were determined. The difference between liquid limit test values of the specimens for 5 minutes and 30 minutes mixing were calculated and summarized in Table 4.4. A significant difference (i.e. >5% of the liquid limit was 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.

The test results indicate that, the soil of Durame 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 to a lesser extent the larger plasticity index.

Hence the test for Durame soils should be as recommended in Blight [5], that is;

a) Limit the mixing times to not more than 5 minutes

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

Additionally the soil should be broken-down by soaking in distilled water, and not by drying and grinding. The soil should be immersed in distilled water to form slurry, which is then washed through a 425 µm sieves until the water runs clear. The material passing the sieve is collected and used for Atterberg Limit Test.

Table 4.4. Atterberg Limits for 5min and 30min mixing time

Test pits	Depth(m)	Condition	LL(%)	PL(%)	PI(%)	LL(30min)-LL(5min) %
TP1	1.3-1.5	Air dry 5min	65.81	35.12	30.69	
		Air dry 30min	83.60	28.24	55.36	17.79
	2.8-3.0	Air dry 5min	79.40	49.05	30.35	
		Air dry 30min	95.70	41.38	54.32	16.30
TP2	1.3-1.5	Air dry 5min	68.83	32.38	36.45	
		Air dry 30min	77.66	33.41	44.25	8.83
	2.8-3.0	Air dry 5min	69.70	24.58	45.12	
		Air dry 30min	83.50	30.95	52.55	13.80
TP3	1.3-1.5	Air dry 5min	55.40	52.34	3.06	
		Air dry 30min	67.30	30.55	36.75	11.90
	2.8-3.0	Air dry 5min	63.50	29.91	33.59	
		Air dry 30min	76.10	34.19	41.91	12.60
TP4	1.3-1.5	Air dry 5min	68.24	36.87	31.37	
		Air dry 30min	87.22	34.17	53.05	18.98
	2.8-3.0	Air dry 5min	67.05	34.53	32.52	
		Air dry 30min	74.82	42.26	32.56	7.77
TP5	1.3-1.5	Air dry 5min	67.93	34.03	33.90	
		Air dry 30min	82.04	51.48	30.56	14.11
	2.8-3.0	Air dry 5min	66.05	36.58	29.47	
		Air dry 30min	78.44	40.12	38.32	12.39
TP6	1.3-1.5	Air dry 5min	48.77	27.57	21.20	
		Air dry 30min	53.97	27.29	26.68	5.20
	2.8-3.0	Air dry 5min	70.63	35.47	35.16	
		Air dry 30min	71.86	27.42	44.44	1.23
TP7	1.3-1.5	Air dry 5min	70.93	35.19	35.74	
		Air dry 30min	77.50	33.81	43.69	6.57
	2.8-3.0	Air dry 5min	74.78	60.18	14.60	
		Air dry 30min	78.55	58.37	20.18	3.77

4.2.1.3.4. One point Liquid Limit Test

Two methods of determining the liquid limit are provided in ASTM D 4318-95; Method A, Multipoint test as discussed in the previous section and Method B, One-point test. It is recommended that the multipoint method be used in cases where results may be subject to dispute, or where greater precision is required.

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 [16];

$$LL = W\,(N/25)^{\tan\beta} \text{ --- Eq.4.1.}$$

Where: LL = Liquid limit

W= moisture content

N = No. of blows for Liquid limit

$\beta = 0.12$

One can use the value of $\tan\beta$ equal to zero when the number of blows is between 20 and 30 within the required accuracy. But, ASTM recommends β value of 0.12 is adequate for determining the one-point Liquid Limit for lateritic and temperate soils. The results were calculated and shown in Table 4.5.

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

Table 4.5 Comparison between one point and multi-point LL

Test pits	Depth(m)	State	No. of blows	Moisture content	One point LL(%)	Multi point LL(%)
TP1	1.3-1.5	AD	37	55.98	58.68	64.42
			30	69.89	71.44	
			22	65.19	64.20	
			15	67.13	63.14	
		OD	33	50.00	51.69	53.06
			29	51.95	52.88	
			20	55.00	53.55	
			15	58.24	54.78	
	2.8-3.0	AD	33	66.67	68.93	75.00
			28	76.47	77.52	
			19	79.66	77.08	
		OD	28	58.57	59.37	60.00
			21	64.29	62.96	
			19	54.00	52.25	

Table 4.5. Continued

TP2			37	64.70	67.82	
			27	65.22	65.83	
			22	69.44	68.38	
		AD	16	61.25	58.06	65.22
			33	65.09	67.30	
			30	53.00	54.17	
			20	62.24	60.60	
	1.3-1.5	OD	11	54.64	49.51	59.38
			31	64.94	66.64	
			27	67.50	68.13	
			22	65.28	64.29	
		AD	13	65.22	60.30	65.83
			38	57.41	60.37	
			29	61.11	62.21	
			20	66.98	65.21	
	2.8-3.0	OD	13	74.68	69.04	63.88
TP3			36	71.00	74.18	
			32	49.44	50.93	
			21	69.05	67.62	
		AD	15	71.21	66.98	64.90
			34	63.64	66.03	
			30	62.12	63.49	
			23	65.88	65.22	
	1.3-1.5	OD	15	52.78	49.64	61.41
			31	57.65	59.16	
			27	60.87	61.43	
		AD	16	65.56	62.14	60.63
			35	46.43	48.34	
			27	53.49	53.99	
			22	51.06	50.28	
	2.8-3.0	OD	18	55.79	53.63	51.19
TP4			30	79.38	81.14	
			26	80.65	81.03	
			23	74.71	73.97	
		AD	19	82.65	79.97	79.22
			36	57.66	60.24	
			33	61.80	63.89	
			21	54.02	52.90	
	1.3-1.5	OD	13	53.40	49.37	57.02

Table 4.5 Continued

			39	77.88	82.15	
			30	74.73	76.38	
			24	74.04	73.68	
		AD	17	62.65	59.82	71.42
			35	52.94	55.12	
			33	54.87	56.73	
			18	53.95	51.86	
	2.8-3.0	OD	12	58.10	53.20	54.59
TP5			35	68.96	71.80	
			26	72.37	72.71	
			23	64.10	63.46	
		AD	14	65.63	61.22	68.11
			34	57.47	59.63	
			26	57.50	57.77	
			22	55.10	54.26	
	1.3-1.5	OD	19	69.89	67.63	59.94
			34	68.13	70.69	
			26	67.00	67.32	
			24	74.42	74.06	
		AD	15	56.08	52.75	67.19
			33	55.81	57.70	
			31	53.33	54.72	
			15	53.21	50.05	
	2.8-3.0	OD	12	51.95	47.57	54.04
TP6			31	48.95	50.23	
			26	51.11	51.35	
			21	50.91	49.86	
		AD	12	54.23	49.66	50.46
			28	40.21	40.76	
			26	46.90	47.12	
			21	43.52	42.62	
	1.3-1.5	OD	18	46.51	44.71	43.61
			37	68.27	71.56	
			26	72.41	72.75	
			21	68.57	67.15	
		AD	18	59.50	57.20	69.88
			37	47.17	49.44	
			28	48.03	48.69	
			19	45.97	44.48	
	2.8-3.0	OD	15	46.15	43.41	47.52

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TP7			30	69.41	70.95	
			26	73.03	73.37	
			22	69.04	67.99	
		AD	12	81.11	74.27	71.18
			31	54.64	56.07	
			29	55.95	56.96	
			24	50.94	50.69	
	1.3-1.5	OD	10	60.95	54.60	54.74
			36	73.77	77.07	
			29	73.02	74.33	
			21	83.33	81.60	
		AD	12	76.92	70.43	76.35
			34	66.64	69.14	
			28	64.29	65.17	
			20	69.81	67.97	
	2.8-3.0	OD	11	69.05	62.57	66.96

4.2.1.3.5. Plasticity Chart

Plasticity Index, numerical difference between liquid limit and plastic limit, represents the range in water content through which a soil is in plastic state. A high numerical value of plasticity index is an indication of the presence of high percentage of clay in the soil sample [23], which implies that the plasticity values increase with the corresponding increase in clay contents.

The type of clay in the sample, however, may be obtained by considering the plasticity index in relation to the liquid limit. This is done by means of a plasticity chart developed from soils tested from different parts of the world [7]. Clays, silts, inorganic and organic soils lie in distinct region on the chart. The line defined as “A-line” is expressed by (Eq.4.2). 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. The soil under investigation fall below the A-line, except the sample taken from TP3-1(AD),TP5-1(AD), TP5-2(AD) and TP6-1(AD and OD). Test results below the A-line is to mean that soils contain minerals of Kaolinite, Chlorite and Halloysite.[6]. A test result above the A-line shows red clays with Latosols having strong Montimorillonitic influences, which are inorganic. Laterites consist of minerals predominantly of Kaolinite.

PI = 0.73 (LL-20)………..…………………………….…………………..Eq. 4.2.

Line "U" is defined by the equation Eq. 4.3. Line "U" defines the upper limit of the correlation between plasticity index and liquid limit. Results above this line indicate erroneous test hence conducting the test repeatedly is recommended. According to Fig. 4.3. the test results are all below the U-line. Hence the test results are considered acceptable.

PI = 0.90 (LL-8) ………………………..……………………………….....Eq. 4.3.

Where: Both PI and LL values are expressed in percent of equations Eq. 4.2. and Eq. 4.3..

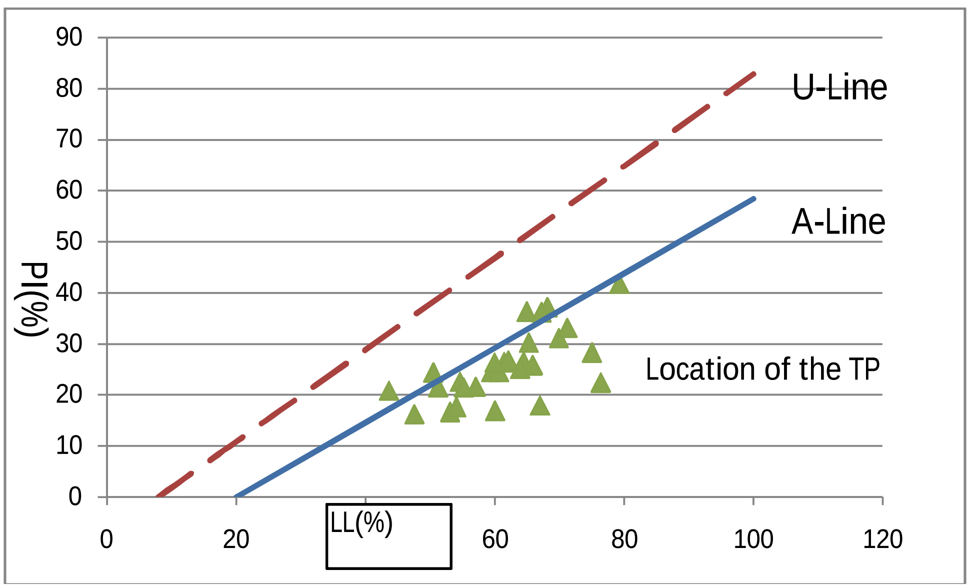

Fig.4.3. Plasticity chart

4.2.1.4. Activity

Since the plastic property of soil is due to the adsorbed water that surrounds the clay particles, we can expect that the type of clay minerals and their proportional amounts in a soil will affect the liquid and plastic limits. Skempton (1953) observed that the plasticity index of a soil linearly increases with the percent of clay-size fraction (percent finer than 2μmm by weight) present in it.

He defined a quantity called activity that is the slope of the line correlating PI and percent finer than 2μmm. This activity *A* may be expressed

$$\text{Activity number, } A_c = \frac{PI}{C} \text{ --Eq. 4.4.}$$

Where C is the percent of clay fraction finer than 2μ and PI is the plasticity index.

Activity has been used for determining the swelling potential of clays. The soil classification according to Activity is shown on Table 4.6 [11].The colloidal activity values for the soils under investigation are calculated and summarized in Table 4.7.

Table 4.6. Degree of Colloidal activity

Activity number , A_c	Soil type
<0.75	Inactive
1.25-0.75	Normal
>1.25	Active

As mentioned by Morin W.J. and Todor P.C. [16], residual soils have low activity number. Because the predominant clay minerals in lateritic soils are of Kaolinite group. These soils are known to be inactive (activity less than 1.25). This is due to the mode of weathering involving the coating of the soil particles with the Sesquioxides. From Table 4.7, one can see that the soil under investigation has activity number <1.25(Inactive and Normal), which agrees with the Morin' investigation of lateritic soils.

Table 4.7.Summary of Skempton's colloidal activity values

Test pits	Depth(m)	condition	PI(%)	Clay fraction(%)	Activity number, A_C
TP1	1.3-1.5	AD	26.47	72.14	0.37
		OD	16.71	20.31	0.82
	2.8-3.0	AD	28.32	62.81	0.45
		OD	16.95	67.15	0.25
TP2	1.3-1.5	AD	30.24	73.50	0.41
		OD	24.54	26.45	0.93
	2.8-3.0	AD	25.83	75.30	0.34
		OD	25.20	24.68	1.02

Table 4.7 Continued

TP3	1.3-1.5	AD	36.32	70.06	0.52
		OD	26.45	56.19	0.47
	2.8-3.0	AD	24.53	49.75	0.49
		OD	21.56	56.30	0.38
TP4	1.3-1.5	AD	41.75	72.04	0.58
		OD	21.66	68.04	0.32
	2.8-3.0	AD	26.72	62.49	0.43
		OD	22.62	50.78	0.45
TP5	1.3-1.5	AD	37.18	69.25	0.54
		OD	26.41	65.78	0.40
	2.8-3.0	AD	36.21	58.96	0.61
		OD	17.68	72.63	0.24
TP6	1.3-1.5	AD	24.43	57.44	0.43
		OD	20.92	27.10	0.77
	2.8-3.0	AD	31.15	55.57	0.56
		OD	16.29	28.74	0.57
TP7	1.3-1.5	AD	33.14	63.61	0.52
		OD	21.52	35.09	0.61
	2.8-3.0	AD	22.46	28.01	0.80
		OD	18.00	14.60	1.23

4.2.1.5. Free swell

Both the amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several physico-chemical aspects of the soil [22].Among clay minerals montimorillonite influences the magnitude of swelling than Illites and Kaolinites.

The free swell test can be done by pouring very slowly 10cm^3 of dry soil which has passed No. 40 (0.425mm) sieve into a 100cm^3 graduated cylinder filled with distilled water. The cylinder is left to stay for approximately 24 hours until all the soils settle completely to the bottom of the cylinder. The final volume of the suspension being read and the free swell is computed using Eq. 4.5.

$$\text{Free swell} = \frac{\text{Final volume - Initial volume of the soil}}{\text{Initial volume}} \times 100\% \quad \text{…………Eq.4.5.}$$

The laboratory free swell tests were done on air-dried (or 50^0C oven temp.) and oven dried (105^0C oven temp.). The drying of soil samples makes the soil particles to come closer and hide the potential of some of the minerals to swell. The results are summarized in Table 4.8. As can be seen from the test results the free swell of the soils under investigation range from 20% to 70%. Generally, soils with free swell of less than 50% are considered to have low degree of expansion [26]. Accordingly, some of the soils in Durame are non-expansive soil (or low in expansion).

Table 4.8 Free swell test results at different Conditions

Test pits	Depth(m)	condition	LL(%)	PL(%)	Free Swell(%)
TP1	1.3-1.5	AD	64.42	37.95	50
		OD	53.06	36.35	59
	2.8-3.0	AD	75.00	46.68	50
		OD	60.00	43.05	50
TP2	1.3-1.5	AD	65.22	34.98	50
		OD	59.38	34.84	20
	2.8-3.0	AD	65.83	40.00	50
		OD	63.88	38.68	35
TP3	1.3-1.5	AD	64.90	28.58	60
		OD	61.41	34.96	50
	2.8-3.0	AD	60.63	36.10	60
		OD	51.19	29.63	40
TP4	1.3-1.5	AD	79.22	37.47	63
		OD	57.02	35.36	40
	2.8-3.0	AD	62.08	35.36	48
		OD	54.59	31.97	35
TP5	1.3-1.5	AD	68.11	30.93	43
		OD	59.94	33.53	35
	2.8-3.0	AD	67.19	30.98	55
		OD	54.04	36.36	30
TP6	1.3-1.5	AD	50.46	26.03	47
		OD	43.61	22.69	38
	2.8-3.0	AD	69.88	38.73	43
		OD	47.52	31.23	37
TP7	1.3-1.5	AD	71.18	38.04	70
		OD	55.19	33.67	66
	2.8-3.0	AD	76.35	53.89	20
		OD	66.96	48.96	35

4.2.1.6. Specific Gravity

Specific gravity of the soils samples under investigation was determined using ASTM test designation D854 – 98 procedures method ‘A’ for oven dry; method ‘B’ for air dry samples. The dry mass of the soil for method B could be calculated by drying the soil specimen in the oven after the specific gravity test has been completed .Specific gravity is used to calculate parameters such as void ratio, porosity, soil particle size distribution by the hydrometer method and degree of saturation.

The specific gravity tests were carried out and summarized for all soil samples under investigation at air dried and oven dried pretreatment conditions, Table 4.9.

The specific gravity of Durame soils tend to reduce with increasing of temperature from air drying condition to oven drying temperature. From the test results, one can see that the range of values is from 2.52 to 2.97. This is in agreement with Morin W.J. and Todor P.C. that the specific gravities of lateritic soils can be low or very high up to 3.5. A decrease in specific gravity is due to aggregation of clay particles on drying and an increased value in test result indicates the presence of minerals constituting iron [5] [28].

Table 4.9 The Values of specific gravity at different conditions for Durame soil

Test pits	Depth(m)	condition	Specific gravity
TP1	1.3-1.5	AD	2.78
		OD	2.69
	2.8-3.0	AD	2.87
		OD	2.52
TP2	1.3-1.5	AD	2.78
		OD	2.71
	2.8-3.0	AD	2.81
		OD	2.74
TP3	1.3-1.5	AD	2.78
		OD	2.69
	2.8-3.0	AD	2.97
		OD	2.74

Table 4.9 Continued

TP4	1.3-1.5	AD	2.72
		OD	2.75
	2.8-3.0	AD	2.95
		OD	2.75
TP5	1.3-1.5	AD	2.92
		OD	2.74
	2.8-3.0	AD	2.87
		OD	2.75
TP6	1.3-1.5	AD	2.83
		OD	2.57
	2.8-3.0	AD	2.80
		OD	2.75
TP7	1.3-1.5	AD	2.78
		OD	2.83
	2.8-3.0	AD	2.88
		OD	2.75

4.2.1.7. Grain size Analysis

4.2.1.7.1. General

The size of the particles that constitute soils may vary from that of boulders to clay. Grain size analysis is an attempt to determine the relative properties of different grain sizes which make up a soil mass. Coarse soil particles are easily tested through nest of sieve mechanically. Finer soils on the other hand, are tested by hydrometer method. Sodium Hexametaphosphate is used as a dispersing agent.

4.2.1.7.2. 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 samples were prepared by spreading the material in trays outside the room for nearly 15 days. The oven dried samples were prepared by drying the sample at oven temperature of 105^{o}C. All the samples were screened through the nest of sieves.

During the preparation, the samples were divided in to two portions, particle sizes retained on No.200(0.075mm) sieve (Coarse size, Mechanical analysis), and the particles passing No.200mm(0.075mm) sieve (fine analysis, hydrometer analysis), and finally for soils of both sizes combined analysis of results was made. The results of these analyses were expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale.

ii) Wet preparation

In the wet method the soil is soaked until the coating material is fully softened. It is important that the fines adhering to the coarse particles should be removed and the fracturing of weak coarse particles should be prevented [16][10].The soaked samples were washed in the manner stated in ASTM D 2217-85, using No.10 (2.00-mm) & No.200 (0.075-mm) sieves. After washing, the materials retained on the No.200 (0.075-mm) sieves were dried in an oven at a temperature of 105^{o}C overnight. Then the dried materials were used for the particle-size analysis using nest of sieves. In addition to this, the hydrometer analysis was used in the determination of particle-sizes less than sieve No. 200 (0.075-mm) in accordance with the procedures stated in ASTM D 422-63 keeping the soil sample in moist condition.

4.2.1.7.3. Test results and discussions

The grain size analysis test results for all soil samples under investigation were summarized in Appendix-B. The corresponding grain size distribution curve is shown in Figs. 4.4 and Figs. 4.5 partly. The figures for the remaining test results are shown on Appendix-A.

4.2.1.7.3.1. Effect of pre-drying

Air-dried (AD) and oven dried (OD) samples were used to investigate the effect of pre treatment on the the grain size distribution of the specimen under investigation. The test results are shown in Fig 4.4, Appendix-A.1 and Appendix-B.

As stated in section 2.2.4, pre-drying residual soils result in a lesser clay fraction due to the aggregation (cementing) effect of tropical soils but due to human errors some of the values are exaggerated. This was observed during the investigation of Durame soil as shown in the Figures and Appendix-B.

4.2.1.7.3.2. Effect of Soil Sampling Locations

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. All soils of investigation show common fine-sized particles.

The soil under investigation also shows different characteristics along its depth. This is the fact that residual soils vary from highly weathered topsoil to unweathered (Intact rock) which is stiff at the bottom. The test results for soil samples TP1-1(AD) and TP1-2(AD), TP6-1(AD) and TP6-2(AD), and TP7-1(AD) and TP7-2(AD) are shown in Fig. 4.5 and the remaining results in Appendix-A.2. Generally, one can see from the test results 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 Durame shows a decreased in fine proportion and an increase in coarse sized particles in going down along the profile. It is also observed that the soil changes to a very stiff (impossible to sample) coarse sized particle over 2.5m. Soil samples with similar gradation curves have high probability of having the same engineering properties. The result for each of the soil under investigation is shown in Appendix-B.

4.2.1.7.3.3. Range of Gradation Curves

The range of grain size distribution curves for the soil samples under investigation for this work is shown in Fig. 4.6. Maximum and minimum gradation curve for oven dried and air dried pretreatment condition is shown in the figure.

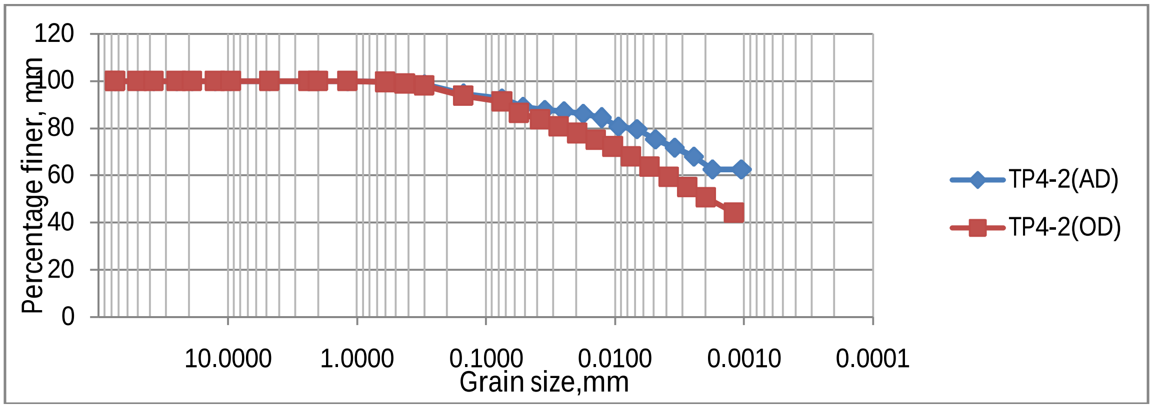

Fig 4.4a Grain size distribution for specimen TP4- 2 at different pretreatment conditions

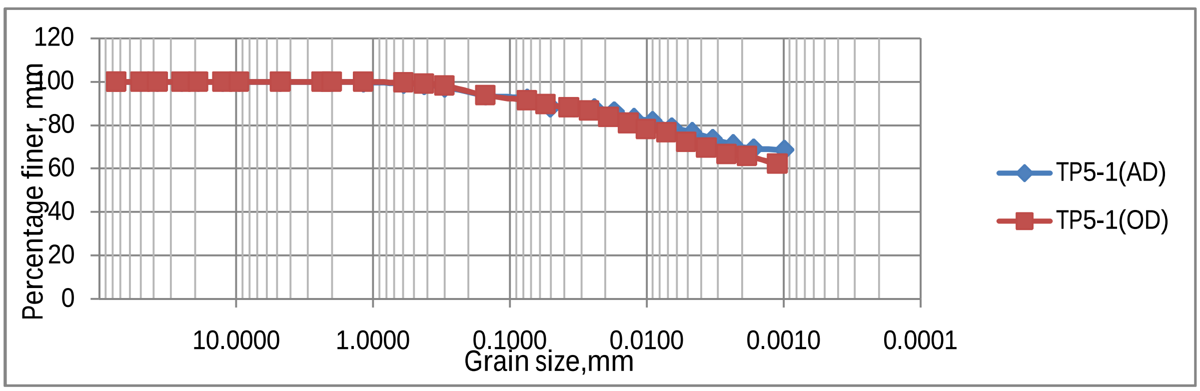

Fig 4.4b Grain size distribution for specimen TP5- 1 at different pretreatment conditions

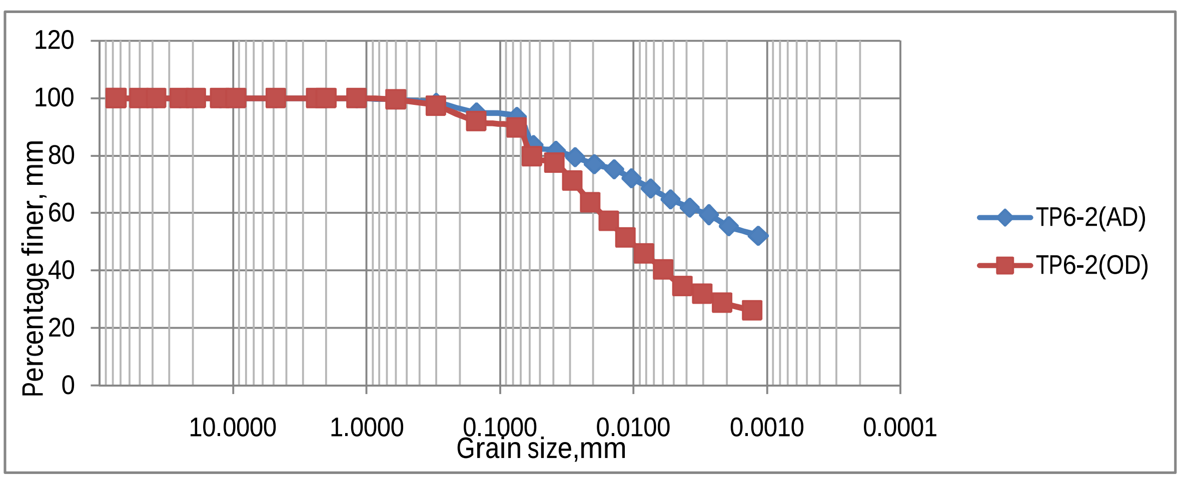

Fig 4.4c Grain size distribution for specimen TP6-2 at different pretreatment conditions

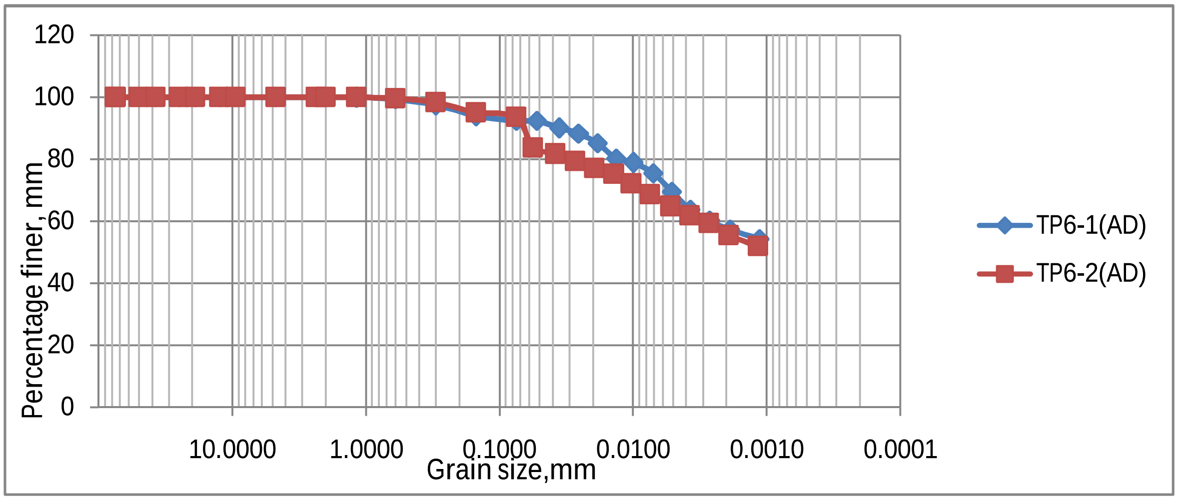

Fig 4.5a Grain size distribution for specimen TP6 at different depth

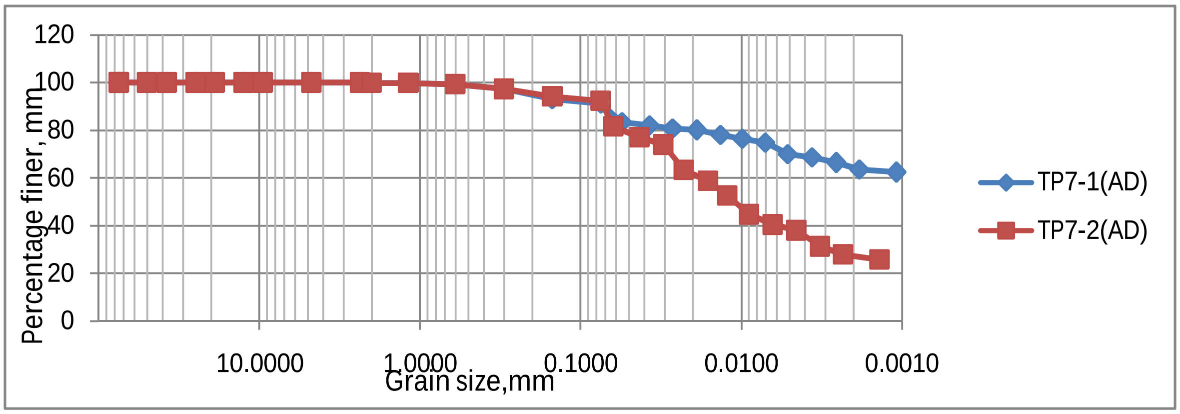

Fig 4.5b Grain size distribution for specimen TP7 at different depth

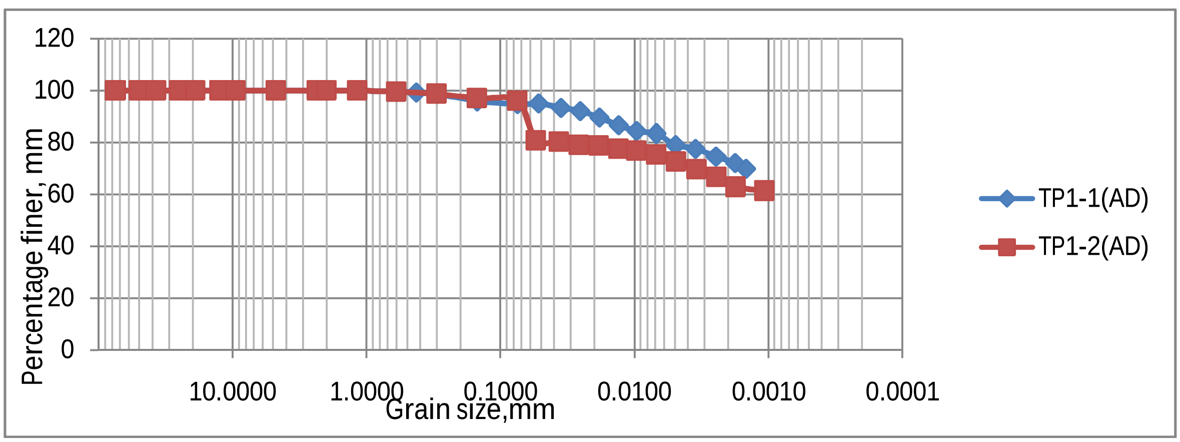

Fig 4.5c Grain size distribution for specimen TP1 at different depth

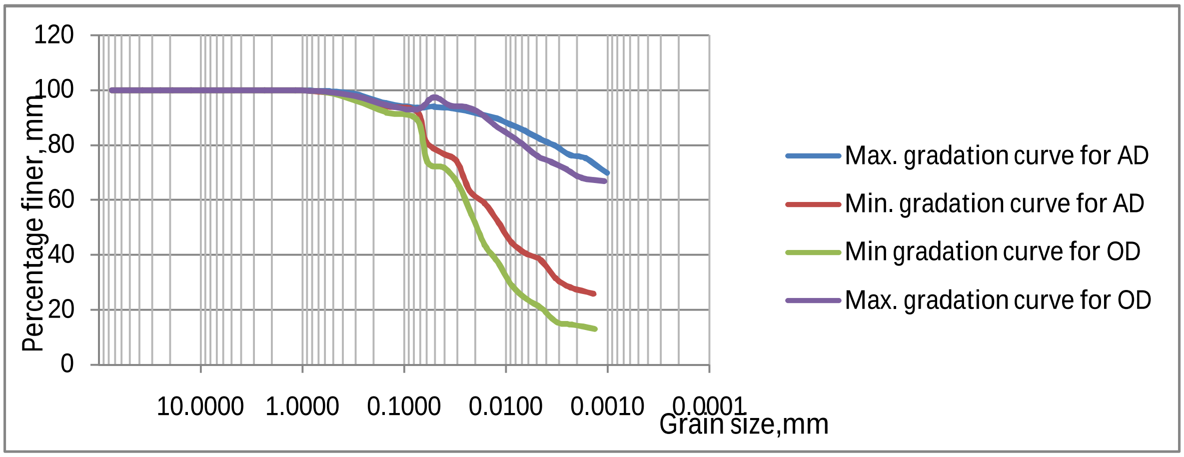

Fig.4.6. Ranges of grain-size distribution curves for different pretreatment conditions

4.2.1.8. Classification of the Soils

Different Authors used different classification techniques to classify residual tropical soils; Wesley L.D. and Irfan T.Y. classify soils based on the mineralogical composition alone, While D'Hoor classify residual soils based on soil forming factors [5][16]. The AASHTO classification system is convenient as the basis for classifying tropically weathered soils [16]. The soil in this work was classified according to the AASHTO M-145 and USCS, and the result is shown in table 4.10 .

4.2.1.8.1. Classification according to USCS

The USCS uses symbols for particular size groups. These symbols and their representations are : G–gravel ,S–Sand, M–Silt, C- Clay. These are combined with other symbols expressing gradation characteristics–W for well-graded and P for poorly graded–and plasticity characteristics–H for high and L for low , and a symbol O for the presence of Organic material. The flow chart shown in Fig.4.7. Provides systematic means of classifying an inorganic fine- grained soil according to the USCS [9]. According to this classification scheme, the soil under study falls on MH, CH, CL and OL.

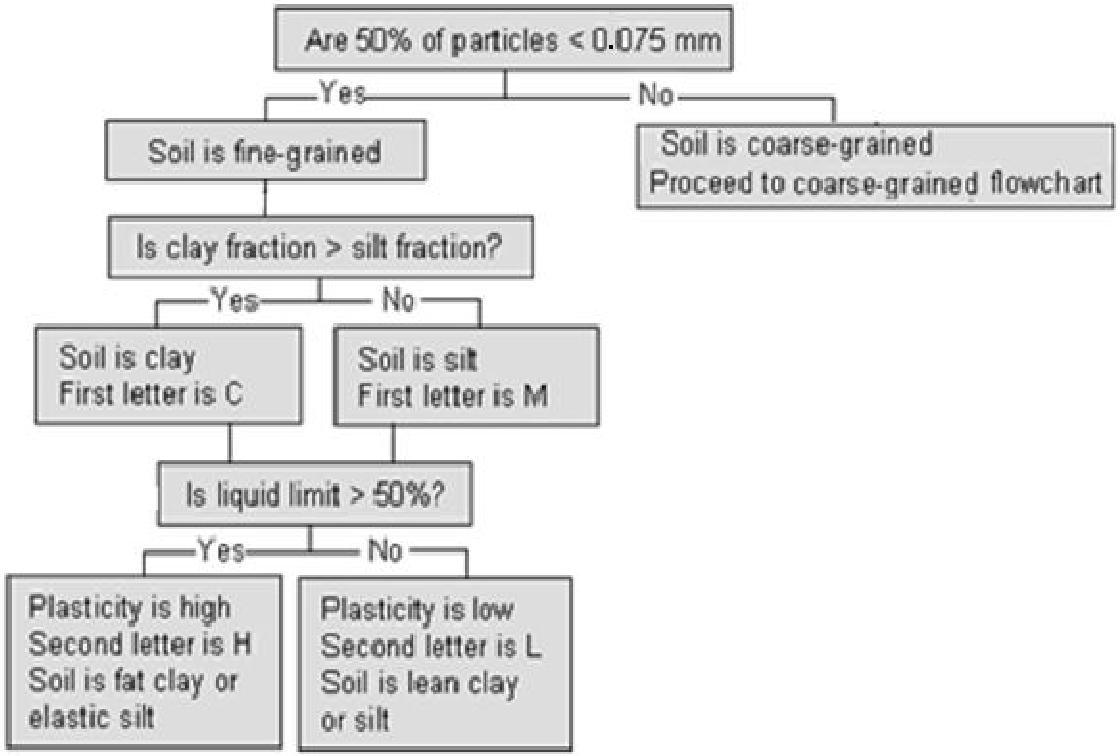

Figure 4.7. Unified soil classification flow chart for inorganic fine-grained soils [7]

4.2.1.8.2. Classification according to AASHTO

According to this system, soil is classified into seven major groups: A-1 through A-7.Soils classified under groups *A-1*, *A-2*, and *A- 3* are granular materials of which 35% or less of the particles pass through the No.200 (0.075mm) sieve. Soils of which more than 35% pass through the No.200 (0.075mm) sieve are classified under groups *A-4*, *A-5*, *A-6* and *A-7*. These soils are mostly silt and clay-type materials. According to this system the soil of the study area falls in the A-7-5, A-7-6 and A-6.

Table 4.10. Classification According to the AASHTO and USCS.

Test pit	Depth (m)	Test Cond.	LL (%)	PI (%)	% amount of passing			Classification According to AASHTO		% amount of particle size				Classification according to USCS
					2	0.0425	0.075	Group	Group Index	Gravel	Sand	Silt	clay	
TP1	1.3-1.5	AD	64.42	26.47	100	99.20	99.20	A-7-5	20	0	5.28	22.58	72.14	MH
		OD	53.06	16.71	100	99.10	99.10	A-7-5	20	0	6.26	73.43	20.31	MH
	2.8-3.0	AD	75.00	28.32	100	98.60	98.60	A-7-5	20	0	4.00	33.19	62.81	MH
		OD	60.00	16.95	100	98.30	98.30	A-7-5	20	0	5.90	26.95	67.15	MH
TP2	1.3-1.5	AD	65.22	30.24	100	99.58	99.58	A-7-5	20	0	4.96	21.64	73.50	MH
		OD	59.38	24.54	100	99.36	99.36	A-7-5	20	0	6.20	67.31	26.45	MH
	2.8-3.0	AD	65.83	25.83	100	99.24	99.24	A-7-5	20	0	6.56	18.34	75.30	MH
		OD	63.88	25.20	100	99.16	99.16	A-7-5	20	0	7.72	67.60	24.68	MH
TP3	1.3-1.5	AD	64.90	36.32	100	97.82	97.82	A-7-6	20	0	7.66	22.28	70.06	CH
		OD	61.41	26.45	100	97.26	97.26	A-7-5	20	0	8.50	35.31	56.19	MH
	2.8-3.0	AD	60.63	24.53	100	97.60	97.60	A-7-5	20	0	8.62	41.63	49.75	MH
		OD	51.19	21.56	100	97.60	97.60	A-7-6	20	0	8.06	35.64	56.30	MH
TP4	1.3-1.5	AD	79.22	41.75	100	98.38	98.38	A-7-5	20	0	6.20	21.76	72.04	MH
		OD	57.02	21.66	100	97.80	97.80	A-7-5	20	0	7.14	24.82	68.04	MH
	2.8-3.0	AD	62.08	26.72	100	98.48	98.48	A-7-5	20	0	7.28	30.13	62.49	MH
		OD	54.59	22.62	100	98.14	98.14	A-7-5	20	0	8.68	40.54	50.78	MH
TP5	1.3-1.5	AD	68.11	37.18	99.8	98.56	98.56	A-7-5	20	0	6.82	22.93	69.25	CH
		OD	59.94	26.41	100	98.94	98.94	A-7-5	20	0	8.68	25.54	65.78	MH
	2.8-3.0	AD	67.19	36.21	100	98.20	98.20	A-7-5	20	0	7.58	33.46	58.96	CH
		OD	54.04	17.68	100	98.40	98.40	A-7-5	20	0	6.40	20.97	72.63	MH
TP6	1.3-1.5	AD	50.46	24.43	100	97.40	97.40	A-7-6	16	0	7.66	34.90	57.44	CH
		OD	43.61	20.92	100	96.68	96.68	A-7-6	20	0	10.90	62.00	27.10	CL
	2.8-3.0	AD	69.88	31.15	100	98.32	98.32	A-7-5	20	0	6.46	37.97	55.57	CH
		OD	47.52	16.29	100	97.24	97.24	A-7-5	16	0	10.30	60.96	28.74	OL
TP7	1.3-1.5	AD	71.18	33.14	100	97.42	97.42	A-7-5	20	0	8.64	27.75	63.61	MH
		OD	55.19	21.52	100	96.38	96.38	A-7-5	20	0	10.64	54.27	35.09	MH
	2.8-3.0	AD	76.35	22.46	100	97.30	97.30	A-7-5	20	0	7.72	64.27	28.01	MH
		OD	66.96	18.00	99.9	96.28	96.28	A-7-5	20	0	10.73	74.66	14.60	MH

4.2.1.9. Geochemical Tests

Geochemical (oxide) tests are carried out to know quantitatively main oxides of the soil material. Almost all soils on earth contain some amount of colloidal oxides and hydroxides. The oxides and hydroxides of aluminium, iron and silicon are of greatest interest since they are the ones most frequently encountered. Iron and Aluminium oxides coat mineral particles, or cement particles of soils together. They may also occur as distinct crystalline units, such as hematite, gibbsite and magnetite [13] [25].

For this thesis work, the geochemical tests were carried out at Geological Survey of Ethiopia Centeral Geological Laboratory in order to obtain the percentage of oxide composition of the soils under investigation. The summary of test results is shown in Table 4.11.

In section 2.1.2.2.2. it is discussed that the degree of laterization of the soil samples can be evaluated based on Silica/Sesquioxides (S-S) ratio. The Sesquioxide, designated as R_2O_3, is the combination of aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3). The chemical formula SiO_2 designates the silica. Accordingly soils having an S-S ratio greater than 2 are non-lateritic tropically weathered soils. For lateritic soils S-S ratio lies between 1.33 and 2 and for those of true laterites the ratio is less than 1.33. Lateritic soils have not under gone a considerable degree of laterization as compared to true laterites.

From the test results as shown in Table 4.11; TP1-1, TP4-1, TP5-1 and TP7-1 have Silica/Sesquioxide ratio lies between 1.33 and 2. This indicates that the soils under investigation are all lateritic.

Table 4.11. Oxide Composition in Percent

Test pits	Depth (m)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOi	SiO_2/R_2O_3
TP1	1.5	48.46	19.52	10.80	0.16	0.76	0.16	1.14	0.26	0.04	1.50	5.71	9.86	1.60
TP4	1.5	47.72	20.23	11.16	0.01	0.80	0.32	1.18	0.26	0.07	1.63	5.59	9.71	1.52
TP5	1.5	48.20	20.25	11.00	1.26	0.96	0.18	1.18	0.28	0.03	1.46	6.09	8.77	1.54
TP7	1.5	49.66	19.66	10.90	0.98	0.72	0.38	1.30	0.28	0.04	1.69	5.45	8.58	1.62

4.2.2. Consolidation

A soil consists of solid grains and void spaces enclosed by the grains. The voids may be filled with air or other gas, with water or other liquid, or with a combination of these. The volume decrease of a soil under stress might be conceivably attributed to:

1. Compression of the solid grains;
2. Compression of pore water or pore air;
3. Expulsion of pore water or pore air from the voids, thus decreasing the void ratio or Porosity.

Under the loads usually encountered in geotechnical engineering practice, the solid grains as well as pore water may be considered to be incompressible. Thus, compression of pore air and expulsion of pore water are the primary sources of volume decrease of a soil mass subjected to stresses. A partially saturated soil may experience appreciable volume decrease through the compression of pore air before any expulsion of pore water takes place; the situation is thus more complex for such a soil. However, it is reasonable to assume that volume decrease of a saturated soil mass is, for all practical purposes, only due to expulsion of pore water by the application of load [27].

When a saturated clay-water system is subjected to an external pressure, the pressure applied is initially taken by the water in the pores resulting thereby in an excess pore water pressure. If drainage is permitted, the resulting hydraulic gradients initiate a flow of water out of the clay mass and the mass begins to compress. A portion of the applied stress is transferred to the soil skeleton, which in turn causes a reduction in the excess pore pressure. This process, involving a gradual compression occurring simultaneously with a flow of water out of the mass and with a gradual transfer of the applied pressure from the pore water to the mineral skeleton is called consolidation [19].

A study of the compressibility of soils is necessary to be able to forecast the problem settlement of structures on different type of soils [24].

Generally, the volume change in a soil deposit can be divided in to three stages: [3]

- Initial consolidation
- Primary consolidation
- Secondary consolidation

4.2.2.1. Test procedure and results

This test was done according to the procedure called standard test method for one dimensional consolidation properties of soils on the ASTM standard, Designation D2435-96.

Undisturbed samples in the form of blocks were obtained from the field. Using sample extruder sample was extruded on to the consolidation ring.

After carefully trimming the soil sample at its top and bottom, it was placed inside the metal ring with porous stone at its top and bottom. A setting load of 7KPa was applied until the soil saturated fully. Load was applied through the lever arm and compression dial reading was taken at a time interval of 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30, minutes and 1, 2, 4, 8, and 24 hours. The load was doubled every 24 hours starting from 50KPa to 1600KPa. This procedure was followed for all the samples. The plot of void ratio versus logarism of pressure and pressure for all the samples is shown in Fig. 4.10 and Fig.4.11 respectively.

4.2.2.2. Pre- consolidation pressure

A soil in the field at some depth has been subjected to certain maximum effective past pressure (pre- consolidation pressure) in its geologic history. This maximum effective past pressure may be equal to or less than the existing effective overburden pressure at the time of sampling. The reduction of effective pressure in the field may be caused by natural geologic processes or human processes. During the soil sampling, the existing effective overburden pressure is also released, which results in some expansion. When this specimen is subjected to a consolidation test, a small amount of compression (that is, a small change in void ratio) will occur when the effective pressure applied is less than the maximum effective overburden pressure in the field to which the soil has been subjected in the past. When the effective pressure on the specimen becomes greater than the maximum effective past pressure, the change in the void ratio is much larger, and the e-$\log\sigma'$ relationship is practically linear with steeper slope [10].

There are a few graphical methods for determining the pre-consolidation pressure based on laboratory test data. No suitable criteria exist for appraising the relative merits of the various methods. The earliest and the most widely used method was the one proposed by Casagrande (1936). The method involves locating the point of maximum curvature, B, on the laboratory e-log *p* curve of an undisturbed sample as shown in Fig 4.8 and Fig.4.9. From *B*, a tangent is drawn to the curve and a horizontal line is also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the preconsolidation pressure, P_c [19].

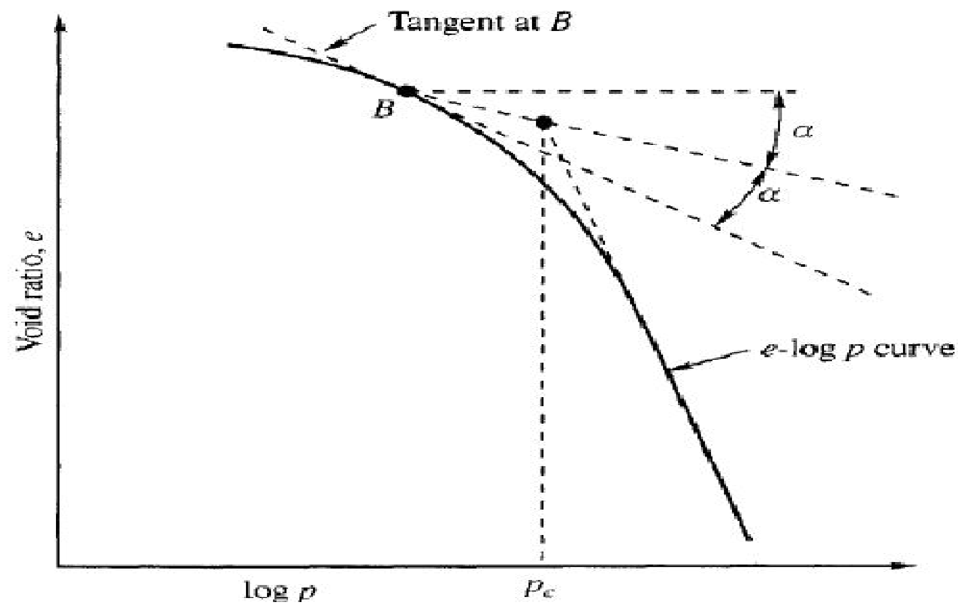

Fig 4.8. Method of determining P_c by Casagrande method

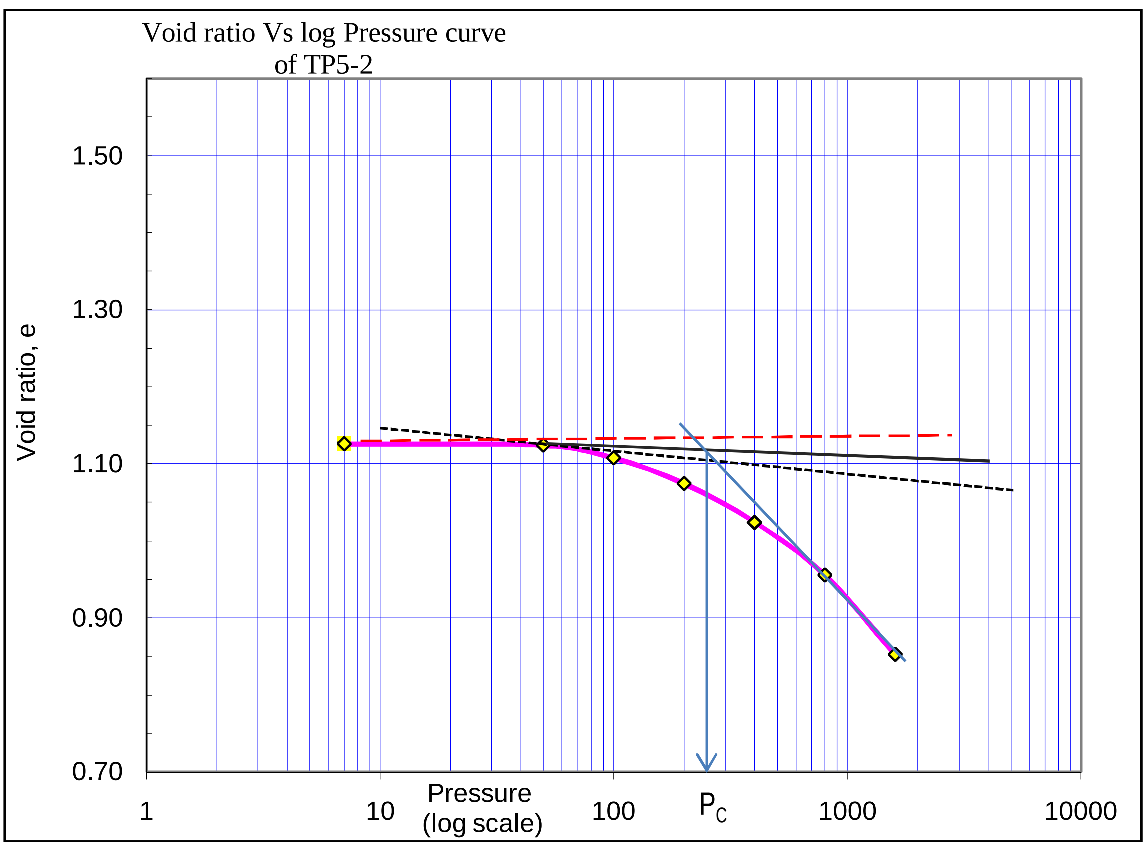

Fig. 4.9. Typical void ratio Vs pressure curve to determine P_c

The pre-consolidation pressure for the four samples is determined as depicted in Fig 4.8.The results are shown in Table 4.12. From Fig 4.10 and 4.11 all the samples have almost similar pre-consolidation pressure except TP7-2. This is may be because of the cementating property of sesquioxides which depend on the location of the test pit on the slope. In our case TP-7 is located on the top of the slope that means all the silica is leached and sesquioxides remains.

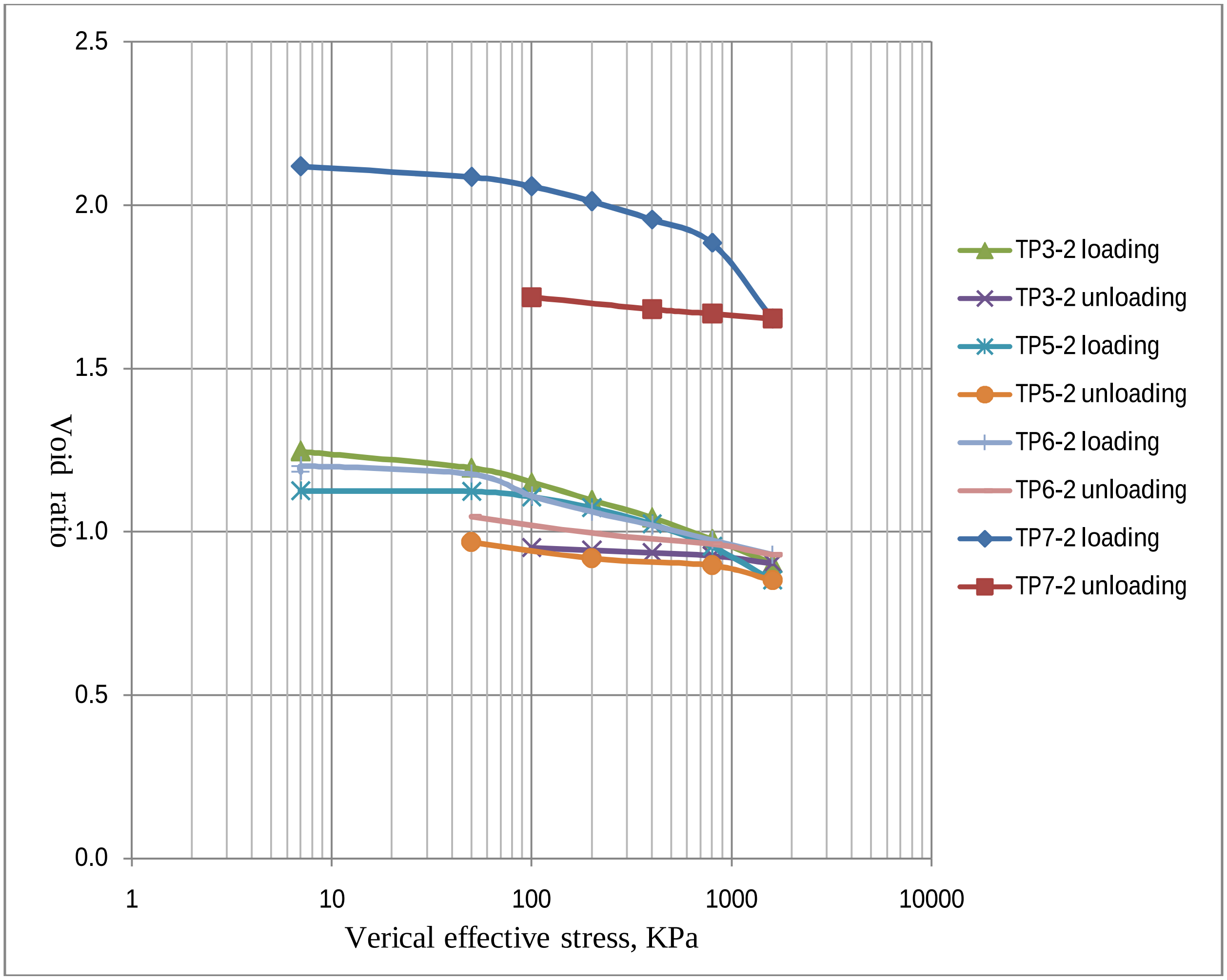

Fig 4.10. Plot of vertical effective stress Vs void ratio on semi-log scale

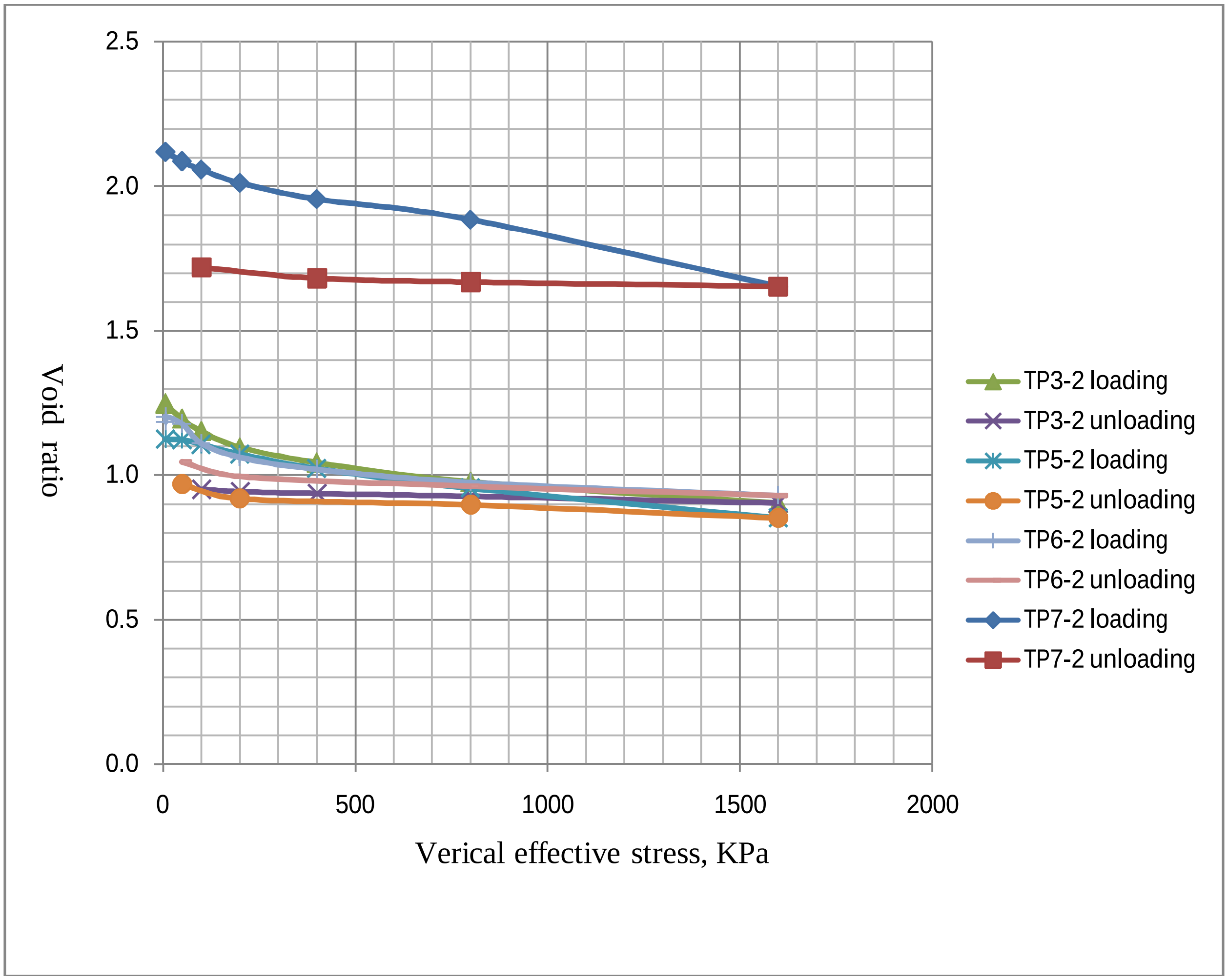

Fig 4.11. Plot of vertical effective stress Vs void ratio on linear scale

4.2.2.3. Compression index (Cc)

The slope of the straight line portion of the e – log p plot gives the compression index (Cc).The test data were plotted as Void ratio against log Pressure and Cc was determined from Fig 4.12. The compression index is useful for the determination of the settlement.

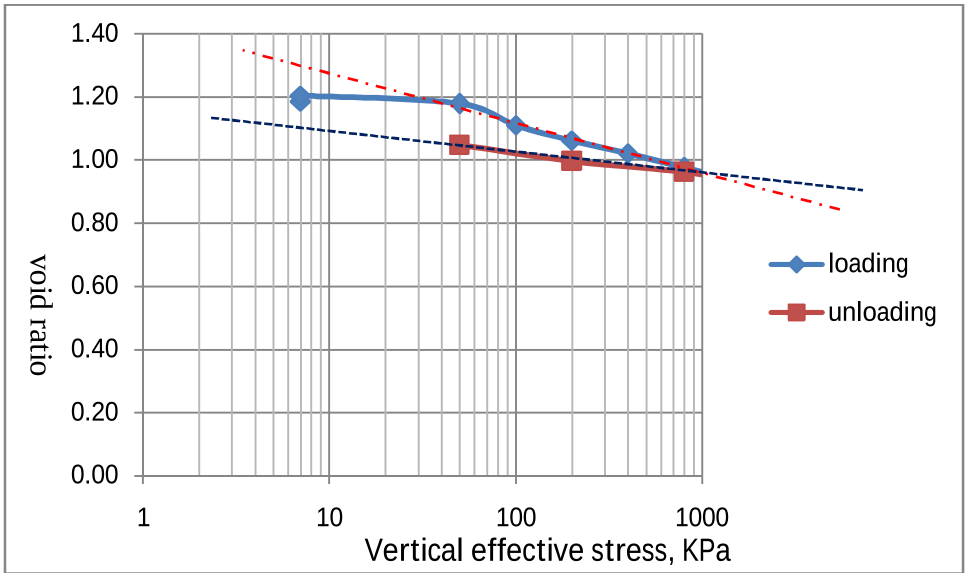

Fig.4.12. Typical loading-unloading curve to calculate the compression index and the recompression index, respectively.

4.2.2.4. Determination of the coefficients of consolidation

The coefficient of consolidation relates how long will it take for a given degree of consolidation to take place. There are two popular methods that can be used to estimate C_v. Taylor (1942) proposed one method called the square root of time method. Casagrande and Fadum (1940) proposed the other method called the log time method. The log time method makes use of the early (primary consolidation) and later time response (secondary compression) while the square root time method only utilizes the early time response, which is expected to be straight line. In theory, the square root time method should give good results except when nonlinearities arising from secondary compression cause substantial deviations from the expected straight lines. These deviations are most pronounced in fine grained soils with organic materials [7]. The square root of time method has been used in this work.

4.12. Summary of the consolidation test results

Test pits	Moisture content (%)	Pressure P (KPa)	Coefficient Of Consolidation (Cm^2/Sec)	Compression Index, C_c	Recompression Index, C_r	Pre-consolidation Pressure(KPa)
TP3-2	35.32	7	-	0.321	0.033	160
		50	0.218			
		100	0.217			
		200	0.254			
		400	0.299			
		800	0.338			
		1600	0.153			
TP5-2	33.71	7	-	0.368	0.097	260
		50	0.077			
		100	0.145			
		200	0.178			
		400	0.204			
		800	0.224			
		1600	0.056			
TP6-2	40.32	7	-	0.219	0.096	60
		50	0.138			
		100	0.170			
		200	0.193			
		400	0.247			
		800	0.274			
		1600	0.351			
TP7-2	61.65	7	-	0.596	0.055	590
		50	0.012			
		100	0.018			
		200	0.021			
		400	0.150			
		800	0.219			
		1600	0.086			

4.2.3. Unconfined Compression test

The Unconfined Compression test is a special case of a triaxial compression test in which the all round pressure $\sigma_3 = 0$. The tests are carried out only on saturated samples which can stand without any lateral support. The test is, therefore, applicable to cohesive soils only. The test is an undrained test and is based on the assumption that there is no moisture loss during the test. The unconfined compression test is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils. These tests can also be performed in the field by making use of simple loading equipment.

Specimens of height to diameter ratio of 2 are normally used for the tests. The sample fails either by shearing on an inclined plane (if the soil is of brittle type) or by bulging. The vertical stress at any stage of loading is obtained by dividing the total vertical load by the cross-sectional area [19]

The UCS tests were carried out on three undisturbed samples obtained, by tube sampling, from the field. Details of testing procedures are given in D 2166 – 98a**.**The results of UCS tests are shown in Table 4.13.

Table 4.13. Result of UCS test

Test pits	Depth(m)	Moisture content(%)	Unconfined compressive strength(KPa)
TP6-2	3m	40.38	302
TP3-2	3m	28.44	148
Tp5-2	3m	33.71	121

From Unconfined Compression test result, TP6-2 is categorized as very stiff clay and, TP3-2 and TP5-2 are categorized under stiff clay according to Table 4.14.

Table 4.14.General relationship of Consistency and Unconfined Compression strength of clay [10]

Consistency	UCS ,KN/m
Very soft	0-25
Soft	25-50
Medium	50-100
Stiff	100-200
Very Stiff	200-400
Hard	>400

5. Comparisons and Discussions of Test Results

5.1. Comparison of Test Results with Laterites, Lateritic Soils of Africa, Nejo-Mendi, Assosa and Wolaita Sodo.

Laterites and lateritic soils of Africa were studied by Morin W.J. and Todor P.C. [16]. During the study, samples were collected from different parts of Africa such as Ghana, Ethiopia, Kenya, Uganda etc. The characteristics and mineralogical content of the soils taken from Ethiopia was studied as Ferrisol.

Comparison was made for the Durame soils with known laterites and lateritic soils of Africa using Index property test results. The soil samples collected from Africa were classified according to D'Hoore classification methods in to Ferrugineous, Ferrallitic and Ferrisol. The results of Index property tests, compaction tests and California Bearing Ratio (CBR) tests of Ferrugineous, Ferrallitic, Ferrisol and laterite soil from Nejo- Mendi, Assosa,Wolayita Sodo area and the soil of Durame area are tabulated in Tables 5.1 to 5.7.

Tables 5.1 to 5.3 show the average values of various tests done at different countries, i.e., Liquid Limit, Plastic Index and Gradation for Ferruginous, Ferrallitic and Ferrisols showing different properties. 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, 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 [16] and the mineralogical compositions are shown in Table 2.1.

Average soil test properties for the three sub group of African laterite and lateritic soils, Nejo-Mendi, Asossa,Wolayita-Sodo soils and the soils of Durame are shown in Table 5.8.

From section 2.1.3.Ferrisol soils occur in regions of between 1250 and 2750mm rainfall per year the soil under investigation falls in this range of annual rain fall according to Fig 3.1.Comparison of the gradation and Atterberg Limits values of Durame soils are almost similar to previously determined Ethiopian Ferrisol soils, Walayita Sodo and Cameron.

Table 5.1 Typical Soil Test Results for Ferruginous Soils [16]

Country	LL%)	PL(%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	OMC	MDD	CBR (%)
Ghana	26	15	11	A-2-6	0						45	20	12	2.044	150
Senegal	39	20	19	A-2-7	0	95	91	68	46	33	27	20			
Upper V.	38	14	24	A-2-6	1	100	97	80	66	51	38	25	14	1.839	35
Niger	21	11	10	A-2-4	0	97	89	73	64	55	40	25	9	2.107	22
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	19		52
Uganda	38	17	22	A-2-6	2	100	100	96	83	61	51	34	13		19
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 5.2 Typical Soil Test Results for Ferrallitic Soils [16]

Country	LL (%)	PL (%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	OMC	MDD	CBR (%)
Ghana	38	18	18	A-6	6	100	100	100	95	81	67	47	14	1.886	15
Liberia	56	29	29	A-2-7	2	100	95	72	57	41	36	27			
Gabon	35	18	18	A-2-4	0										
Sierra Leone	55	31	31	A-2-6	1	100	98	90	68	37	29	27			
Burundi	31	16	16	A-6			100	92	84	76	74	70			
Dahomey	45	21	21	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	19	1.698	
Mali	35	21	14	A-6	3	100	100	89	67	55	51	40	16	1.824	
Uganda	39	19	20	A-6	2	100	100	91	82	73	53	38			

Table 5.3. Typical Soil Test Results for Ferrisol Soils [16]

country	LL (%)	PL (%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	OMC	MDD	CBR (%)
Ghana	53	34	19	A-7-5	3						50	37	17	1.745	45
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	17	1.729	12
Mali	55	31	24	A-7-5	3	100	100	89	61	51	43	38	15	1.886	9
Uganda	46	21	25	A-2-7	0	100	100	91	56	31	24	20	14		16
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	28	1.509	12
Ghana	57	25	32	A-7-6	12	100	100				65	50	19	1.714	15

Table 5.4 Soil test results for Nejo-Mendi soils [31]

Designation	LL%)	PL(%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	OMC	MDD	CBR
Sp-1	56	36	20	A-2-7	0	88	77	59	43	26	19	13	24	1.68	64
Sp-2-1	56	38	18	A-2-7	0	97	84	49	32	21	17	14	26	1.538	45
Sp-2-2	59	37	22	A-2-7	0	94	90	68	52	34	28	24			
Sp-2-3	67	43	24	A-2-7	0	96	90	75	57	37	31	26			
Sp-3-1	54	34	20	A-2-7	0	83	69	46	33	22	17	15			
Sp-3-2	54	34	20	A-2-7	0	92	83	67	55	43	35	30			

Table 5.5 Typical Soil Test Results for Asossa soils [28]

Designation	LL%)	PL(%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm
TP1-1	57	22	35	A-7-6	35	100	100	100	100	100	92	90.42
TP1-2	54	23	31	A-2-7	0	100	100	85.34	67.8	45.5	18.4	12.52
TP2-1	57	22	35	A-7-6	35	100	100	100	100	100	92	91.64
TP2-2	58	26	32	A-7-6	32	100	100	100	100	100	90.5	88.20
TP3-1	55	24	31	A-7-5	33	100	100	100	100	100	96	94.50
TP3-2	48	20	28	A-7-6	0	100	100	96.4	73.13	46.54	18.4	13.71
TP4-1	57	27	30	A-7-6	32	100	100	100	100	100	94.4	93.04
TP4-2	52	20	32	A-7-6	31	100	100	100	100	100	93	90.46
TP5-1	68	22	46	A-7-6	44	100	100	100	100	100	90.6	87.55
TP5-2	67	21	46	A-7-6	44	100	100	100	100	100	89.5	87.40
TP6-1	50	25	25	A-7-6	26	100	100	100	100	100	94.3	92.10
TP6-2	52	21	31	A-7-6	30	100	100	100	100	100	92.3	90.70
TP7-1	58	24	34	A-7-6	35	100	100	100	100	100	94	92.90
TP7-2	56	25	31	A-7-6	32	100	100	100	100	100	93.5	92.00
TP7-3	55	25	30	A-7-6	31	100	100	100	100	100	94	92.50
TP8-1	60	22	38	A-7-6	40	100	100	100	100	100	95.2	94.19
TP8-2	57	23	34	A-2-7	36	100	100	100	100	100	94.6	93.81
TP9-1	69	31	38	A-2-7	0	100	100	100	100	85.42	20.95	14.10
TP9-2	72	40	32	A-2-7	0	100	100	100	100	86.06	17.43	13.06
TP9-3	57	25	32	A-2-7	0	100	100	100	100	79.60	25.99	18.44

Table 5.6 Soil Test Results for Wolayita-Sodo soils [24]

Test pit	Depth	Test cond	LL%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	0.002 mm
TP1	2.0	OD	52	19	A-7-5	20max	100	100	100	100	100	95.09	86.22	49
		AD	57	22	A-7-5	20max	100	100	100	100	100	94.04	88.84	56.3
		AS	65	25	A-7-5	20max	100	100	100	100	100	94.06	87.09	58.3
TP4	2.0	OD	57	21	A-7-5	20max	100	100	100	100	100	90.91	84.64	53.9
		AD	63	21	A-7-5	20max	100	100	100	100	100	94.40	89.51	66.3
TP7	2.0	OD	54	3	A-7-5	20max	100	100	100	100	100	99.38	93.83	48
		AD	59	23	A-7-5	20max	100	100	100	100	100	96.65	92.03	62.9
		AS	71	30	A-7-5	20max	100	100	100	100	100	96.96	90.54	61.5

Table 5.7. Soil Test Results for Durame soils

Test pit	Depth	Test cond	LL%)	PI(%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	0.002 mm
TP1	1.3-1.5	AD	64.42	26.47	A-7-5	32	100	100	100	100	100	99.2	99.2	72.14
			53.06	16.71	A-7-5	21	100	100	100	100	100	99.1	99.1	20.31
	2.8-3.0	OD	75	28.32	A-7-5	38	100	100	100	100	100	98.6	98.6	62.81
			60	16.95	A-7-5	22	100	100	100	100	100	98.3	98.3	67.15
TP2	1.3-1.5	AD	65.22	30.24	A-7-5	36	100	100	100	100	100	99.58	99.58	73.50
			59.38	24.54	A-7-5	29	100	100	100	100	100	99.36	99.36	26.45
	2.8-3.0	OD	65.83	25.83	A-7-5	28	100	100	100	100	100	99.24	99.24	75.30
			63.88	25.2	A-7-5	31	100	100	100	100	100	99.16	99.16	24.68
TP3	1.3-1.5	AD	64.9	36.32	A-7-6	39	100	100	100	100	100	97.82	97.82	70.06
			61.41	26.45	A-7-5	30	100	100	100	100	100	97.26	97.26	56.19
	2.8-3.0	OD	60.63	24.53	A-7-5	27	100	100	100	100	100	97.6	97.6	49.75
			51.19	21.56	A-7-6	26	100	100	100	100	100	97.6	97.6	56.30
TP4	1.3-1.5	AD	79.22	41.75	A-7-5	48	100	100	100	100	100	98.38	98.38	72.04
			57.02	21.66	A-7-5	26	100	100	100	100	100	97.8	97.8	68.04
	2.8-3.0	OD	62.08	26.72	A-7-5	41	100	100	100	100	100	98.48	98.48	62.49
			54.59	22.62	A-7-5	25	100	100	100	100	100	98.14	98.14	50.78
TP5	1.3-1.5	AD	68.11	37.18	A-7-5	40	100	100	100	100	99.8	98.56	98.56	69.25
			59.94	26.41	A-7-5	29	100	100	100	100	100	98.94	98.94	65.78
	2.8-3.0	OD	67.19	36.21	A-7-5	40	100	100	100	100	100	98.2	98.2	58.96
			54.04	17.68	A-7-5	22	100	100	100	100	100	98.4	98.4	72.63
TP6	1.3-1.5	AD	50.46	24.43	A-7-6	16	100	100	100	100	100	97.4	97.4	57.44
			43.61	20.92	A-7-6	20	100	100	100	100	100	96.68	96.68	27.1o
	2.8-3.0	OD	69.88	31.15	A-7-5	36	100	100	100	100	100	98.32	98.32	55.57
			47.52	16.29	A-7-5	16	100	100	100	100	100	97.24	97.24	28.74
TP7	1.3-1.5	AD	71.18	33.14	A-7-5	38	100	100	100	100	100	97.42	97.42	63.61
			55.19	21.52	A-7-5	23	100	100	100	100	100	96.38	96.38	35.09
	2.8-3.0	OD	76.35	22.46	A-7-5	32	100	100	100	100	100	97.3	97.3	28.01
			66.96	18	A-7-5	24	100	100	100	100	99.9	96.28	96.28	14.60

.

Table 5.8. Comparison of average soil properties for this and previous studies

Test executed	Ferruginuous		Ferralitic		Ferrisol		Nejo - Mendi (Zelalem,2005)	Asossa (Wakuma, 2007)	Wolayita Sodo (Hanna,2009)	Durame
Passing sieve size(%)	Ghana	Other Countries	Ghana	Other Countries	Ghana	Other Countries				
25mm	99	99	99	99	95	99	94.6	100	100	100
19mm	98	98	96	96	94	99	88.3	100	100	100
9.5mm	93	89	86	86	86	92	73.3	99	100	100
4.75mm	75	76	70	70	73	74	62.6	94.6	100	100
2.00mm	51	65	54	54	52	61	51.6	89	100	99.9
0.425mm	46	51	46	46	40	51	45.0	74.9	95	98.1
0.075mm	30	32	34	34	37	44	38.3	72	89	92.4
0.002mm	13	16	19	19	25	24	9.2	21	57	53.02
LL	31	33	42	42	46	55	59	59	60	62
PL	18	12	24	24	23	29	38	25	37	36
PI	14	15	19	23	23	27	22	34	23	26
OMC	10	13	12	13	14	21	24			
MDD	2.091	1.949	2.028	1.839	1.918	1.698	1.552			
CBR	75	33	46	24	42	14	38			

5.2. Comparison of Test Results with previously done research work

Table 5.9. Comparison of Test Results with pervious done research work

	Morin & Parry	Previous research (Haile Mariam,1992	Previous research (Abgena,2003	Previous research (Zelalem,2005)	Previous research (Wakuma, 2007)	Previous research (Hanna, 2009)	Previous research (Dagnachew, 2011)	Current research
Soil type	Red clay	Red clay	Red clay	Lateritic	Lateritic	Lateritic	Silt and silt sand	Lateritic
location	Ethiopia	Addis ababa	Bahir Dar	Nejo-Mendi	Assossa	Woyita sodo	Adama	Durame
Clay content, %	34-76	48-73	74-82	2-20.6	2.5-60	48-69.7	5.4-40.5	15-75
activity			0.56	0.97-0.98	0.62-1.02	0.317- 0.488		0.24-1.23
LL(%)	44-66	54-81	61-68	48-67	41-72	48-71	29-73	44-79
PI(%)	14-30	21-30	24.31	17-27	20-48	19-30	13-34	16-42
SL(%)	10-30	14-22	9-12	7.1-15.7		11-22	21-35	
Free swell		10-40		20-40	11-45	28-38	18-50	20-70
Specific gravity	2.61-2.90	2.61-2.79	2.75-2.83	2.78-3.03	2.19-2.94	2.61-2.97	2.4-2.7	2.52-2.97
From Plasticity chart				MH	CH,SC, MH, CL&SM	MH	SM,ML,MH	MH and CH
UCS, KN/m^2	146.5-251	49-250	148-220	165-553		215-385		121-302

5.3. Discussions

The points addressed in the thesis work are discussed as follows:

The soil samples were collected from South Ethiopia, Durame Town. The area had mean minimum and maximum annual temperature lies between 8.6-10.4^{o}C to 21-24.4^{o}C and the mean annual rainfall of around 1260mm. It has been suggested that a mean annual temperature of around 25°C and the minimum annual rainfall at least 750 mm is required for laterite formation [9].This soil forming factors, index tests and geochemical test prove that the soil under investigation is considered as lateritic soils.

Detailed investigations were done to determine the existence of 'Structural Water' that could be driven off from the sample during oven drying at 105^{o}C. The difference in the natural moisture content determined at the oven of 105^{o}C and the air-dried sample showed that there is structural water, i.e., the difference is greater than 4%. Hence one should not use the oven temperature of 105^{o}C, instead air-drying or equivalently partial oven drying 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 air dried samples, 5 minutes and 25minutes. The difference of greater than 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 with a fresh sample for each point with a minimized mixing time of 5 minutes.

According to USCS, the soils fall under CH and MH inorganic clay. Few research works were carried out on tropical soils both artificially combined and actual samples. The test results show that, the values on liquid limit versus plasticity index graph lie below the A – line. It indicates that the soil samples contain of the mineral Kaolinite [31]. The tropical soils properties vary with their minerals composition. Classifying Lateritic soils using only USCS classification system does not tell us about the mineral. Hence soil classification using USCS should be accompanied by mineralogical test results.

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

The specific gravity test results are 2.52 to 2.97. The values are higher than the specific gravity of the temperate zone soils, which is about 2.65 to 2.70. The contributing factor for rise of the specific gravity is due to high amount of iron oxide. Lateritic soils have been found to have very high specific gravities of between 2.6 to 3.4 [16].

6. Conclusions and Recommendations

6.1. Conclusions

Based on the test results investigation on the soil samples of Durame soil the following conclusions can be drawn:

1. Geochemical tests indicate that the soils of Durame area are lateritic having high concentration of iron oxide and aluminium oxide / sesqueoxide /. The degree of laterization, silica to sesqueoxide ratio, is between 1.33 and 2. No significant variations have been seen in different pits located at far distances.

2. The test results showed that the Durame soils are sensitive to the temperature applied prior to testing. Some soils also contain structural water or water of hydration that could be driven off irreversibly when using oven drying of 105^{o}C. Hence air-drying or oven-drying of 50^{o}C with relative humidity (RH) of 30% should be used for every test during sample preparation.

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

4 The specific gravity test results are higher values than the temperate zone soil. This is may be due to high amount of Iron Oxide for soil under investigation. And, during specific gravity test avoid any form of pre-test drying in order to determine the dry mass of the soil rather obtain the dry mass after the test has been done using lower oven drying temperatures, 50^{o}C with relative humidity (RH) of 30%, as some Durame soils have water of hydration or structural water which will be driven off by oven drying of 105^{o}C or due to dehydration and/or aggregation of clay particles of the soils upon drying at higher temperatures.

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, Durame soil is inactive as compared to the swelling characteristic of other fine grained soil.

6. The test result showed that Durame soil lies below the A-line for all soils except the samples TP3-1(AD), TP5-1 and TP5-2(AD) and TP6-1(AD and OD).

7. From the gradation charts and the soil classifications made, Durame soil is a finegrained soil with the percentage of Clay ranges from 15-74%, Silt 18-75%,Sand 4-11% and Gravel 0%.

8. As determined from the one-dimensional consolidation test conducted on soil samples, compression index, C_c, ranges from 0.219 - 0.596, recompression index, C_r, from 0.033-0.097, coefficient of consolidation, C_v, from 0.012 – 0.351 cm^2/sec.

6.2. Recommendations

1. This study did not include the x-ray diffraction test. Therefore this test should be done inorder to identify and characterize the clay minerals of the soil under investigation.

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2. In this research samples of soil were collected only from seven test pits, by increasing the number of sampling area in-depth investigation should be done in future.

3. Further detailed investigation has to be carried out to find UCS of the soil using the insitu moisture content.

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Appendix – A

A.1.Grain size distribution curve for variation in pre treatment condition

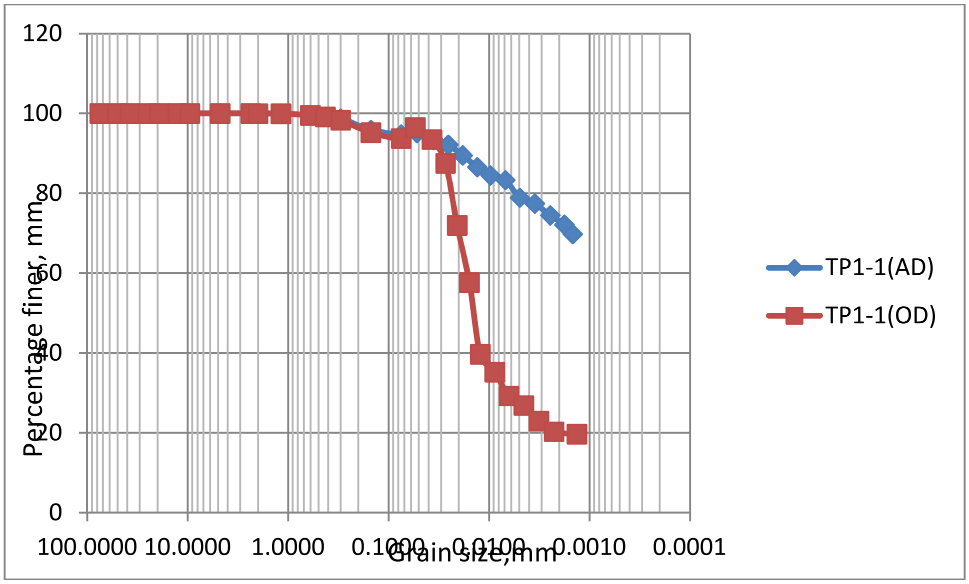

Fig A.1.1 grain size distrubition curve for AD and OD of TP1-1

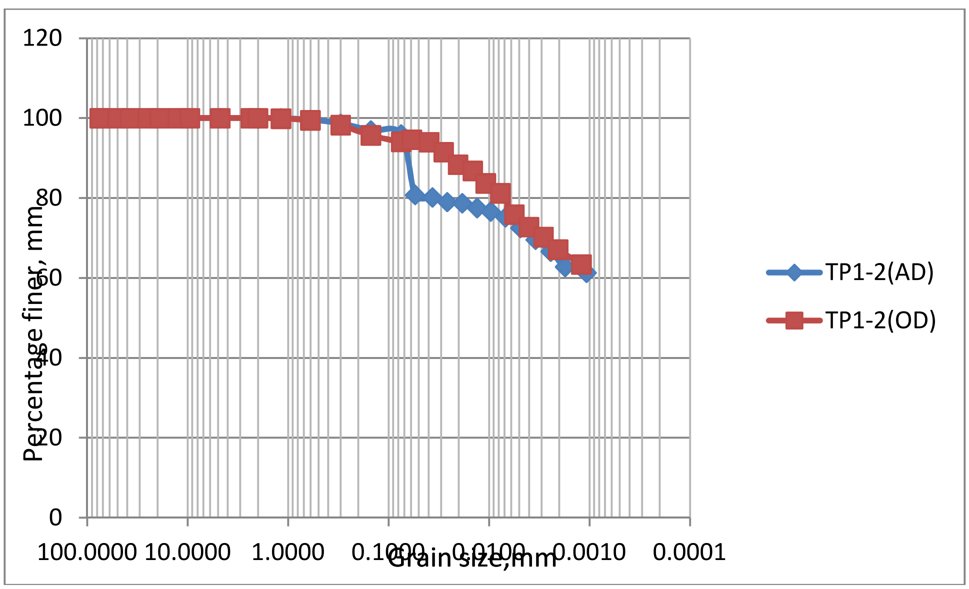

Fig A.1.2 grain size distrubition curve for AD and OD of TP1-2

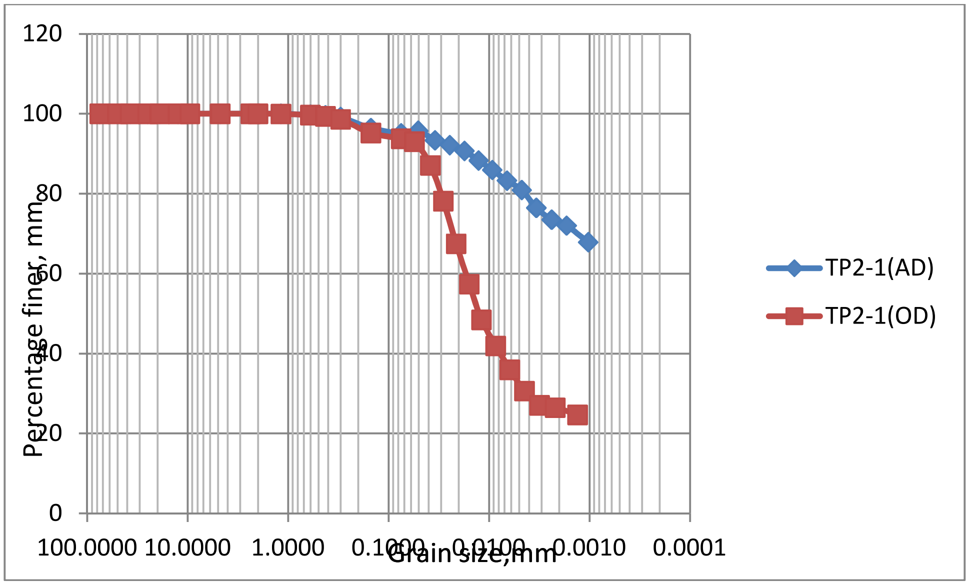

Fig A.1.3. grain size distrubition curve for AD and OD of TP2-1

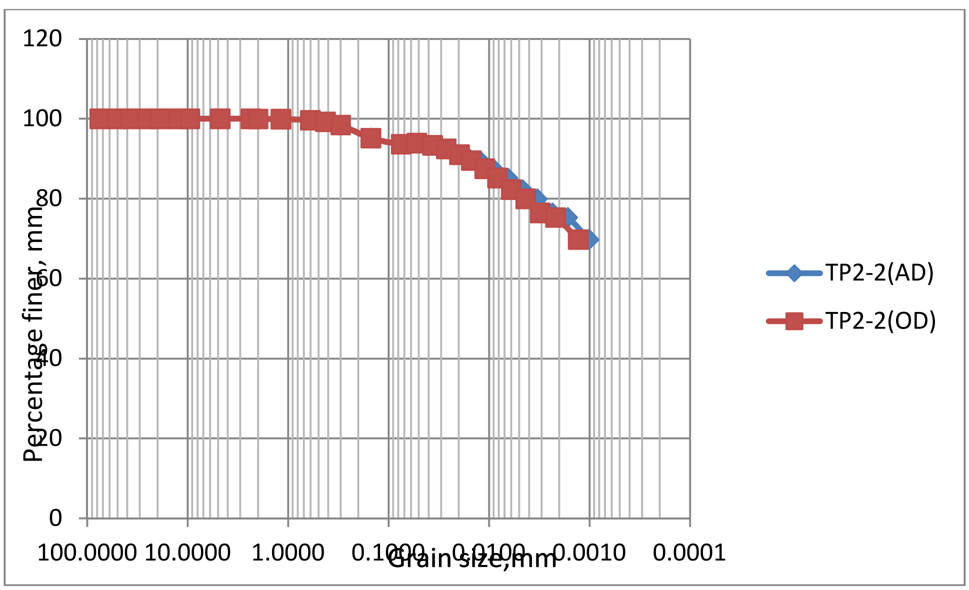

Fig A.1.4. grain size distrubition curve for AD and OD of TP2-2

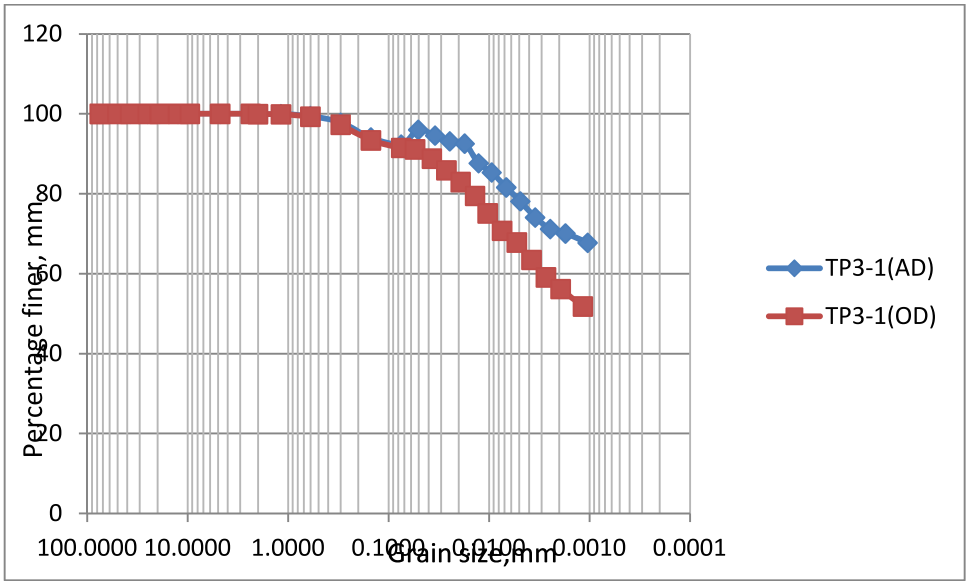

Fig A.1.5. grain size distrubition curve for AD and OD of TP3-1

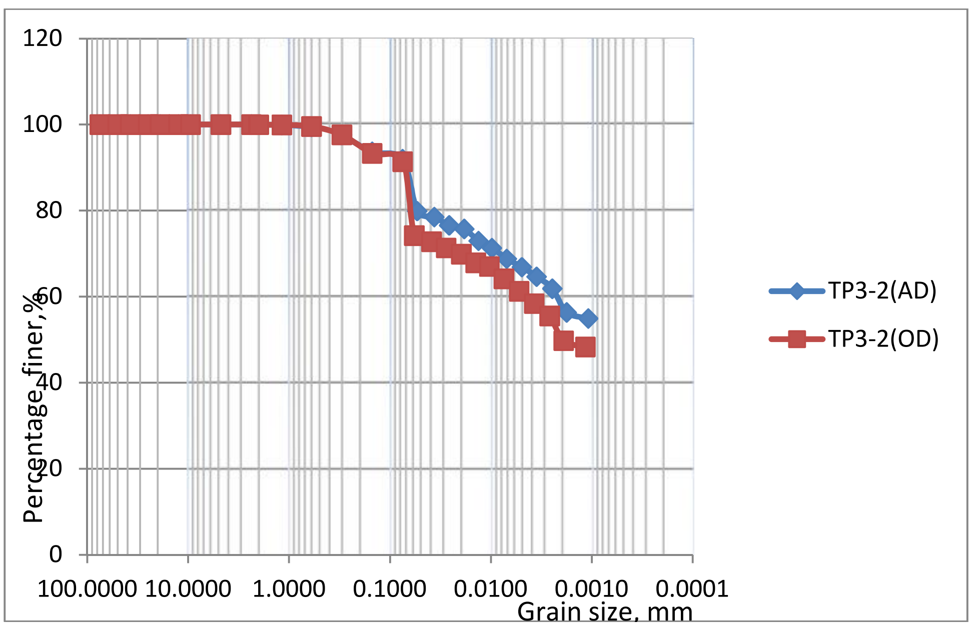

Fig A.1.6. grain size distrubition curve for AD and OD of TP3-2

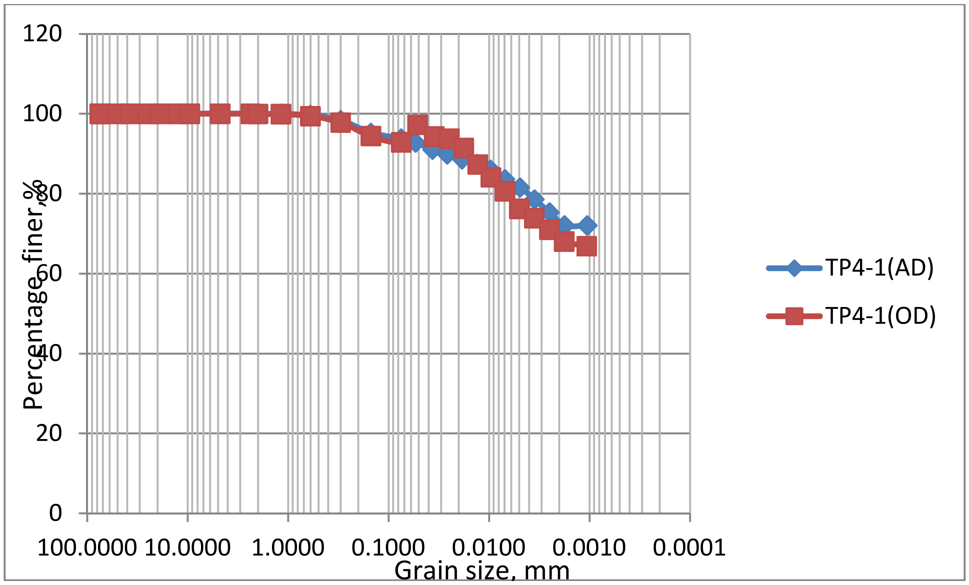

Fig A.1.7. grain size distrubition curve for AD and OD of TP4-1

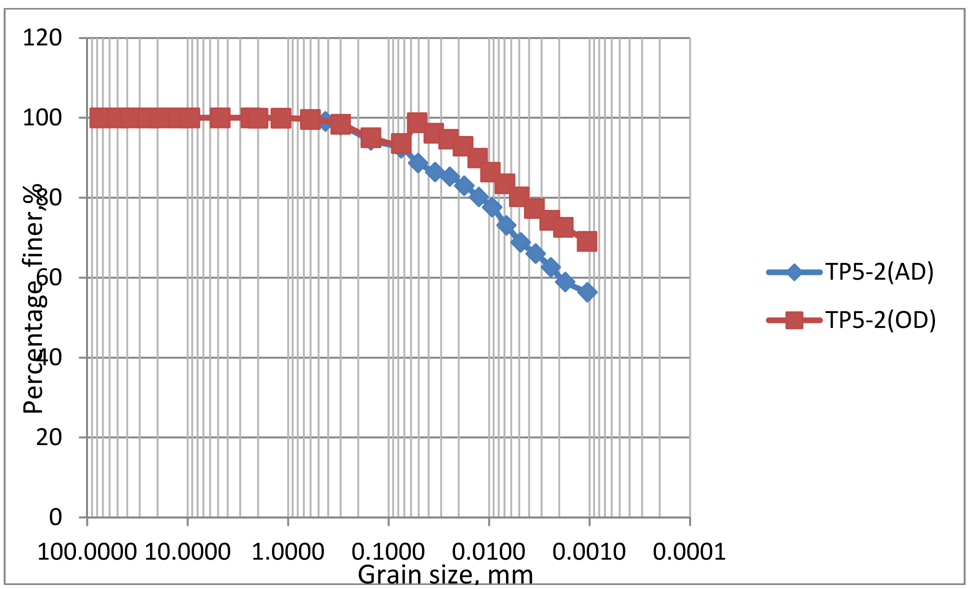

Fig A.1.8. grain size distrubition curve for AD and OD of TP5-2

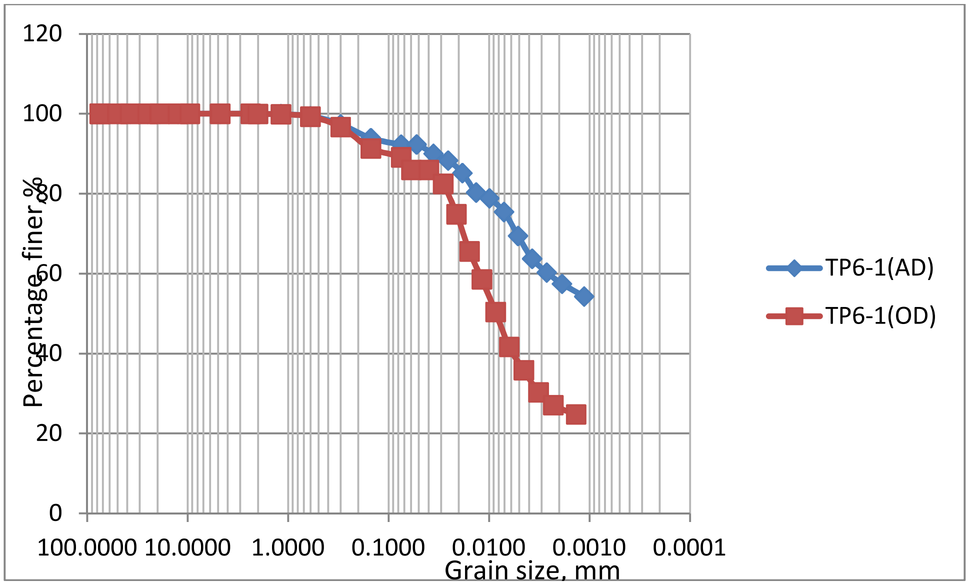

Fig A.1.9. grain size distrubition curve for AD and OD of TP6-1

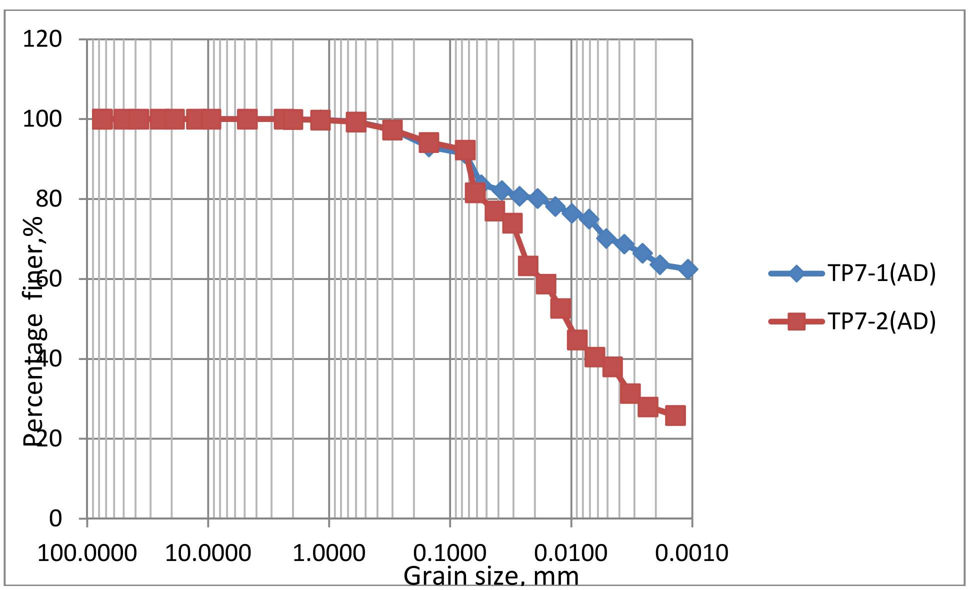

Fig A.1.10. grain size distrubition curve for AD and OD of TP7-1

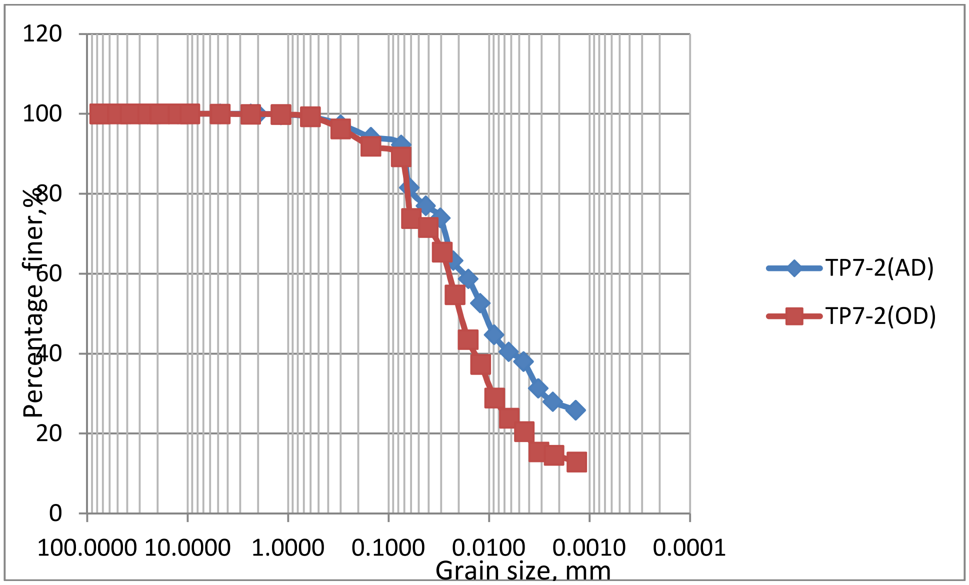

Fig A.1.11. grain size distrubition curve for AD and OD of TP7-2

A.2.Grain size distribution for different depth condition

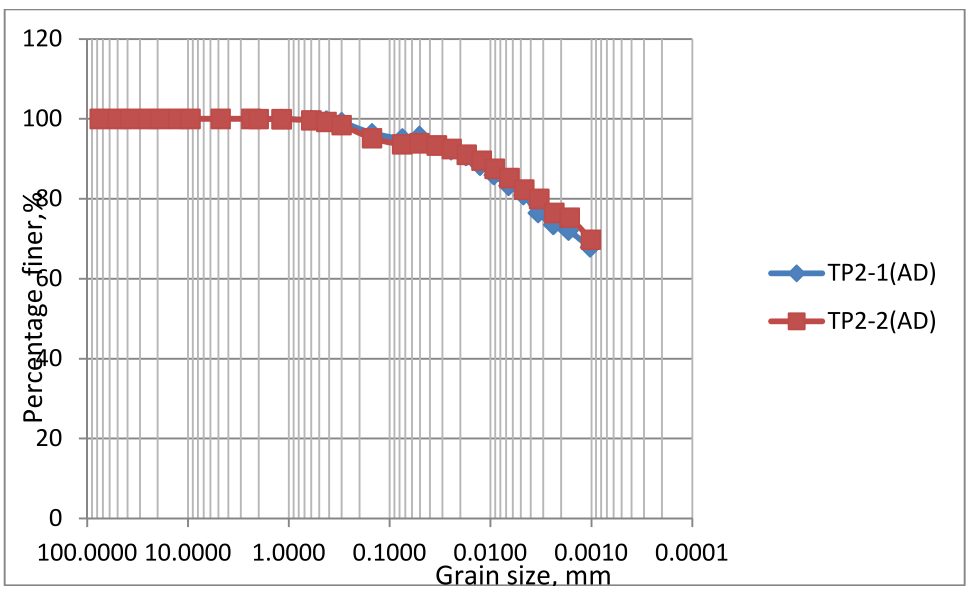

Fig. A.2.1. grain size distribution for TP2-1 and TP2-2

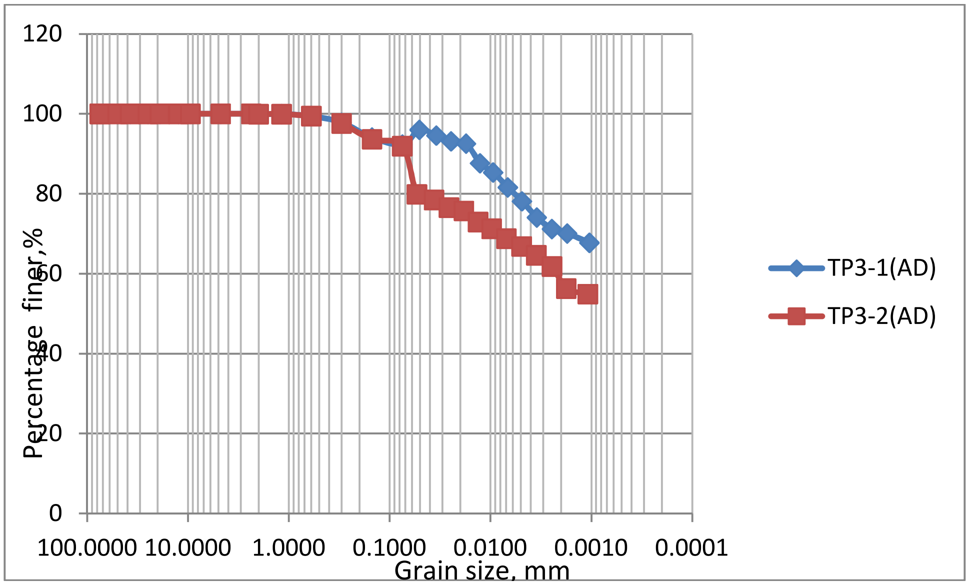

Fig. A.2.2. grain size distribution for TP3-1 and TP3-2

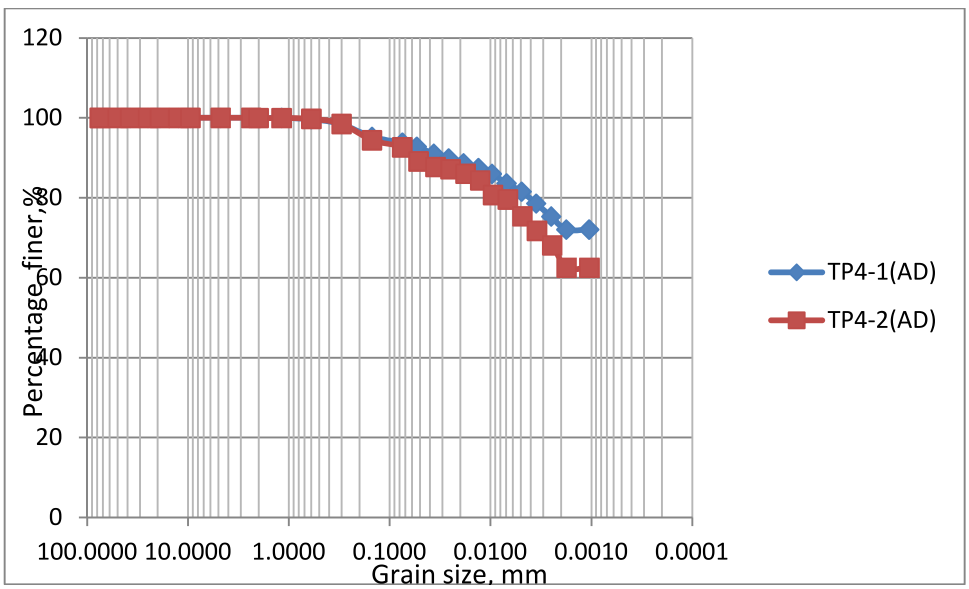

Fig. A.2.3. grain size distribution for TP4-1 and TP4-2

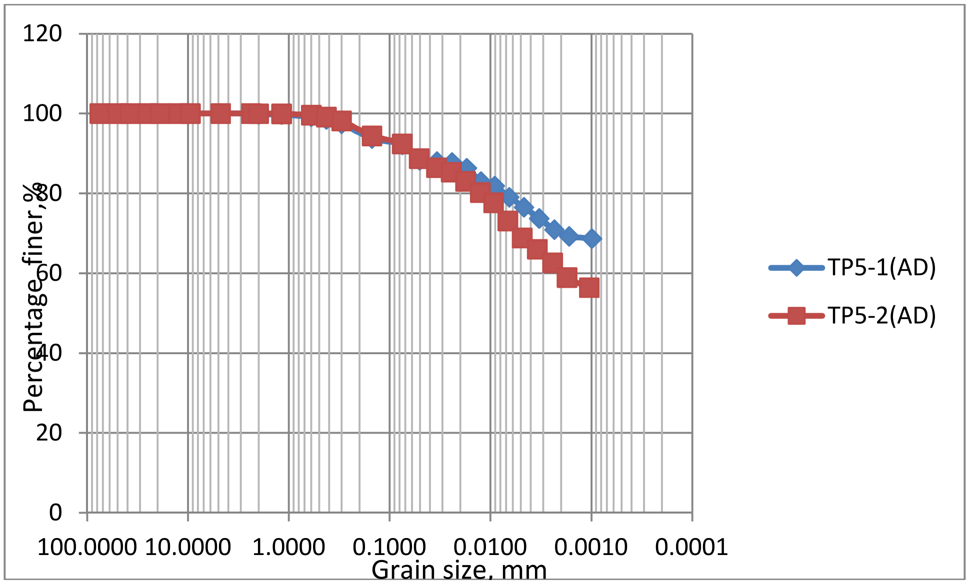

Fig. A.2.4. grain size distribution for TP5-1 and TP5-2

Appendix-B

Percentage Amount of the Grain Sizes for different test conditions and classification

				percentage amount of particles size			
test pit	depth(m)	test condition	classification according to	gravel	sand	silt	clay
TP1	1.3-1.5	AD	AASHTO	0	4.86	22.97	72.14
			USCS	0	5.28	22.58	72.14
		OD	AASHTO	0.04	3.49	76.16	20.31
			USCS	0	6.26	73.43	20.31
	2.8-3.0	AD	AASHTO	0.04	19.16	17.99	62.81
			USCS	0	4.00	33.19	62.81
		OD	AASHTO	0	5.99	26.86	67.15
			USCS	0	5.90	26.95	67.15
TP2	1.3-1.5	AD	AASHTO	0	4.27	22.23	73.50
			USCS	0	4.96	21.64	73.50
		OD	AASHTO	0.02	6.96	66.57	26.45
			USCS	0	6.20	67.31	26.45
	2.8-3.0	AD	AASHTO	0.04	6.05	18.61	75.30
			USCS	0	6.56	18.34	75.30
		OD	AASHTO	0.04	3.26	72.02	24.68
			USCS	0	7.72	67.60	24.68
TP3	1.3-1.5	AD	AASHTO	0.04	3.95	25.95	70.06
			USCS	0	7.66	22.28	70.06
		OD	AASHTO	0.04	11.16	32.61	56.19
			USCS	0	8.50	35.31	56.19
	2.8-3.0	AD	AASHTO	0.04	27.21	23.00	49.75
			USCS	0	8.62	41.63	49.75
		OD	AASHTO	0.04	20.08	23.58	56.30
			USCS	0	8.06	35.64	56.30
TP4	1.3-1.5	AD	AASHTO	0.04	7.16	20.75	72.04
			USCS	0	6.20	21.76	72.04
		OD	AASHTO	0.04	2.71	29.20	68.04
			USCS	0	7.14	24.82	68.04
	2.8-3.0	AD	AASHTO	0.04	10.85	26.62	62.49
			USCS	0	7.28	30.13	62.49
		OD	AASHTO	0.04	16.37	32.81	50.78
			USCS	0	8.68	40.54	50.78
TP5	1.3-1.5	AD	AASHTO	0.18	11.50	19.07	69.25
			USCS	0	6.82	22.93	69.25
		OD	AASHTO	0.04	11.87	22.31	65.78
			USCS	0	8.68	25.54	65.78

Appendix-B continued

	2.8-3.0	AD	AASHTO	0.02	11.25	29.76	58.96
			USCS	0	7.58	33.46	58.96
		OD	AASHTO	0.04	11.59	26.17	72.63
			USCS	0	6.40	20.97	72.63
TP6	1.3-1.5	AD	AASHTO	0.04	7.66	34.86	57.44
			USCS	0	7.66	34.90	57.44
		OD	AASHTO	0.04	14.01	58.85	27.10
			USCS	0	10.90	62.00	27.10
	2.8-3.0	AD	AASHTO	0.04	18.20	26.19	55.57
			USCS	0	6.46	37.97	55.57
		OD	AASHTO	0.04	22.47	48.75	28.74
			USCS	0	10.30	60.96	28.74
TP7	1.3-1.5	AD	AASHTO	0.04	17.81	18.54	63.61
			USCS	0	8.64	27.75	63.61
		OD	AASHTO	0.04	22.33	42.55	35.09
			USCS	0	10.64	54.27	35.09
	2.8-3.0	AD	AASHTO	0.04	22.94	49.01	28.01
			USCS	0	7.72	64.27	28.01
		OD	AASHTO	0.04	28.36	57.00	14.60
			USCS	0	10.73	74.66	14.60