



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Basic Engineering Properties of Lateritic Soils
Found in Nejo – Mendi Road Construction Area,
Welega

By
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November 2005

**Basic Engineering Properties of Lateritic Soils found in
Nejo – Mendi Road Construction Area, Welega**

**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.-Ing Samuel Tadesse 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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Symbols and abbreviations

Designation

Units

LL	Liquid limit	%
PL	Plastic limit	%
PI	Plasticity Index	%
LS	Linear shrinkage	%
FS	Free Swell	%
S _g	Specific gravity	---
W	Moisture content	%
N	No. of blows for Liquid limit	---
NMC	Natural moisture content	%
AD	Air drying or oven drying at a temperature of 50°C with maximum Relative humidity (RH) 30%	---
OD	Oven drying at a temperature of 105°C	---
S	Soaking (saturation)	---
AR	As received /at the natural moisture content/	---
RH	Maximum relative humidity	%
OMC	Optimum moisture content for compaction test	%
MDD	Maximum dry density for compaction test	g/cm ³
CBR	California Bearing Ratio	%
AASHTO	American Association of State Highway and Transportation Officials.	---
ASTM	American Society for testing and Materials.	---
BS	British Standard	---

Abstract

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks in the tropical and sub-tropical regions with hot, humid climatic conditions. Their formation also consists of leaching out of free silica and bases and accumulation of oxides of iron, aluminum or both. This process is called laterization. Laterites are rich in sesquioxides (iron oxides, aluminum oxides or both) and low silicates but may contain appreciable amounts of kaolinite. Due to the presence of iron oxides lateritic soils are red in colour.

Laterites are grouped under group of soils with a strong mineralogical influence derived from clay minerals only found in residual soils. Soil engineering properties under this group are highly influenced by the presence of sesquioxides. Sesquioxides appear to act as cementing agents which bind the other mineral constituents into clusters or aggregations. With sufficient concretion of sesquioxides, the hard concretionary materials are formed. This concretionary bond is broken down during test manipulation for some lateritic soils.

In this thesis work, some peculiar geotechnical and geo-chemical characteristics have been investigated on soils sampled from Nejo- Mendi road construction area. Accordingly, the soil samples under investigation have been obtained to be true laterites, in short referred to as laterites. Moisture content determination using oven temperature of 105°C and oven temperature of 50°C with maximum relative humidity 30% were also carried out on the soil samples to investigate presence of loosely bound water of hydration. It was obtained that the soil samples did not contain loosely bound molecular water in a significant amount.

The soil specimens were tested at different sample preparation conditions prior to testing. The engineering properties investigated in the course of the research work include index tests, compaction and California Bearing Ration (CBR) tests at oven temperature of 105°C dried, air dried (oven temperature of 50°C with maximum relative humidity 30%) and as received conditions on the soil samples. Accordingly, pre-treatment variation has not significantly change index, compaction and CBR test results.

Atterberg limits were investigated 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.

1. Introduction

1.1 General

Welega which is located west of Ethiopia is covered predominantly with reddish soil. Such soils already found in Nejo - Mendi road construction area, soil sampling place, located in west Welega. Depending on soil forming factors such as climate, drainage, topography and parent rocks some red soils can be lateritic soils. Generally the formation of laterites favour rolling slope with good water runoff, distinct rainy season having warm summer (CIRIA, 1995). For the area Nejo-Mendi all soil forming factors are fulfilled and hence one can consider the soil as lateritic soils. In this research work index and chemical test results prevailed that the soils under consideration are laterites.

Laterites are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks under tropical condition (Blight,1997). Laterites are rich in sesquioxides (Fe_2O_3 or Al_2O_3 both) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Due to the presence of iron oxides lateritic soils are red in colour ranging from light through bright to brown shades.

Laterites occur mostly in tropical and sub-tropical regions with hot, humid climatic conditions. It has been suggested that a mean annual temperature of around 25°C is required for their formation, and in seasonal situations there should be a coincidence of the warm and wet periods. The minimum annual rainfall required for laterite formation is generally at least 750 mm (CIRIA, 1995). The higher the rainfall above this value, the greater is the leaching effect and therefore increases the degree of laterization.

Laterites are grouped under group of soils with a strong mineralogical influence derived from clay minerals only found in residual soils (Blight, 1997). Soil engineering properties under this group are highly influenced by the presence of sesquioxides. The sesquioxides within the fine fraction of tropical soils tend to coat

the surface of individual soil particles. It can also cause a physical cementation of adjacent grains, thus producing aggregated particles of coarser size. Both factors reduce plasticity, but intensive remoulding of the soil breaks down the aggregations and the sesquioxides coatings which is called disaggregation, results increase in plasticity. The effect of disaggregation of clay size particles up on test manipulation are checked by executing Atterberg limit tests following different testing procedures.

The water of hydration in the sesquioxides of iron and aluminium may be driven off by oven-drying at 105°C, the standard temperature for testing temperate region soils. This water normally takes no part in the engineering performance of the material, but is reflected in the test results at higher temperature. Hence this effect should be checked which helps in oven selection during laboratory soil testing. If drying soil specimen at such high temperature is affecting loose water by repeated tests then the oven drying temperatures for the subsequent programme of tests should be changed to an appropriate value usually 50°C with maximum relative humidity 30%.

When some laterite soils are oven dried prior to testing at temperature of 105°C, they exhibit lower Atterberg Limit values. This is partly because dehydration of the sesquioxides creates a stronger bond between the particles, which is resistant to penetration of water. Drying is also accompanied by shrinkage, which brings the particles closer together, and the attractive forces become so strong that water no longer penetrates. The process cannot be reversed by re-wetting. The effect takes place during air-drying but becomes more pronounced on oven-drying at higher temperatures.

Physical properties of some lateritic soils show variation when tested under different pre treatment conditions (sample preparation condition prior to testing). The influence of sample preparation on index property tests and compaction characteristics of tropical soils is recommended to be checked by Sintayehu, 2003 thesis entitled "Investigation of Influence of compaction on the suitability of Earthfill Dams of Tropical soils". Lyon associations Ltd., 1971 Book entitled "LATERITE AND LATERITIC soil and other problem soils of AFRICA" strongly recommends

lateritic soils of Ethiopia susceptible to change with air drying be investigated. Hence this research work is intended to check effect of pre-treatment and testing procedures on Index property test and compaction characteristics.

Laterite is a widely available material in Ethiopia as mentioned by ERA (Ethiopian Roads Authority) design manual (ERA, 2001). Now a days most infrastructures of the country have been constructed in the area where laterites are available. The engineering properties of such soils have not been studied satisfactorily. Some roads constructed on such area faces a shortage of construction materials. To use laterites as construction materials detail engineering properties would be known. This thesis work would be provide some basic engineering properties of laterites from Nejo – Mendi area.

1.2 Objectives and Methodology of the Study

The main objectives of this research work are as the following:

1. Check whether the soil of Nejo – Mendi area is lateritic soils by conducting index and chemical tests.
2. Investigate the effect of temperature variations, pre-treatment conditions and testing procedures.

Effect of temperature variations on moisture content determination have been checked in the laboratory using different drying oven temperatures. The difference of the results leading to choose oven temperature for the rest tests to be carry out under this research work.

Different pretreatment methods have been applied to a number of samples tested in the laboratory. These methods were air drying (AD), oven drying (OD), soaking (S) and as received (AR) or at the natural moisture content. The effect on the Atterberg limits of varying mixing time and sample preparation were also studied. The change in compaction and California Bearing Ratio (CBR) characteristics of lateritic soils when subjected to different pre treatment, compaction energies and recompaction were also investigated.

Samples tested for the four pre-treatment methods were prepared in the following manner (Lyon, 1971).

As Received (AR) - at natural moisture content.

Soaked (S) - immersed in water for 24 hours.

Air dried (AD) - dried to constant weight under normal temperature.

Oven dried (OD) - dried in an oven for 24 hours at 105°c.

Execution of soil at its moist condition considered if its field moisture content was about 13% (Lyon, 1971). Regarding air drying one can use oven at a temperature of 50°c with max RH 30% equivalently (Blight, 1997).

1.3 Structure of the Thesis

The thesis has been divided in to six Chapters. In this introductory chapter the background, objective and a brief summary of the thesis work is presented. The second Chapter gives a brief literature review which discusses about formation, classification, sensitivity to pre-treatment and testing procedure, and considers lateric soils as construction materials. Sampling area description is dealt with in Chapter three. In the fourth Chapter the types of laboratory tests conducted with results for the research are described in detail, more over insitu properties with sample description incorporating photographs are attached. The test results compared with previously done lateritic soils and laboratory test results discussion are presented in chapter five. Chapter six includes the conclusions and recommendations drawn from the research. In addition to the six Chapters appendices are included at the end of the thesis which provide AASHTO designation equivalent to ASTM testing procedures, Grain size distribution curves under different testing conditions and Compaction effort for different proctor testing procedures.

2. Literature Review

2.1 Characteristics of Laterites

2.1.1 General

The soil name "laterite" was coined by Buchanan (1807) in India, from a Latin word "later" meaning brick (Raychaudhuri,1980). The extensive literature on laterite published since Buchanan's time has produced a range of terms referring to many soil types. There is a tendency to apply the term to any red soil and rock in the tropics. On the other hand, laterite is also known by the following names: Brickstone, Iron clay, Laterite (India), Cabook (Ceylon), Canga, Picarra (Brazil), Carapace, Cuirasse (France), Eisenkruste, Krusteneisensteine (Germany), Ironstone (Nigeria), Mantle rock (Ghana), Moco de hierro (Venezuela), Murram (East Africa), Pisolite (Australia), Plinthite (USA) and Ferricrete (southern Africa) (CIRIA, 1995).

Blight, (1997) describes laterites as highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks under tropical condition. The three major agencies of weathering being physical, chemical and biological processes. In the process the parent rock and rock minerals break down, releasing internal energy and forming soils having a lower internal energy which are more stable. Physical processes increase surface area so that chemical attack increases. Biological weathering includes both physical and chemical actions.

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

Laterites are rich in sesquioxides (secondary oxides of iron, aluminum or both) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Due to the presence of iron oxides lateritic soils are red in colour ranging from light through bright to brown shades.

2.1.2 Formation, Occurrence and Distribution

2.1.2.1 Formation and Occurrence

Tropical decomposition tends to favour formation of the clay mineral kaolinite. This is the most common clay mineral in tropical residual soils. Under suitably moist conditions, halloysites will be formed. Under prolonged decomposition, silica can be removed to the extent that free alumina and iron oxides are present (Blight, 1997). The lateritic soil formation involves three major processes which are identified as follows (Makasa, 1998):

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

Leaching: removing of combined silica and bases and the relative accumulation or enrichment of oxides and hydroxides of sesquioxides which is called laterization.

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

Desiccation /dehydration/: Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide rich materials in a manner which is generally not reversible upon wetting. Dehydration also influences the formation processes of clay minerals. In the case of total dehydration, strongly cemented soils

with a unique granular soils structure may be formed (Blight, 1997). Dehydration may be caused by climatic changes, upheaval of the land, or may also be induced by human activities, for example by clearing of forests.

Laterite occurs mostly in the tropical and sub-tropical regions with hot, humid climatic conditions. It has been suggested that a mean annual temperature of around 25°C 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 season, laterites do not develop freely. The minimum annual rainfall required for laterite formation is generally at least 750 mm. The higher the rainfall above this value, the greater is the leaching effect, which removes free silica, reduces the silica/sesquioxide ratio and therefore increases the degree of laterization (CIRIA, 1995).

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

Two aspects of the parent rock affect the formation of laterite. One is the availability of iron and aluminum minerals. These are more readily available in basic rocks. The other is the quartz content of the parent rock. Where quartz is a substantial component of the original rock, it may remain as quartz grains (Makasa , 1998).

2.1.2.2 Regional Distribution

Laterites are soils which cover extensive areas in tropical countries with intermittently moist climate. The six main regions of the world in which laterites occur are Africa, India, South-East Asia, Australia, Central and South America. It should be emphasized that, because of shifts of climatic zone in the geological past,

important areas of laterite can be found in areas now outside the tropics (CIRIA, 1995). The geographical distribution of laterites is in Fig. 2/1.

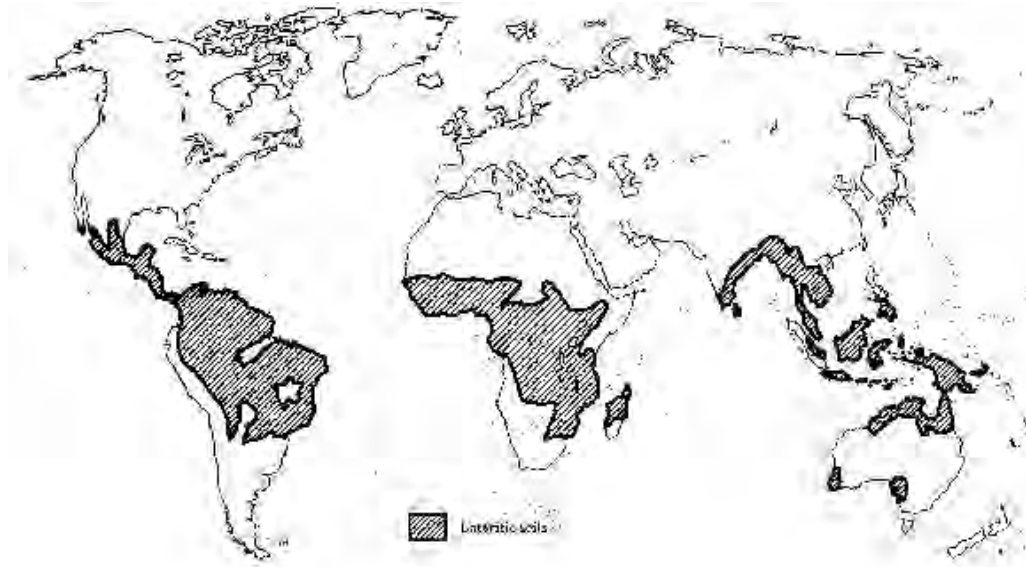


Fig. 2/1 World-wide distribution of laterite soils (IFG, 2004).

2.2 Pedological and Lithological Classification

Wesley L.D. and Irfan T.Y. (Blight, 1997) classify residual soils into three groups on the basis of mineralogical composition alone. The suggested groups are

1. Group A: Soils with out a strong mineralogical influence.
2. Group B: Soils with a strong mineralogical influence deriving from clay minerals also commonly found in transported soils.
3. Group C: Soils with a strong mineralogical influence deriving from clay minerals only found in residual soils.

Group C is further grouped in to three sub-groups according to clay minerals of soils. These are

Sub-group (a) Halloysitic soils

Sub-group (b) Allophanic soils

Sub-group (c) soils influenced by the presence of sesquioxides.

Accordingly lateritic soils are grouped under group C and sub group c. Soil engineering properties under this group are highly influenced by the presence of sesquioxides. Sesquioxides appear to act as cementing agents which bind the other mineral constituents into clusters or aggregations. With sufficient concretion of sesquioxides, the hard concretionary materials are formed (Blight, 1997). Classification of laterites are also possible according to its genetic basis, size of particles and degree of concretion.

Pedological classification system is given by D' Hoore. The soils are broadly differentiated on a genetic basis, determined by soil forming factors. It is a means of identification of lateritic soils (Lyon, 1971). Three main units are used for the description and classification of red tropical soils (CIRIA, 1995).

Ferruginous soils show a marked separation of free iron oxide, either leached out of the profile or precipitated within the profile as concretions. There may be a high proportion of weatherable primary minerals remaining. Kaolinite is the dominant clay mineral. These soils are generally found in areas with under 1850mm rainfall a year and pronounced dry seasons.

Ferrallitic soils are generally deep, with only slightly differentiated horizons. Kaolinite is the dominant clay mineral; and they contain free iron oxides and hydrated oxides of aluminum. They generally occur in more humid areas with more than 1500mm rainfall per year.

Ferrisol soils have profiles similar to ferrallitic soils, but with very few weatherable minerals remaining. The entire clay size fraction comprises kaolinite and amorphous oxides of iron and aluminum. Ferrisol tend to develop at deeper levels, because of surface erosion, and occur in regions of between 1250 and 2750 mm rainfall per year. According to Morine W.J. and Todor P.C., Ethiopian laterites fall under this group (Lyon, 1971).

Lithological classification on the other hand, depends on particle size of laterites (Lyon, 1971).

Lateritic clays	< 0.002 mm
“ silts	= 0.002 ~ 0.06 mm
“ sands	= 0.06 ~ 2 mm
“ gravels	= 2 ~ 60 mm
and cuirasse	> 60 mm

Classification of laterites is also possible depending on the degree of concretionary development. The development of concretions requires sufficient concentration of the hydrated oxides of iron and aluminum for cementation or precipitation growth to start (CIRIA, 1995). The physical properties of laterites accordingly varies widely from soil to rock-like material. A recommended classification system for these is shown in Table. 2/1 (IFR, 2004).

Table 2/1 Classification system for laterite depending on the degree of concretionary development.

Age	Recommended Name	Characteristics	Equivalent terms in literature
Immature (young)	PLINTHITE	Soil fabric containing a significant amount of laterite material. Hydrated oxides at the expense of some soil material. Unhardened nodules present, but may be slight evidence of concretionary development	Plinthite, laterite, lateritic clay
	NODULAR LATERITE	Distinct hard concretionary nodules present as separate particles	Laterite gravel, ironstone gravel, pisolitic gravel
	HONEYCOMB LATERITE	Concretions have coalesced to form a porous structure which may be filled with soil material.	Vesicular laterite pisolitic ironstone, cellular ironstone, spaced pisolitic laterite
	HARDPAN LATERITE	Indurated laterite layer, massive and tough.	Ferricrete, ironstone, laterite crust, vermiform laterite, packed pisolitic laterite
Mature (old)	SECONDARY LATERITE	May be nodular honeycomb or hardpan, but is result of erosion of pre-existing layer and may display brecciated appearance.	

Nodular laterite picture is shown in Fig. 2/2(IFR, 2004).



Fig.2/2 Profile view of nodular lateritic gravel

2.3 Laterites and Lateritic soils

Many conflicting definitions of laterite have been proposed in the technical literature. Buchinan's is the earliest, and is based on the ability of a soft red material to harden on exposure to air. The term laterite became synonymous with the tropical weathering product of virtually all igneous rocks and was applied to red soils, weather hardening was involved or not (CIRIA, 1995).

A more precise definition is resulted in the application of chemical criteria to tropical weathered soils (CIRIA, 1995). Rossiter, 2004 compiled the classification of soils according to the degree of laterization. The degree of laterization is estimated by the silica-sesquioxide (S-S) ratio ($\text{SiO}_2/(\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3)$). The conclusion is

An S-S ratio of 1.33 or smaller = laterite.

An S-S ratio of 1.33 to 2.0 = lateritic soil.

An S-S ratio of 2.0 or higher = non-lateritic, tropical soil.

Laterites and lateritic soils may vary from a loose material to a massive rock. For engineering purposes, the term “laterite” is confined to the coarse-grained vermicular material, including massive laterite. The term “lateritic soils” refers to materials with lower concentrations of oxides. Detail description of laterites and lateritic soils is given below (Rossiter, 2004).

2.3.1 Laterites

Most laterites are encountered in an already hardened state. In some areas of the world, natural laterite deposits that have not been exposed to drying are soft with a clayey texture and mottled coloring, which may include red, yellow, brown, purple, and white. When the laterite is exposed to air or dried out by lowering the ground water Table, irreversible hardening often occurs, producing a material suitable for use as a building or road stone. Frequently, 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 and dried.

2.3.2 Lateritic soils

The lateritic soils behave more like fine grained sands, gravels, and soft rocks. The lateritic soil typically has a porous or vesicular appearance. Some particles of lateritic soils tend to crush easily under impact, disintegrating into a soil material that may be plastic. Lateritic soils may be self-hardening when exposed to drying; or if they are not self hardening, they may contain appreciable amounts of hardened laterite rock or laterite gravel.

Morin W.J. and Todor P.C. use the term lateritic soil for all reddish tropically weathered materials, irrespective of the details of the degree of their weathering and irrespective of the presence or absence of concretions. They explained, this usage carries no implication with respect to the definition or properties of laterites. The distinction use for engineering purposes is based on differences in physical or engineering properties (Lyon, 1971).

4 Effect of Pre- treatment

Some lateritic soils show changes in physical properties when tested under different conditions. Laterites formed under continuously wet regions are likely to be characterized by high natural water contents, high liquid limits, and irreversible changes upon drying. Upon drying the plasticity decreases and grain size increases such that much of the clay sized material agglomerates to the size of silt (Lyon, 1971). The geotechnical behavior of soil altered up on drying due to alteration of clay minerals on dehydration and / or aggregation of fine particles to form larger particles. Important factor contributing to the close spacing of particles is the development of capillary stresses of significant magnitude. These capillary stresses lead to particle aggregation and reduce the available surface for interaction with water which is reflected in the reduction in plasticity characteristics (Pandan et al., 1993). Hence, index properties and engineering properties should be tested by simulating the actual condition.

On the other hand, laterites formed in regions subjected to distinct wet and dry seasons are likely to be characterized by low natural water contents, low plasticity, and the presence of concretions and cemented horizons. Laboratory tests run from the natural water content or from the air dried state lead to essentially the same result (Lyon, 1971).

Changes in pre-treatment type have minor effect on ferrisol with in which Morin W.J. and Todor P.C. recommend that areas with volcanic soils of Ethiopia should be investigated towards susceptibility of pre-treatment (Lyon, 1971).

2.5 The Self-Hardening Concept

The property of self-hardening under cycles of wetting and drying could be important for the performance of certain lateritic soils. Such property is less common in granular lateritic soils. At present self-hardening is not fully understood and cannot easily be predicted. The factors which influence the ability to self-harden may also affect the sensitivity of certain lateritic soils to test procedures. There is no

doubt that some of these soils are sensitive to the way in which they are prepared for laboratory testing and to the actual testing method employed. This sensitivity can be attributed to three basic factors, described below (CIRIA, 1995).

2.5.1 Aggregation of clay-size particles

The sesquioxides within the fine fraction of tropical soils tend to coat the surface of individual soil particles. One reason for this is an electrical bonding between the negatively-charged kaolinite and the positively-charged hydrated oxides. The coating can reduce the ability of the clay minerals to absorb water. It can also cause a physical cementation of adjacent grains, thus producing aggregated particles of coarser size. Both factors reduce plasticity, but intensive remoulding of the soil breaks down the aggregations and the sesquioxide coatings, with an attendant increase in plasticity.

The degree of working required to prepare laboratory specimens for Atterberg Limit determinations is, by comparison, very much greater. The plasticity of the construction material (the soil on site) may thus be lower than would appear from the Atterberg or other laboratory tests on remoulded samples.

2.5.2 Irreversible changes in plasticity on drying

When laterites dry, soils which contain hydrated oxides of iron and aluminium may become less plastic (i.e. exhibit lower Atterberg Limit values). This is partly because dehydration of the sesquioxides creates a stronger bond between the particles, which is resistant to penetration by water. Drying is also accompanied by shrinkage, which brings the particles closer together, and the attractive forces become so strong that water no longer penetrates. The process cannot be reversed by re-wetting. The effect takes place during air-drying but becomes more pronounced on oven-drying at higher temperatures.

2.5.3 Loss of water of hydration on drying

The water of hydration in the sesquioxides of iron and aluminium may be driven off by oven-drying at 105°C, the standard temperature for testing temperate region soils.

This water normally takes no part in the engineering performance of the material, but is reflected in the test results as a higher moisture content.

2.6 Identification of Sensitivity to Test procedures

To identify susceptibility of lateritic soils to the effect of clay mineral aggregation, to drying and to re-wetting (dehydration of sesquioxides), bulk sample at its natural moisture content should be tested in laboratory. The following tests should be conducted (CIRIA, 1995).

2.6.1 Loss of water of hydration

Two test portions should be prepared for moisture content determinations. One should be oven dried at 105 °c until successive test weighings show that no further weight loss is taking place, and the moisture content should be then determined. The other sample should be air-dried or oven dried at no more than 50 °c until successive test weighings show no further weight loss, and the moisture content then determined. The two results should be compared. A.B. Fourie recommends the moisture variation 4-6% or more indicates that structural water is present (Blight,1997). If this is confirmed by repeated tests then the oven drying temperatures for the subsequent programme of tests should be changed to an appropriate value or reduce the difference from moisture content tested conventionally.

2.6.2 Disaggregation of clay-size particles on mixing

As A.B. Fourie (Blight, 1997) suggests five air dried test portions should be mixed with water to give the range of water contents suitable for liquid and plastic limit determinations. The mixing time should be no more than 5 minute, and the mixed samples should be left to cure overnight before testing. After determining the moisture content for each test point on a part of each test portion, the remainder should then be mixed for a further 25 minutes before again determining the liquid limit. A.B. Fourie suggests a “> 5%” difference between the liquid limits of the specimens 5 minutes and 30 minutes mixing times indicates a break down of the aggregations of clay sized particles within the material (Blight, 1997). If this

disaggregation is confirmed by further tests, the main test programme should include the following instructions.

1. limit the mixing times (no more than 5 minutes)
2. use fresh material for each moisture content point in compaction tests, for liquid and plastic limit determinations.

Note:- A.B. Fourie recommends the following procedure for testing sample preparation. Five test specimens should be mixed with water to give a range of moisture contents suitable for liquid and plastic limit determinations. The minimum amount of air drying should be used, and preferably none at all. This should not be too difficult as the in situ moisture content of the majority of soils is at or below the relevant 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. Then follows same procedure mentioned above.

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 a slurry, which is then washed through a 0.425 mm sieve until the water runs clear. The material passing the sieve is collected and used for the Atterberg limit tests (Blight,1997).

2.6.3 Drying and wetting

Some guidance may be obtained by comparing the Atterberg limits of soil prepared from natural moisture content with those of oven dried soil re wetted to the point of test. With no further research, it indicates the preparation of laboratory specimens should simulate sensibly the likely field procedures with respect to wetting and / or drying of the soil prior to compaction.

2.7 Laterites as construction materials

Concretionary laterites are valuable road pavement materials, widely used in the tropics as sub-base, base material and for gravel roads. The term laterite, however, has tended to be indiscriminately applied in tropical highway engineering to any red

soil, and as a result the usefulness of laterites for road construction has been underestimated (CIRIA, 1995). Laterites are a good material for embankment construction.

Laboratory testing to check the suitability of concretionary laterites to be used as road pavement materials should take into account how these, materials are affected by the testing procedures (CIRIA, 1995). Some lateritic soils are sensitive to pre-treatment and testing procedures. So laboratory testing should be simulated to site condition.

Main characteristics of lateritic gravels and gravelly soils as mentioned by Morine W.J. and Todor P.C. are the high content of fines. Consequently, such materials do not fit into the existing temperate zone classification systems for coarse grained soils (Lyon, 1971). In addition, laterites undergo property changes during construction. The most sensitive property is gradation as the nodules tend to crush under heavy compaction.

Some laterites are gap-graded with a depleted sand-size fraction, to contain variable percentage of fines, and to have coarse particles of variable strength which may break down in performance, limits their usefulness as pavement materials on highly trafficked roads. Such laterites need to be improved by appropriate stabilization measures. Lime and cement treatments are common in tropics (CIRIA, 1995).

Laterites of use to the road and embankment construction material are generally thin strata occurring at shallow depth. So a great care should be taken during material investigation and excavation for construction material production. The deposit is likely to vary in thickness, depth and quality both along-slope and down-slope (CIRIA, 1995). Hence, care should be taken to prevent contamination of laterite while removing overburden and stockpiling the laterite.

3. Sampling Area Description

3.1 General

Nejo – Mendi road construction project, a project where the soil samples for this research work was taken, is intended to upgrade the existing gravel surfaced road as asphalt surfaced two-lane road (Rites and UNICONE, 2002). It is located in the National Regional State of Oromia specifically in west Welega. The upgrading of the Nejo – Mendi (74km) road is in line with the Government’s commitment towards an improved trunk road network in the country.

The client of the project is Ethiopian Roads Authority (ERA). Currently the road is under construction by Chinese contractor CRBC consulted by Metaferia Consulting Engineers Plc. The Project is funded by Organization of Petroleum Exporting Countries (OPEC).

West Welega is a well known Coffee growing area. The route facilitates transporting of coffee, Mango and Marble stone. In addition, Assosa capital of Benishangul Gumuz Regional State links with the rest of regional state only thorough this route. Hence the construction of the road is very important.

3.2 Climate, Geologic & Topographical data

The climate is tropical humid with seasonal variations associated with the oscillation of the inter- tropical convergence zone /ITCZ/. Between June and September, the ITCZ is located north of Ethiopia and the area is under the influence of Atlantic equatorial westerly and southern winds from the Indian Ocean. These south - westerly winds ascend over the south-western highlands of Ethiopia to produce the main rainy season. About 80% of the mean annual rainfall occurs during the period of these 4 months. The project area lies in the medium to high rain fall area with the average annual rain fall of around 1600mm (Rites and UNICONE, 2002).

Geology of the area is comprising, granites and various metamorphic rocks including genesis and schists underlie most of the route, with basalts of tertiary age being found largely to the west of Mendi and as intrusions and volcanic plugs in the area between Ghimbi and Nejo. These rocks have been subjected to very deep and intensive weathering processes, and rock exposures are mainly evident only in the areas underlain by granite and genesis (Rites and UNICONE, 2002).

Regarding the topography Rites and UNICONE, 2002 mentioned that the project goes through a rolling terrain for most of its length in the design review report for Nekempte – Assosa Road. The elevation along the existing road alignment is also incorporated. One can see Nejo – Mendi’s elevation having respective distance of 185 km and 259 km from Nekempte in Fig. 3/1.

The schematic diagram and location map of the project extracted from Rites and UNICONE, 2002 are respectively shown in Figs. 3/2 and 3/3.

3.3 Soil Characteristics

Welega province along the line Addis Ababa - Nekempte – Gimbi – Nejo – Mendi route is covered with reddish soil. According to their formation factors, these red soils are being lateritic soils. The soil formation factors such as topography, amount of rain, climate and parent rock seem to favor for laterites formation. Generally formation of laterite soils favour rolling slope with good water runoff, distinct rainy season having warm summer. The minimum annual rainfall required for laterite formation is generally at least 750 mm. For the area Nejo – Mendi as mentioned in section 3.2 the slope is rolling type and about 80% of the mean annual rainfall occurs during the period of 4 months which is seasonal. The rain fall on the average annual basis is equals around 1600mm which is in agreement with the minimum requirement as mentioned above. Geologically the area under consideration comprises of the rock types granites, metamorphic rocks including genesis and schists, and basalts which are basis for lateritic soil formations. From the soil formation and real situation comparison one can consider Nejo – Mendi soil as laterite. Such soil is found near the surface having thin layer.

Laterite soils are formed by the in-situ weathering and decomposition of rocks under tropical condition. They are rich in sesquioxides (secondary oxides of iron, aluminum or both) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Soil engineering properties under this group are highly influenced by the presence of sesquioxides. Sesquioxides appear to act as cementing agents which bind the other mineral constituents into clusters or aggregations. The colour of laterite soils is red

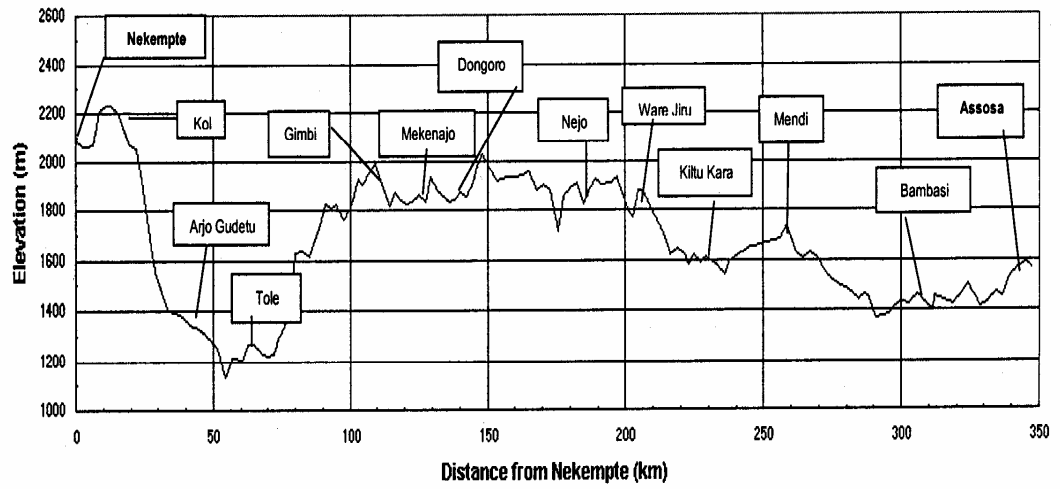


Fig.3/1 Elevation along Nekempte – Assosa Road.

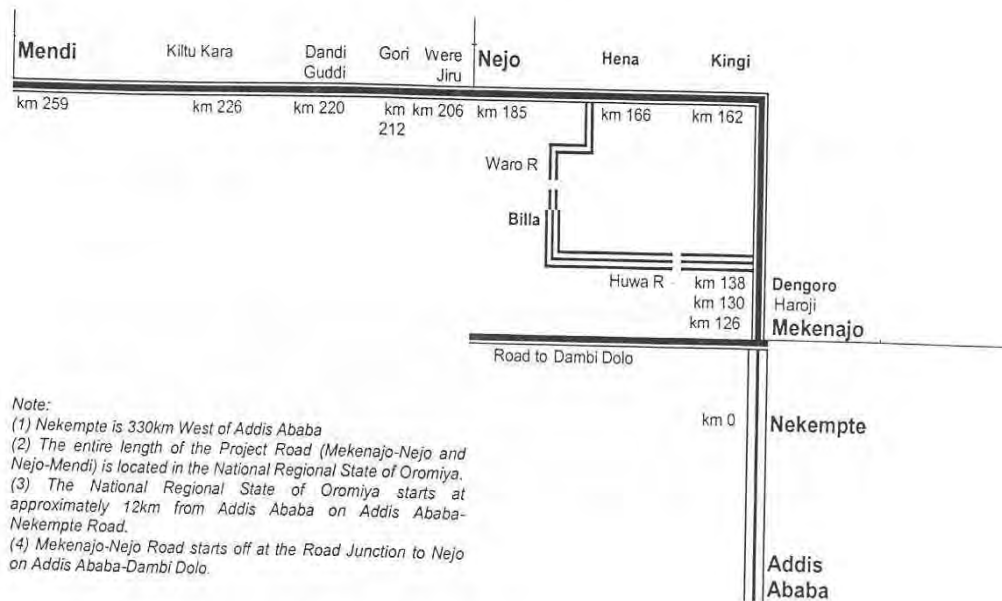


Fig. 3/2 Schematic diagram of Nejo – Mendi area.

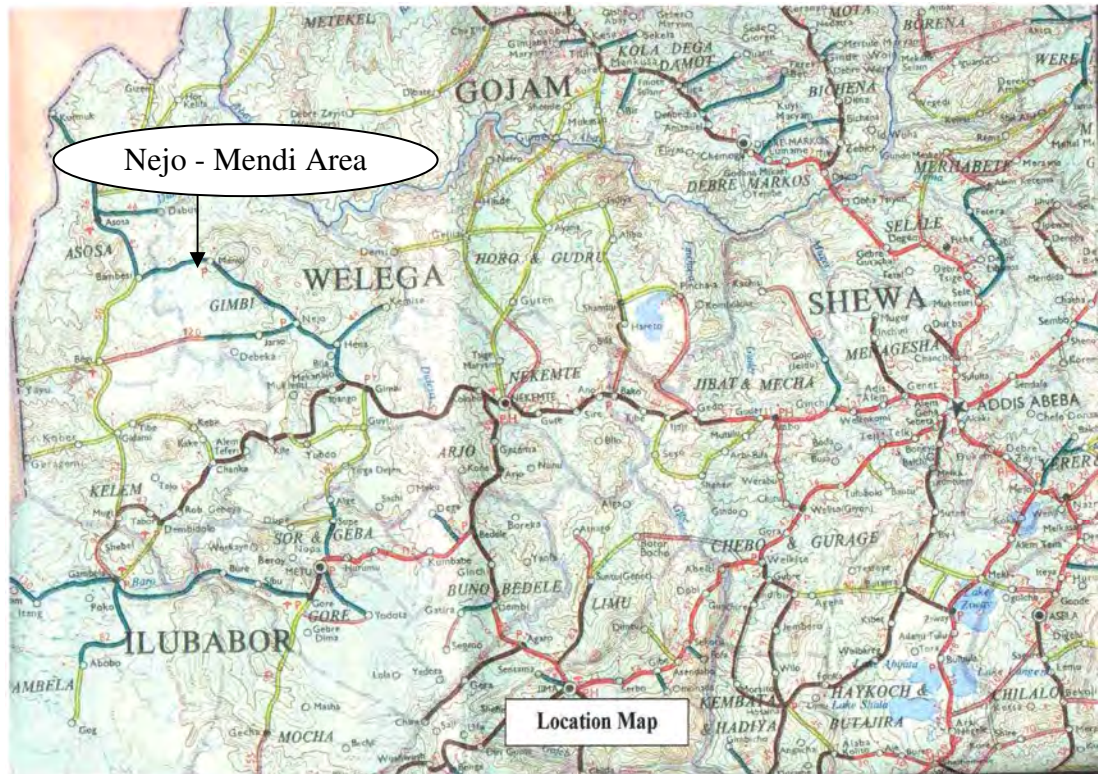


Fig. 3/3 Location map of Nejo – Mendi area.

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

4.1 In-situ Properties Description

4.1.1 Sample Description

Soil samples for this thesis work were collected in the stretch from Nejo to Mendi towns, 515 km to 589 km far away from Addis Ababa respectively. Before the soil samples were sampled, site visit was made with consultant’s material Engineer (of Nejo to Mendi road construction). Upon this site investigation potential places for lateritic soils were chosen. Usually less vegetated area is an indication of existence of lateritic soils (IFR, 2004). Accordingly five places were chosen and bulk samples have been collected for this research work, weighing about 3,728 kg.

Table 4/1. Samples location, depth and the designation used for the Samples.

Serial No.	Sampling Station ¹	Sampling depth [m]	Designation
1	Sta. 185+700,11.2km LHS	0 ~ 0.60 ²	Sp-1
2	Sta. 198+300 LHS ³	0.50 ~ 1.50	Sp-2-1
3	"	1.50 ~ 2.50	Sp-2-2
4	"	2.50 ~ 3.00	Sp-2-3
5	Sta. 249+000,600m LHS	0.40 ~ 1.40	Sp-3-1
6	Sta. 249+000,600m LHS	1.40 ~ 2.50	Sp-3-2
7	Sta. 202+180 LHS	0.50 ~ 1.50	Sg-1
8	Sta. 209+520 LHS	0 ~ 0.50	Sg-2

Due to time constraint and budget limitation bulk samples were gathered only from locations Sp-1, Sp-2-1 and Sp-3-1. These sampling area are located at the beginning, intermediate and end of sampling stretch. The rest samples were collected from the intermediate of the sampling stretch in amounts just enough for identification purpose only.

Sp-1 sample was collected from station 185+700, Nejo town, about 11.2km to Begi. There was almost no vegetation in the area. The over burden soil was found to be about 50cm which was scarified. The soil had been excavated and stocked by the contractor CRBC for testing to use as a road construction material. Disturbed samples were collected from this scarified area. It was difficult to get undisturbed samples, as it was too hard to penetrate by hydraulic jack using vehicle pick up axle weight. Even it was very difficult to dig by labour, but it was used as the least option as it was not possible to get excavator.

Sp-2 was sampled on the area of cultivation alongside the main carriage way. Place of sampling is shown in Fig 4/1. The topography is of moderate slope and burrows by termite and some other animals were visible. Such burrows are indications of the existence of lateritic soils (ILG, 2004). Burrows are shown in Fig. 4/2 which shows in detail the area bounded by the rectangle in Fig. 4/1.

¹ Station 0+000 is at Nekempte which is approximately 330 km from Addis Ababa.

² Over burden soil had been scarified for the road construction purpose.

³ Sp-2 designates the sampling place for both Sp-2-1, Sp-2-2, and Sp-2-3.

Before sampling 50 cm overburden was cleared first. Here excavator was used for excavation purpose. Three samples were taken at different depths. Sp-2-1, which is taken from the top was sampled in bulk quantity. The next Sp-2-2, described as second sample is visually more or less similar to the sample designated by Sp-2-1 but contains more fine particles. The third sample, Sp-2-3, has similar particle sizes as the second sample. Photograph of the pit under consideration is shown in Fig. 4/3.

Sp-3 / Sp-3-1, Sp-3-2 / sampling location is just near Mendi town. Bulk samples were collected from this site at a depth of 0.40 ~ 1.40m designated by Sp-3-1. Sp-3-2 is also sampled from the same area but at a depth of 1.40 ~ 2.50m. The place is less vegetated which is an indication of potential lateritic soils. This place unlike the others contains boulders with surface holes left due to leaching as shown in Fig. 4/4. The over burden is estimated to be about 40 cm.

Sg-1 was sampled from the place where the road is under construction. Depth of sampling is 0.50 ~ 1.50m.

Soil sample from station 209+520 which is designated by Sg-2 was collected from scarified place for road construction purpose on the main route.



Fig. 4/1 Plan view of station 198+300 LHS (Sp-2) before sampling.



Fig. 4/2 Burrows has been seen by nearby view of the area enclosed by the rectangle in Fig. 4/1 for Sp-2.



Fig. 4/3 The profile view of soil sample pit of Sp-2.



Fig. 4/4 The boulders with surface holes for Sp-3-1.

4.1.2 Insitu Properties Description

From the sampling site, moist soil samples were collected using plastic bags. The plastic bags were tied to reduce loss of natural moisture content. Insitu moisture contents were determined for the soil samples under investigation using oven temperature of 50°C and maximum relative humidity 30%. It takes about 5 days to dry constant weight. For the purpose of comparison natural moisture of the soil samples presented in Table 4/2 together with their Atterberg limit test results. The natural moisture content generally lies somewhat below the plastic limit and increases slightly with depth.

Table 4/2 Natural moisture content and Atterberg limit test results.

Serial No.	Designation	Sampling depth [m]	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	NMC %
1	Sp-1	0 ~ 0.60	56	36	20	19.8
2	Sp-2-1	0.50 ~ 1.50	53	35	18	26

3	Sp-2-2	1.50 ~ 2.50	59	37	22	29.4
4	Sp-2-3	2.50 ~ 3.00	67	43	24	33.5
5	Sp-3-1	0.40 ~ 1.40	53	33	20	18.9
6	Sp-3-2	2.00	58	37	21	14.5⁴
7	Sg-1	0.50 ~ 1.50	59	39	20	35.6
8	Sg-2	0 ~ 0.50	54	34	20	25.2

In situ densities of samples Sp-1 and Sp-2-1 were determined using sand replacement method. These test results together with laboratory maximum dry densities and optimum moisture contents are presented in Table 4/3. In situ density tests were conducted on the place where the scarified surface is disturbed to some degree during sampling.

Table 4/3 In situ Density using sand replacement method.

Serial No.	Designation	In situ Density g/cc	Moisture Content %	MDD g/cc	OMC %	Degree of Compaction
1	Sp-1	1.538	18.3	1.68	24	91.6%
2	Sp-2-1	1.438	21	1.538	26.4	93.5%

4.1.3 Profile characteristics Description

The soil characteristics were determined along the profile for soil sample Sp-2 (Sp-2-1 ~ Sp-2-3). Profile in situ characteristics are mentioned in Table 4/4 for illustration. The values of silt and clay sizes, plasticity index and natural moisture contents for locations Sp-2 generally increase slightly with depth up to the depth of investigation.

Table 4/4 The values of particle sizes, PI and NMC for profile analysis.

⁴ Test conducted after the sample lost its natural moisture content.

Serial No.	Designation	Percentage amount of Particle Sizes				Plasticity Index (%)	Natural Moisture Content %
		Gravel	Sand	Silt	Clay		
1	Sp-2-1	79.2	6.5	8.8	5.6	18	26.0
2	Sp-2-2	65.8	9.9	15.2	9.1	22	29.4
3	Sp-2-3	63.4	10.8	16.0	9.8	24	33.5

4.2 Laboratory Test Results and Discussions

4.2.1 Index Properties

4.2.1.1 General

Soil is a complex material. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solids, liquid and gases, where in many instances the solid particles also vary in size. Furthermore the relative quantities of solid, liquid and gases in a given soil is found to change due to any physical cause such as loading, seasonal variation and change of temperature which makes the situation further complicated (Samuel, 1989).

The behavior of soils should thus be understood by conducting tests on physical attributes of the soil particle and soil aggregate constituents (Hailemariam, 1992). The physical properties of soils which serve mainly for identification and classification purpose are commonly known as index properties which can be determined by simple laboratory tests. Index property tests are grain size analysis, Atterberg limits, free swell and specific gravity.

Since the samples were collected from road construction area, the results of this research work may be referenced by some road stake holders. Most of stake holders in road construction area use AASHTO testing procedure and specification. Hence for this research work, the procedure followed in the laboratory tests execution were AASHTO. For easy referencing, ASTM equivalent to that of respective AASHTO testing procedure is attached in the Appendix-A.

4.2.1.2 Effect of Temperature on Moisture Content Determination

The oven temperature 105°C for water content determination is too hot for certain clays and tropical soils. These soils contain loosely bound water of hydration or molecular water which can be lost at this high temperature resulting a change in the soil characteristics (Bowels, 1978). This effect was checked using different oven temperatures.

Moisture contents of the soil samples were determined in the laboratory according to AASHTO T262-93 (2000); Blight, 1997; CIRIA 1995. Drying oven temperatures of 105°C and 50 °c with maximum relative humidity (RH) 30% were used to dry the samples. Two samples from each site were taken for moisture content determination. One set of samples were dried to constant weight using drying oven at temperature of 105°C, and the other at a temperature of 50 °c with RH 30% taking a minimum of five days to get a constant mass in successive measurements. The values of the moisture content variations are compared and summarized in Table 4/5. As mentioned in section 2.6.1 moisture variations 4 - 6 % or more indicates that loosely bound molecular water is present. From the test results, one can see that the differences in moisture contents for all sites under consideration are below 4%, which means that the soil under investigation does not contain loosely bound water of hydration. Hence for subsequent tests execution for the thesis work, can be used drying oven of 105 °c.

Table 4/5. Moisture content comparison by different oven temperatures.

Serial No.	Designation	Sampling depth [m]	Oven Temperature [°C]		Difference [%]
			105 °c	50 °c, RH = 30%	

1	Sp-1	0 ~ 0.60	20.3	19.8	0.5
2	Sp-2-1	0.50 ~ 1.50	27.9	26.0	2.0
3	Sp-3-1	0.40 ~ 1.40	19.8	18.9	0.9
4	Sp-3-2	1.40 ~ 2.50	16.8	14.5	2.4
5	Sg-2	0 ~ 0.50	27.4	25.2	2.3

4.2.1.3 Effects of Mixing Water

Water may be chemically reacting with the oxides of lateritic soils during testing. In order to see this reaction Atterberg limits, Free swell (FS) and Linear shrinkage (LS) tests were carried out with distilled and tap water. The results are tabulated in Table 4/6. From the test results one can see that the respective results of Atterberg limits, Free swell and Linear shrinkage tests vary insignificantly up on changing of testing water type. It is to mean that tap water was not chemically reacting with the oxides of lateritic soils during testing. Hence tap water was used for the soil testing for this research works.

Table 4/6. Test results comparison with different mixing water.

Serial No.	Designation	Mixing water	LL (%)	PL (%)	PI (%)	FS %	LS (%)
1	Sp-2-1	Distilled	53	34	19	30	8.3
2	Sp-2-1	Tap	52	35	17	30	7.9

4.2.1.4 Grain size Analysis

4.2.1.4.1 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 soil on the other hand, follow hydrometer method.

Here sodium hexametaphosphate is used as a dispersing agent. For soils comprising coarser and finer, both mechanical and hydrometer testing methods shall be done.

4.2.1.4.2 Test Procedures

Dry preparation

The soil sample brought from field was first air or oven 105 °c dried and then pulverized before it was screened through the nest of sieves. During the preparation procedure, the sample was divided in to two portions using sieve No.10 (2mm). One portion contains only particles retained on No.10 sieve, while the other portion contains only particles passing 2mm sieve.

Coarser particles were screened through a nest of sieves. Whereas soil particles passing the No. 10 sieve was subjected to hydrometer analysis and the results were expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale (According to the procedure detailed in AASHTO T88-00).

Apart from the method of preparation of the soil samples, sieve analysis tests were carried out essentially in accordance to AASHTO T87-86. 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 10 days or equivalently put in side oven at temperature of 50 °c with maximum relative humidity 30% for at least 5 days. The room temperature was about 20 °c. The oven dried samples were prepared by drying the soils overnight at 105 °c.

Wet preparation

Wet soil sample preparations were carried out on moist soil samples for grain size analysis tests following the procedures mentioned in (AASHTO T146 -96, Blight, 1997).

4.2.1.4.3 Test Results and Discussions

The grain size analysis test results for all soil samples under investigation at different testing conditions are summarized in Table 4/7. The corresponding grain size distribution curves are shown in Figs. 4/5 to 4/7. The test results presented in the main body of the thesis are only the typical ones. The test result curves of all soil samples under investigation are shown in the Appendix-B. The values obtained from the gradation tests were analyzed with respect to the effect of pre-treatment, soil variations along laterally and depth wise.

Effect of Pre-treatment

Oven dried (OD), air dried (AD) and as received (AR) sample preparations were carried out to investigate the effect of pretreatment on grain size distribution of the soil samples under investigation. The test results are shown in Table 4/7 and Figs. 4/5a & 4/5b. Water content prior to testing for moist soil samples are attached in Table 4/7. From the curves one can observe that the three methods of pretreatment produce a small change in cumulative percentage passing between AD and OD for sample Sp-1 and between OD and AR for sample Sg-1. The AR method of pretreatment resulted finer cumulative percentage passing for sample Sp-1 than both OD and AD. This is due to some coarse grains become weaker and coming finer during washing. Hence, when these soils are dried, the fine particles do not aggregate to form larger particles due to mineralogy alteration and /or development of larger capillary forces between particles. One can carry out routine grain size analysis tests on air dried state.

The grain size distributions of some laterite soils change as a result of hydration reaction when dried specially at high temperature. The test result for dry preparation of sample is expected to result in decreased percentage of the finer fraction (clay). On the other hand, test result on sample carried out wet preparation (as received) is expected the reverse as compared to effect of drying i.e., increased percentage of finer fraction. But the test results of the grain size analysis of the samples under

investigation for this thesis work resulted in negligible difference in gradation following different sample pre-treatment procedures.

Effect of Soil Sampling Locations

Grain size distribution tests were carried out on soils sampled from different locations to see the variation of soils laterally. The size of the particles that constitute soils has a direct influence on the density of the soil and other engineering properties. The gradation test results are shown in Figs. 4/6a & 4/6b. From the curves one can observe that the soil samples Sp-1, Sp-2-1 and Sp-3-1 have the same shape of cumulative percentage passing curve. Distance of sampling is more than 75 kms between soil sample spots Sp-1 and Sp-3-1. Similarly, samples Sg-1 and Sg-2 have nearly same shape of cumulative percentage passing curves. This similarity may indicate that lateritic soils of the area under consideration have the same characteristics according to their corresponding lithological classification. The lithological classification of the soils is mentioned in section 2.2.

To see the variation of soils along the profile, grain size distribution tests were also carried out. The test results for soil samples Sp-2 are shown in Figs. 4/7. The soil samples Sp-2-1, Sp-2-2 and Sp-2-3 were sampled from station 198+300 LHS (Sp-2). Sampling depth is mentioned in Table 4/7. From the curves plotted in Fig. 4/7 one can see that grain size analysis for soil sample Sp-2-1 is coarser than soil samples Sp-2-2 and Sp-2-3. On the other hand, soil samples Sp-2-2 and Sp-2-3 have nearly identical gradation curves. One may see soil properties, including gradation, along the profile may change due to variation in degree of weathering. Soil samples with similar gradation curves are high possibility of having same engineering properties as far as their chemical and mineralogical compositions are similar.

Range of Gradation Curves

The range of grain size distribution curves for the soil samples under investigation for this thesis work is shown in Fig. 4/8. Curve I and Curve II respectively are the maximum and minimum cumulative percentage passing.

Table 4/7. Percentage Amount of the Grain Sizes for different conditions

Serial No.	Designation	Natural Moisture Content %	Test ⁵ Condition	Percentage amount of Particle Sizes			
				Gravel	Sand	Silt	Clay
1	Sp-1	19.8	Oven-dried	74.1	16.0	7.9	2.0
			Air-dried	74.1	12.7	9.8	3.4
			As received	61.3	19.8	13.1	5.8
2	Sp-2-1	26.0	Oven-dried	75.4	8.6	11.5	4.5
			Air-dried	79.2	6.5	9.9	4.4
			As received	63.7	14.2	15.3	6.8
3	Sp-2-2	29.4	Air-dried	65.8	9.9	16.5	7.8
4	Sp-2-3	33.5	Oven-dried	63.1	12.1	18.8	5.9

⁵ Oven dried is oven temperature of 105°C, air dried is oven temperature of 50°C with maximum relative humidity 30% and as received is soil at its moist condition.

			Air-dried	63.4	10.8	19.1	6.7
5	Sp-3-1	18.9	Oven-dried	76.1	8.5	12.3	3.1
			Air-dried	78.5	6.9	11.1	3.6
			As received	53.0	16.4	21.9	8.6
6	Sp-3-2	14.5	As received	56.8	13.4	21.5	8.3
7	Sg-1	35.6	Oven-dried	0	24.4	56.5	19.1
			As received	0	25.9	53.6	20.5
8	Sg-2	25.2	Air-dried	0	20.2	59.2	20.6

Grain size distribution curves under different pre treatment conditions are shown in Figs. 4/5a & 4/5b.

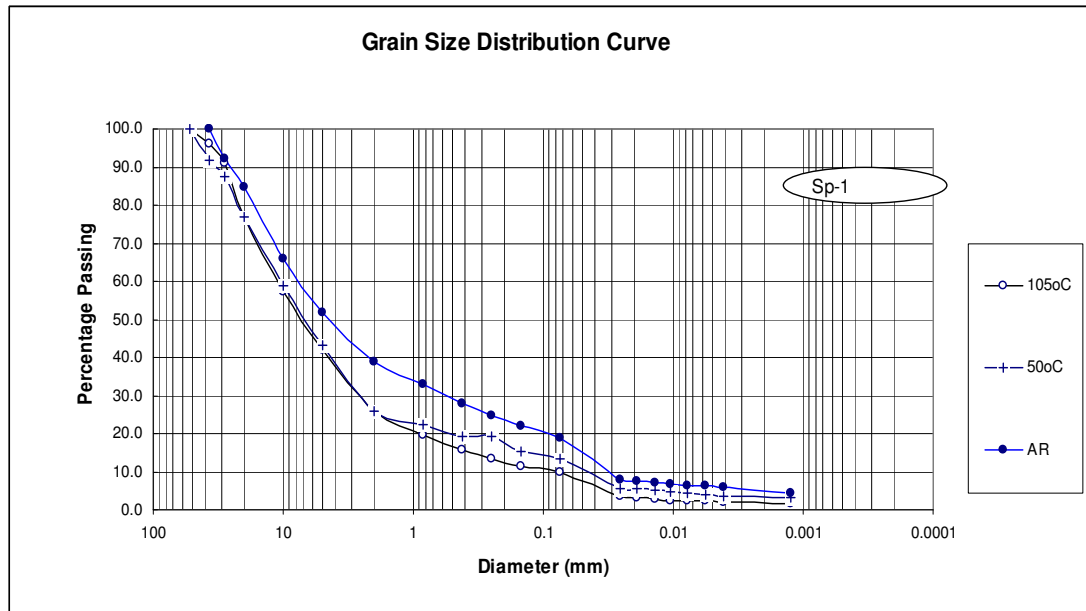


Fig. 4/5a) Sample Sp-1

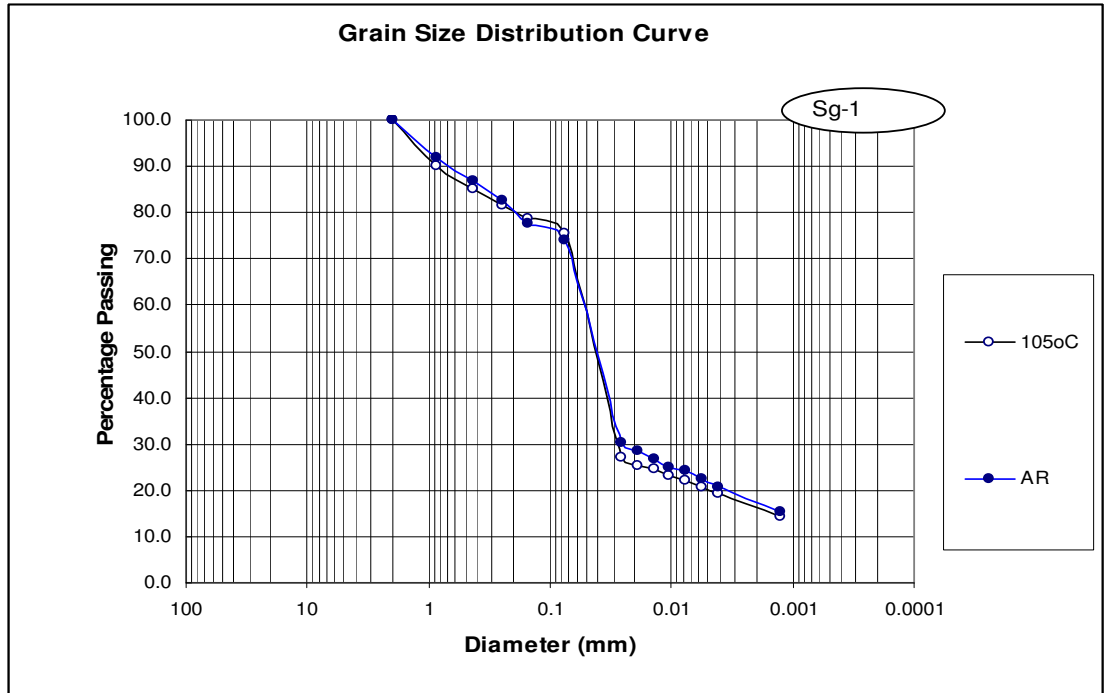


Fig. 4/5b) Sample Sg-1

Fig. 4/5 Grain size distribution curves at different pretreatment conditions. Grain size distribution curves for some soil samples, collected from different places, at different testing conditions are shown in Fig. 4/6a & 4/6b.

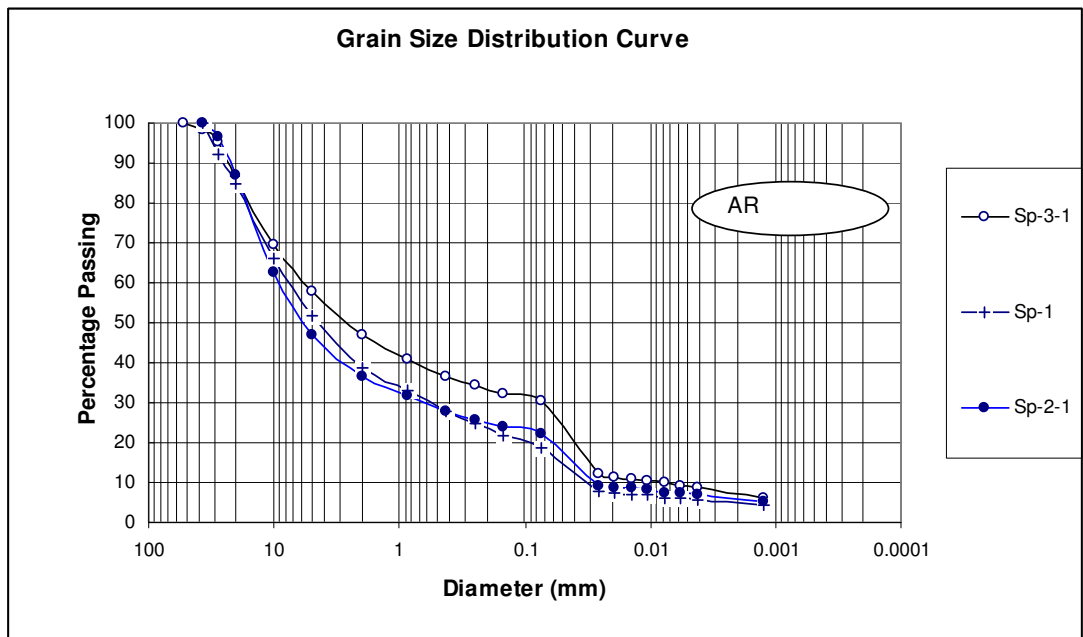


Fig. 4/6a Samples Sp-1, Sp-2-1 and Sp-3-1 AR condition.

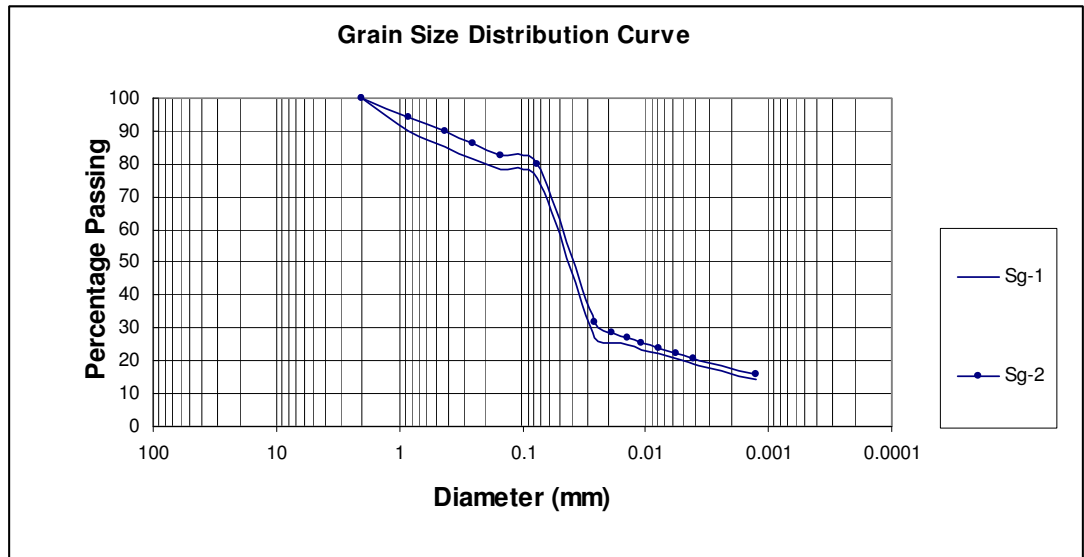


Fig. 4/6b Samples Sg-1 and Sg-2.

Fig. 4/6 Grain size analysis curves for different soils.

Grain size distribution curves for profile investigation under air dried pretreatment conditions are shown in Fig. 4/7.

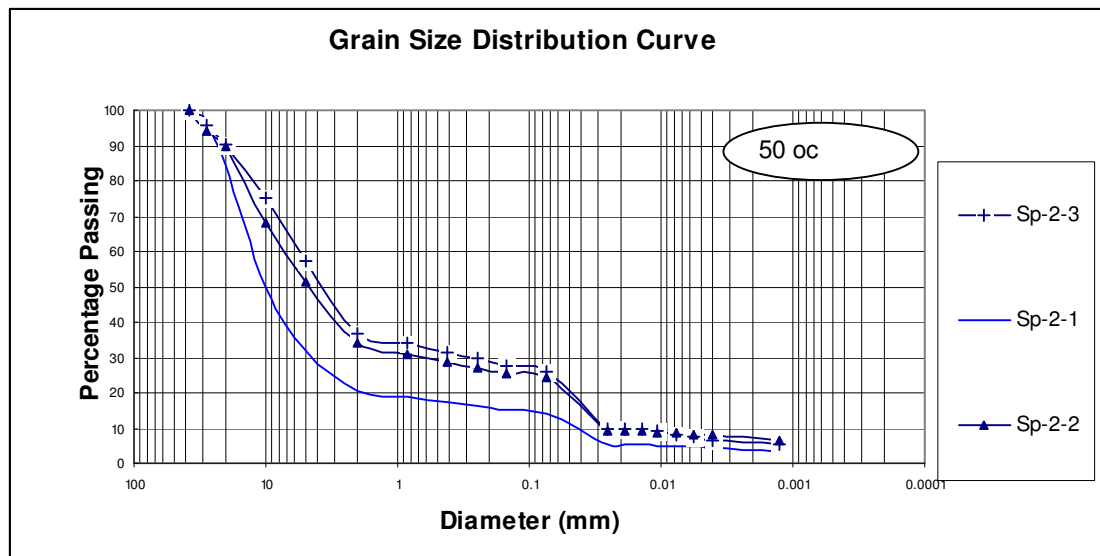


Fig. 4/7 Samples Sp-2-1, Sp-2-2 and Sp-2-3 ; AD condition.

The range of grain size distribution curves for the soil samples is shown in Fig. 4/8.

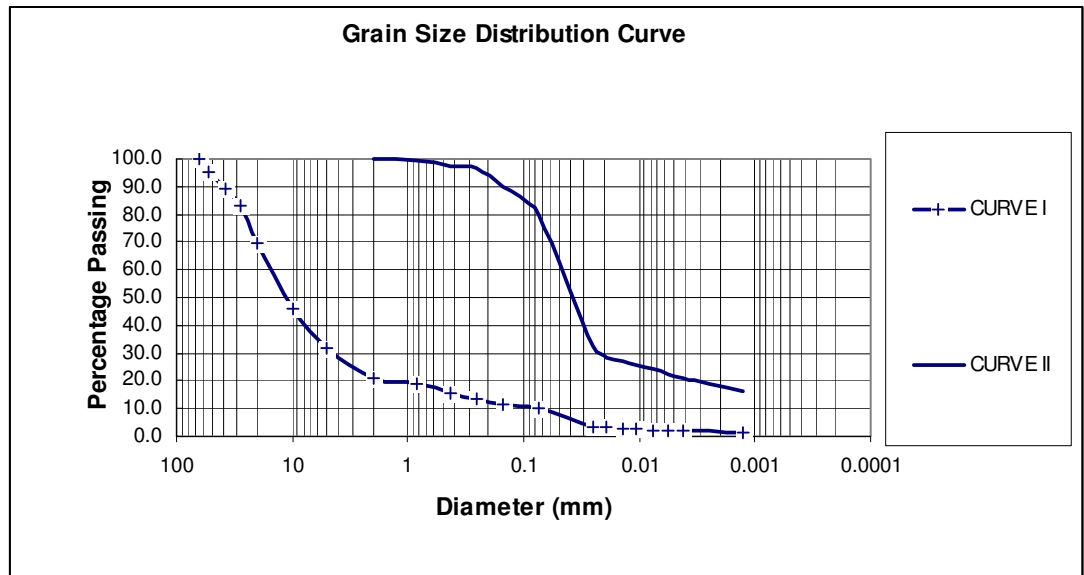


Fig. 4/8 Plot shows range of grain size distribution.

4.2.1.5 Atterberg limits

4.2.1.5.1 General

Atterberg limit tests are carried out to determine the consistency of fine-grained soils. Rossiter D.G. mentioned that this test for laterites and lateritic soils normally give large range of results (Rossiter D.G., 2004). Morin W.J. and Todor P.C. also indicated that when liquid limit tests are carried out on lateritic samples the aggregation of clay particles will be broken down by the manipulation process, this leads to difficulties in obtaining consistent values for the liquid limit (Lyon, 1971).

4.2.1.5.2 Test Procedures

For the determination of the Atterberg limit values, air and oven dried soil samples were tested following the procedure given in AASHTO T89-02 and T90-00 except some variations in sample preparation. 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 10 days or equivalently put inside oven at a temperature of 50 °c with maximum relative humidity 30% for at least 5 days. The room temperature was

about 20 °c. The oven dried samples were prepared by drying the soils overnight at 105 °c. Wet sample preparations were also carried out. Portion of the soil samples passing No. 40 (0.425mm) sieve were kept wet for a period of 24 hrs for moisture content equilibration.

4.2.1.5.3 Test Results and Discussions

Oven dried (OD), air dried (AD) and as received (AR) sample preparations were carried out to investigate the effect of pretreatment on plasticity characteristics of the soil samples under investigation. The test results are shown in Table 4/8. From the test results one can see that different pretreatment conditions create insignificant variation on Atterberg limit values. The test results variations are within the normal reproducible range of the limit tests. Normally 5 to 6 percents would be the average of reproducible results (Lyon, 1971). AASHTO specifies 7% (AASHTO, 2004). Hence pretreatment has only slight effect on the values of Atterberg limits for the soil samples under investigation. Hence, when these soils are dried, the fine particles do not come together and reduce the available surface for interaction with water to reduce the plasticity characteristics. Clay minerals also may not alter on dehydration.

As mentioned in section 4.2.1.4.3, the values of gradation on the soil samples taken from the site under consideration for this thesis work resulted in negligible difference by varying conditions of sample pre-treatment prior to testing. Plasticity index of the soil depends on grain size analysis of the portion passing 0.425mm sieve size. The gradation of the soil portion passing No 40 sieve has not significantly changed up on pretreatment variation. Since the gradation of the soil passing 0.425mm was not changed, the corresponding values of Atterberg limits also should not be changed significantly by such temperature variation prior to testing. Hence the test result shown in Table 4/8 is in agreement with this fact. One can also see gradation analysis of soil passing No 40 sieve for both gravely and fine soils, after removing soils coarser than sieve 0.425mm, are similar. Accordingly, fine and gravely soils have similar plasticity indices.

The effect of different soaking duration for moisture equalization purpose on the values of Atterberg limits were investigated for some soil samples. Plasticity indices (PI) were carried out for different soaking durations on air dried soil sample Sp-1. The PI values respectively for soaking durations 36 hours and 24 hours are 21% and 20%. The variations of the test results are small and even accepted on repeatability by single operator (AASHTO, 2004). From the result, one may soak the soil for 24 hrs with water for moisture equalization prior to Atterberg limit testing. Atterberg limit tests with out keeping soil specimens wet for 24 hours and 24 hours socking for moisture equilibration were carried out and stated in the following paragraph.

The word unsoaked is mentioned under ‘testing conditions’ column in Table 4/8 for soil samples Sp-1, Sp-2-1 and Sp-3-1 to mean that the Atterberg limit tests were carried out on oven 105 °c dried soil samples with out keeping the sample wet for moisture equalization. The test results are shown in Table 4/8 for soil samples Sp-1, Sp-2-1 and Sp-3-1 under testing conditions of unsoaked and oven dried. From the test results one can see that the PI values varied insignificantly. The variations of the test results are small and even accepted on repeatability by single operator (AASHTO, 2004). Fine soils were getting enough moisture even with out keeping wet for longer duration. Hence one can carry out Atterberg limit tests with out keeping soil specimens wet for 24 Hrs for moisture content equilibration. But for this thesis work all Atterberg limit tests were carried out on soil specimens kept wet for 24 Hrs.

Table 4/8 Atterberg limit values at different testing conditions.

Serial No.	Designation	Natural Moisture Content (%)	Testing Condition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	Sp-1	19.8	Unsoaked ⁶	53	34	19
			Oven-dried	54	36	18

⁶ Unsoaked refers to the Atterberg limit tests were carried out on oven 105 °c dried soil samples with out keeping the sample wet for moisture equalization. Its testing condition is mentioned in footnote 5 on page 36.

			Air-dried	56	36	20
			As received	54	34	20
2	Sp-2-1	26.0	Unsoaked	52	35	17
			Oven-dried	53	35	18
			Air-dried	56	38	18
3	Sp-2-2	29.4	Oven-dried	57	35	22
			Air-dried	59	37	22
4	Sp-2-3	33.5	Oven-dried	64	42	22
			Air-dried	67	43	24
5	Sp-3-1	18.9	Unsoaked	48	32	16
			Oven-dried	52	35	17
			Air-dried	54	34	20
6	Sp-3-2	14.5	Oven-dried	54	34	20
			Air-dried	58	37	21
7	Sg-1	35.6	Oven-dried	59	39	20
8	Sg-2	25.2	Oven-dried	48	31	17
			Air-dried	54	34	20

Effect of Test Procedures on Atterberg Limits

Lateritic soils are susceptible to breakdown with manipulation, hence test procedures should be more rigidly controlled. Excessive manipulation during testing leads to crumbling of the soil structure and disaggregating; both consequences produce fines which result in higher liquid limit values. The mixing time was kept to a minimum, generally about 5 minutes for each point (Lyon, 1971).

The effect of disaggregation of clay size particles up on manipulation during Atterberg limit testing were checked by conducting different testing procedures on air dried and as received samples as mentioned in section 2.6.2. The Atterberg limit tests carried out on the soil samples Sp-1, Sp-2-1, and Sp-3-1 according to the procedures mentioned in (AASHTO T89-02, T90-00, CIRIA, 1995 and Blight,1997). The Atterberg limit tests were also carried out on oven 105 °c dried soil samples. The test results are tabulated in Table 4/9. All necessary information regarding mixing time and pre-treatment conditions are also shown in the same Table.

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 not more than 5 minute, and the mixed samples were left to cure overnight before testing. After determining the moisture content for each test point on a part of each test portion, the remainder was then mixed for a further 25 minutes before again determining the liquid limit. The liquid limit values of the specimens 5 minutes (LL 5min) and 30 minutes (LL 30min) mixing times were determined. The difference between liquid limit test values of the specimens 5 minutes and 30 minutes mixing were calculated and summarized in Table 4/9. A “>5%” difference indicates that aggregation of clay size particles are break down up on manipulation. One can refer section 2.6.2 to know how as received soil samples were prepared.

From the test results one can see that the soils are generally sensitive to handling and disturbance. The more the soil's structure is handled and disturbed, the finer the aggregates become in grading and the higher the Atterberg limit. Generally one can see from Table 4/9 that the greater duration of mixing (i.e., the greater the energy applied to the soil prior to testing), the larger the resulting of liquid limit, and to a lesser extent, the larger the plasticity index. This is in agreement with compiled notes of Fourie A.B (Blight, 1997).

Hence the test programme for this thesis work would be including the following instructions.

1. limit the mixing times for Atterberg limit tests not more than 5 minutes
2. use fresh material for each moisture content point in compaction tests.

The word “Normal” is mentioned in Table 4/9 under column testing procedure to mean that the Atterberg limits were carried out following the conventional testing procedures. One can compare the test results of Atterberg limits both carried out with conventional and 5min mixing duration on fresh samples for each trial. The values are more or less in a good comparison but the variation has no a certain. This is due to the uncontrolled amount of mixing duration for conventional testing.

Table 4/9 Atterberg limits at different conditions and Mixing Times.

Location	NMC %	Pre treatment	Testing ⁷ procedure	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	LL (30min) - LL (5min)	
Sp-1	19.8	Air Dried	Normal ⁸	56	36	20	5	
			5 Min	60	36	24		
			30 Min	65	37	28		
		Oven Dried	Normal	54	36	18		7
			5 Min	53	33	20		
			30 Min	60	34	26		
Sp-2-1	26.0	Air Dried	Normal	56	38	18	5	
			5 Min	61	34	27		

⁷ Oven dried is oven temperature of 105°C, air dried is oven temperature of 50°C with maximum relative humidity 30% and as received is soil at its moist condition.

⁸ Normal: To indicate that Atterberg limits were carried out with conventional methods.

Sp-3-1	18.9	Air Dried	30 Min	66	36	30	6
			Normal	53	33	20	
			5 Min	58	37	21	
		Oven Dried	30 Min	64	38	26	
			Normal	52	35	17	
			5 Min	49	30	19	
		As Received	30 Min	54	32	22	
			5 Min	60	37	23	
			30 Min	65	38	27	
Sg-1	35.6	Air Dried	5 Min	64	41	23	6
			30 Min	70	47	23	

Effect of rewetting on Atterberg Limits

The effect of rewetting was checked by conducting and comparing Atterberg limit tests on soil sample prepared from natural moisture content and that of oven dried soil re wetted to the point of test. The test result is shown in Table 4/8 for sample Sp-1. From the Atterberg limit values comparison of saturated and as received pretreatment conditions one can see insignificant variation. Even the result is with in acceptable repeatability variation by single operator. Hence with no further research, it indicates that the preparation of laboratory specimens should not necessarily simulate field procedures with respect to wetting and / or drying of the soil prior to compaction.

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 (Samuel, 1989). Which implies that the plasticity values increase with the corresponding increase in clay contents.

Information regarding 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 (Budhu, 2000). Clays, silts and organic soils lie in distinct region on the chart. Line "A" defined by the equation Eq. 4/1 separates inorganic clays from silts and organic clays. As seen from the chart, Fig. 4/9, the soil samples under investigation fall below the line in the region of silts and organic clays. Test results bellow the A-line is to mean that soils contain minerals of kaolinite, chlorite and halloysite. (Boyce J.R. et al., 1984). As mentioned in section 2.1.2.1 laterites consist of minerals predominantly of kaolinite.

$$PI = 0.73 (LL-20) \dots \dots \dots Eq. 4/1$$

Line "U" defined by the equation Eq. 4/2. Line "U" defines the upper limit of the correlation between plasticity index and liquid limit. Results above this line indicates erroneously execute hence conducting the test repeatedly is recommended. According to Fig. 4/9 the test results are all below the U-line. Hence the test results are considered acceptable.

$$PI = 0.90 (LL-8) \dots \dots \dots Eq. 4/2$$

Where: Both PI and LL values are expressed in percent of equations Eq. 4/1 and Eq. 4/2.

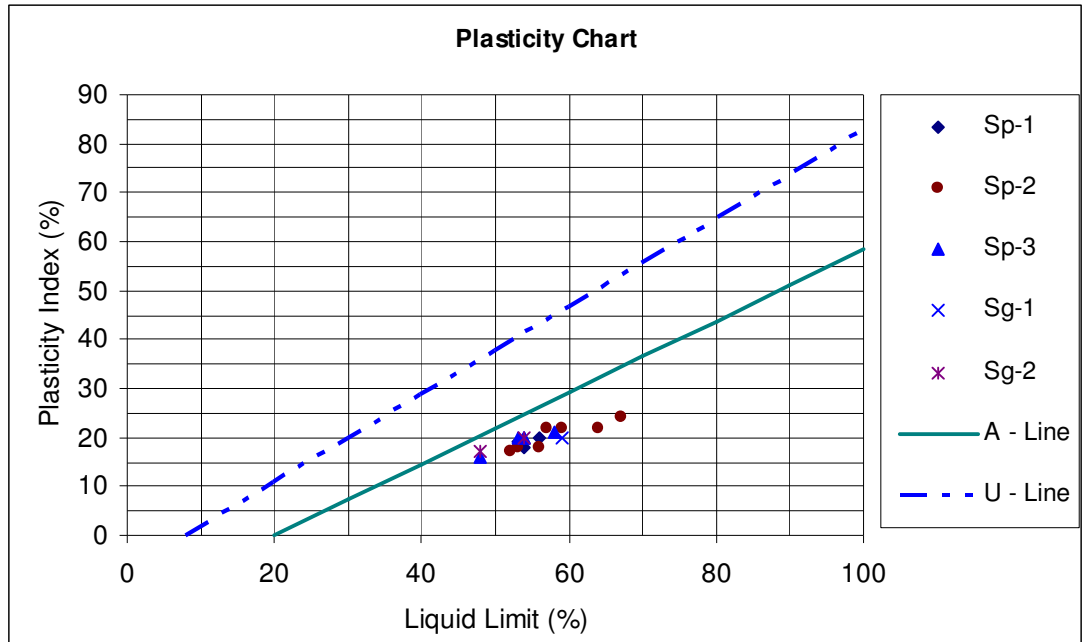


Fig. 4/9 Plasticity Chart

One point Liquid Limit Test Results

The one point liquid limit test is effective in determining the liquid limit of lateritic soils by using the formula

$$LL = w (N/25)^{\tan B} \dots\dots\dots \text{Eq. 4/3}$$

- Where: LL = Liquid limit
W = moisture content
N = No. of blows for Liquid limit
B = 0.12

When the number of blows is between 20 and 30, tan B is assumed to be zero. The result will be within the accuracy of the liquid limit test. Taking the value of tan B = 0.12 gives more accurate result (Lyon, 1971). According to equation Eq. 4/3 and using the value of tan_B = 0.12, few results were calculated and summarized in Table 4/10.

From the test results one can see that the one point liquid limit test is more or less acceptable for lateritic soils. Especially for number of shocks about 25 give a good comparison.

Table 4/10 Liquid limits comparison between conventional and one point test values.

Serial No.	Designation	Test Condition	No. of Shocks	Moisture Content (%)	Calculated LL (%)	Tested LL (%)
1	Sp-1	Oven-dried	34	49.9	51.7	53
			23	52.9	52.4	
			18	54.0	51.9	
		Air-dried	34	52.5	54.5	56
			28	55.5	56.2	
			18	57.0	54.8	
2	Sp-2-1	Oven-dried	33	50.6	52.3	54
			23	54.1	53.5	
			18	54.6	52.5	
		Air-dried	32	52.0	53.5	56
			27	55.1	55.6	
			17	59.3	56.6	
3	Sp-3-1	Oven-dried	32	50.6	52.1	53
			28	52.4	53.2	
			18	54.6	52.5	
		Air-dried	34	50.5	52.4	54
			27	53.9	54.4	
			18	56.1	54.0	

4.2.1.6 Activity

Skempton's colloidal activity is determined as the ratio of the plasticity index of the clay content to fines. He observed that, for a given soil, the plasticity index is directly proportional to the percent of clay-size fraction (i.e., percent by weight finer than 0.002 mm in size). Activity designated by “A_c” is defined as

$$A_c = \frac{PI}{C} \dots\dots\dots Eq. 4/4$$

Where C is the percent of clay - size fraction by weight. Activity has been used as an index property to determine the swelling potential of clays (Das, 1997). Colloidal activity values for the soils under investigation are calculated and summarized in Table 4/11.

The soil classification according to the activity number is given in Table 4/11a.

Table 4/11a Degree of Colloidal Activity.

Activity Number, AC	Soil Type
< 0.75	Inactive
0.75 ~ 1.25	Normal
> 1.25	Active

As one can see from Table 4/11b, Skempton's colloidal activity values for Sg-1 and Sg-2 are less than 1.25. Accordingly, the soil type is normal which is in agreement with Morin W.J. and Todor P.C. (Lyon, 1971). The low activity for lateritic soils due to the mode of weathering which involve the coating of the soil particles with sesquioxide, results in the suppression of the surface activity of clay particles.

Table 4/11b Skempton's colloidal activity values summary.

Serial No.	Designation	Sampling depth [m]	Clay Fraction %	Plasticity Index (%)	A _C (%)
1	Sg-1	0.50 ~ 1.50	20.5	20	0.98
2	Sg-2	0 ~ 0.50	20.6	20	0.97

4.2.1.7 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 (Sintayehu, 2003). Among clay minerals montmorillonite influence the magnitude of swelling maximally than illites and kaolinites.

To study the swelling property of the soils, the simplest test conducted is free swell test. The test is performed by slowly pouring 10cm³ of dry soil which has passed the No. 40 (0.425mm) sieve in to 100 cm³ graduated cylinder filled with distilled water. After 24 hours, final volume of the suspension being read. Hence, free swell is defined as

$$\text{Free swell} = \frac{\text{Final volume} - \text{Initial volume of the soil}}{\text{Initial volume}} \times 100\% \dots \dots \dots \text{Eq.4/5}$$

Free swell test results for both air and oven 105 °c dried samples are summarized in Table 4/12. From the test result one can see that the free swell of the soil under investigation ranges from 15% to 40%. Those soils having a free swell less than 50% are considered as low in degree of expansion (Alemayehu and Mesfin, 1999). Hence all soil samples under investigation are non expansive soils.

Table 4/12 Free swell test results at different Conditions.

Serial No.	Designation	Natural Moisture Content %	Test Condition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Free Swell (%)
1	Sp-1	19.8	Oven-dried	54	36	18	20
			Air-dried	56	36	20	30
2	Sp-2-1	26.0	Oven-dried	52	35	17	30

			Air-dried	53	35	18	35
3	Sp-2-2	29.4	Air-dried	59	37	22	35
4	Sp-2-3	33.5	Oven-dried	64	42	22	30
			Air-dried	67	43	24	35
5	Sp-3-1	18.9	Oven-dried	52	35	17	25
			Air-dried	54	34	20	30
6	Sp-3-2	14.5	Oven-dried	54	34	20	30
			Air-dried	58	37	21	30
7	Sg-1	35.6	Oven-dried	59	39	20	40
8	Sg-2	25.2	Oven-dried	48	31	17	20
			Air-dried	54	34	20	30

4.2.1.8 Shrinkage limit

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

$$LS = \frac{L_o - L_f}{L_o} * 100 \dots\dots\dots \text{Eq.4/6}$$

Where: LS = linear shrinkage

L_o = length of wet soil bar.

L_f = length of dry soil bar.

Linear shrinkage test results are summarized in Table 4/13 for different pre treatment conditions. From the test results one can see that air dried soil samples have generally higher values of linear shrinkage than that of oven dried. The variation is significant for soil samples with high natural moisture content. The drying of soil samples cause solid particles come closer creating high cementation by sesquioxides. That was not reversed up on rewetting results in linear shrinkage reduction.

Table 4/13 Linear Shrinkage limits at different Conditions.

Serial No.	Designation	Natural Moisture Content %	Test ⁹ Condition	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)
1	Sp-1	19.8	Oven-dried	54	36	18	7.1
			Air-dried	56	36	20	8.6
2	Sp-2-1	26.0	Oven-dried	52	35	17	7.9
			Air-dried	53	35	18	8.6
3	Sp-2-2	29.4	Oven-dried	57	35	22	8.6
			Air-dried	59	37	22	11.4
4	Sp-2-3	33.5	Air-dried	67	43	24	12.1
5	Sp-3-1	18.9	Oven-dried	52	35	17	10.0
			Air-dried	54	34	20	10.7
6	Sp-3-2	14.5	Air-dried	58	37	21	10.7
7	Sg-1	35.6	Oven-dried	59	39	20	11.4
8	Sg-2	25.2	Oven-dried	48	31	17	10.0
			Air-dried	54	34	20	15.7

4.2.1.9 Specific Gravity

Specific gravity of the soil samples under investigation were determined using AASHTO T100-03, T85-91 procedures. It is used to calculate parameters such as void ratio, porosity, soil particle size distribution by means of the hydrometer, degree of saturation. The specific gravity tests were carried out and summarized for the some soil samples under investigation at air dried, oven dried and as received pre treatment conditions. The test results summary is shown in Table 4/14. From the test

⁹ Oven dried is oven temperature of 105°C, air dried is oven temperature of 50°C with maximum relative humidity 30%

results one can see that air dried and oven dried pretreatment conditions give nearly similar values. But specific gravity values of as received pretreatment conditions for Sp-2-1 and Sg-2 soil samples significantly vary than that of the two drying conditions prior to testing. Hence specific gravity significantly changes upon drying prior to testing by any means. All test results are from 2.78 to 3.03. The test result is in agreement with Morin W.J. and Todor P.C. (Lyon, 1971). They indicate that specific Gravities of lateritic soils are very high even up to 3.4. Such a high specific gravity test value is due to its high iron content.

Table 4/14 Show the Values of specific gravity at different Conditions.

Serial No.	Designation	Natural Moisture Content %	Test ¹⁰ Condition	Specific Gravity
1	Sp-1	19.8	Oven-dried	3.02
			Air-dried	3.00
2	Sp-2-1	26.0	Oven-dried	2.85
			Air-dried	2.86
			As received	2.95
3	Sp-2-3	33.5	Air-dried	2.87
4	Sp-3-1	18.9	Oven-dried	3.01
			Air-dried	3.03
5	Sp-3-2	14.5	Air-dried	3.02
6	Sg-1	35.6	Air-dried	2.78
7	Sg-2	25.2	Air-dried	2.80
			As received	2.86

4.2.1.10 Classification of the Soils

Wesley classifies residual soils on the basis of minerals and D'Hoore (1964) pedological classification system on the other hand on the basis of climate, drainage, topography and parent material. The AASHTO classification system is convenient as a basis for classifying tropically weathered soils (Lyon, 1971). Some road construction stake holders uses conventional soil classification system using the grain size distribution and the Atterberg limit values. The soils under investigation

have been classified according to AASHTO M-145. Soils classified by UCSC method is also shown in Table 4/15.

Sp-1, Sp-2, Sp-3-1 and Sp-3-2 fall under A-2-7 (GI=0) group according to AASHTO classification system. Whereas the soil samples designated by Sg-1 and Sg-2 fall under A-7-5 with group index higher than 17. Classification according to USCS for soil samples Sg-1 and Sg-2 show that MH (Inorganic silts).

¹⁰ Test condition is mentioned in footnote 7 on page 45.

Table 4/15 Classification According to the AASHTO and USCS.

Serial No.	Designation	LL (%)	PI (%)	%age amount of Passing			Classification According to AASHTO		%age amount of Particle Sizes				Classification According to USCS
				2	0.425	0.075	Group	Group Index	Gravel	Sand	Silt	Clay	
1	Sp-1	56	20	25.9	19.4	13.2	A-2-7	0	74.1	12.7	9.8	3.4	Silty gravel
2	Sp-2-1	56	18	20.8	17.0	14.3	A-2-7	0	79.2	6.5	9.9	4.4	Silty gravel
3	Sp-2-2	59	22	34.2	28.4	24.3	A-2-7	0	65.8	9.9	16.5	7.8	Silty gravel
4	Sp-2-3	67	24	36.6	31.2	25.8	A-2-7	0	63.4	10.8	19.1	6.7	Silty gravel
5	Sp-3-1	54	20	21.5	17.4	14.7	A-2-7	0	78.5	6.9	11.1	3.6	Silty gravel
6	Sg-3-2	58	21	43.2	35.0	29.8	A-2-7	0	56.8	13.4	21.5	8.3	Silty gravel
7	Sg-1	59	20	100.0	85.1	75.6	A-7-5	18	---	25.9	53.6	20.5	MH (Inorganic silts)
8	Sg-2	54	20	100.0	90.0	79.8	A-7-5	17	---	20.2	59.2	20.6	MH (Inorganic silts)

4.2.2 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 (Mitchell, 1979).

Geochemical tests were carried out at Geological Survey of Ethiopia Geochemical Laboratory. To obtain the percentage oxide composition of the soils under investigation Atomic Absorption Spectrometer and Colorometer Analysis methods were used. The test results are shown in Table 4/16.

The degree of laterization of the soil samples can be evaluated based on silica – sesquioxides (s-s) ratio as detailed in section 2.3. The sesquioxide, designated as R_2O_3 , is the combination of aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3). The chemical formula SiO_2 designates the silica. Accordingly unlaterized soils have s-s ratio greater than 2. For lateritic soils s-s ratio lie between 1.33 and 2 and for true laterites the ratio is less than 1.33. Lateritic soil has not under gone a considerable degree of laterization as compared to true laterite.

The test results in Table 4/16 show that the soils under investigation have silica – sesquioxide ratio below 1.33. This indicates that the soils are all true laterites. Which is in agreement with soil forming factors of Nejo – Mendi area leads to laterite soils as mentioned in section 3.3. True laterites are simply referred as laterites. The soil of such kind are highly laterized i.e., sesquioxides content are high.

Mineralogy is the primary factor controlling the size, shape, and physical and chemical properties of soil mechanics. The most widely used technique to determine mineralogical composition is x-ray defraction (XRD) (Mitchell, 1979). It is worth mentioning that the need of mineralogical tests to be conducted. Unfortunately XRD was not functioning at Geological Survey of Ethiopia, Mekelle University, Geology Department (Science Faculty) and Agricultural Research Organization's Soil Laboratory during preparation of this thesis document. Hence it was not possible carrying out the test for this thesis work.

Table 4/16 Oxide Composition in Percent

Designation	Sampling depth [m]	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	MnO	H ₂ O	LOI	Ti ₂ O	P ₂ O ₅	$\frac{\text{SiO}_2}{\text{R}_2\text{O}_3}$
Sp-1	0 ~ 0.60	25.46	23.76	32.40	< 0.01	< 0.01	< 0.01	0.02	0.05	0.92	12.69	3.27	0.28	0.45
Sp-2-1	0.50 ~ 1.50	30.10	27.81	22.75	< 0.01	< 0.01	< 0.01	0.02	0.05	0.37	14.36	2.83	0.34	0.60
Sp-2-3	2.50 ~ 3.00	19.90	31.57	25.44	< 0.01	< 0.01	< 0.01	< 0.01	0.07	1.49	15.98	4.46	0.37	0.35
Sp-3-1	0.40 ~ 1.40	20.20	23.43	36.60	< 0.01	0.03	< 0.01	0.06	0.22	0.20	14.36	2.90	0.58	0.34
Sp-3-2	1.40 ~ 2.50	21.62	26.12	31.90	< 0.01	0.09	< 0.01	0.14	0.17	0.80	14.17	3.23	0.47	0.37
Sg-1	0.50 ~ 1.50	32.59	28.79	16.97	< 0.01	0.02	< 0.01	< 0.01	0.14	1.22	13.35	3.07	0.22	0.71

4.2.3 Compaction Test

4.2.3.1 General

Compaction places soils in a dense state and hence decreases further settlement, increases shear strength and decreases permeability. Water plays an important role during compaction. If a small amount of water is added to a soil that is then subjected to compaction by a given amount of energy, the soil will be compacted to a certain unit weight. If the moisture content of the same soil is gradually increased and the compaction is done in the same way, the dry unit weight of the soil will gradually increase. The moisture content at which the maximum dry unit weight is obtained is referred to as the optimum moisture content. Adding water beyond optimum value reduces density. Water replaces soil particles and the curve more or less straight and parallel to zero - void line. Zero - void line is a line drawn with proctor curve to check the acceptability of the test. It represents the relationship of water content to dry density for 100% degree of saturation.

4.2.3.2 Test procedures

The specimens are compacted according to AASHTO T180-01 in five layers in a 152 mm diameter steel mould with a Rammer of 4.535 kg weight falling freely from a height of 0.4572m manually. Each layer is compacted 56 blows. Air dried (AD), oven dried (OD) and as received (AR) pre-treatment conditions were examined. Oven drying of wet soil samples were carried out at temperature of 105 °c. Air drying comprises both exposing the wet soil sample to sunlight energy and simply spreading on blue sheet inside laboratory. It was taking a minimum of 8 days to dry wet soil sample. Compaction tests on wet samples were carried out for each point on the curve running from wet to dry state on fresh soil specimens. But for field moisture content below optimum water content, additional moisture is added to make it above optimum. Bulk samples were also taken for modified proctor density determination for Sp-2-1 air dried conditions.

Since the materials are sensitive to handling and disturbance, new materials were used for each point on the compaction curve as mentioned in section 4.2.1.5.3. The material was allowed to cure overnight prior to testing. The amount of soil sample for one point on the compaction curve was taken as 5 kg on dry basis. For gravely soil samples compaction test were carried out by replacement technique.

For comparison purpose Sp-2-1 sample were compacted in a cylindrical mold of 1000 cm³ volume (standard proctor mold) with a mass of a rammer 2.495 kg falling freely from a height of 30.48 cm. Soil specimen preparation was similar except taking a mass of 3kg compacted in three layers, each layer being subjected to 25 blows.

4.2.3.3 Test Results and Discussions

The values of maximum dry densities (MDD) and optimum moisture contents (OMC) for the soils exposed to different drying conditions and method of testing has been summarized in Table 4/17. Plots of dry density versus moisture content together with zero air void curves are also shown in Figs. 4/10 to 4/13. The values obtained from the compaction tests were analyzed with respect to the effect of pre treatment, methods of testing and varying testing procedures.

From the test results which are shown in Table 4/17 and in Figs. 4/10 to 4/12, one can see that the maximum dry density and optimum moisture content results show that oven drying samples always gives the highest maximum dry densities and lowest optimum moisture content while samples at natural moisture content give the lowest maximum dry densities and highest optimum moisture contents. The effect of drying temperature on compaction gives a higher difference between drying at 105 °c and air drying. The effect has been noticeable for the drier side of the optimum moisture content. For as received and air dried conditions almost has the same value. The natural moisture contents at time of testing for samples of station Sp-2-1 and Sp-3-1 respectively are 19 % and 16 % for AR condition.

When a compaction test is performed on lateritic soils, care should be taken to avoid significant breakdown of the nodular concretions and soil particles. The breakdown of such weak concretionary lateritic gravels during compaction was checked by carrying out compaction tests on the soil samples compacting one sample for all points on the compaction curve and fresh soil sample for each point on the curve. The test results are summarized in Table 4/17 and the curves are plotted in Fig 4/11b. From the test results one can see that higher maximum dry density with lower optimum moisture content values are recorded for using one sample for the whole points on the curve than using fresh sample for each point on the compaction curve as compared for air dried pre treatment conditions of soil sample Sp-2-1.

The effect of compaction energy on the values of the maximum dry density (MDD) and optimum moisture content (OMC) was checked by compacting soil sample Sp-2-1 for both standard and modified proctor tests on air dried sample. The test result is shown in Fig 4/11a. From the test result one can see that MDD is higher, and OMC is lower for modified moisture density test execution.

Table 4/17 Summary of compaction tests with different pretreatment condition, method of testing and testing procedure.

Designation	Method of Testing ¹¹	Testing Procedure ¹²	Pre-treatment	Maximum Dry Density (g/cc)	Optimum Moisture Content (%)
Sp-1	Modified	Fresh	105 °c dry	1.724	23.2
Sp-1	Modified	Fresh	50 °c dry	1.68	24
Sp-2-1	Modified	Fresh	105 °c dry	1.584	25.0
Sp-2-1	Modified	Fresh	50 °c dry	1.538	26.4
Sp-2-1	Modified	Fresh	As received	1.533	26.6
Sp-2-1	Modified	Re-compactd	50 °c dry	1.572	25.6
Sp-2-1	Standard	Fresh	50 °c dry	1.42	32.2
Sp-3-1	Modified	Fresh	105 °c dry	1.773	20.2
Sp-3-1	Modified	Fresh	As received	1.75	22.0
Sg-1	Modified	Fresh	50 °c dry	1.511	24

Plots of dry densities versus moisture contents together with the zero air void curves are shown in Figs.4/10 to 4/13 for different pre treatment conditions and testing procedures.

¹¹ Method of compaction testing type refers to modified or standard proctor type.

¹² The soil samples for each point on the compaction curve were used either fresh or one bulk sample compacted repeatedly.

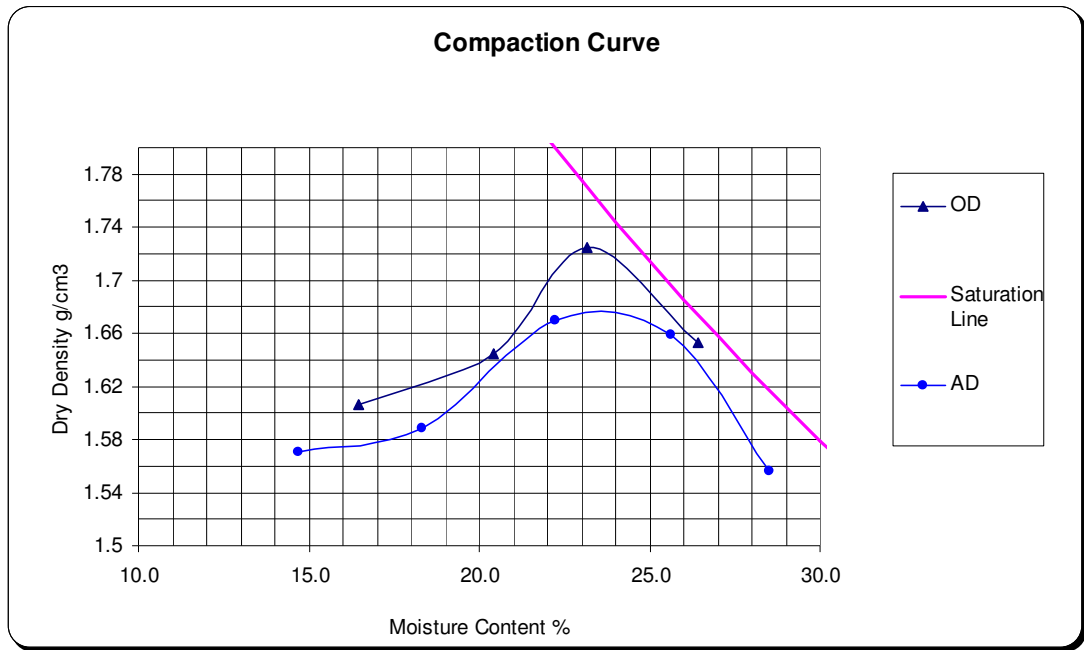


Fig.4/10 Compaction curves oven dried and air dried conditions for Sp-1

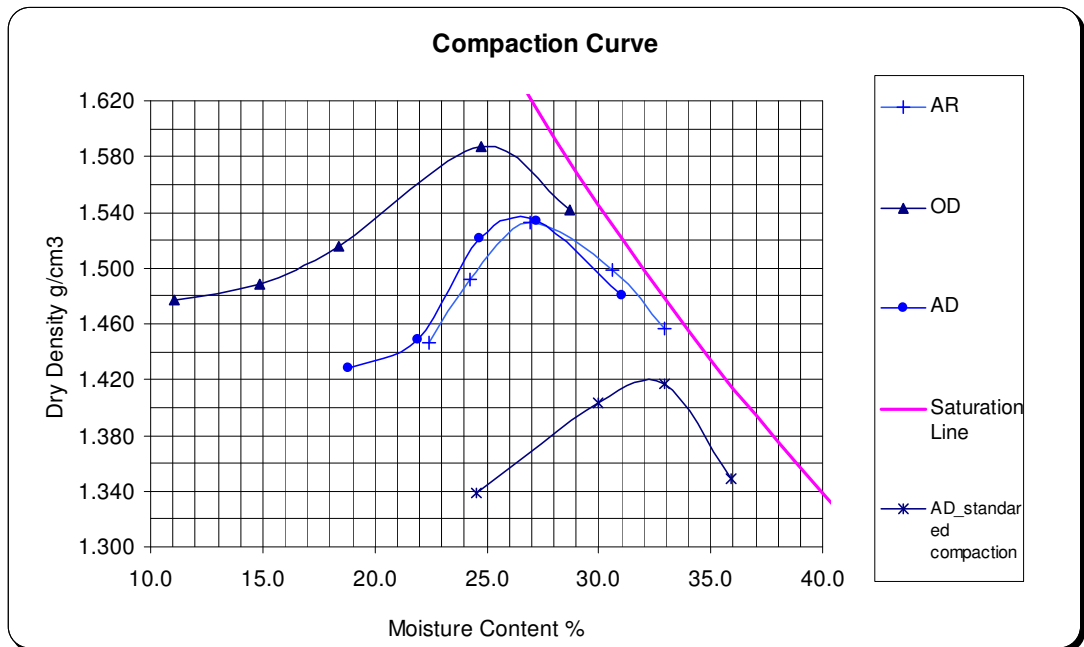


Fig 4/11a Compaction curves under different conditions and compaction effort for Sp-2-1

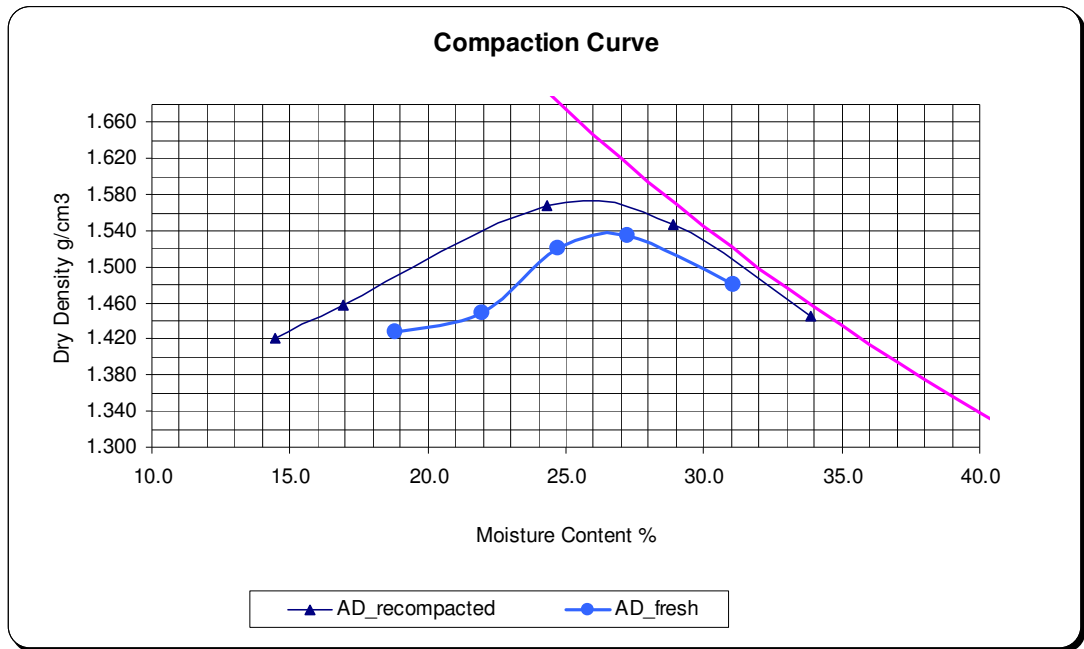


Fig 4/11b Compaction curves for soil sample Sp-2-1 at different testing conditions.

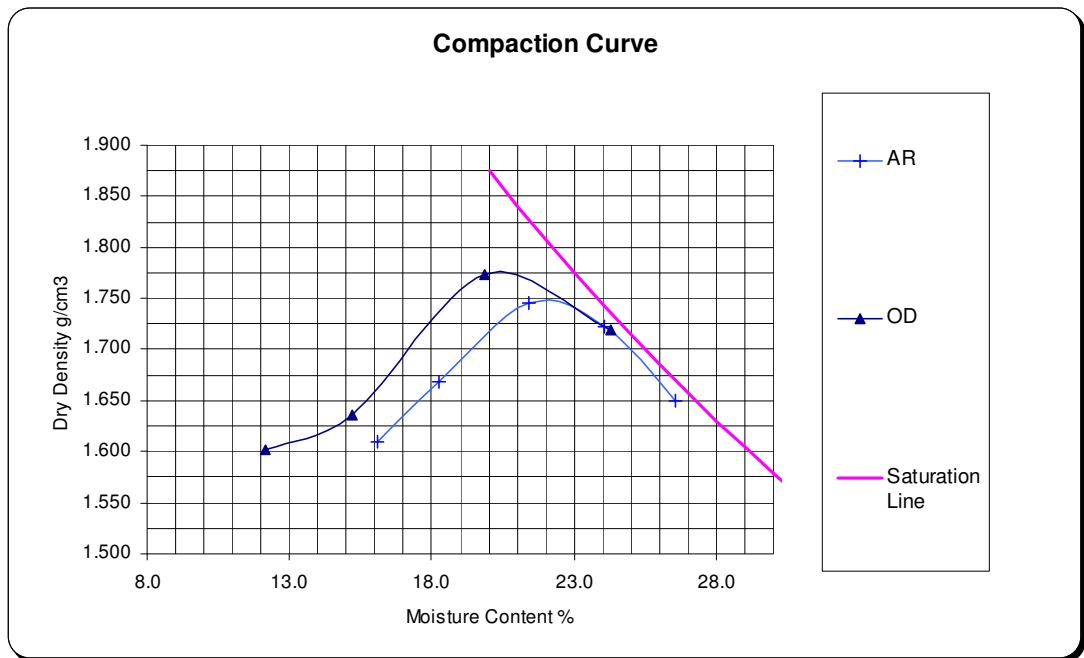


Fig 4/12 Compaction curves under different conditions and testing procedure for Sp-3-1

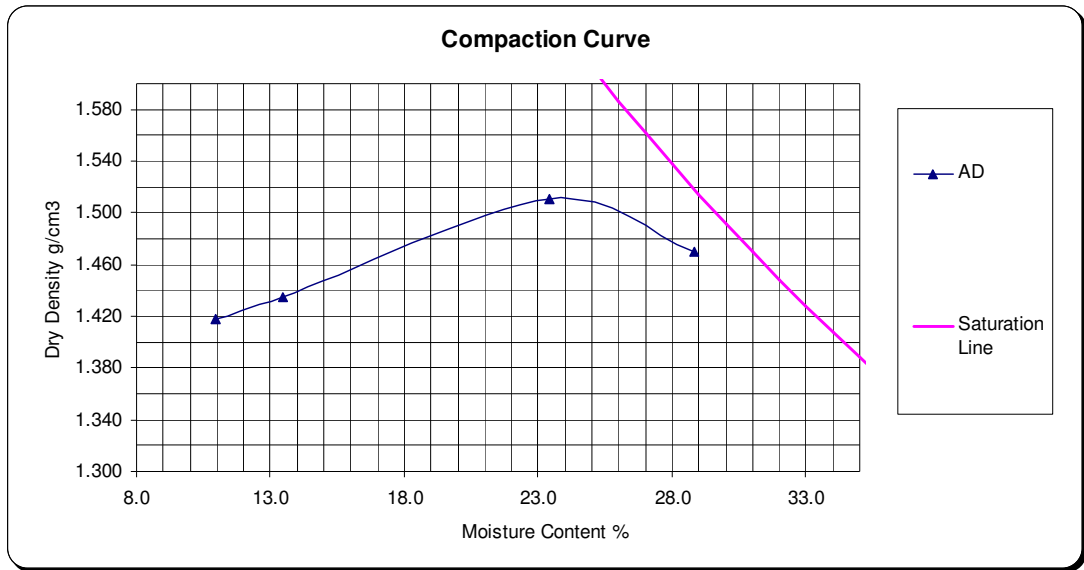


Fig 4/13 Compaction curves for Sg-1

4.2.3.4 Gradation after compaction

The effect of crushing upon compaction has been investigated by carrying out proctor compaction tests by varying both number of blows and methods. Sample Sp-2-1 has been prepared for proctor tests with zero, 30, and 65 numbers of blows for 5 layers using 15.2cm mould and 4.535 kg hammer. Standard proctor test was also carried out on the same sample under consideration. Both samples were compacted at moisture contents around OMC. After compacting the specimen, wet sieve analysis were carried out. The results are shown on Fig. 4/14. From the test results one can see that as the compaction effort increases the grain size comes finer. The effect is more pronounced for uncompacted to standard proctor and between standard proctor and modified proctor with number of blows 30 per each layer. Compacting soil samples above 30 per each layer results not much variation. The number of blows 30 per each layer can be considered heavy compaction as the nodules tend to crush maximally for the soil considered. One can refer the compaction energy difference used for each type of compaction and varied number of blows in Appendix-C.

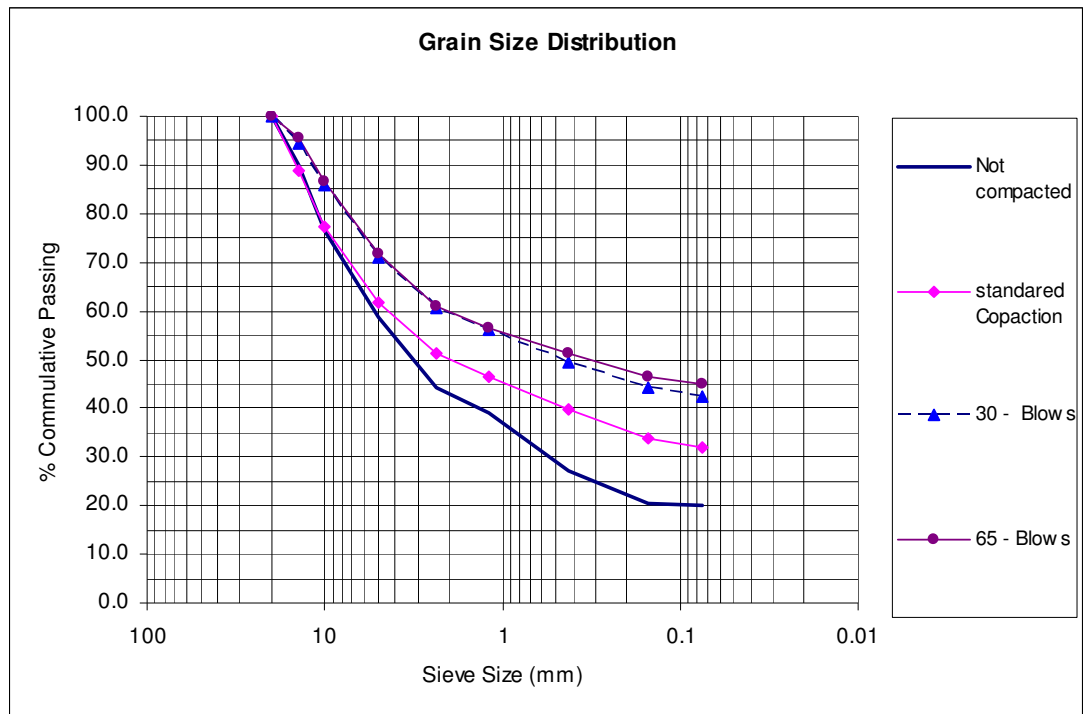


Fig. 4/14 Wet Sieve Analysis on sample Sp-2-1 compacted by different efforts.

4.2.4 California Bearing Ratio (CBR) test

4.2.4.1 General

California Bearing Ratio test was developed by the California Division of Highways in 1929 as a means of classifying the suitability of a soil for use as a subgrade or base course material in highway construction. The test measures the shearing resistance of a soil under controlled moisture and density conditions, i.e., usually at optimum moisture content and corresponding degree of MDD relevant to field compaction value (Bowels, 1978).

4.2.4.2 Test procedures

The California Bearing Ratio tests were carried out following the procedures mentioned in AASHTO T193-99. One specimen was tested right away after compaction at optimum moisture content without soaking. The other specimens were soaked in water for 96 hours with a surcharge weight of about 5.54 kg.

4.2.4.3 Test Results and Discussions

The CBR and its accompanied swelling results are summarized in Table 4/18. Generally as the number of blows increases from 10 to 30 its CBR values increase in a large amount. Whereas the number of blows increases from 30 to 65, its CBR values increase negligibly. Compaction of such soil prior to 30 blows per layer starts to detaching the bond of sesquioxides which results the values of CBR not keep on increasing. CBR values compared with temperate soils having such finer gradation and higher plasticity is high. Higher CBR values correspond with soil particles highly cemented by sesquioxides.

CBR test was executed for soil sample Sp-3-1 under unsoaked condition gives higher value than the corresponding soaked CBR values. This is due to soaking under water weakens the cementing effect of sesquioxides results less CBR values. Also unsoaked soil specimen is partially saturated having high suction pressure leads to high pressure between clay particles results high CBR value.

Table 4/18 CBR values of the specimen under different testing conditions.

Designation	Pre-treatment ¹³	OMC	MDD	No. of blows	CBR %	CBR Swelling %
Sp-1	Air dried	24	1.68	56	64	0.14
Sp-2-1	Oven dried	25.0	1.584	10	22	0.06
				30	45	0.92
				65	46	0.11
Sp-3-1	Air dried	26.4	1.538	56	45	0.6
	As received	26.6	1.533	56	46	0.5
	Oven dried	20.2	1.773	10	25	0.06
				30	42	0.07
65				49	0.06	
56				79*	---	

¹³ Test condition is mentioned in footnote 7 on page 45.

* unsoaked CBR value

Sg-1	Air dried	24	1.511	56	37	1.15
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4.2.5 Unconfined Compression Strength Tests

Unconfined compression strength (UCS) tests were carried out on soil sample Sg-1 by compacting the sample using modified proctor compaction apparatus at different moisture contents. The tests were carried out on cylindrical soil samples compacted at optimum moisture content, at the drier and wetter sides of the optimum moisture content. The compacted soil samples were gradually loaded at its two ends until it was destroyed by brittle or plastic failure. The vertical compression of the sample was measured through out the loading process, while the sample may deform laterally with out confinement. The results are shown in Table 4/19. The high UCS values may be due to the cementing effect of particles by sesquioxides.

Designation	Pre-treatment	Moisture Content %	Dry Density (g/cm ³)	UCS (Kpa)
Sg-1	Oven 105 °c dried	20.0 (drier of OMC)	1.49	345
		24.0 (at OMC)	1.51	553
		28.0(wetter of OMC)	1.48	165

Table 4/19 Unconfined Compression strength values for soil samples Sg-1

5 Comparisons and Discussions of Test Results

5.1 Comparison of Test Results with Laterites and Lateritic Soils of Africa

Laterites and Lateritic soils of Africa were studied by Morin W.J. and Todor P.C. (Layon, 1971). During the study of the soils, samples were collected from different parts of Africa such as Ghana, Ethiopia, Kenya, Uganda etc. The characteristics and mineral content of the soil samples taken from Ethiopia was studied as ferrisol .

For the soil under investigation; Index property tests, compaction tests and California Bearing Ratio tests were studied and a comparison was made with known laterites and lateritic soils of Africa. The soil samples collected from Africa were classified according to D'Hoore classification methods in to ferruginous, ferrallitic and ferrisol. The results of Index property tests, compaction tests and California Bearing Ratio (CBR) tests of ferruginous, ferrallitic, ferrisol and laterite soil from Nejo-Mendi area are tabulated in Tables 5/1 to 5/4.

Tables 5/1 to 5/3 show that the average values of the various properties, i.e., liquid limit, plasticity index, gradation, compaction and CBR, indicate that the ferruginous soils, ferrallitic soils and ferrisol represent distinct soil groups with a characteristic range of properties. The ferruginous soils are lower in plasticity and the compacted densities at AASHO Modified compaction are higher, with higher CBR value, than the other two groups. The ferrallitic soils are similar, to some extent, to the ferrisol,

exhibiting higher plasticity and lower CBR values than ferruginous soils. There are major differences between soils of the ferruginous group and the soils of the ferrallitic and ferrisol groups. The data indicate that there is an apparent similarity in the physical properties of the ferrallitic and ferrisol soil groups. The mineralogical testing data is shown in Table 5/5 for the three soil sub group of African laterite. From the test results one can see that soil sub groups are differ in mineralogical composition (Layon, 1971).

The Nejo - Mendi soil upon comparison with previously tested laterite and lateritic soils of Africa are similar, to some extent, to ferrisol and ferrallitic soil sub groups with respect to index tests as shown in Tables 5/2 to 5/4. The data indicates that there is higher plasticity as those of ferrisol and ferrallitic soil sub groups. On the other hand, the CBR values for the soils under consideration have generally higher than the values of both ferrisol and ferrallitic. This is due to the degree of laterization is too high for Nejo – Mendi soil than those of lateritic soils of Africa. At high degree of laterization physical cementation of adjacent grains with sesquioxide become strong resulting high CBR value. Lateritic soils are soils with less degree of laterization as compared with true laterites. One has to conduct mineralogical tests to classify type of soil sub group according to D’Hoore soil classification.

Average soil test properties for the three sub group of African laterite and lateritic soils and Nejo- Mendi soils are shown in Table 5/6. Comparison of the gradation, Atterberg limits, and compaction values are similar for both Nejo- Mendi soils and those of Ferrisol soils of Africa excluding Ghana. The data shows that having high plasticity and lower values of compaction. Regarding CBR values the Nejo – Mendi soil has higher values than the corresponding Ferrisol soil has. This is due to Nejo- Mendi soil has higher degree of laterization. It is worth mentioning that D’Hoore’s soil classification was based on soil forming factors resulting in soil subgroup with wide soil properties variation.

Comparison between Plasticity Charts

Percentage of kaolinite and location of common clays on Casagrande's plasticity charts, and plasticity chart of the soils under investigation are shown respectively in Figs. 5/1-3 for comparison propose. Fig.5/1 show a plot of Casagrande's plasticity chart for soils containing different amounts of kaolinite minerals. One can see that all test results plotted below A – line with respective increase of the percentage increases along the plasticity chart. Respective of montmorillonites, illites, kaolinites, halloysites and chlorites are shown on Fig. 5/2 Chlorite, halloysite and kaolinite are all below A – line. Plasticity chart for the soil under investigation show that all are below A – line having a place around same as soils having mineral kaolinite with its quantity about 50%. One can assure that with the absence of mineralogical tests, the laterite soils under investigation may contain kaolinite mineral significantly.

Table 5/1. Typical Soil Test Results for Ferruginous Soils

COUNTRY	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	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 Volta	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

COUNTRY	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	OMC	MDD	CBR %
Ghana	38	18	20	A-6	6	100	100	100	95	81	67	47	14	1.886	15
Liberia	56	29	27	A-2-7	2	100	95	72	57	41	36	27			
Gabon	35	18	17	A-2-4	0										
Sierra Leone	55	31	24	A-2-6	1	100	98	90	68	37	29	27			
Burundi	31	16	16	A-6		100	100	92	84	76	74	70			
Dahomey	45	21	24	A-2-7	4	100	100	99	85	72	55	39			
Ivory Cost	62	31	31	A-7-6	22	100	100	100	100	99	88	69	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

COUNTRY	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	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

Designation	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHTO	GI	25 mm	19 mm	9.5 mm	4.75 mm	2 mm	0.425 mm	0.075 mm	MDD	OMC	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			
Sg-1	59	39	20	A-7-5	18					100	85	76	24	1.511	37
Sg-2	54	34	20	A-7-5	17					100	90	80			

Table 5/5. Dominant mineral contents for laterite sub group (Layon)

Ferruginuous	Ferralitic	Ferrisol
Hematite	Gibbsite	kaolinite
Geothite	Geothite	Geothite
kaolinite	kaolinite	hematite gibbsite

Table 5/6. Average soil properties comparison (Layon)

Test Executed	Ferruginuous		Ferrallitic		Ferrisols		Nejo - Mendi laterite
	Ghana	Other Countries	Ghana	Other Countries	Ghana	Other Countries	
Passing sieve size (%)							
25 mm	99	99	99	99	95	99	94.6
19 mm	98	98	96	97	94	99	88.3
9.5 mm	93	89	86	90	86	92	73.3
4.75 mm	75	76	70	80	73	74	62.6
2.00 mm	51	65	54	70	52	61	51.6
0.425 mm	46	51	46	54	40	51	45.0
0.075 mm	30	32	34	40	37	44	38.3
0.002 mm	13	16	19	26	25	24	9.2
LL	31	33	42	47	46	55	59
PL	18	12	24	24	23	29	38
PI	14	15	19	23	23	27	22
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

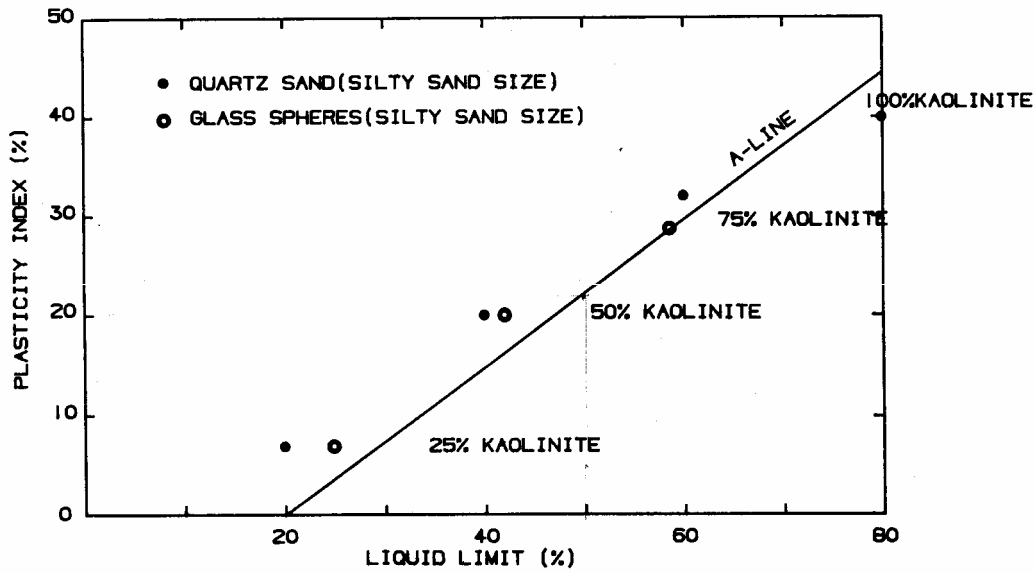


Fig.5/1. Kaolinite with various percentage of silty sand admixtures plotted on Casagrande's plasticity chart.

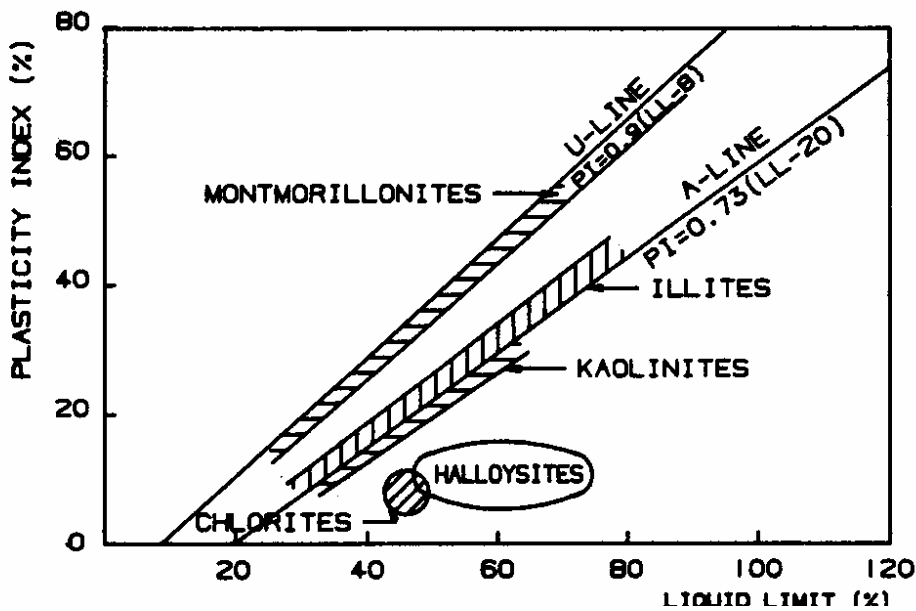


Fig. 5/2 Location of common clay minerals on Casagrande's plasticity chart.

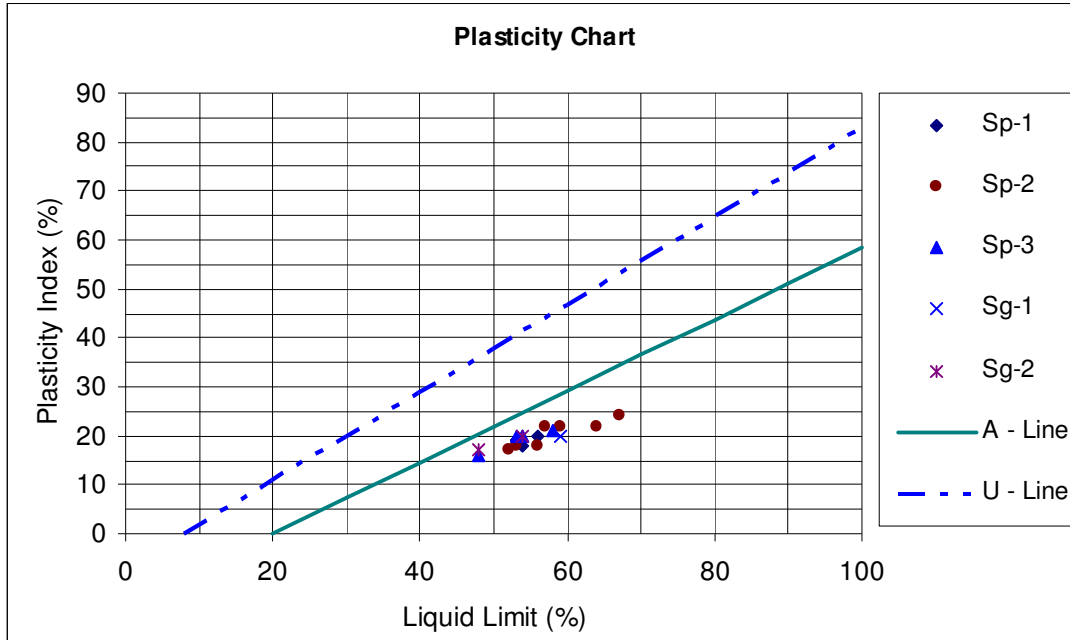


Fig. 5/3 Plasticity Chart of Nejo - Mendi soils.

5.2 Discussions

The points addressed in the thesis work are reanalyzed and discussed as follows.

Soil samples were collected from Nejo – Mendi road construction area which is located in west Welega. The area lies in the medium to high rain fall with the average annual value around 1600mm mostly occurs during the period of June to September. Hence the climate is tropical humid with seasonal variation. The existing road of Nejo – Mendi goes through a rolling terrain comprising geologically of granites and various metamorphic rocks including genesis and schists. These are the sufficient conditions for laterites to be formed. Site investigation of soil samples comprises of checking places for lateritic soil by inspecting presence of burrows by insects, termites and other animals, and less vegetated area. Lateritic soils are less fertile. All soil forming factors and site conditions are pointing out that the soil of the area is laterite. The test results of index and geochemical tests prove that the soil under consideration is laterite soil.

It is tried to check loss of water of hydration on soil samples under investigation. The difference in moisture contents between that of oven temperatures of 105^oc and 50^oc with maximum relative

humidity 30% for all soils under investigation are below 4 %. Below 4% variation in moisture content indicates that the soils do not contain loosely bound water of hydration in significant amount. Hence one may use oven temperature 105 °c for water content determination. It is not too hot for the soils of Nejo – Mendi area.

The effect of pre treatments were checked by conducting index tests on oven 105°C dried, air dried, as received (moist condition), and saturated (rewetted) soil samples. The corresponding test results show that the values under different conditions prior to testing results not significant variation. Laterites collected from distinct wet and dry seasons are not sensitive to pre treatment as mentioned by Morin W.J. and Todor P.C. (Layon, 1971). Since soils under investigation collected from regions subjected to distinct wet and dry seasons, the pretreatment has not affect the test results which is in agreement with their findings.

The effect of disaggregation of clay – size particles upon test manipulation were obtained for some soil samples under consideration by varying liquid limit testing methods. All pretreatment conditions were considered. The test results show that the soil under investigation contains concretionary which is broken down by testing manipulation. Force induced during test manipulation detaches the bond between particles due to the presence of sesquioxides. Hence one has conduct compaction and limit tests with fresh samples for each point.

It has been tried to see the effect of drying and wetting on Atterberg limits of soils prepared from natural moisture content with those of oven dried soil rewetted to the point of test. The test results show that it has not as such significant variation. Hence the soil is not sensible to the likely field procedures with respect to wetting and / or drying of the soil prior to compaction. Drying was not affecting its Atterberg limits so as rewetting too.

According to USCS, the soil Sg-1 and Sg-2 are fall under MH inorganic silts. 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. The tropical soils properties vary with their minerals

composition. Classifying laterite soils using only USCS classification system not shows any about the mineral. Hence soil classification using USCS should be accompanied by mineralogical test results.

Laterite soils have high CBR (California Bearing Ratio) values, as compared with temperate soils of such finer contents and high plasticity indices, due to sesquioxides cement particles together. This results a concretionary soil specimens resulting high CBR values.

Activity test results for soil samples Sg-1 and Sg-2 are less than 1.25. Activity greater than 1.25 is an indication of active soils. Laterite soils are inactive or normal due to the sesquioxides suppress the activity of the clay particles.

The specific gravity test results are 2.78 to 3.03. The values are higher than the specific gravity of the temperate zoon 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.

It is tried to see the effect of oven 105°C and air (oven 50°C with maximum relative humidity 30%) drying prior to compacting soils. Although the variation is small, relatively higher dry densities have been obtained for oven dried samples than air dried ones. The lowest dry density and highest moisture content is corresponds to the soil sampled at moist condition. The effect has been noticeable for the drier side of the optimum moisture content.

The gravely soil according to lateritic soil lithological classification met the specification specifies for sub base material for light traffic roads on ERA (Ethiopian Roads Authority) specification (ERA, 2001). But to use the soil as sub base construction material for heavy traffic roads, the Atterberg limit values are higher than the specified values (PI = 15%). To reduce Atterberg limits and use as a sub base construction material for heavy traffic roads, one may blend Nejo- Mendi gravely soil with non plastic soils, cement or/and lime. Checking of cost benefit analysis has a great value. Test results show that the gravely soils are good for embankment construction material.

6 Conclusions and Recommendations

6.1 Conclusions

Based on the test results investigation on the soil samples of Nejo –Mendi area the following conclusions can be drawn:

1. Geochemical tests indicate that the soils of Nejo – Mendi area are laterites having high concentration of iron oxide and aluminium oxide / sesquioxide /. The degree of laterization, silica to sesquioxide ratio, is below 1.33. No significant variations have been seen in different pits located at far distances with corresponding lithological classification category.
2. These laterites indicate not sensitive to pre treatment, hence samples may be dried prior to testing. Also the soils under consideration do not contain a significant amount of loose molecular water. One can use oven temperature 105^oc to determine amount of water content.
3. The Nejo – Mendi area soils indicate sensitive to test procedures which are affected during testing manipulation. Hence, the Atterberg limit and compaction tests should conduct using fresh sample for each testing points. The Atterberg limit should be limited to only 5min mixing time duration.
4. The specific gravity test results are higher values than the temperate zone soil. This is due to high amount of iron oxide for soil under investigation.
5. The CBR values are high as compared with soils of temperate zone with such high plasticity and finer grain size. This is due to the presence of sesquioxides which cement particles together. Nejo-Mendi laterite has higher values of CBR as compared with the values to the previously done lateritic and laterite soils of Africa. The reason may be laterites of Nejo-Mendi have higher degree of laterization which create higher bond between particles resulting in high strength values.

6.2 Recommendations

1. Further detailed investigation has to be carried out on disturbed and undisturbed soil samples deeply to correlate and specifying guidelines for design purpose.

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

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