ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

INVESTIGATION ON IMPROVING THE GOETECHNICAL PROPERTIES OF LATERITIC SOIL BY BLENDING WITH CHEMICAL STABILIZER

(The Case of Gidole, South Ethiopia)

By

Abas Kedir

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INVESTIGATION ON IMPROVING THE GOETECHNICAL PROPERTIES OF LATERITIC SOIL BY BLENDING WITH CHEMICAL STABILIZER

(The Case of Gidole, South Ethiopia)

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

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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	**%**
N	No. of blows for liquid limit	-----
NMC	Natural moisture content	%
RH	Relative humidity	%
OMC	Optimum moisture content for compaction test	%
MDD	Maximum dry density for compaction test	kg/m^3
CBR	California Bearing Ratio	%
AASHTO	American Association of State Highway & Transportation Officials	---
BS	British Standard	---
Ua	Pore air pressure	---
Uw	Pore water pressure	---
TP1	Test pit one	---
TP2	Test pit two	---
SM1	Sample one	m
SM2	Sample two	m
XRD	X- Ray Diffraction	----

Abstract

In road construction, earth roads become muddy and slippery during wet season and cause dust problem during dry season. At the time of road construction obtaining good road construction material is becoming scarcer and as much as possible use in-situ material. One of the in-situ materials is laterite soils.

The objective of this research work was to study the usefulness of Con-Aid as a stabilizer for laterite soil. Sampled from Gidole town (South Ethiopia) has been investigated.

Four specimens were taken from two test pits at different depths from Gidole town (South Ethiopia).The geo-chemical characteristics have been investigated on soils sampled. Accordingly, the soils under considerations were laterites. Moisture contents determination using oven temperature of 105^{o}C and oven temperature of 50^{o}C with maximum relative humidity (RH) 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.

Atterberg limits were investigated for testing procedure 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. The Atterberg limits, compaction and soaked CBR tests carried out without and with Con-Aid chemical, to evaluate the change in the engineering properties of the stabilized soil after curing the treated samples for different periods. From the test results, were not seen a promising reduction of plasticity, increment of maximum dry density and improvement of the CBR value. These indicate that the Con-Aid effect does not exceed the natural effect of the laterite soil. Full reactions of Con-Aid could not take places, because the soil under investigation in Gidole town was naturally cementeous material.

1. INTRODUCTION

1.1 General

In Ethiopia the construction of road is increasing from time to time. Initially it requires appropriate design. Rural roads network is one of the key factors for rural development. It helps the rural community being accessible to economic and social services. It also increases agricultural product. For low volume and low cost un-surfaced earth and gravel roads in-situ materials should be utilized as much as possible. However, these materials are not always suitable and many problems usually arise, like deterioration of the surface (rutting and potholes). One of the commonly available in-situ materials is laterite soil. Laterite is a widely available material in Ethiopia according to Ethiopian Roads Authority Design Manual (ERA, 2001). In many areas where laterite soils occur, there is no suitable alternative construction material.

Laterites are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks under tropical condition; that occur mostly in tropical and sub-tropical regions with hot, humid climatic conditions (Blight, 1997).

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. The sesquioxides within the fine fraction of tropical soils tend to coat the surface of individual soil particles (Blight, 1997).

Clay minerals with certain quantities of water exhibits property of plasticity. By plasticity is meant the property of the moistened material which is deformed under the application of pressure, with the deformed shape being retained when the deforming pressure is removed (Samuel, 1989).

Lateritic soil has a high percentage of clay fractions and consequently high plasticity, Hence improvement of lateritic soils for road construction is un-avoidable. The improvement methods usually employed including replacement, compaction and stabilization.

Soil stabilization is the process by which a stabilizing agent is added to natural soil deposit to improve the engineering properties of soils by mechanical or chemical means. The aim of this thesis is to study the liquid chemical stabilizer Con-Aid for stabilizing laterite soils in order to improve their properties as un-surfaced earth road construction materials. Con-Aid changes the hydrophilic (water adsorption) nature of clay materials to hydrophobic (water repellent), rendering the material stable in wet conditions. In addition to this, Con-Aid lubricates the particles, facilitating compaction of soil to a higher density, increasing the bearing capacity of the soil (user manual, Con-Aid). The application of Con-Aid stabilizer is not yet practical in Ethiopia; therefore, it is very important to adopt for local soil conditions in Ethiopia. Thus, the effect of Con-Aid stabilizer on laterite soil will be properly investigated in the laboratory.

1.2 Objective of study

The main objective of this research work was to study the usefulness of Con-Aid as a stabilizer for laterite soil for all weather roads.

The specific objective of this research work was the following

- To study the effect of chemical stabilizer con-Aid on the strength characteristics and performance of lateritic soil.

1.3 Methodology

Four Specimens were taken at two different locations from two test pits. From each test pit two samples were collected. The laboratory investigations were carried out in accordance with the procedure given in AASHTO. The CBR test is accomplished on the compacted state placed in the CBR molds for 4, 7 and14 days curing. The following laboratory tests conducted without and with Con-Aid chemical to evaluate the change in important engineering properties of the soils:

- Atterberg limit tests
- Compaction tests
- Soaked CBR and CBR swell tests

1.4 Structure of study

This thesis consists of five Chapters. The introductory Chapter consists of the background, objective, and methodology of the work. The second Chapter covers the literature review of laterite soils, index tests of residual soil, California bearing ratio, stabilization of soils and chemical stabilizer Con-Aid. The third Chapter consists of the sampling area descriptions and topography of the area of study. The fourth Chapter is devoted to in-situ properties and laboratory test results. The last Chapter, Chapter five, presents the conclusions drawn and the recommendation made. References and appendices are presented at the end of this thesis.

2 . Literature review

2.1 General Characteristic of Laterite soils

2.1.1 General

The term laterite was first introduced by Buchanan (1807) to describe a ferruginous, vesicular, unstratified and porous material due to high iron content occurring in Malabar, India. The freshly dug material was soft enough to be readily cut into brick blocks with an iron instrument but rapidly hardened on exposure to air and was remarkably resistant to the weathering effect of climate. This material was locally used as brick for building and was hence called `` laterite`` from the Latin word `` later`` meaning brick. All later attempts to replace the word `Laterite`` with others failed and by the end of the 19th century laterite was recognized as tropical and subtropical weathering products of various crystalline igneous rocks, sediments, and volcanic ash, and it was morphologically identified as surface or near- surface occurrences in various tropical and subtropical regions of the world.

Fermor (1911) abandoned the criterion of physical hardness of the laterite in its natural state or on exposure, and developed a comprehensive system of nomenclature of laterite soils on the bases of their chemical composition. He defined various forms of laterites on the basis of the relative contents of the so-called laterite constituents (Fe, Al, Ti and Mn) in relation to silica. A similar and more comprehensive chemical classification system was proposed by Lacroix (1913), who divided laterites into: (a) true laterites; (b) silicate laterites; and (c) lateritic clays; depending on the relative content of the hydroxides.

Alexander and Cady (1962) summarized ``Laterite is a highly weathered material, rich in secondary oxides of iron, aluminum, or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying`` (Gidigasu, 1976).

Genesis of lateritic soils has emphasized the physical (hardening) and mineralogical aspects of the laterization processes. According to Moh and Mazhar (1969), the increasing degree of laterization results in an increase of the thickness of free iron oxide coating of the soil particles. The soil particles later coagulate into large clusters with subsequent reduction of specific surface. It seems that much of the differences between temperate-zone and lateritic soils may be explained on the basis of this coating and coagulation of the soil particles.

Other definitions have been based on the ratios of silica (SiO_2) to Sesquioxides (Fe_2O_3, Al_2O_3). In laterites the ratios are less than 1.33. Those between 1.33 and 2.00 are lateritic soils, and those greater than 2.00 are indicative of non-lateritic soils (Blight, 1997).

2.1.2 Origin and Formation

A Residual soil is a soil-like material derived from the in-situ weathering and decomposition of rock which has not been transported from its origin location. Residual soils can have characteristics that are quite distinctively different from those of transported soils. Particles of residual soil often consist of aggregates or crystals of weathered mineral matter that break down and become progressively finer if the soil is manipulated. The permeability of residual soils is usually governed by its micro and macro-fabric and jointing and by superimposed features such as slicken siding, termite or other bio-channels (Blight, 1997).

Residual soils are affected by Climate, Weathering process and Topography.

CLIMATE

Climate exerts a considerable influence on the rate of weathering. Physical weathering is more predominant in dry climates while the extent and rate of chemical weathering is largely controlled by the availability of moisture and by temperature. According to Uehara (1982) the clay mineralogy of the soils of the world changes in a predictable way with distance from the equator. Climates do not vary uniformly with distance from the equator, but are affected by topography, ocean currents, etc.

Climate has further effects on the properties of tropical residual soils that of unsaturation. Even in sub-humid tropical or subtropical areas, water tables are often deeper than 5 to 10 m and the effects of unsaturation, desiccation and seasonal or longer term re-wetting have to be taken into account in geotechnical design. There are many accounts of the effects of unsaturation on the behavior of soils and the best form of the effective stress relationship is governed by the stress difference (σ - Ua) and the suction (Ua-Uw) where Ua and Uw are, respectively the pore air and pore water pressures in the soil. In most practical situations, Ua equals the atmospheric pressure and can be equal to zero. The conventional form of the effective stress equation can be used with little error for soils that are unsaturation, but reasonably close to saturation (Blight, 1997; Hanna, 2008).

WEATHERING PROCESS

Residual soils are formed by the in situ weathering of rocks, the three major agencies of weathering being physical, chemical and biological processes. In the weathering 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 comminute the rock, expose fresh surfaces to chemical attack and increase the permeability of the soil to the percolation of chemically reactive fluids. Chemical processes, chiefly hydrolysis, cation exchange and oxidation alter the original rock minerals to form more stable clay minerals. Biological weathering includes both physical and chemical actions (Blight, 1997). Most commonly, residual soils form from igneous or metamorphic parent rocks, but residual soils formed from sedimentary rocks are not uncommon. Chemical processes tend to predominate in the weathering of igneous rocks, where as physical processes dominate the weathering of sedimentary and metamorphic rocks. However, chemical and physical weathering is so closely interrelated that one process never proceeds without some contribution by the other (Blight, 1997).

TOPOGRAPHY

For a deep residual soil profile to develop, the rate at which weathering advances into the earth`s crust must be exceed the rate of removal of the products of weathering by erosion.

Topography 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 age of the profile by controlling the rate of erosion of weathered material from the surface. Thus deeper residual profiles will generally be found in valleys and on gentle slopes rather than on high ground or steep slopes. Soil profiles developed from basic igneous rock on hillsides. The depths of weathering increased down the slope, whereas kaolinite/halloysite was the predominant clay minerals at the top of the slope that at the bottom of the slope was smectite (Blight, 1997).

The formation of lateritic soil involves three major processes which are identified as follows

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

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

The 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: desiccation or dehydration involves partial or complete dehydration (sometimes involving hardening) of the Sesquioxide rich materials and secondary minerals. The dehydration of colloidal hydrated iron oxide involves loss of water and the concentration and crystallization of the amorphous iron colloids into dense crystals, in the sequence; Limonite, Goethite with Hematite to Hematite. Dehydration may be caused by climate changes, upheaval of the land, or may also be induced by human activities, for example by clearing of forests (Jiregna, 2008,).

2.1.3 Pedological and Lithological classification

Residual soils need special classifications that are not adequately covered by conventional methods of soil classification because of the following (Blight, 1997).

1. The unusual clay mineralogy of some tropical and sub tropical soils.
2. Soil mass in-situ may display a sequence of material ranging from a true soil to a soft rock depending on degree on weathering.
3. Conventional soil classification systems focus primarily on the properties of the soil in its remoulded state; this is often misleading with residual soils.

The specific characteristics of residual soils which distinguish them from transported soils can generally be attributed either to the presence of specific clay minerals found only in residual soils, or to particular structural effects, such as the presence of un-weathered or partially weathered rock. Blight, (1997) proposed residual soils to be classify into three groups on the basis of mineralogical composition alone, without reference to their undisturbed state. His suggested groups are:

1. Group A : soils without a strong mineralogical influence.

2. Group B : soils with 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.

The group C, can be classified in to three sub-groups (Blight, 1997)

Group C; sub-group (a) Halloysitic soils

The principal influence of halloysite appears to be that the engineering properties of the soil are good, despite a high clay fraction, and fairly high values of natural water content in terms of Atterberg Limits (i.e. a high Liquidity Index).

Group C; sub-group (b) Allophonic soils

Allophonic soils are probably the most distinctive of all residual soils due to the very unusual properties of the amorphous mineral allophone. Allophone soils have a natural moisture contents ranging from about 80% to 250%, but which still perform satisfactorily as a construction material. They are superior to other soils with similar water contents.

Group C; sub-group(c) soils influenced by the presence of Sesquioxides

The principal role of sesquioxides appears to be act as cementing agents, which bind the other mineral constituents in to clusters or aggregations. With sufficient concentration of sesquioxides, the hard concretionary materials called laterite will be formed. This sub groups perhaps be termed as Lateritic group (Blight, 1997).

The extent of laterization residual soil may be measured by the ratio of silica, sio_2, remaining in the soil (except for discrete pebbles of free quartz that may remain) to the amount of Fe_2O3 and Al_2O_3 that has accumulated. The silica: sesquioxide ratio

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

has served as basis for classification of residual soils. Ratios less than 1.33 have been considered indicative of true laterites. For lateritic soils the ratio lies between 1.33 and 2.00 and those greater than 2.00 are non lateritic tropically weathered soils (Lyon, 1971).

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

It was found that most of the tropically weathered soils of Africa could be divided in to three groups on a genetic basis, determined by the soil-forming factors. The three major groups of significance have been defined by D'Hoore 1964, (Lyon, 1971). These are:

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

ii) Ferallitic Soils: These occur in moist sub-humid to very humid areas for lateritic soils and in areas with dense vegetation cover. Gibbsite is the most common clay mineral observed and other hydrated forms of alumina occur as well as hydrated iron minerals. Halloysite is fairly common over volcanic rocks. The annual average rainfall requirement for its formation is 1500 to 4000mm. Both of the above soils have SiO_2/R_2O_2 ratio of less than 2.0 and are classified either as lateritic or laterite soils.

iii) Ferrisols: Those are formed over all types of rocks in intermediate to high rainfall areas where erosion has kept the place with profile development. They have similar profiles to ferallitic soils, but with few weatherable minerals remaining. The entire clay fraction comprises Kaolinite and amorphous oxides of iron and aluminum. These are developed at deeper levels due to the surface erosion, and occur in regions of annual average rainfall of 1250 to 2750mm. According to Morine W.J. and Todor P.C. (1976), Ethiopian laterites fall under this group (Blight, 1997).

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

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

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

On the other hand, Nascimento et al. (1959) have suggested an interesting lithological classification of lateritic soils as follows (Lyon, 1971).

Lateritic clays	< 0.002mm
Lateritic silts	= 0.002-0.06mm

Lateritic sands = 0.06-2mm

Lateritic gravel = 2- 60mm

Lateritic stones and cuirasse > 60mm

Moreover, (Anthony Young, 1976, Lyon, 1971, Jiregna, 2008) has distinguished the following main types and sub-division of laterite:

I) Massive laterite: possesses a continuous hard fabric, subdivided in to
   a. Cellular laterite: With cavities approximately rounded
   b. Vascular laterite: With cavities approximately tubular

II) Nodular laterite: consists of individual particles approximately rounded (also called pisolithic laterite) subdivided in to:

   a. Cemented nodular laterite: Individual concretions can be seen but are strongly joined together by the same iron stone material.
   b. Partially cemented nodular laterite.
   c. Non-cemented nodular laterite: Concretions from over 60% by weight of the total soil.
   d. Iron concretions: Are separated by soil- but forms less than 60% by weight of the total horizon.

iii) Recemented laterite: This contains fragments of massive laterite or ferrugnized rock, broken and wholly or partly cemented.

IV) Ferrugnized rock: Here, rock structure is still visible, but with substantial isomorphous replacement by iron.

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

2.1.4 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 under-estimated (CIRIA, 1995, Zelalem, 2005). 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. Some lateritic soils are sensitive to pre-treatment and testing procedures. So laboratory testing should be simulated to site condition (CIRIA, 1995, Zelalem, 2005).

Main characteristics of lateritic gravels and gravely soils as mentioned by Morine W.J. and Todor P.C.(1969), 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 (CIRIA, 1995, Zelalem, 2005).

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. Hence, care should be taken to prevent contamination of laterite while removing overburden and stockpiling the laterite (Zelalem, 2005).

2.2 Index Tests of Residual Soils

2.2.1 Moisture content

The conventional test for the determination of moisture content is based on the loss of water when a soil is dried to a constant mass at a temperature between 105 and 110 ºC. In many residual soils, however, some moisture exists as water of crystallization, within the structure of minerals presented in the solid particles. Some of this moisture may be removed by drying at the above temperature. The following procedure is therefore recommended:

Two test specimens should be prepared for moisture content determinations. One specimen should be oven dried at 105 ºC until successive weighing show that no further loss of mass. The moisture content should then be calculated in normal way. The second sample should be air dried (if feasible); or oven - dried at a temperature of no more than 50ºC and a maximum relative humidity (RH) of 30% until successive weighing show that no further loss of mass. The two moisture content results should then be compared; a significant difference (4-6% of moisture content obtained by oven drying at 105 ºC) indicates that `structural` water is present. This water forms part of soil solids, and should therefore be excluded from the calculation of moisture content. If a difference is detected using the two different drying procedures, all subsequent tests for moisture content determination (including those associated with Atterberg Limit tests, etc) should be carried out by drying at lower temperature (i.e. either air drying, or oven–drying at 50ºC and 30% RH) if possible, the lower drying temperature of 50 ºC should be used (Blight, 1997).

2.2.2 Atterberg limits

Soils containing clay exhibit a property called plasticity. Plasticity is the ability of a material to be moulded (irreversibly deformed) without fracturing. This behavior is unique to clay and arises due to the electrochemical behavior of clay minerals.

The stiffness or consistency of fine grained soils depends on their moisture content, and varies with variations in the amount of moisture present. Atterberg limits define the moisture contents at which the soil changes from one state to another. These include the liquid limit, the plastic limit and shrinkage limit. They are determined by tests carried out on the fine soil fraction passing the 425µm (No. 40) sieve (BS, 2001). Because the formation of lateritic soils involves differential weathering as well as movement and deposition of dissolved materials, the variation of plasticity characteristics with depth cannot be predicted even in two similar profiles on different topographical sites (Hanna, 2008).

Effect of method and time of mixing on Atterberg Limits

In general, the greater the duration of mixing (i.e., the greater the energy applied to the soil prier to testing), the larger the value of the resulting liquid limit, and to a lesser extent, the larger the plasticity index. This has been attributed to longer mixing results in more extensive break down of the cemented bonds between the clay clusters and within peds (disaggregation of the particles), and thus formation of greater proportions of fine particles. In order to address this problem: Five test specimens should be mixed with water to give a range of moisture contents suitable for liquid limit and plastic limit determinations. This should not be too difficult as the in-situ moisture content of majority of soils is at or below the relative plastic limit. The mixing time should be standardized at 5 minutes, and the mixed specimens should be left for moisture content equilibration overnight before testing. On the following day the liquid limit should be determined with a minimum of further mixing. A sub-sample from each of the specimens used in the test should be used for the determination of moisture content, using the procedure. The remainder of each specimen should then be mixed continuously for a further 25 minutes before again determining the Liquid Limit. A significant difference (of >5% of the liquid limit obtained) between the liquid limit from tests using 5 and 30minutes mixing times indicates a disaggregation of the clay sized particles in the soil. If this disaggregation is confirmed by repeating the above procedures, the entire program of testing should (Blight, 1997):

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

2.3 California Bearing ratio

General

The California bearing ratio (CBR) is to determine the relationship between force and penetration when a cylindrical plunger of a standard cross-sectional area is made to penetrate the soil at a given rate. At certain values of penetration that ratio of the applied force to a standard force expressed as a percentage (BS, 2001).

$$\text{CBR value} = \frac{\text{Penetration Load}}{\text{Standard Load}} \times 100$$

Generally, the CBR for 2.54mm penetration is high. However, if the CBR for 5.08mm penetration is greater than that for 2.54mm penetration, the test is repeated. If the results are unchanged, the value for 5.08mm penetration is used for defining CBR value.

The CBR values are used to determine the thickness of various layers. As it is evident, the required thickness of construction above a material decreases as the CBR value increases (K.R. ARORA, 1997).

The evaluation of CBR values for laterite soils has shown that the stability characteristics of laterite soils may be reliably evaluated using the CBR test. The CBR values of compacted laterite soils which were soaked for 4 days depend on the degree of compaction and mainly the content of concretionary particles as well as on the plasticity of the fines.

2.4 Stabilization of soils

2.4.1 General

In Ethiopia where economic development is based on primarily on agriculture, a network of major highways, secondary roads, and low-cost feeder roads is of utmost important. Economy requires that local materials be used in the construction of these roads. Yet, untreated lateritic materials have presented many problems in road construction and maintenance.

Soil stabilization is the alteration of the properties of an existing soil either by blending (mixing) two or more materials and improving particle size distribution or by the use of stabilizing additives to meet the specified engineering property. Quite often soils are stabilized for road construction in most parts of the world for the following one or more objectives:

- Improve the strength (stability and bearing capacity) for subgrade, subbase, base, and low-cost road surfaces.
- Improve the volume stability- undesirable properties such as swelling, shrinkage, high plasticity characteristics, and difficulty in compaction, etc, caused by change in moisture.
- Improve durability – increase the resistance to erosion, weathering or traffic Improve high permeability, poor workability, dust nuisance, frost susceptibility, etc.

Due to their mineralogical composition, soils may be rather complex materials. Stabilization is therefore not a straightforward application of a given stabilizing agent; a number of aspects should be taken into account in the selection of the proper stabilization technique. The factors that should be considered include physical and chemical composition of the soil to be stabilized, availability and economical feasibility of stabilizing agents, ease of application, site constraints, climate, curing time, and safety. Such factors should be taken into account in order to select the proper type of stabilization (lecture note, Girma, 2008).

Techniques for soil stabilization are:

- ✓ Mechanical stabilization
- ✓ Cement stabilization
- ✓ Lime stabilization
- ✓ Bitumen stabilization

Mechanical stabilization is a method by which a soil is mixed with the original soil in order to improve the grading and mechanical characteristics of the soil. Other methods of stabilization use additives such as cement, lime and bitumen to improve strength, workability or water proofing (lecture note, Girma, 2008).

When selecting a stabilizing agent, different factors must be considered. These are:

- ✓ Types of soil to be stabilized
- ✓ Purpose for which the stabilized layer will be used
- ✓ The desired quality of the stabilized soil
- ✓ Required strength and durability of the stabilized layer
- ✓ Cost and environmental conditions

2.4.2 STABILIZATION OF LATERITE SOILS

Most laterite soils in their natural states are at best suitable for sub-base, but not for standard pavement base, construction material. Most gravels and gravelly soils are easy to win and distribute during construction, and give high laboratory and field compaction densities, however, their performance has been found to be poor under adverse traffic and moisture conditions. Laterite soils have various genetic origin and textural characteristics and of variable chemical and mineralogical composition can be effectively stabilized either mechanically or with single or combined organic and inorganic compounds for engineering purposes. Laterite soil stabilization have been interpreted in the light of genetic characteristics, compositional factors, such as particle-size distribution, organic matter content, chemical and mineralogical composition, and physico-chemical characteristics. Various stabilization processes have considerable influence on the plasticity, density-moisture relation, swell, strength and stability as well as the durability and weathering characteristics of the laterite soils (Gidigasu, 1976).

2.5 CHEMICAL STABILIZER CON-AID

The liquid chemical stabilizer Con-Aid is one of the numerous chemical products on the market, developed in SOUTH AFRICA by Con-Aid (international) (pty) Ltd from a blend of locally produced synthetic chemical products. It was designed for stabilizing poor quality soils containing clayey material in order to improve their properties as road construction materials. With the ion exchange and water repellent properties, the treated soil has the tendency to improve its engineering properties, such as less swelling, higher density and higher strength. Con-Aid anionic soil stabilizer, originated from petroleum, is viscous, deep red colour liquid with no smell or taste. The active agent is weak organic acid. The manufacturers claim that the chemical is totally water soluble, non-hazardous, non-synthetic compound with surface-active properties, which has been devised to change the hydrophilic (water adsorption) properties of clay materials to those of hydrophobic nature (water repellent), (user manual, Con-Aid).

2.5.1 Soils suitable for Con-Aid Stabilization

Con-Aid treatment is most suitable for poor quality soils consisting of some clayey material. Generally speaking, those soils classified as AASHTO as A-2, A-4, A-5,A-6, A-7 with PI of 8 to 35% and percentage fine (passing the 0.075mm sieve) between 15 and 55%. The water used for mixing should have a pH value not exceeding 8; otherwise the reaction of Con-Aid on the soils will not be fully effective. With the ion exchange and water repellent properties, the treated soil has the tendency to improve its engineering properties, such as less swelling, higher density and higher strength(user manual, Con-Aid).

2.5.2 A Guide of Application Rate of Con-Aid

The application rate of Con-Aid depends upon how reactive the clay mineral in the material is to Con-Aid. Although clay minerals are relatively uniform in a specific geological region, the amount of clay present at a given place may vary depending upon the grading sizes of the material. The dilution water ration of Cod-Aid is in a ratio of 1:500(user manual, Con-Aid).

A guideline of application rates using CON-AID with reference to AASHTO classification is provided in table 2.1.

Table 2.1, Suggested Application Rate on Different Soil Types

Group	Subgroup	%passing 0.075mm sieve	Plasticity index	CON-AID Application Rate (liter/m^2)
A-1	A-1-a	15 max	6 max	0.01
	A-1-b	25 max	6 max	0.01
A-2	A-2-4	35 max	10 max	0.01
	A-2-5	35 max	10 max	0.015
	A-2-6	35 max	11 max	0.015
	A-2-7	35 max	11 max	0.020
A-3		10 max	Non-plastic	N/A
A-4		36 min	10 max	0.020
A-5		36 min	10 max	0.025
A-6		36 min	11 min	0.02-0.03
A-7	A-7-5	36 min	11 min	0.02-0.03
	A-7-6	36 min	11 min	0.02-0.03
A-8				N/A

2.5.3 Reaction of Con-Aid on clay Minerals

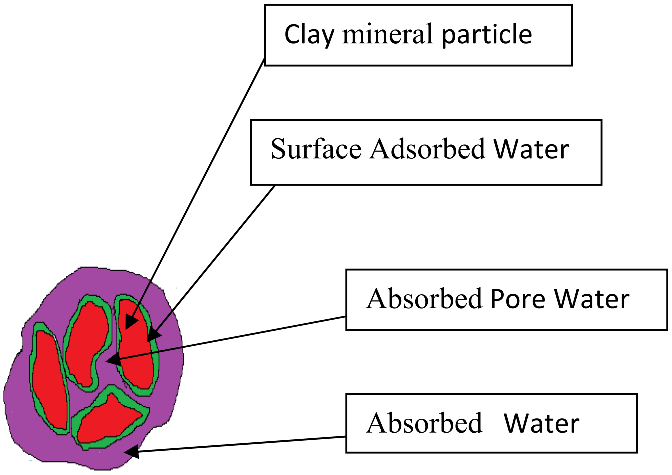
Clay often means a soil which contains some clay minerals as well as other mineral constituents has plasticity. Clay minerals very tiny crystalline substances evolved primarily from chemical weathering of certain rock-forming minerals. Chemically, they are hydrous aluminosilicates plus other metallic ions. All clay minerals are very small, colloidal- sized crystals, and they can only be seen with an electron microscope. In fact, there are only two fundamental crystal sheets, the tetrahedral or silica, and the octahedral or alumina, sheets. The particular way, in which these sheets are stacked, together with different bonding and different metallic ions in the crystal lattice, constitute the different clay minerals.

The tetrahedral sheet is basically a combination of silica tetrahedral units which consist of four oxygen atoms at the corners, surrounding a single silicon atom. The octahedral sheet is basically a combination of octahedral units consisting of six oxygen or hydroxyls enclosing aluminum, magnesium, iron, or other atom. On the basis of their crystalline arrangement, clay minerals are divided into three general groups namely, Kaolinite, montmorillonite and illite.

Clay soils are strongly influenced by the presence of water. The variation of water content gives rise to plasticity, and the Atterberg limits are an indication of this influence. Water is important in fine-grained soils because clay minerals, being relatively small particles, have large specific surfaces (Robert D.H, 1981).

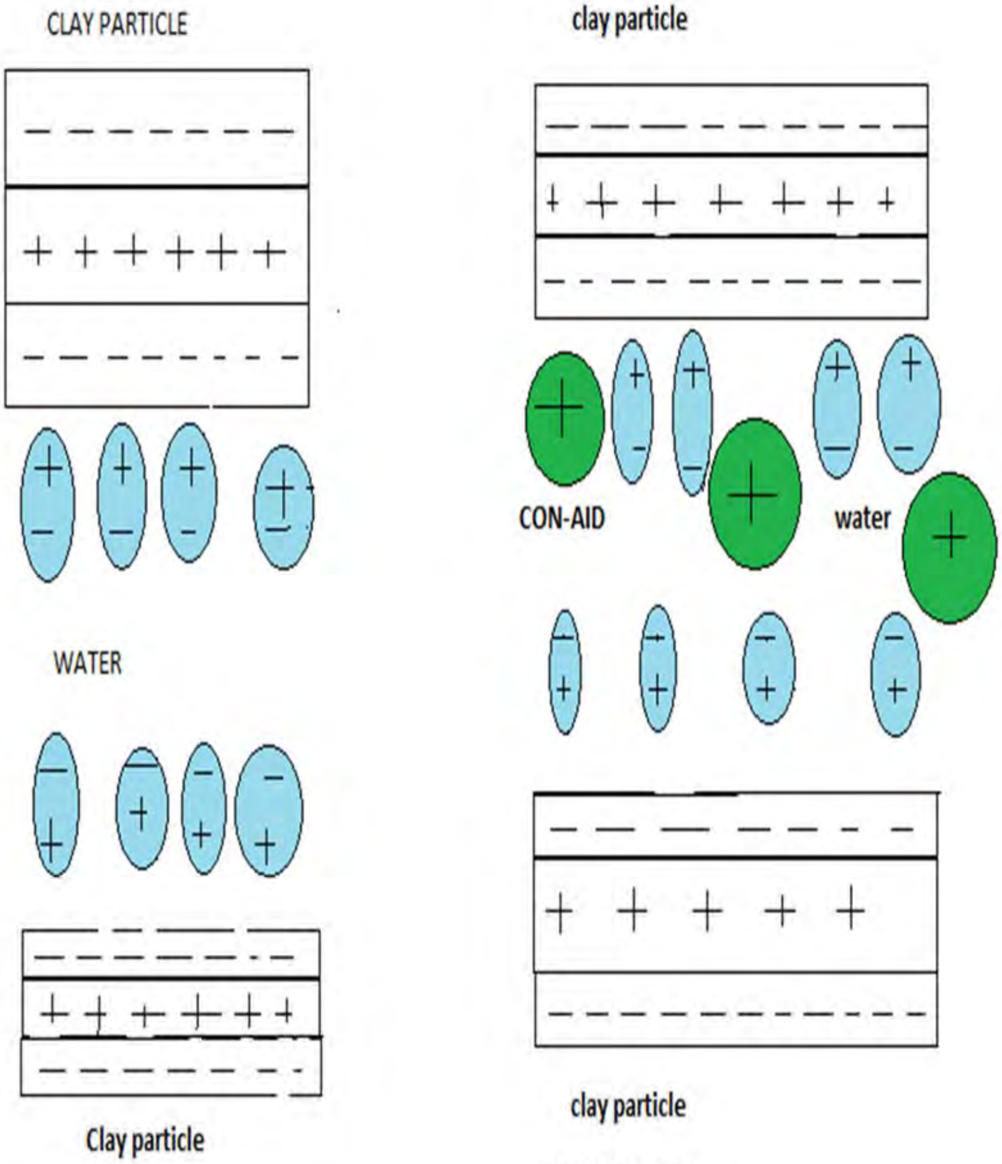
Clay particles carry a net negative charge, to balance the negative charge; the clay particles attract positively charged ions from salts in their pore water (DAS, 1987).

Clay particles are almost always hydrated in nature; that is, there are layers of water surrounding each crystal of clay. This water is called adsorbed water (Fig, 2.1). Absorbed water requires very little energy for its removal, but adsorbed water requires definite energy for its complete removal.



Fig, 2.1 Absorbed and Adsorbed Water in Clay-Water Systems

The large quantities of water and the mobility of cations and anions in a clay water system will produce the undesired plasticity. In order to reduce the plasticity, it is necessary to reduce the mobility of ions in solution and secondly to liberate as much water as possible from the system. Treatment of material with Con-Aid provides the chemicals required to reduce ion mobility and to repel water from the clay minerals (Fig, 2.2, www.cbrplus.com). Clay particles having their inner walls coated with a hydrophobic layer, allows for the free movement of water. This means that water in the soil of a road can move freely in the Con-Aid treated material. With natural evaporation, this free water evaporates from the system more easily and hence increasing the stability of the material (user manual, Con-Aid).



a)No treatment

b)with Con-Aid

Fig, 2.2 Microscopic behavior of clay particle without and with CON-AID

3. Sampling Area Description

3.1 General

The project site can be reached from Addis Ababa via Hawassa main asphalt road and turning to the left at the center of Shashemene town following the sub main asphalt road that passes through Wolayta-Sodo towards Arbaminch town. After Arbaminch there is 34kms of well constructed double surface treatment road, where the project (Wezeka-Gidole) starts at about 539km far from Addis Ababa and ends at 573km (See Fig3.1).

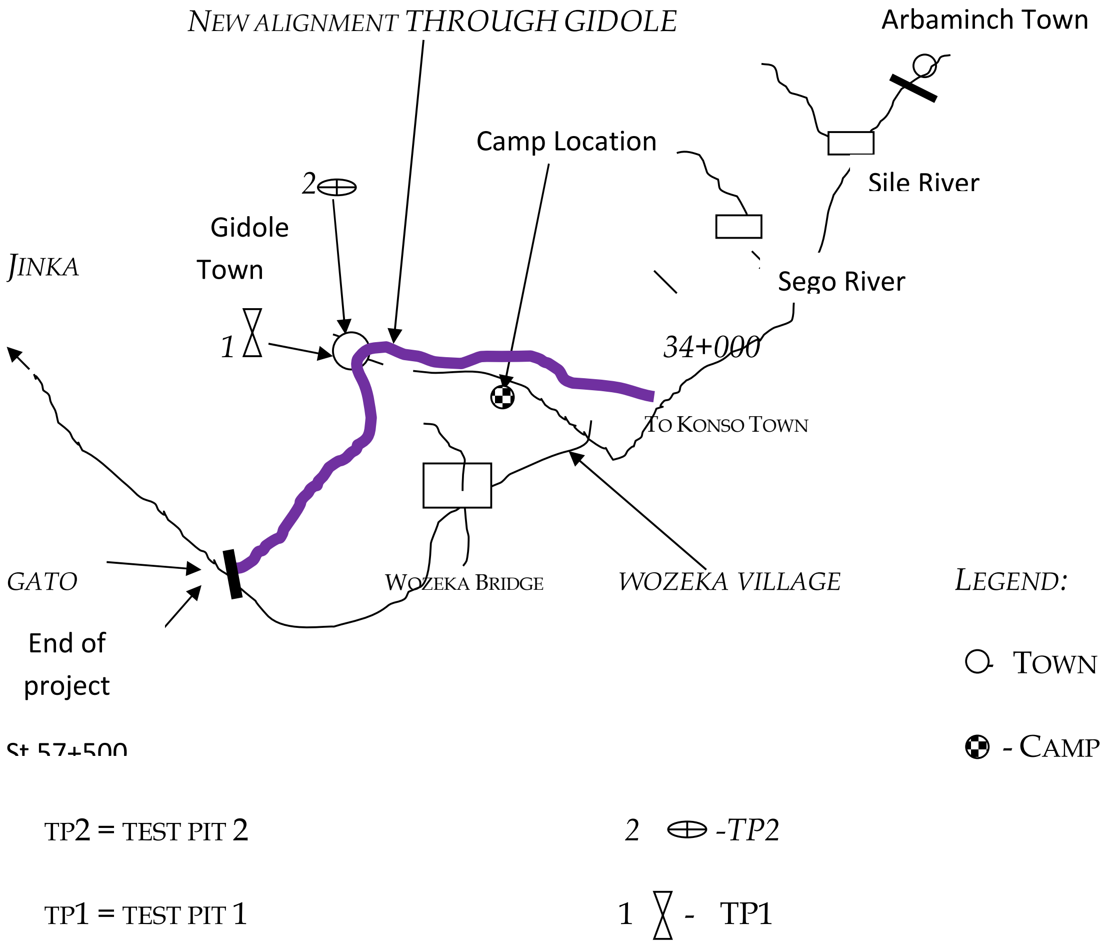


FIG 3.1, SAMPLE AREA LOCATION (Project profile of Wozeka-Gidole raod)

3.2 Topography and climate

The minimum elevation of the project is at km 0+000 with an elevation of 1164.45m AMSL, and the maximum elevation of 2087.93m at km 17+720. The project started at km 34+000 back (km 0+000 ahead) at an elevation of 1164.45m above sea level. Passing through some rolling terrain, starts to ascend from wolayta village (12+500) with an elevation 1780.78m which proceeds through mountainous terrain and reached Gidole town with an elevation of 2027.36m at km 16+600 and going over the ridge of Gidole and started to fall down. Finally stretching through mountainous terrain it reaches the flat area near Gatto with an elevation of 1304.43m at km 33+398.36 back (km 57+500 ahead). Therefore, the 34km length of the project elevation range is from minimum 1164.45m to a maximum of 2087.93m.

The Southern Region and the project area are characterized by two major agro ecological zones: the highland is above 1500m; and the lowlands defined as areas below 1,500 meters. Altitude is a major determinant factor differences in rainfall, temperature, cropping pattern and vegetation cover which characterize these zones. A significant portion of the region's population is settled in the moderately elevated highland (Weyena Dega) areas (1500m - 2300m above sea level), and the more elevated highland areas (Dega) which are 2300m-3500m above mean sea level. Weyena Dega offers relatively high and reliable rainfall (1000-1400mm/year) and cool temperature (16 - 29^{o} c). From the above this project was located both in the high and low land area. The part of the road in the highland area is 59% and that in the lowland area is 41%, therefore a higher portion of the road segment may have the possibility to get a higher rainfall in a year. The climatic classification of the project area is therefore 59% in cold temperature zone, which has a maximum temperature of 25^{o} c. The mean annual rainfall ranges from 800 to 1200 mm. The mean period of on-set is early May and mean period of cessation is late September. The remaining 41% is in warm temperature zone, that is a minimum of 20^{o} c and the moisture index is 0.5 to 1.0 that is intermediate or moist. The mean annual rainfall ranges is from 800 to 1000 mm.

Transport construction design Share Company (TCDSC) has prepared the detail engineering design and has executed tender document preparation for the works and the design review.

Ethiopian Road Authority (ERA) operation department own force division is undertaking the construction of this project and Transport Construction Design Share Company carries out consultancy service for the supervision of the works (Project profile of Wozeka-Gidole raod)

4.In-situ properties and Laboratory Test Results

4.1 In-situ Properties Description

4.1.1 Sample Description

The Soil specimens for this thesis work were collected from Gidole town at 556km and 557km far away from Addis Ababa respectively. Before the soil samples were collected, site visit was made with consultant`s material Engineer (wezeka-Gidole road construction). Upon this site investigation places for lateritic soils were chosen. Accordingly, two places were chosen and bulk samples have been collected for this research work, weighing about 620kg (Table 4.1).

Table 4.1 sampling stations with their depth

Serial No.	Sampling station	Sampling depth(m)	Sample Designation
1	Sta.556+00	0~1.10	TP2-SM1
2	Sta.556+00	1.10~1.60	TP2-SM2
3	Sta.557+00	0~1.00	TP1-SM1
4	Sta.557+00	1.00~1.85	TP1-SM2

Where; TP = Test Pit
SM = Sample

Due to budget limitation bulk samples were gathered only from locations test pit one and test pit two, these sampling areas are located at beginning and end of sampling stretch.

Samples designated as TP1 are named as TP1-SM1 and TP1-SM2 referring to the first sample of the first test pit and the second sample of the first test pit respectively. Samples designated as TP2 are named as TP2-SM1 and TP2-SM2 referring to the first sample of the second test pit and the second sample of the second test pit respectively. The first test pit was laborious to dig the soil due to absorption of moisture by the plants grown over it, but the second test pit almost no vegetation in the area. To avoid contamination, in both test pits the top 60cm were removed prier to sampling and disturbed samples were collected under scarified soil. The pits for TP1 and TP2 are shown in Fig 4.1 and Fig 4.2.

Fig. 4.1 The profile view of soil sample pit of TP1

Fig. 4.2 The profile view of soil sample pit of TP2

4.1.2 In-situ Natural Moisture Content

Along the samples profile the visual color observed was from chocolate brown to red brown. From the sampling site, moist soil samples were collected using plastic bags. The plastic bags were tied to reduce loss of natural moisture content. In-situ moisture contents were determined for the soil samples under investigation using oven temperature of 105^{o}c.The test results presented in Table 4.2; it was seen from table 4.2 the natural moisture content increases with depth.

Table 4.2, Natural moisture content test result

Serial No.	Sample Designation	Sampling depth(m)	Natural moisture content %
1	TP1-SM1	0~1.00	27.68
2	TP1-SM2	1.00~1.85	28.29
3	TP2-SM1	0~1.10	37.94
4	TP2-SM2	1.10~1.60	38.79

4.2 Laboratory Test Results and Discussions

4.2.1 Index properties

4.2.1.1 General

Basically, soil is a more complex material usually realized. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solid, liquid and gases, where in many instances the solid particles vary in size ranging from big boulders to colloidal size. Furthermore the relative quantities of solid, liquid and gases in a given soil is bound to change due to any physical cause, such as loading, seasonal variation and change of temperature which makes the situation further complicated (samuel,1989). Besides, because of their peculiar formation processes and strong mineralogical influences lateritic soils add further complexities. To understand the behavior of soils, the composition, effect of temperature and pre test treatments and the relative influence of each component must be known. To do this, methods of evaluations (tests) have been centered on their physical property as the physical characteristics are of importance to the engineers. Chemical analysis has also been made to supplement the results. The physical properties of soils which serve mainly for identification and classification purpose are commonly known as index properties which can be determined by simple laboratory tests.

Most of stake holders engaged in road construction field use AASHTO testing procedure and specification. Similarly for this research work, the procedure followed in the laboratory tests execution were AASHTO.

4.2.1.2 Grain Size Analysis

Soil particles may consists of size ranges from boulders to fine-sized clays. Grain size analysis is used to determine the effective diameter of the soil particles that constitute and strongly affect the uniformity characteristics of the soil mass. Hydrometer analysis is used to fine-grained soils. From hydrometer analysis of TP1-SM1 the liquid limit was 47 and the plastic limit was 32, consequently the plasticity index was 15. The laboratory observation of the hydrometer after 24-hour solution was shown in Fig 4.3. It was seen from test result the clay content of TP1-SM1 soil sample is 65%. From the above test results the soil under investigation was A-7-5.

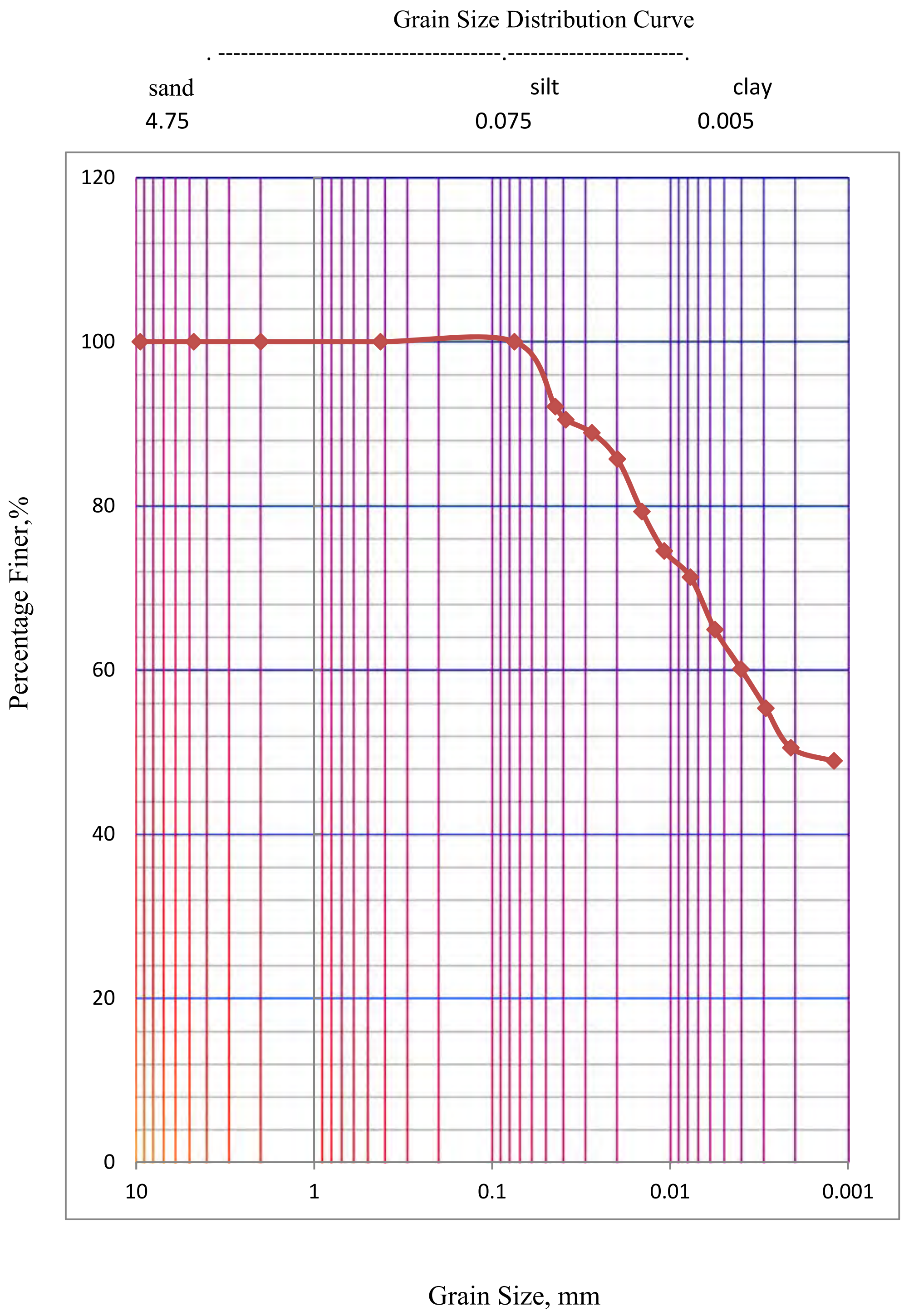


Fig 4.3, Grain Size Distribution Curve of TP1-SM1

Effects of Temperature on Moisture Content Determination

Using an oven drying of 105°c is by far high for certain tropical soils as it can drive out their water of hydration and resulting in an irreversible property change on the soil. This effect can be overcome in the laboratory by conducting the natural moisture content of the soil at different test temperatures. Accordingly, the natural moisture content of the samples was determined in the laboratory as suggested by (Blight, 1997, CIRIA, 1995). That is drying the sample to an oven temperature of 105°c and oven temperature of 50°c with maximum relative humidity (RH) of 30% or equivalently air-drying. To see the existence of such water in the investigated lateritic soils, four test specimens were prepared for moisture content determination. Part of the four specimens were oven dried at 105°c, and the other at a temperature of 50°c with relative humidity 30% taking a minimum of five days up to get a constant mass in successive measurements. The moisture content is then calculated in the normal way. These moisture contents have no relations with natural moisture content shown in Table 4.2. The two sets of results are then compared (Table 4.3). In all the cases, it can be observed that the difference in moisture content is less than 4%, which shows that the amount of structural water is insignificant. Therefore, all the subsequent tests in need of moisture content determinations are based on the conventional drying temperature (105°c).

Table 4.3 effect of temperature on moisture content

Sample Desg.	Oven temperature	Wt. of can(g)	Wt. wet sample + can (g)	Wt. of dry sample + can (g)	Wt. water (g)	Wt.dry sample (g)	Moisture % at temperature		Diff. %
							105°C	50°c RH30%	
TP1-SM1	105°C	85.13	292.71	247.15	45.56	162.02	28.12	-	2.15
	50°C	84.29	272.29	233.53	38.76	149.24	-	25.97	
TP1-SM2	105°C	86.24	325.11	308.4	16.71	222.16	7.52	-	1.71
	50°C	88.48	318.33	305.71	12.62	217.23	-	5.81	
TP2-SM1	105°C	86.81	302.82	246.85	55.97	160.04	34.97	-	3.22
	50°C	85.07	275.78	229.82	45.96	144.75	-	31.75	
TP2-SM2	105°C	84.24	327.17	298.62	28.55	214.38	13.32	-	2.62
	50°C	89.53	324.99	302.23	22.76	212.70	-	10.70	

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 disaggregation; 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 samples as mentioned in section 2.2.2.1. The Atterberg limit tests are carried out on the soil samples TP1-SM1, TP1-SM2, TP2-SM1and TP2-SM2 according to the procedures mentioned in (AASHTO T89-02, T90-00, Blight, 1997).

Five air dried test portions were mixed with water to give the range of water contents suitable for liquid and plastic limit determinations. The mixing time was about 5 minutes, and the mixed samples were left for 24 hour before testing, for moisture equilibrium. After determining the moisture content for each test point on a part of each test portion, the remaining 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 4.4.

A significant difference (i.e.> 5 % of the liquid limit was obtained from the test on a specimen mixed for 5 minutes) between the liquid limit from tests using 5 and 30 minutes mixing times indicates that aggregation of clay size particles are broken down up on manipulation. From the test results one can see that the soils are generally sensitive to handling and disturbance. The more the soils structure is handled and disturbed, the finer the aggregates become in grading and the higher the Atterberg limit.

Generally one can see from Table4.4 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.

Hence the entire programme of testing was done as follows:

1. Limit the mixing times not more than 5 minutes
2. Make use of fresh soil for each moisture content point in Atterberg limit tests.

In Table 4.4 for samples prepared in air dry condition the difference between 5 and 30 minutes mix is greater than 5%. This shows that the soil samples have been sensitive to test procedures.

Table 4.4 Atterberg limits at dry condition and different mixing times.

Test pit	Depth (m)	Dry Condition	Testing duration	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Difference LL30-LL5
TP1-SM1	1.00	Air dry	5 min 30min	47 52	32 39	15 13	5
TP1-SM2	1.75	Air dry	5 min 30min	53.6 59.5	39.85 42.30	13.75 17.20	5.9
TP2-SM1	1.10	Air dry	5 min 30min	62 69	39.2 41.8	22.80 27.20	7.0
TP2-SM2	1.50	Air dry	5 min 30min	56 62.6	31.1 35.3	24.9 27.3	6.6

4.3 Geochemical Tests and X- Ray Diffraction (XRD) Test

4.3.1 Geochemical Tests

Mineralogy controls the sizes, shape & surface characteristic of the particles in the soil. These features along with interaction with the fluid phase, determine plasticity, swelling, compression strength and hydraulic conductivity behavior. Thus, mineralogical composition (together with structure) is an important factor that is fundamental to the understanding of Geotechnical properties. Geochemical (oxide) tests are carried out to know quantitatively main oxides of the soil material.

Almost all soils contain some amount of colloidal oxides and hydroxides. The oxides and hydroxides of Aluminum, iron and silicon are of greatest interest since they are the ones most frequently encountered. Iron and Aluminum oxides coat mineral particles, or cement particles of soils together. It may also occur as distinct crystalline units, such as Hematite, Gibbsite and Magnetite (Hanna, 2008).

Geochemical tests were conducted at Geological Survey of Ethiopia Geochemical Laboratory. Atomic Absorption Spectrometer and Colorometer Analysis methods were used to get the percentage oxide composition of the soils under investigation. Due financial constraint only two samples were observed. The test results are shown in Table 4.5.

The degree of laterization of the soil samples can be evaluated based on ratio of Silica/Sesquioxides as detailed in section 2.1.2 the Sesquioxide, designated as R_2O_3, is the combination of Aluminum oxide (Al_2O_3) and Iron oxide (Fe_2O_3). The chemical formula SiO_2 designates the silica. Ratio less than 1.33 have been considered as true laterites, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of non lateritic tropically weathered soils.

The test results in Table 4.5 Silica – Sesquioxide ratio below 1.33. This indicates that the soils are all true laterites. True laterites are simply referred as laterites. The soil of such kind are highly laterized, i.e., Sesquioxides content are high.

Table 4.5 oxide composition in percent

Test pit	Sampling Depth (m)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	H_2O	LOI	$\frac{SiO_2}{R_2O_3}$
TP1	-1.75	38.12	27.12	19.55	0.01	0.03	<0.01	0.17	0.15	2.38	0.35	<0.01	12	0.82
TP2	-1.1	36.58	23.81	22.55	0.04	0.36	<0.01	0.56	0.22	3.34	0.29	<0.01	11	0.79

4.3.2 X- Ray Diffraction (XRD) Test

X-Ray Diffraction is the most widely used technique for identification and characterization of clay minerals. Clay minerals consist of tiny crystals which are themselves made up of ordered arrays of atoms, arranged in periodic or repetitive way. In the X-ray analysis of minerals by the powder method, the powdered mineral sample is placed in a beam of X-rays, which is diffracted through a limited number of angles by the crystal lattice of the sample. The atomic arrangement of the clay flakes are determined by this method and provide a means of to measure the spacing of the atomic planes, i.e., sheet thickness. The X-ray diffraction patterns are recorded on a photographic film as a series of lines in the form of arcs concentric with the original X-ray beam. From the position of these lines the angles of diffraction, and hence the separation of spacing of the planes of atoms producing them, can be deduced (Gidigasu, 1976). Using the above method the major constituent minerals were determined. These are Kaolinite, Halloysite and Montormorillonite.

XRD test was also undertaken at Geological Survey of Ethiopia Geochemical Laboratory and petrography laboratory using X-Ray Diffraction analysis by powder diffraction method after grinding the bulk soil sample without separating the clay fraction. Here also, due to financial constraints only two samples were observed.
The test results in Table 4.6 show that the major constituent mineral is Kaolinite. This coincides with clay mineral most common in laterite soils, i.e. Kaolinite (Lyon, 1971).

Table 4.6, Mineralogical composition

Test pit	Sampling depth (m)	Mineral identification	Chemical formula	Identified minerals %
TP1	-1.75	Kaolinite Dickite Goethite	$Al_4(OH)_8(Si_4O_{10})$ $Al_2Si_2O_5(OH)_4$ $FeO(OH)$	47.5 39.3 13.2
TP2	-1.1	Kaolinite Quartz Goethite	$Al_4(OH)_8(Si_4O_{10})$ SiO_2 $FeO(OH)$	62.9 18.0 19.1

4.4 STABILIZATION OF LATERITE SOIL WITH CON-AID

4.4.1 Soil- Con-Aid mixture preparation

According to user manual it is recommended that in general, AASHTO soil classification A-7 group proposed application rate of Con-Aid between 0.02-0.03 lit/m^2 for 15cm thickness, which means that 0.133-0.2 lit/m^3. A box size of 50x50x15cm was prepared (Fig, 4.4) and filled with air dried soil sample and weigh the soil to change into weight. The soil samples treated with different application rates (0.02-0.03 lit/m^2) showed have no sign of improvement except the lower limit.

Based on the lower limit (0.02lit/m^2) prepare water con-Aid solution in 1:500 ratios by mixing the solution in mixer (Fig, 4.5) for subsequent tests.

Fig.4.4 laterite soil filled in the box

Fig 4.5, water and con-Aid mixing in the mixer

4.4.2 Atterberg limits

4.4.2.1 General

Atterberg limit tests are carried out to determine the consistency of fine-grained soils. Rossiter D.G. (2004) mentioned that this test for laterites and lateritic soils normally give large range of results. Morin W.J. and Todor P.C. (1969) 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 liquid limit (Lyon, 1971, Zelalem, 2005).

4.4.2.2 Test procedures

To pass the No.40 sieve, air dried soil sample were prepared by spreading out the soil on plastic in the laboratory and leaving it open to the air for 8 days. The room temperature was about 20^{o}c. Prepared two 600 grams of soil sample passing No. 40 (0.425mm) sieve for each tests. Accordingly, prepared Con-Aid chemical and mix with water to 1:500 ratio. The soil samples mixed with water and water- chemical solution separately and kept wet for a period of 24 hrs that covered by plastic bags for moisture content equilibration. For the determination of the Atterberg limit values the samples were tested following the procedure given in AASHTO T89 and T90.

4.4.2.3 Test Results and Discussions

Under this investigation the soil was mixed with and with-out chemical by keeping 5 minutes mixing time and use fresh soil for each Liquid limit tests separately. The values of each liquid limit, plastic limit and plasticity indexes were determined. The test results are shown on table 4.7 and Appendix I. It was seen from test result the plasticity index decrease in-significantly with the addition of chemical.

Table 4.7 plasticity index without and with chemical

Test pit	Depth (m)	Dry Condition	Type of test	Liquid limit %	Liquid limit %	Plastic limit %	Plasticity index (PI), %	Reduction of (PI),%
TP1-SM1	1.00	Air Dry	Without chemical	48	48	34.18	13.82	2.17
			With chemical (0.02lit/m2)	44.5	44.5	32.85	11.65	
TP1-SM2	1.75	Air Dry	Without chemical	54.5	54.5	37.73	16.77	2.99
			With chemical (0.02lit/m2)	49.5	49.5	35.72	13.78	
TP2-SM1	1.10	Air Dry	Without chemical	68	68	35.15	32.85	3.58
			With chemical (0.02lit/m2)	61.38	61.38	32.11	29.27	
TP2-SM2	1.50	Air Dry	Without chemical	52	52	34.05	17.95	2.10
			With chemical (0.02lit/m2)	48	48	32.15	15.85	

4.4.3 Compaction

4.4.3.1 General

The compaction of soil, that is, to place it in a dense state, is desirable for three reasons:

(a) to decrease future settlements

(b) to increase shear strength, and

(c) to decrease permeability

The purpose of a laboratory compaction test is to determine the proper amount of mixing water to use when compacting the soil in the field and the resulting degree of denseness can be expected from compaction at this optimum water content (W.Lambe, 1951).

4.4.3.2 Test procedures

Two 10,000 grams of air dried soil samples were prepared and made to pass through No. 4 (4.75mm) sieve for each test. Accordingly, prepared Con-Aid chemical and mix with water to 1:500 ratio. The soil samples mixed with water and water- chemical solution separately and kept wet for a period of 24 hrs that covered by plastic bags for moisture content equilibration. The soil samples are compacted according to AASHTO T99 in three layers in a 101.6mm diameter steel mould with a Rammer of 2.5 kg weight falling freely from a height of 305mm manually. Each layer was compacted 25 blows.

4.4.3.3 Test Results and Discussions

The values of maximum dry densities (MDD) and optimum moisture contents (OMC) for the soils were determined with and without chemical solution. The test results are shown on table 4.8 and Appendix II. It was seen from test result the maximum dry density increase, as the optimum moisture content is decrease with the addition of chemical.

Table4.8, MDD & OMC with and without chemical

Test pit	Depth (m)	Dry condition	Type of test	Optimum moisture content(OMC), %	Maximum dry density (MDD) Kg/m^3	Increase in MDD Kg/m3
TP1-SM1	1.00	Air Dry	Without chemical	34.6	1430	20
			With chemical	33.5	1450	
TP1-SM2	1.75	Air Dry	Without chemical	29.6	1468	10
			With chemical	28.2	1478	
TP2-SM1	1.10	Air Dry	Without chemical	37	1320	10
			With chemical	36.5	1330	
TP2-SM2	1.50	Air Dry	Without chemical	36.5	1300	10
			With chemical	35.5	1310	

4.4.4 CBR and CBR-swell

4.4.4.1 General

The California Bearing Ratio test is conducted for evaluating the suitability of a soil for use as a sub grade 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 maximum dry density relevant to field compaction value (Bowles, 1978).

4.4.4.2 Test procedures

After the determination of the optimum moisture content (OMC) and natural moisture content, calculate the amount of water for each CBR test. Two 5000 grams of air dried samples were prepared to pass through No.4 (4.75mm) sieve for each test. Accordingly, prepared Con-Aid chemical and mix with water to 1:500 ratio. The soil samples mixed with water and water-chemical solution separately and kept wet for a period of 24 hrs that covered by plastic bags for moisture content equilibration. The soil samples were compacted according to AASHTO T-99 in three layers of 56 blows per layer. To measure the effect of Con-Aid on the CBR, the samples were cured in molds for 4 days, 7days and the other for 14 days for each test. After their respective curing periods, the molds soaked in water for 4 days.

4.4.4.3 Test Results and Discussions

The reading was taken before and after soaking to determine swell. After the soaking period the CBR`s were determined. Penetration at rate of 1.27mm/min to depths of 2.54mm and 5.08mm are used for calculating the CBR value. The standard forces at these penetrations are, i.e., 13.344kn and 20.016kN (ERA, 2002), respectively. Take the higher percentage as the CBR value. The test results are shown on Table 4.9 and Appendix III.

The California bearing ratio test result shows that the application of Con-Aid at a rate of 0.02 lit/m2 and curing for 4 days, 7 days and 14 days has less significant effect on soaked CBR value. As to the swell potential, the four-day soaking period revealed that the Con-Aid treatment of the soil has also less appreciable effect on the expansion of the soil (Table4.9).

Table 4.9, values of CBR without & with chemical and also with different curing periods

Test Pit	Type of test	OMC %	Penetration (mm)	CBR %			
				After Curing			
				24 hours	4days	7days	14days
TP1-SM1	Without chemical	34.6	2.54	5.4	6.04	6.76	7.7
	With chemical (0.02 lit/m^2)	33.5	2.54	5.6	6.25	7.03	8.6
TP1-SM2	Without chemical	29.6	2.54	5.2	5.8	7.1	7.5
	With chemical (0.02 lit/m^2)	28.2	2.54	5.7	6.5	7.8	8.1
TP2-SM1	Without chemical	37	2.54	5.6	6	6.7	7.3
	With chemical (0.02 lit/m^2)	36.5	2.54	5.9	6.5	7.4	7.8
TP2-SM2	Without chemical	36.5	2.54	5.8	6.1	6.8	7.4
	With chemical (0.02 lit/m^2)	35.5	2.54	6.4	6.9	7.7	8.2

Table 4.10, untreated & treated CBR Swell with different curing periods

Test Pit	Type of Test	Swell %			
		After Curing			
		24 hours	4 days	7days	14days
TP1-SM1	Without chemical	4.2	4.1	3.9	3.9
	With chemical (0.02 lit/m^2)	4.1	4.1	4	3.9
TP1-SM2	Without chemical	4.6	4.4	4.3	4.2
	With chemical (0.02 lit/m^2)	4.6	4.3	4.2	4.2
TP2-SM1	Without chemical	4.3	4.2	4	4
	With chemical (0.02 lit/m^2)	4.2	4.2	3.9	3.9
TP2-SM2	Without chemical	4.4	4.3	4.2	4.1
	With chemical (0.02 lit/m^2)	4.3	4.3	4.1	4.1

5. Conclusions and Recommendations

5.1 Conclusions

Based on the test results obtained from the investigation of the selected soil treated with Con-Aid chemical the following conclusions can be drawn:

1. The soils were influenced in-significantly by the addition of Con-Aid liquid chemical stabilizer. Generally there was a decrease in liquid limit and in plastic limit, consequently reducing the plasticity index, but it was not significant.

2. The compaction tests showed a small improvement in maximum dry density and a small decrease in optimum moisture content. Although there was a tendency for better results after treatment.

3. Investigation was carried out to estimate the CBR value with different curing period, samples treated with Con-Aid have showed small increment of the CBR value. This shows that CBR values are not promising after treatment.

4. According to the manufacturer recommendation, the treatment of clay with Con-Aid provides the chemicals required reducing ion mobility and to repel water from clay minerals and reduce plasticity, but specifically in this investigation the above properties were not seen. This indicates that the Con-Aid effect does not exceed the natural effect of the laterite soil, because the soil under investigation is already cementeous material. So that Con-Aid is not appropriate stabilizer for Gidole town laterite soil.

5.2 Recommendation

- Apart from this specific study in Gidole town detailed investigation has to be carried out on Con-Aid chemical stabilizer that lateritic soils be dominant on a localized area.

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Appendices

Appendix l- Atterberg Limits

Appendix ll- Moisture-Density Relationship

Appendix lll-Soaked CBR

Appendix - I

Atterberg Limits

The graphs in this appendix showed the liquid limits for samples from TP1-SM1 up to TP2-SM2.Figs I-1a, 1b, 1c, 1d was plotted for soil samples untreated and treated with Con-Aid chemicals.

Appendix - II

Moisture-Density Relationship (Compaction)

The graphs in this appendix showed the moisture-density relationship for samples from TP1-SM1 up to TP2-SM2.Figs II-2a, 2b, 2c, 2d was plotted for soil samples untreated and treated with Con-Aid chemicals.

Appendix - III

Soaked CBR

The graphs in this appendix showed the soaked CBR for samples from TP1-SM1 up to TP2-SM2.Fig III-3a-1, Fig III-3a-2, Fig III-3a-3 and Fig III-3a-4 were plotted for soil sample TP1-SM1 untreated and treated with Con-Aid chemical for 24hrs, 4days, 7days and 14days respectively. FigsIII-3b-1, Fig III-3b-2, Fig III-3b-3 and Fig III-3b-4 were plotted for soil sample TP1-SM2 untreated and treated with Con-Aid chemical for 24hrs, 4days, 7days and 14days respectively. Fig III-3c-1, Fig III-3c-2, Fig III-3c-3 and Fig III-3c-4 were plotted for soil sample TP2-SM1 untreated and treated with Con-Aid chemical for 24hrs, 4days, 7days and 14days respectively. Fig III-3d-1, Fig III-3d-2, Fig III-3d-3 and Fig III-3d-4 were plotted for soil sample TP2-SM2 untreated and treated with Con-Aid chemical for 24hrs, 4days, 7days and 14days respectively.