**ADDIS ABABA UNIVERSITY**

**SCHOOL OF GRADUATE STUDIES**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**DEPARTMENT OF CIVIL ENGINEERING**


# INVESTIGATION ON SOME OF ENGINEERING PROPERTIES OF SOILS FOUND IN AMBO TOWN, ETHIOPIA


**BY:**

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**'' A thesis submitted to the school of graduate studies of Addis Ababa university in partial fulfillment of the requirements for the degree of Master of Science in civil engineering''**

**Advisor:**

**Dr-ing Samuel Tadesse**

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# ADDIS ABABA UNIVERSITY

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**Approved by board of examiners**

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## List of symbols

AASHTO - American Association of state Highway and transportation officials

Ac –Activity number

ASTM -American standard of testing materials

CC-Clay content

Cc - Compression index

Cv –Coefficient of consolidation

CH –Inorganic clay with high plasticity

e –Void ratio

GI –Group index

Gs –Specific gravity

MH –Inorganic silt with high plasticity

NMC –Natural moisture content

Pc –Pre-consolidation pressure

Po –Over-burden pressure

PI –Plasticity index

TP –Test pit

UCS –Unconfined compressive strength

USCS –Unified soil classification system

UTM –Universal Transverse Mercator grid

Wl –Liquid limit

Wp – Plastic limit

## Abstract

Soil investigation program is necessary to provide information for design and construction and environmental assessment.

Ambo is located at a distance of 112kms from Addis Ababa. Ambo is serving as the main town of west shoa zone of Oromia region. In the town many constructions were under taken, but without detailed geotechnical investigation. Therefore, the objectives of this research is to investigate some of engineering properties of soils found in the town by conducting different types of laboratory tests and to prepare soil map of Ambo town using information and data collected from field observation, laboratory tests and secondary data. This research is useful in providing necessary data or information that can be used in designing civil engineering structures in Ambo town.

Inorder to meet the objectives of this research, 21 disturbed samples and 9 undisturbed samples were collected at different areas and brought to soil laboratory of Addis Ababa institute of Technology for conducting different tests such as: moisture content, specific gravity, Atterberg limits, grain size analysis, free swell, unconfined compressive strength and one dimensional consolidation tests.

Laboratory tests carried out on disturbed and undisturbed samples revealed that the natural moisture content ranges from 23.4-42.1%,specific gravity of the soils ranges from 2.51-2.78,Atterberg limits of soils of the study area has liquid limits ranging from 62-114%, plastic limit ranges from 30-47% and plasticity index ranges from 30-83%.The results of grain size analysis showed that soils of Ambo town have clay content ranging from 28-67.6%, silt content from 22.8-54.4%, sand from 1.1-13.2% and gravel from 0-15.3%.Free swell index of Ambo soils ranges from 35-155%.

Soils of the study area are classified according to AASHTO and USCS.AASHTO classification shows that soils of the study area are A-7-5, which means clay soil with poor quality as a subgrade material. USCS indicates two main types of soils, which are:

CH, high plastic clay soils and MH, high plastic silt soils. The results of unconfined compressive strength test shows that UCS of Ambo soils range from 112-545 $kN/m^2$.

Consolidation test results indicate that CH soil has preconsolidation pressure 225 kPa, swelling pressure 80kPa and over consolidation ratio 3.9. For MH soil, preconsolidation pressure 150kPa, swelling pressure 100kPa and over consolidation ratio 3.03 is obtained.

# 1. `    Introduction

## 1.1 Back ground of the problem

The stability of the foundation of a building, a bridge, an embankment or any other structure built on soil depends on the strength and compressibility characteristics of the subsoil. The field and laboratory investigation to obtain the essential information on the subsoil is called soil exploration or soil investigation [16].

The successes or failure of a foundation depends essentially on the reliability of the various soil parameters obtained from the field investigation and laboratory testing, and used as an input in to the design of a foundation [16].

Soil investigation program is necessary to provide information for design and construction and environmental assessment. The purposes of soil investigation are: to evaluate the general suitability of the site for the proposed project, to enable an adequate and economical design to be made and to disclose and make provisions for difficulties that may arise during construction due to ground and other local conditions [11].

Investigations of the underground conditions at a site are prerequisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies for a proposed project [3].

An exploration program may be initiated on an existing structure where additions are contemplated. The current safety of an existing structure may require investigation if excessive settlements or cracks have occurred. The required remedial measures may be undertaken based on new-found information or on the damage evidence and a reinterpretation of the original data [3].

The scope of soil investigation depends on the type, size and importance of the structure, the client, the engineer's familiarity with the soils at the site and local building codes. Structures that are sensitive to settlement such as machine foundation and high-rise buildings usually requires a thorough soil investigation compared to a foundation for a house [11].

Being located at a distance of 112kms from the capital city of Ethiopia (Addis Ababa), Ambo is serving as the main town of west shoa zone of Oromia region. In the town, many buildings are constructed and being under construction without adequate and detailed geotechnical investigation. The town has one governmental university (Ambo university main campus and Awaro campus), technical college, many commercial buildings and private colleges. However, the engineering properties of the soil are not well studied. Therefore, this research is intended to study engineering properties of Ambo soil by conducting index tests, shear strength test, consolidation test and to prepare soil map of the city.

## 1.2 Objectives of the study

Investigation on engineering properties of soils is important in providing information for safe and economical design of civil structures. Therefore, the objectives of this thesis are:

- To quantify and characterize the engineering properties of soils in Ambo by conducting laboratory tests on both disturbed and undisturbed soil samples.

- To prepare soil distribution map of the town based on laboratory test results, secondary data and field observation.

## 1.3 Methodology

To meet these research objectives, sampling areas were selected from different parts of the town and ten pits were excavated to a maximum depth of three meters (3m). From the excavated pits both disturbed and undisturbed samples were collected for laboratory testing. In the field GPS readings were taken to locate the coordinates of sampling area.

The following tests are done from the collected samples.

- Natural moisture content
- Specific gravity
- Atterberg's limit
  - Liquid limit
  - Plastic limit
- Grain size analysis
  - Sieve analysis
  - Hydrometer analysis
- Unconfined compressive strength
- One-dimensional consolidation

## 1.4 Scope of the study

The scope of this thesis is limited to investigation of index properties, unconfined compressive shear strength test and consolidation tests. To achieve this ten test pits were excavated to a maximum depth of three meters.

## 1.5 Organization of the thesis

This thesis is organized in to eight Chapters. In the first Chapter back ground of the problem, objectives of the research, methodology and scope of the thesis are presented. The second Chapter deals with literature review. The third Chapter deals with description of the study area and soil map of the area of this research thesis conducted. Types of laboratory tests conducted and their results are presented in the fourth Chapter. The fifth Chapter deals with soil classification. The sixth Chapter deals with shear strength and consolidation tests of representative samples. The seventh Chapter is discussion of the results obtained. Finally, recommendation and conclusion are given in Chapter eight.

# 2. Literature review

## 2.1 Soil formation

Soil is defined as a natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water. By contrast rock is considered to be a natural aggregate of mineral grains connected by strong and permanent cohesive force. The process of weathering of rock decreases the cohesive force binding the mineral grains and leads to the disintegration of bigger masses to smaller and smaller particles. Soils are formed by the process of weathering of the parent rock [15].

Soils are formed from the physical and chemical weathering of rocks. Physical weathering involves reduction of size without any change in the original composition of the parent rock. The main agent responsible for this processes are exfoliation, unloading, erosion, freezing and thawing. Chemical weathering causes both reduction in size and chemical alteration of the original parent rock. The main agents responsible for chemical weathering are hydration, carbonation and oxidation. Often chemical and physical weathering takes place in concert [11].

Chemical weathering is much more important than physical weathering in soil formation. Soils at a particular site can be residual (that is weathered in place) or transported (moved by water, wind, glacier, etc.) and the geologic history of a particular deposit significantly affects its engineering behavior [7].

Chemical decomposition of rocks results in the formation of clay minerals. These clay minerals impart plastic properties to soils. Clayey soils are formed by chemical decomposition [8].

Natural soils generally are mixtures of several different particle sizes and may even contain organic matter. Some soils such as peat may be almost entirely organic.

Furthermore because soils are a particulate material they have voids and the voids are usually filled with water and air [7].

## 2.2 Types of soils

According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75 to 76.2 mm are called gravel. If the grains are visible to the naked eye, but less than about 4.75mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eye is about 0.075mm. Soil grains ranging from 0.075 to 0.002mm are termed as silt and those that are finer than 0.002mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials [16].

On the basis of origin of their constituents, soils can be divided in to two large groups: residual and transported soils. Residual soils are those that remain at the place of their formation as a result of the weathering of parent rock. Transported soils are that are found at location far from their place of formation.

Transported soils are mixed with soils of different origin in the course of transportation. They also disintegrate and alter still further. With the decreasing velocity of water, or wind transporting them coarser particles are deposited first followed by fine particles. Thus transported soils are sorted out according to grain sizes [14].

Soils of organic origin are formed chiefly insitu, either by the growth and subsequent decay of plants such as peat mosses or by the accumulation of fragments of the inorganic skeletons or shells of organism. Hence a soil of organic origin can be either organic or inorganic. The term organic soil ordinarily refers to a transported soils consisting of the products of rock weathering with a more or less conspicuous admixture of decayed vegetable matter [15].

## 2.3 Soil structure

The structure of soil may be defined as the manner of arrangement and state of aggregation of soil grains. In a broader sense, consideration of mineralogical composition, electrical properties, orientation and shape of soil grains, also may be included in the study of soil structure, which is typical for transported or sediments soils. Structural composition of sedimented soils influences many of their important engineering properties such as permeability, compressibility and shear strength [5].

### 2.3.1 Single grained structure

Single grained structure is characteristics of coarse grained soils, with a particle greater than 0.02mm.Gravitational force pre dominate the surface force and hence grain to grain contact results. The deposition may occur in a loose state with large voids or in a dense state with less of voids [5].

### 2.3.2 Honey-comp structure

This structure can occur only in fine-grained soils especially in silt and rock flour. Due to the relatively smaller size of grains, besides gravitational forces, inter-particle surface force also play an important role in the process of settling down. Miniature arches are formed which bridge over relatively large void spaces. This results in the formation of a honey comp structure each cell of a honey comp being made up of numerous individual soil grains. The structure has a large void space and may carry high loads without a significant volume change. The structure can be broken down by external disturbances [5].

### 2.3.3 Flocculent structure

This structure is characteristics of fine grained soils such as clays. Inter particle forces play a predominant role in the deposition. Mutual repulsion of the particles may be eliminated by means of an appropriate chemical; this will result in grains coming closer together to form 'a floc'. The formation of floc is flocculation [5].

## 2.4 Clay Minerals

Minerals are crystalline materials and make up the solids constituent of a soil. The mineral particles of fine grained soils are platy. Minerals are classified according to chemical composition and structure. Most minerals of interest to geotechnical engineers are composed of oxygen and silicon-two of the most abundant elements on earth. Silicates are a group of minerals with a structural unit called the silica tetrahedron. Silicate minerals are formed by addition of cation and interactions of tetrahedrons. Silica tetrahedrons combine to form sheets, called silicate sheets, which are thin layers of silica tetrahedrons in which three oxygen ions are shared between adjacent tetrahedrons. Silicate sheets may contain other structural units such as alumina sheets. Alumina sheets are formed by combination of alumina minerals, which consists of an aluminum ion surrounded by six oxygen or hydroxyl atoms in an octahedron [11].

The main groups of crystalline materials that make up clays are the minerals: Kaolinite, illite, and montmorillonite.

### 2.4.1 Kaolinite

Kaolinite has a structure that consists of one silica sheet and one alumina sheet bonded together into a layer about 0.72nm thick and stacked repeatedly. The layers are held together by hydrogen bonds [11].

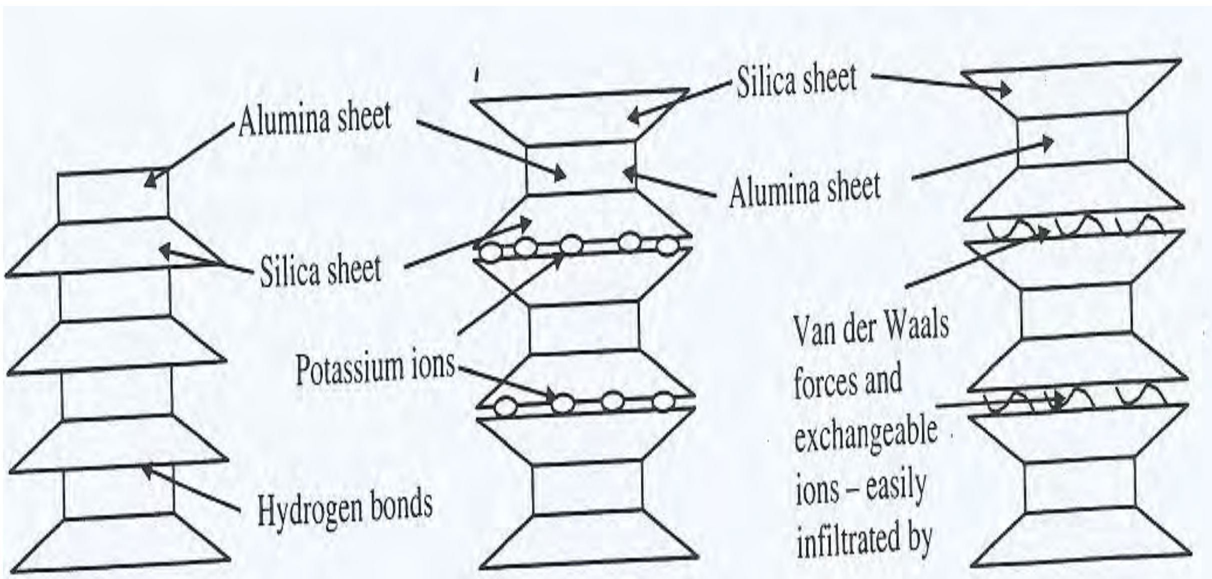
The structural units join together by hydrogen bond, which develops between the oxygen of silica sheet and hydroxyls of alumina sheet. As the bond is fairly strong, the mineral is stable. Moreover, water cannot easily enter between the structural units and cause expansion [13].

### 2.4.2 Illite

Illite consists of repeated layers of one alumina sheet sandwiched by two silicate sheets. The layers, each of thickness 0.96nm, are held together by potassium ions. Illite swells less than montmorillonite. However, swelling is more than in kaolinite [13].

### 2.4.3 Montmorillonite

Montmorillonite has a structure similar to illite, but the layers are held together by weak van der Waals forces and exchangeable ions. Water can easily enter the bond and separate the layers in montmorillonite, causing swelling. Montmorillonite is often called swelling or expansive clay [11].




A) Kaolinite B) Illite C) Montmorillonite

Fig 2.1 Structure of kaolinite, illite and montmorillonite [10]

### 2.5 Soil texture

Common descriptive terms such as gravels, sands, silts and clays are used to identify specific texture in soils. Texture refers to the appearance or feel of a soil. Sands and gravels are grouped together as coarse grained soil. Clays and silts are fine grained soils. Coarse grained soils feel gritty and hard. Fine grained soils feel smooth [11].

## 3. Description of the study area

### 3.1 General

Ambo is one of the 180 woredas in the Oromia region of Ethiopia. Part of the west shoa zone, Ambo is located 112kms west of the capital Addis Ababa, on the road to Nekemte. The town has an estimated total population of 260,193 of whom 131,922 are men and 128,271 are women [18].

Ambo is popular for its immense natural gifts including excellent climate which provides comfortable living and working invironment.The town has also got refreshing recreation centers, like Ambo Abebech hotel with its resort at wonchi lake some 25kms from the town, Ambo Ethiopia hotel with its swimming pool and hot springs as well as Jibat hotel with its Guder water falls [18].

Ambo is known for its mineral water, which is bottled outside of the town; it is reportedly the most popular brand in Ethiopia. Ambo is also the location of a research station of the Ethiopian institution of Agricultural research; initiated in 1977, this station hosts research in protecting major crops in Ethiopia [17].


Picture 3.1 Map of west shoa zone of Oromia region [17]

### 3.2 Climate

#### 3.2.1 Rain fall

Records of National Metrological Agency from Ambo observatory substation show that the mean annual rain fall of 60 years (1954-2014) is 1007.3mm. As it can be observed from Figure 3.1, major rainfall seasons are June, July and August [19]. All data are presented in Appendix-B.

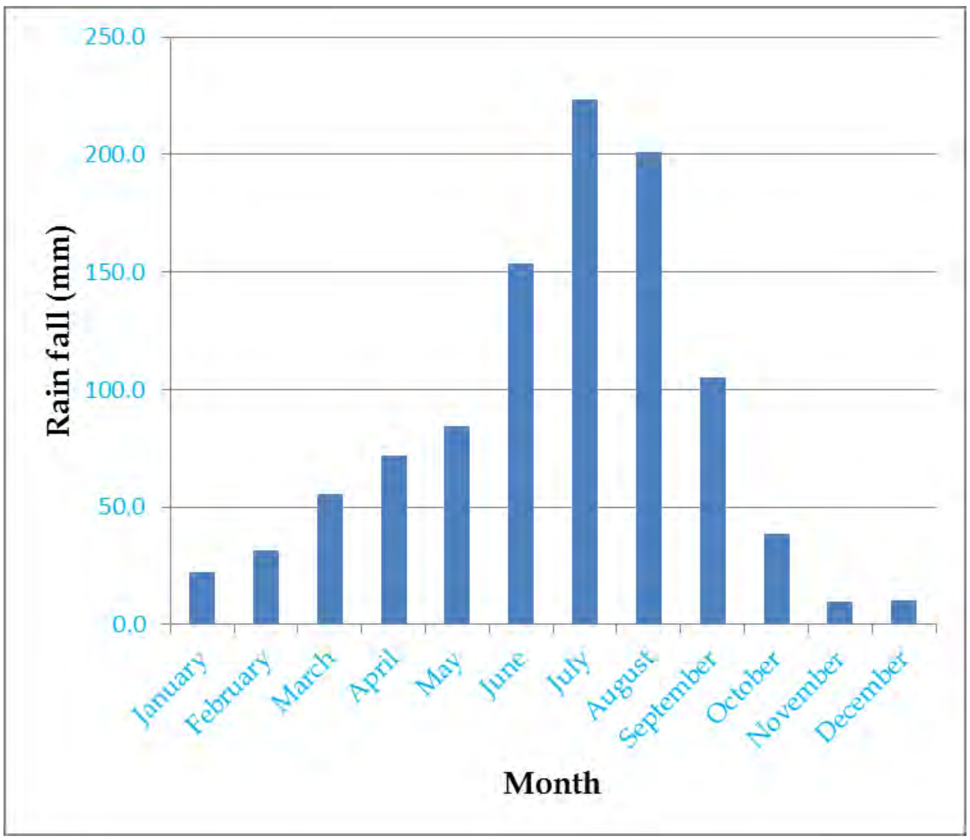



Fig 3.1 Mean monthly rainfall distribution of Ambo town (1954-2014) [19]

### 3.2.2 Temperature

Records of National Metrological Agency from Ambo observatory substation show that the mean minimum, mean maximum and mean average monthly temperature of 60 years (1954-2014) are 9.96°c, 19.82°c and 14.89°c respectively. As one can observe from Figure 3.2, the highest temperature was recorded during the month of February (i.e. 23.5°) and the minimum is during November (i.e. 9.1°c) [19].All data are presented in Appendix-B.

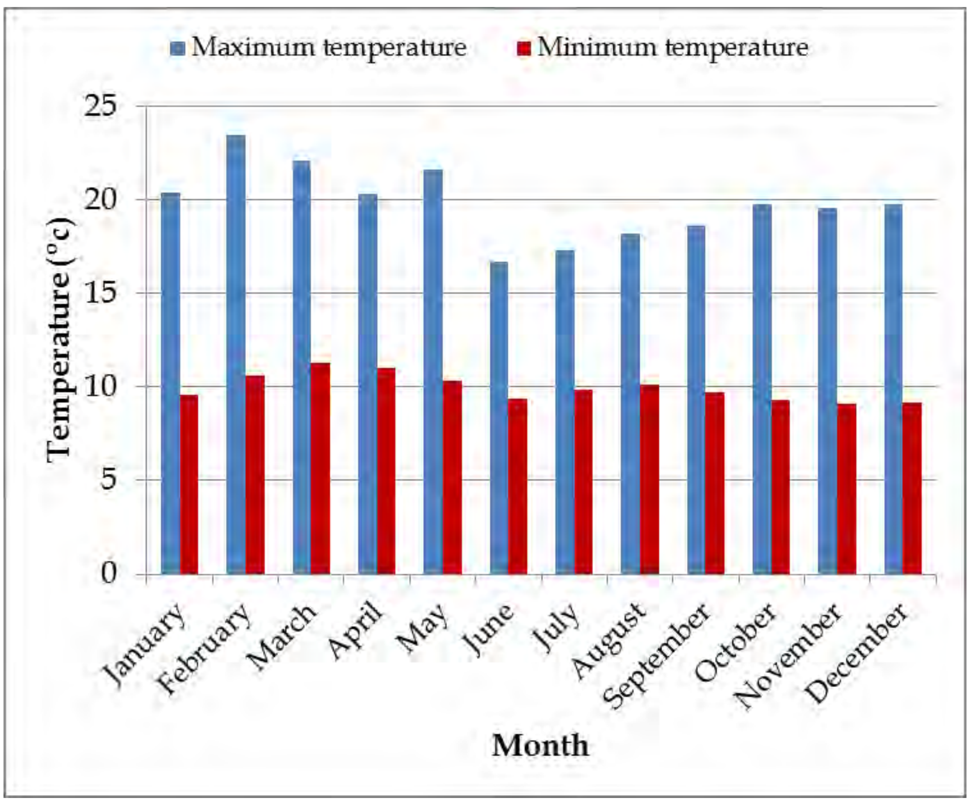



Fig 3.2 Mean maximum and minimum temperature distribution of Ambo town (1954-2014) [19]

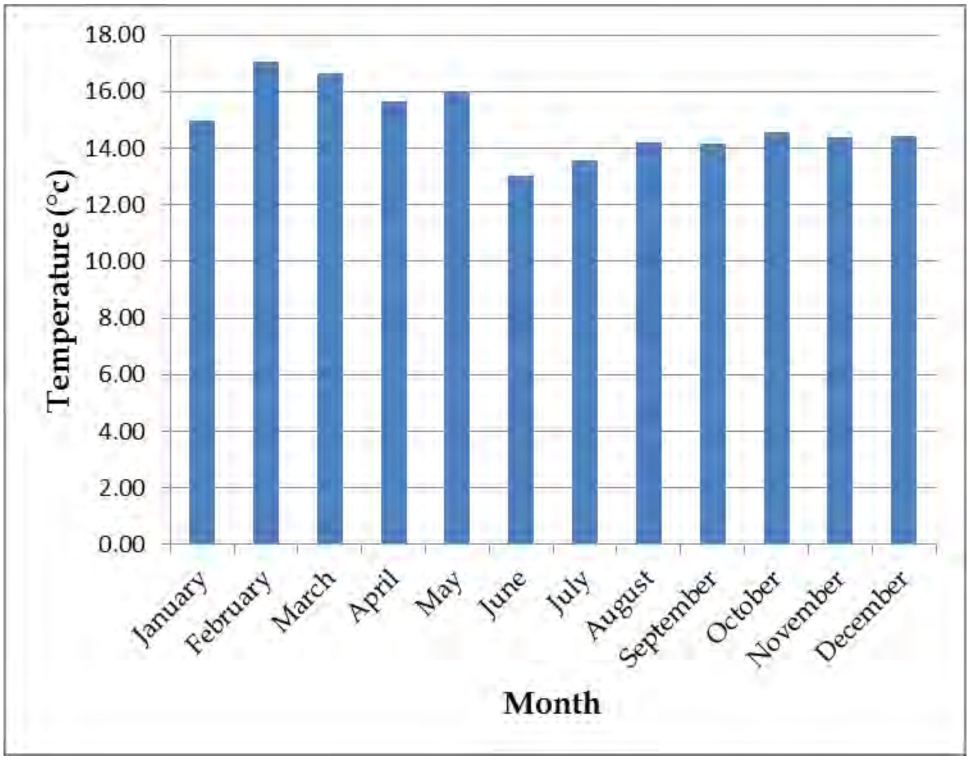



Fig 3.3 Mean monthly temperature distribution of Ambo town (1954-2014) [19]

The setting for the formation of montmorillonite is extreme disintegration, strong hydration and restricted leaching. Expansive soils are found in areas with poor internal drainage and low to moderate rainfall [10].

The climatic condition of Ambo town is favorable for the formation of black and gray color expansive soils. The black and gray color expansive soils of Ambo town are located on flatter slope which have poor internal drainage. Flatter slope and poor internal drainage of the town favor the formation of montmorillonite.

# 4 Laboratory tests

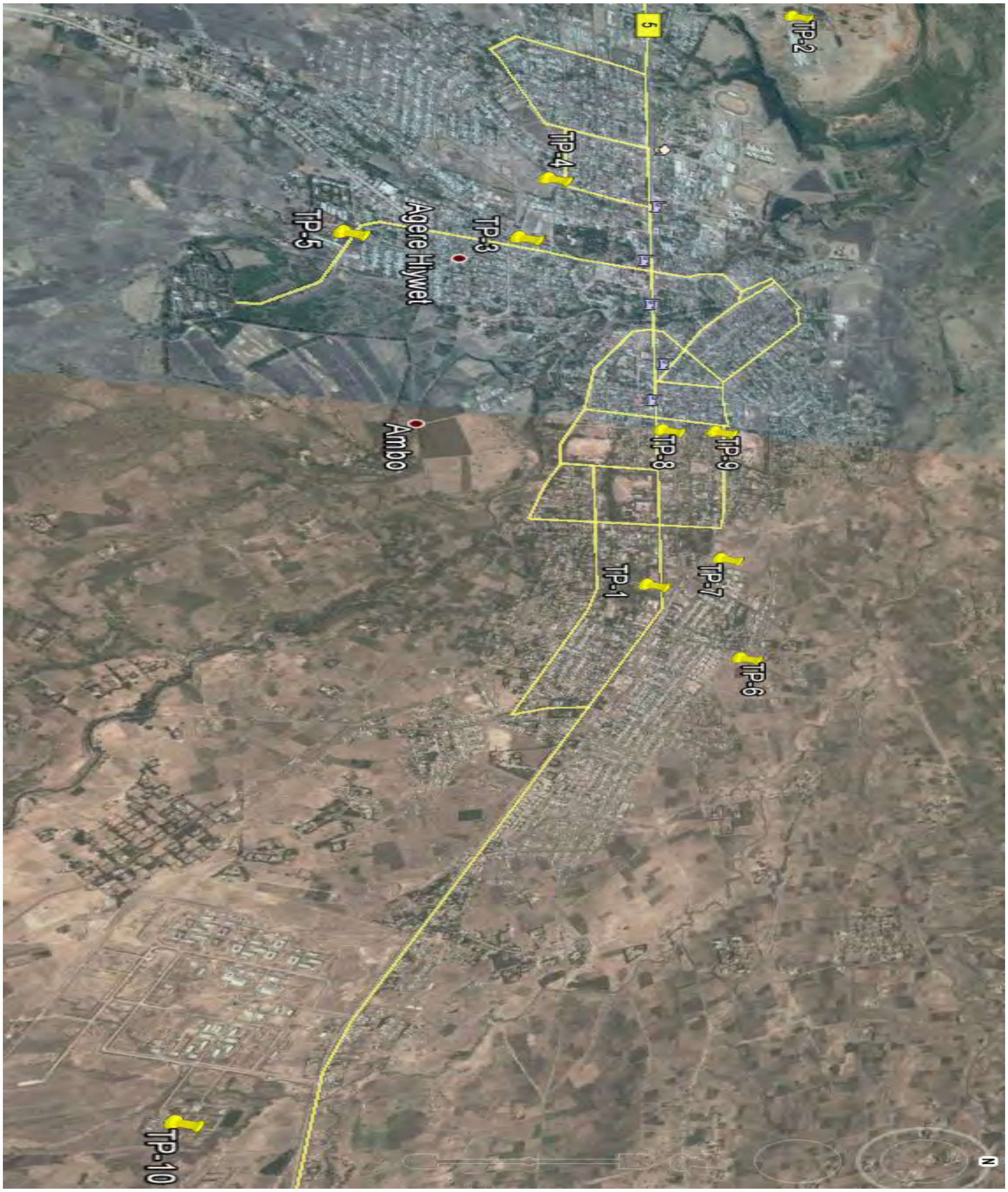
## 4.1 General

After visual investigation of different parts of the town, ten (10) pits were excavated to a maximum depth of three meters (3m).Disturbed and undisturbed samples were collected and brought to the geotechnical laboratory for conducting different types of soil tests. During pits excavation, the coordinates of sampling location were taken using hand held GPS and presented in the Table 4.1

Table 4.1 coordinates of sampling areas

| Sample description | Location | GPS Data (UTM) | | |
|---|---|---|---|---|
| | | Easting | Northing | Elevation(m) |
| TP-1 | Awura Godana | 0375750 | 0992890 | 2140 |
| TP-2 | Ambo Hospital #2 | 0371902 | 0993733 | 2081 |
| TP-3 | Kes Amba | 0373732 | 0992359 | 2106 |
| TP-4 | Kidane Mihret | 0373351 | 0992489 | 2117 |
| TP-5 | Catholic church | 0373872 | 0991665 | 2133 |
| TP-6 | Kisose | 0376221 | 0993351 | 2152 |
| TP-7 | Bole | 0375580 | 0993272 | 2135 |
| TP-8 | Stadium | 0374783 | 0992998 | 2128 |
| TP-9 | Cheri | 0374765 | 0993261 | 2119 |
| Tp-10 | Awaro | 0378409 | 0991058 | 2108 |

Ambo municipality office is refused to give structural map of the town and as a result of this test pits are located on the map taken from Google earth.




Picture 4.1 Location of test pits of the study area (Google earth)

## 4.2 Index tests

### 4.2.1 General

Soils are classified and identified based on index properties. The main index properties of coarse grained soils are particle size and relative density. For fine grained soils, the main index properties are Atterberg limits and consistency [8].

Index properties are bases for distinguishing soils. Index properties may be divided in to two main categories namely, soil grain properties and soil aggregate properties. Soil grain properties are the properties of the individual grain as expressed by size, shape and mineralogical characteristics. Soil aggregate properties are the properties of the soil mass as a whole. Soil mass is commonly considered to consist of solids and voids. The void spaces, often called pores or pore spaces may be partially or wholly filled with water or air [14].

### 4.2.2 Natural Moisture content

Moisture content of soils refers to the total amount of water contained in a soil either as free water or capillary water. It is always expressed as a percentage of the weight of solids in the soil [14].The water content of the soil is an important property. The characteristics of a soil, especially a fine-grained soil, change to a marked degree with a variation of its water content [4].

The natural moisture contents of the soil under investigation were determined following ASTM D2216-98.

Natural moisture content of soils of the study area ranges from 23.4-42.1%

Analysis of the test results are presented in Appendix-C.

Table 4.2: Natural moisture content of soil samples

| Location | Test pits | Depth(m) | NMC (%) |
|---|---|---|---|
| Awura Godana | TP-1 | 1.5 | 30.7 |
| | | 3 | 32.5 |
| Ambo Hospital#2 | TP-2 | 1.5 | 23.4 |
| | | 3 | 28.4 |
| Kes Amba | TP-3 | 1.5 | 33 |
| | | 3 | 39.6 |
| Kidane Mihiret | TP-4 | 1.5 | 41 |
| | | 3 | 41 |
| Catholic Church | TP-5 | 1.5 | 30.2 |
| | | 3 | 35.1 |
| Kisose | TP-6 | 1.5 | 37.4 |
| | | 3 | 38 |
| Bole | TP-7 | 0.8 | 30.3 |
| | | 1.5 | 31.1 |
| | | 2.5 | 31.2 |
| Stadium | TP-8 | 1.5 | 32 |
| | | 3 | 35.1 |
| Cheri | TP-9 | 1.5 | 37.8 |
| | | 3 | 40.7 |
| Awaro | TP-10 | 1.5 | 40.7 |
| | | 3 | 42.1 |

### 4.2.3 Specific gravity

Specific gravity of solid matter in a soil particle may be defined as the ratio of unit weight of solid matter to the unit weight of water. The specific gravity of solid particles without void space is called the true or absolute or real specific gravity and is usually denoted by a letter Gs [14].

The specific gravity of soil solids is useful in determination of void ratio, degree of saturation, etc., besides 'the critical hydraulic gradient' and 'zero air voids' in compaction. It is useful in computing the unit weight of soil under different conditions and also in determination of particle size by wet analysis [5].

In this research, specific gravities of soils of the study area are conducted following ASTM D854-98 [2].

The specific gravity determination of a sample of soil is made by displacement in water using pycnometer (volumetric bottle).The specific gravity we get by this method is the absolute specific gravity. In this test a known weight of oven-dried soil sample is carefully put in a pycnometer which is then half filled with distilled water. The air entrapped in the soil sample is removed by heating or by means of vacuum pump. The bottle is then topped up with distilled water up to a calibration mark and brought up to a constant temperature.

$$\mathbf{Gs = \frac{Ws * G_T}{W_s + W_2 - W_1}} \qquad (4.1)$$

Where:

Ws=Weight of dry soil

$G_T$=Specific gravity of water at temperature T

$W_1$=Weight of pycnometer bottle+water+soil

$W_2$=Weight of pycnometer bottle +water

The specific gravity of Ambo soils is ranging from 2.51-2.78 and summarized in Table 4.3. Analysis of the test results are presented in Appendix-C.

Table 4.3 Specific gravity of soils of the study area

| Location | Test pit | Depth | Gs |
|---|---|---|---|
| Awura Godana | TP-1 | 1.5 | 2.76 |
| | | 3 | 2.75 |
| Ambo Hospital#2 | TP-2 | 1.5 | 2.71 |
| | | 3 | 2.72 |
| Kes Amba | TP-3 | 1.5 | 2.68 |
| | | 3 | 2.69 |
| Kidane Mihret | TP-4 | 1.5 | 2.78 |
| | | 3 | 2.75 |
| Catholic church | TP-5 | 1.5 | 2.51 |
| | | 3 | 2.66 |
| Kisose | TP-6 | 1.5 | 2.78 |
| | | 3 | 2.73 |
| Bole | TP-7 | 0.8 | 2.77 |
| | | 1.5 | 2.69 |
| | | 2.5 | 2.67 |
| Stadium | TP-8 | 1.5 | 2.74 |
| | | 3 | 2.75 |
| Cheri | TP-9 | 1.5 | 2.72 |
| | | 3 | 2.74 |
| Awaro | TP-10 | 1.5 | 2.69 |
| | | 3 | 2.70 |

### 4.2.4 Atterberg's limit

#### 4.2.4.1General

When clay minerals are present in fine grained soil, the soil can be remolded in the presence of some moisture without crumbling. This cohesive nature is caused by the adsorbed water surrounding the clay particles. In the early 1900's, a Swedish scientist named Atterberg developed a method to describe the consistency of fine grained soils with varying moisture content. At very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid. Hence, on arbitrary basis, depending on the moisture content, the behavior of soil can be divided in to four basic state-solid, semi-solid, plastic and liquid states [4].

The moisture content, in percent, at which the transition from solid to semi- solid state takes place, is defined as the shrinkage limit. The moisture content at the point of transition from semi-solid to plastic state is the plastic limit, and from plastic state to liquid state is the liquid limit. These parameters are also known as Atterberg limits [4].

#### 4.2.4.2 Liquid limit and Plastic limit

The liquid limit is the moisture content at which the soil is changed from liquid state to plastic state. At the liquid limit the clay is practically like a liquid but possesses a small shearing strength. The shearing strength at that stage is the smallest value that can be measured in the laboratory.

Plastic limit is the water content below which the soil stops behaving as a plastic material. It begins to crumble when rolled in to a tread of soils of 3mm diameter. At this water content, the soil loses its plasticity and passes to a semi-solid state [8].

The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil [2].

Both liquid and plastic limit tests are conducted according to ASTM D 4318-98 procedures. The air dried portion of the sample passing the No. 40 (0.425mm) sieves were used for preparation of samples for both liquid and plastic limit tests.

Liquid limit test on oven dried samples is done only for 4 samples (for samples fall below A-line). The results obtained were used to compare with the results obtained from air dried samples, which will intern be used to classify the soil as organic and inorganic. The oven dried samples were prepared by putting the samples in an oven for 24hrs at a temperature of 110°c ± 5°c.

Atterberg limits of Ambo soils are summarized in Table 4.4 and results of liquid limits conducted on oven dried samples are summarized in Table 4.5.Liquid limit of Ambo soil ranges from 62-114%, plastic limit ranges from 30-47% and plasticity index ranges from 30-83%.

The test results show that soils of the study area are highly plastic with high plasticity index values. The black and gray soils samples have higher liquid limit than brown or reddish brown soil samples. This indicates that the predominant mineral for samples which have higher liquid limit is montmorillonite. The reason is that the bond between the layers in montmorillonite is weak and large amounts of water can easily infiltrate the spaces between the layers [11].

Analysis of the test results are presented in Appendix-C.

Table 4.4 Atterberg limits of soils of the study area

| Location | Test pit | Depth | Liquid limit (%) | Plastic limit (%) | PI (%) |
|---|---|---|---|---|---|
| Awura Godana | TP-1 | 1.5 | 114 | 31 | 83 |
| | | 3 | 109 | 35 | 73 |
| Ambo Hospital #2 | TP-2 | 1.5 | 76 | 34 | 42 |
| | | 3 | 78 | 33 | 45 |
| Kes Amba | TP-3 | 1.5 | 99 | 32 | 67 |
| | | 3 | 93 | 38 | 55 |
| Kidane Mihret | TP-4 | 1.5 | 112 | 34 | 78 |
| | | 3 | 107 | 47 | 60 |
| Catholic Church | TP-5 | 1.5 | 112 | 37 | 75 |
| | | 3 | 113 | 47 | 66 |
| Kisose | TP-6 | 1.5 | 110 | 32 | 78 |
| | | 3 | 109 | 34 | 75 |
| Bole | TP-7 | 0.8 | 107 | 32 | 75 |
| | | 1.5 | 73 | 42 | 31 |
| | | 2.5 | 64 | 34 | 30 |
| stadium | TP-8 | 1.5 | 99 | 40 | 59 |
| | | 3 | 62 | 30 | 32 |
| Cheri | TP-9 | 1.5 | 101 | 33 | 68 |
| | | 3 | 114 | 40 | 74 |
| Awaro | TP-10 | 1.5 | 110 | 34 | 76 |
| | | 3 | 105 | 33 | 72 |

Table 4.5 Liquid limits of oven dried samples

| Location | Depth (m) | Liquid limit (Wl) |
|---|---|---|
| Bole | 1.5 | 57 |
| | 2.5 | 52 |
| Catholic Church | 3 | 90 |
| Kidane Mihret | 3 | 86 |

Table 4.6 Comparison of liquid limits on air dried and oven dried samples of the study area

| Location | Depth (M) | Liquid limit (Wl) | | % decrease by oven-drying |
|---|---|---|---|---|
| | | Air dried | Oven dried | |
| Bole | 1.5 | 73 | 57 | 16 |
| | 2.5 | 64 | 52 | 12 |
| Catholic Church | 3 | 113 | 90 | 23 |
| Kidane Mihret | 3 | 107 | 86 | 21 |

Organic soil can be defined by using a comparison of the air-drying and oven-drying liquid limit. If the oven-drying decreases the liquid limit by 30% or more, the soil is classified as organic [8].

From comparison (Table 4.6), one can observe that soils of the study area are inorganic soils.

### 4.2.5 Grain size analysis

Particle size analysis is a method of separation of soils in to different fractions based on particle size. It expresses quantitatively the proportions, by mass, of various sizes of particles present in a soil. It is shown graphically on a particle size distribution curve [8].

There are two methods commonly used for the determination of grain size distribution of soil, namely sieve analysis and hydrometer analysis. Sieve analysis is used for the determination of grain size distribution of coarse grained soil (gravel and sand), while hydrometer is used for the determination of grain size of fine grained soils (clay and silt) or soils passing through sieve No 200. For grain size analysis wet sieve method is used after air drying the sample.

Test was conducted by following ASTM D 422-63 procedures [2]. Samples collected from the Sites were air dried and representative samples were selected by quartering. After measuring the weight of representative samples, the samples were washed on sieve No 200.The portion of soils retained on sieve No. 200 were oven dried and mechanical sieves were conducted.

The results of the tests are presented in Table 4.7 and analysis of the test results are presented in Appendix-C.

**Table 4.7 Grain size distribution of soils of the study area**

| Location | Depth | Gravel (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|
| Awura Godana | 1.5 | 0 | 3.1 | 32.14 | 64.76 |
| | 3 | 0 | 4.3 | 33.45 | 62.25 |
| Ambo Hospital#2 | 1.5 | 0 | 3.1 | 29.3 | 67.6 |
| | 3 | 0 | 4.7 | 42.53 | 52.77 |
| Kes Amba | 1.5 | 0 | 3.7 | 43.17 | 53.13 |
| | 3 | 0 | 4.4 | 37.79 | 57.81 |
| Kidane Mihret | 1.5 | 0 | 1.9 | 36.8 | 61.3 |
| | 3 | 0 | 1.1 | 36.12 | 62.78 |
| Catholic Church | 1.5 | 15.3 | 2.6 | 23.3 | 58.8 |
| | 3 | 8.4 | 1.9 | 31.7 | 58 |
| Kisose | 1.5 | 14.5 | 2.8 | 22.77 | 59.93 |
| | 3 | 2.7 | 2 | 35.7 | 59.6 |
| Bole | 0.8 | 9.1 | 3.6 | 27.79 | 59.51 |
| | 1.5 | 4.1 | 11.1 | 54.39 | 30.41 |
| | 2.5 | 5 | 13.2 | 53.81 | 27.99 |
| Stadium | 1.5 | 3.8 | 1.2 | 43.14 | 51.86 |
| | 3 | 3.8 | 12 | 35.76 | 48.44 |
| Cheri | 1.5 | 4 | 3.4 | 39.9 | 52.7 |
| | 3 | 12 | 2.6 | 27.01 | 58.39 |
| Awaro | 1.5 | 0 | 2.7 | 38.3 | 59 |
| | 3 | 0 | 6.3 | 36.7 | 57 |

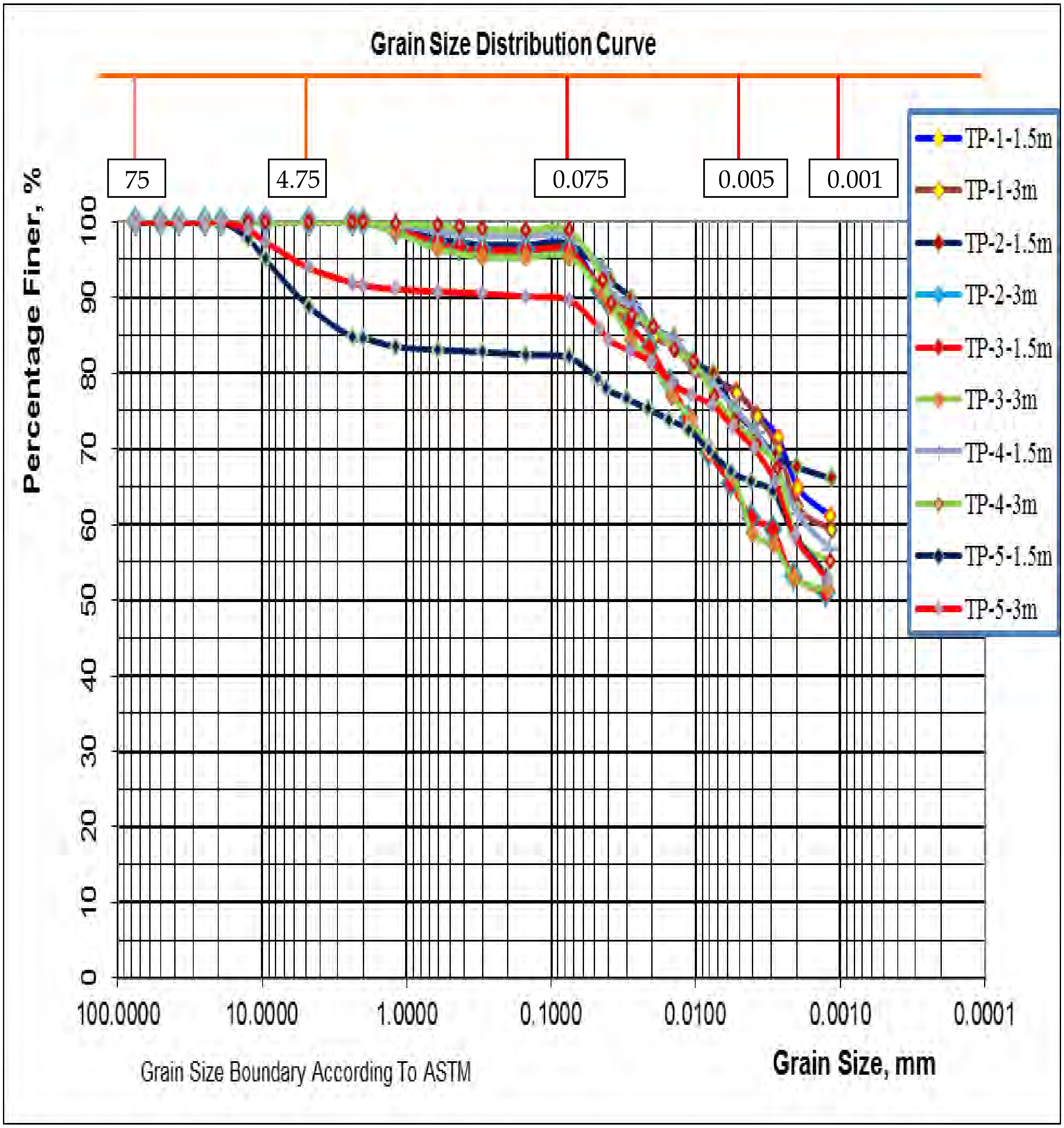



Fig 4.1 Grain size distribution curve of samples from test pit 1 to 5

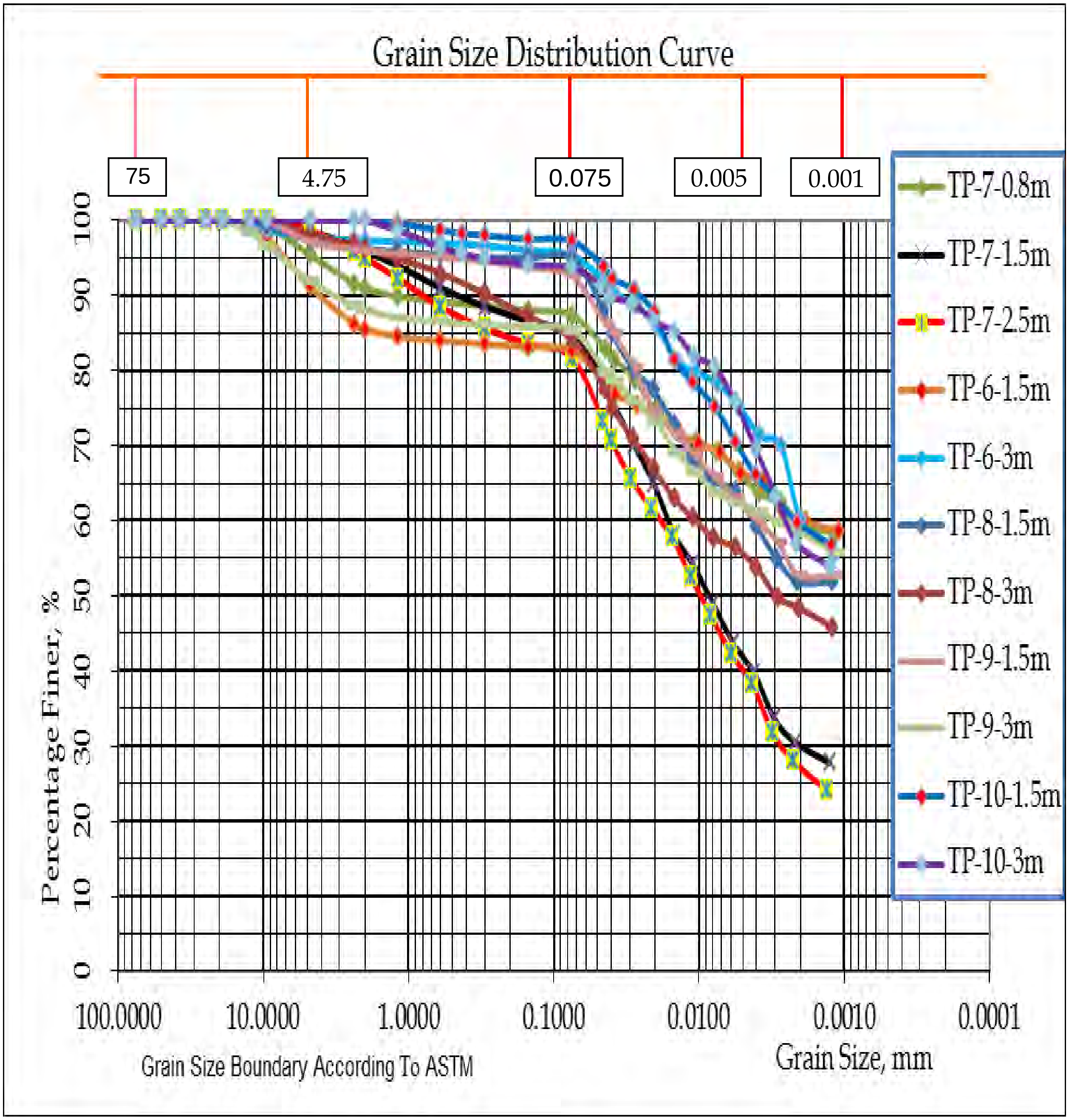



Fig 4.2 Grain size distribution curve of samples from test pit 6 to 10

### 4.2.6 Free swell

The free swell test consists of placing a known volume of dry soil passing the No.40 sieve in to a graduated cylinder filled with water and measuring the swelled volume after it has completely settled. The free swell of the soil is determined as the ratio of the change in volume to the initial volume, expressed as a percentage.

This test tries to give a fair approximation of the degree of expansiveness of a give soil sample.

$$\text{Free swell} = \frac{\text{Final volume} - \text{Initial volume}}{\text{Initial volume}} * 100\% \qquad (4.2)$$

Free swell <50%, Not expansive

Free swell between 50-100%, Marginal

Free swell >100%, expansive

Free swell of the study area is ranging from non-expansive soil to expansive soil. The black and gray soils have high degree of expansiveness than brown and reddish brown soils. The free swell values range from 35-155% and summarized in Table 4.8. Analysis of the test results are presented in Appendix-C.

**Table 4.8 Free swell of soils of the study area**

| Location | Depth | Color | Free swell (%) |
|---|---|---|---|
| Awra Godana | 1.5 | Black | 115 |
| | 3 | Black | 110 |
| Ambo Hospital#2 | 1.5 | Reddish brown | 60 |
| | 3 | brown | 75 |
| Kes Amba | 1.5 | Black | 125 |
| | 3 | Gray | 90 |
| Kidane Mihret | 1.5 | Gray | 120 |
| | 3 | Yellowish gray | 85 |
| Catholic Church | 1.5 | Black | 135 |
| | 3 | Gray | 95 |
| Kisose | 1.5 | Black | 155 |
| | 3 | Gray | 115 |
| Bole | 0.8 | Black | 120 |
| | 1.5 | Yellowish brown | 50 |
| | 2.5 | Yellowish brown | 35 |
| Stadium | 1.5 | Gray | 95 |
| | 3 | Reddish brown | 45 |
| Cheri | 1.5 | Black | 105 |
| | 3 | Gray | 100 |
| Awaro | 1.5 | Black | 115 |
| | 3 | Black | 105 |

# 5. Soil classifications

## 5.1 General

Soil classification system is an arrangement of different soils in to groups having similar properties. The purpose of soil classification is to make possible the estimation of soil properties by association with soils of the same class whose properties are known and to provide the engineer with accurate method of soil description [14].

Classification of soils provides a common language to express briefly the general characteristics of soils.

Today only the unified soil classification system (USCS) and the American association of state highway and transportation officials (AASHTO) systems are commonly used in civil engineering practice [7].

For this research work the methods used to classify soils of the study area are AASHTO and USCS.

## 5.2 AASHTO classification system

The AASHTO classification system, also called public roads administration (PRA) classification, is based on grain size distribution, liquid limit and plasticity index. This system is generally used by highway engineers for classification of sub-grade soils for the highway pavement.

According to this system, soil is classified in to seven major groups, A-1 through A-7.Group A-1, A-2, A-3 are granular materials with 35% or less passing through a No.200 sieve. Soils with more than 35% passing through a No.200 sieve are classified under groups A-4, A-5, A-6 and A-7.These soils are mostly silt and clay type material [13].

To classify a soil using AASHTO soil classification table one must proceed from left to right with required test data available. By the process of elimination, the first group from the left in to which the test data will fit gives the correct classification.

Under this classification system, a characteristic called group index (G.I) is used to describe the performance of a soil when used as a highway subgrade material [8].

$$GI = (F-35)\,[0.2+0.005(Wl-40)] + 0.01(F-15)\,(Ip-10) \quad (4.3)$$

Where F=percentage by mass passing American sieve no 200(size 0.075mm), expressed as a whole number

$W_L$=liquid limit (%), expressed as a whole number

Ip=plasticity index (%), expressed as a whole number

While calculating GI from the above equation, if any term in parenthesis becomes negative, it is dropped, and not given a negative value. The maximum values of (F-35) and (F-15) are taken as 40 and that of (Wl-40) and (Ip-10) as 20 [8].

Soils of the study area are classified after conducting index tests such as liquid limit, plastic limit and grain size analysis. Since the percentage of particles passing No 200 sieve for all soil sample is greater than 35%, soils of the study area are fine grained soil.

Table 5.1 AASHTO classification for soils of the study area

| Location | Depth | Wl (%) | Pl (%) | GI | Classification |
|---|---|---|---|---|---|
| Awura Godana | 1.5 | 114 | 83 | 20 (max) | A-7-5(20) |
| | 3 | 109 | 73 | 20 (max) | A-7-5(20) |
| Ambo Hospital | 1.5 | 76 | 42 | 20 (max) | A-7-5(20) |
| | 3 | 78 | 45 | 20 (max) | A-7-5(20) |
| Kes Amba | 1.5 | 99 | 67 | 20 (max) | A-7-5(20) |
| | 3 | 93 | 55 | 20 (max) | A-7-5(20) |
| Kidane Mihret | 1.5 | 112 | 78 | 20 (max) | A-7-5(20) |
| | 3 | 107 | 60 | 20 (max) | A-7-5(20) |
| Catholic church | 1.5 | 112 | 75 | 20 (max) | A-7-5(20) |
| | 3 | 113 | 66 | 20 (max) | A-7-5(20) |
| Kisose | 1.5 | 110 | 78 | 20 (max) | A-7-5(20) |
| | 3 | 109 | 75 | 20 (max) | A-7-5(20) |
| Bole | 0.8 | 107 | 75 | 20 (max) | A-7-5(20) |
| | 1.5 | 73 | 31 | 20 (max) | A-7-5(20) |
| | 2.5 | 64 | 30 | 20 (max) | A-7-5(20) |
| Stadium | 1.5 | 99 | 59 | 20 (max) | A-7-5(20) |
| | 3 | 62 | 32 | 20 (max) | A-7-5(20) |
| Cheri | 1.5 | 101 | 68 | 20 (max) | A-7-5(20) |
| | 3 | 114 | 74 | 20 (max) | A-7-5(20) |
| Awaro | 1.5 | 110 | 76 | 20 (max) | A-7-5(20) |
| | 3 | 105 | 72 | 20 (max) | A-7-5(20) |

Based on the above results (Table 5.1), soils of Ambo town are classified as clay soil (A-7-5) with higher GI values. Thus, they are not suitable for using as a subgrade material.

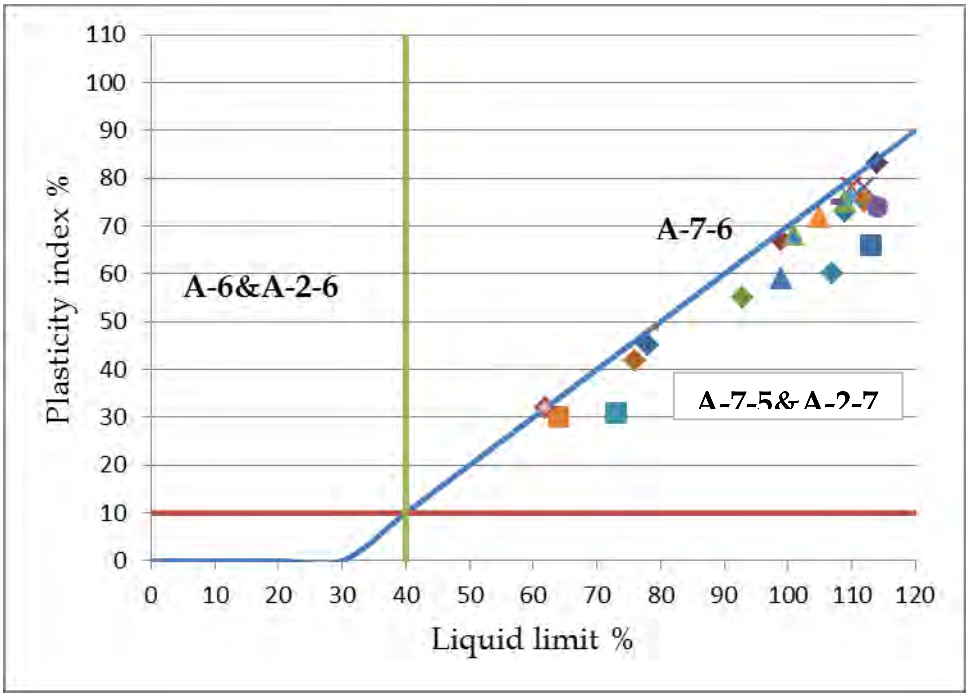



Fig 5.1 Plasticity chart of soils of the study area according to AASHTO classification

## 5.3 Unified soil classification system

This system was originally developed by professor A.Casagrande (1948) for use in airfield construction during world war II.It was modified in 1952 by professor casagrande, the U.S bureau of reclamation and the U.S. army corps of engineers to make the system also applicable to dams, foundations and other constructions. The bases for the USCS is that coarse grained soils can be classified according to their grain size distribution, whereas the engineering behavior of fine grained soil is primarily related to their plasticity. Only sieve and Atterberg limits are necessary to completely classify a soil in this system [7].

Coarse grained soils are those having 50% or more materials retained on sieve No 200.Fine grained soils are those having more than 50% passing through sieve No 200.

USCS uses symbols for the particle size groups. These symbols and their representations are: G-gravel, S-sand, M-silt and C-clay. These are combined with other symbols expressing gradation characteristics. ''W'' for well graded and ''P ''for poorly graded and plasticity characteristics ''H'' for high and ''L'' for low and symbol ''O'' indicating the presence of organic material [11].

According to USCS, soils of Ambo town are classified as highly plastic clay (CH) and highly plastic silt (MH).

Table 5.2 USCS classification for soils of the study area

| **Location** | **Depth** | **Wl (%)** | **Pl (%)** | **Classification** |
|---|---|---|---|---|
| Awura Godana | 1.5 | 114 | 83 | CH |
| | 3 | 109 | 73 | CH |
| Ambo Hospital | 1.5 | 76 | 42 | CH |
| | 3 | 78 | 45 | CH |
| Kes Amba | 1.5 | 99 | 67 | CH |
| | 3 | 93 | 38 | CH |
| Kidane Mihret | 1.5 | 112 | 78 | CH |
| | 3 | 107 | 60 | MH |
| Catholic church | 1.5 | 112 | 75 | CH |
| | 3 | 113 | 66 | MH |
| Kisose | 1.5 | 110 | 78 | CH |
| | 3 | 109 | 75 | CH |
| Bole | 0.8 | 107 | 75 | CH |
| | 1.5 | 73 | 31 | MH |
| | 2.5 | 64 | 30 | MH |
| Stadium | 1.5 | 99 | 59 | CH |
| | 3 | 62 | 32 | CH |
| Cheri | 1.5 | 101 | 68 | CH |
| | 3 | 114 | 74 | CH |
| Awaro | 1.5 | 110 | 76 | CH |
| | 3 | 105 | 72 | CH |

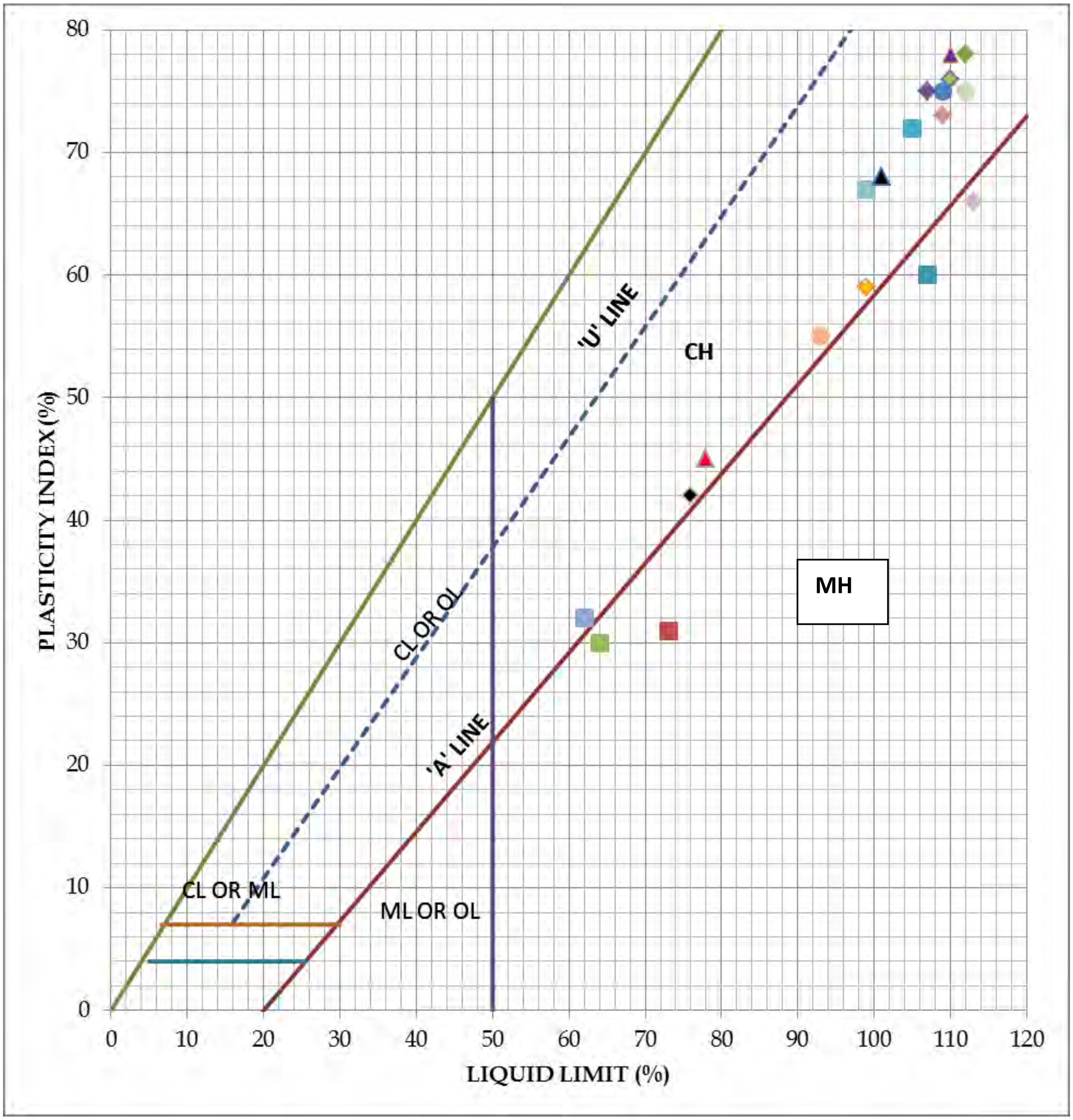



Fig 5.2 Plasticity chart of soils of the study area

For soils fall below A-line, the distinction between inorganic and organic soil is made by oven drying. Since the oven-dried liquid limit of these soil samples is not decreased by 30% or more, soils of the study area which plotted below A-line are inorganic silt.

## 5.4 Classification based on activity

Skempton (1953) showed that for soils with a particular mineralogy, the plasticity index is linearly related to the amount of the clay fraction. He coined the term called activity (A) to describe the importance of the clay fraction on the plasticity index [11].

$$A = \frac{PI}{\text{Clay fraction (\%)}} \qquad (5.1)$$

Activity is a measure of the water holding capacity of clayey soils. The changes in the volumes of a clayey soil during swelling or shrinkage depend upon the activity [11].

Table 5.3 Classification of soils based on activity [11]

| S/N | Activity | Soil type |
|---|---|---|
| 1 | <0.75 | In active |
| 2 | 0.75-1.25 | Normal |
| 3 | >1.25 | Active |

Activities of soils of the study area are computed based on results obtained from hydrometer analysis (% of clay fraction) and Atterberg's limit (PI).Accordingly soils of the study area ranges from in active soil to active soil.

Table 5.4 Activity of soils of the study area

| Location | Depth | PI | % Clay | Ac | Remark |
|---|---|---|---|---|---|
| Awura Godana | 1.5 | 83 | 64.76 | 1.28 | Active |
| | 3 | 78 | 62.25 | 1.25 | Active |
| Ambo Hospital #2 | 1.5 | 42 | 67.6 | 0.62 | In active |
| | 3 | 45 | 52.77 | 0.85 | Normal |
| Kes Amba | 1.5 | 67 | 53.13 | 1.26 | Active |
| | 3 | 55 | 57.81 | 0.95 | Normal |
| Kidane Mihret | 1.5 | 78 | 61.3 | 1.27 | Active |
| | 3 | 60 | 58.11 | 1.03 | Normal |
| Catholic Church | 1.5 | 75 | 58.8 | 1.28 | Active |
| | 3 | 66 | 58 | 1.14 | Normal |
| Kisose | 1.5 | 78 | 59.93 | 1.30 | Active |
| | 3 | 75 | 59.6 | 1.26 | Active |
| Bole | 0.8 | 75 | 59.51 | 1.26 | Active |
| | 1.5 | 31 | 30.41 | 1.02 | Normal |
| | 2.5 | 30 | 27.99 | 1.07 | Normal |
| Stadium | 1.5 | 59 | 51.86 | 1.14 | Normal |
| | 3 | 33 | 48.44 | 0.68 | In active |
| Cheri | 1.5 | 68 | 52.7 | 1.29 | Active |
| | 3 | 74 | 58.39 | 1.27 | Active |
| Awaro | 1.5 | 76 | 59 | 1.29 | Active |
| | 3 | 72 | 57 | 1.26 | Active |

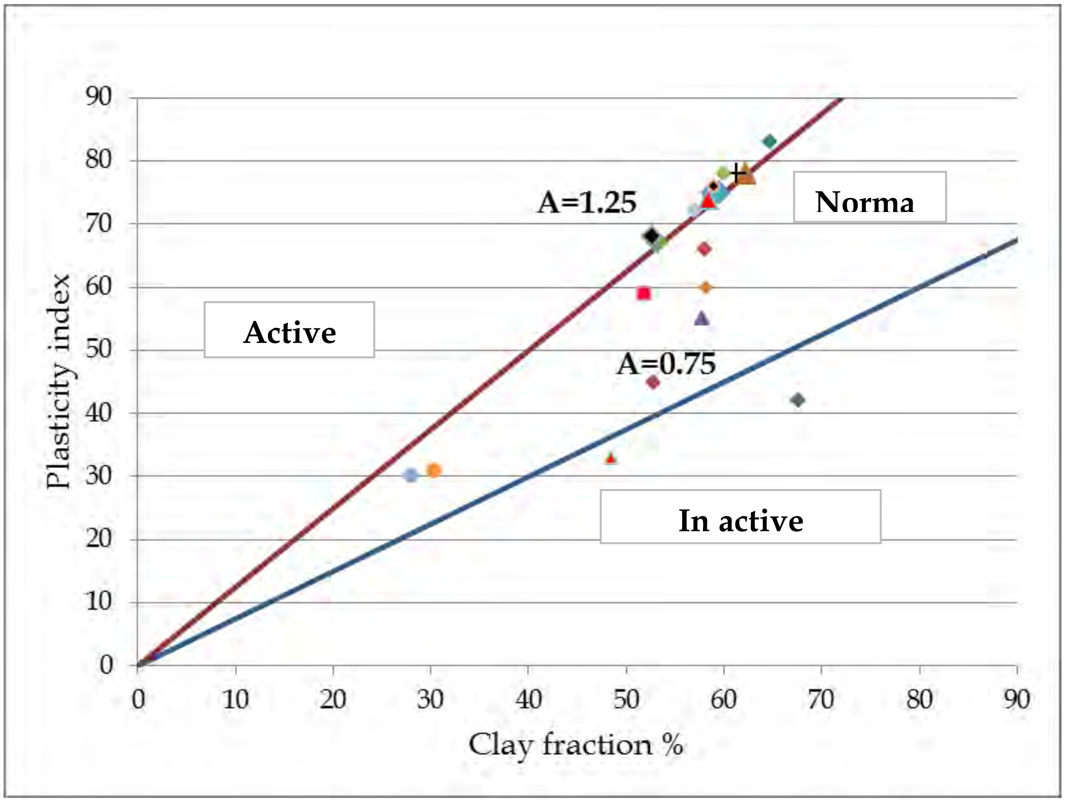



Fig 5.3 Activity chart of soils of the study area

# 6 Unconfined compressive strength and consolidation tests

## 6.1 Unconfined compressive strength

Unconfined compression test is a special case of triaxial compression test in which the all-round pressure $\sigma_3$=0.The test is carried out only on saturated sample which can stand without any lateral support. This test is applicable to cohesive soils only. The test is undrained test and is based on the assumption that there is no moisture loss during the test.This test is one of the simplest and quickest test used for the determination of shear strength of cohesive soils [16].

In unconfined compression test, the minor principal stress ($\sigma_3$) is zero. The major principal stress ($\sigma_1$) is the deviator stress and calculated using Equation 6.1

$$\sigma_1 = P/A \qquad (6.1)$$

Where:

P=Axial load

A=Corrected cross-sectional area

The corrected area can be calculated using equation 6.2

$$A = A_0 / (1-\varepsilon) \qquad (6.2)$$

Where:

$A_0$ =initial cross-sectional area

A =cross-sectional area at any stage of loading

$\varepsilon$ =strain, which is given by $\Delta h/h_0$

Axial stress at which the specimen fails is known as the unconfined compressive strength ($q_u$).The stress -strain curve can be plotted between the axial stress and axial strain at different stages before failure [8].

The specimen of height to diameter ratio of 2 is normally used for the tests. The sample fails either by shearing on an inclined plane or by bulging. The vertical stress at any stage of loading is obtained by dividing the total vertical load by the cross-sectional area. The cross-sectional area of the sample increases with the increase in compression. The cross-sectional area A at any stage of loading of the sample may be computed on the basic assumption that the total volume of the sample remains the same [16].

The consistency of clay soils and other cohesive soils is usually described as soft, medium, stiff or hard. The most direct quantitative measure of consistency is the load per unit area at which unconfined cylindrical samples of the soil fails in compression test.This quantity is known as the unconfined compressive strength of the soil [15].

Table 6.1 shows the general relation between Consistency and unconfined strength of clay soil [15].

Table 6.1 consistency and unconfined strength of clay soil [15]

| **Consistency** | **$q_u$ (kN/m$^2$)** |
|---|---|
| Very soft | <25 |
| Soft | 25-50 |
| Medium | 50-100 |
| Stiff | 100-200 |
| Very stiff | 200-400 |
| Hard | >400 |

Unconfined compressive strength of soils of the study area is conducted for representative samples taken at a depth of 1.5m and 3m.All samples were taken during dry season. The obtained results are listed in Table 6.2

Compressive strength of soils of the study area ranges from 112 kN/m² -545kN/m². This shows that consistency of the soil is ranging from stiff to hard. The consistency of samples taken from Kidane Mihiret, Kisose and Cheri areas is stiff and that of Hospital#2 and Stadium area are hard. The high values of UCS can be mainly due to the dry sampling season. Samples were collected in January, February and March 2014.Analysis of the test results are presented in Appendix C.

Table 6.2 Unconfined compressive strength of soils of the study area

| Location | Test pit | Depth (m) | UCS (kN/m²) | W (%) | Consistency |
|---|---|---|---|---|---|
| Hospital #2 | TP-2 | 3 | 545.00 | 28.40 | Hard |
| Kidane Mihret | TP-4 | 1.5 | 127.53 | 41 | Stiff |
| | | 3 | 151.09 | 41 | Stiff |
| Kisose | TP-6 | 1.5 | 128.53 | 37.4 | Stiff |
| | | 3 | 179.18 | 38 | Stiff |
| Stadium | TP-8 | 1.5 | 530.22 | 32 | Hard |
| | | 3 | 385.00 | 35.1 | Very stiff |
| Cheri | TP-9 | 1.5 | 147.43 | 37.8 | Stiff |
| | | 3 | 112.00 | 40.7 | Stiff |

## 6.2 Consolidation

### 6.2.1 General

Structures are built on soils. They transfer loads to the subsoil through the foundation. The effect of the load is felt by the soil normally up to a depth of about two to three times the width of the foundation. The soil within this depth gets compressed due to the imposed stress. The compression of the soil mass leads to the decrease in the volume of the mass which results in the settlement of the structure [16].

The compression of the soil mass due to the imposed stress may be almost immediate or time dependent according to the permeability characteristics of the soil. Cohesionless soils which are highly permeable are compressed in a relatively short period of time as compared to cohesive soils which are less permeable. The compressibility characteristics of the soil mass might be due to any or a combination of the following factors [16].

1) Compression of the solid mater
2) Compression of water and air within the voids
3) Escape of water and air from the voids

It is quite reasonable and rational to assume that the solid matter and the pore water are relatively incompressible under the loads usually encountered in the soil masses. The change in volume of the mass under imposed stress must be due to the escape of water if the soil is saturated. But, if the soil is partly saturated, the change in volume of the mass is partly due to the compression and escapes of air from the voids and partly due to the dissolution of air in the pore water.

As the pore Fluid is squeezed out, the soil grains rearrange themselves into a more stable and denser configuration, and a decrease in volume and surface settlement results. How fast this process occurs depends on the permeability of the soils. How much rearrangement and compression takes place depends on the rigidity of the soil skeleton, which is a function of the structure of the soil [7].

Deformation may continue for months, years, or even decades. This is the fundamental and only difference between the compression of granular material and the consolidation of cohesive soils. Compression of sand occurs almost instantly, whereas consolidation is a very time-dependent process. The difference in settlement rates depends on the difference in permeability [7].

### 6.2.2 One-dimensional consolidation test

Unified soil classification system shows that soils of the study area are highly plastic clay (CH) and highly plastic silt (MH).Consolidation tests were carried out for representative samples (one for CH soil and one for MH soil) and the test results are tabulated in Table 6.3

After carefully trimming the soil sample at its top and bottom, it was placed inside the metal ring with porous stones at its top and bottom. A sitting load of 7kPa was applied. The loads were applied through the lever arm and the dial gauge readings were taken at a time interval of 0.1,0.25,0.5,1,2,4,8,15,30,60,120,240,480,1440 minutes. The loads were doubled every 24hrs starting from 50kPa to 1600kPa.

### 6.2.3 Pre-consolidation pressure and swelling pressure

#### 6.2.3.1 Preconsolidation pressure

Preconsolidation stress is the maximum vertical effective stress that a soil was subjected to in the past.

Preconsolidation in a soil deposit may be due to one or more of the causes mentioned below: the overburden which had been removed later by erosion, due to loads of buildings and other structures which had been demolished, due to melting of glaciers which covered the soil deposit in the past, due to capillary pressure which acted on the soil in the past but was later destroyed due to a rise in water table, due to desiccation of the clay deposit, due to sustained down ward seepage force and tectonic force[3] .

Preconsolidation pressures of soils of the study area were done for representative samples by using graphical method (void ratio Vs log p curve) as shown in Fig 6.1 & 6.2

#### 6.2.3.2 Swelling pressure

The swelling pressure is defined as the vertical pressure required to prevent volume change of laterally confined sample when it is allowed to take in water [14].

The magnitude of swelling pressure is governed by [14]:

1. Amount and type of clay in the soil
2. Placement conditions which involve initial water content, initial density and confining pressure.
3. Time allowed for swelling

For a given initial moisture content, the swelling pressure increases with increase in dry density.

Swelling pressures of soils of the study area are determined from swell- consolidation test .In this method an undisturbed sample is allowed to absorb water under a load of 1psi (7kN/$m^2$) and is put aside to fully expand and reach equilibrium. Then it is consolidated by increasing the applied pressure in intervals following the conventional consolidation test procedure. The load increment is continued until the sample reaches its initial volume. The load corresponding to zero volume change is taken as swelling pressure.

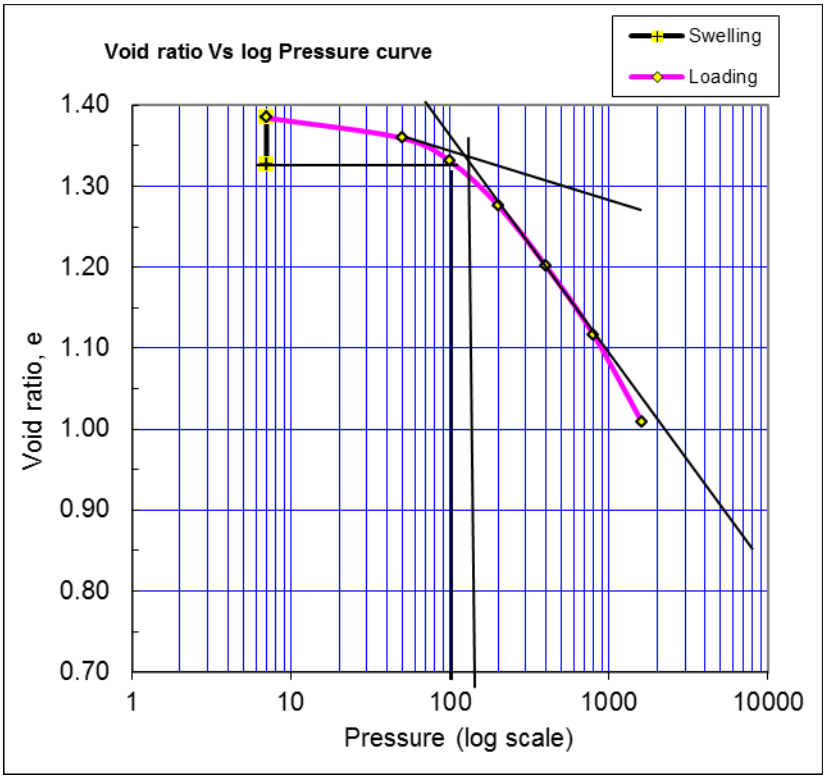



Fig 6.1 Void ratio Vs. log p curve of sample taken from Kidane Mihret area.

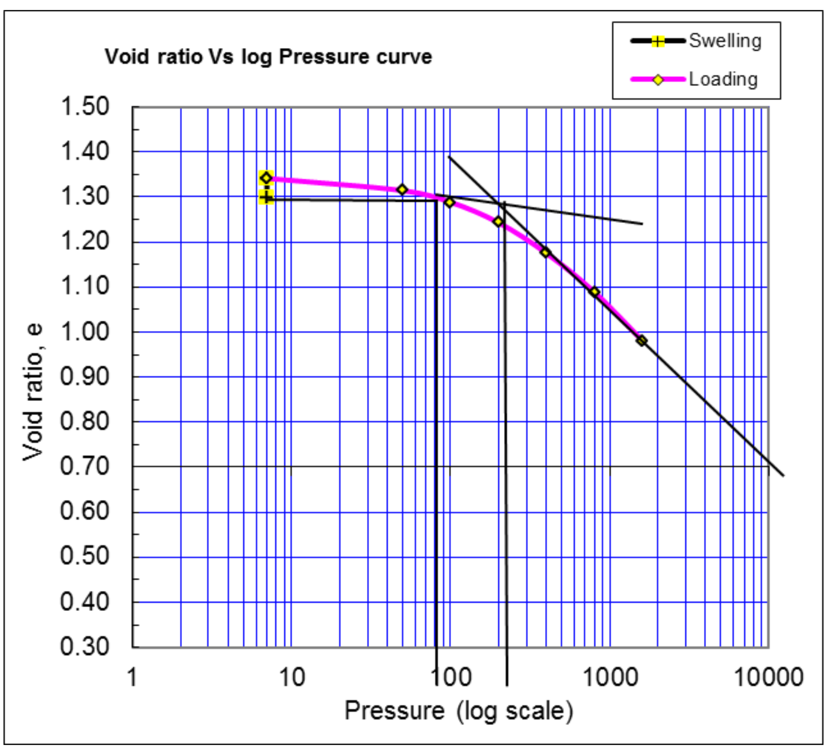



Fig 6.2 Void ratio Vs. logP of sample taken from Cheri area.

Table 6.3 Preconsolidation and swelling pressure test results of soils of Ambo town

| Test pit | Depth (m) | Total unit weight ($kN/m^3$) | Over burden pressure (kPa) | Compression index | Preconsolidation pressure (kPa) | Swelling pressure (kPa) | Over consolidation ratio |
|---|---|---|---|---|---|---|---|
| TP-4 | 3 | 16.5 | 49.5 | 0.355 | 150 | 100 | 3.03 |
| TP-9 | 3 | 19.2 | 57.6 | 0.358 | 225 | 80 | 3.90 |

### 6.2.4 Coefficient of consolidation

The coefficient of consolidation $C_v$ can be evaluated by means of laboratory tests by fitting the experimental curve with the theoretical.

There are two laboratory methods that are in common use for the determination of $C_v$. They are:

1. Casagrande logarithm of time fitting method and
2. Taylor square root of time fitting method.

In Casagrande logarithm of time fitting method, the interval between 0 and 100% consolidation is divided in to equal intervals of percent consolidation. Since it has been found that the laboratory and theoretical curves have better correspondence at the central portion, the value of $C_v$ is computed by taking the time t and time factor T at 50% consolidation [16].

$$Cv = 0.197\frac{H^2_{dr}}{t_{50}} \qquad (6.3)$$

Where

$H^2_{dr}$ = drainage path

Square root of time fitting method was devised by Taylor. The fitting method consists of first drawing the straight line which best fits the early portion of the laboratory curve. Next a straight line is drawn which at all points has abscissa 1.15 times as great as those of the first line. The intersection of this line and the laboratory curve is taken as the 90 percent ($R_{90}$) consolidation point. Its value may be read and is designated as $t_{90}$.

$$Cv=0.484\frac{H^2_{dr}}{T_{90}} \qquad (6.4)$$

Table 6.4 consolidation coefficients of soils of the study area

| Location | Depth (m) | Pressure (kPa) | Void ratio | Coefficient of consolidation, Cv ($10^{-3}cm^2/sec$) |
|---|---|---|---|---|
| TP-4 | 3 | 50 | 1.36 | 1.22 |
| | | 100 | 1.33 | 1.42 |
| | | 200 | 1.28 | 1.63 |
| | | 400 | 1.2 | 1.06 |
| | | 800 | 1.12 | 0.93 |
| | | 1600 | 1.01 | 0.5 |
| T9-9 | 3 | 50 | 1.31 | 2.14 |
| | | 100 | 1.29 | 2.65 |
| | | 200 | 1.24 | 1.21 |
| | | 400 | 1.18 | 1.06 |
| | | 800 | 1.09 | 0.98 |
| | | 1600 | 0.98 | 0.88 |

## 7. Discussion of laboratory test results

The results of grain size analysis conducted on disturbed soil samples were indicated in Fig 4.1 and 4.2 and summarized in Table 4.7. The results indicate that the predominant proportion of soil particles in the study area is clay and silt, which have clay content ranging from 28-67.6%, silt content ranging from 22.8-54.4%, sand content ranging from 1.1-13.2% and gravel content ranging from 0-15.3%.This shows that soils of the study area consists of a wide range of grain sizes ranging from clay to gravel.

The results of specific gravity test indicate that the specific gravity of soils of the study area ranges from 2.51-2.78.Which is in the range of typical specific gravity values of inorganic soils [8].

Test results of Atterberg's limits indicate that soils of the study are have Liquid limit ranging from 62-114%, plastic limit 30-47% and PI ranging from 30-83%. The test results show that soils of the study area are highly plastic soil.

The free swell of soils of the study area ranges from 35-155%.This shows that the degree of expansiveness of the soils is ranging from non-expansive to expansive. The black and gray soil samples have higher free swell value than brown and reddish brownish soil samples.

Table 5.1 and Fig 5.1 indicate classifications of soils of the study area according to AASHTO soil classification system. Accordingly soils of the study area are grouped in A-7-5.The higher group index (i.e. greater than 20) of the soils indicate that soils of the study area are not suitable for using as a subgrade.

Table 5.2 and Fig 5.2 show classification of soils of the study area according to USCS. Accordingly soils of the study area are classified as highly plastic clay (CH) and highly plastic silt (MH).One way of identifying a soil whether its organic or inorganic is by conducting liquid limit test on oven-dried sample. Table 4.6 shows the comparison of liquid limit tests done on air-dried and oven-dried samples. From this table one can observe that the liquid limits of oven-dried samples were decreased by not more than 30% as a result of this, soils of the study area are inorganic soils [8].

Unconfined compressive strength tests conducted on undisturbed representative samples show that unconfined compressive strength of Ambo soils during dry season ranges from $112kN/m^2$-$545kN/m^2$. The higher values of UCS can be mainly due to the dry sampling season. Samples were collected during January, February and March.

Consolidation tests are conducted after soil classification is done. Based on USCS soils of the study area are classified as CH and MH. One representative sample is selected from each type of soils. The test results show that CH soil has Preconsolidation pressure of 225kPa and swelling pressure 80kPa, whereas MH soil has preconsolidation pressure of 150kPa and swelling pressure 100kPa.The swelling pressure of the two soil samples is beyond maximum dead load pressure that can be exerted by most lightly loaded structure[9]. The analysis is presented in Appendix-C.

# 8. Soil map of Ambo town

## 8.1 General

Soil map of Ambo town was prepared based on information collected from GPS data, field visual observation of different areas and laboratory tests results. For rocks, description was done based on secondary data and field observation.

## 8.2 Soil map of the study area

Visual observation made during reconnaissance survey for test pit location shows that most parts of Ambo town are covered with black expansive soil. Areas such as: Awura Godana, Awaro, Bole, Cheri, Kes Amba, Kisose, and Catholic Church (Meja agricultural research center) are covered with black expansive soil. Area around Ambo hospital#2 is covered with reddish brown clay soil. Gray color soils are available around Stadium and Kidane Mihiret areas.

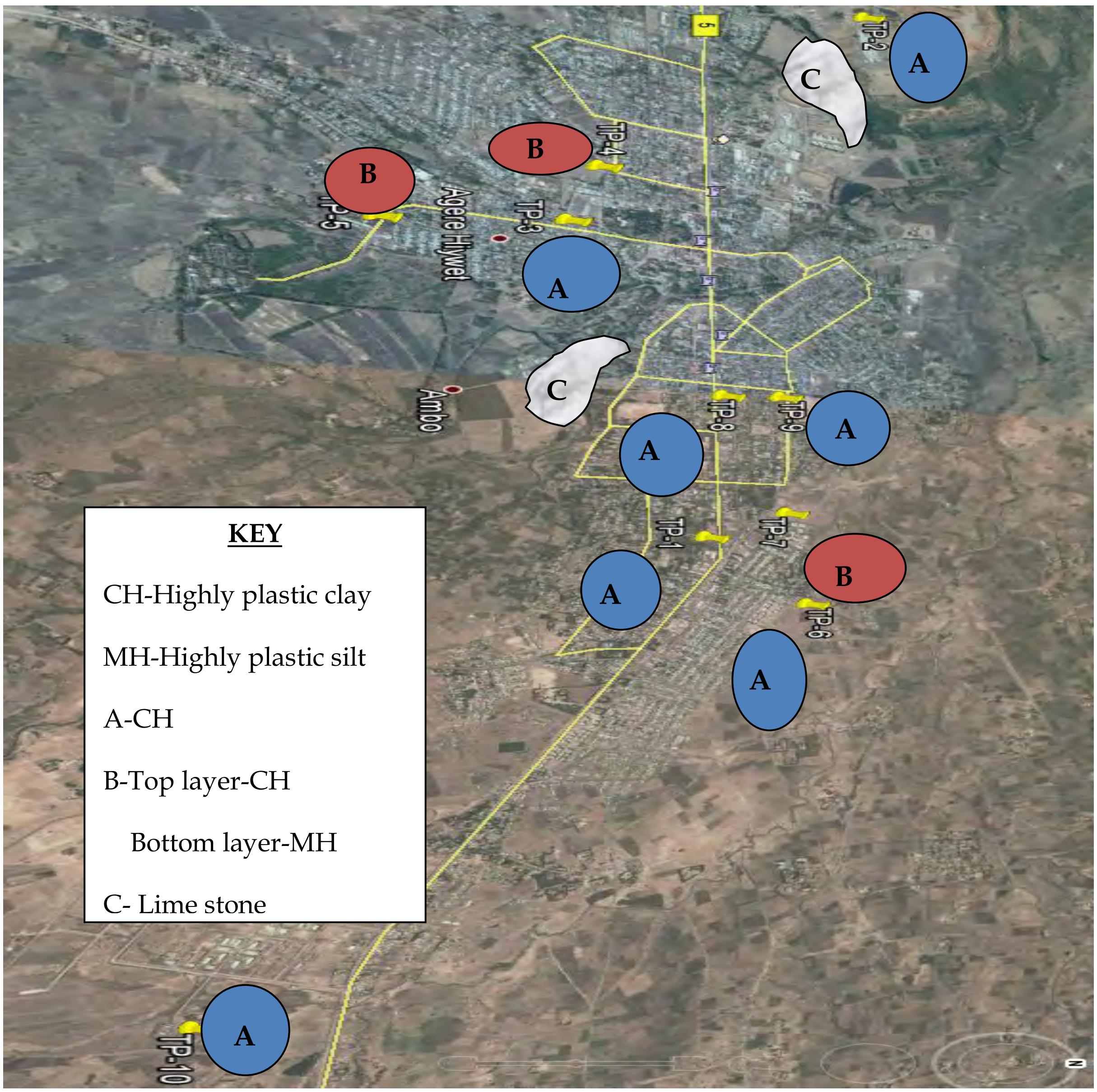
Test pits are excavated to a maximum depth of 3m and the vertical soil profiles (details are presented in Appendix-A) of the ten test pits shows that the depth of black expansive soils ranges from 0.8m-3m.Awura Godana and Awaro areas are covered with black expansive soil to a depth of 3m.For areas such as Bole, Catholic Church, Kes Amba and Kisose only the top layer is covered with black expansive soil.

Index tests conducted in soil laboratory of AAiT indicate that two main types of soils are available in Ambo town.

1) Highly plastic clay soils (CH): These are mainly black and gray expansive soils with high degree of expansiveness. Areas around Awura Godana, Awaro, Bole (top layer), Catholic Church (top layer), Cheri, Kes Amba, Kidane Mihiret (top layer) and Kisose are highly plastic with high plasticity index. Areas around Ambo hospital #2 and Stadium are highly plastic with non-expansive to marginal degree of expansiveness.

2) Highly plastic silt soils (MH): Test results of index tests show that bottom layers of areas around Bole, Catholic Church (Meja area) and Kidane Mihiret are silty soil with high plasticity.

Ambo municipality office refused to give structural map of the town and as a result of this, test pits are located on the map taken from Google earth.




Picture 8.1 Soil map of Ambo town (Google earth)

## 8.3 Description of rocks

The Adigrat equivalent upper Ambo sand stone is one of the major Mesozoic formations exposed as out crops in the area. One can encountered gray color sand stone on the way from Ambo to Wodesa along the bank of Debis River and extends beyond north and it is intercalated with variegated shale. The colorful sandstone is exposed west of the town near the Ambo agricultural college [6].

The following are the local geological unit of the area [6]:

1) Quaternary basalt: this unit is found as a ring surrounding Woliso and Ambo and characterized by volcanic plugs that extruded through it forming different volcanic edifices. Basaltic boulders in Debis stream, Aleltu stream and Huluka stream exhibit denser vesicles in the upper than the lower of the rock.

2) Alaji Rhyolite: It characterize the north west border of the area around Ambo fault belt being confirmed in between Ambo-Woliso quaternary basalt in the south and blue Nile basalt in the northern margin. Its west ward extension is interrupted by Adigrat sand stone which pinch out with in each other.

3) Adigrat sandstone: Adigrat sandstone of Mesozoic sediment is found in Ambo area. It includes various colored sandstones which are naturally decorated. The rock which is known by the name of Ambo sandstone is the classical example which possesses fine to medium grained intact texture. This rock is relatively resistant to weathering.

From visual observation or reconnaissance survey during pit excavation, it was observed that some areas of Ambo town are covered with lime stone. Large coverage is observed around Hora (behind Ambo swimming pool), Fill wuha (Ambo spa) and areas around Ambo hospital No.2. Small coverage is observed in front of bus station on the way to former kebele 05 and around Poly clinic.

The parent materials associated with expansive soils are either basic igneous rock or sedimentary rocks [14]. Expansive soils of Ambo town are derived from the weathering of volcanic rocks such as basal and rhyolite.

Picture 8.2 Lime stone coverage around Ambo hospital (Farisi area)

Picture 8.3 Lime stone coverage around the fence (left side) of Ambo university main campus

# 9. Conclusions and recommendations

## 9.1 Conclusions

Based on the study conducted, the following conclusions are drawn.

1. Results of Atterberg limits tests show that soils of Ambo town have liquid limit ranging from 62-114%, plastic limit 30-47% and PI ranging from 30-83%.This indicate that soils of the study area are highly plastic. Black and gray soils have higher plasticity index than reddish brown and brown soils.

2. One way of identifying whether the soil is organic or inorganic is by conducting liquid limit test on oven drying sample. The comparison made between oven drying and air drying samples indicate that soils of Ambo town are inorganic.

3. Grain size analysis shows that the predominant proportion of the soils is clay size fraction in which the percentage of clay ranges from 28-67.6%, silt from 22.8--54.4% and sand from 1.1-13.2% and gravel from 0-15.3%.

4. The free swell of soils of the study area ranges from 35-155%.The test results indicates that the black and gray soils of the study area are expansive.

5. AASHTO soil classification system shows that soils of the study area are grouped in A-7-5.This indicate that they have poor quality and unsuitable for using as a sub grade material.

6. The black and gray soils of Ambo town are active with activity number>1.25

7. The consistency of Ambo soils in dry season is found to be stiff to hard as the UCS ranges from 112kN/m$^2$-545kN/m$^2$.

8. Consolidation test result shows that samples taken from Kidane Mihiret and Cheri area are over consolidated soils in its natural state with over consolidation ratio greater than one.

## 9.2 Recommendations

1. In this research, due to shortage of budget only ten test pits were excavated to the maximum depth of 3m.Ten test pits are not enough to generalize the engineering properties of soils found in Ambo town. However, by increasing the number of test pits, more detail and accurate results can be obtained.

2. During pit excavations, it was observed that many buildings, masonry walls, concrete and masonry ditches are severely damaged. It is recommended that the causes and extent of the damage be studied and possible remedies be given by conducting thesis on investigation on damages caused by expansive soils of Ambo town.

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