ADDIS ABABA UNIVERSITY

School of Graduate Studies

Faculty of Science

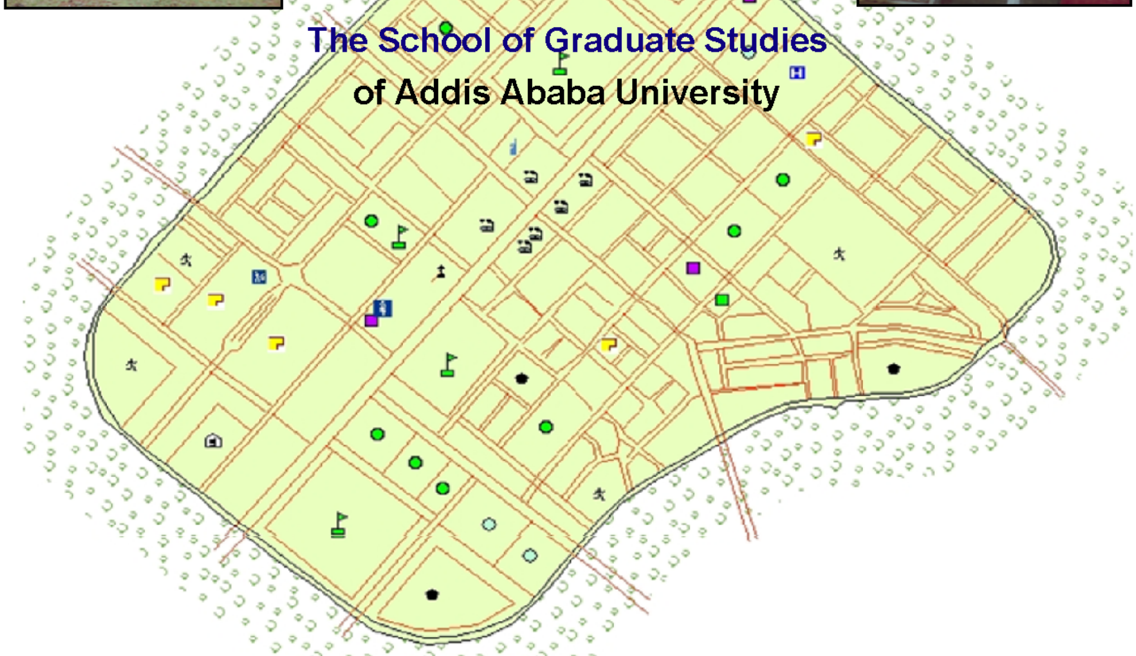
Evaluation of Suitability of Expansive Soils for Safe Building Foundation: A case Study of Tulu Bolo Town, Central Ethiopia

A Thesis

Submitted to

The School of Graduate Studies

of Addis Ababa University



In Partial Fullfillment of the requirements for the Degree of Masters in Geo-Hazards and Disaster Management

Hailu Tadesse

July 2007

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Hailu Taddesse

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List of Abbreviations

A = Activity of soil

CC = Coefficient of consolidation

CH = Inorganic Clays of High Plasticity

ERA TTC = Ethiopian Road Authority Training and Testing Center

FAO = Food and Agriculture Organization

OH = Organic Clays of Medium to High Plasticity

LL = Liquid limit

PL = Plastic limit

PI = Plasticity Index

SG = Specific Gravity

SL = Shrinkage limit

SP = Swelling potential

SS = Soil Sample

VR =Void Ratio

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Abstracts

Expansive soils in many parts of Ethiopia pose significant damages to foundation for light buildings including the study area, Tulu bolo town. Therefore, identification of the location and area extent of these expansive soils and evaluation of them is a paramount importance to mitigate this problem. This particular study was intended to address the major problem of Tulu Bolo town with objective of evaluating the factors for the suitability of expansive soils for safe building foundation design in Tulu bolo town. In order to achieve the objectives of the present study a systematic methodology has been adopted, such as; Literature reviewing, physical observation on the performance of the buildings foundation and associated problems and Laboratory analysis of soil samples. The laboratory analysis for evaluating of expansiveness of soils consists of Grain size distribution and soil type analysis, Atterberg limit analysis, shrinking and swelling analysis and Consolidation test. Average Atterberg limit of all the samples indicates that the values are very high and the soil is very expansive. It is possible to generalize that based on the Atterberg limit all the study area, the town Tulu bolo is located on very expansive soils. Like the Atterber limits value the swelling and shrinking values of the soil sampled showed nearly equal value but found to be very expansive which could cause big cracks. In addition with the expansiveness of the soils the consolidation test for settlement analysis indicates that the soils are very poor for foundation because of high clay content. The spatial variation of the soils in the study area is insignificant and it makes difficult to select the best sight for foundation of buildings. However even for this insignificant variation it was possible to put rank of suitability (Degree of expansiveness) in the study area. Therefore soil sample one is relatively better than the others. When buildings are constructed over expansive soils there are conditions to be considered for safe foundation. This study recommended that any building constructed in the town should be based on causations described in the recommendation part of this paper in order to prevent huge loss of money from construction of buildings.

Key words: Expansive Soils, Buildings' Foundation, Cracks of buildings, Atterberg limits, Soil Consolidation and Tulu Bolo

CHAPTER I

INTRODUCTION

1.1 Background

Expansive soils pose many problems to engineering structures. The estimated damage to buildings, roads and other structures built on expansive soils exceeds billions of US dollars annually (Chen, 1988). With an ability to swell and shrink, in relation to the soil water content, expansive soils are considered as geo-natural hazards and form a challenge to geotechnical and construction engineers. To address the problems associated with these soils, every area has to be evaluated for soil characteristics. Further more, the possible treatment has to be worked out besides evaluation of possible safe foundation design, remedial measures for structures built on expansive soils is of paramount importance.

One of the basic needs of a human being is house in which every thing he owns is bounded. These houses must be safely designed and founded over more suitable earth materials. If the foundation studies are not conducted properly it may affect the performance of the structures. One of the threatening factors on their effective performance is groundwork earth material, of such dangerous earth materials are expansive soils. In fact not only expansive soils but also poorly designed foundation may result in poor performance of structures and high maintenance cost.

Expansive soils owe their characteristics to the presence of swelling clay minerals. As they get wet the clay minerals absorb water molecules and expand conversely as they get dry they shrink by leaving large voids in the soil. Swelling can control the behavior of virtually any type of soil if the percentage of clay minerals such as montimorillonite, exhibit the most profound swelling properties. Therefore, the biggest problem in expansive soil area is related to moisture variation. Sources of water in developed areas are not limited to temporal weather cycles, but can be introduced by people. A frequent source of damage is the differential swelling caused by pockets of soil adjacent to dry soil. For example, garden watering creates a moist zone on the exterior of foundation; whereas the interior is dry this creates differential swelling pressure on foundation. Expansive soils can damage engineering structures in different ways and the most obvious way in which expansive soils can cause damage is by uplifting, as they swell with moisture increases. Swelling soils lift up and crack lightly loaded continuous strip footings and frequently causes diestrum in floor slabs building loads on different portion of a structure's foundation, the result (up lift) varies in different areas. Expansive soils pose the greatest hazards in region with pronounced wet and dry seasons. Soils having repeated annual cycle of wetting and drying are much more susceptible to damage from expansive soils than the regions which maintain most soil conditions through out the year. Potentially expansive soils can typically be characterized in the laboratory by plastic properties. For instance inorganic clays of plastic nature are generally those with liquid limits exceeding 50% and plasticity index over 30%. Expansive nature of soil can also be determined in the laboratory directly, by immersing molded soil sample and measuring its volume change. Soil engineers and engineering geologists test soils for swelling potential when designing building foundation. Simple observation can reveal the presence of expansive soils with the high percentage of swelling clay usually has cracks or a puffy appearance when dry and are sticky when wet.

The study area, which forms a part of Tulu bolo town, faces consistent problem of expansive soils and this attracts researchers' attention to participate in dealing with these problems to take an immediate action. Recent advances in geo-technical engineering research give the tools to properly understand the behavior of expansive soils. In the present study, the swelling character of the soil in the study area has been defined and a systematic approach has been used to evaluate various factors associated with building foundation problems, besides an attempt has also been made to suggest possible safe designs for building foundations in the study area.

1.2 Location of the study area

The present study area forms a part in Tulu Bolo town, which is about 80 km on Addis Ababa Jima road. The study area falls in Ethiopian Topographical Survey Agency sheet No 235 and is defined by UTM co-ordinates 412200 E to 415000E and 956000 N to 957000N in a Universal Transverse Merkator coordinate system. The Location map of the study area is shown as Fig. 1.1.

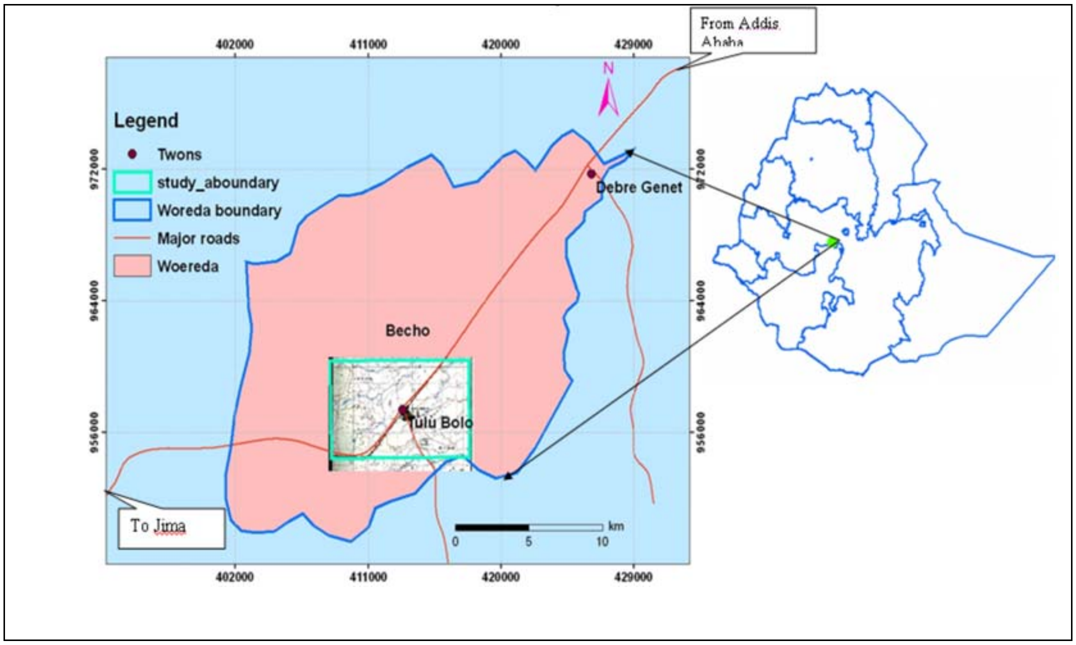

Fig. 1.1 Location map of the study area

1.3 Statement of the Problem and justification of the study

Expansive soils are poor materials to be utilized in the construction of high ways, light weight structures and buildings. These soils contain a large percentage of plastic clay and often demonstrate shrinking and swelling potential when subjected to moisture variations. Expansive soils in many parts of Ethiopia pose significant damages to foundation for light buildings. Since, expansive soils cover a significant areal extent of the country they cause extensive damage to urban buildings and rural access roads and induce remarkable construction difficulties. Litigation against builders, developers, and engineers arising out of damage to structures and infrastructure due to expansive soils is a billion dollar issue. However, the actual damage caused due to expansive soils in Ethiopia are not estimated but definitely would be accounted to be in Billions. These expansive soils occur largely in the highlands of Ethiopia where more prominent infrastructures are undertaken. Major infrastructural developments are undertaken in the capital city and its surrounding towns. Many of the problems are resulted from inadequate design and construction and this is a result of unidentified expansive soils at these sites. Moreover, the foundation failure also resulted from lack of accurate prediction of heave associated with the expansive soil, specification of inappropriate foundation systems, and/or improper construction practices. Foundation engineering for expansive soils sites is completely different from that of “ordinary” sites. Therefore, identification of the location and area extent of these expansive soils and evaluation of these is a paramount importance to mitigate this problem. The present study can help to those people who simply construct their houses with out analyzing the nature of these expansive soils. In addition the study is concentrated on the evaluation of the nature of expansive soils, the need for different site investigation techniques, and different foundation systems to be used on these soils. In this regard most of the urban spread out in Tulu bolo town (The study area) is constructed without systematic scientific investigations. A number of buildings are failed due to improper site selection and having poor foundation condition. Most of the buildings in the town are founded in haphazard ways with out considering the foundation characteristics of the footing soils. In Tulu Bolo Town the expansive soils, mainly black cotton soils are widely distributed. These expansive soils have resulted into wide spread failure of foundation. The degree of damage to structures of the town due to poor foundation conditions has resulted in to crack in the walls to complete collapse of the structures. Therefore, through this present study attempt is being made to study the various factors responsible for building foundation failures. Besides, an attempt has also been made to work out possible remedial measures for safe building foundation design.

1.4 Objectives of the study

1.4.1 Main Objective

The major objective of the present study is to evaluate the factors for the suitability of expansive soils for safe building foundation design in Tulu bolo town.

1.4.2 Specific Objectives

(i) To evaluate the nature of soils in the study area.

(ii) To characterize the engineering properties of soils in the study area.

(iii) To identify distribution and location of the expensive soils in the study area.

(iv) To assess existing building foundation problems.

(v) To evaluate the various factors responsible for building foundation problems.

(vi) To recommend possible remedial measure for safe building on expansive soils

1.5 Methodology

In order to achieve the objectives of the present study a systematic methodology has been adopted. The activities, thus followed are as follows;

(i) Literature reviewing through technical papers, published and un published reports, on line resources and personal interviews.
(ii) Collection of secondary data from various agencies/ organizations.
(iii) Collection of primary data through field survey, soil sample collections, photography, interviews with local people and municipal officials.
(iv) Physical observation on the performance of the buildings foundation and associated problems
(v) Laboratory analysis of soil samples
(vi) Systematic analysis of secondary and primary data.
(vii) Interpretation of results.
(viii) Compilation of Thesis

Generally, the major activities covered were identification and characterization of expansive soils, field investigation and soil sampling and Laboratory testing for expansive soils. In addition an attempt has also been made to evaluate various factors responsible for building foundation problems.

1.5.1 Literature reviewing

The literature reviewing was undertaken in order to provide a framework of the available information regarding expansive soils and its behavior as building foundation. The sources included books, journal, on line resource and unpublished reports. In addition to this experiences from other areas with similar physical characteristics of building foundation problems were referred in some part of the present study. This was mainly done to build up a conceptual framework on the procedures and methods, adopted in those areas, in dealing with expansive soils as building foundation material. The major portions in the literature covers the properties of expansive soils, what damage they cause on buildings, what remedial measures can be adopted and how they are evaluated for their performance for foundation materials.

1.5.2 Secondary data collection

Various data and information were collected from secondary sources to achieve the objective of the present study. The secondary data utilized for the present study are as follows;

- Geological map of the surrounding and the study area: this map has been procured from Food and Agricultural Organization (FAO) with a scale of 1: 000,000
- Land use and land cover map: the land use and land cover map of the town and its surrounding was obtained from Food and Agricultural Organization (FAO) (FAO Report, 1997).
- Soil map: The soil map of the town and its surrounding also obtained from Food and Agricultural Organization (FAO) (FAO Report, 1997).
- Landscape: The topographic condition of the town and its surrounding area was obtained from Food and Agricultural Organization (FAO) (FAO Report, 1997)
- Meteorological: All the meteorological information of the town and its surroundings were collected from the National meteorological Agency of Ethiopia.

1.5.3 Primary data collection

The most important primary data for the present study is the data required for the characterization of the soil and the associated problems of the building foundations. Further, visual observations on nature of soil through test pits, distribution of soil types in the study area, associated building foundation problems and collection of soil samples for laboratory analysis were the major activities during the field work. In total four test pits were made, which were located in each soil type distributed throughout the study area. The soil samples for laboratory analysis have also been collected from these test pits.

The number of samples collected from field: The number of samples were determined largely on the base of distribution of various soil types in the study area. In total four soil sample sites were selected. Disturbed samples were collected from the different horizons of the test pits. Detail description on these soil samples is discussed later in Chapter four.

Location of the soil sample sites: The location of the samples collected from the field was determined by the technique of systematic random sampling. The soil sample sites are systematically assigned and are located three at the western part of the main road and the remaining one is at the eastern part of the road. All these samples were collected in such a way that they represent the various soil types present in the study area. The location of the samples is displayed in the map (Fig.1.2).

How the soil samples were taken: After the soil sample sites have been determined by systematic random sampling techniques the other thing which is important to know was that how to take the soil sample from these sites. A standard soil profile pit for all site have been dug out and samples from each soil profile have been taken. The weight of the soil sample was 5kg at 1m depth and 5 kg at 2m depth for each soil sample sites and totally 40kg soil sample were taken for laboratory analysis.

Fig 1.2 shows the location of the soil samples taken for laboratory analysis. The sample sites, represented as point features in the map, are fairly distributed in the town and supposed to represent the soil condition of the town for analysis of expansive soil. Fig. 1.3 show the profile of soil sample sites. All the soil profiles have been dug with equal depth (2m). Two soil samples having 5kg weigh from each soil profiles were taken at depth 1m and 2m.

Along with collection of soil samples the other important information that had to be collected from the field was to assess the expansive soils hazard that has been occurred in the area. Observations were made on the buildings affected by the effect of expansive soils. The adverse effect of poor foundation conditions is presented in Fig 1.4. As evident from the pictures taken in the study area there exist expansive soils and majority of the buildings were constructed with poor foundation conditions.

Fig.1.2 Soil Sampling sites in the study area

For instance picture A shows that a house is now being cracked before it is completed. Picture (B) shows that the high way is now being destroyed even not more than a year life since it has been giving service starting from its construction. All the pictures explicitly show that the soil of the area are not properly studied and the foundation of the buildings were not also suitably designed as a result their performance is very poor. The building failures in the study area due to expansive nature of foundation soils, includes development of cracks in the walls, upheaval of the floor, dislocation of window and door frame.

1.5.4 Data analysis and interpretation

After all necessary (secondary and primary) data were collected the next step was data analysis. All the soil laboratory analysis have been done by experts but the general principles and methods are presented in the literature and data analysis sections of this paper. After all the laboratory analysis results had been brought and the various soils property indices had been done.

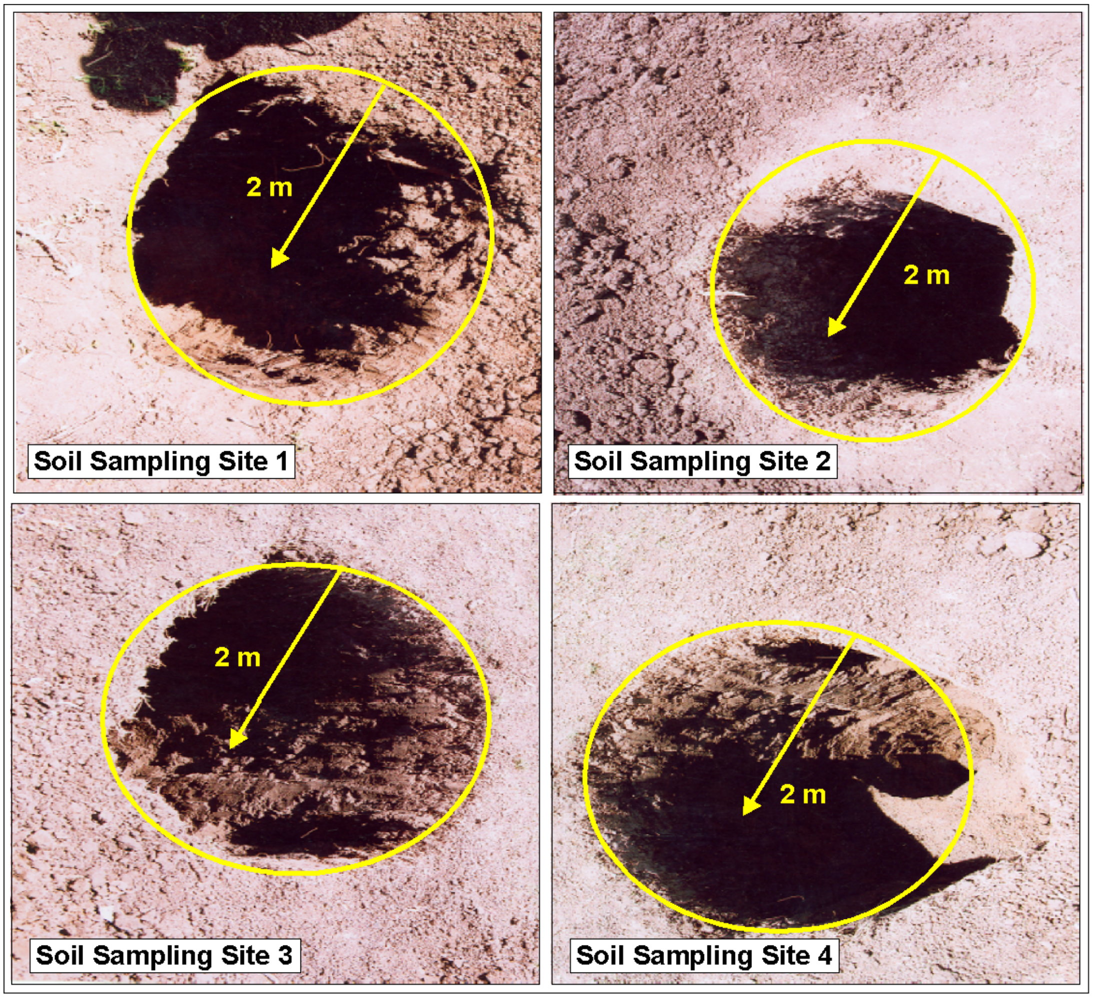

Fig.1.3 Pictures of soil sample sites

To mention some of them plastic limit, liquid limit, swelling index, grains size distribution and others were calculated. Eventually, after all these important soil properties have been calculated which help to evaluate expansive soils. Later interpretation of these results has been made. Using the results of soil property indices degree of expansiveness of soils was interpreted and eventually the zone of expansive soils of the study area was mapped and relevant remedial measures and recommendations were made.

In general all positive steps were undertaken to conduct the present research study in an elaborated and systematic manner, where attempts were made to conduct study with wide filed physical observation supported with actual experimental data generated during this study. However, all these attempts were made under the limitation on finance resource and time.

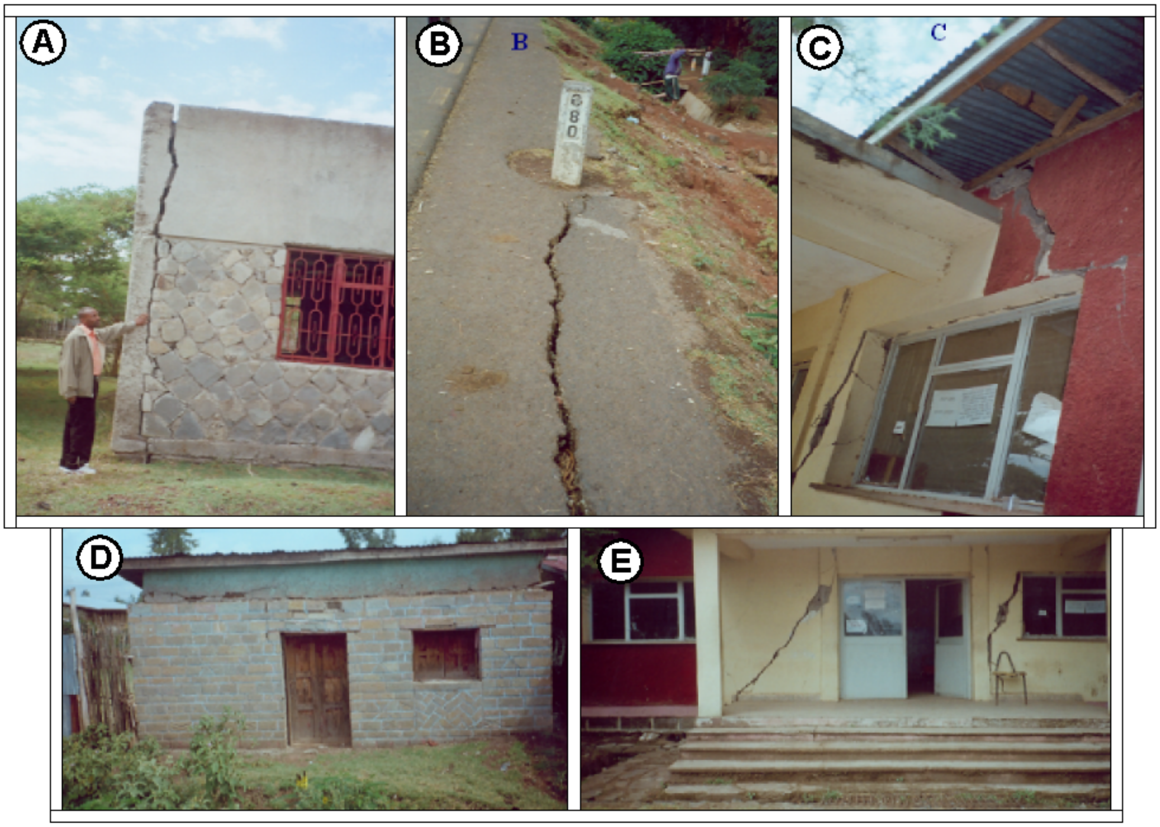

Fig.1.4 Pictures of buildings affected by expansive soil

This may affect the accuracy of the result findings. Therefore, it is strongly recommended to verify these results with more elaborated field and laboratory tests before adopting these results for actual design considerations.

The overall research methodology used during present research study is presented in Fig 1.5.

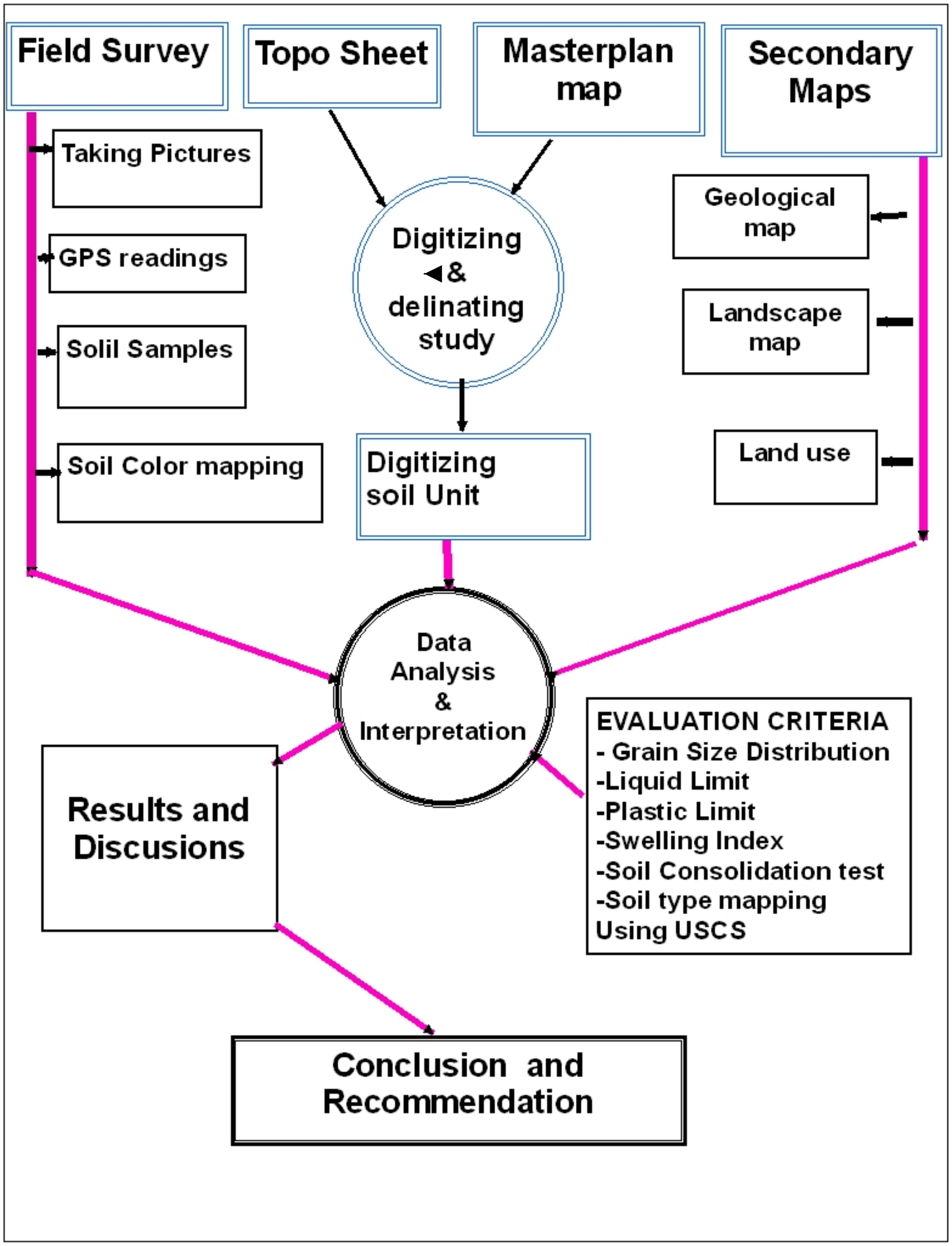

Fig. 1.5 Schematic view of the methodology

Limitation of the study

This study was limited due to lack of financial support and limited time, lake of secondary data which corresponds to this study.

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CHAPTER II

LITERATURE REVIEW

2.1 What are expansive Soils

The phenomenon of expansive soils turns out to be a very complex subject and, until recently, not well understood. So now people know more about expansive soils then what they had ever cared to know. One more fact every one should have in his store of knowledge on the subject, because: "the effect of expansive soil damage on a local, regional or national scale is considerable." As an evidence, insurance companies pay out millions of dollars yearly to repair homes distressed by expansive soils (Krohn, J& Slosson, 1980) .

Expansive or swelling soils, as their name implies, are soils that swell when subjected to moisture. These swelling soils typically contain clay minerals that attract and absorb water. Another category of expansive soil known as *swelling bedrock* contains a special type of mineral called *claystone.* When water is added to these expansive clays, the water molecules are pulled into gaps between the clay plates. As more water is absorbed, the plates are forced further apart, leading to an increase in soil pressure or an expansion of the soil's volume. Soils containing expansive clays become very sticky when wet and usually are characterized by surface cracks or a "popcorn" texture when dry. Therefore, the presence of surface cracks is usually an indication of an expansive soil. Since, expansive soils shrink when dry and swell when wet this movement can exert enough pressure to crack sidewalks, driveways, basement floors, pipelines and even foundations. Pressures can be as great as 15,000 pounds per square foot (Jennings, et. al. 1973).

2.2 Physical properties of Expansive soils

Basically, soil is a complex material, which exists in almost innumerable variations by its combination of solid, liquid and gases. The relative quantity of solid, liquid and gasses in a given soil is bounded to change due to any physical cause such as loading, seasonal variation and change of temperature. To understand this intricate nature of soil, the combination and the relative amount of each component must be known. To do this, methods of evaluation (tests) have been devised to determine their physical properties, is known as Index properties. Correspondingly the expansiveness of a soil can be evaluated using various methods. The most commonly used evaluation criterion is soils property index. According to Chen, 1988, as cited in (Habtewold, 2001) the soil property index includes the following major soil properties that should be determined in order to evaluate the expansiveness of a soil.

2.2.1 Soil Moisture content

There will be no volume change if the moisture content of the clay element is unchanged. When the moisture content of the clay is changed, volume expansion in the vertical and horizontal direction will takes place. Complete saturation is not necessary to initiate soil swelling. Slight change in moisture content in the magnitude of 1 to 2 percent is sufficient to cause detrimental swelling. Soils with moisture content below 15 percent indicates danger because it easily absorbs moisture but moisture content above 30 percent indicates that most expansion is taken place and further expansion will be small. In the dry season the soil shrinks excessively and shrinkage crack as deep as 2 or 3 m is common occurrence (Chen, 1988).

2.2.2 Dry density of soils

The dry density of the soil is another index of expansive soils. Soils with higher dry density will show high swelling potential than lower density soils (Chen, 1988).

2.2.3 Soil Index property

A) Atterberg Limit

In the year 1911, Atterberg proposed the limits: Liquid limit (LL) and plastic limits (PL) and Shrinkage limit (SL), of consistency in an effort to classify the soils and understand the correlation between the limits and engineering properties like compressibility, shear strength and permeability (Afework, 2004). All these limits represent the water holding capacity at different states of consistency. The most useful classification data for identifying the relative swell potential are liquid limit (LL) and plastic index (PI).

Plasticity index and the liquid limit are useful indices for determining the swelling characteristics of most clay soils. Liquid limit and swelling clay both depend on the amount of water absorbed; high swelling soils manifest high index property.

The liquid limit is defined as the minimum moisture content at which a soil will flow upon application of a very small shearing force. When a soil becomes a viscous fluid, the soil will begin to flow under its own weight and very small amount of energy input. The liquid limit is primarily used by civil and geotechnical engineers as a physical property of a soil. The liquid limit allows engineers to classify soils into their applications. For instance one soil may have applications in sub-bases of roads, where another soil may be better suited for foundations of buildings. The moisture content at which a soil stops behaving as a solid and begins to behave like a liquid; in laboratory terms, the liquid limit is the moisture content required to close the groove of a cut soil sample used in a liquid limit test device (Afework, 2004).

The plastic limit is that moisture content of a soil at which it becomes too dry to be plastic, used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart enables the classification of cohesive soils.

B) Linear shrinkage

The shrinkage characteristics of clay should be consistent and reliable index or swelling potential of soils. A soil having high linear shrinkage limit is critical as compared to soils of lower shrinkage limit.

C) Free swell

The swell shrink behavior exhibited by expansive soils due to seasonal moisture variation is known to cause distress to structures resting on them. Not all expansive soils have the same swell potential. Tests can determine the swell potential of a particular soil and the probability for structural damage. Measurement of swell for design purposes should simulate the expected sequence and magnitude of loading and wetting changes that are expected in the field. Swelling pressure, swell potential, and swelling index are identified as three important swelling characteristics, which are required for safe and economic design for structures resting on them. In turn several investigators have developed correlations to predict swelling characteristics basing on placement conditions viz., free swell dry density, initial moisture content and Atterberg's limits (Afework, 2004).

Free swell is a maximum volume change expressed as percent of initial volume. Expansive soils have generally higher free swell value.

D) Colloidal content

The expansiveness of a soil is highly determined by the distribution of particles in the soil. Evaluation of the expansiveness of a soil needs to determine the distribution of particles in a soil. The soil grain size distribution is related to the soils texture classification based on USCS which is discussed in detail in section 2.2. Expansive soils are common where the grain size of the soil is fine as compared with the larger sizes (Afework, 2004).

The grain size characteristics of clay appear to have a bearing on its swelling potential, particularly the colloidal content. For a given clay type, the amount of swell will increase with the amount of clay present in the soil. For any given remodeled clay type, the relationship between the swelling potential and percentage of clay size can be expressed by the equation

S = KC*………………………………………………………………………….2.1

S = Swelling potential, expressed as percentage of swell
C = Percentage of clay size finer than 0.002mm
X = an exponent depending on the type of clay and
K = Coefficient depending on the type of clay

2.3 Soil moisture relationship of expansive soils

Moisture migration depends on the geological formation, climatic condition, and topographic features, soil type and ground water level. The most common method of moisture transfer is by gravity. The seepage of surface water, precipitation and snow melting in to the soil are common examples. Moisture migration can occur in all directions. In stiff clay and in shale bad rock, the flow occurs in the bedding plan or follows continuous fractures and fissures. In fine grain soils, a capillary force is a significant means of water transfer. Thermal gradient is also a cause for moisture migration through the liquid phase of the soil. Vapor and liquid moisture transfer under thermal gradient can be an important cause of the swelling of moisture deficient soils (Afework, 2004). Moisture in the soil varies due to seasonal climatic change of surface conditions and external influences. Climatic change consists of a change in atmospheric temperature precipitation, evaporation, transpiration and relative humidity. Surface condition (change of paved area in to garden) and external influences which is resettlement of new houses around the existing buildings will disturb the moisture content of the foundation soil resulting the variation of moisture content in turn results the swelling and shrinkage of soils. This alternate shrinkage and swelling of the foundation soils creates stress on the structure as a result the structure faced to additional stresses which not yet considered during the design.

2.4 Effect of foundation movement

The magnitude and intensity of structural damage is influenced by the intensity of contact pressure, the type of foundation and the relative steepness of the supper structure. In light weight structure, the contact pressure is normally much smaller than the swelling pressure of the expansive soils. As a result, the whole building will be lifted differentially and creates stress, which are not accounted in the design and this stress creates cracks. The first sign of foundation movement of structures founded on expansive soils is the cracking of the floor slab, door binding, windows sticking and cracks appearing in the exterior and interior walls (Afework, 2004).

2.5 Causes of cracks in buildings constructed in expansive soils

Cracks caused by swelling soils are wide at the top narrow at the bottom. The cause of foundation movement is moisture fluctuation of the foundation soil. It is important to differentiate the different types of cracks and their causes in order to know cracks caused by expansive soils heave. Some of the types and their causes are as follows (Afework, 2004).

2.5 .1 Crack due to shrinkage and expansion of the plaster work

Such cracks are hairline cracks, insignificant tilt of floors or change in level and can be easily maintained. It mainly affects the aesthetic value of the buildings. This type of cracks usually occurs due to the stress induced by shrinkage and expansion of the mortar during drying.

2.5.2 Crack due to structural failure

These cracks are significant cracks and caused due to improper design and / quality control failure. Besides functions and cost such cracks have psychological impact on the owners and can be encountered in high rise buildings and in non expansive soil areas and such cracks occur very rarely.

2.5.3 Cracks due to foundation movement

These types of cracks are usually associated with expansive soils, which can exert a pressure that moves the structure. It is commonly observed in light weight buildings founded on expansive soils areas and such cracks are abundant.

2.6 Methods of Preventing building damages

Methods that have commonly been used to prevent building damages due to heave are moisture control, soil stabilization and structural measures (Tefera, 1992).

2.6.1 Moisture control

Generally, expansive soils will not be a problem if the moisture content is constant throughout the soil. Moisture fluctuation can be controlled by using horizontal barriers, vertical moisture barriers, subsurface and surface drainage. Horizontal moisture barriers can be installed around a building; rigged paving or flexible paving, polyethylene membrane, concert aprons and asphalts membrane can be used as a horizontal moisture barriers. Vertical moisture barriers are used around the perimeter of the building to cut of the sources of water that may enter the under slab soils. Vertical barriers are more effective than horizontal barriers in minimizing drying and shrinkage of the perimeter of the foundation soil as well as maintaining long term uniform moisture conditions beneath the covered area.

Sub surface drainage is another mechanism to control moisture. Intercepting and peripherals drains are used, as a subsurface drainage. Intercepting drains are used in minimizing the wetting of the foundation soils. Intercepting drains are most effective when located along the toe of a slope where the ground water leaves the deep strata. For proper surface drainage the ground surface around a building should be graded so that surface water will drain away from the structure in all directions (Afework, 2004)

2.6.2 Soil stabilization

The swelling potential of expansive soils can be minimized or completely eliminated by flooding or pre wetting, compacting to a lower density, by replacing expansive soils with non expansive soils, by stabilizing expansive soils with chemicals and by isolating soil so that no moisture change will exist in the foundation soil (Chen,1988). Experimental investigations have revealed that expansive soils expand very little when compacted at low densities and high moisture. Hence, by controlling the compaction effort it is possible to arrive at a density that lies well below the optimum (Afework, 2004).

Soil replacement is the simplest method for preventing building damages. The most important requirement for soil replacement is the type of the material for replacement, the depth of replacement and the extent to which the replacement is needed. The material replaced should be non expansive and impermeable. If the replacing material is highly permeable (coarse sand or gravel) it transmits the surface moisture directly on the expansive clay layer that would bring about differential movement the same as the surface. Hence, use of sand, gravel as a replacing material is dangerous. The depth at which the soil to be replaced depends on the depth of the active zone. Active zone is the depth at which the soil does not affect by dry weather. Organic and inorganic chemicals can be used to stabilize the expansive soil.

The most common chemicals used are lime, cement, sodium chloride and sodium silicate. Stabilization using lime reduces the plasticity and the swelling potential of the soil by replacing the weaker ion such as sodium on the surface of the clay particles by calcium ion lime. Cement and other inorganic chemicals such as calcium hydroxide, sodium chloride and sodium silicate reduces the swelling potential, plasticity index and liquid limit and increases the shear strength of the soil (Afework, 2004).

2.6.3 Structural measures

Building can be designed as a rigged unit so that they can act monolithic unit. This can be achieved by reinforcing the building adequately. The other alternative is to make the building flexible so that a certain amount of differential movement is allowed.

2.6.3.1Footing foundation

Footing foundation may be placed on expansive soil provided that one or more criteria are met. One sufficient dead load pressure is exerted on the foundation and two the structure is rigged enough so that the differential heaving will not cause cracking.

2.6.3.2 Mat foundation

Mat foundation is successful in moderate swelling soil areas. In the design of such foundation, the negative building movement produced by the swelling pressure of the soil should be considered and this controls the design. Stiffened slab is the most common foundation system in expansive soils.

2.6.3.3 Drilled pier foundation

There are two kinds of drilled piers, one which, has enlarged base, is called belled piers and the other is straight shaft piers. The drilled piers foundation is a rational solution to combat the problem of the expansive soils; however, the design and construction must be closely controlled. The piers should be placed well below the active zone where seasonal moisture fluctuation of the active soils is minimum.

2.7 Researches done on Expansive soils

Gourley and Scheir (1993) described the extent and engineering significance of expansive soils. Damages caused by expansive soils are almost entirely restricted to light structures, such as houses and roads. This is in part due to the low tensile strength of these structures when compared with the materials at greater depth used in larger structures. The damages caused by expansive soils are often heightened by insufficient identification of expansive soils during the site investigation and testing stages on many projects. It is necessary to identify the source of the expected heave or shrinkage before selecting the design solution. Placement of cutoff membranes, pre-wetting, soil stabilization and removal of expansive soils have been used for many years where these materials have been encountered in the road alignment with varying degree of success (Gourley and Sch&ner, 1993)

Van der Merwe (1980) presented the volumetric changes in the roadbed caused by seasonal moisture and volume changes in expansive soils of Zimbabwe. The work focused on defining the properties of soils, which caused deformation so that they can be identified and determined in the field. The work also included formulating road construction and maintenance strategies to counteract the damaging effect of expansive soils.

Netterberg (2001) carried out a comprehensive investigation to idea the failure of the Addis Ababa-Jima Road at the initial stages of the road. The present study area is located along the side of Addis Ababa-Jima road. Thus, for the present study the various literatures reviewed provide a basis for comparing the physical properties of the expansive soils. Such comparisons will aid in identification soils of the study area.

Gourley et.al. (1993) presented Transport Research Laboratory's strategy of research on expansive soils. The work outlined guidance on design and construction of roads on expansive soils. Particular emphasis was placed on the improved identification procedures, both in the laboratory and in the filed.

Pavements on expansive soils are comprehensively summarized by Holland and Richards (1982). The paper briefly outlines the worldwide problem that result from the construction of pavements on expansive soils. Basic concepts of clay soils heave, including the effects of site drainage and loading were discussed. A brief presentation of the major techniques most commonly used in an attempt to overcome the problems of expansive soils was also included in the paper.

Barry (1986) presented the influence of trees and shrubs on pavement loss of shape. The paper recommended that, to guard pavement loss of shape, from drying of expansive soils by trees, trees and shrubs should be set back at distance equal to 2 times the mature canopy width of the tress or 1.5 times the mature tree height, whichever is greater, from the edge of pavement.

The Geological Society (1997) reviewed the nature of different tropical residual soils and gives valuable information on how their peculiarities influence their testing and use in civil engineering. Each type of residual soil has well defined characteristics deriving from the nature of the parent rock and the climate prevailing in recent geological times. Thus, whenever similar climatic and geological conditions occur, the same types of residual soils are evolving, sometimes at different stages of development. The report discuses the origin, weathering processes and distribution of tropical residual soils and gives a general guidance in predicting the soil groups most likely to be found under any particular combination of parent materials and environmental.

Netterberg (1984) gave descriptions of a full-scale road experiment on the Pretoria Warm bath freeway in South Africa employing four different countermeasures against damage due to the highly active clay roadbed. The entire four counter measures used, i.e. 1.0m replacement, pre-wetting (by rainfall) alone, pre-wetting and membranes; and a combination of 0.5 m replacement, pre-wetting and membranes have performed satisfactorily.

Chen (1988) provided a summary of the state of-the-art knowledge of expansive soils and practical solutions based upon experiences. Theory, practice and typical case studies are also presented in his study.

Katti et.al. (2000) presented results of the research conducted during a period spanning over five decades in India over expansive soils. The test deals with the properties of expansive soils, lateral pressure and bearing capacity aspect. It covers the works on soil improvement and also guidelines for construction including case histories related to the performance of civil engineering structures.

Tadesse Haile (1983) and Nippon (1995) conducted a feasibility study on the Becho Plain that included all of the study area. The studies aimed at identification of flood control and agricultural development potentials of the area. Tadesse Haile (1983) conducted a detail soil investigation to identify the physical and chemical composition of the soils. Nippon (1995) conducted a detail assessment on the water resources and ground water conditions in the area.

Morin and Parry (1971) presented the occurrences and properties and red clay soils. They pointed out that the soils are formed of rocks. Morin (1971) presented the occurrences and the properties of soils. He pointed out that the soils are difficult to utilize in construction because they contain a large percentage of plastic expansive.

2.8 Origin of expansive soils in Ethiopia

Basalt is a common parent material for most expansive soils. African Black clays show a wider range of values of liquid limit and plasticity index. Percent of shrinkage limits were found to be similar for Indian and Ethiopian expansive soils. Ethiopian Black clays show higher specific gravities than both Indian and African clays.

Clay minerals are formed through a complicated process from an assortment of parent materials. The Geological Society (1997) pointed out that, most significant group clay minerals in tropical residual soils are the Shectites, of which Montmorillonite is probably the most commonly occurring. These minerals result from the chemical weathering or hydrothermal alteration of basic and intermediate igneous and metamorphic rocks containing feldspar and ferromagnesian minerals. The three most important groups of clay minerals are Montimorilonite, illite, and kaolinite (Chen, 1988)

African black clay soils causing the most severe problems have formed over basic volcanic rocks, which are geologically, relatively recent in their origin (Morin, 1971). Ethiopian black clay soils have formed over Tertiary to recent basltic volcanic rocks. Ethiopian black clay soils are found in areas with poor drainage and low to moderate rainfall and contain Montmorillonite as the principal clay mineral with accessory Kaolinite and Halloysite (Morin and Parry, 1971). According to the same authors, the black clay soils are principally residual, derived from the weathering of basic volcanic rocks, which cover much of the Ethiopian plateau. The volcanic rocks do not form significant gravel size and sand size material on weathering to form soil. The soils are invariably clays or silty clays. Rarely distinctions could be observed within profiles.

2.9 Distribution of Expansive soils in Ethiopia

Potentially expansive soils can be found almost anywhere in the world and their problem is widespread throughout the globe (Chen, 1988). However, they are naturally occurring materials found in lowlying regions and flood plains. It is estimated that there are at least 280 milion ha areas covered by these expansive soils in the world located mainly in Africa, Australia, India and USA (Willcocks and Browning, 1986). Of the total area covered with expansive soils, 126.5 million ha are found in three African countries (Sudan, Chad and Ethiopia). However, in Ethopia as reported by Berhanu Debebe (1985) and cited in Abinet (2006), the expansive soils cover is about 12.6 million ha, or 10.3%. Fig. 2.1 shows the distribution of the vertisols in Ethiopia adopted by Srivastava et al. 2006 from Land use Planning and regulatory Department of the Ministry of Agriculture, Addis Ababa Ethiopia.

2.10 Remedial Measures for expansive soil

The remedial measures to be taken for a cracked building are simpler once the cause of foundation movement has been determined. Remedial measures to be taken differ in each case. According to Chen, 1988, the commonly remedial measures are as follow:

2.10.1 For distress caused by uplifting of drilled pier foundation

(i) Loosen soil around the pier to reduce the uplift pressure
(ii) Re construct void space beneath the grade beams
(iii) Eliminate the mash room at the top of the pier
(iv) Cut the top of the pier and adjust the pier by shims
(v) Remove all the back fills around the building and replace with compacted non expansive clay to protect surface water entering through the foundation.
(vi) Improve the drainage condition around the building by providing adequate slope away from the building and paving with concert.

2.10.2 For distress caused by uplifting of footing foundation

(i) Decrease the footing size to increase the dead load pressure
(ii) Under pin the pad with piers drilled in to the stable zone or bed rock

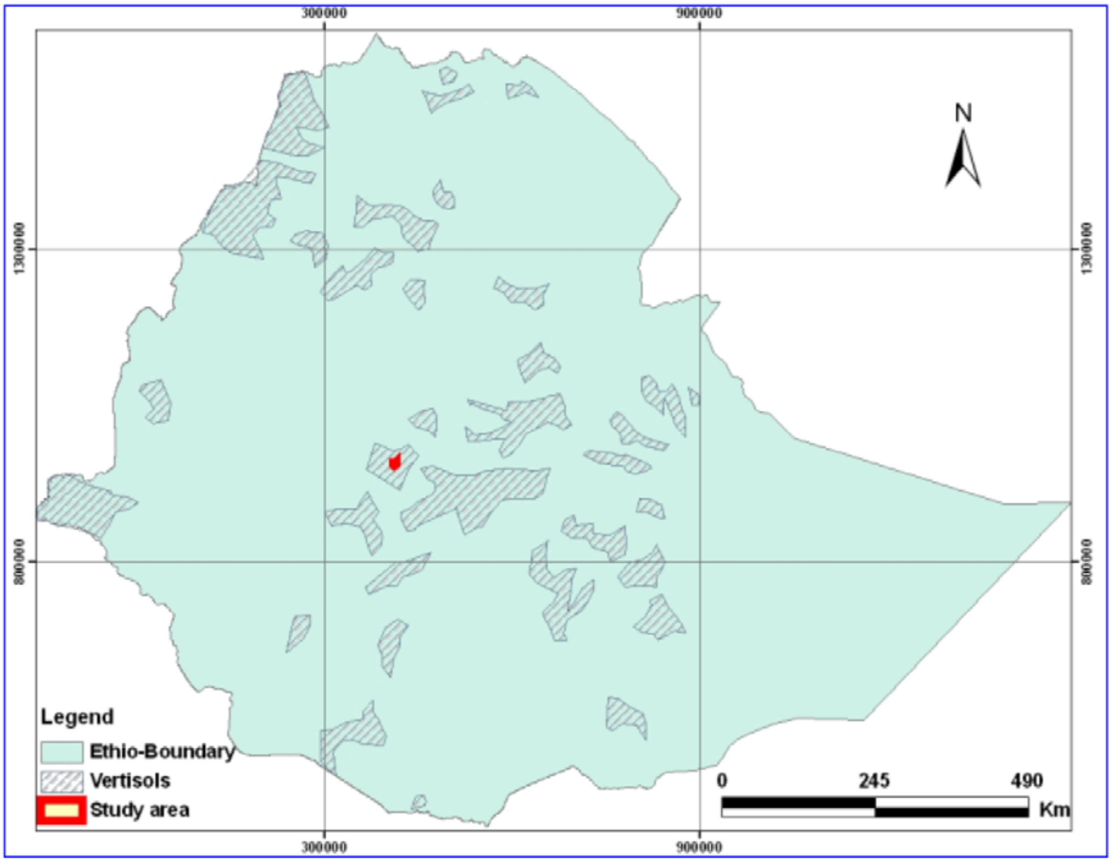

Fig 2.1 Vertisoil (expansive soils) distribution in Ethiopia

2.10,3 For distress caused by heaving of interior slab

(i) Allow free slab movement by providing space between the slab and grade beam or the foundation wall in case of basement.

(ii) Provide slip joints to interior slab bearing partition walls including doors frames and stair case walls.

(iii) Replace the soil beneath the slab with non expansive compacted soils

2.10.4 For distress caused by heaving of continuous footing

(i) Provide voids beneath continues footing at calculated interval to increase the dead load pressure. This can be done by removing soil beneath the continuous footing.

(ii) Reinforce existing foundation walls with new reinforced grad beams to tie the structure as in box construction.

(iii) Post tension the foundation walls to provide structural stability by preventing an equal movement.

(iv) Underpin the foundation with piers drilled in to a stable zone

The general remedial measures applied to all types' foundation movement are as follows;

(i) Provide positive drainage around the building.
(ii) Provide adequate outlet of all down spouts.
(iii) Remove and re compact non expansive backfill.
(iv) Provide concert aprons around the house.
(v) Relocate all lawn sprinkler heads to a distance at least 10ft from the building.
(vi) Remove all shrubs and flowers bed, which are planted adjacent to the house.
(vii) Provide proper sub drain around the building below the lower floor slab.
(viii) Provide a positive outlet for sub drains.
(ix) Maintain any leaking pips around the building

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CHAPTER III

GENERAL DESCRIPTION OF THE STUDY AREA

3.1 Location of the study area

The study area forms a part of Tulu Bolo town which is about 80 km on the way to Jimma from Addis Ababa. The area forms a part in Oromia regional State of Ethiopia. It covers the entire settlement and future extension areas, as per the master plan of the Tulu Bolo town. The total area of the town is nearly eight square kilometer. The study area, is bounded with in coordinates 412200 E, 957000N and 956000 N, 415000E in a Universal Transverse Merkator coordinate system and 8^{o} 49' 12'' N. and 38 ^{o} 10' 49'' E and 8^{o} 38' 29''N, 38 ^{o}13' 38''E in a geographic coordinate system (Fig. 3.1).

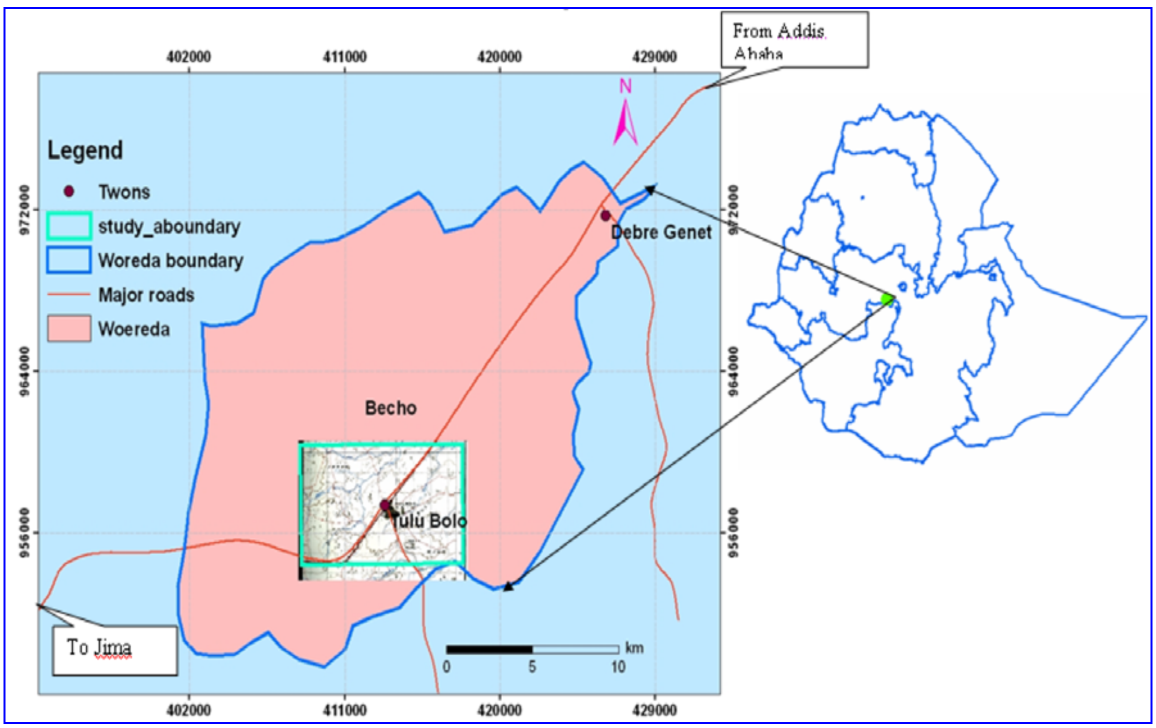


Fig. 3.1 Location Map of Study area.

Tulu bolo town is found in a large flood plain called Becho plain where Awash River originates and the study area forms a part in flood area of Awash. Most of the towns and roads found in this flood plain area suffer cracking problem which probably is associated with the nature of the soil present in the flood plain area. The study area is found at the margin of this flood plain. In addition it is surrounded by highlands and in general, the flow direction for surface and groundwater is towards the study area. Moreover, most of the study area is covered by expansive soils in which the presence of surface and groundwater induces soil swelling and leads to development of foundation problems associated with buildings and roads in the study area.

3.2 Topography and drainage of the study area and its surrounding

The study area is located in a flat area and is bounded with wider chain of hillsides in the northern, eastern and western parts. All the water draining out of the highlands is concentrated in the bottom plains where the town and roads are located. This creates great impact on accessibility especially during the rainy season. The Morphological setting of the area is dominantly flat and has an implication that the area is flood plain and is covered by mainly expansive soils.

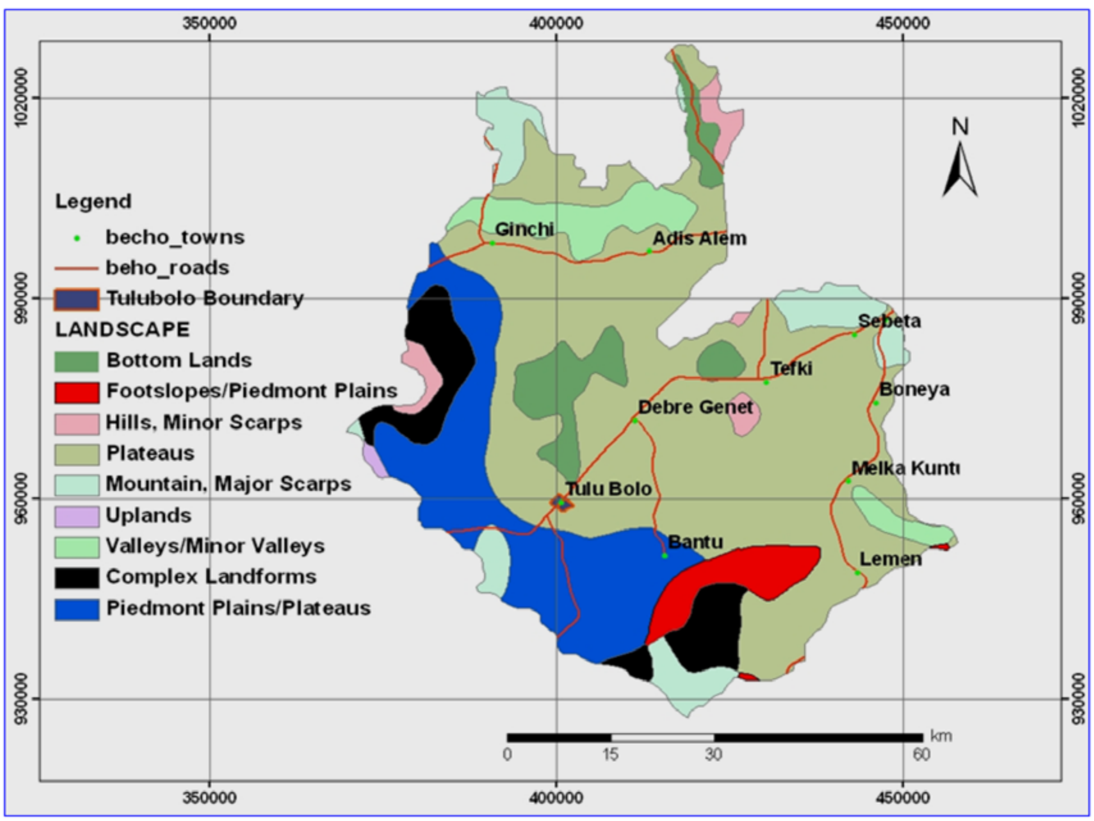


Fig.3.2 General Landscape of the study area and its surroundings

It is already expressed in the literature review (Chapter II) that expansive soils are very common in low laying areas. Moreover, the area is commonly affected by flooding, especially during rainy season.

Three dimensional view of the topography of the surrounding area reveals that the drainage from the surrounding area is towards the study area. In the study area road transport during rainy season is consistently hindered due to water logging which mainly resulted from poor drainage condition in the study area.

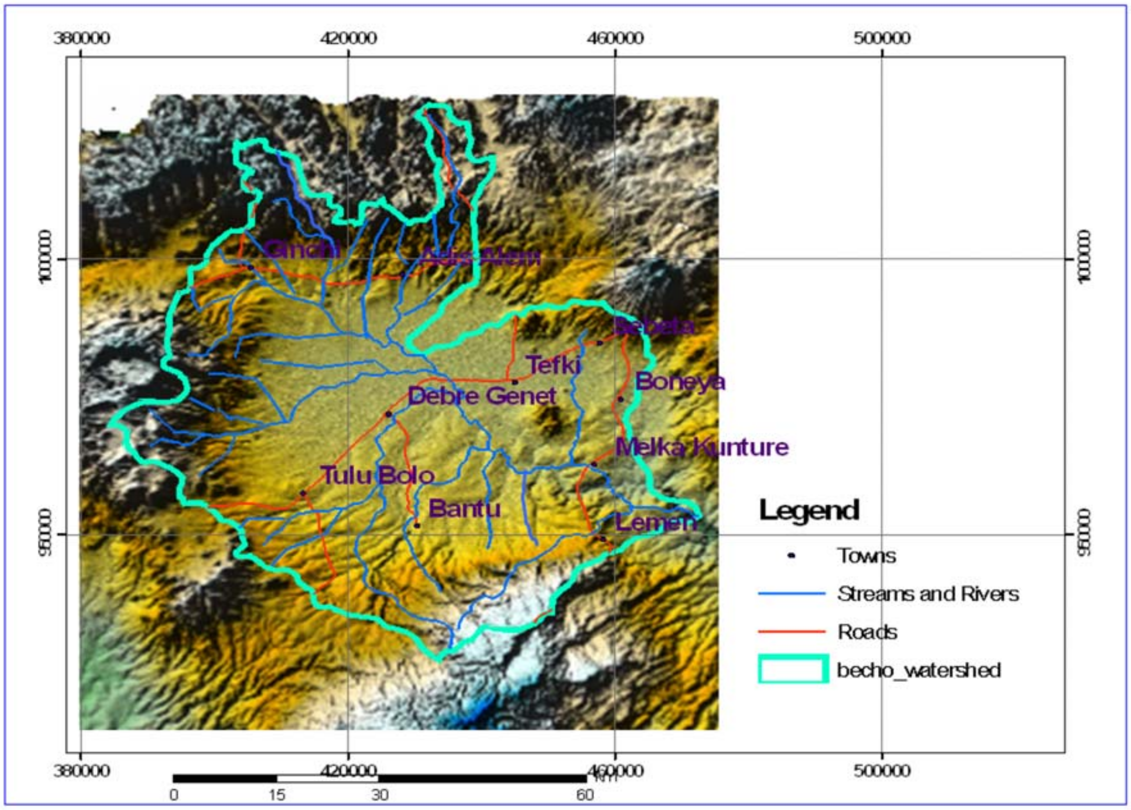


Fig. 3.3 DEM and drainage map of the study area and its surroundings

3.3 Geology of the study area and its surroundings

3.3.1 Regional Geological formation and setting

Ethiopia can be divided into four major physiographic regions; the western plateau, southeastern plateau, the Main Ethiopian Rift and Afar Depression. The Ethiopian plateau underlain, at depth by Precambrian rocks of the Afro-Arabian Shield. The Precambrian basement is covered, for the most part, by glacial and marine sediments of Permian to Paleocene period and Tertiary volcanic rocks with related sediments. The Cenozoic volcanic succession is split apart by parts of the Great East African Rift-System in Ethiopia (i.e. the Afar Depression, Main Ethiopian Rift and related rifts).

Precambrian basement exposures are found in areas not intensively affected by Cenozoic volcanism and rifting and where the Phanerozoic cover rocks have been eroded away. Precambrian rocks outcrop in four major regions around the plateau margins. These areas are in Tigray region in the north; along the Sudan border in Gojam, Wollega, Illubaor and Kefa regions in the west, in Sidamo and Bale regions in the south and in Harerghe region in the east. Two major lithotectonic assemblages have been recognized in the Precambrian basement in Ethiopia similar to those recognized in the neighboring countries of northeast Africa and Arabian Peninsula. These are blocks of gneissic terranes and metamorphosed volcano-sedimentary belts associated with minor ultramafic bodies and intrusives ranging from mafic to granitic in composition.

Intrusions of alkaline magmas of Tertiary age are related to the early phases of rifting in the Afar are also remarkable. Following the Proterozoic to Early Paleozoic tectonic and magmatic activity, peneplanation of the metamorphic basement took place until Carboniferous and Permian (Mengesha et.al.,1996). Late Paleozoic to Early Mesozoic sediments such as Enticho Sandstones, Edaga Arbi Glacials in northern Ethiopia Permian eastern Ethiopia (Mengesha et.al.,1996) and Gura Sandsotne in southern Ethiopia accumulated in shallow basin and narrow channels cuts in the Precambrian basement. Paleozoic continental sediments are also wide spread in Tigray, Harar regions and in the Abay River Gorge (Mengesha et.al.,1996).

Two major transgression-regression cycles took place during the Mesozoic era (Mengesha et.al.,1996). The first transgression started in the Early Jurassic or Late Triassic from the Ogaden region in the Southeast towards northwest and reached its maximum extent in Kimmeridgian. During this time Adigrat Sandstone, Hamanilei Formation, Abay Formation, Urandab and Antalo Formation were deposited.

The regression of the sea started towards the end of Jurassic depositing lagoonal facies of the Agula Formation in the north and Gabredare Formation eastern Ethiopia. The lowest most Cretaceous is represented by the Korahe Formation in Ogaden region. The second major transgression event took place in Aptian to Turonian depositing Mustahil Formation, Ferfer Formation and Belet Uen Formation. In the Late Cretaceous the second regression event took place depositing continental sediments, Amaba Aradom Formation.

A third and less extensive transgressive event took place in Late Cretaceous until Middle to Late Eocene deposing Jessoma Formation, Taleh Formation and Karkar Formation in the eastern part of the country.

In the course of the development of parts of the Great East African Rift System in Ethiopia, a variety of continental sedimentary basins were developed since Miocene. In the Afar Depression, sediments originating from the rapid erosion of the steep escarpments together with abundant volcanic products tended to fill the depression but tectonic deepening was more rapid than volcano-sedimentary infilling. Plio-Pleistocene fluvo-lacustrine sediments are also widespread in the Ethiopian Rifts. In the MER, lacustrine sedimentation is wide spread during the pluvial periods of the Quaternary.

Figure 3.4 Shows the Regional geological Settings of Ethiopia. According to this Figure the present study area, Tulu Bolo town, falls all in all on Quaternary- Tertiary rift sediments and volcano but the larger watershed becho catchment falls in to two geological settings these are Teritiary highlands volcanoes and the remaining part is Quaternary- Tertiary rift sediments and volcano.

The geological map of Ethiopia has been taken from the “Geological survey of Ethiopia” at a scale of 1:2, 000, 000.

3.3.2 Geology of the study area

Since the study area is very small in area and on the contrary the geological map of Ethiopia adopted from Exploration of the Geological Map of Ethiopia” is very small in scale consequently it is very difficult to see the details of the geological setting of the study area. Therefore the specific geological setting of the area was adopted from FAO (Food and Agriculture Organization) 1975 report which is done at a scale of 1: 1,000, 000. However, the geological setting of the area is not very complex. The dominant geology of the area as per Food and Agricultural Organization (FAO Report, 1997) is basaltic rock. In principle the host rock for the expansive soils is basalt.

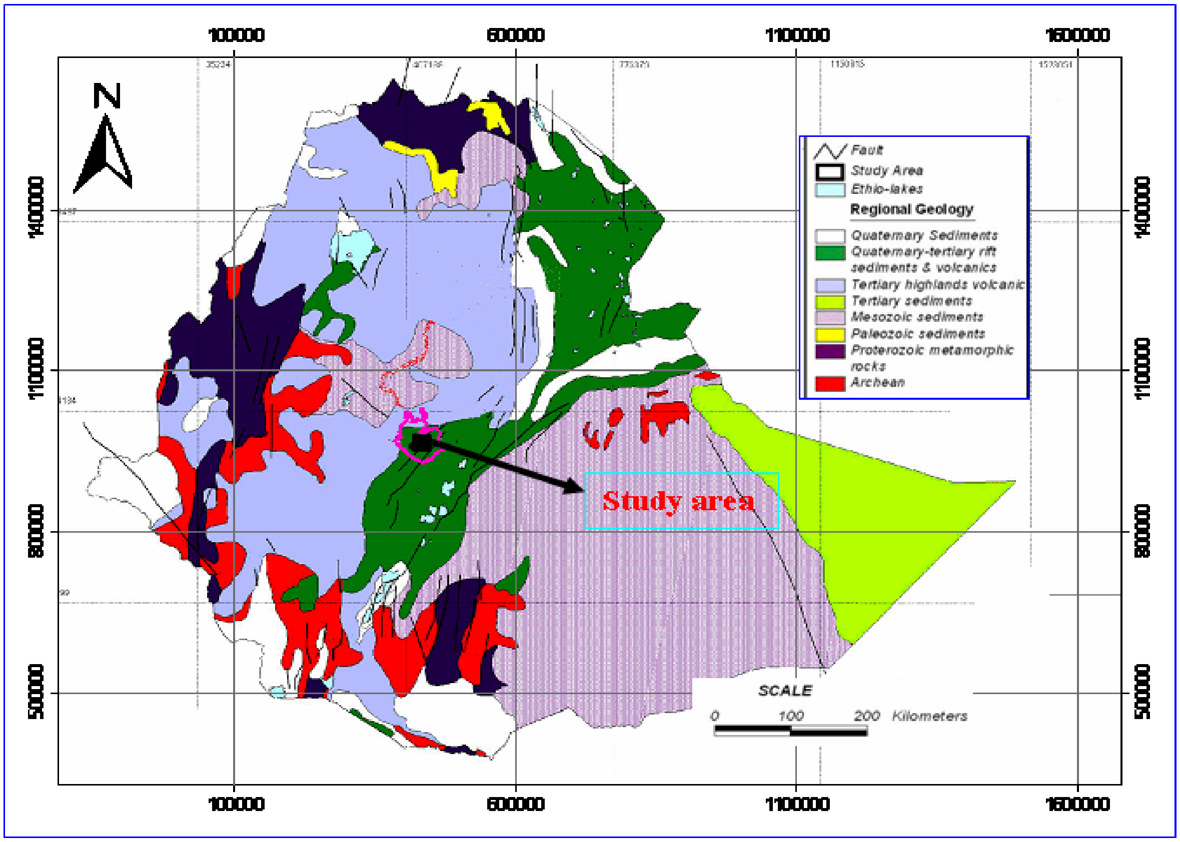
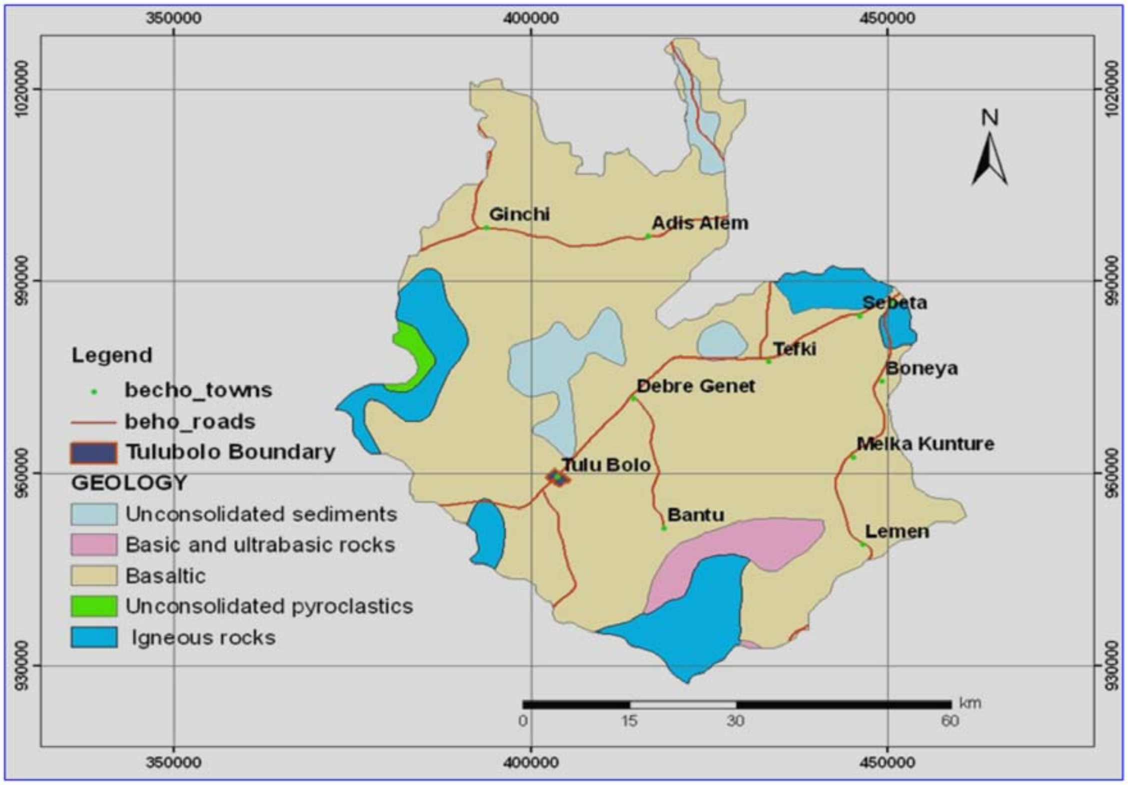


Fig. 3.4 Regional Geological Setting

Even though, the dominant geology of the area is basalt rocks there exist some pyroclastic rocks which are found in the area. Nevertheless there are unconsolidated sedimentary and ingenious rocks in the Northern and southern part of the study area, respectively these accounts insignificant percent as compared with the basaltic rock covers.

3.4 Soil of the study area and its surroundings

The soil of the surrounding and the study area follows the geological setting of the area and can be generalized by a single soil type i.e. Vertisol. The flood plain, which comprises the study area is totally characterized by Cambic vertisol. Even though there are other types of soil found in the surroundings most of them are vertic in nature. In principle shrinking and swelling are the main properties of vertisols when they dry and wet respectively which is the property of expansive soils. From the soil coverage point of view the area has got a major problem of expansive soils because almost all part of the study area is covered by expansive soils.



(*Source: The digital soil and Terrain database of Ethiopia FAO, Version 1.0 April 3, 1997)*

Fig. 3.5 Geological map of the study area and its surroundings

Below are pictures which are taken from the area during field work of the study. These pictures are evidences which explicitly indicate the presence of expansive soils in the area. These pictures are taken in the beginning of the rainy season when moisture variation is supposed to be nearly minimal.

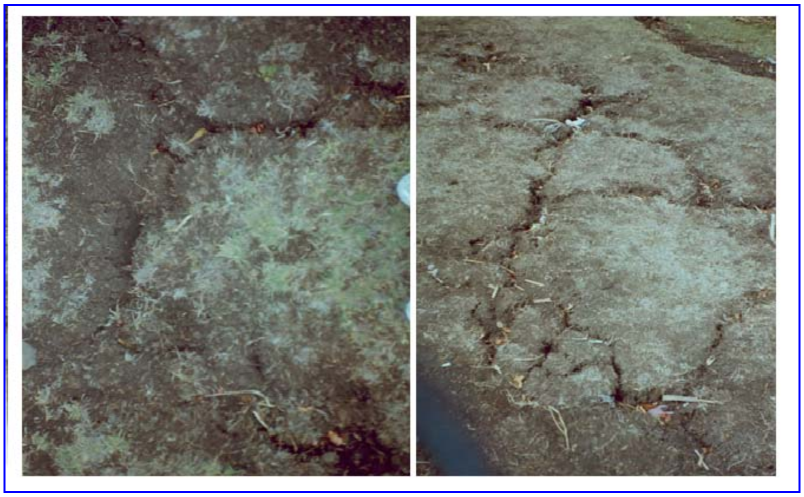
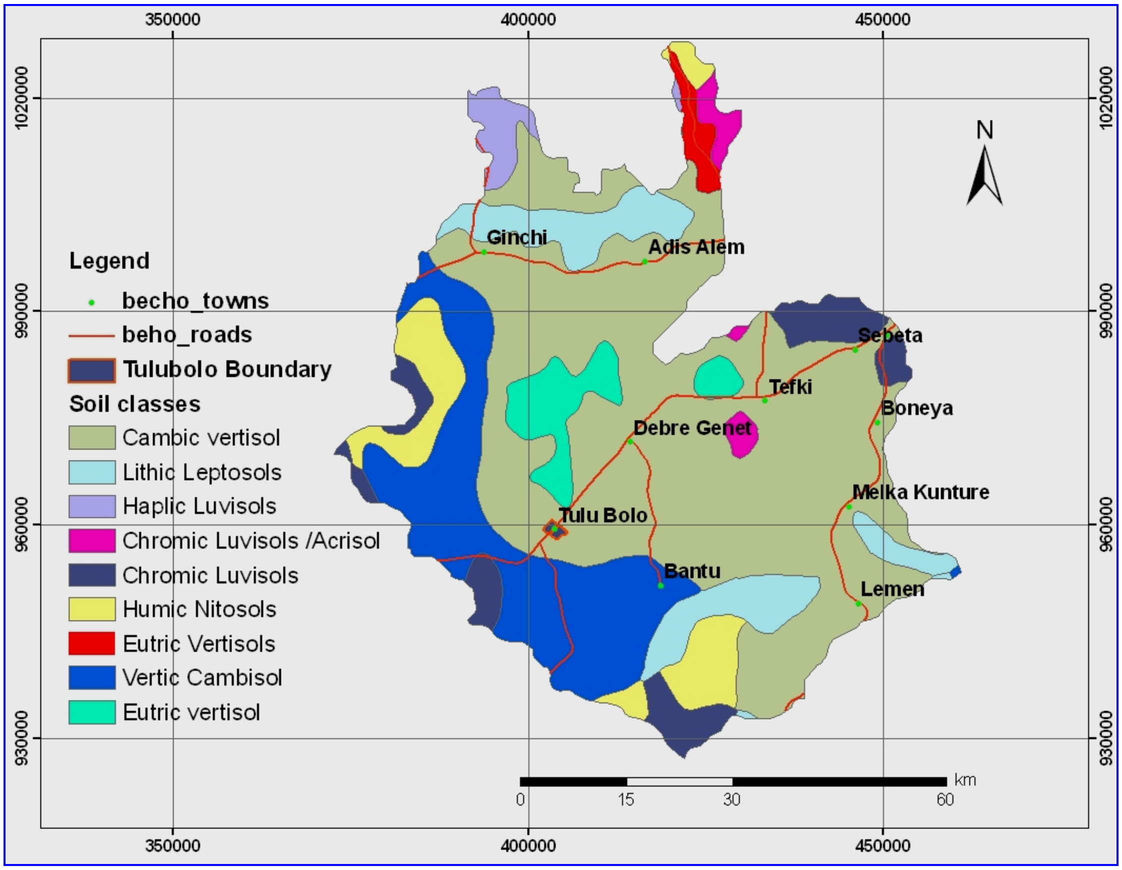


Fig. 3.6 Soil picture taken in the field (cracking soils)

If the pictures would have been taken during the middle of the dry season the width and depth of cracks would have been very big. However it is un-doubtful that the soil of the town is characterized as vertisol.

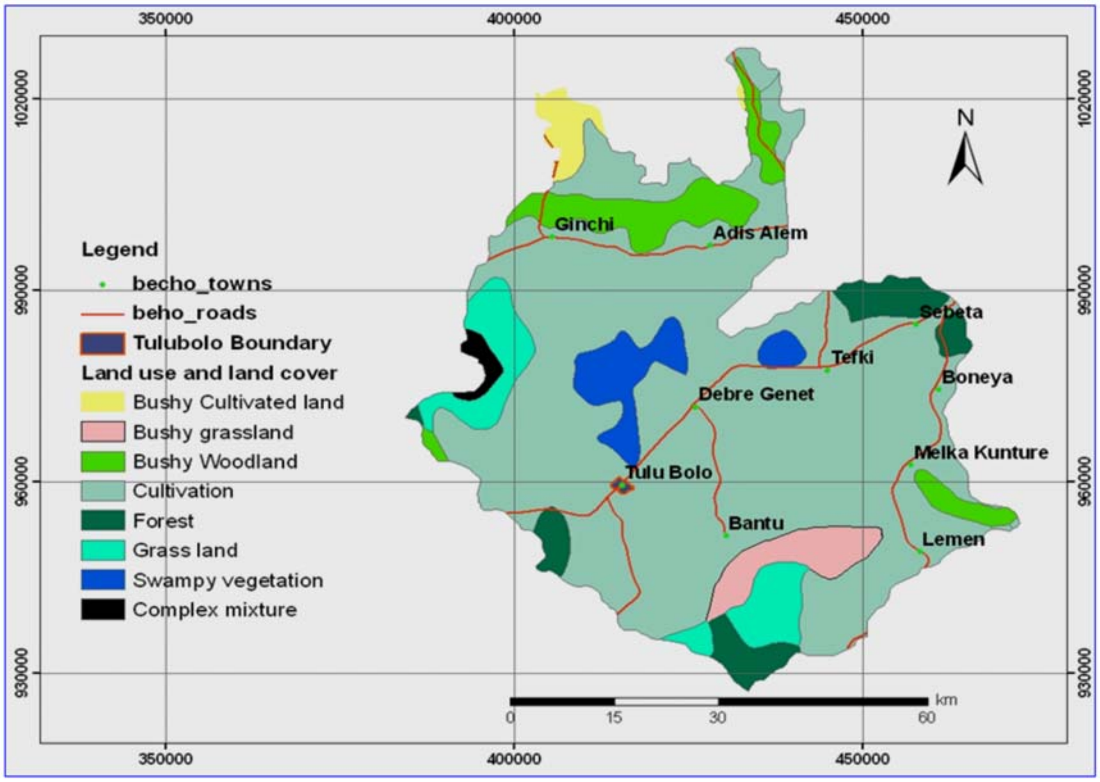


(Source: The digital soil and Terrain database of Ethiopia FAO, Version 1.0 April 3, 1997)

Fig. 3. 7 Soil map of the study area and its surroundings

3.5 Land use and Land Cover of the study area and its surroundings

The land use and land cover of the area is also characterized by generally as cultivation area except some grass land and patch of forests in the north and southern part of the town do exist respectively. There is a swampy vegetation area near by the town and at the middle of the becho plan. The town is surrounded by an extensive cultivation areas where vegetation especially forest cover is insignificant or almost none. This in turn makes the town susceptible to various geo-hazards like flooding and other problems. As per the recent master plan of the town the land use of the town is not completely covered by houses but there are portions of the town where bare land (open lands), Eucalyptus tree cover and grazing land and small (garden) cultivation areas exist. For more clarification of the land use of the town, refer the figure below which is the latest master pan of the town.



(Source: The digital soil and Terrain database of Ethiopia FAO, Version 1.0 April 3, 1997)

Fig. 3. 8 Land use and Land cover map of the study area and its surroundings

3.6 Climate of the area

The rainfall of the area has two distinct seasons with the lesser rains occurring between March and May, usually entertains light rains. The big rainfall months are from Jun through September. The rainfall of three neighboring stations of the Town was taken to understand the rainfall of the area and its surroundings. These are Sebeta, Teji and Tulu bolo Meteorological stations. All the records and their temporal variations are presented in the Annexure part of this paper. The records of all the stations (from 1989 to 2004) show that there is negligible variation of records between the stations except one extreme event during 1982 and 1985 for Sebeta and Teji station respectively when there was a big rainfall record found in these stations otherwise the stations show that there is nearly similar trend of rain fall in the past two or more decades.

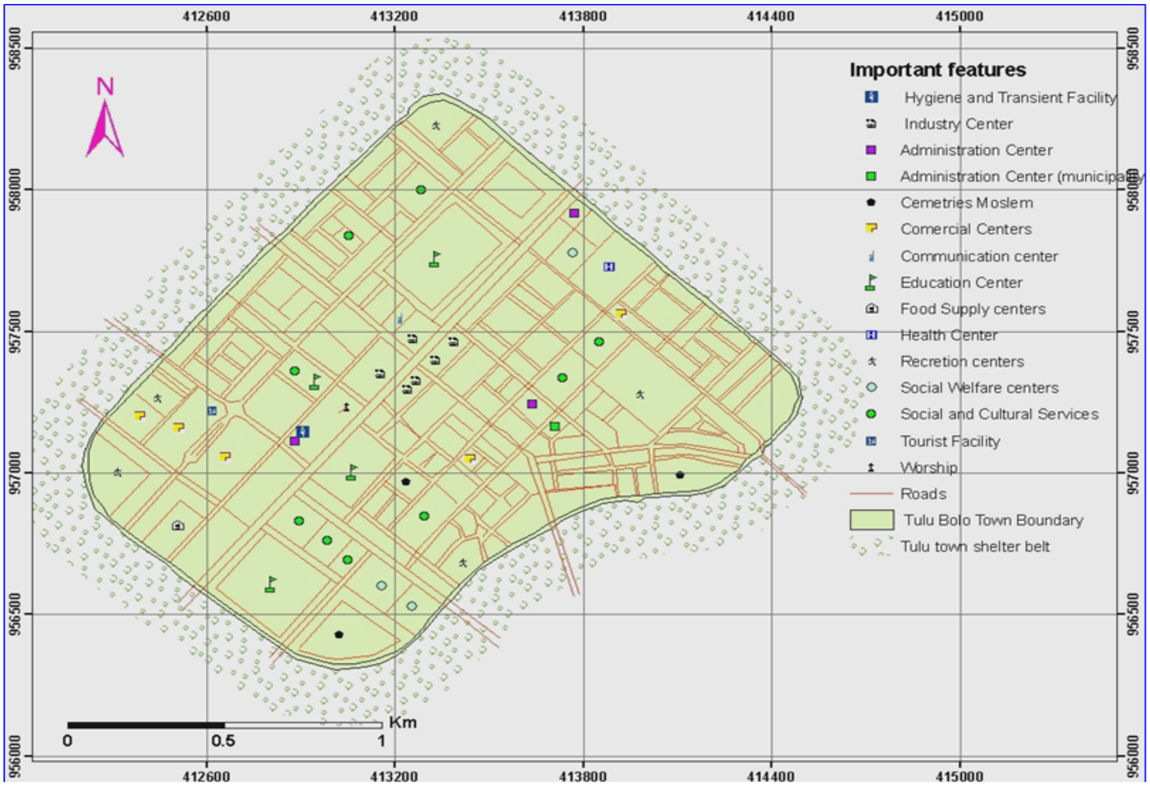


Fig. 3.9 Master plan of Tulu Bolo Town

The most important thing for the problem of expansive soils is seasonal variation of moisture in the soil in conjunction with the property of the soil. In this regard the seasonal variation of rainfall in the area is significant. As the variation is presented graphically in fig 3.8 the summer season rainfall is by far larger than the rainfall in the winter season and this variation with expansiveness of the soil property creates cracks and failure to buildings foundation.

The fluctuation of monthly temperature is also relatively small. The monthly mean temperature ranges between 12.2^{o}C and 16^{o}C. However the daily fluctuation of temperature is remarkable great. The minimum and maximum temperature in a day record varies between -2.4^{o}C and 2^{o}C. This in turn has an impact for expansive soils to crack and swell and in turn results foundation problems of buildings. Generally, according to the Geological Society of Ethiopia (1997), the climatic condition of the area can be grouped as Tropical Wet-Dry climate.

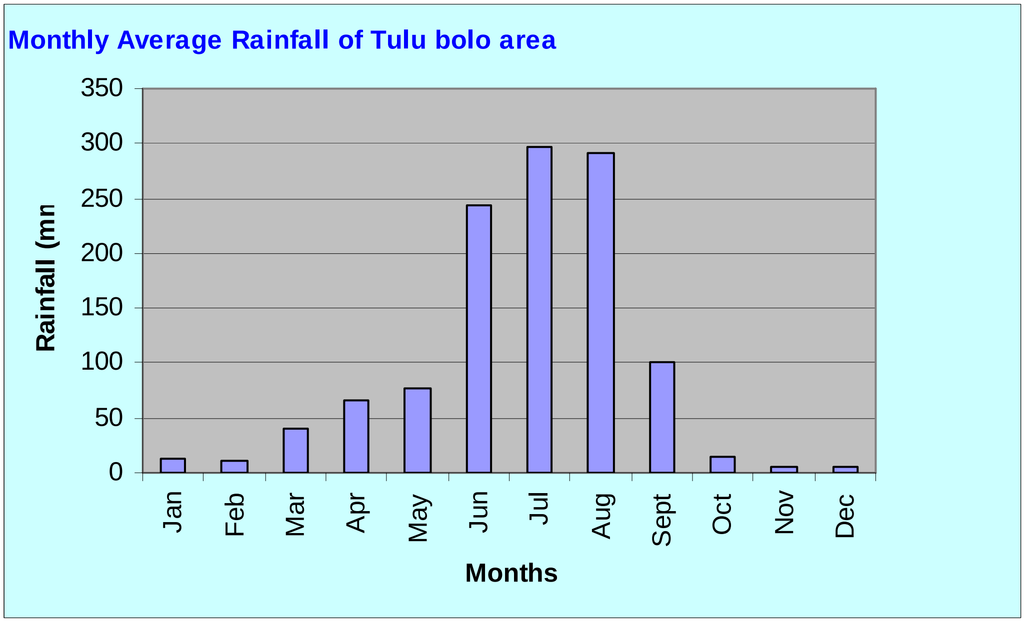


Fig. 3.10 Average monthly rainfall of Tulu bolo

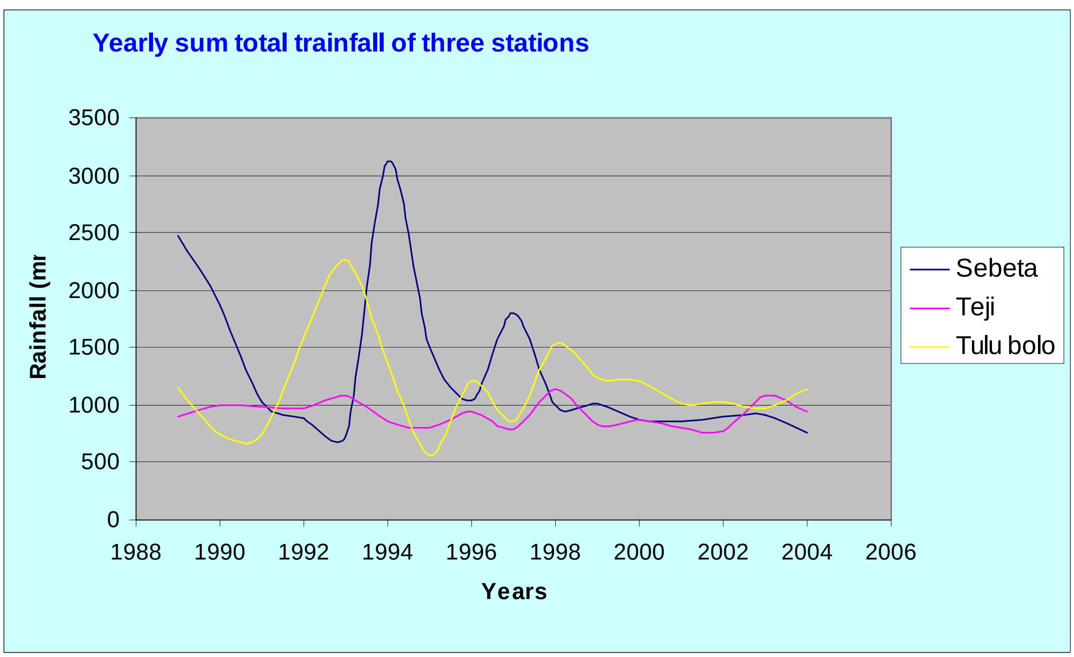


Fig. 3. 11 Sum total yearly rainfall of the three stations around the study area

CHAPTER IV

FACTOR RESPONSIBLE FOR BUILDING FOUNDATION FAILURE

4.1 General background

Identification of key factors for proper design of buildings is to understand anticipated causes of failures and the necessary remedial measures to minimize or avoid the damages caused by them. Though the sensitivity of the factors for the development of cracks on buildings could not be quantified in the present research due to limitations on time and resources, still an attempt is being made to describe the observed factors quantitatively. This section highlights various factors responsible for buildings construction failures.

4.2 Factors responsible for buildings foundation failure

The primary purpose of any foundation is to transmit the loads of the superstructure to the foundation soil in such a way that the bearing soil is not overstressed under any condition. The behavior of soil, in general, varies with saturation conditions. This variation is significant particularly with expansive soils, when the soils are subjected to moisture variations. Thus, the following factors are responsible for building foundation failure;

(i) Shrinkage and swelling of clay soils resulting from moisture change.
(ii) Type of the clay size particles.
(iii) Drainage-rise of ground water or poor surface drainage.
(iv) Load or Compression of the soil strata resulting from applied load.
(v) Pressure of backfill soil.
(vi) Soil softening.
(vii) Climate.
(viii) Location and Vegetation

The evaluation of the above factors may help to minimize the damage caused by expansive soils on buildings. Holland and Richards (1982) summarized the following major factors that affect the magnitude on volumetric changes of clay soils.

4.2.1 Type and amount of clay

The basic mineral, its surface chemistry and the fabric of particular clay together with the salt concentration of the soil water, generally determine the potential for heave. For engineering purpose the type of clay is easily determined indirectly from linear shrinkage or plasticity index and is often related empirically to potential heave. The clay content can also be seen to affect the magnitude on heave. The clay content of the study area and its type, as can be evaluated from visual observation, is very large and shows swelling and cracking when wet and dry, respectively.

4.2.2 Soil thickness

The soil thickness and the location of potential expansive clay layers in the soil profile considerably influence the seasonal heave. If the expansive clay is overlain by a layer of non-expansive topsoil or overlies bedrocks at a shallow depth, the swelling of clay will be greatly reduced. The greatest seasonal heaves likely to occur where potentially expansive soil exists from the surface to at least the depth of equilibrium moisture level.

Previous studies in the study area confirmed that the thickness of the expansive soils of the area is 3m or more on the contrary the equilibrium moisture level identified in the area is below 1m. Therefore, there exists more than 1m moisture deficient zone between the surface and the moisture equilibrium level. Hence, thickness of the soil in the study area has a great influence on expansiveness of the soil (Abinet, 2006).

4.2.3 Site drainage and ground water

When a site is slopping and well drained, the rain falling on it will mostly run off, therefore, the clay will not have a chance to wet up significantly and therefore little seasonal heave will occur. Alternatively, if a site is flat and waterlogged during the rainy months of the year, significant wetting up of the clay will occur, leading to substantial heave. Improvement of site drainage can, therefore, dramatically reduce the magnitude of seasonal heave.

The topography of the study area, which defines the drainage condition, in the area is flat and this leads the soil to seasonal moisture variation and induces cracking and swelling.

Reports of Nippon (1995) have shown that nearly all the investigated wells fall in an area lying below the 2080m contour line. Generally the depth of water table varies from 0.5 to 15.15m. Static and dynamic water levels were 7.43 and 55.33m, respectively. With the low relief of the area, the slow rate of groundwater fluctuation and the depth of the groundwater, it may be concluded that the groundwater has a minimum influence on building foundations in the study area.

4.2.4 Climate

In General, potentially expansive clay soils will only swell and shrink if the prevailing climatic factors lead to significant seasonal wetting and drying. The prevailing climatic condition in the study area has its contribution to moisture fluctuation within the expensive clay underlying buildings. The current climatic conditions display a marked maximum rainfall followed by prolonged dry period, as discussed in Chapter 3. Therefore, it can be said that the physical conditions of soil is linked with the annual climatic variation in the study area.

4.2.5 Loading

Comparatively small loading will significantly reduce clay soil swelling effect. Damage due to underlying clay heave is usually restricted to light-loaded structures. In the town the load of buildings is limited however the damages of expansive soils is still there. Therefore, this confirms that it would be a serious problem for building foundations if heavy buildings were constructed in the town in near future, provided they are not deeply founded.

4.2.6 Location and type of vegetation

Trees and large shrubs draw moisture via their root system and transpire this moisture after removing nutrients from it to the atmosphere. The removal of soil water from clay soils dries the clay (or increases the soil water suction) and causes shrinkage. This leads to localized settlements over the volume of clay from which the tress has drawn the moisture. It is commonly acceptable that tree's root system can spread and causes clay drying up to its height laterally for a single tree and up to one and half times the tree height if planted in a line or a group. The root systems of large shrubs can also dry clay soils up to their height laterally. Root systems tend to spread even further under foundation and where shallow bedrock exists (Abinet, 2006).

Barry (1986) suggested that a certain species should not be planted within building reserves on expansive soils. Among the suggested species Eucalyptus trees were named as a being unsuitable because of their wild growth and observed detrimental effect on buildings. In this regard Eucalyptus trees are dominant in the town and some sections with very wide cracks were observed close to the lines of Eucalyptus trees. Eucalyptus tress are described as being unsuitable because of their wild growth and observed detrimental effects on buildings.

4.2.7 Others

In addition to the above factors there are factors, which aggravate the situation, of which the common problems observed in the study area are poor design, improper design, improper construction, Lacking proper Maintenance and Construction interruption.

Poor design: Designing of structures with little knowledge and experiences of expansive soil can worsen a readily manageable situation. Due to low level of knowledge of the mechanics of heaving and wrong concept of safety associated with conservative design, aggravate the situation. It is not common by house builders considering the dead load pressure with the up lift force produced by the swelling soils pressure. Lack of doing this worsens the situation of foundation failure in the study area.

Improper construction: Construction problems associated with expansive soils are mainly lack of reinforcing steel or insufficient or improperly placed reinforcing steel or inadequate void space between the soil and grade beam. It is also a common practice to compact foundation soil believing that it will have a higher bearing capacity. However, compacting of expansive soil during construction increases the density and results in a higher swelling pressure. This was a common problem in all buildings sites in the study area.

Maintenance failure: Surface water leaking pipe and subsurface drainage are the main sources of moisture disturbance of the foundation soil. Pipes around the building should not leak or assessment should be made of the monthly expense of water supply to know if there is water loss due to broken pipes. Breaking of pipe and splashing of water to the foundation is commonly observed in the study area, which results in moisture disturbance and develops swelling pressure in the foundation area.

Construction interruption: It is a common trend to do foundation or substructure part in one phase and supper structure in the next season due to financial problem of a house owner in Ethiopia. Buildings are designed to the final stage or condition. Construction interpretation results in failure even if the foundation is designed properly with the precautions to be taken for expansive soil. Due to construction interruption the dead load pressure, which counter balance the uplift force gets lower resulting in foundation movement. It is also common practice to pave the surrounding area after the construction is completed. Therefore, it is recommended to complete the construction in one season making all the precaution to be taken in expansive soil like proper surface and subsurface drainage systems.

Finally, it can be concluded that no single factor is independently responsible for the damages observed on the buildings in the study. However, it can be highlighted that all of the above mentioned factors are linked together in one way or another to cause damages on buildings in the study area. From the above discussions it is possible to conclude that the type of the soil and its thickness along with climatic condition of the area are the most responsible factors for building failure. Hence, the identification of factors may facilitate the selection of particular remedial measures.

4.3 Causes of cracks and foundation failures in buildings constructed on expansive soils

Cracks caused in swelling soil are wide open at the top and narrow at the bottom. The causes of foundation movement are moisture fluctuation of the foundation soil.

Normally, the first sign of foundation movement for a structure founded on expansive soil is the cracking of the floor slab, door bending, window stacking and cracks appearing in the exterior and interior walls and even in the ceiling. It is important to differentiate the different types of cracks and their causes in order to know cracks caused by expansive soils heave. It is difficult to construct an absolute crack free building, particularly in expansive soils. The type and their causes are different. Some of the cracks and their associated effects on buildings are discussed in the following paragraphs;

4.3.1 Crack due to shrinkage and expansion of the plaster work

Such cracks are hairline cracks, insignificant tilt of floor or change in levels and can be easily maintained. It mainly affects the aesthetic looks of the building. This type of cracks usually occurs and it is due to the stress induced by shrinkage or expansion of the mortar during drying.

4.3.2 Crack due to structural failure

These cracks are significant and caused due to improper design and or poor quality control. Besides functions and cost such cracks have psychological Impact on the owners and can be encountered in high-rise building and in non-expansive soil areas. Such cracks occur very rarely.

4.3.3 Crack due to foundation movement

These types of cracks are usually associated with expansive soil, which can exert a pressure which moves the structure. It is commonly observed in lightweight buildings founded on expansive soils areas. Such cracks are abundant.

4.3.4 Cracks due to moisture change on expansive soils

Cracks are more readily noticed on buildings constructed on expansive soils. It is a case that cracks are caused on light weight buildings due to settlement. Settlement and shrinkage or heave crack can be distinguished by observing the width of crack as the climate changes. If cracks width changes from season to season, the crack is due to shrinkage and not due to settlement.

Houses with slabs foundation are affected by the climatic change and affected by changes in soil water. If the soil beneath the slab is wetter than the soil outside the slab, the moisture moves from under the slab towards the slab perimeter. The opposite happens if the soil beneath the slab is drier than the soil outside the slab (Afework, 2004).

4.4 Field (Visual) Observation of the Study Area

4.4.1 Soil Physical Properties

For the present study as a part of data collection and analysis visual observations on the soil, materials and foundation of buildings in the study area has been undertaken. This section highlights the most important observations that directly or indirectly relate with failure of the building foundations.

Building cracks

Based on simple observation it may easily be known that the area has a problem of expansive soils. The problem observed on buildings varies from simple crack on walls to sever structural damages, which cause collapse of the whole building. Buildings especially those constructed from stone have suffered from cracks and has effected the performance of the building. The pattern of cracking on buildings as it has been observed in the town is commonly longitudinal crack. The degree of cracking in the town varies from buildings to buildings and from areas to areas. The spatial variation of cracks on buildings is not uniform but linked with the nature of soil variation in the town. In this case expansive soils increases from south to north but it is not possible to link this variation with the cracks of buildings due to these expansive soils. Buildings are more concentrated along the left and right side of the road while buildings away from the road are not very much.

Along with the problem of the expansiveness of the soil in the town it has been observed that people constructing buildings on these expansive soils have little awareness about the expansive soils and its effects on the building performance. The other important problem observed in the town is improper design and foundation and use of poor materials for construction in relation with the nature of the soils. Most of the buildings in the town are founded at shallow depth with poor filling materials and improper arrangement.

The problem of lack of knowledge on expansive soils in the area should be solved by undertaking such kind of research and disseminating the results so that people should build their houses with proper foundation design and able to apply proper remedial measures.

Physical properties of the soil

The property of the soil in the town is not complex since the town is located in a flat area where most of the soil is nearly similar therefore it is possible to generalize the property of the soil by simple observation. The soil of the study area reveals swelling and cracking where expansive nature is very common as the type of the soil is Vertisol. However to characterize in detail the properties of the soil of the study area, four samples and with each samples from 0-1m and 1-2m depth were collected and laboratory analysis were carried out. In general, during field observation the nature of the soil has been evaluated on the basis of the color of the soil. The color of the soil varies from place to place. The color of the soil is largely the result of the presence of organic matter content or certain minerals, which could influence the swelling potential of the soil. The presence of organic matter results the color of the soil to be dark colored particularly to wards the surface of the soil that diminishes with increasing the depth of the soil. Fig. 4.1 shows the generalized classification of the soils on the basis of color in the study area.

4.5 Soil Laboratory analysis and results

4.5.1 Grain size analysis and distribution of the soil

The inherent swelling potential of a soil is directly related to the total amount of clay mineral particles (particles that are < 2 micro meter in diameter) in it. The swelling potential increases with increasing of clay minerals. Moreover, particle size distribution of soil minerals are critical for getting hold of many soil properties such as water holding capacity, rate of movement of water through the soil, kind of structures of soils, bulk density and cohesion of soil. All these are important in the identification of expansive soils. The distribution of particle sizes larger than 0.002 mm is determined by dry sieve, while a sedimentation process using a hydrometer determines the distribution of particle sizes smaller than 0.002 mm.

The grain size analysis consists of shaking the soil through a stack of wire screens with opening of known size. The definition of particle diameter for a sieve test is the size dimension of a square hall.

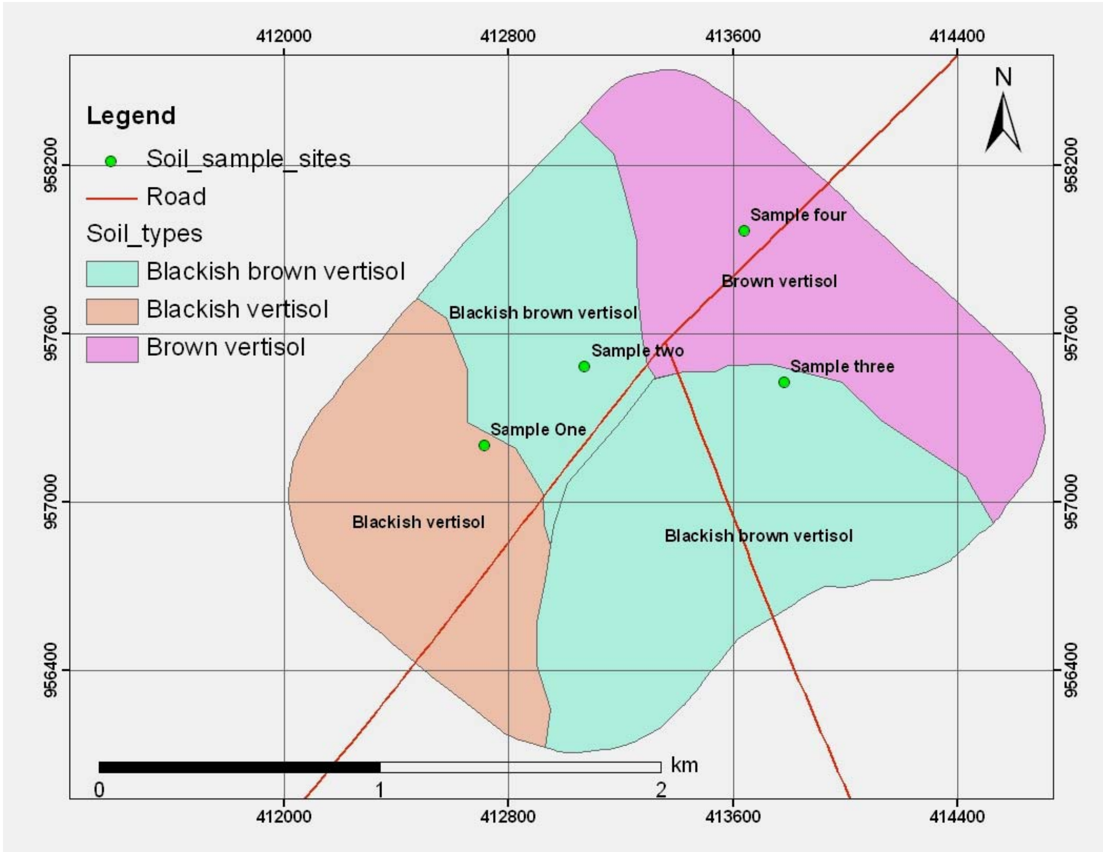


Fig. 4.1Generalised classification of soils based on colour in the study area

The hydrometer method is based on stokes equation, which tries to determine the velocity of a freely falling sphere. The definition of particle diameter for a hydrometer test is, therefore, the diameter of a sphere of the same density as the soil particle, which falls at the same velocity as the particles in question. In this study both methods (sieve and hydrometer) were employed and the particle size distribution is presented in Table 4.1and figure 4.2.

The result of the grain analysis helps to determine the type of the soil and eventually to judge the nature of expansiveness of the soil and its impact on foundation of buildings. From the result above soil sample one (SS1), is characterized as organic and in organic clay soil, Soil sample two (SS2), Organic and in organic clay soils, Soil Sample three (SS3) in organic clay soils and Soil Sample four (SS4), organic and in organic clay soil and all are high plasticity soils. The soil has been classified following Unified soil classification system (USCS). The soils of the study area falls mainly into two groups Inorganic clays of high plasticity (CH) and Organic clays of medium to high plasticity (OH).

Table 4.1 Laboratory test result of Grain size distribution of the soil

Type of Analysis		Location & Depth							
	Sieve Size	SS1 0-1mt	SS1 1-2mt	SS2 0-1mt	SS2 1-2mt	SS3 0-1mt	SS3 1-2mt	SS4 0-1mt	SS4 1-2mt
	4.75 mm	100	100	100	100	100	100	100	100
Sieve analysis	2.00 mm	99.23	99.93	99.72	93.61	100	99.98	99.92	99.88
	0.425 mm	96.56	98.91	97.69	89.60	99.04	99.72	97.85	99.40
	0.150 mm	93.58	96.94	95.73	87.66	97.49	97.73	95.06	98.00
	0.075 mm	91.62	94.36	94.04	86.78	95.09	95.57	92.71	96.05
Hydrometer analysis	0.0117 mm	89.88	85.22	89.72	86.00	93.13	68.27	92.18	95.27
	0.00747 mm	88.16	80.00	86.27	77.29	86.10	56.02	86.96	91.81
	0.00438 mm	77.78	73.04	79.37	72.46	80.83	45.51	80.01	84.88
	0.00313 mm	69.14	66.09	70.74	64.41	73.80	33.26	78.27	79.68
	0.00224 mm	65.68	60.87	63.84	59.58	70.29	32.25	67.83	74.49
	0.00109 mm	53.58	48.69	51.76	48.31	59.74	47.00	53.92	60.63
	0.00048 mm	46.67	38.26	44.86	38.65	54.47	43.50	48.70	53.70
Type of Soil USCS Classification		CH	OH	OH	CH	CH	CH	OH	CH

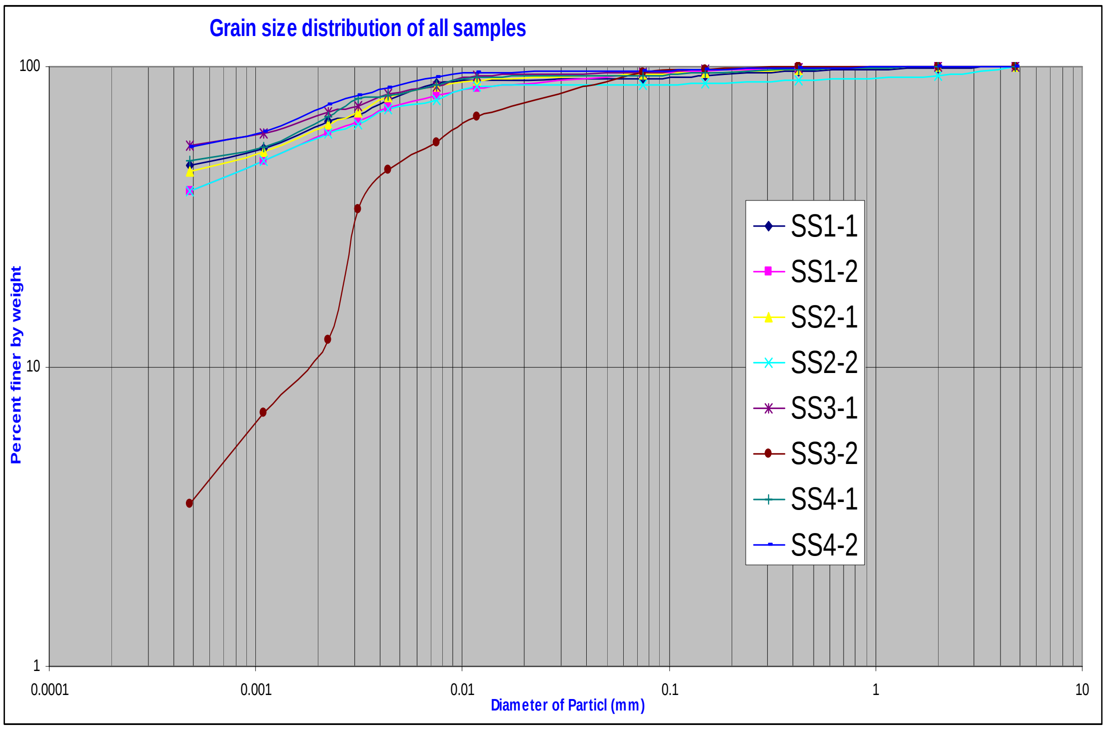


Fig. 4.2 Combined grain size distribution curve for 4 samples collected from the study area

Based on the engineering classification of the soils it is possible to assess qualitatively the general performance and workability of the soil for engineering use. According to Arora (1997) the soils with high plasticity (CH and OH) are impervious, highly compressible and possess poor shear strength (Table 4.3). Thus, with all these adverse engineering properties it may be concluded that the soils of the study area may not be suitable for building foundation.

Table 4.2 Soil type of the samples

Sample number	Depth	Percent of grain size (%)		
		Fine Sand	Silt	Clay
SS1	0-1m	0	35	65
	1-2m	0	29	71
SS2	0-1m	0	32	68
	1-2m	0	28	72
SS3	0-1m	0	36	66
	1-2m	0	30	70
SS4	0-1	0	35	69
	1-2m	0	30	74

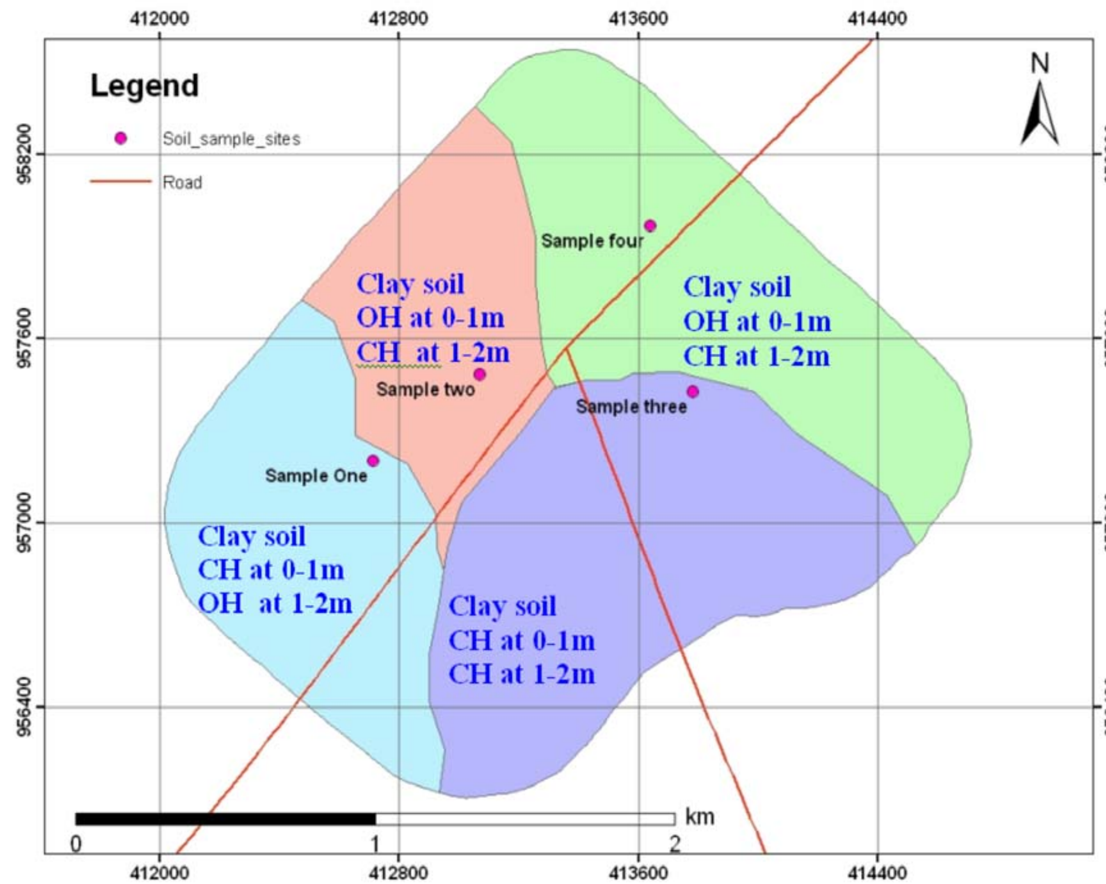


Fig.4.3 Soil type and classification as per USCS of the study area

As from the classification results it has been found that the soils fall in CH and OH groups. High compressibility of the soils of the study area may result into excessive settlement, which may be of differential nature resulting into development of cracks. Further, poor shear strength may result into poor bearing capacity of the soils which again may result into failure of foundation and structure. Moreover, soils falling into CH and OH groups are in general impervious in nature which suggests the soils will be saturated for longer duration which may further result into swelling tendency and exerts an upward thrust over the foundation. This may result into development of cracks. The swelling potential of the soils of the study area is later discussed in this chapter.

Table 4.3 General engineering suitability of High plasticity soils

Soil Group	Permeability	Compressibility	Shear strength	Workability
CH	Impervious	High	Poor	Poor
OH	Impervious	High	Poor	Poor

(Source: Arora, 1997)

4.5.2 Atterberg limits

When soils are remolded over a wide range of water content, the consistency can vary to a great extent. This behavior can be observed from its performance during the Atterberg limits determination. Atterberg established the four states of soil consistency, which are liquid limit, the plastic limit, the semisolid, and the solid states. He also proposed a series of tests for determination of the boundaries known as Atterberg limits between the physical states of soil. Each boundary or limit is defined by the water content that produces a specified consistency (Afework, 2004). In this study from all these limits the following were determined for evaluation of expansiveness of the soil.

Liquid limit Liquid limit is the water content at which a soil changes from liquid state to plastic state. The laboratory test of the samples had resulted the Liquid limit values which are shown in Table 4.4.

Table 4.4 Liquid limit values of the soil

Soil Sample No	Depth of Sampling	Liquid limit (%)
SS 1	0 - 1	72
	1 - 2	98
SS 2	0 - 1	71
	1 - 2	101
SS 3	0 - 1	75
	1 - 2	101
SS 4	0 - 1	73
	1 - 2	84

Plastic limit Plastic limit is the water content at which a soil changes from the plastic state to a semisolid state. Gravel, sands and peat do not have plasticity character rather plasticity is the property of clay soils. Silt soils have slight plasticity around 20% and soils showing plasticity greater 30% are clay soils (Afework, 2004.)The results of the laboratory analysis of the soil samples collected from the study area are presented in Table 4.5.

The plasticity index can be calculated by using Liquid limit and Plastic limit simply by subtracting the plastic limit from the liquid limit and the result indicates that the range over which the soil remains plastic.

PI = LL-PL .... *eq. 4.1*

Table 4.5 Plastic limit and index values of the soil

Soil Sample No	Depth of Sampling	Plastic limit (%)	Plastic Index (%)
SS 1	0-1	32	40
	1-2	43	55
SS 2	0-1	36	35
	1-2	41	60
SS 3	0-1	33	42
	1-2	41	60
SS 4	0-1	37	36
	1-2	34	60

The high plasticity index is an indication of the presence of high percentage of clay in the soil sample. Information regarding to the type of clay in the sample, however, may be obtained by considering the plasticity index in relation to the liquid limit. This is best done by means of plasticity chart. If the plasticity index is drawn against liquid limit the plot is called plasticity chart. For the present study the plasticity chart is prepared which is shown as Fig. 4.4 and the Plasticity index is presented as Table 4.5.

Table 4.6 Atterberg limits for the samples collected from the study area

Soil property Indices and its classification	Sample Numbers							
	SS 1		SS 2		SS 3		SS 4	
	D1*	D2	D1	D2	D1	D2	D1	D2
Liquid Limit %	72	98	71	101	75	101	73	84
Plastic limit %	32	43	36	41	33	41	37	34
Plasticity Index %	40	55	35	60	42	60	36	60
Soil Classification	CH	OH	OH	CH	CH	CH	OH	CH
* D1 and D2 are the depths from where samples were collected, D1 - (0 - 1m) and D2 - (1 -2m)								

The plasticity index is a numerical difference between the liquid and plastic limit. It represents the range in water content through which a soil is in plastic state.

The empirical boundary designed by A-line on the chart separate inorganic clays from silts and organic clays. The chart (Fig. 4.4) is a plasticity chart which shows the soil samples of the study area fall half to the inorganic clays (CH) and half to the Organic clays (OH). It is generally believed that soils with high clay content exhibit high liquid limit.

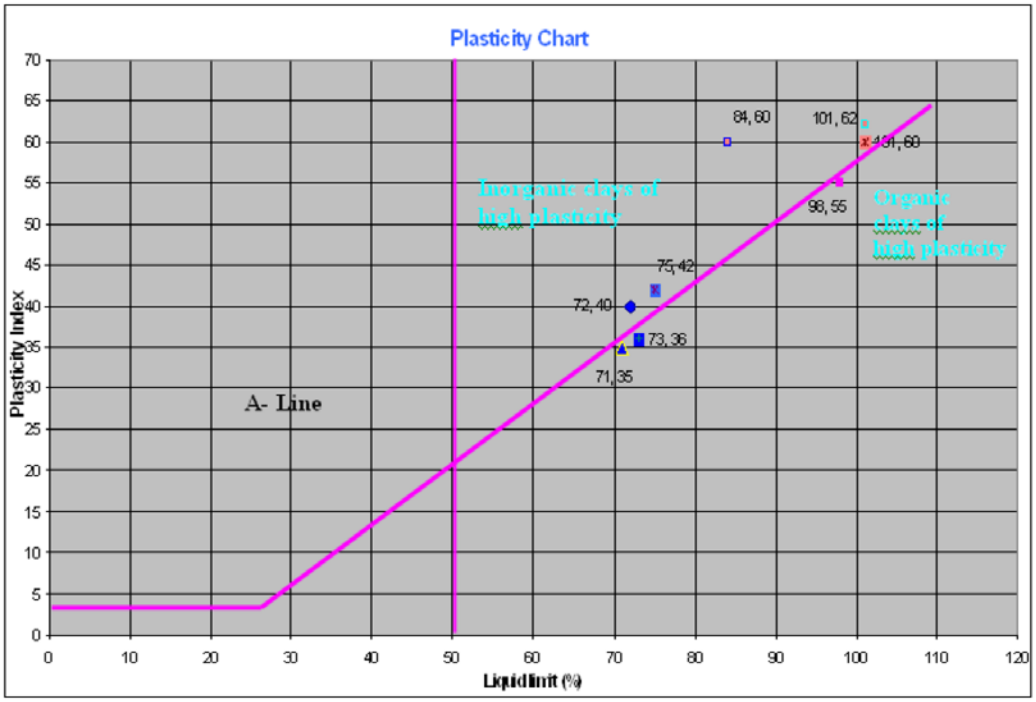


Fig. 4.4 Plasticity chart for samples collected from the study area.

4.5.3 Activity of soil

Seed,et al. (1960), Van der Merwe, (1964) and Skempton (1953) as cited in Abenet (2006) established useful empirical relationships between expansion potential and physical properties of soils such as clay fraction and soil suction. A classification based on percentage clay fraction, soil particles less than 0.002mm and plasticity index can be used to categorize probable severity of expansive soils.

Activity of soil (A) is the ratio of the plasticity index and the percentage of clay fraction (<2 micro meter size). The amount of water in a soil mass depends upon the type of clay minerals present. Activity is a measure of the water-holding capacity of clay soil. The change in volume of clay soil during swelling or shrinking depends upon the activity number. The activity chart is a plot of the clay fraction as X axis and the plasticity index as Y axis, which is used for the classification of the clay soils.

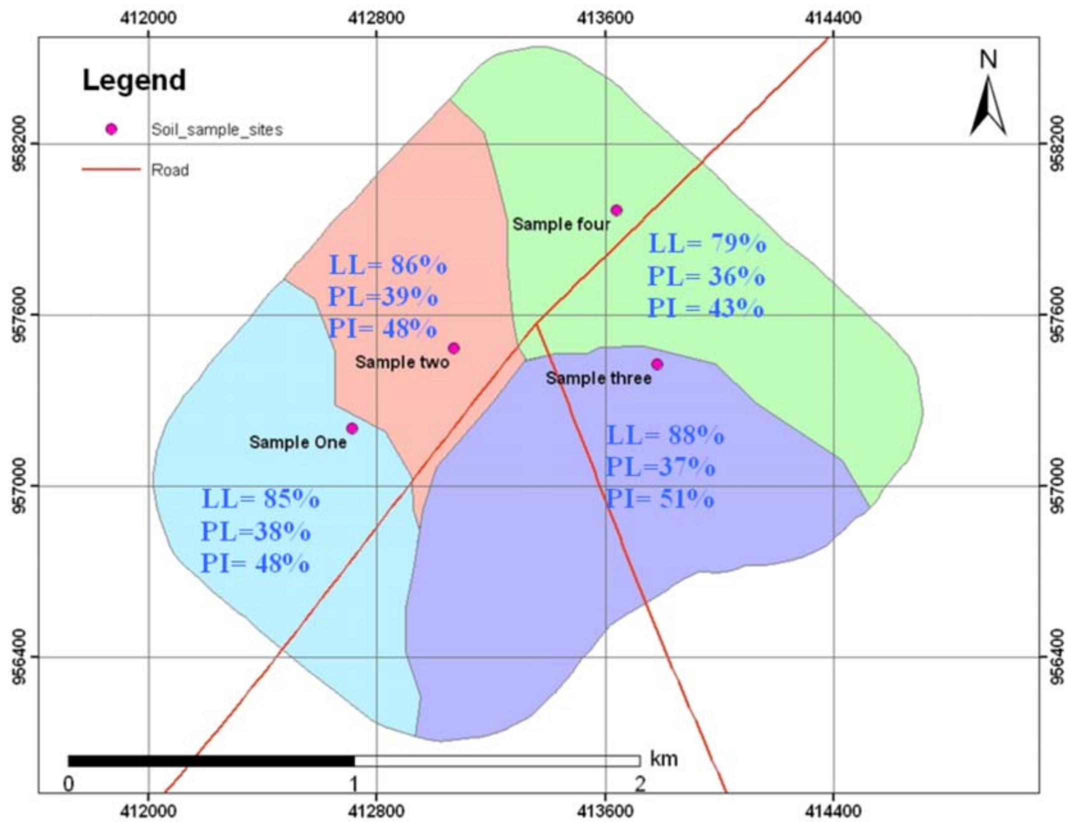


Fig. 4.5 Atterberg limits value map of the study area

The activity of the soils in the study area was calculated and the activity chart was developed to determine the activity of soils of the study area (Fig.4.6).

Activity is a dimensionless ratio of plasticity index to clay content, both taken in percent and it can be calculated as;

$$\text{Activity}(A_C) = \frac{\text{Plasticity index (PI)}}{\text{\% finer than 2}\mu\text{m}} \qquad \text{........}eq.\ 4.2$$

Based on the activity chart (Fig. 4.6) the activity of the samples collected from the depth 0 to 1 m falls in the range 0.5 to 0.75 which implies that the soils are inactive. Whereas samples collected from depth 1 to 2m have activity in the range of greater than 0.75, which implies that the soils are active? Activity of a soil is a measure of the water holding capacity of clayey soils. The change in the volume of clay soil during swelling or shrinkage depends on activity. If the activity of soil is active it implies that the soil has a potential for volume change during swelling or shrinkage process. Thus, it may be concluded that soils in the study area up to a depth of 1m are inactive and the soils below 1m are active and possess a tendency for swelling and shrinkage. Here it is worth mentioning that most of the foundations for buildings are laid down at a depth greater than 1m, therefore the problem of expansiveness of soils exists which may be the cause for foundation failure in the study area.

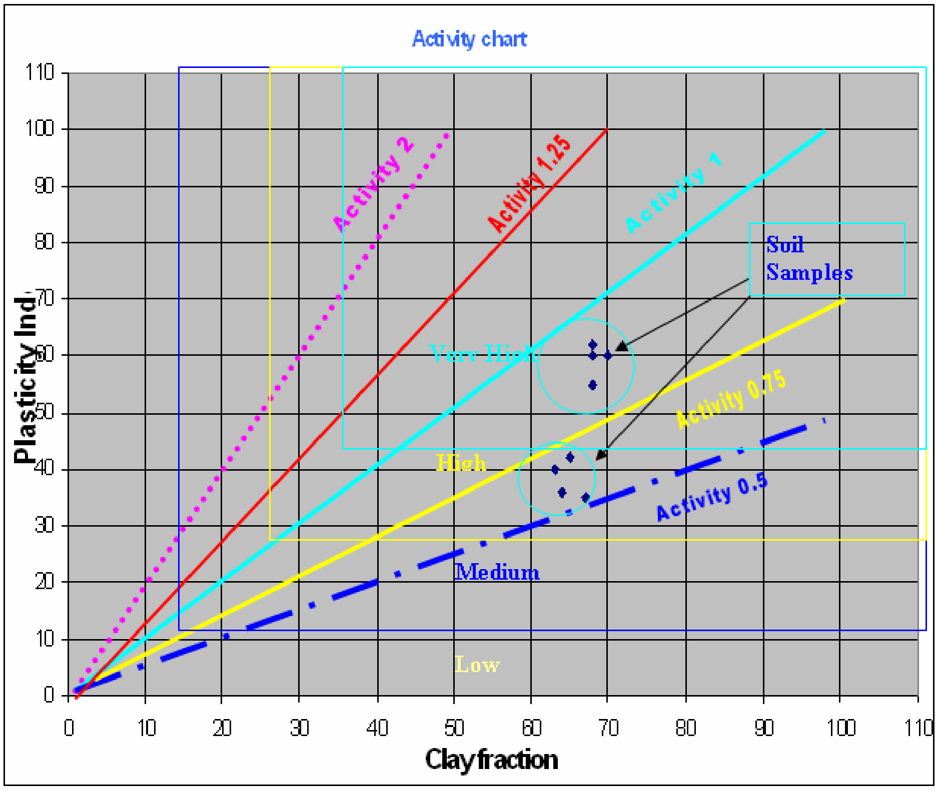


Fig.4.6 Activity chart showing activity of samples collected from the study area

4.5.4 Swelling index

Many tests and methods have been developed for estimating the potential swell of soils. These methods include both indirect and direct measurements. Indirect methods involve the use of soil properties and classification schemes to estimate swell potential. Direct methods provide actual physical measurements of swelling. Another method is by identifying the zone of seasonal movement, which accurately controls the expansive potential of the soil profile. In this study two methods were used to evaluate the swelling nature of the soil in the study area.

Classification of swell based on plasticity table

The change in moisture contents (Atterberg limit) of a soil sample can be used to indicate the degree for potential swell as presented in the Table 4.7. A soil sample with Liquid limit exceeding 70% and plasticity index greater than 35% is judged to have a very high potential swell (Holtz and Gibbs, 1956). This approach is indirect method and very general.

Table 4.7 Relationship of LL, PL and swelling limit values of the soil (Holtz and Gibbs, 1956)

Classification of Potential swell	Liquid limit (%)	Plasticity limit (%)	Swelling limit (%)
Low	20-35	<18	>15
Medium	35-59	15-28	10-15
High	50-70	25-41	7-12
Very high	>70	>35	<11

Based on Holtz and Gibbs (1956) approach the soil samples Liquid limit and plastic limits are taken to determine the swelling potential of the soil of the study area. The result of the swelling potentials are presented in Table 4.8.

Table 4.8 Liquid limit and plastic limit to determine Swelling potential of soil

Sample No	Depth	Liquid limit (%)	Plastic limit (%)	Swelling limit(%)	Swelling potential
SS 1	0-1	72	32	< or =11	High to Very High
	1-2	98	43	<11	Very High
SS 2	0-1	71	36	<11	Very High
	1-2	101	41	<11	Very High
SS 3	0-1	75	33	< or =11	High to Very High
	1-2	101	41	<11	Very High
SS 4	0-1	73	37	<11	Very High
	1-2	84	34	< or =11	High to very high

The higher the swelling limit the lesser the swelling potential and the soil is expansive. Based on this approach the study area soil samples show that all of the soil samples have high to very high swelling potential and are expansive in nature.

Free swell test

Several laboratory methods have been developed to directly determine the soil swelling as moisture content changes. One of them is free swell test. It is one of the direct measurement technique of swelling property of a soil which is very direct and simple (Holtz and Gibbs, 1956). A small sample (10 cm cube) of dry soil passing No. 40 sieve is added to a gradated cylinder and filled with water. The free swell is determined by comparing the initial volume with the final volume. Soils having free swell values greater than 100% are considered to possess potential problems; where as soils with free swell values below 50% probably do not exhibit appreciable volume changes. The free swell expressed as percent by using eq. 4.3 & free swell was determined for 8 samples and the results are presented in Table 4.9.

Free swell % = Change in Volume / Volume * 100 ....*eq. 4.3*

Table 4.9 Free swell of the samples collected from the study area

Sample Number	**SS 1**		**SS 2**		**SS 3**		**SS 4**	
Depth of sampling	**0-1m**	**1-2m**	**0-1m**	**1-2m**	**0-1m**	**1-2m**	**0-1m**	**1-2m**
Initial Volume of Dry Soil (**Vo**)	10 ml	13 ml	12.5ml	12.5ml	11 ml	11.5ml	12 ml	15 ml
Final Volume of wet soil (**Vf**)	34 ml	41 ml	36 ml	46 ml	33 ml	37 ml	33 ml	40 ml
Free Swell (%)	240	215	188	268	200	222	175	167

Soils with free swell less than 50% are not likely to show expansive behavior, while soils with free swells in excess of 50 % could preset swell problems. Values of 100% or more are associated with clay, which could swell considerably, especially under light loadings. In this regard all the samples have greater than 50% swell value. This implies that the area has great problem of expansiveness. Of the entire samples sample SS 1 has highest swelling potential however sample SS 4 has less swelling percent as compared with other samples. However, in general all samples show swelling potential in less varied degree of free swell.

4.5.5 Shrinking limit

Shrinking limit is defined as the water content at which further loss of moisture does not cause a decrease in volume. In other words it is the water content dividing the semi-solid and the solid of the soil. Unlike the swelling property of the soil the shrinking property of the soil is how the soil shrinks or to mean creates crack. The lesser the shrinking limit value the higher the cracking property and the more the expansiveness of the soil. For the present study the shrinking limit was determined from 8 collected samples from the study area. The shrinking limit was determined by using eq.4.4. The various symbols used in the equation are defined in Table 4.10.

$$SL = W - \left(\frac{V - V_o}{W_o} \right) x100\% \qquad \text{……..eq. 4.4}$$

The shrinking limit values of the soil samples are presented in Table 4.10. Soils with a shrinking limit less than 15% are commonly considered as expansive soils with high cracking and swelling property and are taken as expansive soils (Charchan and Jagdish, 2006).

Table 4.10 Shrinkage limit of the soils of the study area

Sample	**SS1**		**SS2**		**SS3**		**SS4**	
Trial Number	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Weight of Dish coated with petroleum jelly + wetsoil **(W_1)**	47.605	45.45	47.33	46.05	48.185	46.9	46.48	47.93
Weight of dish coated with petroleum Jelly + Dry soil **(W_2)**	32.675	29.685	33.535	29.965	34.155	30.37	33.045	35.09
Weight of dish coated with petroleum Jelly **(Wc)**	15.165	15.155	15.395	15.11	15.195	15.35	15.18	15.215
Weight of oven-dried soil pat **(Wo)**	17.51	14.53	18.14	14.855	19.01	15.02	17.865	19.875
Weight of water In wet soil pat **(Ww)**	14.93	15.765	13.795	16.085	14.03	16.53	13.435	12.84
Water content %(**W**)	85.265	108.5	76.05	108.285	74	110.05	75.205	64.605
Volume of wet soil pat **(V)**	22.2	21.8	22.3	22.1	22.35	22	21.95	22.05
Volume of oven dried soil pat (**Vo**)	9.65	8.15	10.05	8.6	11.75	8.815	10.75	11.6
Shrinkage limit (**SL**)	13.60%	14.56%	8.52%	17.41%	18.24%	22.27%	12.51%	12.03%

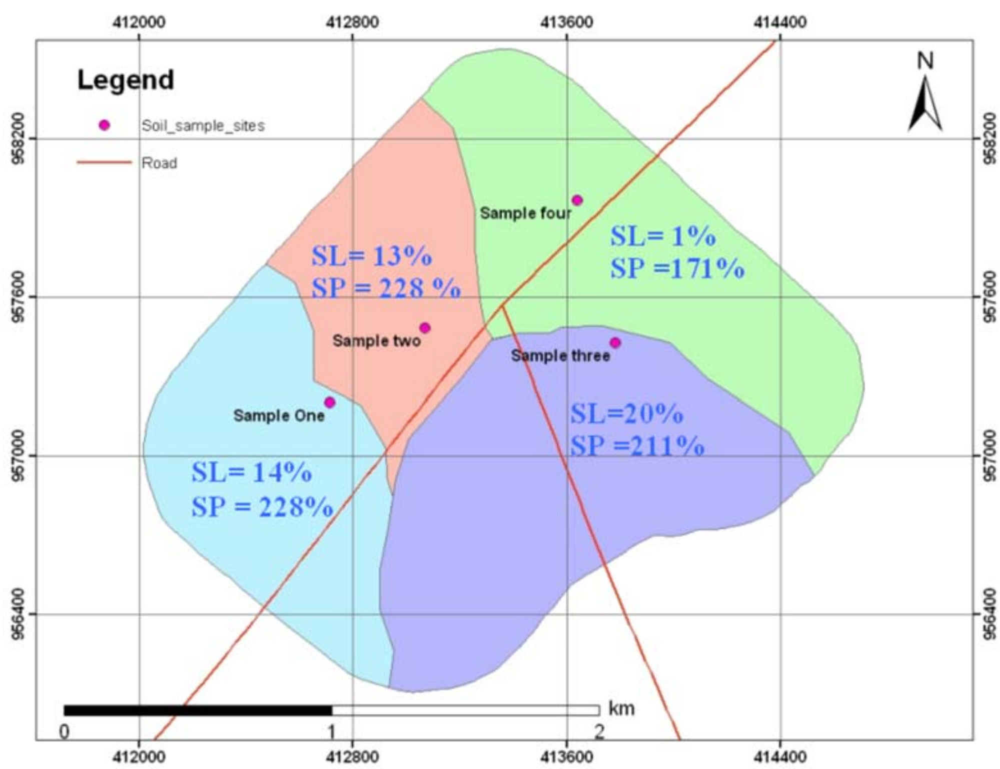


Fig.4.7 Soil Swelling and Shrinking potential map of the study area

The shrinking limit of the soils in the study area falls below 15% except one soil sample (i.e. SS 3). Therefore all the soils in the study area can be categorized as expansive soils based on shrinkage limit, which implies that the soils of the study area have a potential to create building foundation problems.

4.6 Consolidation test

When a structure is built on a saturated soil, the load is generally carried initially by the incompressible water with in the soil. Because of the additional load in the soil the water tend to be extruded from voids in the soil, causing reduction in void value and settlement of the structure. In soils of high permeability (i.e., coarse grained soils), this process requires a short time interval for completion. The reason is that almost all of the settlement has occurred by the time the construction is completed due to instantaneous release of moisture having high permeability. However, in soils of low permeability, which have high moisture and at the same time-release moisture at a slow rate (i.e. fine grained soils, particularly clayey soils), the process requires a long time interval for completion. The reason is that the strain occurs very slowly; these settlements will take place slowly and will continue over a long period of time (Charchan and Jagdish, 2006).

The phenomenon of compression due to the slow extrusion of water from the voids in a fine-grained soil as a result of increased loading (such as the weight of a structure above) is known as consolidation. Associated settlements are referred to as consolidation settlement. It is important to be able to predict both the rate and the magnitude of consolidation settlement of structures because one of the critical cause of failure of foundation of buildings is that the magnitude and rate of settlement of under laying materials. Most of the foundation of big buildings may be destroyed with in short time due to unidentified and examined expansive soils. Various methods are designed to know the rate and magnitude of settlement of foundation soils for proper foundation design and prevent failure of foundation of buildings.

Consolidation is the gradual decrease of the volume at constant load. Consolidation of a saturated soil occurs due to removal of water under static, sustained load. The Consolidation characteristics are required to predict the magnitude and rate of settlement. A structure (building construction) constructed over compressible soft saturated marshy soil settles with expulsion of water if a certain load is added they start to settle and on the contrary when they get water they will start to swell. Therefore understanding the nature and rate of settlement of the soils before constructing houses is mandatory. To work out total settlement and rate of settlement of structure, this test is required. The consolidation of a soil varies depending on the following major factors: Thickness of the clay layer, Volume of drainage face (both of them influence distance through which the water in the soil voids must travel in order to escape the volume of the voids to decrease) Permeability of the soil (which controls the rate at which the water can escape), and Magnitude of the consolidating pressure acting on the clay layer. One of the critical causes of failure of foundation of buildings is resulted from magnitude and rate of settlement of the foundation soils. Most of the foundation of big buildings may be destroyed within short time due to unidentified expansive behavior of foundation soils. Various methods are designed to know the rate and magnitude of settlement of foundation soils for proper foundation design and prevent failure of foundation of buildings.

For the present study consolidation test was conducted for 4 samples (SS 1, SS 2, SS 3 and SS 4). All these samples were taken from a depth between 1 – 2 m, as most of the buildings in the study area are founded at a depth of 1 – 2m. Therefore, it is presumed that soil samples taken from a depth between 1 – 2m will represent the actual foundation conditions and the consolidation behavior of soils at that depth will be the representative for the soils of the study area.

From the Consolidation test the important characteristics of the soils can be determined these are; (i) coefficient of Consolidation, (ii) Coefficient of volume change, (iii) coefficient of compressibility and (iv) compression index. Out of these characteristics of the soils, Coefficient of consolidation helps in estimation of the rate of settlement and void ratio defines the magnitude of consolidation. Consolidation characteristics of soils of the study area are discussed in the following paragraphs;

4.6.1 Coefficient of consolidation

Consolidation test is performed for the purpose of determining the total volume decreased and the time rate of volume change, which is a laterally confined soil sample will under go when subject to an axial load. It is important for all soils having a problem of settlement.

The coefficient of consolidation describes the volume of settlement of the soil at a given period of time with a certain load or pressure. This index is useful for evaluating the weight of the load of the building and the rate of the volume change of the soil caring the building. During the consolidation test of the soil samples the coefficient of the consolidation is found and presented in Table 4.11.

The coefficient of consolidation can be related with the type of the soil. Higher value of coefficient of consolidation indicates high volume change of the soil within very short period of time. This also relate to the water content of the soil. The soil containing more moisture reduces their volume continuously. Therefore expansive soils having high clay content and high water in it will change volume continuously with no permanent settlement. As a result have a small coefficient of consolidation. This characterizes expansive soils property.

From the result of the coefficient of consolidation sample SS1 has higher coefficient as compared with the other values. However, the variation is insignificant. In general the time for a unit of volume change of soil by a certain pressure is very small as compared with the other research results of soil.

4.6.2 Time of consolidation

The time of consolidation can be categorized in to 0%, 50% and 100%. Consolidation of 0% means the change in volume of the original sample is zero. The 50% consolidation is to mean half of the changeable volume of the soil is reduced and 100% consolidation is to mean the maximum changeable volume of the soil reached at time t. The values of time of consolidation and volume change are presented in a log chart Fig.4.8 (a,b,c &d). The time of consolidation indirectly tells the coefficient of consolidation and the nature of the soil. The higher the time to reach 100% consolidation the more the clay content and the more the moisture content and show expansiveness of the soil. Out of the entire samples sample SS 3 and SS 4 have higher time of consolidation for 50% consolidation and sample SS 2 next to sample SS 1 has the least for 50% consolidation.

Table 4.11 Results of consolidation test for the soil samples from the study area

Soil Sample Number	kg/cm2 Pressure, P	Initial height of specimen at beginning of test (m)	Deformation Dial Reading at 50% Consolidation (cm)	Thickness of specimen at 50% consolidation (cm)	Half-thickness of specimen at 50% consolidation (cm)	Time of 50% Consolidation Min.	Coefficient of Consolidation Cm^2/min
SS1	0	1.99	-	-	-	-	-
	0.08	1.99	0.0343	1.9557	0.978	3min	$6.28x10^{-2}$
	0.16	1.99	0.0854	1.9046	0.9523	12min	$1.489x10^{-2}$
	0.32	1.99	0.171	1.819	0.9095	3min	$5.431x10^{-2}$
SS2	0	1.99	-	-	-	-	-
	0.08	1.99	0.101	1.889	0.945	32 min	$5.498x10^{-3}$
	0.16	1.99	0.197	1.793	0.897	3 min	$5.283x10^{-2}$
	0.32	1.99	0.266	1.724	0.862	2 min	$7.310x10^{-2}$
SS3	0	1.99	-	-	-	-	-
	0.08	1.99	0.0310	1.959	0.9795	17min	$1.11x10^{-2}$
	0.16	1.99	0.0760	1.914	0.957	9min	$2.00x10^{-2}$
	0.32	1.99	0.1267	1.8633	0.932	15min	$1.14x10^{-2}$
SS4	0	1.99	-	-	-	-	-
	0.08	1.99	0.0365	1.9535	0.977	16	$1.175x10^{-2}$
	0.16	1.99	0.0772	1.9128	0.956	50	$3.6x10^{-3}$
	0.32	1.99	0.1447	1.8453	0.923	55	$3.05x10^{-3}$

This indirectly tells that the soil sample with higher time of 50% consolidation has high clay content and has high moisture content as a result soil sample SS 4 has more clay content than sample SS 1. Clay soils settle slowly when loaded and expand when reloaded. There are also definite periods of time for settlement to be completed. Even if clay soils are subjected to load less than maximum some of the moisture content in it is released and decreased volume and pressure in consolidation settlement. Therefore consolidation test of these important phenomena is important for even light buildings (Charchan and Jagdish, 2006).

4.6.3 Void ratio and Consolidation

The compression of a saturated soil under a steady static pressure is known as consolidation. It is entirely due to expulsion of water from voids. As the consolidation of soil occurs, the water escapes. The solid particles shift from one position to the other by rolling and sliding and thus attain a closer packing. A study of consolidation characteristic is extremely useful for forecasting the magnitude and time of the settlement of the foundation. Settlement of a foundation is its vertical, downward movement due to a volume decrease of the soil on which it is built (Arora, 1997).

Finer soils have high volume of void to retain more moisture in it. Thus clay soils have high void volume as compared with sand soils as a result their volume of decrement during stress is higher than sands and are bad for foundation materials.

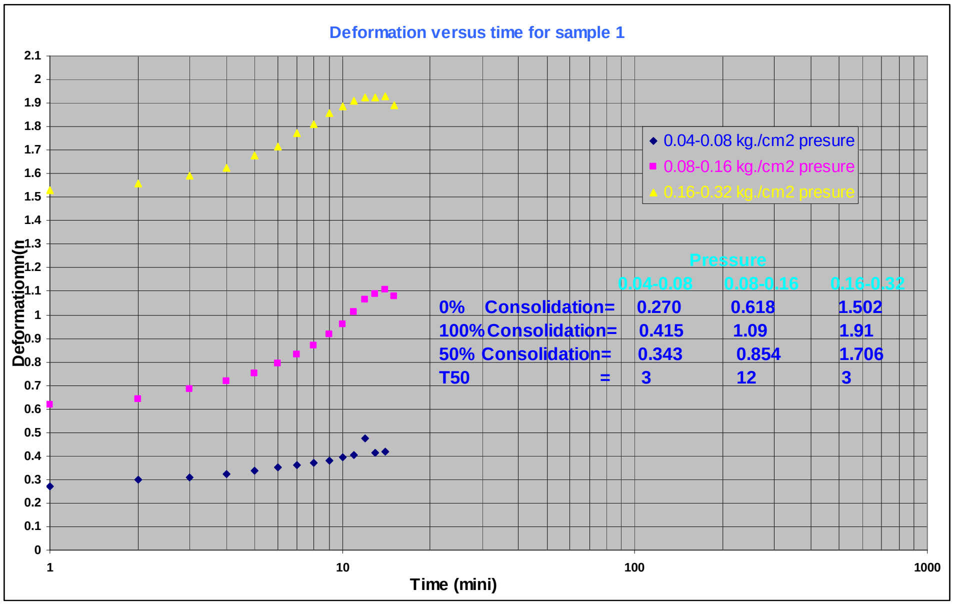


Fig. 4.8(a) **Plot deformation verses time for Sample SS 1 of the study area**

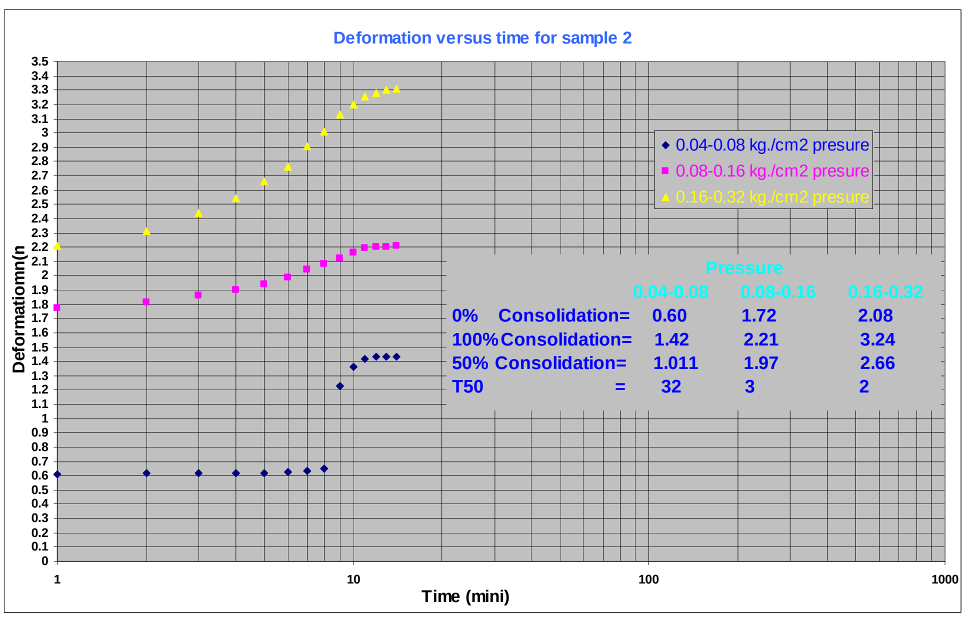


Fig. 4.8(b) **Plot deformation verses time for Sample SS 2 of the study area**

Coefficient of volume compressibility (m_v) and Compression Index (c_c)

Coefficient of volume compressibility (m_v) is important compressibility parameter of soil required for settlement analysis. Coefficient of volume compressibility of soils of the study area is calculated by using following relation;

$$m_v = \left(\frac{H_1 - H_2}{H_1} \right) x \left(\frac{1}{P_2 - P_1} \right) \qquad \text{……..4.5}$$

where, m_v is the coefficient of volume change (m^2/kPa), P_1 and P_2 are pressure increments (kPa), H_1 and H_2 are specimen height at equilibrium pressure (cm).

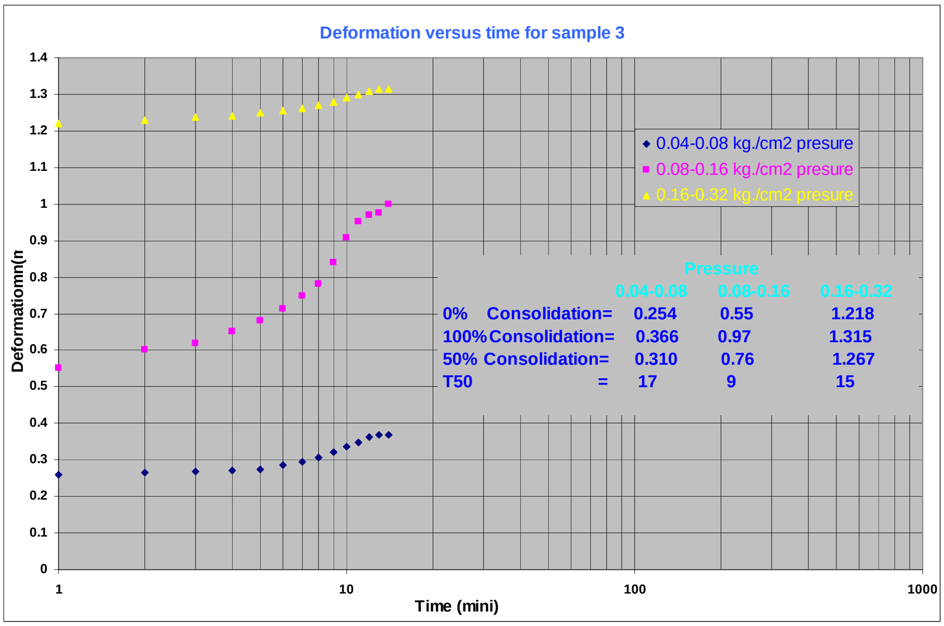


Fig. 4.8(c) Plot deformation verses time for Sample SS 3 of the study area

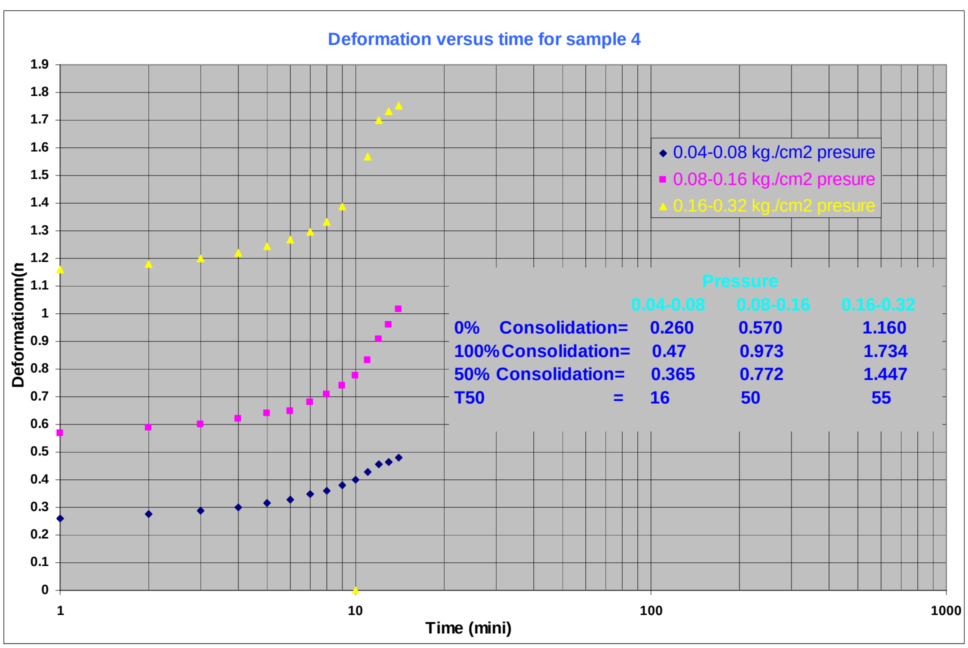


Fig. 4.8(d) Plot deformation verses time for Sample SS 4 of the study area

Compression Index (c_c) is also an important parameter used in settlement analysis. For the present study compression Index is calculated by using the following relation;

$$c_c = \frac{e_i - e_f}{\log_{10}\left(\frac{\sigma_f}{\sigma_i}\right)} \quad \text{……..4.6}$$

where, e_i is the void ratio at initial pressure, e_f is the void ratio at final pressure, σ_i is the initial pressure(kPa) and σ_f is the final pressure(kPa).

The value of C_c is determined between 2 points where curve gets straightened in pressure versus void ratio curve. Fig. 4.9 shows the e-log p curves for four soil samples from the study area.

The calculated Coefficient of volume compressibility (m_v) and Compression Index (c_c) as determined from one dimensional consolidation test are presented in Table 4.12.

Table 4.12 Coefficient of volume compressibility(m_v) and Compression Index (c_c)

Sample No	Depth (m)	Average Void ratio	Coefficient of volume compressibility (m_v) (cm^2/ kPa)	Compression Index (c_c)
SS1	1-2	1.0867	4.57	0.501611
SS2	1-2	0.909	4.80	0.561611
SS3	1-2	0.9235	4.48	0.29339
SS4	1-2	0.9588	4.40	0.29246

The values in Table 4.12 indicate that the Coefficient of volume compressibility (m_v) falls in the range of 4.40 to 4.89 cm^2/ kPa whereas, the Compression Index (c_c) of the soils of the study area falls within the range of 0.293 to 0.561, which is insignificant variation among the samples. The detailed analyses and values on this are presented in Annexure 7.

From the result Soil sample SS2 has highest volume that can be compressed (indirectly to mean the compression index is high) as compared with the others this indicates that the soil in SS2 has more void space as compared with the other soil samples. However, the variation between the soil samples is insignificant all having variation of small decimal values. But generally the changeable volume of the soils during application of a certain load is very high for example in SS2 having a compression index 0.56 nearly 56% of its volume will be changed during stress and very bad for foundation especially heavy loads.

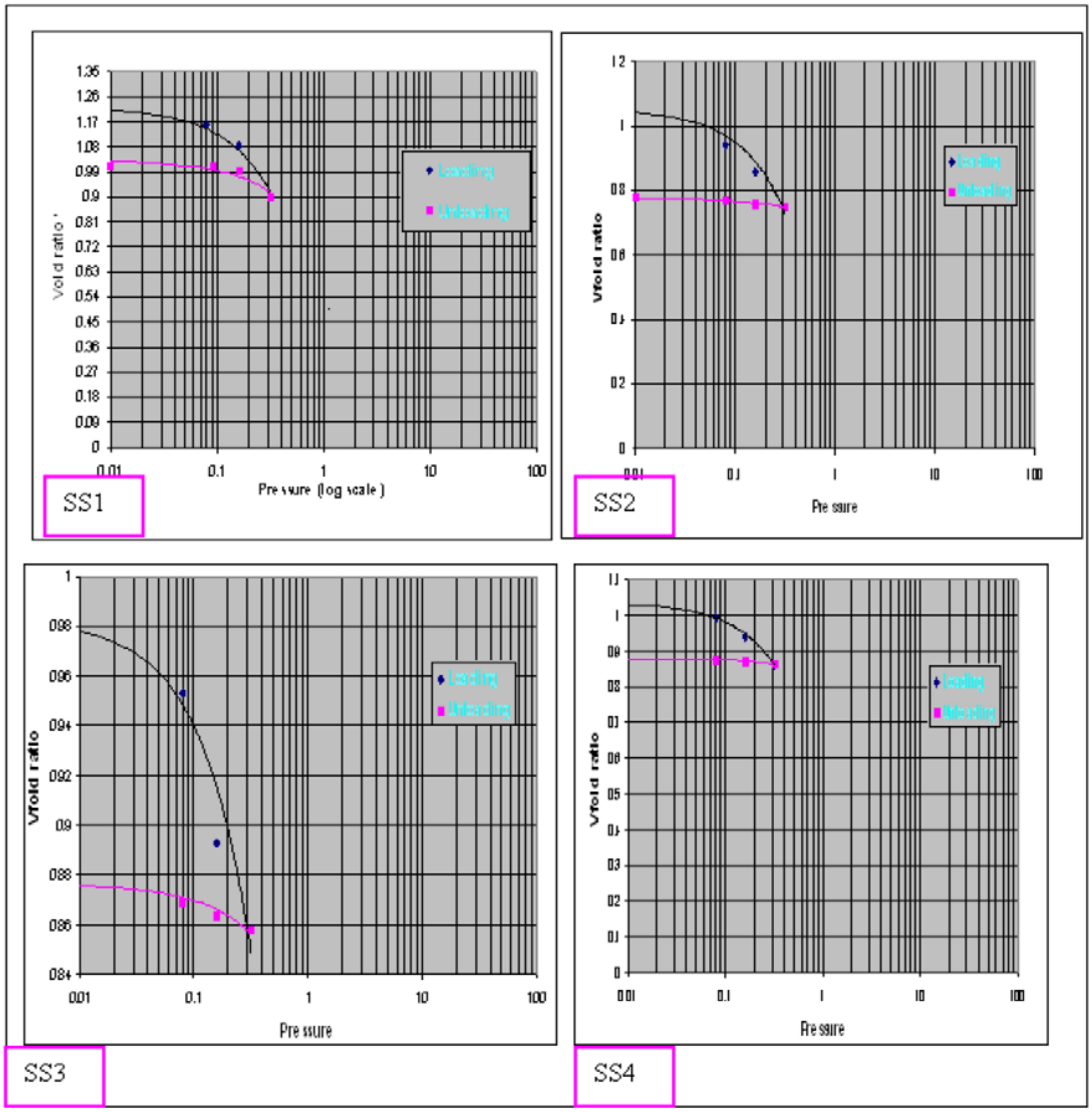


Fig. 4.9 (d) Void ratio verses pressure for Sample SS 1 of the study area

In general the consolidation test depicts similar results with that of the Atterberg limit and swelling test. The soil of the study area all in all is not good for buildings foundation. Based on the consolidation test values suitability of the soil samples for foundation can be selected from the map presented in Fig.4.10.

If rank of the settlement is given based on the coefficient consolidation, void ratio, and compressibility and compression index, out of all the samples, sample SS4 is better as far as consolidation is concerned.

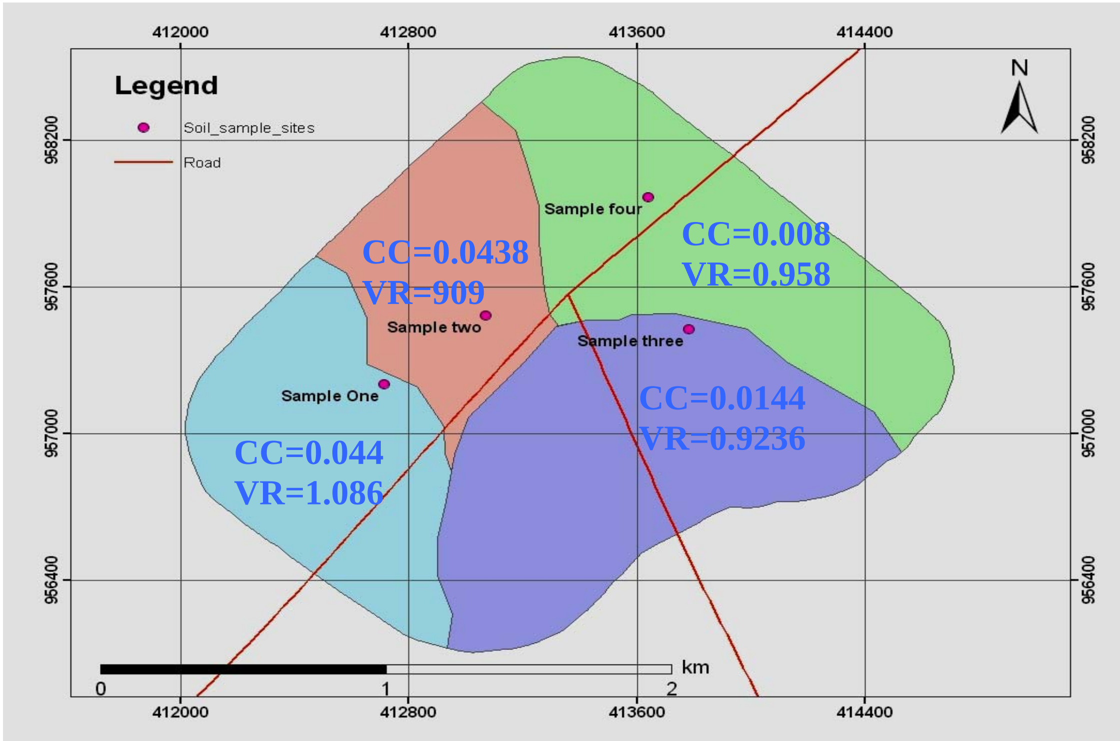


Fig. 4.10 Consolidation test values of all samples in the study area

4.7 Load bearing capacity of soils

The load bearing capacity of soils depend on the size, shape and moisture content of the soil mass. Sand and gravel settle at the end of construction. However, silt and clay settle continuously for longer period and cracks are created. Therefore, gravel and coarse sand soils are better foundation materials for heavy buildings since they can resist the stress of such big loads due to less void ratio that can be compressed and even settle very quickly and creates very minimum cracks on buildings. On the contrary fine soils are bad foundation materials for heavy buildings because they cannot resist big loads due to having high void space that can be compressed during stress of heavy load. On top of that since they have high moisture in the void space which is released slowly their consolidation or settlement magnitude is taken place at a slow rate even after several years after construction and also expand when they get moisture from the surroundings as a result they can create cracks. These expansive soils have very limited weight of which they can carry with insignificant cracking of the buildings. Table 4.12 presents the type of the soils and their bearing capacity (Charchan and Jagdish, 2006). From this Table 4.12 the soils of the study area falls under category 5 i.e. Very Soft clay moderate with easily molded with thumb nail which carry very light weight buildings up to 10 t/m^2 and buildings above this weight suffer high cracking problems.

Table 4.13 Load bearing capacity of soils

S.No.	Type of soil	Load bearing capacity in t/m^2
1	Compacted gravel and sand	45
2	Soft shale hard/stuff clay with dry deep bed	40
3	Medium clay with medium molded with thumb nail	25
4	Soft clay with moderately molded with thumb nail	15
5	Very Soft clay moderate with easily molded with thumb nail	10 (all the samples of the study area)

(Source: Charchan and Jagdish, 2006)

4.7 Evaluation of Factor Responsible For Building Foundation Failure

The building foundation is required to transmit the load of the structure safely to the bearing soil strata. Foundation is designed so that the bearing soil strata are not overstressed. It is also essential to evaluate in the initial stages of foundation investigation the various factors, which may influence the performance of the bearing soil strata. An understanding of such factors in the initial stages of investigation may help in evolving proper remedial measure to improve the foundation condition. For the present study a systematic evaluation has been made by field visual observation and through experimental laboratory analysis of soil samples from the study area. The observation and experimental results reveals the following;

The topography of the study area, which defines the drainage condition, in the area is flat and this leads the soil to seasonal moisture variation and induces cracking and swelling.

The thickness of the expansive soils of the area is 3m or more on the contrary the equilibrium moisture level identified in the area is below 1m. Therefore, there exists more than 1m moisture deficient zone between the surface and the moisture equilibrium level. Hence, thickness of the soil in the study area has a great influence on expansiveness of the soil.

Generally the depth of water table in the study area varies from 0.5 to 15.15m. Static and dynamic water levels were 7.43 and 55.33m, respectively. With the low relief of the area, the slow rate of groundwater fluctuation and the depth of the groundwater, it may be concluded that the groundwater has a minimum influence on building foundations in the study area.

The prevailing climatic condition in the study area has its contribution to moisture fluctuation within the expensive clay underlying buildings. The current climatic conditions display a marked maximum rainfall followed by prolonged dry period. Therefore, it can be said that the physical conditions of soil is linked with the annual climatic variation in the study area.

In the present study area Eucalyptus trees are dominant and some sections with very wide cracks were observed close to the lines of Eucalyptus trees. Eucalyptus tress are described as being unsuitable because of their wild growth and observed detrimental effects on buildings.

In addition to the above factors there are factors, which aggravate the situation, of which the common problems observed in the study area are poor design, improper design, improper construction, Lacking proper Maintenance and Construction interruption.

It has been observed that people constructing buildings on expansive soils have little awareness about the expansive soils and its effects on the building performance. The other important problem observed in the town is improper design and foundation and use of poor materials for construction in relation with the nature of the soils. Most of the buildings in the town are founded at shallow depth with poor filling materials and improper arrangement.

Based on the engineering classification of the soils the soils of the study area have been classified as Inorganic clays of high plasticity (CH) and Organic clays of medium to high plasticity (OH). The soils with high plasticity (CH and OH) are impervious, highly compressible and possess poor shear strength. Thus, with all these adverse engineering properties it may be concluded that the soils of the study area may not be suitable for building foundation. High compressibility of the soils of the study area may result into excessive settlement, which may be of differential nature resulting into development of cracks. Further, poor shear strength may result into poor bearing capacity of the soils, which again may result into failure of foundation and structure. Moreover, soils falling into CH and OH groups are in general impervious in nature which suggests the soils will be saturated for longer duration which may further result into swelling tendency and exerts an upward thrust over the foundation. This may result into development of cracks.

The activity of the samples collected from the depth 0 to 1 m falls in the range 0.5 to 0.75 which implies that the soils are inactive. Whereas samples collected from depth 1 to 2m have activity in the range of greater than 0.75, which implies that the soils are active. Thus, it may be concluded that soils in the study area upto a depth of 1m are inactive and the soils below 1m are active and possess a tendency for swelling and shrinkage. Here it is worth mentioning that most of the foundations for buildings are laid down at a depth greater than 1m, therefore the problem of expansiveness of soils exists which may be the cause for foundation failure in the study area.

Further, it has also been found that the soils of the study area have high to very high swelling potential and are expansive in nature. The shrinking limit of the soils in the study area falls below 15% except one soil sample (i.e. SS 3). Therefore all the soils in the study area can be categorized as expansive soils based on shrinkage limit. This implies that the soils of the study area have a potential to create building foundation problems.

The coefficient of consolidation can be related with the type of the soil. Higher value of coefficient of consolidation indicates high volume change of the soil within very short period of time. This also relate to the water content of the soil. The soil containing more moisture reduces their volume slowly. Therefore expansive soils having high clay content and high water in it will change volume slowly. As a result have a small coefficient of consolidation. This characterizes expansive soils property. From the result of the coefficient of consolidation sample SS1 has higher coefficient as compared with the other values. However, the variation is insignificant. In general the time for a unit of volume change of soil by a certain pressure is very small as compared with the other research results of soil. The summery of all these laboratory results is presented in figure 4.11.

Finally, it may be concluded that the major factor responsible for building foundation problem in the study area is the expansive nature of the soils. The area has Inorganic clays of high plasticity (CH) and Organic clays of medium to high plasticity (OH). These soils are impervious, highly compressible and possess poor shear strength. The soils have high to very high swelling potential and are expansive in nature. Soils upto a depth of 1m are inactive and the soils below 1m are active and possess a tendency for swelling and shrinkage. The topography of the area is relatively flat which possess a poor drainage. In addition to the above factors there are factors, which aggravate the situation, of which the common problems observed in the study area are poor design, improper design, improper construction, Lacking proper Maintenance and Construction interruption. It has been observed that people constructing buildings on expansive soils have little awareness about the expansive soils and its effects on the building performance. The other important problem observed in the town is improper design and foundation and use of poor materials for construction in relation with the nature of the soils. Most of the buildings in the town are founded at shallow depth with poor filling materials and improper arrangement.

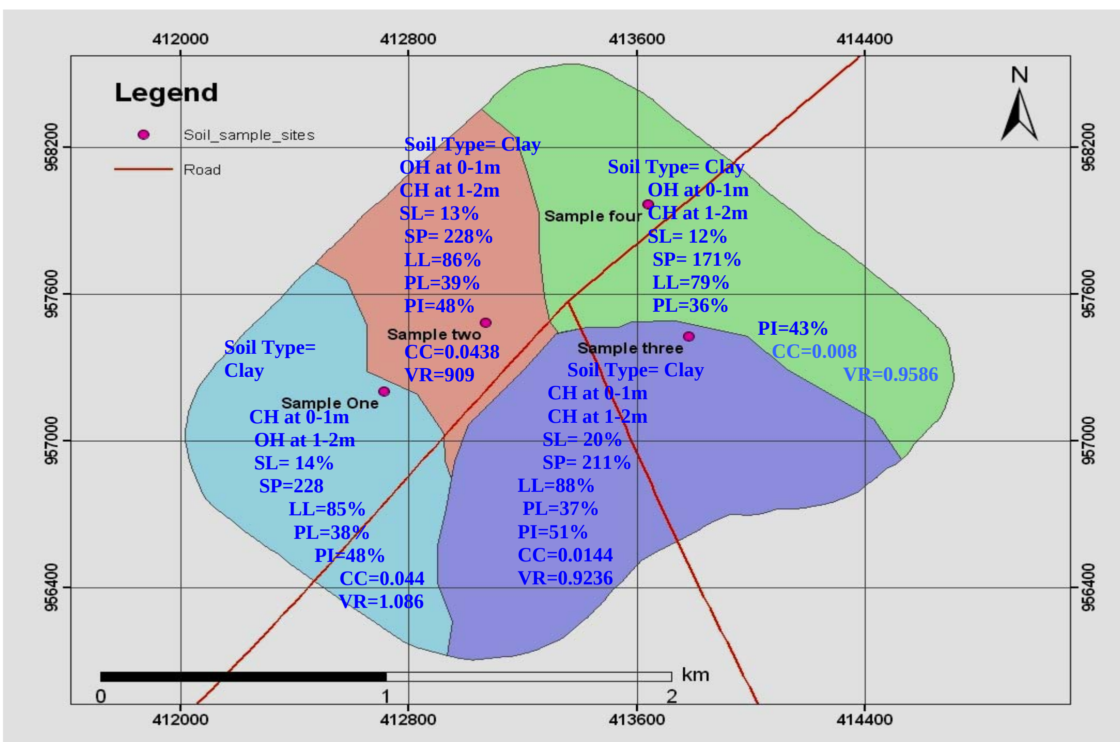


Fig. 4.11 Summery map of all laboratory analysis results

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CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

With an ability to swell and shrink expansive soils pose many problems to building foundations. The expansive soils are considered as geo-natural hazards and form a challenge to geotechnical and construction engineers. To address the problems associated with these soils, every area has to be evaluated for soil characteristics. Further, the possible treatment has to be worked out besides evaluation of possible safe foundation design, remedial measures as suggested for structures built on expansive soils is of paramount importance. Expansive soils can damage engineering structures in different ways and the most obvious way in which expansive soils can cause damage is by uplifting, as they swell with moisture increases. Swelling soils lift up and crack lightly loaded continuous strip footings and frequently causes diestrum in floor slabs building loads on different portion of a structure's foundation, the result (up lift) varies in different areas. Expansive soils pose the greatest hazards in region with pronounced wet and dry seasons.

The study area, which forms a part of Tulu bolo town, faces consistent problem of expansive soils and this attracts attention to participate in dealing with these problems to take an immediate action. Recent advances in geo-technical engineering research give the tools to properly understand the behavior of expansive soils. In the present study, the swelling character of the soil in the study area has been defined and a systematic approach has been used to evaluate various factors associated with building foundation problems, besides an attempt has also been made to suggest possible safe designs for building foundations in the study area.

For the evaluation of various factors responsible for building foundation problem in the study area systematic study has been conducted. For this purpose visual observation in the field were made and representative soil samples were collected to perform laboratory tests pertaining to grain size distribution, Atterburg limit, shrinkage potential, activity of soil and the consolidation characteristics of the soils.

The observation and experimental results reveals that topography of the study area, which defines the drainage condition, in the area is flat and this leads the soil to seasonal moisture variation and induces cracking and swelling. Also, the thickness of the expansive soils of the area is 3m or more on the contrary the equilibrium moisture level identified in the area is below 1m. Therefore, there exists more than 1m moisture deficient zone between the surface and the moisture equilibrium level. Hence, thickness of the soil in the study area has a great influence on expansiveness of the soil. Generally the depth of water table in the study area varies from 0.5 to 15.15m. Static and dynamic water levels were 7.43 and 55.33m, respectively. With the low relief of the area, the slow rate of groundwater fluctuation and the depth of the groundwater, it may be concluded that the groundwater has a minimum influence on building foundations in the study area. Moreover, The prevailing climatic condition in the study area has its contribution to moisture fluctuation within the expensive clay underlying buildings. The current climatic conditions display a marked maximum rainfall followed by prolonged dry period. Therefore, it can be said that the physical conditions of soil is linked with the annual climatic variation in the study area.

The vegetation has also an effect on the building foundations. In the present study area Eucalyptus trees are dominant and some sections with very wide cracks were observed close to the lines of Eucalyptus trees. Eucalyptus tress are described as being unsuitable because of their wild growth and observed detrimental effects on buildings.

All the foundation problem in the study area should not be addressed for natural factors only in fact there are other man made factors also which aggravate the situation, of which the common problems observed in the study area are poor design, improper design, improper construction, Lacking proper Maintenance and Construction interruption. Moreover, it has been observed that people constructing buildings on expansive soils have little awareness about the expansive soils and its effects on the building performance. As a result most of the buildings in the town are founded at shallow depth with poor filling materials and improper arrangement.

Further the laboratory test conducted on representative soil samples from the study area indicates that the soils of the study area are Inorganic clays of high plasticity (CH) and Organic clays of medium to high plasticity (OH). The soils with high plasticity (CH and OH) are impervious, highly compressible and possess poor shear strength. Thus, with all these adverse engineering properties it may be concluded that the soils of the study area may not be suitable for building foundation. High compressibility of the soils of the study area may result into excessive settlement, which may be of differential nature resulting into development of cracks. Further, poor shear strength may result into poor bearing capacity of the soils, which again may result into failure of foundation and structure. Moreover, soils falling into CH and OH groups are in general impervious in nature which suggests the soils will be saturated for longer duration which may further result into swelling tendency and exerts an upward thrust over the foundation. This may result into development of cracks.

The activity of the samples collected from the depth 0 to 1 m falls in the range 0.5 to 0.75 which implies that the soils are inactive. Whereas samples collected from depth 1 to 2m have activity in the range of greater than 0.75, which implies that the soils are active. Thus, it may be concluded that soils in the study area upto a depth of 1m are inactive and the soils below 1m are active and possess a tendency for swelling and shrinkage. Here it is worth mentioning that most of the foundations for buildings are laid down at a depth greater than 1m, therefore the problem of expansiveness of soils exists which may be the cause for foundation failure in the study area.

Further, it has also been found that the soils of the study area have high to very high swelling potential and are expansive in nature. The shrinking limit of the soils in the study area falls below 15% except one soil sample (i.e. SS 3). Therefore all the soils in the study area can be categorized as expansive soils based on shrinkage limit. Which implies that the soils of the study area have a potential to create building foundation problems.

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5.2 Recommendations

Even though there are factor associated with the expansiveness of the soil like geological, topographical and climatic factors, which could not be managed with the physical properties of the soils, soils can be improved for better foundation of buildings depending on the Weight of buildings. Following identification and delineation of expansive soils, the engineers and the house owners shall identify the most appropriate methods of mitigation. Mitigation measures will include one or more of the following;

(i) Excavation and replacement with no expansive fill materials

(ii) Moisture conditioning of the expansive material to a high moisture content to cause pres-welling, then capping with non-expansive fill;

(iii) Compliance with the Uniform Building Code, which specifies special foundation/ slab design for residential construction on soils having an expansion potential of “low” or greater;

(iv) designing foundations to span across areas of potential differential expansion;

(v) Submission of special foundation and slab design by the geotechnical and structural engineers and approval of this design by the building official.

Numerous areas within the town of Tulu bolo contain differing amounts of expansive (also called clay) soil. If a home is located in one of these areas there are a few basic precautions, as homeowner, should take to minimize the detrimental effect of the expansive soil on buildings.

Expansive soil is fine-grained clay, which occurs naturally and is generally found in areas that historically were a flood plain or lake area, but can occur in hillside areas also. Expansive soil is subjected to swelling and shrinkage of the soil, varying in proportion to the amount of moisture present in the soil. As water is initially introduced into the soil (by rainfall or watering), an expansion takes place. If dried out, the soil will contract, often leaving small fissures or cracks. Excessive drying and wetting of the soil will progressively deteriorate structures over the years. This excessive wetting and drying causes damage due to differential settlement within buildings and other improvements.

If a building is located on expansive soil it is likely that it will experience more hairline cracks in the walls and slabs than a building built on sandy soil. This is due to the native soil in the area, and not much can be done to prevent minor soil movement. However, it is possible to protect a building from major damage, and minimize the minor cracking by taking a few precautions to ensure that the soil under the foundation does not become either saturated or completely dried out. The following guidelines are intended to assist the problems of expansive soils;

(i) Proper drainage after rains is the most important factor. Rainfall should run off the building surroundings as fast as possible following a storm. About an hour or two after the next storm the area around the building must be inspected to identify any areas where water is "ponding", especially next to the building. If this is the case, the drainage should be improved as soon as possible, as ponding water may saturate the foundation and cause major structural damage. Proper drainage arrangement around the building site is necessary.

(ii) Installation of rain gutters and downspouts can help in the elimination of a drainage problem, however the downspout outlet should not discharge close to the structure, as this could cause a problem. The discharge point should be on walkways, driveways or other paved areas away from the building. Drainage should then flow directly to the street.

(iii) In the summer the lawns should be lightly watered two or three times a week. Heavy watering is not recommended as this could saturate the foundations. However, it should be emphasized that a uniform moisture condition around foundations should be maintained throughout the year. This will prevent periodic drying (shrinkage) and wetting (expansion) which will cause damage to structures.

(iv) Monitoring water consumption is very important to know whether there is any leakage. An unexplained increase in a water bill could indicate a plumbing leak. Any leak should be repaired immediately, as the soil around the foundation could become saturated and distressed if the leak is allowed to continue for a long time.

(v) If a number of ground fissures or cracks are noticed in a short period of time, it would be best to contact a soil engineer who specializes in expansive soil problems. A Soil engineer can investigate the problem and make specific recommendations for elimination of the problem.

(vi) Planting trees (even small ones) within about ten feet from the building is not recommended. Trees tend to extract moisture from soil causing shrinkage. Greater separation is appropriate for larger trees. Plants that require a large amount of moisture are also not recommended near buildings.

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ANNEXURES

Annexure 1

Rainfall of the area and the surroundings (Rain fall at Sebeta Station)

Rainfall (mm)													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**
1989	20	368	15.2	337	54	681	1565	1170	537	103	0	0	2480
1990	3.3	204	95.7	355	19	110	305.1	550	212	19	0	2.1	1875
1991	0	160	18.6	116	34	74.3	245.6	221	136	23.8	4.2	0	1032
1992	2.6	32.4	110	29	22	102	207.6	244	121	16.3	0	0	885.2
1993	41	51.3	46.4	41	71	92.9	356	564	251	120	12	6.9	733.2
1994	25	136	38.6	414	338	216	525.8	1089	289	52.4	0	0	3125
1995	0	0	136	102	147	225	425.7	322	115	0	31	0	1503
1996	0	54	123	734	100	69.1	530.4	315	104	7	0	19	1044
1997	26	0	113	63	281	341	405.2	438	130	0	0.2	0	1798
1998	30	0	33.2	97	12	275	196.5	197	50.9	0	100	0	991.1
1999	108	0	15	30	102	130	214.4	217	106	48.9	0	36	1007
2000	0	23.3	48.2	14	57	114	217	221	75.4	102	1.1	1.3	874.3
2001	0	0	3.2	76	37	96.2	173.7	183	217	26.8	21	25	858.3
2002	0	6.3	168	11	156	115	281.3	164	0	0	0	0	901.4
2003	35	47.2	100	32	31	92.8	173	261	113	0.6	0	21	906.9
2004	2.8	5.8	52.1	76	14	123	-	332	118	1.2	0	39	763.9

Annexure 2

Rainfall of the area and the surroundings (Rain fall at Teji Station)

Rainfall (mm)													
year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Sum**
1989	0	93	49	72	6	67	223	247	114	12	0	18	901
1990	0	150	75	78	30	102	251	211	84	12	0	0	993
1991	0	53	140	3	35	97	245	262	129	2	0	18	984
1992	44	70	61	87	76	123	123	235	90	56	5	2	972
1993	5	94	0	150	100	93	235	289	98	22	0	0	1086
1994	0	0	34	37	28	198	185	242	126	0	13	0	863
1995	0	41	18	98	66	66	224	189	47	1	0	47	797
1996	53	2	100	95	72	113	219	208	73	4	2	0	941
1997	13	0	29	132	29	96	188	144	64	48	49	0	792
1998	90	52	30	71	68	136	309	232	87	64	0	0	1139
1999	6	-	36	6	45	98	242	218	98	77	0	0	826
2000	0	0	14	94	74	94	187	215	149	11	29	2	869
2001	2	1	96	15	165	183	215	121	-	-	-	-	798
2002	14	10	63	-	46	140	215	214	48	0	0	27	777
2003	29	21	82	154	48	163	230	267	84	0	0	10	1088
2004	20	6	22	130	29	168	209	217	67	69	0	0	937

Annexure 3

Rainfall of the area and the surroundings (Rain fall of Tulu Bolo)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
1989	6	69	87	96	0	219	227	335	91	20	0	0	1150
1990	0	28	18	0	27	150	218	260	37	0	0	0	738
1991	9	7	69	11	129	160	192	161	4	0	0	0	742
1992	7	0	62	37	43	337	442	575	66	8	5	3	1585
1993	9	22	14	114	194	549	460	564	322	19	0	0	2267
1994	0	0	86	47	64	284	334	317	233	0	0	0	1365
1995	0	5	43	50	0	133	90	222	0	3	0	15	561
1996	18	0	40	66	88	226	244	338	191	0	4	0	1215
1997	0	0	36	61	42	203	343	0	79	63	37	0	864
1998	0	23	0	90	228	317	344	341	114	69	0	0	1526
1999	16	0	56	0	79	270	357	449	6	0	0	0	1233
2000	0	0	2	159	132	222	321	227	114	6	26	5	1214
2001	11	2	13	78	98	198	290	234	23	54	8	7	1016
2002	46	9	42	61	43	225	237	241	77	0	0	41	1022
2003	37	12	59	94	24	127	315	203	92	0	5	8	976
2004	52	0	11	93	45	271	324	185	154	0	2	5	1142

Annexure 4

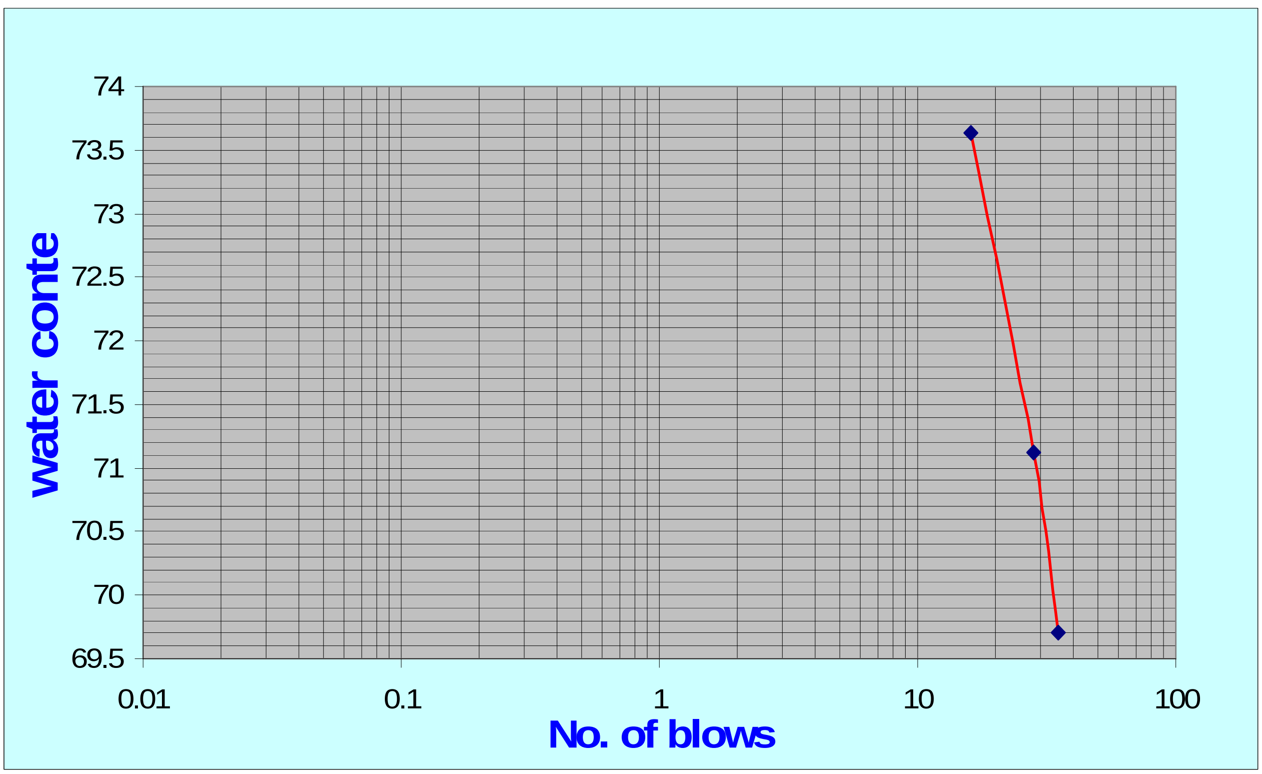
Atterberg limit laboratory test results for Sample 1 & 2. The soil type used was Sub grade type

Soil Sample depth	**At depth 0-1m**					**At depth 1-2m**				
Soil Sample 1	**Liquid Limit**			**Plastic Limit**		**Liquid Limit**			**Plastic Limit**	
Container Number	A-F	A-G	A-H	A-I	A-J	A-A	A-B	A-C	A-D	A-E
Number of Blows	34	28	22			32	27	24		
Wt.of Container + Wet Soil(gm)	42.08	45.27	43.87	24.33	24.49	38.62	43.25	46.78	24.6	24.32
Wt.of Container+ Dry Soil(gm)	33.2	34.88	33.89	23.37	23.51	29.78	32	33.47	23.33	23.14
Wt. of Water (gm)	8.88	10.39	9.98	0.96	0.98	8.84	11.25	13.31	1.27	1.18
Wt. of Container (gm)	20.58	20.39	20.22	20.34	20.48	20.49	20.43	20.03	20.03	20.37
Wt. of Dry Soil (gm)	12.62	14.49	13.67	3.03	3.03	9.29	11.57	13.44	2.96	2.77
Moisture Content (%)	70.36	71.7	73.01	31.68	32.34	95.16	97.23	99.03	42.91	42.6
Indices		**72%**			**32%**	**98%**			**43%**	
Soil Sample 2	**Liquid Limit**			**Plastic Limit**		**Liquid Limit**			**Plastic Limit**	
Container Number	E-1	E-2	E-3	E-4	E-5	G-1	G-2	G-3	G-4	G-5
Number of Blows	32	28	19			34	29	21		
Wt.of Container + Wet Soil(gm)	42.36	42.71	44.81	25.9	26.2	38.57	39.06	38.78	24.23	24.63
Wt.of Container+ Dry Soil(gm)	33.38	33.39	34.54	24.84	25.14	29.71	29.71	29.46	23.12	23.45
Wt. of Water (gm)	8.98	9.32	10.27	1.06	1.06	8.86	9.35	9.32	1.11	1.18
Wt. of Container (gm)	20.26	20.09	20.48	21.9	22.22	20.54	20.23	20.44	20.28	20.64
Wt. of Dry Soil (gm)	13.12	13.3	14.06	2.94	2.92	9.17	9.48	9.02	2.84	2.81
Moisture Content (%)	68.45	70.08	73.04	36.05	36.3	96.62	98.63	103.3	39.08	41.99
Indices	**71**			**36**			**101%**		**41%**	

Annexure 4

Atterberg limit laboratory test results for Sample 3 and 4. The soil type used was Sub grade type

Soil Sample depth	**At depth 0-1m**					**At depth 1-2m**				
Soil Sample 3	**Liquid Limit**			**Plastic Limit**		**Liquid Limit**			**Plastic Limit**	
Container Number	A-A	A-1	A-4	A-E	A-C	A-F	A-G	A-H	A-I	A-J
Number of Blows	31	28	18			34	27	20		
Wt.of Container + Wet Soil(gm)	34.53	40.48	40.88	24.44	24.12	40.99	39.1	41.19	24.31	24.48
Wt.of Container+ Dry Soil(gm)	28.58	32.68	32.73	23.44	23.11	30.72	29.69	30.48	23.15	23.34
Wt. of Water (gm)	5.95	7.8	8.15	1	1.01	10.27	9.41	10.71	1.16	1.14
Wt. of Container (gm)	20.48	22.17	22.11	20.36	20.04	20.58	20.39	20.22	20.34	20.49
Wt. of Dry Soil (gm)	8.1	10.51	10.62	3.08	3.07	10.41	9.3	10.26	2.81	2.85
Moisture Content (%)	73.46	74.22	76.74	32.47	32.9	99.61	101.2	104.4	41.28	40
Indices		**75%**			**33%**	**101%**			**41%**	
Soil Sample 4	**Liquid Limit**			**Plastic Limit**		**Liquid Limit**			**Plastic Limit**	
Container Number	A-M	A-N	A-K	A-O	A-D	A-A	A-B	A-C	A-D	A-E
Number of Blows	35	28	16			35	26	22		
Wt.of Container + Wet Soil(gm)	39.14	41.98	40.77	23.9	24.53	48.38	46.1	46.59	24.39	24.33
Wt.of Container+ Dry Soil(gm)	31.2	33.09	32.25	22.78	23.42	35.9	34.41	34.39	23.36	23.32
Wt. of Water (gm)	7.94	8.89	8.52	1.12	1.11	12.48	11.69	12.2	1.03	1.01
Wt. of Container (gm)	19.81	20.59	20.68	19.73	20.36	20.48	20.41	20.01	20.35	20.37
Wt. of Dry Soil (gm)	11.39	12.5	11.57	3.05	3.06	15.42	14	14.38	3.01	2.95
Moisture Content (%)	69.71	71.12	73.64	36.72	36.27	80.93	83.5	84.84	34.22	34.24
Indices	**73%**			**37%**			**84%**		**34%**	



Annexure 5

Shrinking limit test. The soil used was Clay soil

Sample	SS1		SS2		SS3		SS4	
Trial Number	1	2	1	2	1	2	1	2
Weight of Dish coated with petroleum jelly + wetsoil **(W_1)**	47.605	45.45	47.33	46.05	48.185	46.9	46.48	47.93
Weight of dish coated with petroleum Jelly + Dry soil **(W_2)**	32.675	29.685	33.535	29.965	34.155	30.37	33.045	35.09
Weight of dish coated with petroleum Jelly **(Wc)**	15.165	15.155	15.395	15.11	15.195	15.35	15.18	15.215
Weight of oven-dried soil pat **(Wo)**	17.51	14.53	18.14	14.855	19.01	15.02	17.865	19.875
Weight of water In wet soil pat **(Ww)**	14.93	15.765	13.795	16.085	14.03	16.53	13.435	12.84
Water content %(**W**)	85.265	108.5	76.05	108.285	74	110.05	75.205	64.605
Volume of wet soil pat **(V)**	22.2	21.8	22.3	22.1	22.35	22	21.95	22.05
Volume of oven dried soil pat (**Vo)**	9.65	8.15	10.05	8.6	11.75	8.815	10.75	11.6
Shrinkage limit (**SL)**	13.60%	14.56%	8.52%	17.41%	18.24%	22.27%	12.51%	12.03%

$$SL = W - \left(\frac{V - Vo}{Wo} \times 100\right)\%$$

Annexure 6

Specific Gravity (the type of the material used was Clay soil)

Soil Samples		**SS1**		**SS2**		**SS3**		**SS4**	
Soil Depth		**0-1m**	**1-2m**	**0-1m**	**1-2m**	**0-1m**	**1-2m**	**0-1m**	**1-2m**
Pycnometer Weight	Mp	33.54	33.5	33.515	33.24	33.555	33.515	33.235	33.255
(Pycnometer + Water) Weight	Ma`	133.75	133.72	133.63	133.625	133.735	133.63	133.605	133.615
Initial Temperature of water at Ma` Measured	T`^{o}C	23.5	24.25	28.2	23.1	25.5	28.2	25.7	24
Density of Water at Initial Temperature (T`^{o}c)		0.99742	0.997235	0.99618	0.99752	0.99692	0.99618	0.99687	0.9973
(Pycnometer+ Material+ Water) Weight	Mb	139.695	139.785	139.91	139.805	139.64	139.58	139.475	139.6
Temperature of Mb Measured	T^{o}C	23.15	27.5	23.5	23.5	25.8	26.45	27.85	23.05
Density of Water At T^{o}C		0.997505	0.99638	0.99742	0.99742	0.99684	0.996655	0.99628	0.99753
Pycnometer +Water (Adjusted)	Ma	133.76	133.635	133.755	133.615	133.73	133.68	133.545	133.635
Material Wt. (oven dried)	Ms	10.36	10.675	10.63	10.635	10.37	10.315	10.315	10.34
Specific Gravity at T^{o}C	G_T	2.3355	2.3505	2.3695	2.3865	2.3175	2.3285	2.344	2.3575
Correction Factor	K	0.999295	0.99817	0.99921	0.99921	0.99868	0.998455	0.99807	0.99932
Specific Gravity at 20^{o}C	G_{20}	2.3335	2.3465	2.3675	2.3845	2.3145	2.3245	2.3395	2.3555
Average	**2.334**								

Annexure 7
Consolidation Laboratory test

Specimen used for consolidation test

For all samples the pressure applied was increased from 0.08kg./cm^2 to 0.32kg./cm^2
The type of the material used for test was Clay soil

Sample No	SS1	SS2	SS3	SS4
Wt. Of Specimen Ring + Soil specimen	163.61gm	155.96gm.	165.63gm	170.45gm
Wt.of Specimen Ring	76.38gm	76.34gm	76.38gm.	76.34gm
Wt. Of Specimen	87.23gm	79.62gm	89.25gm.	94.11gm
Diameter of Specimen	6cm	5.99cm	6cm.	5.99cm
Initial Height of Specimen	1.99cm	1.99cm	1.99cm.	1.99cm
Initial Wet unit Weight	1.55gm/cc	1.42gm/cc	1.586gm/cc.	1.678gm/cc
Initial moisture Content	45.63%	33.98%	45.82%	46.53%
Initial Dry Weight of Specimen	59.90gm	59.43gm	61.21gm	64.23gm
Specific Gravity	2.347	2.3845	2.325	2.356
Volume of Voids in Soil specimen	30.73cc	29.21cc	28.05cc	28.55cc
Volume of water in soil specimen	27.33cc	20.19cc	28.04cc	29.88cc
Initial Degree of Saturation	88.94%	69.12%	100%	105%
Final Volume of Solid	25.53cc	26.87cc	28.21cc	27.53cc
Initial Void Ratio	1.204	1.09	0.99	1.04
Wt.of Specimen + Ring (after test wet)	166.14gm	161.73gm	167.75gm	168.69gm
Wt.of Specimen + Ring (after test dry)	136.31gm	140.42gm	141.96gm	141.21gm
Final Moisture Content	49.77%	33.26%	39.33%	42.36%
Final Degree of Saturation	100%	100%	100%	100%
Height of Solid	0.903cm	0.95cm	0.998cm.	0.997cm

Time versus Deformation data For Sample 1 (at depth of 1-2m)

Date	Time	Elapsed Time	Deformation Dial Reading (mm)		
			0.04-0.08 kg./cm^2	**0.08-0.16 kg./cm^2**	**0.16-0.32 kg./cm^2**
29/06/07	3:48	0.10min	0.27	0.62	1.53
		0.25min	0.298	0.64	1.56
		0.50min	0.31	0.685	1.59
		1.00min	0.322	0.719	1.625
		2.00min	0.335	0.751	1.678
		4.00min	0.350	0.792	1.716
		8.00min	0.361	0.831	1.773
		15.00min	0.371	0.870	1.81
		30.00min	0.381	0.918	1.859
		60.00min	0.392	0.962	1.885
		120min	0.405	1.013	1.91
		240min	0.475	1.062	1.925
		400min	0.415	1.089	1.925
		1440min	0.420	1.109	1.930
Rebound Reading			1.68	1.752	1.892

Time versus Deformation data for sample 2 (at depth of 1-2m)

Date	**Time**	**Elapsed Time**	**Deformation Dial Reading(mm)**			
			0.04-0.08 kg./cm^2	**0.08-0.16 kg./cm^2**	**0.16-0.32 kg./cm^2**	
18/05/07	4:00	0.10min	0.612	1.77	2.207	
		0.25min	0.615	1.81	2.311	
		0.50min	0.618	1.86	2.441	
		1.00min	0.620	1.90	2.545	
		2.00min	0.621	1.94	2.659	
		4.00min	0.625	1.984	2.763	
		8.00min	0.630	2.04	2.909	
		15.00min	0.65	2.079	3.006	
		30.00min	1.226	2.119	3.130	
		60.00min	1.363	2.158	3.20	
		120min	1.421	2.191	3.255	
		240min	1.435	2.202	3.28	
		400min	1.437	2.205	3.30	
		1440min	1.433	2.206	3.309	
Rebound Reading			3.06	3.19	3.26	

Time versus Deformation data for sample 3 (at depth of 1-2m)

Date	**Time**	**Elapsed Time**	**Deformation Dial Reading(mm)**			
			0.04-0.08 kg./cm^2	**0.08-0.16 kg./cm^2**	**0.16-0.32 kg./cm^2**	
18/05/07	3:48	0.10min	0.26	0.55	1.22	
		0.25min	0.265	0.60	1.23	
		0.50min	0.267	0.62	1.239	
		1.00min	0.270	0.65	1.242	
		2.00min	0.275	0.68	1.25	
		4.00min	0.285	0.712	1.256	
		8.00min	0.296	0.750	1.262	
		15.00min	0.306	0.78	1.269	
		30.00min	0.321	0.841	1.279	
		60.00min	0.335	0.909	1.29	
		120min	0.349	0.951	1.30	
		240min	0.362	0.970	1.309	
		400min	0.367	0.975	1.315	
		1440min	0.367	0.998	1.315	
Rebound Reading			1.07	1.22	1.28	

Time versus Deformation data for sample 4 (at depth of 1-2m)

Date	Time	Elapsed Time	Deformation Dial Reading (mm)			
			0.04-0.08 kg./cm^2	**0.08-0.16 kg./cm^2**	**0.16-0.32 kg./cm^2**	
29/05/07	4.00	0.10min	0.26	0.57	1.160	
		0.25min	0.275	0.59	1.18	
		0.50min	0.288	0.602	1.20	
		1.00min	0.301	0.620	1.221	
		2.00min	0.316	0.639	1.243	
		4.00min	0.33	0.650	1.27	
		8.00min	0.349	0.681	1.298	
		15.00min	0.361	0.709	1.332	
		30.00min	0.381	0.740	1.388	
		60.00min	0.401	0.778	1..461	
		120.00min	0.428	0.831	1.569	
		240.00min	0.458	0.909	1.699	
		400.00min	0.466	0.959	1.733	
		1440min	0.479	1.017	1.754	
Rebound Reading			1.151	1.548	1.69	

Void Ratio of the consolidation test

Soil Sample Number	kg/cm^2 Pressure, P	Initial deformation dial Reading at beginning of first loading	Deformation Dial reading Representing 100% primary Consolidation (mm)	Change in Thickness of Specimen Δl(cm)	Change in Void Ration	Void Ratio
SS1	0	-	-	-	-	1.204
	0.08	0	0.415	0.0415	0.046	1.158
	0.16	0	1.090	0.109	0.121	1.083
	0.32	0	1.910	0.191	0.212	0.902
SS2	0	0	0	0	0	1.09
	0.08	0	1.420	0.1420	0.149	0.941
	0.16	0	2.210	0.2210	0.233	0.857
	0.32	0	3.240	0.3240	0.341	0.749
SS3	0	0	-	-	-	0.99
	0.08	0	0.366	0.0366	0.0367	0.9533
	0.16	0	0.270	0.0970	0.0972	0.8928
	0.32	0	1.315	0.1315	0.132	0.858
SS4	0	0	-	-	-	1.04
	0.08	0	0.470	0.0470	0.048	0.992
	0.16	0	0.973	0.0973	0.0996	0.9404
	0.32	0	1.734	0.1734	0.177	0.863

Coefficient of Consolidation

Soil Sample Number	kg/cm2 Pressure, P	Initial height of specimen at beginning of test (m)	Deformation Dial Reading at 50% Consolidation (cm)	Thickness of specimen at 50% consolidation (cm)	Half-thickness of specimen at 50% consolidation (cm)	Time of 50% Consolidation Min.	Cm^2/min Coefficient of Consolidation
SS1	0	1.99	-	-	-	-	-
	0.08	1.99	0.0343	1.9557	0.978	3min	$6.28x10^{-2}$
	0.16	1.99	0.0854	1.9046	0.9523	12min	$1.489x10^{-2}$
	0.32	1.99	0.171	1.819	0.9095	3min	$5.431x10^{-2}$
SS2	0	1.99	-	-	-	-	-
	0.08	1.99	0.101	1.889	0.945	32 min	$5.498x10^{-3}$
	0.16	1.99	0.197	1.793	0.897	3 min	$5.283x10^{-2}$
	0.32	1.99	0.266	1.724	0.862	2 min	$7.310x10^{-2}$
SS3	0	1.99	-	-	-	-	-
	0.08	1.99	0.0310	1.959	0.9795	17min	$1.11x10^{-2}$
	0.16	1.99	0.0760	1.914	0.957	9min	$2.00x10^{-2}$
	0.32	1.99	0.1267	1.8633	0.932	15min	$1.14x10^{-2}$
SS4	0	1.99	-	-	-	-	-
	0.08	1.99	0.0365	1.9535	0.977	16	$1.175x10^{-2}$
	0.16	1.99	0.0772	1.9128	0.956	50	$3.6x10^{-3}$
	0.32	1.99	0.1447	1.8453	0.923	55	$3.05x10^{-3}$

Void Ratio Analysis

	Loading		Unloading	
Soil Sample Number	kg/cm^2 Pressure, P	Void Ratio	Void ratio	kg/cm^2 Pressure, P
	0	1.204	1.0099	0.01
SS1	0.08	1.158	1.0083	0.09
	0.16	1.083	0.994	0.16
	0.32	0.902	0.902	0.32
	0	1.09	0.779	0.01
SS2	0.08	0.941	0.769	0.08
	0.16	0.857	0.759	0.16
	0.32	0.749	0.749	0.32
	0	0.99	0.879	0
SS3	0.08	0.9533	0.869	0.08
	0.16	0.8928	0.8632	0.16
	0.32	0.858	0.858	0.32
	0	1.04	0.883	0
SS4	0.08	0.992	0.873	0.08
	0.16	0.9404	0.869	0.16
	0.32	0.863	0.863	0.32

Annexure 8

Summary on Construction Material Test Report

Sample No &Depth	SS 1		SS 2		SS 3		SS 4	
	0-1m	1-2m	0-1m	1-2m	0-1m	1-2m	0-1m	1-2m
Types of Tests	Soil Laboratory analysis results							
Specific Gravity	2.334	2.347	2.3675	2.3845	2.314	2.325	2.3395	2.356
Liquid Limit (L.L)	72%	98%	71%	101%	75%	101%	73%	84%
Plastic Limit (P.L)	32%	43%	36%	41%	33%	41%	37%	34%
Shrinkage Limit (S.L)	13.5%	14.5%	8.5%	17%	18%	22%	12.5%	12%
Plasticity Index (P.I)	40%	55%	35%	60%	42%	60%	36%	50%
Free Swell	240%	215%	188%	268%	200%	222%	175%	167%
Grain Size analysis	%Pass	%pass	%pass	%pass	%pass	%pass	%pass	%pass
Sieve Size 4.75 mm	100%	100%	100%	100%	100%	100%	100%	100%
2.00 mm	99.23%	99.93%	99.72%	93.61%	100%	99.98%	99.92%	99.88%
0.425 mm	96.56%	98.91%	97.69%	89.60%	99.04%	99.72%	97.85%	99.40%
0.150 mm	93.58%	96.94%	95.73%	87.66%	97.49%	97.73%	95.06%	98.00%
0.075 mm	91.62%	94.36%	94.04%	86.78%	95.09%	95.57%	92.71%	96.05%
0.0117 mm	89.88%	85.22%	89.72%	86.00%	93.13%	68.27%	92.18%	95.27%
0.00747 mm	88.16%	80.00%	86.27%	77.29%	86.10%	56.02%	86.96%	91.81%
0.00438 mm	77.78%	73.04%	79.37%	72.46%	80.83%	45.51%	80.01%	84.88%
0.00313 mm	69.14%	66.09%	70.74%	64.41%	73.80%	33.26%	78.27%	79.68%
0.00224 mm	65.68%	60.87%	63.84%	59.58%	70.29%	32.25	67.83%	74.49%
0.00109 mm	53.58%	48.69%	51.76%	48.31%	59.74%	47.00	53.92%	60.63%
0.00048 mm	46.67%	38.26%	44.86%	38.65%	54.47%	43.50	48.70%	53.70%
Soil Classification As per USCS	"CH"	"OH"	"OH"	"CH"	"CH"	"CH"	"OH"	"CH"

- CH (Inorganic Clays of High Plasticity), USCS – Unified Soil Classification System
- OH (Organic Clays of Medium to High Plasticity),

Annexure 9

More pictures showing failure to foundations

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