ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Physical Improvement of Weak Expansive Subgrade Soil Using (Geosynthetics) Geogrid Material

A thesis Submitted to

School of Graduate Studies in Partial Fulfillment of the Requirement for the Degree of Master of Science in

Geotechnical Engineering

By:

Mengistu Garomma

Advisor:

Argaw Asha (PhD)

May, 2018

Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

Candidate's name ____________________________

Signature ____________________________________

Acknowledgements

First of all, I would like to thank and praise the almighty God for his guidance and success in my life. I express my deepest gratitude to my advisor Dr. Argaw Asha of ASTU, School of civil engineering and architecture, department of Civil Engineering, for his valuable advice, guidance and support throughout this work.   I remain greatly indebted to him.

I would like to thanks Ansif Construction laboratory service and China Railway Corporation for providing me soil laboratory services and Geogrid materials.

I am grateful to geosynthetics industrial works from where I just try to conduct some laboratory test on geogrid material.

Finally i am forever remain grateful and special respect to my wife , Ansif Seyoum (Msc in Structural Engineering), Heran Mengistu and Nahili Mengistu for respectfully giving me your golden family time.

Abstract

The quality and life of pavement is greatly affected by the index and engineering properties of subgrade materials**.** But in Ethiopia most of the pavements are constructed over weak and problematic sub grades like expansive soil**.** When there is moisture in expansive soils, volume of soil gets increased therefore swelling pressure of soil is greater than the downward pressure of lightweight structures like road. Conversely; when the soil gets dry the structures face become uneven settlement. Such cyclic movements of soil mass cause different structures like road, light weight buildings, and pipeline to have excessive differential settlement, deformation and cracks. Hence, this study aims the use of geogrid material to improve the strength of poor expansive subgrade soil which plays an important role in load bearing and supporting different traffic load. To do the above objective, first different relevant literatures were reviewed intensively then disturbed soil sample was taken from Bole Arabsa area at specified depth of 2m then index property tests like liquid limit, plastic limit, plasticity index, sieve analysis, free swell, specific gravity and density - moisture tests were carried out, based on which the soil was classified as highly plastic expansive (A - 7 – 5(20)) soil. Since main objective of this study is physical improvement of weak expansive subgrade soil, four day soaked and unsoaked CBR tests were conducted with before and after inclusion of geogrid material at first (25%), second (50%) and third (75%) layers on a given CBR mold measured from bottom. The result showed that both soaked and unsoaked CBR value of expansive subgrade soil was significantly improved. In case of without reinforcements the value of soaked CBR was 2.24% but when the geogrid was placed at first, second and third layer its CBR value increases to 3.93%, 5.49% and 4.88% and also unsoaked CBR value for natural subgrade soil was 6.89% but after reinforcement, unsoaked CBR value was greatly increased to 8.99%, 11.67% and 10.24% respectively.
The result of the study showed that geogrid inclusion is significantly capable to improve the strength of poor subgrade soil. In both soaked and unsoaked case better improvements were observed when geogrid material was reinforced at second layer than other reinforcement layers.

Key Words: Geogrids, CBR, Expansive soil.

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Symbols and Abbreviations

AASHTO	American Association of State Highway and Transport Official;
ASTM	American Society for Testing and Materials;
ASTU	Adama Science and Technology University
CBR	California Bearing Ratio
CH	High Plasticity Clay
CL	Low Plasticity Clay
D	Designation
GP	Poorly Graded Gravel
GW	Well Graded Gravel
HDPE	High Density Polyethylene
PP	Polypropylene
Kg	Kilogram
Km	Kilometer
Kpa	Kilopascal
MDPE	Medium Density Polyethylene
ML	Low Plasticity Silt
^{o}C	Degree Centigrade;
OH	High Plasticity Organic Soil
OL	Low Plasticity Organic Soil.
PI	Plasticity index
LL	Liquid limit
SL	Shrinkage limit
SPR	Standard Penetration Resistance
USBR	United State Bureau of Reclamation
USC	Unified Soil Classification

1. Introduction

1.1. General

Expansive soils are found mostly in arid and semi-arid regions of the world **(Al-Rawas 1992).** Many Countries like; Ethiopia, Ghana, India, Canada, Iran and so on, are reporting about the problems of expansive soil.

Expansive soils are abundant where the annual evaporation and transpiration is greater than the precipitation. When there is moisture in expansive soil, the volume of soil gets increase and at this time the swell pressure of soil is greater than the downward pressure of lightweight structures like road hence; such movement causes deformation and cracks on structures to be happened. On the other hand, when the soil is dry, the structures faces become uneven settlement.

At local and international level expansive soil causes a lot of damages in different civil engineering works such, Nelson and Miller **(1992)** reported that, each year in the United States expansive soil causes $2.3 billion in damages to houses, other buildings, roads, pipelines, and other light weight structures. Often, damage from expansive soils can be seen within the first few months or years after a various civil engineering works are constructed.

Geosynthetic materials are mostly produced from polymers or also called hydrocarbons. Polyester (PET), polypropylene (PP), polyethylene (PE), very low density polyethylene (VLDPE), medium density polyethylene (MDPE), high density polyethylene (HDPE) and polyvinyl chlorides (PVC) are the polymers which are the raw materials to produce geosynthetics. Geosynthetic is a general term for all polymer materials used in combination with soil or rock as integral parts in different civil engineering works.

The common types of geosynthetic material are geogrids, geotextiles, geomembranes, geonets, geofoams and geocomposites with their primary function includes as reinforcement, separation, filtration, drainage and containment **(Koerner, 2012).**

From the listed different types of geosynthetic material, the use of geogrid as strength improvement should be investigated in this study. Geogrid is a synthetic planar structure formed by a regular network of tensile members with appropriate apertures to allow interlocking with surrounding soil or rock for the purpose of reinforcement (**Samson Y., 2017**).

Polypropylene and high density polyethylene goegrid is made from high tenacity polypropylene and polyethylene rods of strips.

Polypropylene and polyethylene are increasingly being used to manufacture reinforcing geosynthetics such as geogrids, because of their high strength.

In geogrid, the open mesh type of structure is formed by bonding polymer strips at their cross point together **(Samson Y., 2017**).

1.2. Distribution of Expansive soils in Ethiopia

Distribution of expansive soil is generally a result of geological history, sedimentation and local climatic conditions. Arid climatic conditions and severe weathering environment prevailing in north eastern part of Africa promoted the widespread occurrence of expansive soils in this region (**Melik Yunus, 2015).**

As shown in Figure 1.1, in Ethiopia, nearly 40% of surface area of the country is covered with expansive soil **(Fikirte A., etal, 2009).**

In Ethiopia, where different construction activities are taking places are mostly covered with expansive soil such as: southern, southeast and southwest of Addis Ababa city, central parts of Ethiopia, following major trunk road like Addis Ababa to Modjo, Addis Ababa to Woliso, Addis Ababa to Debre Berhan and Addis Ababa to Ambo and areas like Mekele, Bahirdar and Gambella and among others.

Hence, in each year as the percentage of construction activities increases, the expectation of more expansive soil areas will be discovered. In expansive soil there is swelling clay minerals; such as monthmorillonite, and illite. Such minerals are categorized under expansive clay mineral. When the unsaturated soils become fully saturated in expansive soil, the clay minerals absorb water molecules and expand **(Bell and Culshaw, 2001).** Conversely; when clay mineral gets dried, then the soil shrinks, leaving large voids in soil mass and therefore, expansive soils are weak and unstable due to fluctuation of moisture content.

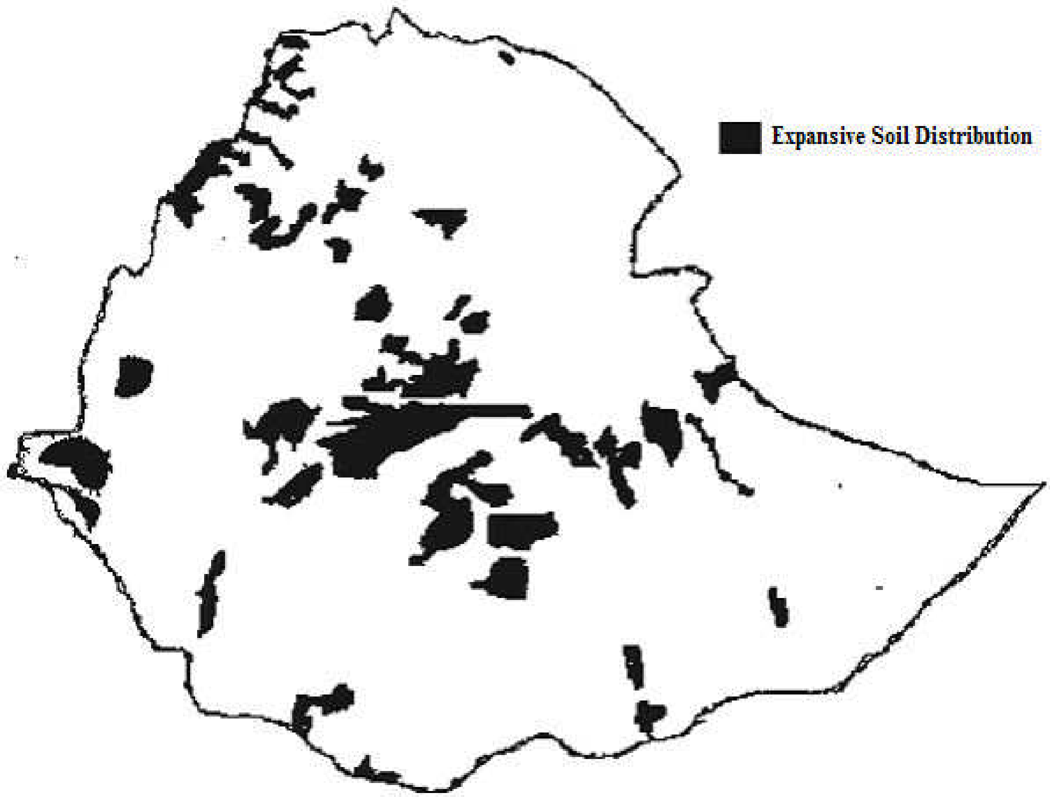


Figure 1.1: Distribution of expansive soil in Ethiopia (after **Affework Sisay, 2004**)

As shown from the above figure, most Southern, South-west and south-east part of the capital Addis Ababa area, in which the most major recent construction are being carried out, are also covered with expansive soil.

1.3. Description of the study area

It is well known that expansive soil covers an appreciable part of Ethiopia. The study area is located in Addis Ababa around Bole Arabsa (shown in Figure 1.2). For this research work disturbed soil sample is collected from a test pit at a depth of 2m below the natural ground level in order to avoid the inclusion of organic matter.

Figure 1.2: Location map of Bole Arabsa and soil sampling sites **(Google Map)**

Nowadays Bole Arabsa is among one of the fast growing industrial cities. According to the master plan of the city, different construction activities have been carried out like construction of high and low rise condominiums, residential buildings, industry parks and airport and construction of low to high volume of roads are among the different constructions currently carried out inside the study area.

The topography of the study area is predominantly plane to slightly undulating and elevation land dominantly forms of isolated hills. According to the climatic classification of Ethiopia as per Lemaa Gonfa (**1996),** Bole Arabsa and its surroundings are classified as warm and temperate rainy climate.

In this classification, the greatest amount of precipitation occurs in August, with an average of 263 mm, with an average of 18.0 °C of temperature and May is being the warmest month.

The lowest average temperature in the year occurs in November, when it is around 14.8 °C.

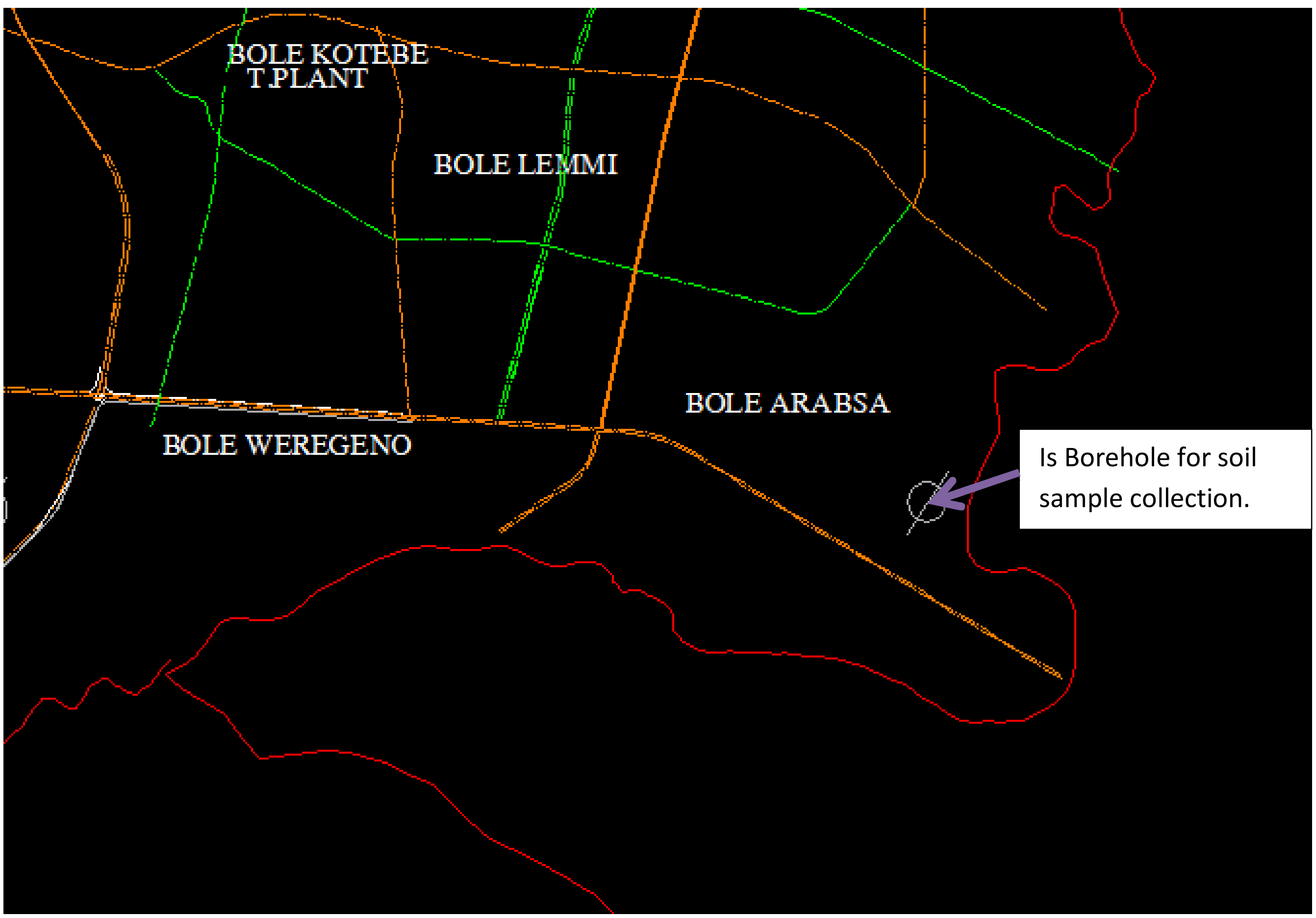


Figure 1.3: Location map of sample collection (AACRA, 2016)

1.4. Statement of the problem

The fact that expansive soils are a major engineering problem makes their study an important research aspect due to the accruing cost involved in terms of economic loss when construction is undertaken without due consideration to the probability of their presence.

The lack of information about the presence of expansive soils may lead to the mistake in structural foundation design, resulting in one of the factors of damage.

Expansive soil like collapsible soil is problematic soil and such problematic soil should be removed and replaced by another selected material or it should be stabilized by using physical or chemical means. Due to the swelling and shrinkage behavior of expansive soil, there is a cyclic volume changes in soil mass which can cause damages to different civil engineering infrastructures. In Ethiopia, even if the economic survey is not yet well organized, expansive soil causes so many damages.

Figure1.4: Deformations and crack problems on study area section due to presence of expansive soils beneath subgarde and foundation soil respectively **(Samson Y., 2017, Affework S., 2004).**

In our countries, considerable research is not yet sufficiently done on improving the strength of expansive soil using different physical (**Geogird**) means of stabilization except that of Samson Y. **(2017)** unpublished thesis study, he tried to carried out the comparative study of expansive subgrade soil using cement kiln dust and geogrid material. Accordingly, representative soil sample is collected from Modjo town, and then treated with CKD material in different proportions and also for comparative purpose the same material is also treated with inclusion of geogrid material at specified position.

The result showed that with increasing the amount of cement kiln dust in expansive subgrade soil, values of soaked and unsoaked CBR were increased from 2.98 and 16.26% of untreated soil to 12.87 and 35.23 of 13% by weight of CKD amount respectively. The CBR swell value also decreased from 4.57% to 1.08% after 13% by weight application of CKD material. Therefore; cement kiln dust material has a potential to improve the strength and swelling properties of expansive subgrade soil.

Also physical reinforcement of expansive soil using bitumen coated polypropylene and high density polyethylene geogrids, causes the improvement of these values from 2.98% and 16.26% to 10.23% and 37.26% for bitumen coated PP and to 7.48% and 23.71% for HDPE geogrids respectively. Hence, comparing the improvement degree of expansive subgrade soil using cement kiln dust and geogrid material, as shown from the above result, better improvement was observed for geogrid reinforcement (Since geogrid material is included only one layer).

But detailed comparative investigation is not reported regarding, improving the strength of expansive subgrade soil by using geogrid material comparatively. Therefore, in this study the potential of geogrid material which help to improve the strength of weak expansive subgrade soil is investigated in detail.

1.5. Objectives of the study

The general objective of the study is physical improvement of weak expansive subgrade soil by inclusion of geogrid material for chosen expansive type of subgrade soil. It is done after classifying and identifying the swelling nature of natural subgrade soil.

The specific objectives of the study are:

- Determining the index parameter and CBR values for selected expansive subgrade soil before treating with geogrid material;
- Evaluating reinforced CBR and CBR swell values after placing geogrid material in layers;
- Identifying as in which layer is more improved strength value is obtained due to inclusion of geogrid material in layers and;
- Evaluating characterizing whether geogrid can be used to improve the strength of expansive subgrade soil.

1.6. Research Question

- To what extent such geogrid material is capable to improve some of the engineering properties of expansive subgrade soil?

1.7. Scope and Limitations of the Study

1.7.1. Scope of the study

In order to accomplish the above-mentioned objectives, soil sample depending on the soil condition and coverage area is being collected then index and strength property tests were made on collected sample before and after stabilizing with geogrid material.

After identifying the strength and swelling properties for selected subgrade material then reinforced CBR test was also done by inclusion of geogrid material in layers. The result of this research work could serve as a basis for improvement of expansive subgrade soil of pavement construction in the study area as comparative analysis in similar environments.

1.7.2. Limitations of the study

- Due to having a limited number of geogrid materials, the reinforced CBR tests were carried only for three different layers.
- The geogrid material taken from Chinese company is basically for railway purpose and welded type; its aperture size is also larger and wider; but it would be better if the geogrid material is punched type rather than welded for the purpose of more crack resistance in pavement materials.
- Due to shortage of intensive laboratory setup for geogrid materials, test types, like tear resistance, puncture resistance, carbon black content test, density test etc. were not done whose importance is not substantial for geogrid material.

1.8. Organization of the thesis

This paper has six chapters. After introducing the main and detail objectives in chapter one, literature review regarding the definition and mechanism of stabilization and improvement of expansive soil has been dealt in chapter two. In chapter three the methodology and test method which are pursued during the process of this research have been presented and chapter four includes different laboratory tests and their results are obtained in tables and graphs. Chapter five covers the findings and analysis of different laboratory test results and finally the conclusion of findings and recommendations are briefly discussed in chapter six.

2. Literatures Review

2.1. Fundamental Concept of Expansive Soil

Expansive soil is a type of soil that is known as a light weight aggregate with a rounded structure, and porous inner. It is a soil that is prone to large volume change (swell and shrink property) which is directly related to change in moisture content inside the soil mass. When there is moisture in soil, the volume of soil become swell and at this time, the swell pressure of soil is greater than the downward pressure of lightweight structures like road. Hence, such movement causes deformation and cracks on lightweight structures to be constructed.
On the other hand: when the soil shrinks the structure likely to have unequal settlement. Such phenomenon can cause structures like road, buildings, and pipeline to move excessive differential settlement and prone to cracks.

2.2. Expansive soil clay mineralogy

Type and amount of clay mineral plays an important role on behavior of fine grained soils. Clay minerals are the primary source and moisture is often the external agent for soil to be swelling (**Sivapullaiah etal, 2000).** The swell and shrink potential of any clay soil is determined based on the amount of clay particles and the type of clay minerals in a given soil. The shape of clay mineral is determined through the arrangements of their atoms which form thin clay crystals. The seasonal shrink and swell potential of expansive soil is mainly determined by its initial moisture content, void ratio, internal structure, vertical stress as well as the type and amount of clay minerals in a soil **(Bell and Culshaw, 2001)**.

In clays the most abundant mineral is called silicates and the principal elements in clay are silicone, aluminum and oxygen. The arrangement and chemical composition of silica and alumina sheets determine the type of clay minerals in a given soil. In tetrahedron clay mineral structure, silicone atoms are positioned in the center with one oxygen atom occupying each of the four corners and due to sharing of electron, the silicone tetrahedron link together with one another to form a thin tetrahedral sheet. Conversely, in octahedron clay mineral structure, aluminum atoms are positioned in the center with oxygen atom occupying each of the eight corners and the aluminum octahedrons are link together to form octahedral sheets (Chen, 1988).

Figure 2.1 below shows tetrahedron arrangement of clay minerals in which silicon atoms were positioned in the center with one oxygen atom occupying each of the four corners.

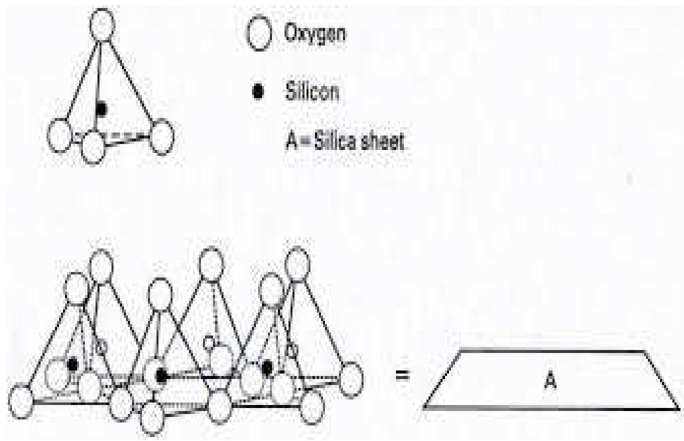


Figure 2.1: a Silica Tetrahedron and a Silica Sheet (Oweis and Khera, 1998)

Figure 2.2 below shows octahedron arrangement of clay minerals in which aluminum atoms were positioned in the center with one oxygen atom occupying each of the eight corners.

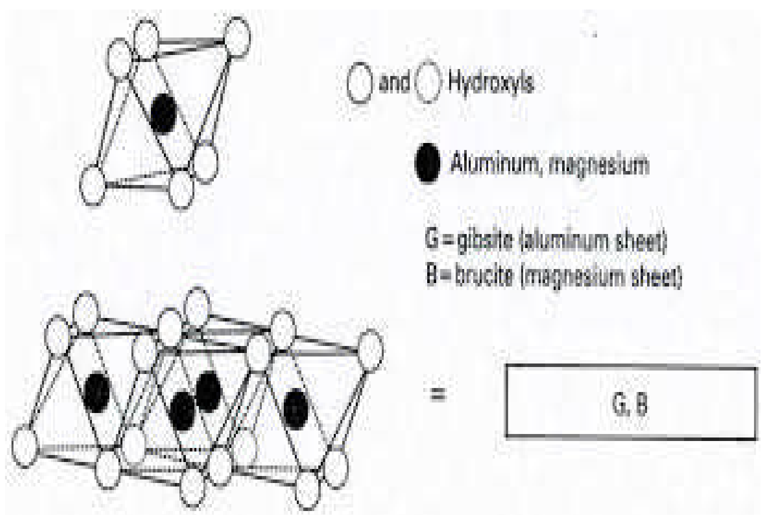


Figure 2.2: an octahedron and an octahedron Sheet (Oweis and Khera, 1998

The Magnitude of expansion depends up on the kind and amount of clay minerals present, their exchangeable ions, electrolyte content of aqueous phase and the clay mineral structure (Chen, 1988). There are three most important clay mineral structural groups which are described for civil engineering purposes: such as, kaolinite, illite and monthmorilonites clay mineral groups.

Kaolinite: - this clay mineral is known as the most stable of the groups of minerals and it is also called non expansive clay soil. In this case, the actual clay crystals are a combination of aluminum and silicone atoms which are held together by intra- molecular forces. Kaolinite crystals consist of tetrahedron and octahedron sheets. The bonding between successive layers is given by van der waals forces and hydrogen (which are comparatively strong) bonds. The bonding is sufficiently strong that there is no inter layer swelling in the presence of water (Mitcher and Soga, 2005).

Illite: - is called a non-expanding clay crystalline mineral and it is the second mineral group in layered alumino – silicate participation and such mineral is common in sediments, soils and argillaceous sedimentary rocks as well as in some low grade metamorphic rocks. Such clay mineral is classified under expansive but commonly do not possess significant problem on different structures and also has the same structural arrangement with monthmorillonite clay minerals.

In illite aluminum octahedron sheet is the basic structure and it is combined between two sheets of silica tetrahedrons. In the octahedral sheet there is partial substitution of aluminum by magnesium and iron, and in the tetrahedral sheet there is also partial substation of silicon by aluminum. The combined sheets are linked together by fairly weak bonding due to potassium ions held between them (Craig, 1997).

Monthmorillonite: - Such clay mineral is commonly known to be potentially troublesome for its high swelling and compressibility characteristics and its low shear strength. In monthmorillonite, the oxygen to oxygen bond between the individual layers is extremely very weak (Fredlund, 1975).

This clay mineral is present in most expansive soil and it is well known that even a small amount of montmorillonite clay mineral has a significant influence on the behavior of soil material. It is also known as highly expansive and problematic clay minerals (Nelson and Miller, 1992)

Montmorillonite are formed from weathering of volcanic ash under poor drainage conditions or in marine waters.

The basic building sheets for smectite are the same as for illite except there is no potassium ion present. The space between the combined sheets is occupied by water molecules and exchangeable cations. There is a very weak bond between the combined sheets due to these ions. Considerable swelling of montmorillonite can occur due to additional water being absorbed between the combined sheets (Craig, 1997; Oweis and Khera, 1998).

Geotechnical engineers need to understand clay crystal structures and the effects of surface chemistry in order to understand these swelling behaviors (Mitchell, 1993).

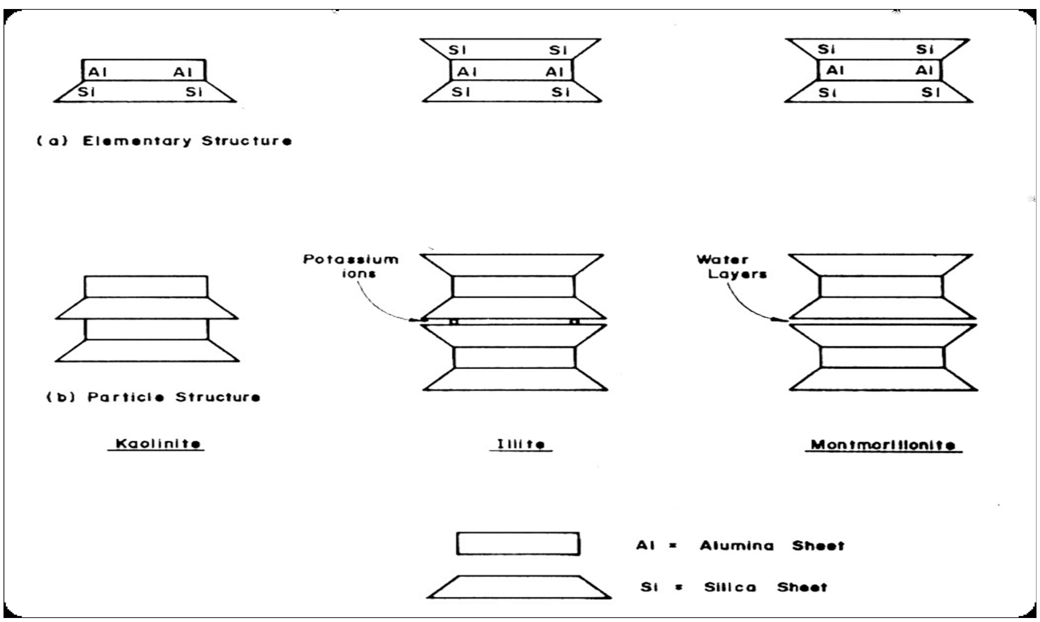


Figure 2.3: Clay mineral Structures (Craig, 1997)

2.3. Some of the general properties of expansive soil

Depending on the amount of water, another important characteristic of expansive soil is its vulnerability to physical changes. In wet season, the clay has the capacity of swelling conversely, in dry season it become shrink and form cracks on surface.

2.4. Identification of potentially expansive soil

The purpose of identification of expansive soil is to know and characterize potentially volume change behavior of existing natural subgrade soil.

2.4.1. Indirect Classification of expansive clay soils

Simple soil property tests can be used for evaluation of the swelling potential of expansive soils (Chen, 1988). Such different tests are easy to perform and should be used as routine test during investigation of different construction sites in which the site is suspected with expansive soils. The different test includes:

- Atterberg limit test
- Free swell index test
- Colloid content test

i. Atterberg Limit Test

- Louisiana department of transportation (1977) uses atterberg limit (liquid and plastic limit) balanced with field experience to classify potentially expansive soil. The method used to classify and identify potentially expansive soil is as:

Table 2.1: Relation between swelling potential and plasticity index, I_p

LL (%)	PL (%)	Potential swell classification
20 - 49	15 - 24	Low to medium
50 - 70	25 - 46	High
>70	>46	Very high to severe

- Holtz and Gibbs (1956) demonstrated that, plasticity index, Ip, and liquid limit, wL, are useful indices for determining the swelling potential of most soils.

Table 2.2: Relation between swelling potential and plasticity index, I_p (Gibbs and Holtz, 1956)

Plasticity Index, I_p, (%)	Swelling Potential
0 – 15	Low
10 – 35	Medium
20 – 55	High
35 and above	Very High

- Kansas Highway commission also uses (1974) Attereberg limit (PI) to classy potentially expansive soil. The KHC criteria for classification of potentially expansive soil are as shown in table below.

Table 2.3: Relation between swelling potential and plasticity index

PI (%)	**Potential swell classification**
<15	Low or none
15 - 35	Moderate
>35	High

ii. Free Swell Index test

The determination of free swell index helps to identify the potential of a soil to swell which might need further detailed investigation regarding swelling and swelling pressures under different field conditions. The test is performed by pouring 10gm of dry soil passing a sieve of size 0.425mm (NO.40) in to a 100mm graduated jar filled with water, notifying the swelled volume of the soil after it comes to rest (Nebro ,2002).

$$\text{Free Swell Index} = \frac{(\text{soil volume in soil} - \text{soil volume in kerosene})}{(\text{Soil volume in kerosene})} \times 100$$

Free swell < 50%, not expansive
Free swell between, 50 – 100 %, marginal
Free swell > 100 %, expansive

iii. Colloid Content

- U.S. Bureau of Reclamation (USBR), this method involves direct correlation of observed volume change with colloid content, PI and SL. The degree of expansion and limits of correlated properties are shown in table below.

Table 2.4: Relation between colloid content, PI, SL and swelling potential and plasticity index

Colloid content	**PI (%)**	**SL (%)**	**Probable expansion (%)**	**Expansion**
<15	<18	>15	<10	Low
13 – 23	15 – 28	10 – 16	10 – 20	Medium
20 – 31	25 – 41	7 – 12	20 – 30	High
>28	>35\	<11	>30	Very High

- In an effort to simplify the USBR method and to provide relative measure of soil density, a correlation was made between odeometer swell data and percent passing sieve N$^{\underline{o}}$200, LL and standard penetration resistance. The resulting classification for degree of expansion is as follows:

Table 2.5: Relation between LL, SPR and swelling potential and plasticity index

F200 (%)	LL (%)	Standard penetration resistance(blows/feet)	Probable expansion (%)	Degree of expansion
<30	<30	<10	<1	Low
30 – 60	30 – 40	10 - 20	1 – 5	Medium
60 – 95	40 – 60	20 – 30	3 - 10	High
>95	>60	>30	>10	Very high

- This test method is usually used to determine the amount of soil which is smaller than 2µm sieve size; therefore, such test method requires hydrometer analysis. In a given clay type, as the amount of clay increases the swell potential to increases. There is direct relationship between colloid content and swelling potential (chen, 1988).

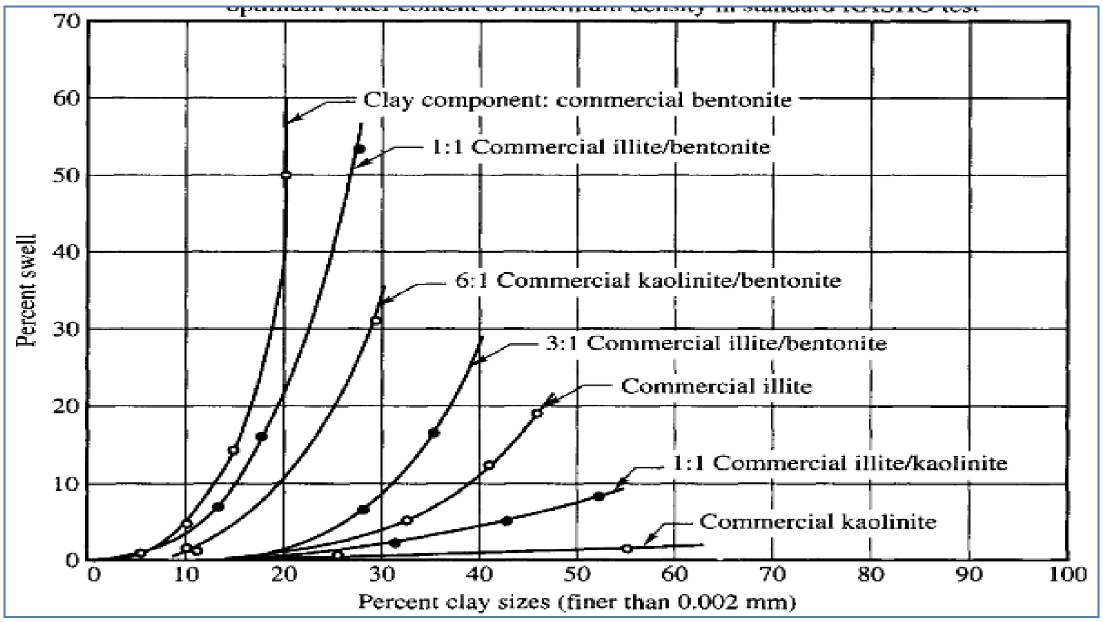


Figure 2.4: Relationship between Percentage Swell and Percentage of Clay Sizes for Experimental Soils (after Seed et al., 1962)

2.4.2. General classification Methods

- **Kantey and Brink (Mckeen, 1976)**

In this method, expansive soil, are recognized by the following criteria.

Liquid limit >30

Plastic limit >12

Linear shrinkage >8

Therefore, if the given soil is in the above classification category then we can say that the soil is expansive.

2.5. California Bearing Ratio (CBR)

I. General

California Bearing Ratio (CBR) value is an important soil parameter for design of flexible pavements. It can also be used for determination of sub grade reaction of soil by using correlation. CBR is one of the most important engineering properties of soil for design of sub grade of both urban and rural roads.

The California Bearing Ratio (CBR), is defined as the ratio of the resistance to penetration of a material to the penetration resistance of a standard crushed stone base material. California Bearing Ratio is the main design input in pavement construction to assess the stiffness modulus and shear strength of subgrade material. The method was developed by the California division of highways as part of their study in pavement failure at World War II **Young (2004)**.

With an intention to adopt a more simplified test method to measure the stiffness modulus and shear strength of subgrade soil a simple test that can be used as an index test was devised. This is where CBR test comes into frame in measurement of subgrade strength. The CBR test is a simple strength test that compares the bearing capacity of a sub grade and material with that of a well graded standard crushed stone base kept in California division of highways laboratory **Young (2004)**. This means that the standard crushed stone material should have a CBR value of 100%. The resistance of the crushed stone under standardized conditions is well established. Therefore, the purpose of a CBR test is to determine the relative resistance of the subgrade material under the same conditions.

The CBR test is essentially a measure of the shearing resistance of a soil at a known moisture and density conditions. The method of evaluating CBR is standardized in AASHTO T 193 and ASTM D 1883.

II. Importance of California Bearing Ratio

The design of pavement thickness in port terminal construction requires the strength of subgrade soil, sub-base and base-course material to be expressed in terms of California Bearing Ratio, so that a stable and economic design method has been realized. A road section for which a pavement design is undertaken should be sub-divided into subgrade areas where the subgrade CBR can be reasonably expected to be delineated uniform, i.e. without significant variations, in order to utilize it in the design of pavement thickness **ERA Manual (2002)**.

On the other way, the value of CBR is an indicator of the suitability of natural subgrade soil as a construction material. If the CBR value of subgrade is high, it means that the subgrade is strong and as a result, the design of pavement thickness can be reduced in conjunction with the stronger subgrade. Conversely, if the subgrade soil has low CBR value it indicates that the thickness of pavement shall be increased in order to spread the traffic load over a greater area of the weak subgrade or alternatively, the subgrade soil shall be subjected to treatment or stabilization.

III. Test Procedures for CBR determination of Subgrade material

California Bearing Ratio (CBR) test can be carried out mostly in laboratory and also at field. The samples may be prepared in two different ways. Accordingly;

- Test can be performed on a remolded sample in laboratory.
- On undisturbed sample carefully extracted from field and trimmed to closely fit the standard mold in laboratory.

IV. Determination of CBR at field level

Field in-place tests are used to determine the relative strength of soils and sub-base course materials in condition at which they exist at the time of testing. Field in-place CBR tests are used for design of flexible pavement components and for other applications in which CBR is the desired strength parameter. If field CBR is to be used directly for evaluation or design without consideration for variation due to change in water content, the test should be conducted less than one of the conditions stated in **ASTM D 4429-93 manual**.

In the field study, since, a set of field CBR tools are setup for carrying out the penetration test, the cylindrical plunger is allowed to penetrate the soil at a given rate. The force required to cause the plunger to penetrate the in-situ soil with respect to the penetration depth would be recorded by means of a calibrated proving ring. Later, results of in-situ soil shall be compared with the relationship between force and penetration to that of a standard load of a crushed stone base material. In order to get a reliable result care measures shall be taken for any construction test activities, such as grading or compacting carried out subsequent to the field in-situ test which will probably invalidate results of the test. It should be further noted that during in-situ testing the removal of larger-sized particles which may adversely affects the test result is not possible **Peter etal (2006)**.

Therefore, the in-situ test is likely to encounter such problems in coarser types of in-situ material, whereas the laboratory CBR test is limited to particles passing 3/4 inch (19 mm) sieve size **Martin (2003)**.

V. CBR Laboratory Testing

Laboratory CBR test is carried out as per the procedure outlined in ASTM D 1883-73 or AASHTO T 193-63. This test method provides the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit weight. The dry unit weight is usually given as a percentage of maximum dry density from the compaction tests of either standard proctor test (ASTM D 698) or modified proctor test (ASTM D 1557).

The Laboratory CBR test procedure is based on the principle of a plunger of standard area advancing into a remolded sample at a specified rate of penetration after determining optimum moisture content. Prepared remolded sample may be soaked for 96 hour. Swell readings are taken during this period at arbitrary selected times.

At the end of the soaking period the penetration test is carried out at a rate of 1.27mm/min and force or load required to cause penetration will be recorded with respect to the standard penetration depths at each 0.5mm penetration, including the load value at 2.54 mm and 5.08 mm until the total penetration is 12.7mm. The penetration resistance load is then plotted against the penetration depth and CBR correction is made for the load Vs penetration curve.

Using corrected value taken from the load-penetration curve for 2.54 mm and 5.08 mm penetration, the bearing ratio is calculated by dividing corrected load by the corresponding standard load, multiplied by 100 %. Its value ranges from 0 % to 100 %, worst to best case respectively.

In the laboratory test, if the soil sample is remolded using one density and one moisture content, the design CBR value will be the one that satisfies the above bearing ratio criteria. Whereas in the case of a range of densities are used in the test, after getting the bearing ratio for each sample, density versus CBR curve is plotted and the design CBR value of the soil will be the one corresponding to the desired dry density from the Density-CBR plot. The later approach is more practiced in different specifications and also the current research has followed this testing procedure.

2.6. Geosynthetics

Geosynthetics are synthetic products used to stabilize different civil engineering projects. They are generally polymeric products used to solve civil engineering problems. The different types of such materials (**shown in figure below**) includes: geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners, geofoam, geocells and geocomposites. The polymeric nature of the products makes them suitable for use in the ground where high levels of durability and strength were required. Geosynthetics are available in a wide range of forms and materials.

These products have a wide range of applications and are currently used in many civil, geotechnical, transportation, geoenvironmental, hydraulic, and private development applications including roads, airfields, railroads, embankments, retaining structures, reservoirs, canals, dams, erosion control, sediment control, landfill liners, landfill covers, mining, aquaculture and agriculture **(Muller etal,2015).**

Figure 2.5: Different products of geosynthetic materials **(Koerner, 2012)**

Geosynthetics have been used in pavement foundation layers for separation, filtration, lateral drainage, and reinforcement purposes (Berg et al. 2000). The mechanisms by which geosynthetics provide reinforcement when placed at the subbase and subgrade interface include lateral restraint or confinement of subbase material, and increase in bearing capacity. The benefits of four different geosynthetics—woven and non-woven (NW) geotextiles, and biaxial and triaxial polymer geogrids are evaluated in this study.

2.6.1. Product and types of Geosynthetics

i. General

According to the American society for testing material (ASTM) committee D35(2001), geosynthetic material can be defined as a planar product which is manufactured from a polymeric material used with soil, rock, earth or other geotechnical engineering related material as an integral part of man - made project, structure, or systems. Geosynthetics are man – made material which are used to improve soil conditions and typically made from petrochemical – based polymers (plastic) that are biologically inert and will not decompose from bacterial and fungal action (Allen etal, 1991). Soil reinforcement using membrane was initially proposed by Casagrande, who idealized in the form of a weak soil reinforced by high – strength membrane laid horizontally in layers (Westergaard, 1938). The oldest historical development of the use of fabric as an aid to road construction over soft ground includes the use of geogrid fabric.

ii. Geotextile

Such product form one of the two largest groups of geosynthetic material. Since such product is being produced from polymeric synthetic material, hence it is less susceptible for bio – degradation. Geotextiles are defined as "any permeable textile used with foundation soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system". They are typically the most used geosynthetic material for agriculture purposes. These are fabric or cloth-like materials that are classified based on the method used to place the threads or yarns in the fabric: either woven or non-woven. Geotextiles typically come in rolls up to approximately 5.6m wide and 50 to 150m long (Singh, 2013).

Geotextiles, as known and used today were first used in connection with erosion control applications and were intended to be an alternative to granular soil filters (Koerner, 1998).

Almost all geotextiles available in the United States are manufactured from either polyester or polypropylene (Geosynthetics Material Association, 2002). Geotextile can be woven and non – woven and also such material can perform at least one of the four discrete functions as: separation, reinforcement, separation and/or drainage.

iii. Woven and non – woven Geotextile

Woven geotextile is like cloth-like fabrics are formed by the uniform and regular interweaving of threads or yarns in two directions as shown in Figure 2.5, below. These products have a regular visible construction pattern, and where present, have distinct and measurable openings. Woven geotextiles are typically used for soil separation, reinforcement, load distribution, filtration, and drainage. They can have high tensile strength and relative low strain or limited elongation under load (typically up to 15%) A. Singh **(2013).** And non-woven geotextile is felt-like fabrics are formed by a random placement of threads in a mat and bonded by heat-bonding, resin-bonding or needle punching, as shown in Figure 2.6, below. These products do not have any visible thread pattern. Non-woven geotextiles are typically used for soil separation, stabilization, load distribution, and drainage but not for soil reinforcement such as in retaining walls. They have a relatively high strain and stretch considerably under load (Geosynthetics Material Association, 2002).

(a) **(b)**

Figure 2.6: woven geotextile (a) and non – woven geotextile (b) (A. Singh, 2013)

iv. Geo-Grids

As per Texas Department of Transportation (2013) the application of geogrid material is primarily in three main functions as: reducing cracks from subgrade desiccation, construction of platforms in subgrade with high sulphate content and construction expedience over soft soils. If plasticity index for the given subgrade material is greater than 35 then it is advisable to place geogrid material between base course and subgrade material.

A geogrid is defined as a geosynthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow strike-through of surrounding soil, stone, or other geotechnical material (Koerner , 1998).They are planar polymeric material consisting of regular open network of connected tensile elements with square or rectangular openings. The linkage between the tensile elements can be extrusion, bonding or interlacing.

As per **Tensar** (**2013**) geogrid International shown in **Figure 2.7**, application of geogrid can reduce cut, fill and aggregate fill thickness works. They are used primarily for soil reinforcement. Their strength can be greater than the more common geotextiles. Geogrids have a low strain and stretch only about 2 to 5% under load (Singh, 2013). Webster et al. (1991) carried out on geogrid reinforcement of flexible pavements for light aircraft.

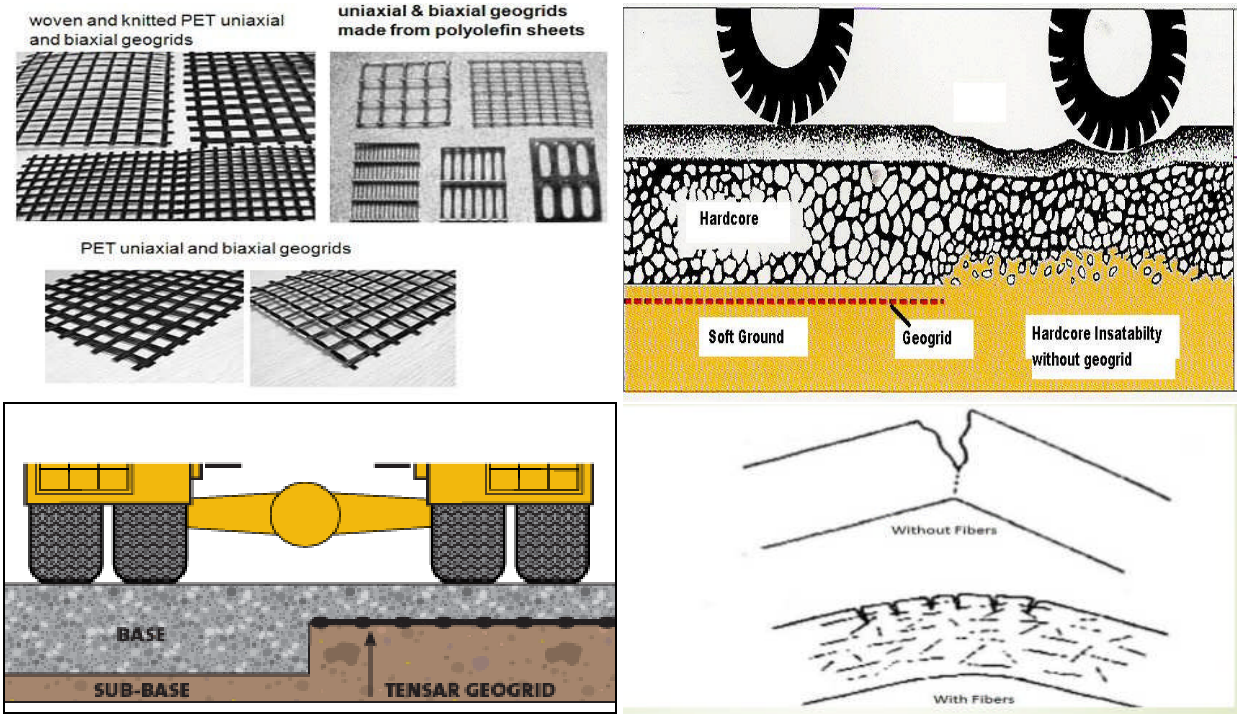


Figure 2.7: Different usage of geogrid materials (Webster, 1991 and Anoop Singh, 2013)

v. Geomemebrane

Alexander (1997) defines geomembranes are thin, two-dimensional sheets of material with very low permeability. This makes them ideal for forming waterproof or gasproof barriers between adjacent bodies of soil or soil and fluid. Geomembranes are polymer sheets used to control fluid movement. These materials have very low permeability and would be used for lining ponds, pits and so on to control leachate. They may be used over top of a geotextile (Geosynthetics Material Association, 2002).

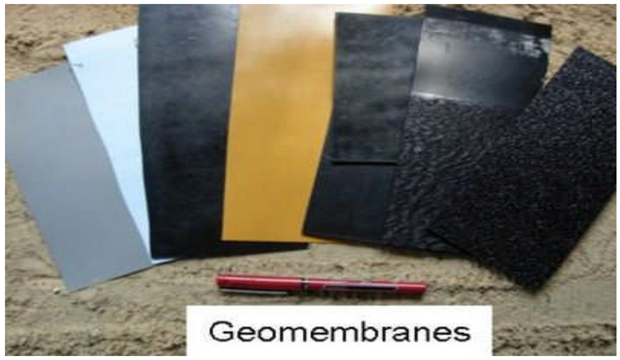


Figure 2.8: A typical geomembrane (A. singh, 2013)

2.6.2. Application of Geosynthetics

The use of geosynthetic was excellent economic alternatives than the conventional solution for different civil engineering problems and the different application of geosynthetic materials are as below:

i. Separation

Roadway failure may occur when fines from the subgrade contaminate an overlying granular layer. High stresses transmitted from vehicle wheel loads on the surface above, combined with saturated subgrade, typically cause a base and subgrade to mix. This mixing causes a reduction in the effective base thickness by reducing the actual modulus of the granular base as well as its physical thickness. Due to wheel loads above, mixing occurs. Mixing is best pictured as granular material pushed down into the soft subgrade and/or soft subgrade pumped up into the overlying granular layer (Tensar Design Manual, 1998).

Porous geosynthetics when sandwiched between two soil types with vastly different particle sizes perform the function of keeping them separate and prevent the mixing of particles. For example, when road pavements are constructed, a base course material that is often gravel sized is placed directly on the subgrade soil. If the subgrade is soft clay, the gravel will tend to penetrate into subgrade soil under traffic load resulting in a mixed soil. The performance of the base course deteriorates with time due to mixing. This can be prevented by placing geosynthetics at the interface between the subgrade and the base course. It prevents mixing and results in improved pavement performance (Singh, 2013).

ii. Filtration

The filtering function is similar to the separation function in that the migration of fines into the base course is reduced. Porous geosynthetics, when located in between two soil layers, one fine grained and the other course grained, through which water is flowing; perform the function of a transition filter. They allow water to pass through them without passage of fine particle of soil along with the water (Alexander, 1997)

iii. Drainage

Porous geosynthetics with high in-plane permeability perform the functions of drains where these are placed within a soil mass to intercept seeping water and carry it rapidly along the in-plane direction without migration of fine particles (Singh, 2013).

iv. Reinforcement

Reinforcement is the ability to distribute a concentrated load over a large area of subgrade, thus avoiding overloading of bearing capacity. Geosynthetics with high tensile strength perform the function of reinforcement in a soil mass when these are placed in single or multi layers to improve the engineering behavior of the soil mass. Soil by itself behaves well under compression but is poor in tension and the performance of the soil is enhanced by the tension carrying capacity of geosynthetics. In geosynthetic reinforcement, loading is distributed over a wider area as a result of the vertical component of the tension, which develops in the geosynthetic material (Alexander, 1997).This improves the bearing capacity of soft soil, enhances stability of steep slopes and reduces earth pressure behind retaining structures (Tensar Design Manual, 199)

v. Hydraulic Barriers

Geosynthetics that are impermeable in the cross-plane and in-plane directions perform the function of hydraulic barriers when placed in a soil mass by preventing seepage of water through the soil mass. Seepage of water from canals can be controlled by placing a geomembrane at the base and along the sides of the canal (Singh, 2013)

vi. Surface Erosion Control slopes

Erosion is often a problem when there is not enough protective cover on steep slopes or in drainage channels that have been designed to rely on vegetation for long-term erosion control. Temporary erosion control geosynthetics comprise of natural biodegradable fibers such as jute. They are spread on the slope in the form of grids or mats and they prevent erosion until vegetative growth occurs and later degrade. Permanent erosion control geosynthetics are porous synthetic polymeric products that furnish erosion control, aid vegetative growth and become entangled with the vegetation to provide reinforcement to the root system (Hand Book of Geosynthetics, 2002).

2.6.3. Mechanism of Geogrid Reinforcement

Subgrade material prepared for understanding the mechanism of geogrid reinforcement is governed by application of such material. The mechanism that held between prepared subgrade and geogrid material is governed by interlocking effect. After inclusion of geogrids with in subgrade material, geogrids interact with the surrounding soil particles to carry the tensile and compression loads induced on it. Since geogrid material is much stiffer in tension than subgrades, lateral stress in geogrid reinforced subgrade and settlement become reduced (Ngoc, 2012)

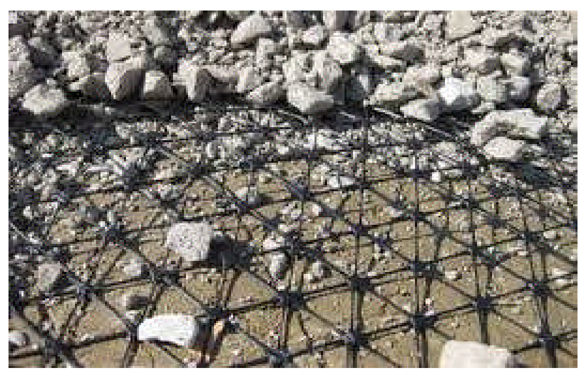



Figure 2.9: A typical interlocked with subgrade and base course material **(AREMA, 2010)**

2.6.4. Geogrid Stabilization

The improved performance of the pavement due to geosynthetic reinforcement has been attributed to three mechanisms: (1) lateral restraint, (2) increased bearing capacity, and (3) tensioned membrane effect (Giroud and Noiray 1981, Giroud *et al.* 1984, Perkins and Ismeik 1997, Holtz *et al.* 1998). These three mechanisms are illustrated in Figure below.

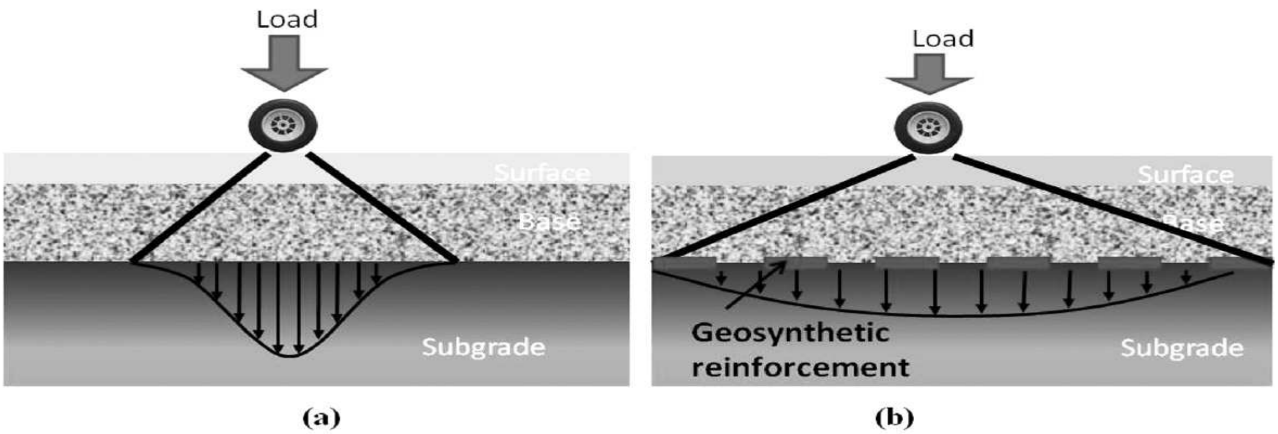


Figure 2.10: Relative load magnitudes at subgrade layer level for (a) unreinforced flexible pavement and (b) geosynthetic-reinforced flexible pavement

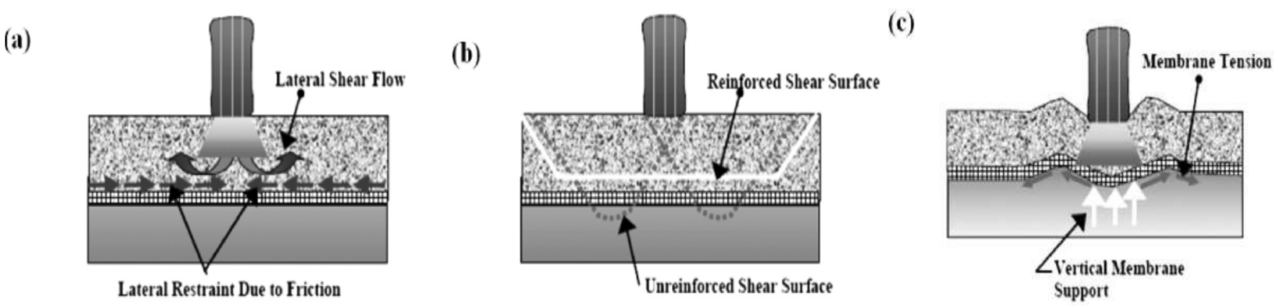


Figure 2.11: Reinforcement mechanisms induced by geosynthetics (Holtz et al. 1998): (a) Lateral restraint; (b) Increased bearing capacity; and (c) Membrane support.

The use of geogrid in roadways construction in order to reinforce the base of the structure over expansive soft subgrade soil nowadays becomes an alternative advantage than removing problematic soils and replacing (improving) by addition of chemical stabilizer. In any case, the traditional undercut and stabilization solution is often costly and time - consuming process; therefore, geogrids are often used as replacement for these traditional solutions. Geogrid help to increase the bearing capacity of expansive subgrade soil.

Netlon developed a more efficient means of utilizing the basic polymer raw materials to yield a product with greater strength and elastic modulus in the form of polymer grids to be used in much soil reinforcement application (Shukla, 2002).

Geogrid reinforcement is gaining acceptance as an effective way of improving on the properties of naturally occurring soils for road pavement construction. Geogrids used within a pavement system perform two of the primary functions of geosynthetics: crack prevention and reinforcement. In many tropical countries, weak lateritic subgrades are common and often rejected after proof rolling during construction due to poor strength (Charles Anum et al, 2014).

Pardeep and etal (2012) studied CBR improvement of clayey CBR improvement for clayey types of soil after inclusion of geogrid reinforcement. As per them one type of clayey soil was selected and the important physical property and classification for selected soil was shown in table below.

Table 2.6: Physical properties and classification of soil selected

Property	Soil
Dry Density (gm/cc)	1.70
Optimum Moisture Content (OMC) %	16.0
Specific gravity	2.60
Coefficient of uniformity (Cu)	8
Coefficient of curvature (Cc)	0.18
Liquid Limit(%)	28
Plastic Limit (%)	15
Plasticity Index	13
Unified classification	CL- Clay of low compressibility

After classification, CBR tests were conducted on selected soil, unreinforced and reinforced with a single layer of geo-grid. To reinforce a sample, the geo-grid was placed in a single layer at different positions: 20%, 40%, 60% and 80% of the specimen height from the top surface. From obtained result it is clear that considerable amount of increase in CBR value of soil with geo-grid reinforcement was obtained. For example, in case of unreinforced soil the CBR value is 2.9% and with geo-grid reinforcement the CBR value increases to 9.4%. The highest increase in the CBR value was achieved when geo-grid was placed at 20% depth from the top of the specimen.

Naeini et al (2007) investigated the effect of geogrid reinforcement on the CBR value of soft clay. In this study three soil samples, with various index of plasticity 10%, 16% and 23% respectively were prepared by adding in different percentages of bantonite to a clay soil. Geogrid material used as reinforcement was cut into a circular pieces with the same diameter of CBR mold and the output of the result showed that, soaked and unsoaked CBR value become increases due to inclusion of geogrid material in layers.

Akolade et al (2013) studied the application of geogrids in the geotechnical properties of poor subgrade soil material. In this case soil sample A, B and C were selected from different Osun state Nigeria. Sample A and C were determined as granular using grain size and Atterberg test; whereas, sample B was silty clay in nature and geogrid material was placed in three independent single layers i.e. 2/5H, 3/5H and 4/5H from the base of the mold. They showed that the 48 hour soaked CBR value before introducing geogrids was given as 3%, 9% and 6% respectively. After placing the geogrids in layers the strength of subgrade material was considerably increased and they found that placing geogrids at the depth of 3/5H from the base of the mold, showed higher soaked CBR value (15.1%, 14% and 12.2%) than when placing geogrid at 2/5H (12.8%, 11% and 8.8%) and 4/5H (11%, 10% and 8.3%) respectively for soil sample A, B and C and they concluded that geogrid has been suitable means of reinforcement for adverse effects on the soil strength posed by increased moisture content. Therefore, from literature review it is concluded that, geogrid stabilization of weak subgrade soil is one of the most important physical stabilization.

Chapter 3

Research Methodology and Materials

3.1. Methodology

To meet the objective of this study, first different related relevant researches were reviewed before conducting laboratory tests then disturbed soil samples were collected from specified site which is carried out as per ASTM standard practice for soil investigation and sampling (D1452 – 09) and different laboratory tests were conducted to know some of the physical properties of existing natural subgrade soil. Hence, the following actions were taken places and **Graph 3.1** shows research methodology design flow chart.

3.2. Selection of the study area for sample collection

The study area is located in central part of Ethiopia, in Bole Arabsa, in Addis Ababa City. In the study area, black and highly plastic soils are predominantly found which cover extensive area with varying thickness.

After knowing the intense distribution, thickness and field identification of expansive soil, and then the samples were collected.

3.3. Collection of disturbed soil samples

Expansive soil was collected from a place called Bole Arabsa because; in this place the distribution of expansive soil is predominant. Disturbed soil samples were taken from open pits at 2 meter depth by digging using hand tools.

Mostly depth of excavation from 1.5 up to 3m is commonly known as the depth in which different Subgrade location and shallow foundation structures are being constructed. For road construction, it is desirable to locate the pavement on the stronger, hard and firm soil.

3.4. Collection of geogrid Materials

Geo-synthetics, in particular, geo-grids, are one of the commercial construction aids to improve the strength of weaker sub-grade. Geo-grids include a large variety of polymer products designed to improve strength of the sub-grade. Geo-grids are extensively used as reinforcement in structures with unbound material like pavements, embankments, slopes and retaining walls. It is placed at interface between the base course and the sub-grade.

Many authors report that the inclusion of geo-grids at the interface between base course and sub-grade significantly improves the performance of the pavement on a weak sub-grade, both in the laboratory and full-scale field experiments.

Their studies showed significant increase in the soaked and unsoaked **California Bearing Ratio (CBR)** values of the soil on the introduction of fibers.

3.5. Laboratory Works

Representative sampling, proper test procedures and adequate test equipment are the most important requirements for good quality laboratory testing.

After collection of the soil sample which was representative soil sample for the given specific site, the following laboratory tests were conducted.

- Uncured free swell index test according to IS 2720 and the specific gravity of soil conducted as per ASTM D854 standards.
- Uncured liquid limit, plastic limit and plasticity index is conducted (called Atterberg limit tests) in accordance with **ASTM D4318 or** AASHTO T89-90. It is the boundaries of several states of consistency for plastic soils. To do representative air dried soil samples which pass through sieve number 40 were taken and soaked for hours in order to moist the soil grains. In order to get accurate results multipoint method is chosen then **LL** and **PL** tests were carried out using the above testing procedures.
- Immediate maximum dry density and optimum moisture content in accordance with BS: 1377 part 4 (1990) standard test methods for laboratory compaction characteristics of soil using standard load.
- Short term and long term strength of subgrade soil determined by measuring its California bearing ratio in accordance with ASTM D1883 standard test method.
- Particle size analyses of soil both sieve and hydrometer analysis as per ASTM standards of D422 or AASHTO T27.
- Tensile and elongation testing of geogrid: ASTM D6637 is Standard test method for tensile and elongation properties of geogrid material.

3.6. Experiment to conduct reinforced CBR test with geogrid inclusion

To conduct reinforced CBR test before and also after inclusion of geogrid material, the required quantity of dry soil and water was determined depending on MDD and OMC for natural subgrade soil; which are obtained from standard proctor test result.

The soil was mixed thoroughly after adding the required amount of water based on OMC. Soil sample was filled in the mold up to the point where reinforcing layer was to be placed at first, second and third layers then compacted up to the desired level to get the required density. CBR tests were conducted on selected soil, unreinforced and reinforced with a single layer of geo-grid.

To reinforce a sample, the geo-grid was placed in a single layer at different positions: 25%, 50%, and 75% of the specimen height from the bottom surface.

The geogrid cut in the form of circular disc of diameter slightly less than that of the specimen to avoid separation in the specimen by the reinforcing layer. The dry weight required for filling the mold was calculated based upon the MDD and corresponding OMC which were achieved from standard proctor test.

3.7. Laboratory Data Analysis and Result

After conducting different laboratory works, the results obtained were clearly elaborated and briefly analyzed for the obtained expansive subgrade soil before and after reinforcing with geogrid material. Then after knowing treated and untreated CBR values, conclusions and recommendations will be made.

3.8. Materials

The soil used in this study is collected from around Bole Arabsa study area. The soil sample was collected from a depth of 2m after removing the top surface soil from natural ground surface. The geogrid material used in this study was also taken from the Chinese companies which is located around Modjo dry port area.

In order to accomplish the objectives of this thesis, different laboratory equipment was used such as:

- CBR test equipment with their accessories
- Tensile test equipment for geogrid material
- Sieve, CBR and Proctor testing mold with their accessories, 100ml and 1000ml cylinder, mold for, Casagrande apparatus, thermometer, and computer for analyzing the result using Microsoft excel.

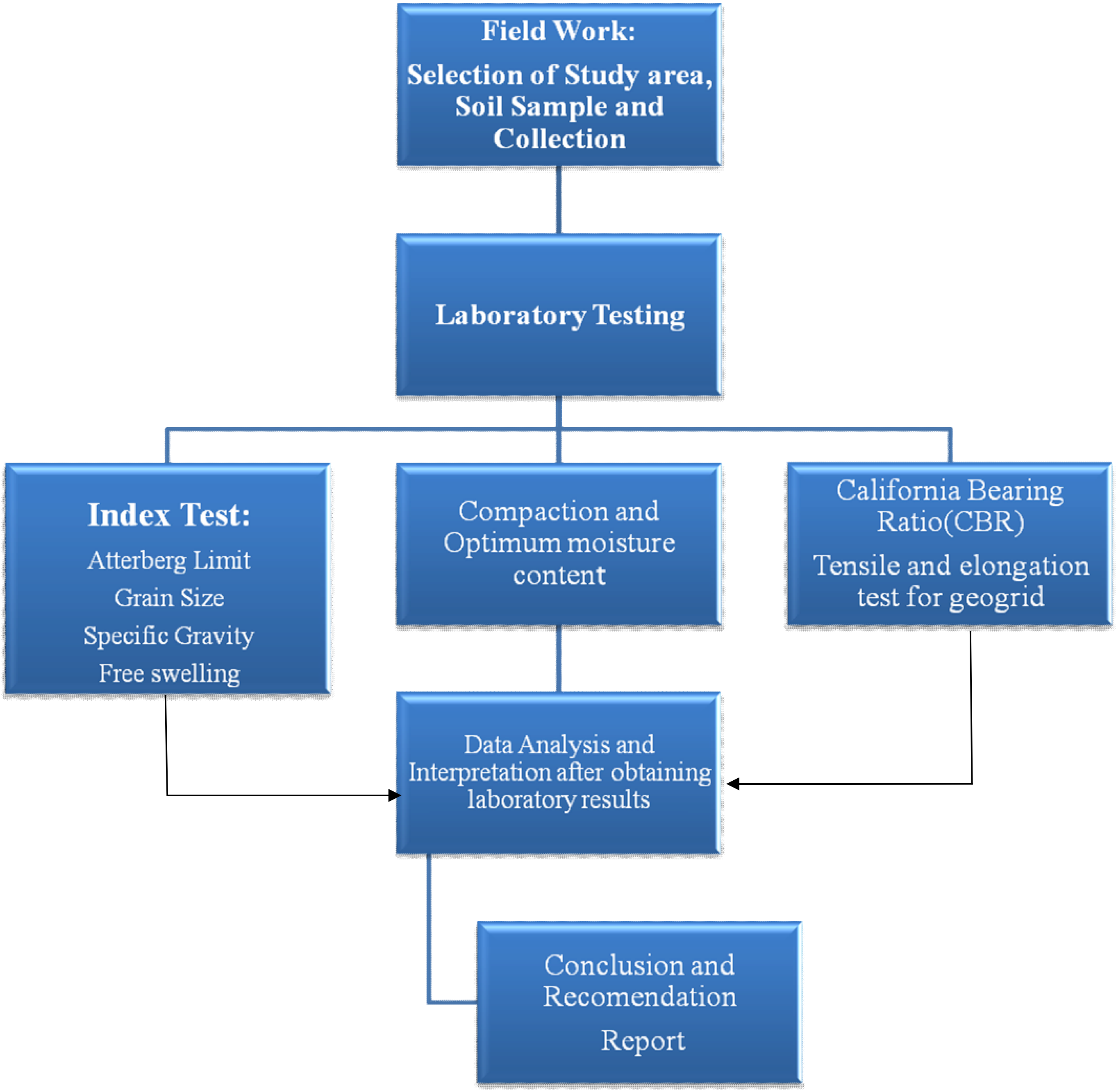


Figure 3.1: Research methodology design flow chart

Chapter four

Test Results

Before conducting the different types of laboratory tests first the sample was collected from specified study area then the following different kinds of laboratory tests were carried out in order to determine some of the engineering and index property test.

Both soaked and unsoaked CBR before and after inclusion with geogrid material were conducted in Ansif Construction Laboratory Service.

4.3. Sieve Analysis

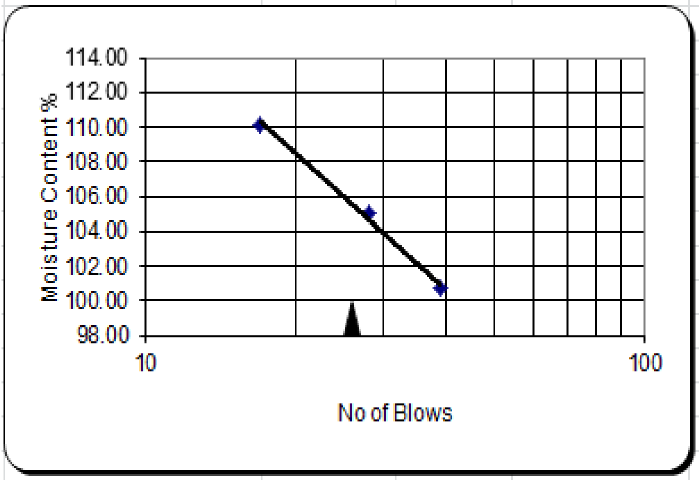
This test method is being carried out as per AASTO T27 standards. After air drying and also weighting the soil sample, it was sieved using wet sieve method and the distribution of particle size was determined by sieve analysis for soil particles greater than 0.075mm. Graph 5.1 shows distribution of particle size in which it was obtained from grain size analysis (using wet sieve method).

4.4. Atterburg Limit Test

Depending on the above stated test procedures, liquid limit and plastic limit tests were conducted for untreated natural subgrade soil. Since this study thesis is focused on only physical stabilization of weak expansive subgrade soil hence there is no effect Atterburg values due to geogrid reinforcement on liquid and plastic limit results except knowing index properties of existing soil. The results of laboratory test for liquid and plastic limits are as shown in Table 4.2.

Table 4.2: Summary of uncured laboratory test result for Liquid and Plastic limit test

		LIQUID LIMIT				PLASTIC LIMIT		
		1	2	3	4	1	2	
No.of blows	N	39	28	17				
Tare	n	G3	F5	H1		A2	H4	
Wt. tare + wet soil	g	37.18	40.42	34.47		21.81	20.76	
Wt tare + dry soil	g	25.95	28.87	25.04		20.29	19.24	
Wt. water	g	11.23	11.55	9.43		1.52	1.52	
Wt. of tare	g	14.80	17.87	16.48		16.96	15.94	
Wt. of dry soil	g	11.15	11.00	8.56		3.33	3.30	
No.of blows	N	39	28	17				
Moisture content	%	100.72	105.00	110.16		45.65	46.06	
						AVERAGE PLASTIC LIMIT		46



LIQUID LIMIT (LL%)		
106		
PLASTIC LIMIT (PL %)		
46		
PLASTICITY INDEX (P.I)		
60		
PASSING SIEVE %		
2.00mm (no 10)	0.425mm (no 40)	0.075mm (no 200)
SOIL CLASSIFICATION (AASHTO)		
A-7-5(20)		

The above obtained table shows liquid and plastic limit test result before application of geogrid materials in layers on a given CBR testing mold size; unfortunately these study paper basically focused on only physical improvement, hence gained values for liquid limit, plastic limit, and sieve size are similar both before treating and un treating with geogrid materials.

4.5. Free Swell Index and Specific Gravity Test Result

According to standard test procedures which were presented in chapter three above, free swell index and specific gravity tests were carried out for natural soil. The outputs of test results were tabulated in Table 4.3 below.

Table 4.3: Summary of uncured laboratory test result for free swell index and specific gravity determination.

No	ID	Free swell index (%)	Specific Gravity
1	Natural Soil	159	2.60

4.6. Optimum moisture content and Maximum dry density

This test method is conducted to know relationship between maximum dry density and soil moisture content. Such test was performed as per BS: 1377 part 4 (1990) standard testing guidelines in order to know exiting OMC and MDD for natural untreated subgrades soil and Their respective results are shown in Table 4.4 below.

Table 4.4: Summary of laboratory results for moisture density relationship of natural subgrade soil

No	ID	Optimum moisture Content (%)	Maximum dry density (kg/m3)
1	Expansive soil	22	1525

4.7. Soaked and non – soaked California bearing ratio

Using AASHTO T-193 testing procedures both soaked and unsoaked CBR were carried out for natural untreated subgrade soil as well as after reinforcing natural subgrade soil with inclusion of geogrid material. These were being done first by determining optimum moisture content from moisture – density relation then by placing prepared geogrid material at first, second and third single layer in CBR mold. Therefore, the results were tabulated below (Table 4.5) and detail laboratory test results are attached in the Appendix.

Table 4.5: Summary of laboratory test result for soaked and unsoaked CBR values including CBR swell values before and after inclusion of geogrid material

No of layer	No of Blows	Load at 2.54mm (soaked)	Load at 2.54mm (Non - Soaked)	Four Day Soaked CBR	Non - Soaked CBR	Four day Soaked CBR Swell
Without Reinforcement	56	296.01	912.78	2.24	6.89	7.67
First Layer	56	520.26	1190.32	3.93	8.99	4.12
Second Layer	56	726.57	1545.53	5.49	11.67	1.95
Third Layer	56	574.08	1356.26	4.88	10.24	2.11

4.8. Physical and Strength Characteristics of Geogrid Material used

Tensile and elongation test for geogrid material is conducted as per ASTM D638 standard in order to determine the ultimate tensile strength and elongation. Single rib tensile tests was tried to conduct at the facilities of Geosynthetic Industrial Works in Addis Ababa but while doing this problems like slippage was frequently observed. Therefore, some of the physical and strength properties for geogrid material which are used for railway construction were gained from Chinese companies and the obtained results are tabulated in Table 4.6 Below.

Table 4.6: Physical and Strength Characteristics of Geogrid Material used **(ERC, 2012)**

Physical and strength properties	Unit	Material Properties
Composition	-	Polypropylene
Aperture Size (Rectangular)	Mm X mm	25 X 25
Rib Thickness (ASTM D1777)	mm	1.3
Carbon Black Content (ASTM D4218)	%	0.5
Junction Efficiency (GRIGG2 – 87)	%	90
Tensile Strength at 2% strain	kN/m	11
Tensile Strength at 5% strain	kN/m	21
Peak Tensile Strength	kN/m	30
Elongation at Peak load	%	10.9
Elongation at Break Load	%	43.4

Summarized result of the laboratory test (grain size analysis, Free swell index, specific gravity, compaction and Atterburg limit and California Bearing Ratio (CBR)) for untreated natural subgrade soil is presented in the table below.

Table 4.7: Summarized Index and Engineering Properties Of Natural Soil Before Treating

Property	Quantity
Unified Soil Classification	CH
Liquid Limit (%)	106
Plastic Limit (%)	46
Plasticity Index (%)	60
Specific Gravity	2.6
Free Swell Index (%)	159
Dry Density (kg/m^3)	1525
Optimum Moisture Content (%)	22
Unsoaked CBR (%)	6.89
Soaked CBR Swell (%)	7.67
Soaked CBR (%)	2.24

Chapter 5

Discussions on Test Results

5.1. Analysis of grain size and Atterburg limit for selected soil samples

Graph for grain size distribution, liquid limit and plasticity index for the given soil samples test results are as shown below.

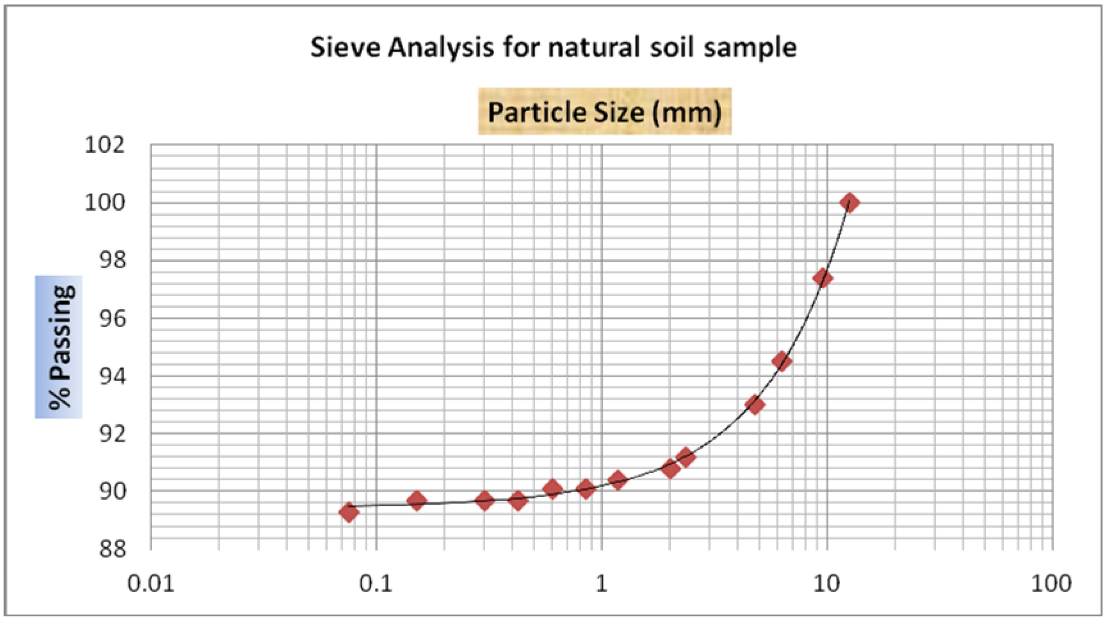


Figure 5.1: Grain size distribution curve for selected subgrade material

From grain size distribution curve shown on the above figure, total percentages of particles corresponding to 7% is gravel, 3.7% is sand and the remaining 89.3% is fine material respectively; the result shows that, more than 50% passes through sieve size 0.075mm.

Liquid limit and plasticity index for selected subgrade material are 106% and 60% respectively. Hence from grain size and Atterburg limit values, it can be generalized that the soil was classified as highly plastic clayey soils and also using AASHTO soil classification system the soil is grouped under A – 7 – 5(20).

Concerning on some of the index properties of soil as stated on previous chapter; shows the summary laboratory results of the preliminary analysis of soil samples. The natural moisture content of the sample was 3.4%. This is a function of the voids ratios and the specific gravities of the soil sample. According to whitlow **(1995),** liquid limit less than 35% indicates low plasticity, between 35% and 50% indicates intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity and greater than 90% extremely high plasticity. This shows that the obtained soil sample relies on extremely high plasticity. Therefore, from the above analysis it can be generalized that such type of soil is well known by its swell and shrink nature due to its high plasticity and presence of expansive clay minerals like illite and monthmorillonite.

5.2. Compaction and moisture content for natural subgrade soil

The relationship between moisture content and dry density for natural subgrade soil is as shown in figure below.

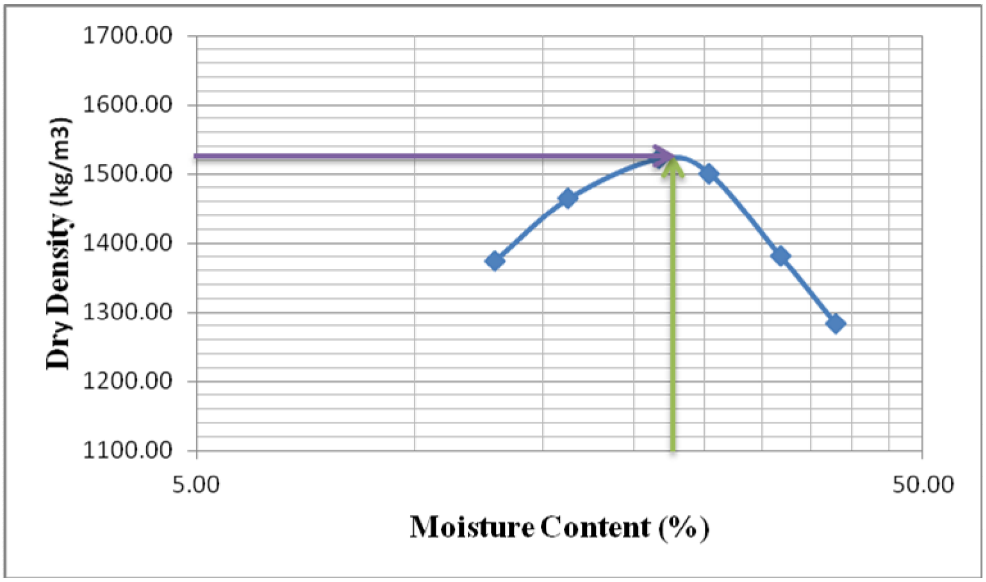


Figure 5.2: moisture content versus dry density result for natural subgrade material

From the above graph it can be observed that optimum moisture content and maximum dry density for natural subgrade soil was 22% and 1.522g/cm^3 respectively. Comparing with Atterburg limit result, better maximum dry density and minimum optimum moisture content was obtained. The reason is that as an increase in soil density or unit weight, accompanied by a decrease in air volume.

5.3. Effect of Geogrid inclusion in layers on CBR and CBR swell values.

While doing compaction of soil, for the purpose of reinforcing soil specimen in layers, a geogrid material was prepared with circular shape of 147mm diameter which is slightly less than the internal diameter of CBR mold in order to prevent separation of soil sample between reinforcing layer. geogrids were placed inside the mold at the specified position **as shown in Figure below** and finally the remaining soil sample was filled and compacted.

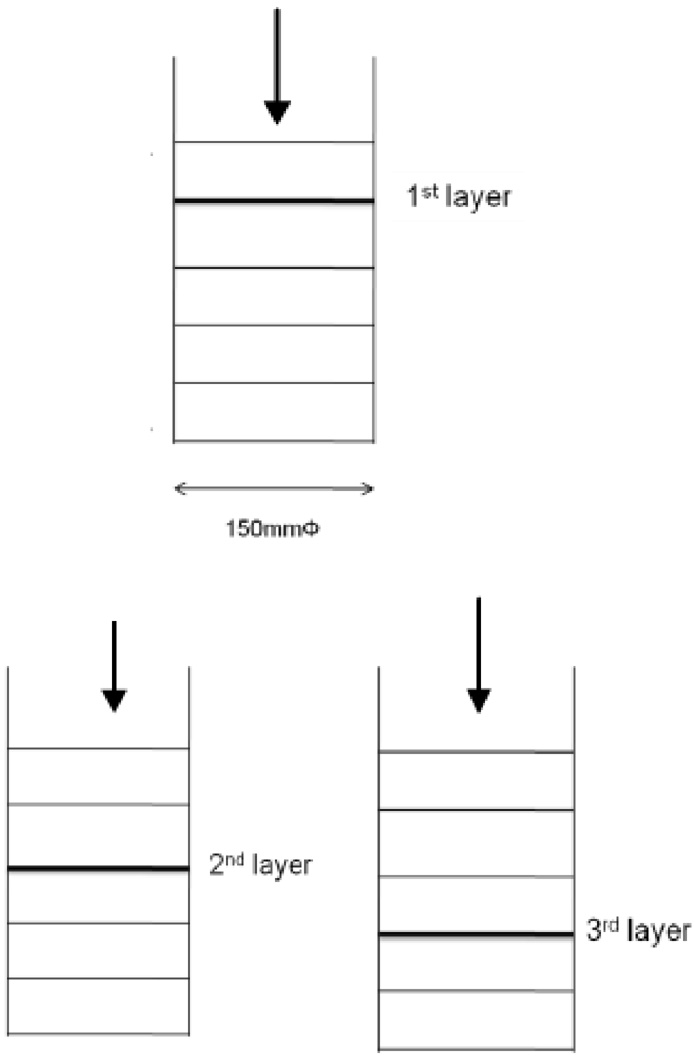


Figure 5.3: Position of geogrid reinforcement in layers

A total of four samples for non-soaked CBR test were tested before and after inclusion of reinforcing material. Also four samples of unreinforced and reinforced type were tested after soaking in water for four days.

The load penetration curve was drawn for the soil samples with geo-grid at different positions and the CBR values were calculated from these curves. Figure 5.4, 5.5,5.6 and 5.7 shows results of soaked and unsoaked CBR values both before and after reinforcing with geogrid materials. From figures shown below; it can be generalized that due to geogrid reinforcement both soaked and unsoaked CBR values were significantly improved.

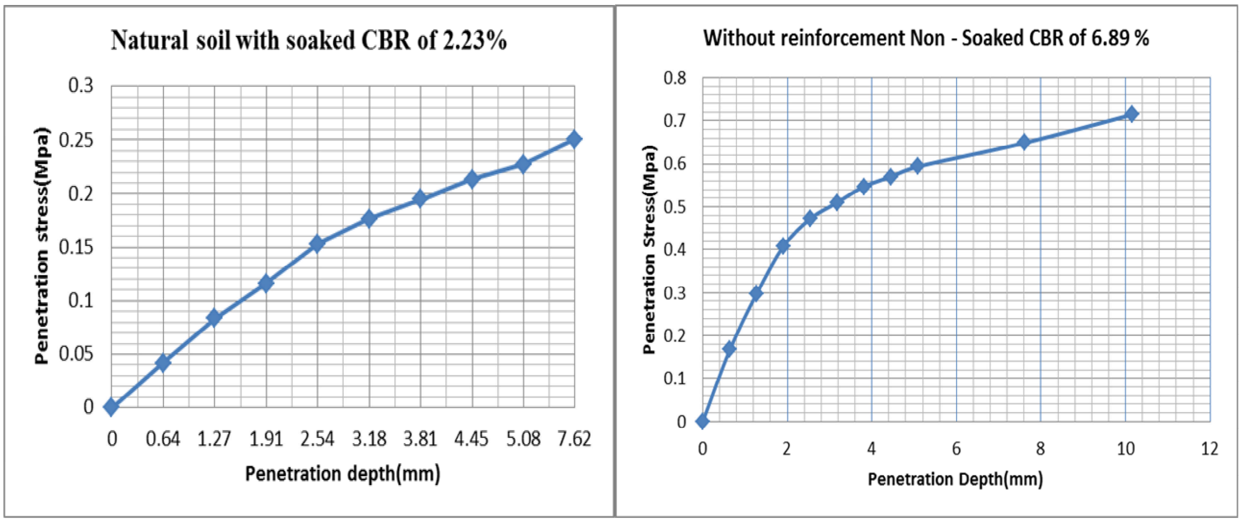


Figure 5.4: CBR Penetration Vs. stress graph of untreated subgrade soil without geogrid reinforcement

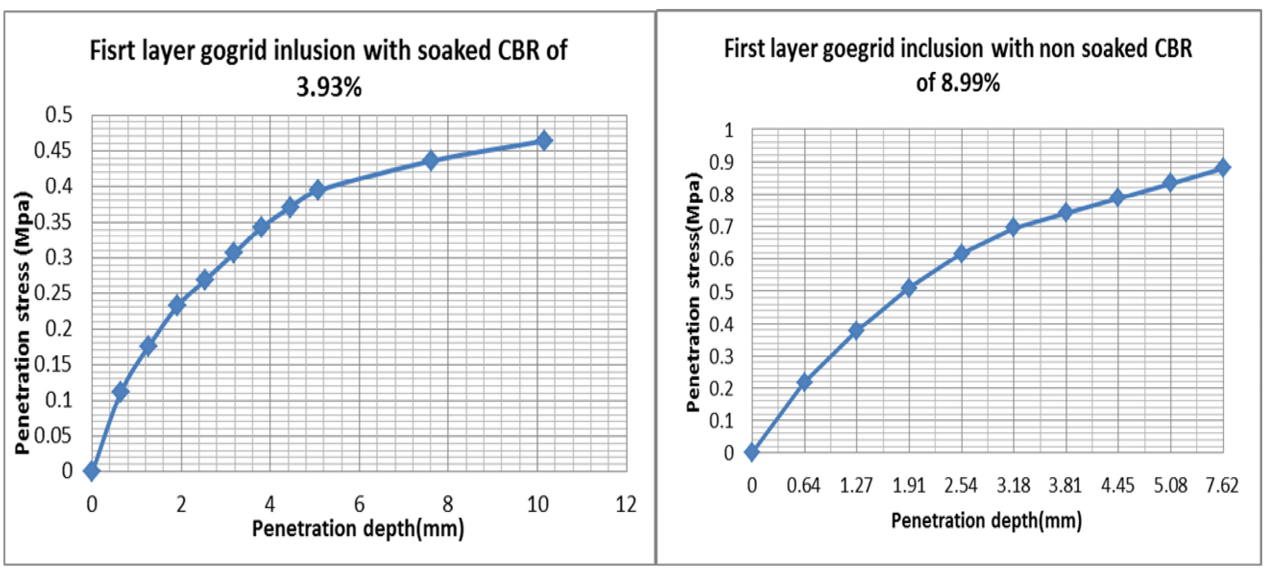


Figure 5.5: CBR Penetration Vs. stress graph of treated subgrade soil with geogrid reinforcement at first layer

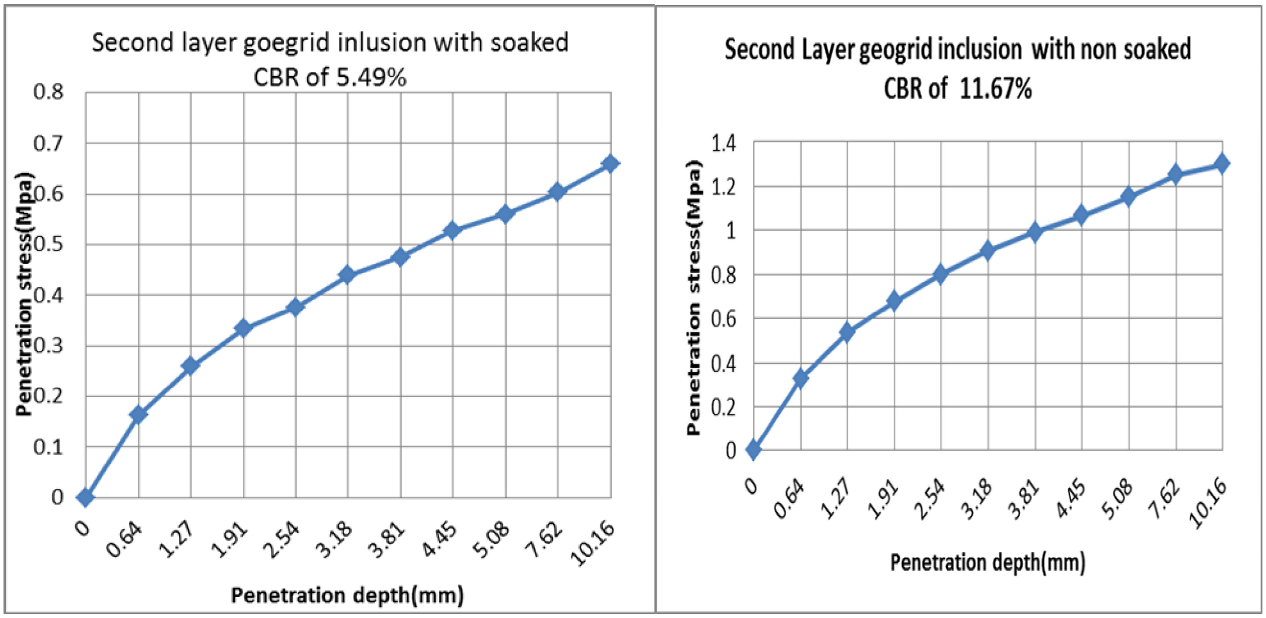


Figure 5.6: CBR Penetration Vs. stress graph of treated subgrade soil with geogrid reinforcement at second layer

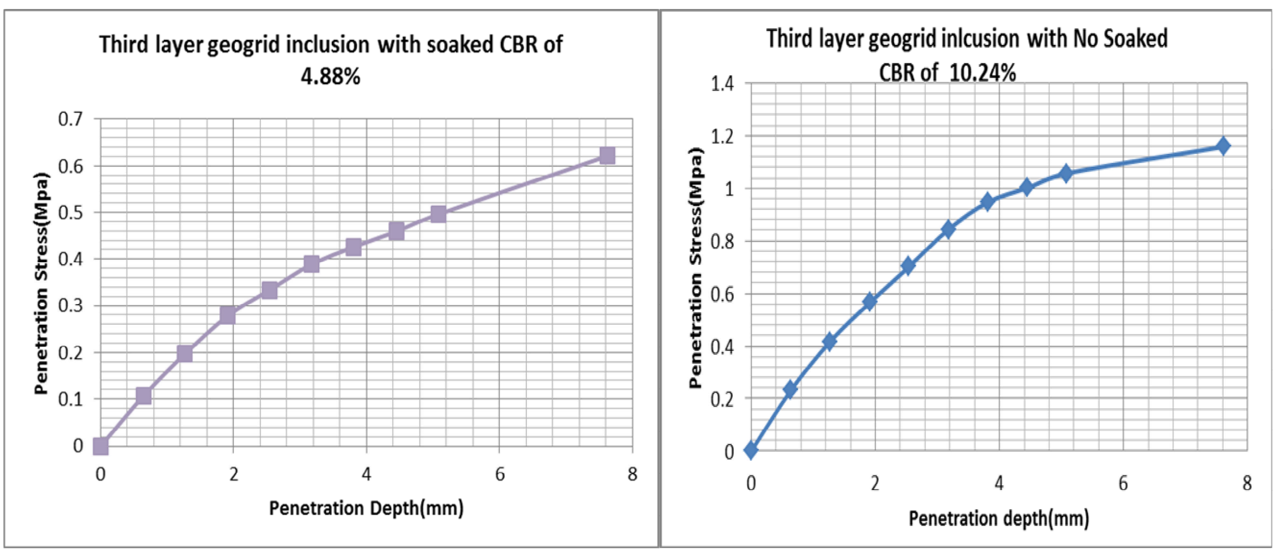


Figure 5.7: CBR Penetration Vs. stress graph of treated subgrade soil with geogrid reinforcement at third layer

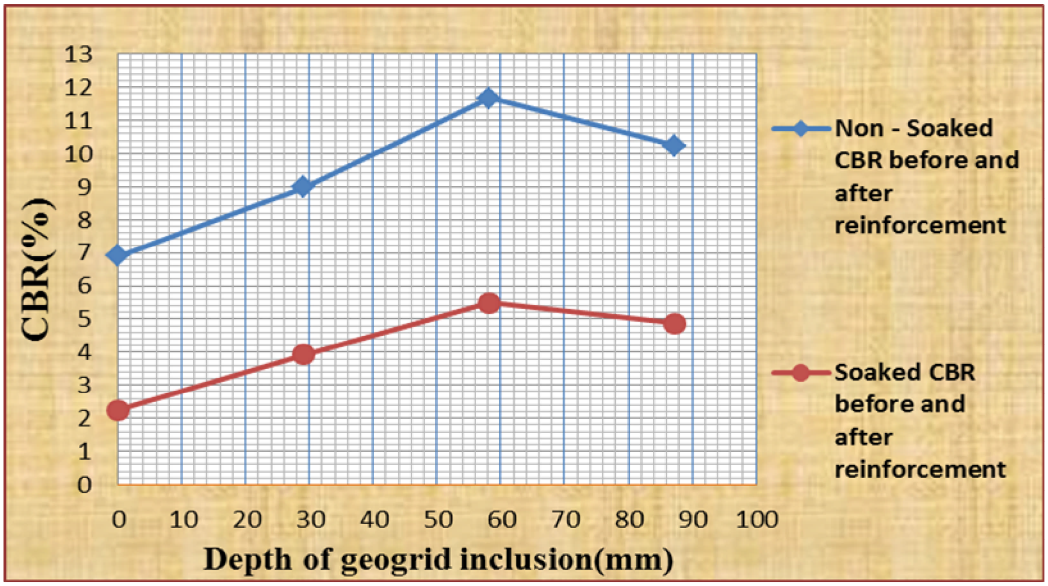


Figure 5.8: Location of geogrid versus soaked and unsoaked CBR value graph

Figure 5.8 shows, the results of CBR tests under different test conditions with geogrid reinforcement in different layers. It is clear that considerable amount of increase in CBR value of soil with geo-grid reinforcement was observed, for example, in case of unreinforced soil soaked CBR value is 2.24% and after inclusion of geogrid (with geo-grid reinforcement) the CBR value increases to 3.93%, 5.49% and 4.88% respectively.

The highest increase in the CBR value of 5.49% was achieved when geo-grid was placed at 50% (58.2mm) depth from the top of the specimen and before inclusion of geogrid unsoaked CBR value was 6.89% but after reinforcement unsoaked CBR value was greatly increased to 8.99%, 11.67% and 10.24% respectively.

Also better non – soaked CBR values was obtained when geigrid material was included at second layer than first and third reinforcement layers. The results of soaked CBR values for soil sample at different depths of geo-grid reinforcement indicated that the highest CBR of 5.49% at 2.5mm penetration for 50% depth from bottom of mold is obtained for obtained expansive subgrade soil.

The reason for increase in CBR value during geogrid inclusion in layers is that:

- Geogrid material works by interlocking soil placed over them and it helps to distribute the loads; thereby reducing stresses on subgrade material.
- Geogrid material has better strength and lower elongation than natural subgrade.

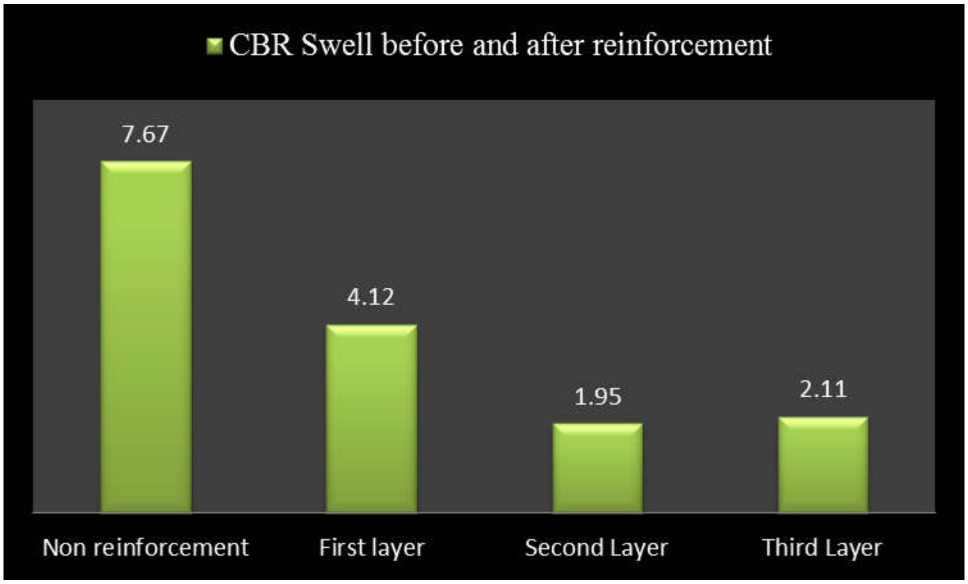


Chart 5.1: CBR swell values versus geogrid reinforcement location

As shown on the above chart, the effect of inclusion of geogrid reinforcement in layers on the values of both soaked and unsoked CBR has a positive impact. As it is clearly shown before inclusion of geogrid on CBR testing mold it's swell value was 7.67% but after inclusion of geogrid in first, second and third layer, CBR swell values were greatly reduced to 4.12%, 1.95% and 2.11% respectively.

A better CBR swell value was obtained when geogrid was reinforced at second layer than other layers. Hence due to geogrid reinforcement the CBR swell value also greatly reduced. The decrease in CBR swell value is attributed to geogrid material relatively better strength and lower elongation properties than that of natural expansive subgrade soil.

Comparing the above obtained results with previous work like **Samson Y. (2017);** there is slight difference. As per him representative soil sample is collected from Modjo town, before treating the soil, some of the index and engineering properties for selected soil sample were shown in Table 5.8 below.

Table 5.8: Properties of Subgrade material **(Samson Y. 2017)**

Property	Quantity
Unified Soil Classification	CH
Liquid Limit (%)	74.05
Plastic Limit (%)	33.67
Plasticity Index (%)	40.33
Specific Gravity	2.49
Free Swell Index (%)	145
Dry Density (kg/m^3)	1270
Optimum Moisture Content (%)	33
UCS (kPa)	81
Unsoaked CBR (%)	16.26
Soaked CBR Swell (%)	4.57
Soaked CBR (%)	2.98

After he identifies some of the index and engineering properties; the soil is treated with geogrid material through inclusion of such material at a single layer of 35 mm depth from CBR plunger bottom. Due to reinforcement, causes the improvement of soaked and unsoaked CBR values (shown in Table 5.8) from 2.98% and 16.26% to 10.23% and 37.26% for bitumen coated PP and to 7.48% and 23.71% for HDPE geogrids respectively. And soaked CBR swell value for unreinforced soil was 4.57% but after introducing bitumen coated polypropylene and HDPE geogrids, the swell values decreased from 4.57% to 1.64% and 2.1% respectively.

- The difference could be due to highly plastic nature of the soil that was taken from Bole arabsa, position of geogrid inclusion in a given CBR mold, tensile, elongation and index properties of geogrid material.

Chapter six

Conclusions and Recommendations

6.1. Conclusions

In this study, reinforced benefits of different layers of a flexible pavement are evaluated in terms of their strength parameters like, soaked and unsoaked CBR and the important findings of this thesis are summarized below:

- Based on both soil classification systems, the soil sample used for this study which was taken from Bole Arabse area was classified as inorganic clay of high plasticity.
- During geogrid reinforcement, the amount of improvement is found to be dependent upon the type of soil (since for this study the worst soil is taken) and position of geo-grid.
- Soaked CBR value for untreated soil is 2.24% but after inclusion of geogrid in first, second and third layers; CBR value increases to 3.93%, 5.49% and 4.88% and also unsoaked CBR value for natural subgrade soil is 6.89% but after reinforcement unsoaked CBR value was greatly increased to 8.99%, 11.67% and 10.24% respectively. Hence due to reinforcement, soaked and unsoaked CBR values of natural subgrade soil were greatly increased.
- 4 day soaked CBR swell value before reinforcement is 7.67% but after inclusion of geogrid in first, second and third layer, CBR swell values were greatly reduced to 4.12%, 1.95% and 2.11% respectively. A better CBR swell value was obtained when geogrid was reinforced at second layer than other. Hence due to geogrid reinforcement the CBR swell value also greatly reduced.
- Soaked and non - soaked CBR value is increased to 5.49% and 11.67% respectively where the geogrid is placed at second layer when compared to other first and third layers.
- The CBR of a soil increases by 50-100% when it is reinforced with a single layer of geo grid.
- The stress-strain behaviour of sub-grade soils under static load condition improved considerably when geo-grid was provided at optimum position.

6.2. Recommendations

Most of the study area is covered with expansive soil, which is not suitable as a sub grade material. The following recommendations could be carried out to improve the characteristics of black Cotton soil.

- The soil sample used for this study is high plasticity expansive subgrade soil; it is also possible to check the improvement of different types of soil other than expansive soil due to geogrid reinforcement.
- In this study, geogrids was used for expansive subgrade soil improvement but, it is possible to carry out the effect of geogrid inclusion in case of between base and sub base and between base and subgrade material.
- It is possible to conduct software supporting model (finite element analysis/ numerical models) on the effect of geogrid reinforced in case of subgrade reinforcement.
- The use of geogrids was tested for the purpose of expansive subgrade soil improvement but, it is possible to improve other than subgrade soils like poor building foundations.
- In addition to subgrade reinforcement, it is possible to investigate or observe the effect of crack prevention due to geogrid reinforcement of weak subgrade layer.
- In this study subgrade reinforcement through inclusion of geogrid material were conducted at laboratory level, but it is possible to observe its validation in the field.

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Appendices

1. Wet sieve analysis

Table: Summarized laboratory test result for wet sieve analysis

Weight Before washing = 136gm **Weight After Washing = 14.5gm**

ASTM Sieve Size(mm)	Cumulative Weight Retained (gm)	Cumulative Retained (%)	% PASS
12.5	0.0	0.0	100.0
9.5	3.5	2.6	97.4
6.3	7.5	5.5	94.5
4.75	9.5	7.0	93.0
2.36	12.0	8.8	91.2
2	12.5	9.2	90.8
1.18	13.0	9.6	90.4
0.85	13.5	9.9	90.1
0.6	13.5	9.9	90.1
0.425	14.0	10.3	89.7
0.3	14.0	10.3	89.7
0.15	14.0	10.3	89.7
0.075	14.5	10.7	89.3

2. Free Swell Index

Table 1: Values of Free swell Index for Natural Subgrade Soil

No	Untreated natural given soil mass	Reading after 24 hours		values of free swell index (%)
		Kerosene	Distilled water	
1	0 % pure soil soil	10	25.9	159.0

3. **Specific Gravity of natural soil**

Table 2: Determination of specific gravity for natural subgrade soil

S/N	Particulars	Observation
1	Weight of graduate cylinder W1 (g)	57
2	Weight of cylinder with oven dry soil W2 (g)	72
3	Weight of cylinder with dry soil and water W3 (g)	174.73
4	Weight of cylinder with full of water W4 (g)	165.51
5	Weight of dry soil (W2 - W1) 9g)	15
6	weight of an equal volume of Water (W2 - W1) - (W3 - W4) (g)	5.78
7	Specific gravity of the soil G = (5)/(6)	2.60

4. **Moisture content versus dry density for natural subgrade soil**

Table 3: moisture content and dry density result

Wt mass & mould (gm)	5850.00	6000.00	6100.00	6180.00	6120.00	6070.00
Wt of mould(gm)	4300.00	4300.00	4250.00	4300.00	4300.00	4300.00
Wt of sample(gm)	1550.00	1700.00	1850.00	1880.00	1820.00	1770.00
Volume of mould(gm)	999.00	999.00	999.00	999.00	999.00	999.00
Bulk density(kg/m3)	1551.55	1701.70	1851.85	1881.88	1821.82	1771.77

Container No	1	2	3	4	6	5
wet sample(gm)	139.00	145.00	140.00	139.00	142.00	138.00
dry sample(gm)	130.00	133.00	127.00	123.00	121.00	116.00
wt of container(gm)	60.00	59.00	67.00	60.00	55.00	58.00
wt of water(gm)	9.00	12.00	13.00	16.00	21.00	22.00
wt of dry soil(gm)	70.00	74.00	60.00	63.00	66.00	58.00
moisture content (%)	12.86	16.22	21.67	25.40	31.82	37.93
dry density(kg/m3)	1374.79	1464.25	1522.07	1500.74	1382.07	1284.53

5. CBR penetration versus load

Table 4: Soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for untreated natural Subgrade soil

Pen(mm)	One Point Method Test			
	Dial Gauge Reading	Load (N)	Stress (Mpa)	CBR (%)
0	0	0	0	0
0.64	4.5	80.73	0.04172093	
1.27	9	161.46	0.08344186	
1.91	12.5	224.25	0.115891473	
2.54	16.5	296.01	0.152976744	2.235725076
3.18	19	340.86	0.176155039	
3.81	21	376.74	0.194697674	
4.45	23	412.62	0.21324031	
5.08	24.5	439.53	0.227147287	2.19765
7.62	27	484.38	0.25033	
10.16	21	376.74	0.194697674	

Table 5: Swell (for specimen height of 116.4mm) for no geogrid inclusion

Time (h)	**Date**	**Time**	**Swell**
0	1/2/2018	3:00pm	0
24	2/2/2018	3:00pm	2
48	3/2/2018	3:00pm	3.89
72	4/2/2018	3:00pm	4.78
96	5/2/2018	3:00pm	8.93
Percent swell =			7.67

Table 6: Non soaked CBR penetration Vs. load result for without geogrid reinforcement

Pen(mm)	**One Point Method Test**			
	Dial Gauge	Load	Stress	CBR
	Reading	(N)	(Mpa)	(%)
0	0	0	0	0
0.64	18	322.92	0.16688372	
1.27	32	574.08	0.29668217	
1.91	44	789.36	0.40793798	
2.54	50.88	912.7872	0.47172465	6.89
3.18	55	986.7	0.50992248	
3.81	59	1058.46	0.54700775	
4.45	61.5	1103.31	0.57018604	
5.08	64	1148.16	0.59336434	5.74
7.62	70	1255.8	0.64899	
10.16	77	1381.38	0.71389147	

Table 7: Soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for first layer geogrid inclusion of natural Subgrade soil

time	**One Point Method Test**			
	Dial Gauge Reading	**Load (N)**	**Stress (Mpa)**	**CBR (%)**
0	0	0	0	0
0.64	12	215.28	0.111255814	
1.27	19	340.86	0.176155039	
1.91	25	448.5	0.231782946	
2.54	29	520.26	0.268868217	3.93
3.18	33	592.02	0.305953488	
3.81	37	663.78	0.34303876	
4.45	40	717.6	0.370852713	
5.08	42.5	762.45	0.394031008	3.81
7.62	47	843.18	0.43575	
10.16	50	897	0.463565891	

Table 8: Swell (for specimen height of 116.4mm) for second layer geogrid inclusion

Time (h)	Date	Time	Swell
0	14/02/2018	3:45pm	0
24	15/02/2018	3:45pm	1.78
48	16/02/2018	3:45pm	2.68
72	17/02/2018	3:45pm	3.86
96	18/02/2018	3:45pm	4.79
Percent swell =			4.12

Table 9: Non soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for first layer geogrid inclusion of natural Subgrade soil

Pen(mm)	**One Point Method Test**			
	Dial Gauge Reading	**Load (N)**	**Stress (Mpa)**	**CBR (%)**
0	0	0	0	0
0.64	23.55	422.487	0.218339535	
1.27	40.78	731.5932	0.378084341	
1.91	54.99	986.5206	0.509829767	
2.54	66.35	1190.319	0.615151938	8.99
3.18	75	1345.5	0.695348837	
3.81	80	1435.2	0.741705426	
4.45	85	1524.9	0.788062016	
5.08	90	1614.6	0.834418605	8.07
7.62	95	1704.3	0.88078	
10.16	115	2063.1	1.06620155	

Table 10: Soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for second layer geogrid inclusion of natural Subgrade soil

Pen(mm)	**One Point Method Test**			
	Dial Gauge Reading	**Load (N)**	**Stress (Mpa)**	**CBR (%)**
0	0	0	0	
0.64	17.5	313.95	0.162248062	
1.27	28	502.32	0.259596899	
1.91	36	645.84	0.333767442	
2.54	40.5	726.57	0.375488372	5.49
3.18	47.4	850.356	0.439460465	
3.81	51.23	919.0662	0.474969612	
4.45	57	1022.58	0.528465116	
5.08	60.5	1085.37	0.560914729	5.43
7.62	65	1166.1	0.60264	
10.16	71	1273.74	0.658263566	

Table 11: Swell (for specimen height of 116.4mm) for second layer geogrid inclusion

Time (h)	Date	Time	Swell
0	14/02/2018	3:45pm	0
24	15/02/2018	3:45pm	0.67
48	16/02/2018	3:45pm	1.68
72	17/02/2018	3:45pm	1.96
96	18/02/2018	3:45pm	2.27
Percent swell =			1.95

Table 12: Non soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for second layer geogrid inclusion of natural Subgrade soil

Pen(mm)	**One Point Method Test**			
	Dial Gauge Reading	**Load (N)**	**Stress (Mpa)**	**CBR (%)**
0	0	0	0	0
0.64	35.2	631.488	0.326350388	
1.27	58	1040.52	0.537736434	
1.91	73.12	1311.7728	0.67791876	
2.54	86.15	1545.531	0.798724031	11.67
3.18	98	1758.12	0.908589147	
3.81	107	1919.58	0.992031008	
4.45	115	2063.1	1.06620155	
5.08	124	2224.56	1.149643411	11.12
7.62	135	2421.9	1.25163	
10.16	140	2511.6	1.297984496	

Table 13: Soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for third layer geogrid inclusion of natural Subgrade soil

Pen(mm)	**One Point Method Test**			
	Dial Gauge Reading	**Load (N)**	**Stress (Mpa)**	**CBR (%)**
0	0	0	0	0
0.64	11.5	206.31	0.106620155	
1.27	21.34	382.8396	0.197849922	
1.91	30	538.2	0.278139535	
2.54	36	645.84	0.333767442	4.88
3.18	42	753.48	0.389395349	
3.81	46	825.24	0.42648062	
4.45	49.5	888.03	0.458930233	
5.08	53.47	959.2518	0.495737364	4.80
7.62	67	1201.98	0.62118	
10.16	78	1399.32	0.723162791	

Table 14: Swell (for specimen height of 116.4mm) for third layer geogrid inclusion

Time (h)	Date	Time	Swell
0	14/02/2018	3:45pm	0
24	15/02/2018	3:45pm	0.75
48	16/02/2018	3:45pm	1.75
72	17/02/2018	3:45pm	2.06
96	18/02/2018	3:45pm	2.46
Percent swell =			2.11

Table 15: Non soaked CBR Penetration Test data with Ring Factor of 17.94 and plunger area of 1934 mm^2 for third layer geogrid inclusion of natural Subgrade soil

Penetration (mm)	**One Point Method Test**			
	Dial Gauge Reading	**Load (N)**	**Stress (Mpa)**	**CBR (%)**
0	0	0	0	0
0.64	25	448.5	0.231782946	
1.27	45	807.3	0.417209302	
1.91	61	1094.34	0.565550388	
2.54	75.6	1356.264	0.700911628	10.24
3.18	91	1632.54	0.843689922	
3.81	102	1829.88	0.945674419	
4.45	108	1937.52	1.001302326	
5.08	114	2045.16	1.056930233	10.23
7.62	125	2242.5	1.15891	
10.16	145	2601.3	1.344341085	