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Stabilization of Expansive Clay Soils Using Quarry Waste

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Addis Ababa University
School of Graduate Studies

Stabilization of Expansive Clay Soils using Quarry Waste

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DECLARATION

I hereby declare that this thesis is my original work under the supervision of Dr. Messele Haile, in school of Civil and Environmental engineering, Addis Ababa University during the year 2017 as part of Master of Science program in Geotechnical engineering.

I further declare that this work has not been submitted to any other University or institution for the award of any degree and all sources of materials used for this thesis are duly acknowledged.

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LIST OF ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials
USCS	Unified soil classification systems (USCS)
ASTM	American Society for Testing and Materials
ERA	Ethiopian Roads Authority
CBR	California Bearing Ratio
UCS	Unconfined compressive strength
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
SCSA	Sugarcane Straw Ash
CSH	Calcium Silicate Hydrate
CAH	Calcium aluminate hydrate
LL	Liquid Limit
PL	Plastic Limit
PI	Plastic Index
CH	Highly Plastic Clay

UNITS

gm	Gram
kg	Kilogram
km	Kilometer
KN	Kilo Newton
mm	millimeter
g/cm^3	Gram per centimeter cube
kN/m^2	Kilo Newton per meter square
kPa	Kilo Pascal
mm	millimeter
^0C	Degree Centigrade
cm^3	Centimeter cube

ABSTRACT

Extensive researches has been carried out by different researchers to find solutions associated with problems of expansive soils .The construction industry has presented a number of ground improvement techniques to modify expansive nature of soils and to minimize or eliminate the danger of damage of structures because of heave and shrinkage. Soil-stabilization is one among different ground improvement alternatives being used worldwide. Soil-stabilization is any treatment applied to a soil to improve its strength and reduce vulnerability to heave. There are different methods of soil stabilization that have been identified to improve the expansive nature of soils. Due to the growing cost of these stabilizing agents and the need for the economical utilization of industrial and agricultural wastes, in modern days of industrialization it becomes imperative to use waste materials from various industries for expansive soil stabilization.

This research work is aimed at exploring whether a waste from quarries i.e. quarry dust, can be used as stabilizing material for expansive soils or not. The performance of quarry dust was evaluated based on laboratory test results on expansive soil collected from Addis Ababa around Bole area. The soil was initially characterized and classified based on index tests and found to be A-7-5 according to AASHTO and CH according to USCS systems. Soils with this category have very low load bearing capacity and are highly expansive soils. The effects of quarry dust on the engineering properties of the soil were evaluated by treating the soil with quarry dust passing No. 200 sieve in stepped concentration of 2%, 4%, 6%, 8%, 10%, 20% and 30% by dry weight of the soil. All treated soil samples were cured for 7 days before the tests were conducted. Test specimens were subjected to Atterberg limit, free swell, swelling pressure,UCS, compaction and CBR tests.

The analysis of results showed reduction in plasticity index, free swell, swelling pressure, OMC and UCS with all higher quarry dust contents and a slight increase in the maximum dry density and soaked CBR values. Generally, it was concluded from the results that quarry dust is not an effective stabilizer for the improvement of most of the geotechnical properties of the soil, while swelling properties showed significant reduction to the level in which the uplift pressure of expansive soil can be controlled by the counter pressure of light weight structures.

Additional study has also been incorporated to investigate the effect of blending granular quarry waste material (Passing No.4 and retaining No.200) with expansive soil, so that it can be used as a mechanical stabilizer for expansive subgrade soil. Compaction and CBR tests were performed and the results showed a very slight improvement in both test values. From this study it was found out that soil mechanically stabilized with granular quarry waste do not meet the minimum requirement of ERA pavement manual specification for use as a sub-grade material in road construction, in the context of this study.

CHAPTER ONE

INTRODUCTION

1.1 General Background

Expansive soil is the term generally referred to any soil or rock that has potential for shrinking or swelling under changing moisture condition. The primary problem that arises with regard to expansive soil is that the deformations are significantly greater than elastic deformations and they cannot be predicted by classical elastic or plastic theories (Nelson, and Miller, 1992).Movement is usually in uneven pattern and of such a magnitude that it causes extensive damage to the structures and pavements resting on it. Engineering problems due to expansive soils have been reported in many countries all over the world, costing millions of dollars due to severe damages of structures. In order to prevent these problems it is essential to stabilize existing soils before commencing construction activities.

Expansive soils can be used effectively after improvement of their performance characteristics by appropriate stabilization methods. So far industrially manufactured soil improving additives (cement, lime etc.) have been introduced by researchers (Tesfaye, 2003; Nebro, 2002; Argu, 2008; Nigussie, 2011 etc). These stabilizers were effective in improving the property of expansive soils; but kept the cost of construction on stabilized soil financially high due to the high cost of these stabilizers. The need to bring down the growing cost of soil stabilizers has led to intense global research towards economic utilization of wastes for engineering purposes. Recent trend in research works in the field of geotechnical engineering and construction materials focuses more on the search for cheap and locally available materials such as bagasse ash, sugarcane straw ash, fly ash, rice husk ash, coconut husk ash etc. as stabilizing agents for the purpose of full or partial replacement of traditional stabilizers like cement and lime. The researches focused more on the use of potentially cost effective materials that are locally available from industrial and agricultural waste, in order to improve the properties of expansive soils and to meet geotechnical engineering design requirements. Although a growing number of investigations have been undertaken so as to stabilize expansive soil using various additives, waste by-products and agricultural wastes, there are still not adequate studies on the influence of waste materials from quarries, on stabilization of expansive soils.

According to researches, a large number of quarry sources have been identified in Ethiopia as potential sources of construction materials. There are also several abandoned quarries which still have potential for use (Abdurhaman, and Tegegn, 2010).Sample quarry sites were visited in and around Addis Ababa, and it was estimated that 5% of the quarry will generate waste in each production of construction materials. Meanwhile quarry samples were taken from the visited sites and their chemical composition were studied. The results indicate that quarry waste samples can be used as chemical stabilizers. According to ASTM C618 standard, if the combined percent composition of SiO_2, Al_2O_3 and Fe_2O_3 is more than 70%, the material can be used as chemical stabilizer. Since the quarry waste is cheap and readily available construction material, the utilization of it as stabilizer and as a replacement for stabilizers such as cement and lime, will bring fruitful results in the construction industry not only by being very cost effective but also environmental friendly.

This study focuses on using quarry waste to stabilize expansive soils. Specifically, quarry dust passing No.200 sieve was used as chemical stabilizer (i.e since powder, slurry or liquid material is required for chemical stabilization); and granular quarry waste (passing No.4 and retaining No.200), as mechanical stabilizer. Study was made on the effects of quarry waste on some properties of the expansive soil used in this specific study. If the study leads to positive outputs, quarry dust can be used as chemical soil stabilizing agent replacing the costly stabilizers such as cement and lime. On the other hand, granular quarry waste can be used as an alternative mechanical stabilizer.

1.2 Statement of the problem

Since a large no of quarry sources have been identified in the country, the possible use of waste from quarries for stabilization purpose will be useful in the sense that it will cut down initial costs of new projects. In the meantime waste management can be done economically. This study enables many construction companies to stabilize expansive soils using this material which will be cheaper and abundant.

1.3 Objectives of the Research

The general objective of this study is to evaluate the suitability of quarry waste as a stabilizing agent for expansive soil.

Specific Objectives

The specific objectives of this study are:

- To determine the physical and engineering properties of soil under study to confirm whether the soil is expansive or not.
- To evaluate changes in the physical and engineering properties of the soil after treating it using quarry waste.

1.4 Scope of the research

This study has been supported by different types of literatures and a series of laboratory experiments. However, the findings of the research are limited to expansive soil sample from one location. The results are also specific to two types of quarry waste additives from different quarry sites. The granular part, as well as the dust part of the quarry waste have been used for experimental work.

1.5 Research Methodology

In order to achieve the above objectives of the study the following methodologies were adopted:

- Different literatures on expansive soil, rock quarries, soil-stabilization and other relevant materials were collected and reviewed. Literature sources include reports, books, journals and online materials available on internet.
- Quarry waste samples were collected from different quarry sites in and around Addis Ababa i.e. Sululta, Gorro and Legetafo quarry sites. These samples were tested for their oxide composition in order to give justification to use the quarry waste as chemical stabilizer.
- Disturbed and undisturbed expansive soil samples were collected from an active site around Bole specifically Brass Hospital area. Classification of soil was made by running grain size distribution and Atterberg limits tests. After the samples were confirmed to be potentially expansive, full characterization and classification of the soil were made by conducting necessary laboratory tests. These tests include free swell, swelling pressure, UCS, compaction and CBR tests.
- Quarry waste i.e. quarry dust passing No.200 sieve was prepared and added to the expansive soil with predetermined percentage of stabilizer varying from 2% to 30%.The soil-quarry dust mixtures were cured for seven days in order to give sufficient time for chemical reaction leading to stabilization. Simple tests like Atterberg limits and free swell tests were first performed on soil-quarry dust mix; for 2%, 4%, 6%, 8%, 10%, 20% and 30% stepped concentration of quarry dust. Swelling pressure, UCS, compaction and CBR tests were then performed for that proportions of quarry dust which have showed significant improvement while performing the simple tests.
- Granular quarry waste sample was prepared to meet the proper grain size distribution for subgrade material and blended with expansive soil with 20% and 30% concentrations. In this case the laboratory tests are limited to moisture density relation and CBR tests.
- Evaluating the effects of quarry waste on engineering properties of the soil by Analyzing and discussing laboratory test results.
- Formulation of conclusions and recommendations based on the results obtained.
- Finally compiling and writing of the thesis work was done.

1.5 Organization of the Thesis

The thesis is divided into six chapters. In the first Chapter the background, objective and brief summary of the work is presented. The second Chapter gives a literature review on expansive soils, rock quarries and soil stabilization. The third Chapter explains the materials and methods used in the study. The test results and analysis are presented in the fourth chapter. The fifth Chapter compares the results obtained using quarry dust and granular quarry waste. Finally, the last Chapter presents the conclusions drawn and recommendations made from the findings.

CHAPTER TWO

LITRATURE REVIEW

2.1 Expansive soils

2.1.1General

Expansive soils are fine grained soils or decomposed rocks that show large volume change when exposed to fluctuations of moisture content. Swelling-shrinkage behavior is likely to take place near ground surface where it is directly subjected to seasonal and environmental variations. Expansive soils are most likely to be unsaturated and have highly reactive clay minerals. The three most important groups of clay minerals are Montmorillonite, Illite, and Kaolinite. Montmorillonite is the clay mineral that is mostly present in expansive soil. When these minerals are exposed to moisture, water is absorbed between the inter-layering lattice structures and exerts an upward pressure, which is the cause for most damages associated with expansive soil (Lemi, 2015).

Expansive soils can be found anywhere in the world but they are basically confined to semi–arid and arid regions. These areas are naturally characterized by marked dry and wet seasons with low rainfall, poor drainage and exceedingly great heat. The climate condition is such that the annual evapo-transpiration exceeds the precipitations (Chen, 1988). Ethiopia is amongst the list of countries where the occurrence and spatial distribution is recognized as significant.

2.1.2 Origin of Expansive Soils

The origin of expansive soils is related to a combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, expands. Variations in the conditions and processes may also form other clay minerals, most of which are non-expansive. The conditions or processes, which determine the clay mineralogy, include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected.

i. Mineralogy of expansive soils

Expansivity of soils is due to the presence of clay minerals. Clay particles have sizes of 0.002mm or less. However, according to Chen (1988) the grain size alone does not determine clay minerals and he emphasized that the most important property of fine grained soils is their mineralogical composition.

Clay minerals are crystalline hydrous alumino-silicates derived from parent rock by weathering. The basic building blocks of clay minerals are the silicate tetrahedron and the alumina octahedron and combine into tetrahedral and octahedral sheets to form the various types of clays (Chen1988; Murray, 2007; Nelson, 2010). Kaolinite, illite and montimorillonite are the common groups of clay minerals most important in engineering studies (Chen, 1988; Nelson, 2010). Kaolinite is a typical two-layer mineral having a tetrahedral and an octahedral sheet joined to form a 1-1 layer structure held by a relatively strong hydrogen bond. Kaolinite does not absorb water and hence does not expand when it comes in contact with water (Murray,2007; Nelson,2010).

The montmorillonite group clays on the other hand have a 2-1 layer structure formed by an octahedron sandwiched between two tetrahedrons. This group of clays can have significant amounts of magnesium and iron substituting into the octahedral layers. The most important aspect of the montimorillonite group is the ability for water molecules to be absorbed between the layers, causing the volume of the minerals to increase when they come in contact with water (Nelson,2010).

The illite clays have a structure similar to that of muscovite, but are typically deficient in alkalies, with less aluminum substitution for silicon. Calcium and magnesium can also sometimes substitute for potassium and illites are non-expanding clays (Murray, 2007).

ii. Parent Material

The parent materials that give rise to expansive soil are classified into two. The first group comprises the basic igneous rocks, which are low in silica, generally about 45% to 52% and rich in metallic base such as pyroxenes, amphiboles, biotitic and olivine. Such rocks include the gabbros, basalts and volcanic glass. The second group includes sedimentary rock that contains montmorillonite as a constituent. These include shales and claystone, and limestone and marls rich in magnesium (Chen, 1988).

iii. Weathering and Climate

The weathering process by which clay is formed includes physical, biological and chemical process. The most important weathering process responsible for the formation of montmorillonite is the chemical weathering, which include hydrolysis, hydration, oxidation, carbonation and solution, of parent rock mineral which generally consists of ferromagnesium mineral, calcic feldspars, volcanic glass, volcanic rocks and volcanic ash. The formation is aided in alkaline environment, presence of magnesium ion and lack of leaching. Such condition is favorable in semi-arid regions with relatively low rain fall or seasonal moderate rainfall particularly where evaporation exceeds precipitation. Under these conditions enough water is available for the alteration process but the accumulated cations will not be removed by rain water (Chen, 1988).

2.1.3 Distribution of expansive soils

Potentially expansive soils can be found almost anywhere in the world. In the underdeveloped nations, many of the expansive soil problems may not have been recognized because of less intensity of construction. It is to be expected that more expansive soil regions related problems would be reported each year as the amount of construction increases. Expansive soils are in abundance where desiccation phenomenon is common i.e., where the annual evaporation exceeds the precipitation. The problem of expansive soil is widespread throughout the five continents.

Expansive soils are widespread in African continent, occurring in South Africa, Ethiopia, Kenya, Mozambique, Morocco, Ghana, Nigeria etc. In other parts of the world case of expansive soils have been widely reported in countries like USA, Australia, Canada, India, Spain, Israel, Turkey, Argentina, Venezuela etc. (Teferra, A., and Leikun, M., 1999).

The aerial coverage of expansive soils in Ethiopia is estimated to be 24.7 million acres (Lyon associates, 1971; as cited by Nebro, 2002). They are widely spread in central part of Ethiopia. Also areas like Mekele and Gambella are covered by expansive soil.

2.1.4 Identification of Expansive Soils

Expansive soils that exhibit high swelling potential can be recognized by both field observation and laboratory tests (Chen, 1988; Nelson,1992).

2.1.4.1 Field identification

Some of the important field identification method that indicates the potential for expansiveness of a soil is the following: [Chen, 1966]

- A shiny surface is easily obtained when a partially dry piece of the soil is polished with a smooth object such as the top of a finger nail.
- The wet samples of the soil is sticky and it will be relatively difficult to clean the soil from the hands
- The appearance of cracking in nearby structures
- They usually have a color of black and/or gray
- Open or closed fissures, (a joint or similar discontinuity)
- Slickenside, (highly polished or glossy fissure surface)
- Shattering or micro-shattering, (presence of fissures forming granular fragments of clayey soils)

2.1.4.2 Laboratory identification

Generally, there are three different method of identifying expansive soil in the laboratory.

i. Mineralogical identification

This method is used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and charge deficiency and surface activity of clay particle. These properties are a fundamental factor controlling expansive soil behavior. [Chen, 1966] The various techniques under these methods are

- -X-ray diffraction
- -Differential thermal analysis
- -Dye absorption
- -Electron microscope
- -Base exchange capacity, etc

These methods are not suitable for routine tests. This is because they are time consuming, require expensive test equipment and the results can only be interpreted by specially trained technicians.

ii. Indirect methods

These methods include simple soil property test that a practicing engineer resort to use for identifying expansive soil. Such tests are easy and can be performed in average soil mechanics laboratory, and yield an excellent indices of expansive properties. In this method, measurement of the plasticity, swelling and shrinkage characteristics of the soil are conducted for identification of soils and provide a wide acceptable means of rating by using liquid limit, plastic limit, shrinkage limit, free swell tests, colloid content test, etc.

iii. Direct measurement

The most accurate and dependable method of determining the swelling potential and the swelling pressure of expansive clay is by direct measurement. These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer.

2.1.5 Classification of Expansive Soils

Soil identification tests have been combined in a number of different classification schemes. The different classification systems are categorized into two:

1. General classification systems which have evolved over many years and are based largely on correlation with actual performance
2. Those devised specifically for classification of expansive soils. Theses system is based on indirect and direct prediction of swell potential, as well as combinations, to arrive at a rating.

2.1.5.1 Classification Using General Methods

American Association of State High Way and Transportation Officials (AASHTO) and Unified soil classification systems (USCS) are the most widely used general classification systems.

i. AASHTO Classification

Soils that are considered to be potentially expansive are rated by A-6 or A-7 by AASHTO classification (Nelson, 1992).

Table 2.1: AASHTO soil classification chart

General Classification	Granular Materials (35 per cent or less passing No. 200)							Silt-clay Materials (More than 35 percent passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis per cent passing No. 10 No. 40 No. 200	50 max 30 max 15 max	50 max 10 max	51 min 10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40 sieve Liquid limit Plasticity Index	6 (max)		N.P	40max 10max	41 min 10max	40max 11 min	41 min 11min	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min
Group index	0		0	0		4 max		8 max	12 max	16max	20 max
Usual types of significant constituent materials	Stone fragments gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as sub-grade	Excellent to good							Fair to poor			

The A-7 group is subdivided into A-7-5 or A-7-6 depending on the plastic limit. For P.L.<30, the classification is A-7-6; for P.L ≥30, it is A-7-5.

ii. Unified Soil Classification Systems

In this classification system a correlation is made between swell potential and unified soil classification as follows.

Category	**Soil classification system**
Little or no expansion	GW, GP, GM, SW, SP, SM
Moderate expansion	GW, SC, ML, MH
High volume change	CL OL, CH, OH
No rating	Pt

In the above classification soils rated as CL or OH may be considered as potentially expansive.

2.1.5.2. Classification Specific to Expansive Soil

A parameter determined from the expansive soil identification tests have been combined in a number of different classification schemes to give qualitative rating on the expansiveness of the soil. But the direct use of such classification systems as a basis for design may lead to an overly conservative construction in some places and inadequate construction in some areas (Nelson, D.J., and Miller, J.D., 1992). Hence, it is very important to emphasize that design decision has to be based on predicting testing and analysis, which provide reliable information. An indirect prediction of swell potential includes correlations based on index properties, swell and a combination of them. Some of such classification systems are:

i. Method of Chen

Chen (1988) presented a single index method for identifying expansive soils using only plasticity index. In this method relation has been made between the swelling potential of clays and the plasticity index as shown in Table 2.2.

Table 2.2: Expansive soil classification based on plasticity index (Chen, 1988).

Swelling potential	Plasticity index
Low	0-15
Medium	10-35
High	20-55
Very high	35 and above

ii. Method of Daksanamurthy and Raman (1973)

Daksanamurthy and Raman (1973) presented a single index method for identifying expansive soils using only liquid limit. They suggested four classes of clays according to their liquid limits as shown in Table 2.3 (Amer, and Mattheus, 2006).

Table 2.3: Relation between the swelling potential of clays and the liquid limit

Swelling potential	Liquid limit
Low	$20 < LL \leq 35$
Medium	$35 < LL \leq 50$
High	$50 < LL \leq 70$
Very High	$LL > 70$

iii. USBR Method

This method is developed by Holtz and Gibbs; it is based on direct correlation of observed volume change with colloid content, plastic index and shrinkage limit. The classification is as given in Table 2.4.

Table 2.4: Classification based on bureau of reclamation method (Chen, F.H., 1988; Ranjan, G., and Rao, A.S.R., 2002)

Colloid content (%)	Plasticity index (%)	Shrinkage limit (%)	Probable expansion (%)	Degree of 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

iv. Method of Skempton

This method is developed, by combining Atterberg limits and clay content into a single parameter called Activity. Activity is defined as:

$$A_C = {}^{PI}\!/_{\text{Percentage finer than } 2\mu\text{m}} \tag{2.1}$$

Where, Ac= activity

PI= plasticity index

Skempton suggested three classes of clays according to their activity shown in Table 2.5.

Table2.5: Relation between clay activity and potential of expansion

Activity	Potential expansion
$A_C < 0.75$	Low (inactive)
$0.75 < A_C < 1.25$	Medium (Normal)
$A_C > 1.25$	High (Active)

2.2 General review on Rock Quarries

A quarry is a place from which dimension stone, rock, construction aggregate, riprap, and slate has been excavated from the ground. Accordingly, Quarry Waste is an industrial waste obtained from stone crushing/rock Quarries. General review on rock quarries is given in the following section.

2.2.1 Rock classification

i. Rock with high rock mass strength (Rhi): The Basalt and Trachytic lithological units have 1 to 8MPa index point load strength value that is normalized to IS_{50}. This is comparable to the estimated unconfined compressive strength (UCS) of 16 to 88MPa. From the values the Basalt and Trachyte are classified as rock with high mass strength. The degree of weathering is slight to moderate. Although the average water absorption is only 3%, extreme variations are expected of rocks falling in the engineering geological unit. This could be attributed to the presence of abundant inhomogeneous discontinuity that is at smaller scale. The similar extreme variation in porosity on the other hand suggests the effect of differential weathering rather than presence of fractures. In general, the bulk density is higher than the rocks in the other rock mass strength units. (Tsehayu, and H.Mariam, 1990).

ii. Rock with medium rock mass strength (Rhi): Precambrian and Paleozoic sand stone and Pyroclastic deposits (mainly comprised of ignimbrites) fall in medium rock mass strength category. This unit has 0.4 to 6MPa index point load strength (IS_{50}).The corresponding UCS value ranges from 3.75 to 45MPa and hence falls in the medium rock mass strength category.
The water absorption of ignimbrites is high making them very limited for use as aggregate for concrete and asphalt. The ignimbrites have moderate to high degree of weathering. Relatively higher water absorption is noted in the samples of moderate strong rock units than the high strength rock mass units. Slightly lower bulk density is observed relative to the stronger rock mass units. (Tsehayu, and H.Mariam, 1990).

iii. Rock with medium to low rock mass strength (RMe to RLo)
The Mesozoic sandstone and lime stone units are categorized in this class. The point load index strength ranges from 0.2 to 1.1MPa which is comparable to UCS values of 4.57 to 26MPa. The lithologic units hence are categorized as having low to medium rock mass strength. Overall moderate degree of rock mass weathering is notable in the lithologic units. In this rock mass units the water absorption and porosity are very low while a slight increase in the bulk density is observed. Filling of discontinuities and pore spaces by higher degree of weathering could be the cause for such behavior. (Tsehayu, and H.Mariam, 1990).

iv. Rock with low rock mass strength (RLo)
Mudstone and Gypsum unit are categorized in this class. No significant test could be made in this unit due to their low overall strength. Hence these units have been classified as rock with low rock mass strength. (Tsehayu, and H.Mariam, 1990).

2.2.2. Construction material resources

Rock quarry sites of basalt, trachyte and ignimbrite were identified as construction material resources.
i. Basalt and Trachyte: The basalt and the trachyte are slightly to moderately weathered, columnarly jointed and thus they can be used as aggregate or various purpose accordingly. (Abdurhaman, and Tegegn, 2010).

ii. Ignimbrite: The outcrops show good quality for dimension stone and explitation is eased due to the developed columnar joints, fresh to slightly weathered. Locally the rock is used as source of masonry for construction of houses. (Abdurhaman, and Tegegn, 2010).

2.2.3. Rock quarry sites in and around Addis Ababa town

According to researches, a large number of quarry sources have been identified in Ethiopia as potential sources of construction materials. There are also several abandoned quarries which still have potential for use (Abdurhaman, and Tegegn, 2010). Sufficient volume of quarries that can be used for various construction purposes are inventoried close to Addis Ababa town. Some of the discovered quarry sites are presented in Table2.6.

Table 2.6: Existing and potential quarry sites in and around Addis Ababa town (Abdurhaman, and Tegegn, 2010).

Quarry no.	Estimated volume(m^3)	Type of material	Potential usage material	location
Q1.	50,000	Trachy basalt	masonry	Burayou Mariam
Q2.	1,250,000	Ignimbrite	masonry	Burayou
Q3.	50,000	Ignimbrite	masonry	Keta
Q4.	125,000	Trachyte	masonry	Bburayou
Q5.	500,000	Ignimbrite	masonry	Asko
Q6.	1,000,000	Ignimbrite	masonry	Sululta
Q7.	8,000	Basalt	aggregate	Abado
Q8.		Basalt	aggregate	Sululta
Q9.		Trachyte	masonry	Yeka Tafo
Q10.	500,000	Ignimbrite	masonry	Lege Dadi
Q11.	50,000	Ignimbrite	masonry	Meri
Q12.	500,000	Ignimbrite	masonry	Bole
Q13.		Basalt	abandoned	Intoto
Q14.		Scoraceous basalt	abandoned	Keta

2.3 Review on Soil Stabilization

2.3.1 Soil Stabilization

Soil stabilization is the process of modification of one or more engineering properties of problematic (expansive) soils to achieve the desired specification for certain construction purpose. It is required when the soil available for construction is not suitable for the intended purpose. The term stabilization is generally the process which alters the soil material itself for improvement of its properties (K.R Arora, 2003).The process may include blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (Guyer, 2011; US Army, 1994).

2.3.2 Types of Soil Stabilization

2.3.2.1 Mechanical Stabilization

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil. The main methods of mechanical stabilization can be categorized in to compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation (Guyer, 2011; Makusa, 2012).

2.3.2.2 Chemical Stabilization

Chemical stabilization depends on chemical reaction between stabilizer and soil minerals to achieve the desired effect. Chemical stabilization is mixing of soil with one or a combination of admixtures of powder, slurry or liquid to improve or control its stability, strength, swelling, permeability and durability (Wubshet, 2015). Chemical stabilization can achieve improvement of soil by three chemical reactions.

i) Cation Exchange

Cation exchange is the interchange between a cation on the surface of any negatively charged particle (clay particle) and the stabilizer. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation (Wubshet, 2015). Higher valence cations easily replace cations of lower valence. The size of the hydrated ion becomes important for ions of same valence. A typical replaceability series is (Wubshet, 2015):

$Na^+ < Li^+ < K^+ < Rb^+ < Cs^+ < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+} < Fe^{3+} < Th^{4+}$

An example of the cation exchange;

$Ca^{2+} + Na^+\text{-Clay} \rightarrow Ca^{2+}\text{-Clay} + Na^+$

The thickness of the diffused double layer decreases as replacing the divalent ions (Ca^{2+}) from stabilizers with monovalent ions (Na^+) of clay. Thus, swelling potential decreases.

ii) Flocculation and Agglomeration

Cation exchange results in change in the electrical charge around the clay particles, therefore, result in an increase in the interparticle attraction causing flocculation and agglomeration. This leads to the reduction of clay-sized particles and hence the soil surface area, which accounts for the reduction in plasticity and swelling of the soil.

iii) Pozzolanic Reactions

Time dependent pozzolanic reactions play a major role in the stabilization of the soil, since they are responsible for the improvement in the various soil properties. Pozzolanic constituents produces calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

$Ca^{2+} + 2(OH)^{-} + SiO_2$ (Clay Silica) → CSH

$Ca^{2+} + 2(OH)^{-} + Al_2O_3$ (Clay Alumina) → CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure which increases the soil strength.

Stabilizers can also be divided into three groups (Petry, 2002);

1. Traditional stabilizers (lime, cement, etc.)

2. By-product stabilizers (fly ash, quarry dust, baggase ash, phospho-gypsu, slag, etc.)

3. Non-traditional stabilizer (sulfonate oils, potassium compounds, polymers, enzymes, ammonium chlorides, etc.)

i. Traditional stabilizers

- **Lime:** Lime stabilization has been used successfully on many projects to minimize swelling and improve soil plasticity and workability. Many departments have researched lime stabilization and frequently use this treatment method. Lime tabilization is done by adding lime to a soil. When lime reacts with soil , there is exchange of cations in the adsorbed water layer and decreased plasticity, increased workability and increased strength of the soil occurs(Little,1995). The resulting material is more friable than original clay and is therefore, more suitable for construction purposes. The amount of lime required for stabilization varies between 2 to 10% of the soil.
- **Cement:** Cement stabilization is done by mixing pulverized soil and portland cement with other and compacting the mix to attain a strong material. The material obtained by mixing soil and cement is known as soil – cement. The soil – cement becomes hard and durable construction material as cement hydrates and develops strength.Plastic clays may need about 13% cement. The actual quantity of cement required for a particular soil is ascertained by laboratory tests.

ii. By product stabilizers

- **Straw ash:** Amu, O. O., Ogunniyi, S.A. and Oladeji, O.O. studied the geotechnical properties of expansive soils (Osun state, Nigeria) stabilized with sugarcane straw ash. Geotechnical properties of expansive soils treated with SCSA showed significant improvement with increased percentage of SCSA from 0 to 8%. They found that sugarcane straw ash was an effective stabilizer for improving the geotechnical properties of expansive soils.

- **Baggase ash:** K.J. Osinubi, V. Bafyau, A.O. Eberemu and O. Adrian studied stabilization of lateritic soil using baggase ash. They found that the MDD and OMC of the treated soil showed trends of decreasing and increasing respectively with increasing SCBA content. The UCS increased from 366KN/M2 for the natural soil to 836,842 and 973KN/m2 for samples treated with 2% bagasse ash and cured for 7, 14 and 28 days, respectively. CBR value also increased from 10% to 16% for soil treated with 2% bagasse ash.

iii. Non-traditional stabilizers

Potassium Chloride: According to the International journal of Advance in engineering and technology, University College of Engineering, JNTUK, Kakinada, India, June 2012, the performance of chemically stabilized expansive soil was evaluated using some salts. Among these salts potassium chloride is one and the addition of 1% KCl by dry weight of soil, decreases liquid limit by 57%, PI by 26%, differential free swell by 40%. The addition of 1% KCl increases CBR by 80% and UCS by 133%. Earth science research published by Canadian center of science and education, June 29, 2012, stated the influence of the mineral salt KCl on swelling properties of expansive soil. The result showed that the stabilization by the addition of KCl modified the properties of the soil and results are quite satisfactory in significantly reducing the swelling properties of the soil.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

The stability and durability of pavements and buildings are largely dependent on the characteristics of the soil underneath. The soil mass might vary from non-expansive to highly expansive and when the expansive soils are encountered it poses problems unless and otherwise proper improvement measures are taken.

For proper treatment of expansive soils, it is important to adequately identify and understand characteristics of expansive soils and materials used for soil treatment. Proper treatment procedures should also be adopted for successful characteristic improvement of expansive soil. Therefore, the investigation that should be conducted on such soils is a determining factor to select appropriate improvement methods in a technically and economically feasible manner.

The materials used and the methods adopted for the research work, are described briefly in this chapter.

3.2 Materials

3.2.1 Expansive Soil

The Expansive soil sample used for this research work was collected from an active site in Addis Ababa Bole Sub City, around Brass Hospital area. The soil is gray in color. Both disturbed and undisturbed soil samples were collected at a depth of about 1.5m. Full properties the soil is addressed in Chapter three. General view of the sampling area is shown in Figure3.1.

Figure 3.1: An overview of the sampling area

3.2.2 Quarry waste

Because of the high strength characteristics, Basaltic and Trachyte quarry site wastes were selected to be used for the stabilization purpose. Quarry waste samples were collected from different quarry sites in and around Addis Ababa city. Quarry waste samples that have been found relevant to be used for this specific research were collected from Sululta, and Legetafo quarry sites in which their classification lies under Basaltic rocks, and Trachyte rocks respectively. The chemical composition for both quarry waste samples were determined and given in Chapter Four.

Sululta quarry site

Legetafo quarry site

Figure 3.2: An overview of quarry sites

Sululta quarry waste

Legetafo quarry waste

Figure 3.3: A picture showing quarry waste from two quarry sites

3.3. Methods

3.3.1. Sample Preparation and laboratory testing

Sample preparation should be made on the natural soil and quarry waste material in order to make them suitable for the successive laboratory tests. Tests for soil classification included grain size distribution, and Atterberg limits. These are indicative tests that are usually used for identifying whether the soil is expansive or not. The conducted tests however included wet sieve analysis, hydrometer analysis, Atterberg limits, free swell, swell consolidation; UCS, moisture density relation, CBR and percent swell of CBR to fully characterize the natural and the treated soil and to attain the objective of the research.

3.3.1.1 Sample preparation

Prior to testing, sample preparation was basically made in accordance with the method described in AASHTO T87-86 .The following preparation procedures have been followed in this research project.

- Air drying of natural soil and/or quarry waste samples by spreading the material out to be exposed to air.
- Breaking up the soil aggregates by rubber covered mallet. Sieving was performed for quarry waste samples to separate the quarry dust from granular quarry waste.
- Soil was then mixed manually with quarry dust and again with granular quarry waste with predetermined percentages to get uniform mix ratio for each test.
- Treated soil samples with different concentrations of quarry dust were cured for seven days. Curing was done by sealing the samples with plastic cover and keeping them in humidity chamber.
- After curing; air drying ,pulverizing and then sieve analysis was performed to separate the soil-quarry dust mixture in accordance with different laboratory tests

3.3.1.2 Laboratory Tests

3.3.1.2.1Grain Size Analysis test

Grain size analysis test includes sieve analysis and hydrometer analysis. The aim of the test is to determine the different grain sizes which make up a soil mass. Sieve analysis was carried out for coarser soil particles of the natural soil. Wet sieve analysis was employed to determine the grain size distribution of the soil sample in accordance with AASHTO T-88 Test Method for particle size analysis of soils. In addition hydrometer analysis was conducted for finer particles to know the silt and clay fractions.

3.3.1.2.2Atterberg Limits

The nature and response of soil upon change to moisture content is determined by Atterberg limit tests. This parameter is basic in the AASHTO and USCS soil classification systems. The Atterberg limit depends on the type of predominant clay mineral available in the soil mass. The different types of limits under this method are Liquid limit, Plastic limit and plasticity index. The tests are conducted for the natural soil and treated soil samples in accordance with AASHTO T-89 and T-90 test methods.

3.3.1.2.3. Free Swell Tests

The test includes the determination of the free swell for the natural soil and soil-quarry dust mixture. This test has not yet been standardized by AASHTO and ASTM. The method was suggested by Holtz and Gibbs, (1956) to measure the expansive potential of cohesive soils. Free swell is determined as the ratio of change in volume to the initial volume, expressed as percentage. The free swell test gives a fair approximation of the degree of expansiveness of the soil sample.

3.3.1.2.4 Swelling Pressure

Swelling pressure is defined as the pressure which prevents the specimen from swelling or that pressure which is required to return the specimen back to its original state (void ratio, height) after swelling (ASTM, 1996). Basically, the methods of measuring swelling pressure can be either strain controlled or stress controlled.

Among the techniques used to determine the swelling pressure, one-dimensional odometer (stress controlled method) is used in accordance with AASHTO T-216 test method. The test is performed for the natural soil and soil-quarry dust mixtures. This test can be done on both undisturbed and remolded soil samples. In this specific research project swelling pressure tests are performed on undisturbed and remolded samples for the natural soil and for the soil-quarry dust mixture respectively.

3.3.1.2.5 Unconfined Compressive Strength

This test is performed in accordance with AASHTO T-208 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. In this test the soil goes to failure by axial load only with no confining stresses. Unconfined compressive strength testing provides a quick and simple means to measure the unconfined compressive strength (qu). The test was performed on undisturbed and remolded samples for the natural soil and for the soil-quarry dust mixture respectively.

3.3.1.2.6 Moisture Density Relations of the Soil

Standard Proctor compaction tests were conducted on the natural and treated soil samples to determine the relationship between the moisture content and dry density for specific compaction effort according to AASHTO T99 testing procedures.

3.3.1.2.7 CBR and CBR-swell

The CBR is expressed by the force exerted by the plunger and the depth of its penetration into the specimen; it is aimed at determining the relationship between force and penetration. The CBR test indirectly measures the shearing resistance of a soil under controlled moisture and density conditions; usually at OMC and the corresponding MDD relevant to field compaction value. One point soaked CBR and CBR-swell tests were conducted in accordance with AASHTO T193 for the natural and treated soil.

3.3.2 Design of Experiment

Design of experiment was prepared in order to be able to use time properly. According to the design, Simple tests like Atterberg limits and free swell tests will be performed first on soil-quarry dust mix; for 2%,4%,6%,8%,10%,20% and 30% stepped concentration of quarry dust. This gives an indication about the percentage of quarry dust which can bring significant improvement on the characteristics of the natural expansive soil. Swelling pressure, UCS, compaction and CBR tests are then performed for that proportion of quarry dust which have showed significant improvement while performing the simple tests. Those percentages of quarry dust for this specific research have been found to be 20% and 30%. It was desired to make easy comparison between the results obtained using quarry dust and granular quarry waste; Accordingly it was designed to blend granular quarry waste and expansive soil with 20% and 30% concentrations of the quarry waste. The design is summarized in the following table. In the table, “A” represents soil treated with sululta quarry dust; while “B” represents soil treated with legetafo quarry dust.

Table 3.1: Summary of design of experiment

Types of tests			Addition by % of quarry waste						
			2%	4%	6%	8%	10%	20%	30%
A	Atterberg limits	LL, %	✓	✓	✓	✓	✓	✓	✓
		PL, %	✓	✓	✓	✓	✓	✓	✓
	Free swelling index		✓	✓	✓	✓	✓	✓	✓
	Swelling pressure							✓	✓
	UCS							✓	✓
	Compaction							✓	✓
	CBR and CBR-swell							✓	✓
B	Atterberg limits	LL, %	✓	✓	✓	✓	✓	✓	✓
		PL, %	✓	✓	✓	✓	✓	✓	✓
	Free swelling index		✓	✓	✓	✓	✓	✓	✓
	Swelling pressure							✓	✓
	UCS							✓	✓
	Compaction							✓	✓
	CBR and CBR-swell							✓	✓

CHAPTER FOUR
TEST RESULTS AND DISSCUSSIONS

4.1. Introduction

In this Chapter laboratory test results are briefly discussed and the effect of quarry waste is evaluated for each laboratory tests. The physical properties of in-situ soil have also been summarized, to make the comparison between treated and untreated soil samples easier. This chapter presents the results of laboratory tests and a discussion pertinent to the results. The tests include Atterberg limits, free swell, swelling pressure, unconfined compressive strength, moisture density relationship (compaction) and California bearing ratio (CBR).Soil samples treated with quarry dust were cured for 7 days before the tests were conducted.

4.2 Properties of Materials used in the Study

4.2.1 Natural Soil

According to the laboratory test results of the natural soil sample obtained during the present study, almost 99.46% of the soil is passing through No. 200 sieve; it exhibits a liquid limit of 104.8%, a plastic limit of 42.2% and plasticity index of 62.6%. Accordingly the soil is classified in to A-7-5 as per the AASHTO and CH as per the USCS classification systems. As far as the engineering performance of soils of these classes is concerned, such soils are potentially expansive soils which have high volume changing properties with variation in moisture content (Chen, 1988; McKeen, 1976). Liquid limit between 70% and 90% indicates very high plasticity (Whitlow, 1995) and the value obtained here is even beyond this range. Hence, the value indicates that the soil is highly plastic clay. The liquid limit and plasticity index values are also very much greater than the Ethiopian Roads Authorities requirements ;(i.e, liquid limit less than 60% and plasticity index less than 30%.) Generally the soil is classified as a material of poor engineering property to be used for construction purposes.

Swelling characteristic of the soil also revealed that the soil is highly expansive clay with a free swell of about 140%; which is greater than 100%.

Furthermore, the CBR and percent swell of 1% and 13% respectively indicate that the soil has a very low load bearing capacity and high swelling potential when compared to ERA's specifications of CBR > 5% and percent swell of less than 2%. This shows that, the soil sample does not fulfill the requirements as a sub-grade material and is determined to be unsuitable for sub-grade in road construction.

The soil generally fell below the standard recommendations for most geotechnical construction works. Therefore, the soil requires initial modification and/or stabilization to improve its workability and engineering property.

The results of the tests conducted for identification and/or determination of properties of the natural soil before applying quarry dust are presented in Table 4.1. The soil is gray in color.

Table 4.1: Geotechnical properties of the natural soil

Property	Quantity
Percentage passing no.200 sieve	99.5
Liquid limit, %	104.8
Plastic limit, %	42.2
Plastic index ,%	62.6
AASHTO soil classification	A-7-5
Unified soil classification	CH
Free swell, %	140
Maximum dry density, g/cm3	1.19
Optimum moisture content, %	38
UCS, kPa	148.1
Swelling pressure, kPa	225.1

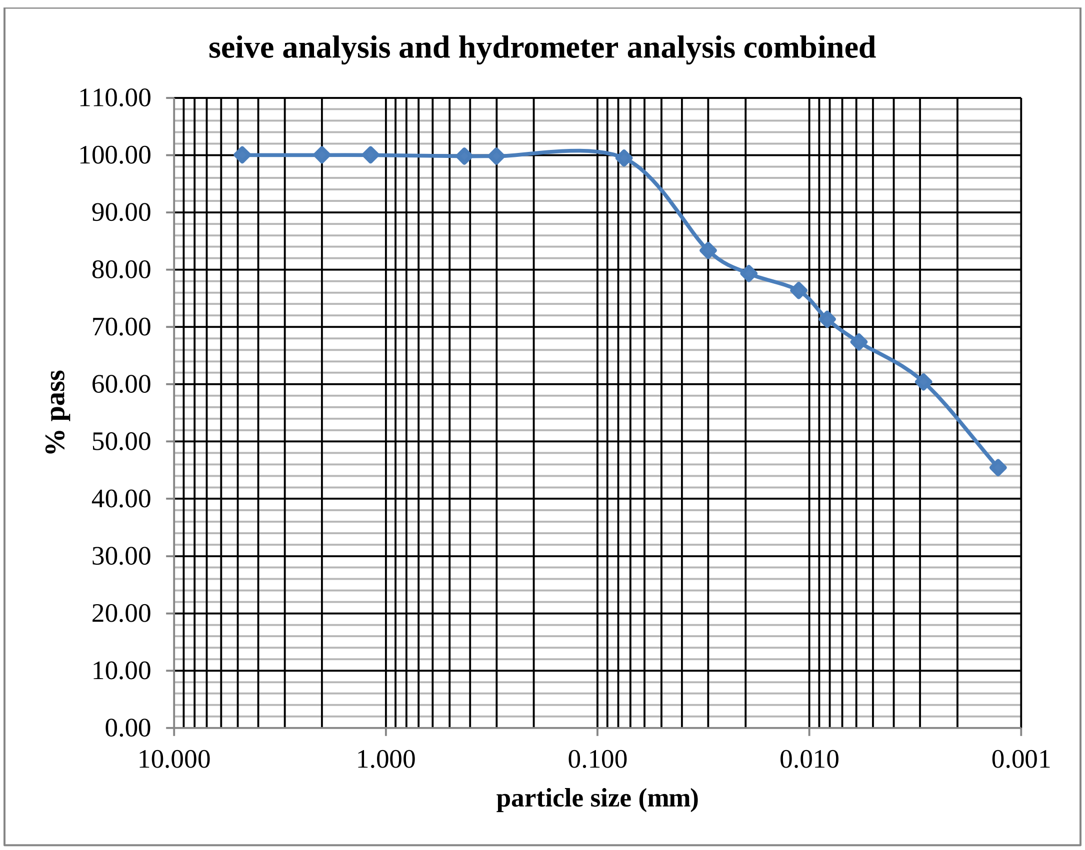

Figure 4.1: Particle size distribution curve for the natural expansive soil sample

4.2.2 Quarry Waste

Chemical composition of quarry waste samples to be used in this research project is studied in Geochemical Laboratory of **Geological survey of Ethiopia Geochemical Laboratory Directorate**. The oxide composition of quarry waste samples from two quarry sites is shown in Table 4.2. The results indicate that the quarry dust can be used as chemical stabilizer. The combined percent composition of SiO_2, Al_2O_3, and Fe_2O_3 is more than 70% and the Loss On Ignition is less than 10% this is adequate to meet the requirement of ASTM C618 standard for Chemical stabilizers shown on Appendix 1.

Table 4.2: Oxide composition of Quarry waste

Constituents	**Location of quarry sites**	
	Sululta	**Legetafo**
SiO_2	56.68	68.58
Al_2O_3	14.94	10.53
Fe_2O_3	6.70	5.12
CaO	8.24	0.48
MgO	9.44	0.72
Na_2O	2.58	5.48
K_2O	<0.01	6.88
MnO	0.12	0.10
P_2O_5	0.36	0.05
TiO_2	0.72	0.15
H_2O	0.22	47
L.O.I	0.33	0.90

4.3 Effects of Quarry Dust on Engineering Properties of Soil

Quarry waste samples were collected from two quarry sites around Addis Ababa. To see the effects of both basaltic and trachyte quarry dust, samples from Sululta and Legetafo quarry sites respectively were used for the stabilization purpose. The expansive soil in this research was treated with quarry dust i.e. passing No.200 in stepped concentration of 2%, 4%, 6%, 8%, 10%, 20% and 30% by weight of dry soil. The treated soil samples were cured for 7 days before performing any test. After performing tests the effect of quarry dust on the engineering properties of expansive soil is presented as follows.

4.3.1. Effect of Quarry Dust on Atterberg Limits

Atterberg limit tests were performed on the treated soil samples cured for 7 days. The introduction of quarry dust into the soil caused a general decrease in liquid limit and plasticity index. Plasticity index generally decreased with increase in quarry dust content. The decrease is observed for all higher quarry dust contents. The maximum decrease in PI value was seen at 30% quarry dust and the PI value is decreased from 62.6% to40.5% and 48.1% for soil treated with Sululta and Legetafo quarry dust respectively. The summary of the test results for varying percentage of quarry dust are shown in Table 4.3 and figure 4.2.

Table 4.3: Effect of quarry dust on Atterberg limits

Content of quarry dust (%)	Source of quarry dust	LL value (%)	PL value (%)	PI value `(%)
0	Sululta quarry	104.82	42.21	62.61
2		103.60	41.96	61.64
4		102.42	41.71	60.71
6		100.56	41.47	59.09
8		99.70	41.23	58.47
10		97.01	41.11	55.90
20		88.13	40.24	47.89
30		79.64	39.18	40.46
0	Legetafo quarry	104.82	42.21	62.61
2		104.28	41.77	62.51
4		102.77	41.07	61.70
6		99.48	39.62	59.86
8		97.77	39.05	58.72
10		96.54	38.70	57.84
20		88.18	35.56	52.62
30		80.16	32.04	48.12

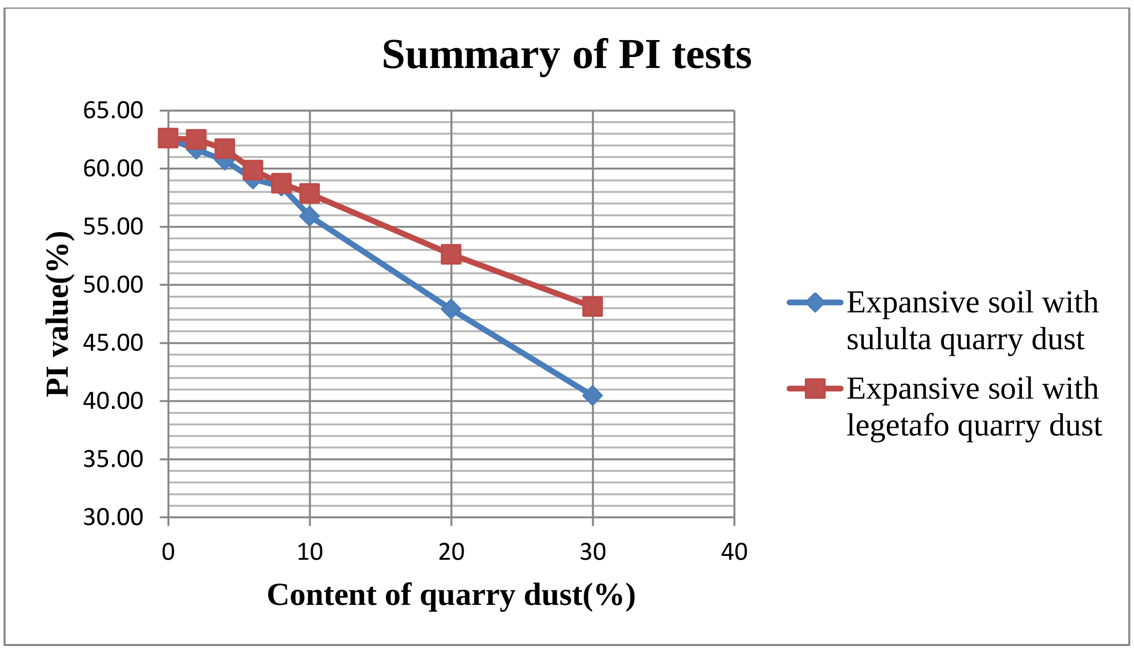

Figure 4.2: Variation of plasticity index with addition of different bagasse ash contents

In general, the plasticity of the soil decreases by the addition of quarry dust content. This is clearly shown by the fact that Plasticity Index of treated soil decreased with increasing quarry dust content. The simple reason for this is the partial replacement of plastic soil particles with quarry dust which is non-plastic material. The other reason is expected to be the presence of alumina in the quarry dust. Almina replaces the water sheet sand witched between two Structural units of Montmorillionite which imparts expansive and plastic properties to the soil.

Expansive soil treated with Sululta quarry dust has showed more decrement in PI value than expansive soil treated with Legetafo quarry dust. This may be due to the greater amount of aluminum oxide (up to 14%) in the oxide composition of Sululta quarry waste.

However a general decrease in plasticity of the treated soil is observed as the content of quarry dust increases, the observed decrement is nominal because soils of plasticity index greater than 35% are classified as highly plastic as reviewed in section 2.1.5.2.

4.3.2. Effect of Quarry Dust on Free Swell

The free swell of both treated and untreated soil samples were determined and the results summarized in Table 4.4 and Figure 4.3.

Table 4.4: Effects of quarry dust on Free Swell of soil

No.	Content of quarry dust	source of quarry dust	Free Swell Final Reading (ml)	Free Swell (%)
	0		24	140
1	2	Sululta quarry site	24	140.00
	4		23.5	135.00
	6		23	130.00
	8		23	130.00
	10		22	120.00
	20		20	100.00
	30		19	90.00
	0		24	140.00
2	2	Legetafo quarry site	24	140.00
	4		23.5	135.00
	6		23.5	135.00
	8		23	130.00
	10		22	120.00
	20		21	110.00
	30		19	90.00

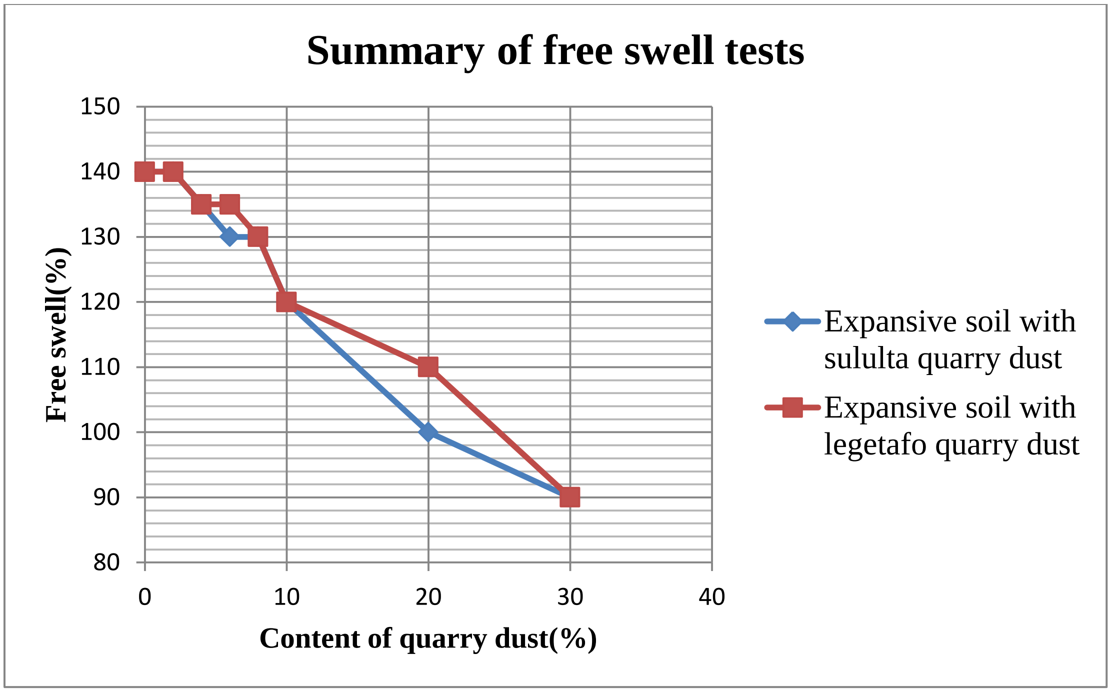

Figure 4.3: Effects of quarry dust on free swell of expansive soil

There is a reduction in the free swell value which is directly proportional to the quantity of quarry dust added to the soil. Soil treated with Sululta quarry dust showed almost similar reduction in free swell value as the soil treated with Legetafo quarry dust. The highest reduction in free swell is attained when the expansive soil is treated with 30% quarry dust. The free swell value decreased from 140% to 90%. The decrease in free swell values is mainly due to the replacement of expansive clay minerals with quarry dust particles which have less affinity for absorbing water as compared to expansive soil. According to swell classification based on free swell, the treated soil still has high degree of expansion. The addition of silica (holding the greater percentage in the oxide composition of quarry waste) may have caused the decrease of free swell value to be insignificant. Effect of silica is not inferred as soil mineral already contains most of it so any further addition of silica is not likely to be fruitful. The negatively charged surfaces of the silica sheet attract water which contributes for the expansion of soil-quarry dust mixture.

4.3.3. Effect of Quarry Dust on Swelling Pressure of Expansive Soil

The effect of quarry dust on the swelling pressure for the soil-quarry dust mixtures is shown in Table 4.5 and Figure 4.4. When treating the expansive soil at 30% quarry dust content, sample gave swelling pressure of 86kPa for soil treated with Sululta quarry dust and swelling pressure of 97kPa for soil treated with Legetafo quarry dust, from a value of 225kPa for the natural undisturbed soil sample. The swelling pressure of expansive soil decreased as the concentration of quarry dust increased.

Table 4.5: Effect of quarry dust on swelling pressure

1kg on hunger gives pressure of 22kPa			
Content of quarry dust	**Source of quarry dust**	**Load on hunger (kg)**	**Swelling pressure (kPa)**
0	sululta quarry	10.23	225.06
20		6.873	151.206
30		3.908	85.976
0	legetafo quarry	10.23	225.06
20		7.98	175.56
30		4.428	97.416

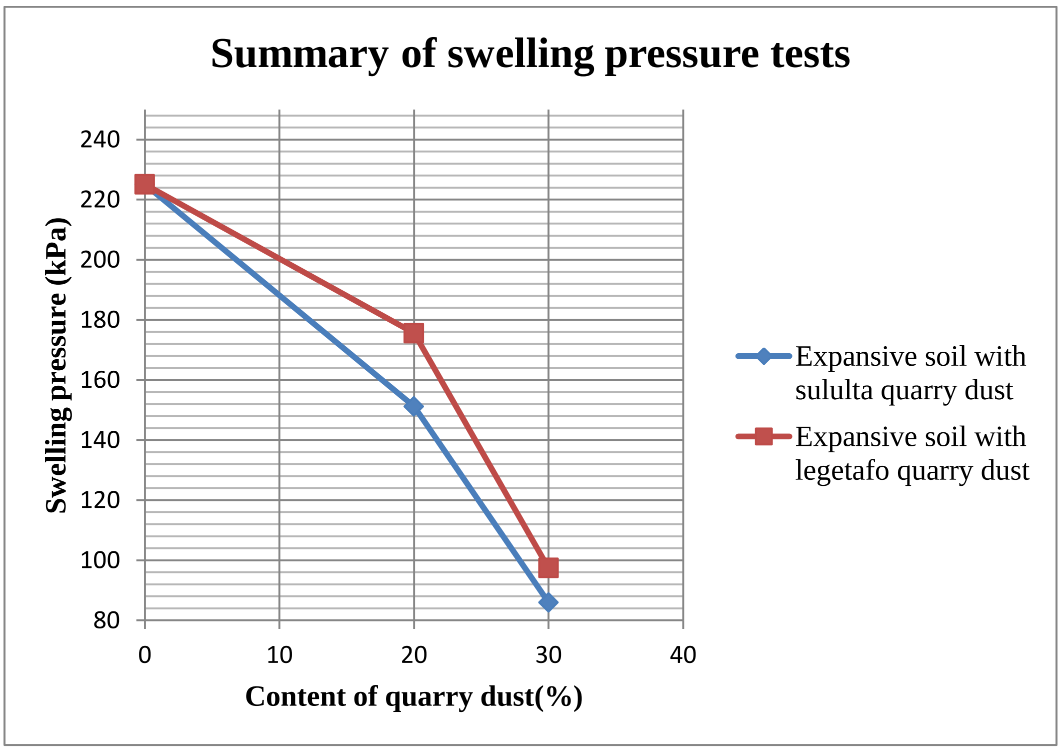

Figure 4.4: Effect of quarry dust on swelling pressure

Those values of swelling pressure obtained at maximum quarry dust concentrations indicates that the swelling pressure of expansive soil has decreased to the level that can be counteracted by the load coming from light weight structures(i.e. the treated soil requires low pressure to go back to its original volume) . The reason for this significant improvement is expected to be chemical reactions taking place in the soil-quarry dust mixtures. For the case of this study, the decreased swelling pressure enables to construct light weight building structures; taking care of the determination of the load of the structure to be built on a specific soil.

4.3.4 Effect of Quarry dust on Unconfined Compressive Strength of the Soil

The unconfined compressive strength of undisturbed natural soil sample and remolded soil-quarry dust mix samples prepared at Maximum Dry Density and Optimum Moisture Content with addition of 20% and 30% quarry dust to the expansive soil are presented in table 4.6 and figure 4.5.

Table4.6: Effect of quarry dust on UCS of soil

Content of quarry dust	Source of quarry dust	UCS value kPa
0	sululta quarry	148.09
20		109.29
30		95.43
0	Legetafo quarry	148.09
20		104.16
30		81.41

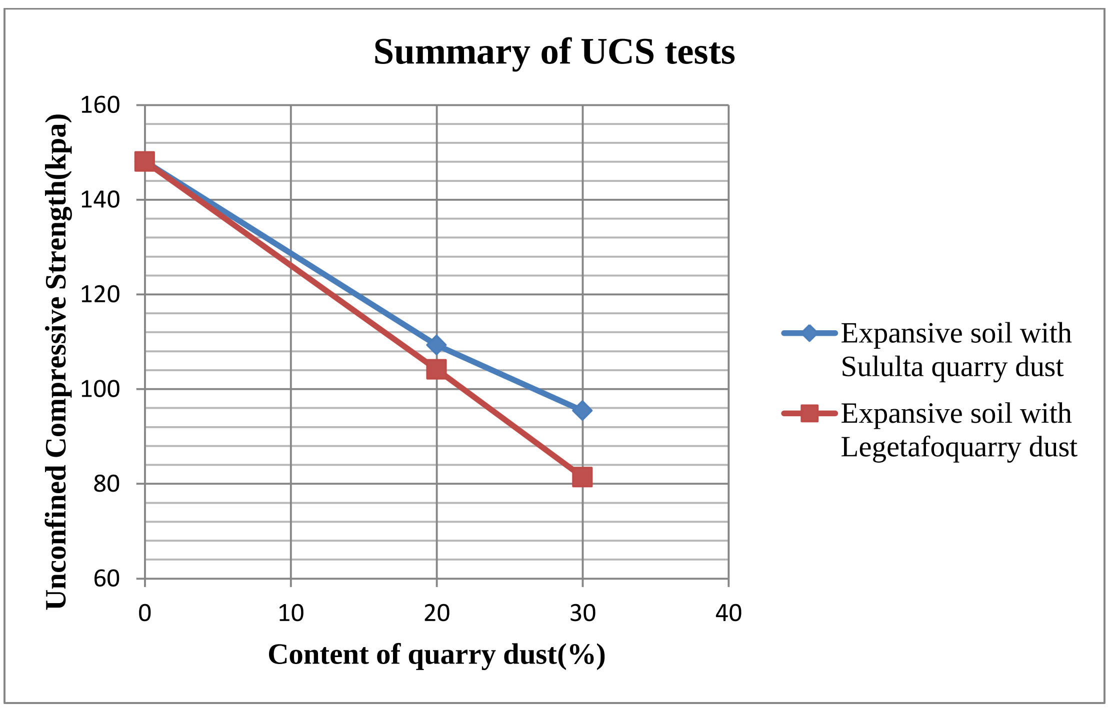

Figure 4.5: Effect of quarry dust on UCS of soil

It is observed that the unconfined compressive strength of the treated soil is decreasing as the amount of the quarry dust is increasing. From this one can judge that both quarry dust samples (i.e. Basaltic and Trachyte samples from the two quarry sites) do not exhibit any pozzolanic property. Therefore the decrease in UCS value seems due the partial replacement of the cohesive soil with cohesionless quarry dust. The breaking down of the cohesive force between the soil particles due to the addition of quarry dust may be the other reason. This leads to high reduction in the cohesion of expansive soil. Therefore, at higher percentage of quarry dust the UCS value of the treated soil gets lower and lower.

4.3.5 Effect of Quarry Dust on Moisture Density Relations of the Soil

Standard proctor test was carried out according to AASHTO T99. Moisture content versus dry density graph was produced and optimum moisture content (OMC) and maximum dry density (MDD) were determined from the graph. The summary of the test results for varying percentage of quarry dust are shown in Table 4.7 and figure 4.6 and 4.7.

Table 4.7: Effect of quarry dust on moisture density relations of the soil

Content of quarry dust	Source of quarry dust	Optimum moisture content (%)	Maximum dry density(g/cu.cm)
0	Sululta quarry	38	1.19
20		35	1.28
30		34	1.36
0	Legetafo quarry	38	1.19
20		36	1.26
30		35	1.32

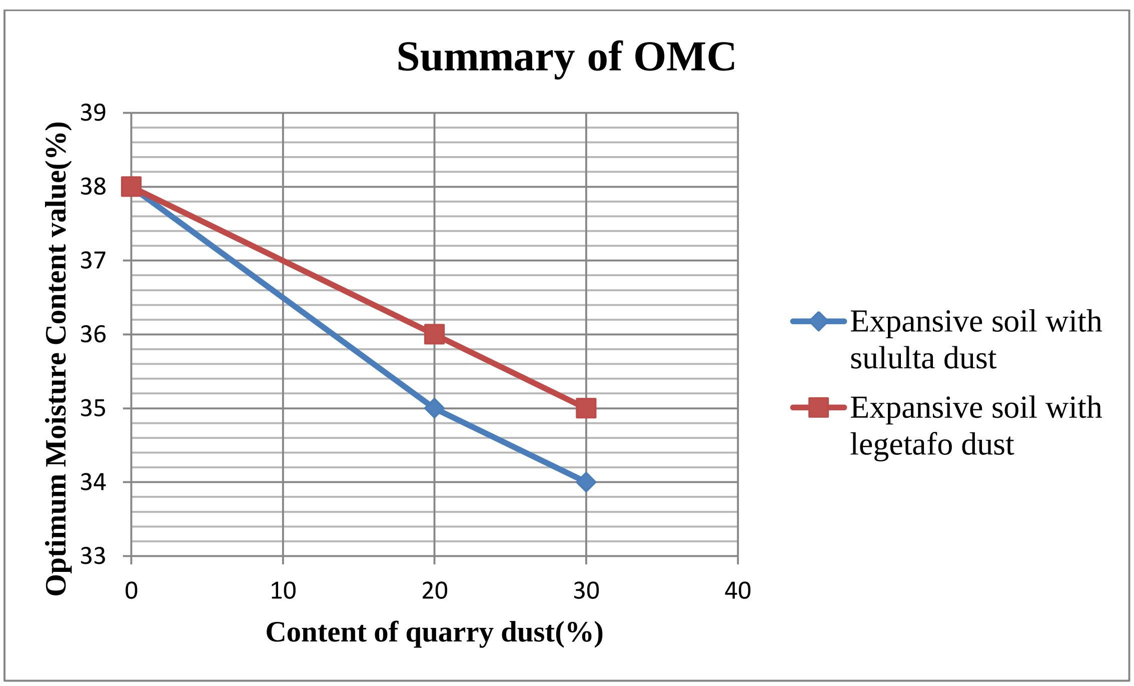

Figure 4.6: Effect of quarry dust on optimum moisture content

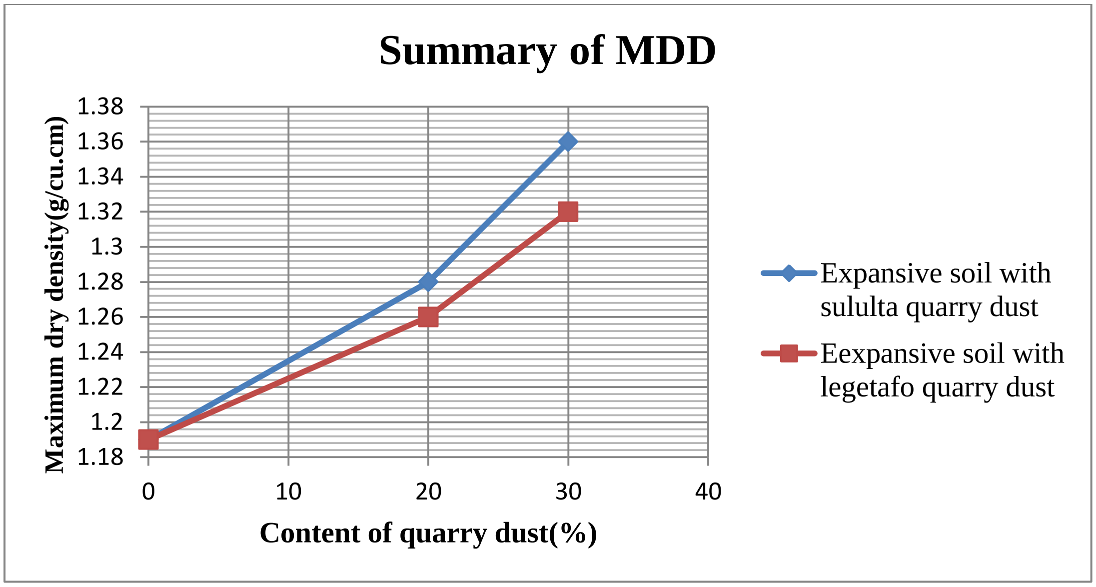

Figure 4.7: Effect of quarry dust on maximum dry density

Generally, increasing the percentage of quarry dust led to increase in the maximum dry density and decrease in optimum moisture content. The decrease in OMC is mainly due to addition of quarry dust caused by the less absorption of water by quarry dust. The small increase in MDD could be a result of chemical reactions taking place in the soil-quarry dust mixtures. These reactions may have given the treated samples a tendency of being compressed easily, leading to corresponding increase in dry density.

4.3.6 Effect of Quarry Dust on CBR

Samples for CBR test were prepared at MDD and Optimum Moisture Content with addition of 20% and 30% by weight of quarry dust to the expansive soil. As it is observed from the result of the CBR test, as the percentage of quarry dust increases the CBR value also increases in a very small amount, which may be negligible. When treating the expansive soil at 30% quarry dust content the soil-quarry dust sample gave a peak CBR value of 1.6% from a value of 0.8% for the natural soil. This is shown in Table 4.8 and Figure 4.8.

Table 4.8: Effect of quarry dust on CBR

Content of quarry dust	Source of quarry dust	CBR value (%)
0	sululta quarry site	o.8
20		1.3
30		1.6
0	Legetafo quarry site	0.8
20		1.2
30		1.6

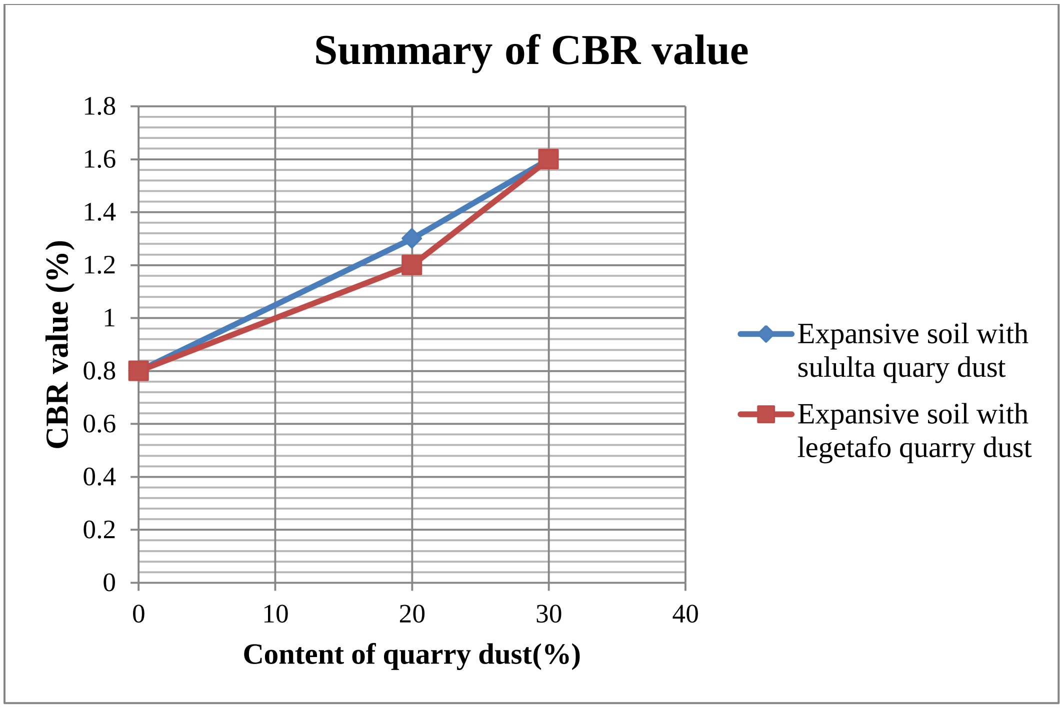

Figure 4.8: Effect of quarry dust on CBR

The slightly improved MDD values probably have made the treated soil to attain better load bearing capacity as compared to the natural soil.

The increase in the CBR value is not considerable since it does not satisfy the minimum requirement of ERA's specifications. According to Ethiopian Roads Authority pavement design manual specification, quarry dust treated soil will not satisfy the minimum requirement which is CBR value not less than 5%. The reason for the slight increase in strength could be due to inadequate amounts of CaO in the oxides composing quarry dust; to produce stable calcium silicate hydrate (CSH), and calcium aluminate hydrates (CAH) which generate long -term strength. The quarry dust had little content of lime (CaO) and almost similar chemical composition as most of expansive soils. As a result, the addition of quarry dust did not bring a significant change on the strength of the soil.

4.3.7 Effect of Quarry Dust on CBR- Swell of the soil

CBR-Swell values were determined for 20% and 30% concentrations of quarry dust. When treating the expansive soil at 30% quarry dust content the soil treated with Sululta quarry dust gives CBR-swell of 4.5% while that of the soil treated with Legetafo quarry dust CBR-Swell is 6.03% from a value of 12.97% for the natural soil. The values of CBR-swell for 20% and 30% addition of quarry dust are presented in Table 4.9 and Figure 4.9.

Table 4.9: Effect of quarry dust on CBR-swell

Content of quarry dust	Source of quarry dust	CBR swell value (%)
0	Sululta quarry site	12.97
20		8.23
30		4.5
0	Legetafo quarry site	12.97
20		9.06
30		6.03

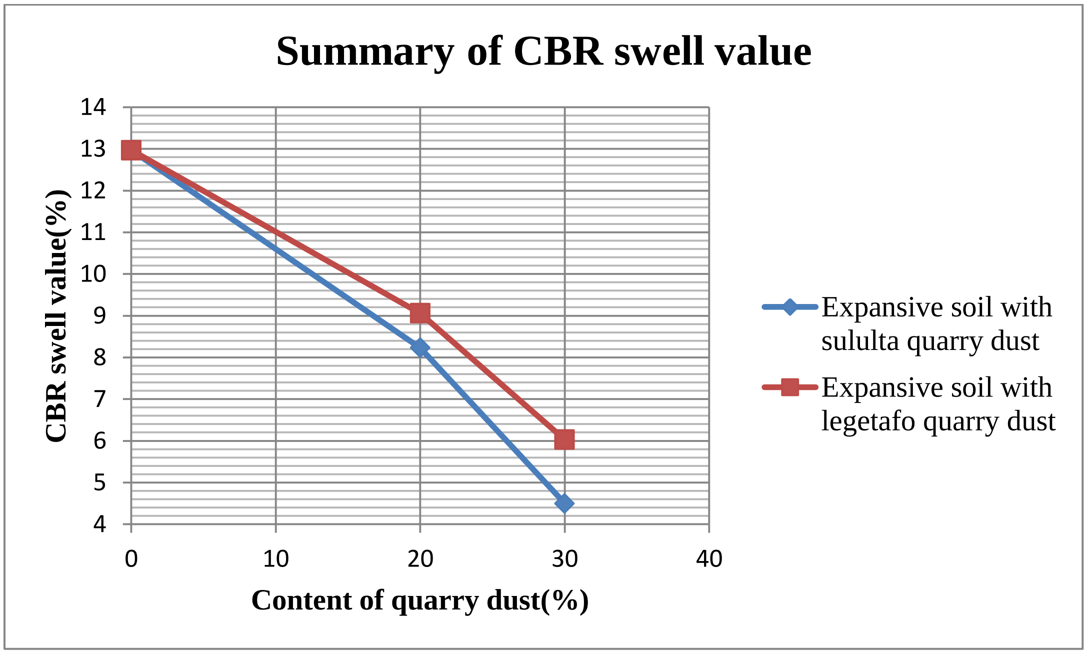

Figure 4.9: Effect of quarry dust on CBR-swell

The CBR-swell of expansive soil decreased as quarry dust content increased. This shows that the swelling potential of the sample decreased with the addition of quarry dust. This is due to replacement of the volume that is previously occupied by expansive clay minerals by quarry dust which has low affinity for absorbing water. For the case of this study, with the increment of quarry dust content up to 30%, the decreased CBR-swell values will not satisfy the minimum requirement of ERA’s specifications which is CBR –swell less than 2%.

4.4 Effect of Granular Quarry Waste on Engineering Properties of Expansive Soil

In this study it has been tried to consider the other perspective of stabilization which is mechanical stabilization, by using granular quarry waste for the stabilization purpose. In this case the soil is considered as a subgrade material and the laboratory tests are limited to moisture density relation and CBR tests since these tests alone can give clear cut indication about improvement in engineering Characteristics of subgrade material. Preparation of the quarry waste material has been made based on the proper grain size distribution for sub grade soil (i.e. passing No.4 and retaining No.200). The quarry waste material was blended to the soil by 20% and 30% by weight of the soil, and Compaction and CBR tests were performed. The results are discussed as follows.

4.4.1 Moisture Density Relation Tests

Table 4.10: OMC and MDD values for soil mechanically stabilized with granular quarry waste

Content of quarry material	Source of quarry material	OMC(%)	MDD(%)
0	Sululta quarry site	38	1.19
20		29	1.44
30		26	1.48
0	Legetafo quarry site	38	1.19
20		30	1.36
30		28	1.44

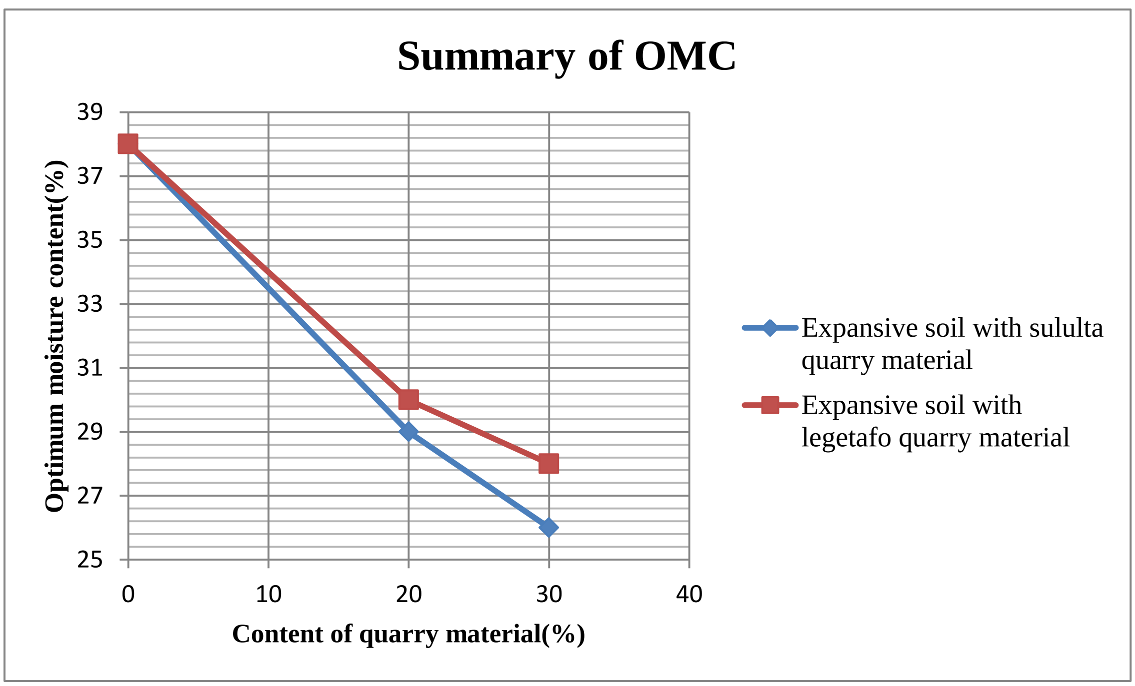

Figure 4.10: OMC values for soil mechanically stabilized with granular quarry waste

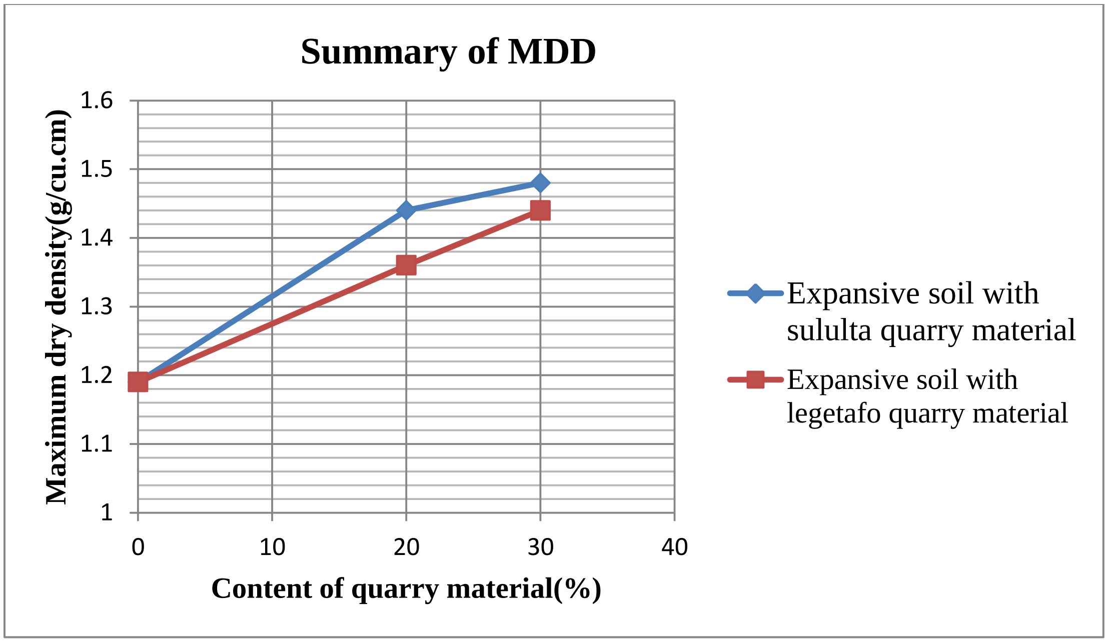

Figure 4.11: MDD values for soil mechanically stabilized with granular quarry waste

Increasing the percentage of granular quarry waste material has led to increase in the maximum dry density and decrease in the optimum moisture content. The comparative increase in MDD could probably be the result of Partial replacement of light weight soil particles with comparatively heavy granular quarry waste particles, occupying smaller space. The coarser and heavier quarry waste particles can be compressed easily and result in the maximum dry density. The slight and/or inadequate increase in MDD value is probably due to the presence of Clay and friable particles in the form of lumps in granular quarry wastes. The Clay Lumps may act as filler in the voids.

4.4.2 CBR and CBR-Swell

Table 4.11: CBR values for soil mechanically stabilized with granular quarry waste

Content of quarry Material	Source of quarry material	CBR value (%)	CBR swell value (%)
0	Sululta quarry site	0.8	12.97
20		0.9	12.54
30		1	12.08
0	Legetafo quarry site	0.8	12.97
20		1	12.63
30		1	12.14

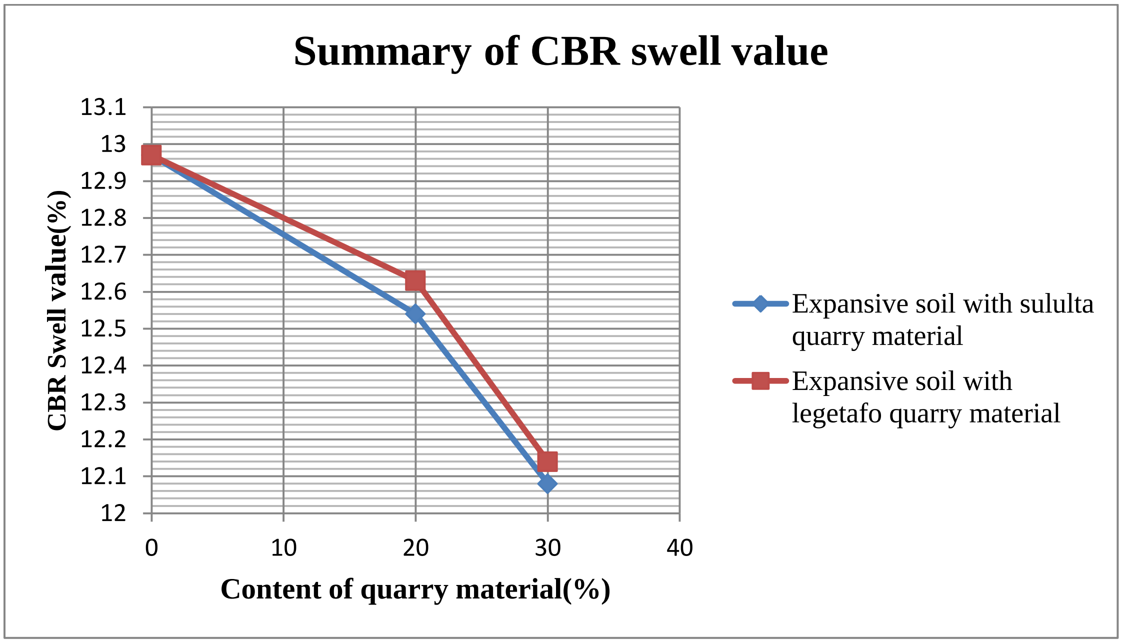

Figure 4.12: CBR-Swell values for soil mechanically stabilized with granular quarry waste

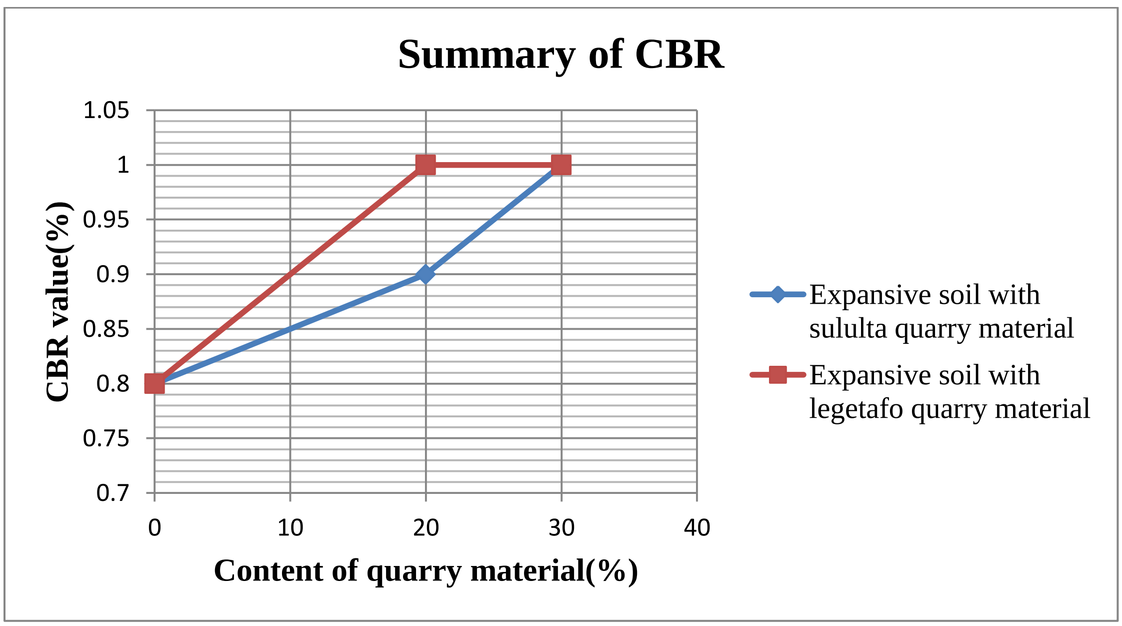

Figure 4.13: CBR values for soil mechanically stabilized with granular quarry waste

Increasing the percentage of granular quarry waste has led to a slight increase in the CBR value and decrease in CBR-swell value. But those improved values will not still satisfy the minimum requirement for ERA's specification. The reason for this could be the presence of Clay Lumps. Excessive clay lumps in a processed aggregate (i.e. granular quarry waste) may interfere with the bonding between the granular quarry waste and expansive soil. It may also add the property of clay to the soil resulting insignificant improvement in strength of the treated soil.

CHAPTER FIVE
COMPARISION OF TEST RESULTS

5.1 Comparison of Test Results obtained using Quarry Dust and Granular Quarry Waste

It has been tried to compare the values obtained using the quarry dust and granular quarry waste material for the purpose of chemical and mechanical stabilization respectively. The comparisons are presented in the following tables and figures.

Table 5.1: Comparison of OMC and MDD values obtained using quarry dust and granular quarry waste

Content of quarry waste	Source of quarry waste	Using quarry dust		Using granular quarry waste	
		OMC(%)	MDD(g/cm^3)	OMC(%)	MDD(g/cm^3)
0	sululta quarry	38	1.19	38	1.19
20		35	1.28	29	1.44
30		34	1.36	26	1.48
0	legetafo quarry	38	1.19	38	1.19
20		36	1.26	30	1.36
30		35	1.32	28	1.44

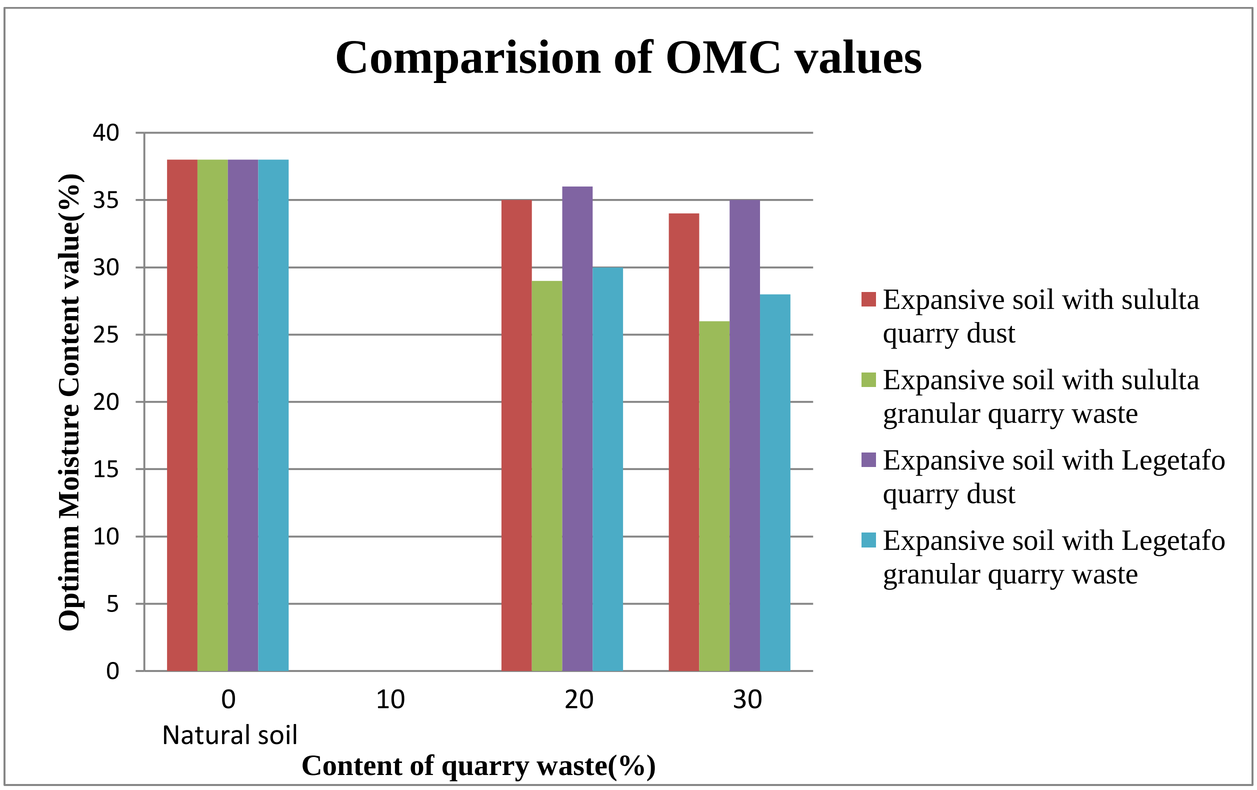

Figure 5.1: Comparison of OMC values obtained using quarry dust and granular quarry waste

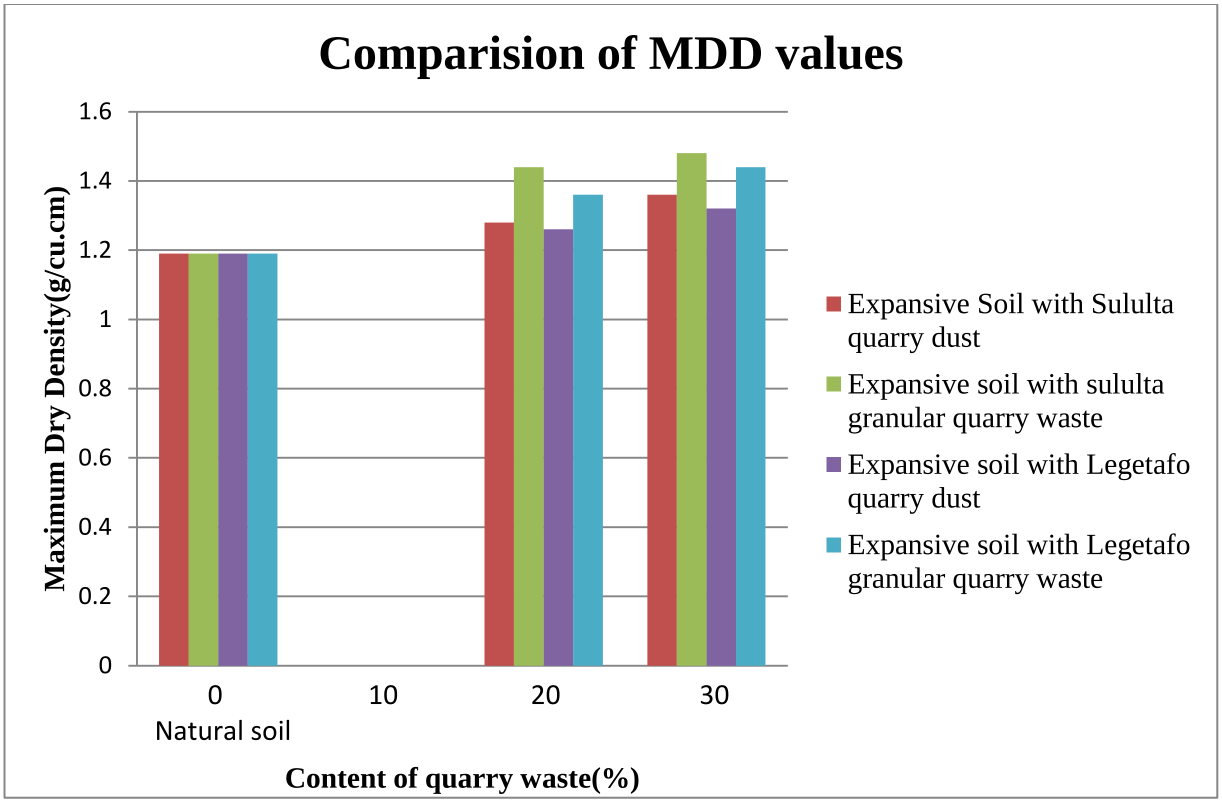

Figure 5.2: Comparison of MDD values obtained using quarry dust and granular quarry waste

As it can be clearly observed from the above values, using the granular quarry material has not bring that much significant difference in improving the moisture density relationship of the soil. The slight improvement can already be obtained by using quarry dust; since using granular quarry waste material may not be very effective.

Table 5.2: Comparison of CBR & CBR-Swell values obtained using quarry dust and granular quarry waste

Content of quarry waste	Source of quarry waste	Using quarry dust		Using granular quarry waste	
		CBR value(%)	CBR-swell value(%)	CBR value(%)	CBR-swell value(%)
0	sululta quarry site	o.8	12.97	0.8	12.97
20		1.3	8.23	0.9	12.54
30		1.6	4.5	1	12.08
0	Legetafo quarry site	0.8	12.97	0.8	12.97
20		1.2	9.06	1	12.63
30		1.6	6.03	1	12.14

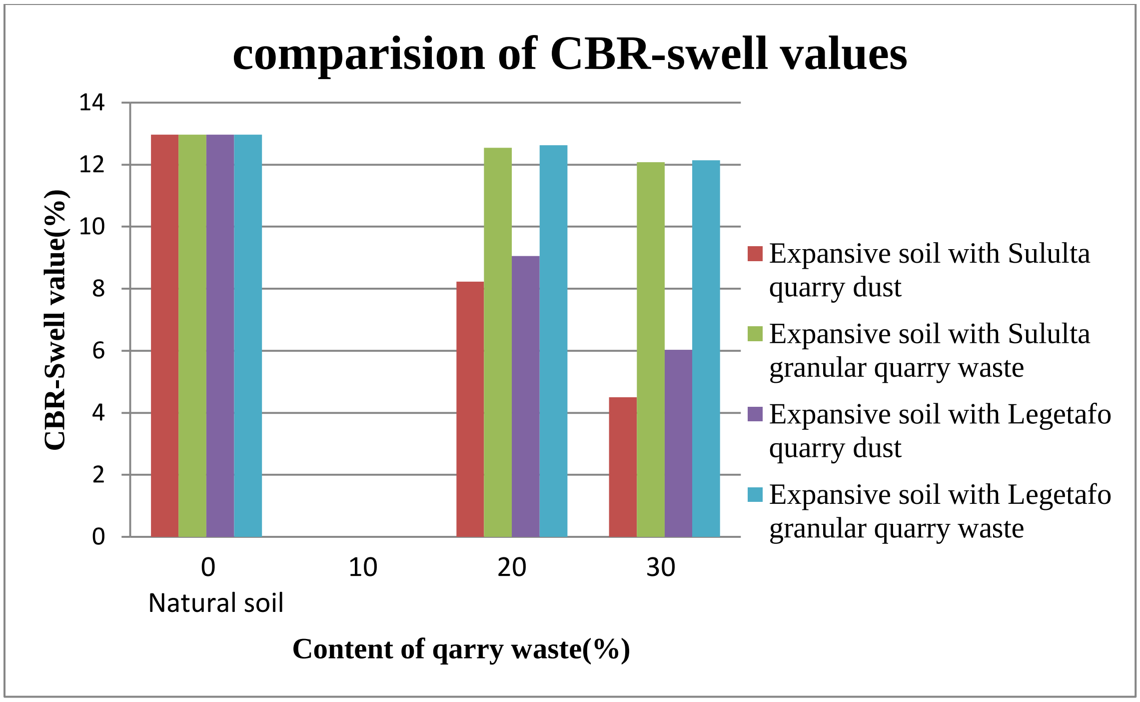

Figure 5.3: Comparison of CBR-swell values obtained using quarry dust and granular quarry waste

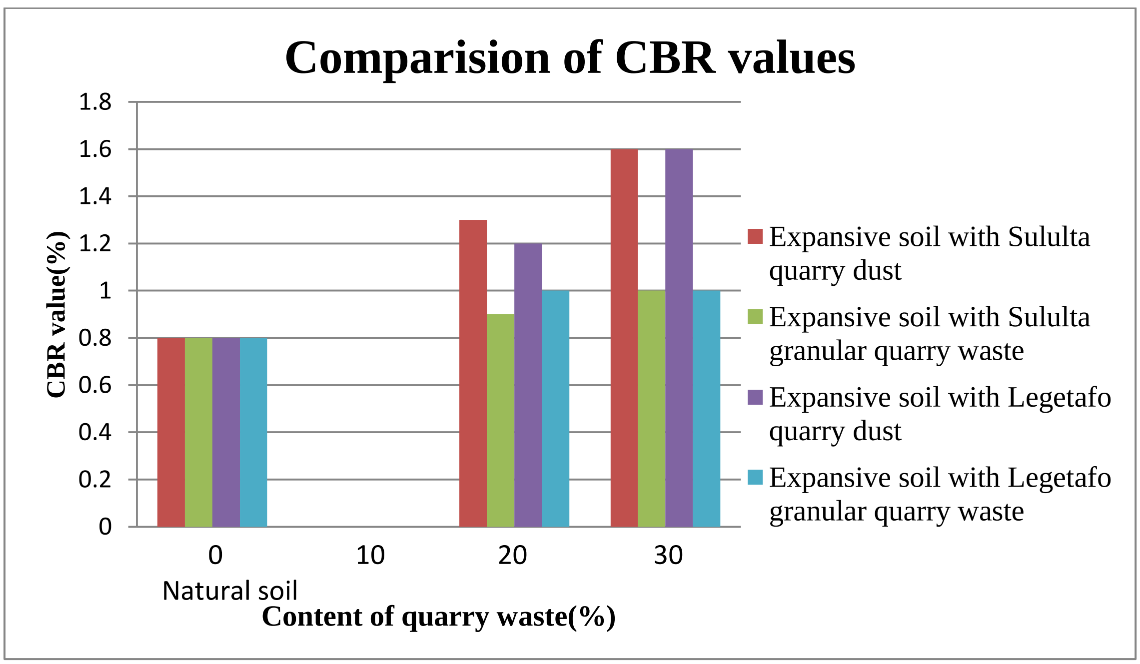

Figure 5.4: Comparison of CBR values obtained using quarry dust and granular quarry waste

Using the granular quarry waste material has not brought any significant change in improving the CBR value of the soil and in decreasing the CBR-swell of the soil. Instead the quarry dust has brought a relatively better improvement, even if the improvement is below the minimum requirement for ERA’s specification.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A study was undertaken to investigate the effects of Quarry Dust on some geotechnical characteristics of expansive soil. The following conclusions can be drawn from the results of the study.

1. Plasticity index showed a slight decrease with increasing amount of quarry dust.
2. Free swell and swelling pressure also showed decrease with increasing amount of quarry dust. Swelling pressure showed reduction to the level in which the uplift pressure of expansive soil can be controlled by the counter pressure of light weight structures.
3. UCS of the treated soil decreased with increasing amount of quarry dust. This revealed that, both quarry dust samples (i.e. Basaltic and Trachyte samples from the two quarry sites) do not exhibit any pozzolanic property.
4. OMC and CBR-swell values decreased while MDD and CBR of the treated soil showed a very slight increase for all increased concentrations of quarry dust. Addition of quarry dust did not bring significant improvement in strength characteristics of the soil. This is due to the presence of reactive silica in greater amount with low amount of calcium content(for the formation of elements responsible for strength gain) in quarry dust.
5. In almost all test results a slight difference has been observed between soils treated with Sululta quarry dust (Basaltic quarry dust) and Legetafo quarry dust (Trachyte quarry dust). Soil treated using basaltic quarry dust has showed relatively better improvement than the soil treated with Legetafo quarry dust. This may be due to the greater amount of alumina in the oxide composition of Sululta quarry waste; which replaces the water sheet sandwitched between two Structural units of Montmorillionite.
6. Based on the results discussed above, quarry dust is not a very effective chemical stabilizer for improving the geotechnical properties of highly plastic expansive soils; although some improvement is observed. However, it can be utilized for building construction purposes; i.e. to construct light weight building structures, taking care of the determination of the load of the structure to be built on a specific soil.

For the other perspective of the study i.e. tests have been performed to check the mechanical stabilizing ability of the quarry waste by using granular quarry waste and based on the test results the following conclusions have been made.

1. The optimum moisture content decreased while the maximum dry density values increased with percentage increment of granular quarry waste.
2. The CBR-swell and CBR values showed a slight decrement and increment respectively.
3. The treated soil cannot satisfy the minimum requirement to be used as a subgrade material. In the meantime mechanically treated soil samples in this case have not showed any significant improvement in properties of the soil than the already observed improvement in the case of chemical stabilization.

6.2 Recommendations

i. In this research work it has been observed that the geotechnical properties of the expansive soil were improving for every higher concentrations of quarry dust. This is basically due to the partial replacement of the expansive soil particles with non-expansive quarry dust particles. Therefore the construction industry should consider partial (greater than 30% by weight) replacement of expansive soils with quarry dust, for construction purposes.
ii. The properties of the quarry dust may be affected by environmental conditions as it lasts long being abandoned at the quarry sites. The effect of time factor on the properties of quarry dust as a stabilizing material have not been taken into account in the study. Further studies of this aspect may be important.
iii. The effect of quarry dust on expansive soils with an addition of previously studied successful stabilizers like cement and lime should be studied.
iv. Satisfactory results were not obtained while using the granular quarry waste as a mechanical stabilizer. Clay and friable particles may be present in the form of lumps in natural aggregates and this may be the cause for the lack of bondage between the expansive soil and the quarry waste. As a result they will be the cause for the lack of improvement in characteristics of soil-quarry waste mix. Specifications frequently limit these particles to a maximum of 1% and they can be avoided by washing. This perspective should be considered in future studies.

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Appendix

Appendix 1: ASTM C 618 – 03 chemical requirements for pozzolana (ASTM standard 2003)

Chemicals	Pozzalana class		
	N	F	C
$SiO_2 + Al_2O_3 + Fe_2O_3$ (min %)	70	70	50
SO_3 (max %)	4	5	5
Moisture content (max %)	3	3	3
Loss on ignition (max %)	10	12	6

Appendix 2: Oxide composition of quarry waste samples

Geological Survey of Ethiopia:Geochemical Laboratory Directorate
Geochemical Laboratory Complete Silicate Analysis Report Format   Form G0004
FILE ID ;7443/16 pvt   Originator; Eden Asres
Sample type; rock   Date Submmitted; 28/12/2016
Preparation :-200 MESH
Number of Sample: 3   **Element to be determined Major Oxides & Minor Oxides**
Analytical Method: LiBO2 FUSION , HFattack,GRAVIMETERIC,COLORIMETRIC and AAS
Analytical Results in PERCENT

FIELD NO	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Sululta Quarry	7443/16	56.68	14.94	6.70	8.24	9.44	2.58	<0.01	0.12	0.36	0.72	0.22	0.33
Gorro Quarry-1	7444	73.44	10.42	5.34	<0.01	0.34	4.66	3.74	0.10	0.10	0.21	0.13	0.76
Lagatafo Quarry-3	7445	68.58	10.53	5.12	0.48	0.72	5.48	6.88	0.10	0.05	0.15	0.47	0.90

Analysts
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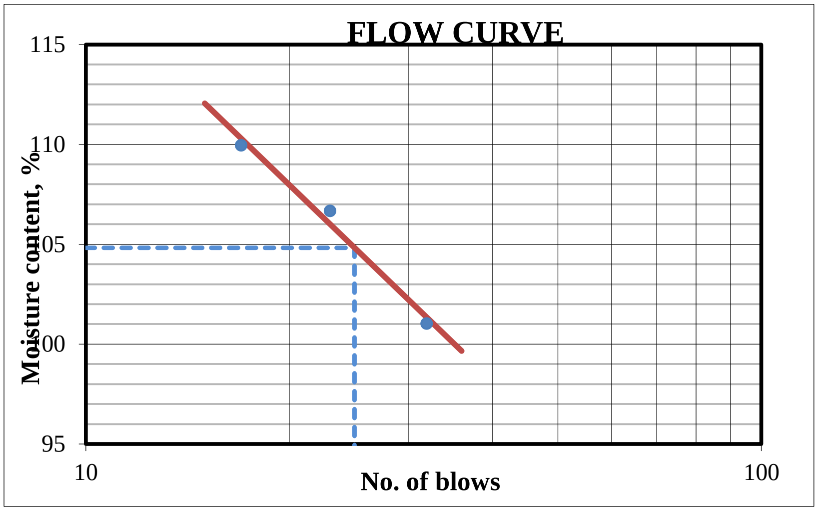
Appendix 3: Atterberg limits with varying percentage of Quarry dust

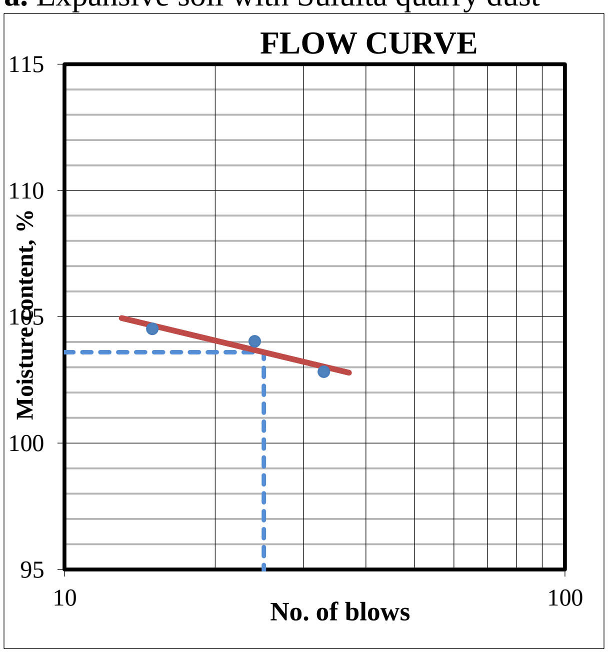
1) Quarry dust Content = 0 % (Natural soil)



LL=148.82%
PL=42.21%
PI=62.61%

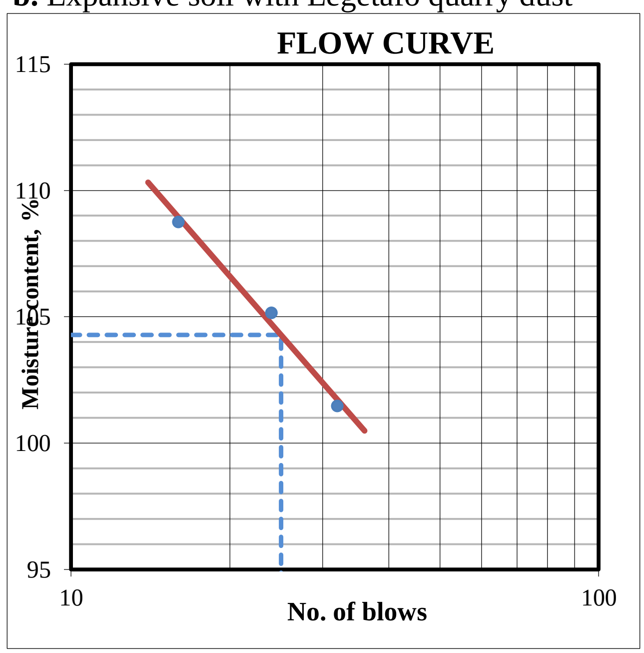
2) Quarry dust Content = 2% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=103.60%
PL=41.96%
PI=61.64%

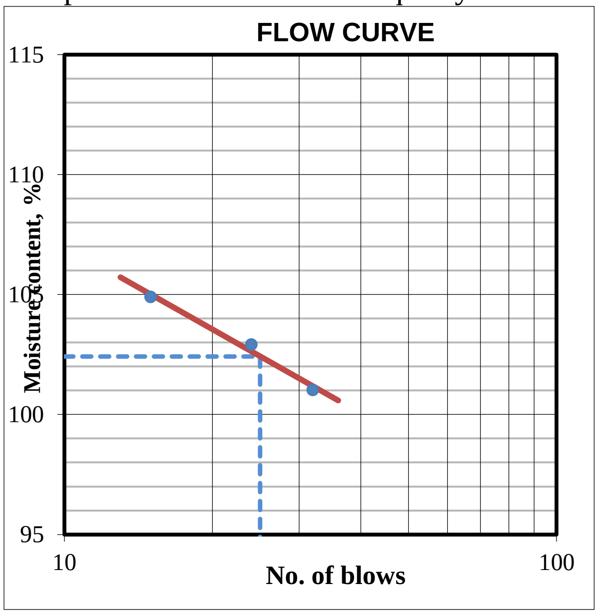
b. Expansive soil with Legetafo quarry dust



LL=104.28%
PL=41.77%
PI=62.51%

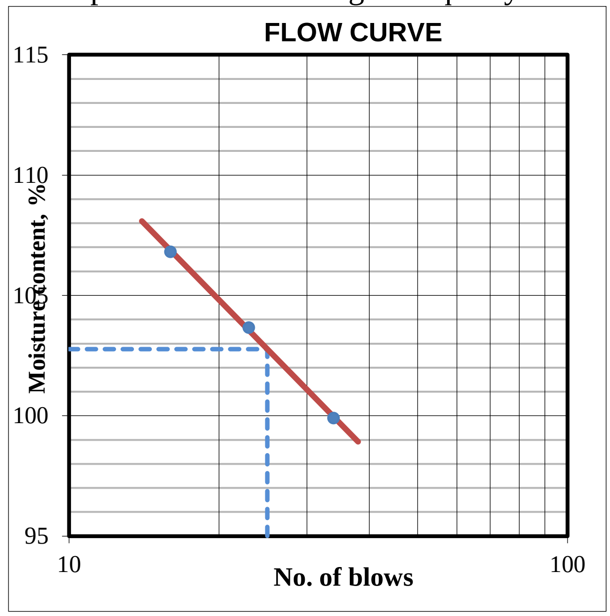
3) Quarry dust content=4% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=102.42%
PL=41.71%
PI=60.71%

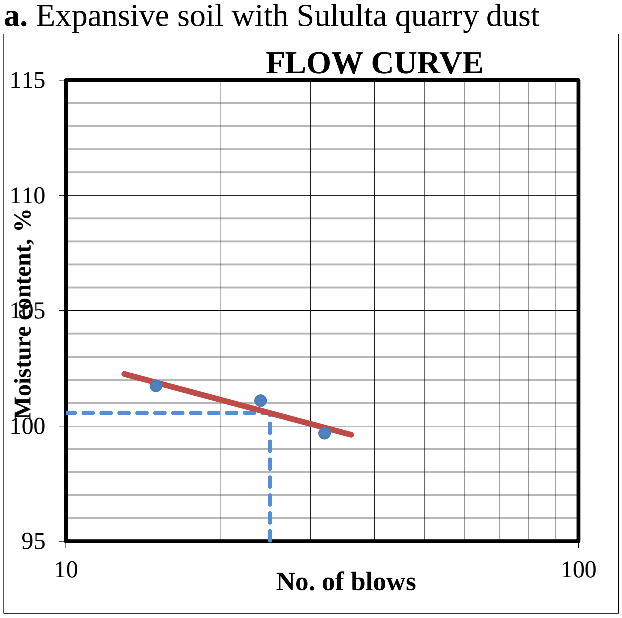
b. Expansive soil with Legetafo quarry dust



LL=102.77%
PL=41.07%
PI=61.69%

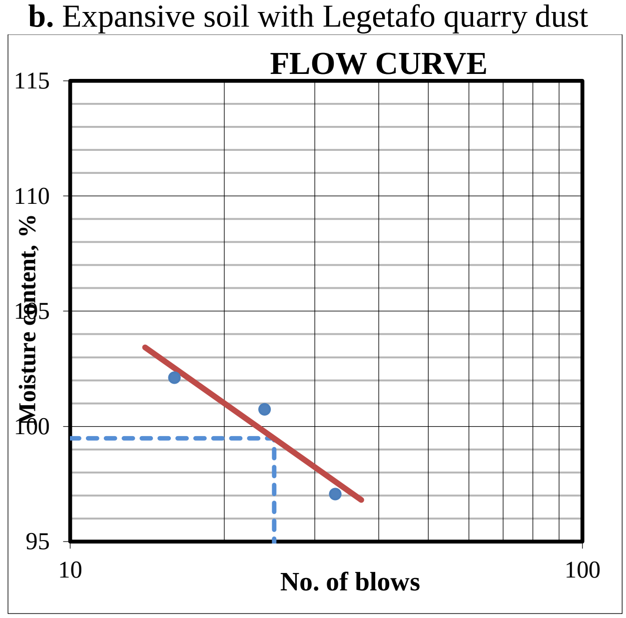
4) Quarry dust content=6% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=100.56%
PL=41.47%
PI=59.09%

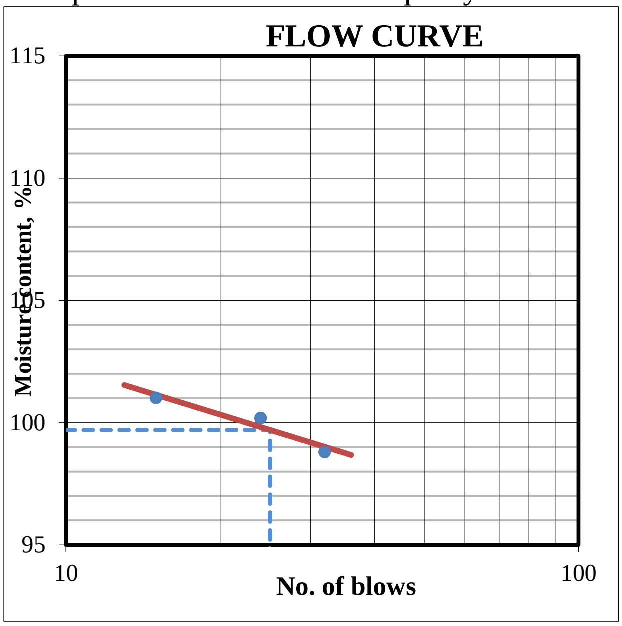
b. Expansive soil with Legetafo quarry dust



LL=98.48%
PL=39.62%
PI=59.86%

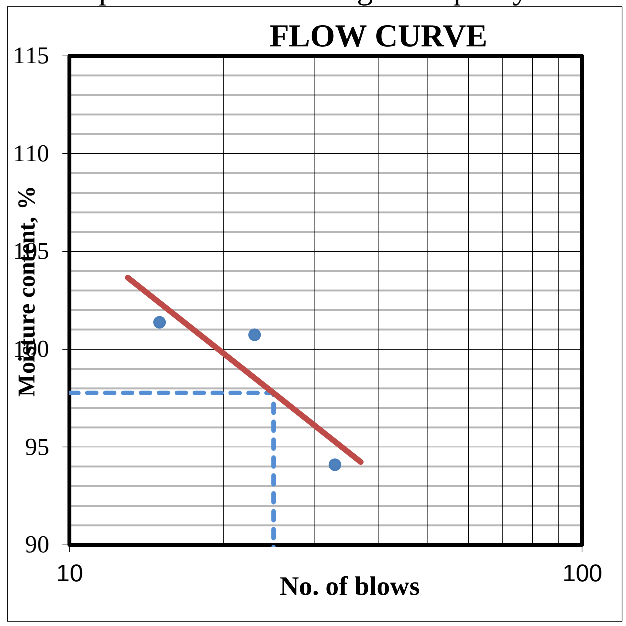
5) Quarry dust content=8% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=99.70%
PL=41.23%
PI=58.48%

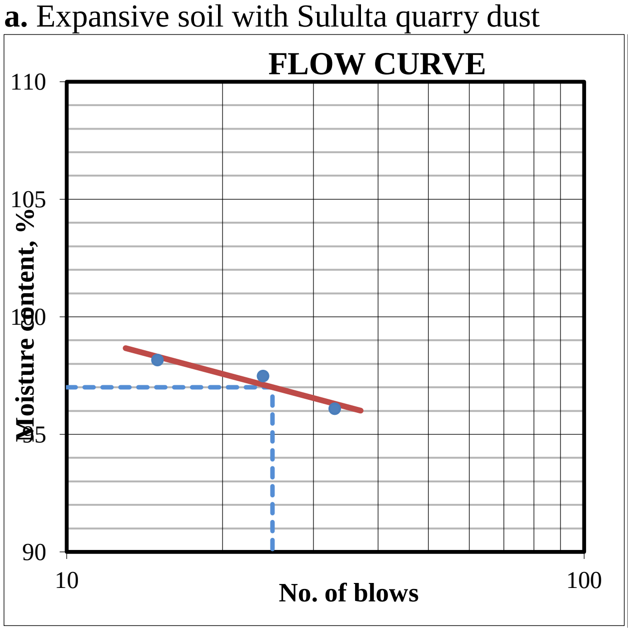
b. Expansive soil with Legetafo quarry dust



LL=97.77%
PL=39.05%
PI=58.71%

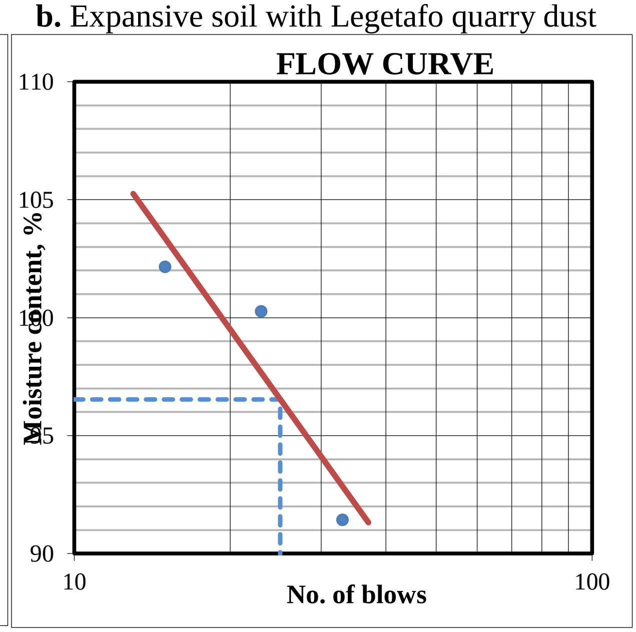
6) Quarry dust content=10% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=97.01%
PL=41.11%
PI=55.89%

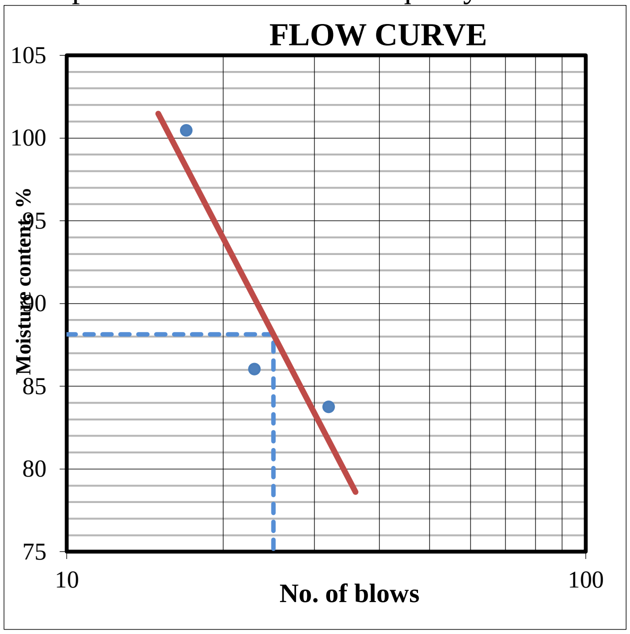
b. Expansive soil with Legetafo quarry dust



LL=96.54%
PL=38.70%
PI=57.84%

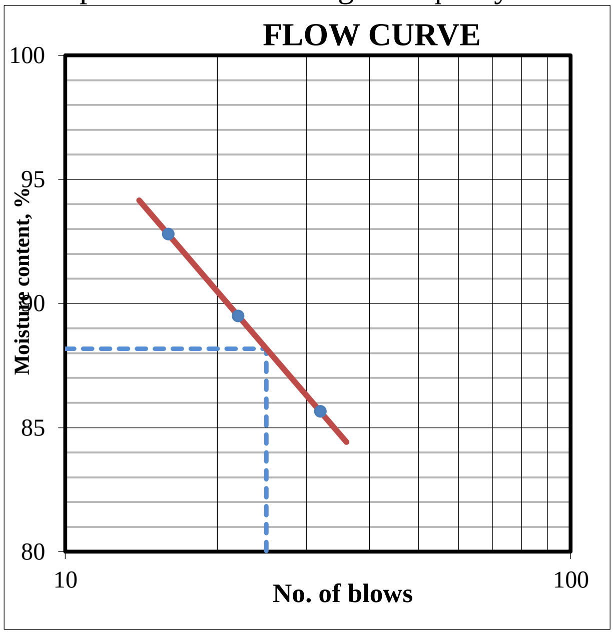
7) a. Quarry dust content=20% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=88.13%
PL=40.24%
PI=47.89%

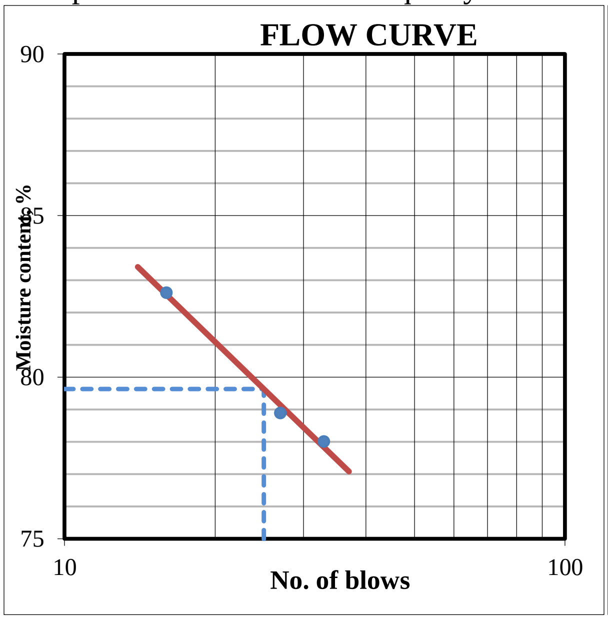
b. Expansive soil with Legetafo quarry dust



LL=88.18%
PL=35.56%
PI=52.62%

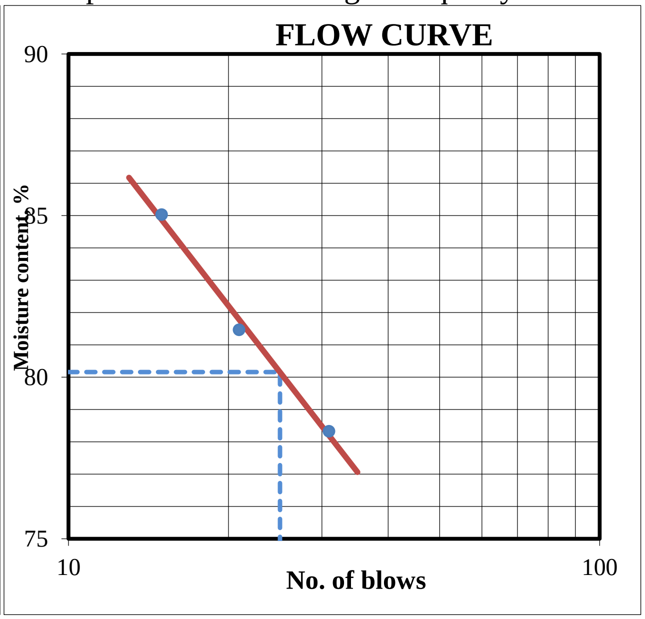
8) Quarry dust content=30% (Sululta Vs Legetafo quarry dust)

a. Expansive soil with Sululta quarry dust



LL=79.64%
PL=39.18%
PI=40.45%

b. Expansive soil with Legetafo quarry dust

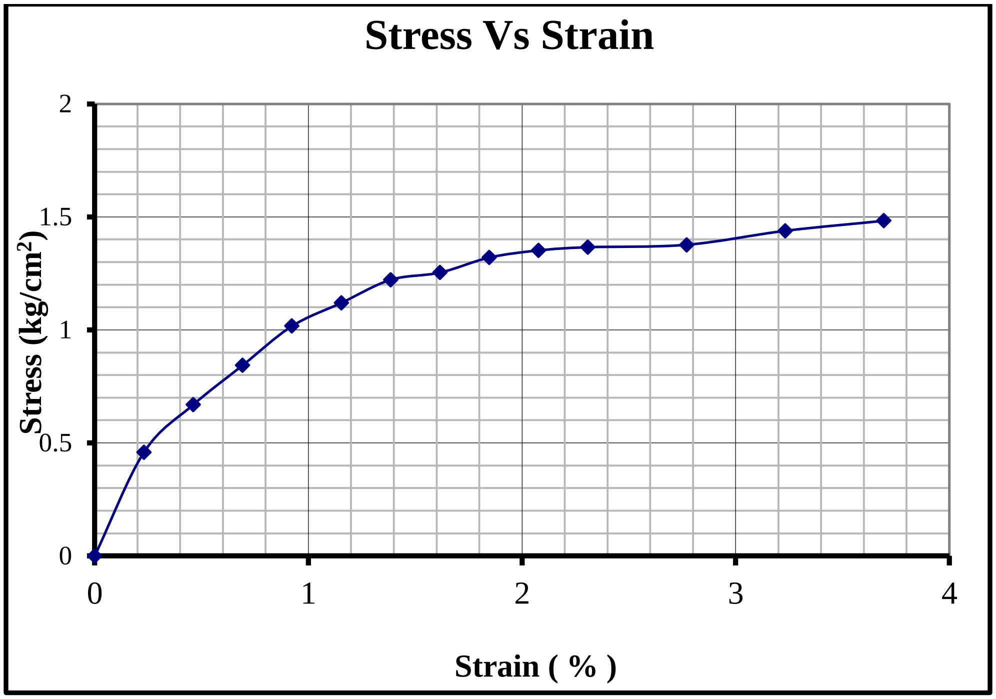


LL=80.16%
PL=32.04%
PI=48.12%

Appendix 4: UCS curves with varying percentage of Quarry dust

1) Quarry dust content = 0%

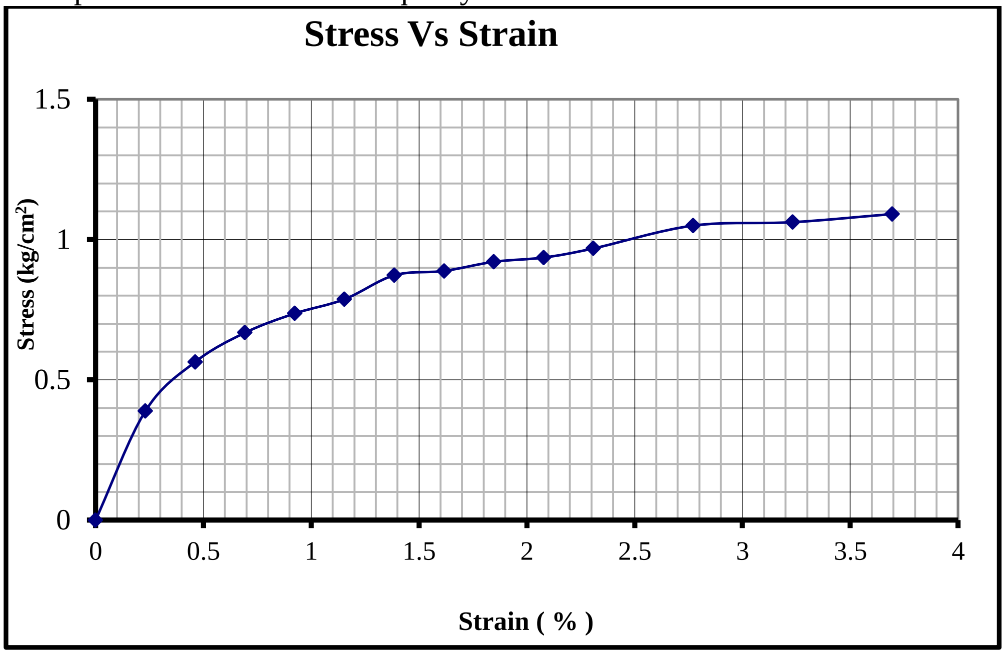
a. Natural soil



qu =1.51Kg/cm^2 →148.09KPa

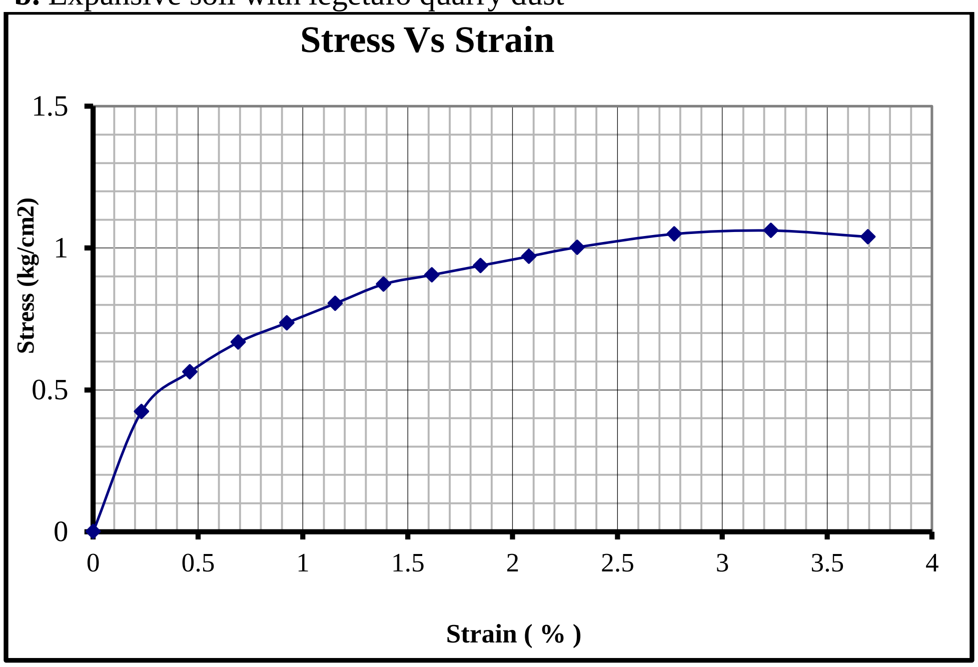
2) Quarry dust content = 20%

a. Expansive soil with sululta quarry dust



qu =1.11Kg/cm^2 →148.09KPa

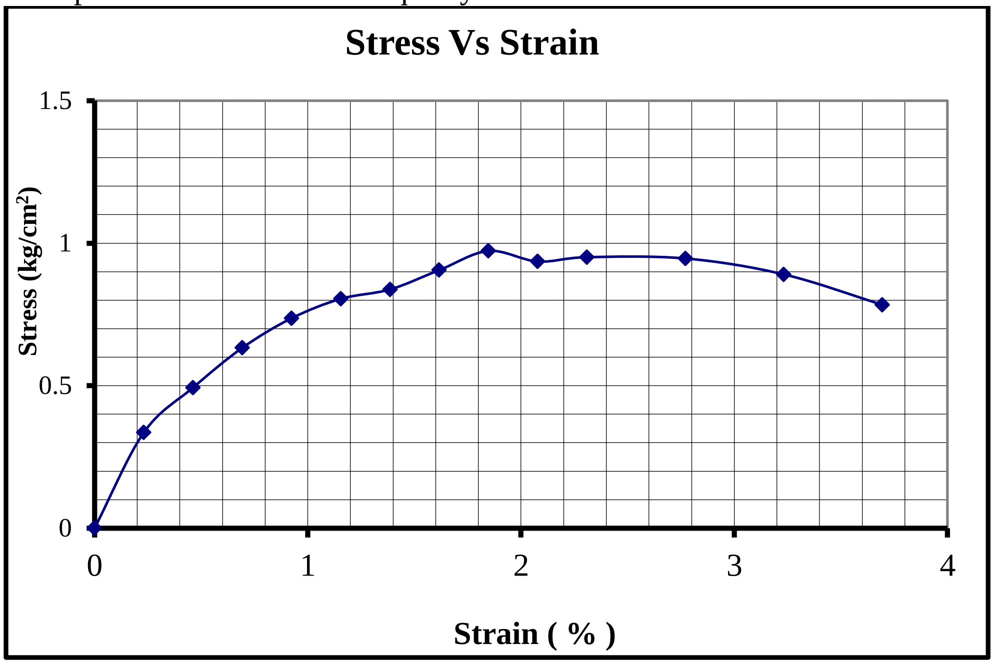
b. Expansive soil with legetafo quarry dust



qu =1.06Kg/cm^2 →148.09KPa

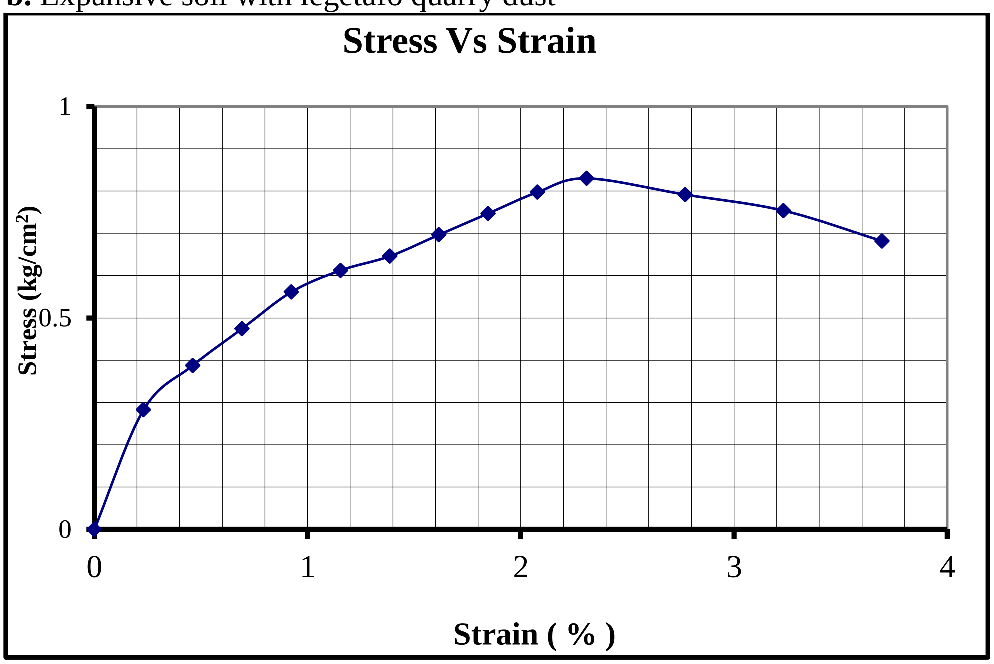
3) Quarry dust content=30%

a. Expansive soil with sululta quarry dust



qu =0.97Kg/cm^2 →95.43KPa

b. Expansive soil with legetafo quarry dust

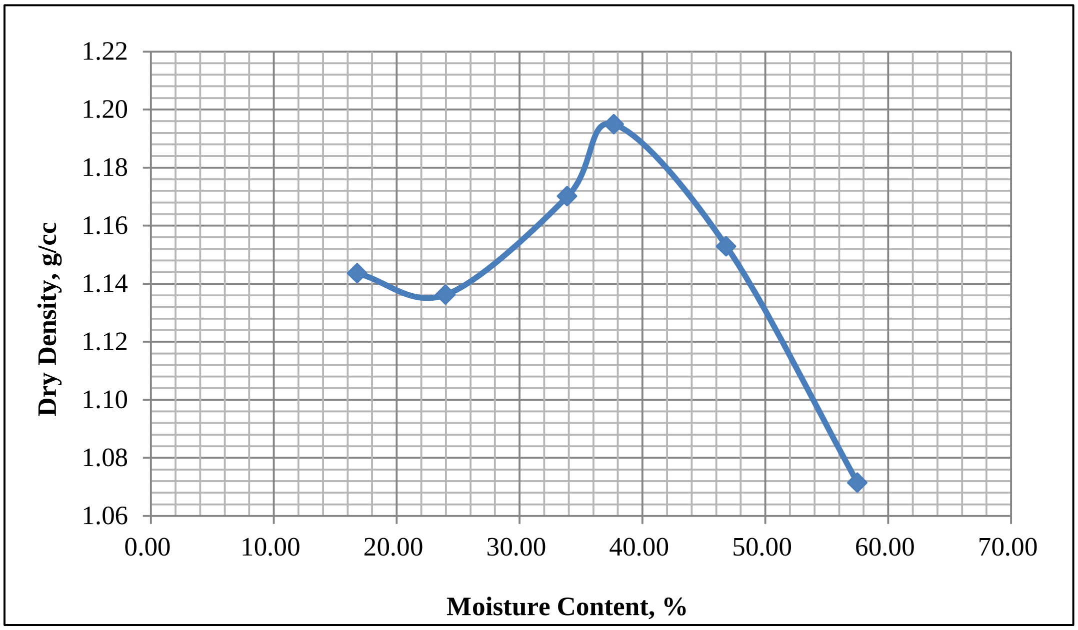


qu =0.83Kg/cm^2 →81.41KPa

Appendix 5:OMC and MDD relations with varying percentage of Quarry dust

1) Quarry dust content=0%

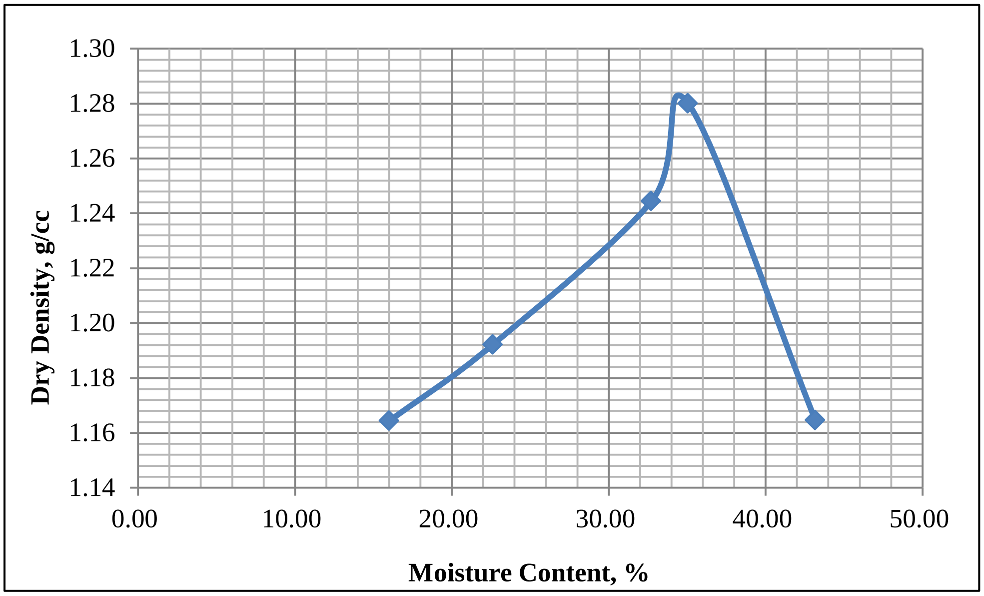
a. Natural soil



MDD=1.193gm/cc and OMC=38.0%

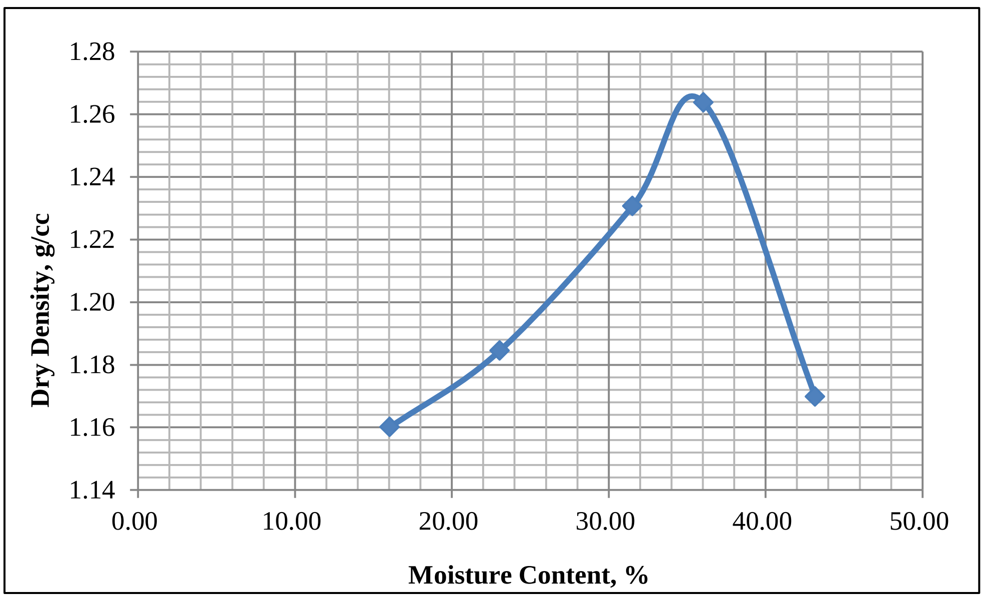
2) Quarry dust content=20%

a. Expansive soil with Sululta quarry dust



MDD=1.280gm/cc and OMC=35.0%

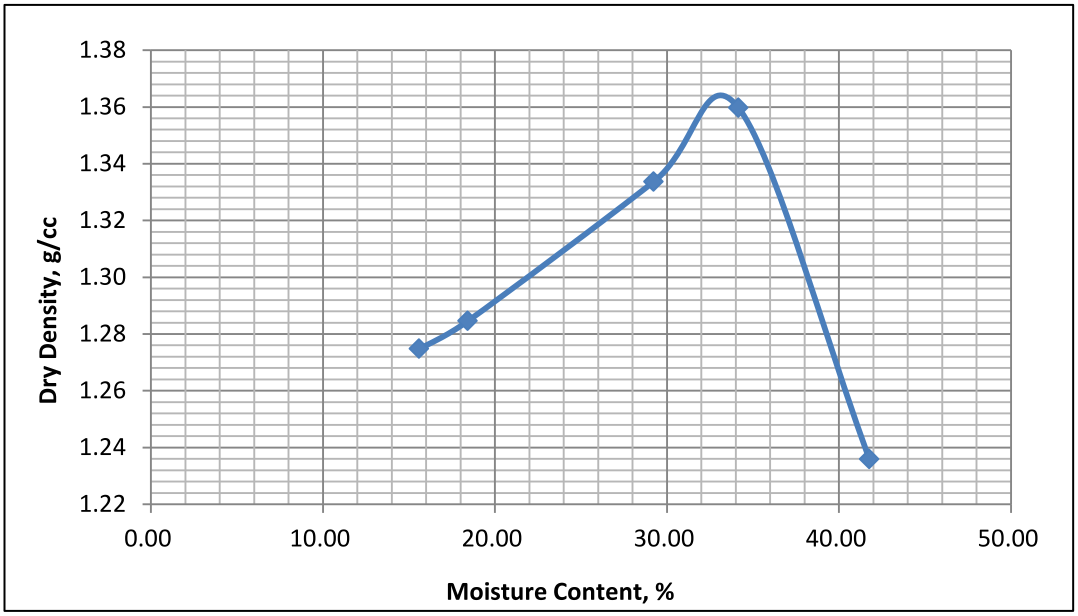
b. Expansive soil with Legetafo quarry dust



MDD=1.264gm/cc and OMC=36.0%

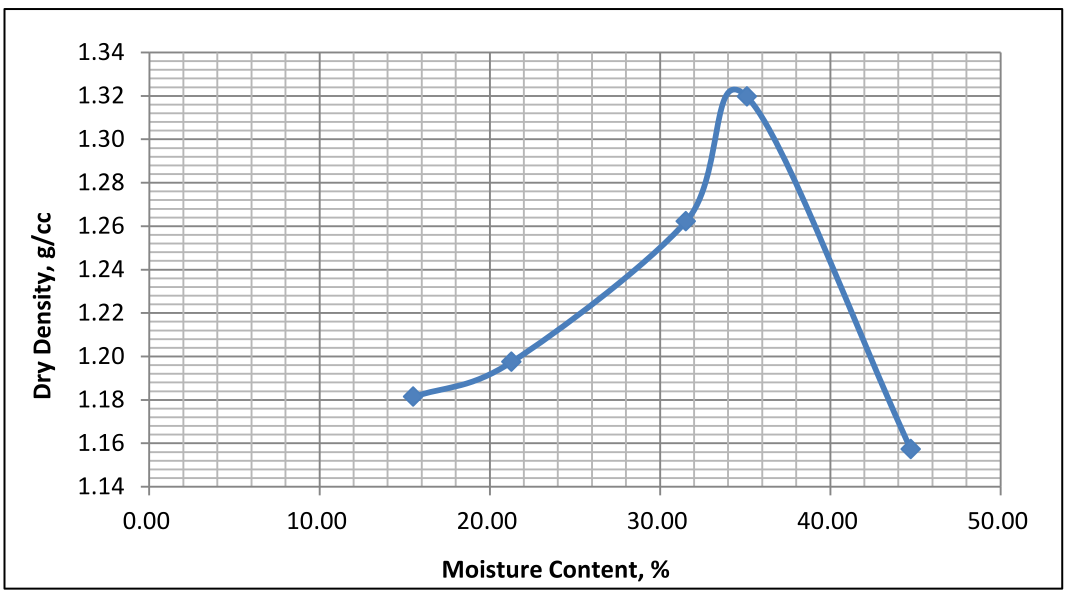
3) Quarry dust content=30%

a. Expansive soil with sululta quarry dust



MDD=1.360gm/cc   and   OMC=34.0%

b. Expansive soil with Legetafo quarry dust

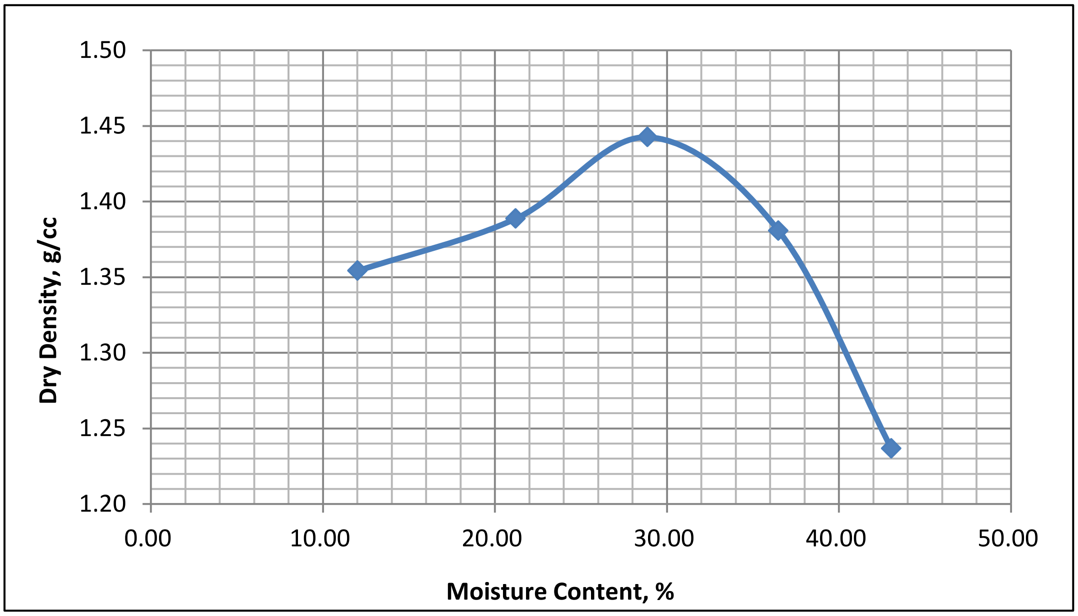


MDD=1.320gm/cc   and   OMC=35.0%

Appendix 6: OMC and MDD relations with varying percentage of granular Quarry waste

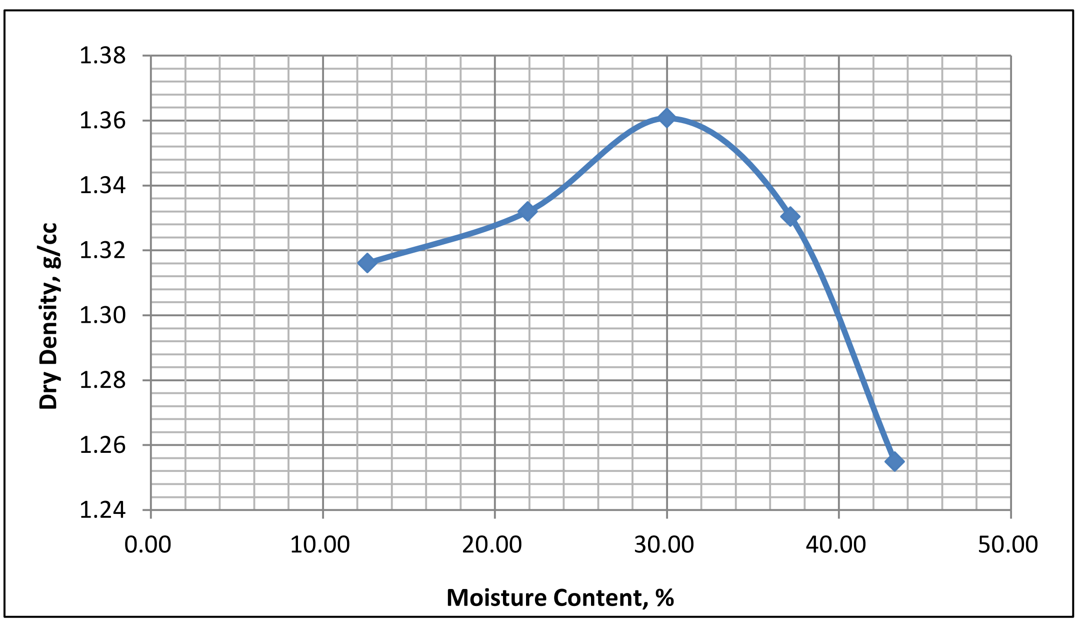
1) Quarry waste content=20%

a. Expansive soil with Sululta quarry waste



MDD=1.443gm/cc and OMC=29.0%

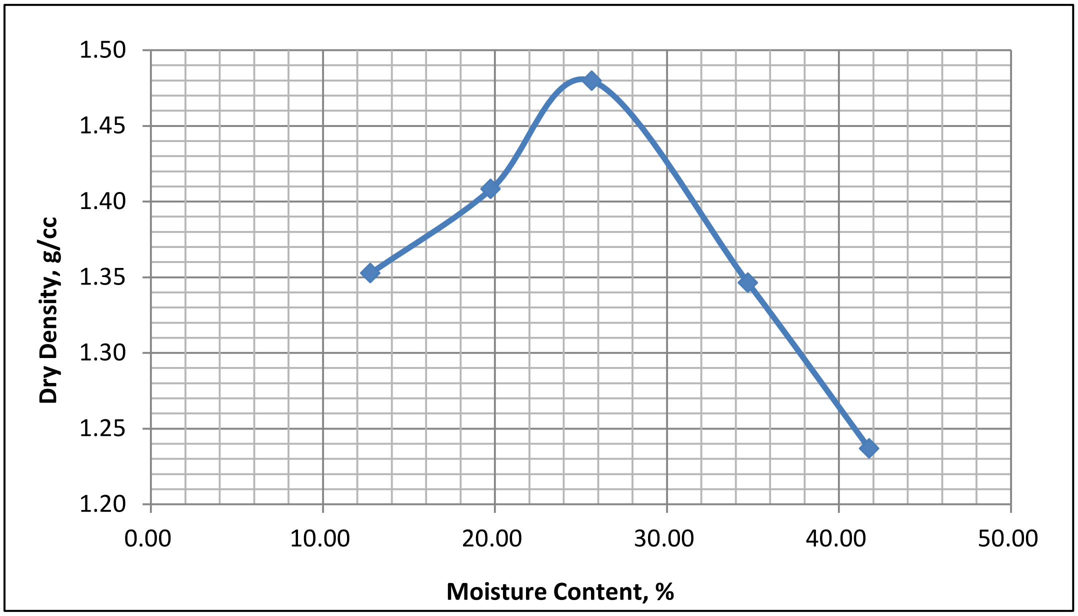
b. Expansive soil with Legetafo quarry waste



MDD=1.361gm/cc and OMC=30.0%

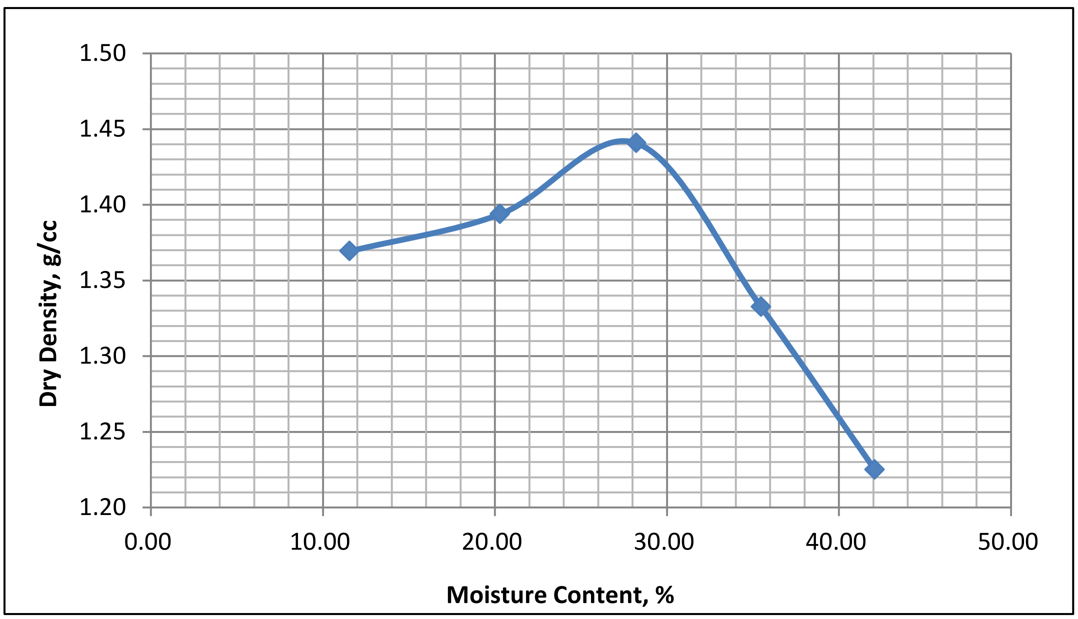
2) Quarry waste content=30%

a. Expansive soil with Sululta quarry waste



MDD=1.480gm/cc and OMC=26.0%

b. Expansive soil with Legetafo quarry dust



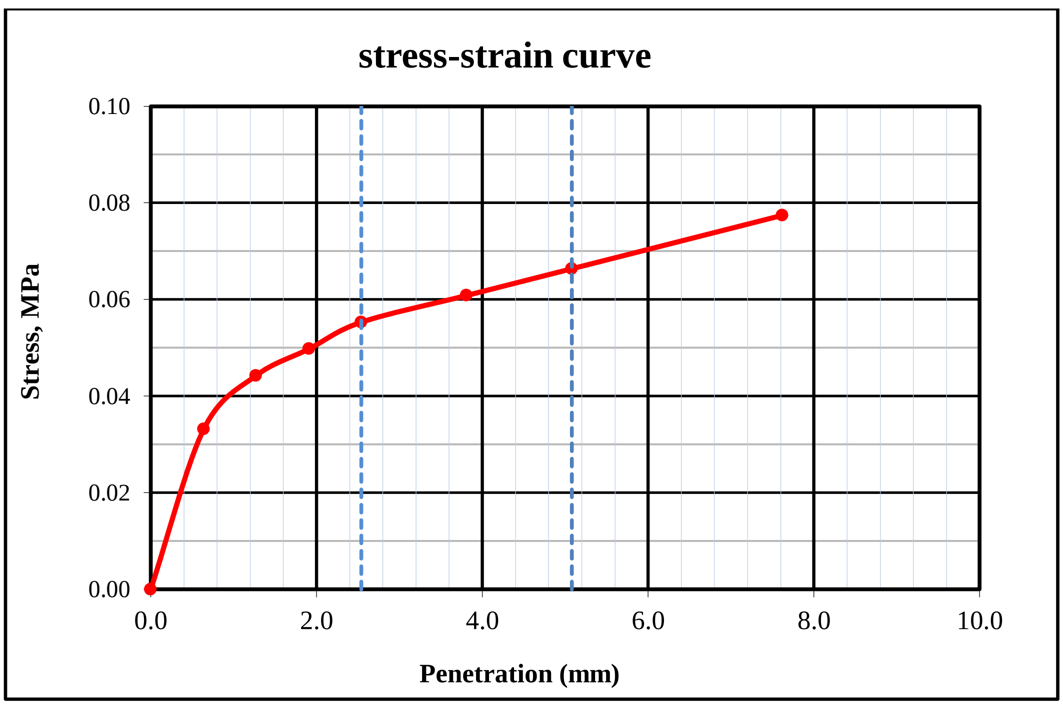
MDD=1.440gm/cc and OMC=28.0%

Appendix 7: CBR curves with varying percentage of Quarry dust

1) Content of quarry dust=0%

a. Natural soil

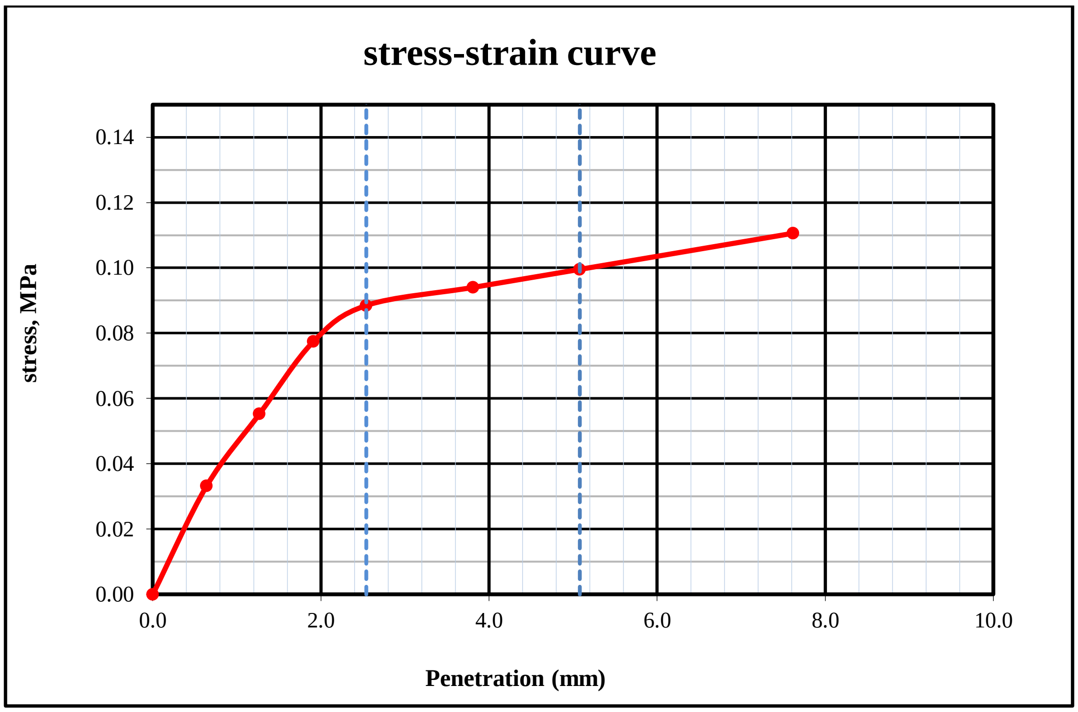
Penetration	56 Blows/5layers CBR value,%=0.8 swell,%=12.97				
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	4	0.04			
1.91	4.5	0.05			
2.54	5	0.06	0.1	6.9	0.8
3.81	5.5	0.06			
5.08	6	0.07	0.1	10.3	0.6
7.62	7	0.08			



2. Quarry dust content=20%

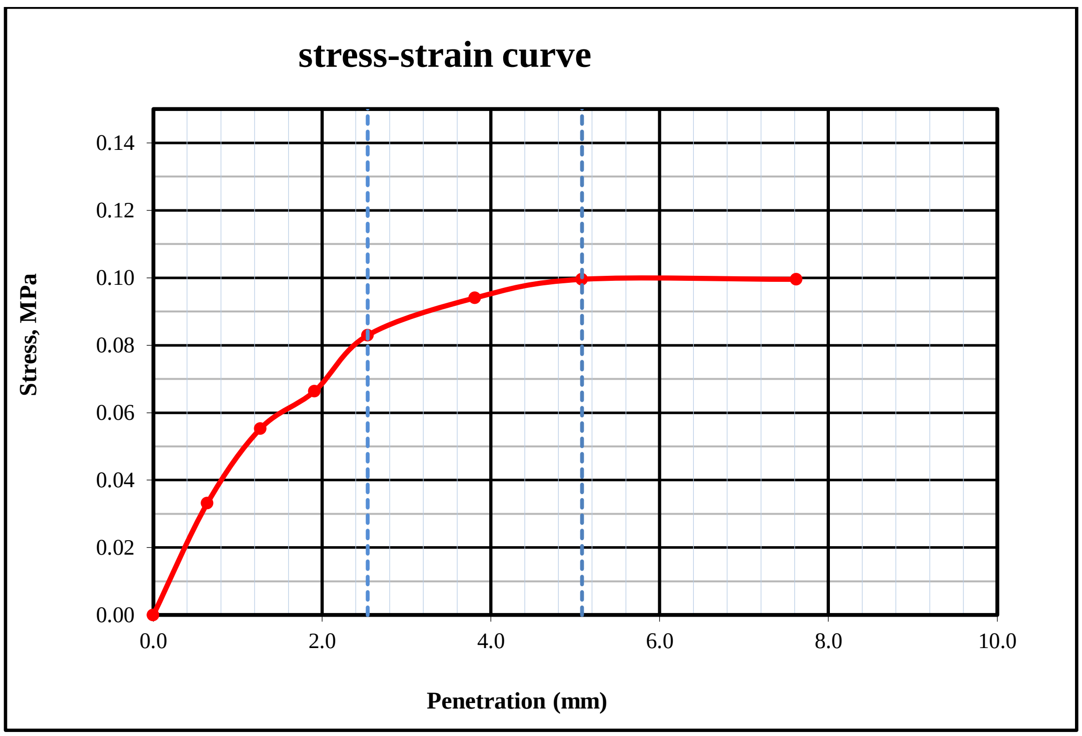
a. Expansive soil with Sululta quarry dust

Penetration	56 Blows/5 layers CBR value,%=1.3 swell,%=8.23				
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	5	0.06			
1.91	7	0.08			
2.54	8	0.09	0.1	6.9	1.3
3.81	8.5	0.09			
5.08	9	0.10	0.1	10.3	1.0
7.62	10	0.11			



b. Expansive soil with Legetafo quarry dust

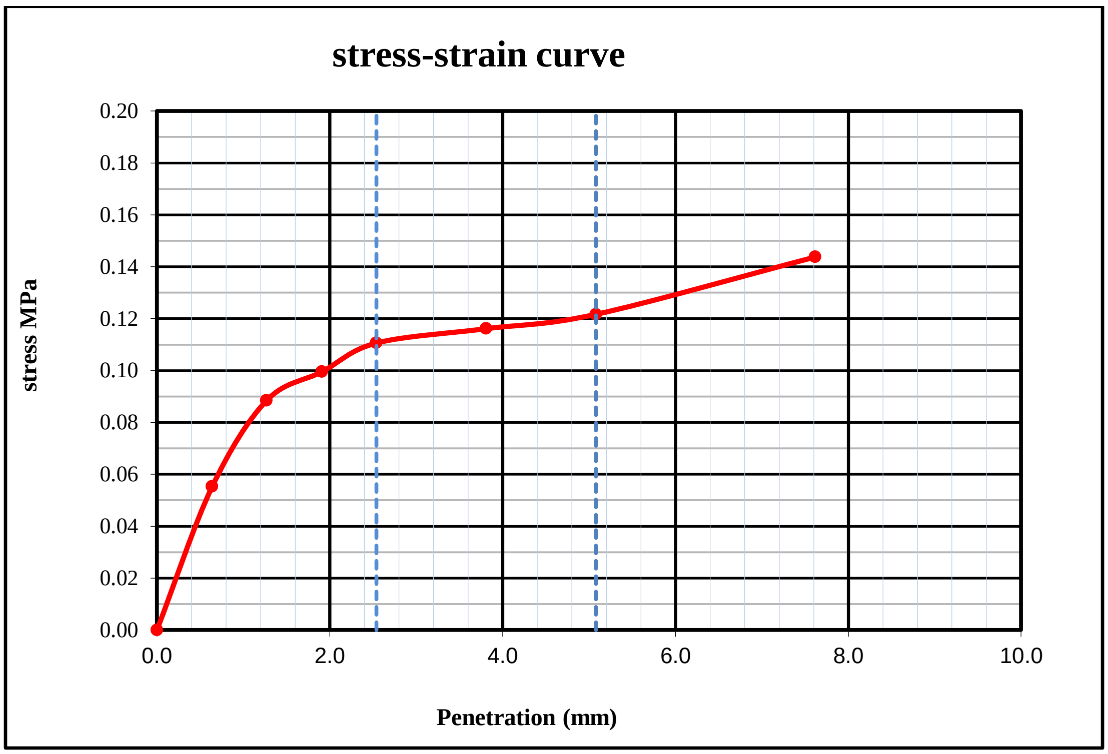
Penetration	56 Blows/5layers CBR value,%=1.2	Swell,%=9.06			
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	5	0.06			
1.91	6	0.07			
2.54	7.5	0.08	0.1	6.9	1.2
3.81	8.5	0.09			
5.08	9	0.10	0.1	10.3	1.0
7.62	9	0.10			



3) Content of quarry dust=30%

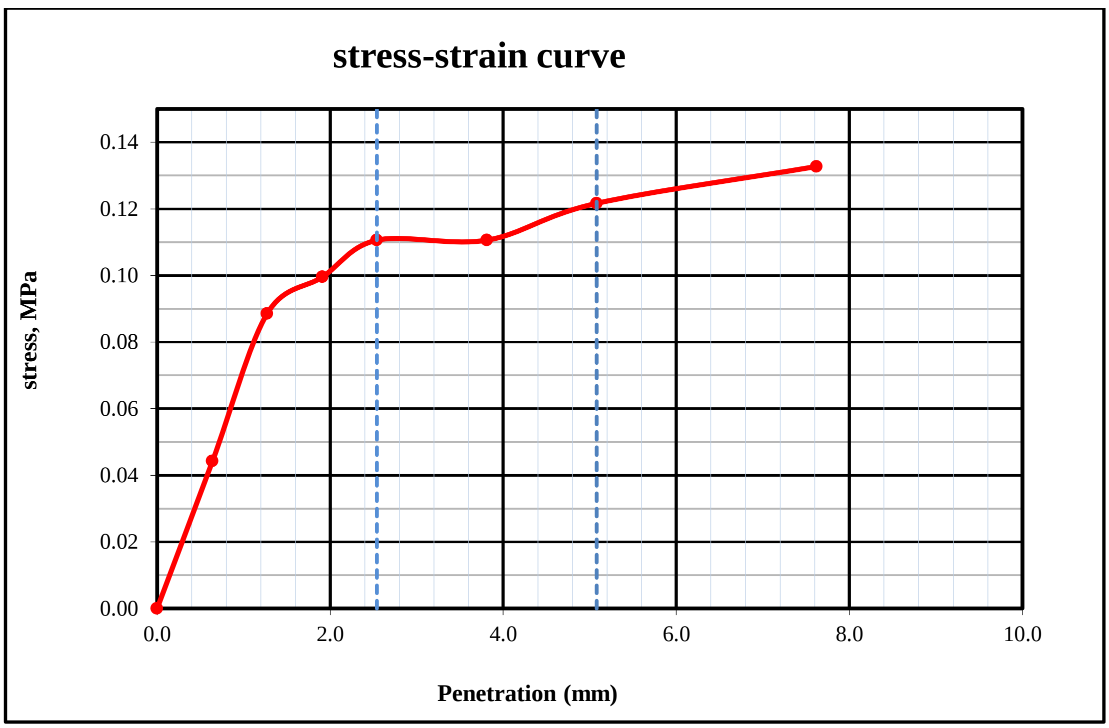
a. Expansive soil with Sululta quarry dust

Penetration	56 Blows/5 layers CBR value,%=1.6 Swell,%=4.5				
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	5	0.06			
1.27	8	0.09			
1.91	9	0.10			
2.54	10	0.11	0.1	6.9	1.6
3.81	10.5	0.12			
5.08	11	0.12	0.1	10.3	1.2
7.62	13	0.14			



b. Expansive soil with Legetafo quarry dust

Penetration	56 Blows/5 layers CBR value,%=1.6 Swell,%=6.03				
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	4	0.04			
1.27	8	0.09			
1.91	9	0.10			
2.54	10	0.11	0.1	6.9	1.6
3.81	10	0.11			
5.08	11	0.12	0.1	10.3	1.2
7.62	12	0.13			

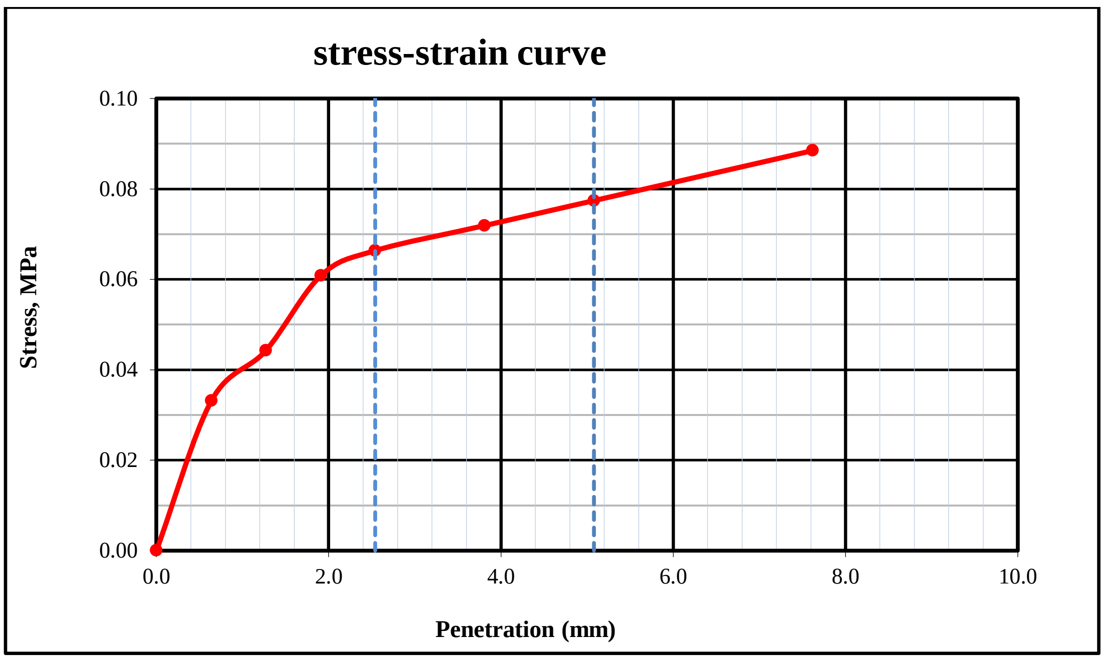


Appendix 8: CBR curves with varying percentage of granular Quarry waste

1) Quarry waste content=20%

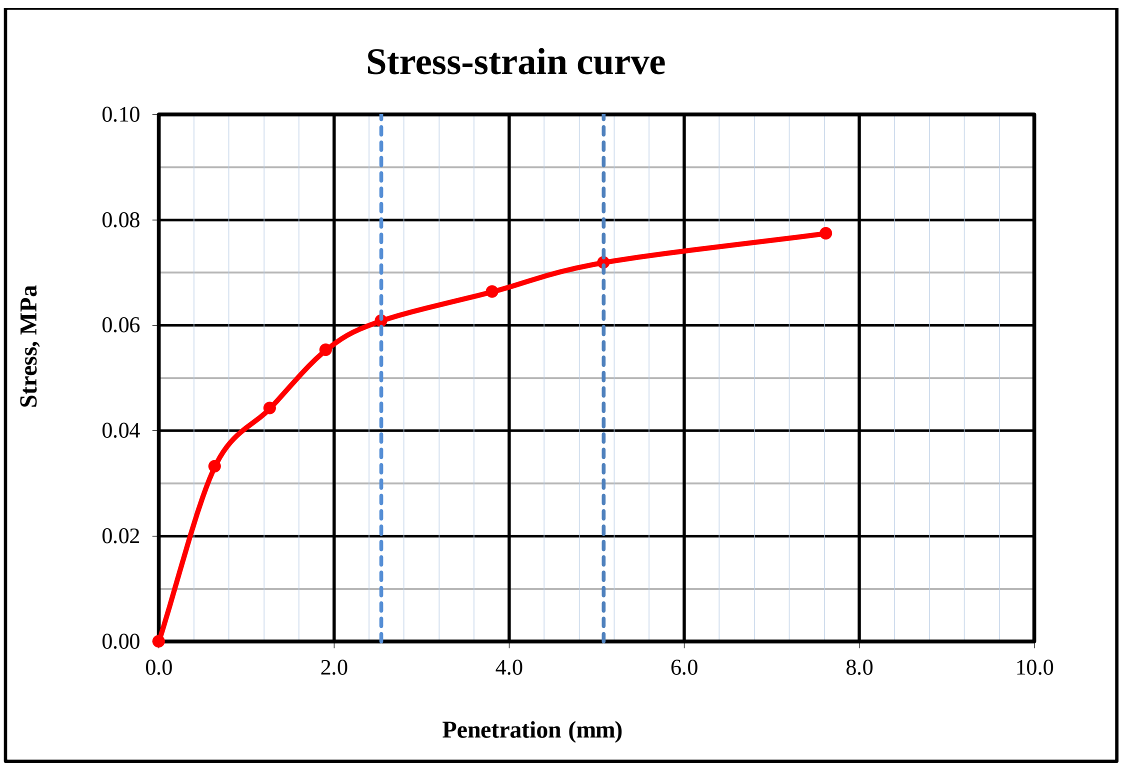
a. Expansive soil with Sululta quarry waste

Penetration	56 Blows/5 layers CBR value,%=1 Swell,%=12.54				
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	4	0.04			
1.91	5.5	0.06			
2.54	6	0.07	0.1	6.9	1.0
3.81	6.5	0.07			
5.08	7	0.08	0.1	10.3	0.8
7.62	8	0.09			



b. Expansive soil with Legetafo quarry waste

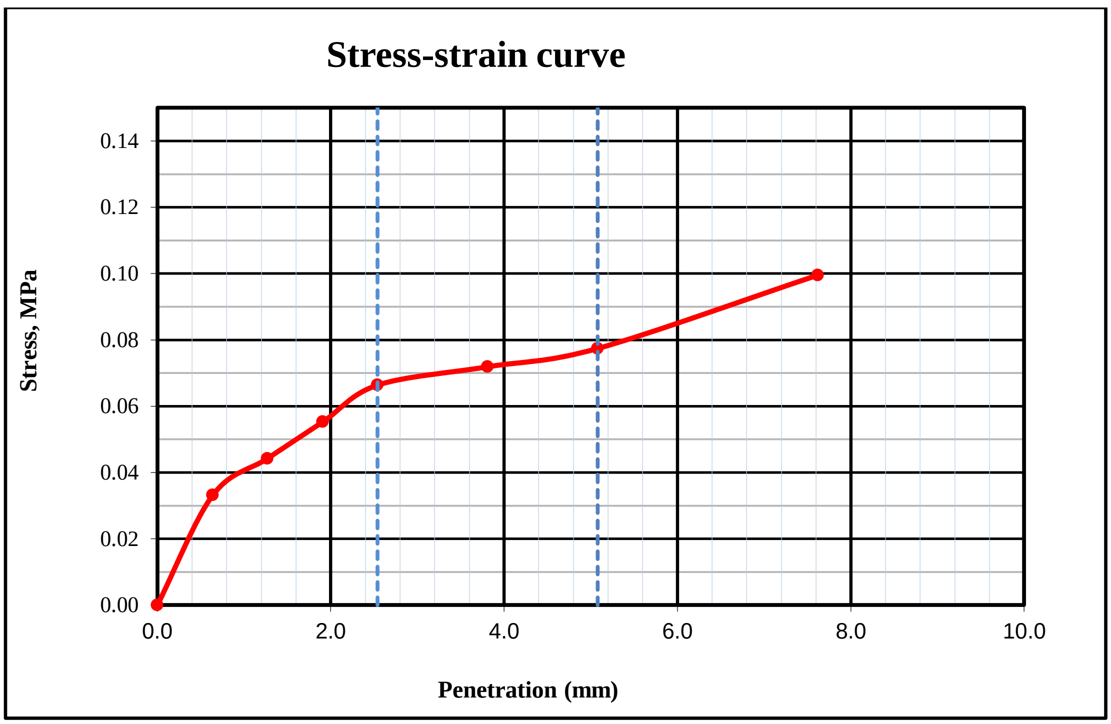
Penetration	56 Blows/5 layers CBR value,%=0.9		Swell,%=12.63		
mm	Dial Read. div	stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	4	0.04			
1.91	5	0.06			
2.54	5.5	0.06	0.1	6.9	0.9
3.81	6	0.07			
5.08	6.5	0.07	0.1	10.3	0.7
7.62	7	0.08			



2) Quarry waste content=30%

a. Expansive soil with Sululta quarry waste

Penetration	56 Blows/5 layers CBR value,%=1 Swell,%=12.08				
mm	Dial Read. div	Stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	4	0.04			
1.91	5	0.06			
2.54	6	0.07	0.1	6.9	1.0
3.81	6.5	0.07			
5.08	7	0.08	0.1	10.3	0.8
7.62	9	0.10			



b. Expansive soil with Legetafo quarry waste

Penetration	56 Blows/5 layers CBR value,%=1 Swell,%=12.14				
mm	Dial Read. div	Stress Mpa	Corr. Stress Mpa	Standard stress Mpa	CBR %
0	0	0.00			
0.64	3	0.03			
1.27	4	0.04			
1.91	5	0.06			
2.54	6	0.07	0.1	6.9	1.0
3.81	7	0.08			
5.08	8	0.09	0.1	10.3	0.9
7.62	9	0.10